Modeling spatial variations in energy budgets of humans exercising in outdoor urban recreational parks and spaces

Jennifer K. Vanos * Jon S. Warland, Terry J. Gillespie
School of Environmental Sciences, University of Guelph, ON, Canada

Graham A. Slater, Robert D. Brown
Landscape Architecture, University of Guelph, ON, Canada

and Natasha A. Kenny
Teaching Support Services, University of Guelph, ON, Canada

ABSTRACT

Continuing growth of cities and the intensification of urban heat islands (UHI) has provoked research into outdoor human comfort with respect to human health. Urban and recreational planning must incorporate bioclimatic design to provide suitable spaces for increased use and exercise to benefit societal health. The current study applied the COMFA outdoor energy budget model to simulate the thermal comfort of users exercising in outdoor parks in Toronto, Canada. This is a direct example of how a thermo-physical based numerical model can link the outdoor human-climate relationship with design of neighbourhoods and recreational parks based on human biometeorology. Further applications of this model include quantifying crucial weather parameters for heat events, estimating and mapping greenspace and vegetation present and/or needed in built-up areas, and analysing thermal comfort and health trends of various urban regions throughout the world.

1. Introduction

Rapidly dysfunctional urbanization can be detrimental to urban health when greenspace conservation is not employed. Tools for bioclimatic design in outdoor spaces must be created for all users to comprehend and for beneficial incorporation of knowledge by landscape architects or urban planners. Such application is warranted, and it has been found that small urban parks can be up to 7°C cooler than their surrounding streets, which in some instances extends almost 100m beyond the parks boundaries (Slater 2010).

Very few studies in the physical sciences have been completed on exercising individuals in field settings using thermo-physical inputs as a basis for estimating human thermal comfort. Due to physiological and psychological variations, many studies have been completed to asses overall adaptive processes (Fanger and Toftum 2002; Yao et al. 2009), with additional large focus on how humans will adapt their lives – particularly in urban areas – to the resounding threat of climate change (Nikolopoulou and Lykoudis 2006; Golden et al. 2008) particularly for vulnerable individuals – elderly, young, unacclimatized and unconditioned – who may have implicated thermoregulation.

The purpose of the current study is to quantify the thermal sensations experienced by humans while exercising in outdoor urban areas and parks parks using the COMFA outdoor energy budget model (Brown and Gillespie 1986, 1995; Kenny et al. 2009a,b).

2. Methods of Site Selection, Microclimate Data Collection and Budget Modelling

As the largest city in Canada, Toronto is densely populated with a heterogeneous mix of classic built up areas with high-rise buildings, as well as dense yet low residential and suburban areas. The city is within Canada's warmest climate and experiences a humid continental climate.

Microclimate data was collected along 'street-park-street' transects in September, 2009, during a select time period between 1300–1630hr. Air temperature (T_a) was measured using a fine (0.02mm) copper-constantin (Type 'T') thermocouple (Omega, Canada); total incoming shortwave radiation (K_{in}) was measured using a lightweight portable LI-200 pyranometer (LI-COR Inc., USA); relative humidity (RH) was measured using an HC-S3 temperature and RH sensor probe (Rotronic Instrument Corp., USA). All data was recorded at 0.8s intervals using a 21X datalogger (Campbell Scientific Instruments, Logan, UT) and fastened 1.5m above the ground to the front of a bicycle, moving at ∼9km/h speed.

