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Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads

Task 4 — Characterization of Air flow Within Drainage Cavities and Drainage Components

**Wahid Maref, Hamed H. Saber,
Gnanamurugan Ganapathy and Michael Nicholls**


30 March, 2015



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Summary

A benchmark assembly and a series of ten client wall assemblies were developed as part of the project “Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads”.

The purpose of this project was to assess the performance of wall drainage components and sheathing membranes (drainage system) in their ability to provide sufficient drainage and drying in Canadian climates with a moisture index (MI) greater than 0.9 and less than 3400 degree-days, or MI greater than 1.0 and degree days ≥ 3400 (primarily coastal areas). In these regions, the 2010 National Building Code requires a capillary break behind all Part 9 claddings. Currently, acceptable solutions to the NBC capillary break requirement include:

- (a) A drained and vented air space not less than 10 mm deep behind the cladding;
- (b) An open drainage material, not less than 10 mm thick and with a cross-sectional area that is not less than 80% open, behind the cladding;
- (c) A cladding loosely fastened, with an open cross section (i.e. vinyl, aluminum siding)
- (d) A masonry cavity wall or masonry veneer constructed according to Section 9.20 (i.e. 25 mm vented air space)

In this project, the performance of proposed alternative solutions for the capillary break was compared through laboratory evaluation and modeling activities to the performance of a wall built to minimum code requirements. The proposed drainage system would be deemed an alternative solution to the capillary break requirement in the National Building Code for use with all code compliant Part 9 claddings provided it exhibits adequate moisture performance as compared to a NBC-compliant benchmark wall assembly.

In This Report — A detailed description is provided of the test protocol and test apparatus necessary to assess air flow in drainage cavities of wall assemblies such that results from these tests could be used to benchmark the flow of air through cavities as simulated using the hygIRC-C model. The air flow characterization also included air flow through the various types of drainage components of interest to the project partners. Results from air flow tests of clear unobstructed cavities as well as air flow through the different porous media are given. These results permitted benchmarking hygIRC-C, the numerical simulation model used in this project to evaluate the hygrothermal performance of wall assemblies incorporating venting and drainage components.

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Benjamin Obdyke Incorporated
Canadian Concrete Masonry Producers Association
Cosella-Dorcen
DuPont Tyvek Weatherization Systems
HAL Industries Incorporated
Home Protection Office of British Columbia – HPO
Keene Building Products™
GreenGuard® Building Products (formerly Pactiv Building Products)
Roxul Incorporated
STO Corporation
TYPAR® Weather Protection System (Polymer Group Incorporated)

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Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads –

Task 4 – Characterization of Air Flow within Drainage Cavities and Drainage Components

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A Report for the

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30 March, 2015

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Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads –

Task 4 – Characterization of Air Flow within Drainage Cavities and Drainage Components

Final Report Task 4

Wahid Maref, Hamed H. Saber, Gnanamurugan Ganapathy and Michael Nicholls

1. Introduction and Background

A benchmark assembly and a series of eleven client wall assemblies were developed as part of the project “Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads”¹.

The purpose of this project is to assess the performance of wall drainage components and sheathing membranes in respect to their ability to provide sufficient drainage and drying in Canadian climates with a moisture index (MI) greater than 0.9 for degree-days <3400, or MI greater than 1.0 for degree days \geq 3400 (primarily coastal areas). In these regions, the 2010 National Building Code requires a capillary break behind all Part 9 claddings. Currently, acceptable solutions to the NBC capillary break requirement include:

- a) A drained and vented air space not less than 10 mm deep behind the cladding;
- b) An open drainage material, not less than 10 mm thick and with a cross-sectional area that is not less than 80% open, behind the cladding;
- c) A cladding loosely fastened, with an open cross section (i.e. vinyl, aluminum siding)
- d) A masonry cavity wall or masonry veneer constructed according to Section 9.20 (i.e. 25 mm vented air space)

In this project, the performance of proposed alternative solutions for the capillary break will be compared through laboratory evaluation and modeling activities to the performance of a wall built to minimum code requirements. If the system exhibits adequate performance, it will be deemed an alternative solution to the capillary break requirement in the National Building Code for use with all code compliant Part 9 claddings.

¹ A list of Project reports is provided in Appendix 1 of this report.

2. Objectives

The primary objective of Task 4 was to develop a test protocol and test apparatus necessary to assess the air flow in a drainage cavity of wall assemblies such that results from these tests could be used to benchmark the flow of air through cavities as simulated using the hygIRC-C model.

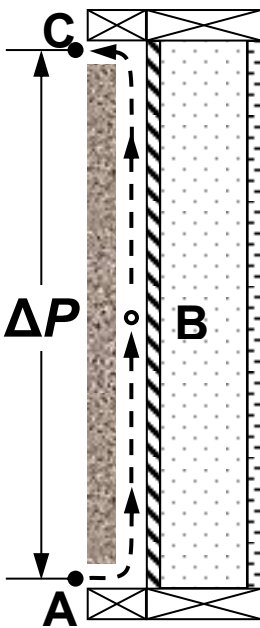
It was intended that the test apparatus be conceived such that the characteristics of air flow through different depths of cavity could be determined as a function of driving pressure and as well, that the characterization would also include air flow through the various types of drainage media of interest to the project partners.

To achieve these objectives, the experimental approach, as described below, allows defining the test parameters necessary to generate suitable data for benchmarking the model, that in turn permits development of details for a prototype apparatus and establishing requirements of instrumentation to ensure the proper type of sensors, and the accuracy and repeatability of the data acquired over the course of a test sequence.

The apparatus would thus need to provide air flow velocity profiles in cavities of varying depth when subjected to differential air pressure gradients.

