Energy and Buildings 82 (2014) 799–811

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

A study of passive ventilation integrated with heat recovery

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A R T I C L E I N F O

Article history:
Received 9 December 2013
Received in revised form 25 February 2014
Accepted 21 May 2014
Available online 5 June 2014

Keywords:
Air supply rate, CFD
Natural ventilation
Rotary wheel
Wind tower
Wind tunnel

A B S T R A C T

To meet the demand for energy demand reduction in heating, ventilation and air-conditioning systems, a novel design incorporating a heat recovery device into a wind tower was proposed. The integrated system uses a rotary thermal wheel for heat recovery at the base of the wind tower. A 1:10 scale prototype of the system was created and tested experimentally in a closed-loop subsonic wind tunnel to validate the Computational Fluid Dynamics (CFD) investigation. Wind towers have been shown to be capable of providing adequate ventilation in line with British Standards and the Chartered Institution of Building Services Engineers (CIBSE) guidelines. Despite the blockage of the rotary thermal wheel, ventilation rates were above recommendations. In a classroom with an occupancy density of 1.8 m^2/person, the wind tower with rotary thermal wheel was experimentally shown to provide 9 L/s per person at an inlet air velocity of 3 m/s, 1 L/s per person higher than recommended ventilation rates. This is possible with a pressure drop across the heat exchanger of 4.33 Pa. In addition to sufficient ventilation, the heat in the exhaust airstreams was captured and transferred to the incoming airstream, raising the temperature 2 °C, this passive recovery has the potential to reduce demand on space heating systems.

1. Introduction

The statutory requirement to reduce UK greenhouse gas emissions by 80% from pre-1990 levels by 2050 is a major driving force in decreasing energy demand for the operation and maintenance of buildings in the UK [1]. Space heating currently accounts for 40% of total energy demand in residential and service sector properties in the UK and other developed nations [2]. A reduction in the energy required to heat domestic and non-domestic buildings, most commonly recognised as office, school and retail buildings, presents one part of a solution to reach the goal of cutting greenhouse gas emissions.

Mechanical ventilation fulfils many uses through the use of fans and blowers; circulating internal air back through the building or drawing external air into the building, removing stale and polluted air as well as conditioning the occupied space for thermal comfort. These processes are highly energy intensive. Mechanical ventilation systems which provide heating and cooling are commonly referred to as heating, ventilation, and air-conditioning (HVAC) create a significant demand of the total energy used in many buildings [3]. Natural ventilation uses pressure differences in and around a building to force external air into a building and draw internal air out, in this way no mechanical processes or energy input are required [4]. Pressure differences created by wind flow around a building provide a higher level of ventilation compared to the pressure differences created by the buoyancy effect of warmed air [5].

Wind towers are a traditional Middle Eastern technology that utilises natural ventilation to encourage ventilation and cooling in buildings [6,7]. This technology has been used for many hundreds of years and has been adopted commercially in the UK [8]. Wind towers have been proven as an effective replacement to air-handling units in schools and commercial office buildings in ventilating rooms during summer months [9]. Wind towers are designed as a ventilation aid to bring in fresh air from outside and remove pollutants; therefore their use is generally limited to the cooling seasons in the UK, as can be seen in Fig. 1. This is due to the potential for low incoming air temperatures to cause thermal discomfort to the occupants and 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. There are examples of wind towers in use in winter months but this is generally restricted [10]. However, 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 as stated by CIBSE and the Department for Education and Skills (DfES), which can lead to poor mental performance and ill health [11].

To improve the year-round capabilities of wind tower systems to enable consistent use during cooler months, a retrofit heat recovery system is desirable. This study introduces and discusses the

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http://dx.doi.org/10.1016/j.enbuild.2014.05.050
0378-7788/

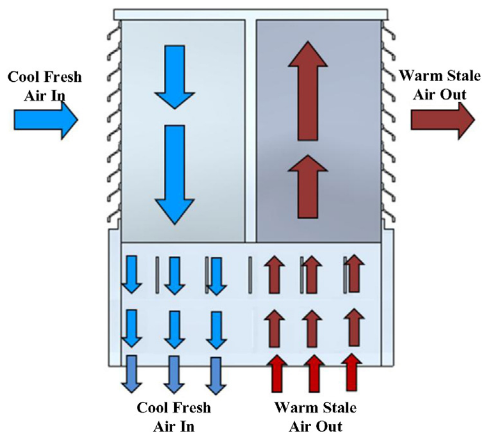

Fig. 1. Ventilation through a standard commercial wind tower.

