A heat recovery system for a passive ventilation wind tower

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ABSTRACT

Wind towers provide passive building ventilation, where natural air flows generate air exchange between the building and outside environment. The harnessing of natural air flows results in zero energy input for ventilation. A drawback of such an approach is that there is no control over the air drawn into the building. If the air is cold, then building users may feel increased discomfort. Heated air drawn out of the building represents a loss and an energy demand. To increase building comfort and reduce energy demand a heat recovery system was investigated to transfer heat from the air leaving the building to the air entering. A series of full-scale tests were carried out in a wind tunnel at the BRE, with liquid-vapour heat pipes used for heat recovery between the two air streams. The results show that the system is effective at recovering heat from one stream to the other.

Keywords: Passive ventilation, Wind tower, Heat recovery, Heat pipes, Energy Reduction.

INTRODUCTION

The UK has set out legally binding targets in the Climate Change Act to reduce carbon emissions by over 20% by 2030, and almost complete decarbonisation by 2050. The Committee on Climate Change consider that one of the most cost-effective means of meeting these targets is improving the efficiency of buildings (Committee on Climate Change, 2019). The UK's Clean Growth Strategy highlighted that improved business energy efficiency could lead to £6 billion in cost savings by 2030 and would constitute one of the largest CO_2 savings (Department for Business Energy & Industrial Strategy, 2019).

In the UK, space-heating and air-conditioning of buildings accounts for 23% of total energy demand and contributes 20% of CO_2 emissions (European Commission, 2019). Non-domestic buildings account for 25% of CO_2 emissions from buildings (Committee on Climate Change, 2018). The RIBA estimates space-heating in school buildings costs £159 million per year while space and air heating in NHS England hospitals costs £250 million per year. For school buildings if a 20% reduction in space-heating is achieved then £31.8 million would be saved per year. However, thus far while the energy efficiency of domestic properties has improved, the efficiency of non-domestic properties has shown little change.

New buildings are highly insulated and airtight to prevent heat loss to improve efficiency. However, this is detrimental to indoor air quality (IAQ) in increasing airborne pollutants and the potential for summertime overheating. A particular building type is required to have rate of ventilation depending on the function to ensure a healthy environment. Poor IAQ may affect occupant thermal comfort, health and wellbeing and productivity. In non-residential buildings heating, ventilation and air conditioning systems (HVAC) are used to provide fresh air and control the air temperature. Mechanical HVAC systems, commonly used to deliver ventilation and air-conditioning, are energy intensive and if not maintained adequately may contribute to poor IAQ. This presents a complex problem. For increased efficiency, buildings are insulated and airtight which then require energy intensive ventilation, heating in winter and cooling in summer.

Passive ventilation systems are able to supply ventilation air to a building to maintain good IAQ with little or no energy demand. Wind and buoyancy forces can be exploited to generated passive air flows for building ventilation. Windows, wind towers and ventilation stacks are some features incorporated into buildings to achieve passive ventilation. Wind towers are an example of a passive ventilation system which allow fresh and stale air to be exchanged effectively in a building. However, wind towers do not currently have a means of regulating the temperature of the incoming air. This limits the periods of operation to times when the incoming air will not adversely affect the occupant thermal comfort. In this circumstance any benefit of the wind tower is lost, IAQ may be reduced and energy intensive mechanical systems may be employed.

There are estimated to be around 1.5 million installed wind towers in the UK (estimated from manufacturer sales figures). This presents a significant opportunity for energy demand reduction if the effectiveness of these existing wind towers can be enhanced. The employment of heat recovery technology to transfer heat from the air leaving the building to the air entering the building is one such way to improve the viability of wind towers and other passive ventilation. This would increase the attractiveness and potential for uptake of wind towers in new non-residential buildings and to increase the effectiveness of existing installations through retrofit.