3. Experimental program

The approach in defining the experimental program initially focused on the use of the simulation model to help frame the question of air flow in a vented or ventilated drainage cavity of a wall assembly, as is shown



schematically in Figure 1. In this figure, the path of air is shown moving inwards at the base of the wall assembly (A) and thereafter moving upwards through the drainage cavity to the outlet at the top of the wall (C). It is assumed that a pressure difference exists (ΔP) that drives air from the lower to the upper portion of the wall, although this flow might be reversed under different conditions; pressure differences might arise due to natural convective effects or the effects of pressure fluctuations on the exterior wall surface due to the buffeting action of the wind. Irrespective of whichever effect causes the pressure difference, of importance is knowledge of the rate of change in volume of air as might flow through the cavity due to a pressure difference as this would determine whether any moisture present in the cavity would be prone to dissipate, remain stagnant or accumulate. To estimate the volume exchange rate for the drainage cavity, there is a need to know the air velocity in the drainage space (e.g. at point B) as well as at the inlet and outlet of the space. To accurately estimate the average velocity in the rectangular drainage cavity, one would also need to know the air velocity profile across the width and depth of the cavity given the reduced velocity of air in proximity to the cavity boundaries.

Figure 1 – Idealised representation of air flow in a ventilated drainage cavity

As is depicted schematically in Figure 2, hygIRC-C was used at the outset of the experimental program to support development of a prototype test apparatus, the test protocol and selection of instrumentation. More specifically, the simulation model was used to understand flow in an idealized representation of the ventilated drainage cavity and to help predict the range of air velocities and corresponding pressures that arise at the inlet, outlet and along the height of the cavity space. This information was in turn used to determine the proper type air velocity sensors to acquire, the appropriate measurement range and accuracy of these sensors and the number of sensors needed to properly characterize the air velocity profiles in the cavity. Finally, information derived from simulation also permitted optimizing the location of sensors at the inlet, outlet and a mid-height of the cavity space.

Following the finalization of the design of the prototype apparatus, it was then fabricated (§ 3.2), the instrumentation calibrated (§ 3.3), as required, and preliminary tests undertaken to ensure that data could readily be acquired. Thereafter, the apparatus was commissioned for use (§ 3.4), a test protocol developed (§ 4), and the air flow characteristics on several different variations of a ventilated cavity were determined, the results of which are given in §5.

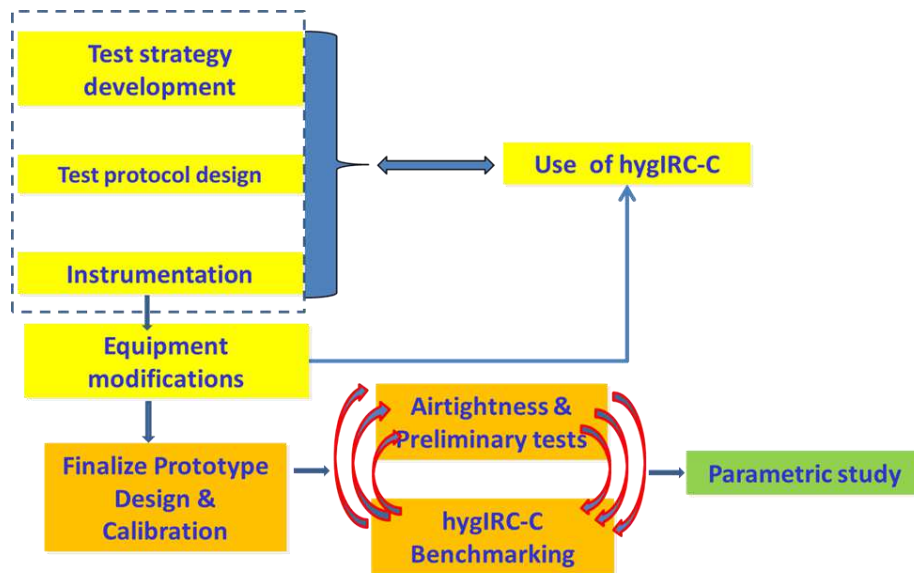


Figure 2 – Experimental program to characterize air flow in wall cavities and provide information to benchmark simulation model

3.1 Test parameters

It is evident from the previous discussion as regards the idealised representation of air flow in a ventilated drainage cavity that to characterize the airflow of the drainage cavity, or the cavity and drainage component combined, the pressure drop (ΔP) across the cavity must be determined, the cavity being represented by two vertical parallel plates. The plates thus form the boundary of the “control volume” from which measurements are extracted. The air flow rate through the control volume should also be known as well as the temperature and relative humidity of the air in this space. In addition, the pressure as well as the air velocity should be acquired at the inlet, outlet and the air velocity along the path of the control volume. Finally, the air tightness of the test apparatus should be known as any air leakage from

the apparatus should necessarily be taken into account. In summary, the following test parameters were acquired over a test sequence:

- Air pressure at the inlet and outlet of the control volume (permits calculating the pressure differential between the inlet and outlet);
- Air velocity at the inlet, outlet and at mid-height of the control volume;
- Air temperature and relative humidity at the inlet and outlet (permits calculating the air density);
- Air flow rate;
- Air tightness of test apparatus (delimits extraneous air leakage of apparatus).

3.2 Test Apparatus Prototype

The test apparatus prototype is shown in Figure 3. It consists of an air pump; conduit to a diffuser at the inlet (inlet diffuser); the inlet chute, the cavity formed by two parallel plates (the distance between the plates defining the cavity depth, and set by the use of a metal spacer of predetermined thickness); the outlet chute; and the outlet diffuser. The use of diffusers at the inlet and outlet permitted transition from turbulent flow to a more regular air flow, if not to say laminar flow prior to entry at the inlet chute or exit at the outlet chute. A filter was placed within the diffuser to further regulate the flow upstream of the

placement of sensors, as shown in the figure. As such, the air velocity profiles could be maintained within the spaces downstream of the diffuser at the inlet, upstream at the outlet and across the cavity depth within the control volume, thereby permitting placement of air velocity and other sensors in these controlled spaces.

