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BRE Report

Performance testing of a passive heat recovery ventilation device

Prepared for: **Ben Hughes**

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1 Introduction

Free Running Buildings Ltd. requested BRE to test an innovative ventilation wind catcher tower incorporating a heat pipe-based heat recovery system. The aim of the investigation was to assess the heat recovery potential of the system with two different heat pipes installed within the wind tower across a range of wind speeds and outside to room air temperature differences.

The objective of the testing undertaken at BRE was to produce a data set of the operation of the heat recovery tower for a range of wind speeds and inside to outside air temperature differences. Each data set could then be used to compare the actual performance of the tower against CFD models of the tower. Each data set was required to be one hour at steady state conditions.

A total of 24 tests were agreed to be undertaken at two wind speeds, three room air temperatures and two different outside air temperatures, repeated for each of the heat pipe arrays.

Free Running Buildings Ltd. tested a similar wind tower system for coolth recovery in 2019 and BRE proposed setting up a similar test rig configuration for the testing of this heat recovery version of the tower.

A test room 3.5 m long by 2.3 m wide and 2.2 m high was constructed in one of BRE's environmental chambers. The room was then built into a wind tunnel section and fans installed to draw air over the roof of the test room, simulating wind passing the tower.

2 Test programme

The objective of testing of the heat recovery wind catcher tower was to produce data sets of the operation of the heat recovery tower at a range of wind speeds and inside to outside air temperature differences. Each data set could then be used to compare the actual performance of the tower against CFD models of the tower. To ensure that the temperature in all locations was at steady state, the structure of the test room was constructed to be very thermally lightweight. The environmental chamber was run continuously to ensure that it had achieved steady state across each batch of tests at a given outside air temperature.

To simulate wind passing the tower, a bank of speed-controlled fans was installed down-wind of the tower, creating a purpose built wind-tunnel section to draw air over the test room roof. Within the wind-tunnel section, a test room of approximately 3.5 m x 2.3 m x 2.2 m high was built with the wind catcher located on the roof.

Full details of the test room and the environmental chamber are provided in Section 3 below; drawings and photographs are provided in Appendix A and B.

Initially it was proposed to undertake the testing at wind speeds of 2 and 6 m/s. However, at the higher wind speed the heating system installed in the test room could not generate heat and achieve sufficient mixing with the incoming cold outside air to provide effective mixed exhaust air temperatures. Following discussions between Free Running Buildings Ltd. and BRE, it was agreed that the high wind speed should be limited to 4 m/s.

Two outside air temperatures were generated in the environmental chamber; 5 and 10°C, and the room was heated to three different temperatures; 24, 27 and 30°C.

The test matrix of air temperatures and wind speeds is provided in Table 1. The wet bulb temperature of the air in the environmental chamber was not controlled.

The temperature of the air entering the room after passing down over the heat pipes was measured in three locations below the upwind quadrant of the tower. The temperature of the air leaving the room was measured in two locations below the leeward quadrant of the tower and in one location on each of the side quadrants of the tower.

The room air temperatures were measured at three locations vertically and two locations within the room. Due to the speed of the air exchange within the room limiting the ability to achieve full mixing to the required room temperatures, the air temperatures at the highest level of the room were taken as being that of the exhaust air.

To provide an indication of the exhaust air temperature from the leeward quadrant of the tower, the air temperature close to the wall of the tower above the heat pipes was also measured.

Outside (wind) air temperature was measured at two locations upwind of the tower.

Test	Environment chamber	Test room temperature	Approximate air flow velocity over wind-catcher tower	Duration of test at steady state
1	5°C T_{db}	24°C T_{db}	2 m/s	1 hr
2	5°C T_{db}	27°C T_{db}	2 m/s	1 hr
3	5°C T_{db}	30°C T_{db}	2 m/s	1 hr
4	5°C T_{db}	24°C T_{db}	4 m/s	1 hr
5	5°C T_{db}	27°C T_{db}	4 m/s	1 hr
6	5°C T_{db}	30°C T_{db}	4 m/s	1 hr
7	10°C T_{db}	24°C T_{db}	2 m/s	1 hr
8	10°C T_{db}	27°C T_{db}	2 m/s	1 hr
9	10°C T_{db}	30°C T_{db}	2 m/s	1 hr
10	10°C T_{db}	24°C T_{db}	4 m/s	1 hr
11	10°C T_{db}	27°C T_{db}	4 m/s	1 hr
12	10°C T_{db}	30°C T_{db}	4 m/s	1 hr

Table 1. Test matrix of test room and outside air temperatures and wind speeds. Test matrix repeated for both heat pipe arrays.

3 Test room

The tests were carried out during September and October 2020 in a purpose-built test room inside a large environmental chamber in BRE's Building 74 environmental test facility, located at BRE's main Garston site.

Sketches showing the layout and dimensions of the test room and environmental chamber are provided in Appendix A. The test room measured internally 2.3 (W) x 3.50 (L) x 2.15 m (H). The environmental chamber measured internally 11.0 (L) x 6.6 (W) x 3.68 m (H). Photographs showing the test room, wind-catcher tower and instrumentation are provided in Appendix B.

The walls floor and roof of the test room were constructed from 50 mm thick PIR insulation board.

The wind catcher tower was mounted inside an aperture cut centrally in the test room roof. A flange on the outside of the tower rested on the roof of the test room.

The air flow fans were mounted on an internal wall and arranged to draw air across the test room roof and past the wind catcher tower. The fans had individual inverter speed control.

Heating of the room was provided by a 12 kW gas boiler feeding a heating coil located within the test room. Air was drawn across the heating coil by an inline boxed fan and discharged back into the room through an array of semi-rigid ducts and supply plenums. The configuration of the duct and supply locations was investigated and at low wind speeds provided a relatively mixed air temperature within the test room. As the wind speed increased, the level of mixing within the room decreased and it was found that a second inline box fan drawing air through the heating coil was required. This fan discharged warm air into the leeward side of the room directly. Photographs of the heating system are presented in Appendix C.

The positioning of the air temperature sensors for the fresh air outside and at a range of locations within the test room are shown in Figure 1 to Figure 3. The temperature of the fresh incoming air after the heat pipes was made in two regions of the upwind quadrant of the tower to capture the variations in temperature due to the significant differences in air speed between the middle of the tower (sensor number 5) and the front, or leading upwind edge of the windward quadrant (sensor numbers 3 & 4).

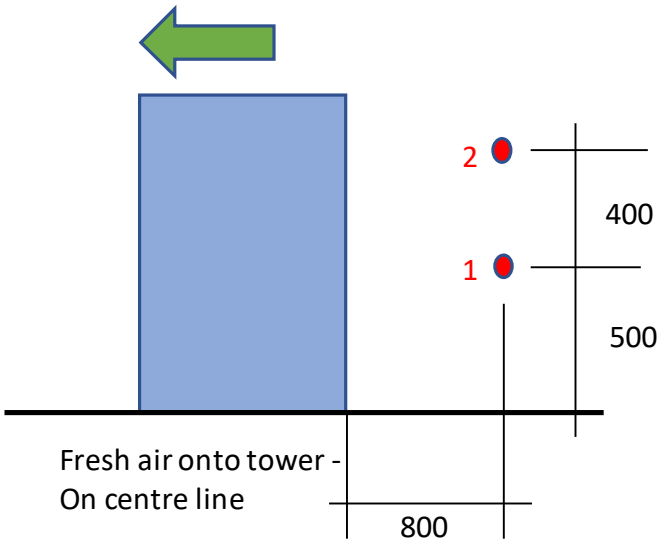


Figure 1. Location of air temperature sensors measuring fresh air temperature up wind of the tower.

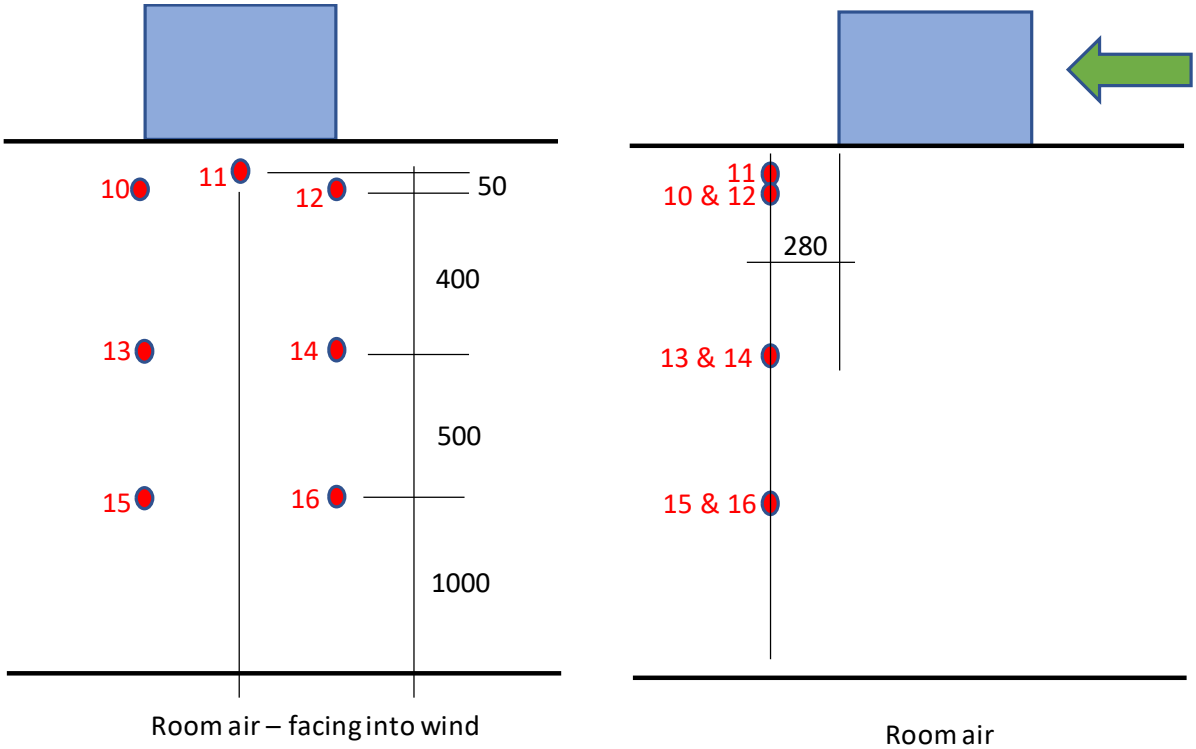


Figure 2. Location of air temperature sensors within room, on downwind side of tower.