Wind towers have in the past been equipped with technologies to improve the thermal performance. The use of heat pipes has been investigated to pre-cool and pre-heat incoming air streams in wind towers, with the prospect of 15.6 °C of cooling and 3.3 °C of heating (Hughes, Chaudhry and Calautit, 2014). When installed in a wind tower heat pipes were able to reduce the temperature of incoming air in hot climates by up to 12 °C (Calautit, Hughes and Shahzad, 2015). In cold climates rotary thermal wheels have been shown to pre-heat incoming air by between 1-4 °C (Calautit *et al.*, 2019). A 3 °C reduction in demand for heating energy could be expected to result in energy savings of around 20% (World Business Council for Sustainable Development, 2009).

In this article, a testing programme is outlined in which a wind tower was equipped with heat pipes for the purposes of heat recovery. The experimental setup, testing programme and results will be outlined and the effectiveness of the heat pipes will be discussed.

EXISTING TECHNOLOGY

1.1. Wind Towers

A wind tower, or wind catcher, is a technology used to create natural ventilation in buildings. Traditionally, wind towers have been used for thousands of years in North Africa and the Middle East. A wind tower enables airflow into and out of a building through wind pressure. An open side of a wind tower will bring air into the building, while the lower pressure on the opening on the opposite side draws air out of the building. A wind tower can therefore provide a supply of fresh air to a building but without a means of temperature control, building user comfort may suffer.

1.2. Heat Pipes

A heat pipe is a heat transfer device which can effectively transfer heat between two regions. Heat transfer is enabled using thermal conductivity and the evaporation-condensation process. A simple heat pipe is constructed of a sealed pipe, often made of copper, which contains a liquid in fluid and vapour form. The pressure of the heat pipe is selected at manufacture to enable the vaporisation temperature to be appropriate for the application. In the case of heat recovery in buildings this will be much lower than 100°C, if water is the working fluid in the pipe. If a temperature gradient if applied across a heat pipe, the addition of heat energy at one end causes liquid to vaporise. The vaporised liquid increases the vapour pressure and the pressure gradient causes vapour flow along the pipe. The vapour flow reaches the cold end of the pipe and condenses, which releases the heat energy. The condensed liquid then returns to the warm end of the pipe by gravity or capillary action. Heat pipes are highly effective due to the exploitation of the evaporation-condensation process and the heat of vaporisation being significantly higher than the specific heat capacity.

HEAT RECOVERY

The concept investigated in the experimental programme presented in this article is the combination of a wind tower with heat pipes installed to enable heat recovery. The design of the wind tower allows air to enter the building on one side and leave on another. Heat pipes installed between these two air streams are intended to enable heat recovery from the warm air leaving the building to the cool air entering the building. This would be the expected situation in a heated building during a cold period. A schematic of the system is shown in Figure 1.

The intention of the heat recovery is to reduce the heating demand introduced by the use of passive ventilation. Through recovering heat from the air leaving the building and adding the energy to the incoming air, the energy demand from heating will be reduced. Additionally, by increasing the temperature of the air entering the building, the discomfort which may be created to building user through the presence of cold draughts may be reduced.

