reviewed paper

Endangerments on Schools

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1 ABSTRACT

The project "Endangerments on schools" maintained by the Department of Physical Geography within the Faculty of Regional and Environmental Planning at the University of Kaiserslautern, Germany, analyzed the air quality of elementary school sites primarily not to be viewed as air hygiene loaded places. However, surveys of the traffic situation of the nearby vicinity of diverse schools in the city of Kaiserslautern indicated that these must be regarded as potentially polluted. In many cases, the combination of local emission sources and the locally limited exchange rate of the urban canopy layer proves to be a little-noticed negative factor. Pursuing this fact at the beginning of the project several elementary schools were selected within the city of Kaiserslautern, which could be classified as an urban, suburban or rural location due to its location and to the adjacent building structure. At all school sites meteorological as well as air quality parameters were measured simultaneously to allow a direct comparison of the assessed data. Initial results have shown that some analyzed school sites not only have short-term air pollution exposure, following the concentration peaks of the morning and mid-day traffic of the children. In dependence of the reduced near surface atmospheric exchange, due to the current weather situation and diverse environmental aspects the air quality limits, e.g. for particulate matters (PM10), were exceeded over longer periods. These could verifiably accumulate within the nearby vicinity of the school and even worse, within the schoolyard, respectively.

2 SCIENTIFIC BACKGROUND

2.1 Urban Geometry

What we need is to understand microclimatological modifications within urban areas so that we may affect the spaces to create a better environment from the biometeorological sight. At the same time, understanding and especially being able to predict these microclimates may also help to improve aspects of the performance of the adjacent buildings. If the environmental quality of the outside spaces is enhanced, there will be more opportunity for the people to stay outdoors, with beneficial effects on health (Erell et al. 2011).

Due to the heterogeneity of every urban structure it is useful to describe the fabric of buildings, open and green spaces respectively. Though, it is possible to give a statement that expresses e.g. the density or other physical properties influencing the micro-scale climate. One of the most used models for making such a description is the urban street canyon. This refers to a linear space bounded on both sides by vertical elements (walls of adjacent buildings). All in all the geometry of an urban street canyon could be described by three principal descriptors:

- the aspect ratio (height-width-ration),
- the canyon axis orientation and
- the Sky View Factor (SVF).

- Fig. 1: Upward-looking fish-eye lens photograph for the estimation of the Sky View Factor limited by the urban geometry (left) and making only the apparent sky visible (right).

The Sky View Factor is closely related to the aspect ratio. It is the proportion of the sky dome that is "seen" from a surface, either from a particular point on the surface or integrated over its entire area (s. Fig. 1). The calculation of the SVF is focused to determine the street`s geometry for the analysis of this project. These geometric descriptors of an urban street canyon are correlating in a useful way with a number of climatic effects. Both the aspect ratio and the SVF indicate a direct relationship with the urban heat island effect. One of these influences can be shown by different wind regimes or general patterns of air-flow over the urban surface (Souza et al., 2003; Gal et al., 2007, Erell et al., 2011).

Different numerical models as well as scale-model simulations could show that the skimming flow is always present and that the aspect ratio of the urban street canyon determines the number and strength of the vortices formed within the street. So a single vortex could be formed, with its centre a little downwind within the urban canyon. Another theory suggests that deeper urban street canyons will be able to exhibit two counter-rotating vortices. And this second one definitely could have an influence on the urban air quality near the ground because of less potency in comparison to the upper vortex (s. Fig. 2) (Erell et al., 2011).

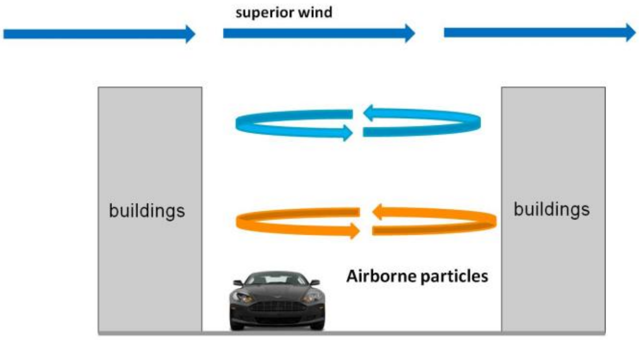

Fig. 2: Scheme of an idealized representation of two counter-rotating vortices formed in a deep street canyon by above-roof wind blowing perpendicular to the canyon axis.

