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Measurement of the air jet and some chosen parameters

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Contents

Objective of the study

The objective of the 2nd part of the study is the same as in the 1st part of the study. The only difference is that in the 2nd part the shifting cycle was extended from 30 and 120 seconds to respectively 240 and 360 seconds.

Fans cycle and air flow determination

In the 2nd round of measurements units were tested for 2 cycles. The shifting cycle between units was increased from 1st round from 30 and 120 seconds to respectively 240 and 360 seconds. This means 60 mm micro fans in 2 units are shifting (blowing air in or out of the chamber) with a 240 sec and 360 sec sequence. When the small 60 mm fans are in the sequence that they are blowing air out of the chamber the respective big 120 mm fans responsible for admixing air are switching to min speed. When the small 60 mm fans are in the sequence that they are blowing air in to the chamber the respective big 120 mm fans responsible for admixing air are switching to one of the speed that gives air flow of 20l/s, 40l/s and 60l/s.

According to the voltage measurements, the speed of fans is different over time. When the max input voltage is above 7V for 60mm or 120mm fans, 120mm and 60mm fans have full speed when the micro fans are not working. When the micro fans are rotating, the power supply of both 120mm and 60mm fans is set to 7V.

The air flow from the units was measured using cone Model Company . The aim in the measurements was to obtain air flow at 20l/s, 40l/s and 60l/s. The real (measured) air flows are collected in the Table 1. What is more, measured voltage for different air flows for 120mm fans are also presented in the Table 1.

Design flow	Cone constant 22	Velocity calculated	Voltage measured	Velocity measured (cone)	Real flow (per unit)
[l/s]		[m/s]	[V]	[m/s]	[l/s]
20	0,91	0,92	2,62	0,91	20,0
40	1,82	1,82	4,55	1,82	40,0
60	2,73	2,73	7,32	2,73	60,0

Table 1. Design and measured air flow in the Inventilate unit when blowing air in to the room.

Relation between fans' input voltage and air flow through the unit

The fans provider documentation does not give air flow in function of voltage supply to the fans. In addition, the pressure losses through the heat recovery units are significantly affecting the air flow through the unit in function of the input voltage to the fans.

Temperature Measurements

Air temperature is measured in different points of the set up. Temperature measurements are performed with Type K thermocouples and FLUKE Helios Plus 2287A. Every thermocouple has been calibrated separately. The precision for temperature measurement is 0,1K.

Air Velocity Measurements

Air velocity is measured in different points of the set up. Velocity measurements are performed with Hot Sphere Anemometers and a Dantec Transducer. Every anemometer has been calibrated separately with the wind tunnel, orifice plate and FC510 Micromanometer.

Set Up Description

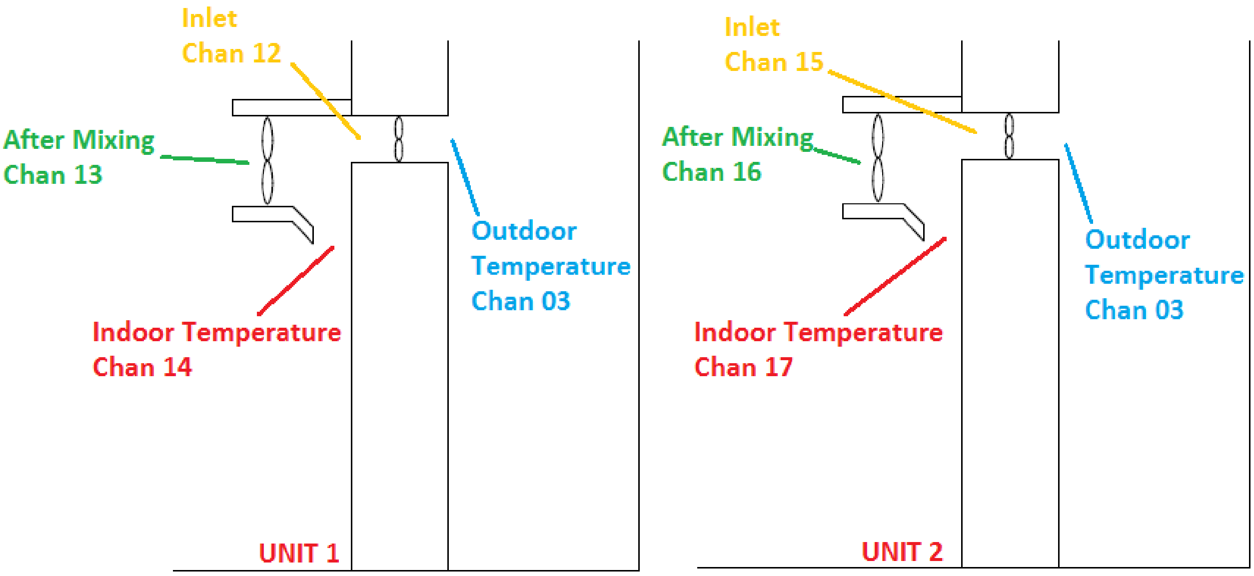


Figure 1 *Thermocouples position for air temperature measurement in ventilation units.*

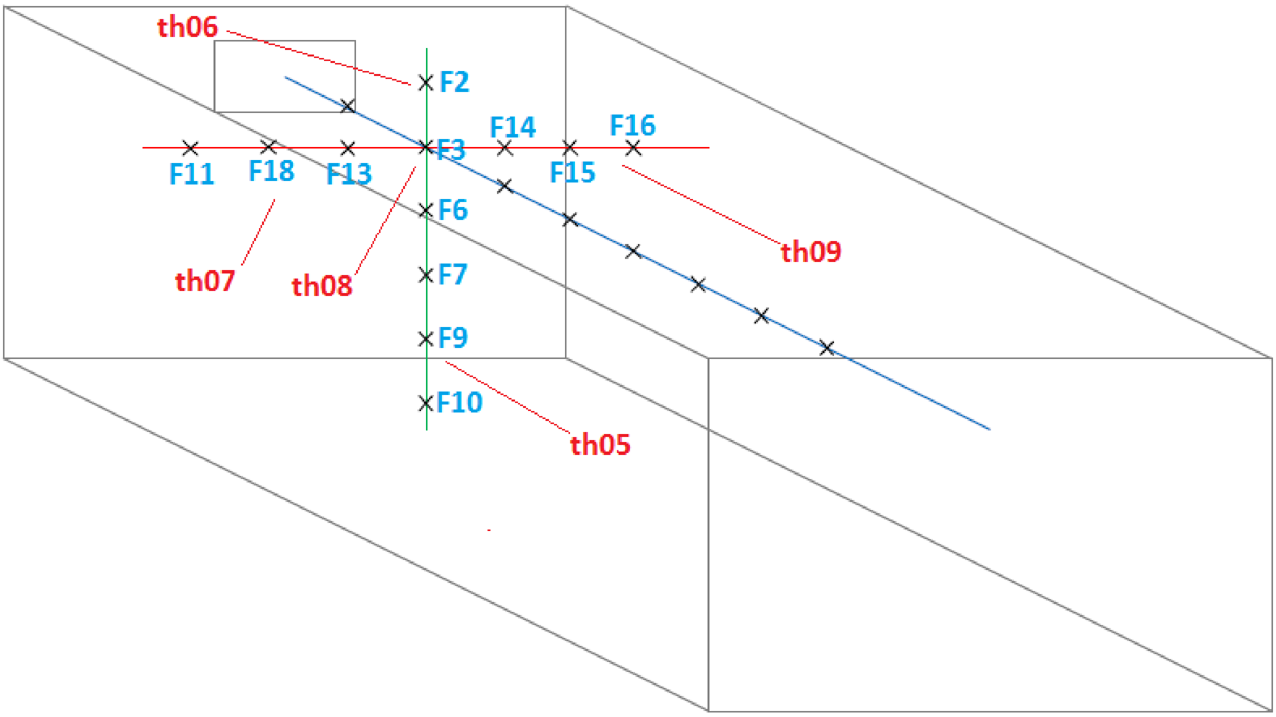


Figure 2 *Positioning of anemometers (F2, F3, F6, F7, F9, F10, F11, F18(12), F13, F14, F15, F16) and thermocouples (th05, th06, th07, th08, th09) in the room.*

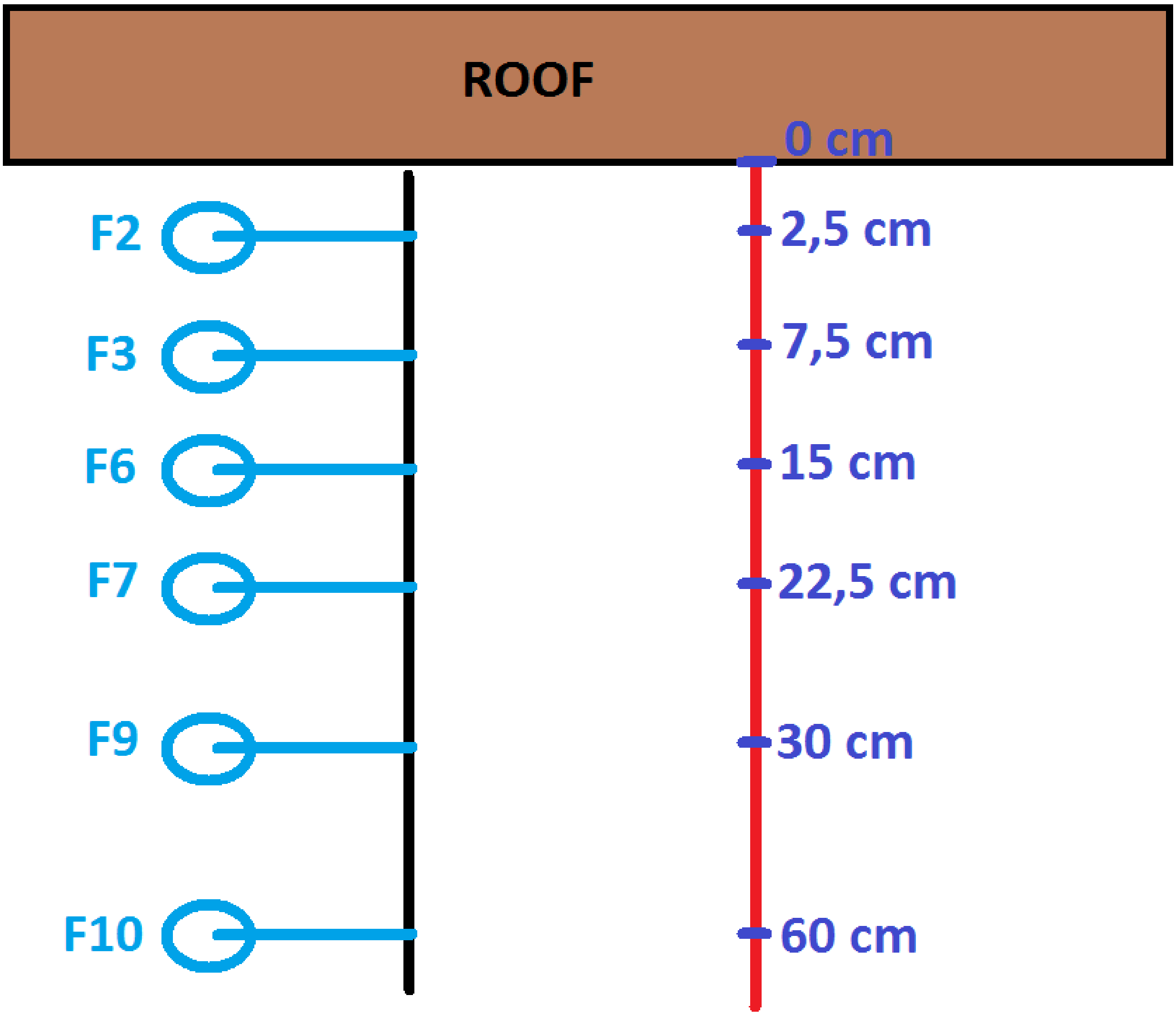


Figure 3 *Distance of anemometers from the roof on the vertical pole.*

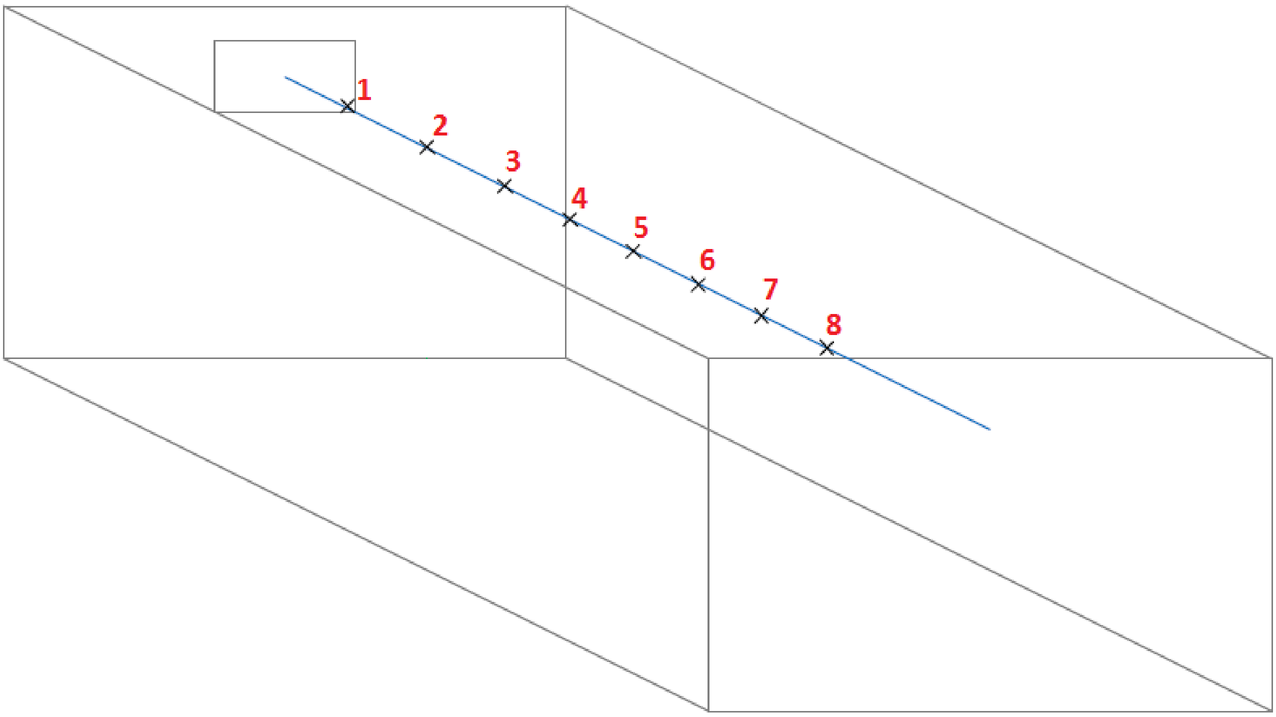


Figure 4 *Horizontal placement of poles for each step of ventilation test.*

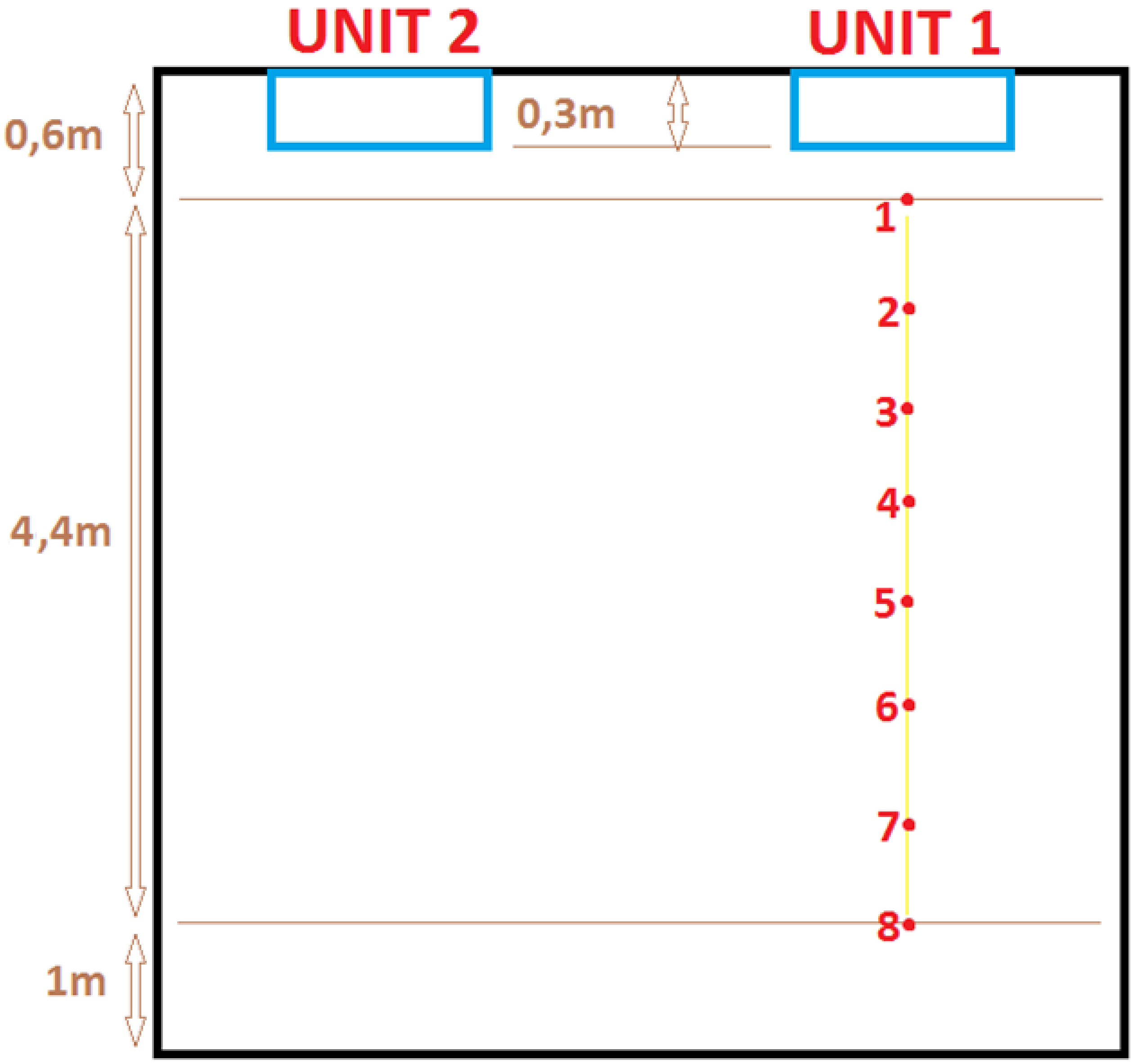


__Figure 5__ Horizontal placement of poles for each step of ventilation test.

Outdoor Temperature

During the measurements the outdoor air temperature is kept constant. Fluctuations due to technical limitations make the outdoor temperature oscillate following a sinusoidal curve. Nevertheless, the average temperature is very stable over time and averaging values over a long period provide very good steady state measurements. In addition, the inertia of the ventilation units compensates the outdoor temperature variations.

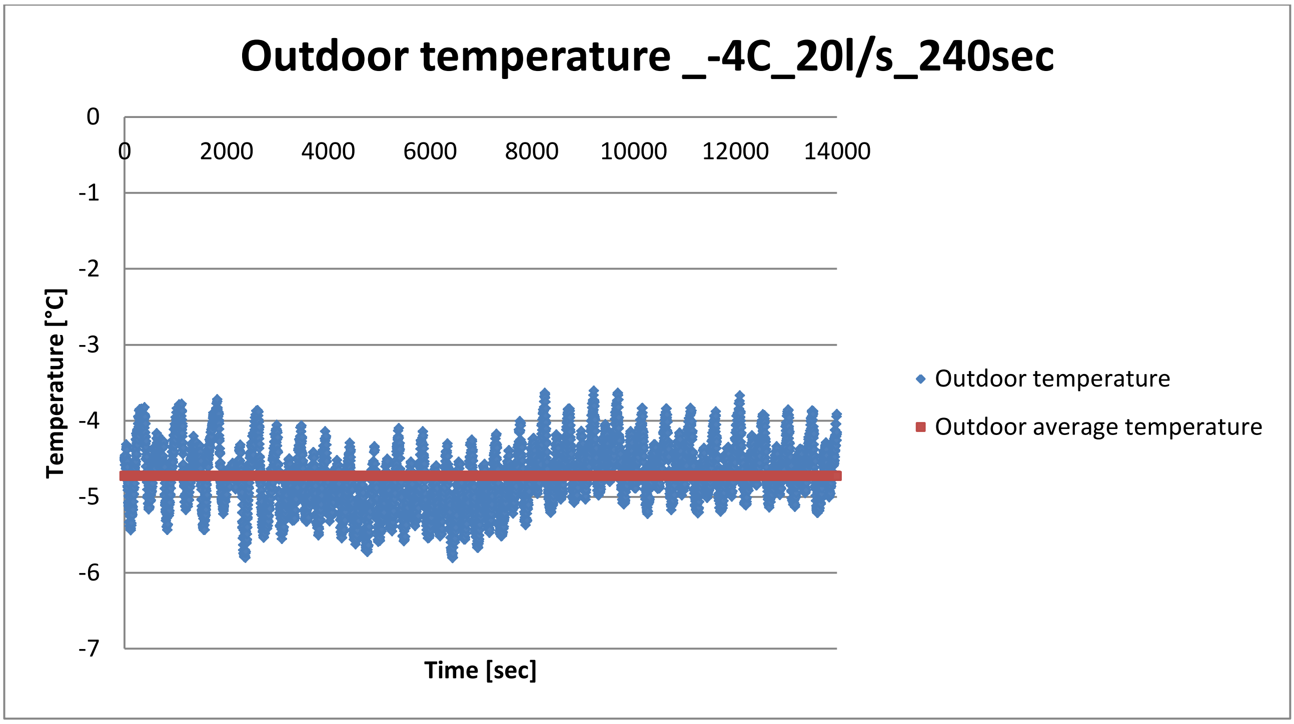


Figure 6 Temperature in the cold chamber "Outdoor temperature" for chosen measurement.

As can be observed in Fig. 6 average outdoor temperature in reality was different than the design temperature and respectively instead of having -4°C the outdoor temperature was closer to -5°C in average.

Unit test – shifting sequence

The two units, after synchronization time, are working perfectly alternatively.

In Fig. 7 is shown that the two units are working the same way (their temperature profiles are very similar).

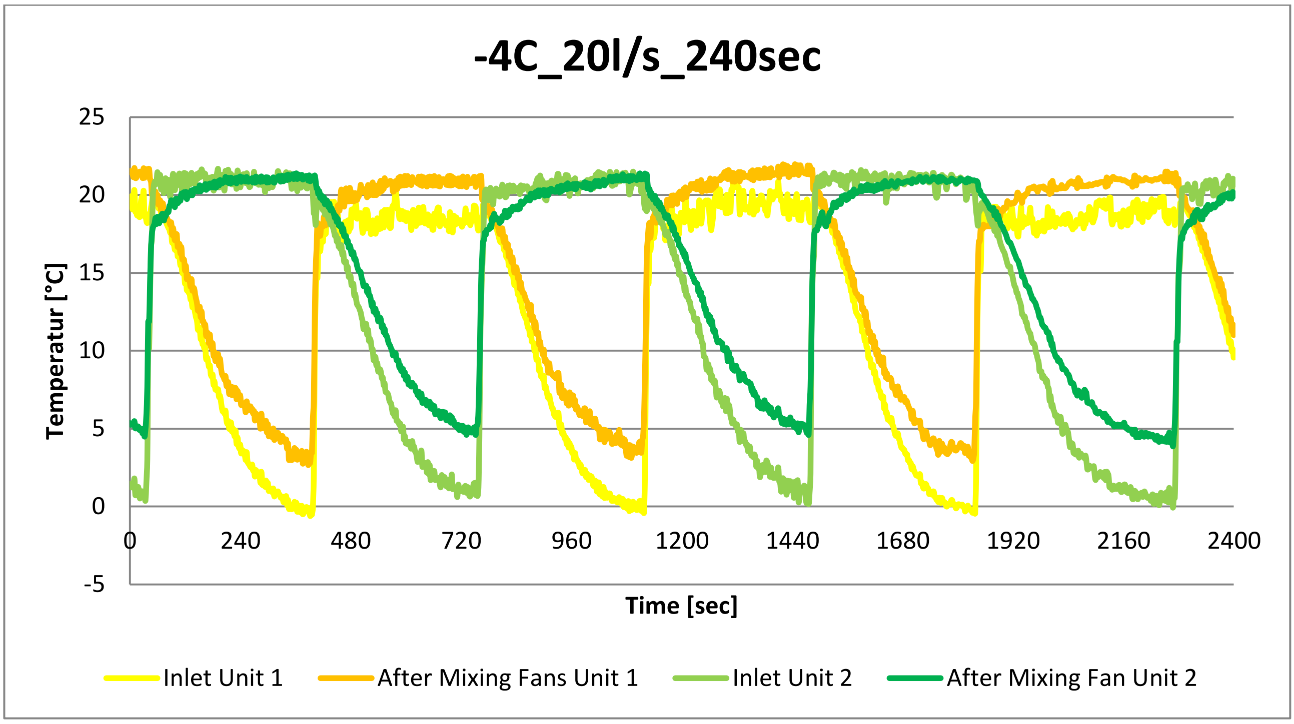


Figure 7 Synchronization of unit 1 and Unit 2.

Heat recovery of ventilation units can be calculated from the following formula:

$$\varepsilon = \frac{\theta_{air\ intlet} - \theta_{air\ external}}{\theta_{air\ internal} - \theta_{air\ external}}$$

Temperature in space

In this chapter are presented temperatures in the test chamber for the chosen experiments. It was observed that temperatures in the chamber are uniform and the inlet jets do not influence local temperatures significantly. Observed fluctuations, for most of the time are between 21°C and 22°C, and are most probably caused by the PID controller of the heating floor wire used to simulate heating load in the chamber and to maintain constant temperature in the chamber. Moreover, observed temperature fluctuations have much longer time interval than the time shift between Inventilate units and therefore could not be caused by the units. Another reason for the temperature fluctuations in the chamber could be temperature fluctuations in the surrounding laboratory where temperature is maintained by the radiators with thermostats.

Below presented Figures from 8 to 15 are presenting temperatures as a function of time of the particular measuring test. The logging of the temperature was started and the poles with sensors were moved from point 1 to point 8 (as presented in Figure 4 and 5). With the present logging system it is not possible to distinguish at which location is taken each measurement of temperature in the chamber.