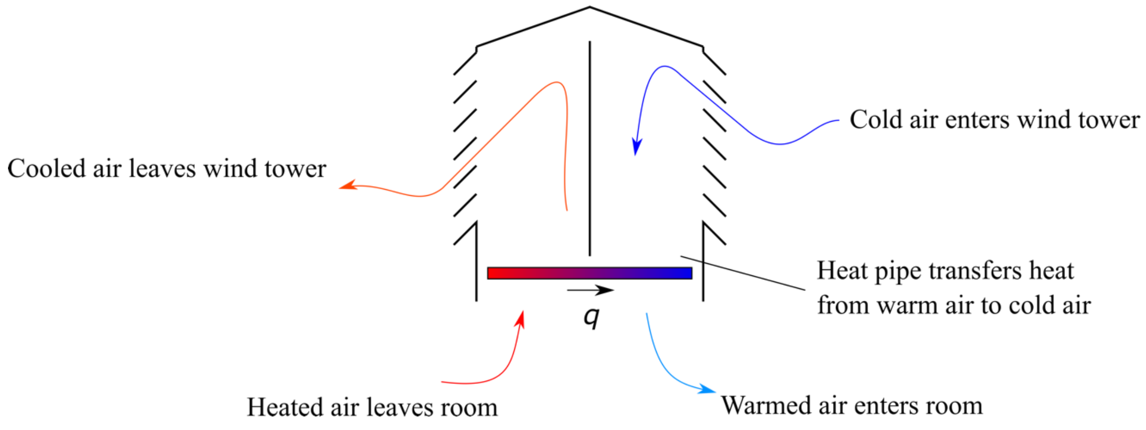

Figure 1. Schematic of wind tower heat recovery using heat pipes

EXPERIMENTAL DESIGN

The objective of the experimental programme was to establish the heat recovery performance of a wind tower equipped with heat pipes for heat recovery. The programme produced a set of data for heat recovery at a range of temperatures and wind conditions.

The testing was carried out at full scale using the wind tower shown in Figure 2. This wind tower has a footprint of 1000 mm x 1000 mm and is four sided, meaning that air can flow into or out of any side. Internally the wind tower is divided into four triangular sectors. Heat pipes were installed horizontally between two opposing sides of the tower, between in incoming and outgoing air streams.

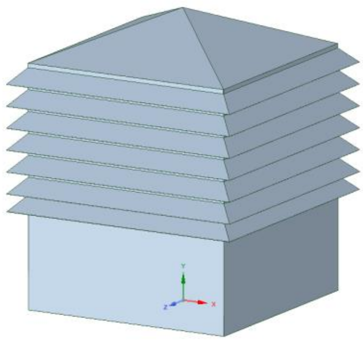

Figure 2. CAD representation of the wind tower and heat pipe arrangement.

The heat pipes selected were 990 mm long and 15 mm diameter, filled with water liquid and vapour. 35 heat pipes were installed in two horizonal layers in the lower section of the wind tower. The individual pipes were divided horizontally by 50 mm and the two layers by 30 mm. The two layers were offset by 25 mm to create an irregular pattern. The arrangement is shown in Figure 3

Experimental testing was carried out at the Building Research Establishment (BRE). The heat recovery wind tower was installed on a specially constructed test room built in an environmental chamber. The test room had dimensions 3500 m x 2300 mm x 2200 mm. The test room was built into a wind tunnel test section, with fans installed to simulate wind passing over the roof of the room and the wind tower. The whole environmental chamber had dimensions 11.0 m x 6.6 m x 3.7 m. So that the test room had low thermal mass the structure was constructed from 50 mm insulation board.

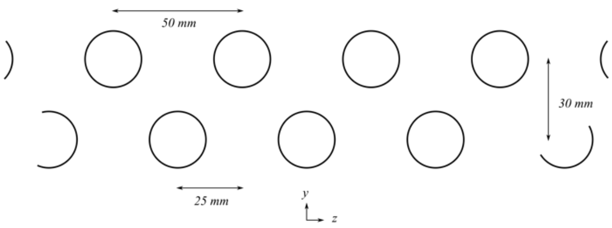

Figure 3. Heat pipe arrangement

The inside of the test room and wind tower are shown in Figure 4. The internal division of the wind tower can be clearly observed. Figure 5 shows an external view of the test room and wind tower, within the larger environmental chamber.

Figure 4. Wind tower and heat pipes viewed from within the test room

Figure 5. External view of the wind tower

TESTING

A testing programme of 12 tests was carried out: two wind speeds of 2ms^{-1} and 4 ms^{-1}, two external temperatures of 5 °C and 10 °C and three room temperatures of 24 °C, 27 °C and 30 °C. Each test was run such that 1 hour of steady state conditions was observed. The air in the room was heated using a 12 kW gas boiler via a heating coil within the room, over which air was drawn and discharged into the room.

Temperature reading were taken at a variety of points within the wind tower, test room and within the external air flow. For the purposes of the analysis in the article the measuring points of interest are shown in Figure 6 and Figure 7.