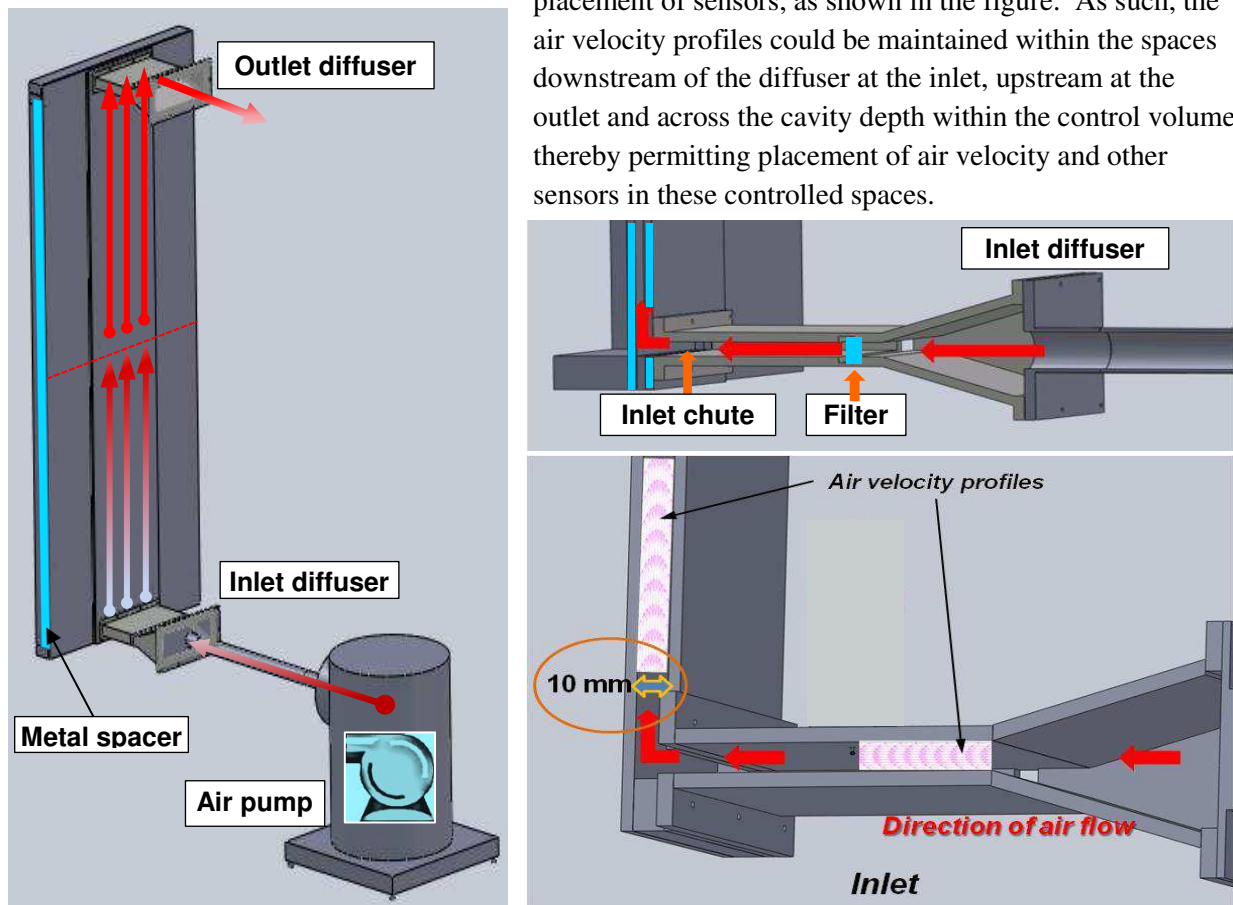


Figure 3 – Test apparatus prototype showing air pump, inlet and outlet diffuser, metal spacer to maintain selected cavity depth of control volume

3.3 Instrumentation

The instrumentation was necessarily determined in relation to the test parameters, as provided in Section 3.1; thus these included sensors to acquire data of: air pressure, velocity, temperature and relative humidity and air flow rate. The make and model of the respective sensors is given in Table 1.

Table 1 – List of Sensors and respective accuracies for Cavity Air Flow Characterization Apparatus

Sensor	Make and model(s)	Operational range and accuracy
Air pressure	Setra pressure Transducers	Range: ± 60 Pa (0.25"WC), accuracy: 1% of full scale
Air velocity	Schiltknecht omnidirectional anemometer; Model : ThermoAir 64	Range: 0-1 m/s; accuracy: + 0.5% of full scale Range: 1-5 m/s; accuracy: 1.5% of value; +0.5% of F.S.
Temperature	T-Type Thermocouples	Range: -30°C to $+30^{\circ}\text{C}$; accuracy: $\pm 0.2^{\circ}\text{C}$
Relative humidity	Vaisala Relative Humidity Sensors; Model : HMP110	Range: 0-90% RH; accuracy: $\pm 3\%$ RH

3.3.1 Location of sensors

The placement of the respective hot wire anemometer air velocity sensors is shown in Figure 4. These are located at each of the control locations: at the inlet chute, outlet chute and at mid-height of the cavity space. In proximity to the anemometers and at each of the three control locations two pressure taps were installed that were joined to a respective set of pressure transducers using plastic tubing. In this same space, thermocouples were installed from which temperature measurements could be made. Finally, the relative humidity of the air flow was monitored with a set of three relative humidity sensors, one each located in the air stream at the respective control locations.

3.3.2 Sensor calibration

All of the sensors used for the cavity air flow characterization apparatus were calibrated prior to undertaking the mock up tests and thus helped ensure the proper commissioning of the apparatus.

