Using Microscale Climatological Simulation in Landscape Planning - an ENVI-met3 User's Perspective

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In the lower urban boundary layer exist different patterns of local climates conditions, which are very sensitive to structural changes. By considerate planning these urban climates can be altered and eventually improved. The processes which create these climates are very complex.
Therefore the most precise way to calculate or assess the impact of changes is by usage of numerical methods. There already exist several models, which are able to cope with the complexivity of urban structures and even take into account human thermal comfort. Various case studies show that they are good instruments to analyse the effects of general structural changes (different development structure) as well as in impact of small structural changes (different surface cover). They give very precise information of what the climate would look like depending on the given input parameters.

In order to understand the recent possibilities the model ENVI-met version 3.0 is analyzed. This analysis includes an introduction to the mathematical and meteorological basics, its usage, a comparison of the simulation results with real data and finally to recognize its dangers and limits. It is often difficult to understand the significance of the calculated values for the human beings living and moving in this climate.

To get a deeper understanding of human thermal comfort, the most important biometeorological theories and models are briefly introduced.
Then the most important climatic background knowledge necessary to work with this topic is summarized.
After that it is explained how to use ENVI-met.

Then a free space analysis describes two existing sites in Vienna. They are similar in their geometry and orientation, but differ in their amount of vegetation.
The atmospheric condition of the places will be simulated in ENVI-met and climatological parameters measured to compare the results of the model with reality.

Finally there is a discussion about the usability of ENVI-met in landscape planning and a microclimatic conclusion.

1 Introduction

1.0.1 Personal Motivation

After spending much time studying many different aspects of landscapes and townscapes, I had the feeling that most of the time a very important element in the social-ecological complex landscape planners is hardly given any attention. The way if and how we use an open space is often basically influenced by its climate. Who would like to sit in the radiant sun when it's really hot anyway or linger on a windy shady bench in winter? The way how the sun moves in the course of a day and a year seems to be trivial to us. But every day I can see that many expensively designed and accomplished free spaces or even whole city quarters seem to be planned without taking into account neither the sun nor wind or shelter. I am not happy with that, so I started searching for solutions. Still I am convinced that the best designs result out of time and tradition because the only way how to really get to know the local climate is when you live there. But mostly there is no time nor money to wait until the planners really understand what's going on climatologically. So in my opinion we should make use of the wonderful possibilities that science and modern computers can offer to us. There has to be a way to simulate a potential free space, with all its climatic parameters relevant to human beings. Unlike planning, a simulation does not show how a space should be, but how it would be if it were. A Simulation does not try to assess the subjective qualities, but merely calculates the likely facts. Knowing what a place would be like, it is much easier to avoid the most devastating mistakes that a planner can make and the innocent users of the place have to pay for every single successive day. Luckily there has already been lots of research done, indices have been invented and models designed. But how far can all these accomplishments be used in the planning process?

1.0.2 Context

In the lower urban boundary layer exist patterns of varying local climate conditions(produced by the interaction between different natural and artificial elements), which are very sensitive to structural changes. By considerate planning the urban climate can be improved in many ways. This includes

a, saving energy by optimized heat distribution, usage of low-energy architecture and natural energy resources,

b, reducing health risks by assuring ventilation and decreasing the near surface pollutant concentrations and

c, improving life quality by creating comfortable bioclimate conditions.

The processes are very complex. Therefore the only way to calculate or assess the impact of changes is by usage of numerical methods. Several models already exist which are able to cope with the complexivity of urban structures and take into account human thermal comfort. Various case studies show that they are good instruments to analyse the effects of general structural changes as different building constellations, as well as in impact of small structural changes. They give very precise information of what the climate would look like.

It is often difficult to translate these meteorological facts and understand their significance for the human beings living and moving in this space. Therefore, additional models are used, which take the meteorological results as input and produce 'second-order' information about the data. They try to describe the biometeorological consequences on urban life. The models dPET or MEMI are able to simulate the interactions between the human body and the environment in detail. [Bruse(1999)]

The thermal complex of human-biometeorology compises of the meteorological factors air temperature, air humidity, wind velocity as well as the short- and long wave three dimensional radiative fluxes which affect people in indoor and outdoor climates. This complex is relevant to human well-being and health due to a close relationship between thermoregulatory mechanism and circulatory system ([Jendritzky et al.(1990)Jendritzky, Menz, and Schirmer]). In contrast to the air pollution complex, the thermal complex is often underestimated, especially in Central Europe. But this is not justified, because long aterm data statisics show increasing mortality rates under extreme thermal conditions. [Laschewski and Jendritzky(2002)]
[Matzarakis et al.(2002)Matzarakis, Mayer, and Rutz]

1.0.3 Content

In order to understand the recent possibilities I want to analyze a certain model. This includes being able to use it and to run a simulation, comparing the simulation results with real data and understanding the mathematical and meteorological basics and finally recognize its dangers and limits. I choose to discuss the model ENVI-met 3.0 due to various reasons. It is a freeware, runs on nearly every common computer, is easy to handle and well documentated. Within a short time an interested user can produce all necessary input files and run the simulation. The output can effectively be presented in Leonardo, another freeware available at the same address. Another option is to use the BOTWorld, which tries to simulate the urban biometeorology using virtual pedestrians with given physiological properties. The BOTWorld is the follow up project of ENVI-met and is able to make the abstract meteorological data more usable for planning purposes. Unfortunatley there still does not exist any documentation and the BOTWorld is not as simple to access as ENVI-met, therefore I will focus on the latter. Nonetheless, it is an important tool for everyone who is interested in human comfort within urban structures.

To get a deeper understanding of human comfort, the most important biometeorological theories and models are briefly introduced. Then the most important climatic background knowledge necessary to work with this topic is summarized.

After that I will explain how to use ENVI-met and discuss its possibilities and difficulties. A short introduction into BOTWorld is also given.

Then a free space analysis describes two existing sites in Vienna. They are similar in their geometry and orientation, but differ in their amount of vegetation. The atmospheric condition of the places will be simulated in ENVI-met and meteorological parameters measured to compare the results of the model with reality. Finally there is a discussion about the usability of ENVI-met in landscape planning.

2 Methodology

2.0.4 Approach

What are the difficulties,dangers and limits using simulations in landscape planning? In order to evaluate the importance of ENVI-met in the planning process there are two main questions about the model to be answered. What is possible with this program and how can it be used. My aim is not to evalutate the model but to test how it can be used in modern planning processes.

1. Possibilities (Resolution, Accuracy, Fields of Application)

How precise can ENVI-met simulate an urban space? How close to reality are the calculated values? In which situations can ENVI-met be used to simulate?

2. Usability (Essential Previous Knowledge, Sources of Error)

Which parameters should the planner take into account? What are the parameters relevant to human comfort planning urban spaces? How well/deeply do I have to understand the model to be able to sensibly use it? What is the usability of the model?

To answer these questions three methodologies will be used. First, a study of literature, to get aquainted with the topic in general and actual tendencies. Then a free space analysis of two places in Vienna will follow. Equipped with the knowledge about climate, bioclimate and the space qualties of the site a simulation with ENVI-met will be made. The results of the model will be compared with measurements and discussed regarding its usability in landscape planning.

2.1 Literature Study

2.1.1 ENVI-met

First I started to read all available documentation and publications about ENVI-met to get to know the model. Moreover I tried to understand how dynamic models work.

2.1.2 Climate

In order to understand ENVI-met I needed to learn more about the physical, meteorological and climatic basics. To make a good simulation I had to learn about the climate of Vienna, especially the inner city climate.

2.1.3 Human Comfort

The relevance of the microclimate for open spaces? Which role does the climate play in the context of free space design and usage? What parameters are relevant to human comfort? Which indices and models describing human comfort exist? Which criteria can be defined, which actions implemented to improve the urban open space qualities in the context of the specific type of free space, regarding microclimate.

2.2 Site Analysis

Introduction

The analysis records, illustrates and evaluates the qualities and quantities of the space and the functions of the analysed area and its direct environment. The analysis is carried out in written and graphical or photographical form. It is important to include relevant relationships. The result is a site inventory which might be a map or a list of recorded facts and an analysis which is either an analytical map and/or a list of perceived relations.

2.2.1 Graphical or Photographical Recording

To understand the proportions and the spacial relationships the space is presented in different perspectives, cuts and with photographs.
Relationships between free space and buildings, transitions, distinctive details, the uniqueness of the site and its diversity, light and shadow are explained visually.

2.2.2 Background Information and Introduction

Information about the historical and social development influencing the site and the present social situation is gathered. The regional climate and microclimatic features that influence the site are explained in a seperate chapter, coping with the climate from the general to the specific.

2.2.3 Site Inventory - Analysis of the 'Gestalt'

First the 'Gestalt' of the site is analysed from off-site. Then an on-site view is described.

Type of Free Space and Visual Connections

What kind of free space do I cope with? What are the visual and constructive borders? Which partial spaces are within the site? Visual and spacial relationships to adjacent spaces, buildings and structures are recorded.

View from On-Site

'To understand a site, the designer must analyze on-site natural and human-made factors, and must also interpret off-site influences. Depending on the scale and complexity of the site, relevant on-site natural factors can include geological substrate, topography or landform, subsurface and surface water, soils, vegetation and wildlife, microclimate, and spatial and visual considerations. On-site site human-made factors can include existing structures, pavements, gravity-flow support systems such as storm and sanitary sewage systems, and pressure-flow systems such as those used to distribute gas, electricity, and telecommunications systems, adjacentland use, visual considerations, and so on.' [Motloch(1991)]
Natural and man-made landforms, type of soil, soil profile, topography, amount of sun and shade caused by buildings or other elements, type of vegetation and wild life species, space structures, elements and borders, partial spaces and spacial hierachies, design elements, pathes, description of the buildings and existing artwork, used materials, architectural style, condition, functions, entries, heights and relation to free space.

2.2.4 Site Analysis - Functional Relations

Urbanistic Context

Development structure of the district, population structure

Accessability

Is the site accessible by public and private transport? How easily can the site be reached? What kind of transport links exist? What is the catchment area of the site? Where do the users come from? Which distances do they have to cover to reach the site? Which other off-site influences, acoustic irradiation, noise and olfactory exposures are there?

Paths

Where do paths come from and lead to? What functional relationships exist between the site and its environment, and within its partial spaces? How are adjacent buildings used?

Usage

What is the actual usage of the free space? Who is using and taking care of the space? Which traces of usage can be found? What do the users demand and expect from the site? How intensive is the use of the site? Which social interactions take place?

Restrictions

Is the site public or private? Is it accessible at any time, for everyone? Is access and usage of the site encouraged?
[Frohmann et al.(2000)Frohmann, Gerlich, Grimm-Pretner, Licka, Mellauner, and Posch]

2.2.5 Microclimatic Needs

To bring the site analysis to a close I will try to summarize my impressions about usage and microclimate of the site. I want to accentuate the items which are of importance for the thermal comfort balancing the different usages. A sitting person needs sunlight in the winter and shade in the summer. An active person, either walking, playing or doing other kinds of active movements, prefers sunlight in the winter and shade in summer as well, but searches for a cooler enviroment than a sitting person. Motorized traffic does not care about microclimate at all. People trying to read or simply stay on a place for a longer time are very sensitive about the wind speed. Moving people care less about wind speed, or even appreciate a slight breeze.

2.3 Meteorologic Simulation and Measurement

Simulation

My aim is to find out how complex the geometry of the input area can be and how sensitive the model is to the change of several parameters. I want to make a simulation that comes closest to the real conditions, with changing the least default values.

Comparison with Measurements and Discussion

In the end the results received from the model will be compared to real values measured on the site. There we will find out how close a one-day simulation can come to reality.

3 Human Comfort

In this chapter an overview over the State-of-the-Art of assessing human comfort is presented. Can subjective comfort be calculated and what are the relevant parameters?

3.1 'Climatological Thermal Comfort'

Parameters

The most significant parameter is definitely the air temperature. We feel hot or cold. But there are various other aspects with can intensify or lessen the effect that the air temperature has on us.

In cold regions the second most obvious factor is wind. The windier the colder we feel or the less annoyed we are by hot temperatures. We call this effect 'windchill'.

In hot regions the second most obvious factor is humidity. Humidity can cools down an environment by taking energy for the evaporation process. In an cold environment excessive humidity condensates or freezes. Combined with heat excessive humidity can cause uncomfort known as sultriness. The effect that humidity has on comfort can be estimated e.g. with the wet bulb temperature, which is part of many thermal comfort indices.

Apart from the air temperature also the radiative temperature plays an important role. On the molecular level, temperature is the result of the motion of particles which make up a substance. This is measured as air temperature. The radiative temperature is the temperature other bodies (walls, roads, trees) emit from their surface. On a hot day concrete is hotter than air, because thanks to his high heat transmissivity it heats up much faster and stores more energy. According to the Stefan-Bolzmann law (see next chapter) the hotter a body the more energy it emits. This means that concrete will have a high radiative temperature. Therefore, although the air temperature might be comfortable, if there are surfaces with high radiative temperatures the place will feel really hot. On the other hand, when we approach cold surfaces, this gives us a sensation of cold as well. Many indices therefore include the radiative temperature.

Finally I want to remind of the albedo. Although the albedo does not directly act on human comfort, high albedo walls can produce incomfortable glare. And by reflecting the radiation without absorbing it it can lead to a more homogeneous heating (vgl. Spengenberg2004).

Thermal Indices

Long term human-biometeorological studies already exist. To estimate thermal comfort and integrate the different parameters various indices where developed. In the past thermal indices were frequently used to assess the thermal environment. These indices were based on single or composite meteorologigal parameters, such as wet bulb temperature or equivalent temperature. In the 1970s some scientists began to use physiologically significant indices which derived from models for the human engergy balance (e.g. thermal index PET on the basis of the model MEMI, see [Höppe(1993)][Höppe(1999)](from:

[Matzarakis et al.(2002)Matzarakis, Mayer, and Rutz])Simple methods who do not include all parameters ignore climatologic coupling and feedback mechanisms. There are many possibilities to get a certain value calculated by different parameters. That does not mean that it has the same thermophysiological effect. Every climatic region has its own characteristics and meanings of an index. It has to be adjusted to the local situation and cannot be used globally. Nowadays complex models availabel as well as high computer capacity, so there is no major need to keep using indices.
[Jendritzky et al.(1990)Jendritzky, Menz, and Schirmer] In this chapter I will introduce the most popular indices and models dealing with human thermal comfort. The model ENVI-met and BOTWorld will be discussed in a separate chapter.

3.1.1 Predicted Mean Vote PMV (1972)

In the 1960s there was still a great lack of knowledge about thermal comfort. For better understanding P.O. Fanger initiated five years of research at the Laboratory of Heating and Conditioning, Technical University of Denmark, and at the Institute for Environmental Research, Kansas State University. Based on the results and experiences in this research he wrote the book 'Thermal Comfort' which is the first important work on that topic. It is impossible to consider the effect of any of the physical factors influencing thermal comfort independently, as the effect of each of them depends on the level of other factors. Therefore he tries to find a way to assess thermal enviroments by introducing comfort equations who include all known interactions and processes. The equations result in a thermal index which he calls Predicted Mean Vote. It relates the (simple) energy balance of the human body to the thermal comfort of the person.
Normally the PMV value is used between -4 (very cold) and +4 (very hot), but as it is related to the energy balance it can also reach higher or lower values.

3.1.2 Klima-Michel-Modell (1990)

The Klima-Michel-Modell is an energy balance model for the human organism. It was introduced by Jendritzky in 1990 and is now used by the Deutsche Wetterdienst. It is based on the comfort equation of Fanger (1972) and the PMV value and includes a correction by Gagge (1986) which is dependent upon humidity. Taking into account the relevant parameters for the human thermal metabolism, the model is able to describe the sensation of temperature of an average person according to comfort and thermal stress. This average person is called Michel and is 1.75m high, weights 75kg, has a body surface of $1.9m^2$ and an age of 35 years. The thermal sensation is described as a function of the person's activity, the isolation of clothing, the air temperature, the windspeed (see windchill), the water vapour pressure (see humidex) and the mean radiative temperature. The level of clothing is adapted to the thermal condition in order to reach optimal comfort. The default value for human activity is set as 116 Watt per m2 body surface and equals a quick walk.For better understanding of the results, they are transformed to C which represents the felt temperature.

3.1.3 MEMI (1999)

The model MEMI (Münchner Energiebilanzmodell für Individuen) was developed by Höppe(1984). It includes skin, core and cloths temperature, sweating rates, the degree of skin wetness and calculates the Physiologically Equivalent Temperature.

3.1.4 RUROS, BUGS

In the Fifth Framework Programme 1998 - 2002, which was co-financed by the European Union, various science projects were conducted. One part of the program was the 'greencluster' which consisted of GREENSCOM, URGE, GREENSPACE, BUGS and RUROS. The latter two cope with urban climate and the quality of urban free spaces.

BUGS

BUGS stands for 'Benefits of Urban Green Spaces'. This was also the main question in the project, which was split into 12 work packages (urban planning, traffic flow, remote sensing, economy, marketing, meso and micoclimate, noise measuring social wellbeing,...). In the first phase the project partners from various fields of study improve and adapt their methods to these specific questions. Different disciplines have to collaborate and harmonise their models and data. In the second phase the methods are used in a concrete case study. The topics are micro and mesoclimate, noise, traffic and pollution, usage of space, social aspects and participative planing methods. ENVI-met is used in the work package 'MICRO'. (http://www.vito.be/bugs last access: 16.4.2007)

RUROS

RUROS stands for 'Rediscovering the Urban Realm and Open Spaces' and acknowledges that the quality of urban spaces contributes to the quality of life within cities or contrarily enhance isolation and social exclusion. This relates to the physical and social environment, the underlying hypothesis being that these conditions affect people's beheaviour and usage of outdoor spaces.
A common platform has been developed for the analysis of open spaces in the urban environment, combining the physical environment (i.e. microclimate, thermal, visual and audible comfort, urban morphology, etc.) with user requirements and satisfaction.
Various models and tools have been developed, tackling different issues of the physical environment and the resulting environmental performance. These provide insight on the different aspects of the environment, and means for analysis at different levels of complexity. Methodologies have been developed for evaluating the velocity profil of an area with simple design recommendations and the environmental impact of alternative urban forms (environmental performance of urban textures), a methodology for drawing comfort maps, for describing soundscapes, for connecting social issues with physical properties characterising an open space, a graphical tool to evaluate thermal comfort and relationships between measureable parameters and users' sensations for the luminous environment.
Extensive field surveys have been carried out across Europe, including extensive microclimatic monitoring and modelling of open spaces, along with questionnaire guided interviews with users of open spaces. Two open spaces of different typology have been investigated at seven cities (GR: Athens, Thessaloniki; IT: Milan; CH: Fribourg; UK: Cambridge, Sheffield; D: Kassel). The data set formed the basis for the various models presented in the RUROS publications. [RUROS(2004)] (http://alpha.cres.gr/ruros last access: 16.4.2007)

3.1.5 RayMan (1996)

The model can calculate the atmospheric influences of short- and long-wave radiation. It is especially valuable in complex urban structures or other micro-scale environments. The topographic input data consists of building and vegetation data, the horizontal limitation or fish eye photographs. Additionally air temperature, vapour pressure, wind speed and climatic factors such as cloud cover, albedo and bowen ratio are required. The sunshine duration, shade, short and longwave fluxes are calculated. The final result is the mean radiative temperature, which is necessary for the human-biometeorological assessment of thermal environments by means of thermophysiological indices like PMV, PET or SET. It works well for clear sky weather and simple geometric structures. New versions are being developed to cope with clouds and more complex structures. The output is given in graphs and text data. The model RayMan is freely available for general use. (http://www.mif.uni-freiburg.de/rayman last access: 27.2.2008)

3.1.6 TownScope

A geometrical analysis of three-dimensional townscapes (including tilted roofs, different tree forms,...) Landscapes can be imported in different formats. The shadow, the incoming solar radiation, the sky view-factor during the course of a day and a year can be calculated and displayed easily. It gives a quick impression on how the sun will move and affect an open space.

3.2 'Non-climatological Human Comfort'

3.2.1 Thermal vs. Aesthetical and Social Comfort

While talking about the human thermal comfort in a bioclimatic environment we must not forget the multidimensional aspects of free space. A free space is more than the physical facts we can photograph and measure. Other factors than climatological parameters influence strongly how people feel towards a space or city quarter. Although they cannot be measured, they are sometimes even as important as the hard physical facts, if it comes to a person feeling comfortable or uncomfortable. This goes as far as people feeling 'hot' or 'cold' without a measurable reason.
Still I chose to talk about the climatological part of human comfort. One reason is that the aestetical and social value is much more difficult to assess than climatological data.
Another reason is that there are studies that prove that the climate does make a diffence in human comfort.(cp [Fanger(1970)],[RUROS(2004)]) So if there is something landscape planners can do definitely wrong - why not try to find out how to avoid it?
Finally, when it comes to the social value of a place, I found it is very difficult or even impossible for a landscape planner to alter the social situation. Mostly it lies in the hands of politicians or economists. Therefore mostly landscape planner can merely recognize the situation and try to change the usability, the aestetics, the microclimate on a small scale or in the small range of our authority.

3.2.2 Aesthetics

A successful open space is often associated with a positive visual experience. The aesthetical value of a garden, space or simply a tree depends on many aspects.

Space

Unobstructed views towards the landscape, to the surrounding buildings or beautiful objects give visual contentment. Open spaces give a feeling of freedom and power, shelters and small places give a feeling of security. Every person feels comfortable in different spaces. The history of mankind is also the history of creating spaces. Some manmade spaces resemble natural forms like monumental buildings remind of mountains or pittoresque gardens resemble meadows, forests or riverbanks. Other designs do not have any natural archetype. Simple or complex geometric forms like we can see in the baroque gardens represent domination and control over nature.

Light

To ensure 'visual comfort', adequate illuminace levels (measured in lux) have to be provided throughout the space, while preventing glare sensations. More precisely, disability or discomfort glare occurs when the field of view contains either great luminance values or great luminance contrasts. An open space design should be well adapted to the daytime and nighttime natural and artificial light resource [RUROS(2004)].

Forms, Colors, Smell

Nice vegetation, spectacular facades, well designed urban furniture can give an aesthetic impression. Colors have many symbolic and historical meanings and can cause different emotions. Also a smell can taint the impression of a place strongly. It can be a good, bad, known or unique smell, which stays in our memories.

Sound

The acoustic environment is an essential aspect of the comfort of urban open public spaces. When we cannot talk or even think, it is impossible to linger on a place. A pleasant sound such as a fountain or a bird singing can attract people to change their route or to stay longer on a site. The acoustic comfort is described at length in [RUROS(2004)]

Feelings

We can be aquainted with a place because we know the place itself, or it reminds us of a place or a person we used to visit frequently. When we are 'feeling at home' this feeling might be stronger than other aspects. Memory can also remind us of something terrible that happen in the past and give us feelings of fear or anger. In anycase we are not indifferent to a place we know, because we have a personal relationship it. [Frohmann(2003)],[RUROS(2004)]

3.2.3 Social Value

The positive feelings towards a space also depend on its usability and how the person in the space is able to access and use it.

Restrictions

Is the area public or private? Who is watching me? Do other users claim the space? Who is allowed in? How much do I have to pay to enter? How long am I allowed to stay? What is admitted? A place I cannot access or only illegaly access produces different feeling than my own private place, where I can linger undisturbed.

Dysfunctionality

Can the place be used? How can the place be used? Are there benches, shade or quiet corners? Am I allowed to sit in the meadow? How functional is it? Is it open to different forms of usage? What happens when the users of the space get older, have children or increase in number? Is the space able to adapt to different demands? [Schneider(2001)]

4 Climate

In order to understand the bioclimatic processes dominating our cities, it is necessary to understand some basic physical laws. I cannot cover this topic in detail, because it is not my main topic, but I do not want to skip it completely in order to make it easier for non-meteorologists to read this work. The most important parameter in biometeorology is radiation. Excessive or missing radiation is the main reason why we feel too hot or too cold. I will introduce the most important radiation laws and explain the different kinds of radiation. Humidity and air flow will be mentioned only briefly, focusing on their influence on radiation input and human thermal comfort.

4.1 Radiation

Definition

Radiation is energy transport by means of electromagnetic waves. It does not need any medium to propagate. Therefore it can cross the space and bring energy directly from the sun to the earth. Every body emits and absorbs radiation. The energy from the sun comes to earth in various wavelengths, the longest being radio waves and the shortest are gamma rays. Approximately 40% of the radiant energy the earth receives from the sun is visible light. Visible light ranges from red, with an wavelength of 780nm to violet, with a wavelength of 390nm.

Planck's Law

It describes what wavelengths to which percentage of the full radiation are emitted by a body. Planck's Law can be graphically described as a unsymmetric bell-shaped curve which starts and ends with cero radition emitted. Its shows that every body emits in nearly all wavelength, but the main radition is emitted in a certain range of wavelength.

Stefan-Bolzmann Law,Emissivity ϵ

$$J = \sigma \times T^4$$

$J ... [W/m^2]$
$\sigma = 5.67 \times 10^12 J/cm^2 \times s \times K^4 ...$ constant
T ... absolute temperature of the radiating surface [K]

The Stefan-Bolzmann law describes that the amount of energy emitted by a body is dependent on its surface temperature. No other parameters like air temperature, air pressure or humidity influence it. The law applies perfectly only to 'black bodies'. Real objects emit less radiation. The emissivity is empirically defined by ϵ. Most surfaces in nature have an emissivity between 0.90 and 1. Metals have a lower emissivity.

Kirchhoff's Law

Bodies which can absorb well certain wavelengths, can also emit these.

Wien's Law

$$\lambda_{max} = \frac{\eta}{T}$$

λ_{max} = wavelength of the most intense radiation
η =natural constant 2880μm $\times K$
T = absolute temperature of the radiating surface

Wien's law says the warmer the body is the shorter the wavelength of the emitted radiation is.

4.1.1 Astronomic and Geographic Factors

On the edge of the atmosphere the incoming solar radiation has an intensity of $1399 W/m^2$ which is called the solar constant. The distribution of radiation on earth is dependend on various factors.

The Elliptic Earth's Orbit

It causes a variation of 6.5% of radiation in the course of a year

The Inclination of the Earth Axis

The earth axis is inclined 23.5 $^\circ$. The Lambert Cosinus Law describes how the energy per area is decreased because it is distributed over a bigger area. I=$I_0 \cos\delta$

The Spherical Shape of the Earth

Dependent on the degree of latitude the incoming angle and the length the sun rays have to go through the atmopshere change and influence the radiation received on the earth surface.

The Earth's Rotation

The radiation varies in the course of a day.

The Topography

An exposition of 0 $^\circ$ of a slope or wall means that it faces North, whereas an expositon of 180 $^\circ$ means it faces South. The inclination describes the angle to the zenith. Both strongly influence the received radiation.

4.1.2 Shortwave radiation

Radiation emitted by the sun is called shortwave radiation (also: solar radiation) and ranges from 0.1 to $3\mu m$. It includes the visible light which has the wave length from 0.3 to $0.7\mu m$.

The amount of shortwave radiation absorbed by the earth can be described as:

$$R_{sw} = R_O + R_D - r(R_O + R_D)$$

R_O Direct Radiation

Is defined as the rays coming directly from the sun.

R_D Diffuse Radiation

Is defined as the radiation not coming directly from the sun including the atmospheric shortwave counter radiation.

Reflex Radiation

Is defined as the radiation reflected on surfaces.

Albedo

The percentage of radiation that is reflected is called reflexivity or albedo (r). If a surface has r=0.1 that means, it reflects 10% of the incoming radiation.

4.1.3 Longwave Radiation

The radiation emitted by the earth is called longwave radiation (also: terrestrial radiation) and ranges from $3\mu m$ to $60\mu m$ and is felt as heat or warmth.

The amount of longwave radiation can be described as:

$$R_{lw} = R_E + R_G$$

R_G **Atmospheric Counter-Radiation, Cloud Cover**
The atmosphere itself absorbs, emits and reflects longwave radition, but mostly the clouds influence the engery budget strongly. In the day they let less energy reach the earth surface, during the night they hold the warmth. On a clear night there is nearly no atmospheric interaction and the earth cools down. Different types of clouds influence the energy budget differently.

R_E **Infrared Radiation of the Surrounding Surfaces**
As already mentioned in the beginning (see Planck, Bolzmann, Wien) every body emits radiation. This is important when we talk about human thermal comfort, because the hotter the surrounding surfaces are the more uncomfortable a human being feels. Unlike the air temperature the radiative temperature is difficult to measure but much more meaningful.

Mean Radiative Temperature T_{mrt}

Is defined as the uniform temperature of a surrounding surface emitting blackbody radiation (ϵ=1), which results in the same radiation energy gain for a human body as the prevailing raditative fluxes which are usually very varied under open space conditions. Measuring the T_{mrt} is very complex and time-consuming(Höppe,1992;Matzarakis,2001) (Radiation and Thermal Comfort,Matzarakis)

4.1.4 Radiation Balance

Energy cannot be lost. So the complete solar energy is transformed or reflected. The incoming radiation can be direct (R_O) or diffuse (R_D), which means it has been scattered in the atmosphere. They are both short wave electromagnetic radiation. When they reach the surface they are reflected, depending on the surface's albedo(r). This part goes back to the atmosphere and is partly lost, partly reflected from the atmosphere back to the earth(R_G). Some part of the radiation is already reflected in the sky.(R_E)

$$R = R_O + R_D - r(R_O + R_D) - R_E + R_G$$

4.2 Heat Balance

The solar energy reaching the earth's surface, which is not reflected, is transformed to other forms of energy:

$$R = H + LE + G + Ph + M + \Delta S$$

R Radiation Balance (W/m^2)

H Sensible Heat Flux

Energy used and stored in heating the air and move it by convection.

LE Latent Heat Flux

Energy used and stored by evaporating water.

G Soil Heat Flux

Energy used and stored to warm the soil.

Ph Photosynthesis

Energy used by the plants.

M Metabolism

Energy used by animals and humans for their metabolisms.

Δ S

Energy stored.

4.3 Humidity

Thanks to the water, the solar energy, which reaches the earth can be stored in a great amount. First, energy can be stored by the warming of water itself. This may be the ocean, the sea, rivers, the water content of the soil or the air. Water gives away its heat slowly by emitting long wave radiation. Water in an ecosystem softens the extremes and slows down and delays the radiative changes.

Second, a lot of energy is stored by evaporating water. This energy is released when the air is saturated and the vapour condensates or even sublimates to ice crystals. Humidity is strongly influenced by the capability of water storage in the soil and the vegetation layer, unless there is daily rain.

4.4 Wind

Wind takes away humidity and hot air. This means it takes away energy in its latent and sensible form. Therefore wind is an important factor for human comfort. The windier it is, the colder it feels. Wind can make a place feel more comfortable when it is hot, but on a cool day the wind makes you feel cold. This effect is called windchill. At very high wind speeds it can be impossible to enjoy an open space because it is physically difficult or annoying to move.

4.5 Processes in Urban Structures

4.5.1 Urban Climate

The urban climate is generally defined as 'Climate, modified by the interferences with buildings and their effects including lost heat and emissions of pollutants' (WMO,1981)
How the urban climate of a specific city develops is dependent on the natural circumstances - like the physiogeographical setting, the form of the terrain, the regional climate - as well as the man-made changes - like land use changes and urban forms.

Urban Heat Island

The most famous phaenomena in the urban climate is the formation of the urban heat island. The temperature in the city center can be up to 10 K higher than in the surrounding area. The strongest heat island builds up in summer nights with little wind and no cloud cover('Strahlungsnächte'), when the previous days had a similar strong radiation. More warmth is stored in urban areas and less water is evaporated because of the lack of vegetation. Less long wave radiation can leave the urban atmosphere because of the high concentration of pollutants. In the winter heating of the buildings adds more warmth and pollutants to the urban atmosphere.

Alteration of the Wind Field

The second feature of urban climate is the strong alteration of the windfield compared to the surrounding area. Close to high buildings and in streets oriented parallel to the wind direction the wind can speed up significantly. In streets running at right angles to the wind eddies are created and calms persist at the bottom of deep courtyards and other small, confined spaces. Gusts and lulls, eddies and jetlike winds, occur simultaneously within several hundred meters of one another or from one second to another in the same place, a product of interaction of changing regional wind speeds adn directions with surface topography, the aerodynamic shapes of nearby buildings, the size and shape of the space surrounding them, and the form of the city upwind. Although we can feel gusty turbulences within the city, the high roughness of urban structures causes an average slow down of the windspeed. The city as a whole acts like a huge obstacle for the wind. Up to the height of 100m the atmosphere is strongly affected by buildings. The higher air levels up to 2000m are strongly affected by the urban climate. When there is little air exchange the effects of urban climate are very strong. When the wind is strong the decline of the windspeed as well as the jetlike winds in the street canyons can be felt very clearly.

The wind determines whether the polluted air at street level is rapidly dispersed and diluted or lingers to concentrate to dangerous levels. Wind also enforces evapotranspiration and helps to cool the surface.

In the project RUROS the influence of urban structure on the wind field have been analysed and following observations and conclusions made:

- The bigger the square, the higher the wind speed in the space.

- The bigger the square, the more turbulent is the wind flow.
- The higher the wind velocity in 10m height (V10), the higher is the wind speed in the square.
- The flow pattern and level of turbulence is almost unaffected by the wind speed V10.
- The higher the boundary buildings compared to the neighbourhood, the higher is the wind speed and turbulance on the square.
- The more the overall wind direction varies from the main orientation of the space the more chaotic becomes the flow pattern.
- There is no clear relation between the overall wind direction and the wind speed on the square.
- There is no clear relation between the wind speed on the square and the location of the openings to the space.
- Openings in the corners on the square give a more turbulent flow pattern than openings in the middle.
- The bigger the openings, the more turbulent the wind pattern.

To minimize the wind speed a place should be as small as possible, with the boundary buildings lower than the neighbourhood and the openings should be in the middle of the space.

Characteristics of the Urban Climate

Element	Compared to Rural Environs
Condensation nuclei	10 times more
Gaseous admixtures	5 to 25 times more
Total radiation on horizontal surfaces	0-20%less
Clouds	5-10% more
Fog, winter	100% more
Fog, summer	30% more
Precipiation amounts	5-15% more
Snowfall, inner city	5-10% less
Snowfall, lee of city	10% more
Temperature (annual mean)	0.5 - 3 K more
Heating degree days	10 % less
Relative humidity (annual mean)	6%less
Annual mean windspeed	20-30% less
Extreme gusts	10-20% less
Calm	5-20% more

[Landsberg(1981)]

4.5.2 Air Pollution and Heat Excess

Within the urban area the emission of pollutants is generally higher than in the countryside. In the past domestic fuel and industry caused most of the pollution. In the last decades traffic has become the main polluter. In combination with the reduced air exchange, the concentration of pollutions is increased in urban areas.[Schwab and Steinicke(2003)] The character and severity of air pollution problems varies from city to city.

The city's added heat increases summer discomfort and the energy required for air conditioning day to day, and during the heat waves contributes to more deaths than occur in the cooler suburbs. Problems of dirt and comfort are linked. Automobiles, power plants, furnaces and factories poison and heat the air. Dense buildings block the wind, preventing the dispersion of dirt and heat. Valleys and street canyons trap pollutants. Stone and concrete absorb heat and store it during the day, then give it off at night. Together, these factors produce a city climate distinct from that of the surrounding countryside. Urban activities, forms, and materials, and the manner in which they are combined, account for the wide variation in microclimate and degree of air pollution from spot to spot within the city. The characteristics of city climate, its causes and effects, are well known, but the knowledge is rarely exploited.

All too often, the builders of cities - governments and corporate officials, engineers, architects, landscape architects, and city planners - are oblivious to the effects they have on urban climate and air quality. Air pollution, discomfort, and energy consumption are treated separately when they are addressed at all, not as the interrelated whole they represent. Attempts to solve one problem often create several new ones.'[Spirn(1984)]

Five air pollutants - sulfur dioxide, nitrogen oxides, ozone, carbon monoxide, and total suspended particulates - are monitored in most metreopolitan regions as indicators of air pollutantion.

Sulfur dioxide is the primary ingredient of London smog. Sulfur dioxide and dust, for centuries the major urban air pollutants, have recently been displaced by photochemical smog and carbon monoxide.

Carbon monoxide, an odorless, invisible killer, is most concentrated at the city center where cars, trucks, and buses clog narrow streets flanked by tall buildings, and most severe on weekdays during morning and afternoon rush hours.

City dust ist more than common dirt. Although automobile exhaust produces a relatively small proportion of the total suspended particulates in the ambient air above the city, these particulates have a substantial impact on health. They are not only emitted at breathing level but are also small and easily inhaled, and embedded in the lung.

Apart from the toxic effects of pollutants, they cloud the atmosphere and act as condensation nuclei. Less radiation reaches the street level and inversions have less chances to be dissolved.

Occasionally, the normal pattern of stratification of the atmosphere may be 'inverted', with cooler air below and warmer air above: when air mass moves in over cooler one; when warm air flows over a colder suface; or when the air near the ground is cooled from below at night. The cooler air, unable to rise into the warmer air above, is trapped near the ground for hours or even days and all the city's poisonous emissions with it. The longer the inversion persists, the higher the concentrations of air pollution within the city. Inversion are occasional and brief events in all cities, and frequent and prolonged ones in cities with a topographic or climatic predisposition. Inversions can form at the scale of an entire metropolitan region, or at the scale of a street canyon. [Spirn(1984)]

The Ideal Urban Climate

The Fachausschuss 'Bioklimatologie' of the Deutsche Meteorologische Gesellschaft has defined the 'ideal urban climate' as such: 'Das ideale Stadtklima ist ein rumlich und zeitlich variabler Zustand der Atmosphre in urbanen Bereichen, bei dem sich mglichst keine anthropogen erzeugten Schadstoffe in der Luft befinden und bei dem den Stadtbewohnern in Gehnhe (charakteristische Lnge 150 Meter) eine mglichst groe Vielfalt an Atmosphrenzustnden (Vielfalt der urbanen Mikroklimate) unter Vermeidung von Extremen angeboten wird.'

[Schwab and Steinicke(2003)] ('The ideal urban climate is a spatiotemporal condition of the atmosphere in urban areas, with the lowest air pollution and the highest diversity of atmospheric conditions for the citizens within walking distance, avoiding extremes.')

4.6 Climatic Value of Plants

Plants interact with the atmosphere and the soil in various ways. Some effects are caused by their shape itself - like the alteration of wind and shading, some are produced by their metabolisms. A living plant interacts differently with its environment than a dead plant. A plant with plenty of water acts differently than a plant that is close to dying because of drought. Different species have different needs, and at each age a plants metabolism changes. Each plant can adapt to the climate in a certain range. The steadier the climate the easier it it for the plant to get used to its environment.

