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A Methodology for Calculating Cooling from Vegetation Evapotranspiration for Use in Urban Space Microclimate Simulations

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Abstract

Vegetation affects the urban space microclimate in many ways, almost all of them being highly beneficial. At the level of city block, street or individual building, cooling from evapotranspiration is one of the most significant effects of vegetation with an impact on urban microclimate. However, this effect is difficult to be quantified in energy simulations. A tool that would contribute to the integration of fully parameterized vegetation effects into environmental analysis software for buildings and urban spaces would be of great usefulness. To this end, this work proposes a methodology that attempts to quantify evapotranspiration from single trees and vegetation ground cover. Of great importance is the simplicity in its implementation, as well as the minimum and easily obtained user input requirements.

This methodology is primarily based on the Pennman-Monteith evapotranspiration equation, as modified by the Food and Agriculture Organization of the UN. By a combination of collecting data for vegetation parameters from literature and incorporating equations for estimating some of the physical tree properties necessary as input to this method, a tool is assembled. Several tree species were categorized and included as options when calculating the cooling effect of vegetation in a system, based on this research. Evapotranspiration is then calculated depending on the specific tree species selected and the environmental data entered. The inclusion of the results in CFD environmental analysis is demonstrated.

Variations in the calculation method are applied, depending on the desired time-step of the simulation. Thus, the tool can be used either in static or dynamic form, according to the available data and required accuracy. A web version of the tool in its static instance has been created, as a form-based webpage. An executable version will provide hourly calculations of evapotranspiration by importing weather data files and dynamically altering the equations according to the environmental variables, plotting the results in graphs.

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Keywords: Urban Microclimate; Vegetation; Evapotranspiration; Pennman-Monteith; Vegetation Simulation.

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1. Introduction

Nomenclature

ET	evapotranspiration rate [mm/day]
ET_o	reference evapotranspiration rate [mm/day]
K_c	crop coefficient
Δ	slope of vapour pressure curve [kPa/°C]
R_n	net radiation at crop surface [MJ/m^2 day]
$R_{n,tree}$	net radiation intercepted by single tree canopy [MJ/m^2 day]
G	soil heat flux [MJ/m^2 day]
e_s	saturation vapour pressure [kPa]
e_a	actual vapour pressure [kPa]
$(e_s - e_a)$	saturation vapour pressure deficit of the air [kPa]
γ	psychrometric constant [kPa/°C]
T	mean daily air temperature at 2 m height [°C]
u_2	wind speed at 2 m height [m/s]
A_p	area of the canopy projected perpendicularly to the sun angle [m^2]
A_c	tree crown area [m^2]
S	tree spread [m]

The microclimate, which can be defined as a small scale pattern of climate that is influenced by site topography as well as local built forms and materials, can be heavily affected by vegetation. In constantly growing cities, where temperatures can rise up to 10 °C higher than their surrounding rural settings[1,2], green areas are always regarded as small oases inside the built environment. The aim of this work is to study the ways trees and plants affect the urban microclimate with regard to the performance of buildings, mainly focusing on cooling provided by evapotranspiration, and how these effects can be modeled and adapted for use in computer analysis software.

The major effects of vegetation in these situations are to provide surface shading, evaporative cooling, humidification, air scrubbing, water runoff prevention, soil and water purification, and, when exposed to breezes, some level of acoustic masking and diffusion of winds. In addition, the psychological effect of vegetation on people is undisputable, as they provide a link with the natural environment and demonstrate the change of seasons.

From the point of view of a designer, the effects of vegetation are not easily integrated into the design process. This is mainly because of the lack of adequate information and data, as well as the difficulty of simulating those effects effectively in environmental analysis software. Although some models of plant behavior do exist, most of them have been developed for uses other than individual small scale environmental building design. The main objective of this work is to investigate such models and algorithms and derive a methodology for quantifying evapotranspiration using a tool that can contribute in effective vegetation modeling.

1.1. Evapotranspiration

Evapotranspiration is the process by which a plant transpires the water it absorbs from the ground into the air through its leaves in the form of water vapor. In order for the water to be converted into vapor, heat is absorbed from the atmosphere resulting in air temperature decrease. A large tree can transpire up to 100 gallons of water (about 370 litres) per day. In hot arid climates this equals to five air conditioners running for 20 hours[1].

The effect of evapotranspiration cannot be measured separately from shading, but the combined effects have been measured in many cases. A vegetation cover of 30% has been reported to be able to decrease peak temperatures in urban areas by up to 6°C in favorable conditions[2]. In computer simulation studies, the combined effect of shading and evapotranspiration has been calculated to reduce annual energy use by 53%, 70% of which was due to evapotranspiration. However this percentage may be overestimated, due to the assumption that evapotranspiration is not limited by soil moisture[3]. In general, surface shading is usually more effective than evapotranspiration in