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The Impact of Urban Green Spaces on Climate and Air Quality in Cities

Abstract

Every urban landscape is significantly different from any other environment. These urban landscapes having green spaces decreased are mainly made of artificial surfaces which have unique physical attributes unlike any other landscape surface. The combination of dominant artificial surfaces and decreased vegetation creates an urban climate which influences the air quality, outdoor thermal and human comfort. Although, half of the Earth's population live in cities, the importance of urban air quality and climate issues do not have a high impact on urban planning processes despite the fact that urban weather and climate is essential for human well-being.

The main objective with the present study is to investigate how urban green spaces impact on the air quality and the microclimate in cities. Each section examines an urban climatic process and how this process differs in an urban environment which includes vegetation. The final section discusses how urban green spaces can help ease the local consequences of climate change..

Key words

Urban climate; Urban air quality; Urban green space; Urban landscapes; Environmental planning

1. Introduction

Urbanisation has a major effect on landscape surfaces: it is replacing vegetated areas with mostly impervious artificial surfaces (GILL, S. E. *et al.* 2007). It has been recognised since the early 1800s that the main characteristics of vegetation interacts with climate (BONAN, G. B. 2002), for example plants can provide ecosystem functions like shading and cooling through evapotranspiration (GILL, S. E. *et al.* 2007). However, the impact of impervious urban surfaces (cities) on climate significantly differs from those of vegetated (countryside) areas. These differences modify surface energy balance through change in absorption and reflection of solar radiation (BOWLER, D. E. *et al.* 2010). Beside energy, they also tend to alter the water cycle between land and atmosphere. Impervious urban surfaces block water from infiltrating the soil, and vegetation also cannot intercept water, if it is absent. This less effective rainwater interception and storage generates more runoff and reduces evapotranspiration in urban areas (BONAN, G. B. 2002; GILL, S.E., *et al.* 2007).

These effects of the urban environment lead to altered climatic conditions in cities which may have negative impacts on the well-being of urban dwellers (BROWN, C. – GRANT, M., 2005). Present demographic forecasts show that human populations are becoming increasingly urbanised: Today, in the second decade of the 21st century, approximately 50% of the global human population lives in cities and this rate is expected to rise in the next 50 years. Therefore now—with the well-known urban air pollution—negative impacts of urban climatic conditions will also affect more and more people around the globe (BOTKIN, D. B. – BEVERIDGE, C. E. 1997; GRIMM, N. B. *et al.* 2008). With the predicted effects of climate change, urban climatic conditions are becoming an even more pressing problem. Regional consequences of changing climate can be more serious in an urban area, particularly the problem of increasing temperature, but several studies have showed that anticipated negative impacts of climate change in urban areas can be eased by properly vegetated areas (GILL, S. E. *et al.* 2007; BOWLER, D. E. *et al.* 2010).

Before further investigation of the subject, the definition of urban green spaces should be clarified: *"Urban green spaces are public and private open spaces in urban areas, primarily covered by vegetation which are directly (e.g. active or passive recreation) or indirectly (e.g. positive influence on the urban environment) available for the users."* (BAYCAN-LEVENT, T. – NIJKAMP, P. 2009). However, the definition of urban green spaces differs from country to country; therefore, this is not a categorical declaration of the concept, merely one which was carefully selected for this paper. Since this review is primarily written for city planners, non-governmental organisations, scientists and other actors who contribute to urban spatial planning and implementation to help them understand more accurately how the climatic system works in cities, and how vegetated surfaces can ease the arising problems caused by urban climatic conditions. Planning and implementation usually approach the concept of green spaces from the aspect of users; therefore, the author of this article finds this definition the most appropriate for this paper.

2. Aims of the study

This paper is an overview that summarises part of the currently available literature on urban climatic conditions, urban air quality, and the expected impacts of climate change on urban climate and, furthermore, how these conditions can be altered by urban green spaces. With expectedly increasing problems in the urban climatic environment, urban climatic conditions should be an issue of higher importance in urban planning. The main purpose of this study is to help urban planners, governments and other specialists who will form the spatial future of urban environments to have a better understanding of the urban environment and the importance of vegetated areas in it. This knowledge could be useful in practice and it might contribute to the right decision making while developing a surface which may modify local urban climatic conditions. The article might become useful for some research groups as well, especially ones doing research on urban spatial planning (for example the *European Commission Seventh*

Framework Programme, *Project Green Surge*[1]) and working with scientists with many different areas of expertise.

The article presents the behaviour of energy exchanges and flows, advection characteristics, humidity, precipitation and runoff in urban environment, and it also discusses urban air pollution, the heat island phenomena and the expected effects of climate change in cities. Each section of the article shows how different vegetated areas might alter these examined climatic properties.

3. Research methods

This study overviews findings of several researches on urban climatic conditions, impacts of urban vegetation on these unique climatic conditions and, moreover, how climate change interferes with these. This paper does not contain any empirical research results. The aim is to give a proper overview on the main findings and expert opinions of the most relevant literature on the discussed subjects.

To find proper and the most relevant studies in these topics, search engines were used, in particular *Google*[2] and *Google Scholar*[3] Many different kind of search key words were used—because the article concerns several areas of different disciplines—such as "urban climate", "urban atmosphere", "urban heat island", "air pollution in cities", or "climate change in cities", "climate change adaptation in cities", "impacts of evapotranspiration", "ecology of cities", "climatic effect of urban vegetation", "urban green areas" and "urban greening to cool cities". The articles were searched for on several websites, mostly on *ScienceDirect*[4] and *SpringerLink*[5]. Each list of references was also thoroughly examined for every study that proved to be a useful material for this literature research paper. The articles which cited the actual paper were searched for, too.