4.6.1 Shade

Approximately 40% of the radiant energy the earth receives from the sun is visible light. The violet to blue and red to orange ranges are the most often used in photosynthesis. Most light in the green range is reflected. Of the visible light that reaches a leaf, approximately 80% is absorbed. Under a tree only a little radiation reaches the surface and the soil cannot heat up strongly.

4.6.2 Alteration of the windfield

Each plant is an obstacle to the wind. Depending on its size and the density and flexibility it influences the air flow. It can slow down the wind, cause turbulences or trap air within the vegetation layer. Compared to solid buildings, plants slow down wind more effectively because they create less turbulences.

4.6.3 Photosynthesis

Photosynthesis is the process by which light energy is captured, converted and stored in simple sugar molecule. This process occurs in chloroplasts and other parts of green organisms. It is a backbone process, in the sense that all life on earth depends on its functioning. The following equation sums up the process:

$$6CO_2 + 12H_2O + lightenergy- > C_6H_{12}O_6 + 6O_2 + 6H_2O$$

Carbon, Water and sunlight radiation is transformed to water, sugar (in the form of glucose) and water. As you see from the equation, this process is vital to plants and humans, because it transforms carbon dioxide into oxygen, which we need with every breath and produces sugar, which the plant needs as a source of energy.

4.6.4 Transpiration

The water utilized in photosynthesis is the source of oxygen released as a photosynthetic byproduct. Not even 1% of the water that is absorbed by plants is used in photosynthesis, the remainder is either transpired or incorporated into protoplasm, vacuoles or other cell materials. On a hot day, when water is available to the plant it will transpire a lot. This action changes the heat flux. More energy goes into the latent heat flux and less into the sensible heat flux, therefore the plant cools down itself and its enviroment. When the soil dries out there is no more water to transpire, so the plant will close its stomata and stop its interaction with the atmosphere. In this case the sensible heat flux will rise again and there will be no noticeable cooling effect by the plant apart from the shadow it casts.

The crucial role of plants in the water circle is to bring water in the atmosphere and cool the air at ground level.

Effects of Trees on the Radiation Balance

Most of the urban soil is shaded, therefore the energy flux in large part takes place at roof level. During daytime at street level no big difference in air temperature compared to the temperature outside the city can be measured. During the night, especially when the sky is clear, on the outskirts the air cools much faster. The heat that is stored in the city during the day prevents cooling at night. Narrow streets do not allow the wind to mix the air which makes it difficult to sleep at summer. [Kuttler(1997)]
One way to improve the situation is to plant trees, because they produce shade, but do not store heat, due to the low heat capacity of leaves. Unsealed soil is always more humid than sealed soil and cools the air at ground level of evaporation. On the other hand the tree crowns prevent cooling at night and make free spaces more comfortable, even in the cold seasons. A good example in Vienna is the frequently found Aesculus hippocastanus in the gardens accompanying restaurants and 'Heurige'. Besides these general principles the orientation and geometry of the site play a crucial role as well.
The air in parks and green spaces cools down considerably. This effect can only be noticed in the vicinity up to 100 meters. [Bruse(2000)]

Effects of Trees on Air Pollution

Due to their big surface, leaves can absorb pollutants and accumulate them on their surface, which is especially relevant for the ¡PM10, which are highly oecotoxiologic. Apart from CO_2 trees do not absorb important quantities of gases.
Trees influence the distribution of particles and gases by changing the wind field, which can be dangerous in small highly frequented streets when the crowns prevent the polluted air to mix with upper layers. On the other hand, in such a case the pollutants are not distributing and polluting other parts of the city like parks, which are predestined to deposition and sedimentaion of all kinds of particles from elsewhere due to their high roughness and big surface. Parks often get much more pollutants than they can cope with. [Bruse(2000)]

4.7 The Viennese Climate

[Schwab and Steinicke(2003)] Vienna has probably one of the highest life quality of all cities worldwide. The city lies on the northeastern foothils of the Alps and enjoys a temperate-mild climate. The most important role in the Viennese climate iss the Wienerwald. Cities are in general similar to stone deserts. But unlike other metropolises, which have to fight with smog and stagnant air, the frequent Westwind blows fresh air from the Wienerwald into the city.
Human settlements have always been adapted carefully to the local climate. The effects of the urban climate, that started being noticeable when industrialisation proceeded were first examined in the 18th century. Even Poets like Adalbert Stifter wrote about the Viennese climate.[Stifter(1844)]

There are two main wind directions. Mostly the wind comes from the west and north-west and brings cool and humid air. The second frequent wind direction is south-east. When the wind comes from this direction it brings warm and dry air. In autumn and winter there are more winds from the south-east. In spring and summer the dominant wind direction is west. North winds are most frequent in spring.
The windspeed and amount of precipitation differs strongly in Vienna because of its diverse landscape. The most important features in the viennese climate is the Wienerwald, which lies in the west of the city. It lifts the wind up from its main direction and causes a precipitation maxima over the Wienerwald.

While the Wienerwald gets an annual precipitation of 800mm, the southeast gets less than 600mm. In wet years high places in the Wienerwald can get up to 1000mm precipitation, whereas in dry years the southeast receives only 350mm.
There is a second precipitation maxima east of the Danube, which is caused by air pollution. Here the air brought from the west finds condensation nuclei produced by the industry, traffic and households of Vienna. Generally mostly in the summer there is a precipiation maxima, followed by a second maxima in November.
Because of the high sealing degree most of the precipiation leaves the city before it can evaporate. The urban air is drier and warmer than in the surroundings, because of the large amount of sealed areas and the lack of transpirating and cooling vegetation. Compared to the neighbouring Wienerwald, the annual average temperatures of Vienna are up to 2.5 K higher, and compared to other parts of the Viennese basin (Wiener Becken) up to 1.5K higher. The average daily maxima are 2.9 K higher.
The temperature differences at midday are relativly small. In the city center at street level it can be slightly cooler in the summer and slightly warmer in the winter. In the evening, night and early morning is considerably warmer in the summer and slightly warmer in the winter.
Within this heat island there are multiple differentiations. Wide green areas in the city centers are cold islands and compensate the urban climate. On a small scale that also happens in greened back yards. [Schwab and Steinicke(2003)]

Fig.4.1 to fig.4.8 come from the Zentralanstalt für Meteorologie (ZAMG), Vienna. They are derived from the measurement series of the station in Viennas city center ('Wien Innere Stadt') from 1971 to 2000.

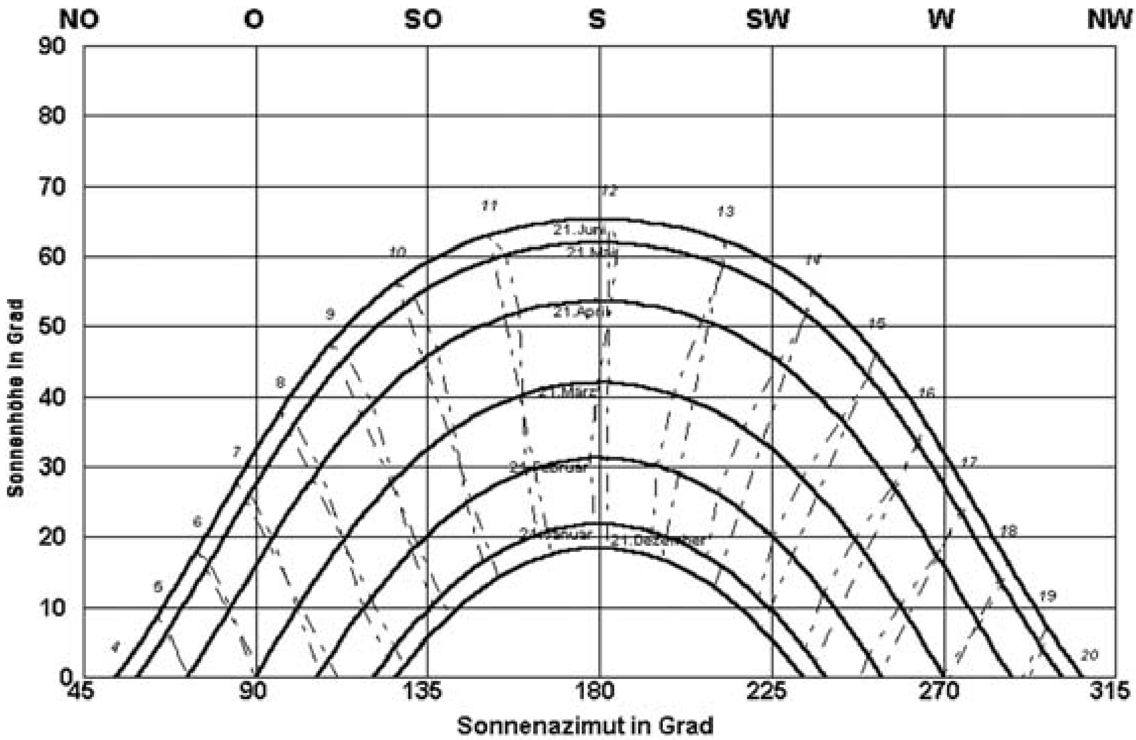


Figure 4.1: sun's orbit in Vienna(48 ˚ 15')

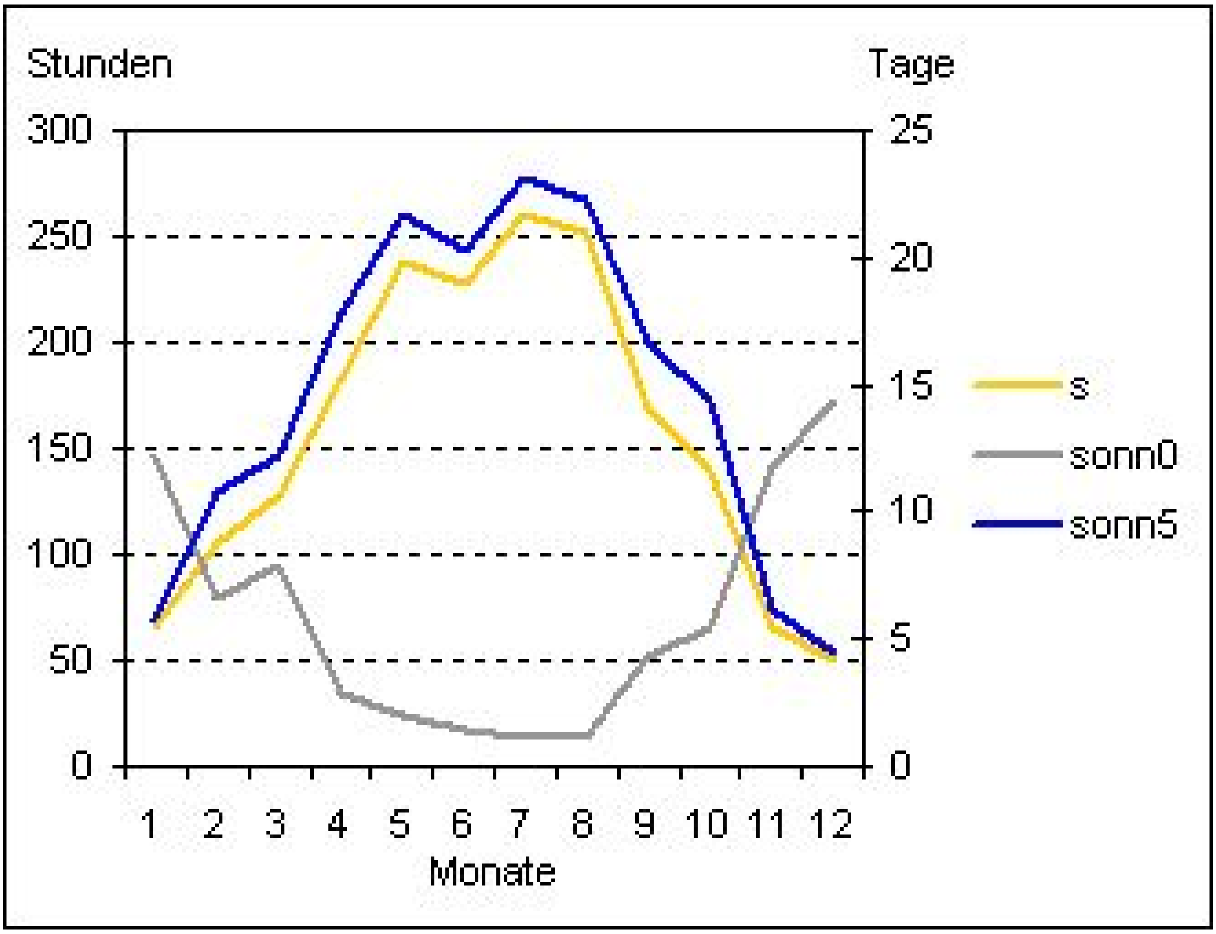


Figure 4.2: hours of unlight

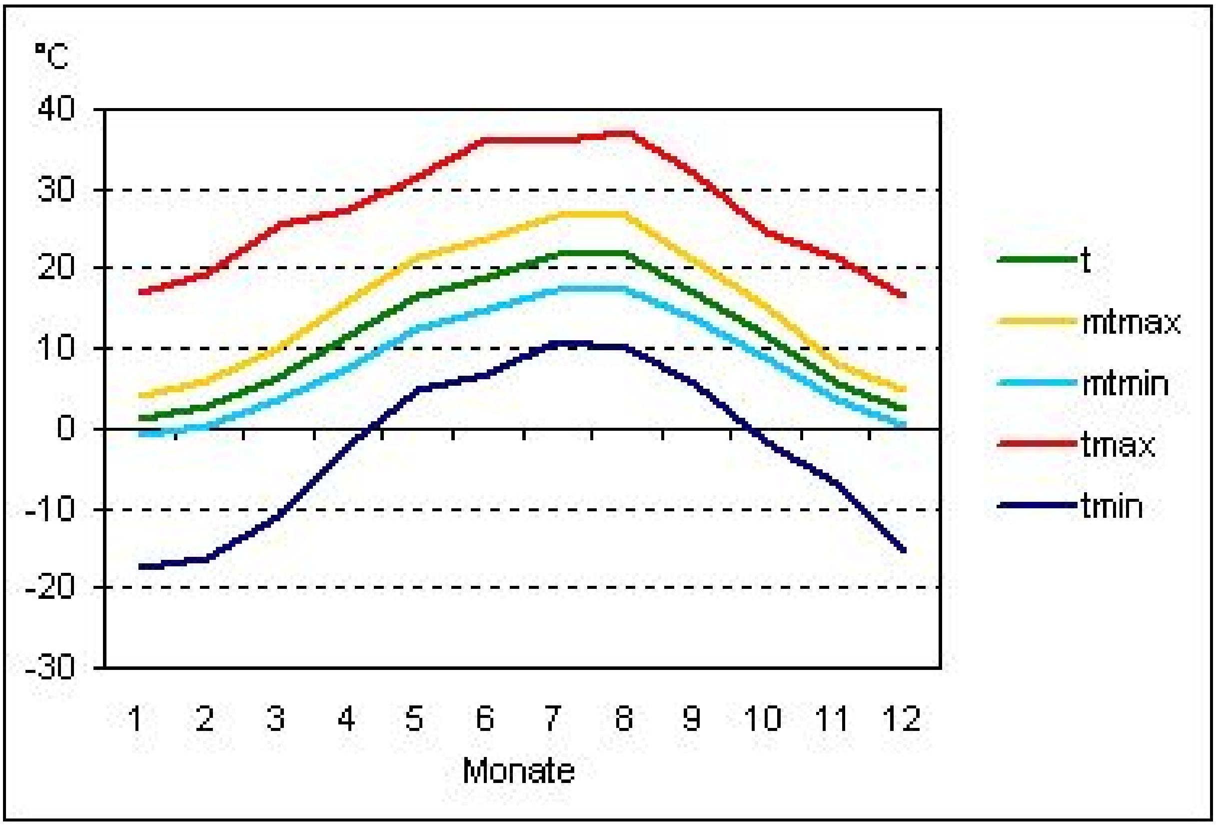


Figure 4.3: temperature

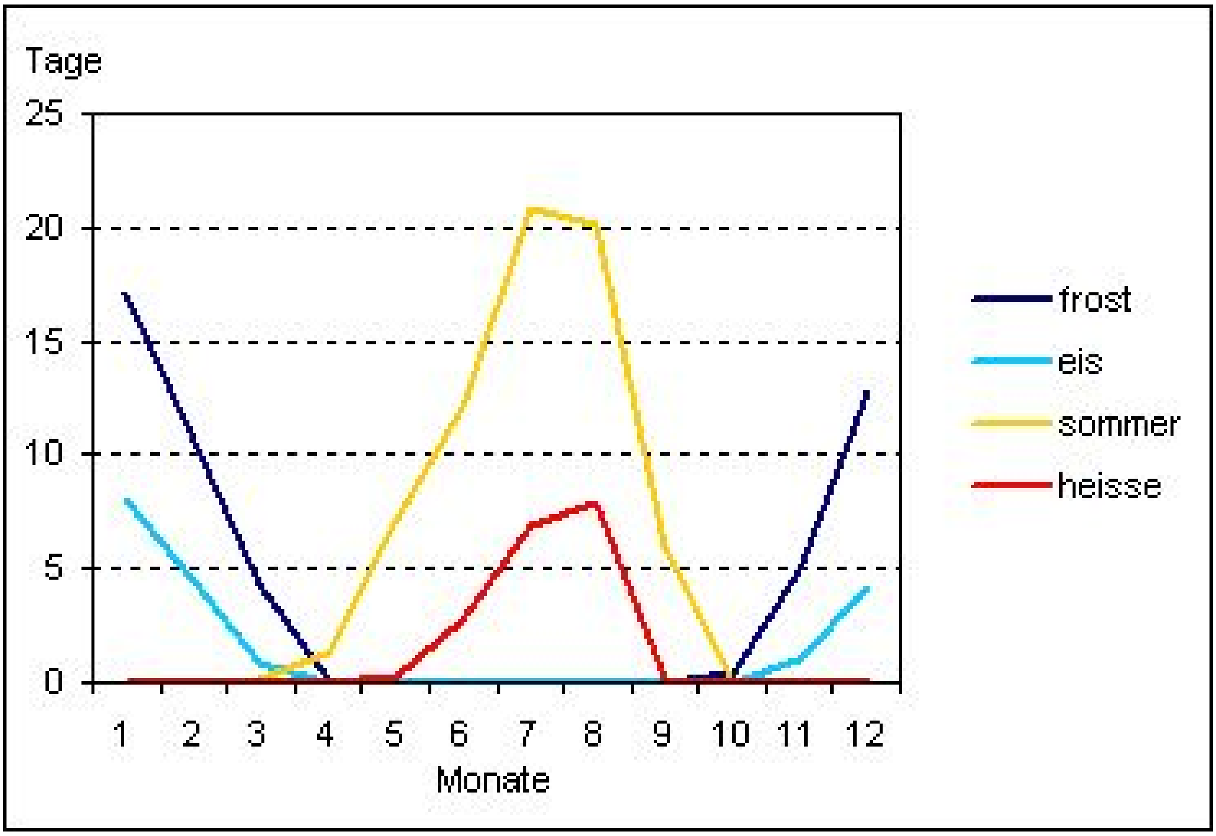


Figure 4.4: days of frost, ice, summer temperature and heat

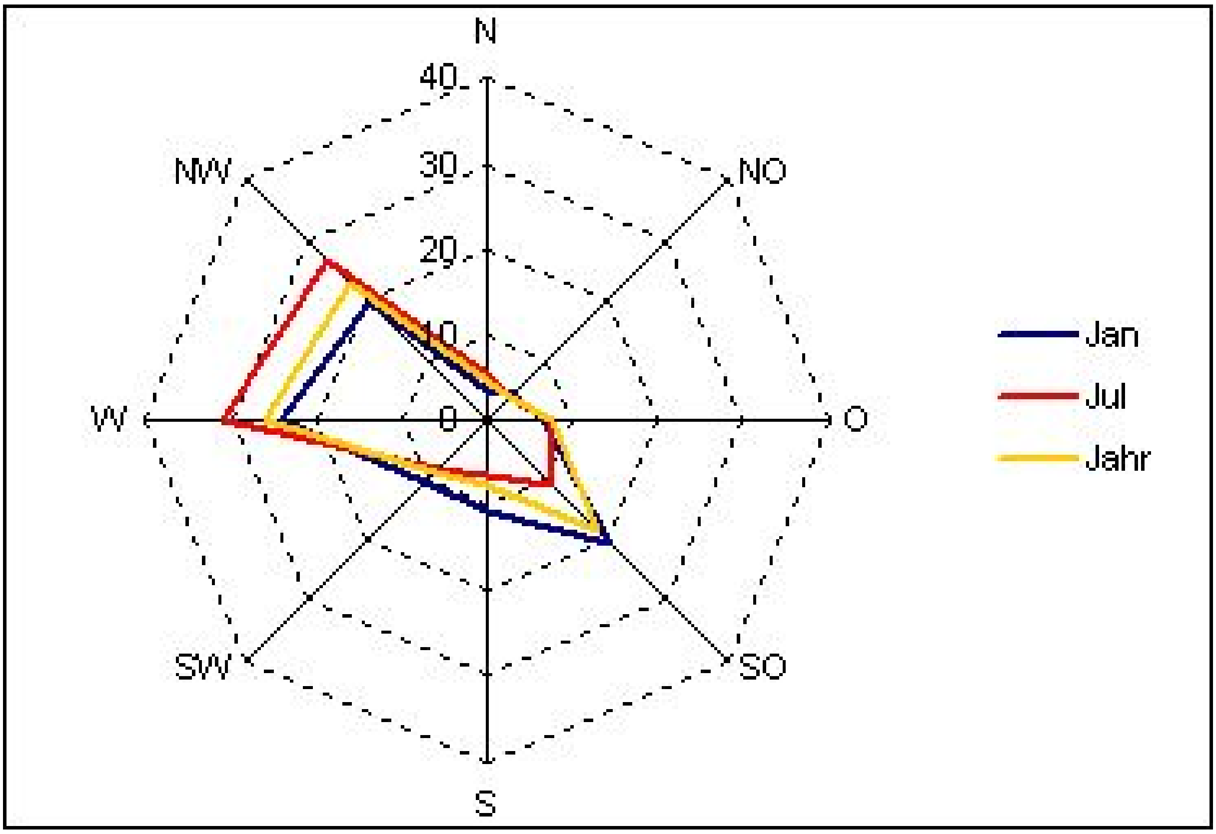


Figure 4.5: wind directions

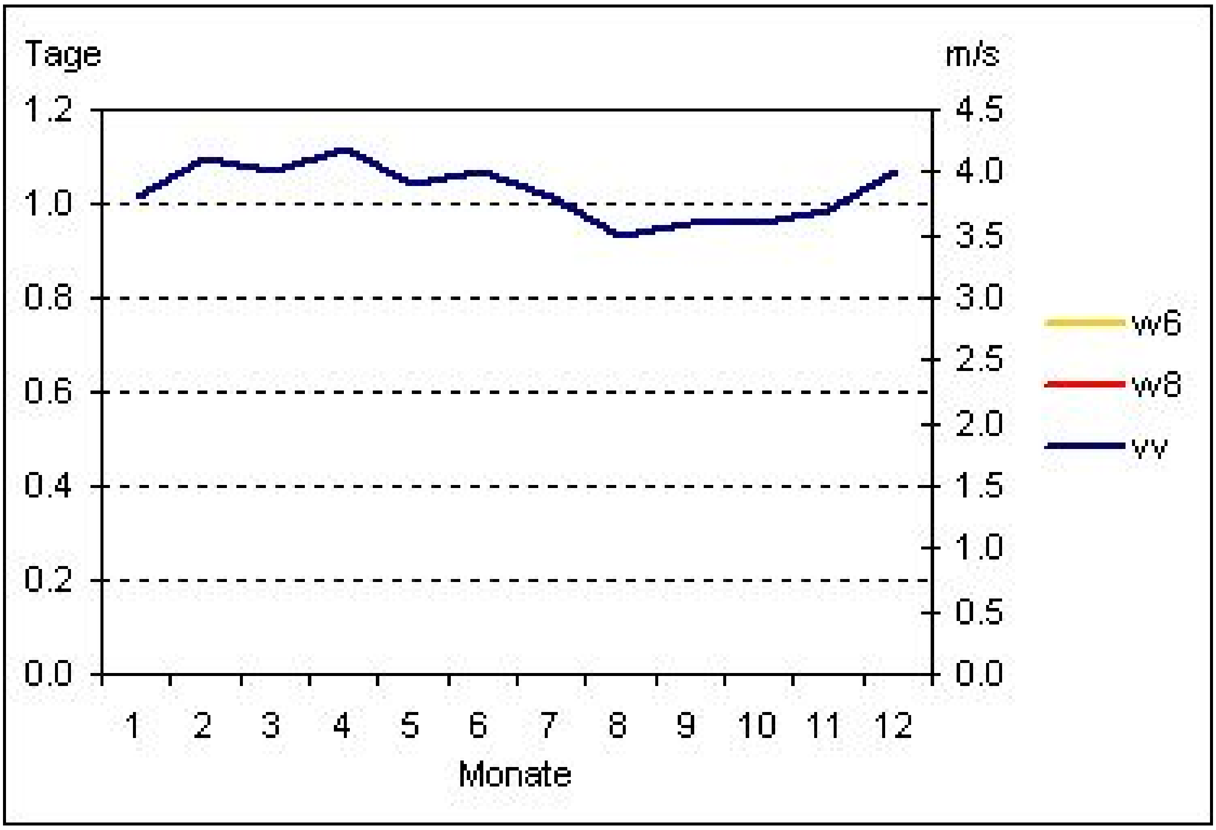


Figure 4.6: windspeed

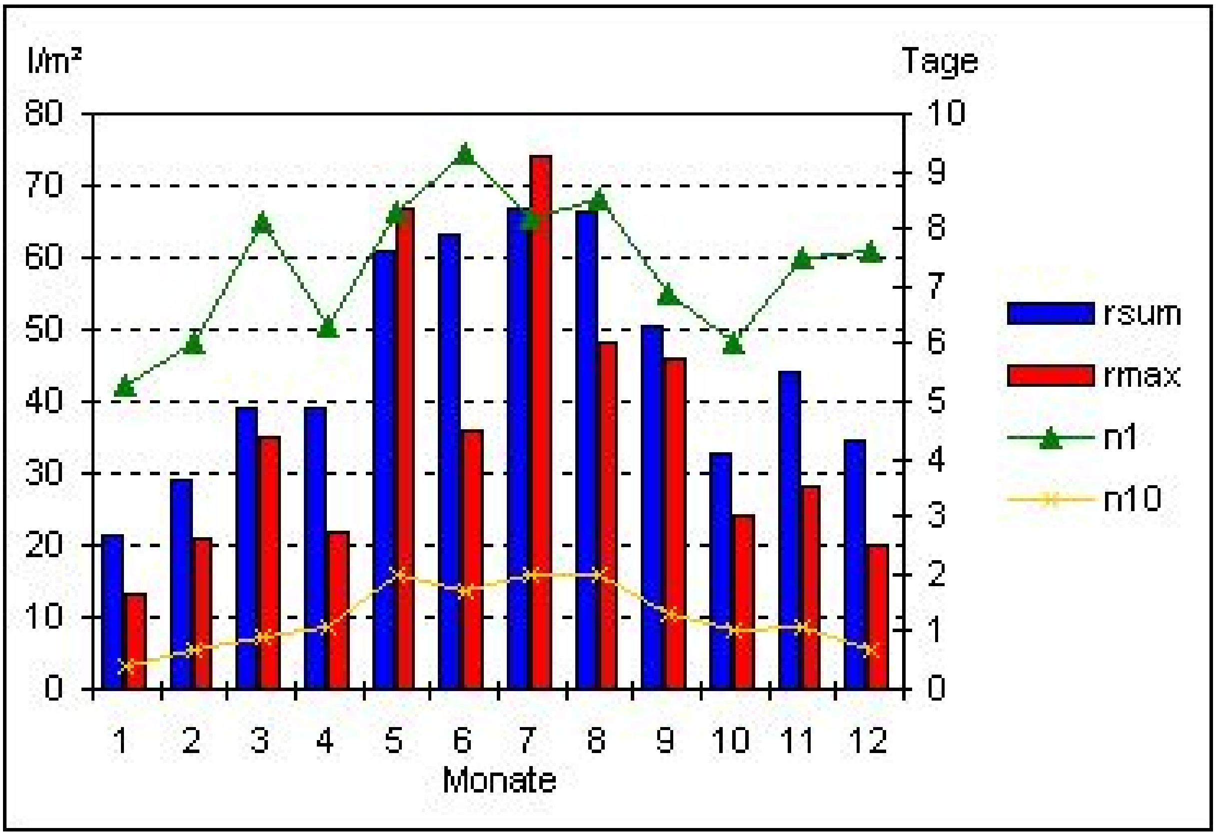


Figure 4.7: precipitation

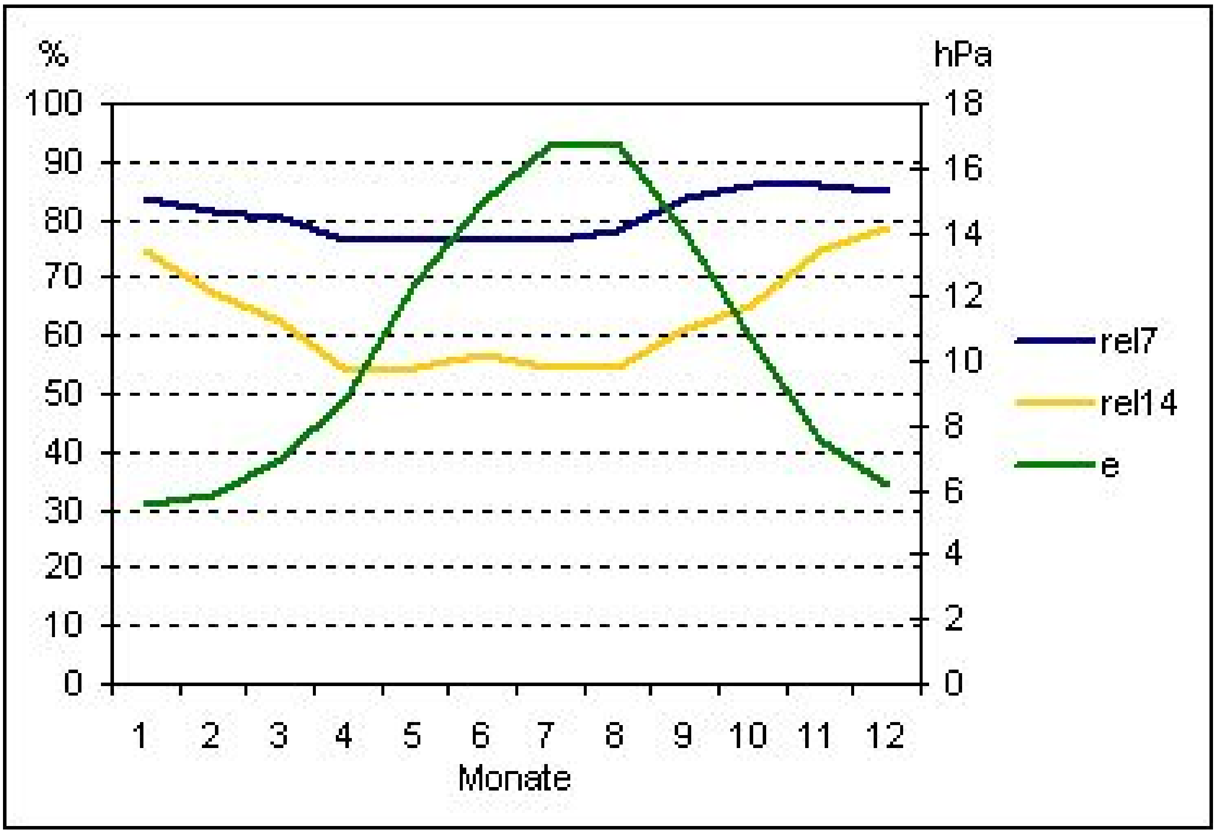


Figure 4.8: humidity

4.8 Climatic Features of Josefstadt

Figure 4.9: ortophoto of Josefstadt

Urbanistic Features

Why do I choose these sites? What microclimatic parameters are important?
Both places that I chose to analyse are situated in the eighth district. This district was dominately built in the age called 'Gründerzeit'. Its structure can be characterized by the equal height of the buildings of about 20m, the relatively narrow streets of 8 to 20m and the existance of backyards. All buildings are built without leaving distance to the streets apart from the pavement. Behind this facade every block has its own free space, which can be detached in different ways. This type of building structure is called 'gründerzeitliche Blockrandbebauung'. This building pattern spreads concentrically from the old city center to the Gürtel and beyond.

Does the orientation and width of streets influence the air flow?

Generally the streets which are oriented east - west are better aerated than the ones who are oriented north - south. On the other hand narrow streets have much lower wind speeds. Measurements have shown that when we take the Opernring as 100% the wind speed in Kärnterstaße is only 33 and the one in Seilergasse 20%. All three streets are in the city center of Vienna. Opernring is about 50m and Kärnterstraße about 15m wide. Seilergasse is about 8m wide and resembles the streets that pass the two places I will analyse in size. [Steinhauser et al.(1959)Steinhauser, Eckel, and Sauberer]
Comparing the streets studied by Steinhauser with the streets that lead past the places that will be analyzed I show the orientation of each street and its width. The percentage describes the wind reduction at street level in the center of a street compared to the side. It is clear to see that in the narrow streets I analyse, the influence of the wind does not play a crucial role anymore and the different orientations of the streets will not make a great difference in the wind exposition on the place itself.

streets studied	orientation	approximate width [m]	wind speed [%]
Opernring	ese - wnw	50	100
Kärntnerstraße	nne - ssw	15	33
Seilergasse	nne - ssw	8	20
Piaristengasse	nnw - sse	10	
Florianigasse	ene -wsw	6	

Horizontüberhöhung and Sunshine duration

Horizontüberhöhung results from the relation between height and width of places and streets. Its value defines the amount of radiation reaching the ground directly. The lower the value, the more sun comes in.
In both places the buildings height is about half the size of the places width. That means that the 'Horizontüberhöhung' is close to 45 $^\circ$ in the center and 27 $^\circ$ on the margins.
The width of Piaristengasse and Florianigasse is about half the height of the adjoining buildings. When we calculate with these values we get an Horizontüberhöhung of 76 $^\circ$ in the center and 63 $^\circ$ on the sides.

Höhenwinkel(Piaristenplatz) $= arctan(23/50) = 24.70\,^\circ$
Höhenwinkel(Schlesingerplatz) $= arctan(24/46) = 24.70\,^\circ$
Höhenwinkel(Florianigasse) $= arctan(24/15) = 57.99\,^\circ$

There is a difference in east-west and north-south oriented streets. The east-west streets have more sun during the summer but less sun during the day in the winter. They aleways have sun in the morning and in the evening. The north-west streets have sun the whole year around, but only at midday. Places with the same ratio between height and width as streets get less sunshine than streets.

Orientation of the Facades, Reflectivity and Albedo of the Surfaces

The facades to the North only have direct sunlight in the early morning and late evening in the summer. The eastern facades get sunlight in the morning, and the western facades in the evening. The southern facades get the most constant sunlight. The higher the Horizontüberhöhung the less sunlight reaches the facades. Sometimes only the upper stories get sunlight especially in the winter.
The reflectivity of the surfaces can alter the light illuminating a place and the amount of radiation that can be stored as warmth.

First Assumptions and Questions

What bioclimatic parameters are important? Before analysing and simulating the sites I wrote down my thoughts, questions and assumptions. The most important parameters for human thermal comfort are the air and surface temperature, the windspeed and the sun radiation. Because this topic is new for me I will predominantly focus on only one parameter: the surface temperature, because it shows the strongest variations on different materials within one day, and also is an important input parameter for thermal comfort indices like the PMV.

Jodok-Finkplatz

The place is small, so I assume that the shading effect is so big that the heating up off the sealed surface is not large enough to produce a thermal uncomfortable situation in the place. The wind speed will also be reduced strongly. But are there any turbulence effects? Are the plastic benches pleasant to sit on if it is sunny? How warm do the surfaces get? How cold does it get in winter? Does the sun reach every corner, the whole year around?

Schlesinger Platz

Does the meadow really make a difference? Are the trees big enough to show effects? Can the fountain be taken into account. The place seems to be really pleasant in summer, but cold and uninvitingly in winter. (But which place is that, in wintertime?)

Relevant Meteorological Situations

For estimating the thermal comfort it is important to know what extreme weather sitations can form. Even more important is the thermal comfort during a very frequent meteorological situation, or an extreme situation which can prevail for more than 5 days, like a heat wave. In Vienna it is cold and windy in the winter, and hot in the summer. For assessing the entire thermal comfort for a place it would be crucial cope with the winter and summer situation seperately and additionally seperate between common and extrem sitation in both seasons. Due to lack of time I cannot cover all this, and focused on the summer. In the winter its possible to look for shelter indoors and turn on the heating whereas when the heat excesses a certain limit, there is no way to escape. This produces a mayor problem in modern cities and on this topic I focus the simulation.

5 ENVI-met

5.1 Different Approaches on Climate Modelling

5.1.1 Modelling Dynamic Climate Systems

One approach is trying to simplify a complex system as much as possible. Many processes can be described with one-dimensional equations like inflow minus storage equals output (water). If we know enough simple connections it is possible to describe a lot parameters of the system. This is an old method used in modelling the global climate, economic or ecological systems as well as biological and health systems. It is not possible to get precise information or a spacial solution but it can be an important tool to assess the impact certain changes in a system can have. We could estimate for example what would happen if we change the percentage of unsealed soil in a urban system from 5 to 20 percent. More water would be stored and the evaporation would increase significantly. That would result in a higher humidity and reduced temperature during a hot day. This is a simple example that can be extended arbitrarily if there is more knowledge about urban climatic processes. [Robinson(2001)]

5.1.2 High-Resolution Climatic Modelling

If we are not satisfied knowing how the system as a whole would change but how certain areas within the system would behave, we need more complex equations which are able to cope with three-dimensional geometry and flow, as far as turbulence. This means partial differential equations like the Navier-Stokes equations have to be solved, which makes the model much more complex and ask for (much) more cpu power.

