ABSTRACT

This contribution explores the effects of climate change on open spaces and street canyons in urban environments, using the “Aspern” New Town development in Vienna as a principal case study. Specifically, the effects of alterations in the urban fabric are analysed with regard to sun exposure and ventilation. Results of future regional climate scenarios are incorporated in a second series of microclimate simulations. Future climate conditions are based on regional climate simulations for the years 1960-2050, carried out by the authors in previous studies.

Microclimate conditions are simulated with the ENVI-met tool, simulating climate dynamics within a daily cycle reproducing the major microscale atmospheric processes, based on the laws of fluid dynamics and thermodynamics. 3D-block models of the planned Aspern development with 5m cell resolution are introduced to consider effects of different spatial characteristics due to block layout and tree distribution at a local level.

INTRODUCTION

Urban climates differ distinctly from those of rural areas. In urban environments climate change is expected to have a significant impact upon levels of thermal comfort in open spaces and in buildings themselves. This is the case not only in traditionally hot countries, but also in regions of mid- and northern latitudes that presently have a moderate climate. Within these, urban environments will be exposed in particular: air ventilation can be restricted by structures; thermal stress is likely to increase, due to the entrapment of radiation via reflection; local heat fluxes and higher heat storage capacity will increase through block layout and volume of buildings.

To cope with future urban climate conditions, urban planners, architects, and property developers need reliable information concerning changing microclimate conditions in order to make the right decisions regarding building design, block layout and shading facilities so that the built environment will be properly adapted to future climate change.
eastern section manufacturing businesses are to be located and to the south a research and education quarter is envisaged (serviced by a 2nd light rail station).

The Aspern development will be divided by a W-E directed blue-green corridor with a large scenic lake dominating the centre of the development (Fig. 3). Besides its recreational and aesthetic value, the lake also functions as a fresh air reservoir and cooling facility. The expansive open space encourages the movement of air, the low specific heat capacity of the water lowers air temperatures. The entire area will be surrounded by a green belt.

**Fig. 3: Aspern lake area, viewing north; (Rendering: AIT)**

**URBAN CLIMATE SIMULATION FRAMEWORK**

The simulation has been carried out using ENVI-met, a 3D-microclimate modelling software, to analyse the small scale interactions between urban design and the immediate climatic surrounds, with resolutions ranging from 0.5 to 10 m (www.envi-met.com). The model calculates fluid dynamics parameters such as wind flow and thermodynamic processes (temperature, humidity) taking place at walls, roofs, ground surface interacting with soil, plants and the atmospheric boundary conditions (Bruste et al. 1998).

The model simulates the atmospheric processes for grid cells – the appropriate way to model continuous transition processes over space and time. The software can handle a model domain of up to 250 x 250 cells, thus providing results for an area of up to 2.5 x 2.5 km². Such a simulation area would be sufficient to simulate the entire Aspern cityscape. To provide more detailed results and to consider non-rectangular block layouts better, however, the grid spacing has been reduced to 5x5 m and the grid was twisted 15° towards the east to reduce diagonal block orientation, avoiding staged shapes.

To conduct the simulation, the study area with its 3D- and 2D conditions has to be defined by several input data sets using identical grid spacing: building shapes and heights, as well as properties of these structures such as heat storage capacity and irradiance reflection; plant sizes and characteristics relating to shading/wind protection; surface conditions of roads and open space including tree locations, surface roughness, moisture content etc.

Initial simulation framework conditions are integrated at the beginning of the model runs, requiring inputs such as geographical positioning, date and time (to calculate the solar altitude), wind speed and direction at ground level, the initial temperature at ground level, the specific humidity at 2500m and the relative humidity at ground level. Meteorological information comes from a nearby monitoring site or is derived from climate model-outputs for the respective grid-cells covering the

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**Fig. 2: Layout concept (from top to bottom): (a) northern high rise quarters, (b) blue-green corridor, (c) ring road, (d) manufacturing quarters, (e) science / education quarters (Source: City of Vienna, 2008b)**
The microclimate model needs at least 6 hours simulation time to deliver plausible results. ENVI-met has been used by various authors for a range of applications for several years. It can therefore be seen as a validated method for climate simulations.

