G Model
SCS-412; No. of Pages 9

ARTICLE IN PRESS

Sustainable Cities and Society xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Sustainable Cities and Society

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

Analysis of urban heat island phenomenon and mitigation solutions evaluation for Montreal

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

[a] School of Human Settlements and Civil Engineering, Xi'an Jiaotong University, China
[b] Department of Building, Civil and Environmental Engineering, Concordia University, Canada

ARTICLE INFO

Article history:
Received 30 September 2015
Received in revised form 10 April 2016
Accepted 19 April 2016
Available online xxx

Keywords:
Urban heat island
Sky view factor
Simulation
Policy

ABSTRACT

Urban climate change in cold-climate cities of Canada is an important consideration for global climate moderation, energy consumption, citizen safety and wellbeing. Recently, many Canadian cities have started to pay attention to climate change adaptation and mitigation strategies. They need policy-relevant data and analysis in these efforts. The current data mostly focuses on the consideration of greenhouse gas emissions levels rather than providing specific adaptation strategies on the urban scale.

In this research, we analyze and demonstrate how street vegetation planting, albedo and urban canopy characteristics affect urban climate in a specific Canadian city, Montreal. We use ENVI-met (a three-dimensional computer model which analyzes micro-scale thermal interactions within urban environments) to calculate the sky view factor (SVF) for a 300 m × 300 m section of the city, and simulate the environmental conditions including air temperature (Ta), human weighted mean radiant temperature ($MRT_{h\text{-}w}$), wind speed, and physiologically equivalent temperature (PET) at the community scale. These simulation comparisons demonstrate the effects on each environmental factor for a typical summer day and provide hints for mitigation of the urban heat island (UHI) and new urban development. The effectiveness of each UHI mitigation strategy is evaluated for providing guidelines for policy development.

1. Introduction

The urban heat island (UHI) effect is a phenomenon whereby a metropolis is usually significantly warmer than its rural surroundings. This occurs because (1) urban surfaces are typically darker than those of surrounding areas, (2) there is less vegetation in urban areas, and (3) buildings and street surface materials, which have high heat capacities, store heat during the day and release heat slowly at night (Rao, 2012; Oke, 1988). The adverse energy and environmental effects of UHIs, and methods to alleviate them, has become a major research topic in sustainability programs. Decreasing the energy consumption of buildings is also an important topic in environmental engineering.

Up to now, neither policy nor behavior has shifted far enough to achieve climate stabilization. Several specific conflict points arise because of the complicated scientific data: the lack of consideration of socio-economic scenarios, no salient information for local users or communities, and the difficulty of providing community outreach to link actions to planning on adaption to climate change (Sheppard, 2008).

In general, most people go to work in the weekdays, go shopping after work or on the weekends, and stay at home at night. The peak hours of energy consumption in an official district, in a commercial district, and in a residential district are different, because of general human living habits. That is to say, diverse urban functions present different energy demand characteristics, and energy consumption also varies with changes in the time of day.

Studies of air-conditioning energy use in hot climates have shown that the air-conditioner load in residential buildings can be particularly high in the nighttime. As an example, in a study of residential air-conditioner operation on a summer day in nine Chinese cities, the peak time was observed between 6 pm and 11 pm (Yoshino et al., 2006). In a study of two Chinese office buildings, the highest energy consumption was observed in the daytime, as the operating schedule of offices is normally between 7 am to 6 pm (Pan, Yin, & Huang, 2008). A similar result was also observed in the campus of the University of California at San Diego provides, which showed the highest energy demand between to 6 am to 5 pm, and the peak hours were 3 pm and 4 pm (Agarwal, Weng, & Gupta, 2009). In cold climates, air-conditioning (AC) energy use in residential buildings may not be very significant for most of the summer.

* Corresponding author at: School of Human Settlements and Civil Engineering, Xi'an Jiaotong University, China.
E-mail address: wang-yupeng@outlook.com (Y. Wang).

http://dx.doi.org/10.1016/j.scs.2016.04.015
2210-6707/

Please cite this article in press as: Wang, Y., & Akbari, H. Analysis of urban heat island phenomenon and mitigation solutions evaluation for Montreal. *Sustainable Cities and Society* (2016), http://dx.doi.org/10.1016/j.scs.2016.04.015

However, the few days in the summer that require residential AC use at night can significantly impact utility peak demand. A report from Hydro Quebec states that energy demand is likely to peak at two times of the day: 7–9 am and 4–8 pm (Hydro Quebec, 2014). The first peak period roughly aligns with the beginning of a typical work day and the second peak period may be when people return home after work. Therefore, reduction of peak energy consumption should focus on the evening peaks.

