IMPACTS OF VEGETATION ON THE MICROCLIMATE: MODELING STANDARDIZED BUILDING STRUCTURES WITH DIFFERENT GREENING LEVELS

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1 ABSTRACT

Different building structures in urban areas show different microclimatic behaviour, especially when they are greened. In order to learn more about the impacts of different levels of green, a classification scheme for typical European urban building types have been developed and analysed systematically with the microscale climate model ENVI-met. A number of simulations have been conducted varying the level of greening as well as some of the typical building parameters, such as canyon geometries or different sealing rates. The simulation results where analysed primarily in view of thermal advantages and disadvantages of increased green and of the effects on pollution dispersion and accumulation. It is shown, that especially in densely build up block structures, greening with trees leads to higher pollution concentration, while in more open structures the thermal advantages of greening, due to shadow effects, can be fully used for the improvement of the microclimate.

2 INTRODUCTION AND GOALS

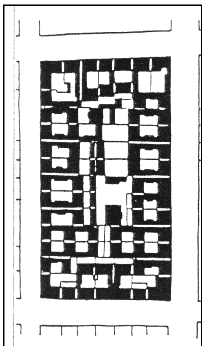
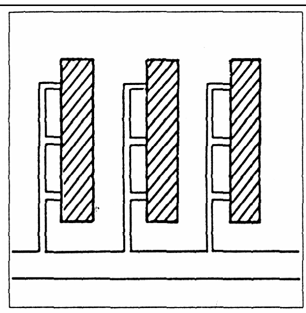
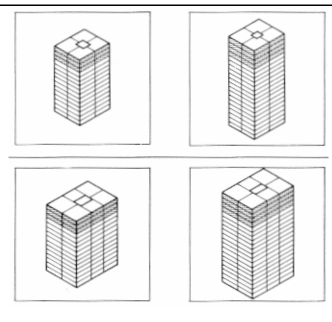
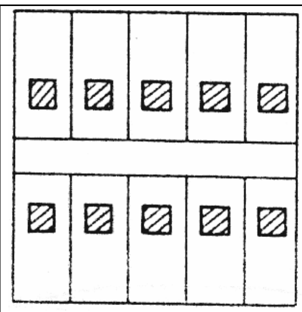
European cities are build of numerous different building structure types, which are characterized by different sealing rates or building densities and, as a very important matter to this work, of variable greening levels. As a part of the EU-project "Benefits of Urban Green Space (BUGS)", the goal of this study was to detect the different microclimatic behaviour of urban structures, especially of different greening levels, and to identify the advantages and disadvantages of structural changes. The obtained results can then be used to make a first assessment of the effects of vegetation in urban planning scenarios.

3 CLASSIFICATION OF BUILDING STRUCTURES

There are many different possibilities to classify urban building structures. Some of them are more, some are less suitable for the development of representative model areas for simulation. Four structure types where chosen for this purpose. They are in order of decreasing density: "*Block*", "*Line*", "*Point*" and "*Parcels*" (see Table 1)

A *Block* consists of open or closed building rows on all (mostly four) sides. Different building densities are possible from built up backyards with only small free spaces down to complete building-free yards, which can be used by green structures in different degrees. The *Line* type emerged from the block structures in the history of architecture. The ideal Line consists of elonged, parallel buildings, which are orientated perpendicular to the street. The buildings themselves are connected to the street by pedestrian paths, so that pollutant emissions only occur at the forehead sides of the buildings. *Point* structures are built up of mostly square-shaped buildings, which are distributed homogeneously over an area. *Parcels* are, strictly speaking, no urban building structure but are typical for suburbs or smaller towns. Detached or semi-detached houses are arranged in rows parallel to the street with a certain space used as foreyard.