Finite Element Analysis FEA

The FEA is a useful method to solve the flow in dynamic fields like electromagnetism, heat, waves and fluids in two or three dimensions. It is a numerical approach in which the field domain under study is divided into a multitude of regions, each giving rise to one or more equations. The main task is to solve all these hundreds of simultaneous equations, which was impracticable before the days of transistorized computers. Now programs exist where you can enter the equations and boundary conditions required by your mathematical model, solve them automatically and present the results graphically in a variety of ways. The program Flex PDE uses this method (http://www.pdesolutions.com last access:10.09.2008).

Finite Difference Method

Unlike the finite element analysis the differential equations in the model are solved on a staggered grid system. The calculations do not adapt to the concrete field which is processed, but solve the equations for every point in a fixed grid. ENVI-met uses this method.

5.2 Scientific Works using ENVI-met

5.2.1 Case Study in Sydney CBD Area

Bruse, M. (1999): Simulating microscale climate interactions in complex terrain with a high-resolution numerical model: A case study for the Sydney CBD Area Paper, Poster In: Proceedings International Conference on Urban Climatology + International Congress of Biometeorology, Sydney, 8-12. Nov, Australia, 6 pages (and in) – (2000): –, Biometeorology and Urban Climatology at the Turn of the Millennium, WMO/TD No. 1026, World Meteorological Organisation, Geneva, CH, ISBN 92-63-01026-9, 6 pages

The paper describes the fundamentals of the model (equations) as it was in V2. The poster shows the application of ENVI-met to the Sydney CBD area around Circular Quay.
ENVI-met is used to study the interactions between environment and the athmosphere on local scale in the CBD of Sydney, Australia. The Sydney CBD Area, including the harbour district and the Botanical Gardens, build a system of very different urban elements forming the local climate by interacting in a complex way. Very tall buildings in the main CBD create a strong modification of the atmospheric boundary up to a height of more than three hundred meters. This area of high roughness is surrounded by the Botanical Gardens with grass and occasional trees as well as by the Pacific Ocean. Both systems have moderate daily surface temperature amplitude, high transpiration rate and reduced wind friction offering good ventilation properties.
Because of their complexity, the results cannot be shown in a suitable form in a paper. They are presented on the accompanying poster on the ICUC/ICB Conference. (Can be downloaded from the ENVI-met Website)
The figures used in the poster show the surface temperature and the air temperature at the first model level in 3 m above ground at 14:00 and 18.00 local solar time(LST). All temperatures are given relative to the average temperature used for the inflow boundary conditions.
It can be seen that during the day (14:00) the CBD complex has a negative heat island due to the shading by buildings. The coldest surfaces (up to -10 K) can be found in the water areas inside Circular Quay, followed by the left corner of the Royal Botanic Gardens. The shaded streets are colder than average, but due to heat stored inside the roads and missing evaporation the average temperature reduction is around -3 K and much lower than in the park area. In general, the air temperature distribution corresponds with the surface temperature. As the air flows through the colder parts of the CBD, it cools down to -2 K below average. In reality, the air coming from the Pacific Ocean is probably colder than predicted by the (simple) inflow model from ENVI-met.
In the evening at 18:00 LST the CBD area shows a positive heat island. The differences in surface temperatures are much smaller than at noon now showing slightly warmer surfaces inside the CBD (+2 K in average). Small differences can be observed due to varying Sky-View factors and wind sheltering by buildings. The air temperature follows the surface temperatures and warms up while passing the CBD area.
In addition to the normal meteorological data fields, ENVI-met also provides biometeorological information. In this study, the Predicted Mean Vote (PMV) and the PPD Value are presented. PPD is based on the PMV results and provides information about the percentage of person not feeling comfortable with the local climate conditions. For this simulation a 30 year old male person wearing average clothes (clo= 0.8) under light activity has been choosen.
At 14:00 the distribution of PMV/PPD is dominated by shading effects with small variances inside the shaded areas due to different wind flow situations. In general, the thermal conditions on a friendly Sydney winter day are pleasant with a small trend to warm outside the shaded areas.
At 18:00 the PMV/PPD indicates slightly cool thermal conditions: Between the sheltering buildings, the

thermal comfort is near to neutral, in the wind exposed areas people would probably prefer to wear a warmer pullover.

5.2.2 Rooftop Greening

Bruse, M.; Skinner, C. J. (1999): Rooftop Greening and local climate: A case study in Melbourne Paper, Poster In: Proceedings International Conference on Urban Climatology + International Congress of Biometeorology, Sydney, 8-12. Nov, Australia, 6 pages (and in) –,– (2000): –, Biometeorology and Urban Climatology at the Turn of the Millennium, WMO/TD No. 1026, World Meteorological Organisation, Geneva, CH, ISBN 92-63-01026-9, 6 pages

Simulation

The effects of urban green, especially of urban green placed on a roof on the local climate are simulated. The paper presents a numerical study carried out for Melbourne, VIC,AUS.

For the simulation a hot afternoon in the inner suburbs is choosen, because in this situation a small change in temperature has strong effects for the thermal comfort. The temperature at 2500m was set at 20C, the horizonal resolution is 3m, the vertical resolution 2m. The area includes a flat market building with 4 to 6 m high and sealed parking sites west and southwest of it. Other buildings, which reach 3 to 11m high, surround the place. Two scenarios are simulated. In the greenroofs case all rooftops are greened with 5cm high grass. The market building is positioned in the center of the area, and 2m high and 3m broad acacia bushes are planted on the borders. In the allgreen case additionally trees placed in the parking lots and next to the streets, which range from 10 to 20m height.

Results

The study shows that the additional vegetation reduces temperature and wind speeds, with the greatest reductions in the all greened case, thereby improving thermal comfort for pedestrians.

Influence of Wind Speed
The maximum wind speed reduction just above market roof level is around 0.90m/s in the greenroofs case whereas in the allgreen case a reduction up to 1.30m/s can be found. The zones of reduced wind speed are mainly limited to the areas where the plants are placed. Due to the sheltering row of street trees arond the market, the wind speed in the allgreen case is a little lower across the whole market platform. Inside the stand of tall trees, the trees reduce wind speed inside the leaf layer but between the plants the wind is canalised and the reduction effect is considerably less.

Influence of Air Temperature
In general, a maximum temperature reduction of 1.4K above market ground level in the green-roofs case and of 2.4K in the allgreen case can be observed. The areas of local air temperature reduction are largely restricted to the green roof locations and are advected with the main northerely airflow toward the south of the area. This rooftop cooling effects a large area slightly and but also produces a clear area of direct influence
By contrast, in the allgreen case, the reduction of air temperature is more uniform. There is a maximum temperature reduction of 2.4K, south of the tall trees on the western side of the Market. Here, the cooling effects of the rooftops and of the street-level vegetation combine to act as a single system.
In both cases, the area of reduced air temperature extend upward to around 42m above ground level. Little difference in vertical extent can be found between the two greening scenarios. In intensity, the allgreen case shows an effective reduction in air temperature up to twice the reduction of the greenroof

scenario.
No measurements have been made to compare with the simulation results.

Discussion

In old town centers people are sheltered from the wind by the closely spaced buildings or roughly uniform height. Streets were narrow, as movement was mostly on foot. Our new cities have, due to cheap and popular transport, wider roads and, due to technological possiblilities, buildings of varied heights. Open parking lots do not offer wind shelter to pedestrians. As bricks and concrete have replaced vegetation, the cooling effects of plants, through shading and transpiration, has been lost. This case study shows how additional vegetation can improve the climatic comfort of pedestrians, in an area which depends on visitors for its financial survival.

5.2.3 Influence of Facade Greening

Bruse, M.; Thönnessen M.; Radtke U. (1999): Practical and theoretical investigation of the influence of facade greening on the distribution of heavy metals in urban streets
A Paper analyzing the effects of vertical gardens (facade greening) on pollutant dispersion in an urban street canyon. Greening the facade of urban buildings using climbing plants modifies the interactions of the building system with the surrounding atmosphere. This could not only improve the outdoor or indoor climate but can also have an effect on the distribution and accumulation of particles inside the street canyon due to filtering by the climbing plants. The Japanese Creeper (Parthenocissus tricuspidata) is an industrial resistant climbing plant with very low pedochemical and pedophysical demands. It covers a facade with a homogeneous 30 to 40 cm thick vegetation pad with a height up to 15-20m.
To estimate the filtering effects of facade greening, it is necessary to study the relationships between the accumulation of particles on the leaf surfaces and the local pollutant concentration fields inside the street canyon. In order to separate the amount of heavy metals absorbed by the leaf surface (airborne immission) from those parts being extracted from the soil by the plant roots, different cleaning techniques have been tested to extract the particles from the leaf surface. This paper restricts to the typical urban heavy metals Lead (Pb) and Cadmium (Cd). These are typically released by cars and other traffic and basically originate from different fuel and oil components. Another typical source, especially for Cd, is the rub-off from tires and brakes. In order to describe and understand the system of particle emission, dispersion and accumulation in detail, some additional numerical simulations concerning the emission rate and the dispersion of particles have been made with the model ENVI-met and the results were compared to the results of the field studies.

Field Experiments in Düsseldorf

Leaves from the Japanese Creeper were collected from the facade plant cover at seven houses located in the urban area of Düsseldorf (Germany) during the years 1991-97. Düsseldorf is located in the West of Germany near to the river Rhine with winds typically coming from the WSW to SSW directions during the vegetation period with a typical speed around 3.5 ms-1 in 10m above ground over flat terrain. The main differences between the seven house are the structure of the nearby buildings, the amount of the by-passing traffic and the orientation of the greened facade.
Leaf cleaning experiments
In this investigation the total amount of heavy metals in uncleaned dried leaf material of Parthenocissus tricuspidata was determined using Atomic Absorption Spectrometry. To prove the hypothesis that nearly the whole content of lead and cadmium in the leaves comes from particulate air matter depositions, leaf cleaning experiments were conducted. Up to 90% of Cd and Pb could be removed and the REM-scans

showed totally clean leaf surfaces. The dust and aerosol particles could be completely removed and damages of the epidermis cells have not been found. These results prove that most of the Cd and Pb found in the Parthenocissus leaves come from direct air-path immissions. For these elements it seems legitimate to accept the results of the total digestion of the leaves as airborne immissions. All results for the cleaned leaf samples are close to or under the detection limit.

Numerical Analyses of the release and the dispersion of particles inside the street canyon

Two different models were used for the numerical analyses of the heavy metal emission and dispersion inside the street canyon.

First, the emission of heavy metals by car traffic was calculated with model ISIS Kfz [ISIS(1999)]. ISIS Kfz is based on a complex database published by the Umweltbundesamt, which contains information about the emission of different car engines with respect to driving mode, traffic flow and exhaust cleaning. Unfortunately, Lead and Cadmium are not directly provided by ISIS Kfz, so that the emission information for particles in general has been used. The data from the streets passing the points H1 to H6 in Düsseldorf have been used to calculate typical average particle emissions.
The microscale climate model ENVI-met was used to calculate the meteorological situation and the particle distribution inside the street canyon located at H2. For a more detailed description see paper Simulating microscale interactions in complex terrain (...) by the same author. The model was extended with a mass-conserving particle dispersion model using the advection-diffusion equation.
Here, u,v and w are the local components of the wind flow and Km is the turbulent exchange coefficient for mass. Two additional terms are included to consider the influence of sources (Q.) and sinks (S.) on the concentration field. As only the general dynamics of particle distribution should be studied, the simulations have been carried out with dimensionless emissions.
In this paper, the results from the simulations for H2 are shown. Two emitting line sources have been set in the first grid above ground inside the main street canyon where H2 is located as well as in the crossing streets in the North and the South to simulate the emission by cars. The dimensionless emission level was set to 1 E*s-1, the emission release begins immediately after the simulation start. The emissions were treated as an inert gas, no sedimentation or deposition rate was applied. This assumption was used due to the lack of proper theories about the behaviour of non-gaseous elements in complex flow fields and at plant foliages.

Results and Discussion

It can be seen that the amount of absorbed mass correspond with the local traffic conditions and the building density of the surroundings. To understand these figures in more detail, model simulations have been carried out. First, the emission rate for particles has been calculated with ISIS Kfz.
As expected, the street with the highest traffic volume also has the highest particle emission rate. The second highest value can be found in the dense industrial area. Here the very high amount of trucks (41.2 % 47.2 %) outweights the low total traffic volume. The highest concentration of particles was found in the leaves from narrow, closed streets. Although the emission rate is reasonably lower than in streets of open settlements or dense industrial use, the close street canyon captures the particles and a recirculation leads to an increased concentration in the in-canyon air. In contrast, wide streets have ventilation due to lower buildings and less dense structures. Looking at the vertical heavy metals concentration of the leaves from H2 and, less obviously from H6, it can be seen that there is local minimum at the second level above ground (4.5 m). This effect was found for both heavy metals and for each year of the analyses.
To understand the dynamics of the particle dispersion inside a closed street canyon, the canyon along H2 was analysed with ENVI-met in more detail. It was assumed that the wind comes from the SW with 3 m/s at 10 m height above flat terrain. Figure 4 shows the horizontal flow field and the normalised

particle concentration at 2.4 m above ground. H2 is indicated with a red dot. Inside the canyon the wind is channeled into a street parallel flow. At points with lower surrounding buildings, the wind above roof level with a SW orientation influences the near surface flow. Maximum concentrations can be found near the crossings and between the higher buildings of the street canyon.
However, the simulated concentration fields along the wall of H2 shown in Figure 6 do not explain the measured vertical concentration profile. It can be seen that there is a steep vertical gradient below the 4 m level and a change to a quasilinear concentration decrease with height above the 6 m level.
If we assume that the deposition of particles on the leaf surface is linear to the concentration in the air near to the wall,the normalised concentrations can be used as proxies for the deposition rate. It is obvious that the results of the simulation does not match the results from the field experiments. As the model results agree with wind tunnel studies, the reason for the rapid decrease of accumulated particles in the 4.5 m level found at H2 and H5 cannot be found in the atmospheric part of the dispersion and accumulation process.

Conclusions

A very characteristic vertical distribution of accumulated heavy metals was found inside the closed street canyon at H2. It was not possible to explain this distribution using standard meteorological parameters such as mass concentration or local wind speed. As the results are replicable for different years and seem to be typical for a closed canyon situation, further research, especially in the behavior of particles in complex flow fields and at the plant foliage is necessary to explain the behavior found in the field studies. It is shown that the general mechanisms inside the street canyon and at the facade can be reproduced by the model, but the model fails to calculate some detailed characteristics found at two houses in the field experiments.

Other publications that cover these topics
Bruse, M. (1999): Modelling and Strategies for improved urban climates.
[Bruse(1999)]
Bruse, M. (2000): Anwendung von mikroskaligen Simulationsmodellen in der Stadtplanung [Bruse(2000)]

5.2.4 A Small Urban Park

Lahme, E.; Bruse, M. (2003): Microclimatic effects of a small urban park in densely built-up areas: Measurements and model simulations;ICUC5, Lodz 1-5- September 2003, 4 pages
A case study in an urban park is shown and compared with results from the ENVI-met model.
In the framework of the EU-project BUGS (Benefits of Urban Green Spaces), which ran from March 2001 until February 2004 the Model ENVI-met was used. BUGS investigated how inner urban green can meliorate the microclimate. There are many influencing aspects, therefore the intention of BUGS was to find an interdisciplinary assessment scheme that focuses on the practical realisation of the suggestions for improvement.
The influencing aspects are such as: micro, meso and macroclimate, noise, traffic flow, emissions, usage of space, social aspects and planning methods, which include the expertise and wishes of the inhabitants. More information about the project is available under: www.vito.de/bugs.
The aspect 'microclima' was investigated by the working group Klimaforschung of the Geographical Institute of the Ruhr-University Bochum
http://klima.geographie.ruhr-uni-bochum.de). They investigated,using ENVI-met simulations and meteorological measurements, how urban green can affect the microclimate.

Measurement Campaign

The measurement campaigns were carried out in and around the 'Stadtgarten', which is a relatively small park area close to the CGD of Essen, Germany. The city of Essen is situated in the center of the Ruhrgebiet-Area, a large agglomeration of cities in Western Germany.
The field campaigns consisted of three permanent climate stations, operating in and around the park, and of some in-depth manual measurements by foot and a climate bus during selected autochtonous weather situations.
The permanent stations recorded air temperature, humidity, wind speed and direction at approximately 3m height, all through the vegetation period, from March to November 2002.
The in-depth campaign was executed using manual measuring devices, recording air temperature at 0.05m and 2m height using NiCr-Ni sensors with an accuracy of +/- 0.4K. In addition, the surface brightness temperature has been recorded using infrared measurement technique with a relatively coarse resolution of only 1K and an accuracy of 2.0K.
Other data such as wind direction and speed have also been taken at all manual measurement points, but produced too huge uncertainties due to technical and handling limitations to be interpreted.
Several in-depth campaigns have been executed in 2002. The one that was selected for the paper, seems to offer the most representative weather conditions from all campaigns. It was executed on the 13th of September 2002. On that day, three in-depth tours have been carried out starting at 15:30, 19:30 and 22:00 CET. The obtained data have been linearly related to the time of starting the routes. That unavoidable method adds some uncertainties to the data in case of the routes walked by food because they have been more than an hour long and the assumption of a linear cooling rate might be wrong for some of the points.

Model Simulation

The model simulations have been carried out with the three-dimensional non-hydrostatic climate model ENVI-met Version 3.0 (Bruse and Fleer 1998) which has been updated in the context of the BUGS project. For the model simulations, the area around the Stadtgarten has been transformed in a model grid with the dimension 90 x 112 x 20 grids with a resolution of 6 m x 6 m x 2m resulting in an total area of 540 x 672 m in the horizontal extension. In this simulation, the wind was blowing constantly at 0.5 m/s at 10 above ground from NE. The model has not been nested into another model providing meteorological data at the model borders. The only data provided have been the initial values of air temperature, humidity etc. for the beginning of the 48 hours simulation cycle. Running a microscale model in such a non-nested way makes it impossible to reproduce trends in the meteorological data that came from larger scale phenomena (change of wind direction, air mass advection,). On the other hand, the dynamics of the model domain become more visible if no external data are forced into the model. Several simulations have been carried out to investigate the dynamics of the park and to compare it with measured data.

Results

The poster presents several results from the measurement campaigns as well as from the model simulations. Both results are compared with each other in order to identify weaknesses in the model and to define the range of uncertainty both in numerical simulation as well as in the field experiments. Figure 3 shows the comparison between the observed air temperature at the 13 measurement points at 2 m height and the corresponding model results at 1.8 m height (due to the vertical model resolution). The data show the results from the in-depth campaigns started at 15:30 and 22:00 CET. Two model simulations are plotted against the data: one called ẅetẅith a well watered inner Park area (50-60% relative soil humidity) and the other called d̈ryẅith less available water (30-40% relative soil humidity). During the day, the observed maximum temperatures are clustering around the 21 C level. Inside the built-up area significant differences can be observed depending on radiative situations at the single points. There is no clear tendency in the differences between the simulated data and the observed ones. During the night it can be noticed that the temperatures inside the built-up area are well reproduced whereas the simulated data are too high inside the park area. One of the reasons for his effect is certainly the fact that the model is not able to calculate katabatic flows out of the park. Instead, it assumes a constant wind coming from NE direction. This results for example in lower simulated temperatures at P14 which is leeward of the park and receives the cold air from the inner park areas. In contrast P10 is too warm in the model simulation. During the measurement campaigns it could be observed that actually there is a katabatic flow at this point coming out of the park and decreasing the air temperature at P10 significantly.

Conclusions

During the year 2002 several measurement campaigns have been made in the area of the Stadtgarten. These results found here have been compared to model results obtained with the model ENVI-met. It was found, that even for a non-nested model run, ENVI-met reproduces the observed data with a sufficient accuracy. However, some phenomena such as katabatic flows that have been observed in the measurement campaigns could not be reproduced by the model due to the model physics used. This problem is not of a physical nature, but a problem of limited computer resources not allowing to resolve these sensible wind flows. Overall, it has been proved that ENVI-met is a reliable tool to simulate the different urban scenarios to be designed in the framework of the BUGS project.

More urban green does not necessarily improve local aspects of the urban climate like air quality.

Other publications that cover this project

Jesionek, K.; Bruse, M. (2003): Impacts of vegetation on the microclimate: Modelling standardized building structures with different greening level; ICUC5, Lodz 1-5- September 2003, 4 pages
Typical central Europe building structures are compiled and it is analyzed, how additional greening influences the micro climate and air quality. Poster presents results more in detail

Bruse, M. (2003): Stadtgrün und Stadtklima- Wie sich Grünflächen auf das Mikroklima in Städten auswirken
LÖBF-Mitteilungen, 1/2003, 66-70, 5p, in German. An introduction on urban climate and green spaces written for non-specialists

5.2.5 Street Orientation in Desert Cities

The last years work Fazia Ali-Toudert and Helmut Mayer analyzed the outdoor thermal comfort in the old desert city of Beni-Isguen, Algeria using ENVI-met. [Ali-Toudert and Mayer(2003)][Ali-Toudert and Mayer(2005)] They studied the effects of asymmetry, galleries, overhanging facades and vegetation on thermal comfort in urban street canyons and the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. Later also the thermal comfort in an east-west oriented street canyon in Freiburg (Germany) under hot summer conditions where studied. [Ali-Toudert and Mayer(2006a)] [Ali-Toudert and Mayer(2006b)]
[Ali-Toudert and Mayer(2007a)] [Ali-Toudert and Mayer(2007b)]

5.2.6 Climatic Improvement of Tropical Cities

The mastersthesis of Jrg Spengenberg [Spengenberg(2004)] is using ENVI-met to analyze possible improvements of urban climate in Rio de Janeiro. He documentates the usage of the programm in a tropic region.

5.3 Description of the Program

This chapter is obtained from: http://http://www.envi-met.com/ (last access: 10.September 2008)

5.3.1 How to get started

ENVI-met is a Freeware program based on different scientific research projects and is therefore under constant development. ENVI-met comes along with a number of additional software ranging from an editors up to graphical visualization tools for the model results. You can use it for any purpose you want, research or commercial without paying. All they ask for is to register to their e-mail list so that they can contact you if serious errors have been found or new versions are available. In addition, ENVI-met Professional edition comes along with a more sophisticated object model, more model sizes and advanced analysis tools.

ENVI-met has recently become available for machines running MS WINDOWS with 128 Mbytes RAM min and 500 MHz and better. A LINUX version is planed but not available at the moment. Multiple-Processors Systems are not supported. The exact memory requirements depend on the number of grid points used. A rough overview of the memory requirements is:

60 x 60 x 30 Grids 128 Mbytes
80 x 80 x 30 Grids 128 Mbytes
120 x 120 x 30 Grids 256 Mbytes
130 x 130 x 30 Grids 256 Mbytes
200 x 200 x 25 Grids 512 Mbytes
250 x 250 x 25 Grids 1 GByte

5.3.2 The Physical Model

ENVI-met is a prognostic model based on the fundamental laws of fluid dynamics and thermodynamics. The model includes the simulation of:

- Flow around and between buildings
- Exchange processes of heat and vapour at the ground surface and at walls
- Turbulence
- Exchange at vegetation and vegetation parameters
- Bioclimatology
- Particle dispersion

ENVI-met is a three-dimensional non-hydrostatic model for the simulation of surface-plant-air interactions not only for but especially inside urban environments. It is designed for microscale with a typical horizontal resolution from 0.5 to 10 m and a typical time frame of 24 to 48 hours with a time step of 10 sec at maximum. This resolution allows analysis of small-scale interactions between individual buildings, surfaces and plants.

The model calculation includes:

- Shortwave and longwave radiation fluxes with respect to shading, reflection and re-radiation from building systems and the vegetation
- Transpiration, Evaporation and sensible heat flux from the vegetation into the air including full simulation of all plant physical parameters (e.g. photosynthesis rate)
- Surface and wall temperature for each grid point and wall
- Water- and heat exchange inside the soil system
- Calculation of biometeorological parameters like Mean Radiant Temperature or Fanger's Predicted Mean Vote (PMV) -Value
- Dispersion of inert gases and particles including sedimentation of particles at leafs and surfaces

Buildings, vegetation, soils/ surfaces and pollutant sources can be placed inside the model area. Besides natural and artificial surfaces, the model is also able to handle water bodies.

5.3.3 The Atmosphere

Wind Field

The three-dimensional Navier-Stokes equations are used in the Boussinesq approximated non-hydrostatic form including sink terms for drag forces at vegetation elements. The pressure perturbation is removed from the equations and an auxiliary velocity field is computed. Mass conversation is satisfied by correcting the auxiliary field by an iterative solution of the Poisson-Equation and correction at the outflow boundaries.
The flow is updated at given time intervals. ENVI-met also supports a real-time flow calculation which means that the flow field is treated as a normal prognostic variable and calculated each step. Due to the very small time steps needed here, this way of calculation needs very powerful computers.

Temperature and Humidity

Advection and diffusion of temperature and humidity is calculated using the previous calculated wind field. The ground surface and vegetation is incorporated using a source/sink term in both equations, building walls are only acting as a source/sink for temperature.

Turbulence and Turbulent Kinetic Energy (TKE)

The turbulence is calculated using the E-epsilon 1.5order closure ("E-epsilon" or "k-epsilon" model). Two prognostic equations for turbulent energy production (E) and its dissipation (epsilon) are used to simulate the distribution of turbulent energy. Exchange coefficients in the air are calculated using the Prandtl-Kolmogorov relation.
For low wind situations, the 1st order mixing length model can be used instead of the E-epsilon model (which often fails in this situations).
Improved troubleshooting has been added since version 2.5, which effectively reduces the number of problems with the turbulence model even under difficult atmospheric conditions.

5.3.4 The Soil System

Temperature and Water flow inside the soil

The vertical distribution of temperature and water is calculated for natural soils as well as for artificial seal materials. For each vertical grid box a different soil material can be chosen in order to simulate different urban soils. The flow of water inside natural soils is calculated using the formulae from Clapp and Hornberger. The hydraulic equations include a sink term for water uptake by plant roots. The thermodynamic properties of the soil are estimated by means of the actual water content.

Water Bodies

Water bodies are represented as a special type of soil. The calculated processes inside the water include the transmission and absorption of shortwave radiation inside the water.
No second energy balance is used for the ground surface of the water pool, so that heating of shallow systems is lower than under real conditions where the main source of energy is the convection from the water ground surface rather than the absorption of radiation.
In addition, no turbulent mixing is included in the model so that the use is restricted to still waters (e.g. lakes). The water parameterisation will be extended to turbulent mixing (oceans) later on. Special water usage (e.g. fountains) cannot be calculated with the model at the moment.

5.3.5 The Vegetation

Foliage Temperature

The average temperature of the leaves in one grid box is calculated by solving the energy balance of the leaf surface with respect to the actual meteorological and plant physiological conditions. Turbulent fluxes of heat and vapour are calculated from the given wind field and the geometry of the plant (see next section). The calculation of radiative fluxes include the shading, absorption and shielding of radiation as well as the re-radiation from other plant layers.

5.3.6 Heat, Water and Vapor exchange with in-canopy air

The gas and heat exchange between the vegetation and the atmosphere is controlled by the local energy balance steering the leaf temperature and by the stomata conductance controlling the gas exchange (vapour and CO2).
The actual stomata conductance of a plant is a complex function depending on external meteorological conditions (air temperature, available solar radiation PAR and many others) as well as on the plants physiological processes (Photosynthesis rate, CO2 demand, CO2 fixation,...). ENVI-met uses a sophisticated model to simulate the stomata behaviour of the vegetation.
To define the height and the shape of a plant, the model uses standard normalized functions (Leaf area density profile LAD, Root area density profile RAD) which can be applied for grassy surface as well as for huge trees.

5.3.7 Water interception and transport

Liquid water on the leaves influences highly the evaporation of the plant. The condensation of water of the leaves, the absorption of rain and the transport between different layers or the ground surface due to gravity is treated as an independent system inside the model.

5.3.8 The Surfaces

Ground surface

The energy budget is calculated at the ground surface. The results are the surface temperature and humidity as well as the fluxes of sensible and latent heat. The ground surface and the walls are used as boundary conditions for the atmospheric model (ground surface and walls) and for the soil model (ground surface).

Wall/ Roof surface temperature and heat exchange

The temperature of the walls and the roofs is calculated for each grid point with respect to surface orientation, albedo and heat exchange with the temperature inside the building.
Heat exchange between the walls and the atmosphere are given by the pre-calculated flow and local turbulence.

5.3.9 Biometeorology

PMV-Value

The PMV Model (=Predicted Mean Vote Model) is probably the best know biomet model. Based on Fangers (1972) model, it relates the energy balance of the human body to the personal feeling (thermal comfort) of persons exposed to the corresponding climates. Originally developed for indoor situations, it was adapted for outdoor climate by Jendritzky (1993). Normally, the PMV scale is defined between -4 (very cold) and +4 (very hot) where 0 is the thermal neutral (comfort) value: But as the PMV value is a function of the local climate, it can reach also values above or below the [-4] - [+4] values. PMV is a stationary value, which means that a person is assumed to be exposed long enough to a constant climate situation until all energy exchange processes at the human body have become stationary. This is, of course, only the case if this person stands exposed to the same climate conditions for quite some time (up to 20 min in some cases). The PMV Model used in ENVI-met is a special adaptation to outdoor conditions made by Jendritzky/ DWD (see http://www.dwd.de/services/gfmm/gfmm_kmm.html). To use PMV in your model, you must have a [PMV] section in your configuration file.To use the PMV-model, you need to add the PMV-section to the .CF file. There it is possible to define the Walking Speed (m/s), the Energy-Exchange (Col. 2 M/A), an mechanical Factor and the heat transfer resistance of cloths.

PPD-Value

In addition to the PMV value, ENVI-met provides the associated PPD value (=Predicted Percentage of Dissatisfied) which tells the percentage of people who would be dissatisfied with the climate conditions found. PMV and PPD have a linear relationship (=they can be directly transformed into one another). Therefore the PPD maps have the same spatial structures as the PMV maps have.

The climBOTs

Why not ask the people living in your model world what they think about the design and the local climate? With the climBOT model it is possible. The Botworld is introduced in the Annex. (see www.botworld.info last access: 10.09.2008)

5.3.10 Behind the scenes: The Mathematics

Behind the friendly WINDOWS user interface there are a lot of numerical routines doing hard work to calculate the climate in your model area. Just a few keyword, on what is used in ENVI-met:The model equations are solved in three dimensions using the ADI (alternating direction implicit) method. Using a fully implicit scheme allows ENVI-met to use time steps up to 10 sec without becoming numerically unstable. Of course, different modules have to be solved one after the other in order to manage the data flow. For example, first all the surface temperatures are calculated from the energy budget and then the 3D temperature in the atmosphere is calculated using these surface temperatures.
Some modules require smaller time steps such as the turbulence, the pollutant dispersion model, especially if sedimentation processes are involved. To calculate the wind flow, the pressure is removed from the Navier-Stokes equations and an auxiliary flow field is computed first (splitting method). After that, the Poisson equation is solved to calculate the corresponding pressure perturbation field. Here, the SOR algorithm is used. It is a little bit slower than a direct method, but in general more "friendly". Although it is possible to calculate the wind field continuously (each time step), recent computers are still too slow to do that because the calculation of the wind field requires very small time steps due to steep gradients e.g. at building walls. Therefore the usual way is to "update" the wind flow after a given time interval in order to match it with the stratification of the atmosphere. As a drawback of this method, slow thermal flows cannot be calculated with this approach.

5.4 Input

For most settings there are reasonable default values, so it is possible to merely built the geometry and set some trees to run the simulation and see results. Once the user gets aquainted with the possibilities nearly all parameters can be changed. Not all $*.in$ files are valid, but on the webpage most of the common mistakes are described. Reading the output during the calculation and consulting the documentation it's possible to solve most problems.

5.4.1 area.in

This file can either be written directly or created by using the program EnviEddi, which is much easier. Here the user can include all kind of available information that represents the area of interest. It is possible to load a $*.bmp$ as background image and set the gridpoints on top.

- **number of gridcells** x,y,z: 40 - 150, which determines the calculation speed
- **resolution** - gridcellsize x,y,z: 1m - 10m
- **number of nesting grids + soil profils of nesting grids**
- **orientation**
- **type of soilprofil for every gridpoint**
- **type of vegetation for every gridpoint** Only vegetation defined in plants.dat or another file in the same format can be used.
- **height + position of buildings** Depending on the gridcell size the buildings can be designed more or less exactly. Due to the grid structure it is not possible to construct tilted roofs or round buildings.

5.4.2 soils.dat

In this file a certain type of soil like clay, sandy clay,... can be defined.

- **ns** volumetric water content $[\frac{m^3}{m^3}]$
- **nfc** volumetric water content at field capacity$[\frac{m^3}{m^3}]$
- **nwilt** volumetric water content at wilting point$[\frac{m^3}{m^3}]$
- **matpot** Matrix Potential at saturation [m]
- **hypr** hydraulic conductivity at saturation $[\frac{m}{s}]$
- **cp** volumetric heat capacity $[\frac{J}{m^3K}]$
- **hcn** heat conductivity of the material $[\frac{W}{mK}]$

5.4.3 profils.dat

Here the several soils can be put together in a vertical soil to build a realistic soil profile.

- **the soil type** as defined in soils.dat in different depth (.015, .025, .035, .045, .055, .07, .09, . . . 1.75)
- **z0** roughness length of the surface [m]
- **a** short-wave albedo of the surface (dependent on soil wetness and sun elevation angle)
- **em** long-wave emissivity of the surface

5.4.4 plants.dat

This or a file with the same formatting rules can be used to create one's own vegetation layer.

- **C?** defines the type of plant according to the CO2 fixation
- **TY** plant type for aerodynamic calculations: deciduous, conifers or grass
- **rs_min** minimum stomata resistance of the plant, recommended values: 400 for trees and 200 for grasses
- **a_f** short wave albedo of the plant leaf, recommended value: 0.20
- **HH.HH** height of the plant[m]
- **TT.TT** total depth of the root zone[m]
- **LAD1 to LAD10** Leaf Area Density in m^2/m^3 for 10 data points defines the form of the plant
- **RAD1 to RAD10** Root Area Density in m^2/m^3

The most sensitive, important and sophisticated of this input section is LAD. Many vegetation-atmosphere models require structural information describing the canopy in order to calculate rates of mass and energy exchange. One of the most important pieces of information is the variation with height is leaf area density, but it is difficult to measure these. Bruse himself mentions, 'that the LAD profiles provided by ENVI-met are rather hand made and based on a few reference profiles' and states that this is a simple and normally also very reliable way of estimating them. It should also be mentioned that LAD still is a sipli-fied numerical method to describe plant properties, which does not consider foliation changes depending on the climatic circumstances during the course of the year and thus the temporal/spatial variation of the LAD. Another problem of LAD is, that actually each individual would have to be modelled individually for most exact modelling. Further can only one plant type be applied to one grid, which results, that the combination of a tree canopy and a grass ground cover below is impossible to apply to a single grid. A solution to that could be tree plant data including also LAD on the ground level. [Spengenberg(2004)]

5.5 Output

During the simulation following parameters are calculated. They are stored in three files which can be read either directly or presented graphically in the program Leonardo. Most data has only one value for each grid point. For certain data layers like wind speed there also exists a corresponding vector layer which gives additional information. In the case of wind speed the data layer tells us how many m/s the wind blows, whereas the vector layer shows us arrows which point in the wind direction.

5.5.1 AT Atmosphere

3 dimensional Wind Flow
Total Wind Speed m/s and Wind Speed Change % compared to inflow
Relative Pressure Perturbation Pa
Wind direction °
Potential Air Temperature K, Air Temperature Difference to inflow and Change of Air Temperature in time
Specific Humidity Air g/kg
Turbulent Kinetic Energy m^2/s^2
Dissipation of TKE
Turbulent exchange coefficient m2/s
Shortwave Direct Radiation W/m2
Shortwave Diffuse Radiation W/m2
Shortwave Reflected Radiation W/m2
Longwave Radiation received from the environment
Sky-View-Factor
Temperature Flux from vegetation per unit leaf area
Vapour Flux from vegetation per unit leaf area
Amount of liquid water on leafs
PMV value Predicted Mean Value
PPD value Percentage of People Dissatisfied
Mean Radiative Temperature K
Gas/Particle concentration
...

5.5.2 FX Flux

Ground Surface Temperature K, Difference Temperature, Change of Temperature
Specific Humidity of Surface g/kg
Wind Speed at first grid level above ground surface
Sensible heat flux into the air W/m2 A positive value means the heat goes towards air.
Exchange coefficient for heat between surface and air m/s
Latent Heat Flux into the air W/m2
Soil Heat Flux A positive value means the flux is directed towards deeper layers.
Direct Shortwave Radiation reaching ground surface
Diffuse Shortwave Radiation reaching ground surface
Longwave radiation budget of ground surface
Longwave radiation received from vegetation layers above
Longwave radiation received from bildings
Water Flux from/to the ground surface
Sky View Factor
Surface Albedo
Deposition speed
Mass deposed

5.5.3 SO Soil

Soil Temperature K
Water content of the soil matrix m3/m2
Relative wetness of the soil compared to its saturation value %

6 Concerns and Questions

6.1 Geometry

With the inclination the incoming radiation changes. ENVI-met offers only limited possibilites to work with complicated geometry. Are there nonetheless reasonable ways to make a useful simulation?

6.1.1 Roofs

The model roofs are always ”flat”. At the moment it is not possible to construct inclined roof surfaces. The tilt of the roofs and the unevenness of the ground cannot be considered, although they might have a strong effect. A tilted roof can be built by setting the grid points which define the building on different heights. The simulation assumes the average surface of the building, which is defined by the grid points. In this case it assumes the roof is tilted. This is only possible when the resolution is high compared to the width of the roof. At least two points are needed to define a non even roof. On the other hand it is not possible to define a kind of step on the roof, because the gridpoints will always be connected to form a slope.

6.1.2 Topography

Just like the roofs, the topography is also always flat. It is not possible to construct a slope, hill or valley. Version 3.1 supports a simple block - topography, but this feature is not officialy available, because there are still many unsolved boundary conditions. For example: How does the area end at the border?

6.2 Vegetation

6.2.1 Green Roofs

It is not possible to define the soil profile of a roof. The albedo and the heat transmissivitiy can be changed for all rooftops in the area and vegetation elements like trees, shrubs and grass can be defined. Therefore only the changed windfield and the effects caused directly by the vegetation by assimilation can be simulated. Important effects like the waterstorage of greened roofs cannot be calculated.

6.2.2 Green Facades

It is possible to change the heat transmissivity and the albedo of all the walls in the area but one cannot attach plants directly to a wall. A good solution for this problem is to define a plant with the height of the building on the grid points directly next to the wall. These plants will act as if the facade itself was greened.

