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Appendix **A1**

Design criteria

A1.1 Local thermal discomfort indices

In DS/EN ISO 7730 [2006] can be found equations for Percentage Dissatisfied caused by vertical air temperature difference (PD_{VTG}), see (A1.1), and caused by radiant assymetry related to cool ceiling (PD_{RA}), see (A1.2).

$$PD_{VTG} = \frac{100}{1 + \exp(5.76 - 0.856 \cdot \Delta t_{a,v})} \quad \text{for} \quad \Delta t_{a,v} < 8^{\circ}C \tag{A1.1}$$

PD_{VTG}	Percentage Dissatisfied due to vertical temperature gradient [%]
$\Delta t_{a,v}$	Vertical air temperature assymetry between head and feet [°C]

$$PD_{RA} = \frac{100}{1 + \exp(9.93 - 0.50 \cdot \Delta t_{pr})} \quad \text{for} \quad \Delta t_{pr} < 15^{\circ}C \tag{A1.2}$$

PD_{RA}	Percentage Dissatisfied due to temperature assymetry related to cool ceiling [%]
Δt_{pr}	Radiant temperature assymetry [°C]

Appendix **A2**

Experiment set-up

A2.1 Equipment

This section consider equipment used for measuring velocity, temperature, concentration and power for heat gains. Logging equipment, sensors and theirs precision are given. Measuring points are described in main report in section 4.2.

Velocity is measured in 15 points on five movable columns using Dantec 54R10 hot-sphere anemometers, see figure 4.8(b) in main report. The accuracy of the sensors can be estimated to $\pm 5\%$ of reading, see Cena and de Dear [1998], but also depends on the accuracy of calibration. According to Stannov et al. [1998] and DS/EN ISO 7726 [2001] required accuracy of mean air velocity measurments is equal to ± 0.05 $^{m}/_{s}$, so used velocity sensors fulfill accuracy requirements. These anemometers are low velocity transducers and are connected to two dataloggers, which are next connected to laptop with a control software, see figure A2.1.

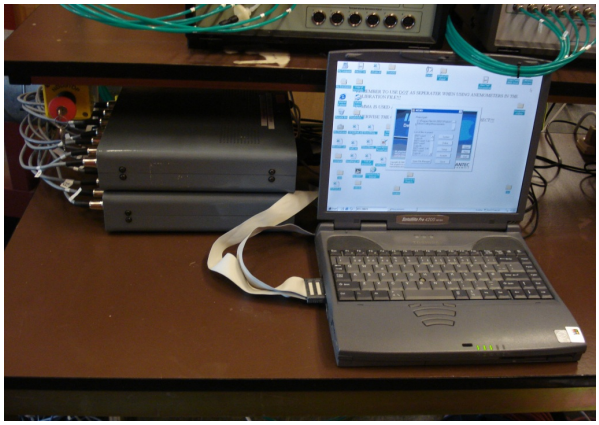
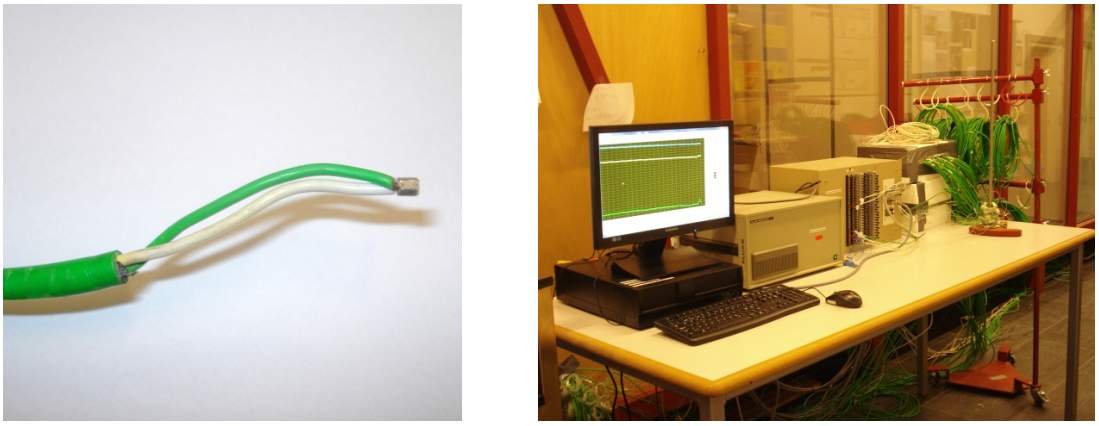


Figure A2.1: *Set-up of equipment measuring velocity.*

Temperature is measured by thermocouples. Two kind of type K thermocouples are used, which are thick and thin. The main difference is size of the sensor and their time constant. Thin thermocouple can be seen on figure 4.12(a) in main report and thick thermocouples is presented on figure A2.2(a). Thin thermocouples are used to measure surface temperature and temperature gradient below the ceiling and the rest of thermocouples are thick. According to DS/EN ISO 7726 [2001] required accuracy of air and surface temperature measurements is ± 0.5°C and desired is equal to ± 0.2°C.

For sensors the uncertainty can be estimated to be equal to 0.08 K for thick thermocouples and 0.09 K for thin thermocouples, see Artmann et al. [2008], so used thermocouples fulfill both required and desired accuracy. The thermocouples are connected to compensation boxes and next to Helios Fluke Datalogger, which is linked to a personal computer that saves the results. Temperature in each of two compensation boxes is measured by two thick thermocouples, which are connected to Ice Point Reference. Data from Ice Point Reference is also logged by Helios Fluke Datalogger. The set-up for thermocouples can be seen on figure A2.2(b).

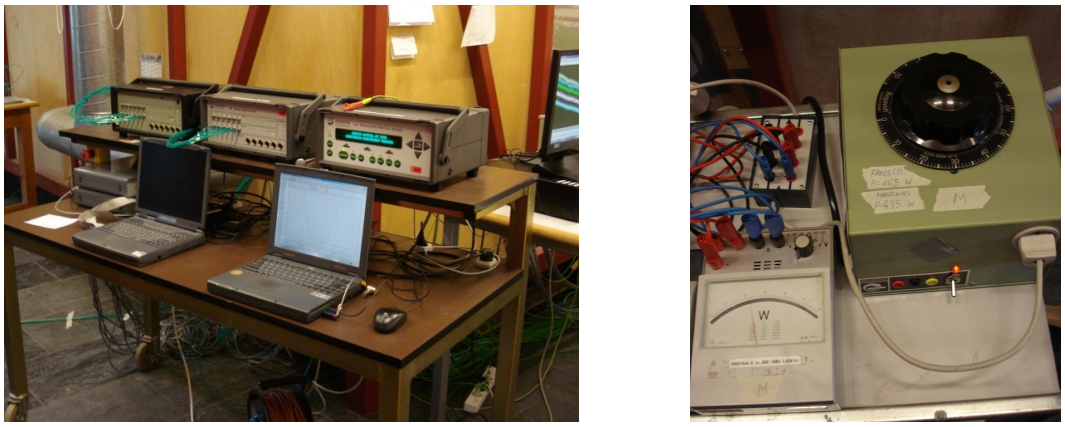


(a) (b)

Figure A2.2: *Pictures of a) thick thermocouple sensor, b) set-up for equipment measuring temperature.*

Concentration is measured by Innova 1412 Photoacoustic Field Gas-Monitor connected to Multipoint Sampler and Doser INNOVA 1303. It is possible to measure concentration at six points at the same time, when the Multipoint Sampler and Doser is used. This equipment, see figure A2.3(a), is used to observe concentration of tracer gas, N_2O, in the chosen sampling points. Sampler and Doser collect samples and one by one transfer them to Gas-Monitor. Sensitive microphone measures radiation level in measuring chamber and using calibration factors concentration of N_2O in the sample can be calculated. Detection level for nitrous oxide is equal to 0.05 ppm.

The last large set of equipment is used to measure power supplied to mannequins, radiators, light bulbs or heating wires. Three variable AC power supplies are used. Each of them is connected to wattmeter. The set-up is presented on figure A2.3(b). Power supplied to the room is monitored, but it can variate due to changes of voltage in power grid. Error is estimated to $\pm 2\%$ of the reading.



(a) (b)

Figure A2.3: *Picture of a) set-up of equipment measuring velocity and concentration, b) variable AC power supply with watt meter to measure power supplied to heat gains.*

A2.2 Test cases

In this section detailed drawings of heat sources locations for different cases will be presented. For all the cases drawings presenting plane view will be given, cross-section showing heights of the heat sources will be presented only for Case 5, with mannequines densely located in one part of the room and light bulbs. For other cases the heights of the heat sources are equal to the mentioned one. It should be noted that heating wires are not presented on the cross-section, as they are located on the floor.

Legend with symbols of the heat sources used on drawings in this section is presented in table A2.1.

Symbol	Description
⊗	Light bulb
M	Mannequin
▭	Radiator
≡	Heating wires

Table A2.1: *Legend of symbols of the heat sources.*

Mannequins equally distributed in the room
Cases: 1, 2, 3

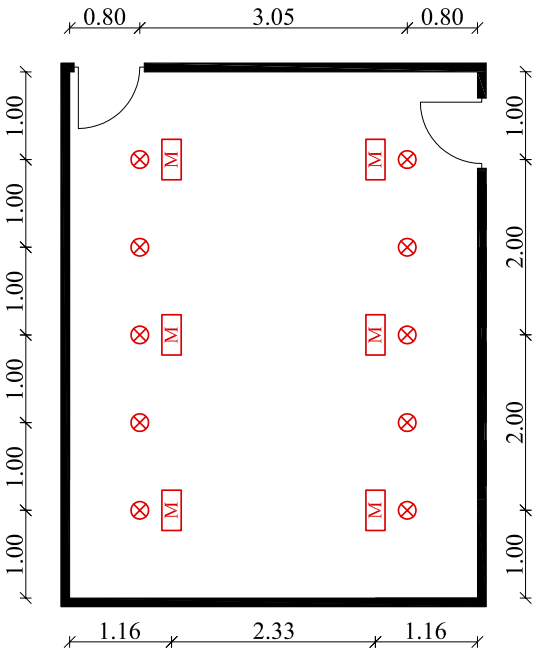


Figure A2.4: *Plane view of the room with heat sources location for the cases with mannequins equally distributed in the room.*