Table 1: The four classes of building structure types, which where used for development of model areas

			
Type Block	Type Line	Type Point	Type Parcels

4 DEVELOPMENT OF MODEL AREAS AND SIMULATION

For this set of four basic building structures several model areas were developed using varying characteristic parameters. Some of these basic parameters are: geometry of the buildings (height, broadness, depth), space between buildings, space between buildings and street, broadness of streets, sealing rate of non built up areas and others.
Not all parameters have been varied for all structure types. Most variations were made for the Block structures. In addition to the variation of these parameters, a greened variation of all model areas have been developed. In the greened model areas, trees of 20 m height where distributed homogeneously over the whole area, which means along the streets as well as in the backyards or in the free spaces between the buildings (non-greened model areas have only grass vegetation in the backyards). The trees have distinct and dense crowns in the level between 10 m an 20 m height.
For the building type Block a set of four subtypes was developed by varying the building height and the broadness of the street. The reference type for the analyses is Block1, which is shown in Figure 1. This subtype has a building height and street width of both 12 m which equals a height-to-width ratio (H-W) of 1. The H-W rations of the other subtypes are: Block2: 24/12 = 2, Block3: 12/24 = 0.5, Block4: 24/24 = 1 (similar ratio as Block1).
An other variation has been made changing the building densities and sealing rates, but only for the subtype Block1. Figure 2 shows the greened model area of Block1. Figure 3 shows profiles of all Block-subtypes. In addition to the different height/broadness ratios, the position of the tree crowns in relationship to the buildings can be seen clearly.
For the line type, only building height and space between the buildings has been varied. Figure 4 shows the model area of the reference type with a building height of 14m, Figure 5 shows a part of the greened model area. The Point structure was not varied with respect to the building geometry. Only one non-greened and one greened model area was used (see Figure 6). The building height is relatively high with 28 m. For the parcels two subtypes, one with detached, and one with semi-detached buildings where developed (see Figure 7). All simulations have been executed with ENVI-met for the 21st of July in Bochum, Germany with a wind direction of 270° (West) and wind speed of 2.5 m/s in 10 m height.

5 DATA EVALUATION AND INTERPRETATION

5.1 Type Block

The analysed parameters where primary analysed with regard to air temperature and pollutant concentrations of PM10-particles. In addition to this, some other parameters like surface temperature, wind flow, turbulent exchange where analysed to explain the observed distributions. In the following section, the main results for the Block type are presented.

There are three dividable areas in the Block structures (backyard, street canyon crosswise to wind direction = N-S canyon and street canyon parallel to wind direction = W-E canyon). The distribution of the air temperature is mainly driven by the vertical air flow, produced by the overflowing of the buildings orientated perpendicular to the wind direction. The W-E-canyons are relatively warm at day because of the lack of vertical flow components transporting cooler air form the higher levels. The different surface temperatures in the yard (due to sealed or vegetated areas) or the N-S-street (due to different radiation) have only small influences on the air temperature above them. In the W-E-canyon the northern exposed areas are distinctly warmer than the southern parts.
The particle concentration is decreasing rapidly with increasing distance from the sources. Due to the absence of sources the backyards generally have a much lower pollution burden then the street canyons. In the W-E-canyons the particle concentration increases due to advective summation effects showing very high concentrations there. Particles emitted in the N-S-canyons, in which a cross-street wind vortex develops are transported in parts towards the leeward backyard. This happens by overflowing of the building roofs as well as by horizontal transport through the entrance gates.
By varying the street geometry different flow patterns occur in the N-S-canyons as well as in the backyards. Due to the larger shaded areas in the subtypes with double building height, a general decrease of air temperature around 1 K can be observed. In the W-E-street especially Block2 with very narrow canyons shows a local cooling of nearly 2 K against reference value due to the complete lack of incoming direct radiation. The particle concentration is doubled against the reference value in the N-S-canyon of Block2, where the air exchange is significantly reduced (see Figure 8).
The greening with trees results in a reduced air temperature of about 0.5 K at daytime due to lower mean surface temperatures. Particle concentrations at the tree crown level are higher compared to the non-greened cases in all zones and all subtypes. In the backyards the relative increase barely passes 50 % against the non-greened case, while in the canyons a tripling of the value is not unusual, as Figure 9 shows for the N-S-canyon.
From other simulations with different rates of building porosity it was found that a closing of the passages leads to lightly different flow patterns resulting in a lower particle concentrations in the N-S-canyon *and* in the backyard. In the case of more porous block structures the concentrations are lower in the N-S-canyons too, due to better horizontal air exchange. The concentrations are distinctly higher in the completely closed canyon, when trees are added (+ 450 %). The reason for this dramatic change is, that the tree crowns can hinder the air exchange more effectively, when no horizontal streaming components (through passages or building gaps) are possible. The

lowest increase in pollution due to greening occurs in the detached type, because of the horizontal flow into the leeward yard.