6.3 Mesoclimate

Effects of mesoscalic climate like valley effects (katabatic winds), the position in the urban heat island (citycenter/outskirts) and continentality (balancing effects of the sea) are not taken into account in the

simulation. Also meteorological processes like existing inversions are not considered.
It is therefore necessary to get real data about the area and adapt the input parameter to the given situation. In future versions it will be possible to embed ENVI-met in mesoscalic simulations.

6.4 Timescale

What can be calculated within one day? Which typical features need one month or longer to develop - longer simulation time? How long is the summer heat stored in the walls/roofs and grounds and effects the microclimate in autumn and winter?
Theoretically the model can simulate several month. The simulation timing is only limited by the impatience of the user, hardware or financial shortage. There are two reasons why it does not make sense to let the simulation run for weeks or months. First of all, like in most climatic simulations, the heatstorage is limited. Only a limited amount of energy will stay in the system, so that a kind of climatic equilibrium will build up very soon, and it will not make much difference to the results if I start the simulation three days or three weeks before the actual date I want to simulate. Second, the simulation stands on its own and is not influenced by the synoptic changes or the general climatic changes in a region. It would be possible to embed the simulation into another mesoscalic one. But then it would be a different thing.

6.5 Configuration

6.5.1 Building Properties

As optional data the inside Temperature of buildings, the heat transmission coefficient and the albedo of the walls and roofs can be set. If they are not set, the default values are used. The same settings are applied to each building and they stay constant during a model run. So the different heat storage capacities inside the houses are not taken into account as well as there is no possibility to define differently coloured walls or roofs with varying heat conductivity or reflectivity.

6.5.2 Radiation, Clouds

In the default setting the simulation runs without cloud cover. But a certain cloud cover (high/middle/low) can be set as an additional modul. The cloud cover cannot change during one simulation. Typical processes which can dominate an urban area like a clouded sky in the morning which clears in the course of the day cannot be simulated.

6.6 Usability

It takes a while to get familiar with the program and be able to use it effectively. Its easy to create simulations, but there are many things to be aware of in order to make it a useful simulation. ENVI-met3 is well documentated and nearly any problem that arises can be solved consulting the online manual. If there are still errors being produced Markus Bruse answers really quickly on any questions sent to him by email. But even if the simulation is produced fine, non-meteorologist will have difficulties interpreting the data. Now there is a internet plattform conncecting people using ENVI-met. (http://www.envi-met.com/phpbb/index.php last access: 10.09.2008)

7 Site Analysis

7.1 Jodok-Fink Platz

On the 21th of january 2008 between 2 and 4pm I visited the site to do an intensive site analysis. It was a sunny, warm winter day. During the time of the measurements in May and June 2008 I noticed additionally other climatic features and forms of usage.

Background Information and Introduction

In 1597 Hl. Josef von Calasanz (1557-1648) founded the fraternity Patres scholarum piarum in Rome. In 1697 the emperor Leopold I. gave the fraternity the permission to build a school in the newly built district of Vienna called Josefsstadt. The classes started in 1701. The church Maria Treu has the position of a Basilika minor. Today the Kollegium maintains a primary school with boarding school. Although the work started in 1698 the dome obove the main hall was not finished until 1752. The church was consecrated in 1770. [mariatreu(2008)]

Shade, Wind, Acustics

On the Jodok-Fink Platz it was significantly windier than on the Schlesingerplatz on the day of the analysis. One reason might be that the Maria-Treugasse opens to the west, which is the main wind direction and the open place cannot slow down the wind. The church is twice as high as the surrounding buildings and acts as a massive obstacle to the air current. I recognize strong eddies in front of the church, where the leaves gather and are drawn up into the air up to 15m.
The sun shines on the facade of the church in the morning and moves towards the south orientated wall during the day. The cobblestones keep the warmth after sunset.
I notice a strong Hall effect which amplifies the noise of the construction site in the Piaristengasse and the works on the site.

7.1.1 Site Inventory

Visual Connections

Under the treetops, which are nearly opaque, even in the winter, it is possible to observe the place from the Piaristengasse and from the restaurants as well as from Maria-Treugasse. The streets are very narrow and therefore the place can be seen only shortly before it is reached.

Type of Free Space, Partial Spaces, Borders

It is a public space, which is dominated by the church 'Piaristenkirchen', which defines the western border of the place. On the Northern and Southern side the place is concluded with the adjoining buildings of the Volksschule, the Gymnasium, the Kindergarten and the Pfarrsaal. On these sides we can find grey plastic benches on concrete blocks. On the Eastern side there are seven trees (Acer campestre) planted in metal dices, which build the visual border. Their height ranges from 5 to 10m. Behind these trees Piaristengasse passes. It is 8m wide, including parking lots on both sides and is accompanied on both

Figure 7.1: view from Maria-Treugasse

Figure 7.2: view to Piaristengasse

Figure 7.3: people gathering in front of the pizzaria

sides with a 2m wide stepped pavement. From Piaristengasse the slightly smaller Maria-Treugasse leads away.
The place is 55m by 49m big. The towers of the church are 62m high, while the adjoining buildings and the ones opposite the church are 23m high. In the center there is a statue 10m high.
There are three partial spaces: A public place, which is open and clearly arrranged. Second, the street, where pedestrians and cars move. These two spaces are visually and constructively detached by trees and a fence. The third space, the intersection is defined by various traffic calming arrangements (narrowed streets, broadened sidewalk, ramps to slow down the cars) and infrastructure for cyclists and pedestrians (three zebra crossings, nine bicycle stands, two restaurants, 'entry' of the place)

Horizontal Elements

The square is laid with granite cobblestone sized 20x20cm laid in concrete. The streets and the pavement are made from concrete. There is a flowerbed around the statue.

Vertical Elements

The facades of the church and the adjoining buildings are white and yellow. The baroque architecture resembles the three positions of Maria in the passion. The statue in the middle was built by J. Ph. Prokop in 1713 and reminds of the Immakulata, the victress over the evil. There are four lamps from the 19th century and seven Acer campestre (Feldahorn/field marple) of five to eight meters height.

7.1.2 Site Analysis - Functional Relations

Urbanistic Context

The development structure of the 8th district is very uniform. It is dominated by perimeter block development with three to five storied buildings of 20 to 25m hight. The streets are less than ten meters wide and have parking on at least one side and a one meter sidewalk on both sides. Because of lack of space most of them are one-way streets. The analysed places are situated between Josefstädter and Alserstrasse, which both are significant as shopping streets and as radial axes from the periphery to the center. There are only a few free spaces in this area. Other free spaces nearby are Bennoplatz, Robert-Hammerlingplatz and Schönbornplatz. Especially the two last ones are strongly covered over by bushes and trees and offer plenty of partial spaces and niches. They are both very popular and used by young people and families. Famous meeting points in the area are the restaurants 'der Tunnel' and 'the Café Merkur', the yard of the 'alte AKH' and the pubs on the 'Gürtel'. The district is one of the wealthiest in Vienna. Few migrants, lots of students and old people can be seen on the street.

Off-site influences

Because of the square's closed geometry there are hardly any influences from outside. There is a small noise exposure from the street. Thanks to the trees, which detach the square from the street, the place becomes more private and less influenced by the sudden intrusion of passing by traffic. The fact that the waiters have to pass the street in order to serve the schanigartens means the cars can only drive slowly and stop frequently rather than rush through Piaristengasse.

Accessability, Pathes

The place is accessible from Piaristengasse and Maria-Treugasse by foot, car, bicyle and alike. The stops for the bus 13a and the tram 5 and 33 are around the corner. In five minutes one can reach the U6 station Josefsstädterstrasse or the U2 station Rathhaus.

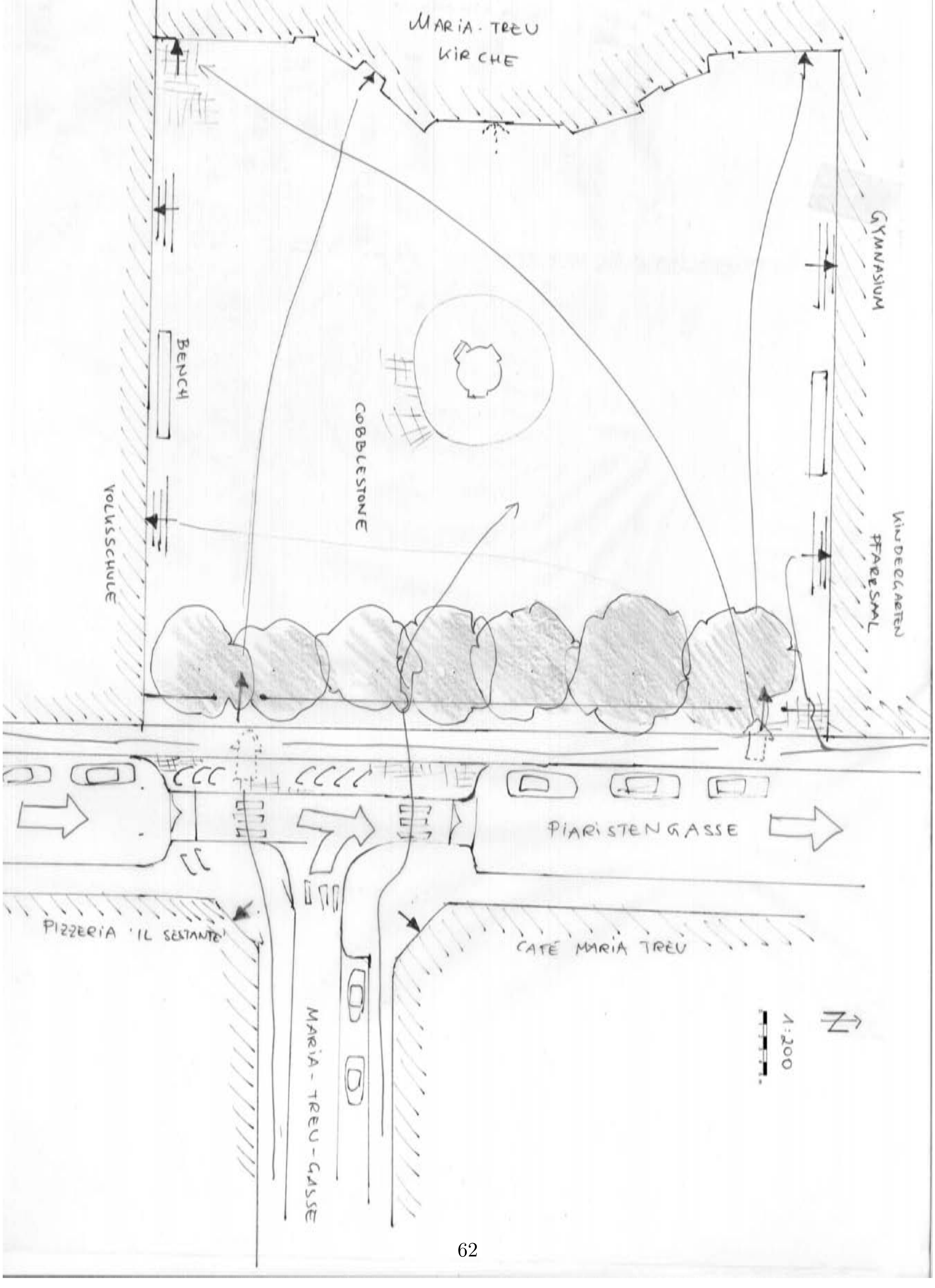


Figure 7.4: plan view of Jodok-Finkplatz

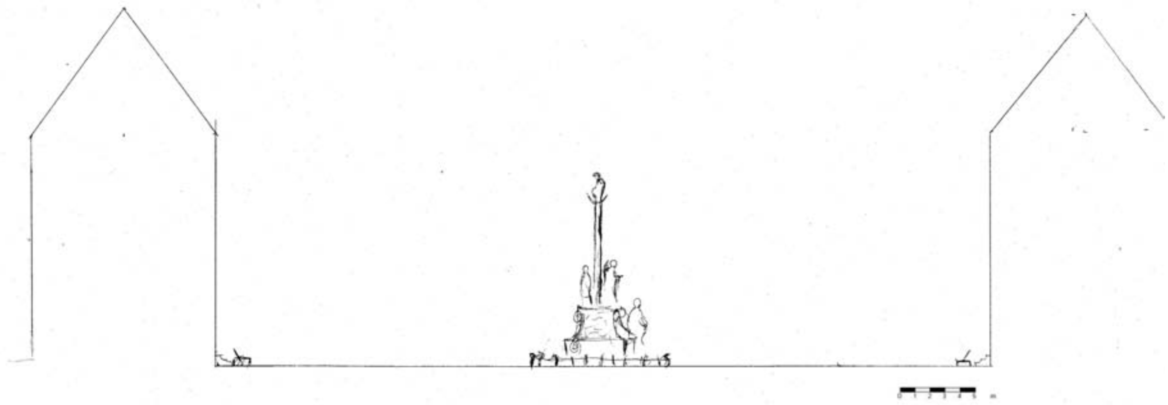


Figure 7.5: cross section of Jodok-Finkplatz

Figure 7.6: cobbedstone

Figure 7.7: baroque statue in the center of the place

Usage

The place is public. The church is the dominant element of the square. The square is centered around the Kindergarten, Volksschule, Pfarrsaal and Gymnasium. It is used as a meeting point and representative space before and after the holy mass and the classes. It is equipped with benches which are used constantly in winter and summertime. Once I witnessed a charity buffet infront of the church offering cake and coffee. Moreover the place is used as an old Christmas tree collection point in Janurary.
In the summer half of the square is occupied with three 'Schanigarten' (restaurant gardens), operated by 'Café Maria Treu', the pizzaria 'Il Sestante' and the restaurant 'Piaristenkeller'. They partly use the shade of the trees and put up additional sunshades to avoid the bright sunlight. They are frequented from 11am until midnight with a clear peak in the evening hours. At dinner time it is difficult to get a table. (see fig. 9.4 and fig. 9.6) This district is built in a very dense way therefore it offers an useful free space which is also accepted by people of all ages who live, work and study in the area.

Restrictions

A fence made of concrete stands, which are conncected with a heavy low iron chain runs between Jodok-Finkplatz and Piaristengasse. Only at two points is the fence interrupted, and the place could even be accessed by car if there were not barriers. The fence is not respected by many users who simply step over it to keep their direct route.

7.1.3 Usage and Microclimatic Needs

To bring the site analysis to a close I will try to summarize my impressions about usage and microclimate of the site. I want to highlight the items which are of importance for the thermal comfort balancing the different usages.

Figure 7.8: door

Figure 7.9: people sitting in the sun

Figure 7.10: children footballplaying and an accumulation of old christmas trees

Figure 7.11: children going to school

Figure 7.12: people going to church

Disfunctional Space

There are many users who pass through the place in all directions, who linger and sit on the benches, waiting, talking, reading or eating and some are doing activities like playing soccer. We can call it a strongly dysfunctional space. It is great that so many things are happening on the site, and the place should always be able to offer the possibility to do many different things.

Urban Climatic Environment

The place is really open and unprotected, apart from the small trees on the side. In the summer I estimate that the place will heat up a lot, and shelter would be a pleasure. In the winter it might be a comfortable place when the granite manages to hold enough of the little radiation the sun offers in that season.
When the quality of the usage stays like it is now, it is difficult to make major changes. The thermal deficit that the unsheltered place might have in the summer is its profit in the winter. In the summer there are schanigarten on the site, which is a thermal and functional adaption that works perfectly for this site.

Climatic Inventory

Following parameter mainly influence the microclimate on Jodok-Finkplatz:

1. radiation shelter effects by trees and buiding geometry
2. amplification of radiation input by building albedo
3. heat storage in concrete, cobbed stone surface and building walls
4. wind shelter effects by trees and building geometry
5. cooling effects by evapotranspiration (trees)

7.2 Schlesingerplatz

On the 21th of January 2008 between 11am and 1pm I visited the site to do a site analysis. It was a sunny, warm winter day. During the time of the measurements in May and June 2008 I noticed other additional climatic features and forms of usage.

Background Information and Introduction

Until three years ago the street run around the place and there was parking on both sides. It was not illuminated but overgrown with one big old tree and lots of bushes. There were old benches, the paths were made of concrete and the statue stood in the middle. He was labyrinthine and according to the waiter of the Café on the site, the place was not used a lot because there was not enough space. In the district the demand to build a underground parking was getting stronger. The project was rejected on various sites. On Schlesingeplatz there were protests as well, but after one and a half years the project was realized in 2004 to 2005. Now there are mainly parking lots for monthly pass holders. The new place was designed by italian architects.

Shade, Wind, Acustics

Only on the northern side of the building around midday is there sun. The bright wall reflects the light and makes the place seem very bright.

7.2.1 Site Inventory

Visual Connections

Schlesingerplatz lies very hidden. It is constructively detached from outside. Only shortly before entering the place it can be seen from Floriani and Schönborngasse. From the Café Florianihof, which lies opposite the Amtshaus, it can be observed as well.

Type of Free Space, Partial Spaces, Borders

On the West, North and East side the place is surrounded by buildings which are approximately 15 to 20m high. The place is slightly smaller than the Jodok-Fink Platz. Like in the former square, we can find a statue of about 10m height in the center. A small spring is included in the momument. There is a small place around it, which is equipped with benches, from which one can watch the fountain. Around the center there are four fields, which are stepped 50cm above the ground level. These fields are covered with grass and trees. Between and around these fields it is possible to walk on concrete. The space of concrete between the buildings and the fields is 7m broad at the back, and 5m broad on the sides. The place is surrounded on the West, North and East side by the 'Amtshaus Josefsstadt'. Different facilities of the magistrate like the Standesamt (civil registry office), Elternberatung und Elternschule der MA11 (consulting service for parents), Krankenfürsorgeanstalt der Bediensteten der Stadt Wien (institute of medical care for civil servants), Magistratsabteilung 27 EU-Strategie und Wirtschaftsentwicklung, Bestattung Wien, MA 15 Impfstelle and the Stadtschulrat can be found in this building. [josefsstadt(2007)]
There is one main room and seven partial rooms. The main room is structured by four greened spaces, which build another space with a spring in the center and benches to wait and relax. There is the pedestrian way and access road to the official buildings and finally the space dominated by Florianigasse.

Horizontal Elements

The place is laid with granite cobblestone sized 10x10cm laid in a sandbed. The streets and the pavement are made from concrete. The fields are covered with lawn.

Vertical Elements

The neo-classical statue includes a fountain to drink from at its bottom. The buildings are of the same age and the facades are made from white and bright yellow limestone. The trees are Prunus serrulata (Japanische Blütenkirsche) of about 5m to 7m height. There are 13 modern lamps and a modern glass entry for the underground parking.

7.2.2 Site Analysis - Functional Relations

Urbanistic Context

Schlesingerplatz lies in the same part of Josefsstadt, therefore the urbanistic context from Jodok-Finkplatz are valid for it as well.

Figure 7.13: view of the Amtshaus and the statue

Figure 7.14: above: Schlesingerplatz in spring, below: Florianigasse

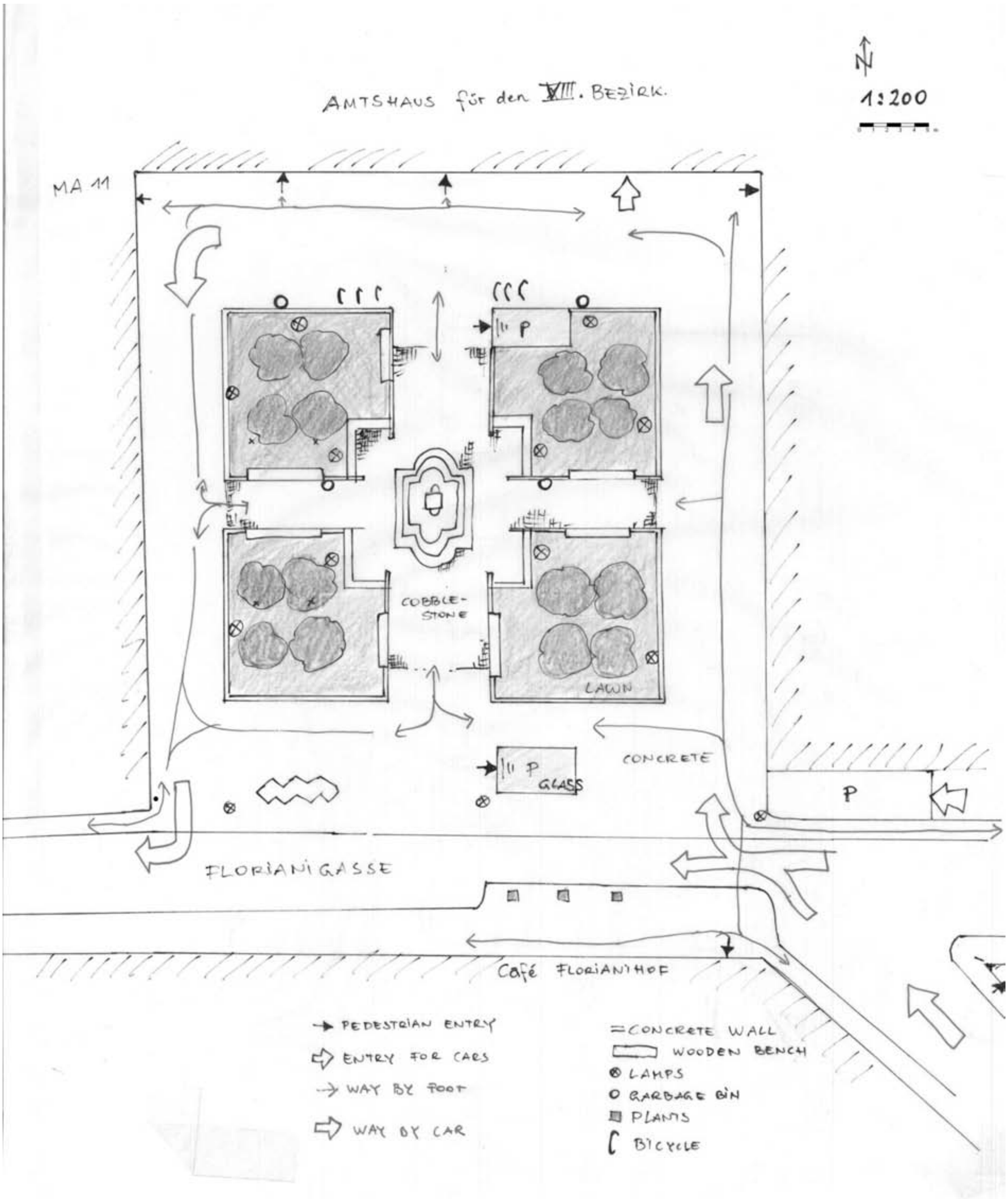


Figure 7.15: plan view of Schlesingerplatz

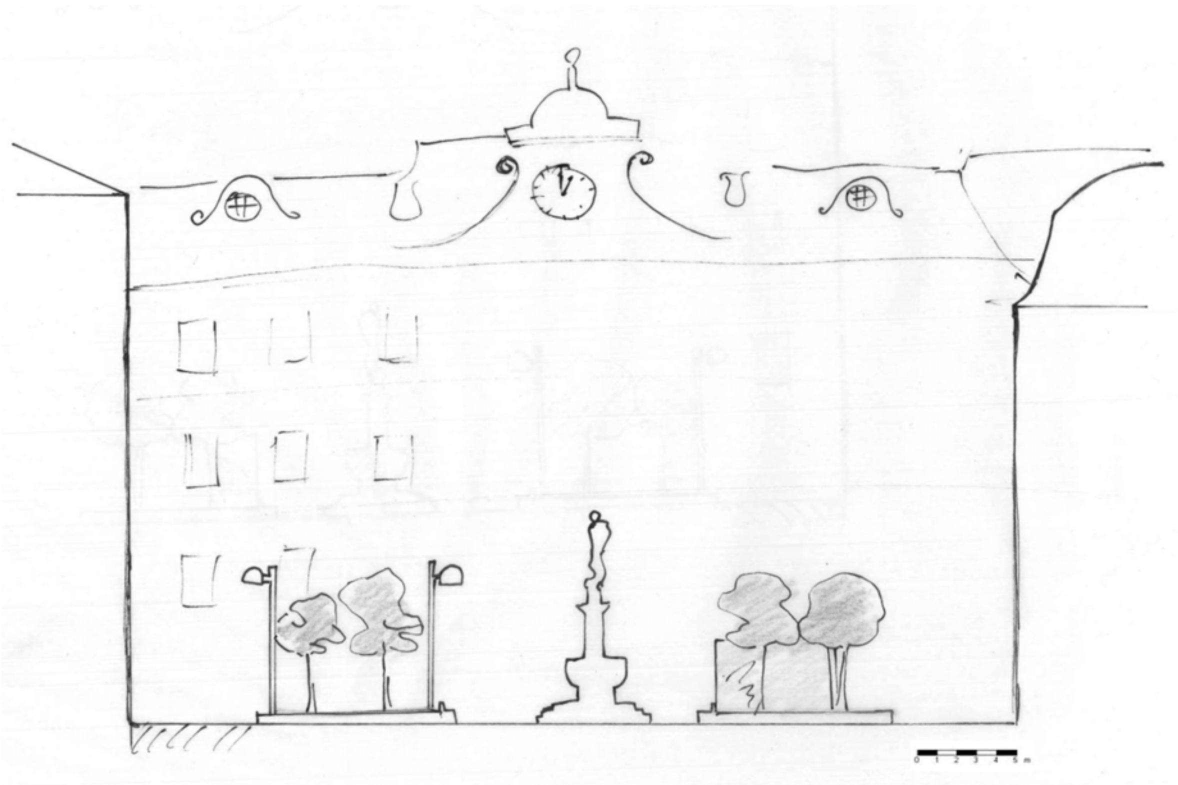


Figure 7.16: cross section of Schlesingerplatz

Figure 7.17: lawn

Figure 7.18: cherry trees and neo-classical statue

In a conversation with the waiter of 'Florianihof' an interesting idea, that I want to add to the analysis, came up. Although the 'Rathhaus' (city hall) of the 8th district is on the Schlesingerplatz, it does not have the function of a 'Hauptplatz' (central/main square). This position is taken by J.M.Hauerplatz in front of Caf Hummel on the corner of Josefsstaedter and Albergasse. There the 'Bauernmarkt' (farmer's market) takes place, and the political parties represent themselves there during the election campaign. In my opinion one reason is the busy shopping street Josefsstaedterstrasse and the meeting of the concetric and radial trams (5,33,J) and the vicinity of the underground U6.

Off-site influences

Because of the closed geometry of the place there are hardly any influences from outside. There is a small noise exposure from the street. Still there is no visual protection between the street and the place, therefore it cannot give a feeling of privacy and exposes all users to the traffic passing by.

Accessability, Paths

The square is accessible from the Florianigasse by foot, car, bicyle and alike. The stops for the bus 13a and the tram 5 and 33 are around the corner. In five minutes one can reach the U6 station Josefsstädterstrasse.

Usage

In the winter the square is mostly used by people on their way to a civil service. Those are predominately older people and single persons. I did not see anyone younger than 20 in the time I spend there in January. A second group of users are jogger and cyclists who cross the square at its border. During my observation time I did not see anyone sitting on the benches.
In winter hardly any traces of usage can be found, although the square is said to be used more than before the rearrangement. In the summer, due to an increase of people lingering on the site more rubbish can be found on the lawn. (Including strange things like uncooked rice spilled on the light spots in the laws)
In the summer the place is said to be used by residentials and students. Because of the little traffic children use the street and the place to learn how to cycle. In the summer the café serves prosecco to wedding parties on the place and has a small schanigarten on the sidewalk. The waiter says in the summer there are more people sitting in the schanigarten outside than in the café, which I can verify.
And indeed, after the cherries bloom around February the square slowly gets more populated. After frequenting the place in the summer, I observed various metal grid canvas chairs, who where put up on the eastern side of the square on the lawn around april, which where nearly constantly in usage. The trees provide enough shade to create a comfortable situation to read, picknick or simply lie around to do nothing and enjoy the summer. Some people even take their own blankets to transform the rather uncomfortable metal chair into a cosy place that they take possession of for a couple of hours.

Restrictions

In a converstation I learned that in the summer young people use to bring covers and lie in the lawn, but after a while the police keeps banishing them. This summer, seemingly to avoid this problem metal canvas chairs have been situated on the lawn, so that the lawn itself is less endangered. The lawn seems to be very important to the people managing the place. It is cleaned frequently and in summer the automatic irrigation plant runs from 9.30am to 10.30 am, which restricts the usage of the lawn and the place, because the water also reaches the paths between the lawn. This asks for attention of the busy people on their way to the civil services in the morning.

Figure 7.19: Schanigarten of Cafe Florianihof

Figure 7.20: people relaxing on Schlesingerplatz

7.2.3 Usage and Microclimatic Needs

To bring the site analysis to a close I will try to summarize my impressions about usage and microclimate of the site. I want to accentuate the items which are of importance for the thermal comfort balancing the different usages.

Structured, Restricted Place

The place is designed functionally. There are less users than on Jodok-Finkplatz, which has only slightly changed in summer. There is less usable space, because the usable space is strongly structured and leaves less kinds of usage. The lawns that are neatly cultivated seem to be completely forbidden to step on. The main usages are passing through to the public offices and sitting on the benches. In the summer the metal canvas chairs open the lawn areas for five to ten people. Other usages which would use more space, like ball playing, are restricted. Luckily there is hardly any traffic so in the summer children learn how to ride a bike partly on the street.

Climatic Park Environment + Comparison to Jodok-Finkplatz

In the summer the place looks microclimatically quite attractive. The lawn and the trees promise a cooling down effect in the hot season, and shade from the bright summer sun. Unfortunatly the cherries are quite small and thin. I wonder how much effect they really have on the temperature. Does the lawn really show effects? There is also a fountain, which I have not taken into account in the simulation, but might show effects in the measurements. There are also the glass huts for the parking garage entry. I cannot simulate them, but they might influence the radiation balance. In the winter to me it gives an cold impression and is less inviting than Jodok-Finkplatz. In the summer the green areas make the place itself cooler. Still, the meadow and the small trees cannot compete with the articifial shade and the older trees on Jodok-Finkplatz. Althought Jodok-Finkplatz itself is hotter, the fact that it provides proper, effective continuous shade makes it a more attractive place to spend lunch break in the hot season. In the evening and night time, after the sun has set behind the buildings both places are thermically comfortable, whereas Schlesingerplatz cools down faster.

Climatic Inventory

Following parameter mainly influence the microclimate on Schlesingerplatz (nearly the same as on Jodok-Finkplatz):

1. radiation shelter effects by trees and buiding geometry
2. amplification of radiation input by building albedo
3. heat storage in concrete, cobbed stone surface and building walls
4. wind shelter effects by trees and building geometry
5. cooling effects by evapotranspiration (lawn and trees)

8 Simulation

In order to understand the possibilities of the model, I am simulating two different sites in Vienna. The first site is covered with cobbed stone. The second site is similar, but laid out with four lawn areas and trees planted inside. It is in the close neighbourhood of site A. It has approximatley the same size, the streets which pass have nearly the same width. They are not oriented in the same direction, but because of their small dimension their influence will not be significant [Steinhauser et al.(1959)Steinhauser, Eckel, and Sauberer]. The surrounding buildings have equal heights. I want to find out if the model is precise enough to show such a difference.
First I will describe the input data and the configuration. The model size and the cf - file applies on both cases. Later on I want to go into detail and test the sensitivity of the model for different albedos, soil profils and vegetation. This is necessary to get an understanding of how precise input files and configuration files have to be, and what effects small changes can make on the calculations. Due to flow error I have not managed to simulate Jodok-Finkplatz. Therefore I will only briefly introduce it and discuss the problems. The detailed discussion about different parameters are focused on the Schlesingerplatz.

8.1 area.in

8.1.1 Model Size

I based my input files on the orthofotos included in the online citymap of Vienna, which is freely available on www.wien.gv.at. I saved the *.jpg file, converted it to a *.bmp file and used it as a background image on which I tried to build the geometry of this area as precisely as possible. I chose the best resolution possible to get precise results. I visited the site to avoid any misinterpretations and made final adjustments. The two limiting factors are the size of the place and the model size of ENVI-met. I stuck to the 4:3 proportion of the original orthophoto that I used as well. I chose an area of 150m x 112m, to show the square, the surrounding buildings and streets. For this area I use 75x56x25 grid points and a grid size of 2m in the x, y and z dimension. A smaller grid size did not seem to give any additional information, and a bigger size fails to represent small structures like the cherry trees on Schlesingerplatz. The horizontal resolution is the same for both places. The vertical resolution differs, because in case A the highest point in the model is 62m while in case B it is only 26m. The equidistant vertical grids would only cover 55m. Therefore telescoping is needed to make the model high enough. In Simulation A I use 7% telescoping. After simplifying the geometry in Simulation B no telescoping is needed at all.

8.1.2 Nesting Grids

In both cases I increased the number of nesting grids up to 5 to avoid flow problems. Soil A is defined as p (pavement) and Soil B as 0 (default unsealed soil). For Simulation A the model was also rotated -9°for Simulation B +13°from North.

8.1.3 Buildings

To get precise information about the buildings dimensions I studied the original plans of the surrounding buildings of both sites.

Figure 8.1: orthophoto of Jodok-Finkplatz

Figure 8.2: orthophoto of Schlesingerplatz

Jodok-Finkplatz

The plans for Jodok-Finkplatz were found at the office of the Pfarre Maria Treu. The side buildings are 24m high at the highest point and 15m at the eaves. The roof of Maria Treu Kirche is 27m, the middle part 41m and the two towers extend up to 62m in the sky. After various flow arrows, which I will describe later on, I simplified the geometry and transformed the tilted roofs to flat roofs. The towers I simplifed as 55m high and 6 x 8m broad. Still the Maria-Treu Kirche on Jodok-Fink-Platz seems to be too complicated to be represented in the model. The towers seem too thin and too high to enable the calculation.

Schlesingerplatz

The plans of the Amtshaus were accessed with a paper of authorization at the Baupolizei (MA 38) of the 8th district. The plans of the parking garage should be at the Straßenverwaltung (MA 28), but cannot be found there. The Amtshaus is 24m high at the sides and 26m above the main entry. I tried to construct the tilted roof by having gridpoints with 24 or 26m high in the middle and lower gridpoints at the eaves, but I got various flow errors. ('Updating flow: Cancelled after 200 steps; Warning: Flow module failed to convert solution! Increase border grids! Please refer to Knowledge Base 10: Flow Problems in the ENVI.met manual!'). First, I increased the border grids up to 4 gridpoints, then the nesting areas up to 5. The flow Problems did not stop so I decided to simplify the geometry and transform all the tilted roofs into a flat roofs of 22m height. Only the part over the main entry of the Amtshaus is a platform of 24m height. I did not get any more flow problems with this geometry.

site	Jodok-Finkplatz	Schlesingerplatz
model size	75 x 56 x 25	75 x 56 x 25
grid size	2m x 2m x 2m	2m x 2m x 2m
area	150m x 112m x 50m	150m x 112m x 50m
max building height	62m	26m
simplified max building height	55m	24m
telescoping	7%	0%
nesting grids	5	5
soil A	p	0
soil B	0	0
model rotation	-9°	13°
plants used	ds,sk	gs,ch,MO

8.1.4 plants.dat - Vegetation

I use two different trees: the self defined Cherry (ch) and the predefined 20m tree, average density (MO). First, I also used the predefined 10m high tree with a dense, distinct crown layer on the square, but there are noticable differences between the real trees on the site and the ones available in plants.dat, which I will describe later on. The lawn I defined as 10cm high grass (gs).

8.1.5 profils.dat - Soil Profile

For the lawn I use the soil profile 0 (unsealed). The street and the sealed parts of the place I defined as p (pavement).

8.2 *.cf

MAIN-DATA ———————————
Start Simulation on Day (DD.MM.YYYY): =14.05.2007
Start Simulation at Time (HH:MM:SS): =00:00:00
Total Simulation Time in Hours: =24.00
Save Model State each ? min =60
Wind Speed in 10 m ab. Ground [m/s] =1
Wind Direction (0:N..90:E..180:S..270:W..) =135
Roughness Length z0 at Reference Point =1
Initial Temperature Atmosphere [K] =293
Specific Humidity in 2500 m [g Water/kg air] =7
Relative Humidity in 2m [%] =50

OPTIONAL-DATA

POSITION
Longitude (+:east -:west) in dec. deg: =16.37
Latitude (+:northern -:southern) in dec.deg: =48.21
Longitude Time Zone Definition: =15.0
SOIL - Settings for Soil
Initial Temperature Soil & Surface [K] =293
Relative Humidity Upper Layer (1.5-15 cm) =50
Relative Humidity Middle Layer (25-45 cm) =60
Relative Humidity Deep Layer (below 75 cm) =60
BUILDING
02. Heat Transmission Walls[W/m2K]: 1.94
03. Heat Transmission Roofs[W/m2K]: 3
04. Albedo Walls: 0.4
05. Albedo Roofs: 0.3

Timing

I left most parameters at their default values and only changed some, so to get a better understanding on how they influence the calculations. For the simulation date I chose 14.5.2007, because then the leaves are already out and I will have already finished the literature study, the site analysis and the simulations and we can do the measurements more effectively.
I start the simulation at midnight, to give the model enough time to stabilize before the sun comes up. I let it run for a whole day, to see all the effects of before and after sunrise, midday and before and after sunset, when the solar radiation stops and the cooling process starts. It is possible to start later in the early morning, but on these simulation runs I stuck to this timing.
It is also possible to let the simulation run for more than 24 hours. I let it run for 48 hours in the beginning, but noticed that there is no noticable difference in the results. It might make a difference to let it run for more than a week, or a month, but one simulated day needs a half up to one real day to be calculated. I focused on realistic timespans, because in a planning process most likely the simulation will run for just one day as well.

Meteorological Input

The simulated day is sunny, with no clouds in the sky, little wind and the wind direction is southeast, as is very likely in Vienna when there is high-pressure weather.
I did not have any wind data from the simulated area (It would have been difficult to measure the 10m above ground wind speed in the middle of the eighth district). But I was advised by experts that 1m/s would be a more realistic value in the 8th district than the default 3m/s. So I changed the wind speed to 1m/s, which has the positive side effect to get clearer temperature results, because the faster the wind the less stable the temperature. The following parameters are still default values. The roughness length is 0.1, the initial air temperature at 2500m is 20°C, the specific humidity in 2500 m is 7g Water/kg air and the relative humidity at 2m over ground is 50%. It is important to note that the roughness length does not refer to the average roughness of the urban situation modeled in the domain but only to the roughness of its ground surface. Bruse recommends setting the parameter to the value 0.1 and to leave it unchanged. Test simulations have shown that the parameter is highly sensitive and has significant impact on results. [Spengenberg(2004)]

The Heat Transmission

I could not find any information about the real heat transmission in the buildings, which is much easier with modern buildings, because now it is common to document values used for energy efficiency calculations. So I kept the value $1.94 W/m^2K$ for the walls, but on the roofs I changed it from 6 to 3 W/m^2K.