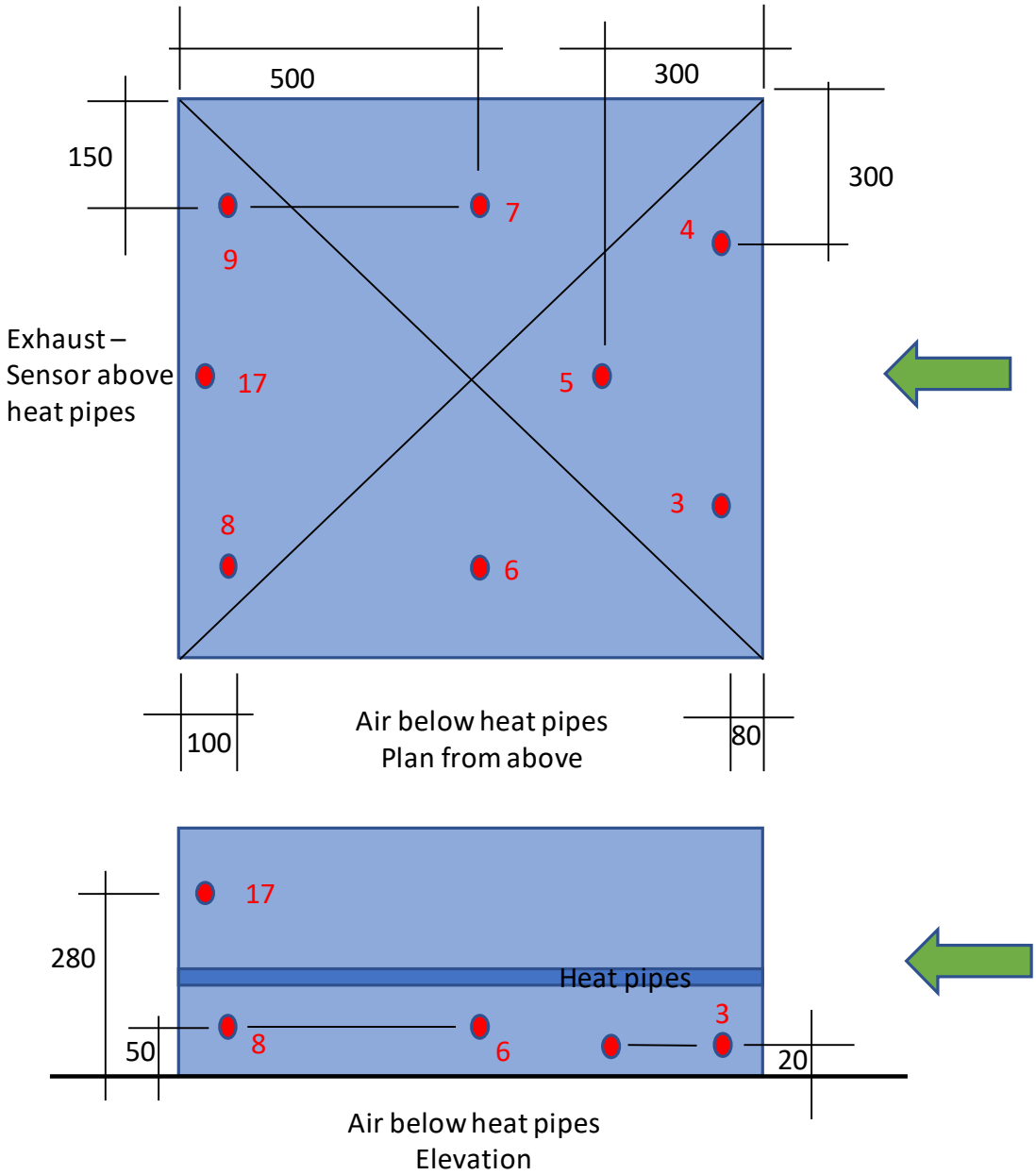


Figure 3. Location of air temperature sensors below the heat pipes on the upwind fresh air quadrant and the exhausting leeward and side quadrants. One sensor, number 17, was placed above the heat pipes measuring the exhaust air temperature after the heat pipes in the leeward quadrant.

4 Test results

4.1 Air velocity across wind catcher tower

A set of tests was undertaken to establish the required fan speeds to provide the specified air velocities (2, 4 and 6 m/s) onto the wind-catcher tower. The air velocity profile of the air supply on the upstream side of the tower was measured by traversing with a rotary vane anemometer (Testo 435) and the weighted mean air velocity obtained from the readings at each fan speed condition. A combination of trial and error adjustments to the fan speeds and interpolation of plots of air velocity against fan speed allowed the speed of the 3 fans at each of the specified air speeds (2, 4 and 6 m/s) to be obtained.

4.2 Room air speed measurements

Room air speed was measured using omni-directional spherical hot bead anemometer probes (TSI 8475 air velocity transducers) mounted on a moveable instrument stand at 300, 800, 1300 and 1800 mm height.

The instrument was positioned at seven floor locations, as shown in Figure 4. Measurements were undertaken for wind speeds onto the wind catcher of 1.3, 2.0, 4.2 and 6.0 m/s

The air speed values shown in are the mean readings taken over a 2-minute period.

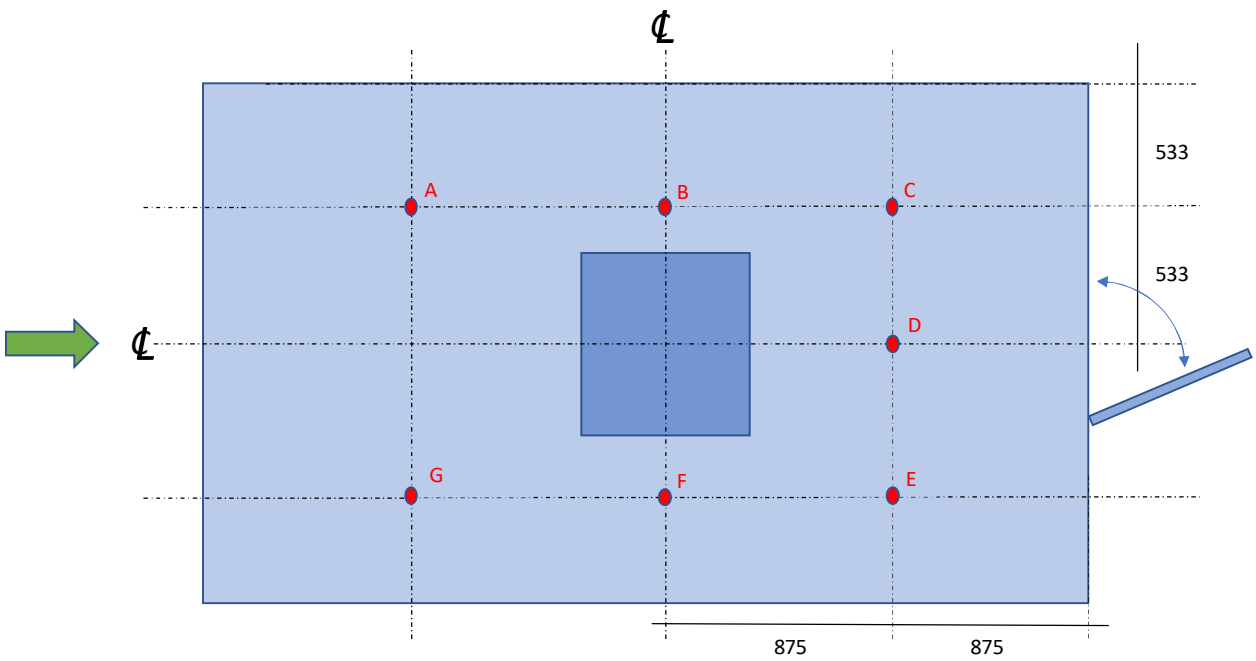


Figure 4. Location of air speed measurements within room. Measurements made at four heights at each location A~G.

Height (mm)	Location						
	A	B	C	D	E	F	G
300	0.08	0.04	0.06	0.04	0.06	0.06	0.08
800	0.06	0.06	0.04	0.05	0.04	0.04	0.05
1300	0.02	0.03	0.07	0.04	0.05	0.05	0.05
1800	0.01	0.08	0.08	0.06	0.03	0.03	0.03

Table 2. Air speed measurements taken within the room with the windspeed at 1.33 m/s.

Height (mm)	Location						
	A	B	C	D	E	F	G
300	0.12	0.12	0.15	0.15	0.15	0.14	0.14
800	0.08	0.15	0.10	0.09	0.10	0.18	0.10
1300	0.04	0.08	0.08	0.13	0.10	0.05	0.04
1800	0.02	0.04	0.03	0.14	0.06	0.04	0.04

Table 3. Air speed measurements taken within the room with the windspeed at 2.02 m/s.

