Vegetation & the Urban Microclimate

Improving human thermal comfort with urban greenery

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1 Introduction

In high-density cities, land can be scarce and thus vegetation can often be neglected in the public space. Even in many tropical cities, urban greenery is limited. Natural vegetation and the permeable soil have been replaced by high-rise buildings, asphalt, and concrete. Urban growth tends to decrease the natural green areas. Insufficient green infrastructure in a city, or the lack of it, can have many negative impacts. These can be low air quality, recurrent flooding, and an increase in urban heating and urban heat islands (Emmanuel, 2016).

Vegetation is an integral part of creating nice and resilient cities and it contributes to numerous positive effects. Urban greenery improves the biodiversity in the city, creates a nice streetscape that many people enjoy and provides recreational spaces. It also has a mitigating effect on natural disasters and an influence on the microclimate of the urban space (Emmanuel, 2016).

Comfortable microclimatic conditions is an important aspect for people wanting to spend time outside in a city. Vegetation is definitely not the only urban element that has an impact on the microclimate. The form and material of the built environment, as well as urban functions, also influence it. But vegetation is the most versatile way to modify the microclimate (Oke, 2017). Therefore it is important to make use of vegetation and utilize its good qualities.

This paper will discuss design strategies for urban greenery regarding the microclimate, focusing on high-density tropical cities. I will discuss different vegetation typologies and how they can improve the urban microclimate, resilience, and mitigation. I will also reflect on my experiences from the field trip to Manila, Philippines, in February 2018 as a part of the Urban Shelter master course at Lund School of Architecture.

Figure 1 & 2. Urban greenery in Singapore. The street trees with wide canopies provide shade and improve the microclimate. (Yury, 2016)

2 Literature Review

Microclimate

Microclimate is the climate of a small space, which differs slightly, but sometimes substantially, from that of the surrounding area. In an urban environment, this space may range in size from several kilometers wide down to a few centimeters. The microclimatic conditions are affected by the physical environment of the surroundings along with the climate of the region. Things in a microclimate that differ from the surroundings may be radiation, wind flow, humidity and air temperature. (Erell et al., 2011)

The form of the built environment and it's materials has a huge impact on the microclimate of a site. The urban climate consists of numerous microclimates that individually can be managed through design (Oke, 2017). For example, a high-rise concrete building surrounded by dark asphalt provides different microclimatic conditions than that of a low-rise wooden house surrounded by a wooden deck. Even urban functions influence the microclimate, as a highway with a traffic jam creates a different microclimate than a pedestrian street.

But what is a pleasant microclimate? The thermal comfort zone comes from a combination of different environmental factors creating a climate that a majority of people experience to be comfortable. Thermal comfort is based on the human experience and can be defined as *"a condition of mind that expresses the satisfaction with the thermal environment"* (Johansson, 2006, p. 46).

The environmental factors that affect the thermal comfort are air humidity, air speed, air temperature, and radiation. Besides that, two personal variables influence how we experience the thermal environment; clothing and level of activity (Johansson, 2006). The personal variables lie beyond the control of the planner, but all of the environmental factors can be influenced by urban design.

Urban Heat Island

In high-density cities, air temperature is usually higher than the surrounding rural or suburban air temperatures. This is called the urban heat island (UHI) effect and was first observed by meteorologist Luke Howard in London 1833 who noticed that the city was warmer than its surroundings at night (Ng, 2010). Since Howard's first observation a lot of research has been done and the UHI effect is now a well-understood phenomenon.

The main reason for the UHI effect is rapid urbanization and the replacement of natural landscapes with huge hard surfaces. Building facades, roads, and pavements store heat and re-radiate solar energy to the surroundings. The UHI is enhanced by the lack of moisture due to the impervious hard surfaces that have replaced the permeable soil which could hold rainwater (Ng, 2010).

The lack of vegetation means a lack of natural cooling of the air through evapotranspiration. Evapotranspiration is the natural process where plants transform water from liquid to gas which leads to a lower leaf temperature, lower air temperature and higher humidity (Santamouris and Kolokotsa, 2016). Heat generated from human activity also contributes to the UHI effect in the city. The greenhouse effect of pollutants combined with the heat from combustion engines and air-conditioning increase the air temperature (Ng, 2010).