Mannequins and radiators on one side the room
Case: 4

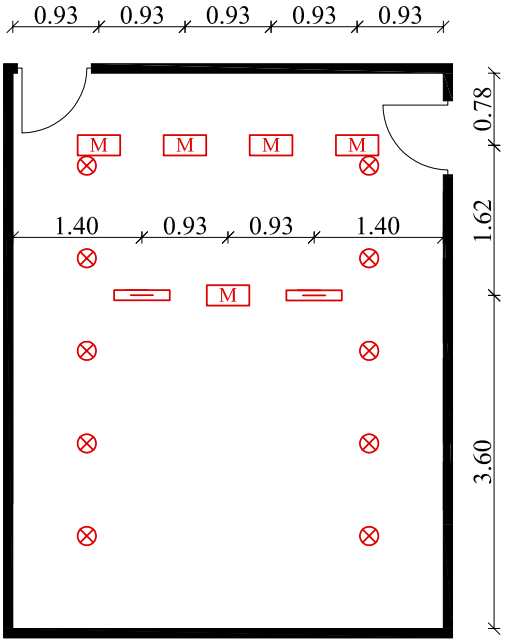
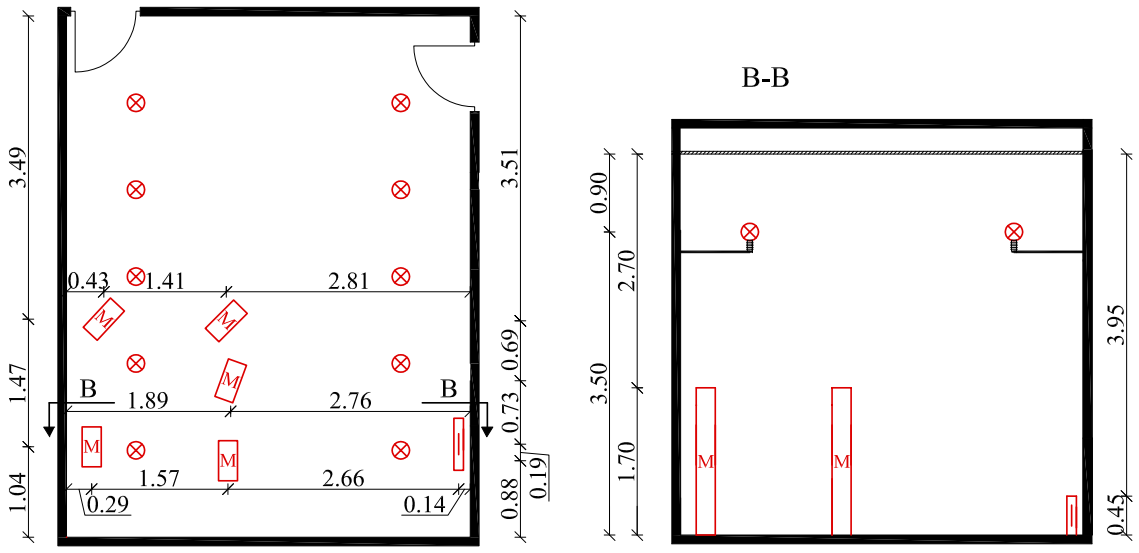


Figure A2.5: *Plane view of the room for the case with heat sources located on one side of the room.*

Mannequins densely located in one part of the room and light bulbs
Case: 5



(a) (b)

Figure A2.6: *Drawings for the case with mannequins densely located in one part of the room and light bulbs a) plan view, b) cross-section.*

Radiator in the corner
Case: 6

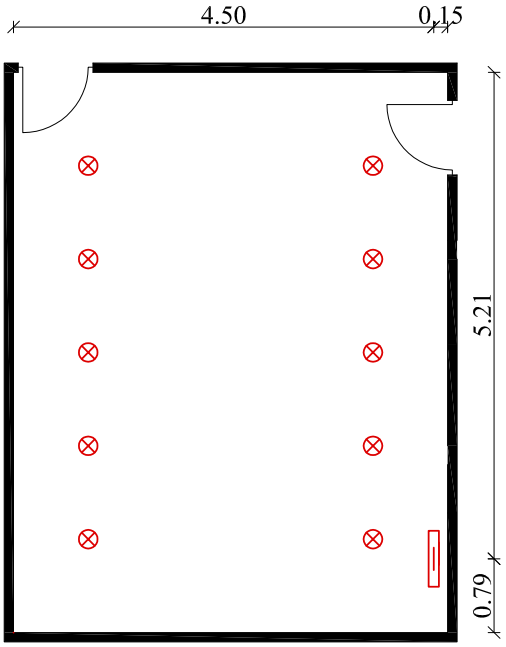


Figure A2.7: *Plane view of the room with radiator located in the corner.*

Radiator in the middle
Case: 7

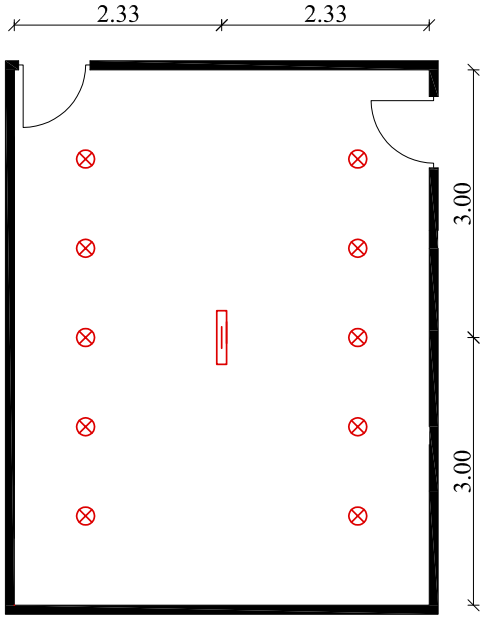


Figure A2.8: *Plane view of the room with radiator located in the middle of the room.*

Heating wires and light bulbs
Cases: 8, 9, 10

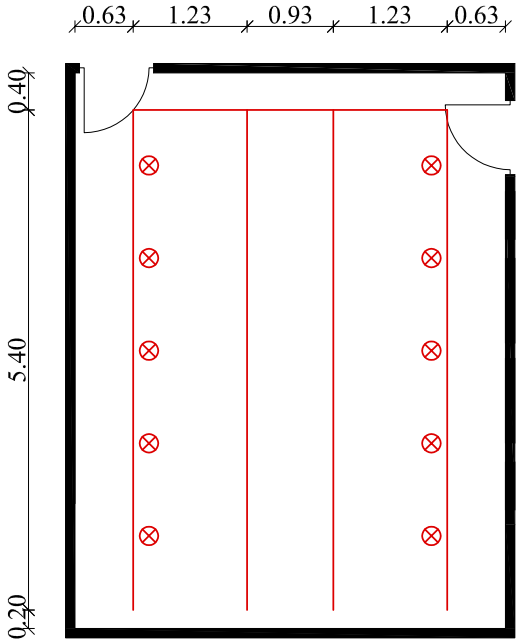


Figure A2.9: *Plane view of the room with heating wires and light bulbs.*

Appendix **A3**

Experiment results

A3.1 Airflow distribution

A3.1.1 Velocity distribution

In this part mean velocity results, which are not presented in the main report are introduced.

Cases with unequally distributed heat sources

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.16	x	x	0.17	0.19
	1.1 m	0.13	0.17	0.16	0.15	0.17
	0.1 m	0.09	0.12	0.16	0.13	0.13
2	1.7 m	0.13	x	x	0.13	0.28
	1.1 m	0.11	0.25	0.13	0.10	0.20
	0.1 m	0.11	0.15	0.15	0.07	0.14
3	1.7 m	0.08	x	x	0.10	0.07
	1.1 m	0.09	0.08	0.06	0.11	0.07
	0.1 m	0.12	0.18	0.12	0.10	0.18
4	1.7 m	0.07	x	x	0.10	0.09
	1.1 m	0.08	0.08	0.13	0.11	0.13
	0.1 m	0.17	0.23	0.28	0.17	0.24
5	1.7 m	0.09	x	x	0.11	0.23
	1.1 m	0.11	0.20	0.21	0.11	0.20
	0.1 m	0.20	0.22	0.19	0.18	0.19

(a)

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.13	x	x	0.11	0.18
	1.1 m	0.10	0.15	0.14	0.10	0.14
	0.1 m	0.08	0.11	0.11	0.07	0.07
2	1.7 m	0.10	x	x	0.10	0.21
	1.1 m	0.08	0.19	0.10	0.09	0.14
	0.1 m	0.06	0.11	0.13	0.05	0.10
3	1.7 m	0.08	x	x	0.08	0.06
	1.1 m	0.08	0.07	0.05	0.10	0.06
	0.1 m	0.12	0.13	0.09	0.07	0.10
4	1.7 m	0.06	x	x	0.08	0.07
	1.1 m	0.10	0.10	0.11	0.11	0.10
	0.1 m	0.19	0.27	0.23	0.20	0.22
5	1.7 m	0.08	x	x	0.07	0.15
	1.1 m	0.09	0.17	0.21	0.06	0.13
	0.1 m	0.15	0.18	0.16	0.15	0.18

(b)

Figure A3.1: *Velocity distribution in the room for a) Test 4a, b) Test 4c.*

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.07	x	x	0.17	0.06
	1.1 m	0.07	0.14	0.18	0.16	0.07
	0.1 m	0.16	0.15	0.11	0.14	0.16
2	1.7 m	0.07	x	x	0.06	0.09
	1.1 m	0.11	0.09	0.05	0.05	0.10
	0.1 m	0.18	0.19	0.19	0.17	0.17
3	1.7 m	0.07	x	x	0.04	0.07
	1.1 m	0.10	0.07	0.06	0.06	0.09
	0.1 m	0.14	0.18	0.09	0.16	0.17
4	1.7 m	0.10	x	x	0.06	0.06
	1.1 m	0.11	0.12	0.06	0.05	0.07
	0.1 m	0.09	0.12	0.11	0.04	0.04
5	1.7 m	0.10	x	x	0.07	0.20
	1.1 m	0.09	0.11	0.08	0.08	0.08
	0.1 m	0.09	0.06	0.06	0.04	0.04

(a)

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.07	x	x	0.11	0.05
	1.1 m	0.07	0.14	0.15	0.11	0.08
	0.1 m	0.16	0.15	0.14	0.15	0.15
2	1.7 m	0.07	x	x	0.04	0.05
	1.1 m	0.10	0.07	0.06	0.06	0.09
	0.1 m	0.21	0.19	0.20	0.16	0.18
3	1.7 m	0.06	x	x	0.05	0.05
	1.1 m	0.08	0.06	0.07	0.05	0.08
	0.1 m	0.07	0.08	0.08	0.05	0.05
4	1.7 m	0.11	x	x	0.04	0.07
	1.1 m	0.11	0.13	0.05	0.05	0.07
	0.1 m	0.17	0.16	0.09	0.04	0.03
5	1.7 m	0.11	x	x	0.07	0.18
	1.1 m	0.11	0.12	0.08	0.08	0.08
	0.1 m	0.12	0.06	0.05	0.04	0.03

(b)

Figure A3.2: *Velocity distribution in the room for a) Test 5a, b) Test 5b.*

Cases with heating wires and light bulbs

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.19	x	x	0.18	0.22
	1.1 m	0.21	0.21	0.21	0.18	0.20
	0.1 m	0.18	0.20	0.20	0.15	0.15
2	1.7 m	0.14	x	x	0.16	0.11
	1.1 m	0.16	0.14	0.13	0.17	0.14
	0.1 m	0.28	0.31	0.29	0.25	0.24
3	1.7 m	0.12	x	x	0.13	0.09
	1.1 m	0.16	0.12	0.10	0.15	0.13
	0.1 m	0.28	0.16	0.17	0.27	0.25
4	1.7 m	0.14	x	x	0.12	0.09
	1.1 m	0.19	0.12	0.10	0.12	0.09
	0.1 m	0.29	0.17	0.14	0.14	0.12
5	1.7 m	0.16	x	x	0.18	0.19
	1.1 m	0.19	0.18	0.17	0.20	0.16
	0.1 m	0.13	0.12	0.15	0.13	0.10

