04.10 Climate Model Berlin - Analysis Maps (2016 Edition)

Overview

In order to justify the significance of the environmental field of urban climate as comprehensively as possible, extensive model simulations were carried out for the first time in the year 2002/2003 with the mesoscale climate model FITNAH 3D (see Methodology) (SenStadt 2003, SenStadt 2004). The necessary input data and the analysis results were prepared in this first application in a spatial resolution of 200 m x 200 m, in the update of 2008/2009 (SenStadt 2009) then with a resolution of 50 m x 50 m. According to the recording accuracy possible at that time, the results of the model-based climate analysis primarily permitted assessments of the climatic situation and possible effects of construction projects at the level of superior or sub-spatial planning of scale level 1:50,000 till 1:5,000. On the other hand, for actual projects in the scope of the binding urban land-use planning with a scale level of ≤1:5,000, the detailed assessments required there at the level of the individual building structures could not be achieved till now.

Owing to the central importance of the geo-data of the environment atlas for the topic of urban climate, therefore, it became absolutely necessary to provide information with a spatial higher resolution.

For this purpose, the EFRE project **"GIS-supported modelling of parameters relevant for urban climate in the basis of high resolution building and vegetation data"** was carried out from 2013-2015.
This project was financed by European Funds for Regional Development (EFRE) and the City State of Berlin (project number: 027EFRE GDI) for measures for building up the geo-data infrastructure (GDI) (SenStadtUm 2015).

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In the scope of the project, the urban area of Berlin as well as the surrounding region with a total area of around 1,800 km² was analysed and evaluated with respect to climate in a resolution of 10m x 10m. The processing of an investigation area of this expansion with a screen width of only 100m² represented a first country-wide at the time of study and required model attributes of FITNAH-3D optimised and customised mainly to these requirements.
Figure 1 illustrates the multiplication of the detailing of the spatial resolution in the steps 200 m x 200 m to 10 m x 10 m (factor 400).

Fig. 1: Grid widths of the three modelling versions of the climate model Berlin between 2002-2003 (200 m edge length) and 2013-2015 (10 m).

Such an extensive refinement of the spatial resolution of the modelling also requires, at the same time, correspondingly detailed data basis, which were available especially with high-resolution building and vegetation data (SenStadtUm 2014, see Statistical Base).

The 10 m x 10 m screen resolution now available enables a usability of the analysis results also for the evaluation and assessment processes at the level of the binding urban land use planning (land use plan level) or of the corresponding projects.

A modern climatic analysis designed for practice must particularly encompass the process system of air-exchange flows, and attempt to make a connection between these processes and the structuring of the area under investigation into spaces which are favorable and unfavorable, respectively, in terms of urban climate and air-quality. These two terms describe, from a climatic viewpoint, the structure of an area into compensation spaces, affected spaces and connecting structures (air-stream channels), and an understanding of such an area as a construct consisting of compensation and stress areas.

"A **compensation space** is thus an undeveloped space characterized by vegetation, which by generating cool and fresh air, can reduce or eliminate air-quality or bio-climatic burdens in an affected space via functional exchange interaction. An **impact area** is a space which is burdened, built-up or planned for construction, and which is connected to an adjacent compensation space via air exchange processes, or to a non-adjacent compensation space via an **ventilation lane**" (cf. Mosimann, Frey, Trute and Wickenkamp 1999). This procedure thus breaks fundamentally with the previously common static view based on urban climate zones, which subdivided the area of investigation into spatial units in which the micro-climatically most important factors were relatively homogeneous and the effects hardly differed (cf. VDI 1997).

The approach of model use selected here with combined evaluation of statistical base data of climate stations operated for many years (SenStadtUm 2015a) has the following important benefits:

- The comparability of results in the overall area is ensured.
- In addition to the qualitative statements designed to characterize particular urban climatic phenomena, quantitative statements concerning climate-ecological conditions and exchange processes are also possible.
- Climate-ecological compensation and process spaces are localized in the urban area and represented in their spatial dimensions as precisely as possible.
- An important aspect of the climate-ecological compensation potential of open areas - the cold-air balance - has been investigated on a comprehensive city-wide basis for the first time in Berlin.

This investigation, too, supports the repeatedly confirmed connection between the climate of various urban areas and their structure in terms of buildings, open areas and vegetation. However, the typical local climate is not only generated by the structure of an urban area but also by its situation within the city. Hence, different areas of a city can interact mutually, or with the surrounding countryside. The temperature differences between neighboring areas are of decisive importance for the climatic exchange. A reduction of these differences, e.g. due to an increase in the structural density, or the uniformization of structures, will cause the urban climate to deteriorate. The objective of the present updated maps 04.10.01 - 04.10.07 is to present the results of the current application of climate modelling.

As compared to the last edition of 2009, the range of topics of the parameters shown was extended, with respect to the evaluated parameters as well as also the spatial differentiation by offering now the original screen resolution as well as the averaged block (partial) area values as the basis for the planning advice map in the Geoportal (see Method, SenStadtUm 2016).

In order to achieve comparability with the climate parameters already published in the Digital Environmental Atlas, the distribution of air temperature during two time segments is also presented, although a direct comparison of the map representations based on measurements and analogical conclusions with the results of simulations of model applications requires that the differing frameworks be taken into account. This advice has also be considered when **comparing the results of the both FITNAH model applications** of the 2003/2004 edition and 2009. As on the one hand scope and level of detail of the input data, and, on the other hand, model enhancements may result in differing findings and classifications.

Moreover, the representations of the spatial delimitation and quantification of the autochthonous air exchange processes are of special significance. The term "autochthonous" describes climatic events which occur locally or independently (that is without outside effects, e.g. extensive wind flows; the opposite is "allochthonous"). They are based in the climatic effectiveness of the particular utilization structures in their respective environments, and thus provide a sound basis for the derivation of concrete planning recommendations.

Statistical Base

The application of numerical simulation models requires acquisition of basic data and of meteorological ancillary conditions in a territory extending beyond the actual investigation area. This is designed to assure that the model can "swing itself into place", so as to be able to simulate conditions as realistically as possible at the margins of the actual project area (for the methodology of the FITNAH climate model used here, (cf. Methodology / Supplementary Notes). Hence, the investigation area consists of two major components: the approx. 890 km² area of the city of Berlin, and an approx. 900 km² area in the suburbs (cf. Fig. 2).

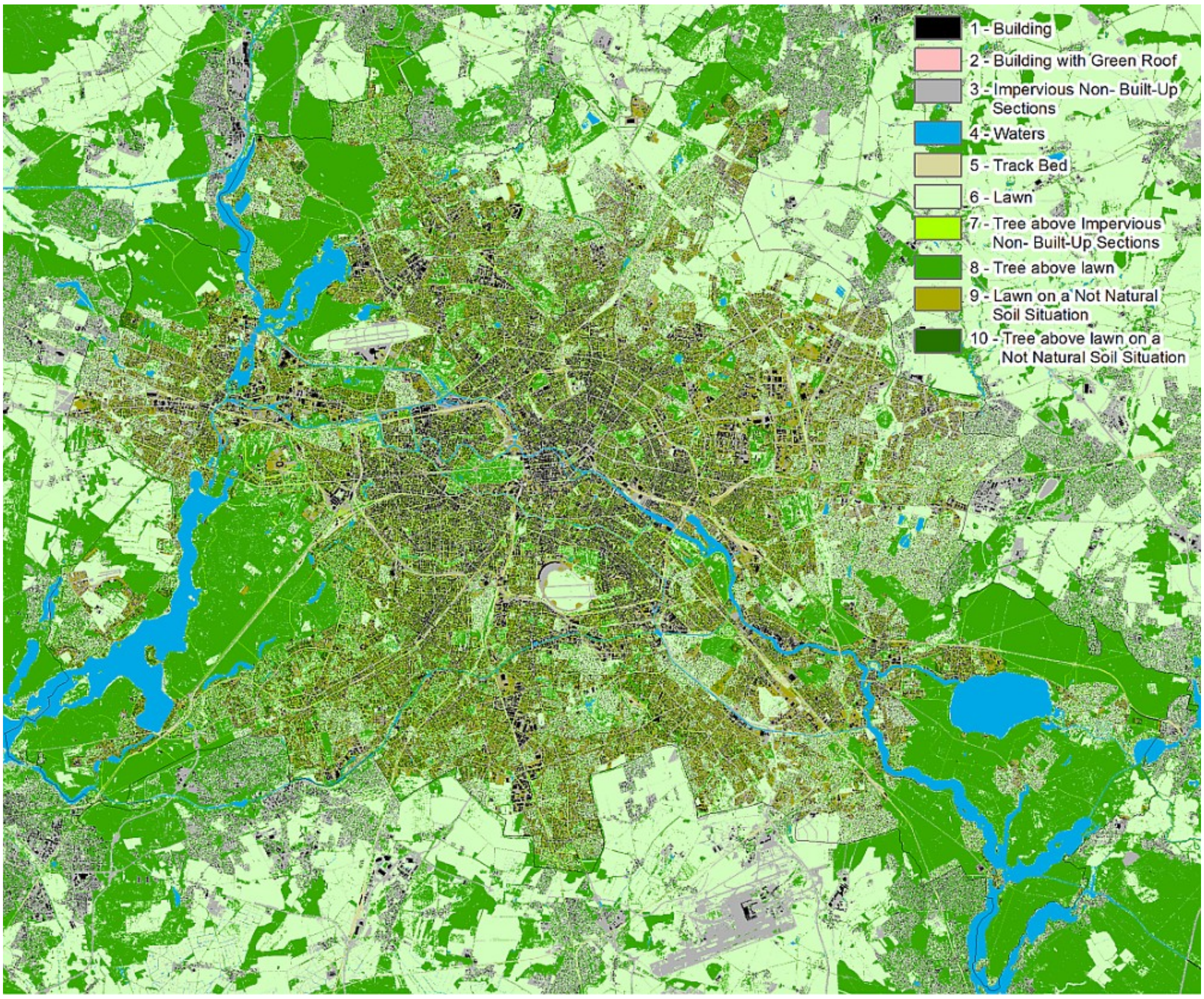


Fig. 2: Expansion of the investigation area (1,800 km²) and classification of the land use for model application. A key with 10 usage classes is used, which is adjusted to the requirements of the model FITNAH 3D.

The quality of the model results depends decisively on the degree of detail of the input data. Till now, the block-based data of the Urban and Environmental Information System (ISU) were used primarily for climatic model applications. The digital block map ISU5_UA 2010 in the scale 1:5,000 represents the reference areas for the information related to block (partial areas), amongst others, for the real area usage and for degree of sealing (SenStadt 2010, SenStadtUm 2012) and is hence a suitable basis for meso-scale modelling in a resolution of 50 m x 50 m. However, this screen size of each 2,500m² also implies that small-scale input data, such as the building data of the automated land register map (ALK) used for the currently present version of the model application (see Fig. 3, SenStadtUm 2015b) cannot be linked adequately resolved. Consequently, for the screen resolution of 10 m x 10 m established in the limiting area between the micro-scale and the meso-scale, an extended approach for including small-scale usage data became necessary.

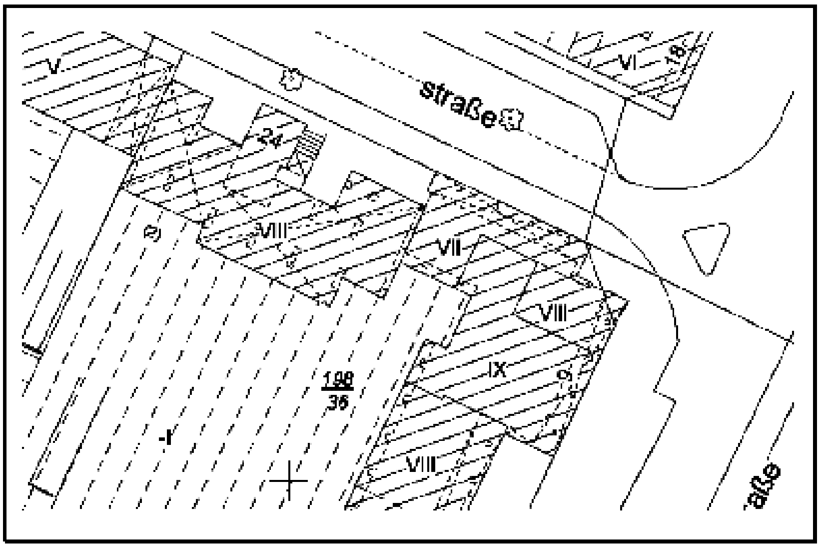


Fig. 3: Section of the automated land register map (specification of building floors in Roman numerals) (SenStadtUm 2015b).

Corresponding preliminary work for equipping this project with land use and vegetation data having very high degree of detail could be done with the elaboration of the map 06.10 "Building and vegetation heights" (SenStadtUm 2014). Along with the actual object data: 'Area size', 'maximum, minimum and mean height' as well as 'Use according to object type catalogue of ALK' and 'Greening of the roof yes/no', the technical data entered for the individual buildings and vegetation objects also enable links to the official building codes as well as to the block (partial) area codes of ISU5_UA 2010. Over and above the stock of around 540,000 ALK building objects (as on 06/2014), from the mentioned stock of building and vegetation height entries approx. 70,000 additional building objects like scales, garages, leaves and other non-ALK objects could also be considered.
Owing to their degree of detail, this data represents the decisive basis for the present climate modelling with a resolution of 10 m. The most important geo-basis data are summarised in Fig. 4.

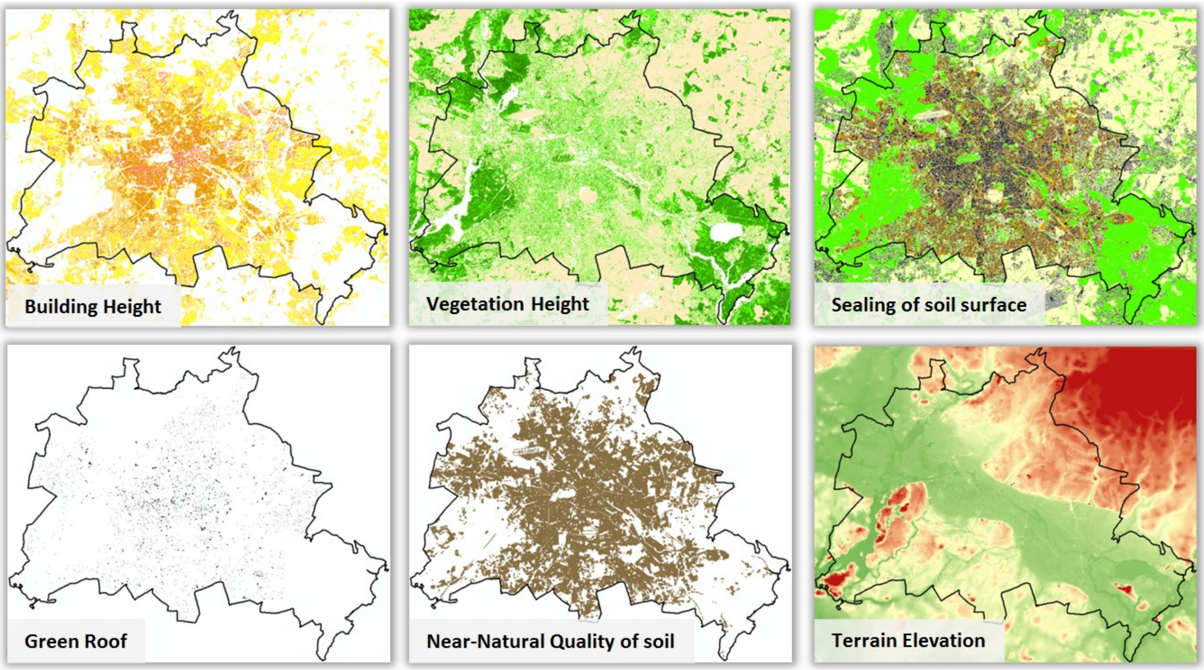


Fig. 4: Geo-data basis for the application of the climate model FITNAH 3D

On the whole, the application of the climate model Berlin in its current version, is based on the following components building upon one another:

1. the evaluation of long-term operation of measurement stations in Berlin and Potsdam as the basis for calibrating the model results (SenStadtUm 2015a)
2. extensive analysis steps for working out an established database, as well as

3. the preparation of three planning advice maps that supplement one another (SenStadtUm 2016).