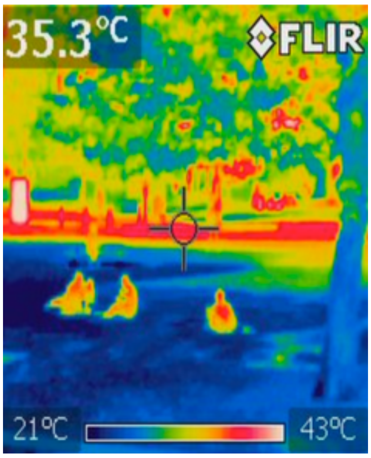
The UHI effect can raise the urban air temperature by as much as 10 ^{O}C. This, of course, can cause a lot of problems, especially with the presence of air pollutants. Heat islands can cause the accumulation of smog, put the human health at risk and damage the natural environment. In addition, UHI can cost a lot of money for house owners because of the increased amount of energy it takes to cool buildings in the city (Ng, 2010).

Urban greenery

Through purposeful design, we can control the microclimate of a site to a certain degree and hopefully reduce the UHI effect and generate a comfortable urban environment. As mentioned earlier vegetation is the most versatile design tool we have to influence the microclimate. No other urban element can alter both airflow, drainage, erosion, evaporation, noise levels, air pollutants, air temperature and radiation (Oke, 2017). So it's essential to integrate vegetation in the urban planning if we want to create a pleasant microclimate in a city.

Urban greenery can come in many forms. It can be divided into five main typologies; urban parks, street trees, landscaping within the vicinity of buildings, green roofs, and vertical landscaping (Ng, 2010). The first four typologies can reduce the ambient air temperature while vertical landscaping on facades mostly affects the surface temperature of the building (Emmanuel, 2016).

Vegetation mitigates urban warming through shading, which reduces radiation exchange, and evapotranspiration, the evaporative cooling explained earlier. The heat mitigation effect of plants is complex and can depend on different things. These factors can be the size of the plant, type of species, water availability, meteorological conditions, soil, the canopy physical structure, and the total size of the continuous green area (Emmanuel, 2016). In general, the temperature difference between a continuous green area and the adjacent urban area increases with the green area size (Erell et al., 2011).



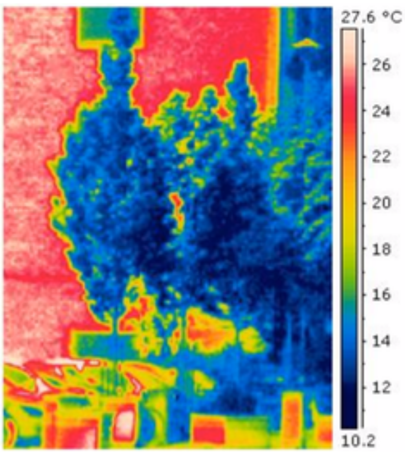


Figure 3 & 4. Pictures taken with a thermal camera show how the shade from the trees cools the ground. On the right, we can see the cooling effects of evapotranspiration in the canopies. (Ennos, 2015)

The Park Cool Island (PCI) is a green urban area which, because of the vegetation, has a lower temperature than the built-up surroundings. PCIs usually form in medium to large-sized parks which may have a considerably lower air temperature than the neighboring built-up area. Studies have shown that PCIs can be as much as 7 ^{O}C cooler in ideal conditions. Different types of parks form PCIs during different times of the day. If there is a lot of soil moisture and shading from trees the relative coolness usually peaks in the afternoon or early evening. And if the park is dry and has few trees to provide shade the relative coolness peaks at night (Erell et al., 2011).

Table 1: Characterization of Park Cool Islands (PCIs). (Erell et al., 2011, p.169)

	Daytime PCI	**Night-time PCI**
Type of park	Irrigated park with substantial tree cover	Dry parks with sparse tree cover
Mechanisms involved	Evaporation and shading: trees shade the surface, while grass is typically cooler than paved surfaces if it is well irrigated	Long-wave radiant cooling: sky view factor close to unity
Temporal pattern: time of maximum intensity	Afternoon (forest type) or early evening (garden, savannah and multi-use types)	Several hours after sunset

The cooling effect of vegetation is usually limited to the planted area itself. But if the green area is large enough, and depending on the wind conditions, the cooling effects can be felt beyond the park edge. Temperatures gradually increase with the distance from the park and the temperature difference can be seen up to a distance of about one park with. If the green area is small and perhaps limited to road trees or small planted plots the effect of the microclimate is often very local (Emmanuel, 2016).