[1] http://greensurge.eu/
[2] www.google.com
[3] http://scholar.google.hu/
[4] www.sciencedirect.com
[5] http://link.springer.com/

Since this study is a review, results are seen under the section 'Discussion'.

4. Discussion

Unique climatic conditions in urban areas are results of the built environment formed by varied artificial surfaces that have different water and energy receipts and losses from those of rural areas. Quality, quantity and geometrical characteristics of the built surfaces have significant impact on local climatic conditions, as well. The urban climate is also characterised by the lack of vegetated areas and the continuous and intensive anthropogenic activity like indoor heating and cooling (SMITH, C. – LEVERMORE, G. 2008). This environment results in a climate which is specific to urban areas. Cities on the northern hemisphere have average 2°C higher temperature, 12% less solar radiation, 8% more clouds, 14% more rainfall, 10% more snowfall and 15% more thunderstorms annually compared to the conditions of rural environments (TAHA, H. 1997).

4.1. The planetary boundary layer above cities

With the surface altered and climatic conditions modified, the planetary boundary layer above cities is changed, as well. The structure of this layer is primarily determined by the heterogeneity and physical attributes of artificial surfaces and the geometry and density of the built environment (ARNFIELD, A. J. 2003). The urban environment results in a unique boundary layer above cities. This is a sub-layer of the planetary boundary layer (PBL) and is called urban boundary layer (UBL). To properly examine its structure, see *Figure 1*.

The urban boundary layer (UBL) is characterised by strong turbulences enhanced by the roughness of city surface and long wave radiation emitted by urban surfaces (ARNFIELD, A. J. 2003). The lowest layer of the UBL is called urban canopy layer (UCL) which is located between the ground and the rooftop levels (ARNFIELD, A. J. 2003; COLLIER, C. G. 2006). In the UCL the airflow and energy exchanges are determined by microscale, site-specific characteristics and processes (ARNFIELD, A. J. 2003). The urban canyon (UC) is a special type of UCL which has tall buildings tightly next to each other along both sides of the street. Airflow and energy exchanges are defined here like in the UCL, but the flows are mostly horizontal (ARNFIELD, A. J. 2003).

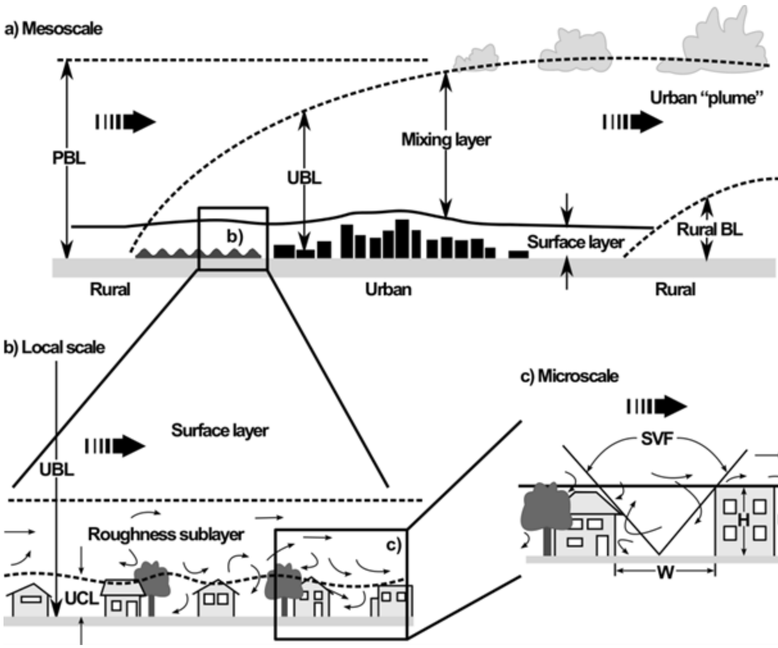

Figure 1 – Structure of the urban boundary layer. SVF is the sky view factor

Source: COLLIER, C. G. (2006)

The next layer upwards is the roughness sub-layer. The most determinative here is not the height and vertical temperature gradient of urban elements, but the horizontal distance scale determined by inter-element spacing. Strong vertical shear, large turbulence intensities and local advection resulting from extreme heterogeneity are common in this layer (ARNFIELD, A. J. 2003). The significance of individual roughness elements decreases above the roughness sub-layer because of the blending effect of turbulent mixing (ARNFIELD, A. J. 2003). In this layer, air and energy flows are determined by the cumulative effects of a larger part of the urban surface; therefore, the height of turbulent fluxes is constant (COLLIER, C. G. 2006).

The urban mixed layer (UML) fills the rest of the UBL upwards. Individual buildings and streets alone do not have much impact on the flows and structure of the UML; these are rather determined by mesoscale urban processes and elements. With low wind velocity the UML may string out above rural areas downwind of the city even for hundreds of kilometres long, and therefore it is usually called urban "plume" (COLLIER, C. G. 2006).

The microclimatic conditions of urban areas and the climate of entire cities are defined by physical interactions and processes between the urban surfaces and the layers presented above (ARNFIELD, A. J. 2003; COLLIER, C. G. 2006).

4.2. Energy exchanges and flows in urban environments

On the *Earth's* surface, the main source of energy in the climatic system is the *Sun*. Incoming solar radiation reaches the atmosphere and, as it passes through, some of it may be absorbed by molecules in the air, some of it is scattered in all directions. The scattered radiation is called diffuse and the non-scattered is called direct solar radiation (BONAN, G. B. 2002).