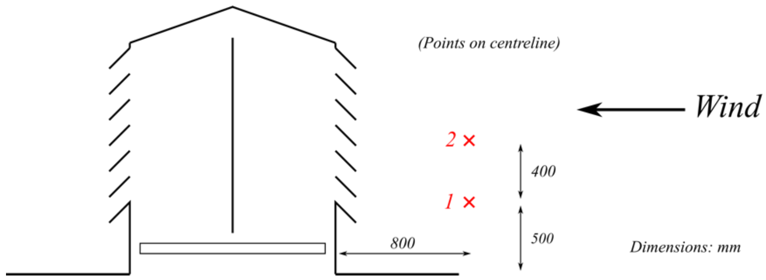

Figure 6. Location of the external measuring points

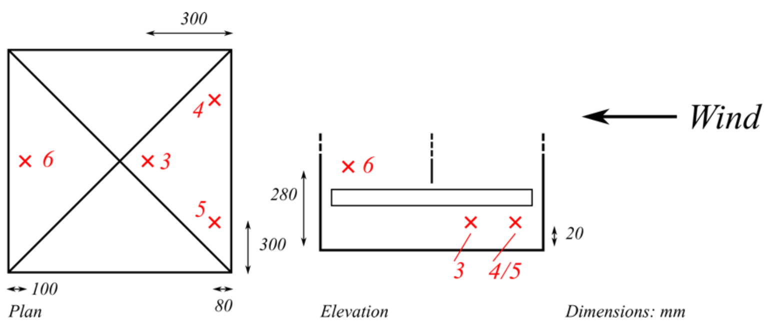

Figure 7. Location of the wind tower internal measuring points

The measurement points allow the temperature gain of the incoming air to be determined. The air temperature at points 1 and 2 is that of the external temperature. The temperature at points 3,4 and 5 is that after being warmed by the heat transferred from the air leaving the room through the opposite side of the wind tower. Any temperature change between points 1 and 2 and points 3, 4 and 5 is due to heat transfer. The temperature at 6 can be compared to the room temperature to determine the temperature decrease due to the heat pipes transferring heat from the exhausting air.

RESULTS

1.3. Heat Recovery

The temperature gain to the incoming air due to heat recovery is shown in Figure 8 for the 2 ms^{-1} wind speed and Figure 9 for the 4 ms^{-1} wind speed. The temperature of the incoming air was calculated using an area average and the temperature at points 3,4 and 5. The temperature gain for the lower wind speed is generally higher. The larger temperature difference for an external temperature of 5 °C also generates consistently higher temperature gains.

The temperature at the exhaust side of the wind tower shows the effectiveness of the heat pipes in recovering heat. The exhaust temperature change is calculated by finding the difference between the temperature at point 6 and that of the room temperature. Figure 10 and Figure 11 show the exhaust temperature change for the two wind speeds. The very significant reductions in temperature at this point indicate effective heat transfer by the heat pipes in the vicinity.