Most urban aerosols are anthropogenic in origin. A large proportion of these result from combustion processes (e.g. domestic fuel, industries, traffic), which are typically the main source of particulate matters within urban streets and the urban canopy layer respectively. Several studies show that the particle number concentration at street level is linearly correlated with traffic volume as well as being inversely correlated with wind speed (Henninger, 2011; Errel et al., 2011). So the dispersion of aerosols and pollutants is directed on wind and in particular on turbulence. Depending on the atmospheric stability and the roof geometry clean air may be entrained at roof height and directed downwards into the canyon near the windward wall. At ground level the flow is directed opposite the above-roof wind. Ideally, traffic emissions from the middle of the street are carried to the base of the leeward wall and then sucked upwards by the vortex flow. But if there is the above mentioned second vortex this dispersion is prevented (s. Fig. 2) (Hotchkiss & Harlow, 1973; Yamaritino & Wiegand, 1986; Erell et al., 2011).

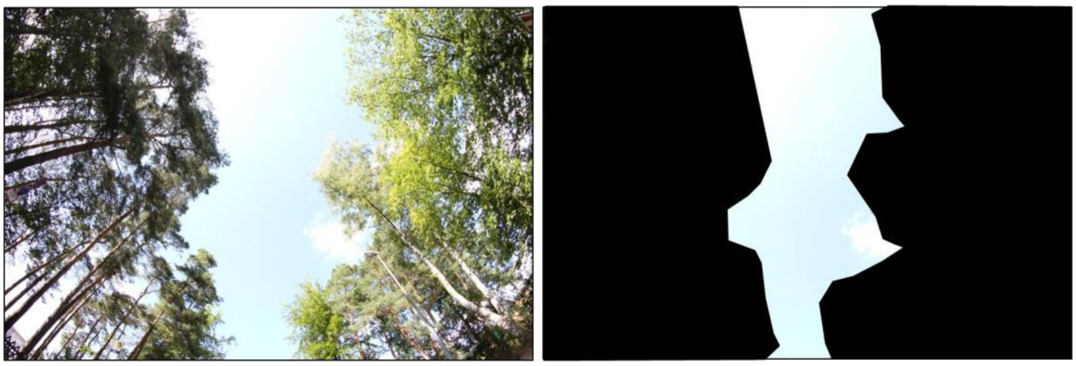

Fig. 3: Upward-looking fish-eye lens photograph for the estimation of the Sky View Factor limited by the tree geometry in summer (left) and making only the apparent sky visible (right).

2.2 Permeability of trees

The Sky View Factor could also be estimated for other types of space, whose geometry differs from a linear-type of an urban street canyon (s. Fig. 3). Trees are often employed as shading devices for buildings as well as for pedestrian spaces (Brown & Gillespie, 1995). However, this idealized behavior could not always be observed in practice for several reasons. One of these is that the branches may still create a substantial obstruction to the sunrays and the tree crown is able to close up broad parts of a street, like it is known by the urban street canyon bounded by the walls of the surrounding buildings (comp. Fig. 1) (Canton et. al, 1994; Erell et al., 2011). Thus, trees have the capacity to filter the air by absorbing a variety of undesirable pollutants. But however, the effect of the trees on air quality within urban streets is not absolutely beneficial (Taha et al., 1997; Erell et al., 2011; Henninger, 2012).

