WINDCATCHER: A PASSIVE ADAPTIVE SYSTEM FOR THE NEW CLIMATE

Abstract

Human life has become heavily urbanized, and cities have become more populated. Crowded cities have a greater urban metabolism, which results in hotter cities. Moreover, new, higher-density urban forms have the potential to reduce wind velocity in the streets. These fundamental changes in urban climate have been accompanied by climate change. To cope with climate change, cities need to be prepared to adapt to changes. This paper proposes borrowing environmentally sustainable adaptation strategies for a hotter future climate in order to cope with climate threats. For this purpose, the windcatcher has been suggested as a passive cooling solution to penetrate more wind into street canyons; it may also increase the air turbulence and thus reduce the temperature and increase the outflow of pollutants from neighborhood environments. The windcatcher is an Iranian traditional architectural element in arid climates to create natural ventilation for buildings and maintain comfortable indoor temperatures. In this paper we will introduce it as an urban element that not only could provide urban identity, but also could improve urban microclimates.

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Keywords

Windcatcher, urban heat, adaptation, street canyon

Introduction

According to the World Meteorological Organization (Scott et al., 2019), the 20 warmest years on record have been the past 20 years. Most climate forecasting models predict that the current drought, beginning in the mid-1990s, will only intensify in the coming decades. Cities will be warmer, not only because of climate change but also because of urban heat islands. Urban climate influenced by interconnected factors is a multi-scale phenomenon which is mostly divided into three scales of study: building groups (local scale), settlement (mesoscale), and urban (macroscale) (Mills, 2006). Built environment research primarily focuses on building scale; however, urban climatology is a new branch of study that focuses on how urban features affect the urban climate. Recently, neighborhood scale and street canyons have attracted significant research on making cooler environments in outdoor spaces. Some research examines how to lower air temperature, but only a fraction of this research focuses on improving wind velocity in urban canyons. Most urban heat mitigation scenarios involve changing neighborhood configurations and highlight how these changes influence wind penetration (Ramyar, 2019). However, changing the configuration of existing neighborhoods can be prohibitively expensive.

Instead of changing neighborhoods' layouts, we introduce a new affordable option: the windcatcher, a feature of vernacular architecture in Iran. This architectural element can cool neighborhoods without expensive reconfiguration by directing wind blow and velocity at street level. In developing neighborhoods, examining the different configurations

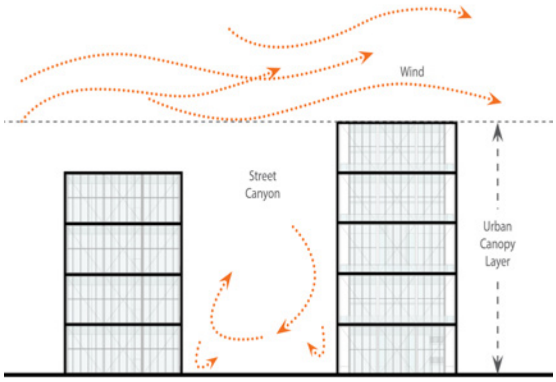

Figure 1: Lower wind velocity in street canyons.

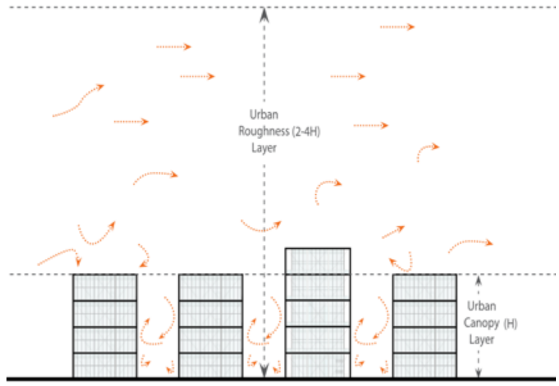

Figure 2: Urban roughness layer and urban canopy layer showing how urban form changes urban velocity.

and neighborhood layouts to provide cooler environments is justifiable and affordable in terms of expense. However, in developed neighborhoods, adding or replacing elements to reduce urban heat would be the most cost-effective solution.

Currently, adaptation is attempting to achieve a proper integration of adaptation strategies with urban planning and design (Ramyar & Zarghami, 2017). Adaptation to climate change has been defined as "modulation of ecological, social, or economic systems in response to current or expected climate stimuli" (Smith et al., 1998). To cope with climate threats, adaptation becomes the main strategy for urban planning (Ramyar et al., 2019b). Adaptation, however, is not a new concept in urban climate literature. Adaptation to climate has existed since prehistoric times to protect against extreme weather or natural threats. Vernacular architecture and urban planning in areas with harsh climates show widespread passive adaptation strategies in coping with natural threats, which are adaptable to current needs and climatic threats.