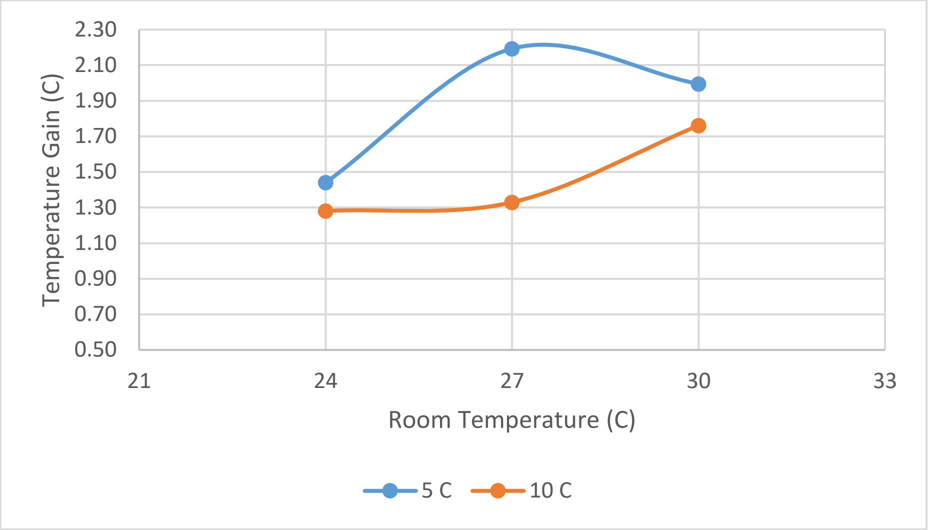

Figure 8. Temperature gain to the incoming air for 2 ms^{-1} wind speed

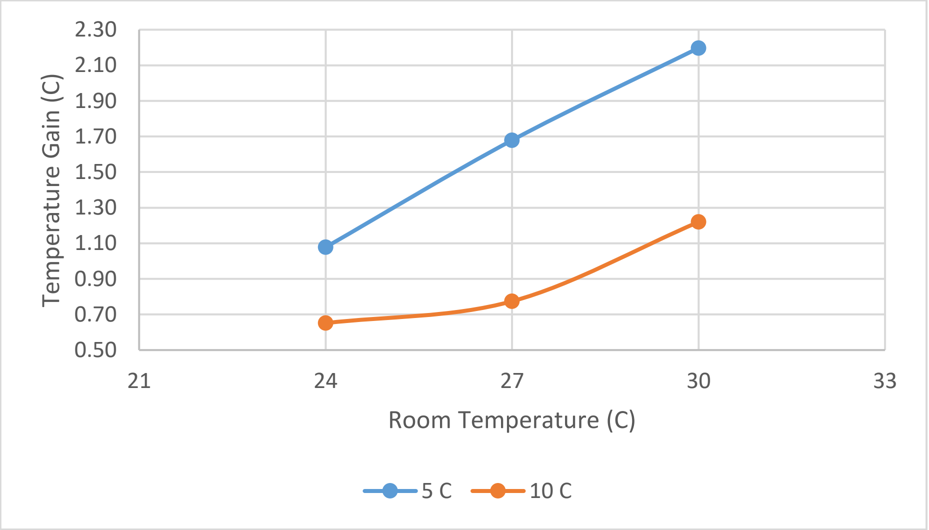

Figure 9. Temperature gain to the incoming air for 4 ms^{-1} wind speed

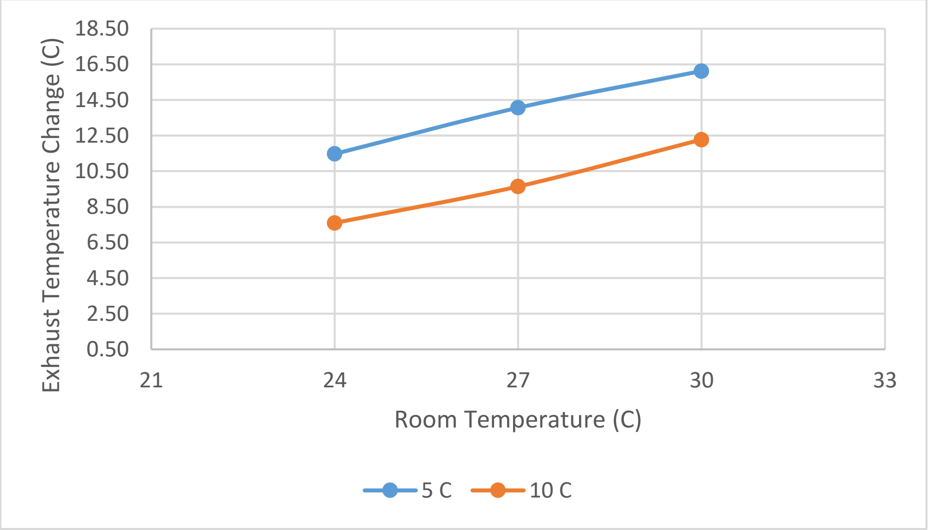

Figure 10. Exhaust temperature change for 2 ms^{-1} wind speed

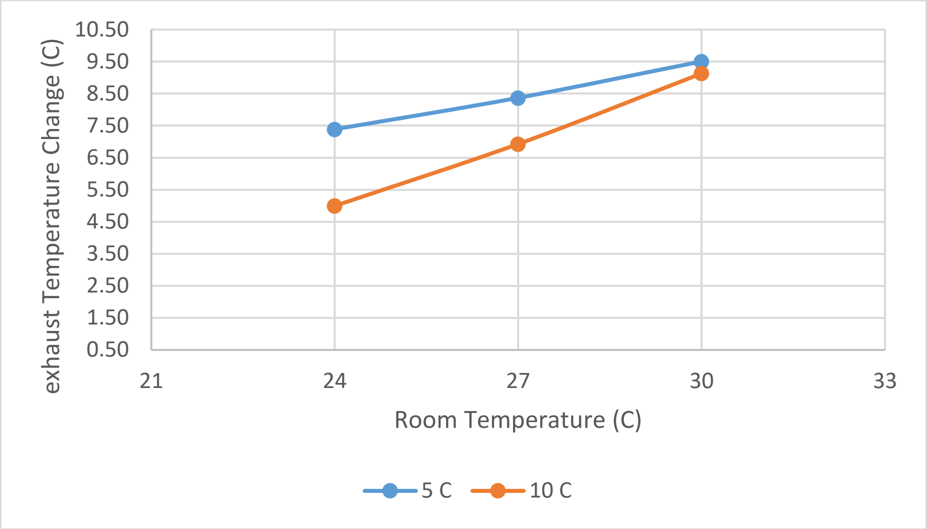

Figure 11. Exhaust temperature change for 4 ms^{-1} wind speed

The trend in Figure 8 shows a contradictory result for the room temperature of 5 °C. This discrepancy is probably due to the way in which heat was added to the room. In this case, to maintain the room temperature required a large heat input which involved jetting hot air into the room, creating chaotic air behaviour. The nature of the air behaviour created uncertainties in some results.

1.4. Heating Savings

To evaluate the effectiveness of the heat recovery, the saving in heating power due to heat recovery was calculated.

As part of the programme of tests, the room heating was calculated by taking temperature measurements on the inlet to the heating coil and the room air supply. Along with the air supply rate to the room, this allowed the room heating power to be calculated.

Velocity measurements were taken in the side inlet side of the wind tower. Measurements were taken at 6 points arranged in a pattern so that each was at the centre of an equal sized area. These readings were used to calculate the flow rate of air into the room. The flow rate of air and the temperature gain allowed the heat recovery power to be calculated.