As incoming solar radiation reaches the surface, it is either absorbed or reflected back to the atmosphere. The amount of radiation that reaches the surface depends on the cloud coverage, air pollution and the shading objects on the surface (BONAN, G. B. 2002).

The cloud coverage is a very important factor of how surface and near-surface air temperature develops that and it has opposite effects during the daytime and at night. During the daytime part of the incoming solar radiation is absorbed and reflected by the clouds, therefore the surface cannot absorb as much long wave radiation as without or with a less extent cloud cover. On the other hand, nocturnal cloud cover leads to an opposite effect, it absorbs the long wave radiation emitted by the surface, hence keeps a significant amount of heat near the surface (RAMANATHAN, V. *et al.* 1989).

The amount of incoming short wave radiation that reaches the surface in urban areas is typically 2–10% lower than in rural areas. This is primarily caused by higher pollutant concentration in the city air. Aerosol particles—which low atmospheric pollution is rich in—are bigger and have darker colour than other particles in the atmosphere and, therefore, have a significant shading effect. The other main reason of the lower amount of short wave radiation in the urban boundary layer is that less radiation can be reflected from the surface. This happens because most urban surfaces have significantly lower albedo values than rural, vegetated surfaces (OKE, T. R. 1982). *Table 1* shows albedo values of a few typical urban surfaces.

Table 1 – Some typical albedo values of urban surfaces

Source: NAGY, I. (2008)

Surface type	Albedo
Street asphalt	0.05–0.02
Concrete wall	0.1–0.35
Concrete wall covered with white paint	0.71
Brick wall	0.2–0.4
Freestone	0.2–0.35
Window glass when incoming radiation's incidence is >60°	0.08
Window glass when incoming radiation's incidence is 10°-60°	0.09–0.52

In the urban boundary layer, significant part of incoming long wave radiation is absorbed by atmospheric pollutants and city surfaces then re-emitted into the air (OKE, T. R. 1982). Due to lower albedo values, urban surfaces can absorb more long wave radiation than green spaces (TAHA, H. 1997). There is also surplus long wave radiation emission from urban surfaces which is derived from anthropogenic activity like indoor heating. Emitted radiation can be absorbed by air pollutants and re-emitted to the atmosphere once again (OKE, T. R. 1982).

In the urban canopy layer, conditions slightly differ from those of the urban boundary layer due to the geometry of surface elements. There are complex shading and reflection patterns which depend on the height of buildings and the orientation of streets. This can create radiative trapping within the canopy layer and result in more solar radiation absorption than expected based on the albedo and the reflectivity of surface materials (BONAN, G. B. 2002).

Table 2 presents how urban and rural environments differ in surface albedo values. This table shows the mean monthly albedo values of different types of urban and—for comparison—rural land-coverage in February, April, July and September. The values are based on satellite data analysis.

Table 2 – Mean monthly albedo values of different types of urban and rural land coverage.

Category names: CDWN – city downtown, HDR – high density residential, COUT – outlying city, MDR – medium density residential, LDR – low density residential, PFOR – forested park, FDEC – deciduous forest, FEVG – evergreen forest, WFOR – forested wetland, WNF – non-forested wetland, AG – agriculture, RANG – range, PNF – non-forested park, L – lake
Source: BREST, C. L. (1987)

	Urban area			Suburban area		Tree vegetated area				Non-tree vegetation				Water surface
	CDWN	HDR	COUT	MDR	LDR	PFOR	FDEC	FEVG	WFOR	WNF	AG	RANG	PNF	L
Feb.	0.089	0.089	0.118	0.126	0.118	0.121	0.108	0.095	0.093	0.078	0.143	0.116	0.200	0.028
Apr.	0.105	0.100	0.130	0.137	0.137	0.150	0.140	0.125	0.117	0.103	0.142	0.145	0.201	0.02
July	0.117	0.114	0.144	0.150	0.156	0.167	0.177	0.163	0.169	0.192	0.177	0.187	0.203	0.017
Sept.	0.106	0.105	0.134	0.138	0.137	0.145	0.147	0.135	0.137	0.143	0.169	0.152	0.203	0.023

Radiative trapping and the amount of radiation that reaches the surface greatly depends on the *Sky View Factor (SVF)* which measures the fraction of the sky that can be seen from ground level. For an infinitely long street sky view factor is

$$\psi = \cos(a)$$

where a is the angle defined by

$$\tan(a) = 2\frac{H}{W}$$

where H is building height and W is street width (BONAN, G. B., 2002). *Figure 2* shows sky view factor of three types of urban area.

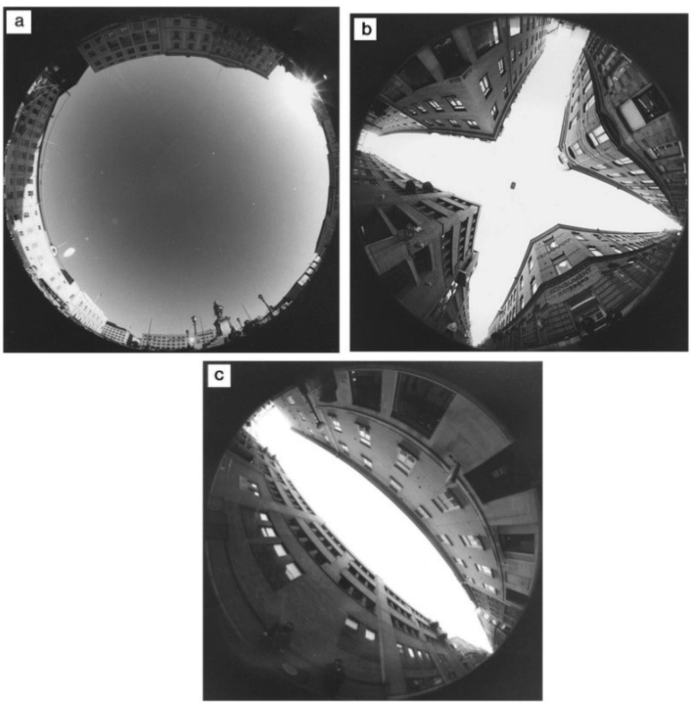

Figure 2 – Three 180° fisheye photographs of particular sites of Göteborg and their SVF.

