# CLOSING THE GAP BETWEEN URBAN CLMATE AND URBAN PLANNING

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## 1. INTRODUCTION*

Knowledge of local climate, the resulting air quality situation and their functional relationships are important aspects of environmental precaution in urban planning.

The positive effect of urban green spaces is non-controversial. However, it is important to take into account that even green spaces like urban parks are quite capable of influencing the air quality of a site adversely. The applied, planning oriented urban climatology in this case represents the link between climatology and urban planning. Urban climatology can offer an extensive range of solutions that both appear in areas with microclimatic and air quality issues.

## 2. CURRENT CHALLENGES

Urban climate analysis, climatological function maps and planning recommendation maps allow urban planning to address major climatic aspects within the municipal operational framework. Especially for the responsible for urban and environmental planning it is now – more than ever – important to receive subject-specific responses to climatic and air quality problems in urban areas.

The phenomenon of “shrinking cities” offers a large number of vacant areas. These potentially free spaces can be integrated into future urban planning by using urban climate knowledge. In urban areas the creation of green spaces is a useful strategy. Especially, in this context arise different areas of activity for applied, planning-oriented urban climatology. These include, for example, the roadside vegetation and urban parks.

### 2.1 Roadside vegetation

Basically roadside vegetation contributes to the improvement of local climate and also has an air-purifying function (Litschke & Kuttler 2008). Nevertheless, care should be taken of the air hygiene perspective in choosing the tree species, especially concerning the treetops. If trees with tight and closed treetops, like e. g. the horse chestnut (*Aesculus hippocastanum),* are planted on both sides of the road as an avenue, it has to be assumed that the “convergence” of the treetops reduce air exchange on the traffic route close to the ground. Then similar accumulations of pollutants such as within an urban canyon can be achieved, depending on the seasonal trend of the foliage (Henninger 2013). In Errel et al. (2011) – the seasonal effect of broad-leaved trees is shown concrete on the example of reduced light incidence along the stem (see fig.1).

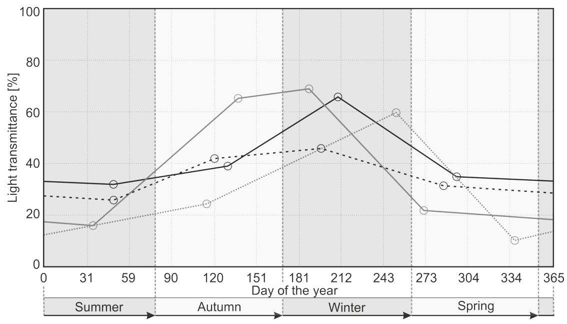


**Fig. 1**: Variability of light transmittance of treetops as a function of leaf development, modified by Errel et al. 2011.

However, this applies only along these traffic routes, which are characterized by a high traffic volume.

### 2.2 Inner-urban green areas

Similarly, the value of inner-urban green areas for regeneration purposes is indisputable and the positive local climatic effect on the surrounding area of urban parks is well-known as a function of size and design (Horbert 2000). This positive effect is not restricted to large spaces since it has been proven that even smaller parking areas have a cooling effect on the surroundings, thus ensuring a reduction in the thermal load. However, this is limited to the directly adjacent area (Bongardt 2006). This phenomenon, called „park cool island“ as well, is justified, that a more or less cooling effect assumes on urban green spaces. Due to the evapotranspiration during daytime there is an energy consumption and accordingly to that a reduction of air temperatures within the green area. An additional increase of this effect is caused on the shading of the trees. During evening- and night-time hours cold air is formed over the green areas. These passes through the so-called „park-breeze“, an airflow from the urban park, with the effect of cooling down the adjacent areas. However, it has to be observed, not each green area shows the same effect to the urban environment. As shown in Tab. 1, the effect of the “park cool island” depends on the available water supply and population of vegetation.

