Building and Environment 81 (2014) 309–319

Contents lists available at ScienceDirect

Building and Environment

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

Heat mitigation strategies in winter and summer: Field measurements in temperate climates

Mohammad Taleghani [a, *], Martin Tenpierik [a], Andy van den Dobbelsteen [a], David J. Sailor [b]

[a] Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, The Netherlands
[b] Department of Mechanical and Materials Engineering, Portland State University, Portland, OR, USA

ARTICLE INFO

Article history:
Received 2 May 2014
Received in revised form
8 June 2014
Accepted 10 July 2014
Available online 24 July 2014

Keywords:
Vegetation and water body
Summer and winter
Courtyard
Temperate climates
Urban heat island effect
Park cool effect

ABSTRACT

Natural elements such as vegetation and water bodies may help reduce heat in urban spaces in summer or in hot climates. This effect, however, has rarely been studied during cold seasons. This paper briefly studies the effect of vegetation and water in summer and more comprehensively in winter. Both studies are done in courtyards on two university campuses in temperate climates. A scale model experiment with similar materials supports the previous studies. The summer study is done in Portland (OR), USA, and the winter study (along with the scale model) in Delft, the Netherlands. The summer study shows that a green courtyard at most has a 4.7 °C lower air temperature in the afternoon in comparison with a bare one. The winter study indicates that the air temperature above a green roof is higher than above a white gravel roof. It also shows that, although a 'black' courtyard has higher air temperatures for a few hours on sunny winter days, a courtyard with a water pond and with high amounts of thermal mass on the ground has a warmer and more constant air temperature in general. Both the summer and winter studies show that parks in cities have a lower and more constant air temperature compared to suburbs, both in summer and winter. The scale model also demonstrates that although grass has a lower albedo than the used gravel, it can provide a cooler environment in comparison with gravels and black roof.[1]

1. Introduction

The urban heat island (UHI) phenomenon affects the heating and cooling energy demands of buildings in cities and human (and other species') health and thermal comfort. This phenomenon occurs mainly because of the replacement of natural elements (such as vegetation and water bodies) by man-made structures and surfaces that trap and buffer solar heat (asphalt and building materials). Architects and urban designers can alleviate the UHI effect by bringing nature back into the city and urban spaces.

Several studies have shown the ability of vegetation and water bodies in urban environments to reduce UHI in summer [1–10]; these natural elements may also have an important role in the urban energy balance during winter. In summer, evapotranspiration by vegetation and evaporation from water bodies require heat taken from the surroundings, cooling the nearby ambient air as a result. As an example, a study in an institutional campus in the subtropical-humid climate of Saga (Japan) showed that the average daily maximum temperature would decrease by 2.7 °C when the quantity of the trees was increased by 20% in the campus area [11]. Several other studies have shown the importance of reduced mean radiant temperature by vegetation on outdoor thermal comfort [12–15]. In contrast, during winter, vegetation moderates a microclimate. In combination with sugar, the water within vegetation freezes below 0 °C. Moreover, the roughness of a surface or volume of leaves and grass breaks cold winds, reduces wind chill, and protects stems and roots of plants. The thermal mass of the soil is also an important factor that may result in a higher temperature at night. Table 1 summarises a number of studies that investigated the effect of vegetation and water bodies in summer. Few studies have addressed the effect of green roofs, vegetation and water bodies in winter [16,17]. Sailor [18] states that green roofs can increase the heating energy demand of buildings due to their shading effect that is beneficial in summer, but detrimental in winter. The thermal conductivity of water in wet green roofs and the

* Corresponding author. Tel.: +31 6 19957368.
E-mail addresses: mohamadtaleghani@gmail.com, m.taleghani@tudelft.nl (M. Taleghani), m.j.tenpierik@tudelft.nl (M. Tenpierik), a.a.j.f.vandendobbelsteen@tudelft.nl (A. van den Dobbelsteen), sailor@pdx.edu (D.J. Sailor).

[1] This is a follow up study based on the key findings published by the authors in Building and Environment, Volume 73, March 2014, Pages 138–150.

http://dx.doi.org/10.1016/j.buildenv.2014.07.010

Table 1
The summary of the key findings of different heat mitigation studies in summer.

	Location/climate	Season	Natural element	[a]Temperature reduction	Reference
Vegetation	Saga, Japan/Subtropical humid	Aug 2012	20% tree coverage	2.7 °C T_a	[11]
	Lisbon, Portugal/Subtropical-Mediterranean	Aug 2006	0.24 ha green space	6.9 °C T_a and 39.2 °C T_{mrt}	[23]
	Göteborg, Sweden/Oceanic	Summer	Park	5.9 °C T_a	[24]
	Tucson, Arizona/Hot dry	Summer	171 ha park	6.8 °C T_a	[25]
	Ouagadougou, Burkina Faso/Hot semi-arid	Oct–Dec 2003	A densely vegetated area	5.0 °C T_a	[26]
	Vancouver, Canada/Oceanic Marine west coast	Jul–Aug 1992	Dry grass park	1–2 °C T_a	[27]
	Sacramento (CA), USA/Mediterranean-type climate	Summer 1992	Watered grass park	5–7 °C T_a	[27]
	Portland (OR), USA/Temperate	Jul–Aug 2013	A green and bare courtyard	4.7 °C T_a	[5]
Water	Bornos, Spain/Hot and dry	Summer	A courtyard with pond	5.25 °C T_a	[28]
	Kawasaki City, Japan/Hot humid	Aug–Sep 2006	Water holding pavement	3–5 °C T_a	[29]
	Manama, Bahrain/Hot arid	–	Water bodies in urban spaces	3–5 °C T_a	[30]
	Nantes, France/Oceanic climate	July	A water pond and trees	35–40 °C T_{mrt}	[13]

