Sustainable Cities and Society 27 (2016) 122–128

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

The effects of street tree planting on Urban Heat Island mitigation in Montreal

Yupeng Wang[a,b,*], Hashem Akbari[b]

[a] School of Architecture and Civil Engineering, Chengdu University, China
[b] Department of Building, Civil and Environmental Engineering, Concordia University, Canada

ARTICLE INFO

Article history:
Received 15 August 2015
Received in revised form 17 March 2016
Accepted 18 April 2016
Available online 30 April 2016

Keywords:
Urban Heat Island
Urban vegetation
Environmental simulation
Cold climate

ABSTRACT

The effects of climate change and Urban Heat Island (UHI) phenomena have raised the attention for monitoring and evaluating the outdoor thermal comfort. The urban vegetation system is playing a significant role for UHI mitigation and adaption. The fraction of the ground covered by trees and other vegetation is smaller and contains less biomass than in nonurban areas. The absence of vegetation impacts the UHI in several ways, since vegetation, and in particular trees, intercept solar energy, and their shade reduces the temperature of surfaces below while increasing the latent heat exchange for the evapotranspiration process. In this paper, the common tree types and the size of trees in Montreal are investigated; and the effect of tree size and space between trees on outdoor comfort are compared by using environmental simulation. It's demonstrated that, the correlation (R^2) between tree cover (SVF) and urban Ta is about 0.64 at summer mid-night. In the daytime, tree cover could reduce air temperature at the tree level (4 °C at 20 m height from the ground), as well as higher level (2 °C at 60 m from the ground).

1. Introduction

Urban warming trends are observable in large cities across the world (Kataoka, Matsumoto, & Ichinose, 2009;Streutker, 2003). Rapid urban expansion is accelerating the Urban Heat Island phenomenon, accelerating higher urban energy consumption, leading to lower thermal comfort, and greatly increased risks to human health. As the data observed in the city of Melbourne, increases in the wind speeds in excess of 2.0 m/s resulted in a statistically significant reduction in UHI magnitude (Morris, Simmonds, & Plummer, 2001). Shade from tree cover can create a more comfortable pedestrian environment in a city with hot summer temperatures. It was observed that at air temperatures over 20 °C, there is a tendency for people to move into the shade or out of direct sunlight (Zacharias, Stathopoulos, & Wu, 2001). Vegetation can also greatly improve the urban microclimate by reducing summer air temperatures. The effect from vegetation is not only within the boundaries of the green area, but extends beyond to the leeward side (Dimoudi & Nikolopoulou, 2003; Wang & Zacharias, 2015). This extension effect was also demonstrated by several simulation studies (Akbari, Pomerantz, & Taha, 2001; Akbari, Davis, Dosano, Huang, & Winnett, 1992; Hideki & Masakazu, 2007; Park, Hagishima, Tanimoto, & Narita, 2012).

Urban Heat Island (UHI) is a metropolitan area that is significantly warmer than its surrounding rural areas due to human activities. The UHI effect is studied in several hot and dry cities, whereas discussion about UHIs in cold climates is rare. Nonetheless, understanding UHIs in high latitude cities is an important to inform climate change mitigation and energy use reduction strategies. Research carried out in eight Canadian cities compared observed number of annual hot days (with a temperature high of 30 °C) between 1961 and 1990 to the forecasted average after 2020, number of annual hot days will be increased from 10 to 22 days. Projected temperature increases in Canada are even more dramatic than in the lower latitudes (Health Canada, 2011). Health Canada reported that in 7Canadian cities, when the daily average temperature is higher than 20 °C, the relative mortality is increased by 2.3% for every degree increase in the air temperature; a UHI intensity of 2–3 °C translates into a 4–7% increase in the mortality rate (Health Canada, 2011). Over seventy percent of Canadians are living in urban areas. UHI, global warming and their effects on electricity infrastructure is a significant threat to Canadian safety and security, community safety and citizen wellbeing. This paper aims to demonstrate the environmental effect of street tree planting patterns in a city central area in Montreal, it contributes to future UHI mitigation guideline development for urban vegetation system design.

* Corresponding author at: School of Architecture and Civil Engineering, Chengdu University, China.
E-mail address: wang-yupeng@outlook.com (Y. Wang).

http://dx.doi.org/10.1016/j.scs.2016.04.013
2210-6707/

Table 1
Land use and building height properties.

Category	Value
Land cover (%)	46.3
Grass (%)	1.5
Tree (%)	1.9
Vegetation cover (%)	3.4
Asphalt (%)	50.4
Average building height (m)	28
Median building height (m)	12

Table 2
Initialization input parameters for simulation.