5.2 Other types

The Line type shows a lower dependency of air temperature and pollutant concentration on the building geometries than on the wind direction. When the wind direction is parallel to the streets, the same advective addition as in the Block structures occurs, while the free spaces between the buildings are reached only by a very small part of the pollutants. When the wind direction is changed to a flow parallel to the buildings, the pollution concentration is distinctly higher between the lines, while the maximum concentration near the sources are much lower than in the former case. The effects of greening are less significant than observed in the Block canyons simulations.With growing opening of the building structures in the Line and Parcels types, the differences inside the model areas decrease, with the consequence of lower maximum concentrations, but a general pollution level in the whole area. The greened case shows only a relatively small increase of the locale pollutant concentrations, so that the thermal benefits of the shadowing tree crowns can be fully used in these structure types.

6 CONCLUSIONS

The model simulations have shown that inside dense urban building structures such as the Block type, adding local green can lead to a local increase of air pollutants. Greening should only be done with care in the these structures to avoid negative drawbacks. In the other structure types the benefits of the trees, especially on air temperature can be fully used, because pollutants can disperse much better there.

7 ACKNOWLEDGES

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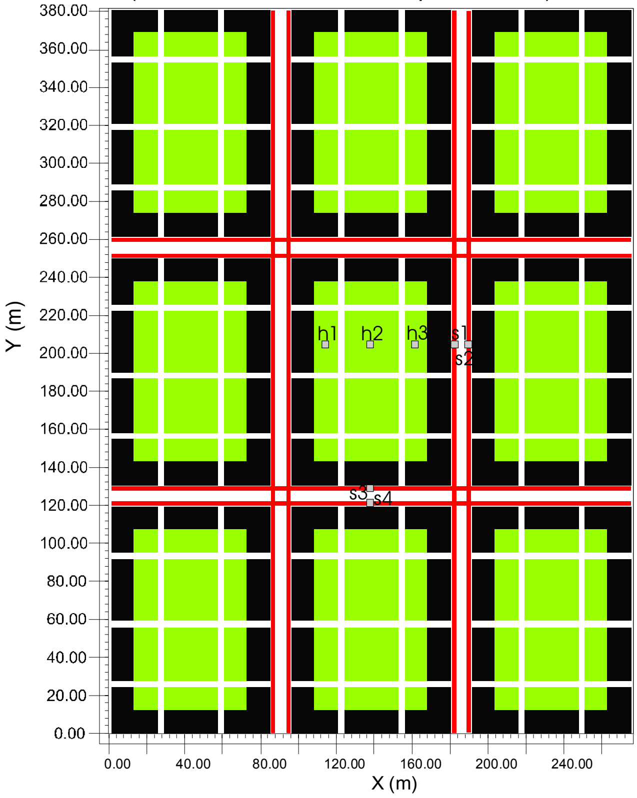

Figure 1: Model area of "Block1 lightly sealed" with buildings (black) and grass vegetation (green); white pixels are streets, paths or passages; red lines show the pollution sources; the points show the position of receptors (points, for which data are saved in special profile- or time-line files)

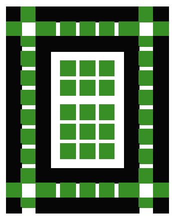

Figure 2: Clipping of the greened model area of "Block1 lightly sealed"; shown are only buildings and tree crowns (grass vegetation is existing as in the non greened model area)

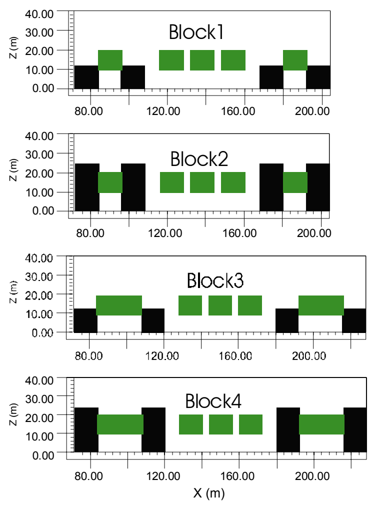

Figure 3: Cross-section through the greened model areas of all four block-subtypes with buildings and tree crowns