Height (mm)	Location						
	A	B	C	D	E	F	G
300	0.28	0.14	0.14	0.25	0.18	0.19	0.23
800	0.16	0.16	0.08	0.06	0.12	0.09	0.18
1300	0.20	0.08	0.12	0.13	0.09	0.06	0.14
1800	0.06	0.10	0.04	0.18	0.08	0.08	0.04

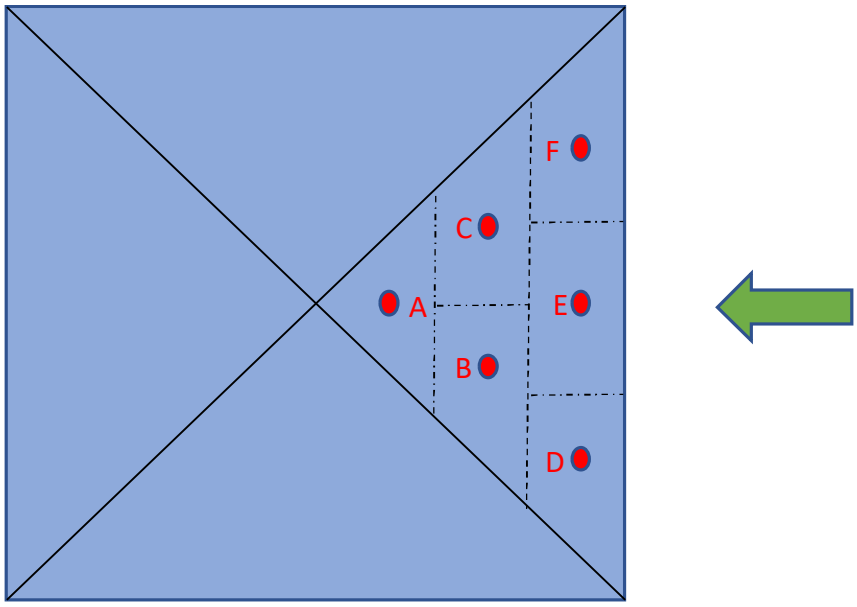
Table 4. Air speed measurements taken within the room with the windspeed at 4.17 m/s.

Height (mm)	Location						
	A	B	C	D	E	F	G
300	0.40	0.46	0.35	0.38	0.28	0.29	0.45
800	0.16	0.24	0.18	0.18	0.14	0.20	0.18
1300	0.12	0.12	0.12	0.12	0.12	0.18	0.22
1800	0.05	0.16	0.04	0.10	0.10	0.21	0.06

Table 5. Air speed measurements taken within the room with the windspeed at 5.96 m/s.

4.3 Estimation of incoming fresh air flow rate

Air speed was measured below the heat pipes underneath the upwind quadrant of the wind catcher at four different wind speeds. The area was split into six approximately equal areas and the air speed measured at the centre of each area. See Figure 5.



Plan from above

Figure 5. Location of air speed measurements below heat pipes to estimate rate of fresh air entering room. Total area of inlet quadrant divided into six approximately equal areas.

Wind speed (m/s)	Location						Approx. fresh air flow rate into test room (m^3/s)
	A	B	C	D	E	F	
1.33	0.9	0.8	0.7	0.5	0.8	0.5	0.17
2.02	1.2	1.0	1.2	0.7	1.1	0.6	0.21
4.17	2.6	1.8	2.2	0.9	2.0	0.8	0.41
5.96	3.9	3.0	3.4	1.4	1.7	1.6	0.60

Table 6. Estimated total fresh air flow rate into room at a range of wind speeds.

4.4 Temperature measurements across steady state periods

Data sets in Excel spreadsheet format of steady state temperatures at the locations 1 to 17 shown in Figure 1 to Figure 3 have been forwarded to Free Running Buildings Ltd. covering all 12 tests on each of the two heat pipes installed in the tower.

Using the mean temperatures from the steady periods, relationships between wind speed, temperature difference and the heat pipes installed can be assessed.

Plotting the increase in temperature of the fresh air passing over the heat pipes on the upwind side of the tower against the room to outside air temperature difference shows a broad relationship of increasing temperature gain as the room to outside air temperate increased. This can be seen in Figure 6 to Figure 9.

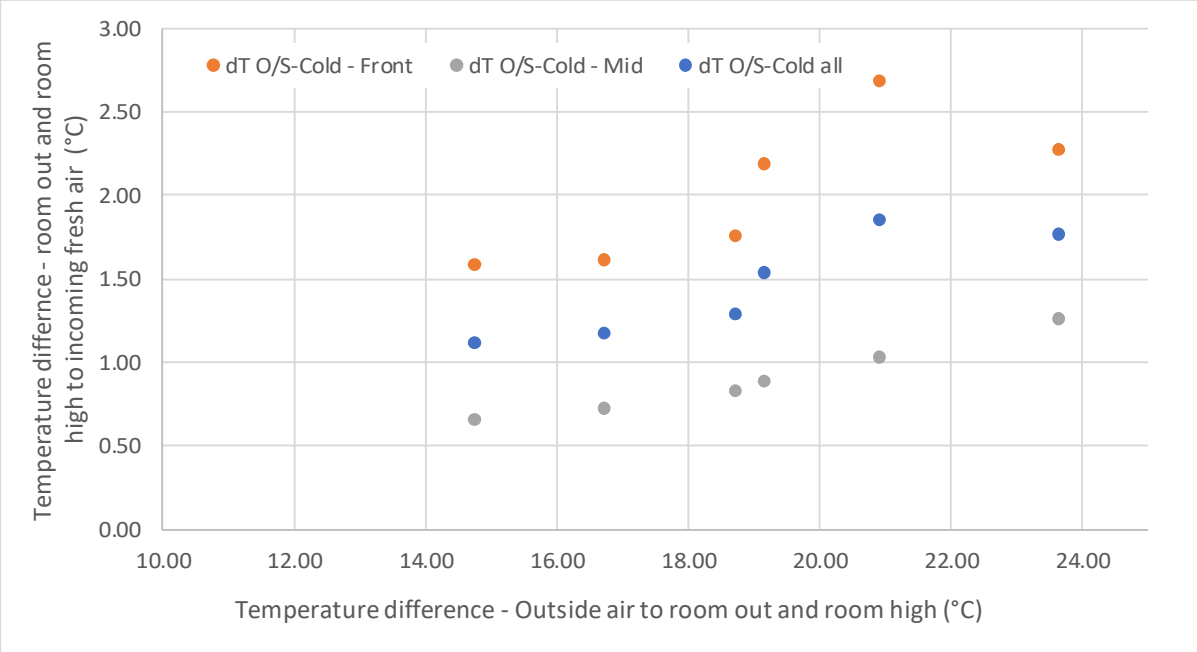


Figure 6. Temperature increase in fresh air after heat pipes compared to room / outside air difference. Heat pipe 1, wind speed 2 m/s. (Cold – Front, is the mean of sensors 3 & 4. Cold – Mid, is sensor 5. Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

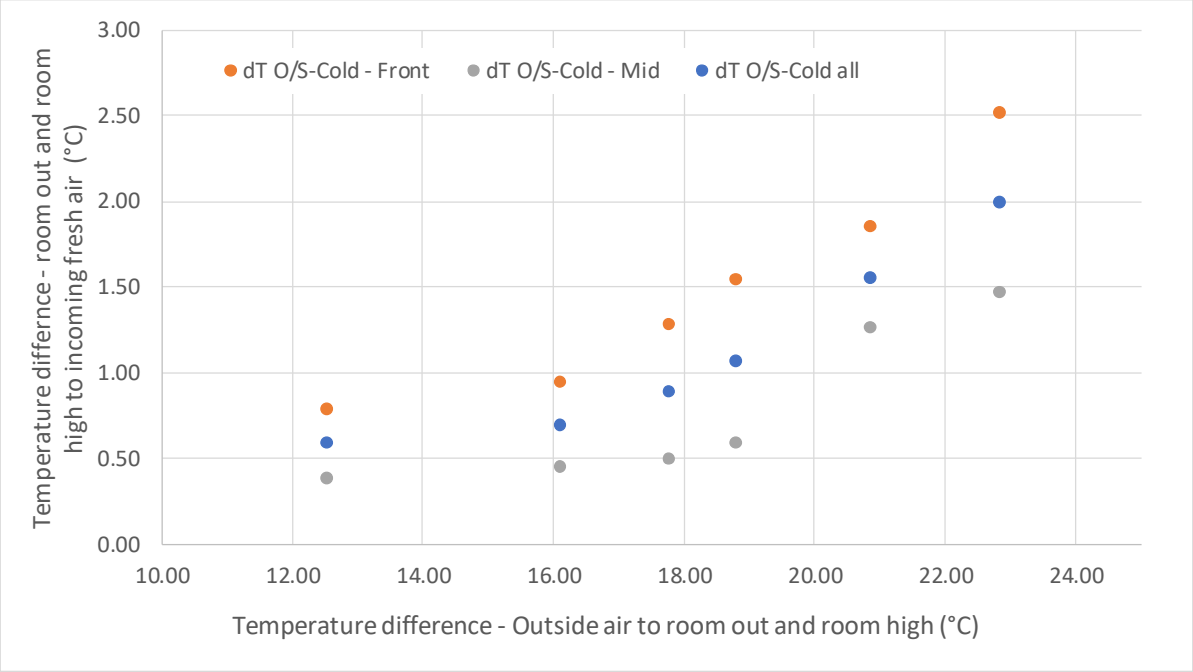


Figure 7. Temperature increase in fresh air after heat pipes compared to room / outside air difference. Heat pipe 1, wind speed 4 m/s. (Cold – Front, is the mean of sensors 3 & 4. Cold – Mid, is sensor 5. Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