Different wind tunnel studies could confirm results of computer simulations showing that a row of trees planted along city pavements interferes with the formation of the lee vortex. They are responsible for the removal of traffic induced pollutants originating within the street. This results in less dispersion of pollutants and consequently poorer air quality. Again, as it is known for the aspect ratio of street canyons these could be simulated for adjacent trees at street level and lead to the above mentioned second vortex near the ground (s. Fig. 4). It is worth noting that even very porous tree crowns have a big effect on pollutant concentration. Tree crowns should not occupy large street canyon volumes in order not to suppress the ventilating canyon vortex system and the trees height should not exceed the roof level. Otherwise, air exchange is hindered and the concentration of pollutants at street level may rise (Gromke & Rush, 2009; Erell et al., 2011).

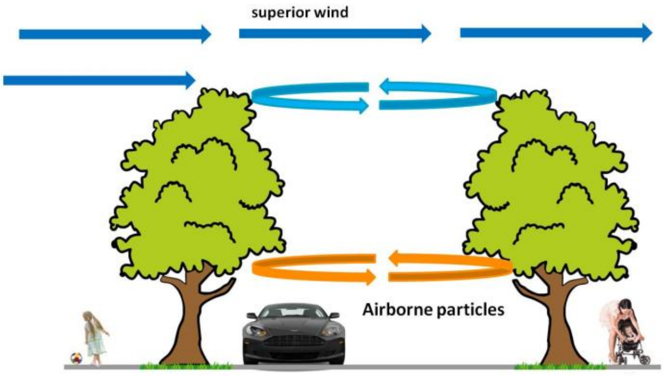

Fig. 4: Scheme of an idealized representation of two counter-rotating vortices formed by the densely tree geometry by above-roof wind blowing perpendicular to the street axis.

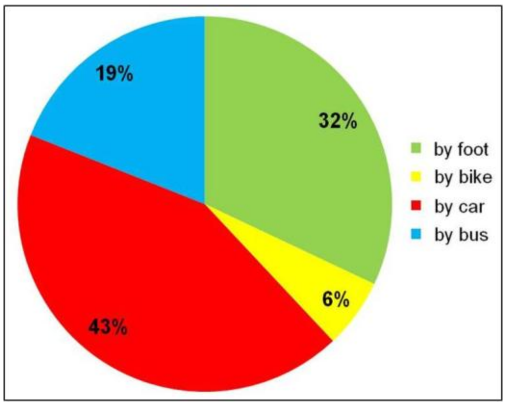

Fig. 5: How pupils of the investigated school reach the schoolyard; results of an evaluation (n = 291).

3 AIM & METHOD

The research primarily concentrated on the analysis of airborne particles, how they were modified by different times of the day in dependence of the current traffic and how these were influenced by the surrounding buildings and tree geometry. Therefore, exemplarily one investigation area was chosen, which is conspicuous particularly with regard to its temporal traffic density. The so-called area of “Pfaffenberg” is situated in the south-western part of the city of Kaiserslautern, Germany and could be considered as a typical suburban terrain with small single-family houses, blocks of flats and a heterogeneous structure of sealed-up areas in connection with urban green spaces and adjacent forest areas. The measurements were done within and in the nearby vicinity of the elementary school called “Pestalozzi-School”. Evaluations of the traffic situation along this street offered that most parents transport their children by car, less pupils are going by bike or schoolbus (s. Fig. 5). So first of all, in consideration of the street system, it is obvious that there is not enough parking area along the street which leads to “wild parking” and a permanent fight for the best places, resulting in criss-cross parking. This indicates that a high volume of traffic is a directly physical danger to the pupils.