- Air pressure sensors were calibrated at NRC using the air pressure sensors calibration facility; the calibration results are provided in the Appendix;
- Air velocity sensors were acquired with a calibration certificate; these are provided in the Appendix;
- Thermocouples were calibrated at NRC using the thermocouple calibration facility; the calibration results are provided in the Appendix;
- Air flow sensors were acquired with a calibration certificate; these are provided in the Appendix.



Figure 4 – Location of anemometers at each of the control locations of the cavity air flow characterization apparatus; at inlet and outlet chutes and at mid-height of cavity space

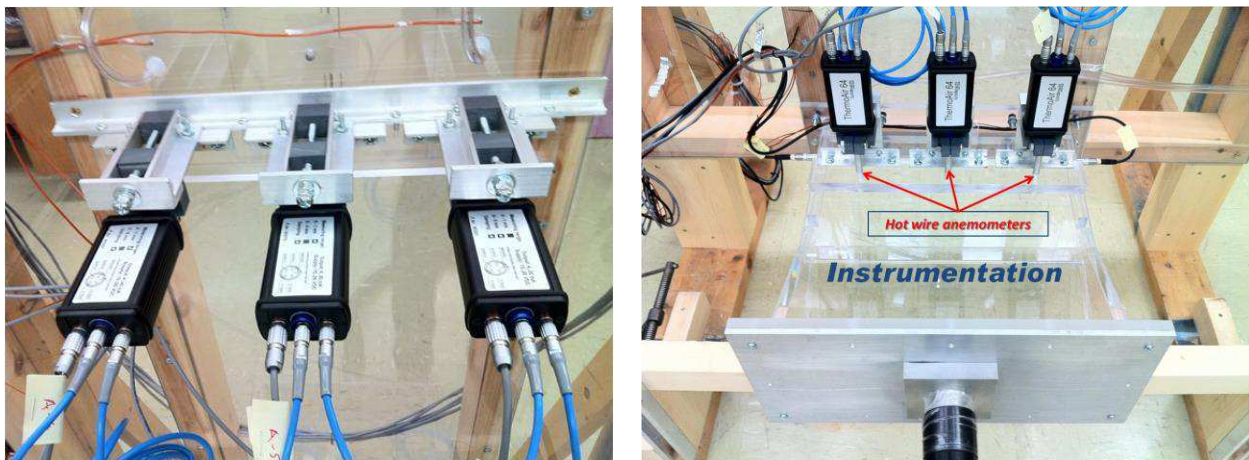


Figure 5 – Showing anemometers in place at (A) mid-height of cavity space and (B) at inlet chute

3.4 Commissioning

Prior to undertaking the cavity air flow characterization (CAFC) tests, the apparatus was commissioned by completing air leakage tests to establish the extraneous air leakage rate for apparatus. Thereafter, a set of preliminary tests were undertaken from which the velocities acquired using the anemometers were determined and orders of magnitude of the different sensors established. Both of these tasks are described in the subsequent sections.

3.4.1 Air Leakage Test

An air leakage test was completed on the test apparatus for each of the spacers. The results from these tests show that the extraneous air leakage of the cavity air flow characterization (CAFC) apparatus for all configurations tested, was below the measureable value of the air flow sensors, thus essentially not measurable and taken as zero.

As such the CAFC apparatus was deemed sufficiently tight to permit undertaking tests with confidence.

3.4.2 Apparatus commissioning

The apparatus was commissioned through a set of preliminary air flow tests such that:

- The order of magnitude of air velocities acquired at the inlet and outlet chutes was measurably the same;
- For a cavity air space having depths of 10 mm and 20 mm, the velocities acquired at mid-height of the apparatus were greater than that acquired at the inlet and outlet for which the cavity depth at these locations is 25 mm;
- A low range anemometer (i.e. air velocity ranging from 0 – 1m/s), be used for the configuration having cavity depth of 10 mm and to ensure that velocities are not exceeded, the maximum pressure difference should not exceed ca, 5 Pa between inlet and outlet pressures.
- A higher range anemometer be used (i.e. (1 – 5m/s) for tests undertaken at greater pressure differences.

The preliminary cavity air flow characterization (CAFC) tests undertaken to commission use of the apparatus (results of which are shown in Figure 6) also helped determine that:

- Low range anemometer (0 – 1m/s) be used at the inlet chute for all tests (i.e. all ΔP s), and for the outlet chute and mid-height locations at pressures < 15 Pa;
- High range anemometer (1 – 5m/s) be used at the central axis of the apparatus locations, and for the outlet and mid-height locations for pressures differences of >15 Pa.

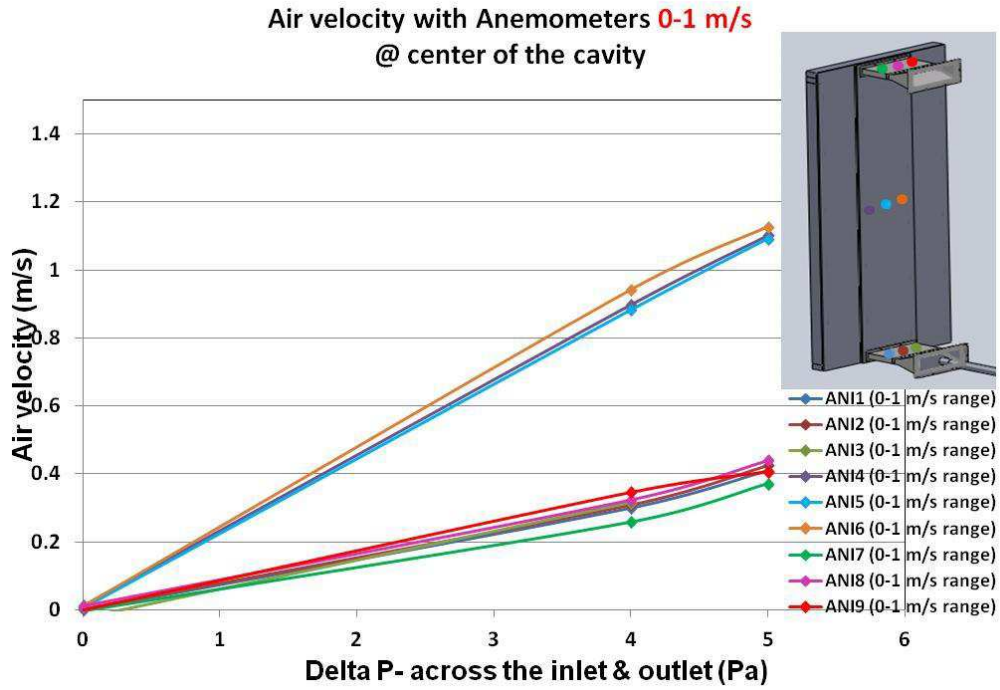


Figure 6 – Air velocity(m/s) as a function of pressure difference (Pa) between inlet and outlet chute along center of chute