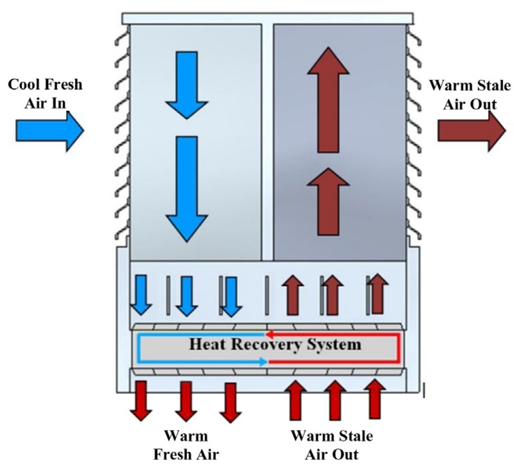

Fig. 2. Ventilation through the proposed wind tower system with integrated heat recovery technology.

potential of this concept through the use of CFD analysis and wind tunnel experimental for validation.

The concept is to attach a rotary thermal wheel to the bottom of a wind tower, as shown in Fig. 2. Using the properties of the thermal wheel as a heat exchanger, the thermal energy in the internal exhaust air is recovered to the incoming air. This concept raises the incoming air temperature. By raising the temperature of the incoming air from the wind tower, adequate year round ventilation is maintained and during the heating season, energy demand for heating systems is reduced.

It has been previously noted that wind towers are capable of delivering adequate levels of ventilation, as given in BS5925:1991, to meet pollutant removal guidelines [12]; therefore the blockage cause by the rotary thermal wheel must not impede the ventilation rate of the wind tower to a level where these guideline ventilation rates are no longer met.

The two characteristics that were investigated were the flow distribution around the room and the air flow through the four quadrants of wind tower; this was used for the calculation of ventilation supply and exhaust rates. The study shows the inclusion of the rotary thermal wheel will affect the air supply rate into the room/building and determines if the guideline air supply rates are met for standard occupancy. In addition, the potential for heat recovery is analysed with preliminary results presented.

2. Previous related work

In recent years, wind towers have undergone considerable amount of research to better understand the effect of airflow through and over wind towers as well as the ventilation rates that can be provided by these systems. Further to this, attempts have been made to improve the thermal comfort that can be provided to occupants, either through the cooling of air for hot climates or warming in cooler climates. The work has been conducted through the use of CFD modelling as well as scaled wind tunnel testing and in some cases, in situ or field testing in order to understand the effects in a real world environment.

Understanding the ventilation rates through the use of wind towers is essential in encouraging the uptake of the technology for the wider public. In order for this to be successful, research needs to confidently show that acceptable levels of ventilation can be achieved. Hughes and Ghani [13] used CFD analysis to show that wind towers are capable of supplying the recommended air supply rates even at low external wind velocity. This simulation work is supported by in-situ wind tower testing focussed on the ventilation rates that were achievable. Jones and Kirby [8] investigated ventilation rates in schools and saw a 46% increase when a wind tower was used in conjunction with natural ventilation strategies such as opening windows and doors to aid circulation. Kirk and Kolokotroni [14] investigated ventilation rates in office buildings and recorded an increase of 87% in ventilation rates compared to mechanical ventilation when a wind tower was used.

CFD analysis can also be used to determine the most effective configuration of wind towers by analysing the flow effects around the unit. Liu et al. [15] found that the optimal number of louvers in the design of a wind tower was found to be between 6 and 8. Beyond this value the airflow rate did not increase by a significant amount to warrant the additional material.

In addition to CFD analysis, scaled wind tunnel testing is essential to gain qualitative and quantitative data from concepts and prototypes in a controlled environment. Wind tunnel testing can be used to validate work previously analysed using CFD models. Walker et al. [16] used scaled model testing in wind tunnels to validate CFD models. The results from their data showed high levels of correlations. This shows that when the CFD models are calibrated to best replicate the conditions found in wind tunnels, errors are eliminated. Montazeri et al. [17] and Montazeri [18] used wind tunnel testing for the qualitative visualisation of air streams for alterative wind tower shape designs. Testing in this way furthers understanding of the air flow and characteristics through a building model, giving a transient solution that CFD sometimes is not able to replicate. Elmualim [19] showed the use of full scale models in large wind tunnels has shown positive results and validation of CFD analysis. However it should be noted that with these tests, atmospheric conditions cannot be replicated in a small wind tunnel as the roof of the wind tunnel will lead to artificial acceleration of the air. Shea et al. [20] and Elmualim [21] have conducted far-field testing of wind tower systems in order to determine the suitability of the system outside of a wind tunnel.

Following work investigating the effects of flow around a wind tower, various attempts have been made to enhance the cooling and heating potential of wind towers. Bouchahm et al. [6], Bahadori [7] and Bansal et al. [22] focussed on the inclusion of additional cooling techniques for wind towers. The work sought to make use of the evaporative cooling technique which was commonly used in the traditional designs to cool the incoming air. Though cooling has had more attention in the past, little work has been carried out in the area of heat recovery or heating incoming air in wind towers. Shao et al. [23] noted that passive stack systems are designed without heat recovery which leads to large amounts of wasted heat. Woods et al. [24] looked at the use of wind towers during the winter