PREDICTING AIR TEMPERATURES IN CITY STREETS ON THE BASIS OF MEASURED REFERENCE DATA

A thesis submitted to The University of Adelaide in fulfilment of the requirements for a degree of Doctor of Philosophy

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SYMBOLS

The symbols used conform to notation that has become established as a *de facto* standard in most of the recent publications on urban climatology. Most equations have been introduced in the format proposed by the original authors, to allow easy reference to the published reference. This has resulted in some inconsistencies, most notably in the use of the symbol α, which refers to both the absorptivity of a surface and its albedo, as well as appearing in a number of parameterisation schemes. To avoid confusion, each of the equations presented in the text is followed by a list of the symbols used.

Greek capital letters

symbol	quantity	SI units
Δ	net change in a quantity	
X	ratio of total surface area to plan area of street canyon	
Ψ_m	stability function	

Greek lower-case letters

symbol	quantity	SI units
α	surface albedo	
	absorptivity of a surface	
β	Bowen ratio (Q_H/Q_E)	
	empirical correction constant in latent heat expression	
γ	psychrometric constant	$Pa\ K^{-1}$
ε	surface emissivity	
θ	potential temperature	K
κ	thermal diffusivity of a substance	$m^2\ s^{-1}$
λ	wavelength	m
λ_p	plan area index	
λ_f	frontal area index	
μ	thermal admittance	$J\ m^{-2}\ s^{-1/2}\ K^{-1}$
ρ	density of a substance	$kg\ m^{-3}$
	reflectivity of a surface	
σ	Stefan-Boltzmann constant	$W\ m^{-2}\ K^{-4}$
τ	transmissivity of a material	
ψ	view factor	

Roman capital letters

symbol	quantity	SI units
A'	lot area	m^2
A*	silhouette area	m^2
C	heat capacity of a substance	$J\ m^{-3}\ K^{-1}$
C_D	coefficient of drag	
E	evapotranspiration	$kg\ m^{-2}\ s^{-1}$
F	anthropogenic water vapour release	mm, $kg\ m^{-2}\ s^{-1}$
H	canyon height	m
I	piped water supply per unit horizontal area	mm, $kg\ m^{-2}\ s^{-1}$
K	short wave radiation	$W\ m^{-2}$
K*	net short wave radiation	$W\ m^{-2}$
K↓	incoming short wave radiation	$W\ m^{-2}$
K↑	reflected short wave radiation	$W\ m^{-2}$
L	long wave radiation	$W\ m^{-2}$
	Obukhov length	m
L*	net long wave radiation	$W\ m^{-2}$
L↓	incoming long wave radiation from the atmosphere	$W\ m^{-2}$
L↑	outgoing long wave radiation from a surface	$W\ m^{-2}$
P	total atmospheric pressure	Pa
Pr	Prandtl Number	
Q	heat energy	J
Q*	net all-wave radiation flux density	$W\ m^{-2}$
Q_A	horizontal energy transport in the air per unit horizontal area	$W\ m^{-2}$
Q_E	turbulent latent heat flux density	$W\ m^{-2}$
Q_F	anthropogenic heat flux density	$W\ m^{-2}$
Q_S	sub-surface (storage) heat flux density	$W\ m^{-2}$
Q_H	turbulent sensible heat flux density	$W\ m^{-2}$
R^0	total hemispherical radiation emitted by an object	$W\ m^{-2}$
Re	Reynolds Number	
Ri	Richardson Number	$W\ m^{-2}$
R_g	proportion of surface covered by vegetation	
T	temperature	K, ^oC
W	canyon width	m
Z_H	building height	m

Roman lower-case letters

symbol	quantity	SI units
a_i	coefficients of the OHM model	
c	specific heat	J kg^{-1} K^{-1}
d	zero plane displacement	m
e	vapour pressure	Pa
g	acceleration due to gravity	m s^{-2}
h	surface heat exchange coefficient	W m^{-2} K^{-1}
k	von Karman constant	m
	thermal conductivity	W m^{-2} K^{-1}
m	mixing coefficient	
n	fraction of sky covered by clouds (tenths)	
p	precipitation	mm
r	thermal resistance	W^{-1} m^2 K^1
s	slope of the saturation vapour vs. temperature curve	Pa K^{-1}
t	time	s
u	horizontal wind speed	m s^{-1}
	cross canyon component of wind	
u_*	friction velocity	m s^{-1}
v	along canyon component of wind	m s^{-1}
w	vertical wind speed	m s^{-1}
z	vertical distance	m
z_0	roughness length	m
z_d	zero plane displacement	m

Common subscripts

symbol	
a	air
c	convection
dif	diffuse
dir	direct
r	rural
	radiation
s	sky
u	urban

ABSTRACT

Knowledge of site-specific conditions is essential for the development of an architectural design that responds to the local environment. However, while meteorological data are recorded by the weather service in stations that are assumed to be representative of the surrounding region, generally no account is made of changes in local conditions caused by urban development – though these may be substantial.

Micro-climate in city streets can be predicted by computational fluid dynamics (CFD) with fine spatial resolution. However, CFD requires extremely detailed input, involves long computation times and is thus limited to simulating short periods. The aim of this project was to create a model capable of simulating weather conditions for extended periods, with simplified inputs and less detailed, yet accurate, outputs.

The CAT (Canyon Air Temperature) computer model predicts site-specific air temperature in a city street based on data from a rural reference station. In addition to a rudimentary description of the two sites, it requires only inputs measured at standard weather stations, yet is capable of predicting accurately the evolution of air temperature in all weather conditions for extended periods. It simulates the effects of urban geometry on radiant exchange; the effect of moisture availability on latent heat flux; energy stored in the ground and in building surfaces; air flow in the street based on wind above roof height; and the sensible heat flux from individual surfaces and from the street canyon as a whole.

A monitoring program was carried out in Adelaide, South Australia, in which weather conditions were recorded continuously at two streets and at a reference location outside the city centre for nearly a year. In addition to providing data required to calibrate and to validate the CAT model, the measurements provided evidence of a substantial nocturnal heat island in the city, of up to 8.6 ^{o}C. The weather records also demonstrate the existence of an urban cool island during the daytime of up to 3.8 ^{o}C, the intensity of which is related to the diurnal temperature range.

The CAT model may be used to generate realistic, site-specific temperature inputs for building thermal simulation software, required to produce more accurate modelling of energy use. It may also be used to evaluate the effect on micro-climatic conditions of proposed development at new urban locations.

This work contains no material which has been accepted for the award of any other degree or diploma in any other university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Signed ………………………

Date ………………………..

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