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Numerical Analysis of a Wind Catcher Assisted Passive Cooling Technology

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Abstract

Buildings are responsible for almost 40% of the world energy usage. Heating Ventilation and Air-Conditioning (HVAC) systems consume more than 60% of the total energy use of buildings. Clearly any technology that reduces HVAC consumption will have a dramatic effect on the energy performance of the building. Natural ventilation offers the opportunity to eliminate the mechanical requirements of HVAC systems by using the natural driving forces of external wind and buoyancy effect. One technology, which incorporates both wind and buoyancy driven forces, is the wind catcher. Wind catchers are natural ventilation systems based on the design of traditional architecture. Though the movement of air caused by the wind catcher will lead to a cooling sensation for occupants, the high air temperature in hot climates will result in little cooling to occupants. In order to maximise the properties of cooling by wind catchers, heat transfer devices were incorporated into the design to reduce the supply air temperature. The aim of this work was to investigate the performance of a wind catcher integrated with heat transfer devices using numerical modelling and wind tunnel experiment. The wind catcher model was incorporated to a building, representing a small room of 15 people. Care was taken to generate a high-quality CFD grid and specify consistent boundary conditions. An experimental model was created using 3D printing and tested in a wind tunnel. Qualitative and quantitative wind tunnel measurements were compared with the CFD data and good correlation was observed. The study highlighted the potential of the proposed wind catcher in reducing the air temperature by up to 12 K and supplying the required fresh air rates.

Keywords Buildings; Computational Fluid Dynamics (CFD); Energy; Heat transfer device; Passive cooling.

1. Introduction

Extensive efforts have been focused on an environmentally friendly approach to building design, revealing the on-going interest of the scientific community on the topic [1]. Passive cooling technologies such as wind catchers are increasingly being employed in buildings for increasing fresh air rates and reducing energy consumption. A wind catcher is a wind driven ventilation device, which captures air at high elevations and directs the air into the interior of the building. The internal volume of the device is divided into quadrants, which allow fresh air to enter while also allowing stale air to escape, regardless of wind direction [2]. In this study, Heat Transfer Devices (HTD) were integrated into the passive terminal of a commercial wind catcher to reduce the temperature of supply air (See Figure 1).

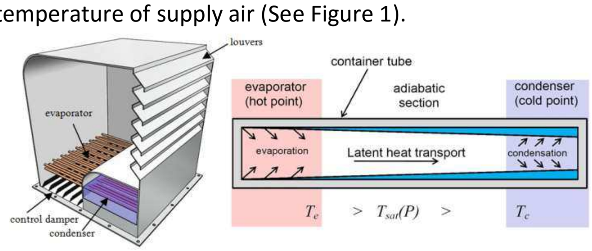

Figure 1. **(a)** A wind catcher with HTD **(b)** Operation of HTD.

A number of studies have assessed the natural ventilation performance of wind towers using Computational Fluid Dynamics (CFD) and wind tunnel analysis [2]. Several research projects investigated the integration of cooling techniques into wind towers for hot climates [2]. The aim of this study was to investigate the performance of a commercial wind tower integrated with Heat Transfer Devices (HTD) using CFD and wind tunnel analysis. An experimental scale model was created using 3D printing. The scale model was tested in a closed-loop wind tunnel to validate the CFD model.

2. Methodology

2.1. CFD Method

The basic assumptions for the numerical simulation include a three-dimensional, fully turbulent, and incompressible flow. The flow was modeled by using the standard *k*–epsilon turbulence model, which is a well-established method in research on natural ventilation [3, 4]. The CFD code was used with the Finite Volume Method (FVM) approach and the Semi-Implicit Method for Pressure-Linked Equations (SIMPLE) velocity-pressure coupling algorithm with the second order upwind discretisation. The governing equations are detailed in [5].

The wind catcher geometry was created using a Computer-aided design (CAD) software and then imported into ANSYS Geometry to create a computational domain [5]. The domain was separated into three parts: the macro-climate (outdoor), wind catcher and micro-climate (indoor). The macro-climate was created to simulate the outdoor airflow. The macro-climate consisted of an inlet on one side of the domain, and an outlet on the opposing boundary wall. The wind catcher was incorporated to a micro-climate with dimensions of 3 m x 5 m and 5 m, representing a small room [6, 7]. The heat transfer devices, each with an outer diameter of 0.02 m, were integrated in to the lower part of the channel as shown in Figure 1. Due to the complexity of the model, a non-uniform mesh was applied to volumes of the computational domain [8, 9]. Mesh adaptation was used to verify the computational mesh of the model. The process increased the number of elements between 1 and 7.2 million.

2.2. Experimental Method

A 1:10 scale model of the wind catcher was used in the experimental study. The investigation was conducted in a closed-loop wind tunnel detailed in [10, 11]. The creation of an accurate scaled wind tunnel prototype was essential for the experimental study. Therefore, the model of wind tunnel was constructed using 3D printing. The model of the wind catcher was connected to a 0.5 x 0.5 x 0.3 m room, which was mounted underneath the test section. The airflow into the room was measured using a hot-wire anemometer, which was positioned below the channels of the wind catcher. The hot-wire sensor gave airflow velocity measurements with uncertainty of ±1.0 % of reading at speeds lower than 8 m/s.

3. Results and Discussion

Figure 2 displays a cross-sectional plot of the temperature distribution inside the room with a wind catcher. The average temperature inside the room was 310.4 K when the temperature of the outdoor wind was set at 318 K. The temperature was reduced further at the immediate downstream of the heat transfer devices with a supply temperature value of 309 K. Figure 3 shows the effect of the variation of wind speed on the thermal performance of the wind catcher system. The decrease in wind speed showed a significant improvement in thermal performance.

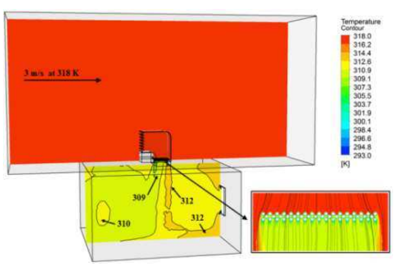

Figure 2. CFD contours of airflow temperature.

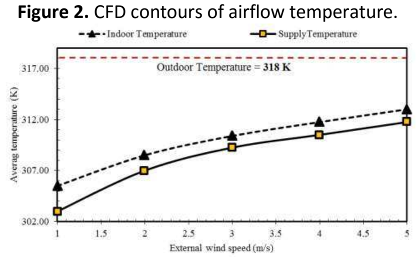

Figure 3. Effect of wind speed on thermal performance.

Figure 4 shows a comparison between the predicted and experimental results for the air velocity measurements below the wind catcher channel. Good agreement was observed between both methods with error below 10 %.

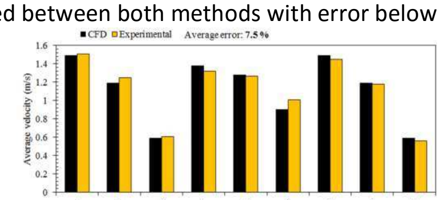

Figure 4. Comparison between CFD and experimental data.

4. Conclusions

The integration of wind catchers as a low energy alternative to HVAC systems has the potential to improve the thermal comfort of occupants, the indoor air quality and reduce energy consumption and greenhouse gas emissions. In this study, a roof-mounted wind catcher was integrated with heat transfer devices to reduce the temperature of the supply airflow. A cooling potential of up to 12 K was identified in this study. There was good agreement between the wind tunnel measurements and CFD results with error below 10 % on average.

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