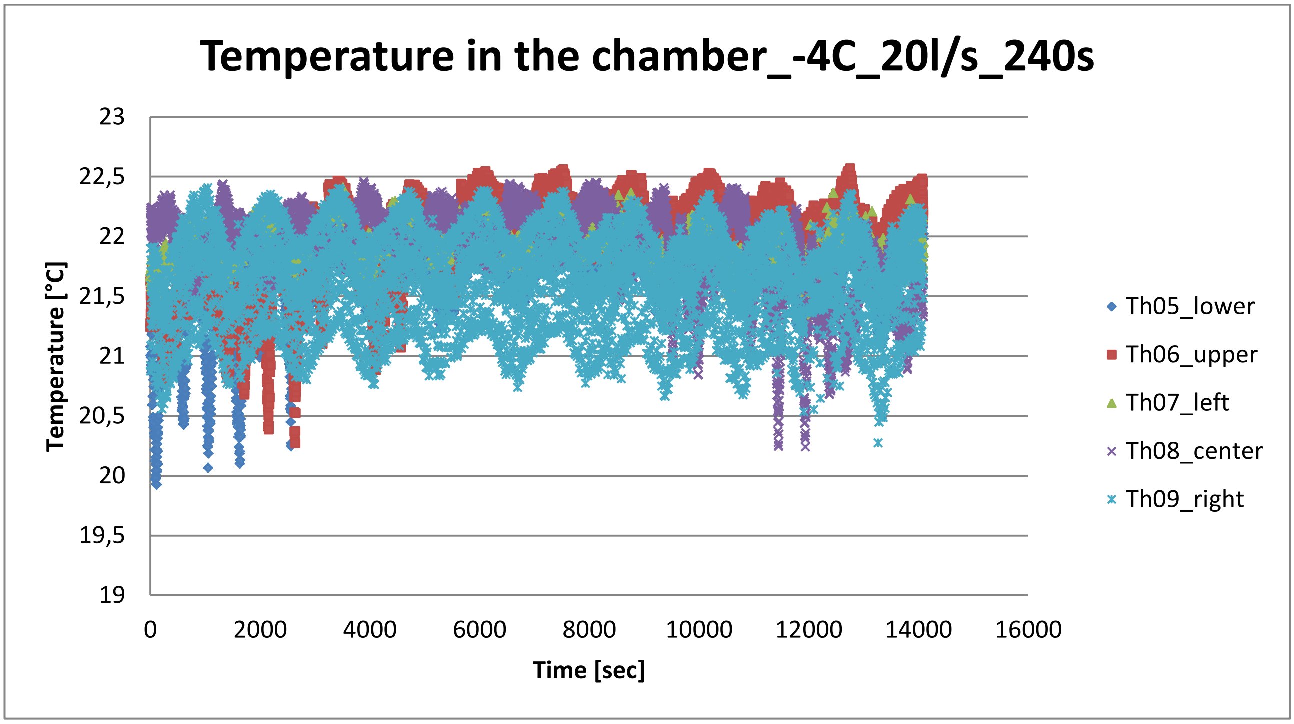


Figure 8

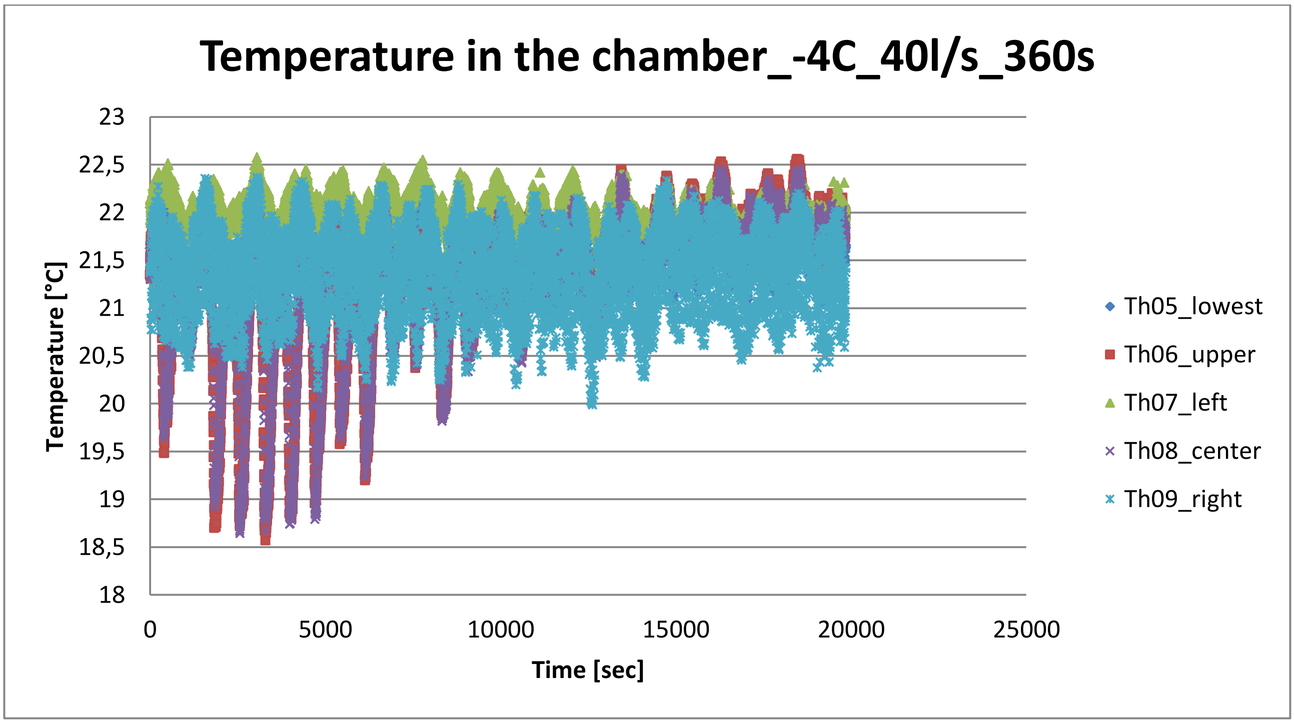


Figure 9

Moreover, in Figure 10 and 11 (measurements with air flow at 40l/s)as an example, it can be observed that thermocouples located close to the inlet unit, just in front of the unit and above unit, are influenced by air jet to the chamber.

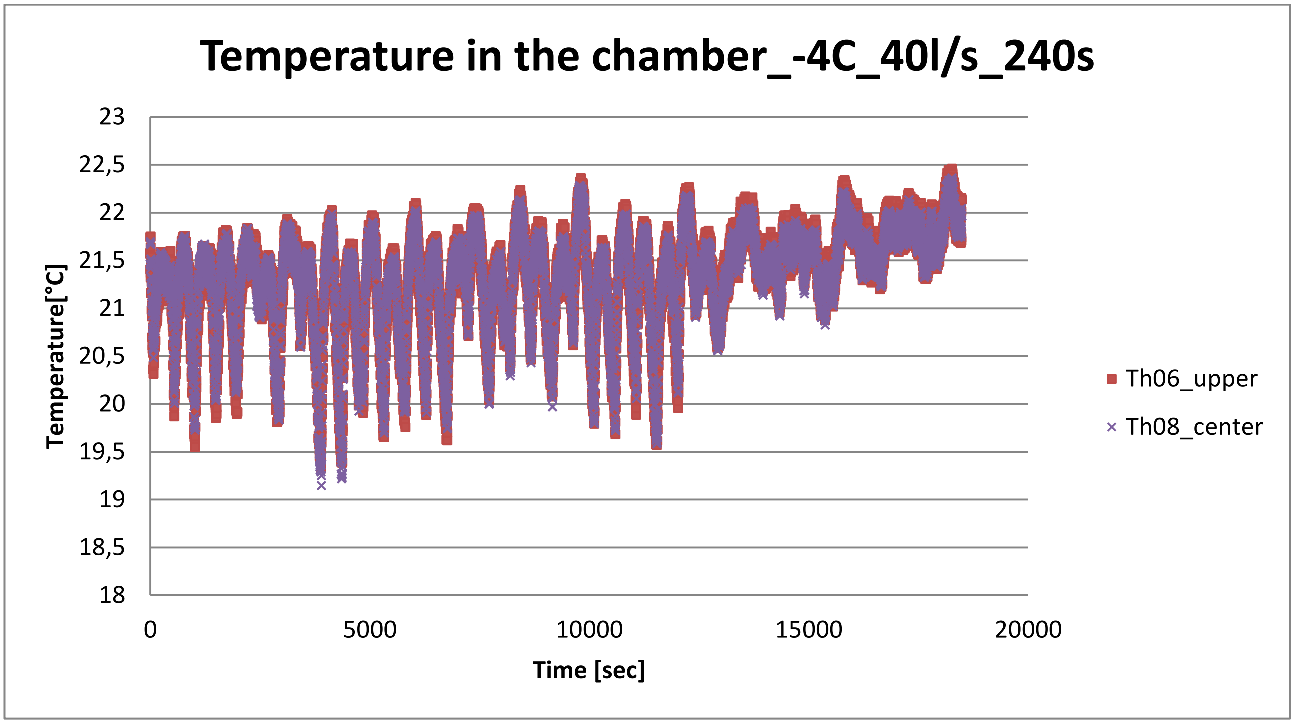


Figure 10

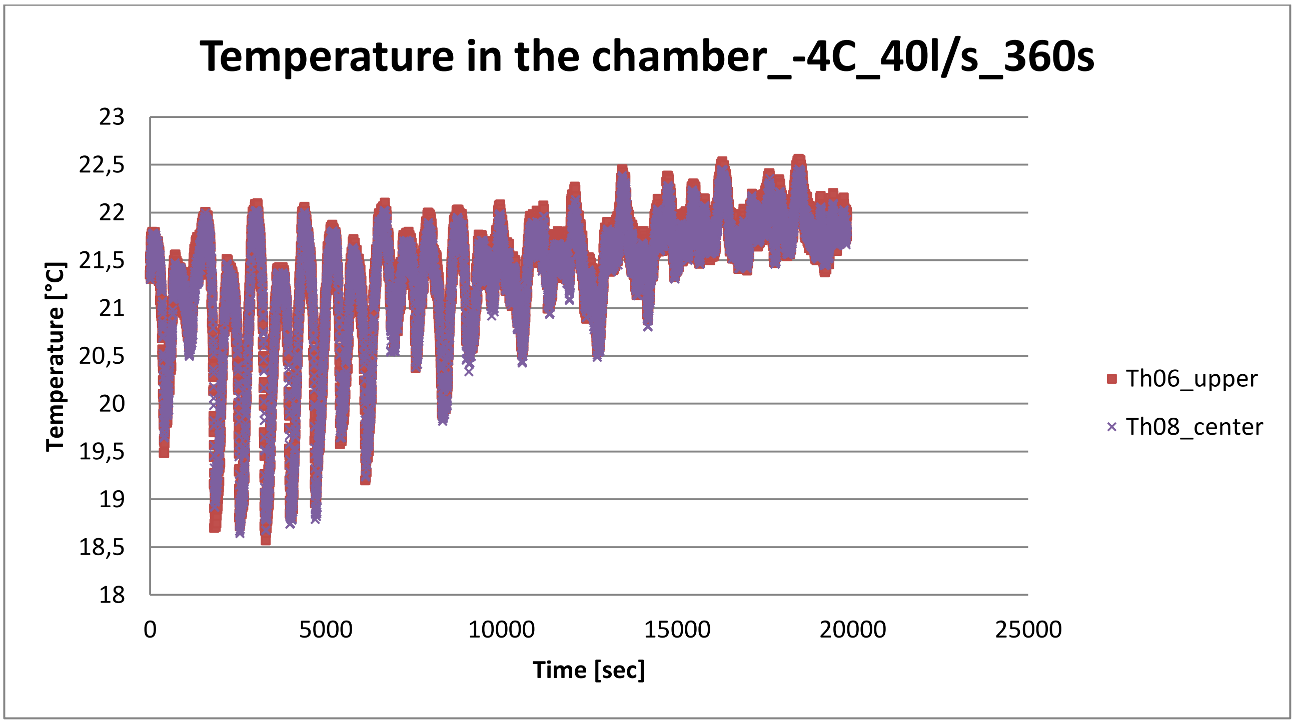


Figure 11

In the investigation focus was also paid to check the temperature along the air jet close to the occupation zone, see Figure 12-15. The thermocouple number 5 is the lowest thermocouple located on the vertical pole, see Fig. 2. This thermocouple is located approximately 60 cm from the ceiling and was chosen to investigate if the temperature of the jet close to the occupation zone is low and if it is falling to the occupation zone. In this chapter only results from some chosen measuring series are presented.

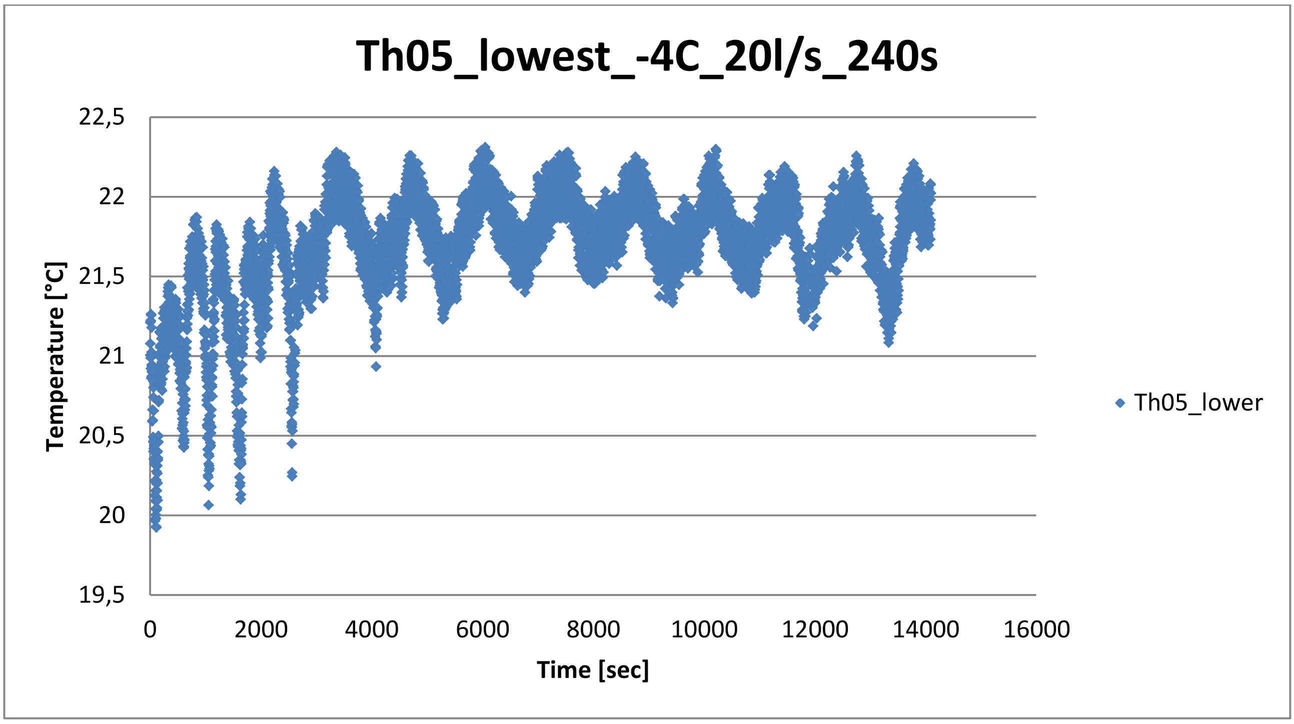


Figure 12

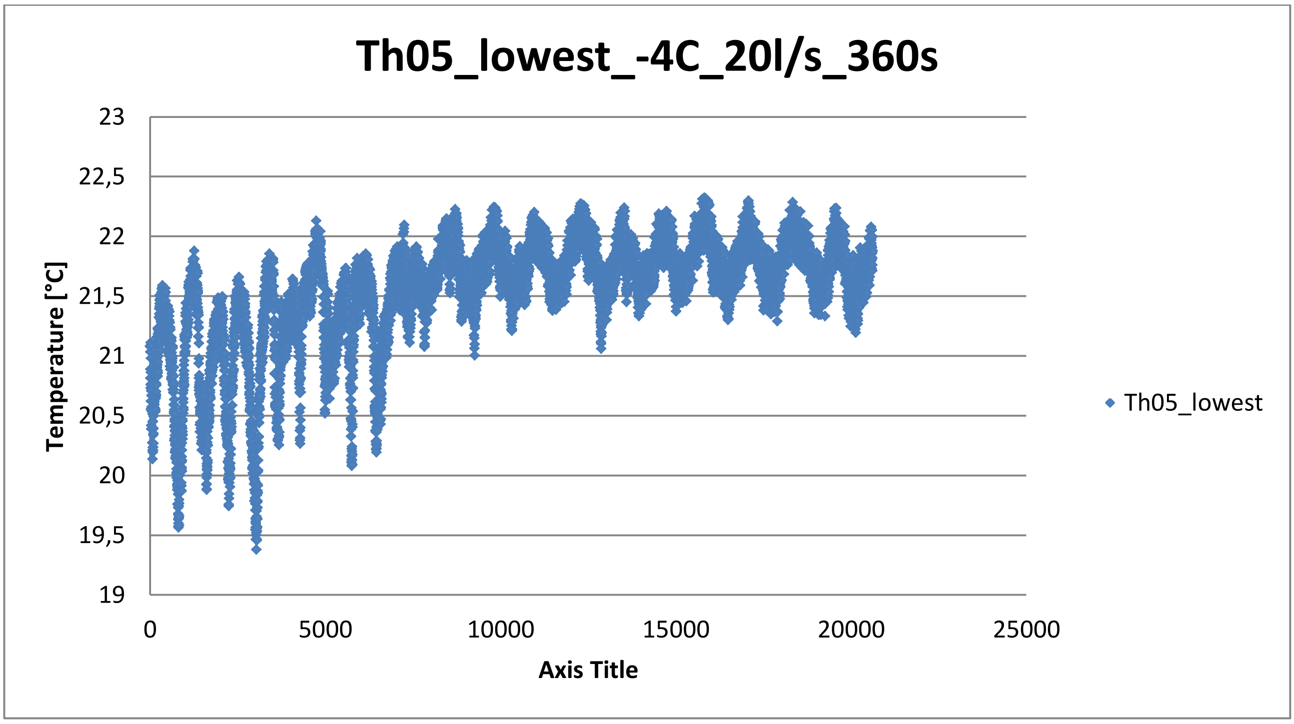


Figure 13

For test with low air flow 20l/s and 240 seconds and 360 second shift between units, see Figure 12 and 13 it can be observed that there might be a risk of down drought from the inlet units. This will be further and more carefully investigated during the last round of measurements with the final prototype of the Inventilate unit.

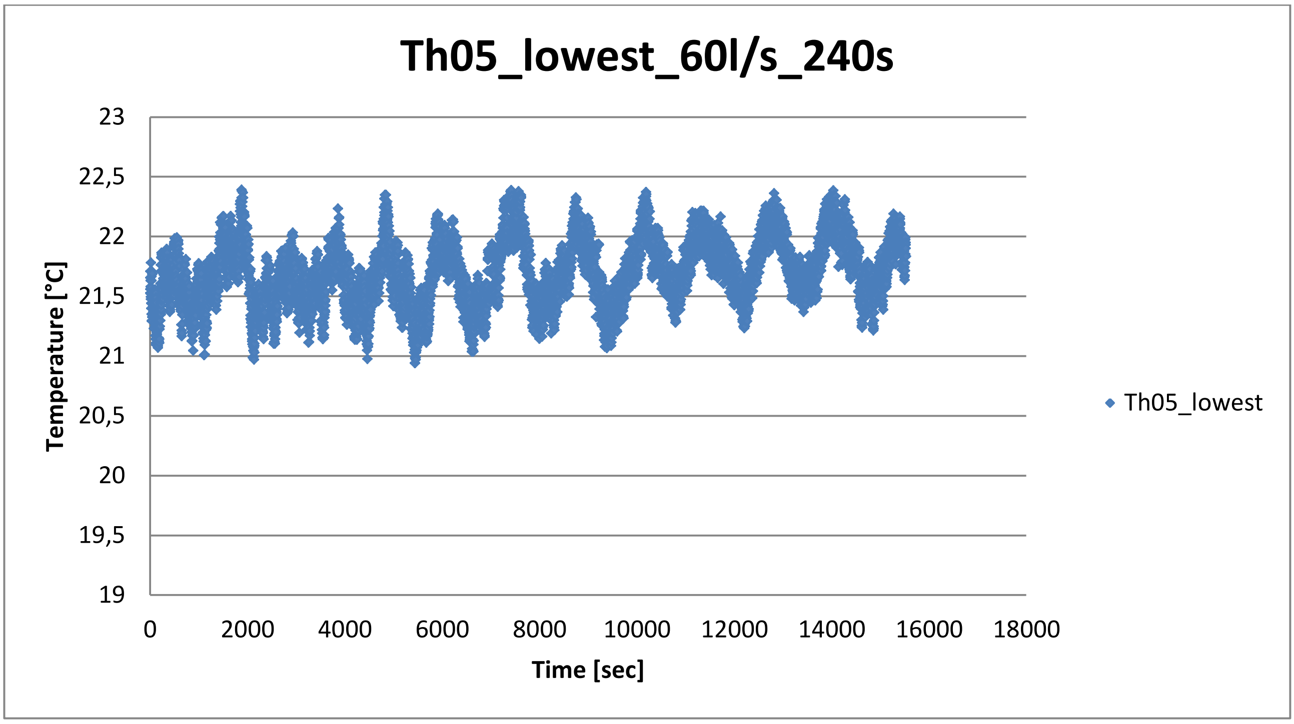


Figure 14

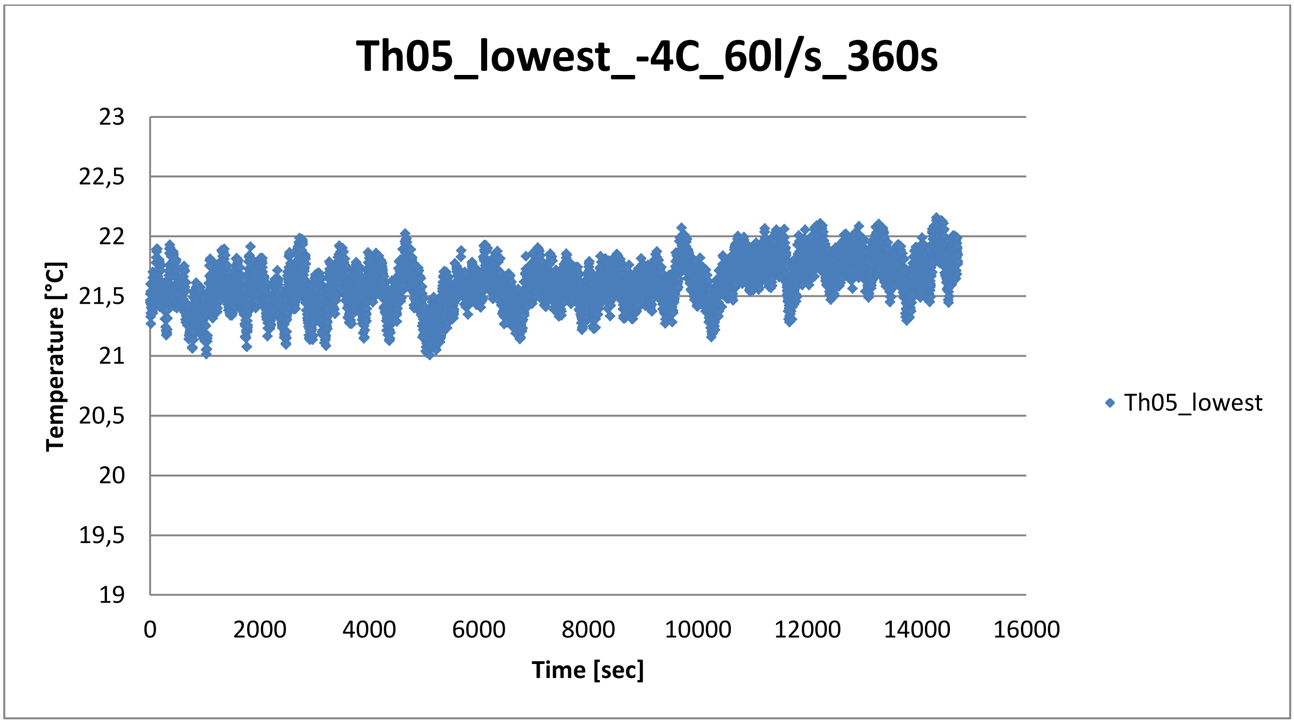


Figure 15

Temperatures presented in Figure 14 and 15 are valid for the tests with high air flow (60l/s). It can be observed that temperatures are very uniform and no down drought or low temperatures can be observed.

Temperature logged for tests with 40 l/s are not presented in this report, but logged results indicated there is no evidence of down drought and low temperatures close to the occupation zone.

Determination of jet penetration length

In the conducted measuring set up the jet has a form of three-dimensional wall jet that can be analytically described using following Equation 1.

$$\frac{V_x}{V_o} = K_a * \frac{\sqrt{a_o}}{x} \qquad \text{Eq. 1}$$

Where:

V_x – air velocity in distance x from the inlet [m/s]
V_o – air velocity in the inlet opening [m/s]
K_a – constant
a_o – inlet area [m^2]
x –distance from the inlet [m]

Results from all conducted measuring series are plotted on the double logarithmic chart and a trend line is fitted. The place where trend line is crossing V_x/V_o = 1 can be considered as a length of the core of the jet. In the presented case it was calculated that K_a = 8. Knowing K_a coefficient it is possible to calculate maximum velocity at the inlet that will result in f.e. velocity of 0.2 m/s at the entrance to the occupation zone.