[a] Temperature reduction is a result of the presence of the natural element with a bare surrounding.

evapotranspiration of vegetation also lead to heat loss [19,20]. Lazzarin, Castellotti [21] found that a wet green roof has 40% more outgoing heat flux compared to a typical insulated roof. Furthermore, McPherson, Herrington [22] showed that in cold climates, evergreen plants are not suitable for green roofs in winter because their shading effect reduces solar absorption in winter.

In this research paper, the effect of vegetation and water bodies on microclimates is studied through field measurements in both summer and winter in two university campuses. The summer study (July–August 2013) was done in Portland (OR), USA, and the winter study (November–December 2013) in Delft, the Netherlands; both temperate climates. The field measurements were done within university courtyards because the form of a courtyard provides a protected microclimate that makes the study of different variables such as vegetation and water bodies easier to quantify and compare.

2. Methodology

This paper is based on two field measurement campaigns in summer and winter in two similar temperate climates (Fig. 1). The main aim was to compare the thermal effect of vegetation and water bodies on the outdoor microclimate in summer and winter. The first case study is in Portland (OR), USA; the second in Delft, the Netherlands.

The summer study was carried out on the campus of Portland State University (an urban campus) in Portland (OR), USA (Fig. 2a and b). Portland (45°N, 122°W) experiences a temperate oceanic climate typified by warm, dry summers and mild, damp winters. The climate of Portland is classified as a dry-summer subtropical or Mediterranean climate zone based on the climatic classification of Köppen–Geiger (Csb) [31]. The mean annual dry bulb temperature is 12.4 °C and the prevailing wind in summer is from the north-west. In the Portland field study, HOBO U12-006 data loggers were used for the measurements (Fig. 2c). The accuracy of this device is ±0.25 °C. An air temperature sensor protected by a white solar radiation shield was attached to the HOBO. The position height of the sensor was 1.4 m. The measurements were done in July and August 2013. First, the air temperature and relative humidity were measured in three courtyards on the campus for two weeks. The courtyards were bare, with vegetation and with a water pond, respectively. Second, the air temperature of the campus park was measured one week and compared with the suburban areas of the city. For this purpose the weather station of the Airport of Portland (PDX) was selected, which is located at 17 km distance from the campus (to the north-east).

The winter study was done on the campus of Delft University of Technology (TU Delft), the Netherlands (Fig. 2d and e). The climate of Delft (52°N, 4°E) is also classified as warm temperate, fully humid, warm summer (Cfb). In this climate, winters are milder and cloudier than in other climates at similar latitudes, and summers are cool due to cool ocean currents [31]. The mean annual air temperature is 10.3 °C and the prevailing wind is south-west. The measuring tools in the Delft field study were Escort Junior data loggers that measure air temperature. The accuracy of this device is ±0.3 °C. The data loggers were placed in a bin that was shielded with aluminium cover to minimise the influence of solar radiation (Fig. 2f). The measurements took place in November and December 2013. First, the air temperature above three different roofs (green, black and white) was measured at the height of 0.3 m and compared (for one week with 5 min interval). Subsequently, the air temperature in three courtyards was measured for 17 days. The first courtyard had grass on the ground, the second was bare and black (bituminous), and the third courtyard had shrubs and a water pond. Simultaneously, the air temperature of the TU Delft botanical gardens was measured for the same period and compared with the air temperature of Rotterdam-The Hague Airport located 13 km from the campus to the south-east.

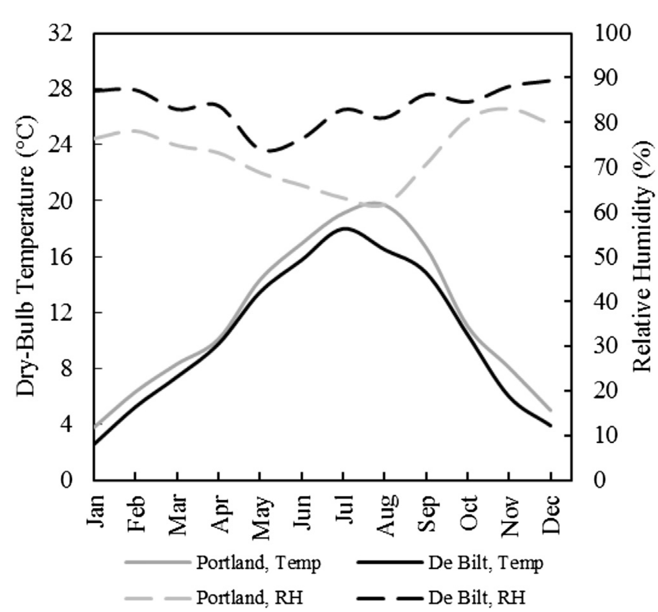

Fig. 1. Comparison of air temperature and relative humidity in Portland and Delft [32].