(a) Open square, SVF=0.93; (b) street intersection, SVF=0.47; (c) street canyon, SVF=0.29

Source: ELIASSON, I. (2000)

Another significant aspect of urban energy balance is the ratio of latent and sensible heat. Ratio of latent heat fluxes decreases with the increasing ratio of artificial surfaces (OKE, T. R. 1982; BONAN, G. B. 2002) because these surfaces are impervious and cannot keep as much water in the local climatic system as vegetated surfaces can (GRIMM, N. B. *et al.* 2008).

4.2.1 Energy exchanges and flows in urban environments with vegetated areas

One of the significant impacts of vegetated areas both on urban and rural climate is that surfaces planted with trees have less diffuse and direct solar radiation income than open spaces with herbaceous plants, asphalt or other artificial surfaces. Direct radiation values differed more between tree-covered and open spaces than diffuse values; therefore, trees have greater influence on direct radiation income (TOOKE, T. R. *et al.* 2011).

Part of the incoming solar radiation which impinges upon vegetated surfaces is absorbed by them.

Plants use some of this absorbed energy for photosynthesis which process has a heat lowering effect on the air nearby. However, the efficiency of the energy transformations of photosynthesis is relatively low; so it has an effect of no significant consequence on air temperature (GIVONI, B. 1991).

Most of the absorbed solar radiation is used in evaporation (GIVONI, B. 1991) which occurs when unsaturated air and any kind of wet surface, thus also leaf surfaces come in contact. The other significant energy consuming phase transition that comes into question about vegetation is transpiration. It occurs since plants move water of the soil actively into the air through their leaves (BONAN, G. B. 2002). The intensity of transpiration depends mostly on photosynthesis since it happens only when the microscopic pores (stomata) are open on leaf surfaces which CO_2 absorption occurs through. These stomata are only open during the daytime when surrounding climatic conditions are optimal for photosynthesis (BONAN, G. B. 2002).

Evapotranspiration, as being an energy consuming process, has a significant effect on local air temperature while it increases the ratio of latent heat in the local climatic system (BOWLER, D. E. *et al.* 2010). The intensity of evapotranspiration is determined by the stomatal physiologies, the air temperature (when it is too hot or cold, stomata are nearly or utterly closed), humidity of the atmosphere (low humidity increases evapotranspiration) and by wind velocity. Low wind velocity is welcome as it dispatches the air with high humidity above the leaves and brings less humid air, therefore evapotranspiration can be increased. However, too high wind velocity can desiccate the leaves, hence when this condition occurs, stomata are closed (BONAN, G. B. 2002).

One of the most determining factors what controls the intensity of evapotranspiration is the amount of water that vegetation can absorb from the soil. In urban environments most of the rainwater cannot infiltrate the soil, therefore anthropogenic watering can be a crucial element of increasing latent heat ratio (ARNFIELD, A. J. 2003).

Trees and bigger shrubs also have a passive cooling effect on local climate other than evapotranspiration: they block part of incoming net solar radiation from the surface through shading (SHASUA-BAR, L. – HOFFMAN, M. E. 2004). The rate of this cooling effect depends on the type and density of vegetation, geometry of built-up areas, albedo, and nearby traffic load (SHASUA-BAR, L. – HOFFMAN, M. E. 2004).

The shading effect of trees can be measured by the sky view factor of the vegetated surface. Tree canopy can significantly reduce an area's SVF *(Figure 3)* (COHEN, P. – POTCHTER, O. – MATZARAKIS, A. 2012).

When the energy budget of an urban area is studied, albedo of the urban surfaces has to be examined. Low albedo values in cities can be aided by paying attention when picking colours of buildings and surfaces. For example during constructions and renovation the colour of outside walls and other surface materials should be chosen to raise albedo values where needed (SHASUA-BAR, L. – HOFFMAN, M. E. 2004). Vegetated areas can also ease this problem by having higher albedo values than those of the average built environment. Areas covered with mostly herbaceous plants like spontaneous vegetation or cultivated lawns have higher albedo values than areas overgrown mainly with trees (ROBINSON, S. L. – LUNDHOLM, J. T. 2012).