Following data bases were used for conducting the process steps 2 and 3:

- GEO-NET Umweltconsulting GmbH, Hanover: GIS-based modelling of parameters relevant for urban climate based on high-resolution building and vegetation data; EFRE project 027 Urban climate Berlin (SenStadtUm 2015),
- Data of the Urban and Environmental Information System (ISU) of SenStadtUm, III D 1, version 31.12.2010:
  - Block map 1: 5,000 (ISU5_UA),
  - Land Use data (SenStadt 2010),
  - Criteria for evaluating the soil functions, map of closeness to nature (SenStadtUm 2013),
  - Uncorrected degrees of sealing (grid data) - intermediate result of the rule-based classification (SenStadtUm 2012),
  - Building and vegetation heights (SenStadtUm 2014),
- Ground level (DGM5) (SenStadt 2010a),
- Automated land register map Berlin (ALK), version 01.06.2014 (SenStadtUm 2015c),
- Locations of the social infrastructure (Planning area related information system for monitoring and analysis (PRISMA) (SenStadtUm 2015c) as well as Regional Office for Health and Social Affairs (LAGeSo) (LAGeSo 2014),
- Detailed map of the Berlin's network of roads, version 11/2014 (SenStadtUm 2014a),
- State of Brandenburg:
  - ALKIS database Building and actual use, version 10/2013 (LGB 2013),
  - Ground levels (DGM25) (LGB 2013a),

Model calculations use grid-based representations of input variables. For providing the model input data, therefore, the area geometry had to be transferred to 10 m x 10 m grid cells each with a uniform usage structure. This was done in a multi-staged query cascade, which is shown in Fig. 5. In partial areas, the described model input data were supplemented by usage information of the Urban and Environmental Information System (ISU) or by the vector data of the block map 1:5,000 (ISU5_UA 2010). This mainly concerns the information about water bodies, for road space and track areas. While high resolution building and vegetation data can also be used for the neighbourhood of Berlin, the sealing information was present only for the urban area of Berlin. More information about the interface structure could be taken from the ALKIS database of National Survey of Brandenburg.

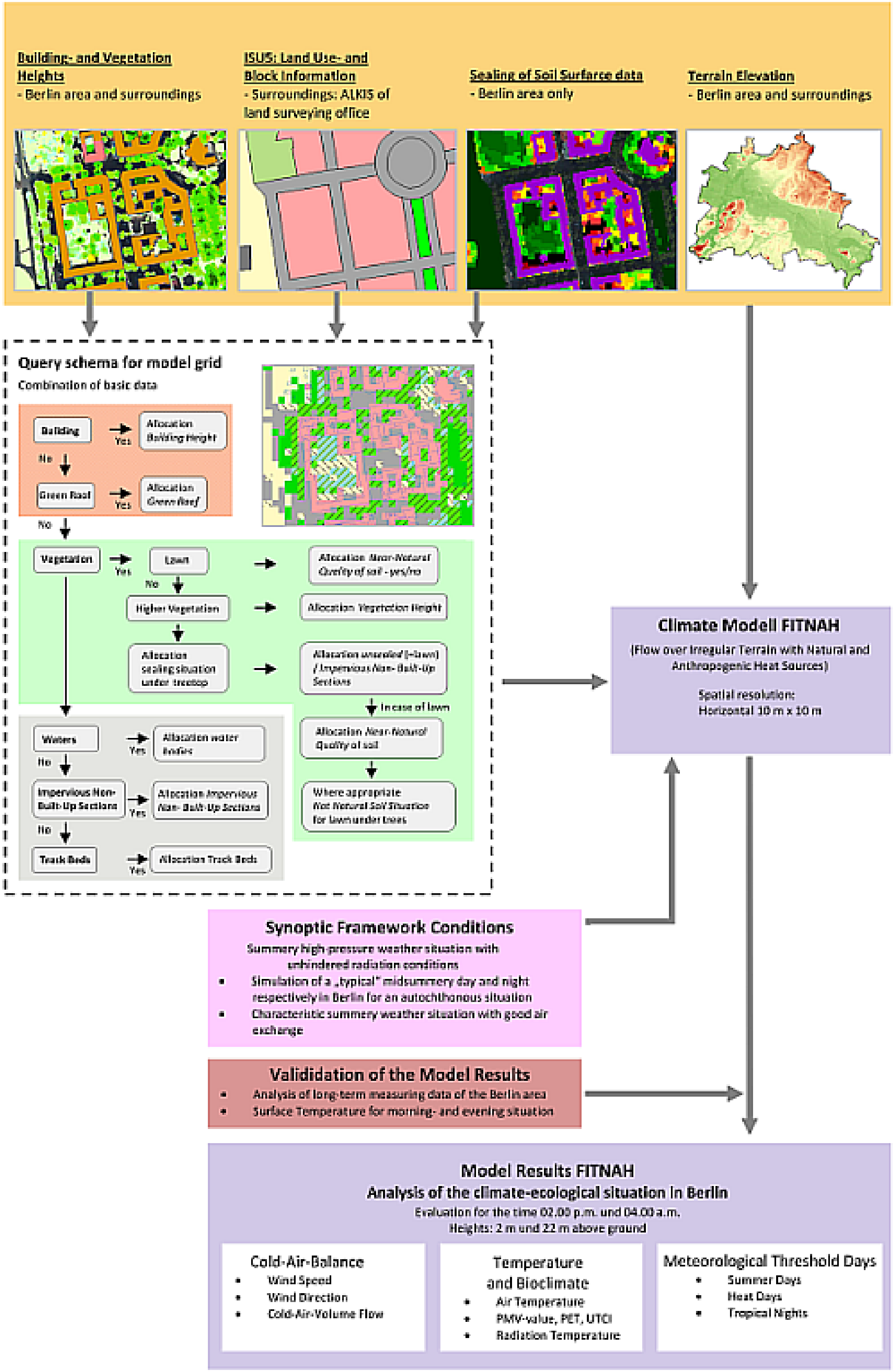


Fig. 5: Database and data flow for the application of the climate model FITNAH 3D

Methodology

One important factor in the creation and formation of an urban climate are the soil and surface characteristics, which have been changed in the urban area in relation to the surrounding countryside. The result is urban overheating and also the local urban wind circulation. Wind and temperature as well as quanta derived from them are the dominant factors affecting the assessment of urban climate from the aspects of human bio-meteorology and air quality.

The **investigation and recording of the urban climate** can be carried out with the help of various methods. These include field measurements, long-range ascertainment methods, wind tunnel studies, and the application of numerical simulation models.

Direct numerical simulation models are particularly well capable of representing the meteorological quanta, which are spatially and temporally very strongly variable, due to the great complexity of the building structure.

The detailed calculation of the wind and temperature conditions in the Berlin area within the scope of this actualization has been carried out using the **FITNAH** (**F**low over **I**rregular **T**errain with **N**atural and **A**nthropogenic **H**eat Sources) model. Groß 1993 and Richter & Röckle n.d. present detailed mathematical and physical descriptions of the model. Further detailed indications for the basic structure and approach of the three-dimensional FITNAH model, and for the interpretation of the model results, can be seen herein, on the basis of an exemplary comparison with measurement data, under Methodology/Supplementary Notes.

Generally, numerical simulation models are accepted for use in many fields of meteorology, since the data obtained provide important basic information for many areas of life (cf. Overview of the Most Important Models). The weather forecast for the next 1-5 days is obtained almost exclusively by means of such complex and extensive computer models. Knowledge of possible changes of our global climate over the next decades can also be derived from such calculations. And finally, models of a similar type are used to calculate the local and the regional distributions of meteorological variables in the atmosphere (Groß 2002).

Independent from the various scales and task definitions, all models are based on the same mathematical-physical system of equations. Only in detail are there scale-specific differences.

Meteorological and synoptic general conditions for model calculation

Along with determinations internal to the model, the meteorological general conditions also play a major role. Under the complete project, two model runs were conducted with the meso-scale climate model FITNAH for a high-summer weather situation with a horizontal resolution of 10 m. The first model run is based on an allochthonous west wind weather condition occurring relatively frequently in Berlin during the summer months. The second model run is based on an autochthonous weather condition without higher-level wind influence used regularly for an analysis of the urban climate. Additional data, differentiated in space, were derived from the various climatological parameters from the resulting meteorological fields. On the whole, therefore, three supplementing extensive data sets are available.

During the high pressure weather conditions (autochthonous weather conditions) the local climatic special features of a landscape can be expressed very well. Such a weather condition is characterised by a cloudless sky and a very weak, overlaying synoptic wind. In case of the numeric simulations carried out here, the large-scale synoptic general conditions were laid down accordingly:

- Cloud cover 0/8
- no overlaying geostrophic wind
- relative humidity of the air mass 50%
- 19°C air temperature at 09:00 p.m.

The comparatively low wind speeds at a low-exchange weather condition cause a reduced exchange of air in the air layer near the ground. A simultaneously high irradiation and emission can consequently lead to local human bio-meteorological and air-hygienic polluted areas. Characteristic for this (high-pressure) weather condition is the origin of independent cold air streams (corridor winds), which are driven by the temperature gradient between the cool open spaces and the warmer settlement areas.

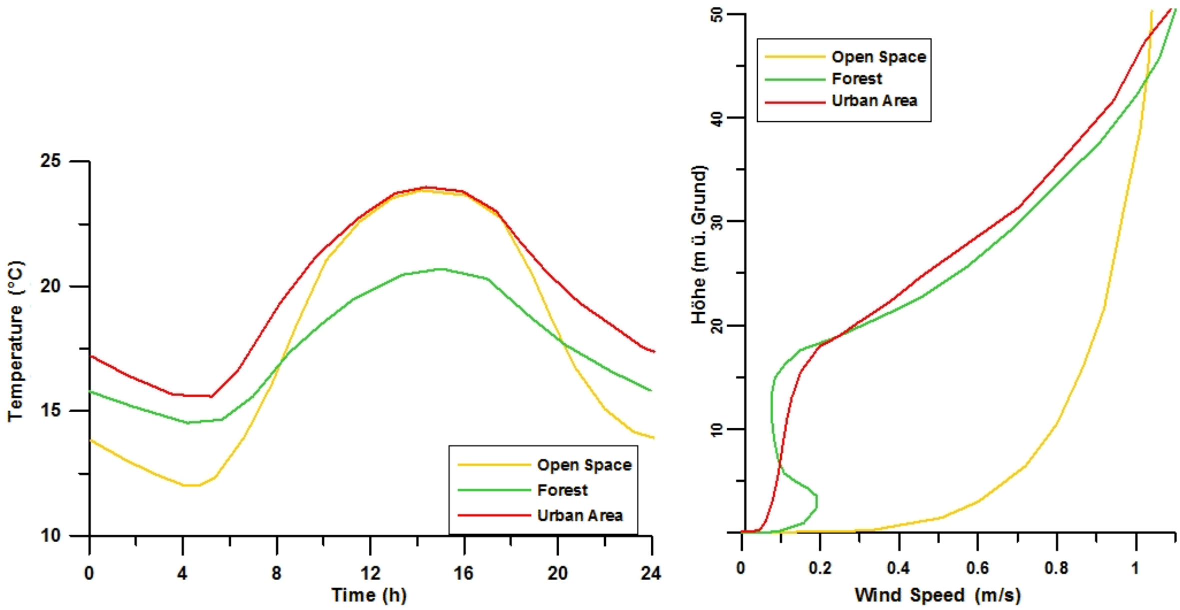


Fig. 6: Course of temperature and vertical profile of the wind speed at noon time for various land uses

Calculated parameters and characteristic values, final climate analysis map

During the analysis phase of the project, a large number of meteorological parameters were calculated at three points of time. Along with the day situation (02:00 p.m.), the evening as well as the early morning were also simulated at time sections 10:00 p.m. and 04:00 a.m. The observed height levels were at 2 m and 22 m above ground.

For the **analysis part 04.10, grid maps and block-based maps are present**, in which the individual parameters as well as also the meteorological climatic parameters are shown as mean area values. The summary Climate Analysis Map 04.10.7 builds the conclusion of the analysis as one of the main results of the study (see Map Description).

Determination of climatic parameters in the Berlin area (04.10.6)

A "climatic parameter" implies a day, on which a defined threshold value of a meteorological parameter is achieved or exceeded. In the context of the topic of urban climate, mainly the following climatic parameters are relevant, because they are closely associated with the occurrence of bio-climatic loads in settlement areas:

- Summer Days (maximum temperature ≥ 25 °C)
- Hot Days (maximum temperature ≥ 30°C)
- Tropical Nights (minimum temperature ≥ 20 °C)

The long-term measurements of climatic parameters (SenStadtUm 2015a) show a characteristic distribution of minimum and maximum temperatures on Summer Days for the various measurement locations in the urban area. The distribution reflects the different heat behaviour of the city, which results as a whole from the different usage structures as also from the position of a location within an urban area. In case of an otherwise similar use, the spatial position within the city thus determines, to what extent a location can benefit from the cooler surroundings or is present in the influence of over-heated adjacent city areas. An open space under the influence of the urban heat island will show a lower diurnal cycle than a similar area outside of the city. Since the absolute level of the summer temperature is determined primarily by the prevalent weather condition and only a modification is done by the situation of the location in the urban area, conclusions can be drawn from the measured temperatures of a location about the level at another location on the basis of the characteristic temperature differences.

The exceeding of defined values for the daily minimum / maximum determines the occurrence of the so-called climatic parameters. Since the daily extremes and also the simultaneously measured temperature differences at the stations show a characteristic distribution among one another, by knowing the temperature difference it can be determined for a reference location, how high is the probability that the threshold values will be exceeded there. If the frequencies of climatic parameters per year are known for a reference location, the frequencies at another location can be estimated.

Reference geometry for designating the climatic parameters is the block map 1:5,000 (ISU5_UA 2010), for which the grid-based temperature values of model simulation given therein were calculated using statistical methods. In a further step, temperature differences were determined for the values calculated for the DWD station Tempelhof (measurement period 2001 to 2010). Based on these temperature differences and the functional relationship between the temperature differences and the occurring frequencies of climatic parameters, these can be interpolated extensively to the urban area.

Climate Analysis Map (04.10.7)

The results obtained by applying the climate model FITNAH led to an extensive latest stocktaking of the climatic situation in the urban area and in the nearby surroundings. According to the VDI guideline 3787, Sheet 1, the Climate Analysis Map represents "t*he spatial climatic attributes of a reference area, which set in based on area usage and topography. The thermal, dynamic as well as air-hygienic conditions are shown. Note: The Climate Analysis Map contains and replaces the earlier synthetic climate function map.*" (VDI 2015).

This restructuring of thermal alignment and naming for preparing climate maps also follows the latest display in environment atlas by replacing the earlier climate function map 04.11.1 as part of evaluation map (SenStadt 2009) by the current Climate Analysis Map as completion of the analytical map part.

The aim of the map is to demarcate the areas of the city according to their different climatic functions i.e. their effect on other areas. Starting point is the classification of the study area in settlements with bio-climatic and/or air-hygienic loads (**effective area**) on one hand, and on the other, in cold-air producing, undeveloped and areas with pronounced vegetation (**compensation areas**) If these areas do not directly touch one another and the air-exchange processes are strong enough, linearly aligned, low developed open spaces (**air channels**) can connect both of them. The mutual demarcation of favourable and unfavourable areas as well as of the connecting structures results in a complex picture of process system of air-exchange streams of the **compensation area-effective area structure**.

The climatic function areas to be demarcated should provide information about the areas, in which

- on one hand there is a potential for relief of other (adjacent and remote) areas,
- on the other hand, the strongest additional loads are expected over and above the large-scale influence,
- preferably air-exchange areas are to be assumed i.e. an important role is assumed for the ground-level transport of fresh air.

The individual legend units are explained below.

The **cold air producing areas** are the open areas with pronounced vegetation, such as forests, parks and small garden areas, which are shown as 'green areas' according to their use. For characterising their compensation effect, the Cold Air Volume Flow is included in the Climate Analysis Map. It expresses the inflow of cold are from the adjacent grid cells in m³/s per 10 m grid cell (map 04.10.1).

The green area portions, which show a **climate-ecological effective Cold Air Volume Flow** of more than 90 m³/s, are highlighted with a shading. This makes it clear, which portions of a green area are to be considered as especially climatically relevant.

The ranges of the positive effects were termed as operation area of **cold air origin areas** in the Climate Analysis Map. These are to be considered as continuation of the Cold Air Volume Flow emanating in the settlement areas from the green and open areas. Frequently, a good aeration is present here as well as a trend towards a lower heat island effect.

A (positive) **development relevant to climate** shows an overall sealing degree of average less than 30 %. Because of their climatically favourable features, these areas show a more or less strong origin of cold air and favour the effect of nightly cold air in the direction of remote settlement areas.