The heating saving was then calculated by comparing the room heating and heat recovery. The data are shown in Table 1.

Table 1. Heat recovery and heating savings

Room Temperature (°C)	External Temperature (°C)	Wind Speed (ms^{-1})	Room Heating (kW)	Heat Recovery (W)	Heating Saving (%)
24	5	2	4.0	346	8.0
27	5	2	5.2	526	9.2
30	5	2	5.9	479	7.5
24	5	4	7.7	517	6.30
27	5	4	9.5	806	7.80
30	5	4	10.2	1055	9.4
24	10	4	5.3	313	5.6
27	10	4	6.9	372	5.1
30	10	4	9.3	586	5.9

The results indicate an average saving of 7.2% for the heating input to the room due to the heat recovery. Depending on conditions this ranges between 5-9%.

CONCLUSIONS

A heat recovery wind tower was tested at a variety of wind and temperature conditions, at full scale. Overall, the heat recovery wind tower exhibited a small level of heat recovery, however the potential to recover heat using zero energy has been shown.

A significant limitation to the testing programme was the ability to determine the nature of air flow and temperature in the naturally driven air flows. As the velocity of the air inside the room and externally increased, the air flowing through the side sectors of the wind tower could not be determined. This will have impacted the apparent temperature gain to the incoming air.

Further analysis using computational fluid dynamics (CFD) using this data for validation will allow uncertainties to be investigated.

ACKNOWLEDGEMENTS

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