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A natural ventilation wind tower with heat pipe heat recovery for cold climates

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ABSTRACT

Commercial wind towers are passive ventilation technology based on traditional wind towers of the Middle East. Typical operation of wind towers in cold – mild climates is generally limited to summer-seasons as the outdoor air is too cold to be introduced into spaces for the majority of the year. In addition, the use of natural ventilation solutions has been seen to increase heat loss in buildings and lead to increased energy cost. Wind towers are normally shut down for the sake of avoiding indoor heating energy losses during winter months. Consequently, the concentration of pollutants has seen to rise above the guideline levels, which can lead to ill health. To improve the year-round capabilities of wind towers, a heat recovery system utilising the combination of heat pipes and heat sink was incorporated into a multi-directional wind tower. This study investigates the potential of this concept through the use of numerical analysis and wind tunnel experiments for validation. The findings showed that the wind tower with heat pipes was capable of meeting the required ventilation rates above an inlet air velocity of 1 m/s. In addition to sufficient ventilation, the integration of heat pipes had a positive effect on thermal performance of the wind tower; it raised the supply air by up to 4.5 K. The technology presented here is subject to a patent application (PCT/GB2014/052263).

1. Introduction

Buildings account for 40% of the world energy usage and are responsible for almost 40–50% of the global carbon emissions [1]. With the increasing demand for thermal comfort, Heating, Ventilation and Air-Conditioning (HVAC) systems have become an unavoidable asset. Space heating currently accounts for 40% of total energy demand in residential and service sector properties in the UK and other developed nations [1]. Therefore any technology which reduces HVAC consumption will have a significant effect on the overall energy performance of buildings [2]. Recently, natural ventilation techniques such as wind towers were increasingly being employed in buildings for increasing the supply of fresh air and reducing the HVAC consumption [3,4].

Wind towers were utilised in buildings in the Middle East for many centuries and their commercialisation had increased over the years [5,6]. A wind tower is divided into quadrants, which allow fresh air to enter as well as stale (used) air to escape irrespective of the prevailing wind direction (Fig. 1). There are two driving forces for the wind tower. The primary force provides fresh air driven by the positive air pressure on the wind-ward side, while exhausting stale air with the assistance of the suction pressure on the leeward side. Wind towers also operate by a secondary action of the stack effect; the density of air decreases as the temperature increases, causing warmer air to rise and exit the wind tower. Cooler, fresh air replaces the outgoing air, either through the wind tower or windows in the structure. A wind tower can provide a significantly higher airflow rate than in an equivalent area ventilated by an open window [7].

Standard operation of wind towers in cool to mild climates is generally limited to summer seasons as the external air is too cold to be introduced into occupied spaces for the majority of the year. Additionally, the perception that the use of natural ventilation solutions will increase heat loss and lead to increased energy costs which are unfavourable for many users [9]. By restricting the use of natural ventilation methods during winter months, the concentration of pollutants have been seen to rise above the accepted guideline levels, which can lead to ill health and poor performance [9].

Heat recovery technology provides a practical solution to reducing energy demand in mechanical ventilation systems by

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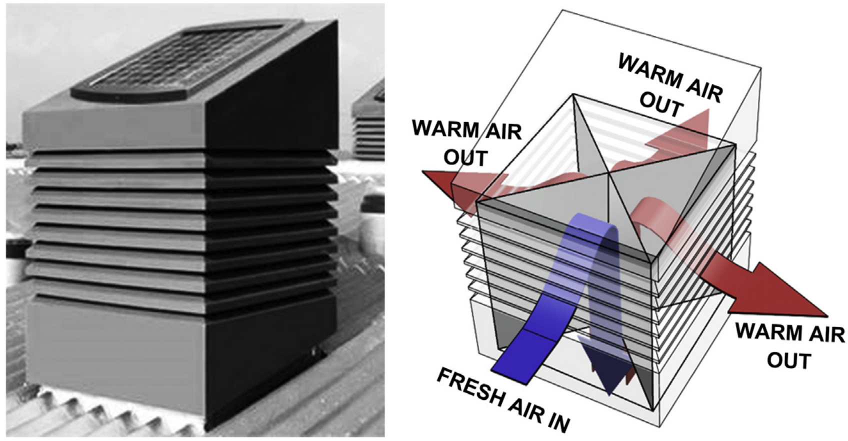