(a)

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	x	x	x	x	x
	1.1 m	x	x	x	x	x
	0.1 m	x	x	x	x	x
2	1.7 m	0.12	x	x	0.13	0.10
	1.1 m	0.13	0.14	0.14	0.14	0.13
	0.1 m	0.21	0.28	0.26	0.23	0.23
3	1.7 m	x	x	x	x	x
	1.1 m	x	x	x	x	x
	0.1 m	x	x	x	x	x
4	1.7 m	x	x	x	x	x
	1.1 m	x	x	x	x	x
	0.1 m	x	x	x	x	x
5	1.7 m	x	x	x	x	x
	1.1 m	x	x	x	x	x
	0.1 m	x	x	x	x	x

(b)

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	x	x	x	x	x
	1.1 m	x	x	x	x	x
	0.1 m	x	x	x	x	x
2	1.7 m	0.11	x	x	0.10	0.11
	1.1 m	0.13	0.14	0.14	0.13	0.13
	0.1 m	0.21	0.26	0.25	0.21	0.22
3	1.7 m	0.12	x	x	0.13	0.10
	1.1 m	0.12	x	0.13	0.16	0.14
	0.1 m	0.14	x	0.15	0.23	0.22
4	1.7 m	0.06	x	x	x	x
	1.1 m	0.16	x	x	x	x
	0.1 m	0.20	x	x	x	x
5	1.7 m	x	x	x	x	x
	1.1 m	x	x	x	x	x
	0.1 m	x	x	x	x	x

(c)

Figure A3.3: *Velocity distribution in the room for a) Test 8a b), Test 8b, c) Test 8c.*

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.13	x	x	0.14	0.16
	1.1 m	0.14	0.16	0.17	0.13	0.15
	0.1 m	0.14	0.14	0.14	0.13	0.12
2	1.7 m	0.10	x	x	0.14	0.11
	1.1 m	0.12	0.12	0.11	0.14	0.12
	0.1 m	0.18	0.22	0.22	0.17	0.17
3	1.7 m	0.09	x	x	0.10	0.06
	1.1 m	0.10	0.10	0.10	0.12	0.10
	0.1 m	0.17	0.22	0.23	0.19	0.20
4	1.7 m	0.10	x	x	0.10	0.08
	1.1 m	0.11	0.09	0.08	0.12	0.09
	0.1 m	0.16	0.20	0.21	0.18	0.18
5	1.7 m	0.15	x	x	0.15	0.16
	1.1 m	0.13	0.15	0.15	0.13	0.14
	0.1 m	0.09	0.06	0.10	0.09	0.07

(a)

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.14	x	x	0.14	0.17
	1.1 m	0.15	0.16	0.17	0.14	0.15
	0.1 m	0.14	0.15	0.16	0.12	0.13
2	1.7 m	0.12	x	x	0.13	0.10
	1.1 m	0.13	0.13	0.12	0.14	0.12
	0.1 m	0.17	0.23	0.23	0.17	0.18
3	1.7 m	0.11	x	x	0.11	0.07
	1.1 m	0.12	0.11	0.11	0.13	0.11
	0.1 m	0.17	0.23	0.25	0.21	0.19
4	1.7 m	0.10	x	x	0.10	0.09
	1.1 m	0.12	0.10	0.09	0.12	0.09
	0.1 m	0.16	0.20	0.22	0.20	0.17
5	1.7 m	0.14	x	x	0.15	0.16
	1.1 m	0.14	0.15	0.15	0.14	0.14
	0.1 m	0.08	0.07	0.11	0.09	0.08

(b)

Figure A3.4: *Velocity distribution in the room for a) Test 9a, b) Test 9b.*

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.12	x	x	0.13	0.16
	1.1 m	0.13	0.17	0.16	0.12	0.15
	0.1 m	0.14	0.15	0.15	0.12	0.12
2	1.7 m	0.11	x	x	0.11	0.10
	1.1 m	0.12	0.13	0.12	0.13	0.13
	0.1 m	0.16	0.21	0.21	0.17	0.18
3	1.7 m	0.11	x	x	0.10	0.07
	1.1 m	0.12	0.11	0.11	0.11	0.10
	0.1 m	0.17	0.22	0.24	0.18	0.19
4	1.7 m	0.12	x	x	0.11	0.10
	1.1 m	0.12	0.10	0.10	0.12	0.10
	0.1 m	0.15	0.19	0.22	0.16	0.18
5	1.7 m	0.14	x	x	0.15	0.17
	1.1 m	0.14	0.14	0.15	0.14	0.14
	0.1 m	0.07	0.07	0.10	0.08	0.07

(a)

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.11	x	x	0.12	0.14
	1.1 m	0.11	0.14	0.13	0.10	0.12
	0.1 m	0.14	0.14	0.15	0.12	0.12
2	1.7 m	0.09	x	x	0.09	0.08
	1.1 m	0.12	0.13	0.12	0.11	0.11
	0.1 m	0.16	0.20	0.19	0.15	0.17
3	1.7 m	0.12	x	x	0.10	0.08
	1.1 m	0.13	0.13	0.13	0.11	0.11
	0.1 m	0.15	0.19	0.20	0.16	0.17
4	1.7 m	0.11	x	x	0.10	0.08
	1.1 m	0.11	0.10	0.10	0.11	0.10
	0.1 m	0.09	0.10	0.12	0.14	0.16
5	1.7 m	0.14	x	x	0.13	0.15
	1.1 m	0.14	0.14	0.14	0.13	0.13
	0.1 m	0.08	0.09	0.11	0.09	0.08

(b)

Figure A3.5: *Velocity distribution in the room for a) Test 9c, b) Test 9d.*

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.08	x	x	0.07	0.10
	1.1 m	0.09	0.11	0.12	0.07	0.10
	0.1 m	0.10	0.10	0.10	0.09	0.07
2	1.7 m	0.09	x	x	0.09	0.07
	1.1 m	0.09	0.07	0.08	0.10	0.08
	0.1 m	0.14	0.15	0.14	0.13	0.12
3	1.7 m	0.05	x	x	0.08	0.04
	1.1 m	0.07	0.04	0.05	0.09	0.04
	0.1 m	0.14	0.10	0.17	0.14	0.13
4	1.7 m	0.07	x	x	0.07	0.05
	1.1 m	0.08	0.06	0.06	0.07	0.05
	0.1 m	0.10	0.08	0.09	0.07	0.05
5	1.7 m	0.10	x	x	0.12	0.12
	1.1 m	0.09	0.11	0.11	0.12	0.10
	0.1 m	0.07	0.04	0.05	0.07	0.03

(a)

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.05	x	x	0.06	0.11
	1.1 m	0.07	0.08	0.10	0.06	0.09
	0.1 m	0.11	0.10	0.08	0.08	0.07
2	1.7 m	0.06	x	x	0.07	0.06
	1.1 m	0.09	0.07	0.07	0.09	0.07
	0.1 m	0.13	0.13	0.13	0.12	0.10
3	1.7 m	0.07	x	x	0.06	0.04
	1.1 m	0.09	0.06	0.06	0.10	0.06
	0.1 m	0.12	0.13	0.14	0.13	0.11
4	1.7 m	0.07	x	x	0.07	0.05
	1.1 m	0.09	0.07	0.06	0.10	0.06
	0.1 m	0.10	0.11	0.12	0.11	0.10
5	1.7 m	0.10	x	x	0.11	0.11
	1.1 m	0.10	0.10	0.10	0.11	0.09
	0.1 m	0.07	0.04	0.04	0.06	0.02

(b)

Figure A3.6: *Velocity distribution in the room for a) Test 10a, b) Test 10b.*

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.05	x	x	0.02	0.03
	1.1 m	0.04	0.02	0.05	0.02	0.02
	0.1 m	0.06	0.07	0.04	0.06	0.06
2	1.7 m	0.04	x	x	0.03	0.04
	1.1 m	0.04	0.03	0.03	0.03	0.04
	0.1 m	0.06	0.06	0.07	0.06	0.05
3	1.7 m	0.06	x	x	0.06	0.07
	1.1 m	0.06	0.05	0.03	0.06	0.06
	0.1 m	0.04	0.04	0.05	0.04	0.03
4	1.7 m	0.06	x	x	0.04	0.07
	1.1 m	0.07	0.05	0.03	0.03	0.05
	0.1 m	0.03	0.04	0.05	0.04	0.04
5	1.7 m	0.07	x	x	0.04	0.04
	1.1 m	0.06	0.05	0.04	0.04	0.04
	0.1 m	0.04	0.03	0.04	0.03	0.03

Figure A3.7: *Velocity distribution in the room for Case 13.*

Case with equally distributed heat sources

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.13	x	x	0.11	0.13
	1.1 m	0.13	0.13	0.10	0.11	0.11
	0.1 m	0.08	0.15	0.13	0.09	0.10
2	1.7 m	0.16	x	x	0.11	0.10
	1.1 m	0.15	0.11	0.09	0.11	0.09
	0.1 m	0.11	0.18	0.16	0.07	0.11
3	1.7 m	0.14	x	x	0.12	0.10
	1.1 m	0.14	0.15	0.10	0.12	0.10
	0.1 m	0.11	0.19	0.18	0.08	0.12
4	1.7 m	0.14	x	x	0.11	0.10
	1.1 m	0.14	0.11	0.07	0.11	0.10
	0.1 m	0.13	0.20	0.18	0.08	0.13
5	1.7 m	0.19	x	x	0.10	0.11
	1.1 m	0.20	0.14	0.10	0.10	0.09
	0.1 m	0.10	0.19	0.17	0.09	0.12

(a)

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.11	x	x	0.08	0.10
	1.1 m	0.10	0.10	0.09	0.06	0.09
	0.1 m	0.09	0.12	0.10	0.08	0.07
2	1.7 m	0.08	x	x	0.09	0.09
	1.1 m	0.08	0.09	0.09	0.09	0.08
	0.1 m	0.06	0.10	0.11	0.09	0.12
3	1.7 m	0.09	x	x	0.07	0.09
	1.1 m	0.09	0.13	0.09	0.08	0.08
	0.1 m	0.09	0.12	0.12	0.07	0.07
4	1.7 m	0.12	x	x	0.07	0.09
	1.1 m	0.11	0.10	0.07	0.08	0.07
	0.1 m	0.11	0.17	0.15	0.06	0.09
5	1.7 m	0.13	x	x	0.08	0.09
	1.1 m	0.13	0.09	0.06	0.07	0.08
	0.1 m	0.09	0.14	0.13	0.06	0.07

(b)