The depiction of the **heat island effect in the settlement areas and in the road space** illustrates the thermal situation in the urban area during the night hours. The basis for this is the respective average night air temperature per area at 04:00 a.m., whereby the value determined over all areas is 17.8 °C. The demarcation of the evaluation classes is based on the method described for Z-transformation in VDI guideline 3785 Sheet 1 (VDI 2008), which is based on the local/regional value level of an analysis and evaluates the deviation of a parameter from the mean conditions in an investigation area. Unlike as in the planning advice map, the spatial characteristic of the nightly heat island effect is present in the foreground so that here the block area are shown differentiated with an exceeding of the area mean value (Z-value < 0). In the planning advice map, the settlement areas are evaluated as bio-climatically favourable with a Z-value of ≤ 0.

Tab. 1: Evaluation of the nightly heat island effect in settlement areas and in road space during the summer sunny weather conditions		
Mean Z-value of air temperature at 04:00 a.m. per area	**Range of mean air temperature at 04:00 per category**	**Evaluation**
≤ 0	14.5 °C to 17.8 °C	Not available
> 0 to ≤ 1	> 17.8 °C to 18.7 °C	Weak
> 1 to ≤ 2	> 18.7 to < 19.5 °C	Moderate
> 2	≥ 19.5 °C to < 21.3 °C	Strong

Tab. 1: Evaluation of the nightly heat island effect in settlement areas and in road space during the summer sunny weather conditions

This corresponds to a temperature value of less than 17.8 °C, at which there is no nightly over-heating. This is contrasted by the settlement / road areas with a mean value of more than 19.5 °C, which are classified as strong heat island effect. This is the same as an over-heating of more than 1.7 Kelvin (K).

The connections of different causes and characteristics in the form of lines and areas serve the air exchange at the ground level. Pathways connect cold air origin areas (compensation areas) and load areas (effective areas) with one another and hence are an elementary part of the air exchange. Four different air exchange types were worked out in the maps under consideration of the process:

- **Cold air pathway**, mainly induced thermally,
- Cold air pathway, mainly induced orographically (e.g. smaller river plains),
- Area-wise cold air outflow to slope ranges (in case of slope inclination >1°),
- Extensive **air and ventilation pathways** (lowlands of larger flowing water bodies).

The identification of cold air pathways is oriented to the autochthonous flow field of the FITNAH simulation. The indicated pathways, except the river lowlands, are areas with pronounced vegetation with a linear alignment to the effective areas.

In order to identify the area with **slope inclinations** >1°, on which an extensive outflow of cold air takes place, a relief analysis was carried out with the ground elevation model used in FITNAH.

For displaying the **traffic-dependent air load**, the data of the environment atlas map 03.11.2 "Traffic-dependent air load" was taken for information (SenStadtUm 2011). In the map, both the central traffic-dependent air pollutants of fine dust (PM10) and nitrogen oxide (NO_2) have been joined together to make an emission index.

The signature **wind field changes** denotes settlement areas having a potential for higher gustiness and sudden change of wind direction. These are the area types of core areas and large settlements, whose development can lead to corresponding effects on the wind field.

Moreover, the **noise control structures** are also shown in the Climate Analysis Maps, which were taken from noise mapping only for information (SenStadtUm 2013a). Their relevance for the climatic functions results from the fact that these are the structures, which sometimes can have a height of several metres. This results in a potential effect on nightly cold air flows. The knowledge of their position represents an important additional information in evaluating the air exchange processes, since the noise protection walls cannot be considered explicitly in the model.

Verification of the results of the climate model FITNAH

The information derived from the model runs was checked by means of data from a study of local climatic functions of open spaces in the Gleisdreieck area of Schöneberg.

On the basis of an extensive comparison, the measurement results of the study were compared with the simulation results of the model application.

As a result of this comparison, a **good level of agreement** can be established between the results of the measurement project and the modeling of the local air-current field in the Gleisdreieck area using FITNAH.

The self-generated, local current phenomena postulated by the model calculations can largely be confirmed by the measurements. Details on flow direction and speed are within the same range. The relevant air exchange processes – small-scale, orographically caused cold-air outflow from the Viktoriapark area of Kreuzberg and thermally induced compensation currents between the open areas of the Gleisdreieck and the adjacent buildings – are recorded and represented equally, both qualitatively and quantitatively (cf. Vogt 2002a, pp. 26 *et seqq.*). However, a more regionally characterized compensation flow between central Berlin and the surrounding countryside cannot be confirmed by either of the two methodological approaches (cf. Methodology / Supplementary Notes).

Approach, data basis and method of the process used for updating the climate data take into account a largest possible, simultaneously extensive detailing of the resulting statements. However, owing to the dynamic development in the city, the initial prerequisites for the evaluation on individual areas change faster than the possible update cycle of the maps in the environment atlas. Therefore, it is recommended to use the overlay function with the respectively latest air patterns in the geo-portal for an area check as well as for a comparison with the technical data of the analysis maps. From this, one can drawn inferences for the usability of the results.

Methodology / Supplementary Notes

In the following, extensive additional information on the topical complex of the methodological processing of the Berlin climate model is provided. The text thus complements the contents of the chapter Methodology.

The concept and methodology of the FITNAH climate model

The **basic structure of the three-dimensional FITNAH model** consists of the conservation equations for impulse, mass and internal energy, as well as balance equations for moist components and additive elements to the air. The various turbulent currents are connected to the calculable mean quanta with the aid of empirical inclusions. The turbulent diffusion coefficient appearing in that context is calculated from the turbulent kinetic energy, for which an additional equation is solved.

The warming and cooling rates in the atmosphere due to the divergence of the long-wave radiant fluxes are calculated by means of a procedure in which the emissivity of the water vapor in the air is taken into account.

For detailed simulations in real terrain, the orography, and particularly the **effect of wooded areas and urban structures** on the distribution of the meteorological quanta must also be taken into account in a realistic manner. For this purpose, FITNAH is provided with special parameterization.

A forest or grove will be incorporated into the model via stock-specific quanta, such as tree height, stock density and tree species. This permits, among other things, the simulation of the reduction of the mean speed in the stock, the rise of the turbulence in the crown area and the strong nightly cooling in the upper crown third, in agreement with available observations.

With consideration for the city-specific quanta building height, sealing and degree of construction coverage, and anthropogenic waste heat, the typical formation of an urban heat island at a reduced mean air current can be simulated (cf. Groß 1989).

The entire system of equations, including the parameterization, is transformed into a coordinate system which corresponds to the terrain. That permits, in particular, the formulation of the ancillary conditions of the various meteorological quanta in a problem-specific manner, specifically at the lower edge, the ground. The calculation of the earth surface temperature is carried out via an energy-flux balance, in which perceptible and latent heat current, the soil heat flow, short and long-wave radiation components, and anthropogenic heat flow are considered.

The differential equation of the equation system used is transferred to finite-difference equations and solved on a numerical grid. The spatial grid size Δx used here is 10 m in the two horizontal dimensions. The vertical grid interval is not equidistant, and the calculation areas are particularly dense in the near-ground atmosphere, in order to incorporate the strong variation of meteorological quanta realistically. The lowest calculation areas up to a height of 22m are 2m, beyond that 4m. The interval Δz becomes ever greater as the height increases, and the top limit of the model is located at a height of 3,000 m above ground. This is the altitude at which it is assumed that the disturbances caused by orography and land use at ground level (cf. Fig. 7) will have faded away.

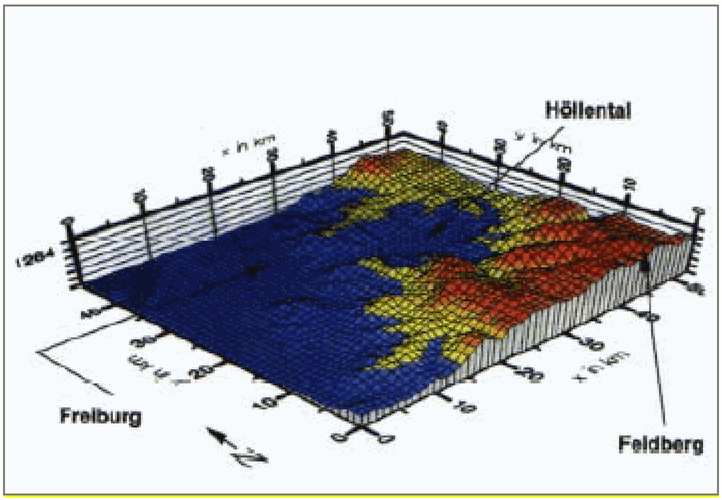


Fig. 7: Example for depicting a natural landscape in the model area character (from: Richter & Röckle n.d.)

Verification of the results of the climate model FITNAH

For checking the information levels derived from the model runs, one can fall back on the evaluation of long-term operated measurement stations in Berlin and Potsdam conducted in the scope of the EFRE project (SenStadtUm 2015a). These station data also helped in deriving maps for distribution of the mean number of meteorological climatic factors 2001-2010 (Map 04.10.6).

To check the informational levels derived from the model runs, a study of local climatic functions in the open spaces of the Gleisdreieck area can be used. The orienting investigation on current and temperature fields in the Gleisdreieck area is methodologically composed of:

- stationary measurement, summer semester 2001 (four measurement operations); and
- mobile measurements, winter semester 2001-2002 (four measurement operations).

The meteorological framework conditions seemed suitable to permit self-generated current systems to develop in the area of the Gleisdreieck (cf. Vogt 2002a and Vogt 2002b).

The following working hypotheses were to be checked by the measurement operations:

1. There is an autochthonous, regional current which transports cold air over the low-friction structures of the track area (i.e., an air-stream channel) from the Teltow area into the center of Berlin;
2. The Gleisdreieck area, which is characterized by open spaces, provides cold air to the immediately adjacent built-up neighbourhoods;
3. There is a cold-air outflow from the area of Viktoria Park in Kreuzberg, which intrudes into the open spaces of the Gleisdreieck area.

These assumptions agree with the hypotheses on the formation of autochthonous current systems between differently structured urban areas in this investigation, and therefore should be ascertainable again in the model results of the FITNAH simulations as well. The measurement data on the current field can therefore be used to check the plausibility of the model results herein.

However, a restricted applicability of this comparison must be assumed:

- The meteorological framework conditions for measurement were not in every case ideal for the clear development of self-generated current systems.
- A mobile and stationary measurement can always have only a random-sample character (spatially and temporally).
- The mobile measurements carried out during the winter semester were conducted during periods of extreme sub-freezing temperatures.
- "Virtually stationary" short-term measurements are involved, since at each of the 37 measurement points in sequence, the wind field parameters were ascertained for approx. 4 minutes. The measurement procedures for the recording of the wind field for this area probably lasted about 4 to 5 hours. Thus, what is represented is not a wind field for a defined period of time.

- In the model runs which were used for the comparison, ideal framework conditions for the formation of self-generated flow systems were assumed, i.e. the top current has a speed of 0 m/s.

Check of the working hypotheses on the autochthonous wind field

In this comparison, the results achieved within the early night time hours at 2.5 m above ground are to be considered as a matter of priority. Thus, far-reaching comparability of the model vs. the measurement results is ensured in this regard. The comparison is carried out on the basis of an established working hypothesis on flow conditions in the area under investigation:

- **There is an autochthonous, regional current which transports cold air over the low-friction structures of the track area (i.e. a ventilation lane) from the Teltow area into the center of Berlin.**

  Neither in the measurement procedure nor in the model calculations can any regional current be ascertained which uses the low-friction open spaces of the railway facilities as an air-stream channel.

  Any such current system would have had to be demonstrated in the measurements at the Monumentenbrücke measurement point (cf. Vogt 2002a, p. 14). However, all that could be ascertained from the measurement operations was the intervention of the top current into the relatively low-friction, vegetal areas of the Gleisdreieck. Even the mobile, winter measurement ascertained no such current (cf. Vogt 2002b, pp. 78 *et seqq.*).

  The model result, too, would not support any extensive exchange flow. The flow field (10 PM) shows a locally determined mosaic of small-scale air exchange cells, which are for the most part thermally induced. As a rule, the spatial extent of these "flow cells" is between 500 m and 1,200 m (cf. Fig. 5).

- **The Gleisdreieck area, which is characterized by open spaces, provides cold air to the immediately adjacent built-up neighborhoods.**

  The measurement provided clear indications of the existence of these local equalization currents (cf. Vogt 2002a, p. 15). However, the less-than-optimal meteorological framework conditions during many of the measurement procedures and the temporal delay at mobile measurements prevented a comprehensive illustration of these current systems.

  On the other hand, the model results generated by FITNAH provide a comprehensive picture of the spatial character of these local, primarily thermally induced current systems. In addition to the item-related statements of the measurements, the model results permit statements concerning the range (i.e., penetration depth) of the flows into the adjacent built-up areas. The area between the Lützowstraße and Kurfürstenstraße test points on the western edge of the Gleisdreieck area can be taken as an example. The cold air formed locally here penetrates approx. 500 m into the built-up area.

  The flow speeds measured or modeled achieve very similar orders of magnitude. As a rule, these thermally induced current systems are accompanied by wind speeds of from 0.1 to 0.5 m/s. The measurement projects indicate that these value were achieved both in the summer and the winter semesters (cf. Vogt 2002a, pp. 19 and 22). There is also a cold air flow at the Möckernstraße, whereas the penetration range amounts up to 150 m (cf. Fig. 8).

- **There is a cold-air outflow from the area of Victoria Park in Kreuzberg.**

  The measurement results on local cold-air outflow from the area of Viktoria Park in Kreuzberg confirm these FITNAH simulation calculations (cf. Vogt 2002a, p. 17). The measurements confirmed the canalization of the cold-air outflow through the Kreuzbergstraße and Großbeerenstraße. This flow was accompanied by low wind speeds of 0.7 to 0.2 m/s.

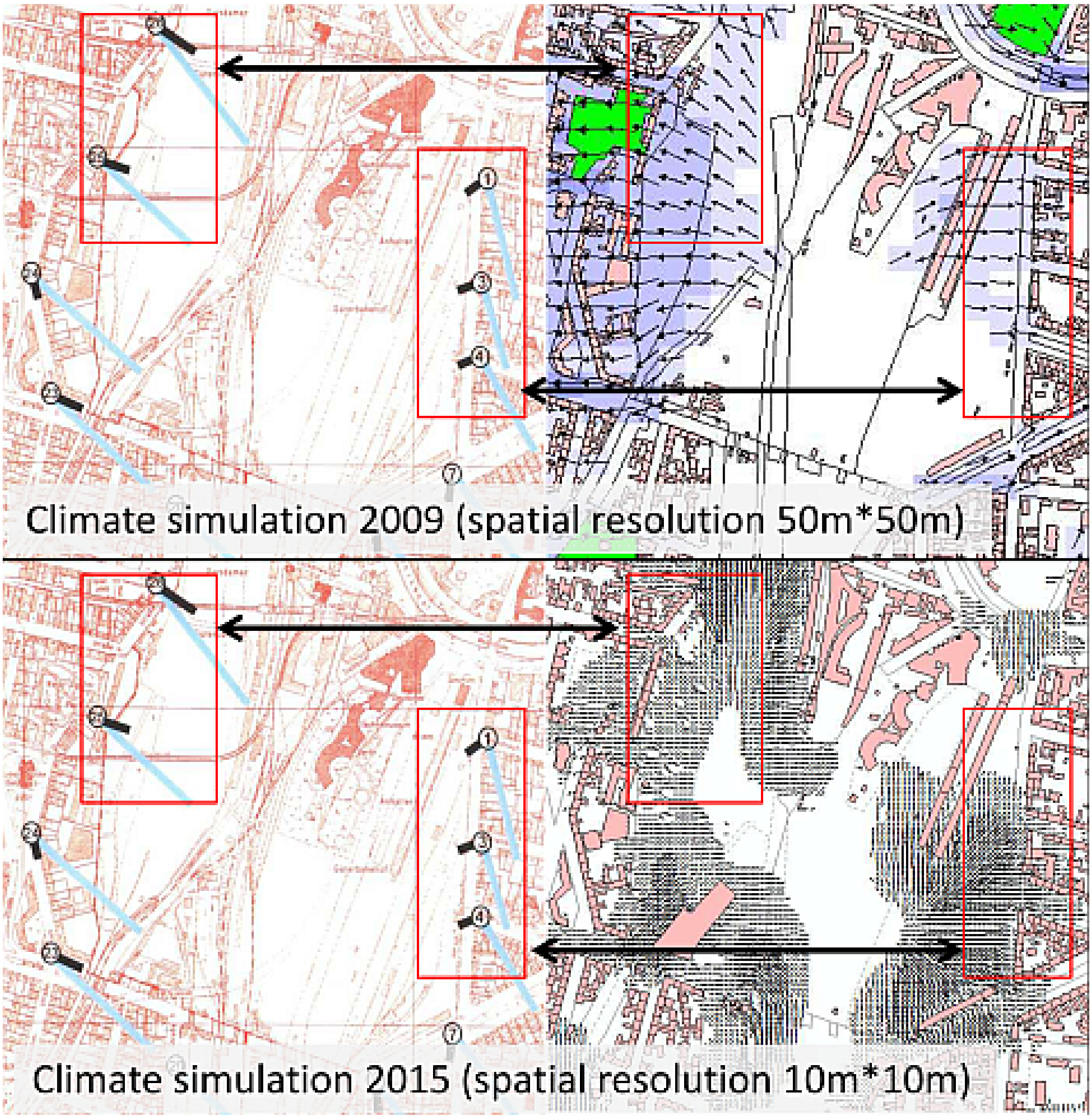


Fig. 8: Verification of the results of the climate model FITNAH 3D, application 2009 and 2015 (always right part of the figure) with the help of stationary and mobile measurements in the area of triangular junction (figure on the left, from Vogt 2002a and Vogt 2002b). In the figure on the left, the lines originating from the measurement points point to the direction, from which the wind comes; in the figure on the right, the wind arrows show the direction of flow

Result

Overall, there is **good agreement** between the results of the measurement procedure and the modeling of the local current field in the Gleisdreieck area using FITNAH.