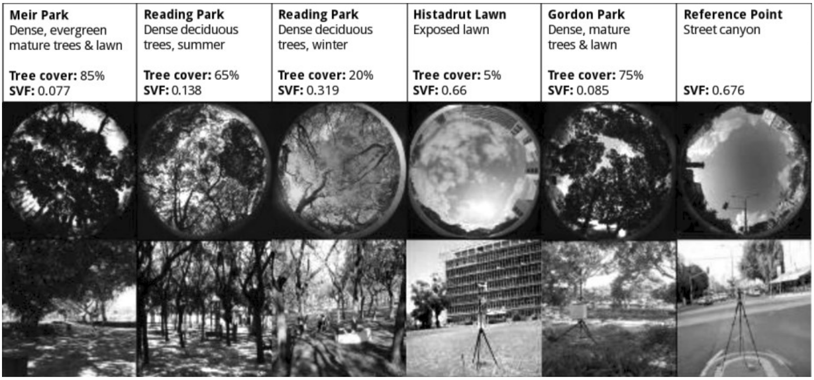

Figure 3 – Some typical urban green spaces with their rate of tree-coverage and sky view factor in Tel Aviv

Source: COHEN, P. – POTCHTER, O. – MATZARAKIS, A. (2012)

Urban green spaces can have a great influence on local climatic energy budget through evapotranspiration, shading and providing higher albedo values. By only evapotranspiration, vegetation can result in a temperature 2–8°C lower in vegetated areas than in their surrounding urban, built environment (TAHA, H. 1997). Even small tree-covered areas and areas overgrown mainly with herbaceous plants can have an average 2–3°C cooler air temperature than their surroundings (HUANG, Y. J. *et al.* 1987).

Areas planted with trees can have the lowest SVF values and evapotranspiration capacity and they have higher albedo than the average surrounding built elements; therefore, they have the most significant cooling effect among urban green areas. The more extensive an area is and the more densely planted with trees it is, the greater its local cooling effect is (BONAN, G. B. 2002; SHASUA-BAR, L. – HOFFMAN, M. E. 2004; ROBINSON, S. L. – LUNDHOLM, J. T. 2012). Furthermore, trees are less sensitive to drought than grasslands; therefore, they cannot lose their ability to evapotranspirate as easily as open spaces planted with herbaceous flora can (GILL, S. E. *et al.* 2007).

4.3. Advection characteristics in the urban atmosphere

Direction and speed of wind in an urban climate are determined by the regional wind patterns, but it can be significantly altered in the urban environment (BONAN, G. B. 2002). When moving air reaches the city it meets roughness elements that are mainly buildings. They wake turbulences and decrease wind speed due to their large surfaces (COLLIER, C. G. 2006). Moreover, street geometry determines the wind direction (SMITH, C. – LEVERMORE, G. 2008) and is able to create areas with higher wind speed and eddy circulations (ELIASSON, I. 2000). However, relatively low wind speed can cause bad ventilation which can lead to unhealthy air quality in the city (ELIASSON, I. – UPMANIS, H. 1999). Street orientation can provide a great deal of help in avoiding poor ventilation. To reach this goal, optimal street angle to the prevailing wind direction should be 45° (SMITH, C. – LEVERMORE, G. 2008).

Temperature differences between the city and the surrounding rural or suburban areas and inside the urban environment can induce weak airflows (ELIASSON, I. 2000) which can turn into local circulations (BONAN, G. B. 2002). *Figure 4* shows two typical urban air circulations.

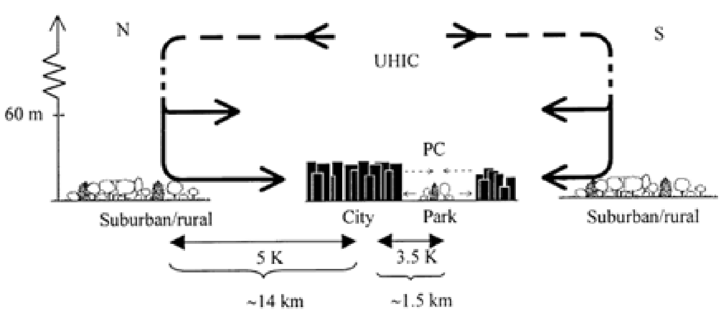

Figure 4 – Urban heat island circulation (UHIC) or country breeze and park circulation (PC) or park breeze

Source: ELIASSON, I. – UPMANIS, H. (1999)

Warmer air rising from the urban climatic system is replaced by cooler air from the surrounding rural area; therefore, circulation is induced in the urban boundary layer. This circulation is called country breeze (ELIASSON, I. 2000; BONAN, G. B. 2002) or urban heat island circulation (UHIC) (ELIASSON, I. – UPMANIS, H. 1999; COLLIER, C. G. 2006). Park breeze or park circulation (PC) is an outflow of cool air from parks towards the surrounding built areas (ELIASSON, I. – UPMANIS, H. 1999; ELIASSON, I. 2000).

4.3.1. How vegetated areas affect advections in urban atmosphere

Urban green spaces can affect local wind patterns such as speed by physically blocking the airflow. The extent of this impact depends mostly on the type of vegetation and on planting patterns. Green areas planted mainly with herbaceous vegetation allow the best ventilation conditions. These areas are disadvantageous where average regional wind speed values are high, especially in cold climates. Bushes mostly affect the airflow near the ground surface while trees impact on higher levels of airflow in the urban boundary layer (GIVONI, B. 1991).

An area with grass and scattered, isolated trees can concentrate the airflows in the canopy layer, while it improves ventilation near the ground level. This can be considered a rather positive effect in hot regions. Densely planted trees and shrubs, however, can significantly reduce wind speed. This can be quite advantageous under cold, windy climatic conditions (GIVONI, B. 1991).

Parks have lower average air temperature than surrounding built urban areas due to their impact on the local climatic system *(Chapter 2.1)*. In the urban canopy layer this temperature difference can induce an air circulation called park circulation or park breeze *(Figure 4)*. The circulation creates a weak airflow from the vegetated area towards the built-up areas (ELIASSON, I. – UPMANIS, H. 1999).

The park breeze is usually best developed between 2–3 hours after sunset and may reach a distance less than approximately 250 metres from the side of the park (ELIASSON, I. – UPMANIS, H. 1999).