Fig. 1. A commercial multi-directional wind tower [8].

transferring heat energy from one airstream to another, thereby having a positive influence on the air temperature supplied to occupants in terms of thermal comfort. However, in order for the ventilation system to provide the required level of supply air to achieve adequate ventilation rate, additional fans and blowers are needed to overcome the pressure drop associated with the heat recovery technology. The additional energy demand of these fans and blowers can offset the energy saved by the heat recovery technology. Commercial wind towers offer a ventilation system which requires zero energy input to deliver the required ventilation rate but presently are only capable of operating when outdoor climate conditions are suitable to provide thermal comfort to occupants. Integrating heat recovery technology into commercial wind towers extends the window of operation for wind towers in all climates [9]. However, integrating heat recovery with natural ventilation systems is a challenging task due to the pressure loss caused by conventional heat exchangers.

Heat pipes offer an alternative approach for heat recovery in naturally ventilated buildings and have several advantages since they have a much higher effective thermal conductivity than conventional heat recovery devices. Individual heat pipes can be independently located in ventilation stacks, making it easier to achieve lower pressure drops and provide the required fresh air supply rates [10].

1.1. Aims and objectives

To improve the year-round capabilities of commercial wind towers, a retrofit heat recovery system is desirable. This study presents and discusses the potential of this concept through the use of CFD analysis and wind tunnel experiments for validation. The concept was to integrate heat transfer devices inside the wind tower channel, as shown in Fig. 2. Using the heat transfer devices as a heat exchanger, the thermal energy in the exhaust air is recovered to the incoming air. By raising the temperature of the incoming air from the wind tower, adequate year round ventilation is maintained and during the winter season, energy demand for heating systems is reduced.

As shown in Fig. 2, the device extends out from the top of a building to catch the wind at roof level and channels fresh air through a series of louvers into the enclosed space under the action of air pressure. Simultaneously, the negative pressure extracts stale air out of the room. At 0 ° wind angle, three of the four quadrants are available to the warm and stale air moving out of the building due to negative pressure. The warm and stale exhaust air is passed through a series of cylindrical heat pipes which absorbs the thermal energy and transfers it to a perpendicular heat sink mounted in the top hat of the wind tower. The thermal energy is transferred to the heat pipes in the intake region of the wind tower where they are cooled as the thermal energy is transferred to the incoming fresh air. Under typical operation, a metal container such as copper contains a small amount working fluid pressurised to its saturation point [10]. The heat transfer system is based on the continuous cycle of evaporation and condensation process. When heat is applied to the outer area of the tube, the liquid inside the tube boils and vaporises into a gas that moves through the tube seeking a

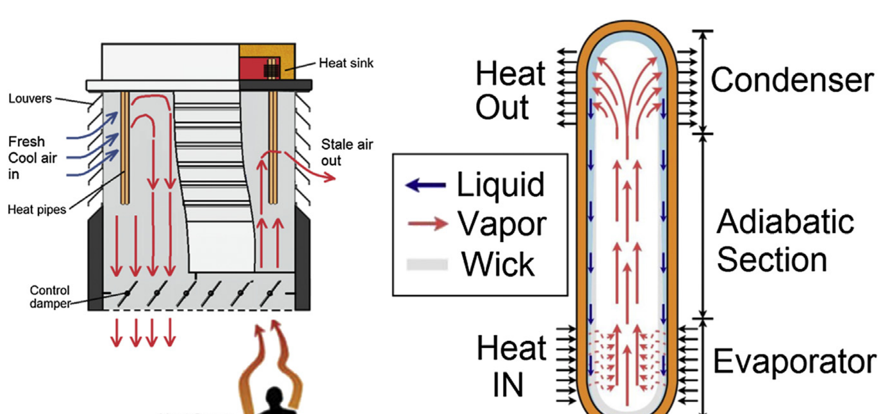

Fig. 2. Multi-directional wind tower design with heat pipes [11].