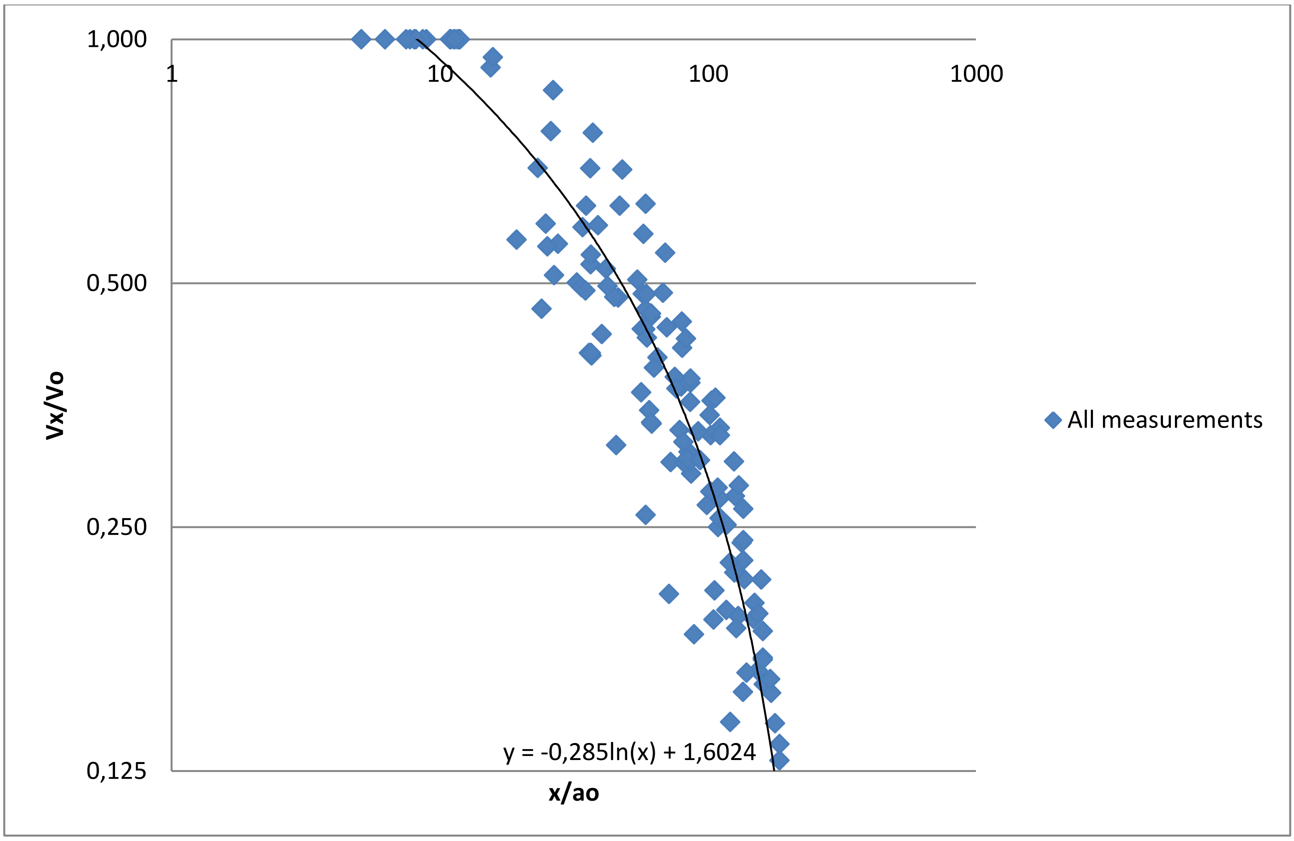


Figure 16

Test 01 (-4C 20l/s 240sec

Average Outdoor Temperature	**-5,13 °C**
Average Indoor Temperature	**21,81 °C**
Average Inlet Supply Temperature	**14,87 °C**
Average after Mixing Fans Temperature	**16,33 °C**
Average Combined Units Heat Recovery	**0,65**

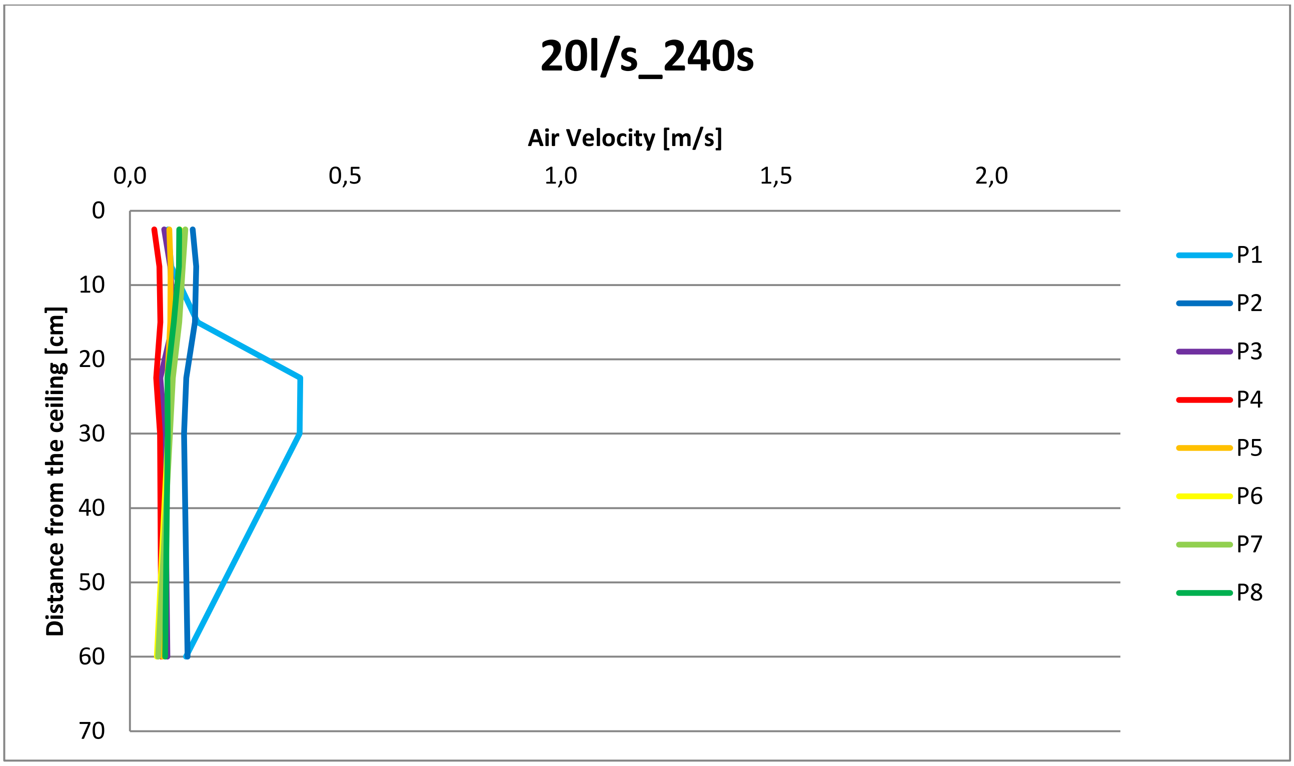


Figure 17

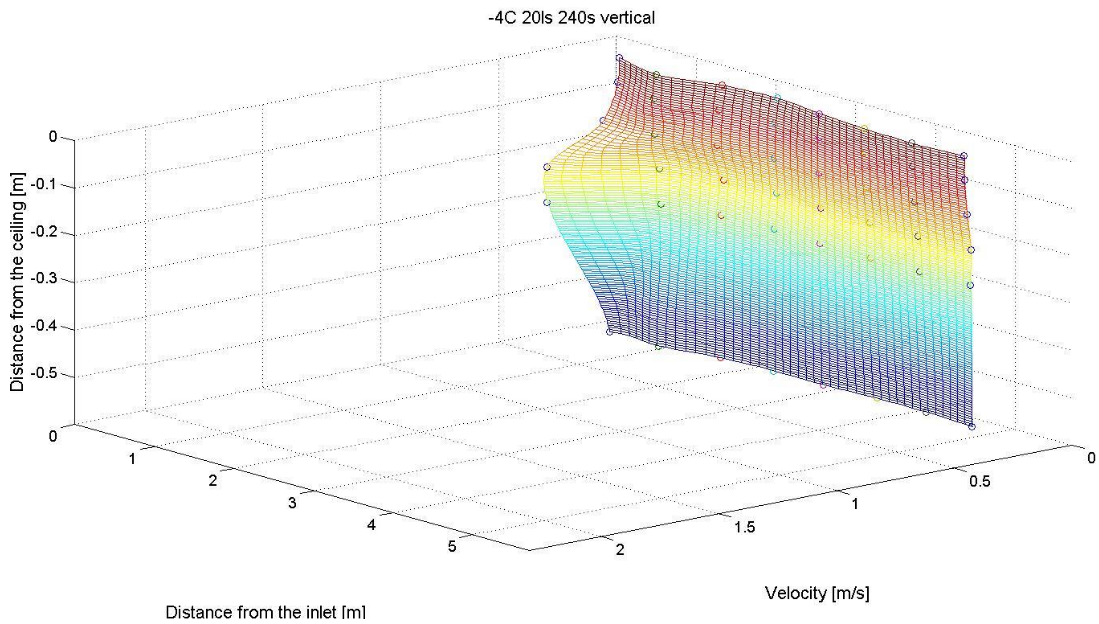

-4C 20ls 240s vertical
Distance from the ceiling [m]
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
1
2
3
4
5
Distance from the inlet [m]
0
0.5
1
1.5
2
Velocity [m/s]

Figure 18

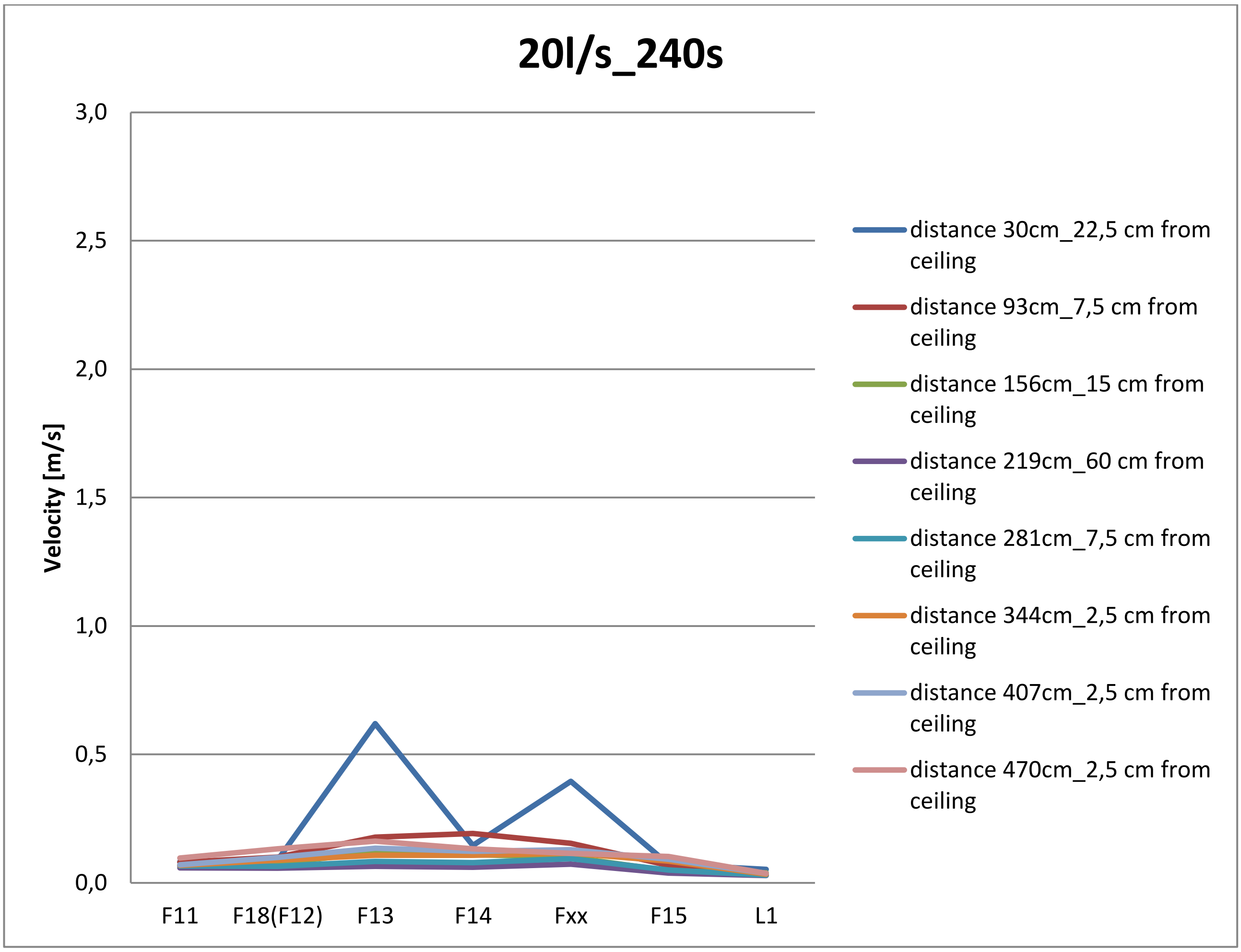

20l/s_240s
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Velocity [m/s]
F11
F18(F12)
F13
F14
Fxx
F15
L1
distance 30cm_22,5 cm from ceiling
distance 93cm_7,5 cm from ceiling
distance 156cm_15 cm from ceiling
distance 219cm_60 cm from ceiling
distance 281cm_7,5 cm from ceiling
distance 344cm_2,5 cm from ceiling
distance 407cm_2,5 cm from ceiling
distance 470cm_2,5 cm from ceiling

Figure 19

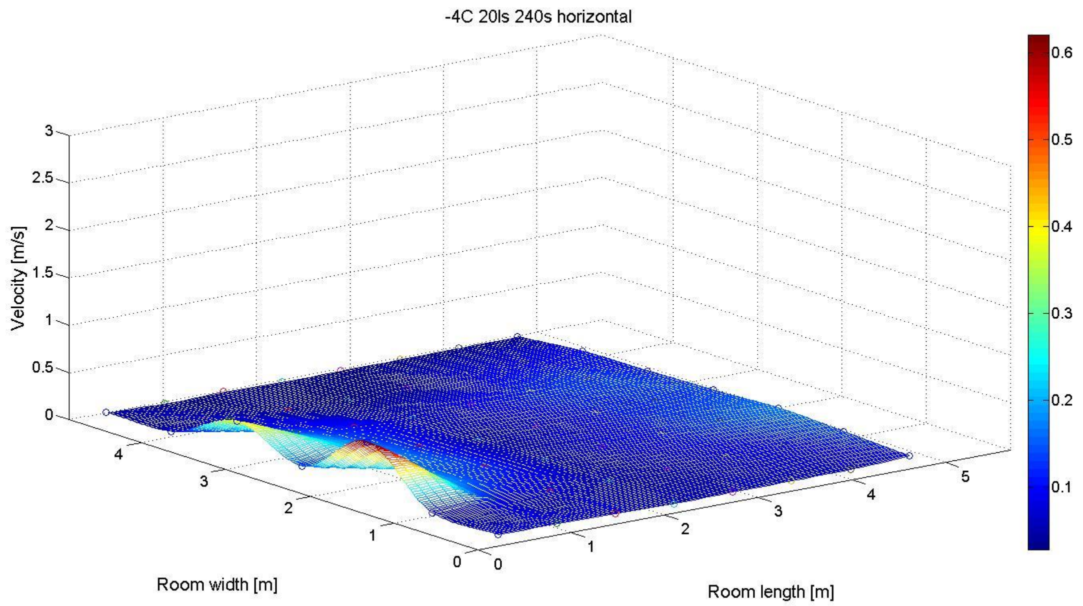


Figure 20

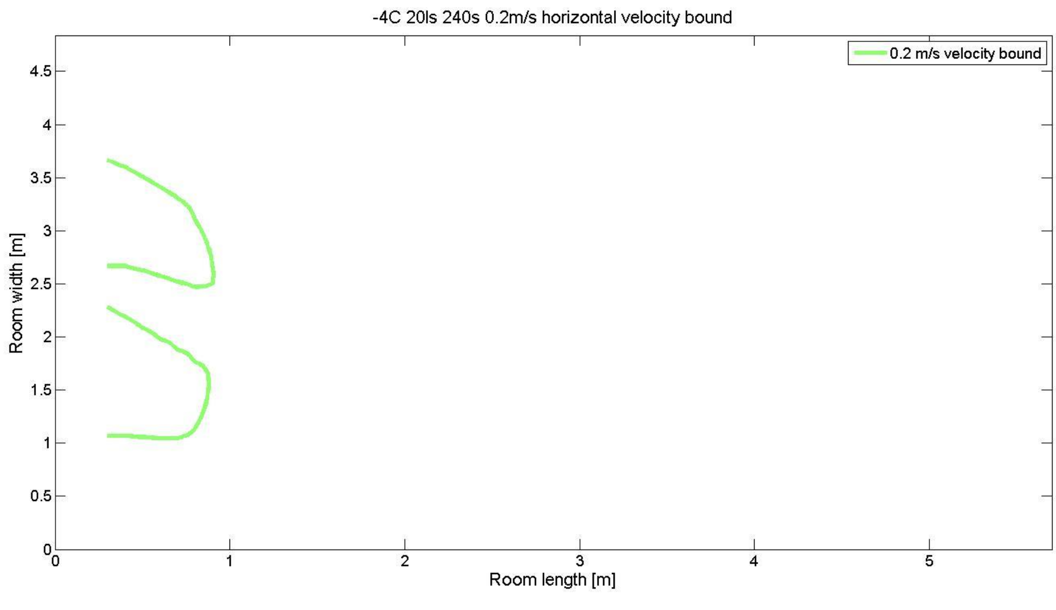


Figure 21

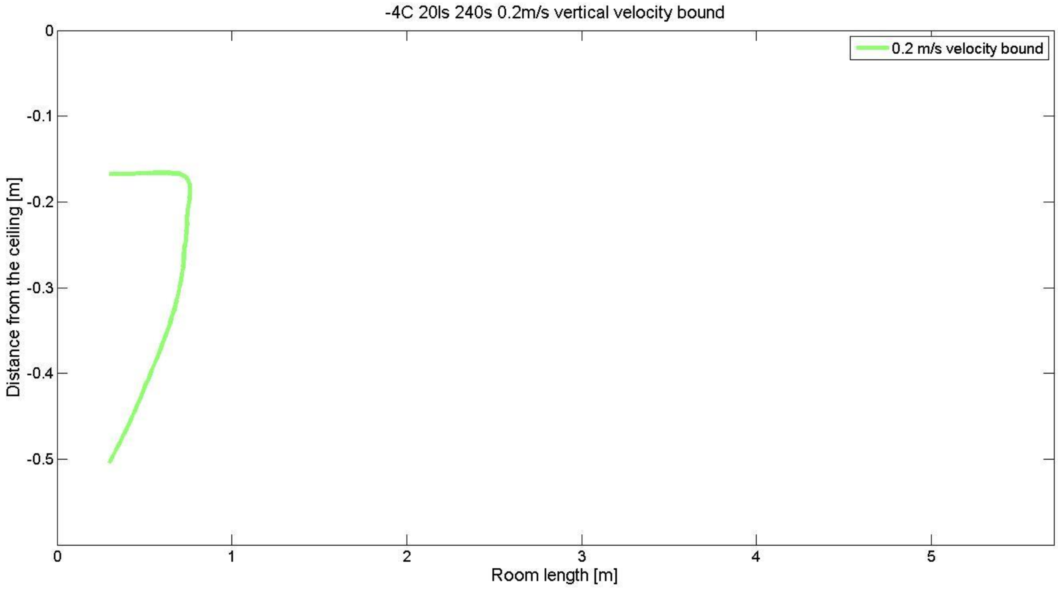


Figure 22

Dynamic representation of some chosen results

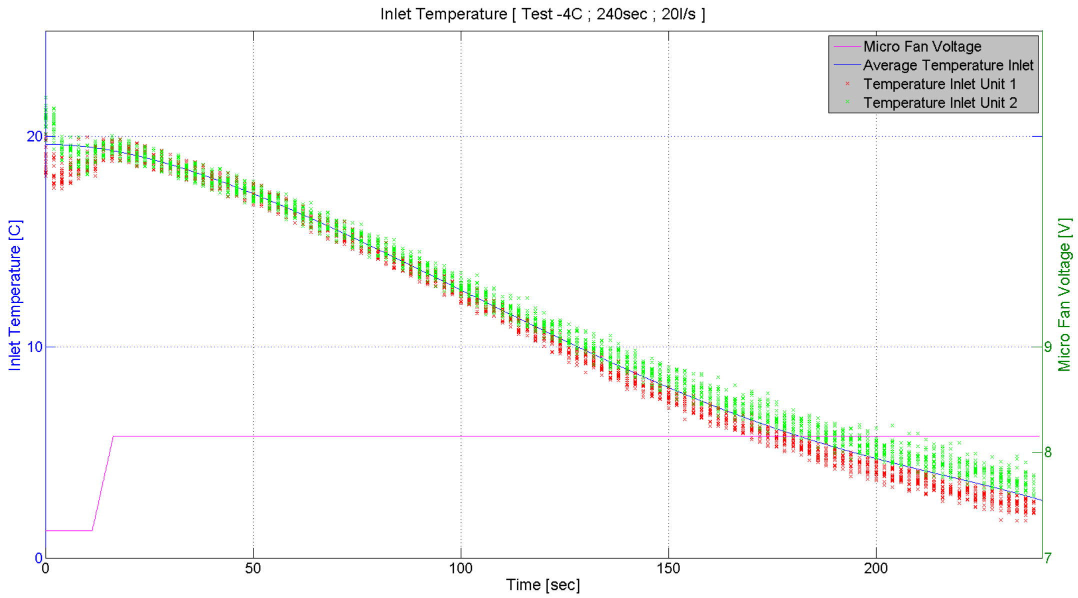


Figure 23

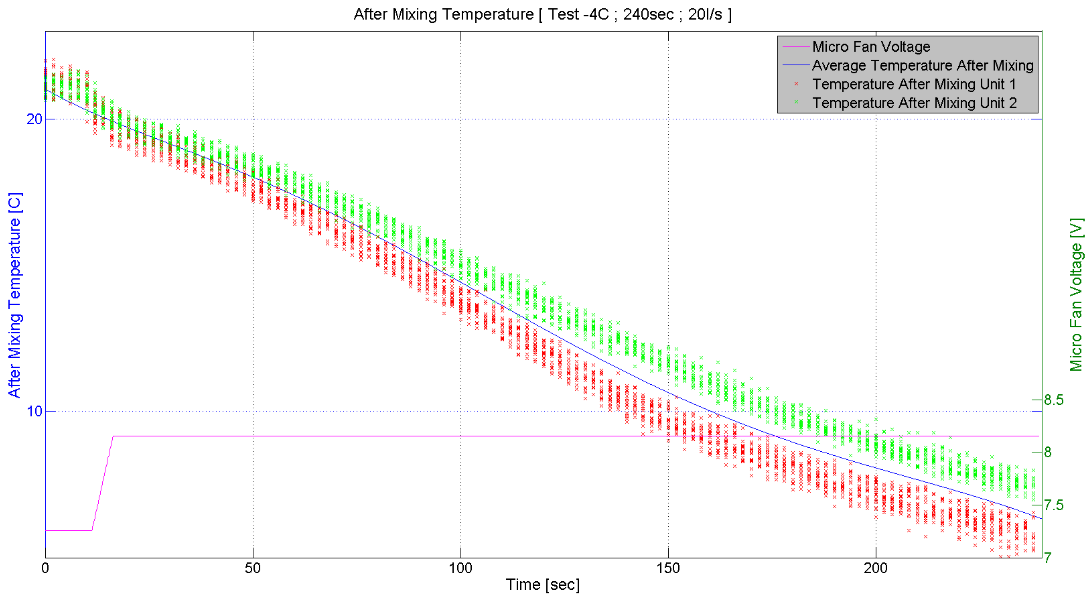


Figure 24

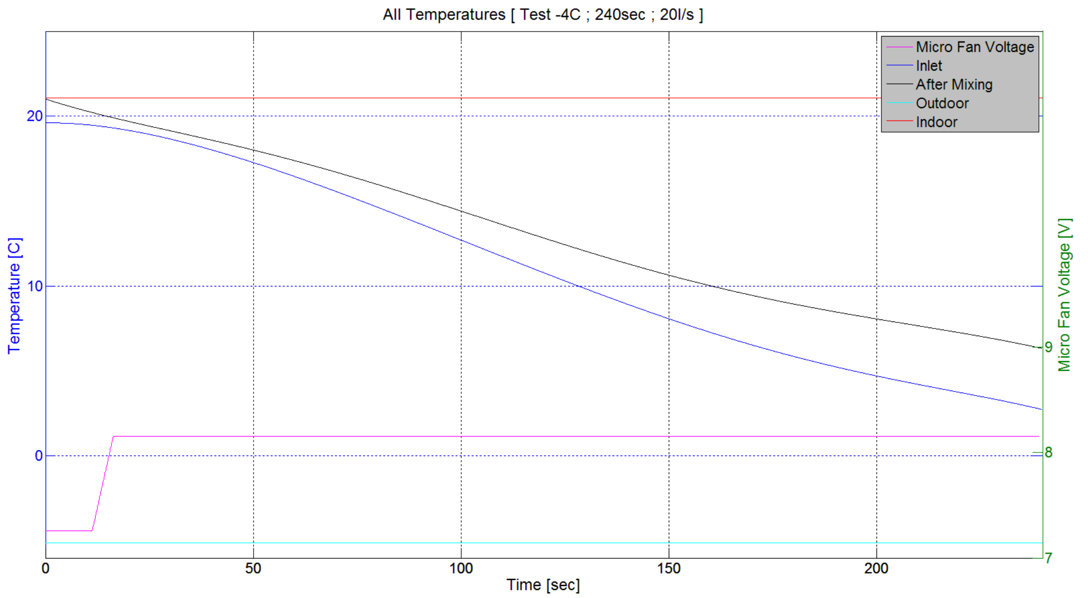


Figure 25

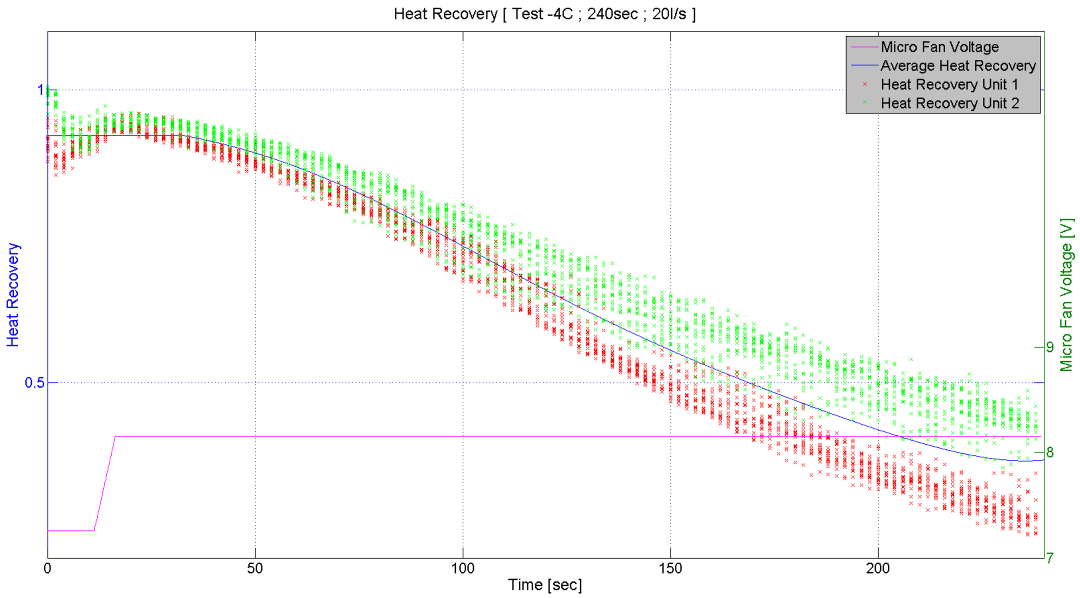


Figure 26

Test 02 (-4C 40l/s 240sec)