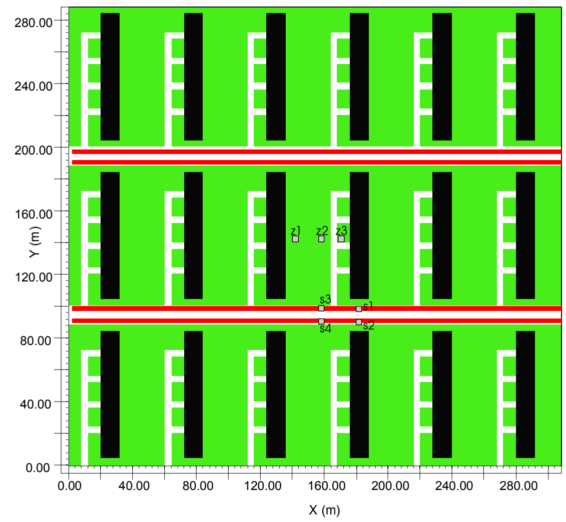

Figure 4: Model area of the reference Line-type with buildings, grass vegetation, sources and receptors

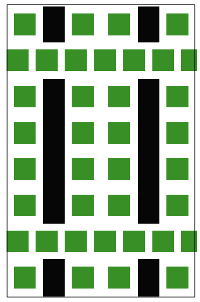

Figure 5: Clipping of the greened reference-line model area with buildings and tree crowns

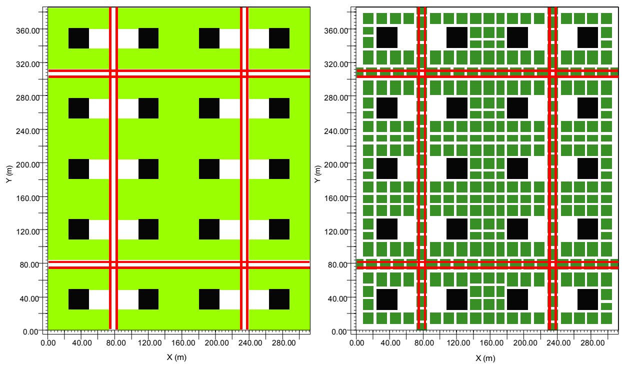

Figure 6: Model areas of the type Line (non-greened: left, greened: right) with sources and grass vegetation (left) or tree crowns right)

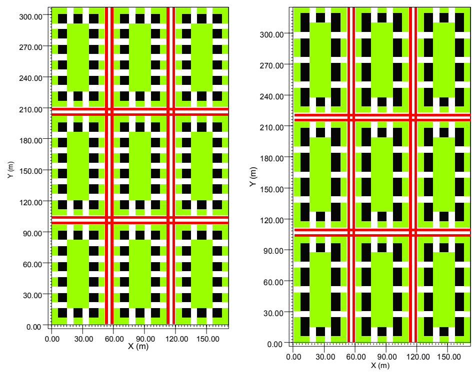

Figure 7: Model areas of the type parcels; left: detached houses; right: semi-detached houses; with sources

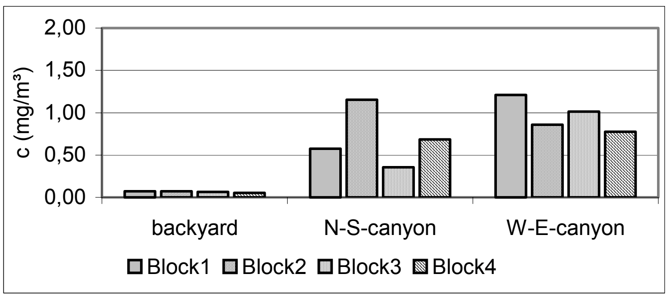

Figure 8: Particle concentrations in 1,40 m height at 15h in the three zones of the four Block-subtypes (mean values of h1/ h2/ h3, s1/ s2 and s3/ s4)

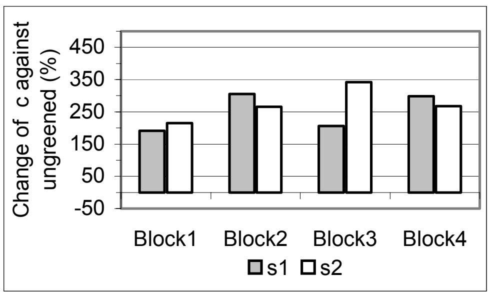

Figure 9: Relative change of the particle concentration against the non-greened case at the receptors s1 and s2 in all Block-subtypes in 1,40 m height at 15h