Also visible or smellable respectively was the fact, that most parents did not stop the engine while parking. This resulted in an accumulation of different air pollutants in the exhaust plume. Considering figure 3 and 4 the situation along the street is reflected very well. Especially for the time of spring and summer the densely planted trees cover most parts of the street. A green street canyon arises (s. Fig. 4), which is, depending on the SVF, comparable to an urban street canyon. So furthermore we decided to analyze the local linear emission sources along the “Pfaffenbergstraße”. Therefore, air quality measurements as well as the climatological ones were taken by three stations. This methodology made it possible to measure air quality as well as meteorology at three different locations; the first one was directly located on the pavement of the street, the second one in the transition area to the schoolyard and the third one right in the middle of the schoolyard. The aim of this measuring methodology was to determine the temporal course of different air pollutant concentration in relation to the meteorological conditions within the urban green area. Thus it should be possible to prove the daily air quality and how it was influenced respectively dependent of different external influencing factors. Especially from the mentioned second and third measuring device we expected to get an impression of the air quality situation of the schoolyard, offside of the street. Beside the particulate matters (PM10, PM2,5, PM1), carbon monoxide and carbon dioxide additionally air temperature, air humidity, solar radiation, wind speed and direction were measured in 2 m above ground level. The air quality indicators were determined by a suction device even at 2 m a. g. l. First of all, using a 3-D sonic anemometer permitted an accurate reading, especially of the expected thermally caused wind field changes. Of course it was also possible to display the results as a time line or in dependence of wind speed, but it is more favorable in dependence of the wind direction. This enables an exact temporal allocation to the potential sources of emission of the specific air pollutants within and outside the investigation area, e.g. by calculating a trace gas wind rose (Henninger, 2012).

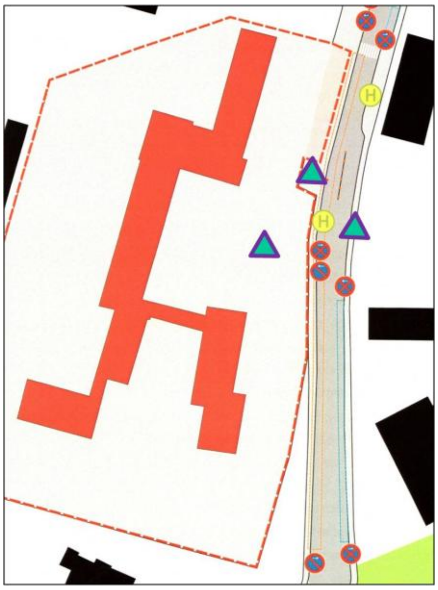

Fig. 6: Location of the investigation area (red line) and the „Pestalozzi School“ (buildings marked in red), the traffic system (grey line), the non-parking areas and the three air quality/ meteorological measuring stations (purple-green triangles).

4 AIR QUALITY AND MICROCLIMATOLOGICAL MODIFICATIONS

4.1 In-situ air quality measurements

Getting a first impression and a better comparison depending on the problem of the traffic induced air pollution figure 7 offers the temporal course for the concentration of PM10 from 7.30 a.m. till 9 a.m. regarded as representative for the air quality situation on weekends and holidays. In respect on the German Federal Immission Protection Ordinance (BImSchV) the particulate matter of PM10 should examplarily be used for the quantification of the air quality situation within the investigations area. It is obvious that the suburban character of the investigation area provides a smooth course of the determined concentration by

ΔPM10 = 28.1 μg m-3. This equated course of the particulate matters reflects the solitude of the location sometimes interrupted by shortly increasing concentration due to the routinely consorting bus and some individual traffic as well.