Average Outdoor Temperature	**-4,65 °C**
Average Indoor Temperature	**21,60 °C**
Average Inlet Supply Temperature	**15,62 °C**
Average after Mixing Fans Temperature	**18,32 °C**
Average Combined Units Heat Recovery	**0,63**

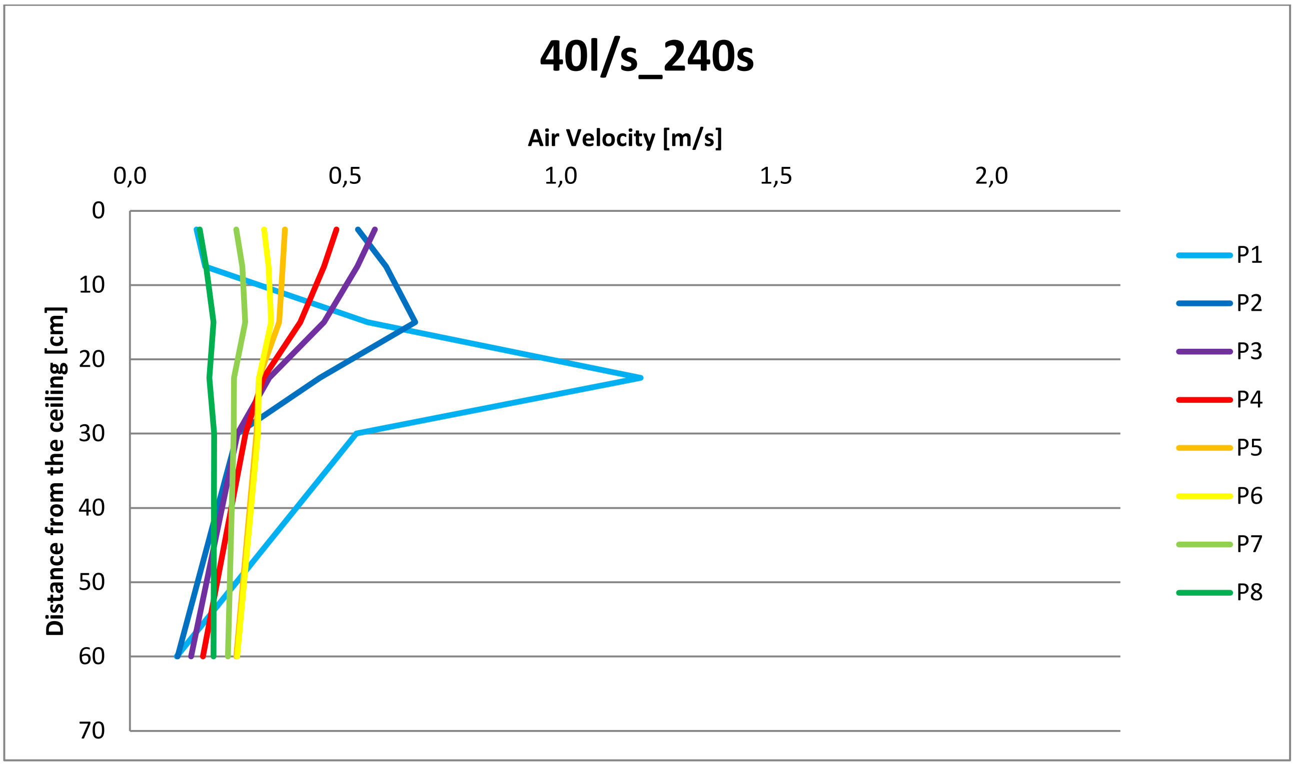


Figure 27

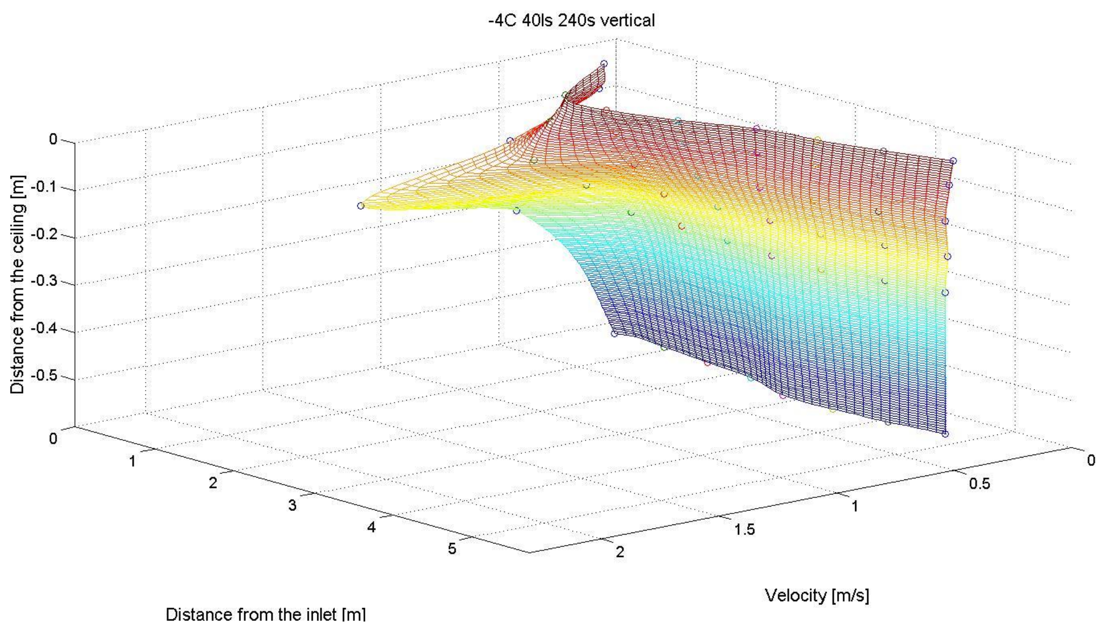


Figure 28

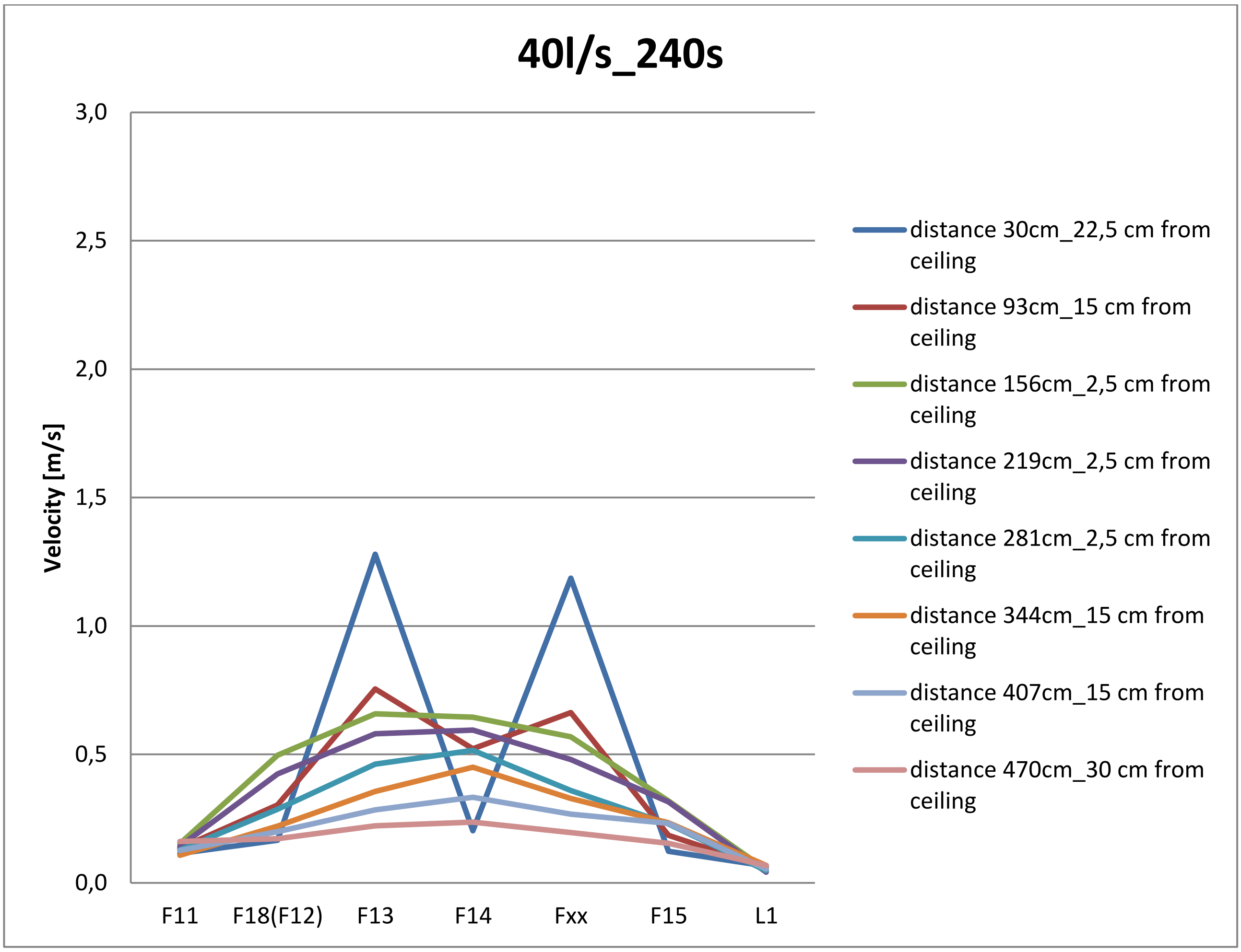


Figure 29

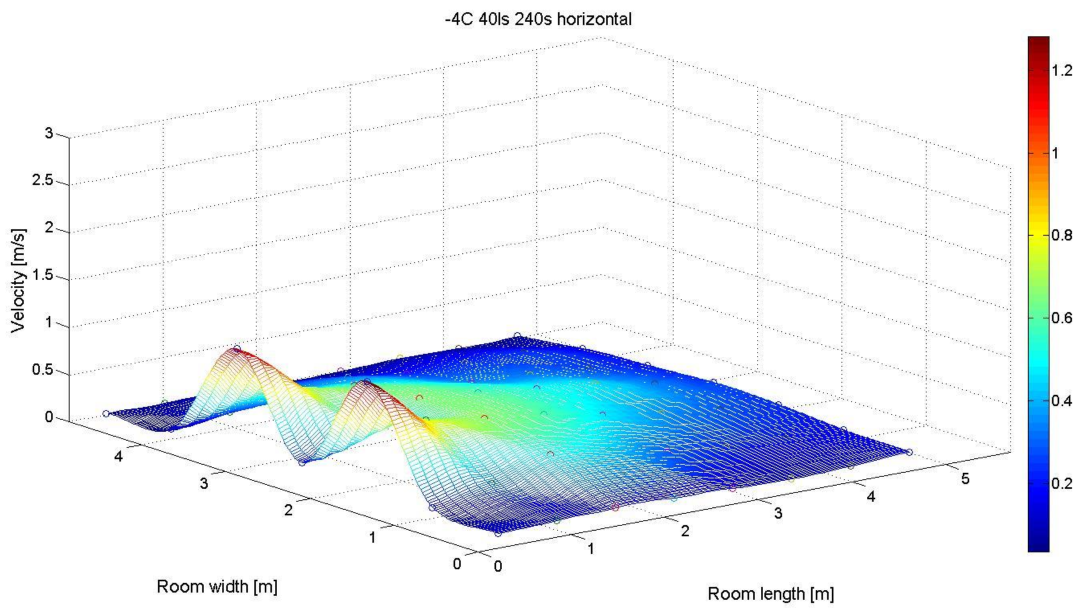
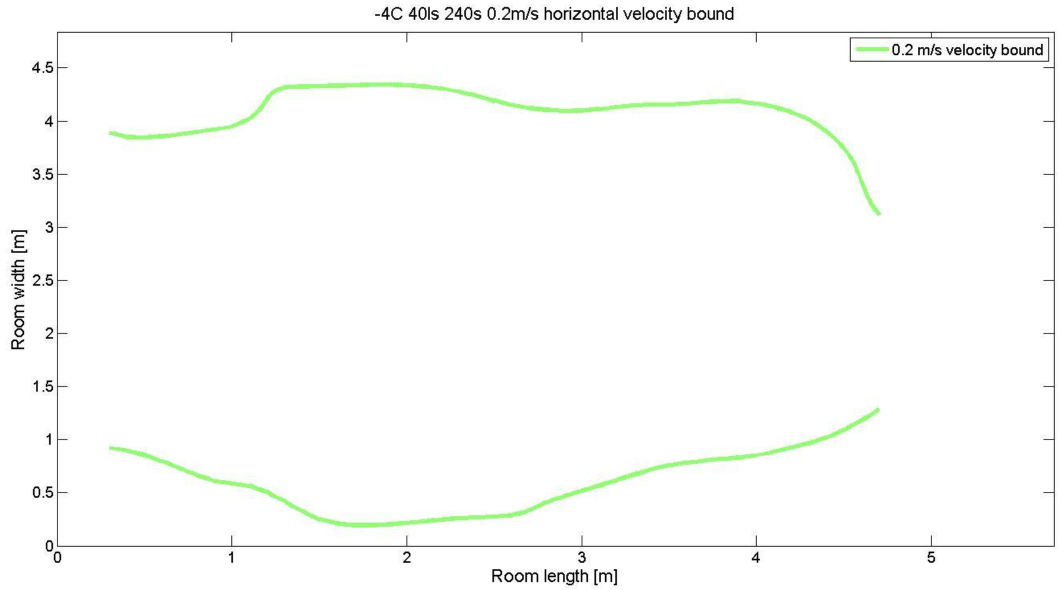


Figure 30



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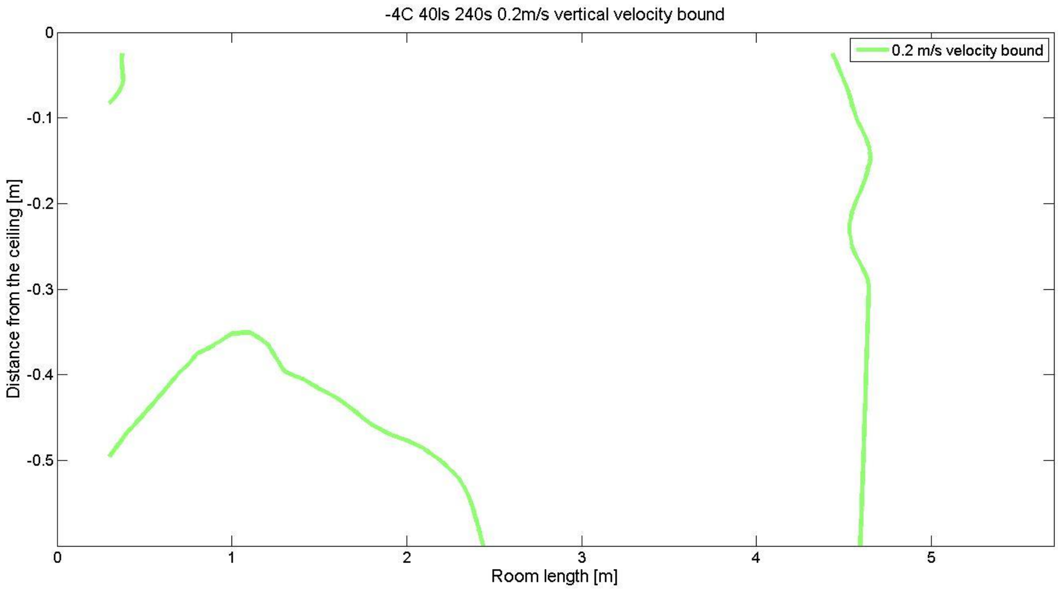


Figure 32

Dynamic representation of some chosen results

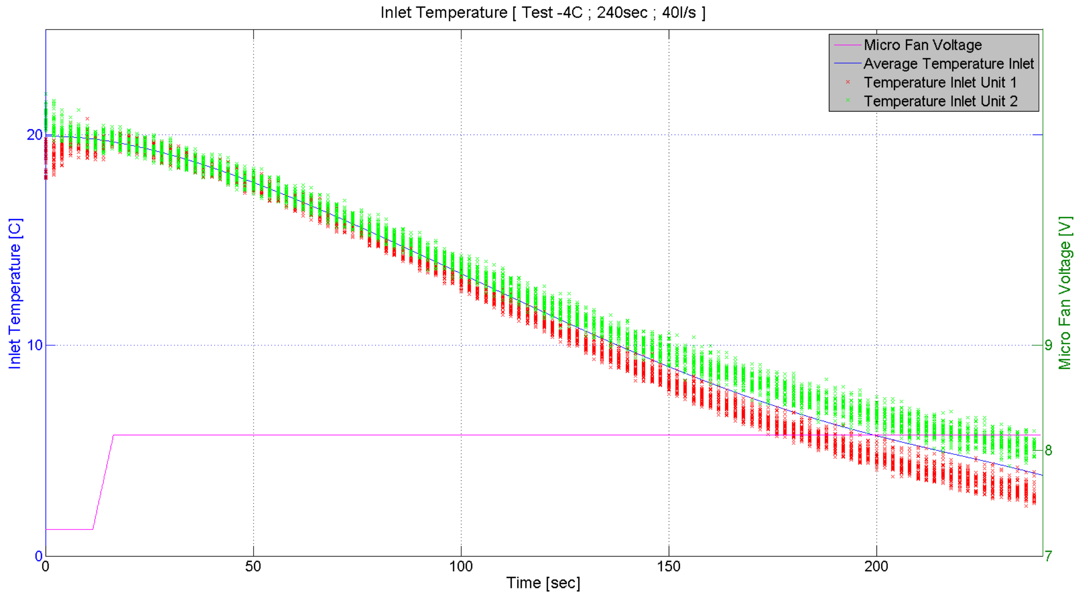


Figure 33

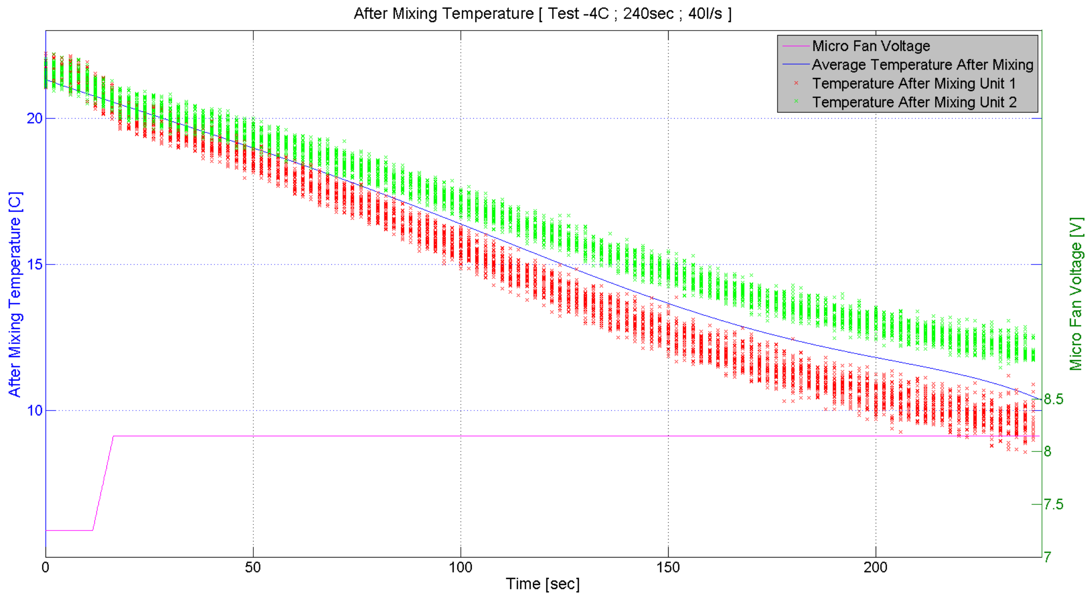


Figure 34

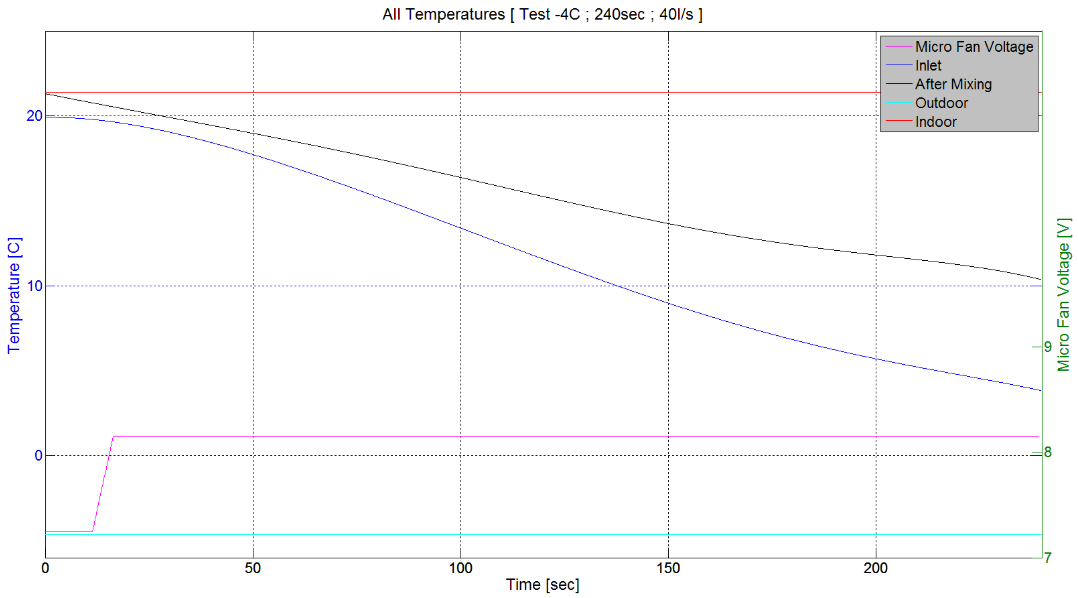


Figure 35

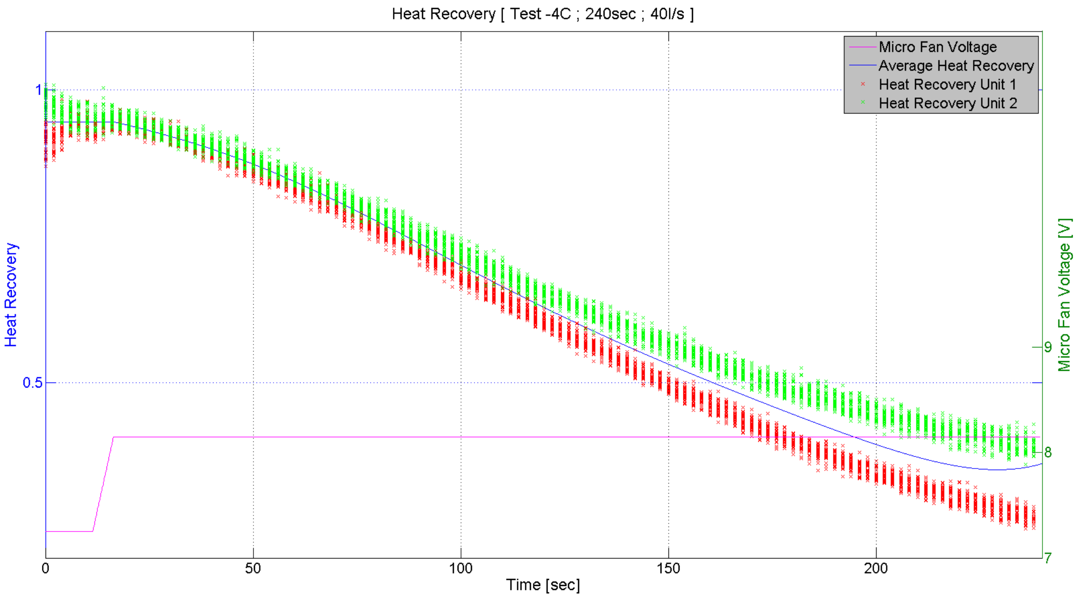
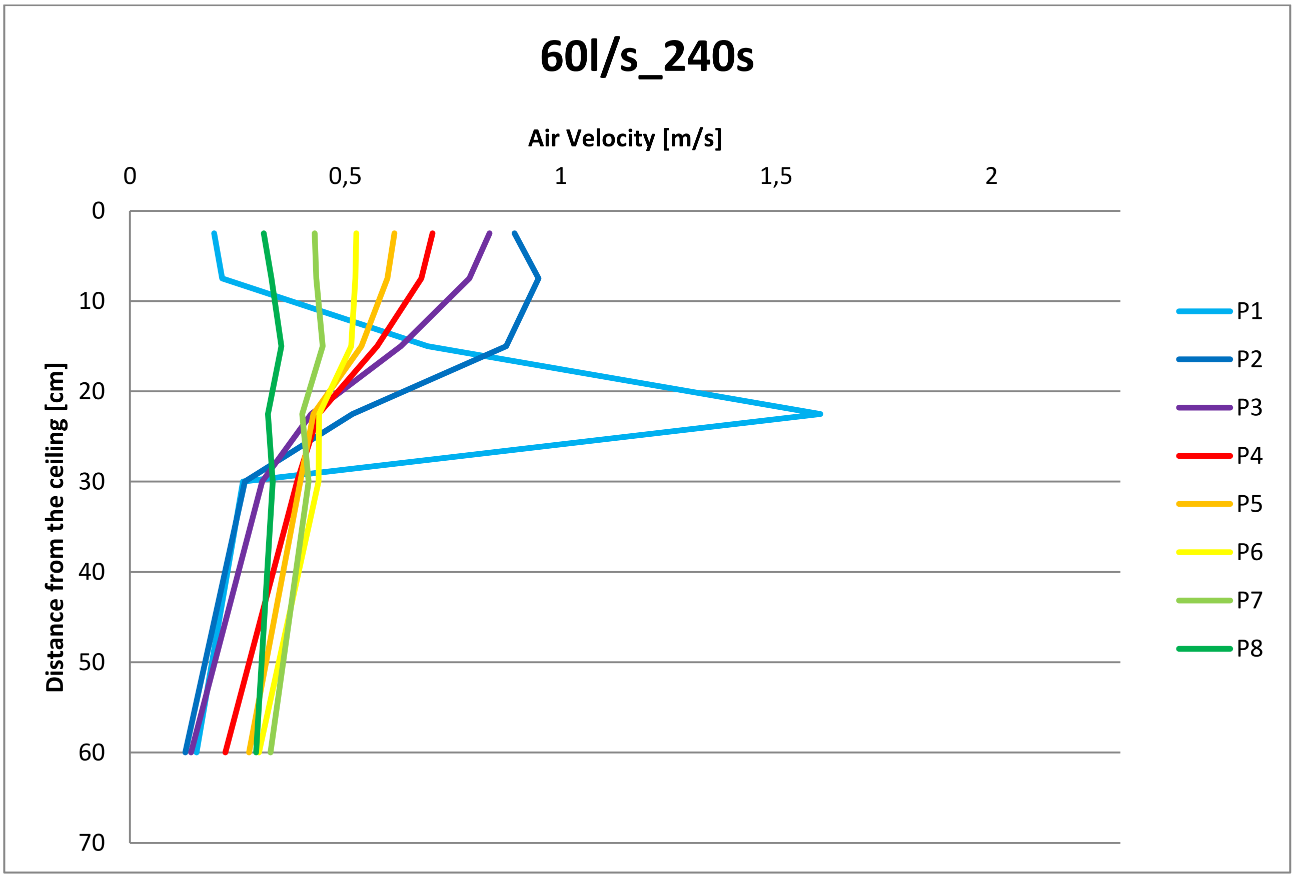