ENVI-met 3.1 runs on MS-Windows-based computers. Testing this version has revealed a number of constraints regarding model performance and output: the simulation for a daily cycle takes several hours. Whilst simulating the entire Aspern site at a high spatial resolution the software crashed several times. Consequently, further model runs were carried out, focusing on progressively smaller areas of the Aspern development. The final area, selected for full 24 hour-cycle simulations with 2 hour measurement intervals, concentrates on a section of the original area with 130 x 130 grids in direction x-y, spanning 650 x 650 m² (and 20 cells in direction z). It covers the northeastern, high-rise building cluster and immediate surrounds, but little blue-green open space. Figure 4 shows all tested model extents, with the final model domain marked in white.

CITY LAYOUT OF ASPERN AND MICROCLIMATE CONDITIONS

The overall urban structure is defined by the master plan of Tovard Architects & Planners. Its elements – the general block layout, ring road, boulevards, axes, public and open spaces – determine the visual readability and identity of space. The main elements of this overarching plan will not be further analysed or altered in the context of this research work, as the master plan is likely to have been chosen precisely on the grounds of principle features. Proposing fundamental changes, therefore, seems unrealistic. These main features include: the general elevation pattern; the position of the green corridor; the ring road and the general radial axis layout (City of Vienna, 2008a).

The radial axis layout seems to be a useful adaptation to climate change. Fig. 5 depicts the streets’ shading fraction resulting from different street orientation and block-height/street-width (H/W) ratio. Here we follow the calculation of Bourbia et al. (2004) for the latitude 33°N in Algeria but consider higher shade fractions due to a more shallow sun-angle for Aspern’s latitude 48°N. It turns out that most roads are oriented NE-SW or NW-SE, which reduces solar exposure of block fronts and increases the street shading capability of block walls. It is also noteworthy that the relationship between buildings and streets frequently exceeds an H/W ratio of 1:1. This design approach ensures sufficient natural lighting for building users on the one hand, but on the other hand it is too wide to provide full shade for the entire street canyons or opposite block walls.

The green belt is an important element able to reduce urban heat island effects and provide ventilation, although the location is not ideal with respect to the prevailing (NE to SW) winds. Fig. 6 depicts the usual wind direction and velocity pattern: the higher speed of the SE-directed wind (dark blue) declines inside street canyons (light blue).

Thus adaptations in block layout refer to a new ventilation corridor through removal of building blocks (red blocks in Fig. 4) and integration of additional green spaces.
CURRENT CLIMATE SIMULATIONS

The microclimate simulations refer to a sunny reference day (June 21) under current climate conditions. The images below show increase of air and surface temperature during the day. The left maps show the original block layout, the right ones effects of an additional NW - SE corridor with slightly higher temperatures. This observation refers to less shading due to the wider streets, and higher surface temperature resulting from the reflection of heat. More distinct changes are noticeable with regard to surface temperatures (and thus irradiance reflection), as well as wind pattern.

Fig.7: Potential temperature (°K)
left: standard block layout
right: additional NW-SE corridor

(June 21, 8:00, 10:00, 12:00, 14:00h)
Fig 8. depicts surface temperature (top) and wind speed (bottom) for morning and noon hours. The local temperature differences are much higher (up to 35°K) than for air temperature, because of differences in heat storage capacity and the ability of the surfaces/soils to cool actively—e.g. through water content and evaporation.

The wind pattern images show higher wind speeds along the new corridor: At the northwestern edge 2m/sec, further south 1m/sec. Without the corridor the wind speed is calculated to be 0.5m/sec or less. Despite temperatures being nearly the same, the increased air movement may induce higher thermal comfort levels, as a result of wind chill.
FUTURE CLIMATE SIMULATIONS
To examine effects of a changing climate, on urban microclimate results of regional climate simulations have been applied to simulate the microclimate of a similar day.

The data applied for the microscale simulations have been generated in the course of previous projects, providing regional climate simulation results until 2050, delivering a large set of hourly data on temperature, radiation, cloud cover, humidity, precipitation, wind parameters, etc. for various atmospheric layers (c.f. Loibl W. et al, 2009, 2010).

Simulation results of a typical summer solstice day of the century 2041-2050 has been selected to serve as input for the Aspern microscale simulations.

The further images show some expected effects.

**Fig. 9:** Potential temperature (°K) for 10h and 14h under future climate conditions (June 21, between 2040-2050, sunny)

Fig. 9 illustrates distinct changes: while the temperature pattern at 10:00h for the future scenario shows only minor differences, when compared to the current climate simulations (Fig. 7), the 14:00h temperature distribution reveals clear increases.