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.08	x	x	0.07	0.11
	1.1 m	0.09	0.10	0.09	0.06	0.09
	0.1 m	0.08	0.11	0.09	0.08	0.09
2	1.7 m	0.09	x	x	0.07	0.09
	1.1 m	0.09	0.09	0.08	0.07	0.08
	0.1 m	0.10	0.13	0.11	0.06	0.07
3	1.7 m	0.08	x	x	0.08	0.09
	1.1 m	0.08	0.11	0.08	0.08	0.09
	0.1 m	0.06	0.07	0.08	0.07	0.07
4	1.7 m	0.10	x	x	0.07	0.09
	1.1 m	0.09	0.09	0.06	0.07	0.07
	0.1 m	0.13	0.16	0.14	0.05	0.08
5	1.7 m	0.12	x	x	0.06	0.09
	1.1 m	0.12	0.10	0.07	0.05	0.07
	0.1 m	0.10	0.13	0.11	0.06	0.07

(c)

Figure A3.8: *Velocity distribution in the room for a) Test 1a b), Test 1e, c) Test 1f.*

Cases with different supply areas

		Velocity [m/s]				
		A	B	C	D	E
1	1.7 m	0.07	x	x	0.09	0.07
	1.1 m	0.07	0.08	0.07	0.08	0.06
	0.1 m	0.09	0.08	0.08	0.09	0.09
2	1.7 m	0.09	x	x	0.08	0.07
	1.1 m	0.08	0.09	0.07	0.09	0.06
	0.1 m	0.09	0.12	0.10	0.06	0.05
3	1.7 m	0.08	x	x	0.09	0.08
	1.1 m	0.09	0.12	0.08	0.10	0.07
	0.1 m	0.05	0.06	0.06	0.06	0.06
4	1.7 m	0.08	x	x	0.07	0.07
	1.1 m	0.07	0.08	0.06	0.07	0.06
	0.1 m	0.12	0.14	0.11	0.08	0.05
5	1.7 m	0.11	x	x	0.07	0.06
	1.1 m	0.12	0.09	0.06	0.07	0.05
	0.1 m	0.12	0.14	0.11	0.08	0.06

Figure A3.9: *Velocity distribution in the room for Test 2a.*

A3.1.2 Stability problem

In this part detailed velocity results with an interval of 0.1 s, which are not presented in the main report are given. Velocity graphs are made for only one measuring point where the maximum mean velocity in the room is measured.