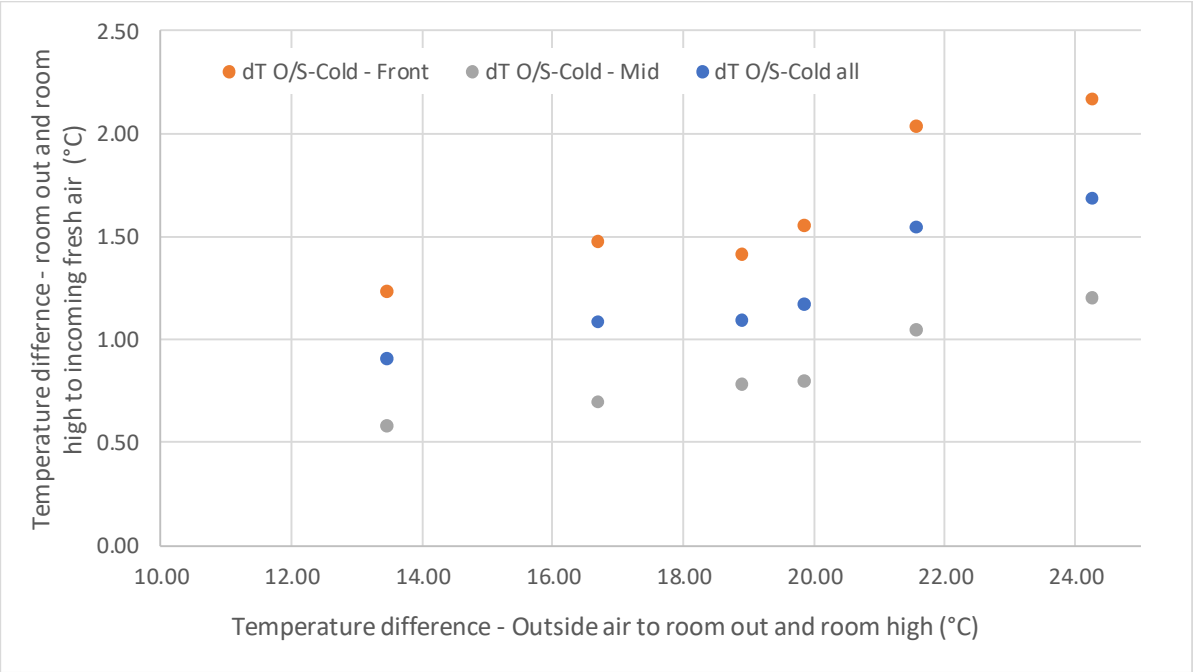


Figure 8. Temperature increase in fresh air after heat pipes compared to room / outside air difference. Heat pipe 2, wind speed 2 m/s. (Cold – Front, is the mean of sensors 3 & 4. Cold – Mid, is sensor 5. Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

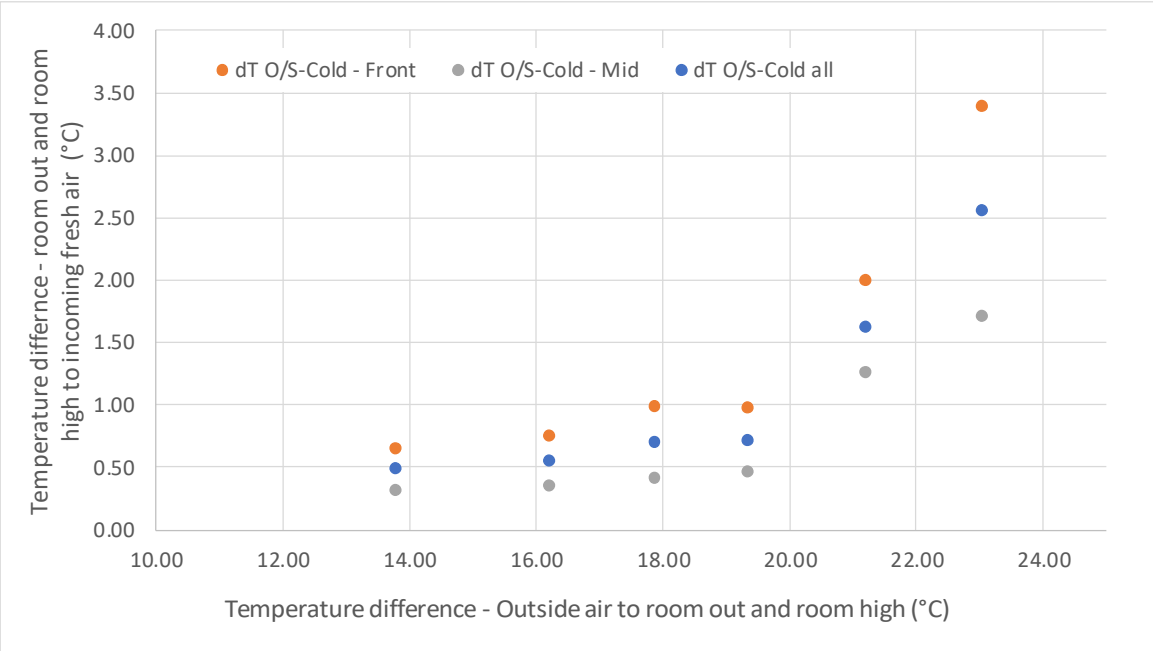


Figure 9. Temperature increase in fresh air after heat pipes compared to room / outside air difference. Heat pipe 2, wind speed 4 m/s. (Cold – Front, is the mean of sensors 3 & 4. Cold – Mid, is sensor 5. Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

Plotting the decrease in temperature of the exhaust air passing over the heat pipes on the leeward side of the tower against the room to outside air temperature difference shows a significantly more consistent relationship of temperature change with changes in room to outside air temperate temperature changes. This can be seen in Figure 10 to Figure 13.

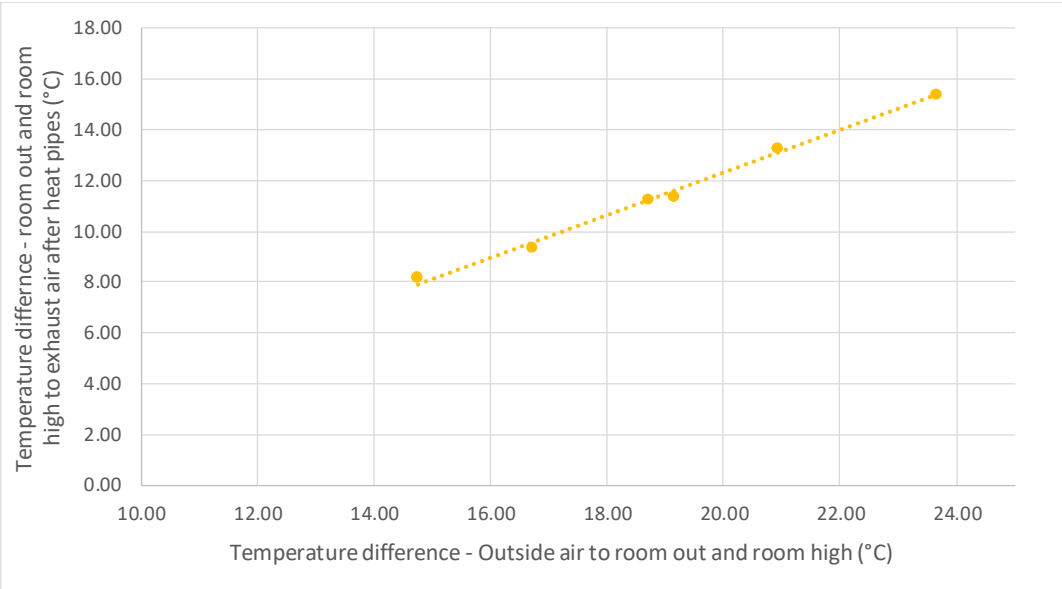


Figure 10. Temperature decrease in exhaust air after heat pipes compared to room / outside air difference. Heat pipe 1, wind speed 2 m/s. (Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

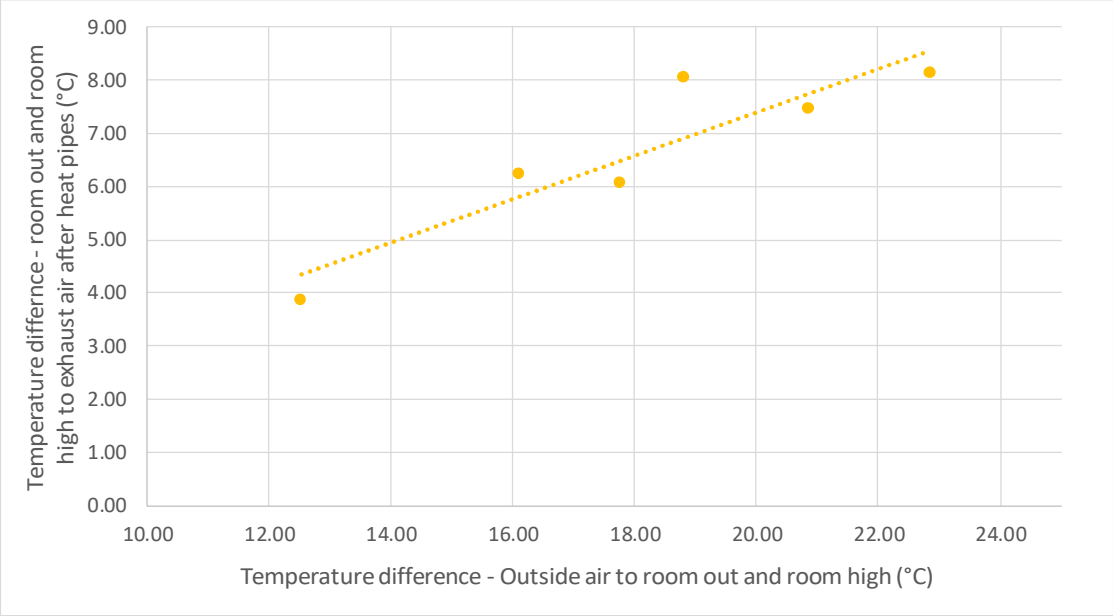


Figure 11. Temperature decrease in exhaust air after heat pipes compared to room / outside air difference. Heat pipe 1, wind speed 4 m/s. (Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