4. Experimental Procedure and Test Protocol

Prior to each test sequence the apparatus was first set up to the required cavity depth by installing the appropriate spacer (Figure 7) and, if required, a drainage component, and thereafter, sealing the apparatus as needed to minimize air leakage.

Once a spacer of given depth was installed in the apparatus, and following the calibration procedure to ensure that the apparatus was airtight (i.e. did not provide an extraneous leakage), a test sequence consisted of first, generating an appropriate level of pressure difference and thereafter, acquiring air velocity, pressure and relative humidity data for a period not exceeding 10 minutes

The test protocol that was developed included the following steps:

1. Air leakage test to quantify the extraneous air leakage of the air flow characterization apparatus (AFCA) and rectify any leakage to minimize measurement errors;
2. Induce air flow through the cavity and adjust flow to the desired pressure differential given the pressure readings at the inlet and outlet chutes;
3. Determine uncertainty of pressure sensor measurements at each location;
4. For each differential pressure:
 - Measure air velocity at inlet, outlet and mid-height of wall cavity;
 - For each of these locations, acquire air velocity profile across width and depth of cavity;
 - The air velocity profile across the width of a cavity is obtained with 3 anemometers, one located along the center of the cavity and the other two an equal distance either side of the center of the cavity;
 - The air velocity profile across the depth of the cavity is acquired by movement of an anemometer to a predetermined depth in the cavity.



Figure 7 – Photo showing metal spacers for cavity depths of 10, 20 and 25 mm

The resulting set of tests and measurements are given in Table 2. In this table the cavity depth is given as is the pressure differential at which the tests were conducted and as well, the depth of the anemometer in the cavity for the respective inlet outlet and wall locations.

Several configurations were tested that included tests undertaken for:

- **CONFIGURATION 1:** Cavity depth of 10 mm
- **CONFIGURATION 2:** Cavity depth of 20 mm
- **CONFIGURATION 3:** Cavity depth of 25 mm
- **CONFIGURATION 4:** 10 mm Cavity Depth with Drainage Medium (Client C)
- **CONFIGURATION 5:** 10 mm Cavity Depth with Drainage Medium (Client G)
- **CONFIGURATION 6:** 10 mm Cavity Depth with Drainage Medium (Client E)
- **CONFIGURATION 6:** 10 mm Cavity Depth with Drainage Medium - sealed (Client E)
- **CONFIGURATION 7:** 4 mm Cavity Depth with Drainage Medium (Client I)

The results from these tests are provided in the subsequent section.

Table 2 – List of data acquired at a given cavity depth and pressure differential for control volumes having unobstructed cavities and those incorporating a drainage medium

Drainage Medium	Cavity Size (mm)	ΔP (Pa)	Inlet Anemometer			Wall Anemometer			Outlet Anemometer		
			Left	Mid	Right	Left	Mid	Right	Left	Mid	Right
Air	10	5, 10, 15, 20, 25	√	√	√	√	√	√	√	√	√
	20	1.3, 4, 5, 6.5	√	√	√	√	√	√	√	√	√
	25	0.8, 1.7, 2.5, 3.4, 4.2	√	√	√	√	√	√	√	√	√
Client C	10	5,10,15,20,25,30,40,50	√	√	√	√	√	√	√	√	√
Client G	10	5,10,15,20,25,30,40,50	√	√	√	√	√	√	√	√	√
Client E	10	5,10,15,20,25,30,40,50	√	√	√	√	√	√	√	√	√
Client E (Sealed)	10	5,10,15,20,25,30,40,50	√	√	√	√	√	√	√	√	√
Client I	5	5,10,15,20,25,30,40,50	√	√	√	√	√	√	√	√	√

5- Experimental Results

The experimental results for each configuration of wall or drainage cavity were obtained in the order given in Table 2. A selection of these results is provided in the subsequent sections. The uncertainty in pressure sensor readings at given pressure differentials for sensors located at the inlet and outlet and mid-height of the cavity (middle), are given in Appendix 2. The values for uncertainty in pressure sensor readings ranges from ± 0.1 Pa for pressures ranging from ca. 2.5 to 6.5 Pa.

5.1 Configuration 1: 10 mm Air Cavity Depth

The results of air flow characterization tests for a wall cavity of 10 mm depth and for which the air velocity profile measurements at a pressure differential of 5 Pa, are given in Figure 8. Values of air velocity (m/s) are provided for the inlet chute, mid-height (wall) and outlet chute as a function of the values in depth of the cavity (re: thickness of chute) and these values are provided for each of the anemometers located across the width of the cavity space.

As can be seen in Figure 8, the velocity profiles across the depth of the cavity are generally parabolic in nature and all three anemometers across the width of the cavity yield essentially the same results. The maximum velocities at the inlet and outlet chutes are less than those at the mid-height of the cavity space (wall), ca. 0.6 m/s at the chutes as compared to 1.1 -1.4 m/s at mid-height. This is entirely expected as the width of the cavity at mid-height is 10 mm whereas it is 25 mm in either of the chutes. The other results at different pressures 10, 15, 20 and 25 Pa are in Appendix 3.