4.4. Humidity of urban air and how urban green areas affect it

The decreased level of evapotranspiration and the low ratio of water absorption, which is normally caused by built surfaces, result in an urban air condition low in moisture. Beyond the ratio of urban green spaces, the humidity of air depends also on incoming solar radiation and city ventilation (NAGY, I. 2008).

Intensity of anthropogenic activity in urban areas can also influence the amount of water vapour in the local air system, since burning of fossil fuels increases the air humidity (SOUCH, C. – GRIMMOND, S. 2006). Evapotranspiration increases the humidity of air through active and passive vaporization (GIVONI, B. 1991; BONAN, G. B. 2002). However, the amount of moisture in the air affects the intensity of evapotranspiration, since, with the amount of water vapour in the air increasing, the water potential—which is a negative suction—decreases. Water is moving from higher to lower water potential; the greater difference between those two values is, the more intensive evapotranspiration is (BONAN, G. B. 2002).

4.5. Precipitation and runoff in urban environments

Urban climatic conditions can alter the characteristics of precipitation in the urban environment. The urban heat island circulation brings air rich in moisture—and has lower temperature than the surrounding rural areas do—in the place of the rising hot, dry urban air. However, the urban atmosphere can be highly polluted and have high concentrations of particulate condensation nuclei. These two conditions combined may result in increasing precipitation and greater cloudiness and fog in the urban environment (ELIASSON, I. 2000; PICKETT, S. T. A. *et al.* 2001; BONAN, G. B. 2002). Average annual precipitation can be higher in cities by 5–10% than in their surrounding rural areas (PICKETT, S. T. A. *et al.* 2001).

Some studies have shown that probability of precipitation is increasing during the week and it reaches its maximum at weekends. This is caused by higher concentration of air pollutants in the urban atmosphere from increased activity of manufacturing and transportation on workdays (PICKETT, S. T. A. *et al.* 2001; BONAN, G. B. 2002).

In cities surface runoff is increased from average 10% to 30% (PICKETT, S. T. A. *et al.* 2001). Rainwater turns to runoff in a higher rate due to reduced vegetated surface areas and the high rate of impervious surfaces like rooftops, streets or parking lots. The rainwater from surface runoff is quickly collected by sewers and other artificial drainage systems and transported into river channels. Thus it eliminates most of the precious water from the urban climatic system (BONAN, G. B. 2002). When intensive precipitation occurs, for example during thunderstorms, the drainage system can fill up quickly, therefore the chance of flood increases (BOTKIN, D. B. – BEVERIDGE, C. E. 1997). Furthermore, the quality of this collected runoff water can be very poor because it accumulates pollutants from buildings, roadways, and parking lots through its way to the drainage system (GRIMM, N. B. *et al.* 2008).

4.5.1. The impact of urban green areas on precipitation and runoff

Urban green areas may increase the probability of precipitation by emitting moisture into the urban atmosphere by evapotranspiration (GIVONI, B. 1991; PICKETT, S. T. A. *et al.* 2001).

In vegetated areas precipitation falls upon foliage, leaves and soil. These surfaces collect most of the rainwater that falls upon them, and when surrounding climatic conditions are suitable, evapotranspiration occurs (BONAN, G. B. 2002). Therefore, vegetated surfaces are more effective in rainwater storage and decreasing runoff than built-up areas. Its efficiency, however, depends on the type of soil and the vegetation that covers it (BONAN, G. B. 2002; GILL, S. E. *et al.* 2007). Trees can hold much more water than shrubs and herbaceous plants and they are the most effective in rainwater storage on sandy soils that water can infiltrate faster (GILL, S. E. *et al.* 2007).

In addition, vegetated areas intercept precipitation, hold water temporarily and return it into the climatic system due to evapotranspiration. These qualities of vegetated surfaces reduce surface runoff also by increasing infiltration into the soil (CAMERON, R. W. F. *et al.* 2012).

4.6. The urban heat island

The *urban heat island (UHI) phenomenon* means that cities often have higher air temperature than their surrounding rural areas (OKE, T. R. 1982). The value of this temperature difference is defined by urban geometry, surface characteristics, urban extent, intensity of anthropogenic activity and further regional climate factors (KIRCSI, A. *et al.* 2005; MCCARTHY, M. P. *et al.* 2010). The main suggested causes of the urban heat island are summarised in *Table 3*.

Table 3 – Suggested causes of the urban heat island

Source: OKE, T. R. (1982)

Layer	Altered energy balance terms leading to positive thermal anomaly	Features of urbanisation underlying energy balance changes
Canopy layer	Increased absorption of short wave radiation	Canyon geometry – increased surface area and multiple reflection
	Increased long wave radiation from the sky	Air pollution – greater absorption and re-emission
	Decreased long wave radiation loss	Canyon geometry – reduction of sky view factor
	Anthropogenic heat source	Building and traffic heat losses
	Increased sensible heat storage	Construction materials – increased thermal admittance
	Decreased evapotranspiration	Construction materials – increased 'water- proofing'
	Decreased total turbulent heat transport	Canyon geometry – reduction of wind speed
Boundary layer	Increased absorption of short wave radiation	Air pollution – increased aerosol absorption
	Anthropogenic heat source	Chimney and stack heat losses
	Increased sensible heat input-entrainment from below	Canopy heat island – increased heat flux from canopy layer and roofs
	Increased sensible heat input-entrainment from above	Heat island, roughness – increased turbulent entrainment

Built-up areas— that mainly form urban environments—can store a large amount of heat due to their high tendency to absorb thermal radiation and their generally low albedo (GRIMMOND, C. S. B. – OKE, T. R. 1999; SMITH, C. – LEVERMORE, G. 2008). Additionally, radiation emitted by built surfaces is reflected or absorbed again by buildings and air pollution, thus net losses of heat by long wave radiation remain low in urban areas and may increase the local air temperature (SOUCH, C. – GRIMMOND, S. 2006; SMITH, C. – LEVERMORE, G. 2008).