The Albedo

The albedo of red tiles is 0.33 [Grüner(1999)] which is close to the default value of ENVI-met. Therefore I did not change this value. The albedo of the walls might be larger than the default value 0.2. Both the church facade and the facade of the Amtshaus is made of bright limestone, with an albedo of 0.4 to 0.6 [Grüner(1999)] while the surrounding buildings are slightly darker and rougher. For my simulations I chose for both sites 0.4 for the wall albedo. Generally it is difficult to assume the albedo with lists instead of measuring it. Spengenberg documentated the albedo of off-white painted walls with 0.56 and the albedo of weathered off-white painted walls with 0.07.

8.3 Testing the Sensitivity of the Model

All successive figures in this chapter were created in the graphical display program Leonardo and use a scale which is otimized to the existing data rate.

Comparing different Albedos

Because there might be big inaccuracies concerning the albedo I started to compare two situations which only differ in their wall albedo. One situation has an albedo of 0.4 like I use in all the other simulations, the other has an albedo of 0.2.
An albedo change shows a marked effect. In the morning the place is warmed up close to the eastern wall much earlier when the albedo is higher. During the day the place heats up stronger, when the albedo is higher, because more radiation is reflected and distributed on the square. This is an important effect also documented by Spengenberg [Spengenberg(2004)]. See figure 8.5, 8.6 (In this simulation the tree ds is used)

Figure 8.3: walls on Schlesingerplatz

Figure 8.4: walls on Jodok-Finkplatz

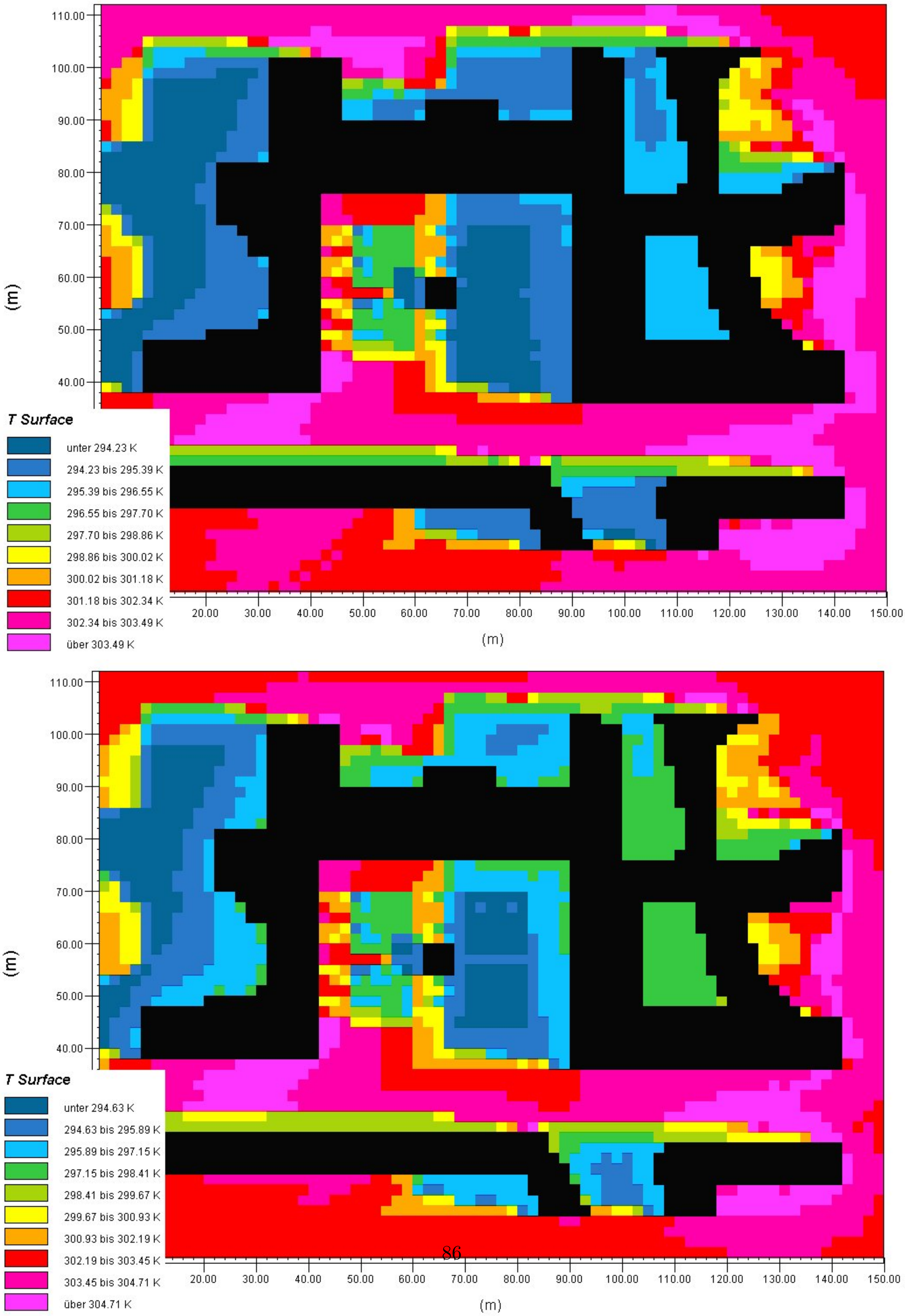


Figure 8.5: 9am, above: albedo 20%, below: albedo 40%

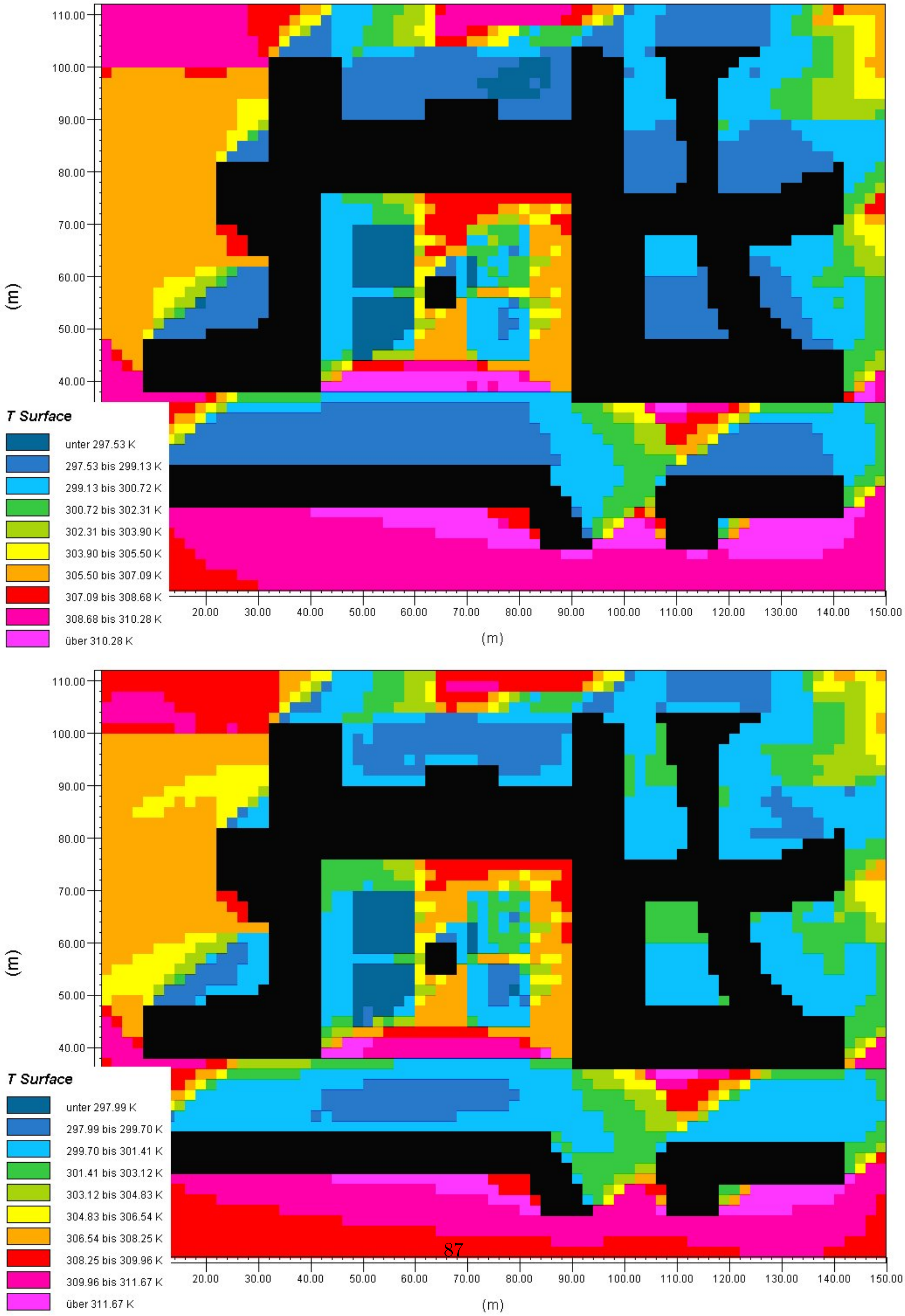


Figure 8.6: 3pm, above: albedo 20%, below: albedo 40%

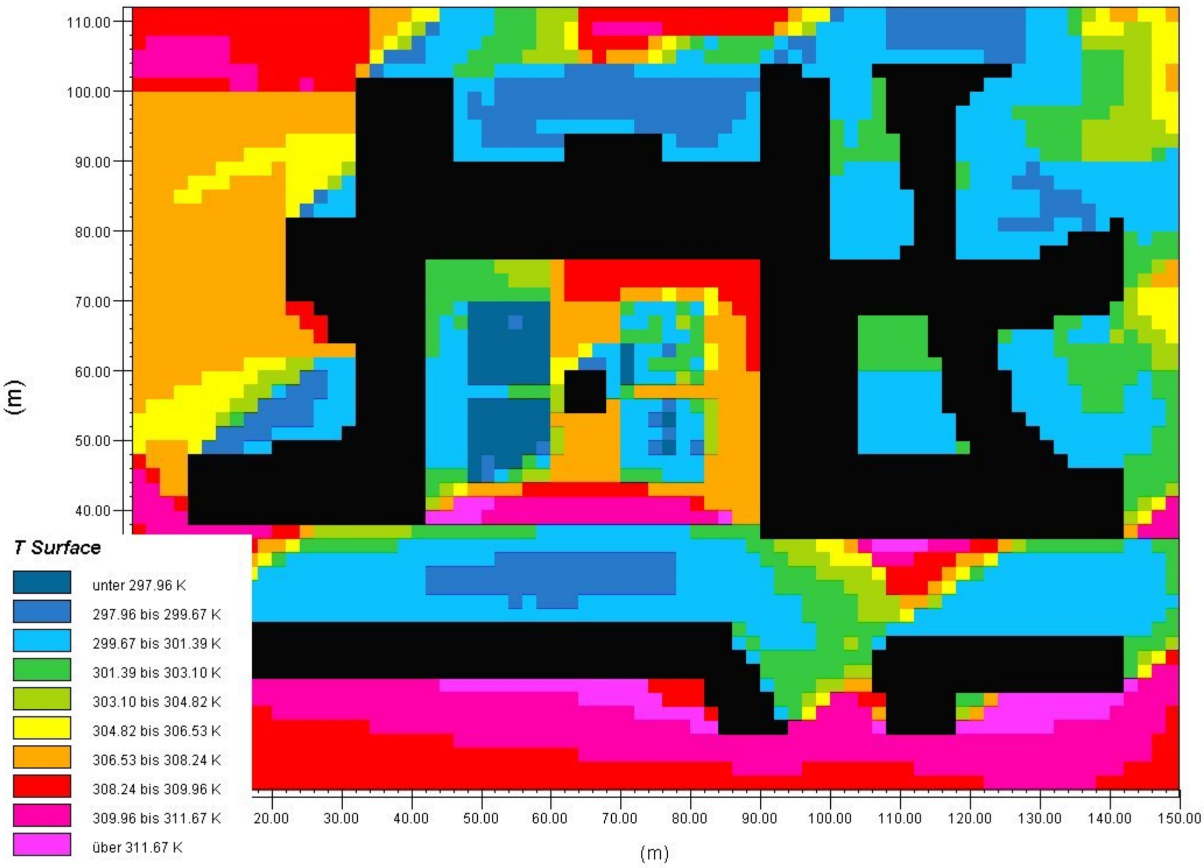


Figure 8.7: 3pm, cherry trees (ch)

Comparing different Soil Profils

I made one simulation with the self defined soil profile pg, which considers the parking garage below the site and where the soil le only extends to 0.45m depth. Below there is concrete (zb). I did not notice any differences between 0 and pg, because the daily fluctuation of temperature never reaches this depth. [Geiger et al.(1927/1995)Geiger, Aron, and Todhunter]

Bare Soil vs Grass Cover

Next I want to find out what influence the usage of the wide possibilities of defining different surface covers makes. I compare the 4 lawn areas defined as default unsealed soil to being covered with lawn. Until 9am the lawn has a higher surface temperature than the bare soil. When the sun reaches the place, the bare soil heats up between one and two Kelvin higher than the lawn. When the influence of the radiation balance becomes negative in the evening, the bare soil cools faster than the lawn. See figure 8.8. The differences can only be seen directly, where the changes were made - on the four lawn areas.

Comparing different Plants

description short	tree, average dense MO	tree, distinct crown ds	cherry tree ch	grass gs
shortwave albedo(%)	0.2	0.2	0.2	0.2
min. stomata resistance	400	400	400	200
Height(m)	20.00	10.00	5.00	0.10
Roots(m)	2.00	2.00	0.50	0.50
LAD 1-4	0.04 - 0.11	0.075	0.00	0.30
LAD 5	0.13	0.25	0.50	0.30
LAD 6 - 9	0.15 - 0.10	ca.1.00	1.00	0.30
LAD 10	0.00	0.00	0.50	0.30
RAD 1 - 10	0.10	0.10	0.10	0.10

Finally I want to find out how the usage of self defined vegetation affects the simulation results. The cherry trees growing on Schlesingerplatz are not among the default plants included in plants.dat, therefore I defined my own cherry tree according to the plant.dat's formatting rules.

In the preceeding simulations I used the ds tree, which comes closest to my cherry tree, but is higher and has a more dense crown layer (see table). Comparing the two an effect can be seen in the ENVI-met results. The ds tree casts more shadow than the cherry tree ch and therefore the surfaces around the cherry trees are up to 2K hotter. This effect is, depending on the hour, noticable up to 5m distance from the trees. One has to take great care in using correctly defined plants. (See fig. 8.6 below and fig. 8.7)

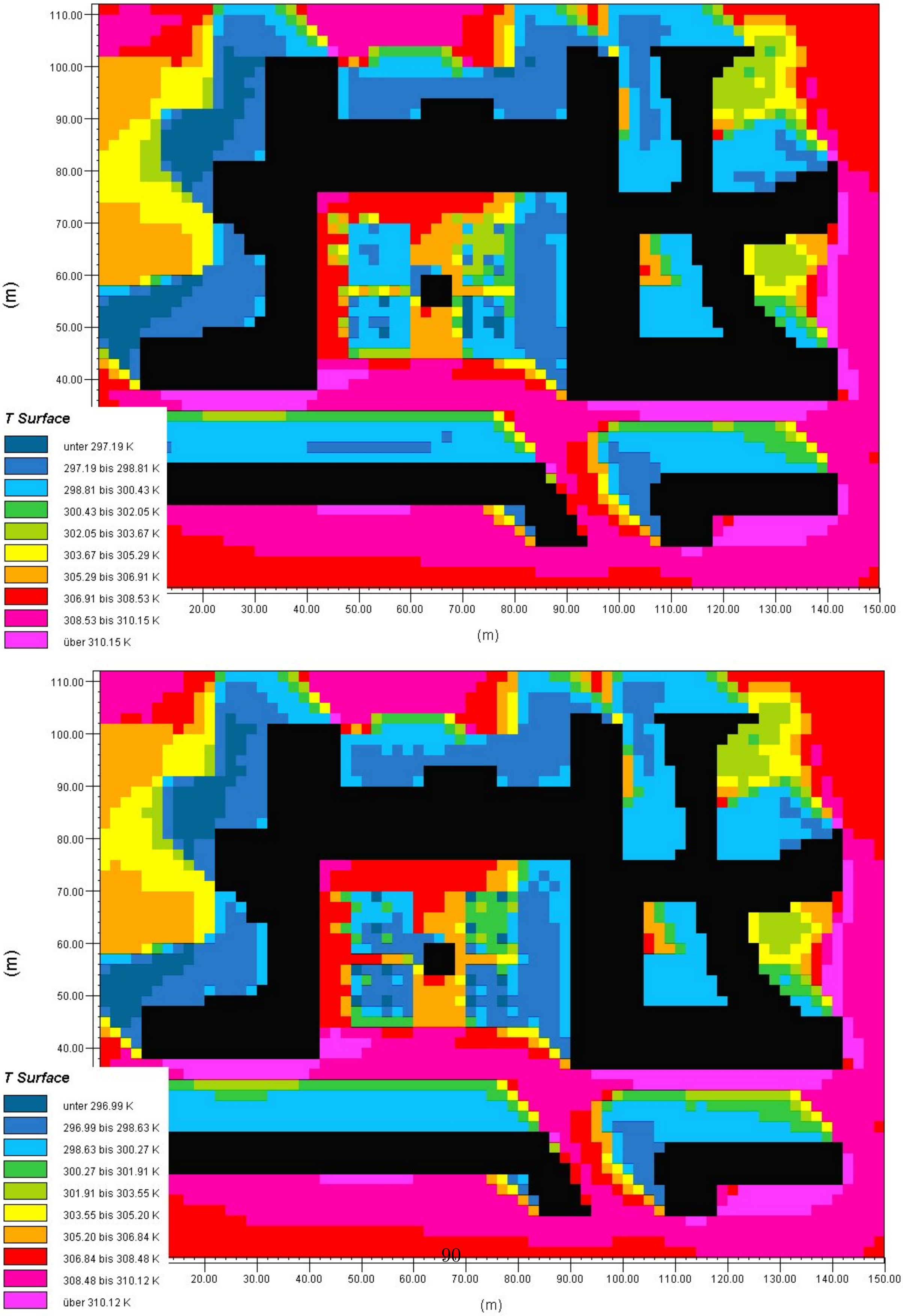


Figure 8.8: 11h, above: bare soil, below: lawn

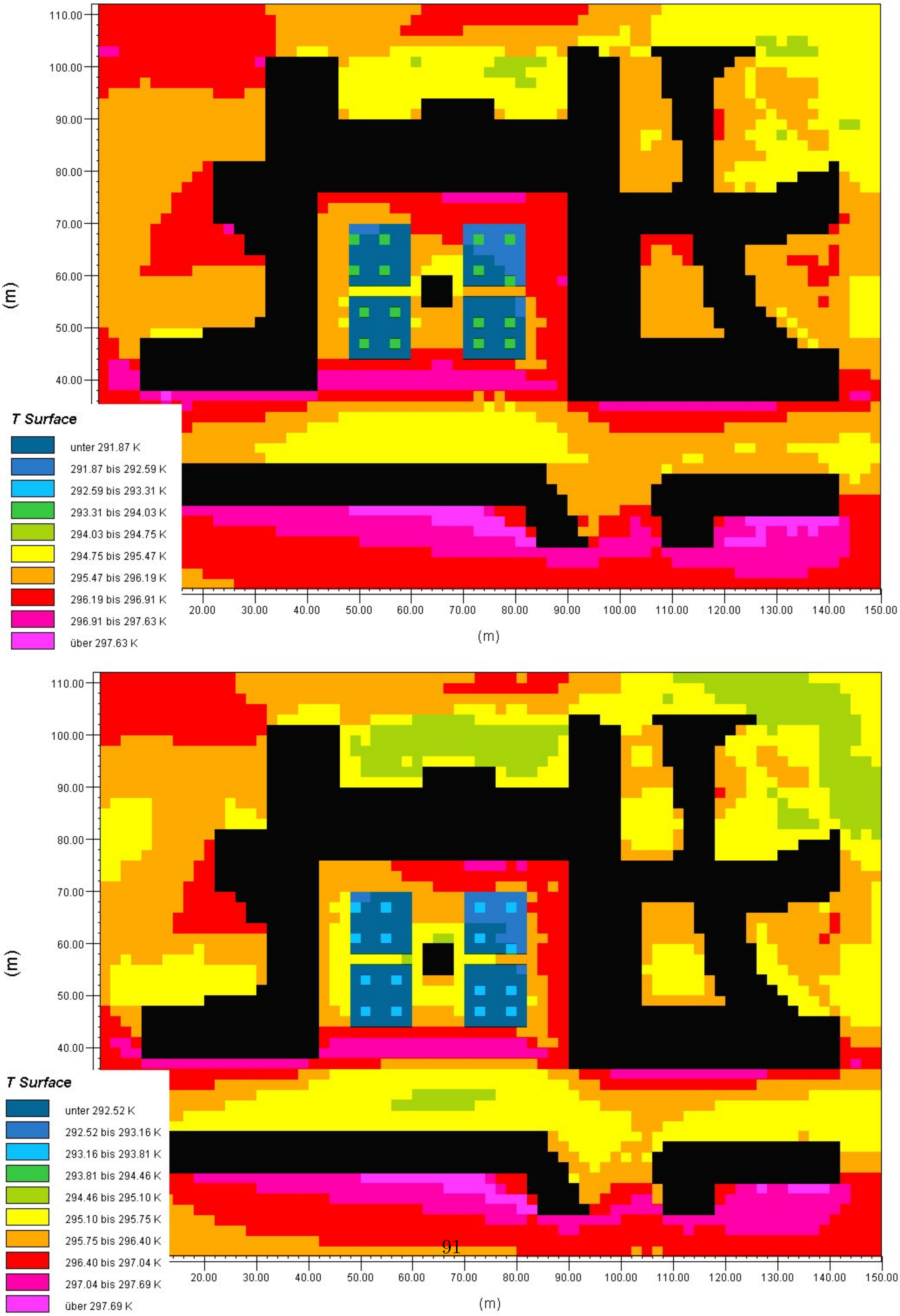


Figure 8.9: 21h, above: bare soil, below: lawn

8.4 A Day

After getting a grasp of how the model works, I will describe how ENVI-met3 simulates a whole day on Schlesingerplatz, using the simulation schlesiNewTryCherry (same as in fig.8.7 with albedo 0.4 and ch as trees. I will refer to the changes of air temperature at 2m height. Due to turbulence and the small scale the differences of air temperature are small (less than 1K), but clear enough to trace and comprehend the microclimatic processes taking place.

It is recommended to let the simulation start before sunrise to give the model time to stabilize. Therefore, I start analyzing at 6am, when the warmest part of Schlesingerplatz is on the northeastern side, which is also the most protected. In the adjacent closed yard it is slightly warmer (around 0.15K). On the street, where the southeastern wind blows strongest, is also the coldest area.

8am

At 8am, when the sun starts hitting the northwestern wall and triggers the warming up of the square, which is reflected in a temperature rise on the western rim.

9am to 11am

From 9am to 11am the hot peak in the northwest intensifies and becomes hotter than the adjacent yard. Shortly afterwards this yard gets a little direct sun and heats up as well, but is still cooler than Schlesingerplatz at 1pm again. (See fig.8.10)

12am

At 12am it starts to wander north and switches to the northeastern corner at 1pm. From there it slides down the eastern wall while the west cools in the shade. (See fig.8.11)

5pm

At 5pm the rays of the setting sun only hit the upper stories.

6pm

At 6pm the small yard is warmer than the square. The street and the square form a unity with only little temperature differences.

9pm

At 9pm the wind influence shows effects, and the more sheltered areas in the corner of the square, as well as the square as a whole stay warmer than the street. Finally a similar situation to that in the morning stabilizes.

Conclusion

During the course of the day we can watch the temperature distribution follow the course of the sun quite clearly. The street gets less radiation, shows considerably higher wind speeds and is generelly cooler than the square. (See fig.8.13 At 2m height the different surface materials do not seem to show significant effects on the air temperature which is rather defined by the solar illuminated walls and the wind speed. To verify this another simulation using the same area.in but replacing the lawn areas with concrete would be needed.

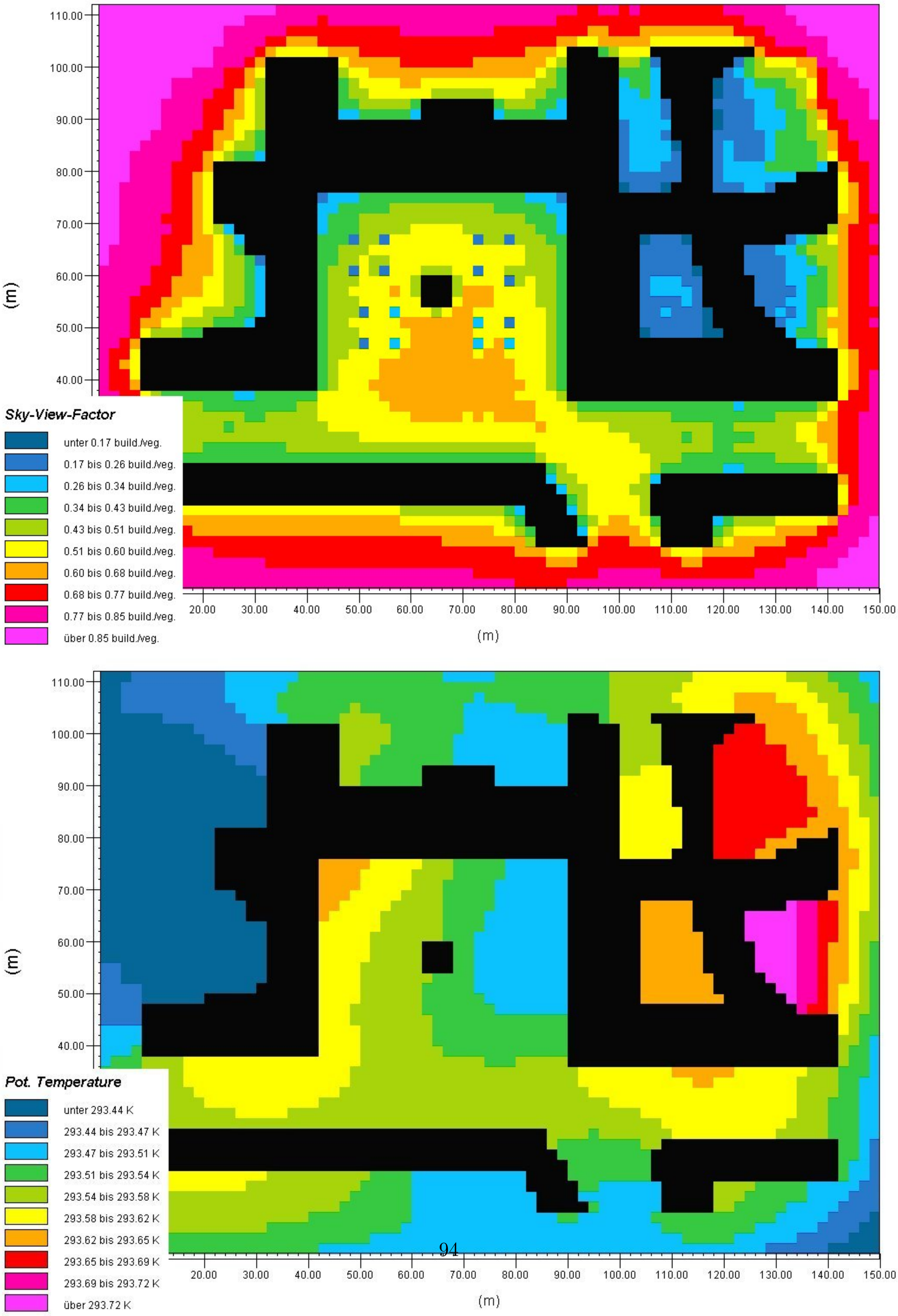
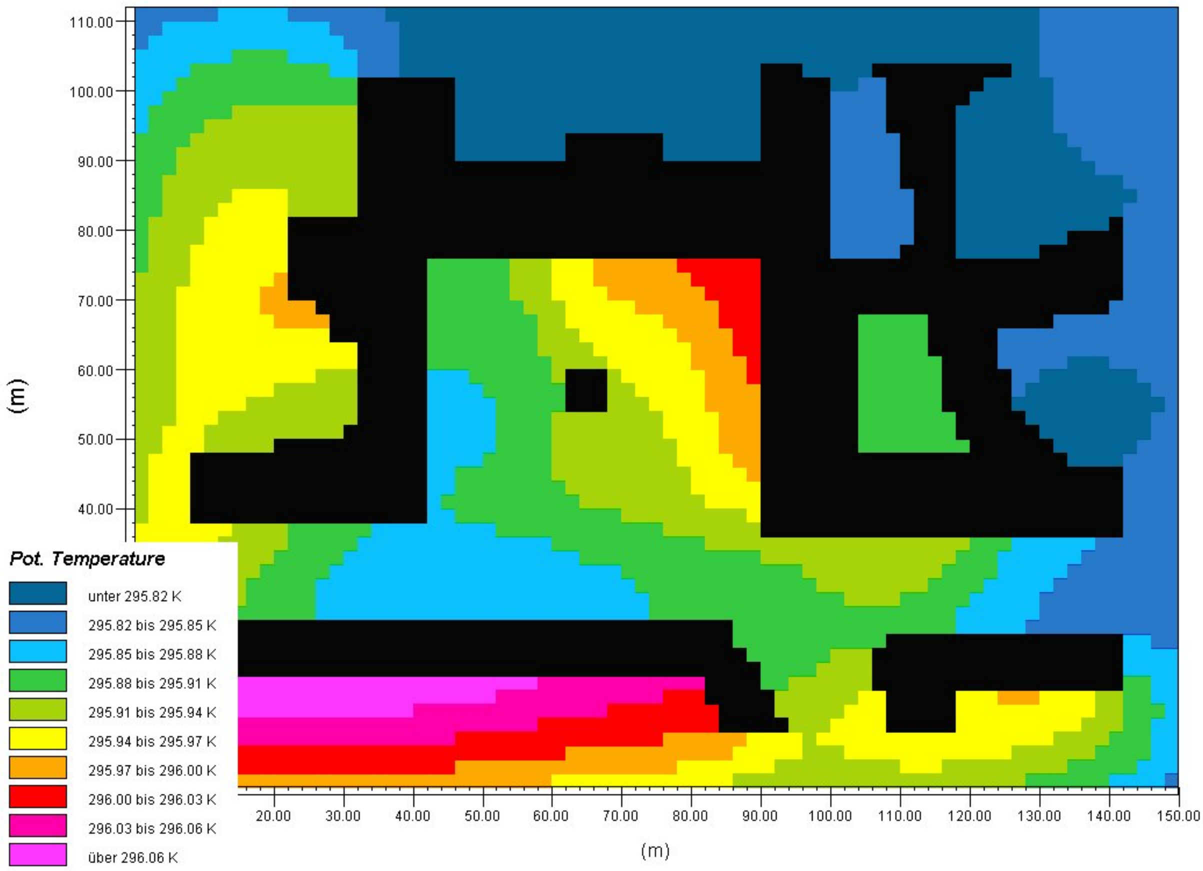


Figure 8.10: above: Sky View Factor, below: potential air temperature 9h



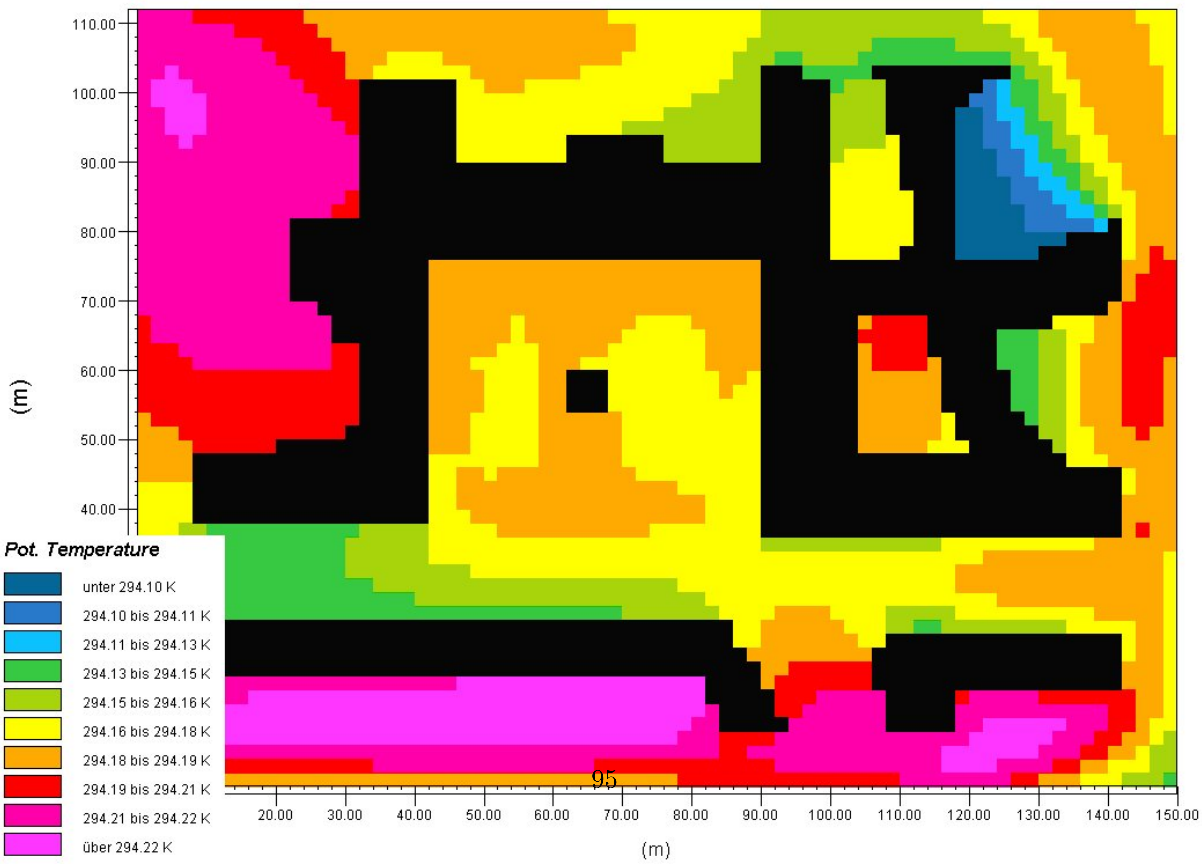


Figure 8.11: potential air temperature [K], above: 15h, below: 21h

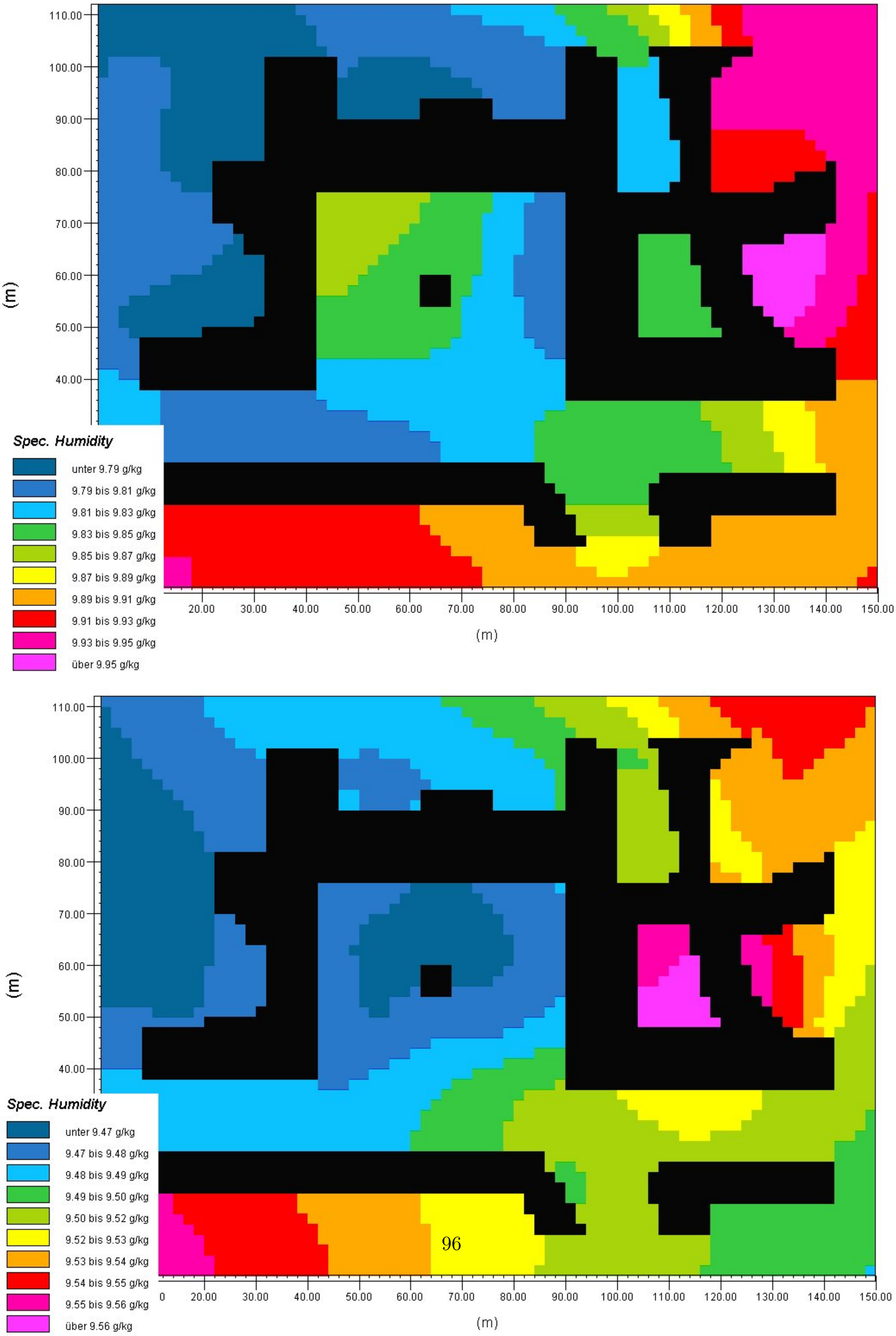


Figure 8.12: specific humidity [g/kg], above: 11h, below: 21h

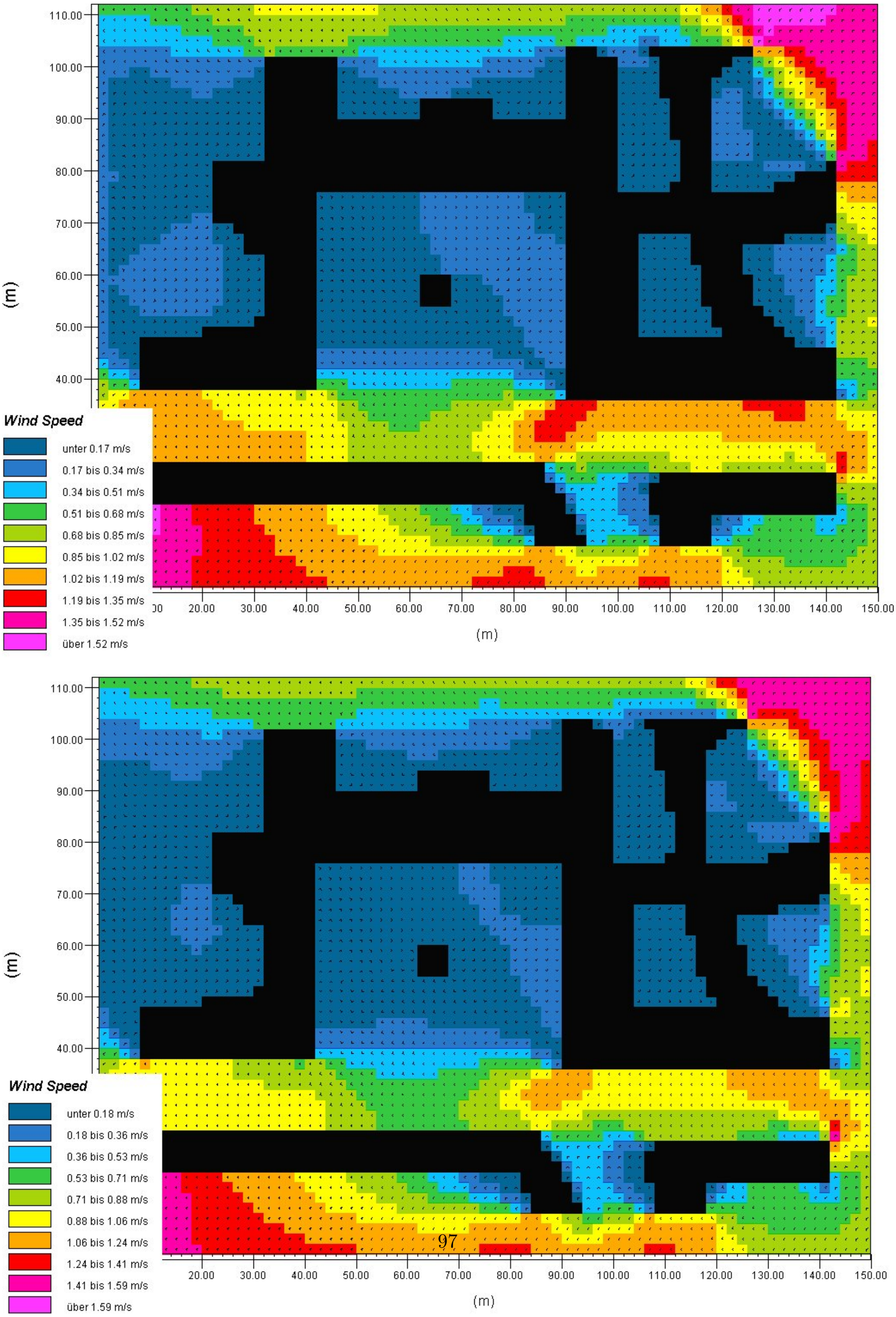


Figure 8.13: windspeed [m/s], above: 11h, below: 21h

9 The Measurements

9.1 Introduction

In the analysis of the simulation I focused on the surface temperature, therefore I also primarily measured this parameter on the site. I wanted to find out if the difference in surface temperature between the lawn and the concrete as well as between the middle of the place and close to the walls was similar to the calculated results. With an infrared camera I was able to make photos of the surface and get high resolution spacial information at one moment at midday. To get continuous temperature data over time I also measured the air temperature at different positions. I admit, it might have been more interesting to measure the surface temperatures continously, but I did not have the possibilities to do so. On a public space it is quite difficult to find a place to fix any measuring device at all. And if a place is found there is a constant risk of damage or thievery. After one summer of measurments in Vienna I was quite surprised that none of our instruments were manipulated, damaged or stolen. Only earwigs and other insects caused a forseeable and avoidable risk. Nonetheless, I chose quite safe locations for the measuring devices, although obvious and public (On trees, road signs and alike). Surface temperature ought to be measured on the ground, where people walk, rain falls and dogs piss - a close to impossible mission in any city. The infrared method turned out to be the best method for my purpose.

