Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 103 (2014) 108–124

SOLAR ENERGY

www.elsevier.com/locate/solener

Heat in courtyards: A validated and calibrated parametric study of heat mitigation strategies for urban courtyards in the Netherlands

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*

Received 17 December 2013; received in revised form 24 January 2014; accepted 25 January 2014
Available online 3 March 2014

Communicated by: Associate Editor Matheos Santamouris

Abstract

Outdoor thermal comfort in urban spaces is an important contributor to pedestrians' health. A parametric study into different geometries and orientations of urban courtyard blocks in the Netherlands was therefore conducted for the hottest day in the Dutch reference year (19th June 2000 with the maximum 33 °C air temperature). The study also considered the most severe climate scenario for the Netherlands for the year 2050. Three urban heat mitigation strategies that moderate the microclimate of the courtyards were investigated: changing the albedo of the facades of the urban blocks, including water ponds and including urban vegetation. The results showed that a north–south canyon orientation provides the shortest and the east–west direction the longest duration of direct sun at the centre of the courtyards. Moreover, increasing the albedo of the facades actually increased the mean radiant temperature in a closed urban layout such as a courtyard. In contrast, using a water pool and urban vegetation cooled the microclimates; providing further evidence of their promise as strategies for cooling cities. The results are validated through a field measurement and calibration.

Keywords: Urban courtyard blocks; Climate change; Urban microclimate; Heat island mitigation strategies

1. Introduction

Growing urbanisation and the extensive consumption of fossil fuels have a profound impact on the thermal environment in cities. The relatively low reflectivity of urban surfaces combined with high density of construction in cities results in an accumulation of heat in the urban environment. The general lack of green (vegetated) areas and surface water also makes cities warmer. As a result, the cooling demand of urban residents increases (Akbari and Konopacki, 2004; Kolokotroni et al., 2012) and the heat stress on pedestrians rises (Oke, 1987; Pantavou et al., 2011). Promising mitigation strategies have been developed in order to cool urban spaces. These strategies are mainly related to the configuration of the built environment in accordance with (un)favourable solar radiation, construction materials used, and presence of water and urban vegetation (Akbari and Matthews, 2012; Moody and Sailor, 2013; Santamouris, 2013; Taleghani et al., 2013a,b).

The novelty of this paper is its focus on heat mitigation strategies in urban courtyard blocks in the Netherlands as one of the countries prone to climate change, i.e. becoming warmer and wetter (IPCC et al., 2007; KNMI, 2012). Thermal studies of urban courtyard designs are mainly studied

* Corresponding author. Tel.: +31 6 19957368 (M. Taleghani).
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).

http://dx.doi.org/10.1016/j.solener.2014.01.033
0038-092X/

in hot and arid environments and less in moderate Western Europe while there are several examples of the presence of this urban form in different Dutch cities (Fig. 1). This paper begins with a comprehensive review of strategies for cooling a microclimate. It then explores the application of these strategies to urban courtyards in the Netherlands. Courtyard blocks or building clusters are commonly used urban patterns in the Netherlands. In Phase 1, the impact of different courtyard geometries and orientations are analysed; in the next phases, the courtyard models are studied in the context of the Dutch climate in 2050. Finally, three heat mitigation strategies are studied parametrically for the current situation on the following features: changing the albedo of the facades of the urban blocks, adding urban green, and adding water ponds.

2. Background

The following brief literature review considers studies of (a) urban geometry and courtyards, (b) microclimate design to cope with climate change, (c) the effects of albedo on a microclimate, (d) the effects of water on a microclimate, and (e) the effects of vegetation on a microclimate.

(a) Urban geometry and courtyards

The interactions between urban geometry and surface properties under a specific climate generate microclimates. These interactions were first discussed by Olgyay (1963) and Oke (1987). Givoni (1998) discussed the thermal impact of urban typologies in different climates and arrived at general design guidelines. He writes that architectural forms, surface materials and urban morphology (compactness, elongations, etc.) can affect the microclimate environment. On this topic, courtyard blocks were studied in several climates addressing different benefits. A comprehensive study on urban courtyards at a latitude of 26–34°N was done by Yezioro et al. (2006) using the SHADING program. They showed that, for cooling purposes, the best direction of a rectangular courtyard was North–South (NS, i.e. with the longer facades on East and West), followed by NW–SE, NE–SW, EW (in this order). They found that the NS direction had the shortest duration of direct sun light in the centre of the courtyard. This finding is in accordance with climates (or seasons) in which less sun is desirable. They also investigated summer thermal comfort, and showed that, although the air temperature difference between shaded and unshaded areas was only 0.5 K, the mean radiant temperature was different up to 30 °C (Berkovic et al., 2012). Steemers et al. (1997) proposed six archetypical generic urban forms for London and compared the incident solar radiation, built potential and daylight admission. They concluded that large courtyards are environmentally adequate in cold climates, where under certain geometrical conditions they can act as sun concentrators and retain their sheltering effect against cold winds. Herrmann and Matzarakis (2012) simulated urban courtyards with different orientations in Freiburg, Germany. They showed that the mean radiant temperature (T_{mrt}) was highest for NS and lowest for the EW orientation at midday and at night. During the night, the mean radiant temperatures were very similar, but the orientation of the courtyard affects the time of the first increase of T_{mrt} in the morning, due to direct sun. In the Netherlands (on average at 52°N), few studies have addressed the Physiological Equivalent Temperature (PET) or other outdoor thermal comfort indices. Among these, van Esch et al. (2012) compared urban canyons with street widths of 10, 15, 20 and 25 m, and EW and NS directions. They concluded that the EW canyons did not receive sun on the 21st of December, while during summer and in the morning and afternoon, canyons had direct sun; at noon the sun was blocked. On the shortest day, the NS canyons got some sun for a short period (even the narrowest canyon) and were fully exposed to the sun in the mornings and afternoons.

(b) Microclimate design to cope with climate change

Global warming is likely to have a significant effect on cooling and heating loads in buildings. IPCC (Change, 2007) provides (and updates) estimations for future climates through different climate scenarios. Accordingly, building and urban designers try to reduce cooling loads of buildings to cope with climate change in the future. The strategies that they use are mainly through:

1. reducing solar heat loads, for instance with appropriate design, sun shading and reflecting materials (Holmes and Hacker, 2007; Matzarakis and Endler, 2010; Hwang et al., 2011);

Fig. 1. Urban courtyard blocks in Amsterdam, Rotterdam and The Hague (left to right).