Resilience and low-carbon cities

In *World Cities Report 2016 Urbanization and Development: Emerging Futures* UN-Habitat expresses its concern over how climate change impacts can compound one another in the future and making the disaster risk management more difficult (UN-Habitat, 2016). Therefore cities need to build resilience against extreme events such as droughts, heat waves, and heavy rainfall. To do so UN-Habitat proposes *”a human rights-based approach to the urban environment”(UN-Habitat, 2016, p. 85)* that should emphasize our dependence on clean and abundant resources. They declare that urban areas worldwide need to respond to the demand for decarbonization and rationalize the use of resources. In the report, UN-Habitat state that *”low-carbon cities and raising standards of urban resilience in the future”(UN-Habitat, 2016, p. 85)* are two main objectives to strive for. Though not mentioning vegetation specifically in the policy points related to this, urban greenery can certainly help in building resilience and creating low-carbon cities.

3 Argument, Critique and Discussion

Building green cities is a necessity, not only for comfortable urban warming mitigation, biodiversity and water management. But also, as UN-Habitat mentions, as a way of dealing with climate change. The many ways in which urban vegetation can contribute to resilience and mitigation, both on a local and global level, is incredible. It is a major asset for us to use when creating urban resilience. The good effects of vegetation make it to a perfect tool to use in the designing of the resilient cities of tomorrow.

Even in cities that have a lot of green infrastructure, the distribution of greenery in the city can be non-uniform and not all can enjoy the benefits. Using Manila as an example, I noted that the middle-class areas we visited during our field-trip had community parks and gardens while the poorer areas were usually lacking sufficient urban greenery. Many neighborhoods felt completely deprived of vegetation. As with many other things, urban greenery and the environmental services it provides are in certain cities limited to wealthier neighborhoods. The social and economic status of the residents is reflected in the outdoor environment. I don't have an answer to have we can accomplish an equal environmental quality and spatial distribution of greenery in this kind of city. But it is important to have in mind that the benefits of green infrastructure should be for all to enjoy.

Land costs money and in a process of rapid urbanization, large urban parks can be seen as a luxury. With high property prices and a heavily built-up environment sometimes small green areas are preferred from the planning point of view. Though not as effective in heat mitigation as large green areas, small green plots strategically arranged or grouped within the vicinity of buildings is the way to go in high-density cities (Emmanuel, 2016). Urban meteorologists agree with that. A study showed that a distribution of several small parks in dense areas is more effective than one large park. Beside park distribution, the same study also looked into the optimal size of urban parks from a microclimatic point of view. They found that a park width of seven times the height of the surrounding buildings is a good low limit to follow (Lenzholzer, 2015). A width below that isn't as effective in cooling the air and spreading it to the neighboring area.

To optimize the transport of the cool park air into the surroundings it is very important not to over-build at the park edge. Even dense vegetation on the perimeter of a park can block the airflow. Looking at the wind-directions of the site you can strategically plan to enable cool park air to flow far into the surroundings. Swedish scientists did a study of a

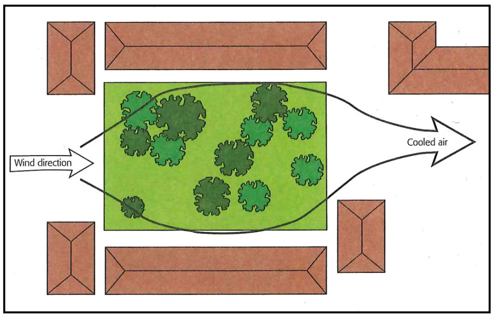


Figure 5. Cool park air move into the surrounding neighborhood. (Lenzholzer, 2015)