9.2 Hemispherical Analysis

Initially, a hemispherical analysis was made, to identify the potential radiative input of the places.

9.2.1 Description

The hemispherical analysis was performed using a digital camera and a 'fish-eye' lens fixed on it. With this method it is possible to demonstrate the Horizontüberhöhung (see Chapter 4.8 Climatic Features of Josefstadt) of a square. It shows the complete upper hemisphere, and therefore also all the obstacles that block the view to the horizont. The higher and closer the buildings and trees are to the position where the photograph was taken, the smaller the bright space that is left for the sky gets. In the program HemiView it is easily possible to lay a graph over the photograph that shows the sun's orbit. On the lines one can read the sunshine duration at this very place on any day of the year. I made three photographs. The first two where shot in the middle of the two places, the last one on the pavement, close to the center of the crossing of Maria-Treugasse and Piaristengasse.
In this case the sun follows the uppermost line in the diagramm. All photographs where taken close to the summer solstice, on the 10th of june at around 2pm summertime which equals 1pm real time. The sun is positioned slighty west of the highest point it can reach in Vienna.

9.2.2 Conclusion

As I expected the Horizontüberhöhung of all sites is quite high. This results in great differences of the radiation input during the course of the year as well as during a day. During the winter there is little direct sun, whereas in the summer at midday there is. In the morning and evening half of the place is

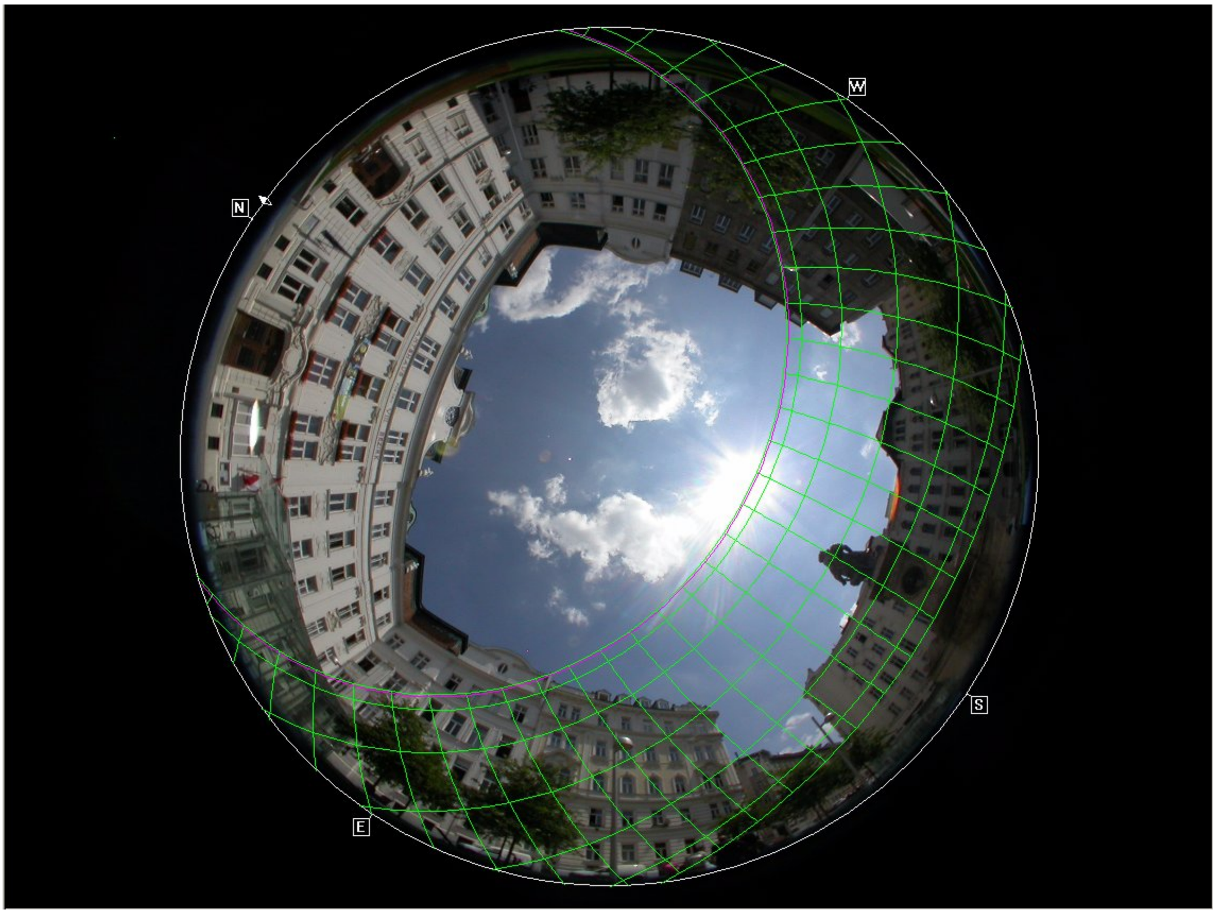


Figure 9.1: fish-eye photograph of Schlesingerplatz

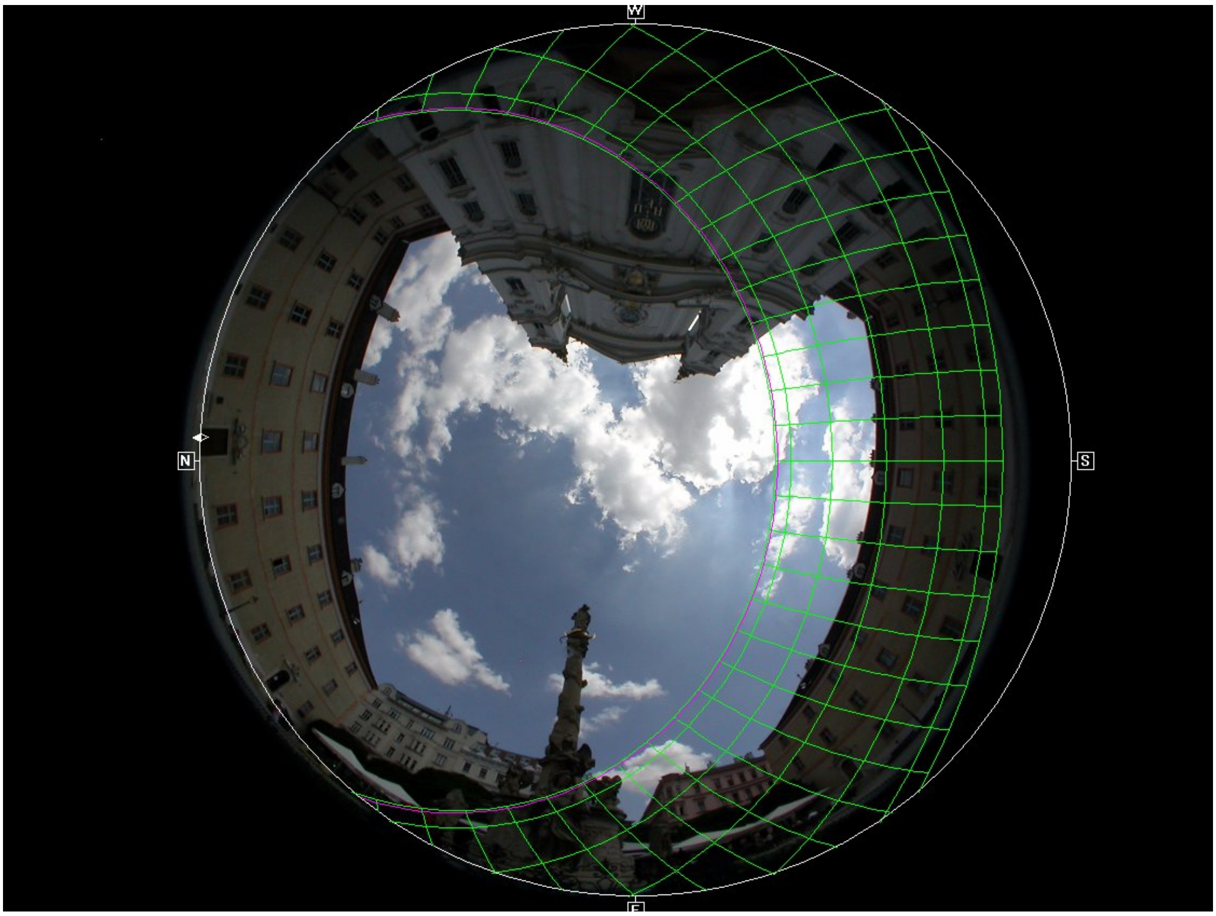


Figure 9.2: fish-eye photograph of Piaristenplatz

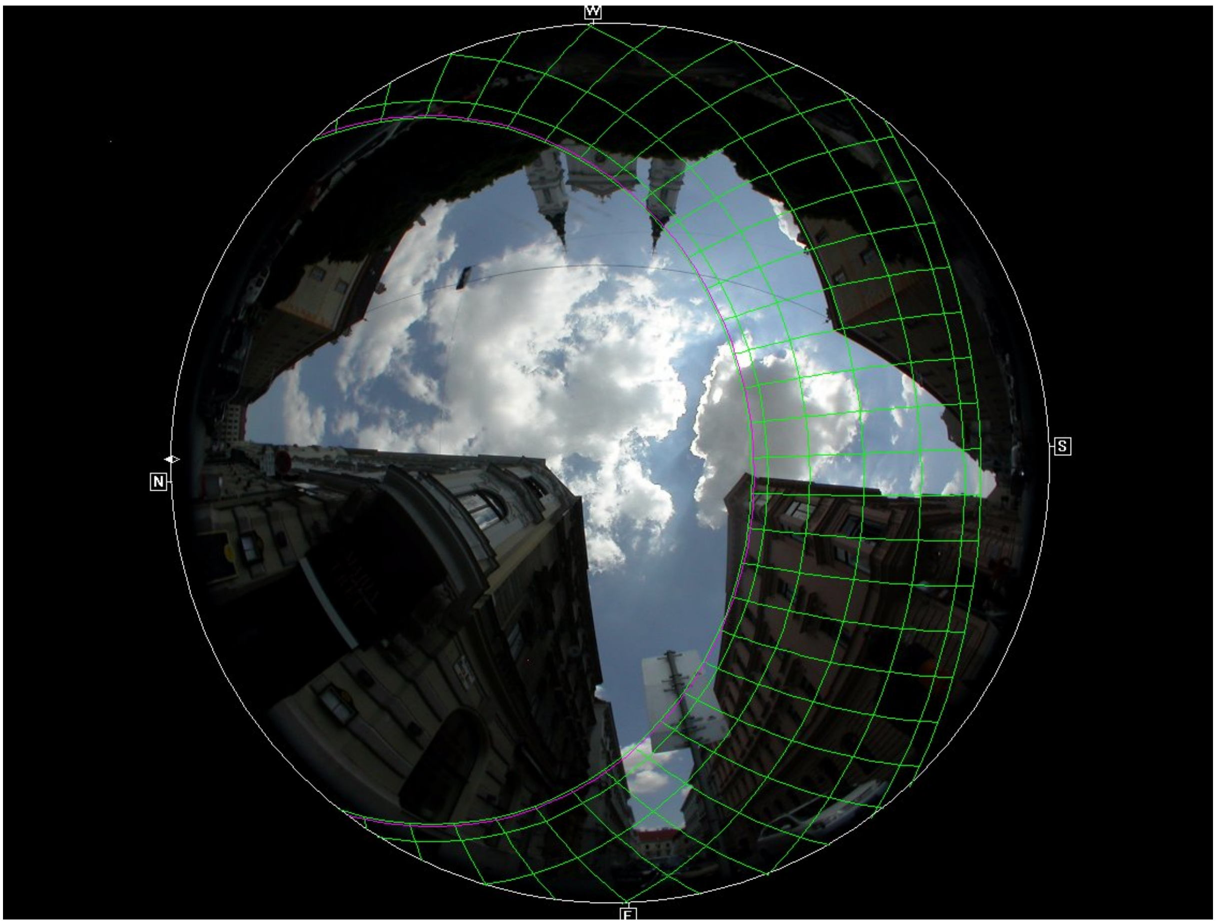


Figure 9.3: fish-eye photograph of the crossing Maria-Treugasse and Piaristengasse

shaded, only at midday is there full sun on the whole place. The streets do not show any effect to the incoming radiation of the squares. Schlesingerplatz gets sun longer in the year than Jodok-Finkplatz.

9.3 Infrared Analysis

9.3.1 Sensor Technology

For the infrared analysis a thermal camera (Troctec IC 80)is employed. The detector used is a microbolometer, a specific kind of bolometer.

Microbolometer

A bolometer is a device for measuring the energy of incident electromagnetic radiation. It consists of an "absorber" connected to a heat sink (area of constant temperature) through an insulating link. The result is that any radiation absorbed by the absorber raises its temperature above that of the heat sink the higher the energy absorbed, the higher the temperature will be. Temperature change can be measured directly or via an attached thermometer (composite design). While bolometers can be used to measure radiation energy of any frequency, for most wavelength ranges there are other methods of detection that are more sensitive. However, for sub-millimetre wavelengths (from around 200 m to 1 mm wavelength), the bolometer is the most sensitive detector for any measurement over more than a very narrow wavelength range.

Microbolometers respond to infrared radiation from a specific range of wavelengths (between 8-13 μm). The radiation strikes the detector material and thus, heating it, changing its electrical resistance. This resistance change is measured and processed into temperatures which can be used to create an image. Unlike other types of infrared detecting equipment, microbolometers do not require cooling. It is a grid of vanadium oxide or amorphous silicon heat sensors atop a corresponding grid of silicon.

Usability

This resistance change is measured and processed into temperatures which can be represented graphically. The microbolometer is commonly found in two sizes, a 320 x 240 array or less expensive 160 x 120 array. Both arrays provide the same resolution with the larger array providing a wider field of view. I used the latter version. It presents a easy and quick to use method to record the actual surface temperature. It works like a camera and it is possible to focus the picture. Therefore whole landscapes, single houses or trees, people or close objects can be photographed. The pictures are loaded on the computer, can be analysed with a special software and exported as a jpg file.

9.3.2 Difficulties

I expected the main difficulty to be finding an elevated place in order to get a picture of the whole site. This was actually not the problem, because the main differences can be clearly recorded even from pedestrian level, and with a certain insistence it is possible to get onto the third floor and get the best perspective for the 160 x 120 resolution of the camera. I quickly abandoned the idea to get a picture from straight above, with merely no perspective involved. It would be really difficult to create such a picture and it is not necessary for my purpose.

Figure 9.4: Northern part of Jodok-Finkplatz

9.3.3 The Places Analyzed

	refering to figure 9.5		
point	temperature	surface cover	sun/shade
Max	53.15	plastic bench	sun
P02	44.98	cobbed stone	sun
P03	39.08	cobbed stone	sun
P04	36.08	cobbed stone	sun
P05	25.76	cobbed stone	treeshade
P06	23.99	grill around treetrunk	treeshade

	refering to figure 9.7		
point	temperature	surface cover	sun/shade
P01	23.03	cobbed stone	shade
P02	37.67	cobbed stone	sun
P03	28.35	flowerbed	sun

	refering to figure 9.8		
point	temperature	surface cover	sun/shade
Max	51.15	concrete	sun
P02	44.33	concrete	shade
P03	41.9	cobbed stone	sun
P04	39.67	concrete wall	sun
P05	28.09	lawn	sun
P06	25.57	lawn	treeshade

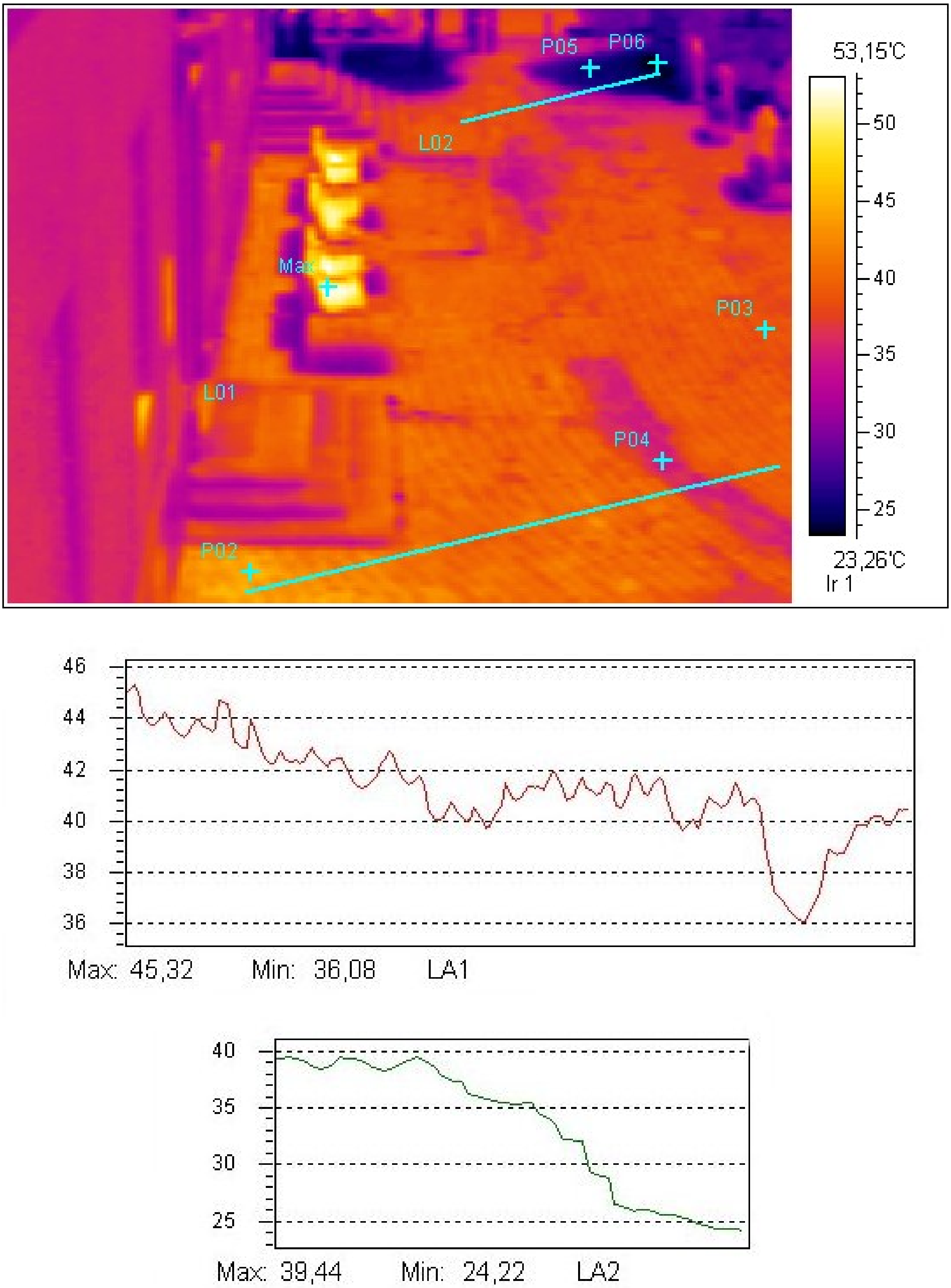


Figure 9.5: Northern part of Jodok-Finkplatz,IR

Figure 9.6: Southern part of Jodok-Finkplatz

9.3.4 Interpretation

The photographs show clearly facts that are already known but are difficult to be explained as precisely as with this method. I will also include with what I noticed while working with the thermal camera and cannot be seen on the photographs presented in this work.

- There is a large difference between surfaces exposed to the sun and shaded ones.
- When the sun leaves, the borders between sun and shade still stay visible in infrared for a couple of minutes. (Also the footprints of a person while walking away can be seen)
- The unsealed material is cooler than sealed material. The lawn is cooler than concrete or cobbed stone and the bare flower bed is cooler than cobbed stone.
- Cobbed stone is cooler than concrete.
- Reflective materials are difficult to analyse. An open window in the shade is cooler, a closed window warmer than the wall. In the sun glas either reflects the sky and appears much cooler than its sourroundings, or it reflects the direct sun and stands out as very hot spots - depending on the camera angle and the position of the sun.
- Wet spots or water lines can be seen on a hot day as cool marks on a warmer surface.
- Tree surfaces are not much cooler than building walls.

9.3.5 Comparison to Simulation

It is not possible to compare the absolute values of the simulation and the photographs, because of different meteorological sitation leading to them, but a qualitive comparison is possible.

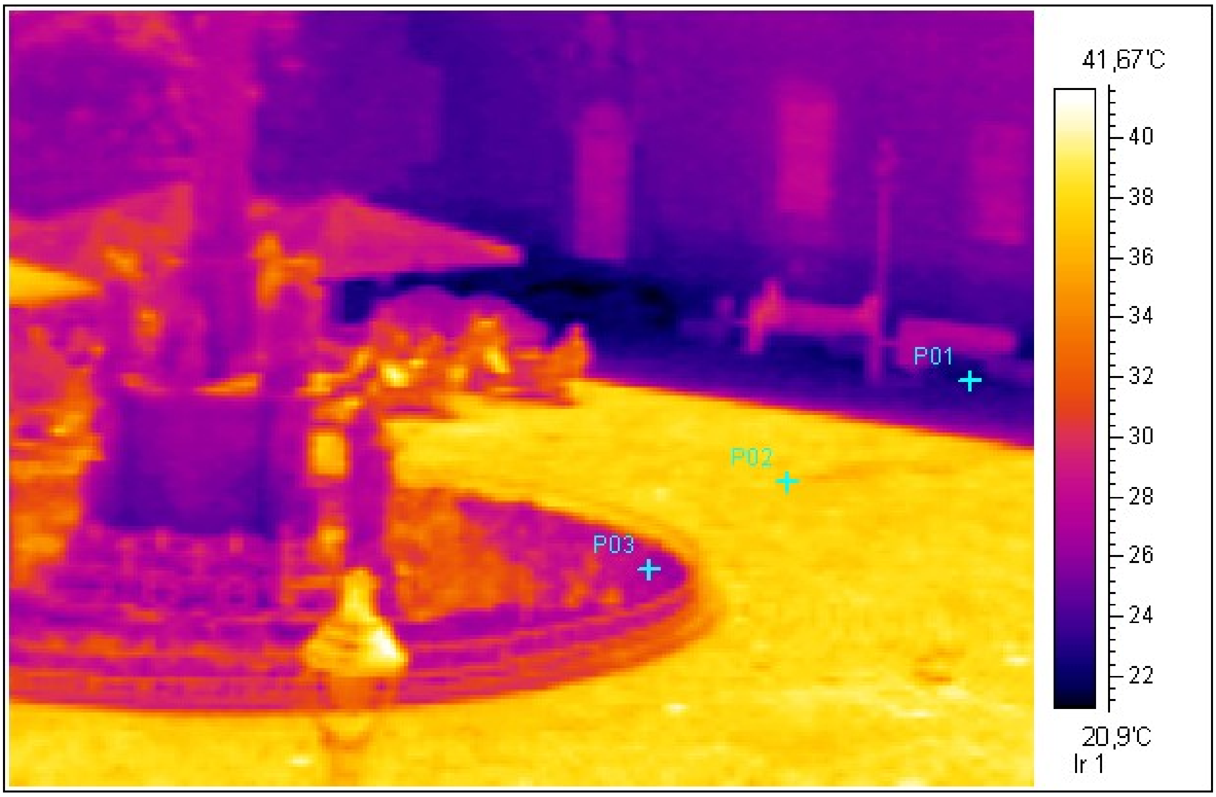


Figure 9.7: Southern part of Jodok-Finkplatz,IR

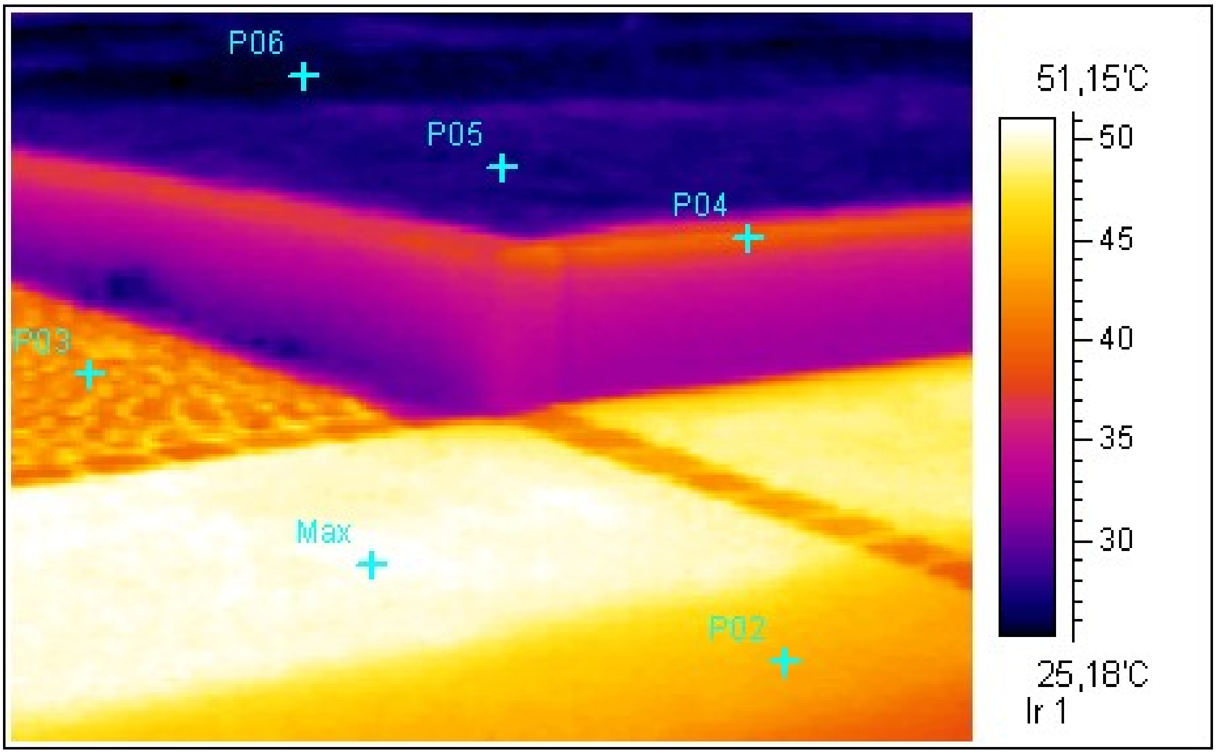


Figure 9.8: the temperature extremes on Schlesingerplatz

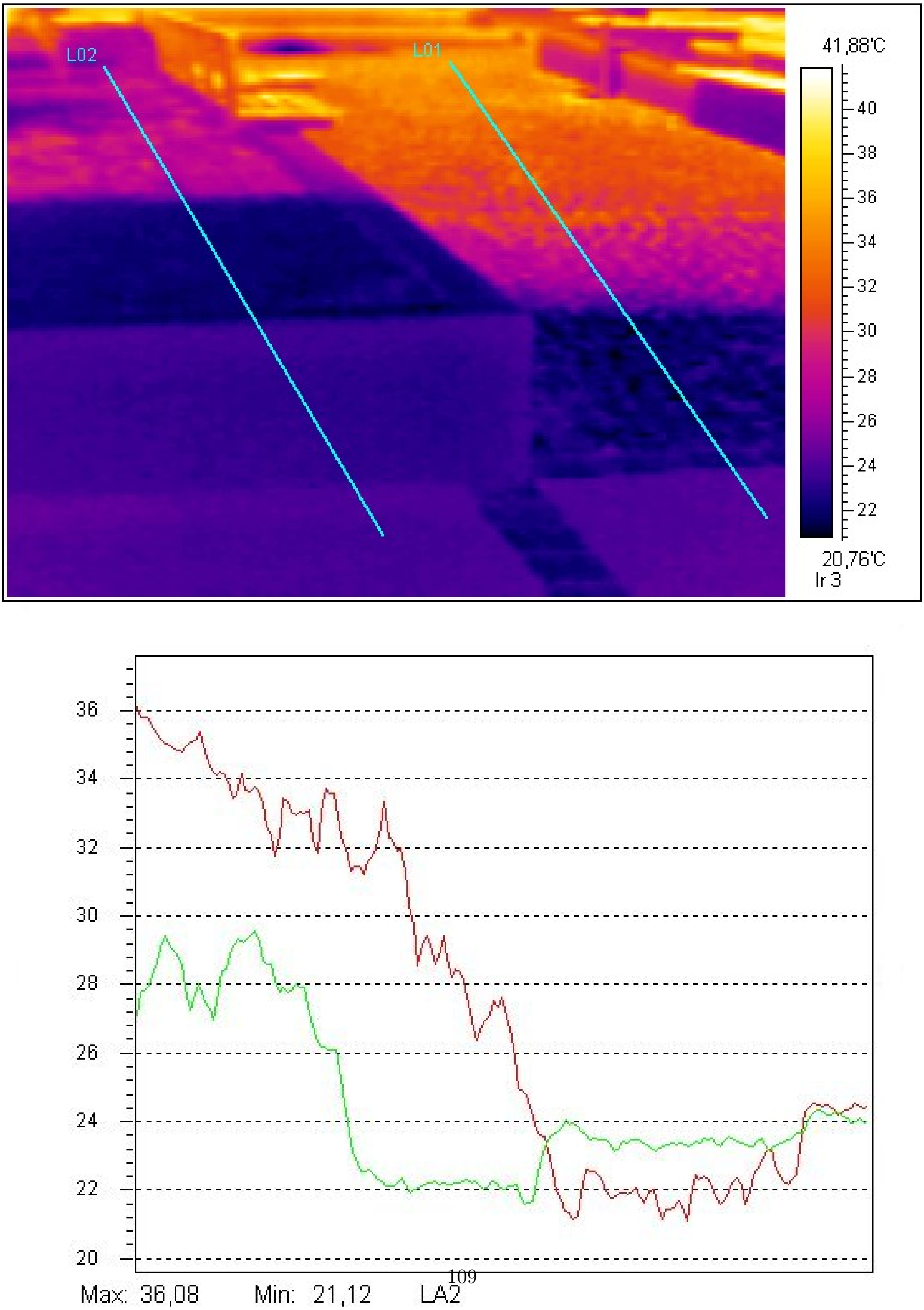


Figure 9.9: the transition from shaded concrete to lawn and cobbed stone

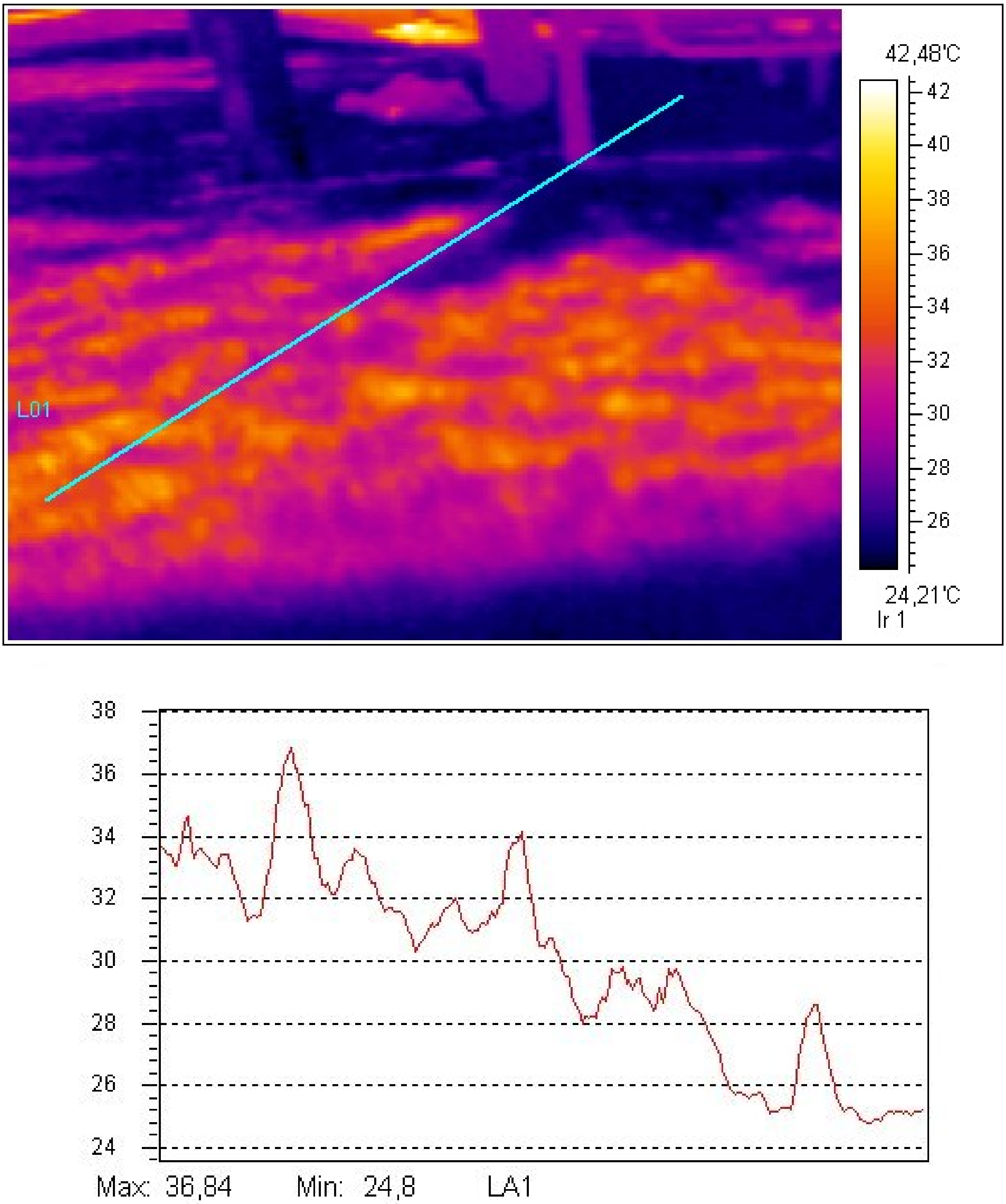


Figure 9.10: the shade of a tree on the lawn

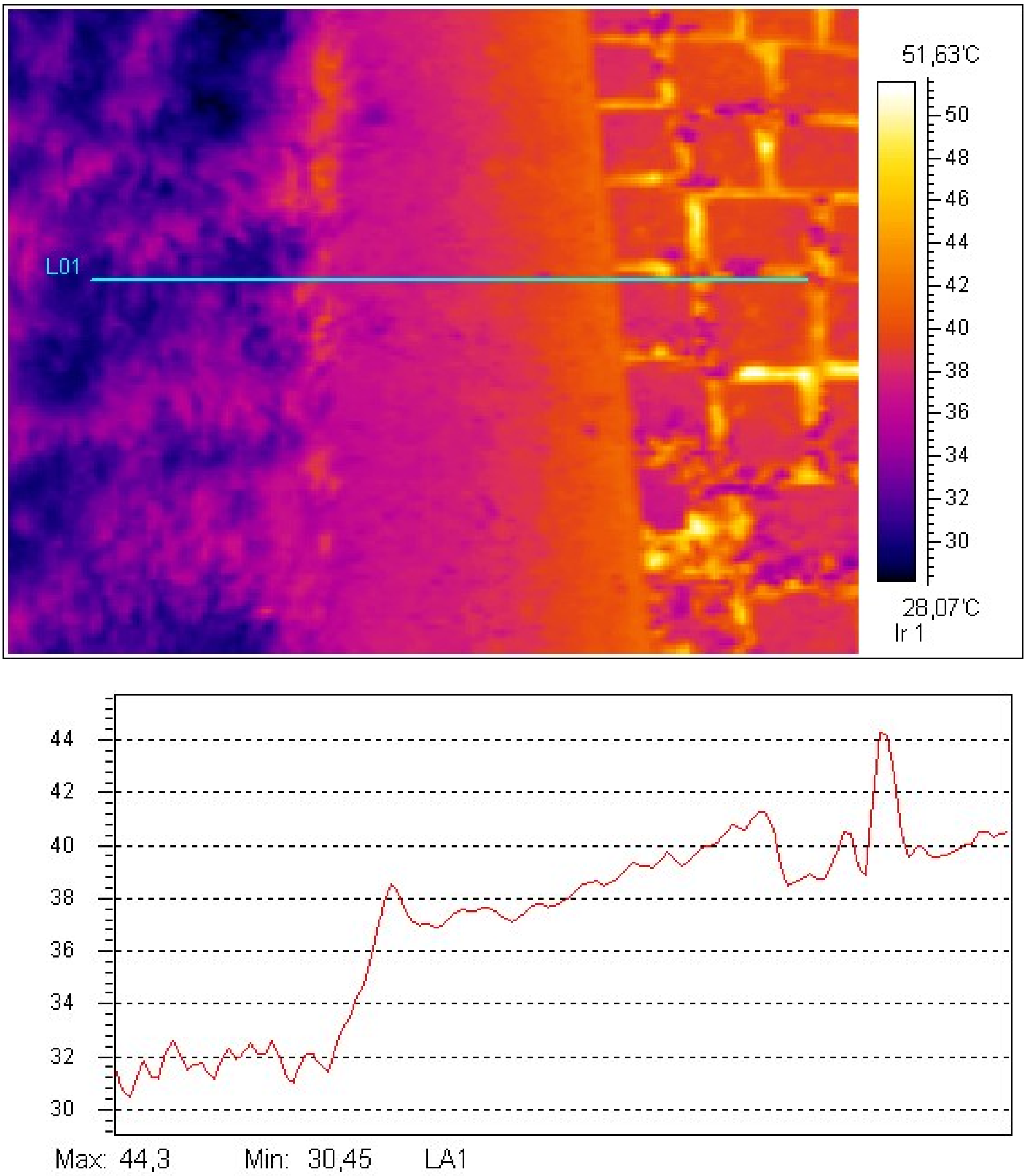


Figure 9.11: transition from cobbed stone to lawn

Like in the simulation the difference between sun and shade is clearly visible in the infrared photos. Also the different surface covers are clearly discernable.
In the case albedo = 20, 3pm, the sunlit lawn has a temperature of 24 $^\circ$C to 27 $^\circ$C and the sunlit sealed surfaces go up until 36 $^\circ$C. The infrared photographs of the 10th of june show a difference of 29.8 $^\circ$C on the lawn to 51.15 $^\circ$C on concrete.