The urban form plays an important role in the UHI, since a dense form generally is responsible for multiple reflections of solar energy, and influences the air convection out of urban canyons by influencing the wind "porosity" of the city (Britter & Hanna, 2003; Wang & Akbari, 2014). The urban form influences the heat loss from within the urban canyons due to the lower sky view factor (SVF). Tall buildings and narrow urban canyons reduce the sky view factor (SVF) and increase the amount of shaded area at the surface, keeping the bottom of urban canyons cooler than the surrounding area by day, but increasing it at night time (Oke, Johnson, Steyn, & Watson, 1991; Unger, 2008).

Urban tree planting provides a more pleasant, healthful, and comfortable environment in which to live, work, and play, saving in the costs of providing a wide range of urban services and substantial improvements in individual and community well-being. 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 (Bonan, 2000; Oke, 1988).

Reflectivity of urban surface materials could affect the absorption of solar radiation in daytime. Cool building and pavement materials result in lowered ambient temperatures. Lower temperature reduces demand for electricity for air conditioning and decreases production of smog (ozone). For pavements, the initial higher incremental cost may be offset by lifetime savings through the energy and smog savings and substantially longer lifetime of cool pavements (Akbari, Pomerantz, & Taha, 2001).

Meanwhile, UHI mitigation techniques provide different contributions in daytime and nighttime. Open urban spaces with a high sky view factor (SVF) obtain more solar radiation than do urban canyons and this leads to higher air temperature in the daytime. The reverse is observed at night where open spaces release more heat to the sky than do urban canyon, which leads to lower air temperature in the nighttime (Wang & Akbari, 2014). Environmental policy implications should consider urban energy distribution and the features of mitigation techniques, and create the optimized guidelines. These policies could address urban development density, which is influenced by urban roughness, urban vegetation style, and urban albedo. These three dimensions of urban fabric are discussed in this research. In addition, this study takes into account the effect of UHI on energy use, urban air quality, and urban thermal comfort.

1.1. The UHI phenomenon and related policy development in Montreal

The UHI effect has been studied in several hot and dry cities, but discussion about UHIs in cold climates is rare. Nonetheless, understanding UHIs in cold cities is an important factor in designing effective climate change mitigation and energy use reduction strategies. For example, research carried out in eight Canadian cities found that the observed number of annual hot days (with a temperature high of 30 °C) is expected to increase from 10 days, the 1961–1990 average, to 22 days after 2020. Projected temperature increases in Canada are even more dramatic than in the southern latitudes (Health Canada, 2011).

Health Canada reported that in seven Canadian 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. Hence a UHI intensity of 2–3 °C translates into a 4–7% increase in the mortality rate. Since over seventy percent of Canadians live in urban areas, UHI, global warming and their effects on electricity infrastructure are a significant threat to Canadian safety and security, community safety and citizen wellbeing.

The combination of UHI and climate change will lead to a higher demand for air-conditioning contributing to increased pressure on electricity generation, transmission and distribution infrastructure. The possibility of blackouts during extreme temperature events is a significant public health threat. Heat waves significantly impact the amount of electricity use. Hotter summer temperature increases the demand for electricity, and the trend is evident in Ontario. Electrical demand during the peak hours in summer has risen steadily from 1994 through 2002 (Liu, 2003). In August 2003, hot weather and high electricity demand caused transboundary blackout shut down Toronto's operations for nearly three days (US-Canada Power System Outage Task Force, 2004). On the other hand, from 1993 to 2005, the proportion of Quebec households with a home air conditioner is increased from 15.2% to 36.4% (Institut de la statistique du Quebec, 2005). This contributes to increase in electricity demand in a hot summer day and is becoming to be a hidden danger in Montreal.

UHI mitigation is discussed at strategic level in Toronto and Montreal, and the city of Toronto has developed a made-in-Toronto Green Development Standard (GDS) to provide guidance for environmental development in communities (Giguere, 2009; Wieditz & Penney, 2007). Building energy consumption mitigation guidelines are carried out, in order to reduce greenhouse gas emissions (CAP, 2013). However, the detailed technique implement about building envelop performance and local urban comfort is not demonstrated. This study extends the consideration of UHI mitigation to cold cities of Canada, demonstrate and explicate the effect with numerical simulation. This research will be an investigation of the methodology for UHI study, which could provide hints to provincial governments for establishing the environmental urban planning standards, what can be used in urban developments and redevelopments.

This research focuses on summer UHI mitigation options. Urban vegetation planning, street and pavement albedo, urban building density and urban canopy control are discussed, based on simulation comparisons in the city of Montreal. The ultimate goal is to provide a framework for developing effective UHI mitigation policies.

2. Research method

2.1. Urban environmental simulation

We used ENVI-met (a three-dimensional computer model that analyzes micro-scale thermal interactions within urban environments) (Bruse, 1987) to simulate the environmental conditions in a selected area in Montreal. ENVI-met is designed to simulate the surface-plant-air interactions in urban environments. It has a typical spatial resolution of 0.5–10 m, 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 1987; Ozkeresteci, Crewe, Brazel, & Bruse, 2003).

For these simulations, the geometry of urban street canyons in the selected area was identified using satellite images and street