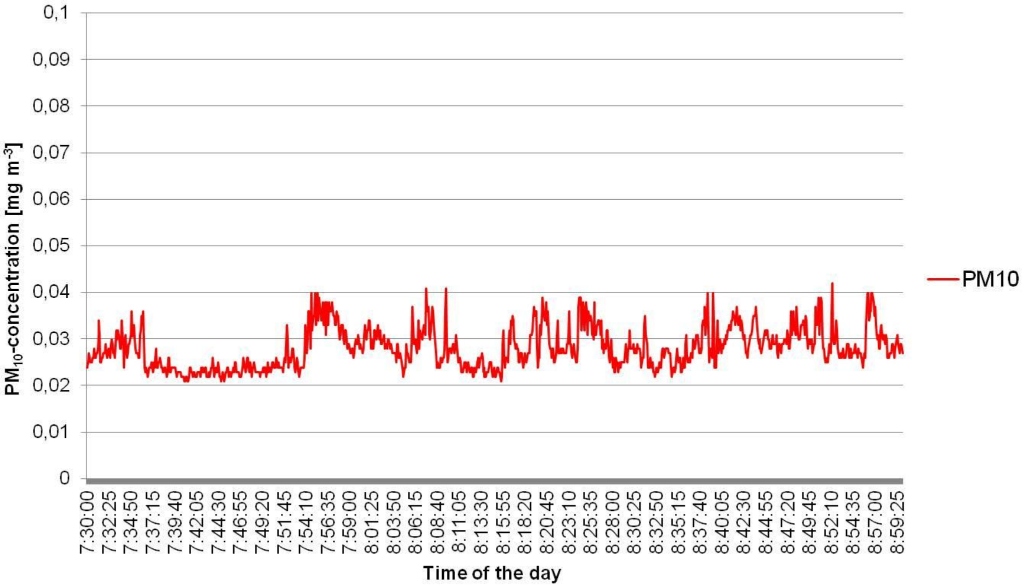

Fig. 7: Temporal course of PM10-concentration [mg m-3] for the street level of the investigation area on a representative holiday between 7.30 a.m. and 9 a.m.

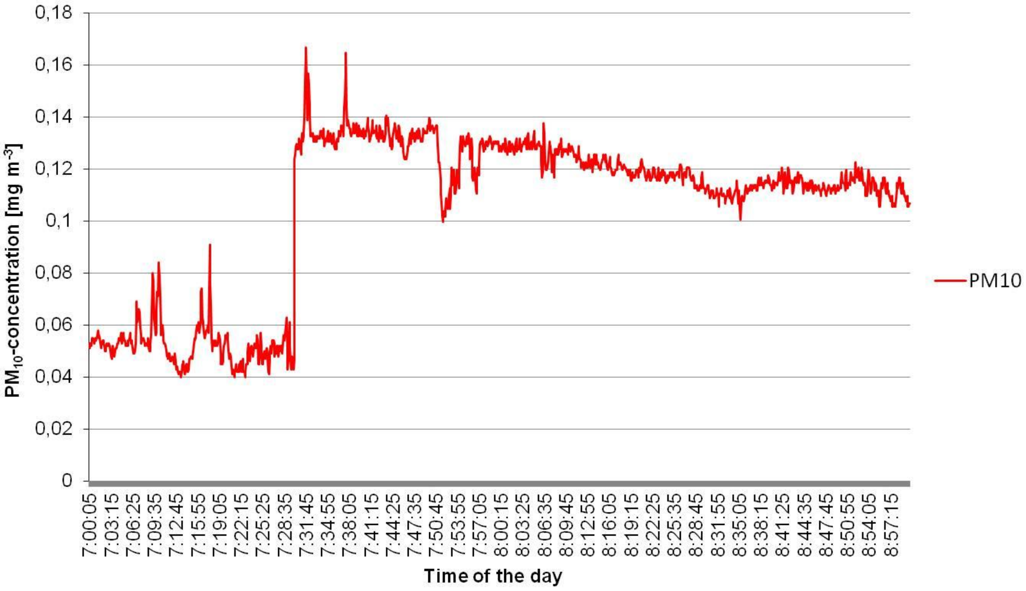

Fig. 8: Temporal course of PM10-concentration [mg m-3] for the street level of the investigation area on a representative schoolday between 7.00 a.m. and 9 a.m.

A completely different air quality situation is offered for weekdays. First and foremost it is obvious that the mean PM10-concentration for the time before school starts (7.00 a.m. till 7.30 a.m.) is by ΔPM10 = 52.2 μg m-3 higher than figured out in the above mentioned course anyhow (comp. Figs. 7 & 8). This could easily be explained by the matter of fact that there are more cars using this street in consequence of the weekdays commuter traffic. Around 7.30 a.m. the mapped air quality situation changes completely. Due to the so-called "open-beginning" of the schools first lesson the "struggle" for ample parking spaces in front of the school buildings starts at this time and the traffic situation is getting worse in this area. This "traffic jam" is replicable in the abruptly increasing PM10-concentration up to 170 µg m-3 (s. Fig. 8).