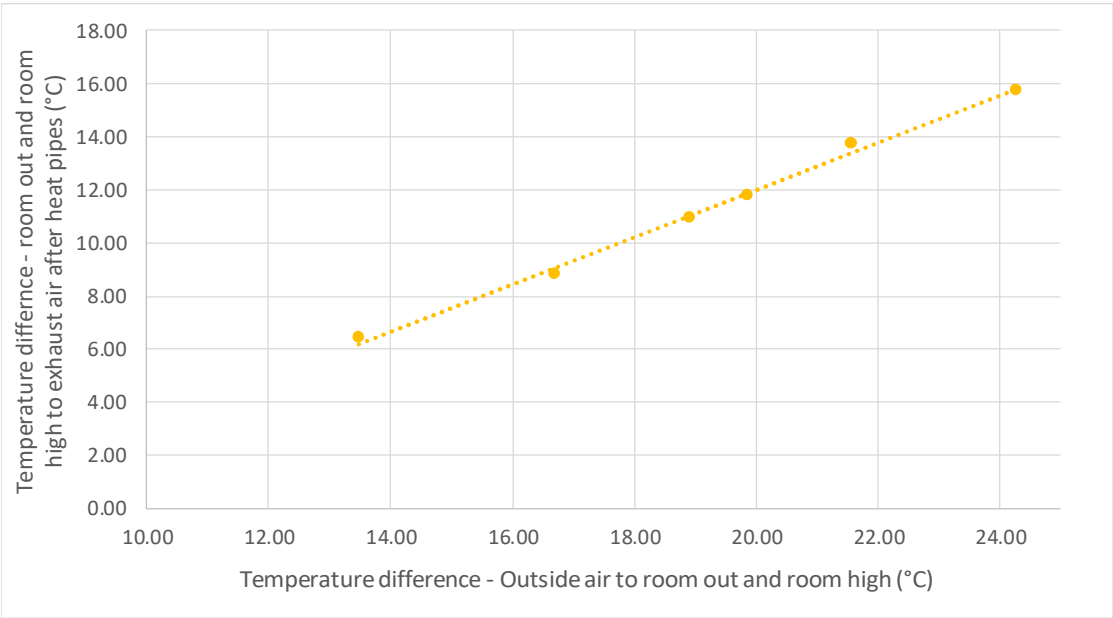


Figure 12. Temperature decrease in exhaust air after heat pipes compared to room / outside air difference. Heat pipe 2, wind speed 2 m/s. (Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

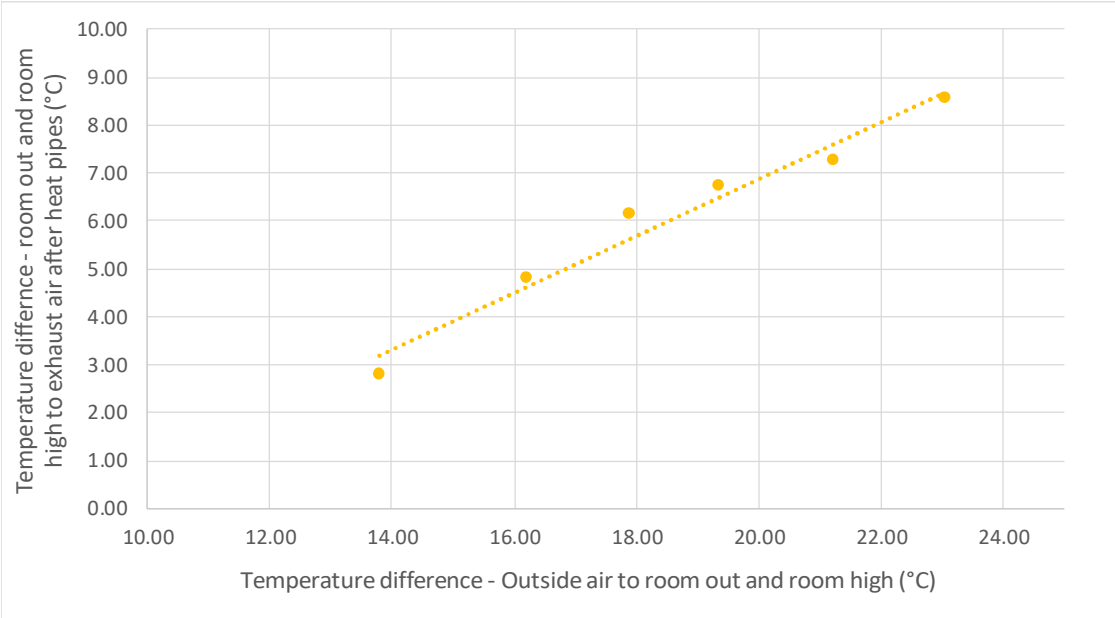


Figure 13. Temperature decrease in exhaust air after heat pipes compared to room / outside air difference. Heat pipe 2, wind speed 4 m/s. (Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

The location of the temperature sensor in the exhaust air stream was not determined prior to installation of the sensor. It is therefore unclear if the sensor is subject to a cool plume off one of the heat pipes or if it's readings represent an average temperature of the exhaust air in the leeward quadrant of the tower.

4.5 Estimation of heat input to room over steady state periods

The heat supplied to the room to maintain the temperature difference to the outside air was not initially measured. However, after the initial tests on the first heat pipes at an outside air temperature of 10°C were completed, it was evident that the load was varying significantly across the test. To allow an estimation of the heat input to the room, for all tests after the initial set on the first heat pipes, the air supply rate into the room was measured and a temperature sensors placed on the inlet to the heating coil and on the room air supply.

At the highest wind speed and greatest temperature difference tested, 4 m/s and outside air temperature at 5°C and room air temperature at 30°C, it was not possible to supply sufficient heat using the supply plenums used in the other tests. For these two tests the plenums were removed and the air discharged into the room from the semi rigid ducts. This achieved greater mixing of the air in the room and allowed the hot air, air flow rate to be increased. For these two tests that air supply rate could not be accurately measured at the supply point, and a traverse of the air flow into the heating coil was made. The accuracy of this data is considered to be lower than that of all the other tests due to the different measurement method.

Heat pipe installed	Outside air temperature (°C)	Wind speed (m/s)	Heating air flow rate (l/s)			Heating input to room (kW)		
			Room air temperature (°C)			Room air temperature (°C)		
			24	27	30	24	27	30
1	5	2	109	137	178	4.0	5.2	5.9
1	5	4	166	185	*230*	7.7	9.5	10.2
1	10	2	Data not collected			-	-	-
1	10	4	120	163	202	5.3	6.9	9.3
2	5	2	100	130	152	4.7	5.5	5.9
2	5	4	160	211	*230*	7.2	8.7	10.1
2	10	2	749	92	117	3.0	3.7	4.7
2	10	4	132	164	189	5.7	6.6	7.5

Table 7. Estimated heat input to room across each steady state test period. (Figures in italics for a wind speed of 4 m/s and the greatest room to outside air temperature difference were measured by traversing the heating coil inlet. This is less accurate than measuring the supply air flow at the supply plenums.)

Figure 14 to Figure 17 show the above data plotted for each heat pipe and wind speed tested.

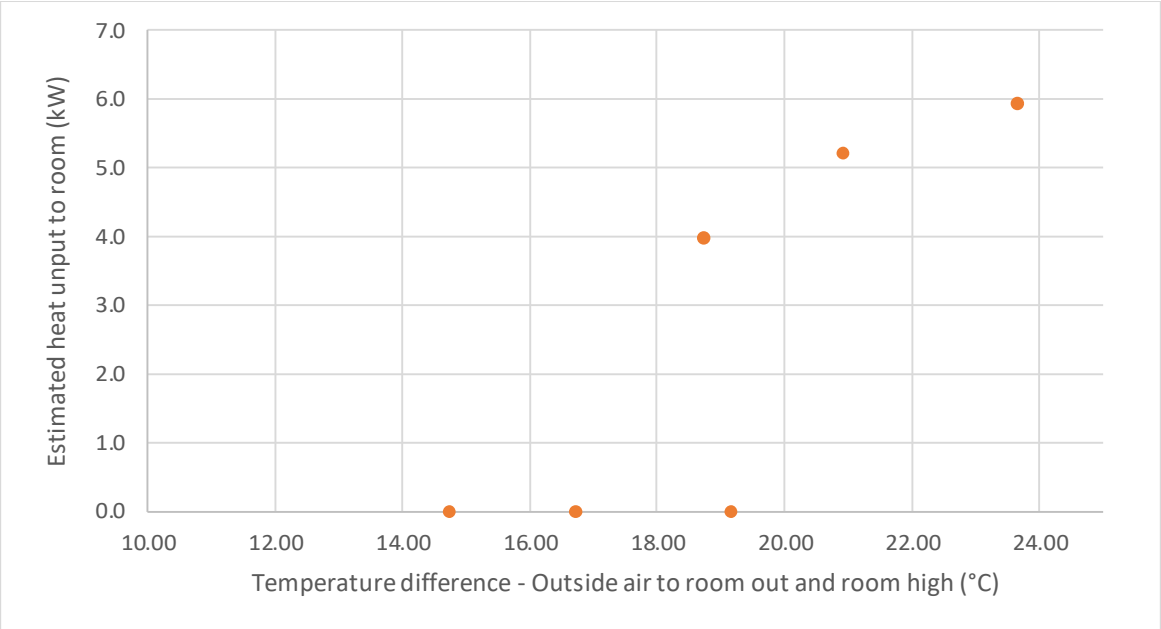


Figure 14. Estimated heat input to room compared to room / outside air difference. Heat pipe 1, wind speed 2 m/s. (Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

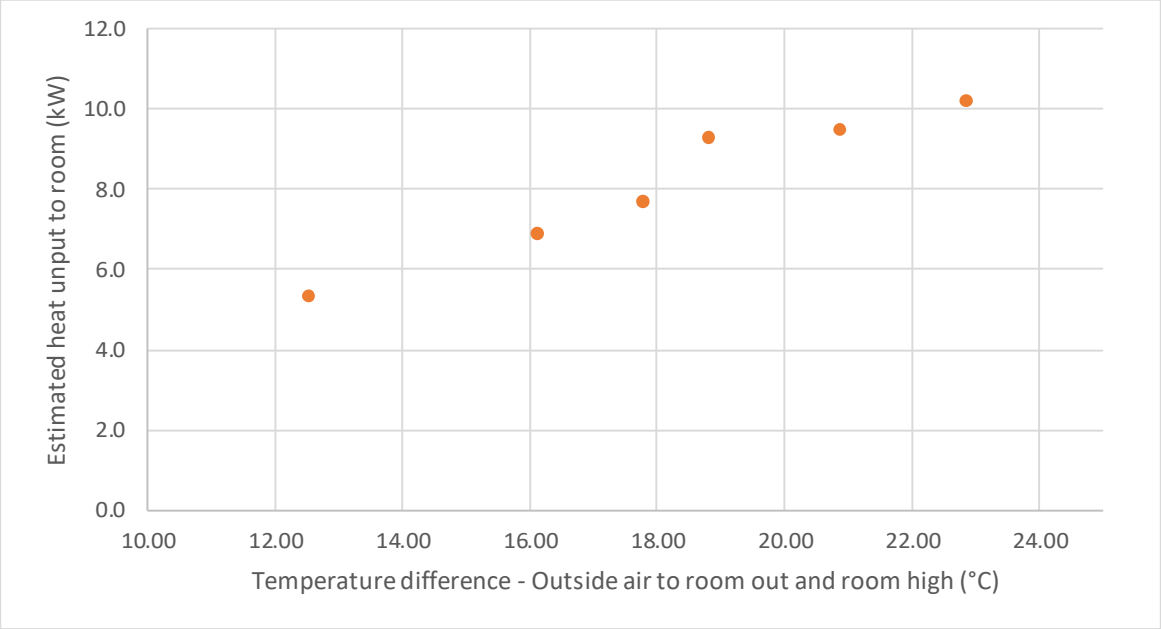


Figure 15. Estimated heat input to room compared to room / outside air difference. Heat pipe 1, wind speed 4 m/s. (Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