Fig. 10 depicts the changes in temperature in more detail: The 10:00h image shows that within the outer parts of the analysed quarter in the north and the west the temperature increase is calculated to be around 1.25 °K, while in the more central south-eastern parts of the area the changes reach 1.5 to 1.7°K. The bottom figure shows higher differences: 1.7°K in >50% of the area for 14:00h.

**Fig. 10:** Differences in potential temperature (°K) between current and future climate of a similar sunny day (June 21, 2010 and between 2040-2050)

Some courtyards show lower temperature increases (in parts 1/10 °K), which might be a valuable finding in terms of climate-sensitive block layout.

The wind fields under current and future climate conditions for a typical summer solstice day look nearly identical. Future regional climate simulations let not expect general changes regarding wind. However, both the frequency and intensity of extreme weather events (including high wind speeds) may increase in future.

**SIMULATION RESULTS AT SPECIFIC RECEPTOR POINTS**
To investigate the effects of block layout on the local climate in more detail, the results have been extracted for certain receptor points that are positioned with respect to sun exposure and ventilation.

The receptors were placed either south or north of building blocks, exposed to the sun or shaded by block fronts or trees to varying degrees. Locations were also selected to measure varying wind conditions, at exposed or sheltered parts of the site.
The following figure shows the locations of the receptors in the model domain.

Fig. 11: Receptor locations in the model domain

Fig. 12 shows in detail the differences in local thermal exposure between the locations (at 2.5m above ground), resulting from varying degrees of sun and ventilation exposure. Differences between the locations remain nearly the same for the 3 simulation runs. Only receptor R5, located in the new corridor, records slightly higher temperatures than for standard block layout (centre figure). The temperature increase during the day was highest for the future scenario.

Fig. 12: Air temperature (°K) for defined receptor points, June 21, sunny, 10, 12, 14h for current climate, with additional corridor and for future climate

Data on wind speeds, resulting from the simulations as depicted in Figure 13 show more pronounced differences, although the range of variance is smaller: The highest wind speeds are observed at the receptor points in the green belt to the south. Along the new corridor (centre figure) air movement is significantly stronger, as documented by receptor points R5 and R6 - wind speeds increase from 0.1 and 0.4m/sec to around 1m/sec, due to better ventilation. During the day a slight acceleration in speed can be observed, which could help to improve the thermal comfort. Between current and future simulations no distinct differences in wind speed can be observed.

Fig. 13: Wind speed (m/sec) for defined receptor points, June 21, sunny, 10, 12, 14h for current climate, with additional corridor and for future climate

CONCLUSIONS

Analysis of the simulation results reaffirms the current understanding that a climate-sensitive block layout and open space allocation has a distinct influence on thermal comfort in open spaces (as well as indoors!). Street canyon orientation and front-height-to-road-width ratio were found to be important factors influencing surface temperature, heat flux and finally air temperature in relation to urban microclimatic changes.

The Aspern block layout turns out to be well suited for temperature increase. The radial street layout with few N-E directed streets results in lower building
front heating and allows higher surface shading fractions in streets and courtyards during warmer summer days.

Corridors following the prevailing wind direction would support ventilation at a local scale (not noticeably affecting adjacent streets). Even when wind speeds are low, a cooling effect would increase thermal comfort in open spaces. However, a wider street layout has to be considered carefully regarding sun orientation as it can on the other hand reduce shading capability, leading to temperature increases. Certain courtyard layouts appear to lend themselves to local passive cooling, thus creating pockets of lower temperatures for inhabitants.

Heat island effects can be reduced through limiting the share of sealed surface, influencing the heat storage capacity, by additional tree shading and high soil humidity supporting cooling through evapotranspiration. The planned large central lake will also contribute to reduce temperature and will encourage higher localised wind speeds, improving ventilation.

In general, exploration of, and improvement to, climate comfort can effectively increase the urban quality of life in light of future climate conditions. Conducting urban climate simulation studies in collaboration with urban planners and architects, to test effects of block layout alternatives, would improve climate sensitive block design.

Further research in this context is set to strengthen a framework for forward-looking building design and construction that could have positive economic impacts, such as energy saving measures related to building maintenance under future climate conditions, as well as bringing environmental and social benefits.

REFERENCES


City of Vienna (2008b) Aspern Airfield Masterplan- short version (English, German), by Tovard Architects & Planners AB; Magistrat der Stadt Wien, 1082 Wien.