Windcatchers or wind towers are tower-shaped architectural elements mounted on the roof of buildings in hot climates to catch the wind from a higher elevation and direct it to indoor spaces for cooling and ventilation. Windcatchers have a big opening at a distance from the roof level (that sometimes is more than five times the building height). The movement of wind at the upper canopy layer creates a positive pressure on the windward side and produces negative pressure at the windcatcher's bottom where there is an outlet (Bahadori et al., 2008). Sometimes the wind passes above a pool near the outlet to add moisture and improve its cooling effect. Windcatchers work as a chimney in a building when there is no wind to exhaust inside hot air. In current active cooling systems for buildings, such elements are not used yet. Low wind velocity and extensive exposed surfaces with a low albedo of solar radiation in the streets' canyons have made urban temperatures higher than in the surrounding countryside (Figure 1). This phenomenon is known as an Urban Heat Island (UHI). Climate change, temperature rise, and the speed of urbanization increase concerns over urban heat (Ramyar et al., 2019a). Expanding wind penetration to urban canyons (below the urban canopy layer) and increasing shaded areas and humidity are three main fundamental solutions to cope with urban heat (Ramyar et al., 2019c). In this regard, this research suggests the use of windcatchers to improve wind penetration and humidity in urban canyons.

This passive cooling method, by improving wind velocity, would not only provide a cooler neighborhood but also reduce building energy consumption for indoor cooling. Using neighborhood-scale windcatchers to modify the microclimate of street canyons is a new idea that needs to be investigated from different perspectives, which will be discussed in this article. In order to use the windcatchers to reduce the temperature and increase the wind velocity in street canyons, we need to redefine *windcatcher* and to pay attention to the details of the new application of windcatchers, as follows:

Windcatchers

A windcatcher is a beautiful and decorative vertical element in Iranian architecture linked to buildings to provide natural ventilation. The main use of windcatchers is to provide natural ventilation in a passive cooling system that acts as an air-conditioning system. In this paper, a windcatcher is a tower-shaped architectural construction that can be linked to a building or stand separately from the building. Its height must be higher than the urban canopy layer that is equal to the mean building height (Oke, 2002) and must be placed in the roughness sublayer, which is equal to 2–4 times of the urban canopy layer height (Barlow, 2014) (Figure 2).

The higher the windcatcher, the greater the positive and negative pressure difference between the inlet and outlet wind flow, and the greater the wind intensity. In warmer climates, where the temperature is high and the prevailing wind intensity is low, such as deserts, longer windcatchers were used (like the Yazd in Iran) (Figure 3). In coastal areas with appropriate wind and breeze velocity, shorter windcatchers were used (like the Loft in Iran) (Figure 4). It is more expensive to build higher windcatchers, which require a more sophisticated structural framework. Hence, choosing an optimal size is essential to reduce the cost.

WINDCATCHER ELEMENTS

Windcatchers have ducts that are usually tetrahedral, but sometimes square. They have a head or sometimes several heads. Some studies have suggested that square windcatchers have better performance due to the intensity of suction pressure on the leeward side (Jomehzadeh et al., 2017). The inlet opening is mounted on the windcatcher head. Its direction is very important (Figure 5). It should be in front of the prevailing wind to catch more wind flow.

Figure 3: Dolatabad garden (Yazd, Iran). (https://rasekhoon.net/)

Figure 4: Loft's urban fabric; a coastal city near the Persian Gulf. (www.iransafar.co)

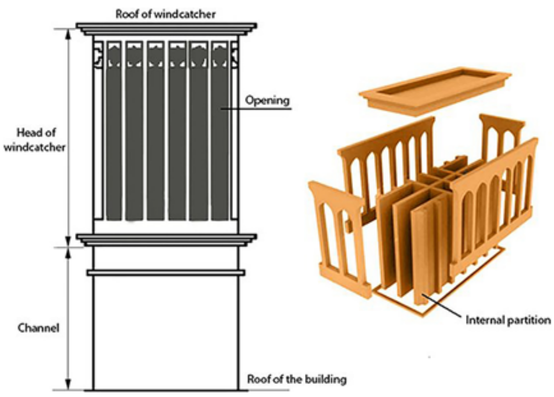

Figure 5: Windcatcher elements. (Jomehzadeh et al., 2017)

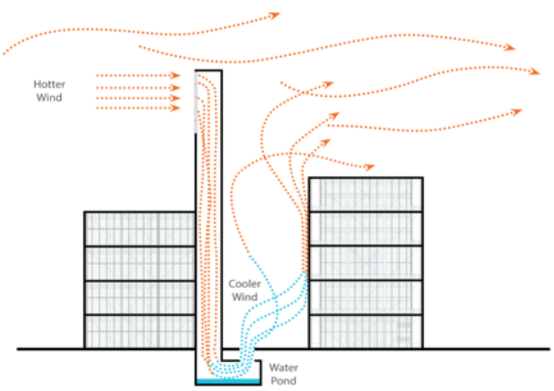

Figure 6: Water pond will add moisture to the wind before blowing in sidewalks and improve evaporative cooling.