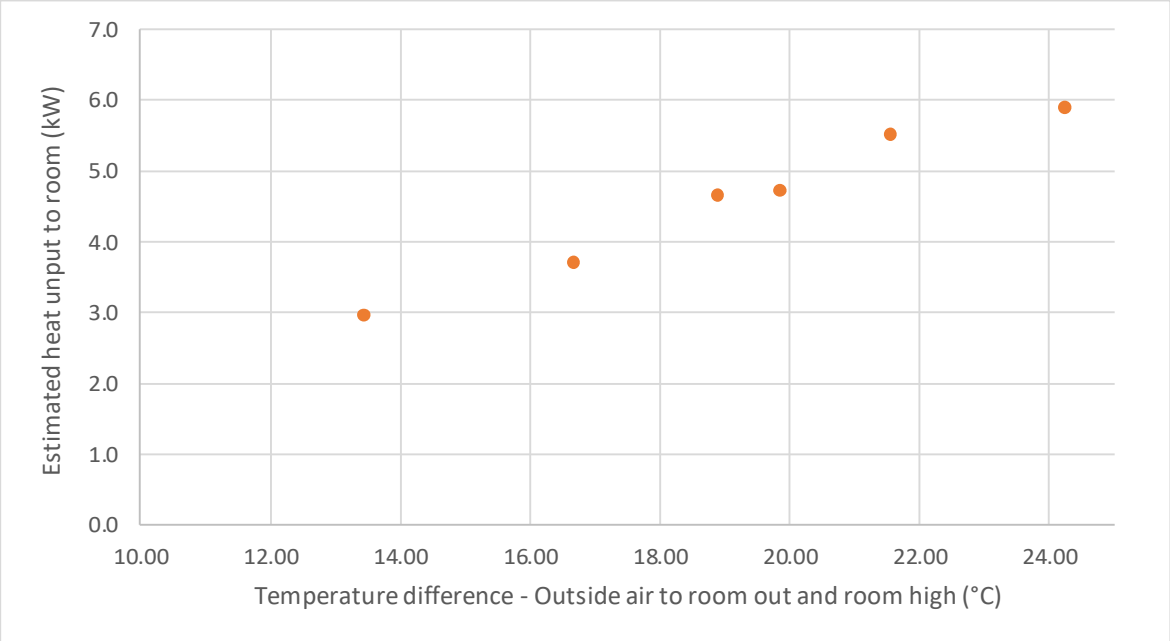


Figure 16. Estimated heat input to room compared to room / outside air difference. Heat pipe 2, wind speed 2 m/s. (Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

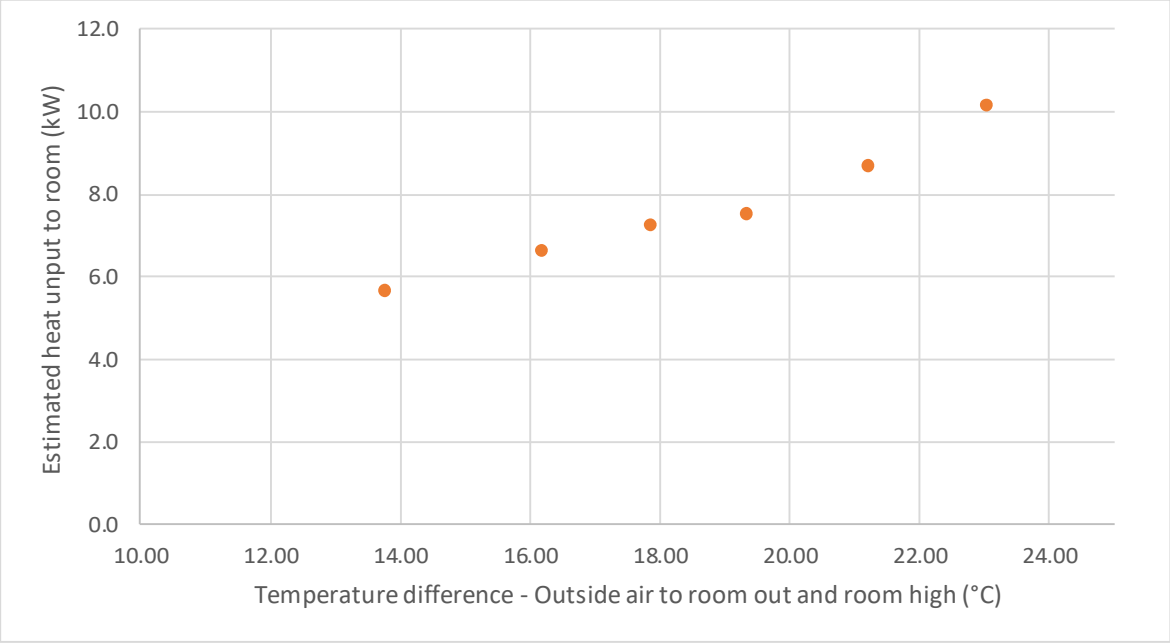


Figure 17. Estimated heat input to room compared to room / outside air difference. Heat pipe 2, wind speed 4 m/s. (Room out and room high, is the mean of sensors 8, 9, 10, 11 & 12.)

5 Comments and Discussion

The wind catcher tower supplied for testing by Free Running Buildings Ltd. was tested with two different heat pipes installed. The testing was undertaken across a range of internal room temperatures and at two outside air temperatures and two wind speeds.

The objective of the testing was to produce data that could be used to compare with CFD model predictions of the heat recovery effectiveness of the tower.

The key limitation in any tests looking at temperature changes in naturally driven air flows is determining a true picture of the air after the heat exchanger without impacting the air flow rate of the system. The testing undertaken at BRE provided point measurements of air temperature in the incoming air stream and also a range of locations both within the room and around the exhausting sections of the tower.

The nature of the fresh air flow entering the room resulted in a strongly rotating air movement within the room. To raise the bulk room air temperature, i.e. achieve a good level of mixing, required that the heat was jetted into the room, and not passively convected off hot surfaces. However, as both the wind speed and the temperature difference between the room and outside increased, the level of jetting needed to achieve a mixed room air temperature became significant. The result of this was that the temperature of the air exhausting from the room was not known with any level of certainty, only the air leaving the leeward side of the leeward quadrant. The air exhausting through the side quadrants of the tower was generally lower than that of the leeward quadrant, and will therefore have impacted the apparent heat gain to the fresh incoming air.

The temperature of the exhaust air after the heat pipes at the leeward edge of the tower exhibited a strong relationship to the room to outside air temperature difference. The very significant reduction in temperature of the air at this location indicated that the heat pipes across the centre of the tower, exposed to the highest air speeds of fresh incoming air were highly effective at removing heat from the exhaust air.

The observed difference in performance between the two heat pipes tested was not significant, with both arrays providing a relatively small overall level of heat recovery. The similarity in performance was also evident when assessed in terms of heat removal from the exhaust air streams.

Due to the nature of the air flow within the room and the isolated point measurement of air temperature, the results of this investigation could not be used to guarantee performance of a tower installed on a building. Changes in wind direction and the size of the room being served by the tower will have very significant impacts on how a tower performs. However, the test results do show the potential of the system to recover heat when driven by wind alone.