Intensity of the urban heat island is increased further by lower wind speeds, less evapotranspiration due the high rate of built surfaces, and anthropogenic activity. Air conditioning, industrial activity and transportation are additional heat sources in urban environments; furthermore, these activities induce weekly cycles in urban heat island intensity (WILBY, R. L. 2008).

Intensity of urban heat island is usually negligible during the day, but after sunset it reaches its maximum shortly (PICKETT, S. T. A. *et al.* 2001; SMITH, C. – LEVERMORE, G. 2008). Approximately 2–3 hours after sunset air temperature of the city can be up to 5–10°C warmer than in the surrounding countryside (Pickett, S. T. A. *et al.* 2001).

The UHI intensity decreases with increasing wind speed and cloud cover, and it is best developed in the warm seasons of the year during anticyclonic conditions (WILBY, R. L. 2008). The effect of UHI may be the contrary, if urban areas have higher rate of irrigated vegetation than surrounding areas do, for example in arid or semi-arid climates. Under these conditions urban air temperature may be cooler during the daytime than in the surrounding countryside (WILBY, R. L. 2008; SCHWARZ, N. *et al.* 2012).

Vegetated surfaces may help ease the problems caused by the urban heat island due to their advantageous impacts on the local climatic system. Further investigation in the subject can be found in *Chapter 8*.

4.7. Air pollution in cities

The atmosphere above urban areas is usually rich in air pollutants due to the intensive anthropogenic activities like burning fossil fuel and industrial activities (BERRY, B. J. R. 1990). In cities, transportation seems to be the most important source of air pollutants such as nitrogen monoxide (NO) and nitrogen dioxide (NO_2). This results in a higher level of tropospheric ozone (O_3) in the atmosphere of the city (MAYER, H. 1999). The concentration of ozone in the urban atmosphere is also determined by the emission of volatile organic compounds (VOCs) (WILBY, R. L. 2008). The O_3 in the atmosphere is produced in chemical reactions from precursors like nitrogen oxides and VOCs (DICKERSON, R. R. *et al.* 1997; MAYER, H. 1999). With high concentrations of ozone, and under certain climatic conditions, photochemical smog can develop which can cause several types of health problems for every being and dweller of the city (DICKERSON, R. R. *et al.* 1997; WILBY, R. L. 2008).

Aerosols are also important air pollutants due to their dangering effects on human health. These are solid or liquid particles not larger than 1–100 nm, and they are made of organic compounds, loose soot and other materials mostly derived from anthropogenic activities (SALMA, I. *et al.* 2012).

Air pollution can reduce incoming solar radiation by up to 20%; therefore, it can have a significant impact on local climatic conditions (ARNFIELD, A. J. 2003).

As mentioned in *Section 1*, when urban plume occurs, it can carry the pollution downwind above the surrounding rural areas (COLLIER, C. G. 2006).

4.7.1 Impact of vegetated areas on urban air pollution

Urban green spaces can influence urban air quality by filtering part of the pollution from the air. The capacity of the filtration increases with the amount of leaf surface, therefore deciduous trees are the most, while evergreen trees and grass are least efficient. With the positive effects on wind conditions, vegetated areas are able to strengthen city ventilation, thus they improve urban air quality (GIVONI, B. 1991).

However, urban green spaces planted with trees and shrubs are the most efficient in decreasing air pollution; grassy open spaces are still more efficient than open spaces covered with artificial surfaces. Little grass leaves make practices in the airflow near the surface drop down, causing a so-called 'lattice-effect'. If trees and shrubs were added to these urban grasslands, a larger volume of air would slow down and settle more of its dust supply (GIVONI, B. 1991).

Although, urban green spaces can significantly enhance urban air quality, in small areas they might cause more harm than good. For example, areas planted with willows or oaks can radically increase VOC (for example *isoprene*) concentration locally (WILBY, R. L. 2007).

4.8. Impacts of climate change in cities and how urban green spaces can help

Every city is exposed to the predicted effects of climate change and these may be more intensive in the urban environment than in rural environments. It is likely that the frequency of hot nights in urban areas is going to be increased by the urban heat island (MCCARTHY, M. P. *et al.* 2010). This can have serious consequences during heat waves, and the frequency of those will also expectedly increase. In rural areas the extended vegetated surfaces allow the air to cool down significantly during the night. However, this positive process is obstructed in cities by the urban heat island (WILBY, R. L. 2007; MCCARTHY, M. P. *et al.* 2010). These conditions increase the thermal stress of urban dwellers and may cause a growth in the rate of mortality during heat waves (MCCARTHY, M. P. *et al.* 2010).

It has commonly been presumed that the risk, intensity and frequency of extreme weather conditions—like heat waves, intense precipitation, destructive thunderstorms and floods—are increased by the changing climate. Due to their thermal and other physical characteristics *(Sections 1–6)*, the urban environment might face the most severe effects of these changes (WILBY, R. L. 2007).

Urban green spaces might affect ease the anticipated negative effects of climate change in cities. Vegetated areas can reduce urban air temperature due to incoming direct and diffuse solar radiation absorption (GIVONI, B. 1991), shading (SHASUA-BAR, L. – HOFFMAN, M. E. 2004), and evapotranspiration. This latter one has the most significant effect on latent and sensible heat flux ratio and with proper vegetation the gradient of sensible and latent heat flux could be greatly reduced by it between rural and urban areas (AVISSAR, R. 1996).