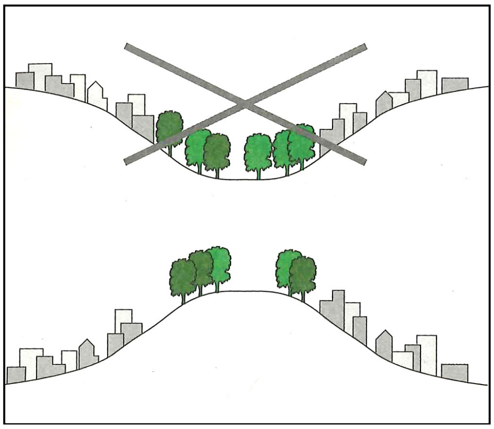


Figure 6. Ideal distribution of greenery in a hilly terrain. (Lenzholzer, 2015)

large park (150 hectares) in Gothenburg, measuring the cooling effect beyond the park edge. They measured a remarkable 6OC cooling effect up to 1100 meters from the park edge (Lenzholzer, 2015). So it is possible to use urban planning as a way of creating neighborhoods that make use of the PCI effect.

To further improve the potential of making use of the cooling effect, one can look at the topography when planning a neighborhood. If you build green areas on the highest points, the heavier, cool park air can stream downhill and reduce the temperature of the built-up surroundings. But if you do the opposite and create green areas at a lower elevation than its surroundings, the cool park air is locked and can't get anywhere. To plan green areas based on the topography is, of course, more effective where the terrain is very hilly (Lenzholzer, 2015).

It is also important to look at the surrounding functions and plan the urban greenery with that in mind. If there are many people in the neighborhood on daytime, for example in office areas or city centers, the greenery should be focused on daytime cooling. Looking at the different kinds of PCIs, we can see that irrigated parks with a substantial tree cover are preferable for cooling during the day. But if you design a park in a residential area where nightly cooling is more important it is better to have a sparse tree cover. Open, green surfaces cool down quickly at night which is favorable here. Mixed-use areas require a mix of vegetation with both trees and open lawns.

4 Urban Shelter Design

In this section, I will go through three typologies of urban greenery; urban park trees, street trees and green roofs, since they have the biggest impact on the urban microclimate. I will list their microclimatic effects and talk about maintenance, planting, and some design strategies.

Urban park trees

Trees in parks usually don't require a lot of maintenance and the planting is rather simple. Things should be fine as long as there is enough space for the roots and the soil conditions are sufficient. You have to plan the park and the surroundings based on things mentioned earlier, as topography, surrounding functions etc.

From a planning perspective, urban parks can meet opposition in high-density cities due to overheated property markets and land-use constraints. This can limit the possibilities of creating large-scale green areas in these cities (Emmanuel, 2016).

Good microclimatic effects: Shadows from trees can reduce the solar radiation on the ground beneath by as much as 50 percent. How much radiation the tree intercepts strongly depends on the chosen species and its canopy size and density. In addition to reducing radiation trees reduce air pollution as well as lowering the ambient air temperature through evapotranspiration. Besides the good microclimatic effects, trees can increase biodiversity and produce fruits and timber. Furthermore, buildings surrounded by trees and vegetation can get a higher real estate value (Lenzholzer, 2015).

Bad microclimatic effects: No real disadvantages for the urban microclimate. However, a dense tree cover can block off radiative cooling at night and retain heat under the canopy level (Erell et al., 2011).

Street trees

For street trees the correct placement is key. The height-width ratio and the orientation of a street can vary a lot so there is no universal street tree solution. The sun path is also different depending on the geographical location. These unique conditions must be taken into consideration. When choosing tree placement there is a need to analyze where people

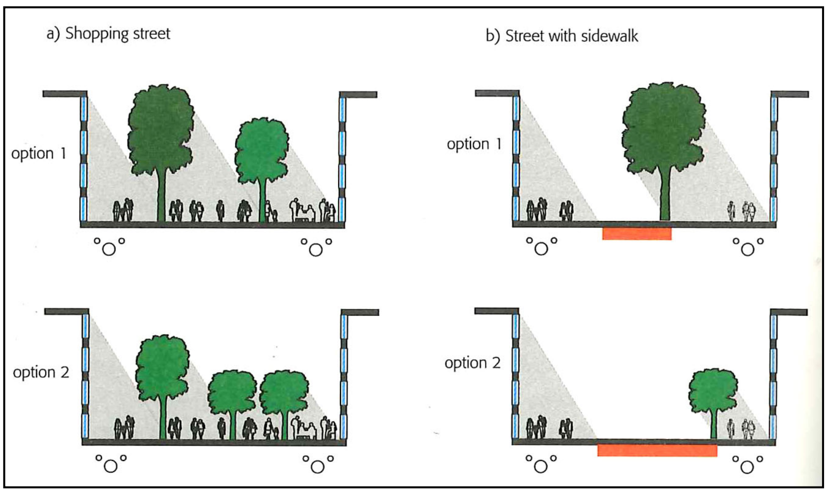


Figure 7. Sections of different solutions for street trees. (Lenzholzer, 2015)