6 Appendix A – Rig drawings

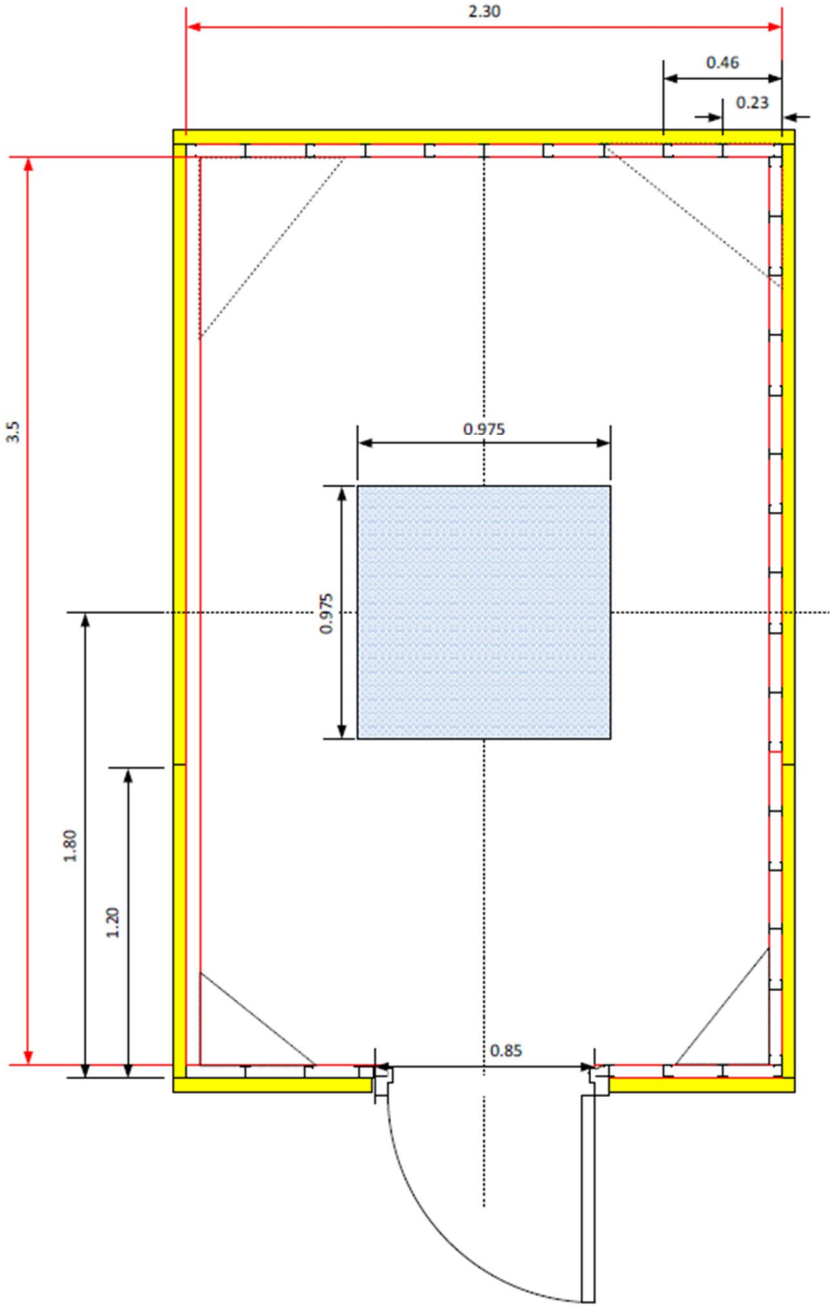


Figure 18. Test room – Plan. Details of test room and location of wind catcher tower in roof.

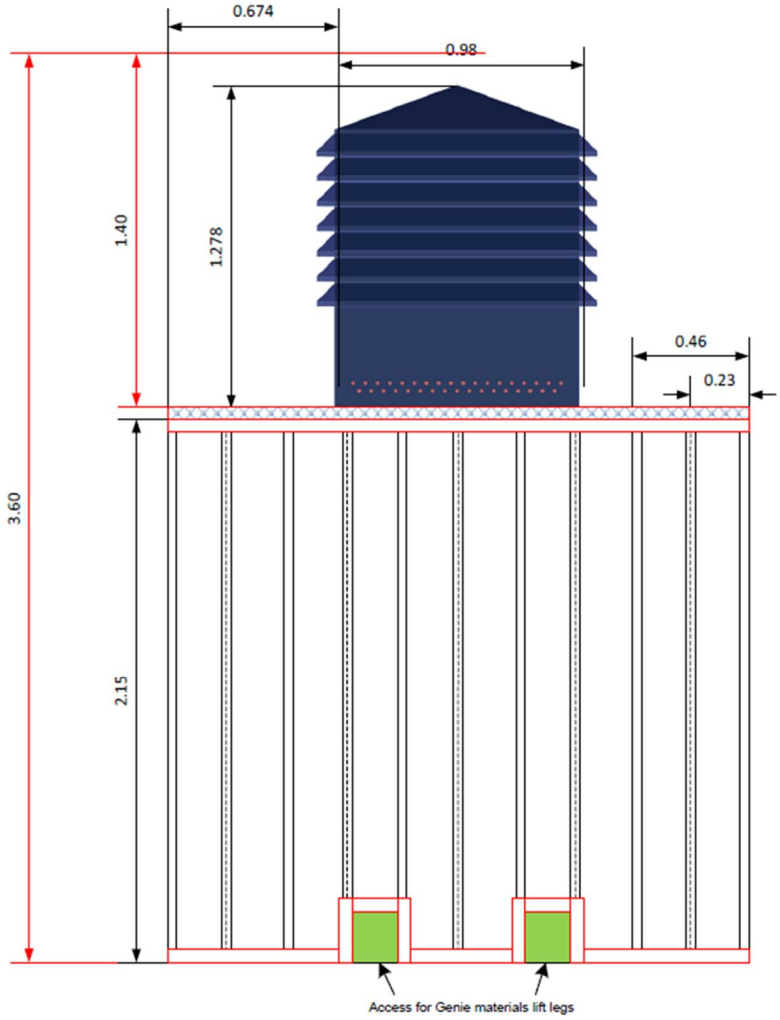


Figure 19. Test room – Elevation. Details of test room and location of wind catcher tower on roof.

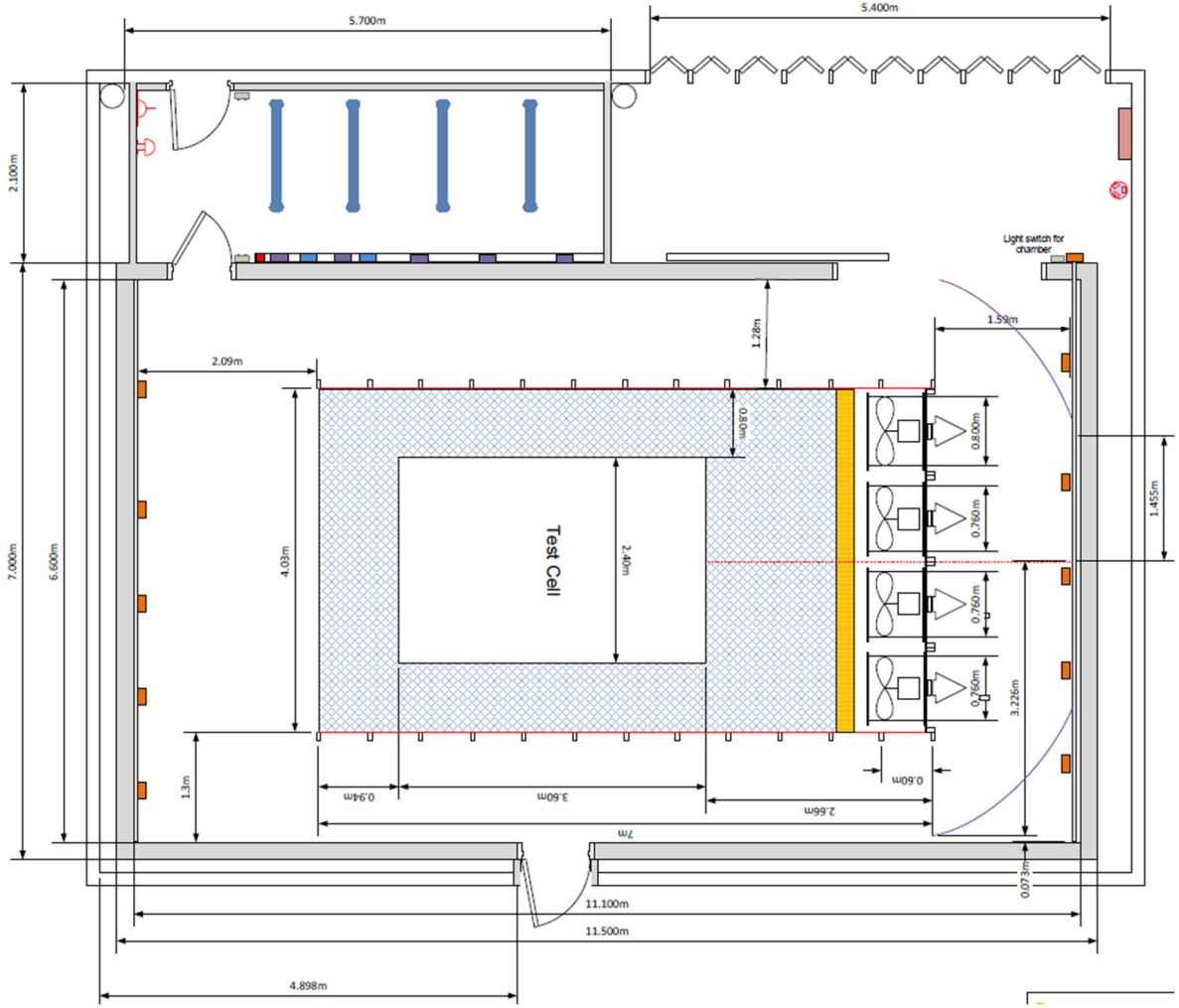


Figure 20. Test chamber – Plan. Details of tests chamber configuration with test room and ‘wind’ fan locations

7 Appendix B – Photographs of test rig

Figure 21. Test room frame under construction. Wind fans located above test room to draw air past wind catcher tower.

Figure 22. Test room walls and roof under construction

Figure 23. Wind catcher tower installed on test room roof.

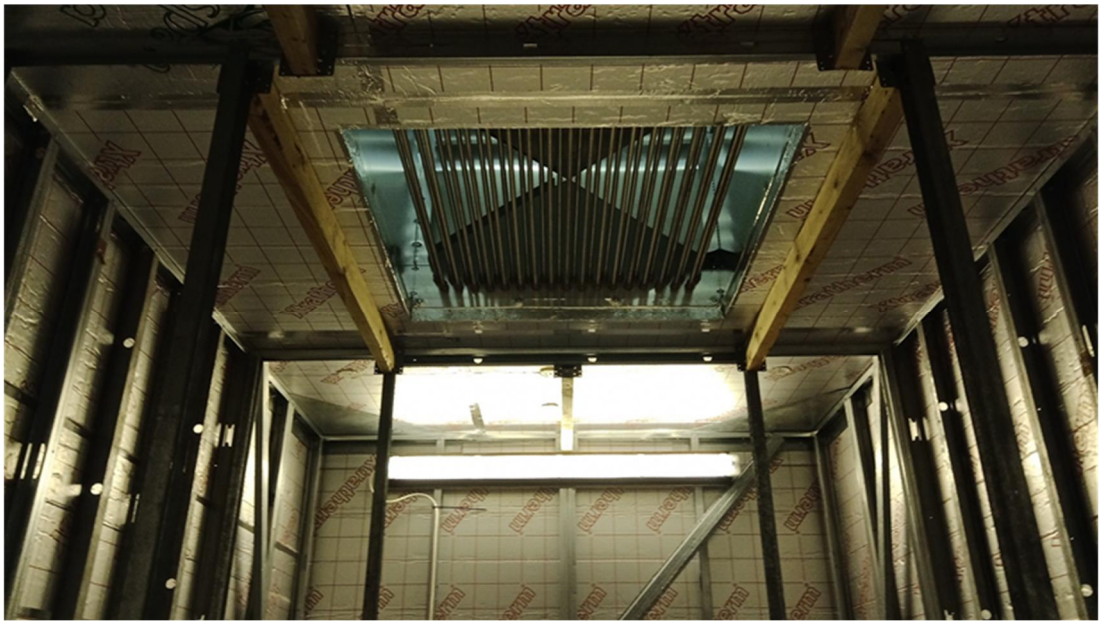


Figure 24. Heat pipes in the base of the wind catcher tower. Tower divided into four segments with two diagonal walls. Segmentation finished above heat pipe array.