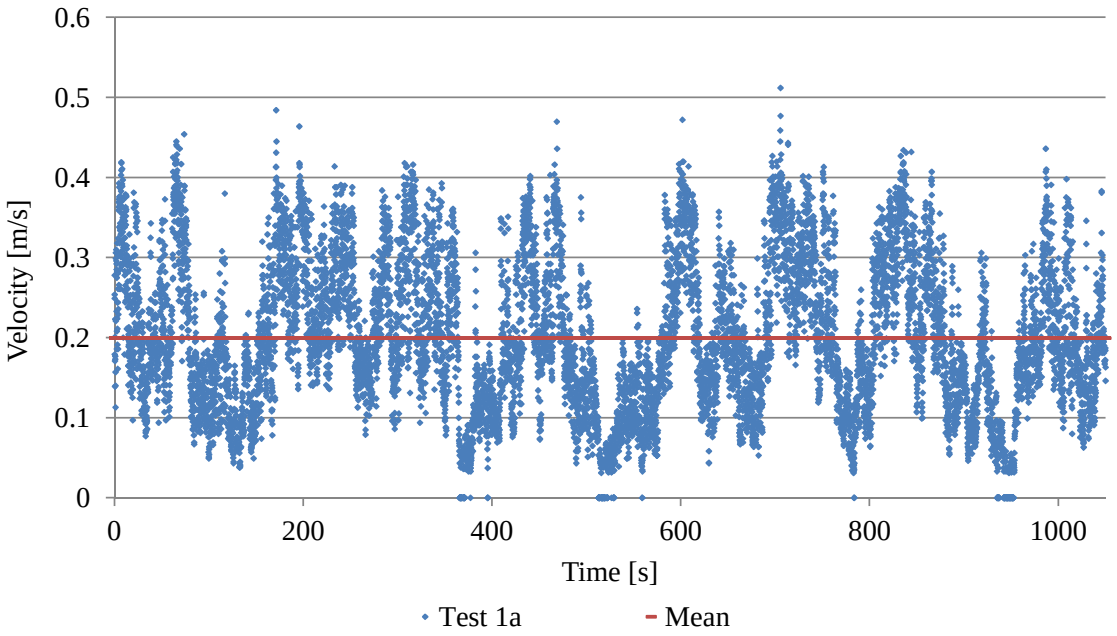


Figure A3.10: *Velocity results for Test 1a with 0.1 s interval.*

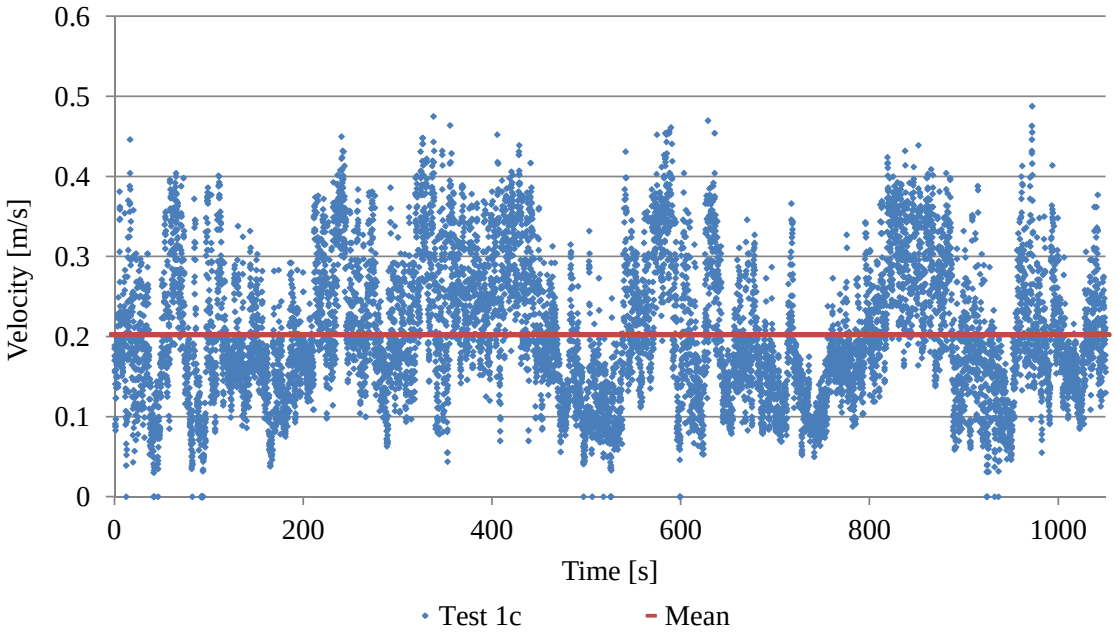


Figure A3.11: *Velocity results for Test 1c with 0.1 s interval.*

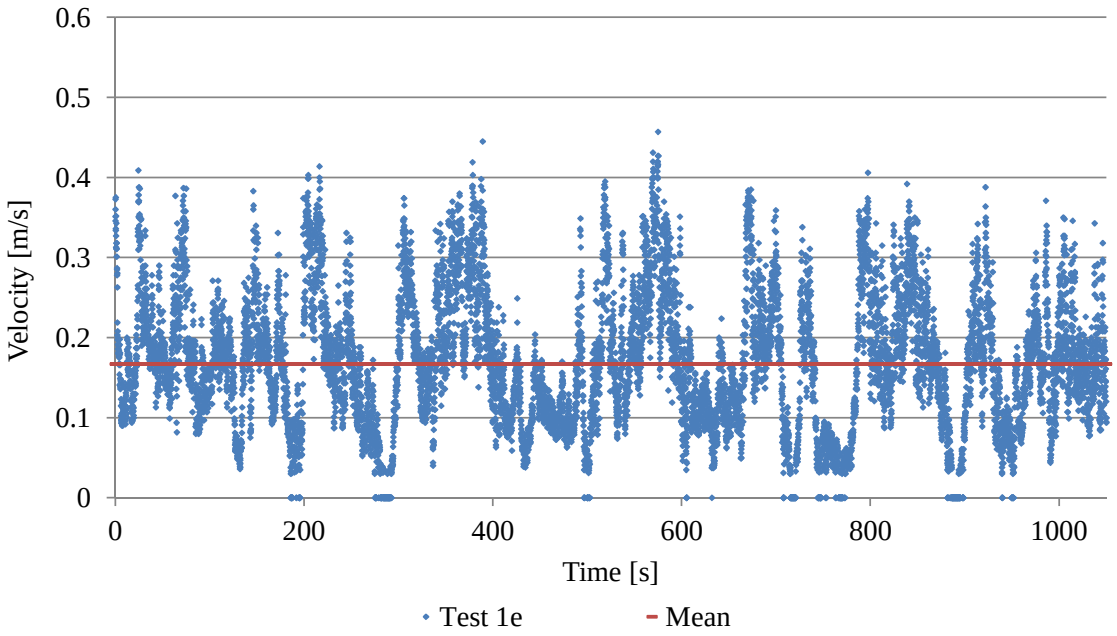


Figure A3.12: *Velocity results for Test 1e with 0.1 s interval.*

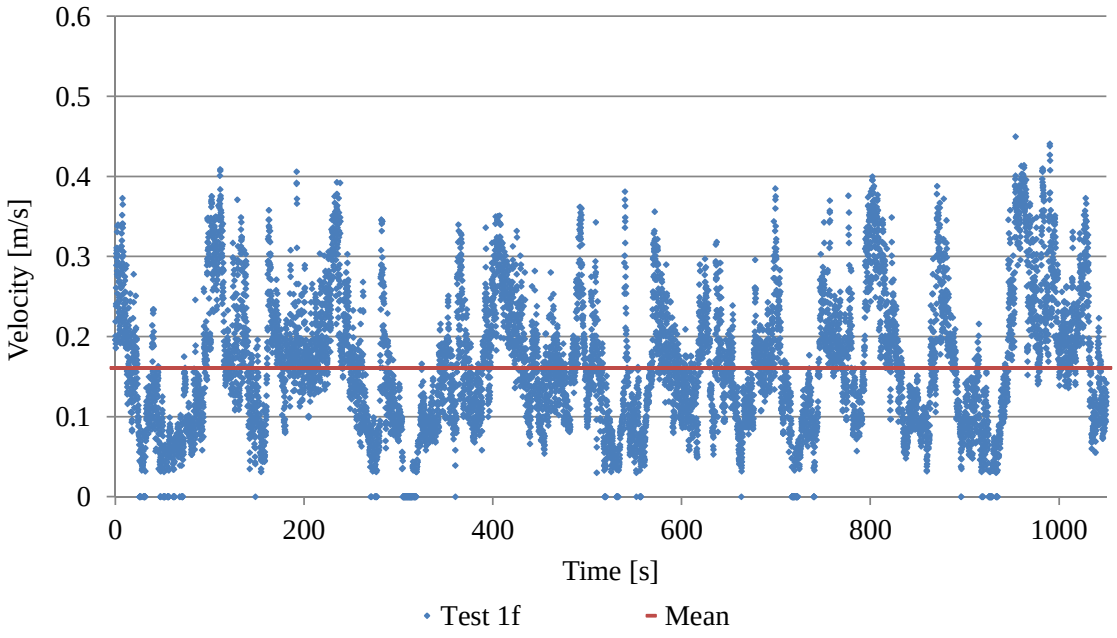


Figure A3.13: *Velocity results for Test 1f with 0.1 s interval.*

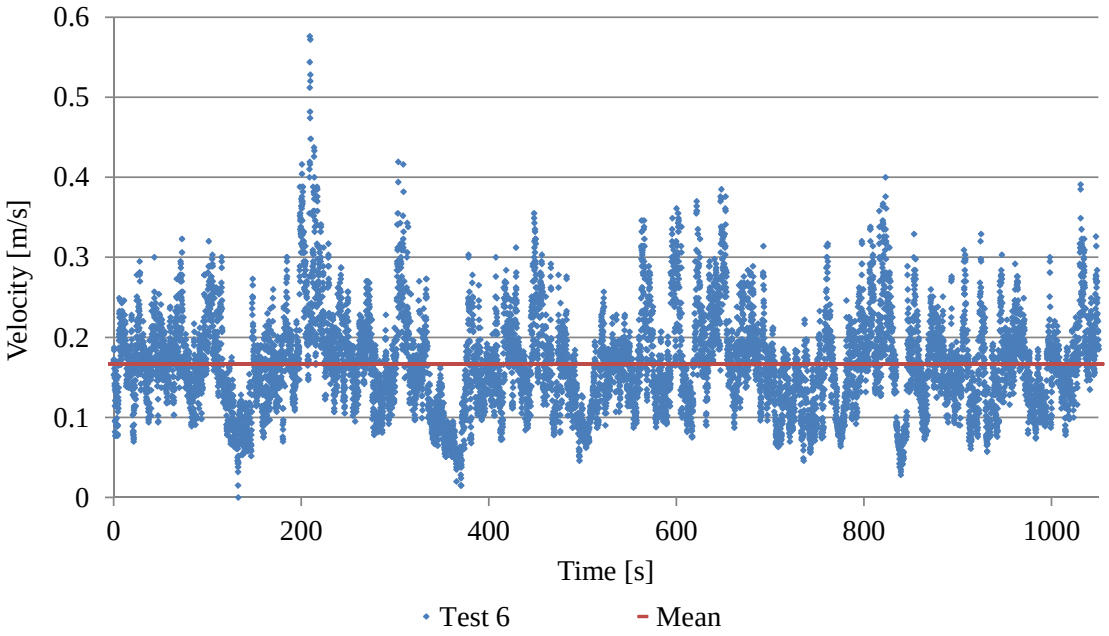


Figure A3.14: *Velocity results for Test 6 with 0.1 s interval.*

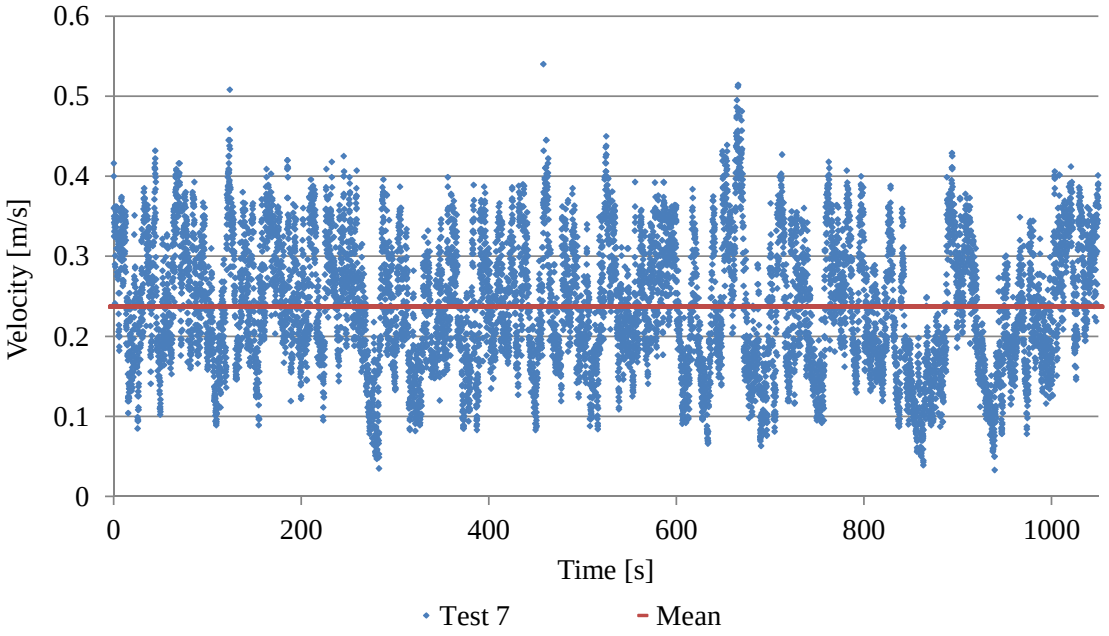


Figure A3.15: *Velocity results for Test 7 with 0.1 s interval.*

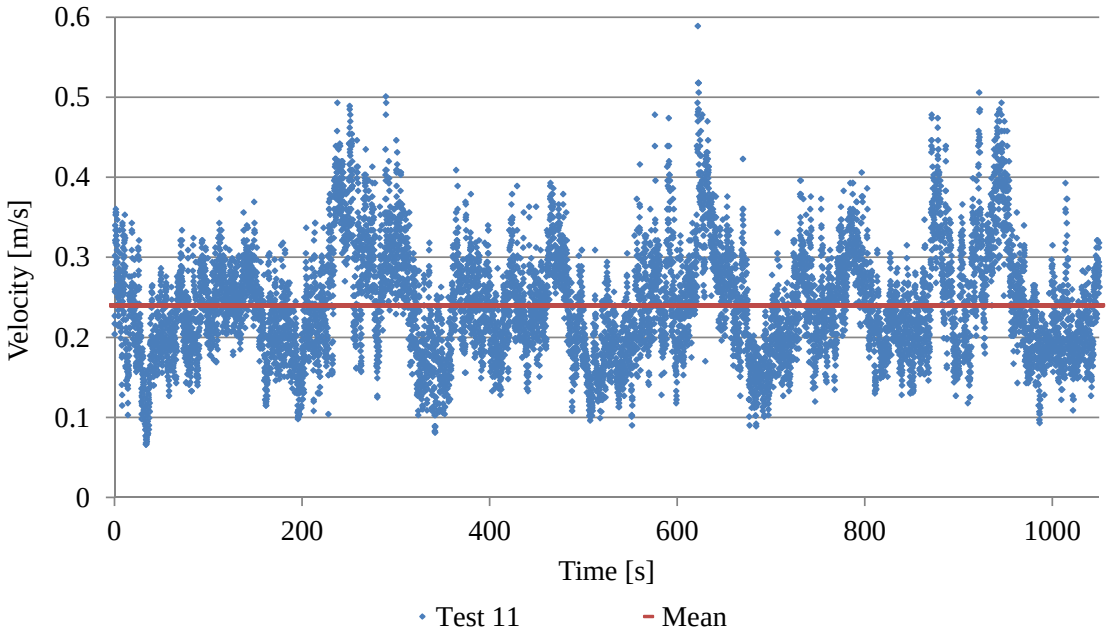


Figure A3.16: *Velocity results for Test 11 with 0.1 s interval.*

A3.2 Tracer gas concentration measurements for Case 13

In this section tracer gas concentration results are presented, which are results of measurements performed for Case 13. Legend for the points is presented in table A3.1 and results are shown on figure A3.17.

Point	Location
1	Bottle
2	Chamber 3
3	Chamber 1
4	Extract duct
5	Middle column 1.7 m
6	Middle column 4.3 m

Table A3.1: *Legend for the points used on graph with tracer gas results (points numbers are shown on the graph under letter C).*

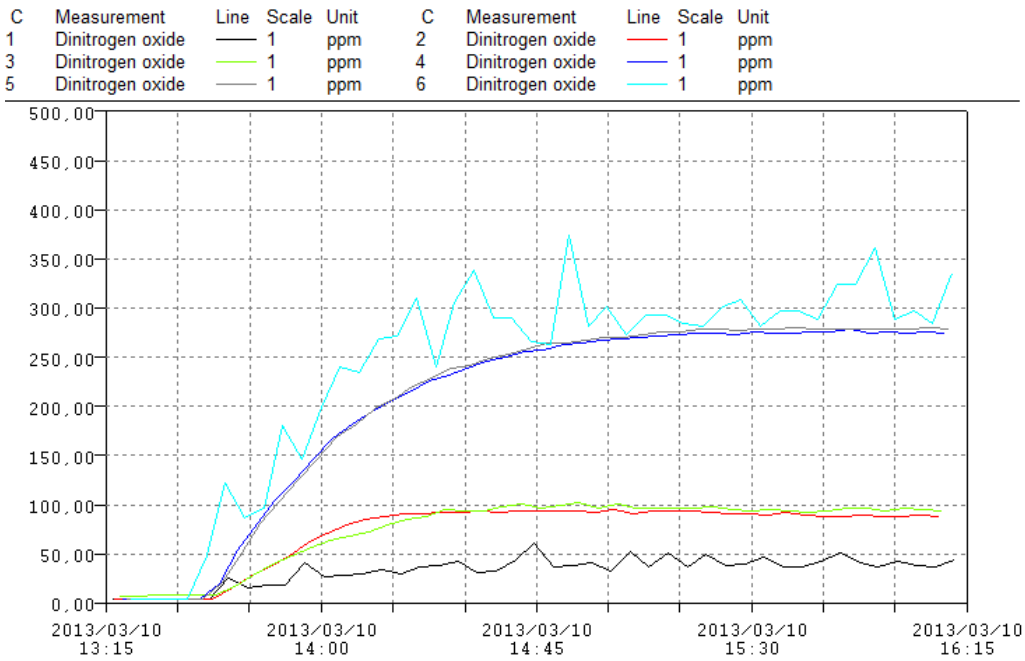
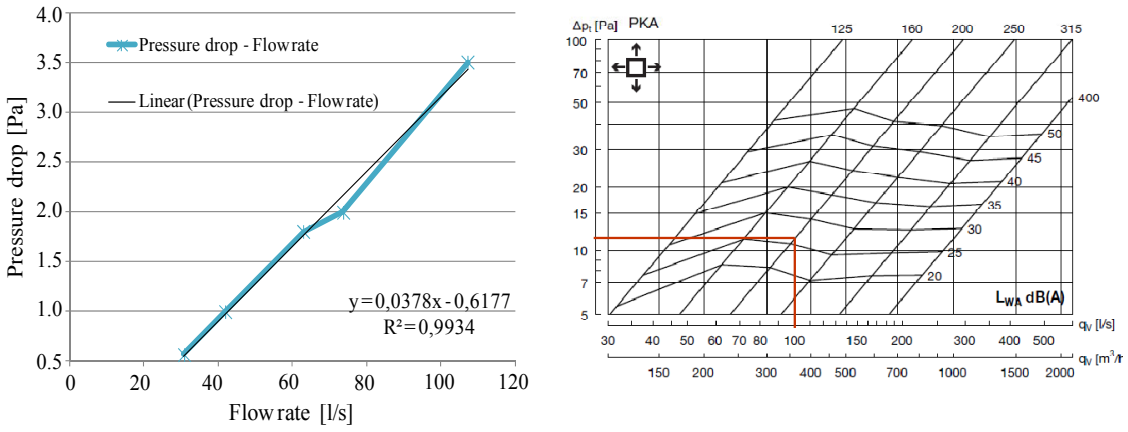


Figure A3.17: *Graph presenting tracer gas concentration results.*

A3.3 Pressure drop

Pressure drop described in Yang [2011] shows that the solution with 7 mm hole used to supply air to the room can be characterised by low resistance for air flow. The results are presented on figure A3.18(a). It is possible that low pressure drop is connected with airflow thought slots and cracks between acoustic panels, which can also be seen for diffuse ceiling presented in Jakubowska [2009].