9.4 Air Temperature

To measure the air temperature and humidity, wireless sensors have been placed on each location. On Schlesingerplatz there 3 sensors are placed (SchT2, SchT4, SchT7) and on Jodok-Finkplatz only one sensor logged the meteorological information (PiaT5), which was placed in the lower tree crown on the first tree counting from south. The position of the instruments is shown in the figure below (figure **??**). We had certain difficulties with the measurements which I will report later.

9.4.1 Sensor Technology

The sensors are soldered on a circuit board and transmit the measured data at 868,35Mhz to a central station, which logs the information. The system can cover 100m distance, the accuracy of the temperature sensor is 0.8 $^\circ$C with a resolution of 0.1 $^\circ$C. The temperature measurement is performed by thermistors.

Thermistor

A thermistor is a type of resistor with resistance varying according to its temperature. The word is a combination of thermal and resistor. Thermistors are widely used as inrush current limiters, temperature sensors, self-resetting overcurrent protectors, and self-regulating heating elements. Assuming, as a first-order approximation, that the relationship between resistance and temperature is linear, then:

$$\delta \mathrm{R} = \mathrm{k}\delta \mathrm{T}$$

(δR = change in resistance, δT = change in temperature, k = first-order temperature coefficient of resistance)

9.4.2 Difficulties

Finding a Position

First, it is really difficult to find representative places to fix a sensor stationary in public space. There are either no places where it is possible to fix it, or they are not accessible, a permission is needed and hard to get, or unexpected things (like the irrigation plant going on, a tree being cut,...) might happen that are difficult to foresee.

The People

Second, there is the risk of anyone taking, destroying or manipulating the sensor during the time of measurement. A restaurant keeper blamed the wireless system the sensor use to transmit the information to the receiver to be the cause the breakdown of his wireless payment system.

The Insects

Third, we had difficulties with the sensors itself. A whole tribe of earwigs kept trying to colonize the receiver case fixed on tree trunks. So I changed the receivers position to an anorganic road sign pole.

The Wind

It was impossible to find the exact same meteorological situation as in the simulation, and difficult to find a similar situation. Many input parameters are not known exactly and have to be guessed. They also might change in the course of the day. The temperature in 2000m height was set to 20 °C in the simulation.
The wind speed at 10m height could not be recorded in the city. I can only compare the wind speed and direction and the change of both parameters measured on Hohe Warte and Wien Innere Stadt to the data I collected in the eighth district, to identify their influence on the measured temperature.

The wind direction used in the simulation was 135 °, which is the most common winddirection on a sunny day in Vienna. During the period of the measurements the 10th of June shows these wind conditions from early morning until late evening. (see fig. 9.12)
The windspeed assumed in the simulation was 1m/s at 10m height. On the 10th of June the windspeed varied between 1m/s and 3m/s. (see fig.9.13) The windspeed at Hohe Warte is recorded at the height of 10m whereas the windspeed at Wien Innere Stadt is recorded on the top of a building at 52m height above ground, which is not representative for the windspeed within the city. Most buildings in the surroundings of Wien Innere Stadt are lower than 50m and the wind at street level ought to be less. Still the windspeed measured at Hohe Warte is higher than at Wien Innere Stadt. Both Hohe Warte and Wien Innere Stadt are permanent meteorological station maintained by the ZAMG.

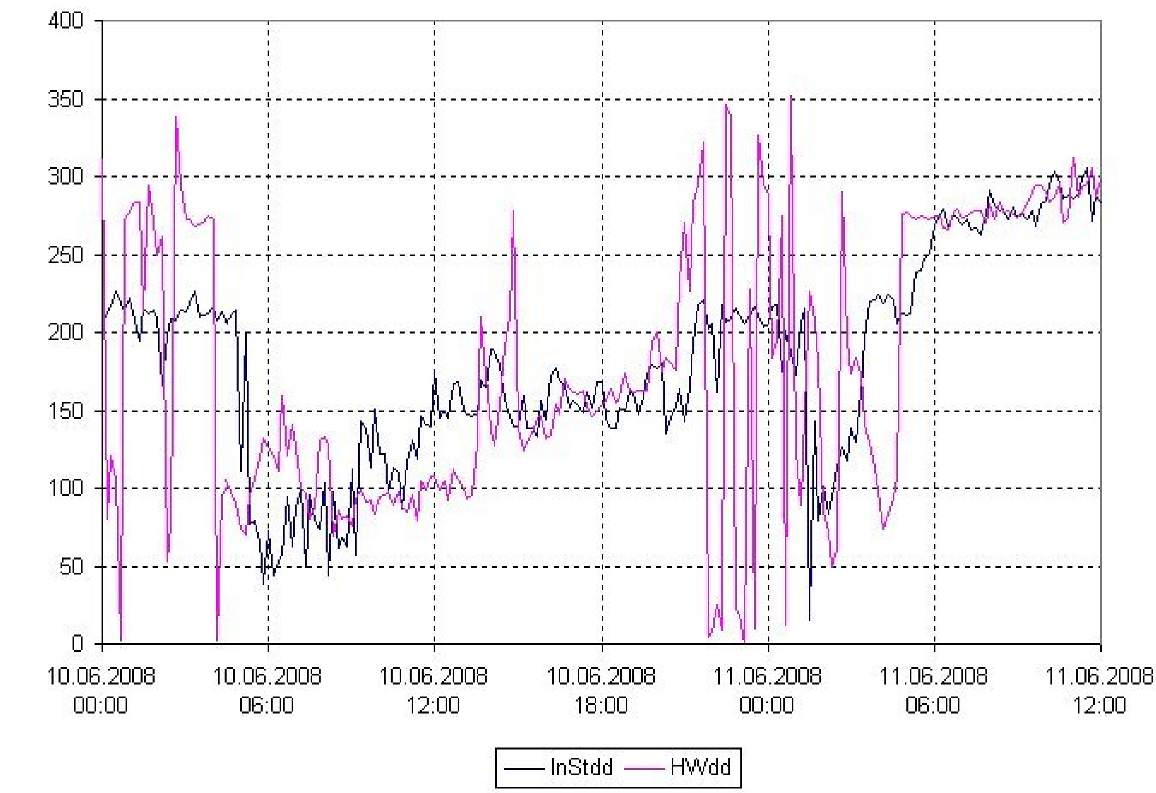


Figure 9.12: winddirection [deg]

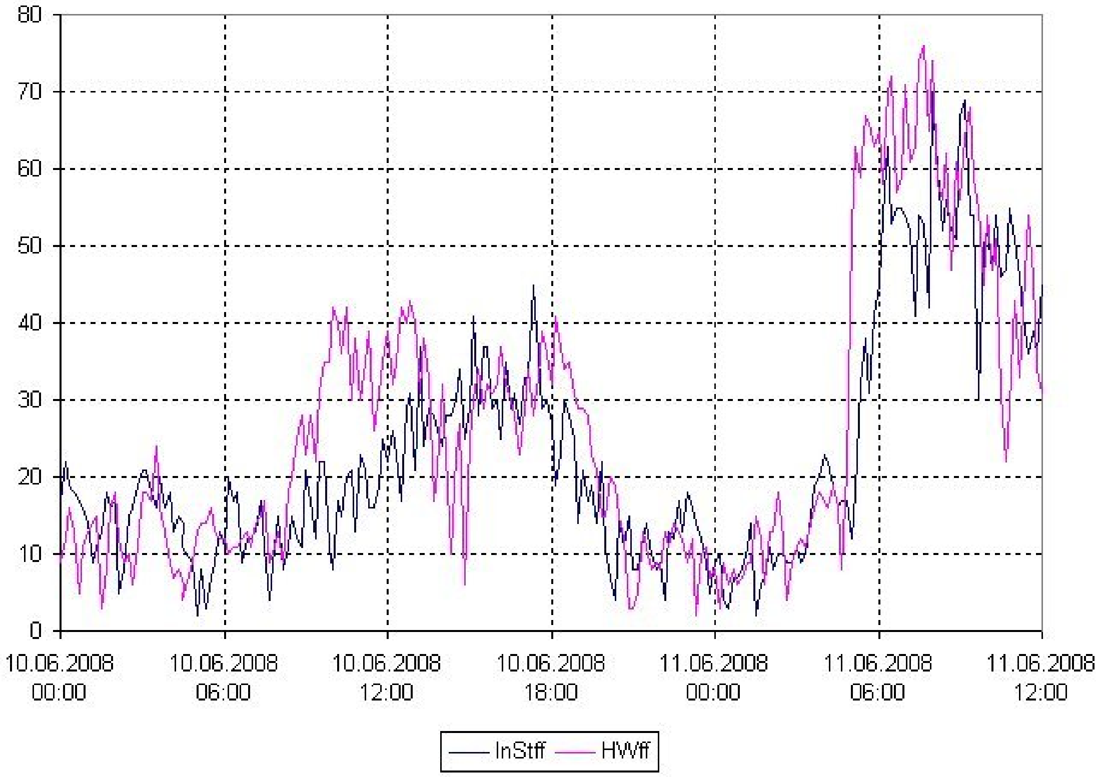


Figure 9.13: windspeed [1/10 m/s]

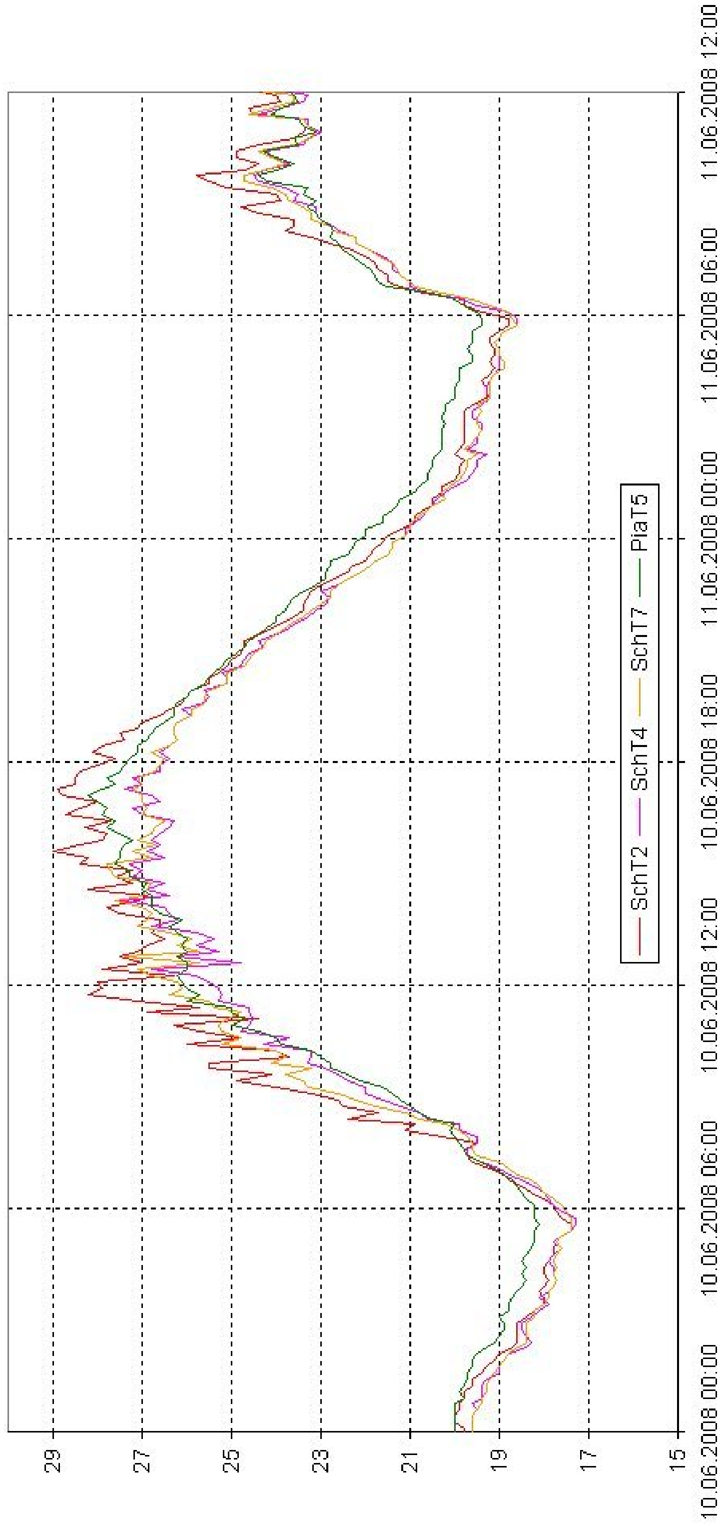


Figure 9.14: air temperatures [$^\circ$ C]in the 8th district

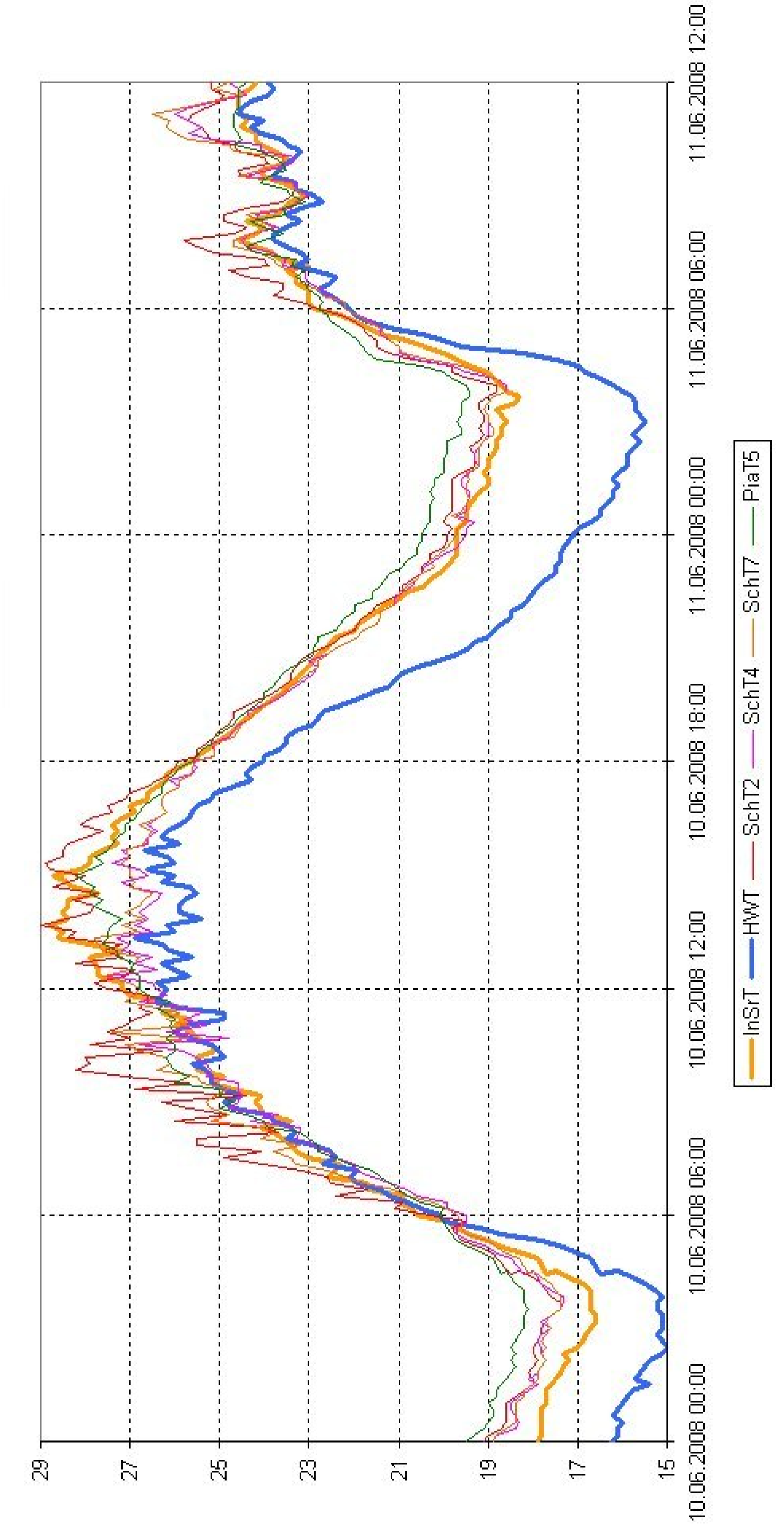


Figure 9.15: air temperature [$^\circ$C]compared to Hohe Warte and Wien Innere Stadt

0/360 $^\circ$	North
45 $^\circ$	Northeast
90 $^\circ$	East
135 $^\circ$	Southeast
180 $^\circ$	South
225 $^\circ$	Southwest
270 $^\circ$	West
315 $^\circ$	Northwest

short.	position	kind of meas.	a.ground.	surf. cover
HWT	Hohe Warte	climatological station	2m	lawn
InStT	Wien Innere Stadt	climatological station	10m	gravel
SchT2	Schlesingerplatz	sensor on traffic sign	2m	concrete
SchT4	Schlesingerplatz	sensor on treetrunk	0.4m	lawn
SchT7	Schlesingerplatz	sensor in treecrown	2m	lawn
PiaT5	Jodok-Finkplatz	sensor in treecrown	2m	cobbed stone

Figure 9.16: temperature and humidity sensor

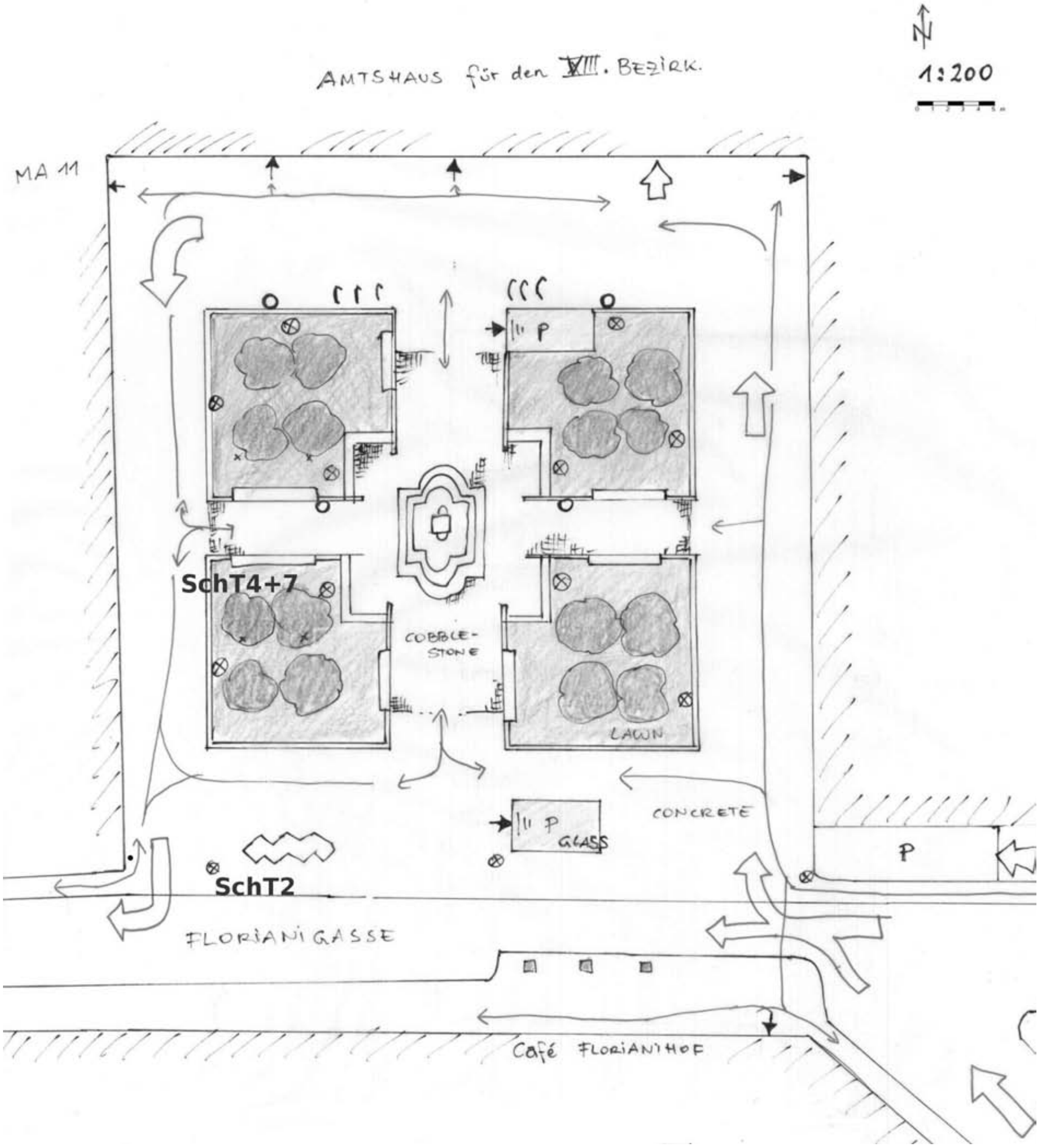


Figure 9.17: position of the sensors, plan view

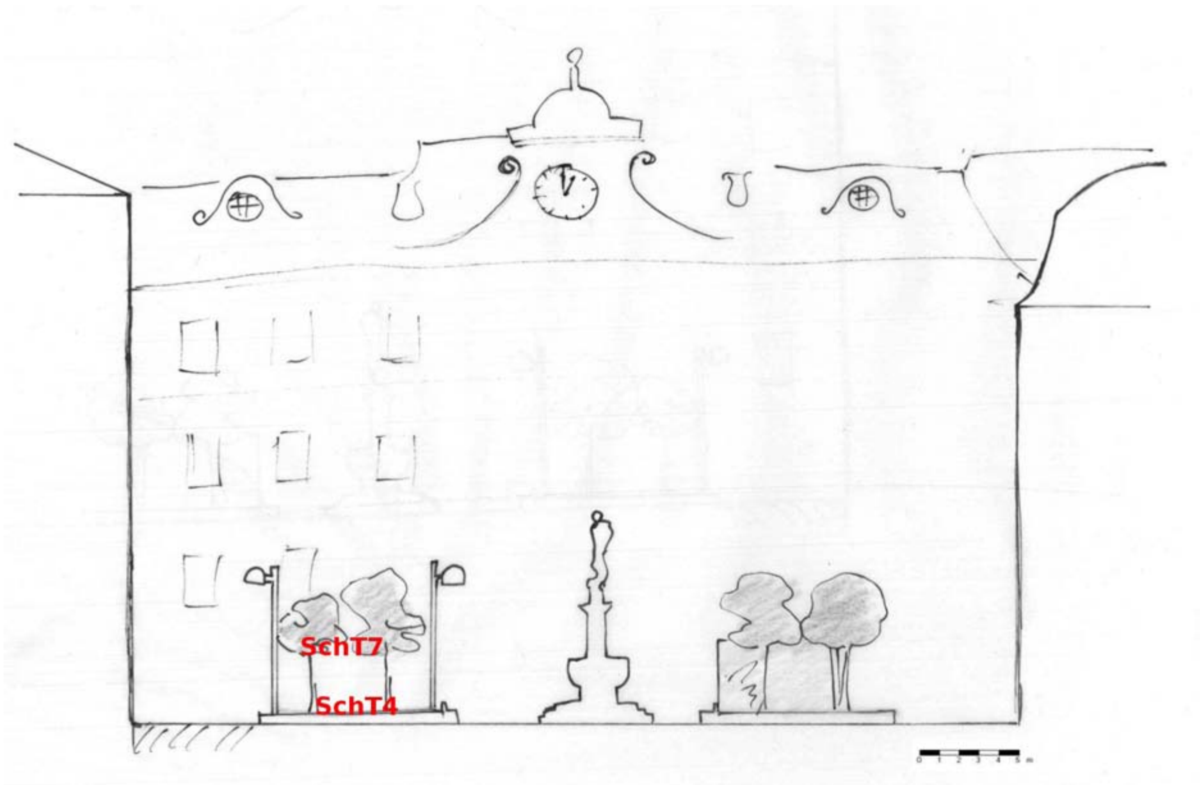


Figure 9.18: position of the sensors, profile

9.4.3 Interpretation of the measurements

When we look at the air temperature measurements (see figure 9.14 first we notice that the temperatures of the sensors have similar characteristics.

Sensors above lawn, Schlesingerplatz

Sensor SchT4 and SchT7 ran nearly simultaneously. The first one is fixed near the ground (see fig.9.16), the second one in the tree crown at about 2m. SchT7 lies higher in the morning hours, maybe because the sun has not reached the ground yet.
In addition there is not much difference between the temperature near the ground and in 2m in the simulation.

Sensor above the sidewalk, Schlesingerplatz

SchT2 is fixed on a traffic sign pole on the sidewalk infront of the square at 2m height. It heats up faster and higher than the latter two, probably due to the concrete surface.
This cannot be varified by the simulation and might be a radiative mistake due to insufficient ventilation of the sensor. The sensor was fixed close to the traffic sign, to avoid it being damaged, stolen or manipulated by third persons which might have had additional effects on the measurement. Maybe the simulation is wrong and the cooling effect of the lawn is strong enough to produce this temperature difference. The temperature measured at Wien Innere Stadt comes close to this sensor in the early afternoon.

Sensor in a tree crown, Piaristenplatz

Sensor PiaT5 was located on Piaristenplatz in a tree crown. There was a second sensor in the middle of the place, but no data was obtained from it. During evening and night time it stays above the temperatures measured at Schlesingerplatz, at midday it exceeds the SchT4 and SchT7. One reason might be the reduced ventilation due to the denser tree crown of the Acer campester which prevents the cooling down process at night and amplifies the heating up during midday.
Unfortunately I cannot compare the measurement at Piaristenplatz with a simulation. I think that the sensor is not representative of the air temperature of Piaristenplatz.

Conclusion

The results of the measurements show that it is really difficult to produce any representative data for a public space. There are many different processes which can influence measurements and sometimes cannot be avoided. Knowing the possible mistakes it is also possible to work with the data, but they should not be passed on without detailed explanations.

9.4.4 Comparison to other Stations

Wien Hohe Warte

Wien Hohe Warte lies in the North of Vienna, close to the Wienerwald in a quarter with low building density and gardens. The tempeature measurement itself is taken above lawn at 2m height.
The minimum temperatures measured at Hohe Warte are about 3 degrees below the temperatures measured in the city. During the morning the temperatures rise at about the same speed, but turn in at a lower level. They start to sink earlier than in the city.

Wien Innere Stadt

Wien Innere Stadt is measured in the dense city center, on the northern terrace on the 2nd floor.
The temperatures measured at Wien Innere Stadt resemble quite well the measurements made on the squares. At night the temperatures drop more and at midday they rise to the level of sensor SchT2. The night time effect might be caused by the missing shelter, the straight facade and higher windspeeds due to the position on the 2nd story. The daytime effect might be an effect of the surface material (gravel).

10 the Conclusions

10.1 Microclimatic Conclusion

10.1.1 Parameters influencing the Microclimate on Schlesingerplatz

Before starting simulation and measurements I noted parameters that influence the microclimate on Schlesingerplatz. Now I want to refer to them again regarding the simulation and measurement results.

Surface Temperature

Both measurements and simulation show that the radiation shelter effects by trees and buiding geometry, the amplification of radiation input by building albedo, heat storage in concrete, cobbed stone surface and building walls and cooling effects by evapotranspiration influence the surface temperatures.

Air Temperature

The air temperature is mainly influenced by radiation shelter effects by trees and buiding geometry as well as the amplification of radiation input by building albedo and wind shelter effects by trees and building geometry. The air temperature differences are smaller and not so clear as the differences in surface temperature.

10.1.2 Microclimatic Problems

The main problem I could identify is excessive heat in the summer. This problem will lessen within a couple of years by the growth of the trees. Unfortunately the soil cover is really thin (parking garage beneath) and the cherry trees are most likely a breed that does not get much bigger.

10.1.3 Possibility of microclimatic Redesign

One way to prevent the concrete from heating up is to replace it with surface material that does not have these properties (like unsealed surfaces), which is difficult due to the intense usage but possible. Nowadays landscape architects and planers know techniques to ensure a solid surface, where cars can drive and still enable rain water to drain away and evaporate from the surface as well.

Another possibility is to install shading devices like brise-solei, awings or more modern solutions.

10.2 Usability of ENVI-met

10.2.1 Possibilities

Compatibility

It is possible to load a bmp file into ENVI-met Eddi. All other formats cannot be read. The files used and produced by ENVI-met can all be read and edited as simple text files, which makes them easier to handle and transport. When the results of ENVI-met are displayed in the graphical program Leonardo there are only three ways to save the produced images. Either it is saved as the *.leo file format, which can only be read by Leonardo itself, it can be exported as *.bmp or an *.avi movie can be created with the maps. All in all the possibilities to import and export graphical and three-dimensional data is very limited. The numerical data can easily be copied. This makes ENVI-met a scientific tool and not a designer tool.
To architects and urban planners who usually work with very precise vector-based CAD-software the input of (still strongly) abstracted (non linear) numerical 3D-model may be unfamiliar at first. If direct (vector-oriented) exchange with such software was available (like i.e. Townscope III) a desirable and more direct feedback of planning modifications could be realized. An auxiliary program, which converts vector-based data like dxf (Data Exchange Format) into the three-dimensional numerical model required by ENVI-met could be a future solution to that. [Spengenberg(2004)]

Resolution

The resolution of the model can be chosen between 1 and 10m. The vertical resolution can be increased a lot by using the telescoping function. This offers a lot of possibilities, because a small place with 10m x 10m can be calculated as well as a large part of a district with 2000x2000m. Also huge buildings can be fit into the model. The user has to make the input file very carefully, because complex geometries of buildings can cause flow errors.

Values

The results have to be regarded relatively not absolutely. In the simulation I calculated a temperature of 36°C on sealed surfaces, whereas with the infrared camera I could measure 51°C in a similar meteorological situation, but increased air temperature and radiation. In both cases the sealed area was considerable (from 9°C up to 20°C) warmer. The potential influence on an public space can be estimated.

Self - defined elements

Plants and soil profiles can be defined by the user. This is a very useful feature of the program. All different kinds of vegetation and soil profiles can easily be imported into the model. The different parameters that can be defined in the *.dat files are explained in detail in the documentation. It is possible to quickly change the size of a plant, or the depth of a soil and when a user is better aquainted with the topic they can also make more professional adjustments.

Definition of the buildings

Albedo and heat transmission of the roofs and walls can be defined, as well as the inner temperature of the buildings. It is not possible to define these values separatly for each building, so different types of building methods cannot be simulated with the same configuration file.
By defining the albedo and the heat transmission new facade materials can be assumed. Still ENVI-met cannot cope with the reflective characteristics of glass facades, which are becoming more and more

popular and I cannot imagine modern cities without them. In the ENVI-met bulletin board I got the recommendation to use a high albedo in the buildings-section to simulate glass facades. The surface temperature will not be very accurate (but this is the case anyway), but at least you take the high reflectivity into account. But glass is very tricky because of the direct reflection (opposed to the diffuse reflection you get on 'normal' walls) which is not taken into account by ENVI-met.
In addition facades of natural materials like wood, shingles, bamboo and clay have qualities that cannot be described with albedo and heat transmission alone. The facade-model in ENVI-met 3.1 is a very simple model that doesn't even take the heat capacity into account. This will change with the facade model that will be introduced in ENVI-met 4.0.
Apart from their albeo and heat transmissivity organic matter and clay also absorb humidity and set it free during draught. Especially clay acts like something between a brick wall and an unsealed soil. And wood does so a little bit as well. Bamboo lets pass air flow to a certain level. But at the moment the ENVI-met developers do not plan to simulate the humidity of walls. Its influence on the heat capacity and transmission of the walls, as well as on the humidity of the surrounding air are probably well below the accurancy of the model.
However, I think all these materials are important when it comes to microclimatic topics. From my own experience I know that it does makes a difference what kind of material a wall is build from, even when it cannot be measured. Here the wisdom of mathematics and physics expires and the human being as an integral of infinite physical and social influences comes in.

Constructive Difficulties

I had great difficulties to define complex architecture and tilted roof. I ended up converting tilted roofs into flat roofs in order to be able to simulate Schlesingerplatz. In the case of Jodok-Finkplatz I failed completely, even after simplifying the geometry dramatically.
Uneven terrain and round buildings cannot be defined. This constricts the fields applications a lot. Especially most old settlements where built into the slope, to appreciate various meso and microclimatic advantages. The water and cold air can run off easily, and there is less danger of frost at night. There are many other economical, practical and social reasons. On a slope the dwellers are better protected against floods and have an better overview to detect arriving armies, dangers or friends. ENVI-met is a model that works best on modern flat roofed simple architecture on a plain field, with no complexity around it. Many of the architectual archievements of mankind to adapt to various climates can still not be represented in the model.
But ENVI-met is still young and the quick releases of new versions and the lively bulletin board (www.ENVI-met.de/phpbb/index.php) promises fast advances.

Constructive Possibilities

Overhanging roofs, galleries, roof and facade greenings can be defined, which is a nice feature, which does not make up for all the difficulties and problems, but opens up the planners' mind for new ways of architecture. It is easier to define a green roof with default 50cm grass than to make a lawn with 10cm grass. Nonetheless it is not possible to define a soil on the roof, so one of the most important features of a green roof, the delay of water run off and storage of rain water, is not included in the model. Also the greening of the facade is just a simple trick, and assumes that the climbing plant covers one grid point which is at least 1m, which is not common for climbing plants. In reality a facade greening which is only a little bit looked after is hardly ever more than 20cm thick and probably has a very specific adaption to the fact that it is growing vertically and gets sunlight only from one side, while the other side is where it is climbing on. One kind of adaption is the tilting of leaves towards the bright side.

Rivers

It is possible to define water that is so deep that light cannot reach its bottom. Shallow and especially running water cannot be defined. A river might be defined as 'unsealed soil' to simulate the slightly increased evaporative cooling above the river. [Spengenberg(2004)]

10.2.2 Essential Previous Knowledge

Each problem asks for different methods. Therefore I added some general considerations how to cope with microclimate as a landscape planner in the end. When I break down the whole microclimatic problem to the point where ENVI-met gets interesting there are some specific points to take into consideration.