The mentioned "traffic jam" continues about ten minutes. Now, everyone would expect, that after the traffic has reassured air quality will normalize by distinct decreasing concentration. Unfortunately, the above explained problem of the street/ tree geometry becomes important. Because of the more or less closed tree crowns the dispersion of PM10 is extremely reduced and it lingers on a high level (ΔPM10 = 121.9 µg m-3) for a longer time.

By 8.00 a.m. a trend of slightly decreasing concentration becomes visible. In consequence of the reduced exchange rate of the air masses within the canopy layer this slow decrease could be explained by the low dispersion rate in the surrounding areas. But comparing the results of figure 8 with the findings of figure 9 introduced a completely new interpretation. A slight time-display to the development provoked by the traffic situation on the street is visible and nearly the same image arises by considering the results of the measuring station within the schoolyard (s. Fig. 9).

Until 8.30 a.m. a smooth course of PM10 is visible by ΔPM10 = 36.2 µg m-3. But afterwards an almost mirror-imaged abrupt increase of the PM10-concentration appears and an equally immediately decrease in air quality within the canopy layer of the schoolyard. Of course this did not reach the high level of the street in front of the school, but by ΔPM10 = 74.4 µg m-3 and a time period of more than two hours before the concentration was decreasing again, but the situation not suitable from the humanbiometeorological point of view. Most notably not considering, that during this time period the pupils were using the schoolyard for the breaks between the lessons.

Now, it must be expected that the air quality development has to be regarded in the context with the situation on the street by the accumulation of the airborne particles. So the question was, how could these particles move so fast from one point to an other? Trying to explain this development a numerical simulation was done.

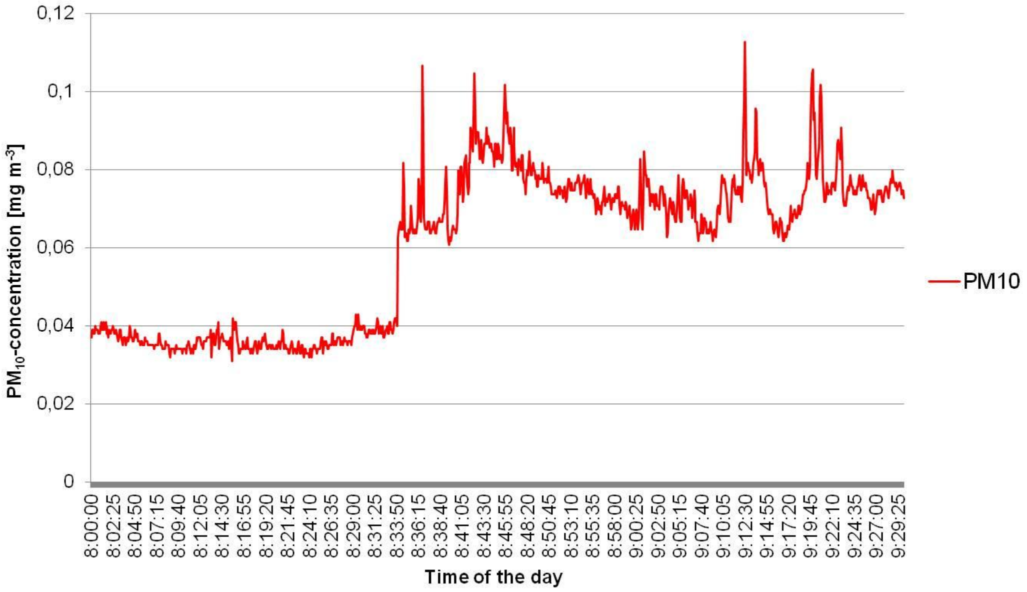

Fig. 9: Temporal course of PM10-concentration [mg m-3] for the schoolyard of the investigation area on a representative schoolday between 8.00 a.m. and 9.30 a.m.

4.2 Modeling the urban microclimate

Trying to find an answer for the dispersion of the aerosols the investigation area was analyzed due to its microclimatic situation by the simulation model ENVI-met 3.2, because analyzing the meteorological parameters showed, that there is a temperature difference between the street outside the schoolyard and the schoolyard itself.