Figure 36

Test 03 (-4C 60l/s 240sec)

Average Outdoor Temperature	-5,11 °C

Average Indoor Temperature	**21,66 °C**
Average Inlet Supply Temperature	**15,69 °C**
Average after Mixing Fans Temperature	**19,31 °C**
Average Combined Units Heat Recovery	**0,62**



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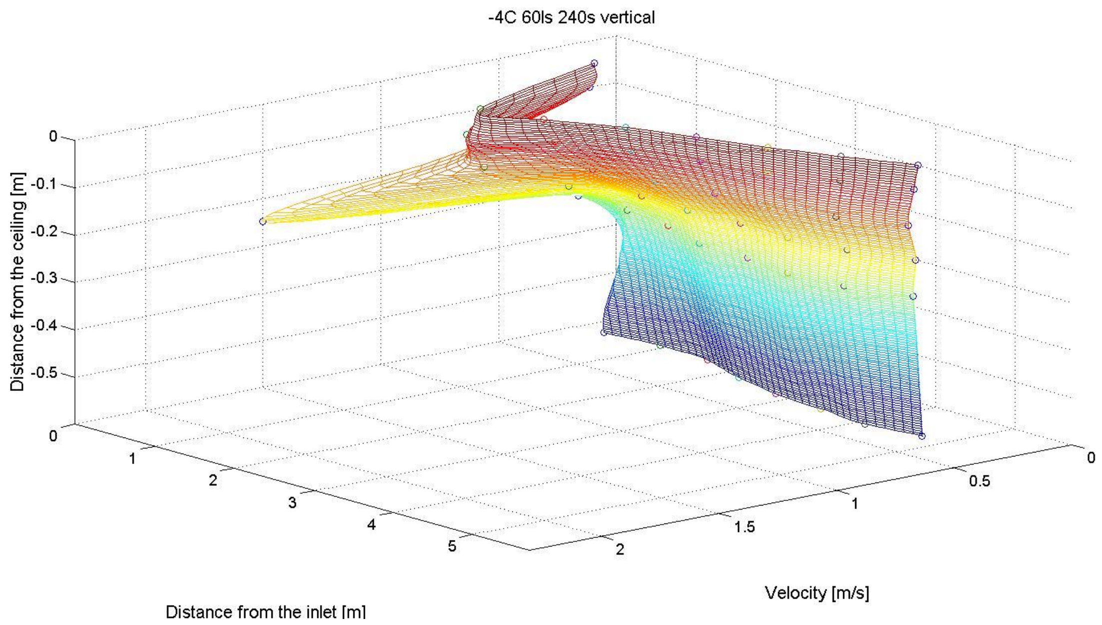

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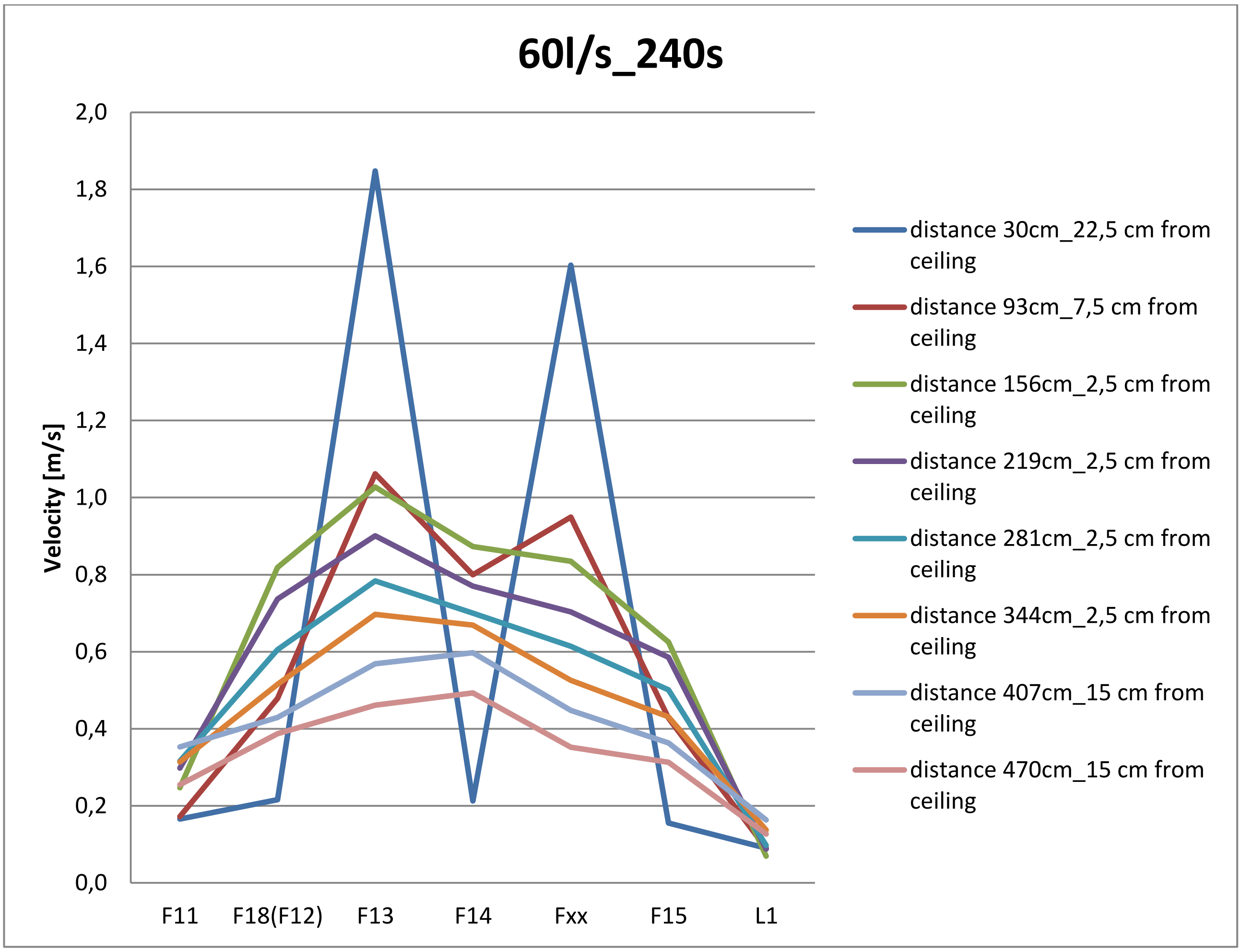
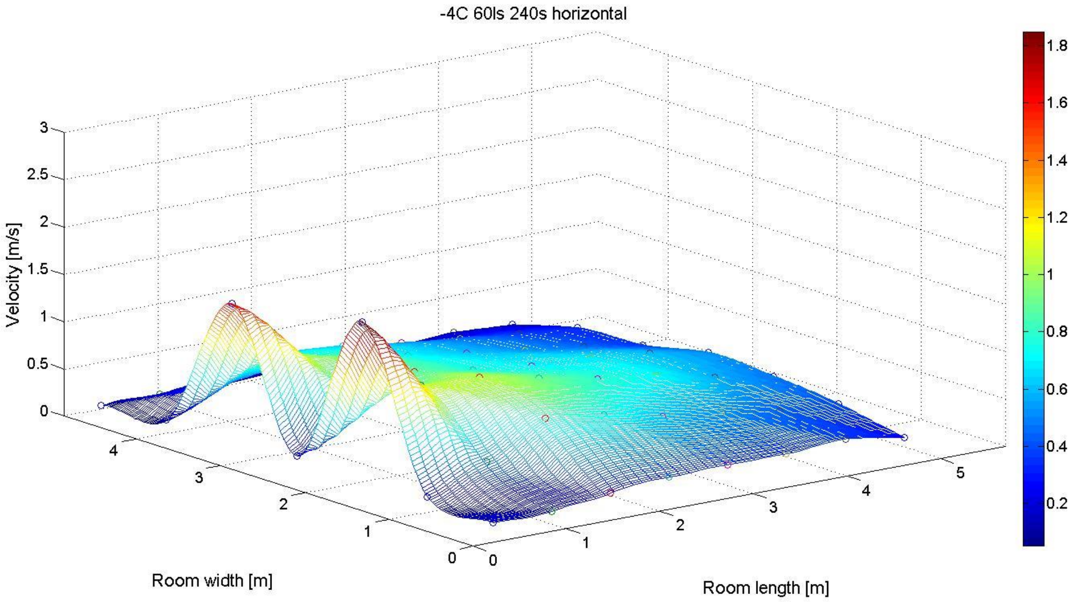


Figure 39



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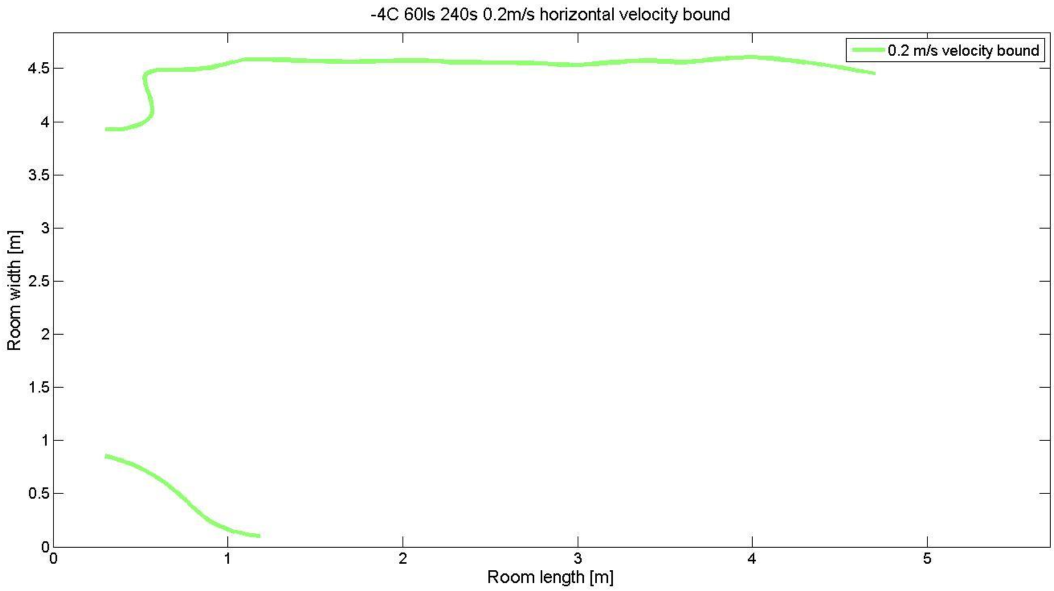


Figure 41

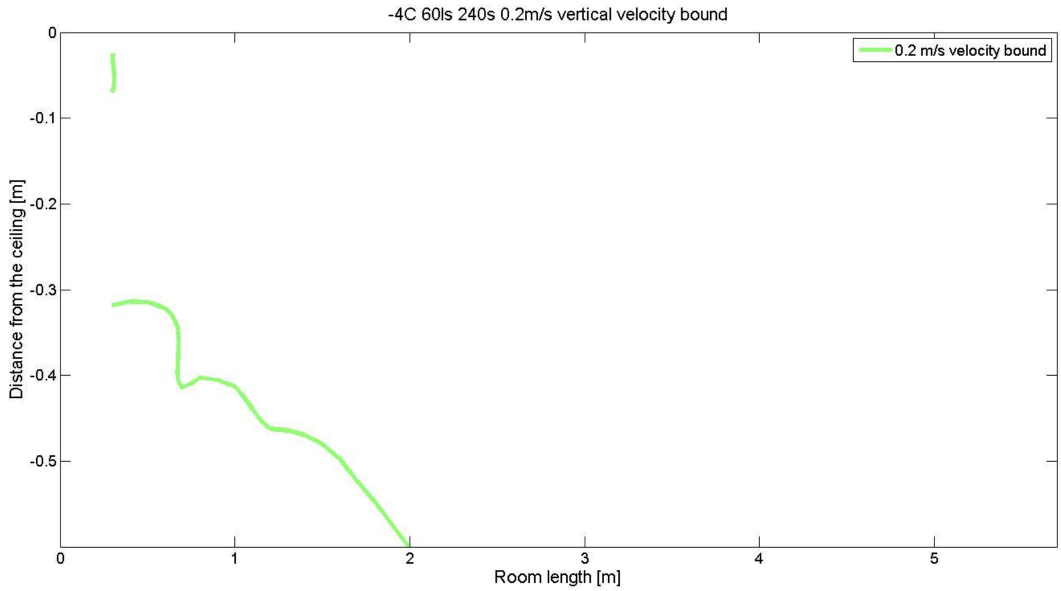


Figure 42

Dynamic representation of some chosen results

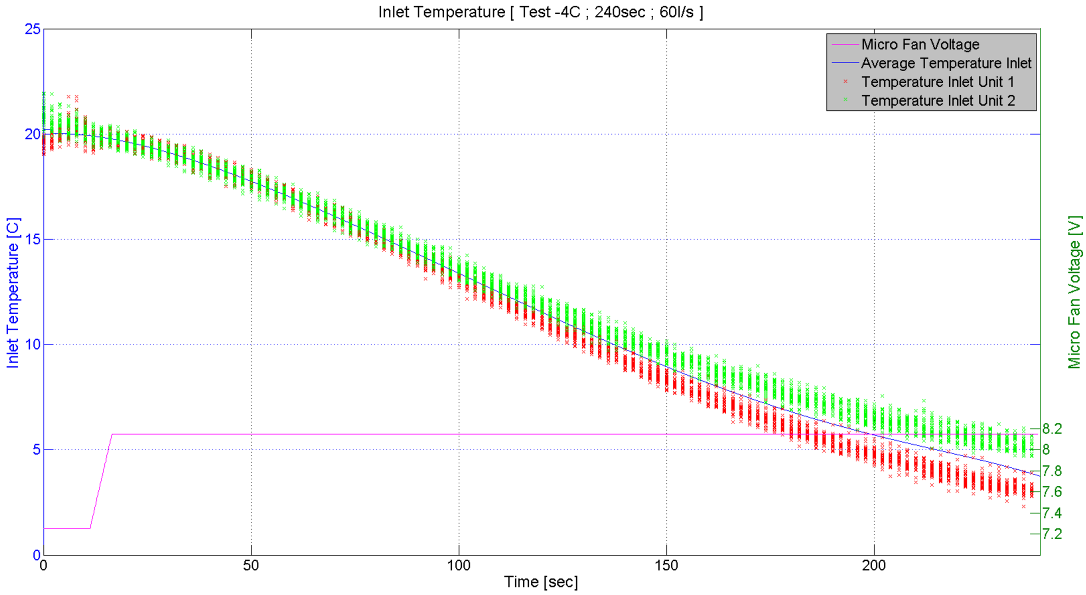


Figure 43

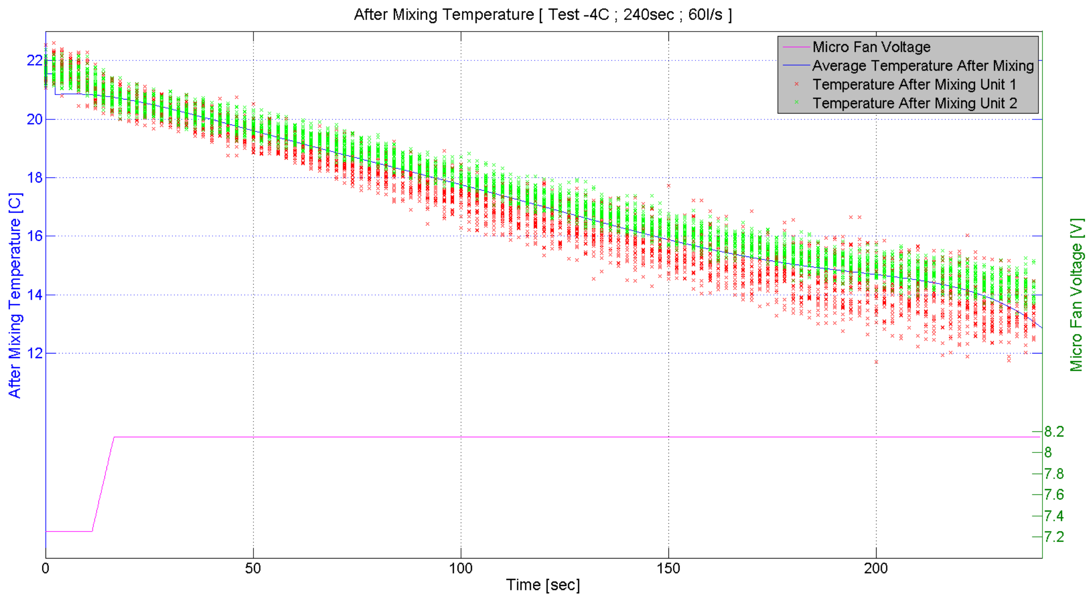


Figure 44

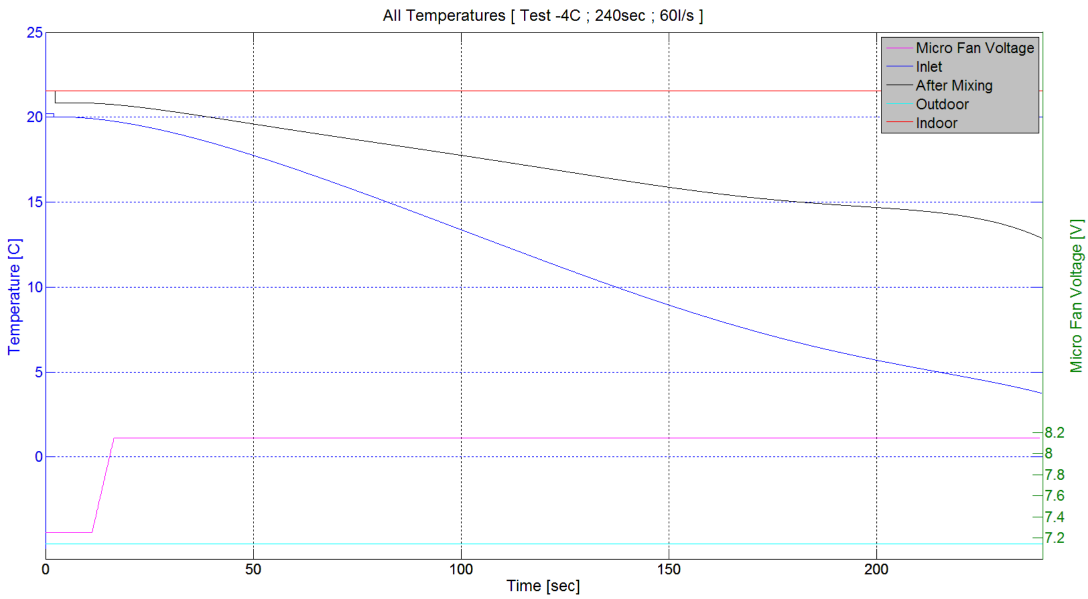


Figure 45

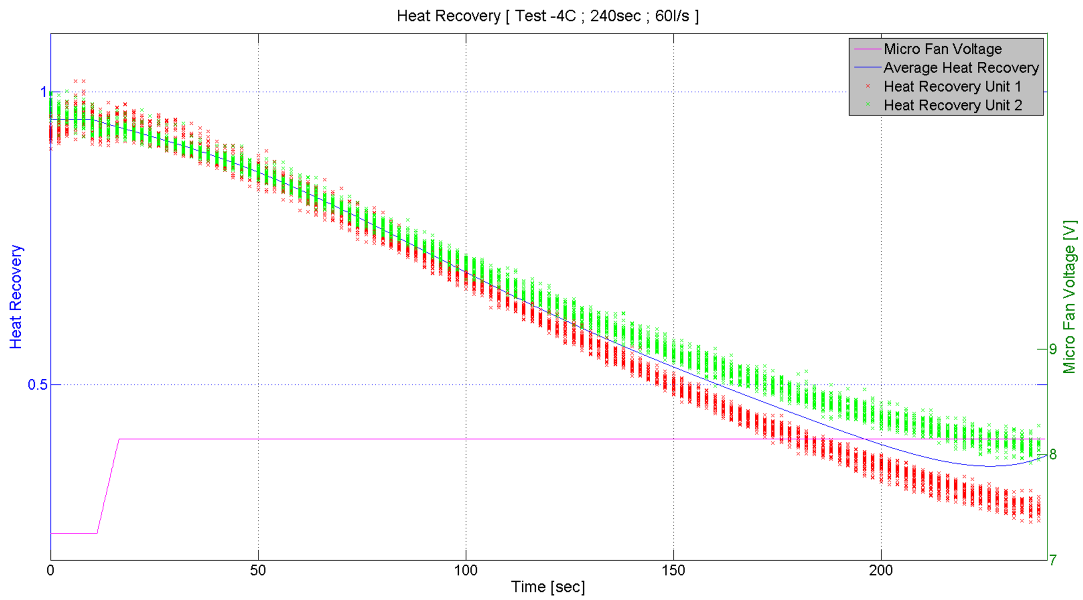


Figure 46

Test 04 (-4C 20l/s 360sec)

Average Outdoor Temperature	**- 4,64 °C**
Average Indoor Temperature	**21,71 °C**
Average Inlet Supply Temperature	**13,49 °C**
Average after Mixing Fans Temperature	**15,20 °C**
Average Combined Units Heat Recovery	**0,51**