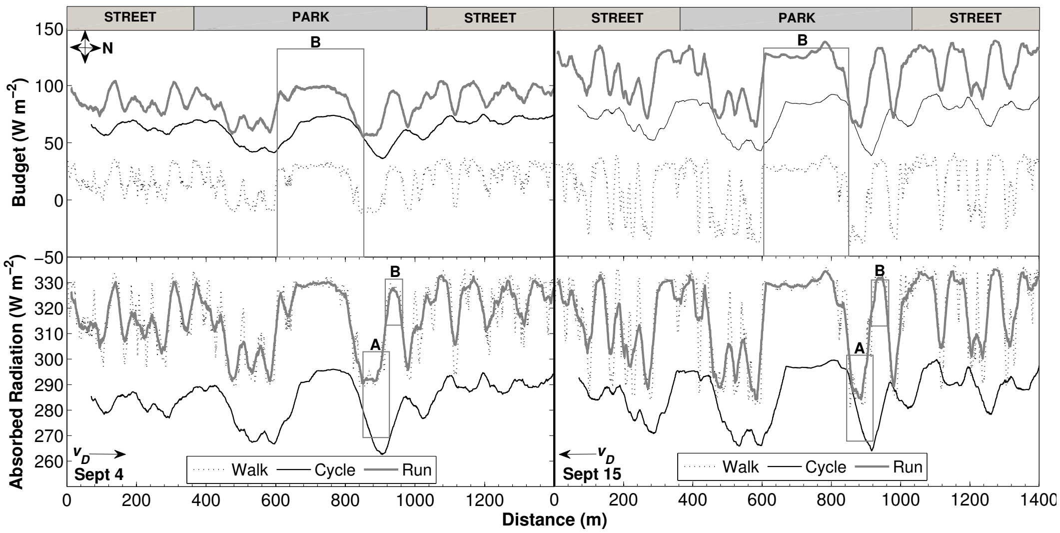

FIG. 1. Trinity Bellwoods Park displaying modelled budget and absorbed radiation (W m^{-2}) for brisk walking, running, and cycling on Sept 4^{th} and 15^{15}, 2009. Boxes labelled 'A' indicates notable tree cover, while 'B' boxes display uncovered areas along the transect.

Precise estimates of absorbed radiation (R_{abs}) can be difficult to obtain due to complexities of short- and long-wave radiation flux interactions; however, Kenny et al. (2008) provide a method for reliable estimates in outdoor environments which was applied in the current study based on K_{in} and environmental biophsyics.

Average cycling and running metabolic activities (M_{act}) were estimated for the average 'conditioned' individual using the general energy expenditure method by Strath et al. (2000), which is appropriate for application to the average population and the current study.

The intrinsic clothing insulation (I_{cl}, clo) referring to the whole body, was estimated based on ambient T_a, with bare and clothed body parts weighted separately.

Wind and activity velocities (v_w and v_a, respectively) were incorporated into the COMFA model based on ISO9920 (2007) to find relative air velocity (v_r). v_a measurements and directions were obtained from the nearest weather station to the corresponding outdoor park. The 10m windspeed was brought to 1.5m using a ratio of the logwind profile for estimated street and park roughness lengths.

3. Results and Discussion

Moving averages of all plotted budget data were used for the analyses. Averaging time windows increased with higher average v_a, with walking, running and cycling windows estimated to be 6m, 25m and 140m respectively.

Figure 1 displays a combination of two transects of Trinity Bellwoods Park on Sept 6^{th} and 15^{th}, showing the budget and R_{abs} of a human at various activity levels. The effect of trees in this park is very evident, seeing that even within the park, a lack of trees causes increased R_{abs}, directly causing the human budget to increase. Particularly during walking and running, trees play an important part in noticeably changing the energy budget by blocking solar radiation. Therefore, improvements can be made by placing trees with low transmittance in bare areas. It is known that the radiant temperature – estimated here as R_{abs} – is a main determinant of human thermal comfort (Hodder and Parsons 2007; Kenny et al. 2009a), correlating strongly with T_a.

Although great T_a reductions have been found in urban parks (Slater 2010), significant budget decreases are not found when there is a lack of tree cover. Additionally, the decrease in budget with higher v_a is present when cycling as compared to running at the same M_{act}, which is due to increased convective and evaporative heat losses.

4. Conclusions

The current study assesses small scale modelling of human thermal comfort budgets while within a heterogeneous urban area. Results from the example park show that the model adequately modelled energy budget, yet within the park, although a temperature drop is found, a budget decrease was not always found due to lack of tree cover. To have a significant effect on thermal comfort and extension into surrounding neighbourhoods, parks must be large – yet more importantly, they must contain adequate amounts of shading trees to block out solar radiation. In doing so, energy budgets can be decreased and, more importantly, individuals can be kept within the 'neutral' safe zone so that heat stress does not occur.

Understanding what can and cannot be controlled in thermal comfort modelling is vital. Small-scale microclimate control can be achieved through bioclimatic design to a point, yet large scale meteorological variations, diverse physiology, broader sensation/comfort ranges during exercise (Havenith et al. 2002; Kenny et al. 2009b), and further psychological variations (motivation, expectation) are factors that can override microclimatic control.

The rapid growth of urban areas has degraded and removed natural greenspace, only to be replaced by impervious surfaces with high heat capacities and anthropogenic heat sources. Heat related mortality statistics warrant increased use of climate sensitive design in urban areas (Vanos et al. 2010). Lowering UHI intensity and increasing park cooling intensity is essential for decreasing negative health impacts of extreme heat events all the while providing beautiful, sustainable and functional spaces for increased use, intensity and duration for a greater proportion of the population. According to many researchers (e.g. Harlan et al. 2006; Eliasson et al. 2007), improved self motivation, behaviour, work, athletic performance and quality of life are linked to thermal comfort.

The ultimate goal is to allow a model, such as COMFA, to be used with a small number of variables that are readily available to landscape architects, thereby allowing them to easily determine the thermal comfort, cooling potential and UHI mitigation of their designs (Slater 2010). Potential benefits to society of the incorporation of bioclimatic design and application has been successfully documented in the research, with the all-encompassing goal of improved health and overall well-being for urban dwellers.

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