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**Tab.1**: Different characteristics of „Park Cool Island"; modified by Errel et al. 2011.

| | **Daytime** ***„park cool island"*** | **Night-time** ***„park cool island"*** |
|---|---|---|
| **Type of park** | - irrigated green area<br>- ample stock of trees | - non-irrigated/ dry green areas<br>- tenuous stock of trees |
| **Formation** | - reduced surface temperature generated by the shading of the trees<br>- increased evapotranspiration above patches of grass (if it is well irrigated) | - high rate of short-wave insolation<br>- high rate of long-wave radiance after sunset |
| **Maximum of intensity** | - afternoon (forest type)<br>- early evening (garden or savannah type) | - several hours after sunset |
| **Specifics** | | - during daytime hours frequently warmer than nearby vicinity |

Despite all local climatic advantages, there is some backlog demand regarding air hygiene. Some species emit different amounts of biogenic volatile organic compounds (e. g. isoprene; Henninger 2012, 2014). The vegetation produces different organic substances that do not necessarily affect the growth and development of plants. Nevertheless, they have an important function, which is expressed in form of defense against herbivores and pathogens, or even in attracting of spreading seminals. These substances are also referred to as phytonutrients. One of these groups of substances are the isoprenoids.

The fact that plants emit isoprene is not a discovery of the recent past. Actually it's already known since the 1950 (Sanadze 2004). But, the phytophysiological relevance of isoprene, compared to other biogenic volatile organic compounds, has not yet been conclusively clarified. However, the assumption is that the isoprene protects the plant from the effects of heat and oxidative stress (e.g. Loreto et al. 2001; Sharkey et al. 2008). Decisive for the amount of the emission rates of the respective plants in terms of biogenic hydrocarbons are the meteorological conditions (air temperature; solar radiation) and how they act on the vegetation inventory (surface temperature of the leaves; Henninger 2012, 2014). Especially, the emission of isoprene is determined by air temperature and the intensity of the photosynthetically active radiation (PAR) (Tingey et al. 1979; Guenther et al. 1991). Accordingly, especially clear and calm weather conditions, that are characterized by a high solar radiation intensity and, consequently, high air temperatures, are best suited to emit isoprene. This in turn means, that even on these days, when a high ozone concentration is expected, the biogenic substance isoprene contributes an additional $O_3$- production. Especially on these places, e.g. within green areas, where a high ozone concentration is not expected (Henninger 2012, 2014).

Isopren ($C_5H_8$) is primary a biogenic volatile organic compound, which is produced by various natural processes (emission of plants, biological process of degradation and decomposition, production of soil biota). Corresponding by the work of Guenther et al. (2006) and Kansal (2009) > 95 % of this emissions derive from vegetation. The major part take the woods, 98% emit of trees (summer-green/ evergreen broadleaf trees 51%) and bushes (46%). Conifers (1%) play a subordinate role (Guenther et al. 2006). The corresponding isoprene emitting trees include oaks (*Quercus*), poplars (*Populus*), plane trees (*Platanus)*, robinia (*Robina)* and willow trees (*Salix).* The spruce (*Picea abies)* is to be mentioned as an emitting conifer. Their emission potential is much lower than in the above mentioned broadleaf trees.

Many of the above mentioned tree species belong to the characteristic urban vegetation. Therefore, a few species of plants are responsible for the entity isoprene emissions. In many places the isoprene emissions, which are not caused by broadleaf trees and bushes, are likely to be negligible (Wagner 2014). Especially, in the urban settlement area, the interest is to pay attention and react on the emission near the ground. At present, enormous amounts of biogenic isoprene are released in the urban area despite to a rather low vegetation density.

This is justified, that urban green areas often show a composition of species, which is not necessarily corresponding to the natural vegetation of the location. A widely spread example is the isoprene emitting tree species of the plane tree (*Platanus acerifolia).* It doesn't primarilly numbered to the local tree species. Nevertheless, due to its resistance to air pollution as well as to a certain insensitivity to condensed soil, it is multiple used as a road tree as well as in urban parks (Wagner 2014).