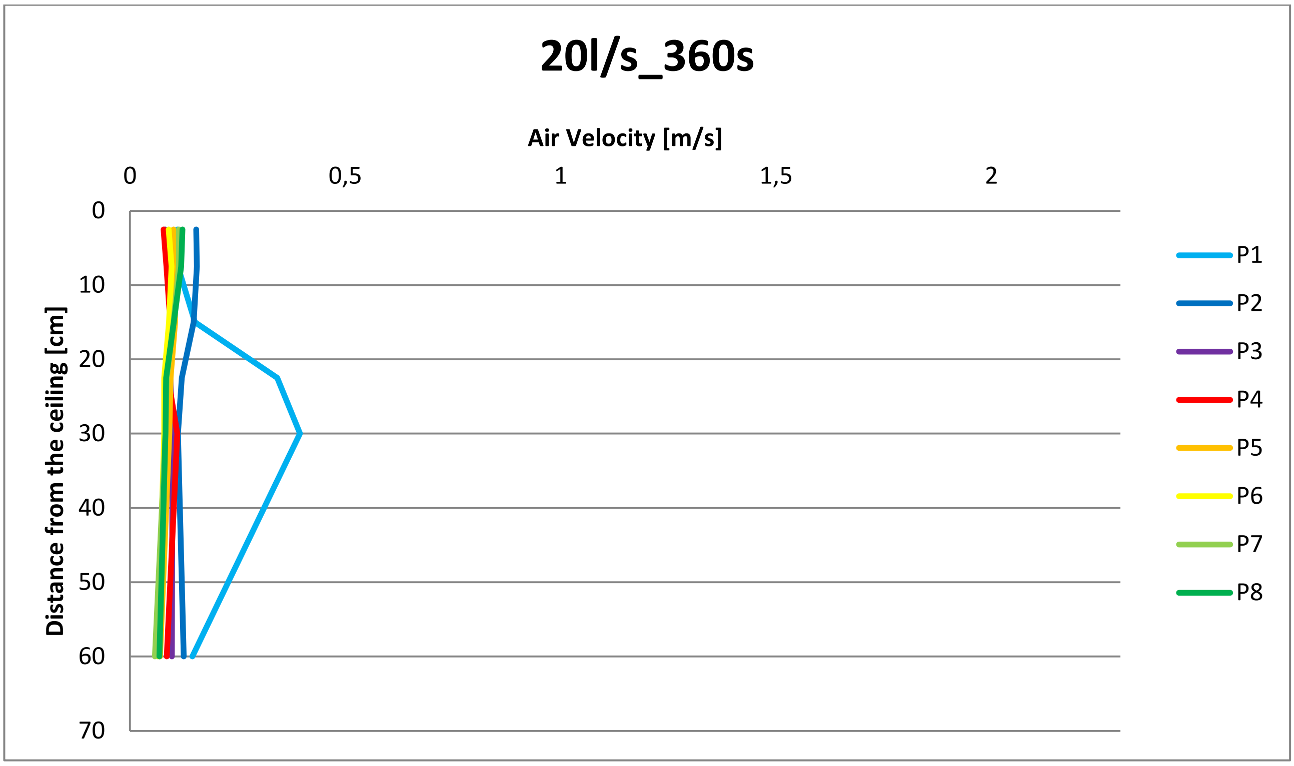


Figure 47

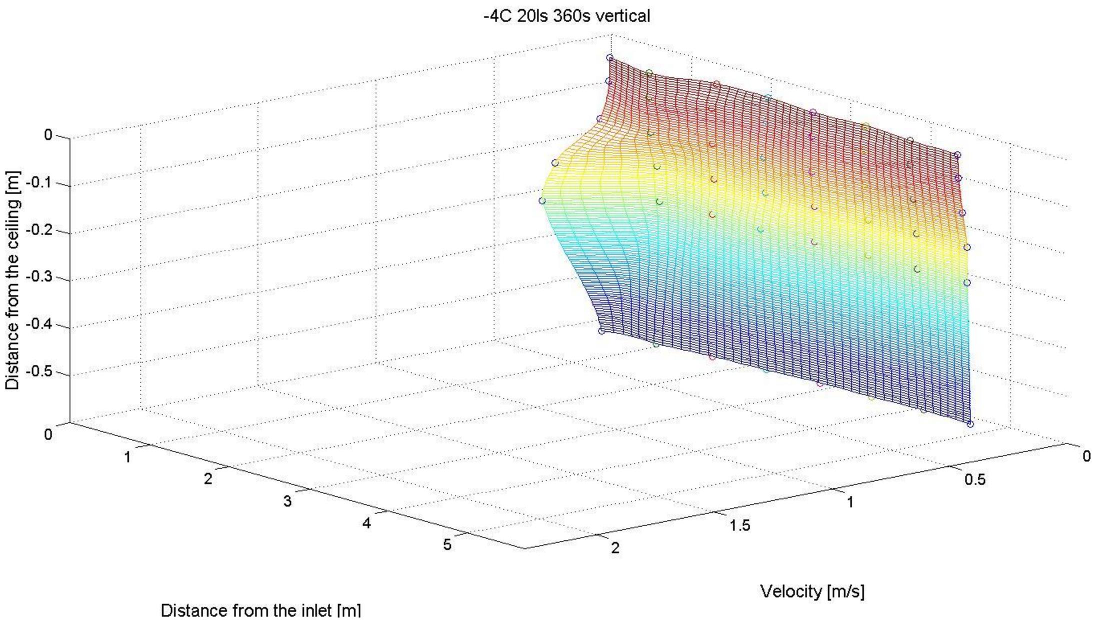


Figure 48

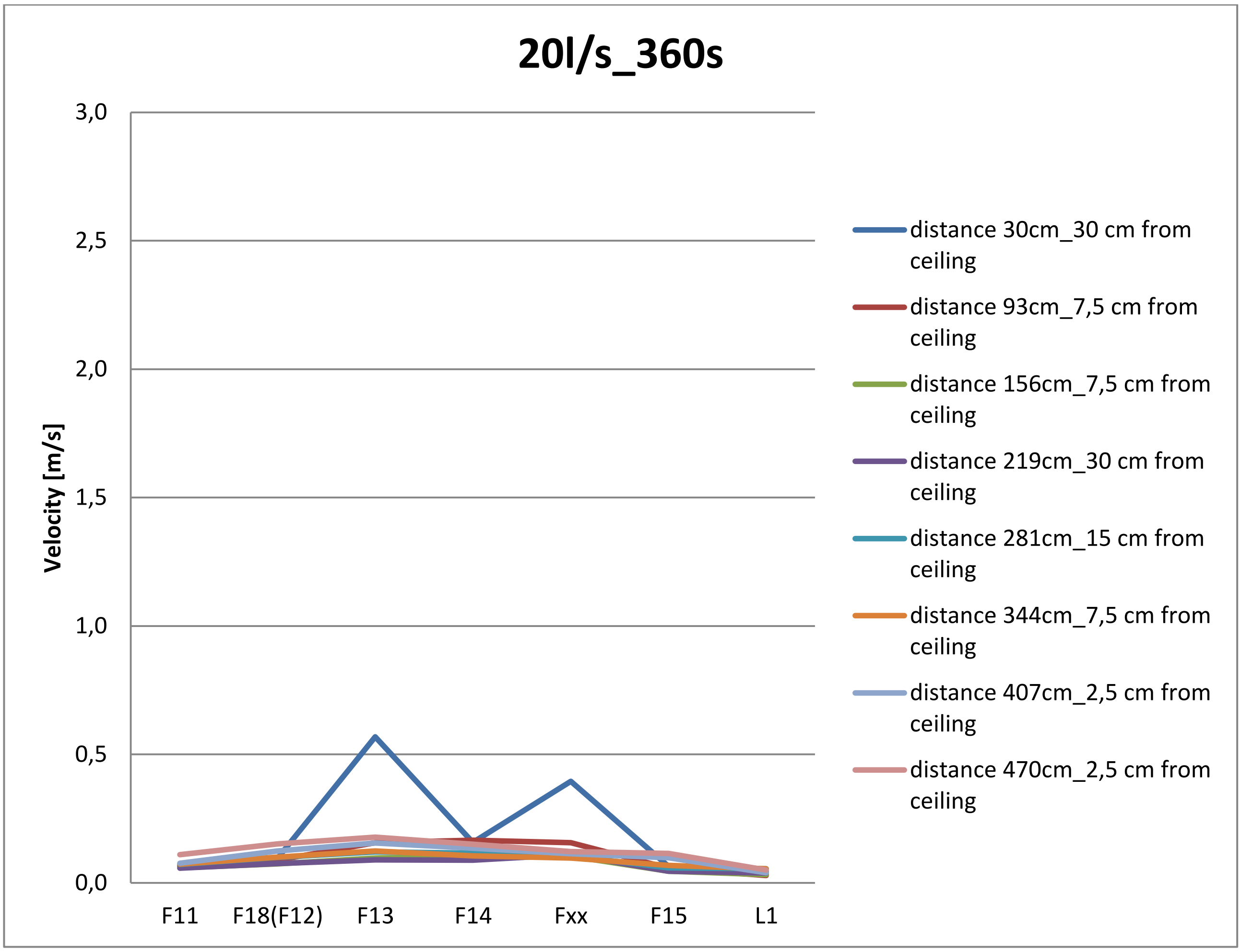


Figure 49

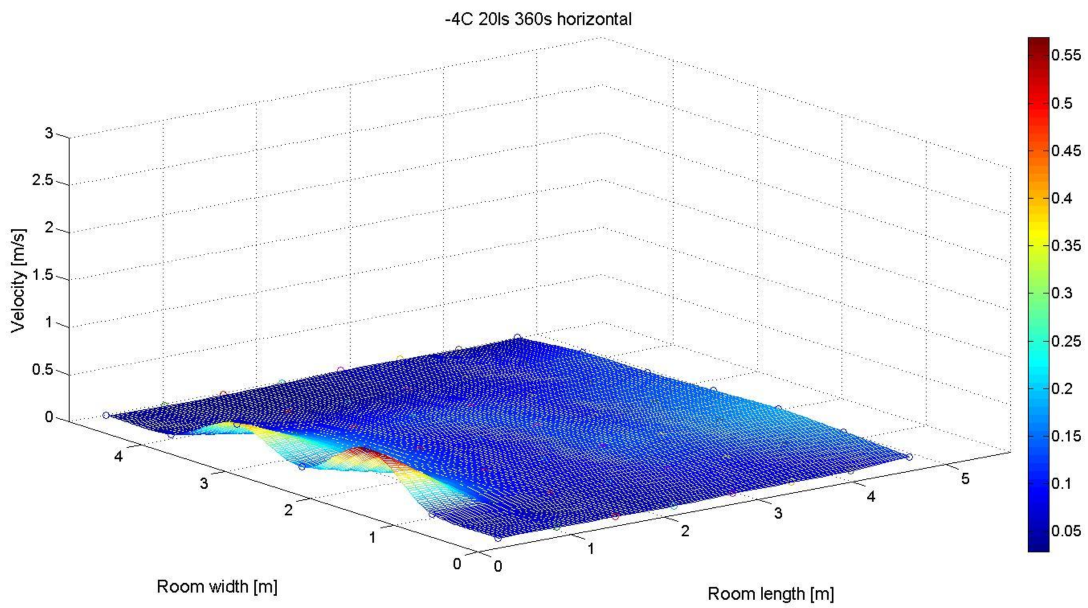


Figure 50

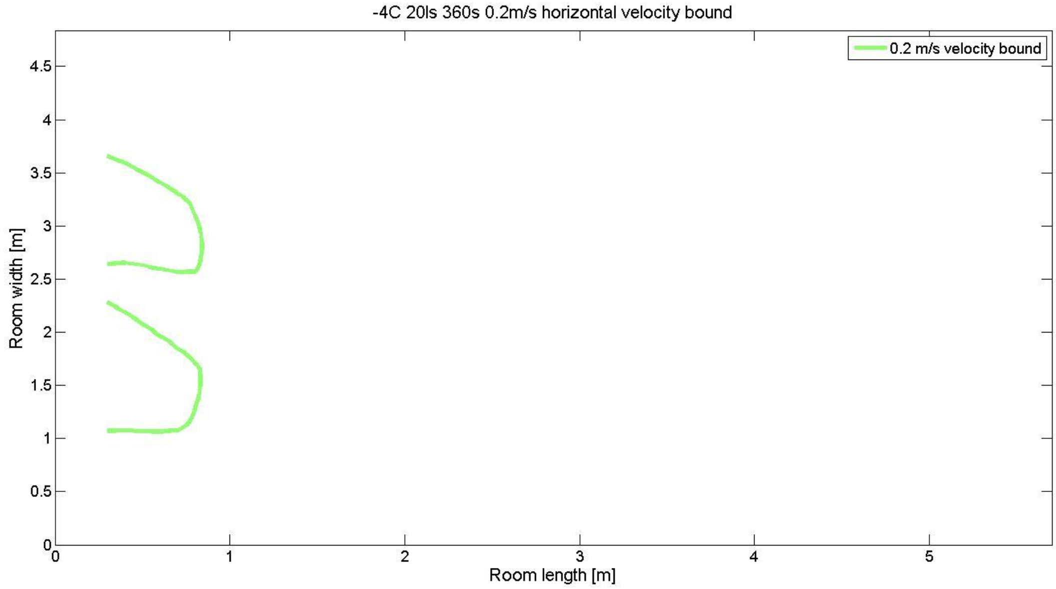


Figure 51

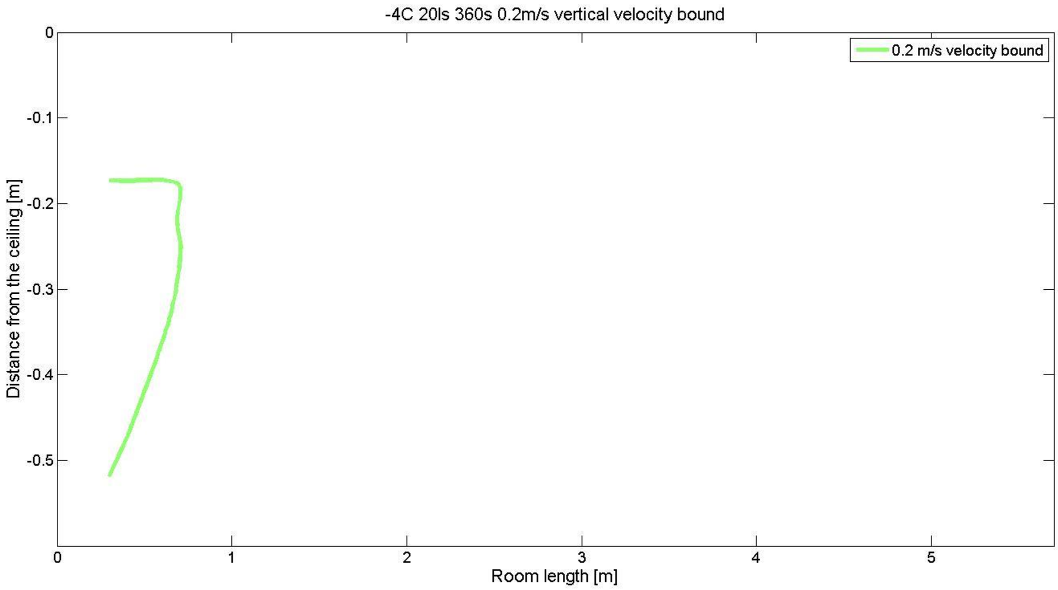


Figure 52

Dynamic representation of some chosen results

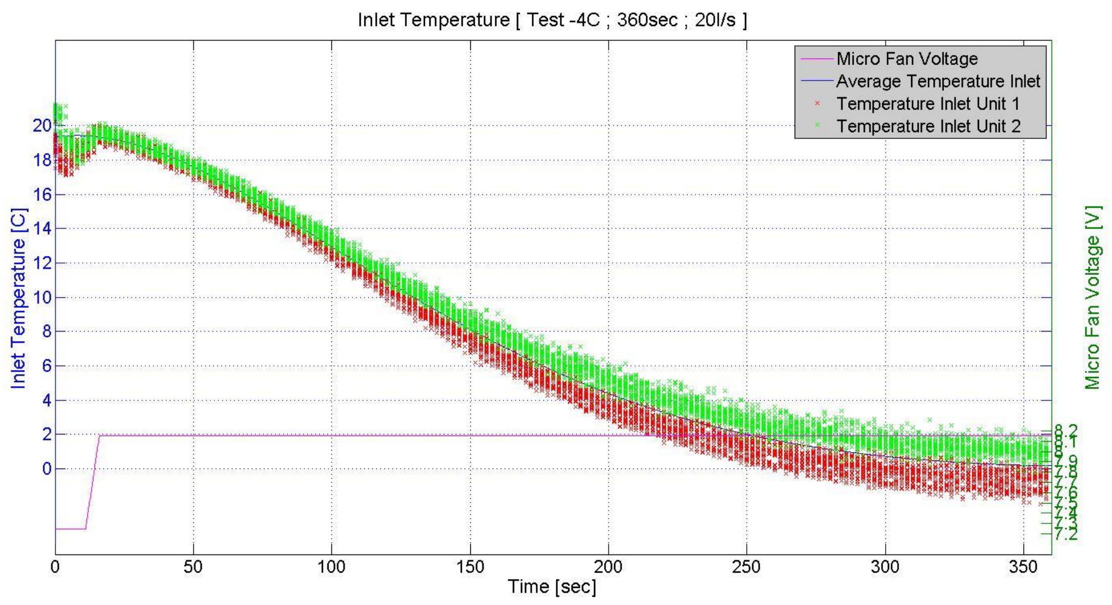


Figure 53

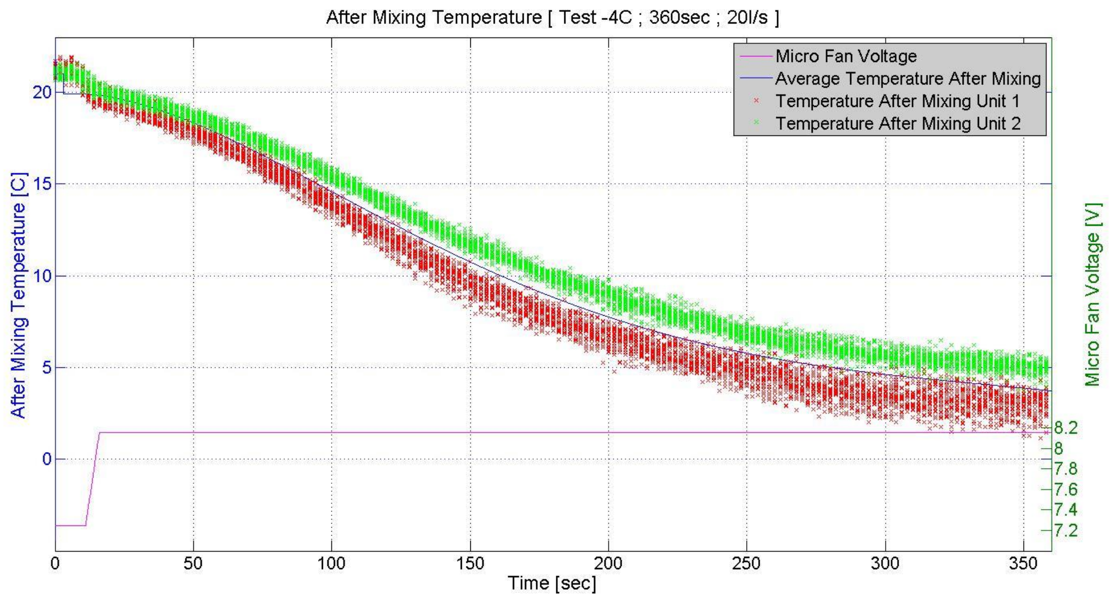


Figure 54

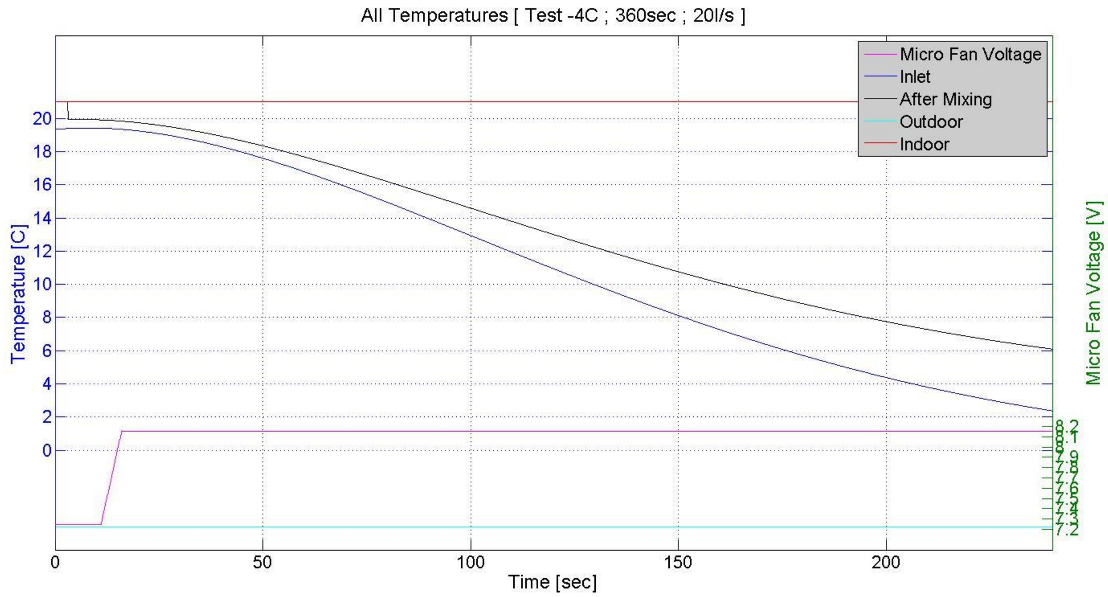


Figure 55

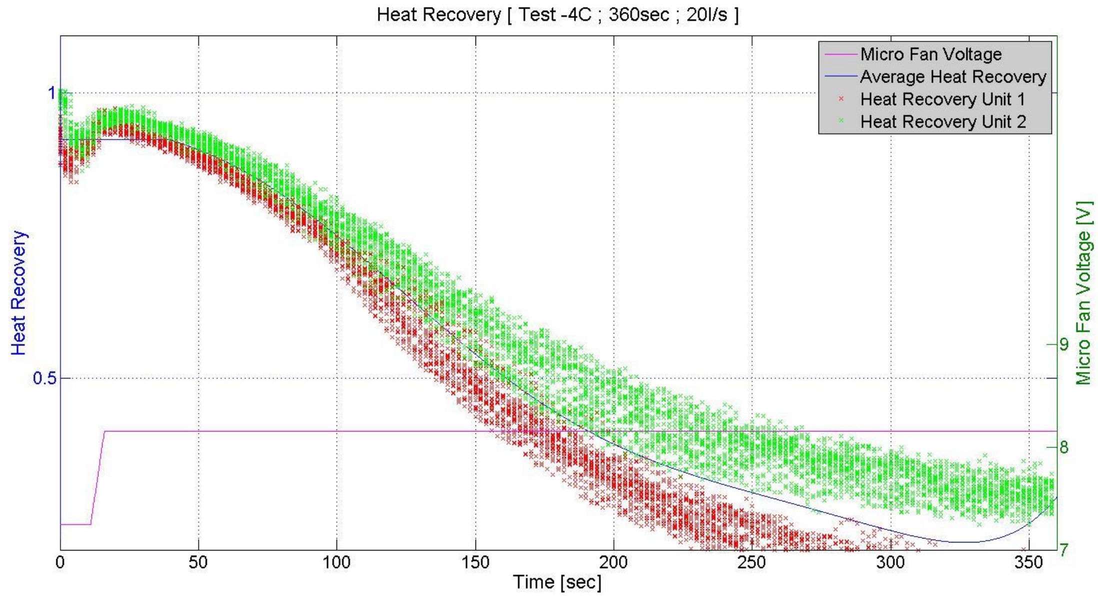


Figure 56

Test 04 (-4C 40l/s 360sec)

Average Outdoor Temperature	**-5,63 °C**
Average Indoor Temperature	**21,53 °C**
Average Inlet Supply Temperature	**14,27 °C**

Average after Mixing Fans Temperature	17,50 °C
Average Combined Units Heat Recovery	0,54

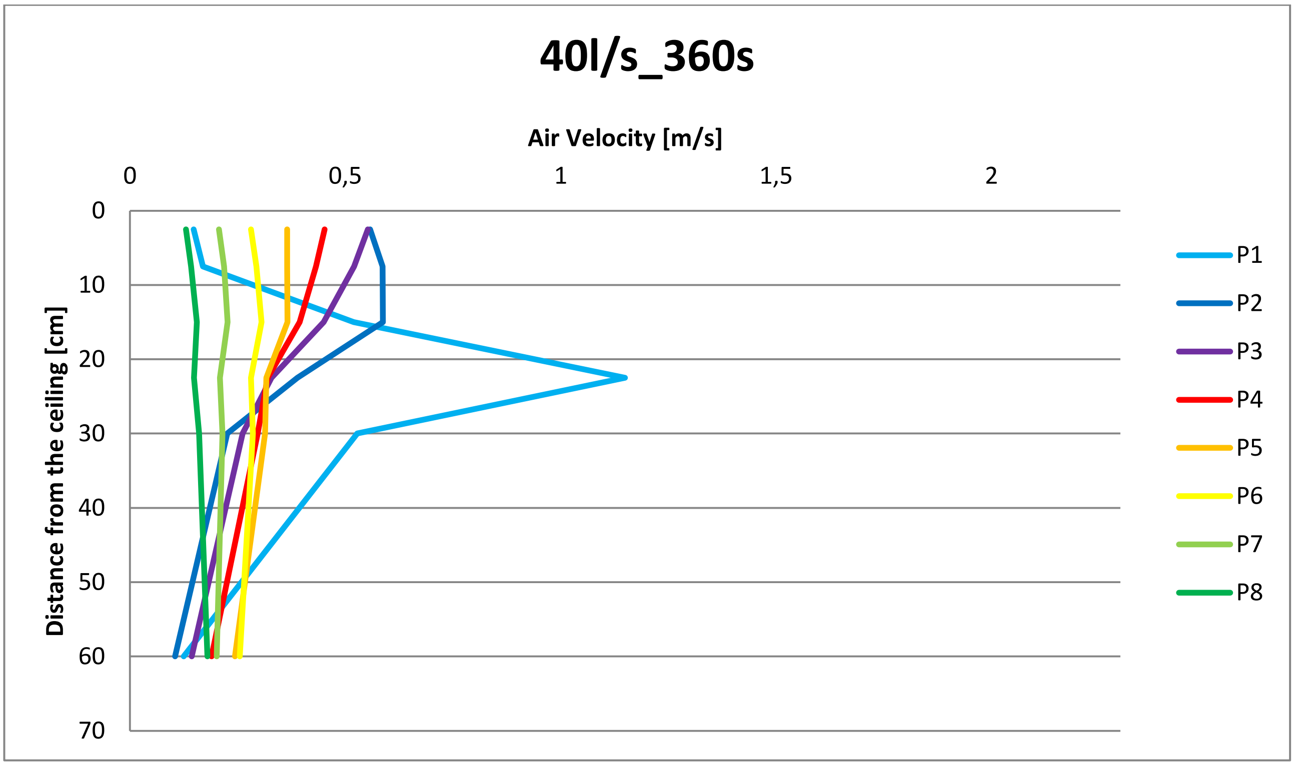


Figure 57

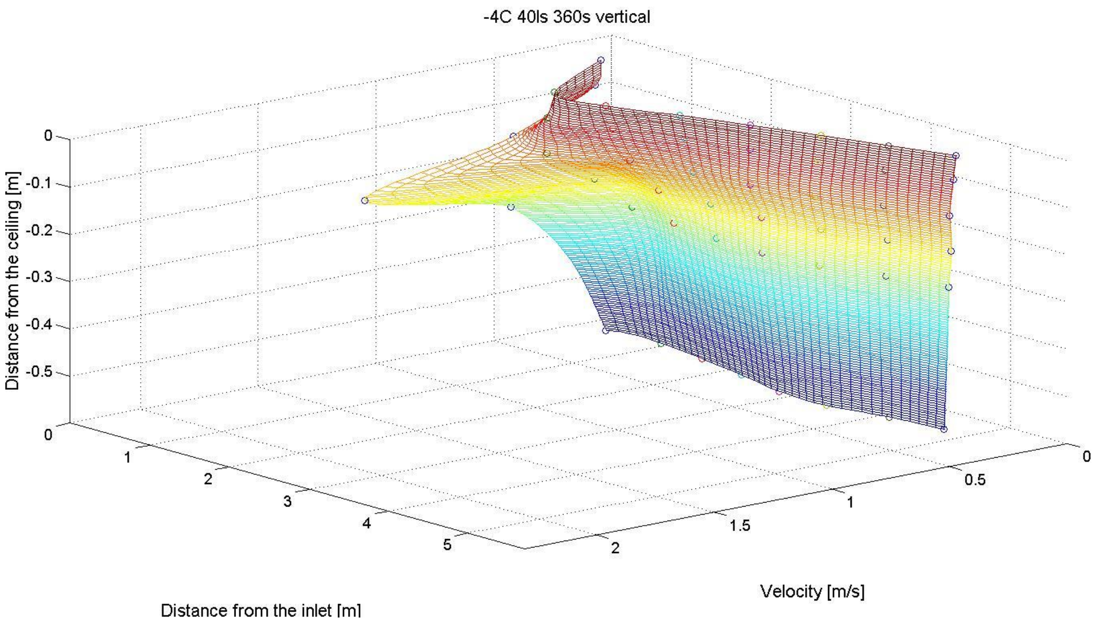
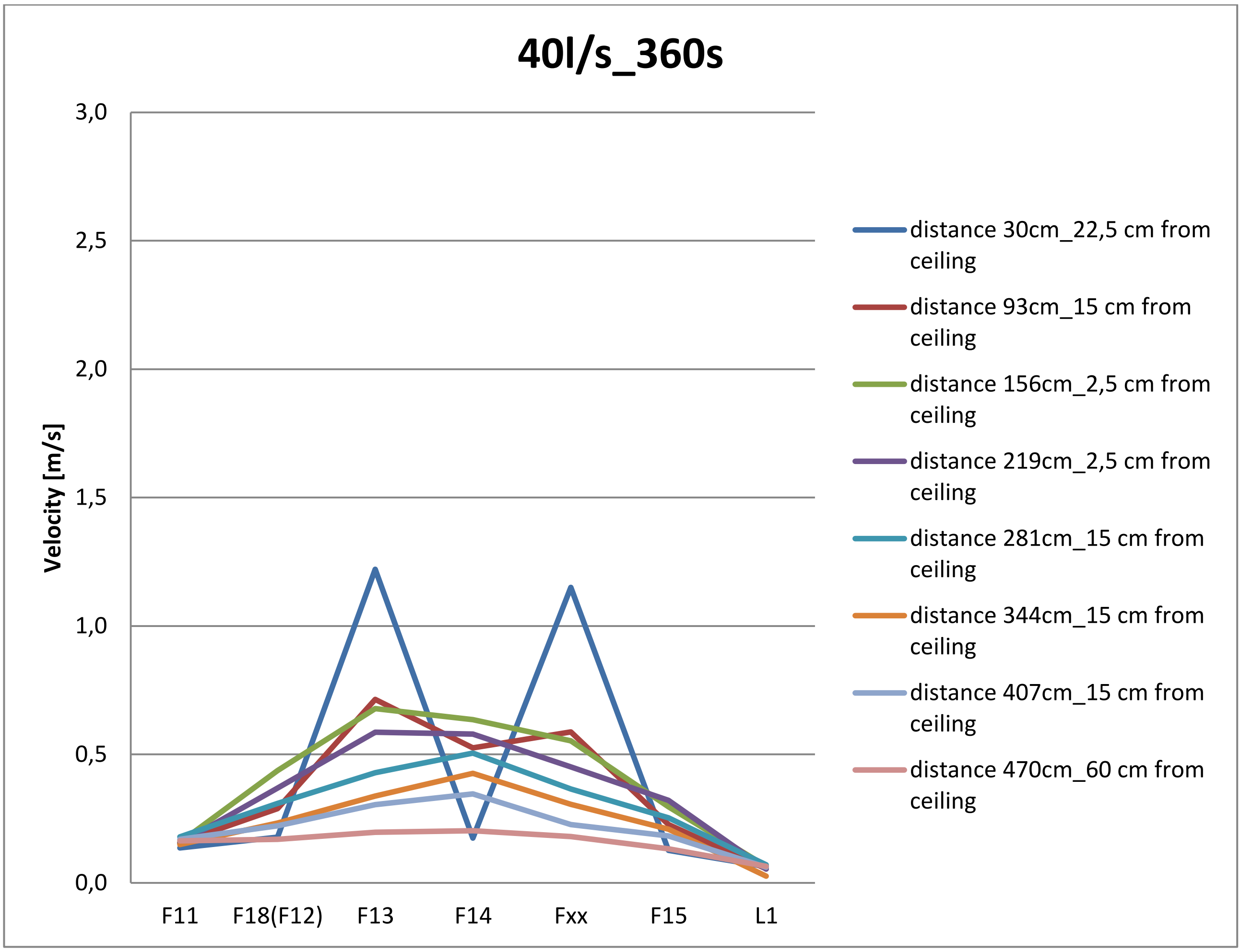