The self-generated, local current phenomena postulated by the model calculations can largely be confirmed by the measurements. Data on flow direction and speed are within the same ranges. The relevant air exchange processes - small-scale, orographically-determined cold-air outflows from the Viktoriapark in Kreuzberg and thermally induced compensation currents between the open spaces of the Gleisdreieck and the adjacent built-up neighborhoods - have been ascertained and represented equally, both qualitatively and quantitatively (cf. Vogt 2002a, pp. 26 *et seqq.*). However, it was not possible, by either of the two methodical approaches, to support any regionally-characterized compensation current between central Berlin and the surrounding countryside.

Map Description

Given below is a joint description for all the individual evaluations of model calculations. Links are given to the individual focus areas for a faster orientation in the text:

- 04.10.1 Near Ground Wind Field and Cold Air Volume Flow (10:00 p.m. and 04:00 a.m.)
- 04.10.2 Air Temperature (02:00 p.m. and 04:00 a.m.)
- 04.10.3 Radiation Temperature (02:00 p.m. and 04:00 a.m.)
- 04.10.4 Nocturnal Cooling Rate between 10:00 p.m. and 04:00 a.m.
- 04.10.5 Evaluation Index of Physiological Equivalent Temperature (PET)
- 04.10.6 Number of meteorological climatic factors in the middle of the years 2001-2010
  - Number of Summer Days
  - Number of Hot Days
  - Number of Tropical Nights
- 04.10.7 Climate Analysis Map

Within the mentioned topics, the different spatial structures (grid, block) as well as the different points of time and height sections are mapped separately as further differentiations in the maps. These different pieces of information can be selected for each topic via the level switching of the Geoportal ( ).
The model calculations were started in the evening at the time of the sunset and carried out till sunrise of the day after the next. The time sections, in which the model results are to be selected, can be selected freely in principle (minutes till seconds). The individual climatic parameters for the various **points of time (MEZ)** are evaluated and shown in the form of maps, which permit inferences about the climatic functions and their significance.

The date **10:00 p.m.** represents the reversal from irradiation to emission situation shortly after the sunset and stands for the start of a phase with a high cooling dynamics in the differently structured partial areas in the city. The date **04:00 a.m.** stands for the maximum cooling within the body of the city in a high summer clear night. Both the points of time are thus relevant mainly for characterising the nightly air-exchange. The time section **02:00 p.m.** is also suitable for evaluating the bio-climatic situation during the day, because at this point of time the solar irradiation and consequently also the air temperatures are strongly pronounced. The time of 02:00 p.m. as evaluation time was also necessary for the evaluation of the bio-climatic stresses during the day newly included in the current version of the planning advice map (SenStadtUm 2016).

The analysis maps 04.10.1 to 04.10.5 are present in grid-based as well as block-based form. In doing so, the statistical, not weighted mean value of all grid cells overlapping the block / partial block areas is shown. The meteorological climatic factors (Maps 04.10.6) as well as the Climate Analysis Map (Map 04.10.7), on the other hand, are present only in the form of a block, since these were not modelled directly, but instead were derived from the grid-based results of climate modelling.

Given below is a brief description of individual, exemplary results of model calculations for the complete city area.

In chapter Map Description / Supplementary Notes, a differentiated explanation is provided for an exemplary area in the district of Charlottenburg-Wilmersdorf

Map 04.10.1 Near Ground Wind Field and Cold Air Volume Flow (10:00 p.m. and 04:00 a.m.)

General comments

The good aeration of the settlement areas can lead to a reduction of human bio-meteorological loads (see Moriske and Turowski 2002). Thus, in the night hours, the bringing up of cooler air from the surrounding areas can lower the temperature level of the warmer air masses present in the city, which leads to a reduction of heat load on the people in the summer months. If this introduced cooler air is free of air pollutants (fresh air), the aeration then simultaneously also leads to an improvement of the air-hygiene situation.

For evaluating the aeration situation, consequently, it is necessary to have the suitable **assignment of load areas and compensation areas**, which provide the correspondingly unloaded air as well as a circulation system, which can bring about the transportation of air masses.

The ground level temperature distribution causes horizontal air pressure differences, which, in turn, are triggers for the local, thermal wind systems. Starting point of these processes are the night temperature differences, which become set between the settlement areas and the open spaces with pronounced vegetation. At the prone areas, the cooled and hence heavy air comes in motion in the direction of the deepest point of the terrain. This gives rise to cold air outflows at the slopes (incl. MOSIMANN et al. 1999).

The wind speed of this small-scale phenomenon is determined primarily through the temperature deficit to the surrounding air and through the inclination of the terrain.

Along with the orographically caused flows with cold air outflow, the so-called floor/structure winds i.e. a direct compensation flow from high to low air pressure are also formed. They arise, when strongly overbuilt or sealed areas get heated more strongly than the surrounding open spaces and, as a result, a thermal trough arises over the urban areas. Consequently, the resulting pressure gradient can be compensated through inflowing cooler air masses from the surrounding regions (Kiese et al. 1992). For characterising these flows, it is important that the air can be accelerated over a certain stretch and is not hindered by the available obstacles, such as the built-up area. The floor/structure winds are closely restricted, often only weakly pronounced flow phenomena, which can be overlaid by a weak overlaying wind. Their speed lies mostly below 0.2 m/s (Mosimann et al. 1999).

The temperature differences typical for land use start building shortly after sunset and can last for the whole night. In doing so, grasslands and arable regions especially prove to be productive of cold air. Depending upon the surface features and cooling rates, the rapid development of cold air streams is associated with this, which at first are very weak vertically (5-10 m layer height) and form between the multitude of areas with different temperatures.

Map contents

Climate-ecological compensatory effects potentially originate from all unbuilt and unsealed areas, inside as well as outside of the city area. To what extent can this potential unfold, depends on the respective boundary conditions, from the size of the area, the vegetation structure, the position in the city area as well as on the surroundings characterised by construction. The large number of open spaces within the city, as compared to the other metropolises, is extremely significant for a city like Berlin not classified topographically to a large extent, because here the city-climatic compensation for the core area of the city takes place primarily through circulations caused thermally, which calls for a highest possible nearness of green and built areas to each other (see Map 04.11.1 Planning Advices Urban Climate 2015, Fig. 8).

The representation of the near-ground temperature field involves the grid instrument of temperature at the near-ground layer of the atmosphere (0-5 m above ground). If several land uses with different area shares are present within a grid cell, the temperature shown is calculated from the proportional weighting. Thus, the simulated temperature values are comparable only for larger areas with a uniform or comparable land use with ground-bound measurements.

Decisive for the temperature distribution are the land-use dependent soil and surface characteristics, as well as their interactions with the atmospheric processes in the near-ground boundary layer. Within the soil, heat and temperature conductivity are of importance in this regard. The greater the heat conductivity of the soil, for example, the faster and more deeply heat can penetrate into the corresponding material - but also: the faster it can escape again.

The surface composition of natural and artificial areas determines, via the albedo (reflection capacity) and the emissivity, the quantity of energy available in the short and long-wave ranges of radiation for warming/cooling. Finally, the turbulence condition of the near-ground atmosphere plays a major role in the transportation of perceptible and latent energy to and from the ground. All processes mentioned are interconnected via the energy balance of the soil, and determine the temperature of the surfaces and the layers of air above them.

The **grid-map levels** represent ground level pronounced cold air flow field at a height of 2 m at the night evaluation times of 10:00 p.m. and 04:00 a.m. in 10 m x 10 m resolution as well as at roof level at a height of 22 m above ground. The wind field in the form of direction of flow and flow speed is mapped via the arrow direction and arrow length in the form of vectors for all cells of the model grid with a minimum speed of ≥ 0.05m/s relevant for the climate. These grid-based data are supplemented by the display of the Cold Air Volume Flow as area value in m³/s. The term of Cold Air Volume Flow implies the product of flow speed of cold air, its vertical (layer height) and horizontal expansion of the flowed cross-section (flow width). It thus describes the quantity of cold air in the unit m³, which flows every second through – in this case - a 10 m x 10 m grid cell (see Fig. 9).

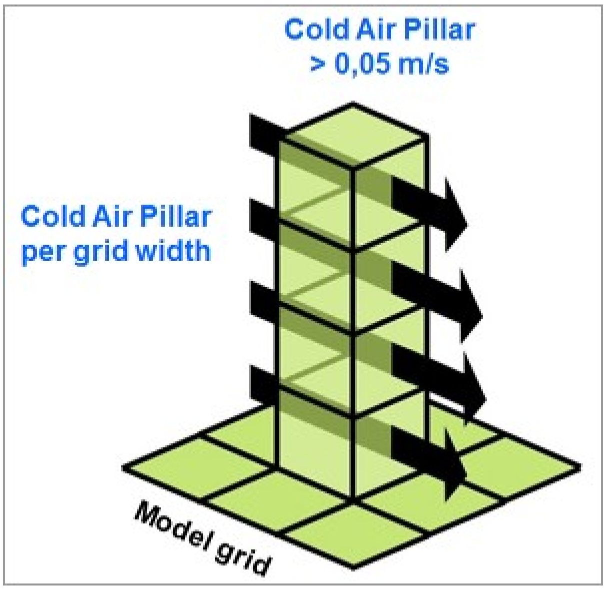


Fig. 9: Schematic diagram of cold air volume flow (Source: GEO-NET 2013)

The Volume Flow is thus a measure of the inflow of cold air and determines the magnitude of the aeration potential. Since it is a parameter integrated over height, there is no display for the roof level. All cells of the 10 m x 10 m grid are mapped with a value of > 60m³/s, for which a potential climate-ecological effectiveness is determined. The qualitative evaluation of this meteorological parameter is shown in Tab. 2. The classification of the grid-based Cold Air Volume Flow is oriented to the method for Z-transformation described in the VDI guideline 3785 Sheet 1 (VDI 2008). This method is based on the local/regional value level in a period of study and evaluates the deviation of a parameter from the mean conditions in this area. This method results in four evaluation categories of grading very favourable / favourable / less favourable / unfavourable.

Tab. 2: Classification of the grid-based cold air volume flow

Mean Z-value per grid cell	Evaluation	Volume flow in m³/s
< -0.5	Low	<= 60
0 to –0.5	Medium	> 60 - 90
1 to 0	High	90 - <= 145
> 1 (upper S1 limit)	Very high	> 145

Tab. 2: Classification of the grid-based cold air volume flow

The penetration depth of cold air in settlement areas and hence also the measure of bio-climatic favourable effect during the high pressure weather conditions in summer depends on the development structure and the intensity of cold air dynamics. In line with the increasing building height and density, single and town house complexes are flown through better than a block and perimeter development.

At the analysis time of **10:00 p.m.**, shortly after the sunset, the evening cooling phase starts, whose intensity depends on the respective structures and hence also influences the cold air flow field that is building up. In the context of inner-city green and open spaces, these are mostly rather a small-scale pronounced air exchange processes, in which the Cold Air Volume Flow hardly exceeds 90 m³/s. Depending upon a cold-air producing area and the surroundings, the cold air acts between 50 m and 300 m in the development. This makes it clear that **mainly an adequate number and favourable position of these relief areas is significant for reducing the stresses inside the city**.

High or very high volume flows in this section of time are observed only in the outlying areas and are mostly related to the local cold air outflows. These are encountered on the eastern bank of the river Havel along the Grunewald or to the south of the Great Müggelsee in the city forest of Bürgerheide.

At the time of **04:00 a.m.**, the cooling of the green and open spaces and hence also the production of cold air is much advanced. The span of the penetration depth varies perceptibly and lies, depending upon the structural conditions, between 100 m and more than 1000 m. In areas of settlement types with lot of greenery, their 'independent' production of cold air is also added, which is then reflected in the favourable bio-climatic conditions there (SenStadtUm 2016). Parts of the inner-city block and perimeter development as well as of the district centres, on the other hand, are not flown through by cold air in the second half of the night too, because their high building density and hence the higher temperature level weaken the possible cold air flows, as long as they are present in the potential activity range of compensation areas at all.

Map 04.10.2 Air Temperature (02:00 p.m. and 04:00 a.m.)

General comments

Decisive for the temperature distribution are the land-use dependent soil and surface characteristics, as well as their interactions with the atmospheric processes in the near-ground boundary layer. Within the soil, heat and temperature conductivity are of importance in this regard. The greater the heat conductivity of the soil, for example, the faster and more deeply heat can penetrate into the corresponding material - but also: the faster it can escape again.

The surface composition of natural and artificial areas determines, via the albedo (reflection capacity) and the emissivity, the quantity of energy available in the short and long-wave ranges of radiation for warming/cooling. Finally, the turbulence condition of the near-ground atmosphere plays a major role in the transportation of perceptible and latent energy to and from the ground (Map 04.06 Surface Temperatures Day and Night, Edition 2001).

All processes mentioned are interconnected via the energy balance of the soil, and determine the temperature of the surfaces and the layers of air above them.

Map contents

The temperature conditions of the ground level atmosphere are similarly mapped based on grid and block at different times of the day as levels of the main map.

In general, although the night temperature distributions are more expressive for evaluating the climatic potentials of relief and loading of areas, they also show the characteristic differences in the noon hours (**02:00 p.m.**) according to area distribution.

Sealed areas as well as **open spaces with lawns** are heated strongly during the day, the reason for which is the intensive solar irradiation, the lack of shading as well as the strong heating of the ground level air layer. The temperatures that occur here can lie between 30 °C and 32 °C, which represent the highest values in the scope of the modelled summer situation.

The **forest areas** as well as larger inner-city green areas, like the Great Zoo show at this time about 3K lower temperatures in their parts having trees.

Areas with pronounced construction are although higher in their overall temperature level, but here a differencing of the temperature behaviour reflecting the respective small-scale situation can be seen here in the grid display. This is an event of further detailing of data basis and model grid associated with this version of climate modelling. This now makes it possible, for instance, to differentiate grid cells with trees or grass from the sealed areas in their temperature behaviour and to evaluate them accordingly. The block-related aggregations smoothens the differences built by the not weighted mean value formation.

The lowest values are encountered over **water surfaces** owing to their specific heat capacity, they behave very homogeneously and act for compensating the climate during the day.

Depending upon the individual surface attributes of the different land uses, the earth surface cools during the night in different intensities, the **temperature distribution at 04:00 a.m.** in the morning reflects the time of the strongest cooling.

While this cooling is very low for **bodies of water**, due to their good heat-accumulating qualities, open areas like **fields and meadows** show a strong drop in temperature. In **wooded areas,** the crowns of the trees protects the near-ground atmosphere below from cooling off strongly; therefore, forests stand out in the temperature distribution as relatively warm areas.

In the **urban areas**, cooling is reduced considerably by the presence of heat-storing materials like concrete and stone. For one thing, the quantity of heat stored during the day causes the temperature not to decline so strongly. Moreover, the low wind speeds of turbulent and latent heat currents, which might otherwise remove warm air, are reduced. The urban areas thus continue to remain warmer on the whole. The temperature differences at the unbuilt city limits or the surroundings can be more than 8K in the early morning hours. These high horizontal differences are not quite achieved in the neighbourhood to the inner-city open spaces, sometimes, there is also a negative effect on the green areas from the built areas.