Compared to anthropogenic hydrocarbon, isoprene as a biogenic hydrocarbon has a proportionally high ozone-generating potential. This appears because of the reaction rate with OH-radicals. This means that isoprene can be observed even at low concentration as a quite serious precursor for the production of ground-level ozone (Henninger 2012, 2014, 2015). Isoprene holds according to its chemical formula $C_5H_8$ five carbon atoms and contains two C=C double bounds. Since C=C double bonds are unsaturated functional groups, they are easily attacked by radicals, whereby isoprene becomes very reactive and gets a certain significance for atmospheric chemistry (Wagner 2014). Based on this background, a possible negative consequence of isoprene emitted vegetation regarding the formation of ozone must be considered.

In particular, urban green spaces, especially in the summer months, are highly frequented by the general public. During summer weather, is has to be expected, that, from the view of air hygiene, unfavorable planting, the emission of photochemical oxidants will increase. The health effects of ozone on the human organism are different (Henninger 2014). As shown in Tab. 2, the following effects, caused by diverse plants extracted $O_3$-production within urban green areas, is a sensitive topic.

**Tab. 2**: Side effects on the human organism caused by ozone.

| | **Side effects on the human organism** |
|---|---|
| **Substance: Ozone ($O_3$)** | - penetrating into the lower respiratory tract<br>- irritation of airways, coughing, headache, dyspnea, runny eyes<br>- decreasing physical fitness<br>- increased frequency asthma attacks<br>- increasing responsiveness to allergies<br>= sensitive reactions by 10-20 % of the population |
| **Risk group:** | Persons with open-air workplaces, athletes, asthmatics, small children and babies |

With Taha (1996), the definitions *„low-emitter*" and *"high-emitter*"-plants are enforced in the planning-oriented applied urban ecology and urban climatology, respectively. For inner-urban green planning the consideration of these trees can have a lasting influence on the biogenic hydrocarbon emission rate and thus on the capability formation $O_3$ (Henninger 2012, 2014, 2015). Since the mid-nineties there have been selected scientific papers, which assume this topic. The focus is the analysis of the capability of formation ozone by urban trees or either roadside green (i.a. Benjamin & Winer 1998; Kesselmeier & Staudt 1999; Solmon et al. 2004; Young et al. 2009, Henninger 2012, 2014, 2015; Wagner 2014). However, there is still a lack of sufficient research on the different emission rates of various plants. Although, it is not the number of measurement amounts. It's rather the comparability with many uncertainties. The specific literature shows, that on the published emission potentials are subject to extreme fluctuations for some tree species. Due to many numerous influencing factors, the emission rate can be modified and influenced i.a. by:

- genetic differences
- variation in the age of the trees,
- variation between plant species,
- variation on a single leaf and between leaves of a plant species,
- variation of soil properties,
- availability of water and nitrogen
- variation of atmospheric $CO_2$ concentration

Based on constant ambient conditions, the isoprene rate of a leaf can be described as nearly constant within a few hours (Guenter et al. 1991). Changing the leaf temperature and/or the light intensity, the emission rate shows within a few minutes an immediate fluctuation (Guenther et al. 1991; Monson et al. 1991). The effects of leaf temperature or light intensity are independent of the plant species. Due to the described dependencies, especially during noon on summer days with high air temperature and solar radiation, a lot of isoprene is released (Wagner 2014). Surprisingly, the closure of the stomata appears to be a subordinate role during heat stress (Monson & Fall 1989). Both, Grinspoon et al. (1991) and Guenther et al. (1991) verified, that young leaves emit a very small amount of isoprene. In the course of leaf development the emission rate increases and reaches the maximum, when the leaves are fully developed (Xiaoshanet et al. 2000).