The results can be compared with other solutions available on the market. One of the solutions can be a diffuser distributed by Lindab company. When for instance airflow equal to 100 $^{l}/_{s}$ is considered pressure drop for the ceiling is equal to 3 Pa, see A3.18(a), when for Lindab's ø125 diffuser it is around 52 Pa, see A3.18(b). However, when noise requirements are taken into consideration, for instance 35 dB(A) for classroom in category B building from CR 1752 [1998], pressure drop can be lowered for ø200 diffuser to 12 Pa.



(a) (b)

Figure A3.18: *Pressure drop a) as a function of a volume flow rate for diffuse ceiling inlet, b) as a function of a volume flow rate and A-weighted sound power level of diffuser from Lindab company. Figures edited from Yang [2011]*

Diffuse ceiling described in Jacobs and Knoll [2009] is made from panels with 25 mm holes. Decentralised system with DCV is compared with traditional and modern systems for schools in Netherlands. It is presented that, when low pressure drop construction for ceiling is used and the size of system is small, due to decentralised location, Specific Fan Power, SPF, and as an effect power consumption of the system can be significantly decreased, see table A3.2. However low pressure drop, energy use and noise level for presented solutions can be only archived for low airflow, see table A3.3. This airflow, when standard CR 1752 [1998] for classroom for category B building is considered, can be enough for 21 person in classroom. For more pupils in classroom airflow can increase and change the presented parameters. It should be noted that medium and high airflows do not fulfill maximum sound pressure in the room.

Ventilation system	**SPF** $[^{kW}/_{m^3}]$
Traditional	5-10
Modern	2-2.5
Primary school Sliedrecht	0.04
Primary school Tilburg	0.5

Table A3.2: *Comparison of specific fan power, SPF, for different ventilation systems. [Jacobs and Knoll 2009]*

Airflow		$\mathbf{L}_p$	**Pressure drop**	**Energy use**
[−]	[$^{m^3}/_s$]	[dB(A)]	[Pa]	[W]
Low	0.18	28	6	8
Medium	0.39	41	60	50
High	0.61	53	144	172

Table A3.3: *Performance of decentralised supply and return ventilation system. [Jacobs and Knoll 2009]*

In addition to pressure drop measurements, tracer gas test is conducted to check the performance and tightness of ceiling's construction. In this experiment set-up the only chamber working as an inlet is Chamber 1 and this chamber is used to distribute tracer gas in the room, while tracer gas concentration is measured in two other chambers, Chambers 2 and 3, which are closed. It can be seen on figure A3.17 that concentrations in Chambers 2 and 3 are constant after a period of time and that concentrations in the chambers increase in a fast manner. This could implicate that there is a fresh air coming to the chambers or an air leakage in the system. It is decided to test this problem. The location of sampling tubes for this set-up is shown in table A3.4.

Point	**Location**
1	Bottle
2	Chamber 2
3	Chamber 3
4	Extract duct
5	Middle column 1.7 m
6	Middle column 4.3 m

Table A3.4: *Legend for the points used on graph tracer gas results presented below. Points numbers are shown on the graph under letter C.*

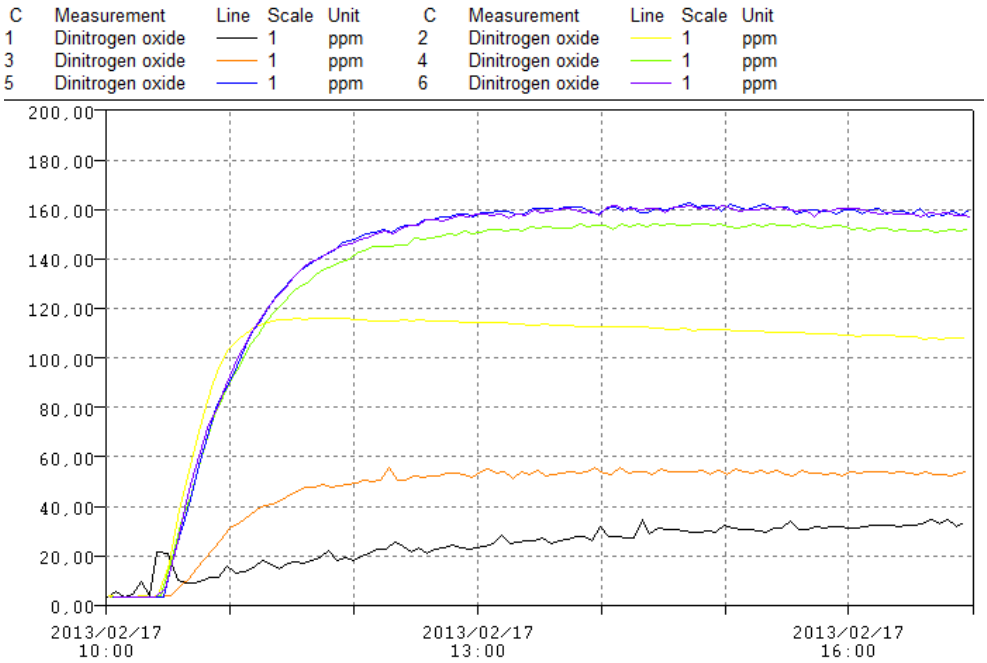
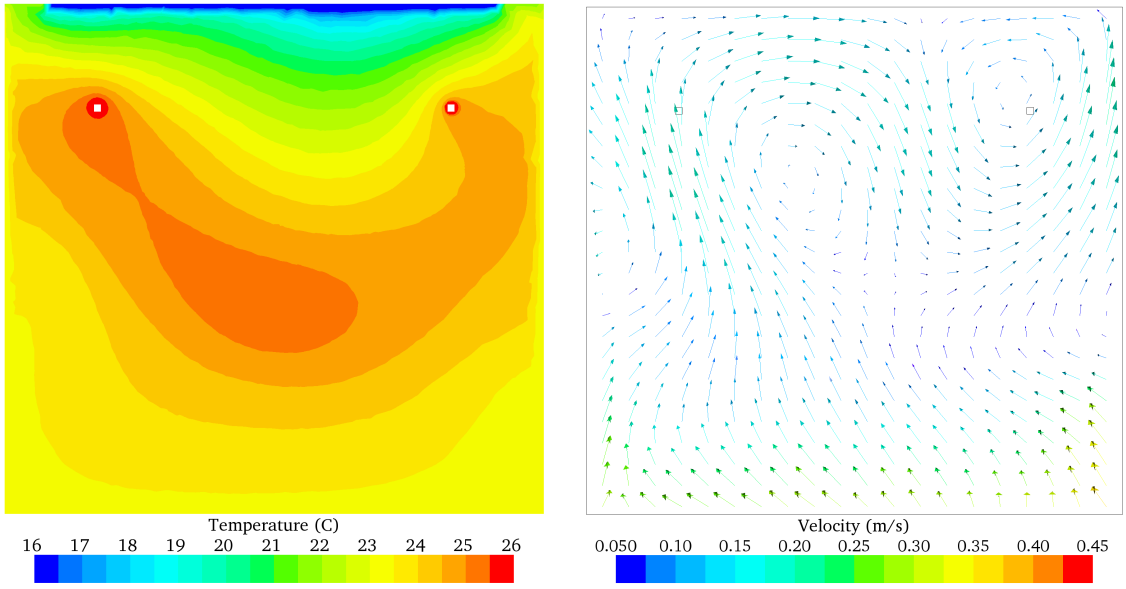


Figure A3.19: *Graph presenting tracer gas concentration results carried out to check the performance of the ceiling's construction.*

Appendix **A4**

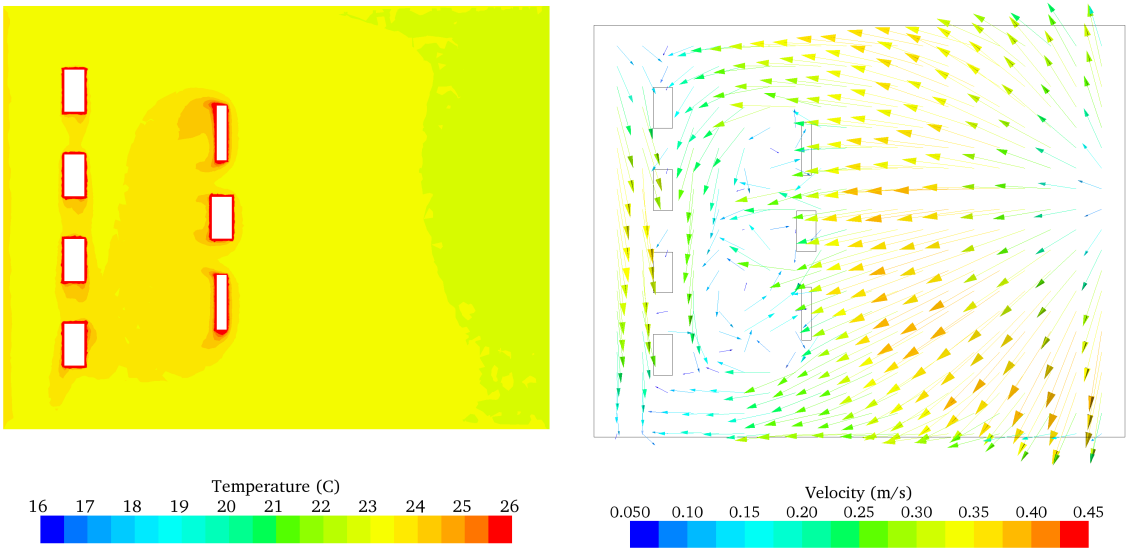
CFD Results

In this chapter the rest of CFD results is presented. High room's model results can be seen on figures A4.1, A4.2, A4.3, A4.4. Low room's model results can be seen on figures A4.5, A4.6, A4.7, A4.8.