Map 04.10.3 Radiation Temperature (02:00 p.m. and 04:00 a.m.)

General comments

The Radiation Temperature is an important component for calculating the bio-climatic evaluation indices, like the indicator PET used here (see map 04.10.5), because it has a high impact on the heat balance of the humans.

It is defined as the "*uniform temperature of a black radiating enclosed area, which leads to the same radiation energy yield of a human being as the current short and long-wave radiation flows*" (Matzarakis, A., Rutz, F., Mayer, H., 2000). It takes into account the different radiation flows on the humans, which include the direct (short wave) solar radiation, the diffuse sky radiation, the short-wave reflex radiation, the counter-radiation of the atmosphere as well as the infra-red radiation emanating from the surfaces. However, the parameters calculated in °C may not be equated with the air temperature values of the observed grid / block owing to this complex composition of the values. The different daily course of the radiation and air temperature is shown in Fig. 10.

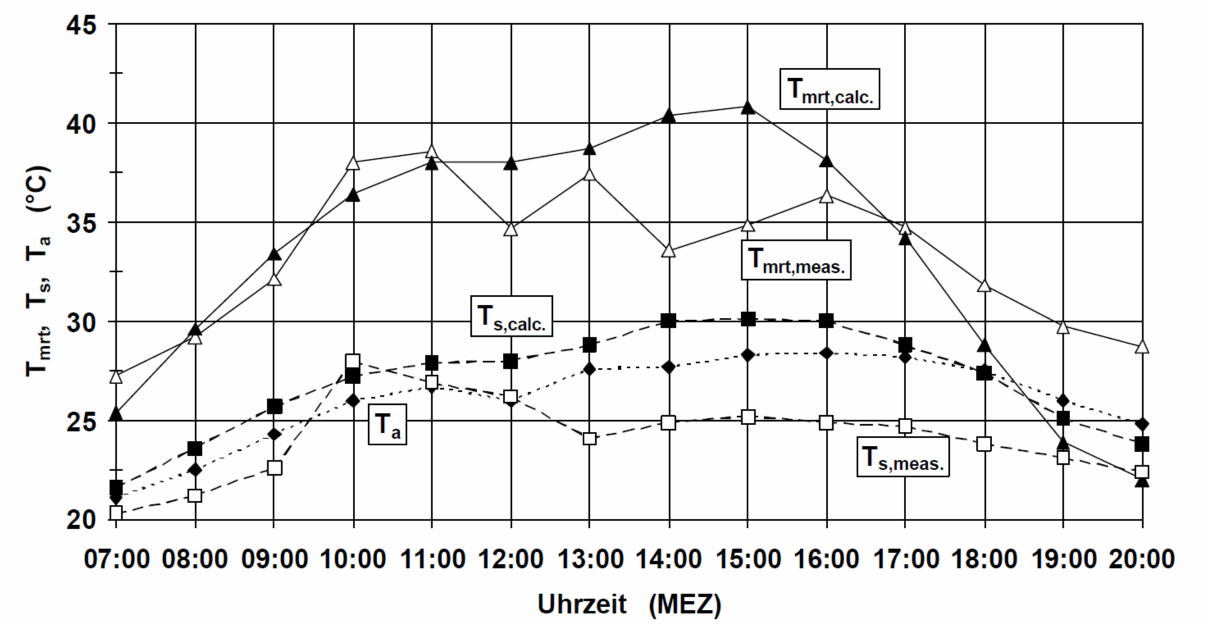


Fig. 10: Diurnal cycle of air temperature T_a, mean radiation temperature T_{mrt} (from radiation measurements: $T_{mrt,meas.}$; calculated via RayMan: $T_{mrt,calc.}$) and ground surface temperature T_s (from radiation measurements: $T_{s,meas.}$; calculated via RayMan: $T_{s,\ calc.}$) on a pleasant summer day over treetops (degree of crown cover: 0.88) on a green area in the northern city centre of Freiburg; reference height for T_a and T_{mrt}: 1.1 m height above ground (Matzarakis, A., Rutz, F., Mayer, H., 2000)

Map contents

The radiation temperature at **02:00 p.m.** shows that the characteristic of this parameter is controlled mainly by the solar irradiation. In doing so, **arable land and pastures** as well as **sealed areas** show the highest values. In **forest areas** the lowest radiation temperature is present owing to the shadow effect of the crown cover. In the **settlement areas**, a small-scale mosaic of high and low temperatures is calculated owing to the buildings, sealed areas and trees being present close to one another. The value level over **water bodies** lies between that of the forest and settlement areas. The reason for this is the high specific heat capacity of water, its special kind of radiation absorption and the turbulent mixing processes taking place in the water body.

At the time of **04:00 a.m.** the radiation temperature is primarily controlled via the (long-wave) heat radiation from the different surface structures. While doing so, the highest values are determined within the densely built settlement areas, which can be traced back to the high construction volume and its heat emission in the night hours. A little less is the radiation temperature over the **water surfaces**, which are now partly emitting the heat stored during the day. The lowest values are present over the **pastures and arable lands**, because their surface simultaneously also show the highest night cooling. Similar to air temperature, the radiation temperature is higher in the forest areas in the night hours than over open spaces, but still less than in the settlement areas.
The possible total difference between the highest (dense block construction) and the lowest values (open spaces) for the radiation temperature lies in the night hours is around 9.5 ° Kelvin (K).

Map 04.10.4 Nocturnal Cooling Rate between 10:00 p.m. and 04:00 a.m.

Map 04.10.4 shows the nightly cooling surfaces of the individual structures between the time sections of 10:00 p.m. and 04:00 a.m. for each grid cell or as block mean value in Kelvin (K) per hour. In doing so, the extent of cooling – depending upon the physical soil and surface attributes according to the land use – can show high differences. To this effect, the city structures become apparent in a characteristic way. Owing to their high heat conductivity and capacity, the lowest cooling lies over **water bodies** as well as **settlement areas with high construction density**. A moderate night cooling is encountered in a major part of the remaining development. **Forest areas** and **settlement types with high greenery**, on the other hand, show clearly higher cooling rates. This is most strongly pronounced over **arable land and pastures**.

Map 04.10.5 Evaluation Index of Physiological Equivalent Temperature (PET) (02:00 p.m. and 04:00 a.m.)

General comments

Meteorological parameters do not act upon humans independent of one another. The evaluation of the thermal effect complex has a special significance. All climatic parameters, which directly influence the heat balance of the humans, play a role here. Air temperature, air humidity, wind speed and thermal-physiologically effective radiation. For evaluating the thermal heat complex, the three methods

- Universal Thermal Climate Index (UTCI)
- Predicted Mean Vote (PMV) and
- Physiological Equivalent Temperature (PET)

were modelled and compared.

For evaluating the day situation, the PET index was included in the result (Höppe and Mayer 1987). As compared to the similarly calculated indices as also the PMV used earlier, the advantage of PET is that it can also be understood better by non-experts owing to its °C unit. Moreover, PET is also a parameter, which has now become a kind of "quasi standard" in the technical world and more strongly takes into account the environmental medicine aspects so that the results from Berlin can also be compared with those from other cities (even from outside of Germany).

The PET was derived from the Munich's Energy Balance Model MEMI and, like other methods, is based on the heat exchange of the human being with his environment (Höppe 1984). In Tab. 3 - with reference to only the day hours - the thermal sensitivity (derived from the behaviour of a "standard person", which represents an average thermal sensitivity) and the physiological load level are compared with the PET index. An optimum comfort sets in at 20 °C. At higher values, a heat load is present, whereas lower values give rise to a cold stress.

Tab. 3: Assignment of threshold values for the evaluation index PET during daytime hours

PET	Thermal sensitivity	Physiological load level
4 °C	Very cold	Extreme cold stress
8°C	Cold	Strong cold stress
13°C	Cool	Moderate cold stress
18°C	Slightly cool	Weak cold stress
20°C	**Comfortable**	**No heat load**
23°C	Slightly warm	Weak heat stress
29°C	Warm	Moderate heat stress
35°C	Hot	Strong heat stress
41°C	Very hot	Extreme heat stress

Tab. 3: Assignment of threshold values for the evaluation index PET during daytime hours (Matzarakis 1996, VDI 2008)

Map contents

The PET values at **02:00 p.m.** show a strong dependency of the heat loads occurring during the day on the local shadowing situation. A moderate heat load on cloudless Summer Days with strong solar irradiation is shown, accordingly, by **forest areas** as well as by areas with pronounced trees and groves.

The reduced direct solar irradiation through shadow formation by the vegetation and the evaporation of water contributes here to comparatively low load potential. As a result of its quality of stay, especially in the neighbourhood of strongly **overbuilt quarters**, a very important role is thus ascribed to the inner-city green areas. These are contrasted by strongly sunny areas, where the heat load shows the highest values during the day. In doing so, similar high temperatures are achieved over **grass fields** as well as over **sealed areas**.

The situation in the early morning for the time section **04:00 a.m.** shows that **fields and meadows** - especially in the outskirts and the surroundings of Berlin - cooled down considerably shortly before sunrise, whereas the **built-up urban spaces** remain at a significantly higher value level. This is only interrupted by the **large inner-city green spaces** like the Tempelhofer Feld, the Gleisdreieck or the Great Tiergarten, which have adjusted to the PET values of the open spaces in the outskirts or the surroundings according to the vegetation structure.

Map 04.10.6 Mean Number of Meteorological Climatic Parameters

General comments

With the knowledge of the climatic parameters at a reference location, the frequencies can be estimated at other places with the help of the present temperature difference. Based on the simulated air temperatures during the day and in the night at the measurement location of Tempelhof (reference time period 2001 to 2010), the difference from the mean temperature for each ISU5 block (partial) area was determined and the frequency of climatic parameters per day was determined (see Methodology / Supplementary Notes).

The number of **Hot Days** represents a subset of the **Summer Days** and is hence included in the map of days with ≥ 25 °C.

The frequency within the **settlement areas** depends on their structural density and their green portion. In doing so, mainly the blocks with corresponding degree of building and less green portion, such as core areas or uses similar to core areas, commercial and industrial areas with dense building or large-area sealing as well as similar area types of residential buildings show the highest values on the summer as well as Hot Days. Similar high values are shown by large settlements and high-rise buildings owing to the high share of open areas with grass, which can get strongly heated up during the day. These are contrasted by green settlement types with a strongly pronounced tree stock e.g. in Charlottenburg-Wilmersdorf with much less number of summer and Hot Days.

Even the **green and open spaces** show a high range, whereby a high number of summer and Hot Days per block is present over the arable land and grass lands because of the more intensive solar irradiation. Because of the micro-climate, the frequency is the lowest within the **forest areas**.

In case of the nightly lowest temperatures and hence also the number of **Tropical Nights**, the effect of the development present and hence the **urban heat island effect** becomes clearly apparent in the block areas. Most of the Tropical Nights can thus be seen in City East and parts of City West. These are contrasted by the green settlement types or the development near the outskirts of the city having a low number. The remaining development takes an average position in its night temperature level and hence in the number of Tropical Nights.

Owing to a strong nightly cooling, the arable land and grass lands show a low number of Tropical Nights. This is a bit more highly pronounced in case of forest areas and somewhat similar to the well green settlement areas, such as villa construction, as far as the number is concerned.

Map 04.10.7 Climate Analysis Map

General comments

The Climate Analysis Map maps the actual state of the climate relevant for planning. To do this, the extent of the urban over-heating, the compensation effects of areas producing cold air as well as the spatial relationships between compensation and effective areas are shown. The effects of open spaces of the surrounding regions on the city area are also included.

The differentiation of spatial units "settlement area" and "green and open areas" follows a system, which derives from the area types of the Urban and Environmental Information System (ISU) (SenStadt 2010). More detailed information for deriving these spatial units is given in the accompanying text for planning advice map urban climate here (SenStadtUm 2016). Fig. 11 represents the spatial distribution over the city area.

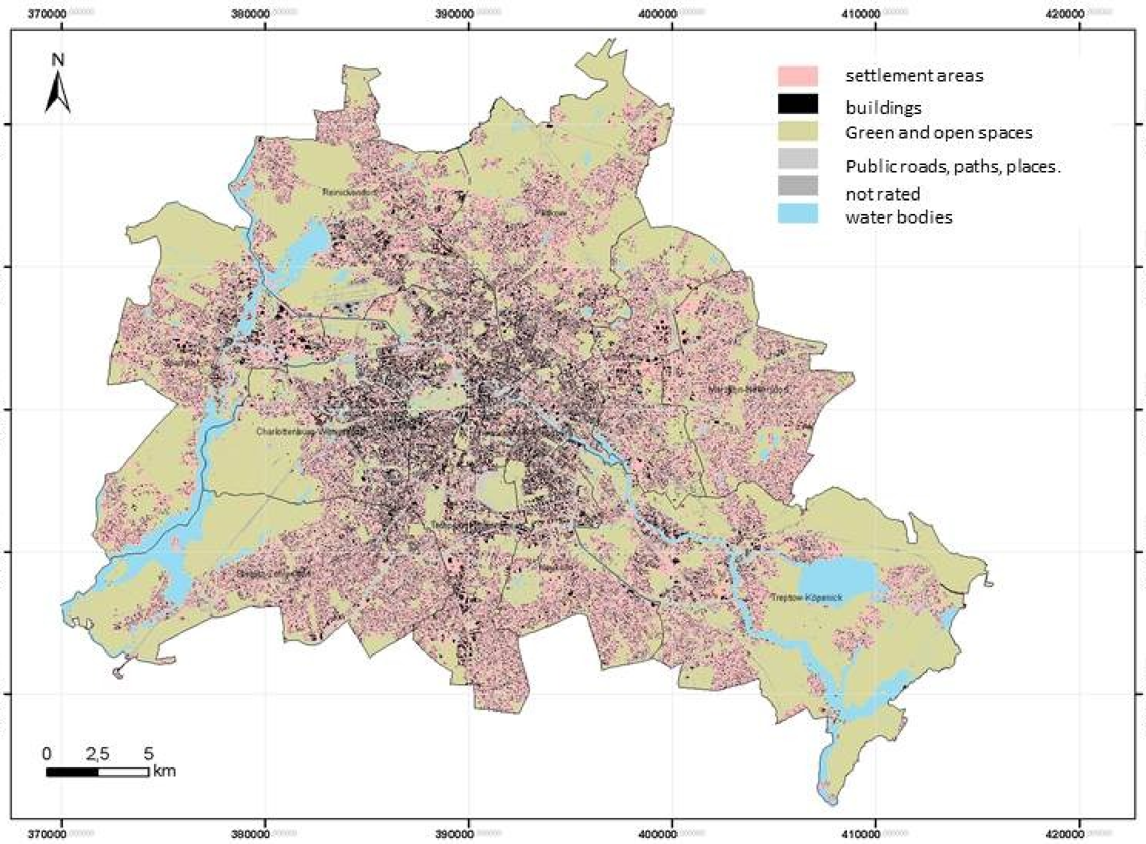


Fig. 11: Complete urban distribution of the spatial units of the climate model on the basis of area types of the Urban and Environmental Information System (ISU) (SenStadt 2010)

Green and open spaces

Open spaces with vegetation having a noteworthy cold air production represent the climate and emission ecological compensation areas. A high long-wave nightly radiation during the low-exchange high pressure weather situations leads to a strong cooling of the ground-level air layer. The quantity of the cold air produced depends upon the prevalent vegetation type, the ground attributes and the related nightly cooling rate.

The total area of the potential cold-air producing green areas within the urban area is approx. 351km², which is the same as an area portion of around 39.5 % of the complete urban area and can be considered as high. In doing so, the characterisation of cold air supply within the green areas is mostly differentiated spatially. Often, the central inner-city green areas show a rather low Cold Air Volume Flow as compared to the one present at the development of the adjacent partial areas. The reason for this is that, driven by the temperature difference between the open space and construction, the cold air must first be accelerated and then the values increase in the direction of construction. In the transition area between green area and construction, the temperature gradient and hence also the intensity of the air exchange are the highest. Areas with a volume flow of >90 m³/s are, therefore, highlighted as areas with high and very high air exchange (see Tab. 2). Partly, these areas also continue as areas with valorisation "Cold air activity area in settlement space" in the constructed areas.