circulate and stay, and which parts of the street that needs shading. The placement must not interfere with underground utility lines and traffic lanes. The trees need to fit the street space and provide big enough shadows without impairing the daylighting in the adjacent buildings.

Street trees require more maintenance than park trees due to more stress factors, such as heat and pollutions. Pruning and cleaning up leaves are necessities that can take up a lot of work. The planting of street trees is more difficult than the planting of park trees. It is a specialist work and the planting sites often require systems for irrigation and aeration (Lenzholzer, 2015).

Good microclimatic effects: The same microclimatic advantages as for park trees apply.

Bad microclimatic effects: Trees can sometimes interfere with the air exchange of the street and the ventilation of the adjacent buildings. If the canopies obstruct the airflow by taking up a large part of the street canyon, air pollution from traffic can be retained on the street level and the concentration of pollutants may rise. Thus, street trees sometimes need longer distances between them. Longer distances between the trees will obviously reduce the shadow effect (Erell et al., 2011).

Green roofs

The effect green roofs have on the urban microclimate depends on the thickness of the substrate, level of irrigation and what kind of vegetation is used. Sedum roofs do usually not cool the air through evapotranspiration. However, intensive green roofs with a lot of vegetation can cool the air. If a mix of different types of vegetation is used the cooling can come from both shading and evapotranspiration.

Green roofs often need a strong construction that can take the high-pressure load. So installment on existing buildings is normally not possible. The weight of the green roof needs to be calculated for the construction of new buildings. The thickness of the substrate layer varies and is at least 25 cm for perennials and a minimum of 80 cm for trees.

Intensive green roofs need a lot of maintenance, both regular check-ups and weeding need to be done. During dry periods green roofs can require a lot of irrigation.

Good microclimatic effects: Green roofs have a huge impact on the surface temperature of the roof. A study in New York measured a 33°C lower surface temperature on a green roof compared to a conventional black roof. However, a temperature reduction of around 20^{O}C is more normal. Even though the impact on roof surface temperature is big, green roofs have to be used to the largest possible extent to cool the ambient air temperature. Green roofs mostly affect the air temperature above the roofs and will usually not increase the thermal comfort for the people on the street level.

Besides the cooling of the air, the insulation the green roof provides helps to lower the indoor temperature. This can result in big energy savings for air conditioning (Lenzholzer, 2015).

Bad microclimatic effects: None.

5 The Role of Architects

To design buildings and urban spaces that are sustainable is a huge part of the responsibility of architects. We need to advocate for and try to implement good solutions. Even if there are developers or politicians that don’t see the point we should still do our best to create sustainable buildings and cities.

As mentioned repeatedly in this paper vegetation can play an important role in the building of the sustainable cities of tomorrow. Architects need to be able to argue for why urban vegetation is important, both from a microclimatic perspective but also on a global scale with climate change as a major challenge. Besides the climatic effects, we should argue for the good effects of urban greenery when it comes to things like biodiversity, stormwater management and the well-being of people.

Guidelines like the ones mentioned in this paper can help architects include urban greenery in the design process. Of course are there factors that we can’t influence as individual architects. We don’t typically choose the site for a project and we don’t make the laws and regulations regarding green areas in cities. Therefore it is crucial that we work in teams with architects and non-architects to inform about the good effects of greenery and what can happen when the green infrastructure in urban spaces is insufficient. We should try to improve the way planners and developers deal with urban greenery.

Maybe I’m wrong but I can imagine that many developers don’t want to choose unconventional, and sometimes more expensive, methods if they are not completely convinced about the good effects. Solutions that are more favorable in the long run may scare off some developers. Hence architects need to design with a longer time period in mind and try to think holistically about urban greenery, even if others don't.

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