1. basic urban climatological knowledge
2. personal visit of the site
3. if there is a planning process involved, a free space analysis is necessary
4. reading of the complete documentation (LBC, nesting areas,...)

In order to use ENVI-met it is crucial to have a basic climatological know how, to be able to estimate what problems may arise on a site, and focus the simulation on these topics.

Before a simulation is started, it is important to visit the site personally. Especially if the simulated area exists in the real world this can - together with the climatological understanding - simplify the simulation procedure and improve the results.

Apart from understanding the climatological features of a place, when a planning process is involved, is must not be ignored that the main reason for a free space is its usage by people. There is a huge difference between designing a parking on the outskirts of a minor city, a park in a densly populated district or a shopping street. Each free space has different demands concerning the microclimate. Therefore a free space analysis is needed, to detect the microclimatic problems and needs of a site depending on its functions and usage.

Finally, it is necessary to read the complete documentation, to have an overview of the possibilites of the model. Each problem ask for a different configuration and I couldn't cover all optional configuration in this work, although they can have a great impact on the quality of a simulation.

10.2.3 Sources of Error

Plants.dat Soils.dat Profils.dat

I think Landscape planners are able to create a valid and precise area.in file. Due to their botanic expertise and knowledge of soils they can also cope well with the plants.dat, soils.dat and profils.dat. Still they have to be very careful using the right trees. In particular the height and the LAD of the trees should be correct. The definition of the right soil and right albedo on the surface is very important. Deeper soil layers are of minor importance and the soil layers below 0.45 m are of no importance for one-day simulations.

Definition of Buildings

The heat transmission and especially the albedo of wall and roofs are important factors that cannoticably change the results produced by the model. A high albedo increases the radiation near the surface. For modern buildings it is easy to find out these values. Regarding houses, which have been built before laws about energy efficency and isolation have been made - which account for at least 70% of Cental Europa, it is difficult to get information. It is necessary to either guess these values or measure them, which causes additional effort. Still one has to be careful, because the wall as well as the roof albedo changes due to wheathering dramatically. I want to remind of the documentated albedo of off-white painted walls with 0.56 and the albedo of weathered off-white painted walls with 0.07 documented by Spengenberg.

Meteorological Input

The meteorologic parameters are not trivial and ask for a good understanding of local climates. It is important to choose the right wind speed, the right wind direction, air and soil temperature as well as a realistic humidity. These values should be chosen together with an meteorologist, or another person acquainted with meteorological data.

Interpretation of the Data

Without the practice of interpreting meteorologic data it is easy to misinterpret the solutions. It is necessary to understand the meteorologic and climatic processes in microscalic structures.

1. The wind direction and speed can alter the solutions significantly.
2. The model runs with no cloud cover or a certain cloud cover, which does not change during the simulation. This has to be taken into account, because especially when it gets overcast or when the sky opens up, the radiative balance changes completely.
3. Regional or local circulation systems like katabatic wind and sea breeze, the effects of the urban heat island, inversions and the effects of cold air gathering in troughs are not taken into account but affect the real meteorologic situation significantly.

10.3 Consideration of Microclimate and ENVI-met in Design

It is a great tool to simulate future projects before they are built, to estimate possible sources of error. To handle it, it needs meteorologic know how. The best way would be to have a cooperation between planners and scientist.

It is often not possible to have meteorological cooperation or advice. Therefore I want to pass an advice to all landscape planners and architects: 'Always keep your goal in mind. There is an incredible amount of climate and microclimate information available, much more than you can ever deal with. Only some if it will be of interest to you. Disregard all other information'[Brown and Gillespie(1995)]
Finally ENVI-met will always remain a meteorological tool and cannot replace planners. For a planning process many other aspects are of importance that are possibly more mightier than the microclimate, therefore I will close this work with a methodology, how to approach microclimate in landcape design. The methology was formulated by Robert D.Brown and Terry J. Gillespie[Brown and Gillespie(1995)] and I added some of my thoughts. Important steps are described, in which ENVI-met might come in as a testing tool in the end. Many other steps are crucial to do before even touching the model.

Key Steps in Thinking about Microclimate

1. Decide on microclimatic goals
2. Set clear, achievable objectives
3. Determine the amount of time and money available
4. Determine the activities, times of day and seasons on the year that you will be designing for
5. Reevaluate your goal and objectives based on the information gleaned through steps 3 and 4
6. Decide on an approach to microclimatic design (intuitive or rational; using the intuitive aproach, when there is little time, a small budget and no real obvious microclimatic problems)
7. Conduct an inventory of the microclimate, including both appropiate climate data (general and typical daily conditions; hourly air temperatures, amounts of radiation and radiation level, wind speed and direction, rel. humidity and how often you might expect each type of day to occur in any given year) and relevant site information (inclination - slope, exposition - aspect, vegetation cover,...)
8. Analyze the data through mapping and determination of inherent characteristics of the microclimate. (Because microclimate has tremendous variability through space and over time, there is no way to map it per se. Instead, map the site characteristics that modify the climate to create microclimates)
9. Superimpose proposed interventions (Producing a suitability map for every goal you have set)
10. Using microclimate modification tools (adding/taking away shading, wind shelter, evapotranspiration,...) to enhance positive microclimates and improve negative ones. First evaluate the situation and identify the problem. There is no right answer, and not even any real prototypes. There are only creative solutions and many times tradeoffs that resolve or partly resolve a problem and create the best situation possible.
11. Testing design proposal before constructions so that any potential microclimatic problems can be identified in the laboratory rather than in the finished product.(Here ENVI-met and other simulation software, wind tunnels, water fumes, design models under an artificial sky,... come in)'We can make our mistakes in the lab rather than in the real world.'

11 Annex

11.1 Updated overview over ENVI-met 3.0

Bruse, M. (2004): Updated overview over ENVI-met 3.0

ENVI-met 3.0:
Updated Model Overview

March 2004

Michael Bruse

1. INTRODUCTION

This document describes the microscale model ENVI-met Version 3.0 (Bruse, 1999; Bruse and Fleer, 1998). It replaces older versions of the same name and should be used in combination with other papers available on the website www.envi-met.com describing several aspects more in detail. In particular, it is an update of the article published in *Environmental Modelling and Software* and should be used instead.

2 THE ATMOSPHERIC MODEL

This section describes the main prognostic variables in the atmospheric model. These variables are the main wind flow, temperature, humidity and turbulence:

2.1 Mean Air Flow

The three-dimensional turbulent air flow in the model is given by the non-hydrostatic incompressible Navier-Stokes equations (1-a) - (1-c):

$$\frac{\partial u}{\partial t} + u_i \frac{\partial u}{\partial x_i} = -\frac{\partial p}{\partial x} + K_m \left(\frac{\partial^2 u}{\partial x_i^2} \right) + f(v - v_g) - S_u \tag{1 a}$$

$$\frac{\partial v}{\partial t} + u_i \frac{\partial v}{\partial x_i} = -\frac{\partial p}{\partial y} + K_m \left(\frac{\partial^2 v}{\partial x_i^2} \right) - f(u - u_g) - S_v \tag{1 b}$$

$$\frac{\partial w}{\partial t} + u_i \frac{\partial w}{\partial x_i} = -\frac{\partial p}{\partial z} + K_m \left(\frac{\partial^2 w}{\partial x_i^2} \right) + g \frac{\theta(z)}{\theta_{ref}(z)} - S_w \tag{1 c}$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{2}$$

where f ($=10^4$ sec^{-1}) is the Coriolis parameter, p is the local pressure perturbation and θ the potential temperature at level z. The reference temperature θ_{ref} represents the larger scale meteorological conditions and is calculated as an average temperature over all grid cells of height z, excluding those occupied by buildings.

The air density ρ was removed from the original compressible Navier-Stokes equations using the *Boussinesq-Approximation,* which leads to one additional source term in the w-equation to include thermal forced vertical motion and one continuity (filter) equation (2) which has to be satisfied for each time step in order to keep the flow field mass conserving. (Note that all three-dimensional advection and diffusion terms are written in Einstein summation (u_i=u,v,w; x_i=x,y,z for i=1,2,3 to save place)

The local source/sink terms S_u, S_v and S_w describe the loss of wind speed due to drag forces occurring at vegetation elements. Following Liu (1996) and Yamada (1982) this effect can be parameterized as

$$S_{u(i)} = \frac{\overline{\partial p'}}{\partial x_i} = c_{d,f} LAD(z) \cdot W \cdot u_i \qquad (3)$$

where $W=(u^2+v^2+w^2)^{0.5}$ is the mean wind speed at height z, LAD(z) is the leaf area density in $[m^2m^{-3}]$ of the plant in this height. The mechanical drag coefficient at plant elements $c_{d,f}$ is is set to 0.2.

Boundary conditions: A *no-slip* condition is used for all solid surfaces. The inflow profile is obtained from the one-dimensional reference model and a zero-gradient Neumann condition is used at the outflow and lateral boundaries. At the top boundary all vertical motions are assumed to be zero. Special boundary conditions are used for the pressure perturbation on all outflow boundaries to keep the model mass conserving.

2.2 Temperature and Humidity

The distribution of the air temperature θ and specific humidity q is given by the combined advection-diffusion equation with internal source/sinks :

$$\frac{\partial \theta}{\partial t} + u_i \frac{\partial \theta}{\partial x_i} = K_h \left(\frac{\partial^2 \theta}{\partial x_i^2} \right) + \frac{1}{c_p \rho} \frac{\partial R_{n,lw}}{\partial z} + Q_h \qquad (4)$$

$$\frac{\partial q}{\partial t} + u_i \frac{\partial q}{\partial x_i} = K_q \left(\frac{\partial^2 q}{\partial x_i^2} \right) + Q_q \qquad (5)$$

Similar to the momentum equations, Q_h and Q_q are used to link heat and vapour exchange at plants with the atmospheric model. The quantity of Q_h and Q_q is provided by the vegetation model described later on. $\partial R_{n,lw} / \partial z$ is the vertical divergence of longwave radiation taking into account the cooling and heating effect of radiative fluxes.

Boundary conditions: The surface temperature of the ground surfaces, of roofs and of walls are used as real physical boundaries. For the inflow profile, Dirichlet, Neuman or cyclic boundary conditions can be selected. At the outflow and lateral boundaries a zero-gradient condition is used. The values for the top of the three dimensional model are obtained from the one dimensional boundary layer model, which extends up to 2500 m.

2.3 Atmospheric turbulence

Turbulence is produced when the air flow is sheared at building walls or vegetation elements. Under windy conditions, the magnitude of local turbulence production normally surpasses its dissipation, so that turbulent eddies are transported by the mean air flow. Depending on the structure of the flow, this leads to an increased turbulence away from the original source of disturbance.
To simulate this effect, a so-called 1.5 order turbulence closure model is used in ENVI-met. Based on the work of Mellor and Yamada (1975) two additional prognostic variables, the local turbulence (E) and its dissipation rate (ε) are added to the model. Their distribution is given by the prognostic equation set:

$$\frac{\partial E}{\partial t} + u_i \frac{\partial E}{\partial x_i} = K_E \left(\frac{\partial^2 E}{\partial x_i^{\,2}} \right) + Pr - Th + Q_E - \varepsilon$$
$$\frac{\partial \varepsilon}{\partial t} + u_i \frac{\partial \varepsilon}{\partial x_i} = K_\varepsilon \left(\frac{\partial^2 \varepsilon}{\partial x_i^{\,2}} \right) + c_1 \frac{\varepsilon}{E} Pr - c_3 \frac{\varepsilon}{E} Th - c_2 \frac{\varepsilon^2}{E} + Q_\varepsilon \qquad (6,7)$$

The terms Pr and Th describe the production and dissipation of turbulent energy due to wind shear and thermal stratification, Q_e and Q_ε are the local source terms for turbulence production and dissipation at vegetation.
The mechanical production Pr is parameterized using the three-dimensional deformation tensor of the local wind field:

$$Pr = K_m \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \frac{\partial u_i}{\partial x_j} \qquad \text{with i,j=1,2,3} \qquad (8)$$

The buoyancy production Th is given by

$$Th = \frac{g}{\theta_{ref}(z)} K_h \frac{\partial \theta}{\partial z} \qquad (9)$$

To calibrate the ε-equation, standard values c_1=1.44 c_2=1.92 and c_3=1.44 given by Launder and Spalding (1974) have been used. It has to be noted, that the application of the 1.5 order closure model to the atmospheric boundary layer is has certain uncertainties. Depending on the specific situation, different calibration values might be used and the production of turbulent energy normally needs to be restricted in the higher layers of the atmosphere.

Following Liu *et al.* (1996) and Wilson (1988), two extra source terms are added to the E-ε System to consider the additional turbulence produced at vegetation as well as the turbulence destruction due to the cascade from larger shear-induced eddies to smaller and waker eddies:

$$Q_E = c_{d,f} LAD(z) \cdot W^3 - 4c_{d,f} LAD(z) \cdot |W| \cdot E \qquad (10)$$
$$Q_\varepsilon = 1.5c_{d,f} LAD(z) \cdot W^3 - 6c_{d,f} LAD(z) \cdot |W| \cdot \varepsilon \qquad (11)$$

where W is the mean wind speed like in (3). The source term for the dissipation equation (11) is based on the Kolmogorov relation (Launder and Spalding, 1974) and should be adjusted by measured data if available (see e.g. Liu *et al.*, 1996).
From the calculated E-ε field the turbulent exchange coefficients are calculated assuming local turbulence isotrophy using the relationships

$$K_m = c_\mu \frac{E^2}{\varepsilon}; K_H, K_q = 1.35 \cdot K_m; K_E = \frac{K_m}{\sigma_E}; K_\varepsilon = \frac{K_m}{\sigma_\varepsilon} \qquad (12\text{ a-d})$$

with c_μ=0.09, σ_E=1 and σ_ε=1.3.

Boundary conditions: At all solid surfaces E and ε are calculated as a function of local tangential friction velocity u_* calculated using the flow components tangential to the concerned surface:

$$E(z=0), E_w = \frac{\left(u_*^2\right)^{tan}}{\sqrt{c_\mu}}, \qquad \varepsilon(z=0), \varepsilon_w = \frac{\left(u_*^3\right)^{tan}}{\kappa \cdot z_0}$$

with k: von-Kármán constant (=0.4) and z_0: microscale roughness length of the surface.

2.4 Radiative Fluxes

As a boundary condition, the incoming shortwave and longwave fluxes are needed at the model top. Those are provided using a two-stream radiative flux approximation for the longwave fluxes and a set of empirical equations for the shortwave wavelength spectra (Taesler and Anderson 1984; Gross 1991).

Inside the three-dimensional model, the radiative fluxes are modified by plants and buildings. To estimate their effect on the radiative conditions, the concept of flux reduction coefficients ($\sigma_{...}$) ranging from 1 for undisturbed fluxes to 0 for a total absorption is used (Bruse 1995).
In total, five different reduction coefficients are defined:

$$
\begin{aligned}
&\text{(I)} \quad \sigma_{sw,dir}(z) = \exp\left(-F \cdot LAI^{*}(z)\right) \\
&\text{(II)} \quad \sigma_{sw,dif}(z) = \exp\left(-F \cdot LAI(z, z_p)\right) \\
&\text{(III)} \quad \sigma_{lw}^{\downarrow}(z) = \exp\left(-F \cdot LAI(z, z_p)\right) \\
&\text{(IV)} \quad \sigma_{lw}^{\uparrow}(z) = \exp\left(-F \cdot LAI(0, z)\right) \\
&\text{(V)} \quad \sigma_{svf}(z) = 1/360 \sum_{\pi=0}^{360} \cos\lambda(\pi)
\end{aligned}
\qquad \text{(13 a-e)}
$$

These coefficients describe the influence of vegetation on direct and diffuse shortwave radiation (I and II) and on the downward and upward flux of longwave radiation (III and IV). Coefficient (V) parameterises the local obstruction of the sky by buildings („*Sky-View-Factor*“) and ranges from 1 (free sky) to 0 (no sky visible) where λ is the maximum shielding angle found by the ray-tracing module in direction π.

LAI is the one-dimensional vertical leaf area index of the plant from level z to the top of the plant at z_p or the ground z=0 :

$$
LAI(z, z + \Delta z) = \int_{z'}^{z'+\Delta z} LAD(z')\, dz'
$$

To calculate the decrease of the direct solar radiation, the three-dimensional index LAI^* is used instead of the one-dimensional vertical LAI. LAI^* is calculated with respect to the angle of incidence from the incoming sun rays and analyses the model environment for objects intersecting with the ray path. If a building is found to lie between the point of interest and the sun, $\sigma_{sw,dir}$ is set to zero immediately (=shaded), if vegetation is found, the intensity is adjusted as shown in (13 a).
The direct and diffuse shortwave radiation fluxes at any point can then be calculated as

$$
\begin{aligned}
R_{sw,dir}(z) &= \sigma_{sw,dir}(z) R^{0}_{sw,dir} \\
R_{sw,dif}(z) &= \sigma_{sw,dif}(z)\sigma_{svf}(z) R^{0}_{sw,dif} + \left(1 - \sigma_{svf}(z)\right) R^{0}_{sw,dir} \cdot \bar{a}
\end{aligned}
\qquad \text{(14 a,b)}
$$

where $R^{0}_{sw,dir}$ and $R^{0}_{sw,dif}$ are the direct and diffuse shortwave radiative fluxes at the model top. The additional last term for the diffuse component considers the reflection of shortwave radiation inside the environment using the average wall albedo ($\bar{a}$) as reflectivity indicator.

In case of the longwave radiation (14 c-e) it is assumed that shielding vegetation layers will absorb parts of the flux and replace it with their own longwave radiation. Horizontal longwave radiation fluxes from building walls (14 e) are calculated by weighting the emitted radiation of the walls with the sky-view-factor. Using the concept of reduction coefficients, the longwave fluxes at level z are:

$$
\begin{aligned}
R^{\downarrow}_{lw}(z) &= \sigma^{\downarrow}_{lw}(z) R^{\downarrow,0}_{lw} + \left(1-\sigma^{\downarrow}_{lw}(z)\right)\varepsilon_f \sigma_B \overline{T}^4_{f+} \\
R^{\uparrow}_{lw}(z) &= \sigma^{\uparrow}_{lw}(z)\varepsilon_s \sigma_B T^4_0 + \left(1-\sigma^{\uparrow}_{lw}(z)\right)\varepsilon_f \sigma_B \overline{T}^4_{f-} \\
R^{\leftrightarrow}_{lw}(z) &= \left(1-\sigma_{svf}(z)\right)\varepsilon_w \sigma_B \overline{T}^4_w
\end{aligned}
\qquad (14\ c,d,e)
$$

with:

$\overline{T}^4_{f+}$, $\overline{T}^4_{f-}$: average foliage temperature of the overlying (+) and underlying (-) vegetation layer,

T_0: ground surface temperature

$\overline{T}_w$: average surface temperature building walls

ε_f, ε_s, ε_w. :emissivity of foliage, the ground surface and of the walls

σ_B : Stefan-Boltzman constant.

3. THE SOIL MODEL

It is typical for urban environments that a wide range of different soil and surface type can be found varying form natural soils to completely artificial materials. To simulate these heterogenous situation, individual soil properties such as thermodynamic and hydraulic conductivity or albedo, can be assigned to each grid cell of the surface/ soil model.

The soil model is organised in 14 layers between the surface and its lower boundary in 2 m depth. The vertical resolution varies between 0.01 m close to the surface and 0.5 m in the deeper layers. The exchange processes are simulated in terms of heat and water transfer between the layers. Except of the uppermost soil layer in which the heat transfer is calculated in three dimensions, the soil is treated as a one dimensional vertical column. The distribution of heat T and soil volumetric moisture content η are given by the one dimensional prognostic equations:

$$\frac{\partial T}{\partial t} = \kappa_s \frac{\partial^2 T}{\partial z^2} \qquad (15)$$

$$\frac{\partial \eta}{\partial t} = D_\eta \frac{\partial^2 \eta}{\partial z^2} + \frac{\partial K_\eta}{\partial z} - S_\eta(z) \qquad (16)$$

For natural soils, the thermal diffusivity κ_s is a function of the available soil moisture η and is calculated after Tjernström (1989). The hydraulic parameters used in (16) are: volumetric water content η, its saturation value η_s , the hydraulic conductivity K_η and the hydraulic diffusivity D_η. All coefficients are calculated using the equations given by Clapp and Hornberger (1978).

As an additional factor, the water uptake by the plant roots (S_η) provided by the vegetation model has to be considered as an internal sink of moisture. Further more, the evaporation of the soil surface as given by (26 c) has to be considered as an external sink (or source in case of condensation) at the top layers of the soil model.

4. THE VEGETATION MODEL

Vegetation is treated as a one-dimensional column with height z_p in which the profile of leaf area density (LAD) is used to describe the amount and the distribution of leafs. The same concept is used inside the soil system: the distribution of roots is represented by the root area density (RAD) profile stretching from the surface down to the root depth $-z_r$. This scheme is universal and can be used for small plants like grass or crop as well as for huge trees if z_p and $-z_r$ are adjusted accordingly.

4.1 Turbulent fluxes of heat and vapour

The interactions between the plant leafs and the surrounding air can be expressed in terms of sensible heat flux ($J_{f,h}$), evaporation flux of liquid water on the leafs ($J_{f,evap}$) and transpiration flux controlled by the leaf stomata ($J_{f,trans}$):

$$\begin{aligned} J_{f,h} &= 1.1 r_a^{-1}(T_f - T_a) \\ J_{f,evap} &= r_a^{-1}\Delta q \delta_c f_w + r_a^{-1}(1-\delta_c)\Delta q \\ J_{f,trans} &= \delta_c (r_a + r_s)^{-1}(1-f_w)\Delta q \end{aligned} \tag{17a,b,c}$$

T_a and q_a are the temperature and the specific humidity of the air around the leaf, Δq is the leaf-to-air humidity deficit with $\Delta q = q_*(T_f)-q_a$. T_f is the foliage temperature and q_* the saturation value of q at the leaf surface. Following Barden (1982), the aerodynamic resistance r_a is a function of the leaf geometry and wind speed:

$$r_a = A\sqrt{\frac{D}{\max(W,0.05)}} \tag{18}$$

where W= wind speed at the leaf surface. The parameter A is 87 $sec^{0.5}m^{-1}$ for conifers and grass and 200 $sec^{0.5}m^{-1}$ for deciduous trees. D is the typical leaf diameter ranging from 0.02 m for conifers up to 0.5 m or more for tropical plants (Schilling, 1990). The max condition ensures that no invalid values appear in the case of very low winds.

The factor δ_c is set to 1 if evaporation and transpiration can occur ($\Delta q \geq 0$), otherwise δ_c is 0 and only condensation is possible. Assuming that only wet parts of the vegetation can evaporate (17b) and, on the other side, only dry parts will transpire (17c), the fraction of wet leaves inside one grid box is needed. Following Deardorff (1978) the wet fraction can be calculated as

$$f_w = \left(\frac{W_{dew}}{W_{dew,max}}\right)^{2/3} \tag{19}$$

where W_{dew} is the actual amount of dew on the leave surfaces and $W_{dew,max}$ is the maximum possible value (0.2 kgm^{-2})

4.2 Stomatal resistance

The stomatal resistance r_s of a vital plant is calculated with respect to actual and maximum shortwave radiation input (R_{sw} and $R_{sw,max}$) and of the available soil water content inside the root zone (η) as described by Deardorff (1978):

$$r_s = r_{s,min}\left[\frac{R_{sw,max}}{0.03R_{sw,max} + R_{sw}} + \left(\frac{\eta_{wilt}}{\eta}\right)^2\right] \tag{20}$$

The minimum stomatal resistance $r_{s,min}$ depends on the type of plant and ranges from 200 $s^{0.5}m^{-1}$ for grass up to 400 $s^{0.5}m^{-1}$ for deciduous leafs. Alternatively to the simple Deardorff-approach, the stomata resistance can also be calculated using a photosynthesis model that allows a more dynamic description of the plant processes (Jacobs 1994).

4.3 Energy balance of the leaf

If the internal energy storage inside the leaf is neglected, the foliage temperature T_f can be obtained from the steady-state leaf energy budget:

$$0 = R_{sw,net}(z) + R_{lw,net}(z) - c_p \rho J_{f,h} - \rho L\left(J_{f,evap} + J_{f,tran}\right) \tag{21}$$

where c_p is the specific heat of the air and ρ the air density, L is the latent heat of vaporization.
$R_{sw,net}$ is the net shortwave radiation absorbed by the leaf surface calculated as

$$R_{sw,net}(z) = \left(F \cdot R_{sw,dir}(z) + R_{sw,dif}(z)\right)\left(1 - a_f - tr_f\right)$$

Here, F is a non-dimensional parameter describing the orientation of the leafs towards the sun (=0.5 for randomly orientated leafs), a_f is the albedo of the foliage and tr_f is a transmission factor (set to 0.3).

The longwave radiation budget for (21) is given by

$$R_{lw,net}(z, T_f) = \varepsilon_f R_{lw}^{\downarrow}(z) + R_{lw}^{\leftrightarrow}(z) + \varepsilon_f R_{lw}^{\uparrow}(z) - 2\varepsilon_f \sigma_B T_f^4 - \left(1 - \sigma_{svf}(z)\right)\sigma_B T_f^4$$

The source/sink terms for the atmospheric model can finally be computed using (17 a-c) with T_f obtained by solving (21):

$$Q_h(z) = LAD(z) J_{f,h} \tag{22}$$

$$Q_q(z) = LAD(z)\left(J_{f,evapo} + J_{f,trans}\right) \tag{23}$$

where LAD is the leaf area density in height z. The equations assume, that only one side of the leaf is participating in the turbulent exchange processes of heat and vapour (the luv side) and absorbs shortwave radiation, whereas in the longwave radiation spectra, both sides of the leaf take part in the radiative exchange process.

4.4 Water balance of the plant/soil system

To ensure a realistic simulation of the feedback mechanisms between water transpiration by the plant and water supply by the soil, the water transpired by the plant must be taken from the soil via root water uptake, resulting in a loss of soil water content. If the soil fails to supply enough water, the stomatal resistance will be increased and the transpiration rate decreases.
The total mass of water (m_{trans}) transpired by the plant is given by the vertical integral over the transpiration fluxes in the different plant layers:

$$m_{trans} = \rho \int_0^{z_p} LAD(z) J_{f,trans}(z)\, dz \tag{24}$$

Following Pielkes' (1984) suggestion, the water is taken from different soil layers inside the root zone of the plant depending on the amount of roots in the layer (RAD(z) value) and the hydraulic diffusivity of the soil layer (D_η (z)):

$$S_\eta(-z) = \frac{m_{trans}}{\rho_w}\left(RAD(-z)D_\eta(-z)\right)\left(\int_{-z_r}^{0} RAD(-z)D_\eta(-z)dz\right)^{-1} \tag{25}$$

5. GROUND SURFACE AND BUILDING SURFACES

The temperature T_0 of the ground surface in equilibrium can be calculated from the energy balance

$$0 = R_{sw,net} + R_{lw,net} - c_p\rho J_h^0 - \rho L \cdot J_v^0 - G \tag{26}$$

in which $R_{sw,net}$ and $R_{lw,net}$ are the net radiative energy fluxes, J_h and J_v are the turbulent fluxes of heat and vapour and G is the soil heat flux. In case of building surfaces (walls, roofs), the soil heat flux is replaced by the heat transmission through the wall or the roof (Q_w) .

5.1 Radiative fluxes

$R_{sw,net}$ and $R_{lw,net}$ are the net shortwave and longwave radiation absorbed by the surface calculated with respect to the temperatures of surfaces and walls „seen" by the ground.
Using the radiative fluxes scheme introduced in section 2.4, the shortwave net flux can be written as:

$$R_{sw,net} = \left(R_{sw,dir}(z=0)\cos\beta + R_{sw,dif}(z=0)\right)\left(1 - a_s\right)$$

where β is the angle of incidence of the incoming shortwave radiation relative to the surface exposition and a_s is the surface albedo.

The calculation of the longwave net radiation must take in account the influence of potential vegetation layers above the surface as well as the longwave fluxes from buildings and reflection of radiation between buildings and the surface. For simplicity, the longwave budget is split into a fraction that is unshielded by buildings ($R_{lw,net}^{us}$) and a fraction obstructed by buildings ($R_{lw,net}^{s}$):

$$R_{lw,net}(T_0) = \sigma_{svf} R_{lw,net}^{us}(T_0) + (1 - \sigma_{svf})R_{lw,net}^{s}$$

where the sky-view-factor σ_{svf} is used to weight the energy budget for the shielded and unshielded fraction according to the situation.
After Deardorff (1978) the exchange of longwave radiation between the ground and the vegetation (unshielded part, first term) and between the ground and buildings (shielded part, second term) can be written as:

$$\begin{aligned} R_{lw,net}^{us} &= \sigma_{lw}^{\downarrow}(0)\left(R_{lw}^{\downarrow,0} - \varepsilon_s\sigma_B T_0^4\right) + \left(1 - \sigma_{lw}^{\downarrow}(0)\right)\frac{\varepsilon_f\varepsilon_s}{\varepsilon_f + \varepsilon_s - \varepsilon_f\varepsilon_s}\left(\sigma_B \overline{T}_f^4 - \sigma_B T_0^4\right) \\ R_{lw,net}^{s} &= \frac{\varepsilon_w\varepsilon_s}{\varepsilon_w + \varepsilon_s - \varepsilon_w\varepsilon_s}\left\{\max\left(\sigma_B\overline{T}_w^4, \sigma_B T_0^4\right) - \sigma_B T_0^4\right\} \end{aligned} \tag{27}$$

$\overline{T}_w$ is the average temperature of the building walls and ε_w the walls' emissivity. For the shielded fraction of the energy balance it is assumed, that the energy flux from the walls is only relevant if the walls are warmer than the ground surface. If the ground surface is warmer, the reflection of the longwave radiation of the surface at the walls is the dominating effect.

In the case of building walls, the radiative scheme is less complex. Here, the effects of vegetation are neglected because only few information are available about the horizontal longwave fluxes from the vegetation layers. For vertical walls, it is assumed, that the unshielded fraction will receive 50% of the longwave radiation from the sky and the other 50% from the ground. For the shielded fraction, 2/3 of the longwave radiation are supposed to come from the emission of other walls and the remaining 1/3 of the radiation is assumed to be radiation from the ground reflected by the walls.
For roofs the radiative components are the same as for the ground surface except that z≠0 and that additional vegetation layers above the roof are not taken into account.

5.2 Turbulent fluxes of sensible heat and vapour

The turbulent fluxes of heat J_h^0 and vapor J_v^0 at the ground surface and at building walls and roofs are calculated as

$$
\begin{aligned}
J_h^0 &= -K_h^0 \left.\frac{\partial T}{\partial z}\right|_{z=0} = -K_h^0 \left.\frac{\theta(k=1) - T_0}{0.5\Delta z(k=1)}\right| \\
J_v^0 &= -K_v^0 \left.\frac{\partial q}{\partial z}\right|_{z=0} = -K_v^0 \left.\frac{q(k=1) - q_0}{0.5\Delta z(k=1)}\right|
\end{aligned}
\qquad (28\ \text{a,b})
$$

where k=1 indicates the first calculation layer above or adjacent to the surface and K_h^0, K_v^0 are the exchange coefficients for heat and vapour between the surface and the air. Both are calculated with respect to the thermal stratification between the surface and the overlying air layer (Asaeda *et al.* 1993). In case of walls, the notations in (28 a,b) have to be adopted according to the orientation of the wall. In case low wind speeds leading to free convection conditions, the so-called $z^{-1/3}$ law is used to describe vertical transport by thermals (Panhans and Schrodin 1980).

The Surface humidity q_0 can be obtained from the soil moisture content at level z=-1 using the β-approach from Deardorff (1978):

$$
\begin{aligned}
q_0 &= \beta q_*(T_0) + (1-\beta) q(z=1) \\
\beta &= \min(1, \eta(z=-1)/\eta_{fc})
\end{aligned}
\qquad (29)
$$

where η is the volumetric soil water content in the first soil layer and η_{fc} is its value at field capacity. The water flux is linked to the soil hydraulic model using an additional sink term $S_{\eta,0}$ related to the evaporation at the surface with

$$
S_{\eta,0}(k=-1) = -\frac{\rho}{\rho_w} J_v^0 \frac{1}{\Delta z(k=-1)} \qquad (30)
$$

in which k=-1 is the first layer of the soil model with the thickness Δz and ρ_w is the density of water. Practical application have shown that it is more realistic to distribute the water loss over the upper two layers of soil and also use these two layers to estimate β in (29) rather than using only the uppermost layer. Otherwise, because of the layers thinness, it will dry out too fast.

5.3 Soil heat flux and heat flux through building walls

The soil heat flux is calculated from the surface temperature and the temperature of the first level of the soil model below the surface:

$$G = \lambda_s(k=-1)\frac{T_0 - T(k=-1)}{0.5\Delta z(k=-1)} \tag{31}$$

where λ_s is the heat conductivity of the first soil layer which depends on the soil material and the water content.
For buildings, G is replaced by Q_w :

$$Q_w = k(T_w - T_{a,i}) \tag{32}$$

in which k is the heat transmission coefficient of the wall material and $T_{a,i}$ is the air temperature inside the building. This approach is rather simple and does not take into account the heat storage inside the wall material.

6. NUMERICAL ASPECTS

6.1 Solution Techniques

The differential equations in the model are solved on a staggered grid system using the finite difference method. The three dimensional advection-diffusion equations are de-coupled using the Alternating Directions Implicit (ADI) method in combination with an upstream advection scheme. This scheme implies a relatively high numerical diffusion but allows a quick and implicit solution of the equations and has therefore been chosen in the ENVI-met model.

To solve the Navier-Stokes equations, a splitting method after Patrinos and Kistler (1977) is used. Here, the prognostic equations for a mass-conserving wind field $u_i^{t+\Delta t}$ are split into an auxiliary flow field (u^{aux}) and a pressure field (p):

$$\frac{\partial u_i^{t+\Delta t}}{\partial t} = \frac{\partial u_i^{aux}}{\partial t} + \frac{1}{\rho}\nabla p \tag{33}$$

The pressure variable is then removed from the prognostic equations (1 a-c) leading to a set of three prognostic equations for an auxiliary flow field:

$$\begin{aligned}
\frac{\partial u^{aux}}{\partial t} + u_i\frac{\partial u^{aux}}{\partial x_i} &= K_m\left(\frac{\partial^2 u^{aux}}{\partial x_i{}^2}\right) + f(v - v_g) - S_u \\
\frac{\partial v^{aux}}{\partial t} + u_i\frac{\partial v^{aux}}{\partial x_i} &= K_m\left(\frac{\partial^2 v^{aux}}{\partial x_i{}^2}\right) - f(u - u_g) - S_v \\
\frac{\partial w^{aux}}{\partial t} + u_i\frac{\partial w^{aux}}{\partial x_i} &= K_m\left(\frac{\partial^2 w^{aux}}{\partial x_i{}^2}\right) + g\frac{\theta(z)}{\theta_{ref}(z)} - S_w
\end{aligned} \tag{34 a-c}$$

This flow field contains the correct vorticity, but is not mass conserving, which means that it does not fulfil the filter condition (2).

The matching pressure field can be obtained by solving the Poisson equation:

$$\nabla^2 p = \frac{\rho}{\Delta t} \nabla u_i^{aux} \qquad (35)$$

using the iterative Simultaneous Over Relaxation (SOR) method. Finally, the correct and approximately mass-conserving flow field can be calculated from

$$u_i^{t+\Delta t} = u_{aux}^{i} - \frac{\Delta t}{\rho} \frac{\partial p}{\partial x_i} \qquad (36)$$

The steep pressure gradients occurring in microscale simulations with obstacles require very small time steps to solve the set of wind field equations. Therefore, the wind field is not treated as a "normal" prognostic variable in ENVI-met, but is updated after a given time interval to take into account changes in turbulence and thermal stratification. Using the wind field as a normal variable is technically possible, but too time consuming on recent computers.

6.2 Computational Domain and Grid Structure

Depending on the problem, the total size of the three dimensional model X,Y and Z as well as the resolution of the grid can be selected within a wide range. By default the spacing Δx, Δy and Δz is equidistant in each direction (only the lowest grid cell above ground is normally split into 5 sub-cells with size Δz_g=0.2Δz to increase accuracy in calculating surface processes).
The three dimensional model is nested into a one-dimensional model which extends up to 2500 m height. The values of the one dimensional model are used as reference values as well as inflow profiles and top boundary conditions for the three-dimensional model.

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11.2 BOTWorld

(see www.botworld.info) What is BOTworld about?

Urban areas would be nothing without pedestrians filling them up with life. Vitality, attractiveness or economic power: Places and street especially in the central districts of towns must offer adequate environmental conditions to attract, hold and please pedestrians and for example, turn them into customers.

But what are those "adequate environmental conditions" and how do they interact with the human behaviour?

Legislative regulations exist for most urban environmental parameters such as air pollutants or noise. In many cases, assessing the environmental quality means to compare local data with the relevant threshold values, if they exist.

But how is the human factor taken into account?

People move through the urban environment and they are exposed to a magnitude of varying environmental conditions in a short time: from hot to cool, from windy to calm, from fresh air to polluted sections. To a huge extend, their actual personal sensation of the close environment depends on the conditions they have experienced before.

Through their movement, pedestrians create linkages between different urban locations in space and time. In order to assess the environmental quality of a certain location, we need to identify and understand these links.

Finding these spatial and temporal linkages is far from being trivial. In addition, if we want to predict the effects of changes in the urban structure, we need to know how these links will react on the purposed variations.

This is where BOTworld comes into play.

BOTworld is a Multi-Agent simulation system, predicting the behaviour and movement of pedestrians in urban areas under the influence of different environmental factors (urban layout, sources of traffic, air quality and micro climate).

BOTworld simulates the individual virtual pedestrian (agent or "BOT") and thereby allows to analyze the environmental system from within. Each BOT is controlled through a number of complex models ranging from simple movement control up to a sophisticated model of the human thermoregulatory system predicting the response of the human body on the local climate and air qualify. To learn about the opinion of the virtual pedestrians, a Fuzzy-Logic-System ("F-A-ST model") is used to link the internal state of the agent with the environmental conditions and get a conclusive assessment.

BOTworld helps you to analyze the urban system. Which routes do pedestrians prefer? How do they feel at certain locations? How do changes in the urban structure modify the flow of pedestrians and their opinions?

BOTworld does not just calculate average values about average pedestrians who do not exist - every single agents has its own personality, preferences and properties.

The BOTworld system supplies a huge number of tools such as Virtual interviews or Statistical Distributions to manage and analyze the virtual community.

List of Figures

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