Large, linearly shaped open areas with relatively low surface friction function as **air-stream channels for cold-air transportation**. In this regard, three areas of the Havel and Spree Valleys are significant. First, the Havel section between Pichel Lake and Ruhlebener Straße which conducts cold air toward the borough of Spandau along an approx. 3 km corridor; second, Rummelsburg Lake, a part of the Spree, stands out as an area through which cold air streams from old Treptow and from the Plänterwald woods toward Rummelsburg; and finally, a section of the Dahme should be mentioned, along the Grünauer Straße-Regattastraße corridor. These results coincide with the results of a report of the German Meteorological Service (DWD 1996).

However, due to the hardly distinctive orography, such relief-determined ventilation lanes are rather rare. An essential contribution to the transportation of cold air from the countryside surrounding Berlin into the urban area cannot be ascertained; rather, only some parts of the river valleys within the urban area function as air-stream channels.

Settlement areas

As already described in the Section Method (cf. Tab.1), the night heat island effect has been determined 2 m above ground with the help of the statistical method of Z-transformation of the modelled night air temperature. With this method, a spatial sub-division of the settlement area can be done according to the criteria of the nightly over-heating as compared to open space conditions. In the scope of determining the areas with bio-climatic load during the night in the planning advice map, similarly, the distribution of the air temperature was included (SenStadtUm 2016).

Mainly the areas classified as "Heat island effect not present or weak" are more or less under the positive influence of a **cold air effective area** and are, in these cases, mostly marked by an adequate aeration, whose range in the construction depends on one hand on the cold air productivity (in the construction itself too), and on the other also on the obstacle effect of the respective construction type. Mainly in the densely built quarters, the blocks present in the influence area of cold-air producing areas can also be evaluated as areas with moderate to strong **heat island effect** in the night hours. These local phenomena indicate that in these cases the effect of the supplied cold air does not suffice to induce a clear reduction of the Air Temperature.

These are contrasted by settlement areas with a high degree of greenery, which show only a weak or no nightly over-heating. **Constructed area with function relevant for climate** show an open settlement structure with a total degree of sealing of less than 30 % as well as no or at the most low over-heating; they thus contribute potentially to local origin of cold air. The concrete local effect, however, depends on the respective local situation i.e. essentially on the vegetation present. Typical area types are the ones of individual, town and double houses, or, in general, the construction with garden and surrounding greenery. They often border at the cold air producing green areas and thus contribute towards aeration of further remote settlement areas having a nightly overheating.

Air exchange

Structures, which enable the air exchange and introduce cold air, are the central connecting link between compensation areas and effective areas with bio-climatic load. Pathways should generally sow a low surface roughness, whereby wood-less valley and meadow areas, larger green areas (mainly with their open areas having low vegetation) and rail lands are considered as suitable structures. Wide roads can serve only for climate compensation owing to their emission load, but not for introducing unloaded air. The pathways are subdivided in the Climate Analysis Map with respect to the process sequence. In the 'ideal case', an area producing cold air also represents a part area of a pathway.

There is a predominance of **mainly thermally** induced pathway types with a compensation flow purely caused by the usage dependent temperature differences. The small garden complex at Priesterweg can be mentioned as an example of such flow areas inside the city, which transport cold air from the cemetery at the Bergstraße in Steglitz as well as from islander to the north direction. The situation is similar with respect to the small park complexes at Heckerdamm as well as the public park Rehberge; here, a part of the cold air produced at the airport Tegel is forwarded towards the city interior.

On the whole, the recognised thermally induced pathways are concentrated in the following areas:

- to the north of the line Tegel - Lichtenberg
- to the west of the castle grounds Charlottenburg till the city limits in Staaken; partly, the cold air is introduced from the northern Gatower field as well as from the surrounding regions
- in the south to the east of city limit to Groß-Ziethen in the city areas of Rudow and Bohnsdorf.

Areas in the direct neighbourhood of greenery/construction are not indicated as part of a pathway.

Mainly orographically induced pathways are concentrated in the eastern area of the city. These are mainly valley areas like the Wuhle and the Mühlenfließ, which function as pathways owing to their alignment, width and surface condition. To this effect, the depression line Hundekehlsee - Dianasee - Koenigssee - Halensee, originating from Grunewald can be arranged in the western part of the city.

The low lands of the larger flowing waters like Spree and Havel go beyond this function and possess, in addition, an attribute as **higher-level air and ventilation pathways**. The favour the air exchange in the adjacent construction even in case of stronger, higher-level weather conditions.

An **extensive cold air outflow** is restricted on areas with slope inclination >1° and occurs rather rarely in the city area of Berlin because of the comparatively lower height differences. For this reason, this process is connected with few areas having a noteworthy slope inclination, such as those of Grunewald and the Körpernicker Bürgerheide. Furthermore, an individual cold air outflow can be assumed to the north of Tegel lake, in Kaulsdorf as well as in Forst Düppel. The cold air supply is above-average high on these sloped forest areas, since the radiation and hence the primary cooling takes place mainly from the upper crown area and not from the immediate ground vicinity. Because of the large, radiating surface of the area, the cold air also flows in and above the crown area, instead of sinking first in the area below the canopy (Groß 1989).

Other identifications

The **air-hygiene situation in the main roads network** is mapped via the index of air load on the basis of nitrogen dioxide (NO_2) and fine dust (PM10) (SenStadtUm 2011). The spatial distribution of the load situation closely depends on the traffic volume as well as on the construction available along the road sections. The latter influences the dilution and the removal of air-hygiene air masses so that a high load is encountered mainly in the densely constructed city areas having a high traffic volume.

Wind field changes i.e. the tendency towards strong turbulences as well as up and down winds can occur in the area of bigger buildings, the way they are present in construction topologies of heterogeneous, inner-city mixed development, large settlements and high rises as well as core area uses. With these changes there are, on one hand, positive effects like stronger turbulence of air-hygiene loads, on the other hand, there are also more and more restrictions in the wind comfort. On days with heat load, a cooling function originates from the **water bodies** in the urban area of Berlin for the nearby surroundings. They also act as air and ventilation pathways even under weather conditions with a strong exchange.

Noise protection devices are available at sections along the noise-emitting traffic paths and correspondingly sensitive uses. They are indicated primarily along the Federal Highway A 113 as well as along the rail tracks in the southern and western parts of the city. They represent an additional information in this map, because they cannot be taken into account explicitly in the modelling with respect to their possible influence on the spread of the air masses.

Areas not evaluated include water bodies, some places, tracks including the surrounding track bed.

Map Description / Supplementary Notes

With the help of an example area with the size approx. 5 km x 3 km in the district of Charlottenburg-Wilmersdorf, the modelled climate parameters as well as the Climate Analysis Map (04.10.7) and the planning advice map (04.11.1) (SenStadtUm 2016) are explained below. This text thus complements the contents of the chapter Map Description.

General comments

The area shows a high bandwidth of the usage topologies available in Berlin and is hence especially suitable for an in-depth display of the city climatic conditions. It stretches from Grunewald lake in south-west till the Hohenzollernplatz in north-east and is characterised by the diagonal run of the highway A 100 (see Fig. 12). Grid cells that represent the buildings are shown in black.

Fig. 12: Expansion and usage structure in the transition area of Forst Grunewald - City West in Charlottenburg-Wilmersdorf

Map 04.10.1 Near Ground wind field and Cold Air Volume Flow

Since the small-scale wind field cannot be mapped in a useful way in the selected section, the display of the cold air flow field is done with the example of the grid-based Cold Air Volume Flow (see Fig. 13). On a large surface, the Cold Air Volume Flow shows a high to very high value level and reaches far in the eastern surrounding development, the reason for which is the intensive origin of cold air in the area of Grunewald. This is favoured additionally by cold air outflows, which occur at slopes of more than 1° inclination over the eastern Grunewald.

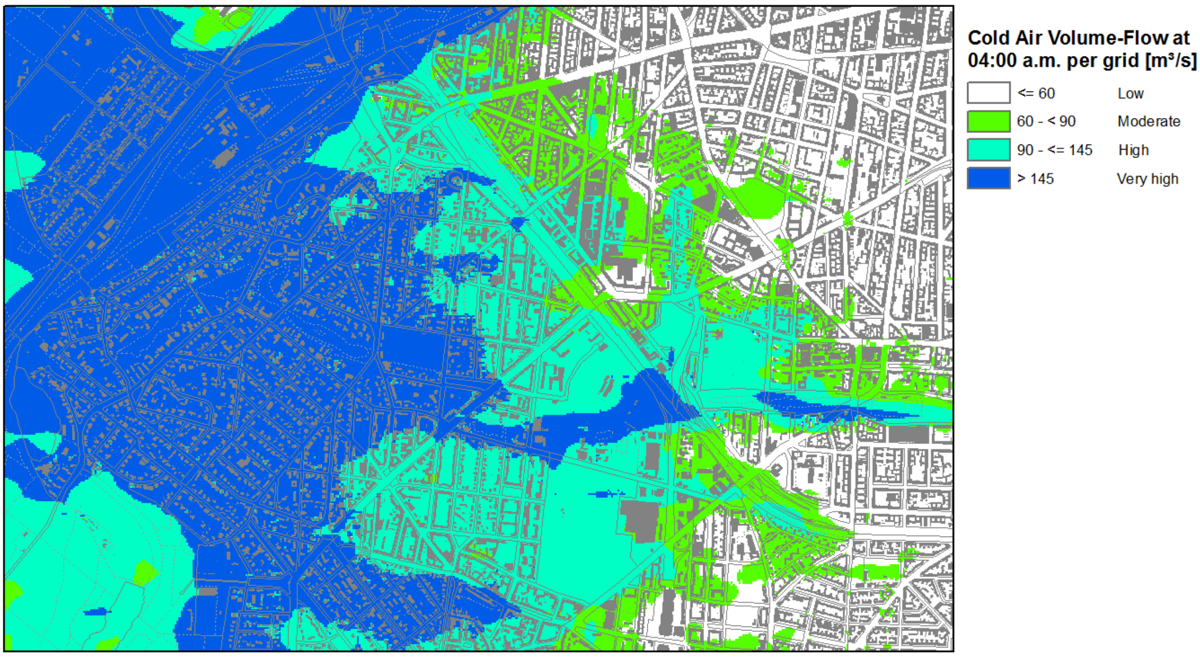


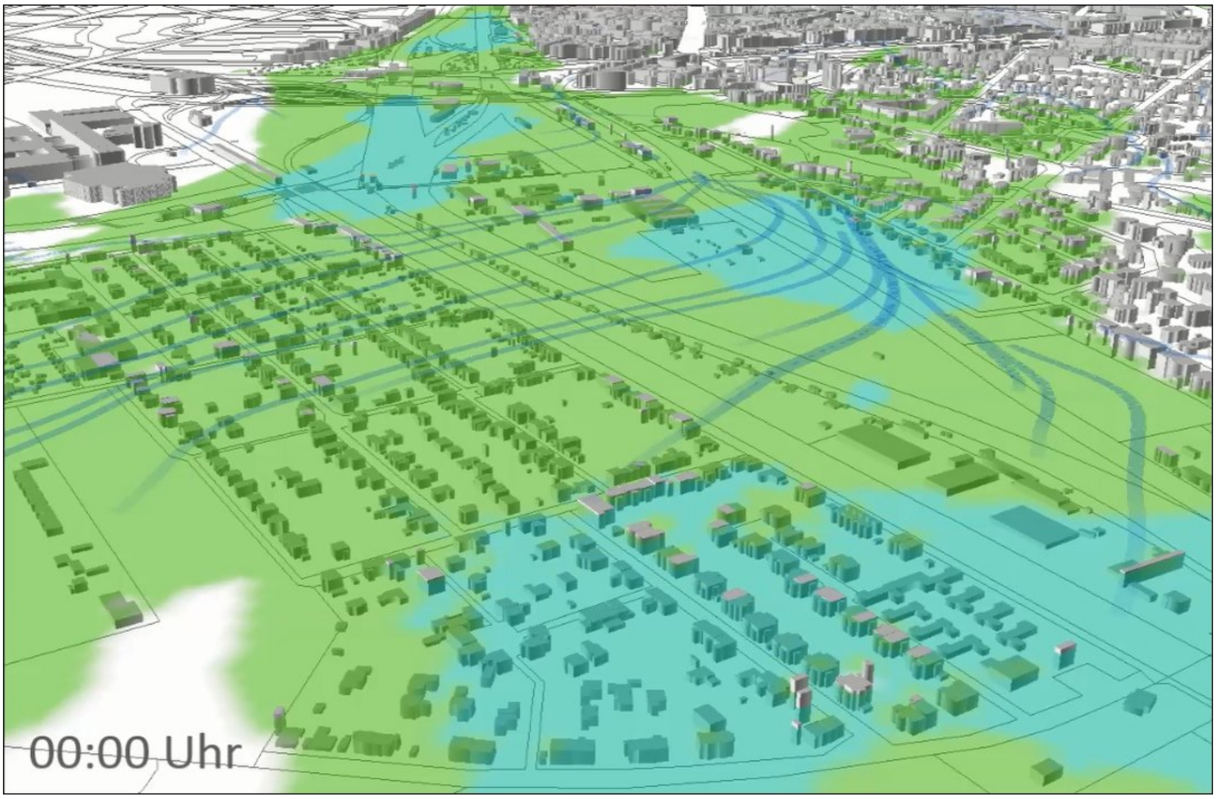
Fig. 13: Cold air volume flow at 04:00 a.m. on a sunny summer day in the transition area of Forst Grunewald - City West in Charlottenburg-Wilmersdorf

In doing so, mainly the adjacent strongly green settlement areas are favoured by a very high volume flow. Owing to their low surface roughness and their own cold air production, these development structures can already be considered in themselves as positively relevant for the climate. Towards the east, the volume flow shows an even higher value till the A 100 and after that reduces to a moderate level. The reason for this is the gradually increasing construction density and the higher temperature level, which weaken the Cold Air Volume Flow. It goes back to a lower value to the east of Brandenburger Straße.

Furthermore, surface structures are prominent in the map, which let the cold air penetrate far in the development. These are less built areas with pronounced vegetation. To the north of the section shown, the green axis Diana lake - Koenig lake - Halen lake emerges to this effect as cold air pathway with a very high Cold Air Volume Flow in the context of the adjacent track areas. To the south, the green complex Sommerbad Wilmersdorf-Friedhof Wilmersdorf/Fennsee can be recognised as the air exchange area. The high to very high volume flow continues beyond the Uhlandstraße till the public park Wilmersdorf and illustrates the pathway potential of such green structures.

Video animation cold air volume flow

In order to illustrate the effectiveness of near-ground airstream channels, a **video animation** was calculated with the help of the climate model FITNAH. This animation exemplifies the influence of the different land use in the borough Charlottenburg-Wilmersdorf on its neighborhood. **The focus is on the transition zone between the Grunewald forest as a relevant cold air generating area and its adjacent development**. Basis for the illustration is the Cold-Air Volume Flow between 22.00 p.m. and 03.00 a.m., which has been evaluated in a temporal resolution of 7,5 minutes. The Grunewald has an important function as a large cold-air production green space for the easterly adjacent development in Charlottenburg-Wilmersdorf and Steglitz-Zehlendorf respectively. The air exchange in the shown area is dominated by spatial Cold Air Flow, which develop at a slope of more than 1°. Based on this near-ground ventilation, the area in the North of the Halensee und between the train stations Grunewald and Charlottenburg can be considered as an Air Stream Channel. The outstanding climatic function of the Grunewald along of its approx. 11 km long transition zone between the forest and the development has been discussed in the accompanying text of the 2009 edition (SenStadt 2009).



Cold-air out-flow in the transition zone Grunewald forest – settlement area Eichkamp – lake Halensee – *visualization of the refrigerant effects of the forest*

The animation shall illustrate the **functionality of cold air delivery areas, here with the eastern Grunewald forest** in the borough of Charlottenburg-Wilmersdorf. A long wave emission within low-exchange nocturnal radiation periods leads to an extraordinary cooling of the near ground air masses. In consequence of this the cold air flows - with a slope inclination of more than 1° - in an eastward direction into the surrounding development. In this context, the surrounding area along the railway track becomes apparent as an Air Stream Channel.

The animation is based on a model calculation with FITNAH, for which overall 40 temporal cuts have been calculated. The Cold Air Volume Flow is illustrated in a qualitative occurrence in four classes. Whereas a low Volume Flow shows no color, a medium value is displayed in green. A high/very high Volume Flow is illustrated in light blue and dark blue respectively.

A second information level is presented by overlaying trajectories of several air packages, which represent the flow direction of cold air. The real time of integration of the video animation amounts to about 5 hours.