	21th July, 2013
Starting time	21:00 pm
Total simulation time	30 h
Wind speed	3.6 m/s
Wind direction	Southwest
Temperature	298.15 K (25 °C)
Relative humidity in 2 m	51%
Building interior temperature	299.15 K (26 °C)

2. Method

2.1. Selected study area

As shown in Fig. 1, the selected area in Montreal is a high-density residential area, next to the city's main commercial area and a university. The 300 × 300 m^2 area models is built for microclimate in simulation, and the simulation domains are defined by 3 × 3 × 3 m^3 grids. There are many high-rise residential buildings of more than 15 floors. Most of the ground surface is asphalt road. For simulation, the building outlines in the aerial satellite view are traced into CAD map to help to define the simulation domain, and the building height is defined by the floor numbers. The detailed land use and building height in this area is shown in Table 1.

2.2. Environmental simulation

We used ENVI-met simulation model (a three-dimensional computer model that analyzes micro-scale thermal interactions within urban environments) to simulate the environmental conditions in the selected area. ENVI-met is designed to simulate the surface-plant-air interactions in urban environments, including the calculation of heat change between vegetation leaves and air. It has a typical spatial resolution of 0.5 m to 10m, and a temporal resolution of 10 s. A simulation is typically carried out for at least 6 h, usually for 24–48 h. The optimal time to start a simulation is at night or sunrise, so that the simulation can follow the atmospheric processes. ENVI-met requires an area input file which defines the 3-dimensional geometry of the target area. This includes buildings, vegetation, soils and receptors. A configuration file, which defines the initialization input, is also required (Bruse, 2016, 1999; Ozkeresteci, Crewe, & Brazel, 2003). In this research, one typical summer day is selected for simulation. The detailed initial input parameters are shown in Table 2 Vector Magic Inc. (2013), and the data flow in ENVI-met is shown in Fig. 2 (Bruse, 2016). ENVI-met uses the 2-equation Turbulence Kinetic Energy (TKE) Model to predict the turbulence in the air. The first equation describes the distribution of the kinetic energy in the air depending on production, advection, diffusion and destruction, the second equation describes the dissipation rate of TKE (Bruse, 2016).

3. Tree types and the urban canopy

In the Montreal city biodiversity report in 2013, the most common trees in Montreal are indicated (Ville de Montreal, 2013). For understanding the characters of each tree type, in order to analyse the effects in the next step, a research of the tree size and lifetime is carried out. The results are shown in Table 3 (Arbor Day Foundation, 2014; North Dakota Tree Information Center, 2014; Kentucky's Champion Trees, 2014). Using the average tree height and crown diameter, all of the common trees are classified to tree types (10 m height, 9 m crown diameter; 15 m height, 12 m crown diameter; 20 m height, 12 m crown diameter). Two tree planting patterns which are with space (A1; B1; C1) and without space (A2; B2; C2) are indicated. In order to compare the variation of tree types and tree planting spaces, six proposed models for each road side tree planting patterns are simulated (Fig. 3). The parameters for trees simulation are explained in Table 4, and the tree size and planting space between trees are explained in Table 5.

Trees affect the urban environment by transpiration from leaves, by shading of the solar radiation and by blocking the wind (Mirzaei & Haghighat, 2010). Increasing the tree crown could increase the volume of tree leaves for transpiration, increase the shading area, and more effective to block the wind in urban area.

Sky view factor is the fraction of sky area when one looks up to the sky. An SVF of 1 is a completely open area, without any buildings or high objects obstructing the view. An SVF of 0 is a completely closed indoor environment. SVF is a quantitative standard to evaluate the spaciousness of open air, or at a point in a street, reflecting to environmental engineering and architectural psychology (Brown, Grimmond, & Ratti, 2001). The averaged SVF of each simulation patterns at human height level (1.8m) are output from ENVI-met, and compared in Fig. 4. The SVF in base pattern is the highest in seven patterns. This is because the less tree cover leads to the urban openness. The averaged SVF in C2 is the lowest, because planting high trees without space between each other creates a deeper urban canopy at the human height level. Changing the trees' height form 10 m to 15 m, and the trees' crown diameter from 9 m to 12 m, the average SVF could be reduced by 34% (comparing A1 and B1) to 63% (comparing A2 and B2); changing the trees' height from 15 m to 20 m, the average SVF is only reduced by about 9% (comparing B1

Table 3
Detailed information of trees that most common in Montreal.

		Height (m)		Crown (m)		Lifetime (Year)	Average	Type
		Range	Average	Range	Average		Height & Crown (m)	
Elm	Siberian elm	8–15	11.5	6–12	9.0	60–150	10–9	A1; A2
Ash	Northern red ash	11–20	15.5	9–12	11.5	30–50	15–12	B1; B2
Linden	Basswood linden	15–21	18.0	9–15	12.0	1000	20–12	C1; C2
	Little leaf linden	18–21	19.5	9–15	12.0	100∼	20–12	C1; C2
Maple	Silver maple	12–20	16.0	9–15	12.0	80–130	15–12	B1; B2
	Norway maple	15–23	19.0	10–15	12.5	60–250	20–12	C1; C2
	Red maple	12–18	15.0	9–12	10.5	80–150	15–12	B1; B2
Honey–locust		9–15	12.0	9–12	10.5	120–150	10–9	A1; A2
Hackberry		12–18	15.0	7–14	10.5	300–400	15–12	B1; B2