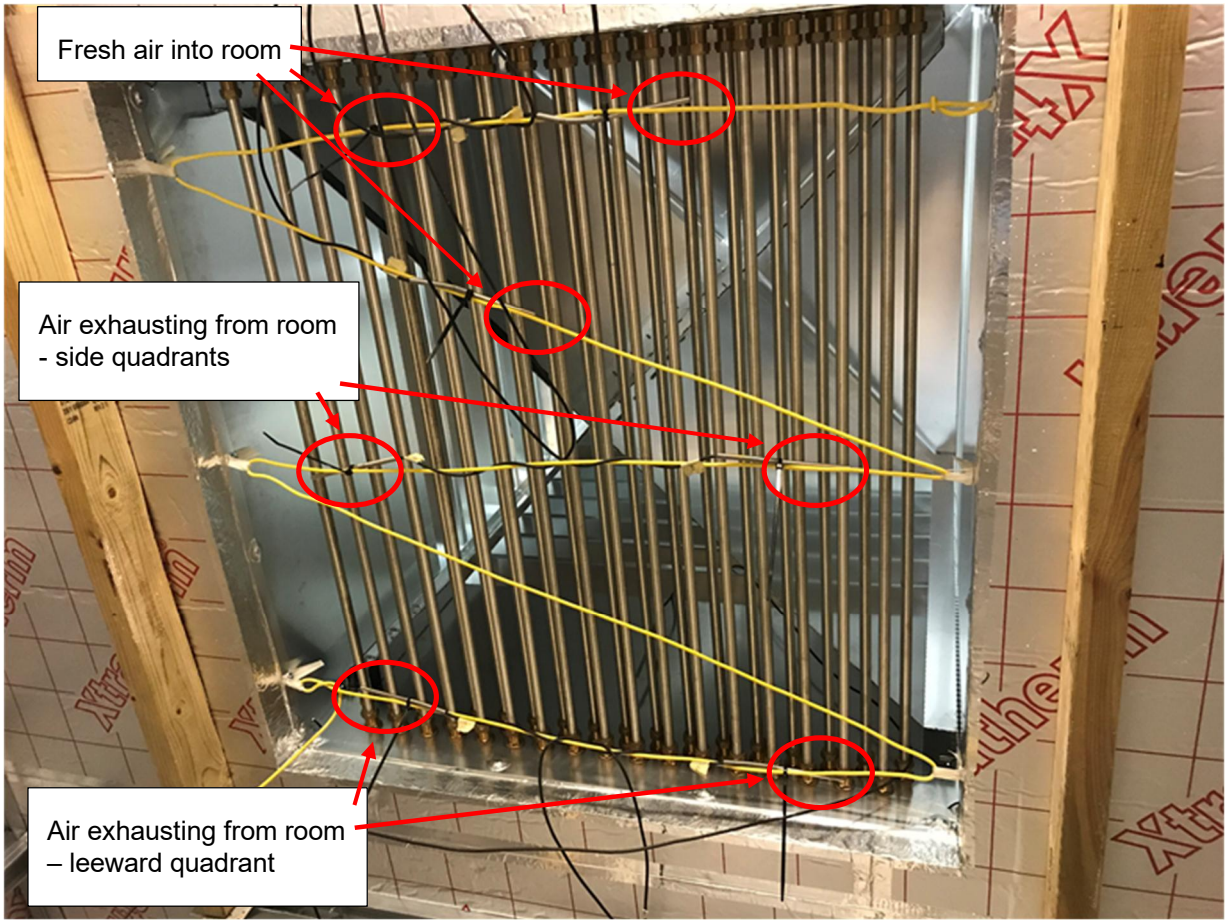


Figure 25. Air temperature sensors located below heat pipes.

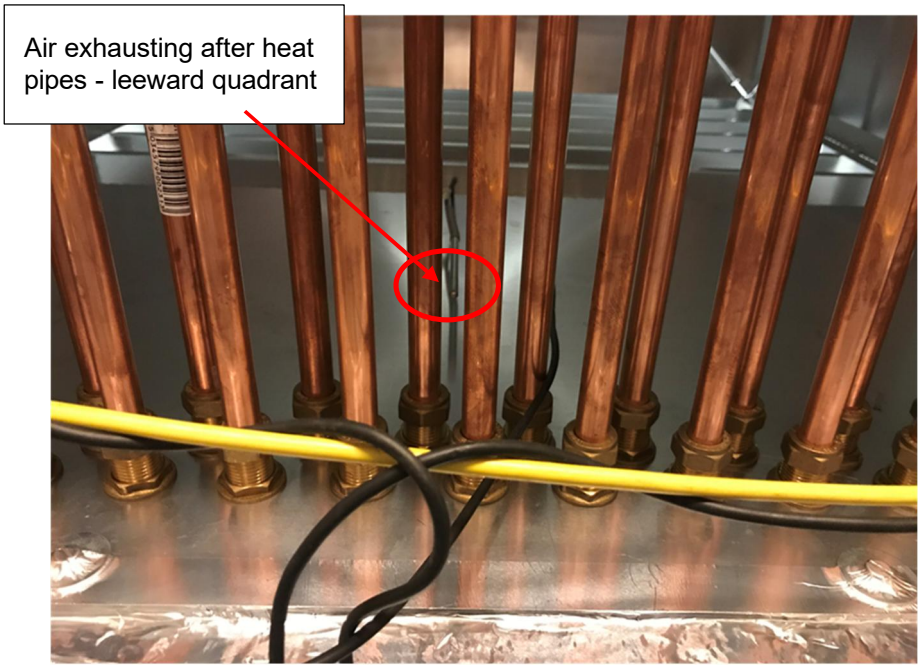


Figure 26. Air temperature sensor located above heat pipe array in exhaust air stream in leeward qudrant of tower.

8 Appendix C – Photographs of test room heating system

Figure 27. Heater battery and inline fan serving six supply legs. Air supplied to room via plenums.

Figure 28. Arrangement of air supply plenums and valves installed on supply legs closest to room acess door – leeward end of test room.

Report Ends

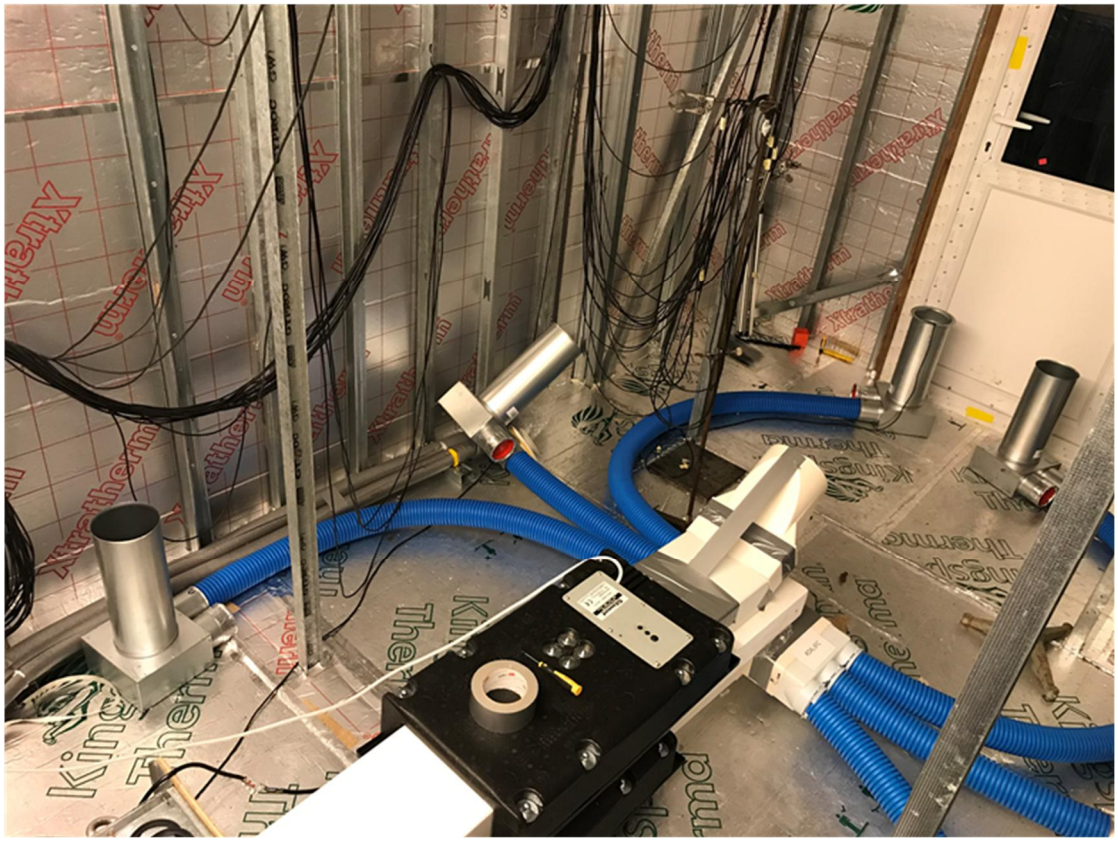


Figure 29. Second inline fan installed ontop of first, warm air dischareged directly into test room to increase room air temperature at high wind speeds.