### 2.3.1 Estimation of biogenic isoprene emission rate – an easy mapping

For an overview of potential "Hot-spots" of isoprene emission within a planning area, a detailed vegetation mapping should be carried out. Subsequently, it is possible to select specific locations, where the plant stock is found, which can be designated as a natural isoprene source. An estimation of the theoretical isoprene emission is potential possible (Henninger 2012, 2014). However, at this point it must be pointed out, that such an estimation of biogenic emission rates is associated with considerable uncertainties. The greatest uncertainty is the potential inaccuracy in the determination of phytomass. It is also difficult to make a precise distinction between solitary-, group- and forest trees, as well as the resulting insolation. Nevertheless, this theoretical estimate of the total emissions should not be dispensed. The results of such a mapping can give a fairly good approximation value, which proves to be quite helpful for the further analysis of the air-thyme situation (s. fig. 2).

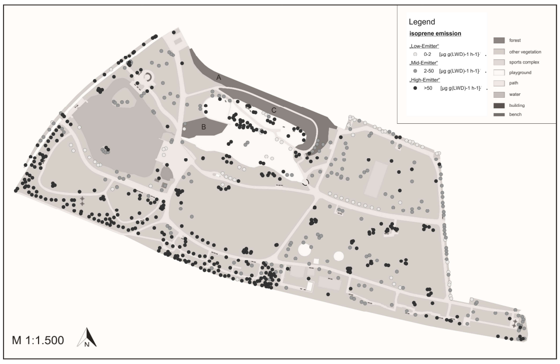


**Fig. 2**: Mapping of the different theoretical isoprene sources in dependence of the different tree species within the "Volkspark", Kaiserslautern, Germany

To calculate the total emission, a simple calculation can be used by multiplication the specific emission rate for isoprene [µg g(dry mass)$^{-1}$ h$^{-1}$] with the respective average biomass [g] (dry mass of leaves 15 kg per tree) number of the individuals. Using the example of an urban green area in the city of Kaiserslautern, Germany, this simple calculation option is shown in Tab. 3.

**Tab. 3**: Assembly of the dominant groves within the “Volkspark“ and their specific rates of isoprene emission plus the rate of emission per tree considering an average leaf mass of 15 kg per individual tree

| Scientific name | Specific rate of isoprene emission [µg g(dry weight)$^{-1}$ h$^{-1}$] | Rate of isoprene emission per individual (15 kg) [µg h$^{-1}$] | Number of individuals | Rate of emission per species [mg h$^{-1}$] |
|---|---|---|---|---|
| *Acer campestre* | 8 | 120 | 25 | 3 |
| *Platanus acerifolia* | 883 | 13,245 | 22 | 291.39 |
| *Quercus robur* | 1,405 | 21,075 | 310 | 6,533.25 |
| *Tilia concordata* | 26 | 390 | 72 | 28.08 |
| *Betula pendula* | 25 | 375 | 45 | 16.88 |
| **Amount** | | | **474** | **6,872.6** |
| **Total park area** | | | **701** | **8,874.05** |

## 4. TRANSFER TO URBAN PLANNING

For urban planning, this means that environmental and urban climate issues need to be involved in the planning of public space in more detail than before. This includes different levels:

At the level of area-based planning the importance of inner-city green spaces for local climate has to be considered specifically. Inner city green spaces can show a positive effect on urban climate if location and size are dimensioned sensibly. This is especially valid for urban regeneration in urban areas with high building density, lack of green spaces and anthropogenically shaped urban climate.

On a smaller scale planting concepts for the greening of road spaces and squares must be ensured by means of simulations of the growth of trees and possibly by modifying to ensure no negative impact on air hygiene arises because of vertical ventilation.

Finally, account must be taken to the emission of photochemical oxidants by certain tree species that have to be excluded from critical areas. These are issues that have hardly been taken into account in the “classical” city and open space planning.

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