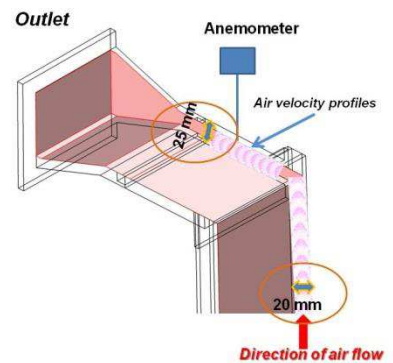
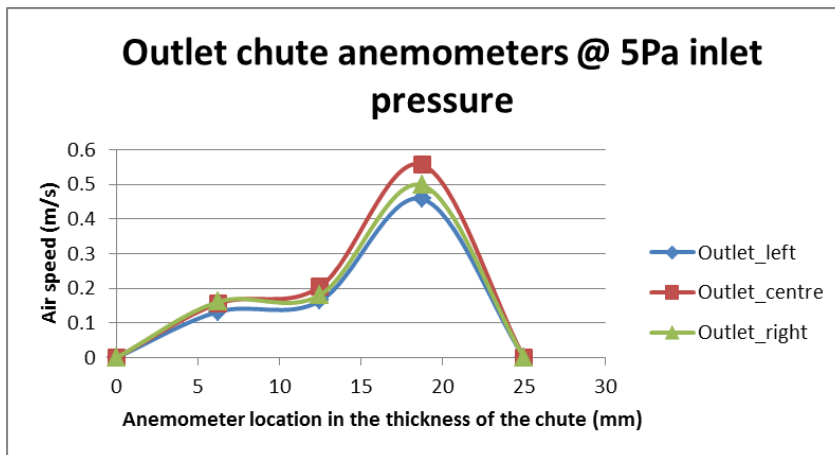
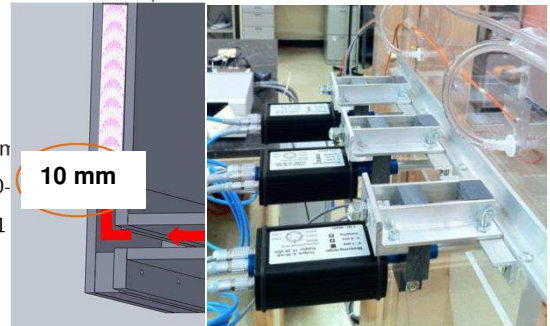
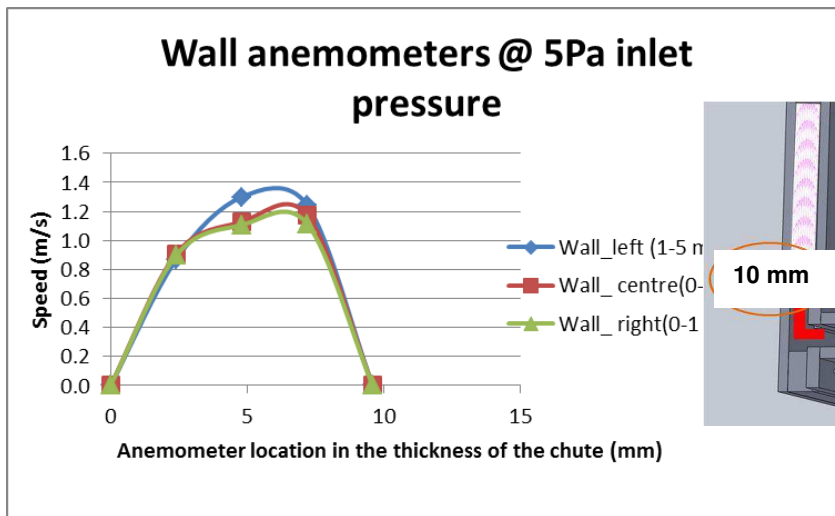
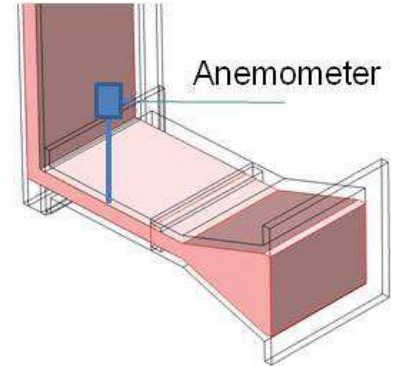
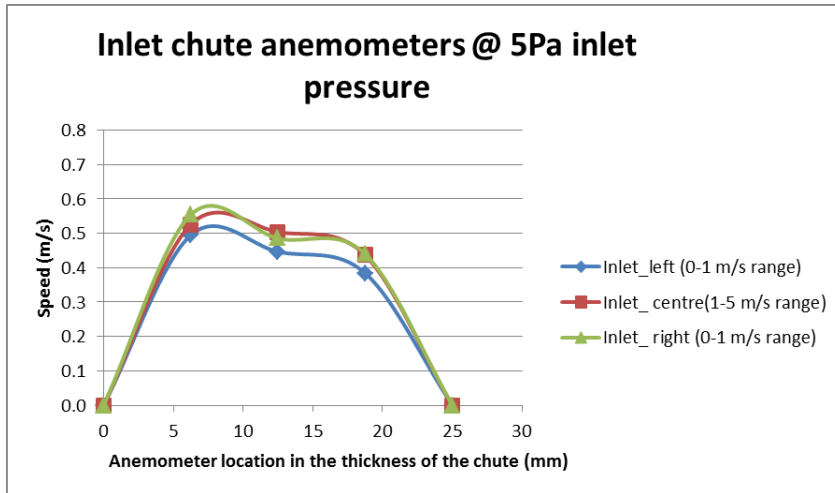


Figure 8 – Air velocity profiles at a pressure differential of 5 Pa for a cavity of 10 mm depth at mid-height (wall), a cavity of 25 mm depth at the inlet and outlet chute

5.2 Configuration 2: 20 mm Air Cavity Depth

The results of air flow characterization tests for a cavity of 20 mm depth and for which the air velocity profile measurements at a pressure differential of 1.3 Pa, are given in Figure 9. Values of air velocity (m/s) are provided for the inlet chute, mid-height (wall) and outlet chute as a function of the values in depth of the cavity (re: thickness of chute) and these values are provided for each of the anemometers located across the width of the cavity space.