Figure 58



40l/s_360s
3,0
2,5
2,0
1,5
1,0
0,5
0,0
Velocity [m/s]
F11
F18(F12)
F13
F14
Fxx
F15
L1
distance 30cm_22,5 cm from ceiling
distance 93cm_15 cm from ceiling
distance 156cm_2,5 cm from ceiling
distance 219cm_2,5 cm from ceiling
distance 281cm_15 cm from ceiling
distance 344cm_15 cm from ceiling
distance 407cm_15 cm from ceiling
distance 470cm_60 cm from ceiling

Figure 59

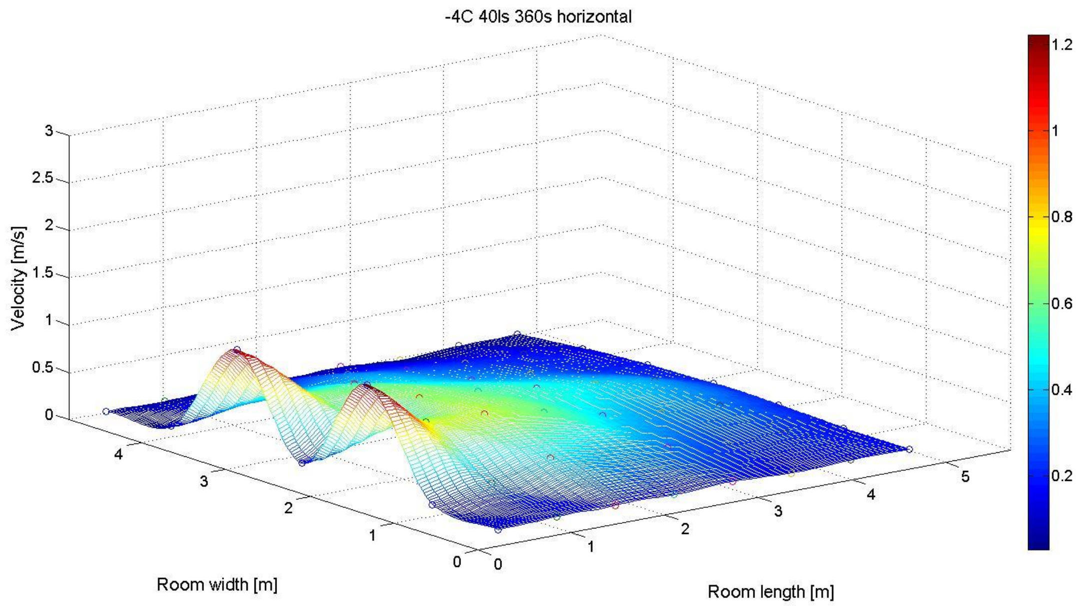


Figure 60

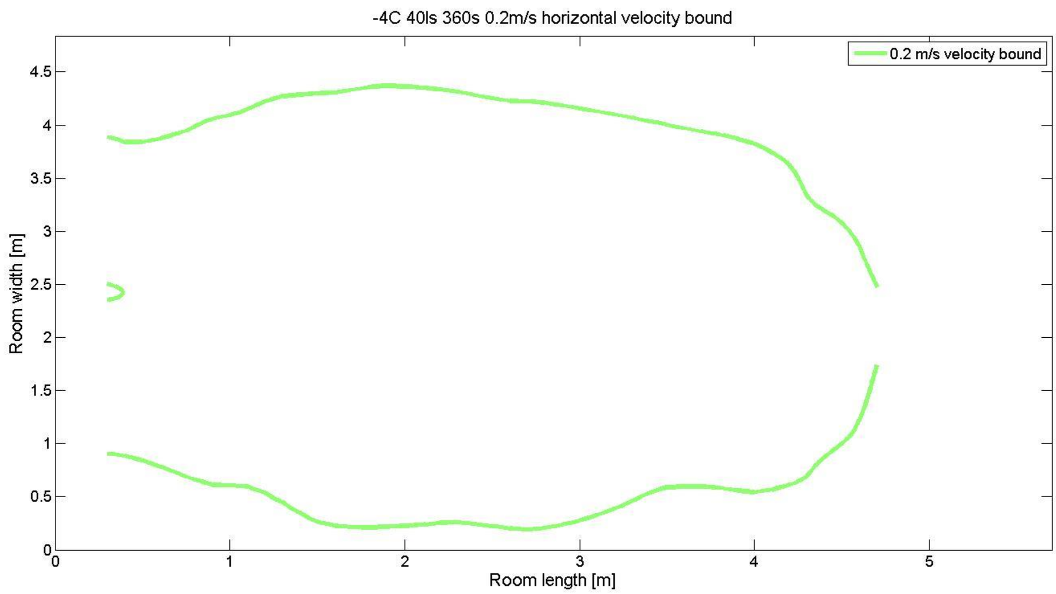


Figure 61

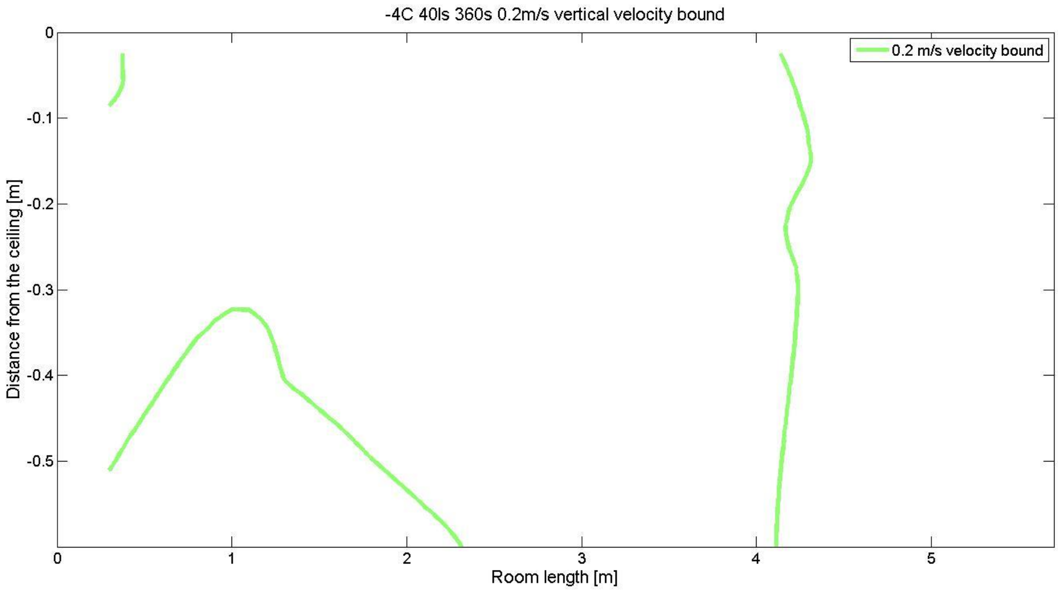


Figure 62

Dynamic representation of some chosen results

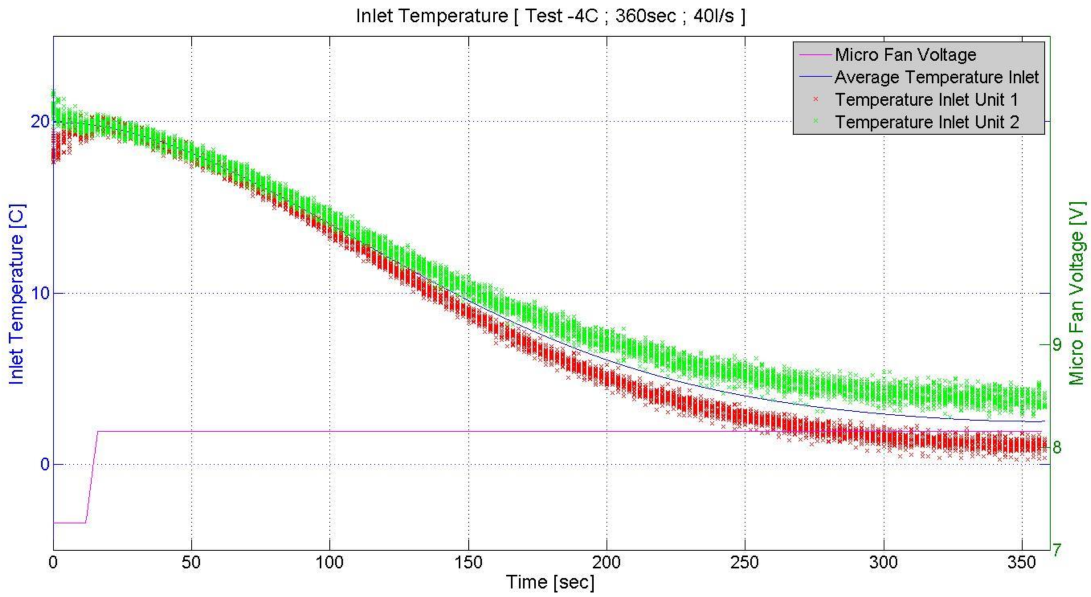


Figure 63

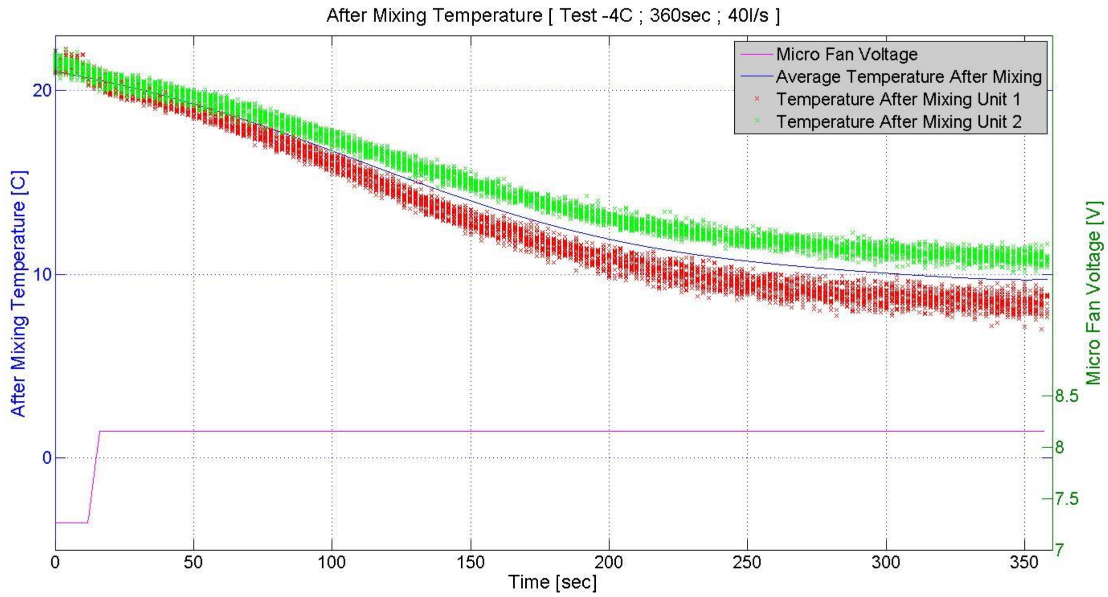


Figure 64

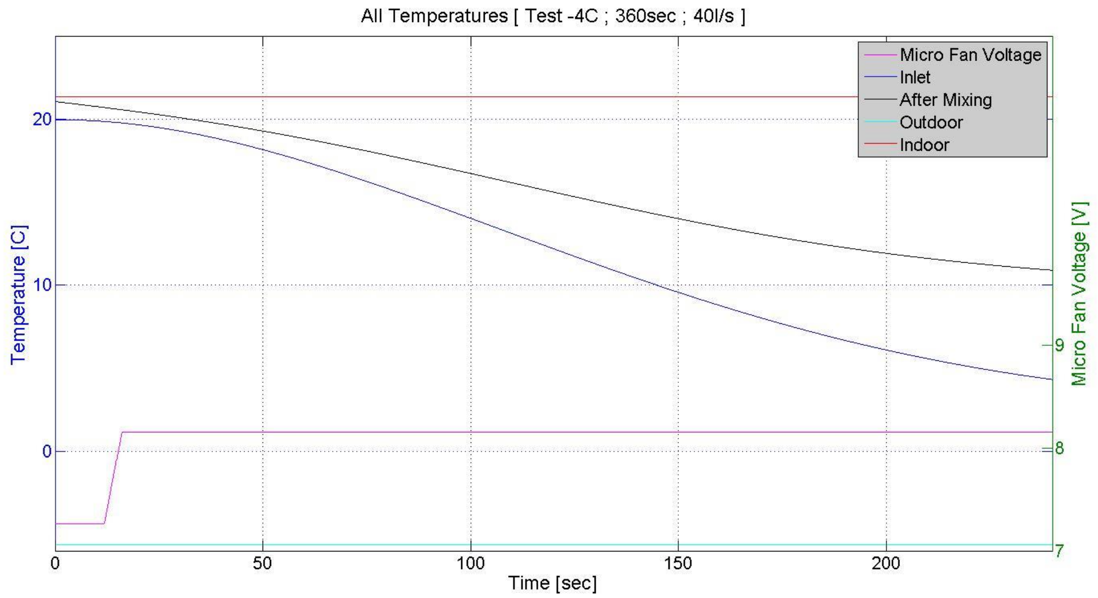


Figure 65

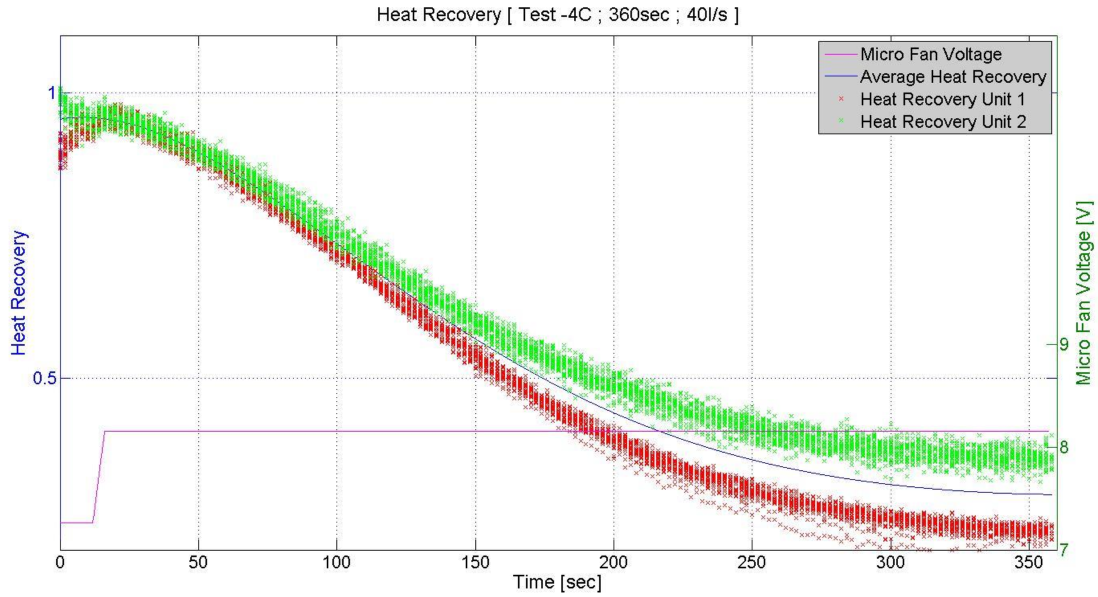


Figure 66

Test 04 (-4C 60l/s 360sec)

Average Outdoor Temperature	**-5,01 °C**
Average Indoor Temperature	**21,54 °C**
Average Inlet Supply Temperature	**14,05 °C**
Average after Mixing Fans Temperature	**18,63 °C**
Average Combined Units Heat Recovery	**0,51**