The respective zones, in which Cold Air Flow and Wind Speed rise in the course of the night, show a concentric increase. Due to the intense cold air production an extensive impact on the settlement area can be observed. As of approx. 01.00 a.m. a very high Cold Air Volume Flow emerges near Hilde-Ephraim-Straße as well as in the surroundings of the motorway junction Funkturm. The outflow of cold air intensifies in the course of the night, so that this area can be considered as an Air Stream Channel. Because of their meaning for climatic interrelation, structures like these deserve a very high level of protection.

Map 04.10.2 Air Temperature

The temperature field simulated for 04.00 a.m. in the night includes a range of about 7 Kelvin (K) between the minimum values of 13.9 °C and maximum values of 21.2 °C (see Fig. 14). In line with the structural characterisation, the temperature increases gradually starting from Grunewald in the direction of City West. The lowest Air Temperature is determined as 13.9 °C to the north of Grunewald lake over the grassland area of Hundekehlefenn. The small garden areas to the south of Forckenbeckstrasse within the development areas are highlighted as another prominent cold air region - also because of its size. Slightly weakly pronounced with respect to their cooling behaviour, the values in the cemetery Wilmersdorf lie between 14.5 °C and 16 °C; over the smaller green areas the nightly cooling is less strongly pronounced depending upon the size of the area.

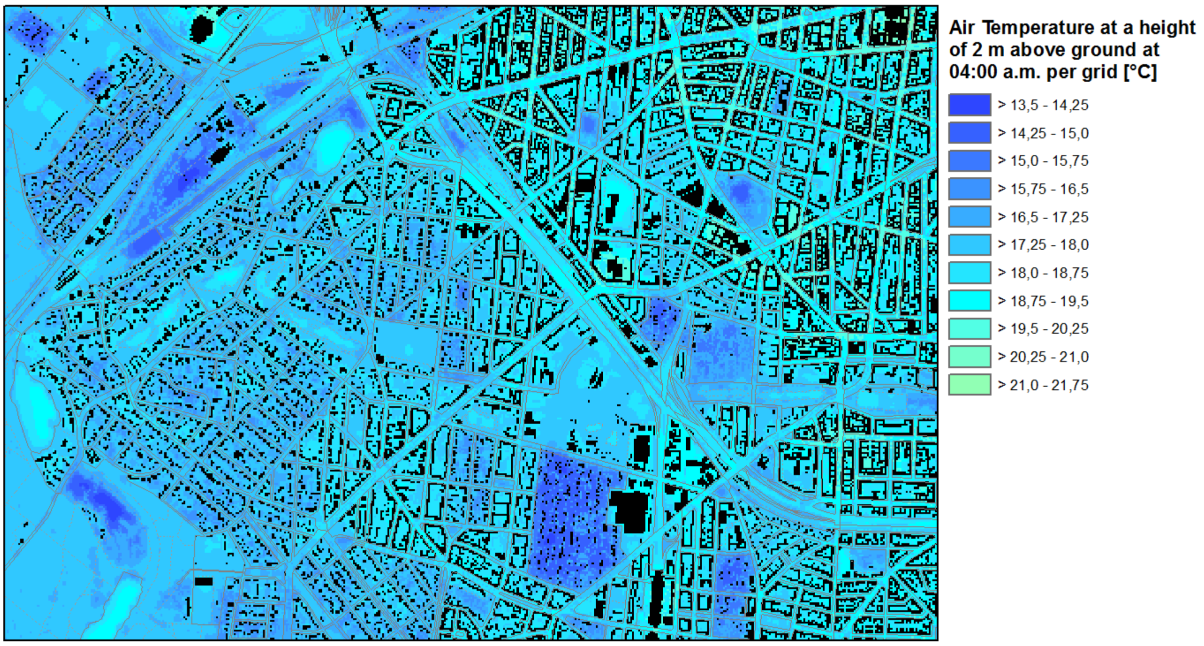


Fig. 14: Air temperature at 04:00 a.m. on a sunny summer day in the transition area of Forst Grunewald - City West in Charlottenburg-Wilmersdorf

Within the built areas, the temperature characterisation is differentiated in space corresponding to the distribution of construction and greenery volumes. While the larger green inner courtyards of blocks can comparatively show lower air temperatures of 17 °C to 18 °C, in (completely) sealed courtyards of similar size as well as on broad road spaces, these are up to 1.5 Kelvin (K) higher. The greened settlement areas show values between 16 °C and 18 °C. The air temperatures above the water bodies are also to be classified at this level.

Map 04.10.3 Radiation Temperature

The characterisation of the Radiation Temperature during the day mainly through the solar irradiation is determined as an important influencing variable for calculating the bio-climatic evaluation index Physiological Equivalent Temperature (PET). In the absorption area shown in Fig. 15, values of less than 35 °C at a height of 2 m occur only in the shade in usages with pronounced trees at the simulated noon hour of 02:00 p.m. on a sunny summer day. For this reason, the comparatively lower temperatures are encountered extensively in Grunewald, whereas this is associated with the available stock of trees in settlement areas. Consequently, in the green settlements adjacent to Grunewald, there is a trend towards lower values than in the more strongly sealed development areas with less greenery to the east of A 100.

Here as well as in the broad road areas, the radiation temperature can rise to more than 50 °C in the unshaded areas. This value level can be interrupted locally by planting trees on the sides of the roads. The Kurfürstendamm at the upper border of the image as well as the Hohenzollerndamm running diagonally across the area are characterised to this extent. It is conspicuous that even the grassy areas within the green areas show high radiation temperatures owing to a lack of shading, which lie only negligibly below those of the sealed areas.

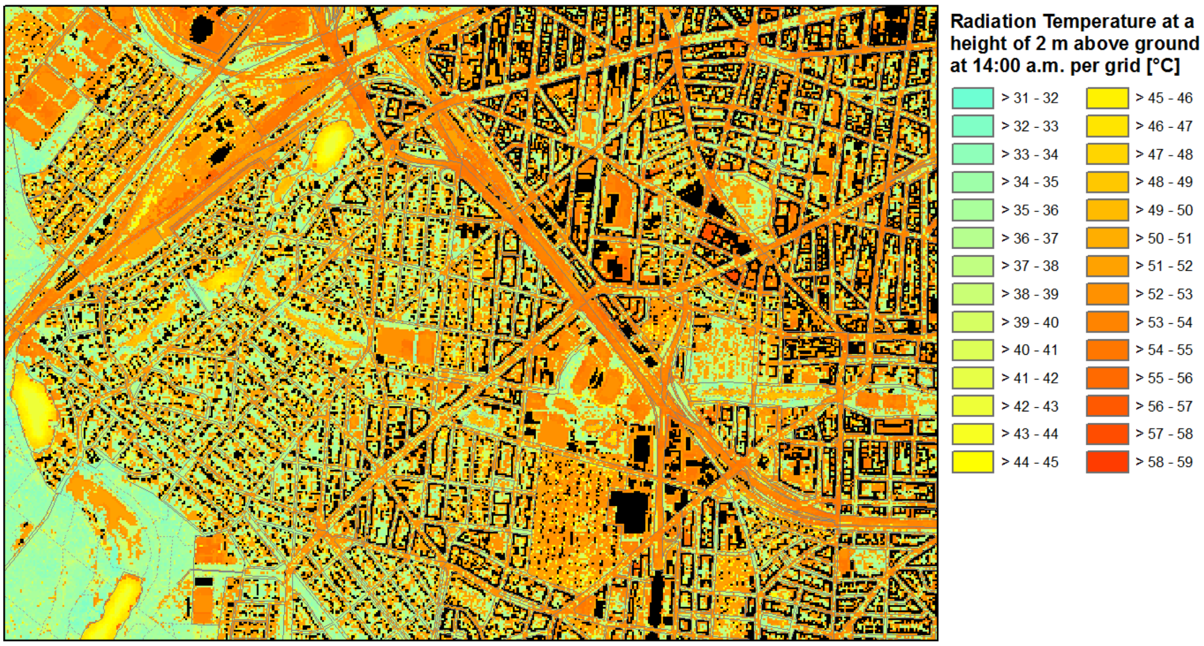


Fig. 15: Radiation temperature at 14:00 a.m. on a sunny summer day in the transition area of Forst Grunewald - City West in Charlottenburg-Wilmersdorf

Map 04.10.4 Nocturnal Cooling Rate

Fig. 16 shows the cooling during the night for each grid between 10:00 p.m. and 04:00 a.m. on a sunny summer night. The cooling of the different surface structures without existing buildings is associated with their respective thermal attributes, such as the heat flow. This influences, how much energy is absorbed by a surface during the day and is stored in the material or else is emitted again to the atmosphere at the ground during the night.

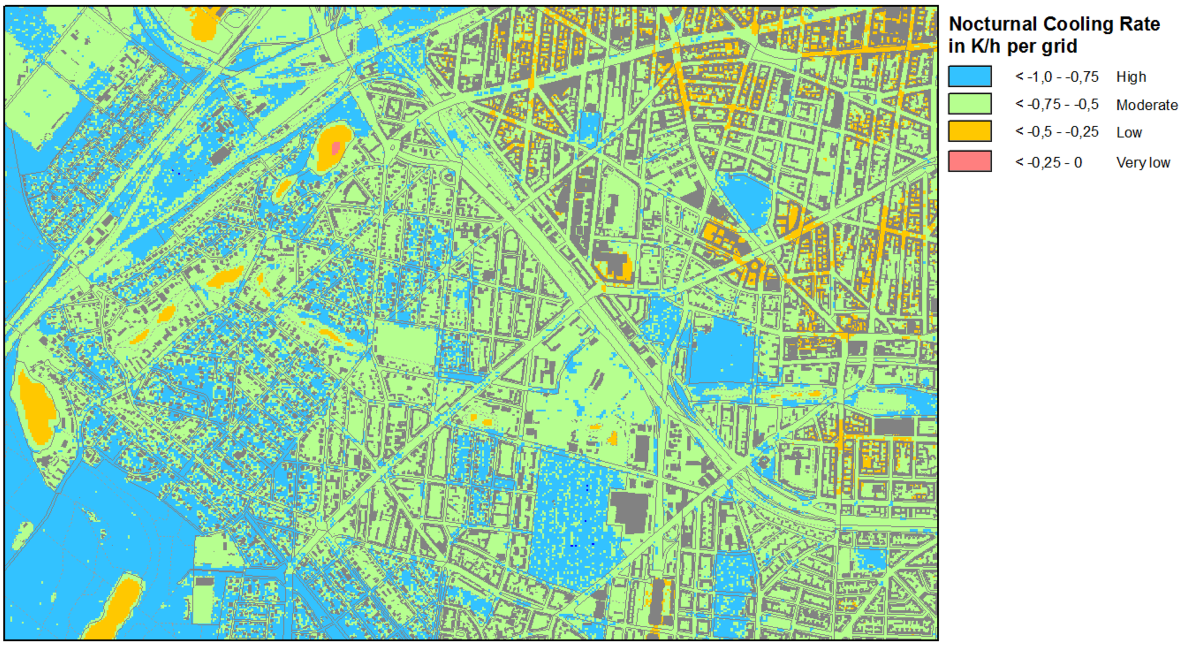


Fig. 16: Nocturnal cooling rate during the night between 10:00 p.m. and 04:00 a.m. on a sunny summer day in the transition area of Forst Grunewald - City West in Charlottenburg-Wilmersdorf

Corresponding to the structural characterisation, there is a dominance of a moderate to low night cooling of -0.75 to -0.25 Kelvin (K) per hour to the east of A 100, which can be traced back to a high percentage of sealed and built-up area. Only the green areas interspersed in the construction show a high cooling rate with -1.0 to -0.75 K. This is seen extensively mainly in Grunewald or in the upstream green settlement types, such as the small gardens at the Forckenbeckstraße as well as the cemetery Wilmersdorf. In keeping with the heat storing properties of water, a similarly low nightly cooling as in the densely constructed city areas is observed over the water bodies.

Map 04.10.5 Physiological Equivalent Temperature (PET)

For evaluating the heat load during the day, the Physiological Equivalent Temperature (PET) is included in the planning advice map (map 04.11.1, SenStadtUm 2016), which is based on the heat exchange of humans with their environment (Höppe 1984). In doing so, the radiation-related energy flows play a central role so that the spatial distribution of the PET is linked closely with the characterisation of the radiation temperature. While the lowest values of less than 30 °C are observed over the water bodies, a PET of about 30 °C to 31 °C occurs in the shade provided by the crown cover of Grunewald (see Fig. 17). Depending upon the stock of trees, this temperature level also continues in the adjacent green settlement areas. For this reason, these areas show favourable bio-climatic conditions during the summer weather conditions with potential heat load even during the day over and above the night conditions.

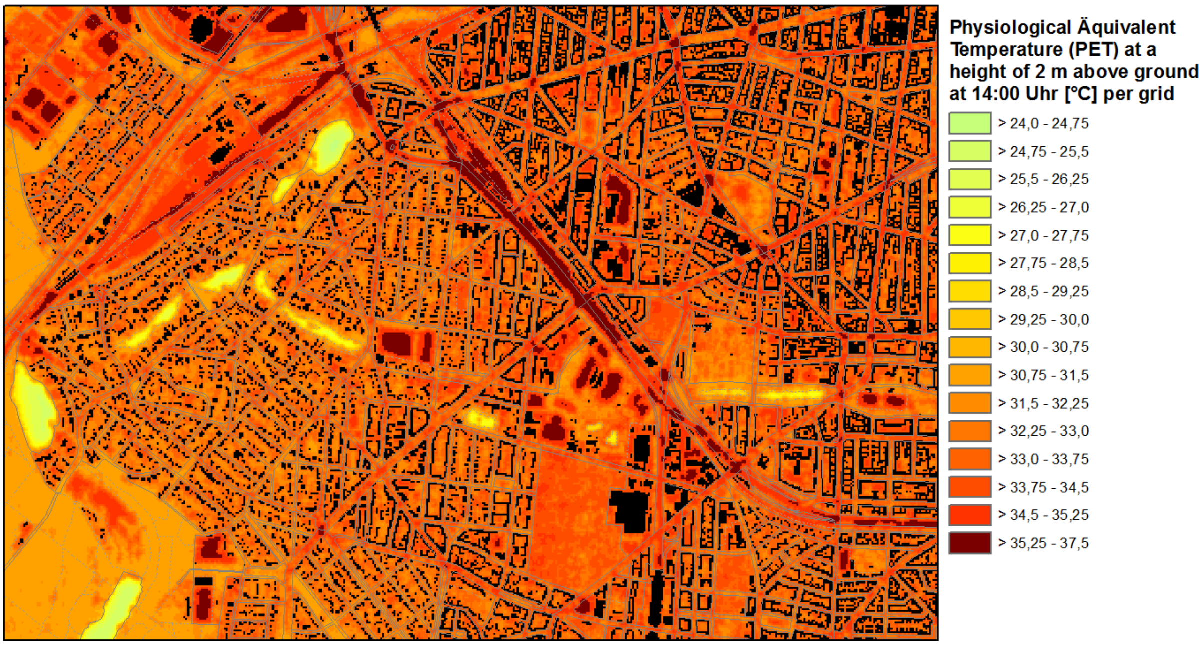


Fig. 17: Behaviour of the evaluation index PET (Physiological Equivalent Temperature) 14:00 a.m. on a sunny summer day in the transition area of Forst Grunewald - City West in Charlottenburg-Wilmersdorf

In the remaining city structures, values between 33 °C and 35 °C are encountered, which can also go beyond the bigger, strongly sunny portions of the areas. To this effect, larger, ground-level sealed areas as well as sports areas become apparent in the course of A 100, which have abundant sunlight. On the roads, the PET is lower by 1 to 2 below the trees so that the quality of staying is considerably improved here and walking or cycling in the shade is always more pleasant. The portions of green and open spaces with grass, on the other hand, show similar high values as a major part of the city area. The range of temperatures occurring in the section shown is thus approx. 13 K. For classifying the values of the PET with respect to the thermal sensitivity and the physiological stress, see Tab. 3.

Map 04.10.6 Mean Number of Meteorological Climatic Parameters

In the scope of the urban climate analysis, different climatic parameters were determined for block and partial block areas of ISU5 (see Method) and the average frequency of the occurrence per year (with respect to the period 2001-2010) was calculated (water bodies and road areas were not evaluated).

The characterisation of the **Summer Days** ($T\_max \geq 25°C$) in the example range is shown in Fig. 18. Areas with a high portion of greenery have a low number of Summer Days. Whereas the number here is less than 42 days/year, it increases with the degree of construction and sealing increasing towards the East. Thus, within the perimeter development in the area of Hohenzollerndamm, a maximum temperature of at least 25 °C occurs on 42 to 44 days/year. Moreover, a number of 46 to 48 Summer Days/year is seen frequently, such as in the area of the stadium Wilmersdorf/Sommerbad; it becomes clear here that the grass areas with an abundant sunlight have an increasing effect on the number of Summer Days with increasing heat during the day (on the other hand, represent areas of intensive cooling in the night) (see Fig. 14 and Fig. 16). To the east of A 100, the number of Summer Days increases small-scale also over 50 days/year.

