The effect of building facades on outdoor microclimate – dependence model development using terrestrial thermography and multivariate analysis

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Abstract

This paper describes ground-based thermal infrared (TIR) data collection and the development of a multivariate regression model to predict brightness surface temperature from thermal images. The statistical model estimates surface temperature regressed against thermal image red, green and blue (RGB) values with high predictive strength ($R^2 = 0.992$) for later multi-image stitching and facet-scale spatio-temporal analyses within a Geographical Information Systems (GIS) environment.

Keywords: Urban microclimate; building facades; ground-based remote sensing; infrared thermography; multivariate regression

1. Introduction

The radiative, thermal, moisture and aerodynamic properties of urban surfaces alter the fundamental energy, mass and momentum exchanges that produce distinct urban climates directly contributing to the urban heat island (UHI) effect [1]. Below mean roof level within the urban canopy layer (UCL) exchange processes operating on urban surfaces at different microscales ($<10^3$m) generate unique microclimates each of which is strongly influenced by the intrinsic properties of the surface and the morphology of its immediate surroundings [1,2]. Efforts to mitigate urban
heating and improve outdoor thermal comfort have focused on alterations to surface thermal and radiative properties, facet geometry, moisture availability and urban form with the aim of quantifying and predicting changes to the physical processes that influence urban climates across relevant temporal and spatial scales [3,4].

Advances in aerial and satellite remote hyperspectral and LiDAR platforms have enabled surface mapping for local and canyon-scale climatology [5,6]. However, thermo-spatial mapping and the development of appropriate visualization, diagnostic and predictive tools for investigating surface-atmosphere exchange at the “architectural” scale (~10^3m to ~10^1m) – where individual buildings are considered to be the fundamental units to create the urban climate [4] – remain underdeveloped yet have the potential to enhance micrometeorological observation, surface thermal specification [7] and the optimization of decision-making for sustainable cities [8].

Surface temperature is of prime importance in urban microclimatology [9]. At any given location surface temperature is controlled by the surface’s surface energy balance (SEB) [10]. Surface temperature is fundamentally related to each non-solar component flux of the surface’s SEB [11] and directly controls surface long-wave (infrared) radiation emission [12]. Once known, the temperature of an urban surface may be used to derive surface thermal properties (e.g. emissivity) and radiative fluxes [13]. However, remotely sensed urban surface temperatures, which are derived from emitted thermal infrared radiation, are indirectly measured and relating the observed signal to the emitting surface is a key challenge [9,14] prone to numerous methodological pitfalls including sensor calibration errors, atmospheric effects, non-blackbody emissivity and thermal anisotropy at local scales [15,16].

This research addresses a gap in ground-based microclimate observations at the building scale and describes one part of the development of a novel mixed-method approach to quantify the effects of building facades on microclimate using a combination of ground-based remote sensors, field measurements, aerial and in-situ spatial data and statistical analysis managed in a geographical information systems (GIS) environment. The aim of the research is to improve understanding of the microclimate effects of building facades and to develop a planning application to predict facade surface temperatures under various architectural design and canyon geometry scenarios with a high confidence level in order to enhance climate-sensitive design. This paper describes the thermal infrared (TIR) data collection and the development of a multivariate regression model to derive “brightness” surface temperature from thermal images.

2. Materials and methods

2.1 Study area

Summer daytime data were collected for 61 multi-storey buildings located in metropolitan Sydney between late-December 2015 and mid-March 2016. Sydney is located on the east coast of Australia at latitude 33° 51’ S and has a temperate climate with typically mild winters and dry, warm summers [17]. Sydney is the largest and most densely populated city in Australia with some inner-city suburbs, including Pyrmont/Ultimo, Potts Point/Woolloomooloo, Darlinghurst and Surry Hills exceeding 13 000 people per square kilometer [18]. Of the 61 buildings surveyed 97% were residential flat buildings and the mean effective facade height was 18.5m.

2.2 Data collection

In-situ data included ground-based remotely-sensed imagery and morphological data for the derivation of urban structure parameters (building form, canyon H/W, etc.). Ground-based images were obtained from 1.5m(h) tripod-mounted high-resolution thermal infrared (TIR) (7.5–13μm), multispectral (0.52–0.92μm) and visible-spectrum (0.4 -0.7μm) digital cameras. A FLIR B335 thermal camera was used to record facade surface temperature (refer Table 1 for IR camera specifications). The mean normal spatial resolution (pixel size) was 48mm at a target distance of 18.5m.

2.3 Basic principles of thermal infrared imaging

Thermal infrared cameras detect infrared radiation which is related to the object’s surface temperature by Stefan-Boltzmann’s Law [19]. Converting infrared radiation to temperature depends on the internal calibration of the
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