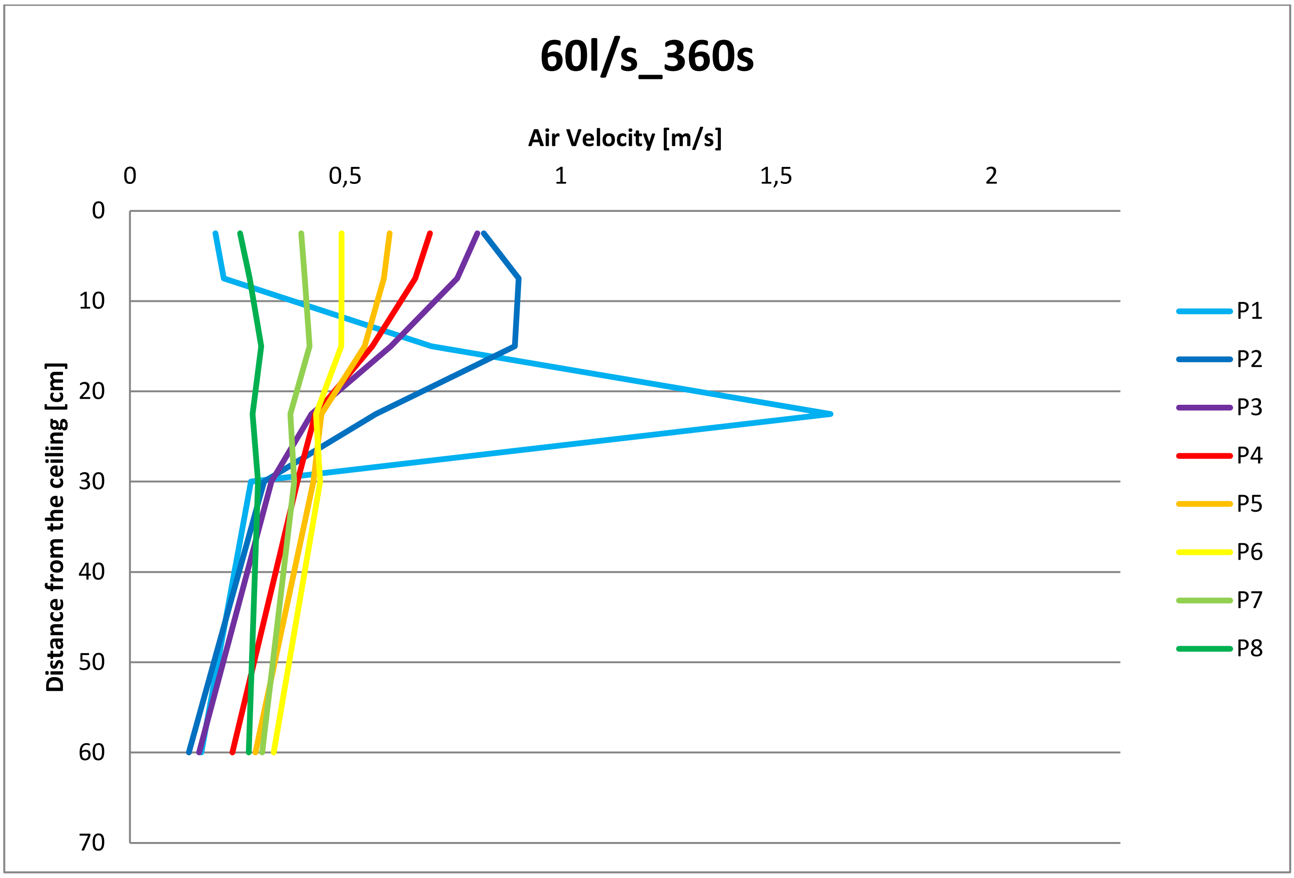


Figure 67

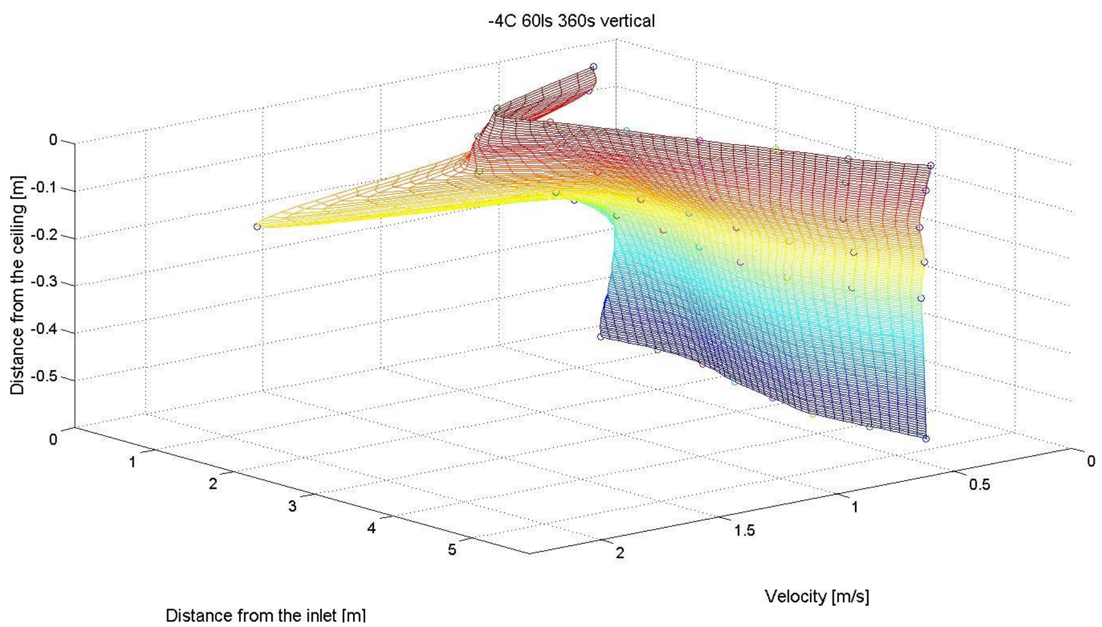


Figure 68

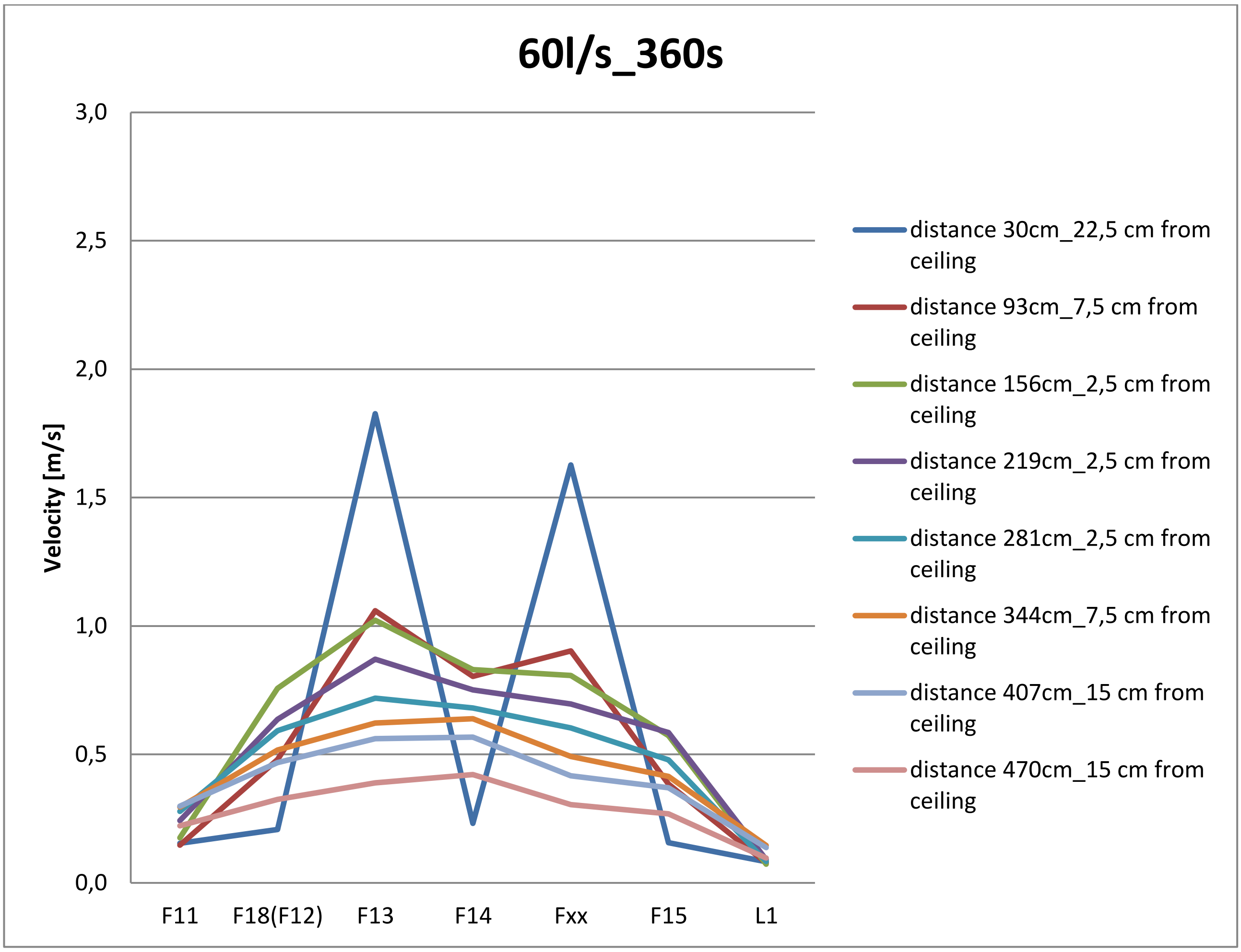


Figure 69

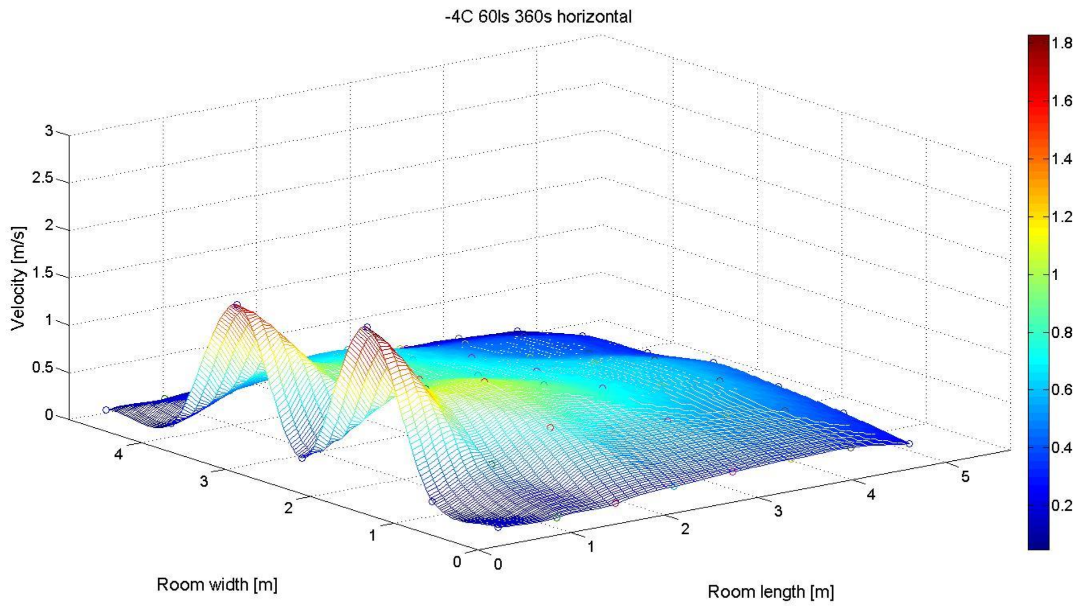


Figure 70

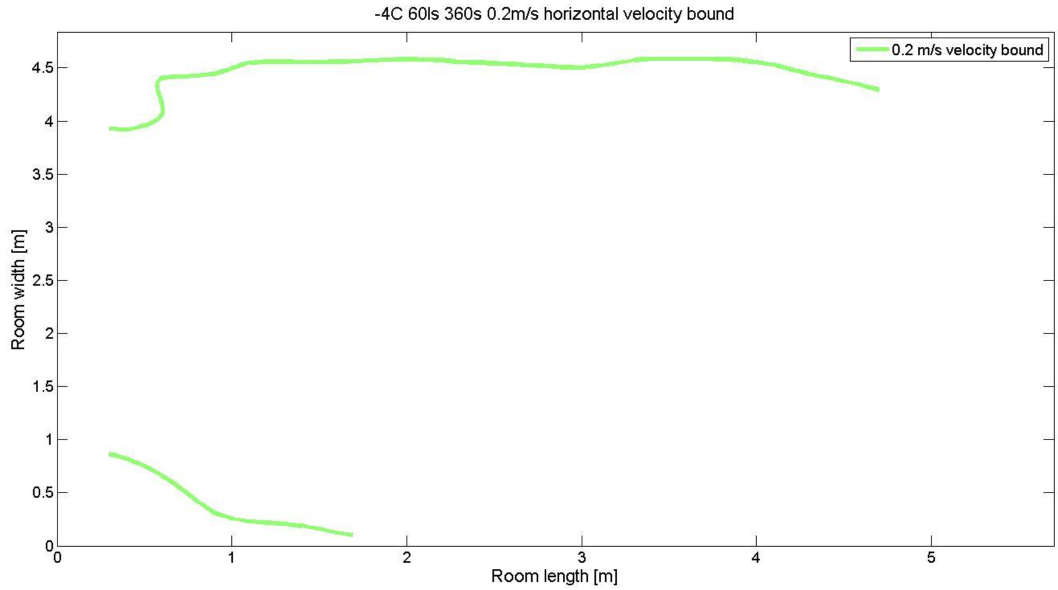


Figure 71

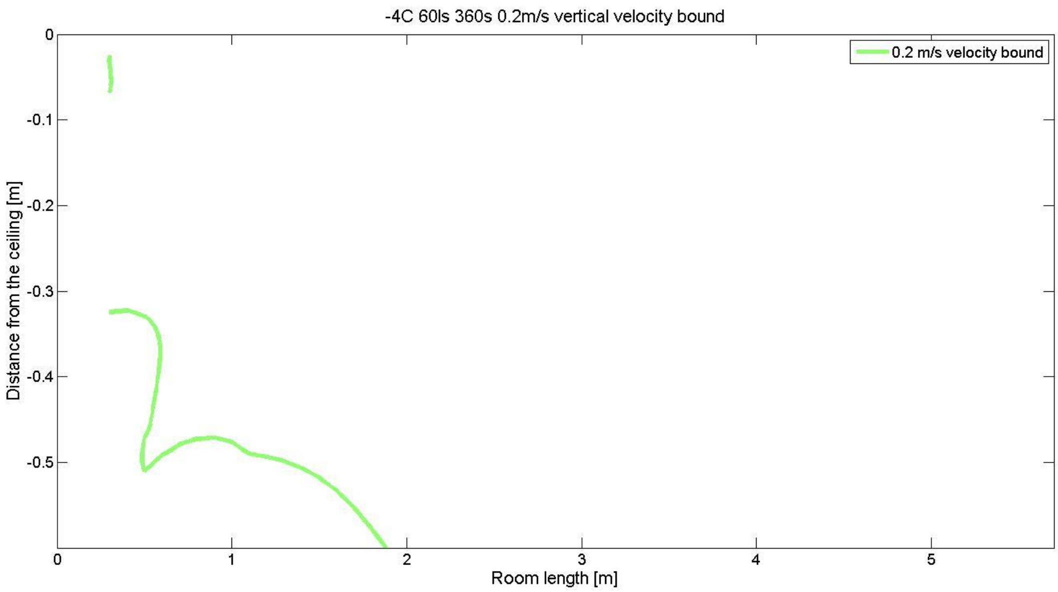


Figure 72

Dynamic representation of some chosen results

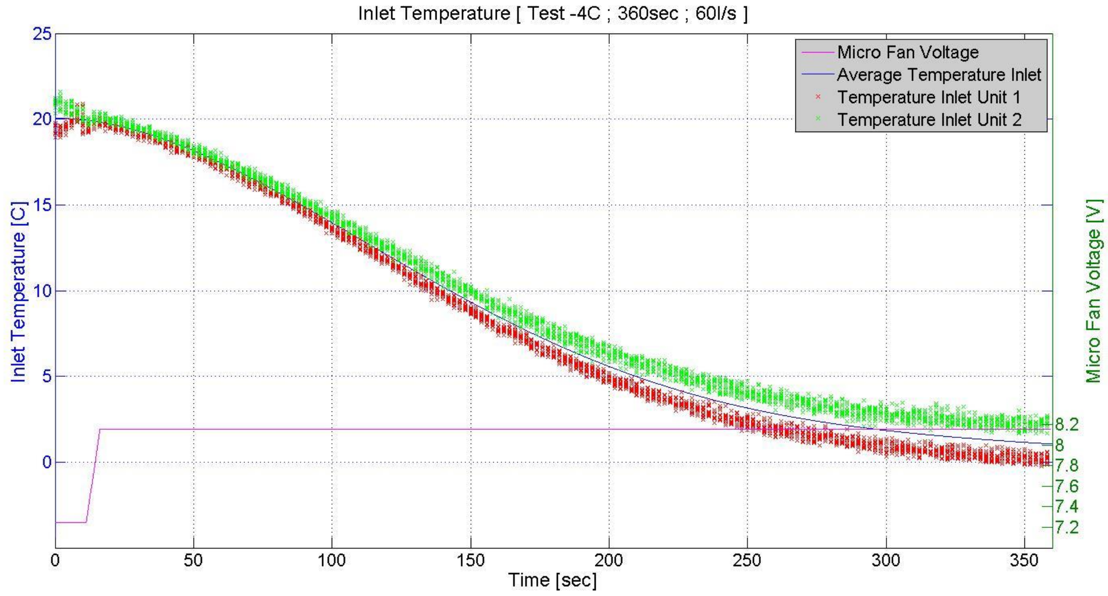


Figure 73

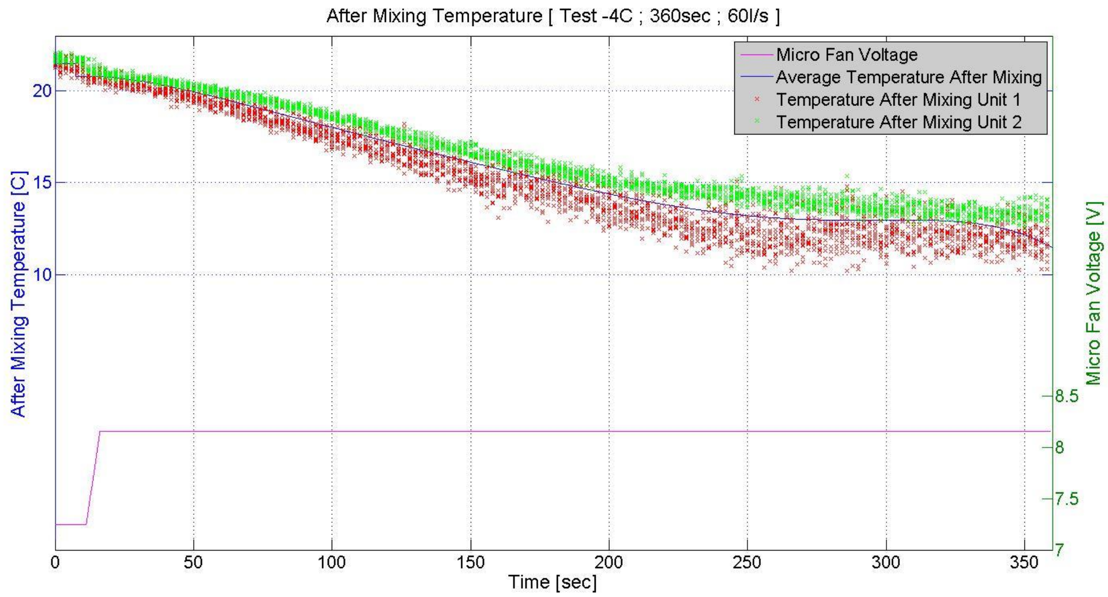


Figure 74

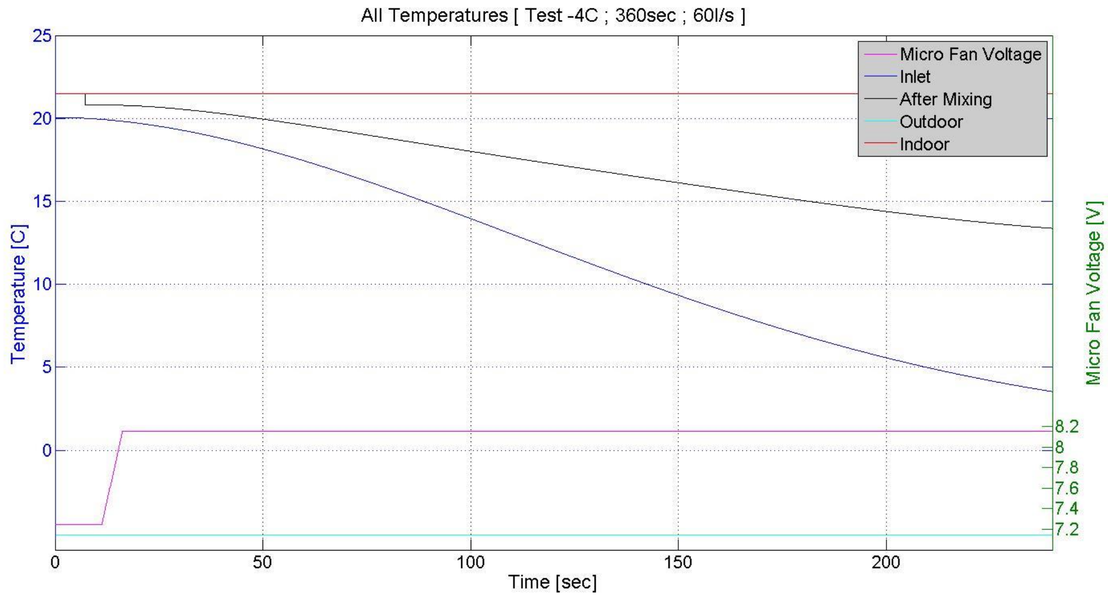


Figure 75

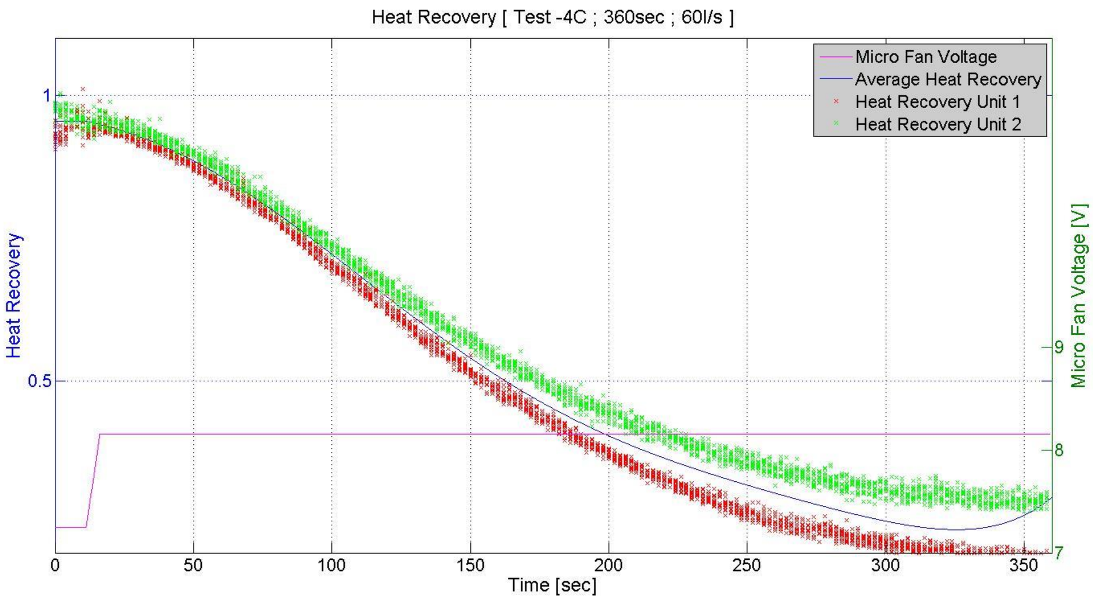


Figure 76

Constant test – 1 unit blow in and one out all the time

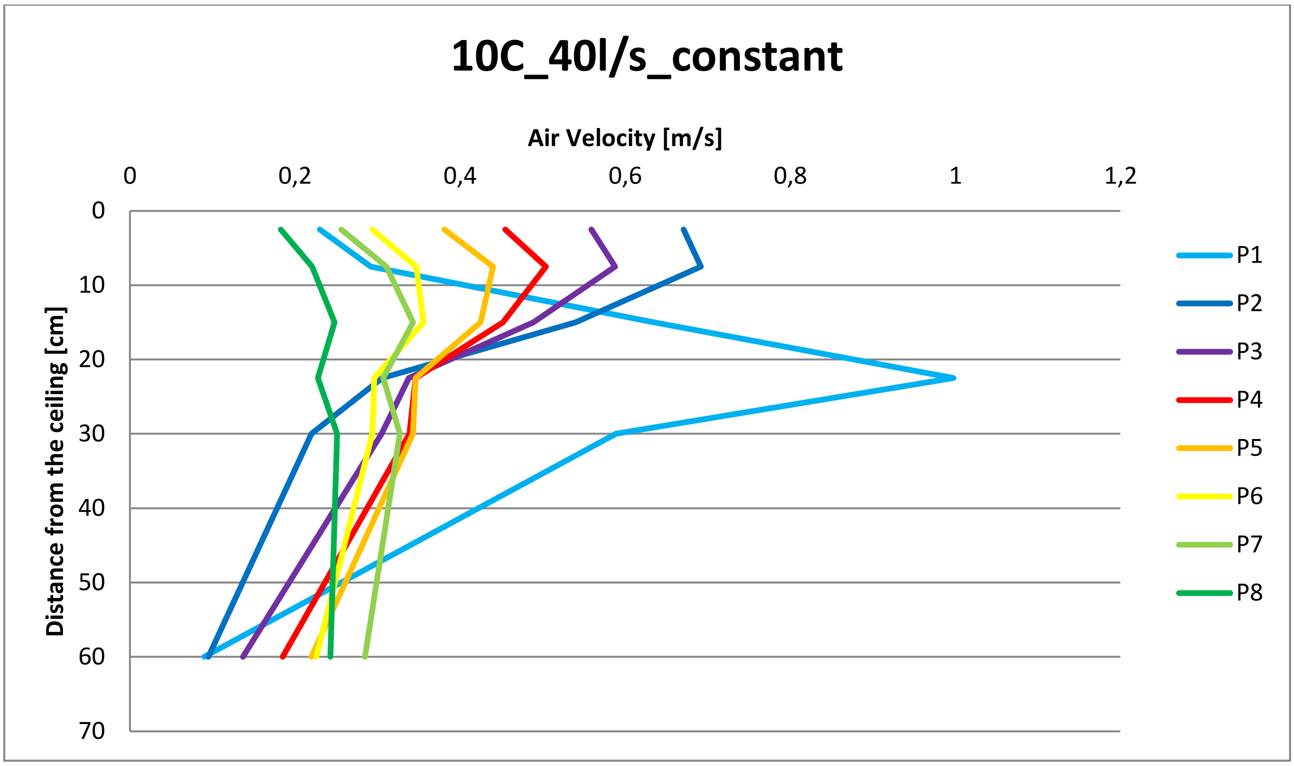


Figure 77

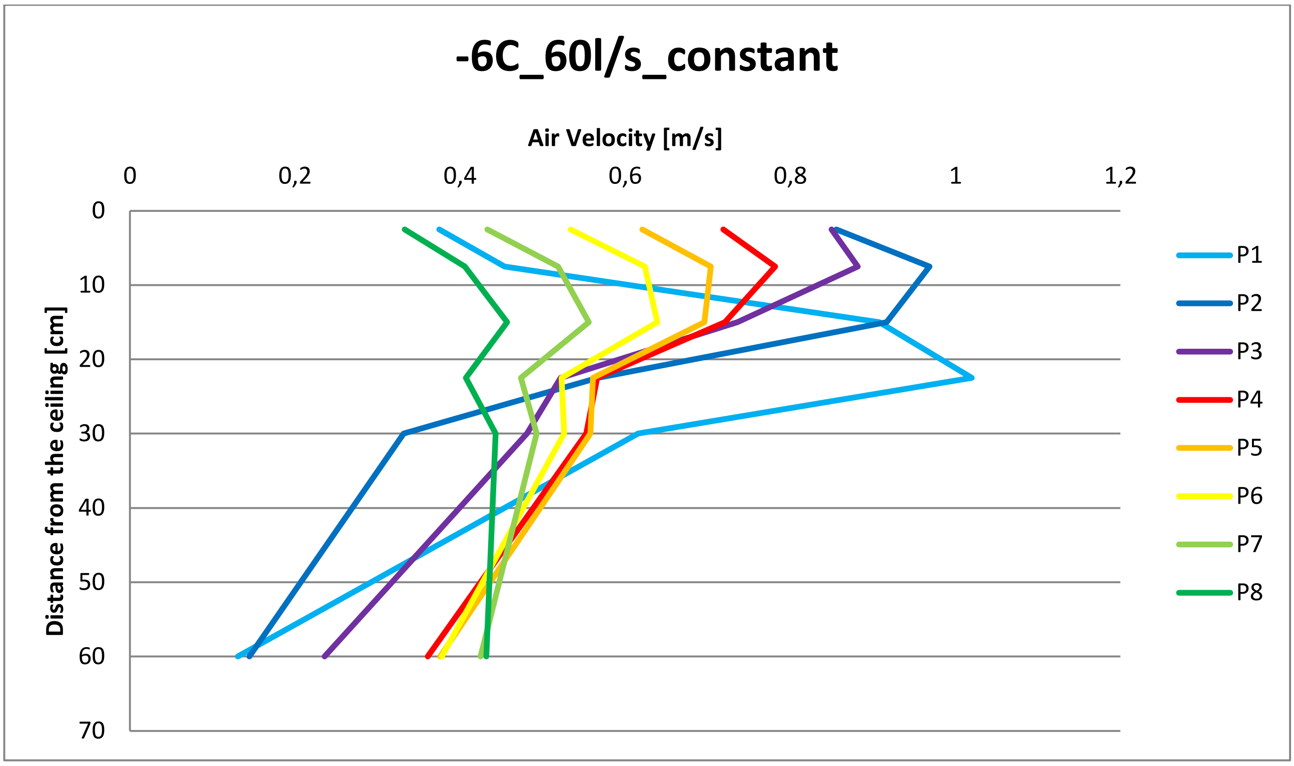

-6C_60l/s_constant
Air Velocity [m/s]
0
0,2
0,4
0,6
0,8
1
1,2
Distance from the ceiling [cm]
0
10
20
30
40
50
60
70
P1
P2
P3
P4
P5
P6
P7
P8

Figure 78

Summary and Conclusion

In this chapter obtained results are summed up and conclusions are drawn.

- Average heat recovery for units shifting with 240 seconds and 360 seconds is calculated respectively at 63% and 52%. All calculated average heat recoveries are summed up and presented in the Figure 79. It can be observed that due to obtained periodic steady-state in the units air flow has no influence on the heat recovery of the units. The only parameter that influences efficiency of heat recovery is the length of the shift.

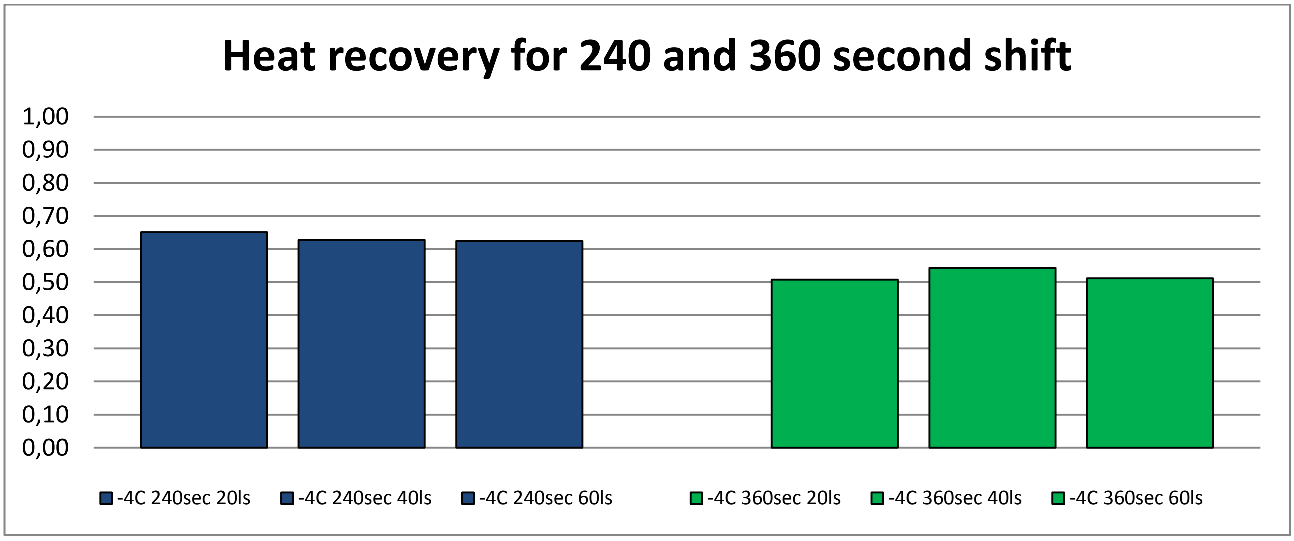


Figure 79

- Dynamic heat recoveries are plotted and presented along the time of the shift (respectively 240 and 360 seconds). It can be observed that heat recovery flattens out after approximately 240 seconds what indicates that longer cycles might not be appreciated when heat recovery is needed.
- Temperature in the cold chamber that imitates outdoor temperature condition is designed to be at -4°C but measurements indicate that in fact it is closer to -5°C.
- Test of Inventilate units showed that inlet temperature from the units and air temperature after mixing are obtaining periodic steady-state and that units are working perfectly alternatively.
- Measurements of the temperature in the chamber where performed in the area of the jet penetration but still showed that air in the chamber is well mixed. Measurements for low air flow at 20 l/s indicate that there might be drop of cold air to the occupation zone close to the inlet devices. There is also possibility that with admixing fans turned off the attached grill is causing that part of the jet is directed upwards (to the ceiling) and part downwards to the space. This issue has to be investigated more carefully in the last round of measurements.
  What is more, the risk of down drought could be due to low temperatures at the end of each cycle due to exploited heat recovery in heat exchanger in the units. As presented in the table below for tests with air flow at 20 l/s temperature is as low as 6-7 °C after mixing fans.

	240 seconds		360 seconds	
	Inlet temperature	After mixing temperature	Inlet temperature	After mixing temperature
	[°C]	[°C]	[°C]	[°C]
20 l/s	3	**7**	2	**6**
40 l/s	4	10	4	11
60 l/s	4	13	4	13

- For higher air flows at 40 and 60 l/s drop of the temperature close to the occupation zone is not observed. What is more, for higher air flows at 40 and 60 l/s temperature sensors located in the chamber at the height of the centre of the units inlet and above units (close to the ceiling) are affected by the jet and show lower temperatures. From this results, it can be drawn a conclusion that air jet is attached to the ceiling.
- Air velocity measurements in the chamber were measured according to DS/EN 12238. These measurements showed that air jets attach to the ceiling for all 3 tested air flows and for both 240 and 360 second shift period. In the first part (closer to the inlet unit) velocities are highest at the height of the middle of the inlet device. Then after, maximum velocities moves towards ceiling and are observed in the anemometers located respectively 7,5 and then after 2,5 cm from the ceiling. Afterwards, in point P7 and P8 which are two furthest measuring locations from the inlet devices air jets (in most of the cases but not all) begins to fall and maximum velocities are observed at 15 and 30 cm from the ceiling. At this locations velocities are rather low and do not exceed 0,2 m/s except the cases with air flow at 60 l/s where velocities are up to 0,4 m/s can be observed.
- The coefficient Ka for the analytical expression of the jet was found at 8 and it is with good agreement with previously found coefficient for a three-dimensional rectangular wall jet with ratio between height to width of the inlet at 5 (like the one tested) that was reported in [Grimitlin, M., Zuluftverteilung in Räumen, Luft und Kältechnik, nr. 5, 1970] to be 8,8.