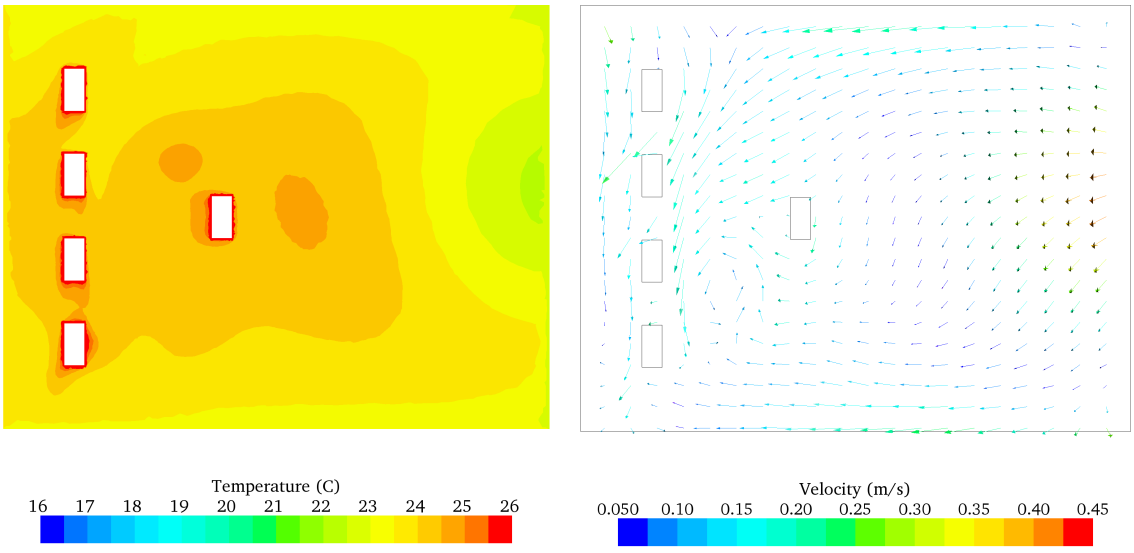
(a) (b)

Figure A4.1: *High room's model results on a Short cross-section for a) temperature, b) velocity*



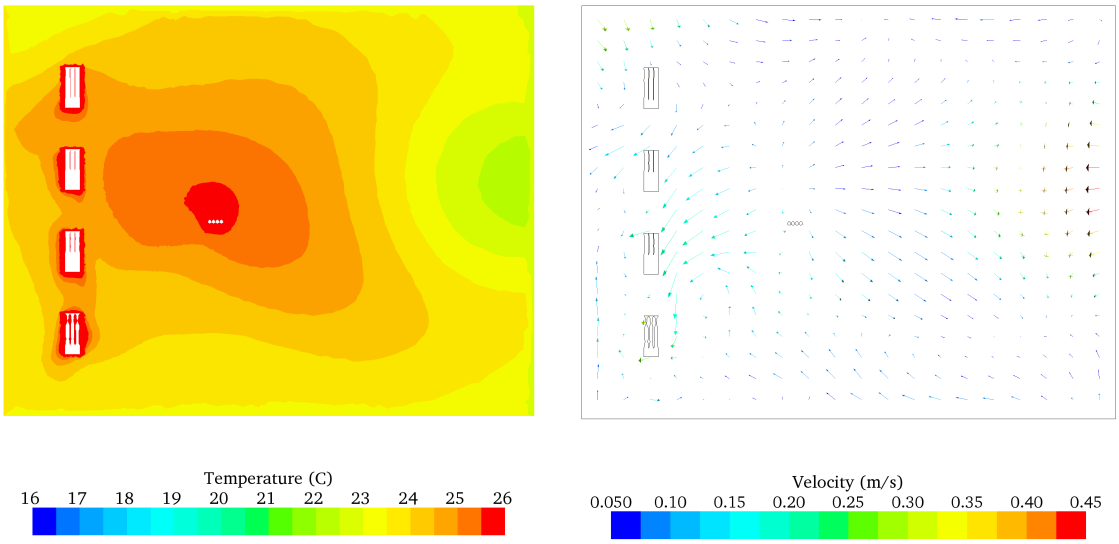
(a) (b)

Figure A4.2: *High room's model results on a 0.1 m plane cut for a) temperature, b) velocity*



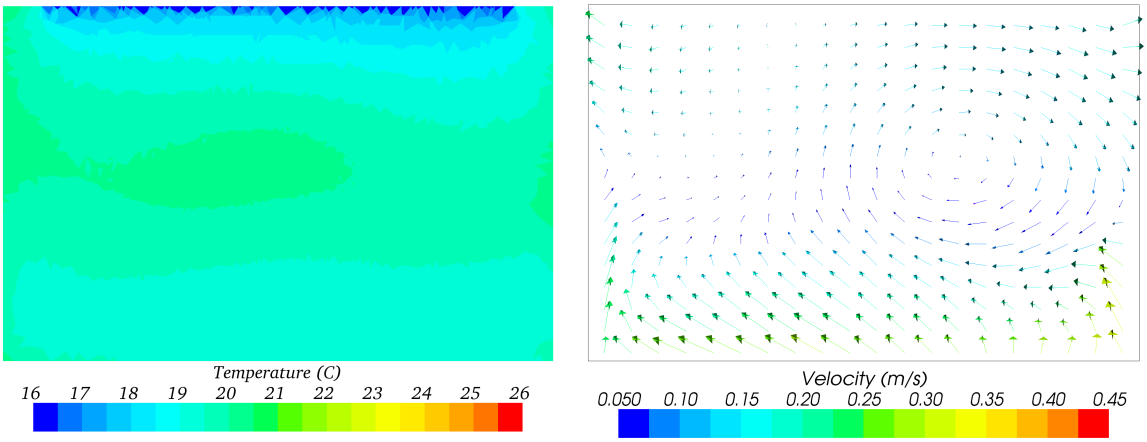
(a) (b)

Figure A4.3: *High room's model results on a 1.1 m plane cut for a) temperature, b) velocity*



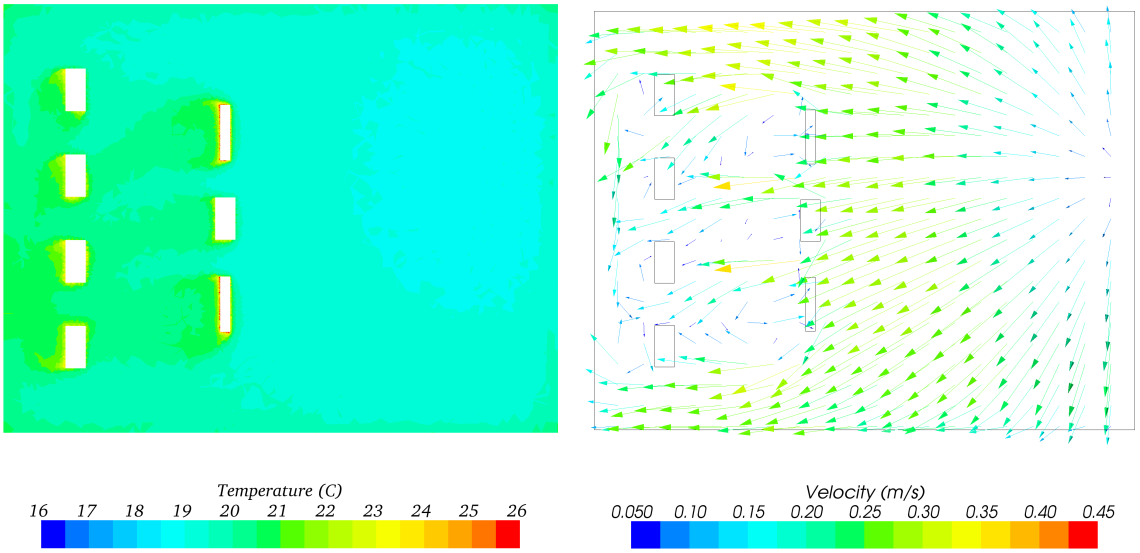
(a) (b)

Figure A4.4: *High room's model results on a 1.7 m plane cut for a) temperature, b) velocity*



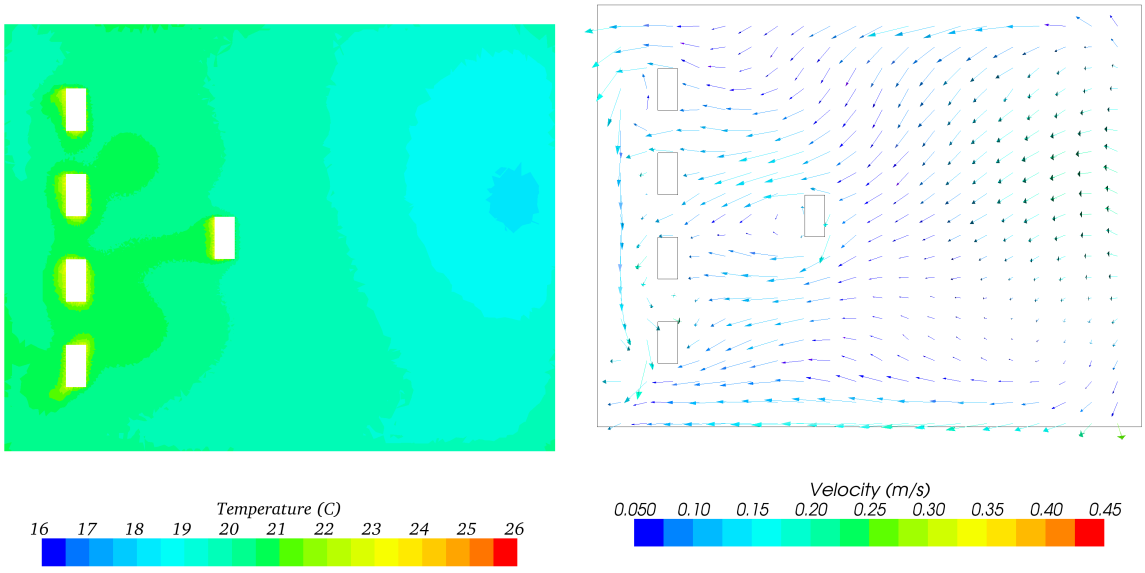
(a) (b)

Figure A4.5: *Low room's model results on a Short cross-section for a) temperature, b) velocity*



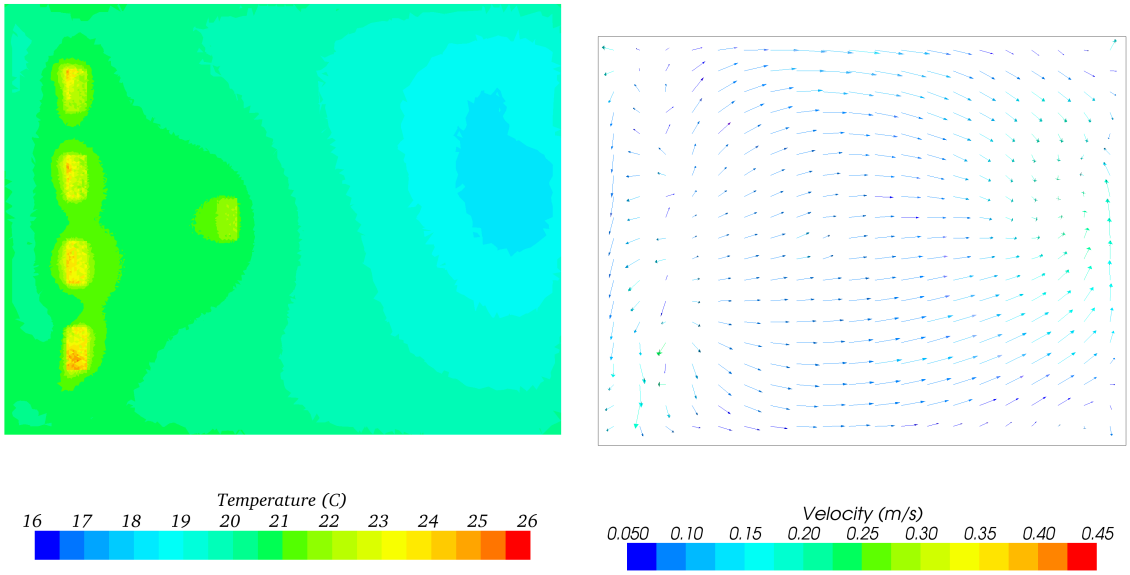
(a) (b)