As can be seen in Figure 9, the velocity profiles across the depth of the cavity are generally parabolic in nature and all three anemometers across the width of the cavity yield essentially the same results. The maximum velocities at the inlet and outlet chutes are less than those at the mid-height of the cavity space (wall), ca. 0.6 m/s at the chutes as compared to 0.8-0.9 m/s at mid-height. This is entirely expected as the width of the cavity at mid-height is 20 mm whereas it is 25 mm in either of the chutes.

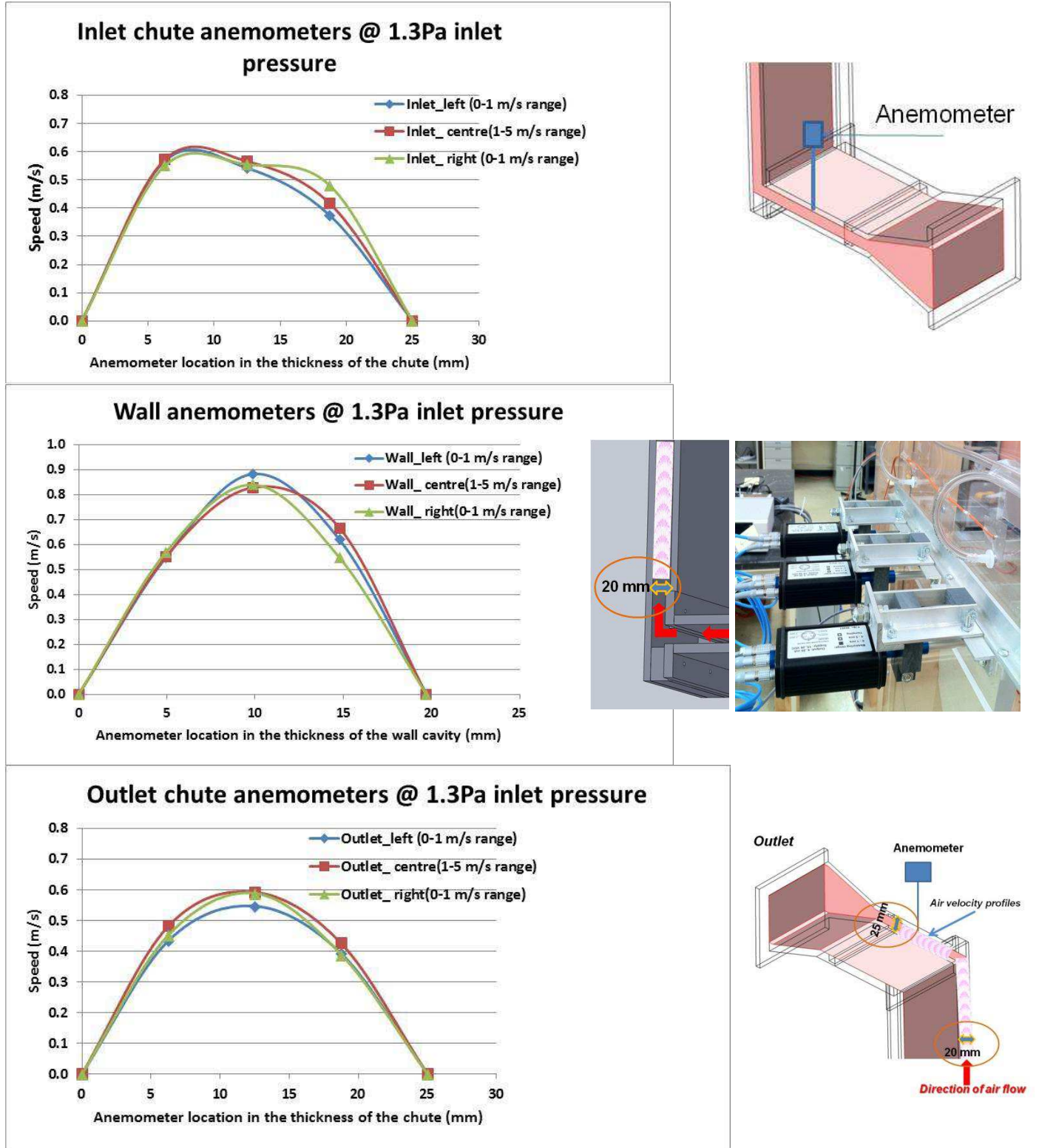


Figure 9 – Air velocity profiles at a pressure differential of 1.3 Pa for a cavity of 10 mm depth at mid-height (wall), a cavity of 25 mm depth at the inlet and outlet chute

5.3 Configuration 3: 25 mm Air Cavity Depth

The results of air flow characterization tests for a cavity of 25 mm depth and for which the air velocity profile measurements at pressure differentials of 0.8 Pa are given in Figure 10, and at 3.4 Pa in Figure 11. As in the previous section, values of air velocity (m/s) are provided for the inlet chute, mid-height (wall) and outlet chute as a function of the values in depth of the cavity (re: thickness of chute) and these values are provided for each of the anemometers located across the width of the cavity space.

As regards the air velocity measurements acquired at 0.8 Pa pressure differential, values at the inlet and outlet chutes and at the mid-height of the cavity are reasonably the same and the shape of the respective air velocity curves across the depth of the cavity are parabolic; maximum values are ca. 0.6 m/s for each of the control locations.