Fig. 18: Number of Summer Days (maximum temperature ≥ 25°C) per block on an average in the years 2001-2010 in the transition area of Forst Grunewald – City West in Charlottenburg-Wilmersdorf

The range of the **Hot Days/year** that occur lies between less than 5 in Grunewald and more than 12 over the larger, ground-level sealed areas e.g. surrounding the Messedamm or in the area of the thermal power plant Wilmersdorf (see Fig. 19). Furthermore, the track areas along the A 100 also show a similarly high number of Summer Days. With respect to the values, the settlement areas lie between these extremes and behave - in a moderated form - similar to the characterisation on Summer Days. The range of the Hot Days occurring here lies mostly between 7 and 11 days/year.

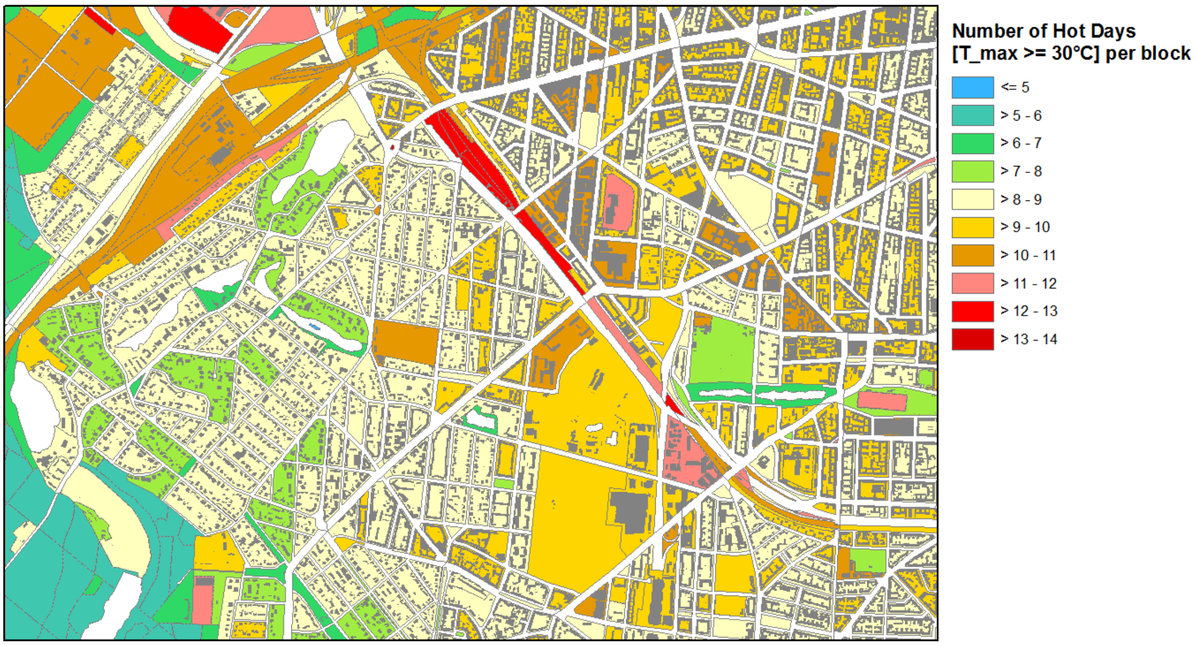


Fig. 19: Number of Hot Days (maximum temperature ≥ 30°C) per block on an average in the years 2001-2010 in the transition area of Forst Grunewald – City West in Charlottenburg-Wilmersdorf

The determination of **Tropical Nights** per year provides information about the night temperature level and the thermal situation associated with it, since bio-climatic load conditions can occur at nightly minimum temperatures of ≥ 20 °C. The number of Tropical Nights/year per block area is closely related to the nightly temperature level. In doing so, these are mainly the areas with a low nightly cooling (see Fig. 16), which are highlighted in Fig. 20 with more than 8 Tropical Nights/year. Associated with a moderate to high night cooling, the number of Tropical Nights is also lower to the west of A 100. In the settlement areas, it is 5 to 8 nights/year and reduces over the track area to the west of the Halen lake as well as the expanded small garden area to the south of Forckenbeckstrasse to less than 4 Tropical

Nights/year and thus confirms their intensive potential for cold air formation. On the whole, therefore, the mosaic of the different uses and their climatic behaviour over the course of the day is reflected clearly in the evaluations of the climatic parameters.

Fig. 20: Number of Tropical Nights (minimum temperature ≥ 20°C) per block on an average in the years 2001-2010 in the transition area of Forst Grunewald – City West in Charlottenburg-Wilmersdorf

Map 04.10.7 Climate Analysis Map with Reference to the Map Planning Advices Urban Climate (04.11.1, SenStadtUm 2016)

The Climate Analysis Map represents the primary result of the analysis portion of the climate modelling with FITNAH 3D and is based on the meteorological parameters described. The demarcation of production and effective areas as well as their connecting structures results in a complex picture of process system of air exchange streams of the structure of built and green areas.

The **green and open spaces** are shown in the Climate Analysis Map as climatic compensation areas, whereby a major part of these also show a climate-ecological effective Cold Air Volume Flow in the observed section owing to the intensive air exchange. Only the smaller green areas to the east of Brandenburg Straße are excluded from this evaluation (see Fig. 21).

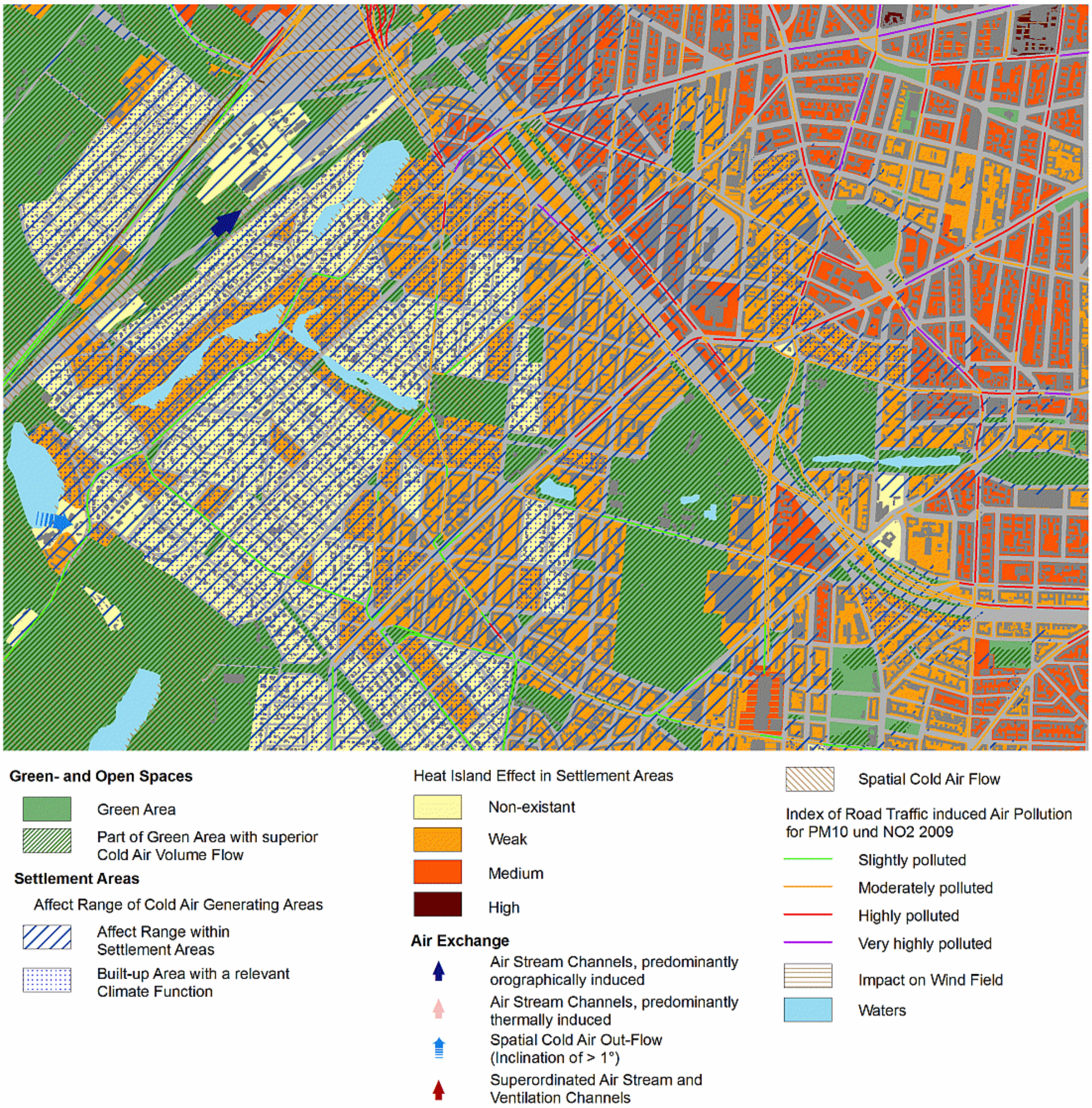


Fig. 21: Statements of the summarised climate analysis map in the transition area of Forst Grunewald - City West in Charlottenburg-Wilmersdorf

Therefore, a major part of the **settlement areas** lies in the **effective area** of these **cold air origin areas**, which continue till the height of the Brandenburg Straße beyond the A 100. In addition, the settlement areas with greenery are indicated as built areas with function relevant for climate. A **night heat island effect** is not observed here, because the air temperature at 04:00 a.m. lies below the average value of all the investigated settlement areas in the city. In the surroundings of Diana lake, Koenig lake and Hubertus lake, the heat dissipation of the water areas is mapped in a light over-heating within the block areas. This increases on the whole in the direction of Hohenzollerndamm and A 100, whereby a moderate heat island effect dominates to the east of A 100. Individual construction blocks then become apparent with a strong overheating at Kurfürstendamm.

The **air exchange** at the eastern Grunewald is characterised mainly by **cold air outflows**, which can occur at slope inclinations of more than 1°. In addition, the area to the north of Halen lake between the suburban train stations of Grunewald and Charlottenburg is to be classified as **cold air pathway**. The **air-hygiene situation** is characterised by the progression of several main roads with high traffic. To this effect, primarily Kurfürstendamm and Hohenzollerndamm show a high to very high air-hygiene stress. To the west of A 100, on the other hand, there is mostly a low to moderate stress through pollutants fine dust (PM10) and nitrogen dioxide (NO_2) caused by traffic (detailed information is provided by Environment atlas map 03.11., edition 2011).

Individual block areas show a potential for **wind field changes**. These are, for instance, big settlements, like the highway construction Schlangenbader Straße or the core area usage in the area of Kurfürstendamm.

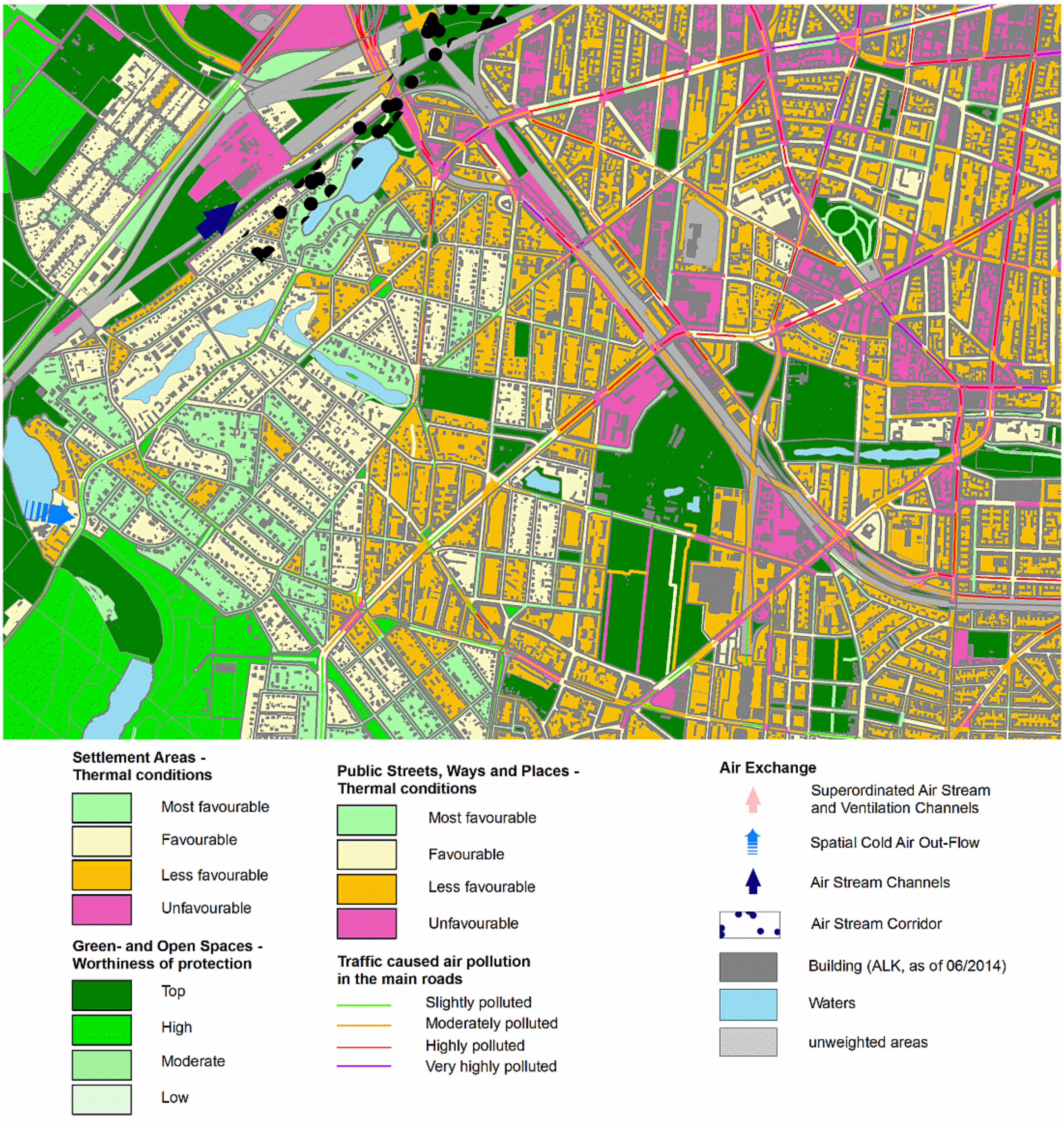


Fig. 22: Statements of the main map for planning advice for urban climate in the transition area of Forst Grunewald - City West in Charlottenburg-Wilmersdorf

An evaluation of the functions shown in the Climate Analysis Map from a planning perspective (worthiness of protection / thermally favourable / unfavourable situation) is done in the **planning advice map for urban climate**. It represents the planning valorisation of the generated model data as well as of the Climate Analysis Map derived from it and is the central basis of information for weighing and decision-making processes from the perspective of urban climate. Fig. 22 shows the corresponding section of the example period.

The evaluation of the **thermal conditions in settlement area** is based on the combination of night air temperature and Physiological Equivalent Temperature (PET) during the day. For this reason, very favourable to favourable conditions are encountered in the green settlement areas to the west of A 100. The degree of construction and sealing, increasing towards the east, also increases the heat stress on the whole. Bio-climatic unfavourable conditions are encountered mainly in the surroundings of Kurfürstendamm, Hohenzollerndamm and Brandenburg Straße

The **thermal situation in the road area** is based on an evaluation of the PET, it is determined as negative on sunny radiation days essentially through the degree of solar irradiation and is determined positively through the shadow effect caused by the buildings / trees. To this effect, some sections of Kurfürstendamm and Hohenzollerndamm are to be classified as favourable to very favourable. These are contrasted by intensively irradiated road spaces during the day, which show a less favourable to unfavourable quality of stay.

The **worthiness of protection of green and open spaces** in the example period is to be considered almost extensively as high to very high, the reason for which is the spatial nearness to bio-climatically stressed settlement areas on one hand, and the intensive night cooling effect on the constructed areas on the other. In addition, the cold area pathway in the height of Halen lake is demarcated extensively as pathway corridor. A detailed description of the method structure of the three maps for planning advice map is given in the Accompanying document.

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