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Creating drafts in urban settings through coloured façades: Exploring a new climate adaptation measure based on thermal stratification

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ABSTRACT

Climate change will lead to more warm and hot days in the Netherlands. Climate adaptation measures are needed to reduce the vulnerability of urban areas. Moreover, proven adaptation measures, such as increased vegetated areas or water surfaces, are not always possible due to a lack of space or undesired aesthetic effects. An alternative option is to make use of coloured façades to create drafts and accelerate wind speed in a street canyon or on a square to attract fresh air from cooler places. Differences in colour and material types already influence the air flow in street canyons in an uncontrolled manner. If this thermal comfort principle can be implemented, it will potentially have a significant impact on many cities throughout the world. This paper presents the results of a first exploratory research based on measurements on scale models and at full scale. This pilot study indicates success of the intended draft principle, advocating further research.

1. Introduction

In 1963 Victor Olgyay considered the outdoor climate essential in urban and architectural design and developed a method to quickly get an insight in the thermal comfort situation of a location. Due to a lack of knowledge of microclimatic processes, this field has been extensively studied by Tim Oke and others since 1973 (Oke, 1973, 1988; Nakamura and Oke, 1988; Bohnenstengel et al., 2004; Ali-Toudert and Mayer, 2006). Within the debate of future climate change effects, human thermal comfort in cities is increasingly important. Many processes within the urban structure can now be simulated with model calculations. To enable urban designers and policymakers to assess the thermal comfort situation of an urban area Mayer and Höppe (1987)) and Höppe (1999) developed a thermal comfort index, named the Physiological Equivalent Temperature (PET).

The current trend of increasingly frequent extreme temperature events is expected to rise with climate change according to the IPCC WGII AR5 Chapter 8 (Revi and Satterthwaite, 2014). To adapt to higher future temperatures we can act now while redeveloping or building new urban areas.

In order to control the thermal comfort conditions in an urban setting there are four physical parameters that can be influenced: air temperature, radiant temperature, humidity and wind speed. There are quite some climate adaptation measures available (Kleerekoper et al., 2011; Kikegawa et al., 2006; Carter, 2011; Mees and Driessen, 2011), these measures

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include protecting and enhancing urban vegetation and water bodies; decreasing the area of hard surfaces; the use of 'cool' materials and implementing sustainable drainage systems (SUDS).

There are many streets where additional vegetation or water is not an option because of a lack of space or technical difficulties. Options to reduce temperatures in these streets are to add coverings such as canvas sheets to provide shade; providing spraying nozzles to cool by evaporation; increasing the surface albedo of pavement or ventilating the streets to bring in cool air (Nishimura et al., 1998; Nikolopoulou and Steemers, 2003). The latter option could be done by orientating streets to the prevailing wind direction or using wind directing elements during hot summer periods.

For The Netherlands the prevailing wind direction during heat waves is North-East. Unfortunately this is also the prevailing wind direction during cold waves, and moreover, the strongest and year-round prevailing wind direction is exactly opposite: the South-West. Therefore, streets oriented from N-E to S-W will be less comfortable in especially winter and during stormy weather. In addition, the measure will not be that effective because wind speed is usually very low during heat waves, around 0.5–2.5 m/s (KNMI, 2011). Another way to bring cool air in a street canyon during sunny weather could be to accelerate the process of thermal stratification. On a larger scale this process is known from situations where cool airflow is generated from a park to a hot urban area adjacent to this park (Eliasson and Upmanis, 2000). On the smaller scale of a street the use of temperature differences could be used to accelerate airflows.

Therefore the hypothesis tested in this paper is as follows:

The colour and material of a façade influences the thermal stratification process in a street profile, so with a darker coloured façade the air will rise more rapidly along the façade's surface, increasing wind speed at street level and increase the mixture of air between the canopy layer and the city's boundary layer.

We know hot air rises: the stratification of air in a street canyon can have a strong influence on the circulation. With an ambient wind speed lower than 3–4 m/s, which is the case during heat waves, air flow processes are dominated by gravitational forces (Santamouris et al., 2001). A stable stratification can reduce the circulation of air, while convective stratification can intensify it (Bohnenstengel et al., 2004). We also know that dark colours absorb solar radiation and light colours reflect radiation. In Table 1 an overview is given of the effect of heated urban surfaces that has been studied by various scholars.

From the numerical and experimental studies mentioned above we can conclude that the heating of a façade has a strong influence on the movement of air within a street canopy when the prevailing wind speed is low. The studies indicate a change – strengthened or weakened – in the circulation pattern where vortexes change direction, and even additional vortexes appear with the increase of surface temperatures. The buoyancy effect of bottom heating in a scale model proved to be strong enough to reach the upper part of the street canyon. In combination with the numerical model result, which determined the strong buoyant force due to façade heating, the expectation is that the effect of heated facades is also strong enough to reach the upper part of the façade and therefore improves the mixing of air between the canyon and the upper layers.

This paper aims to answer the question whether we can make use of coloured façades to accelerate the rising of air in a street canyon in order to attract cooler air into the canyon. Differences in colour and materials already influence the air flow in street canyons, but in an uncontrolled manner. Different colours and materials were therefore studied for their effect on the air speed by means of an experimental test with a scale model. Full scale measurements were carried out on a warm day with low wind speed.

This study is a first step in the development of a new climate adaptation measure which could be applicable to many cities across the world that have to deal with heat stress or air pollution in their cities. An important connotation is the possible up-heating effect of the indoor environment when no precautionary measures are taken. Nevertheless, the proposed adaptation measure offers a new possibility for urban designers and policy makers to acclimatise urban areas where other measures are practically impossible.

2. Research methodology

In order to study the effect of façade colour and material on airflows two types of measurements were executed, those of wind speed and surface temperature. The measurements were first performed (with scale models) outside and inside on warm summer days. The results of these measurements are presented in detail by Kleerekoper et al. (2014) and are briefly summarized in this paper.

The scale model study indicates a significant difference in generated air speed by a black and a white surface. Air speed measurements at full scale were needed to confirm the principle at street scale. Therefore, two full-scale façades were studied on a moderate warm day with relatively low wind speeds.

2.1. Air speed measurements on façade models

The air speed measurements are performed inside (Fig. 1a) and the surface temperature measurements outside (Fig. 1b). The weather conditions on the measurement days are given in Table 2 for De Bilt in The Netherlands with latitude 52°7′0″ N and longitude 5°11′0″ E.