ENVI-met is a CFD application (computational fluid dynamics) comprising a three-dimensional mathematical computer model designed for the specific purpose of analyzing micro-scale interactions between urban design and the microclimate. The model combines the calculation of fluid dynamics parameters (wind flow, turbulences) with thermodynamic processes taking place at the ground surface, like walls and roofs or plants. Using a resolution between 0.5 m and 10 m this enables the model simulating even complicated geometric forms such as terraces, balconies or complex quarters. The model includes the simulation of flow around and between buildings, exchange processes of heat and vapor at the ground surface and the walls, turbulences, exchange on vegetation and vegetation parameters, bioclimatology and particle dispersion (Bruse & Fleer, 1998; s. a. www.envi-met.com).

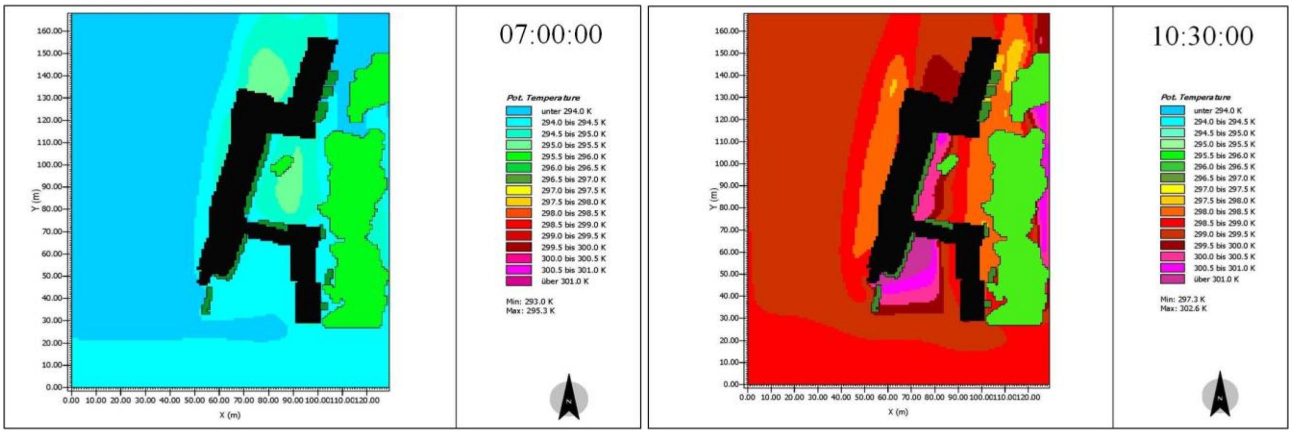

Fig. 10: ENVI-met simulation of the investigation area shortly before the sunrays directly reach the schoolyard (left) and when the schoolyard is heated up after the direct exposure to the sun (right).

Exemplarily, the results of the microclimatological simulation are shown in figure 10. These confirmed the in-situ measurements. It is obvious that in the course of the day the schoolyard (most parts are sealed by asphalt) could heat up by the direct exposure to the morning sun. This resulted in a "thermal hot spot" where a local convective air flow seemed to occur.

Regarding the near surface temperature and the wind direction, predominantly by the data of the measuring device located in the transition area of the schoolyard, the analysis offers a distinct local wind circulation between the cooler tree street canyon and the "hot spot" of the schoolyard. Evidently, the convective air flow above the schoolyard creates a local thermal area of low pressure, which will be set off by an area of higher pressure outside along the street (s. Fig. 11). This results in a measurable movement of the local air masses within the urban canopy layer.