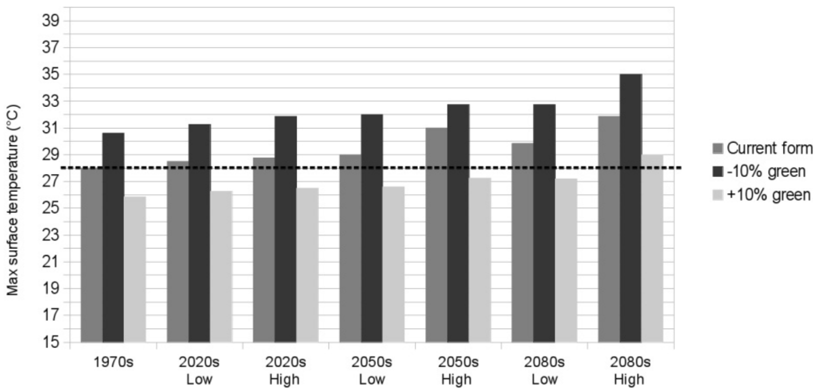

Figure 5 – Maximum surface temperature in high-density residential areas, with current form and when 10 per cent green cover is added or removed. Dashed line shows the temperature for the 1961–1990 current form case.

Source: GILL, S. E. et al. (2007)

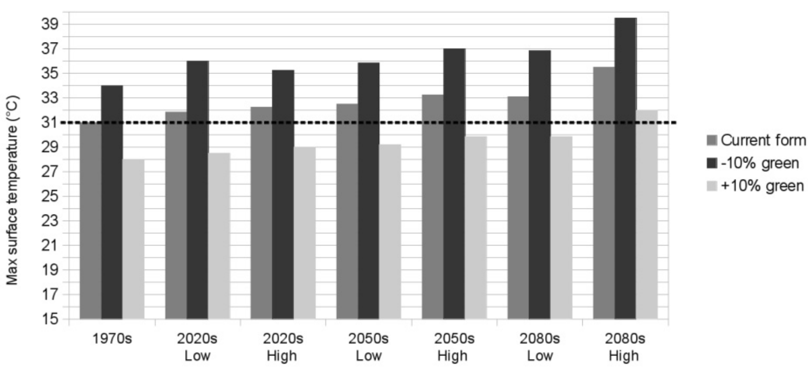

Figure 6 – Maximum surface temperature in town centres, with current form and when 10 per cent green cover is added or removed. Dashed line shows the temperature for the 1961–1990 current form case.

Source: GILL, S. E. et al. (2007)

Figure 5 and 6 demonstrate the probable impacts of increased and decreased green areas on estimated maximal surface temperature till 2080 with high and low global CO_2 emission scenarios in two urban areas.

Vegetated areas might help form sufficient ventilation for the city (GIVONI, B. 1991) and when the park breeze phenomenon occurs, it might decrease the air temperature in the built-up environment around vegetated areas (ELIASSON, I. – UPMANIS, H. 1999).

Urban green areas also increase the moisture in the urban atmosphere (GIVONI, B., 1991; BONAN, G. B., 2002) and decrease the probability and negative effects of serious floods (CAMERON, R. W. F. *et al.* 2012). To achieve the best impacts of urban green spaces on urban climatic conditions and the probable effects of climate change, type and structure of green areas should be selected carefully. In hot, arid climates the best course of action is to plant large parks dense with deciduous trees and shrubs. In these regions positive effects of shading and evapotranspiration are very welcome, and the wind speed lowering effect of this kind of vegetation is not likely to cause any discomfort (GIVONI, B. 1991). However, when the natural water supply is limited, vegetated areas have to be watered artificially to prevent the reduction of evapotranspiration intensity (GIVONI, B. 1991; GILL, S. E. *et al.* 2007). Additionally, wind protection might have crucial effects on urban thermal comfort in arid regions where cold winters are common (GIVONI, B. 1991).

Shade and wind are important in hot, humid climatic regions, therefore providing shade and minimising blockage of the wind should be the most crucial aspects in planning green areas in these regions. To reach this goal densely planted deciduous trees with soils covered with herbaceous plants should be the dominant type of vegetation (GIVONI, B. 1991).

In cold climates access to sunlight and protection from wind should be in the focus when planning green areas. High and dense line of evergreen trees with belts of evergreen shrubs planted here along the border of open green space might provide little shading and sufficient protection from the cold, dry winds (GIVONI, B. 1991).

5. Conclusion

The aim of this review was to give introspection about the state of urban climatic conditions. These might result in an unpleasant and unhealthy environment for city dwellers and with the probable causes of climate change these could indicate that cities are going to face serious problems in the future. The article is also entitled to show that with properly formed urban green areas these problems can be significantly eased. However, to gain the most needed impacts from urban green areas, understanding of urban ecological systems and the urban structures is crucial (PICKETT, S. T. A. – CADENASSO, M. L. 2008).

Today many different actors and decision-making processes alter the face of urban environments; however, to develop an urban area could be quite challenging due to its wield complexity. One single alteration—for example changing the colour of an outside wall of a building, or cutting some trees in a park to have a bit more open green space for social usage—could lead to various types of consequences such as altered climatic conditions. Furthermore, spatial planners and decision-makers have to consider many different economic and social interests as well. As it can be seen, several different areas of expertise are needed for spatial alterations in cities; however, all the required ones are rarely involved in urban spatial planning and implementation. This article might give some necessary information about urban climate and the impacts of urban green areas to various kinds of actors in urban spatial development.

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