PROPOSED USE OF WINDCATCHER IN STREET CANYON

The best position is for the windcatcher to be next to the building, and it must be taller than the surrounding buildings to move the wind from a higher altitude to the street level. The air is channeled to the underground beneath the sidewalks, where it can pass through a water pond that can be filled with gray water from buildings, pick up moisture, and pass through vents in the middle of the street or in the curb (Figure 6). The windcatcher can, of course, be located elsewhere in the city apart from a building, but its visual impact on the urban form and configuration must be carefully considered. Building windcatchers adjacent to the buildings can represent them as an element attached to the buildings, and that their replication throughout the city provides a unique identity and character based on the forms and shapes of the windcatchers.

Concerns About Using Windcatchers

THE BEST POSITION FOR WINDCATCHERS IN STREET CANYONS

Of course, finding the best position for a windcatcher in an urban area is very much related to the shape and form of the street canyon and the configuration and layout of the neighborhood. In some dense cities, buildings are built adjacent to the streets, while in others, outdoor open spaces are found between the buildings and the street. Some cities have very high-density areas and others do not. One form of windcatcher cannot be prescribed for different cities or different parts of a city with varying climatic characteristics. However, windcatchers can be used in various ways to meet the proposed goal of increasing wind turbulence at lower urban levels, on streets and sidewalks, and in different shapes and forms.

OPENINGS AND HEADS OF WINDCATCHERS

A windcatcher's direction is related to the prevailing wind direction. The windcatcher intake and head should face the prevailing wind. In areas where the prevailing wind direction changes during the day or over months, multiple openings must be created in different directions. In this situation, blades must be constructed between the openings to separate them and not allow the entering wind to exit from other openings. The blades should extend to the bottom of the head openings. The windcatchers could have a rotatable head with an opening in one direction and rotate according to the prevailing wind direction. This can happen in a cylindrical windcatcher (a circular-shaped windcatcher).

The intake opening must be high and wide enough to catch a lot of wind. The larger the intake, the more wind it will catch. Therefore, according to need and the speed of the wind, the size of the opening must be adapted (Figure 7). A windcatcher intake opening can be built parallel to one face of a building and can be as wide as the whole face of a building or as one portion of the face. This allows us to have a wide windcatcher. However, we must remember the openings must be in the roughness sublayer higher than adjacent buildings. In constructing windcatchers near tall buildings, we must consider the effect of buildings on wind direction during the year (Figure 8).

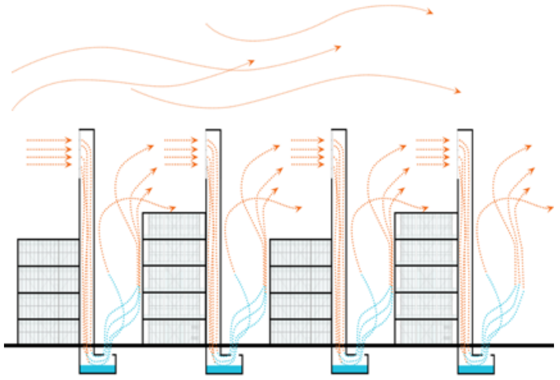

Figure 7: Windcatcher in street canyons could improve wind velocity.

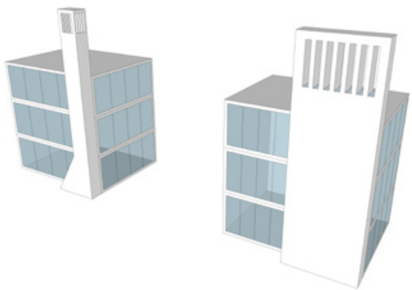

Figure 8: A windcatcher intake opening can be built parallel to one face of a building and can be as wide as the whole face of a building or as one portion of the face.

VERTICAL AND HORIZONTAL CHANNELS

The channels should not be narrow between the intake and output outlets. Obstacles to the wind direction reduce the velocity of the wind.

OUTPUT OUTLETS LOCATION

When the wind is channeled from the opening to the basement, below the sidewalks, it is advisable to provide outlets closer to the channel. The longer and the more tangled the vertical channel, the less the wind output pressure.

WIND DISTRIBUTION IN THE STREETS

Care should be taken to ensure that the wind is evenly distributed from the sidewalks of a street canyon. The output wind blow volume and the distance to the street must therefore be carefully calculated. The distance between the windcatcher and the air volume they could provide for the canyon must be calculated according to the mean speed of the wind and also to the volume of circulated air that is needed according to the urban heat. It is best to plan for the extreme weather, highest wind speed, and hottest days, then provide some moderators to control the windcatcher. It is best to take into account the maximum and minimum wind speed in the area, to design for the minimum winds, and to use wind control elements to control the pressure on high wind-speed days (Figure 7).

DISTRIBUTION AND LAYOUT OF WINDCATCHERS AT THE STREET AND CITY LEVELS

The distribution and number of windcatchers in a given area, such as a street, must be calculated based on the neighborhood density and configuration, and the wind speed. The number of windcatchers and their distances apart can be defined by considering the output speed and calculated wind volume.

Challenges of Using Windcatchers

One of the challenges of using windcatchers to increase wind speeds on sidewalks, especially in dry areas, is the movement of dust from the wind, which needs to be carefully considered. Another challenge is using some mechanical controls to manage the volume of wind for days and times when wind speeds are high and may cause pedestrian discomfort at the street level.

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