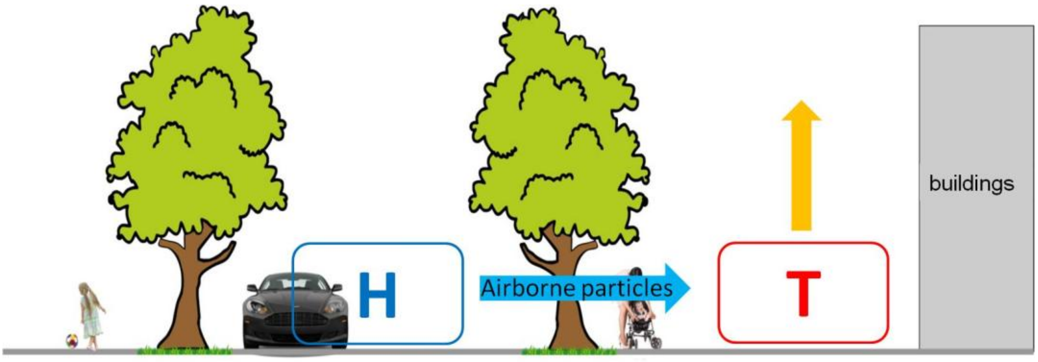

Fig. 11: Scheme of the determined local micro-scale wind circulation within the investigation area.

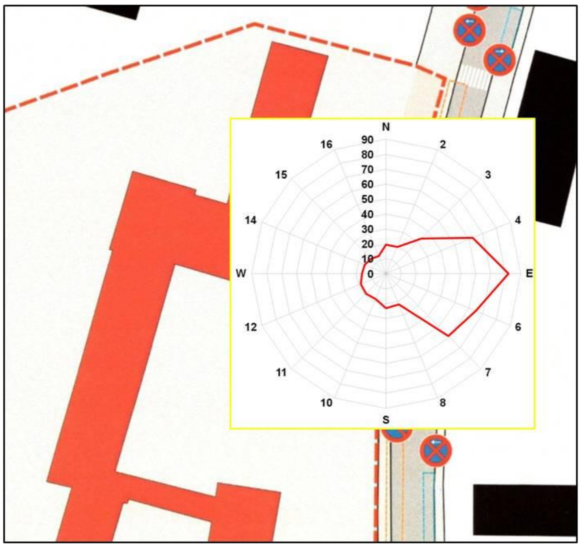

Fig. 12: Trace gas wind rose showing the flow of the PM10 [µg m-3] in dependence of the concentration and the direction of their source.

The development of this local microscale wind circulation explain the above mentioned decreasing concentration of PM10 within the investgated area of the street and also the increasing PM10-concentration within the schoolyard (s. 2.2). The determined compensation flow of this microscale air flow transports the airborne particles from the linear emission source into the schoolyard where the pupils are playing during their breaks between classes. This assumption could be proven by calculating a trace gas wind rose. Such a wind rose uses the arithmetic mean of a trace gas concentration for each wind direction sector, a trace gas wind rose can be calculated. Based on this it is possible to display an elevated trace gas concentration for an individual wind direction and it could be mapped to a potential emission sources (Henninger, 2005).

As it is displayed in figure 12 the wind rose indicates an air flow coming from the street, shifting in a small corridor of wind direction between east and south-east respectively, transporting a load of up to 80 µg m-3 of PM10, passing the entrance of the school and reaching the schoolyard later.

5 CONCLUSION

Among others, a steadily increasing individual traffic load by the parents of elementary school pupils could be made responsible for a local degradation of urban air quality within the urban canopy layer. The daily "battle" for the best parking space in front of the school often leads to obvious dangerous situations. However, it could be shown that the traffic peaks of a school day around the school ground in the morning and early afternoon hours did not only pose a physical danger to the pupils, but also present a hidden and therefore not noticed air pollution problem caused by the emission of the vehicles. With the aid of the project “Endangerments on schools” it was possible to show, using the example of the elementary school location of the “Pestalozzi School” in the south-west of the urban area of Kaiserslautern, Germany, that a high volume of traffic is not only directly, but also indirectly able to affect children. Ultimately, the project results should be used to sensitize the population to ensure that for each elementary school in the city of Kaiserslautern an individually created route-to-school-plan exists, which allows the pupils a safe and fast way to school and reaching it, of course, without a vehicle as well.

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