Figure A4.6: *Low room's model results on a 0.1 m plane cut for a) temperature, b) velocity*



(a) (b)

Figure A4.7: *Low room's model results on a 1.1 m plane cut for a) temperature, b) velocity*

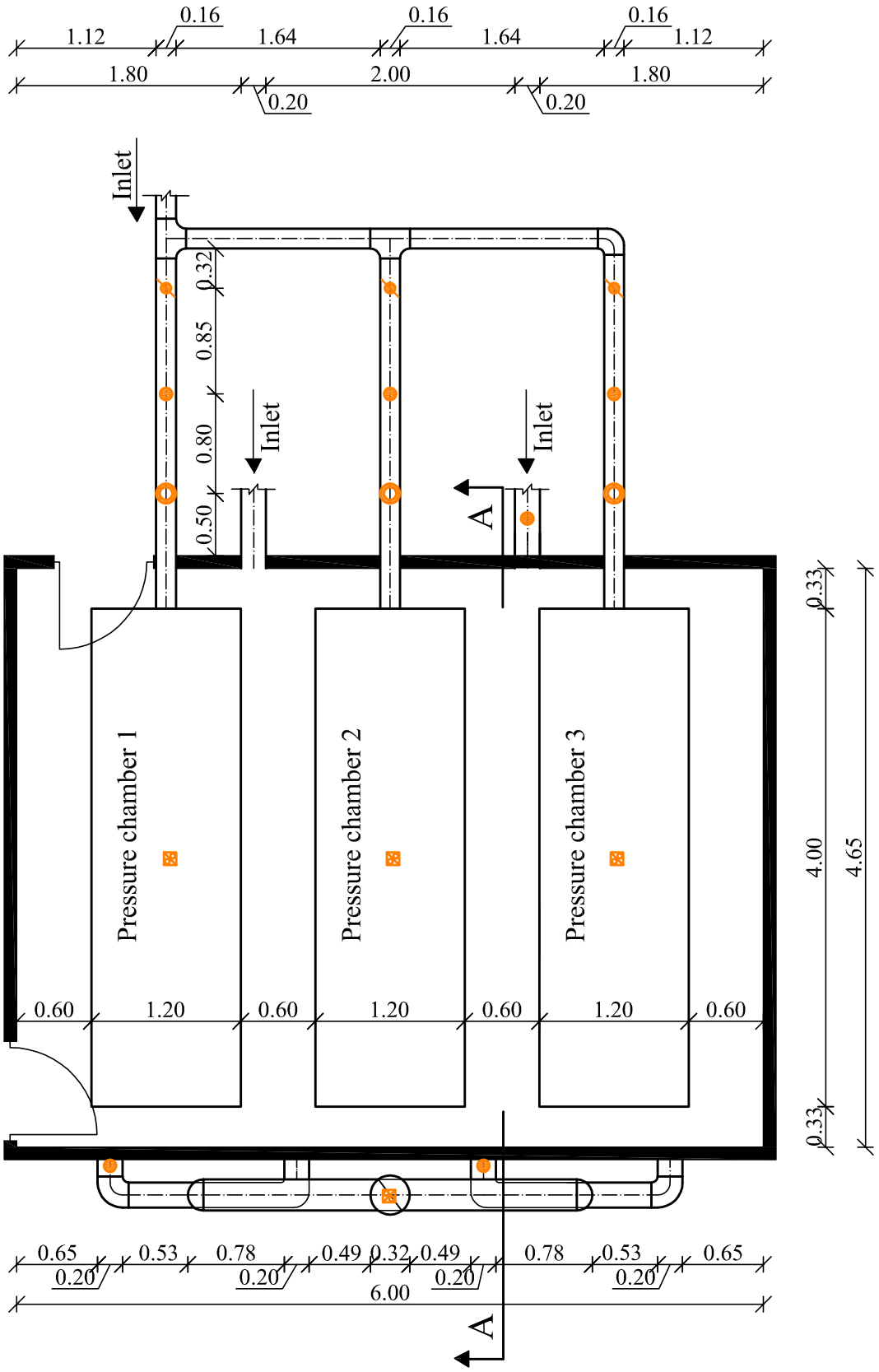


(a) (b)

Figure A4.8: *Low room's model results on a 1.7 m plane cut for a) temperature, b) velocity*

Part I

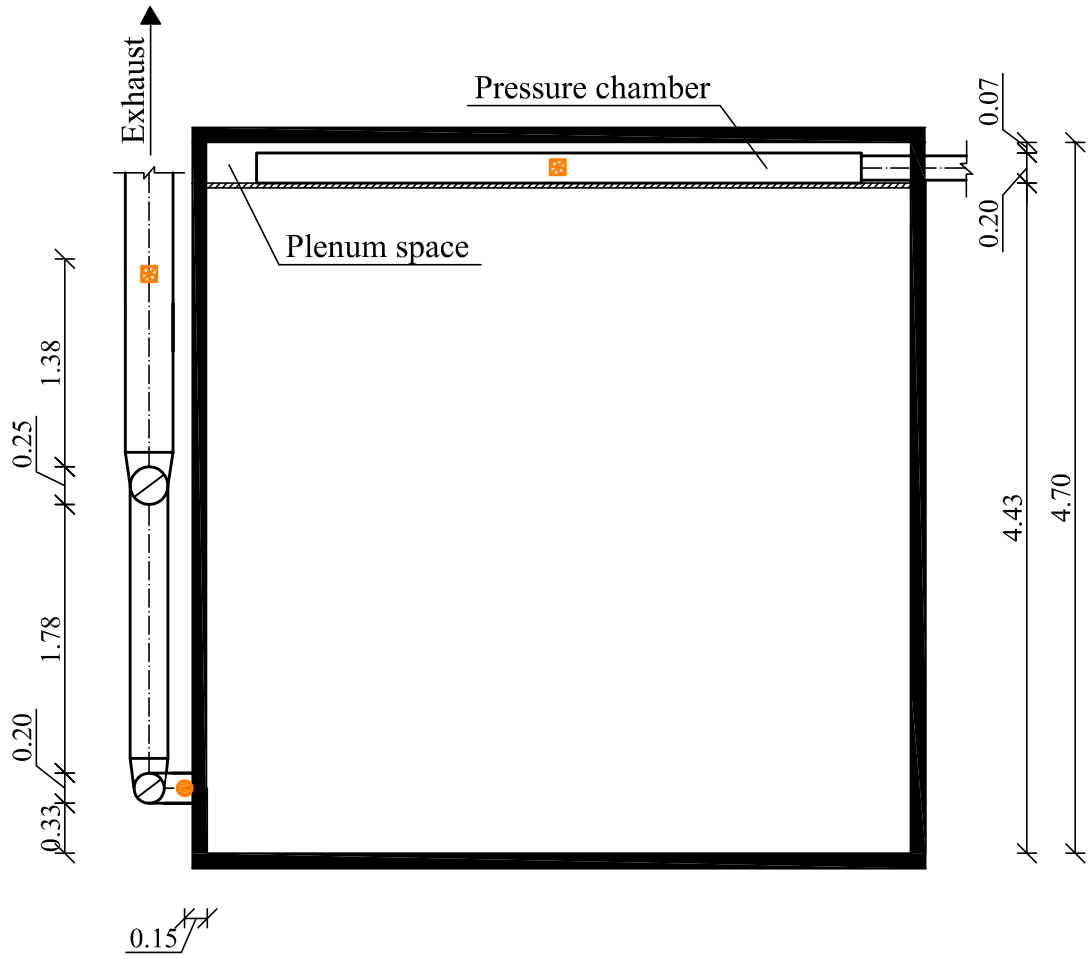
Drawings



	Tracer gas concentration
	Valve
	Thermocouple
	Anemometer
	Orifice plate

Scale: 1:50	Title: Test room plane view
	Authors: Anna Chodor, Piotr Taradajko
Aalborg Univeristy Department of Civil Engineering	Date: 28.02.2013

A-A



	Tracer gas concentration
	Thermocouple

Scale: 1:50	Title: Test room cross-section
	Authors: Anna Chodor, Piotr Taradajko
Aalborg Univeristy Department of Civil Engineering	Date: 28.02.2013

Bibliography

Artmann, Vonbank, and Jensen, **2008**. N. Artmann, R. Vonbank, and R. L. Jensen. *Temperature measurements using type K thermocouples and the Fluke Helios Plus 2287A data logger*. Aalborg University, 2008.

Cena and Dear, **1998**. Krzysztof Cena and Richard de Dear. *Field study of occupant comfort and office thermal environments in a hot-arid climate*. ISBN: 0-86905-648-4, ASHRAE Report. Murdoch University, 1998.

CR 1752, **1998**. CR 1752. *Ventilation for buildings - Design criteria for the indoor environment*, 1998.

DS/EN ISO 7726, **2001**. DS/EN ISO 7726. *Ergonomics of the thermal environment - Instruments for measuring physical quantities*, 2001.

DS/EN ISO 7730, **2006**. DS/EN ISO 7730. *Ergonomics of the thermal environment-Analitycal determination and interpretation of thermal comfort using calculation of the PMV and PPD indicies and local thermal comfort criteria*, 2006.

Jacobs and Knoll, **2009**. Piet Jacobs and Bas Knoll. *Diffuse Ceiling ventilation for fresh classrooms*. 4th Intern. Symposium on Building and Ductwork Air tightness and 30th AIVC Conference "Trends in High Performance Buildings...", October 1-2, Berlin, Germany, 2009.

Jakubowska, **2009**. Ewa Jakubowska. *Air Distribution in Rooms with Diffuse Ceiling Inlet*. COLD CLIMATE HVAC 2009 : Sisimiut Greenland, 16-19 March 2009, 2009.

Stannov, Melikov, Popiolek, and Jørgensen, **1998**. T. Stannov, A.K. Melikov, Z. Popiolek, and F.E. Jørgensen. *Test method for describing directional sensitivity of anemometers for low velocity measurements indoors*. ASHRAE Transactions, Vol. 104, p. 1481–1489, 1998.

Yang, **2011**. Honglu Yang. *Experimental and Numerical Analysis of Diffuse Ceiling Ventilation*. Master Thesis, Technical University of Denmark, 2011.