Air velocity measurements at 3.4 Pa pressure differential at each of the control locations are the same and the shape of the respective air velocity curves across the depth of the cavity are essentially parabolic although the change in slope at the vertex is not as well developed as was seen for the results obtained at 0.8 Pa; maximum values for air velocity attained at mid-depth of the cavity range from 1.2 to 1.4 m/s.

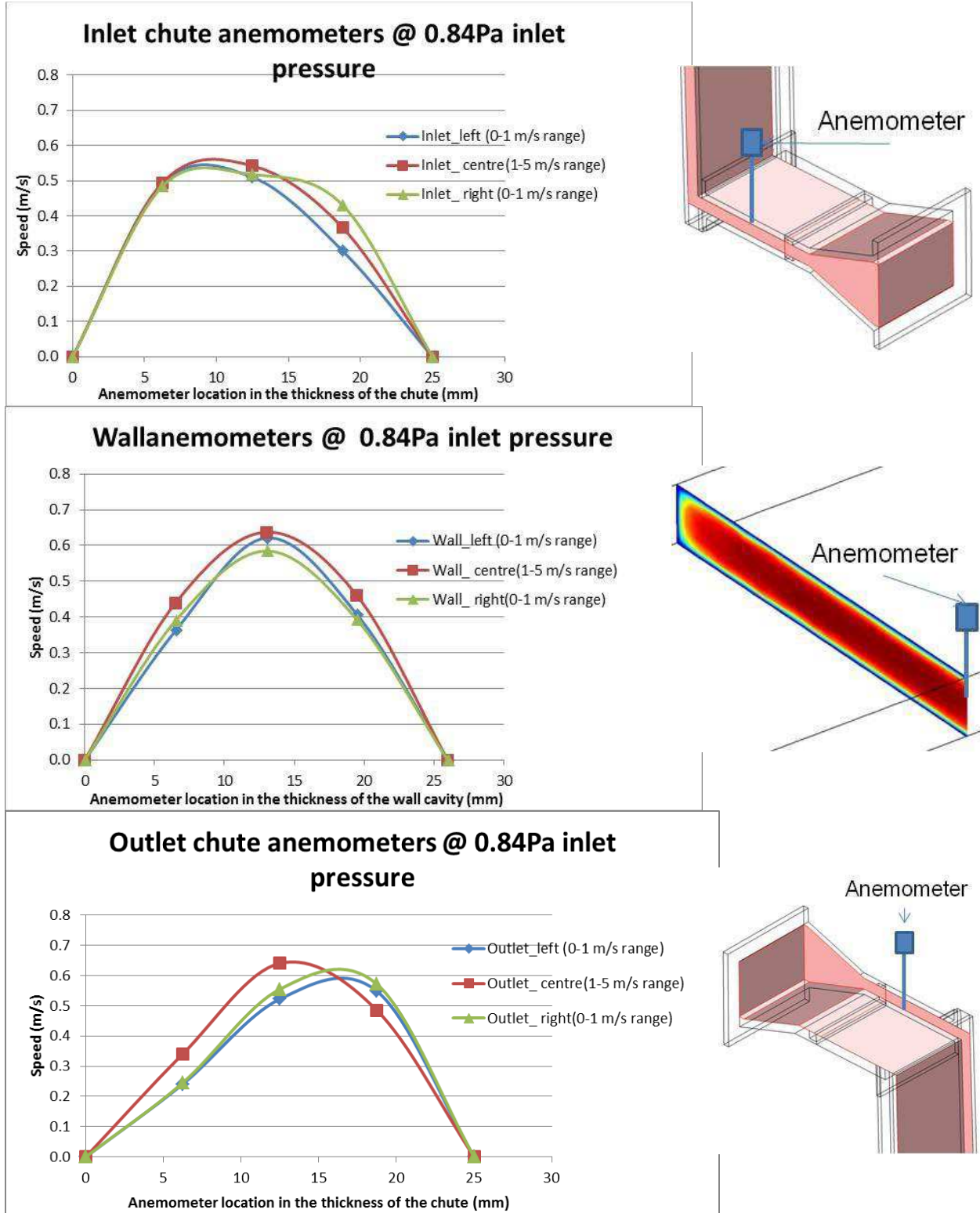


Figure 10 – Air velocity profiles across depth of 25 mm cavity for 3 anemometers (at centre: ●) at pressure differential of 0.8 Pa for inlet chute, mid-height (wall) and outlet chute

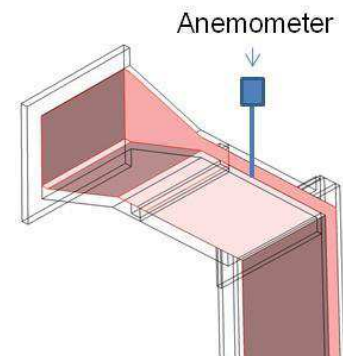
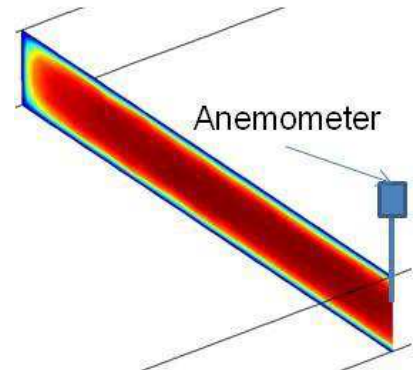
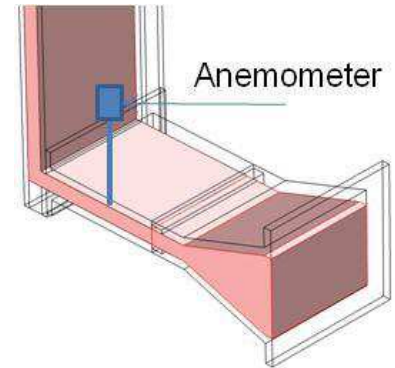
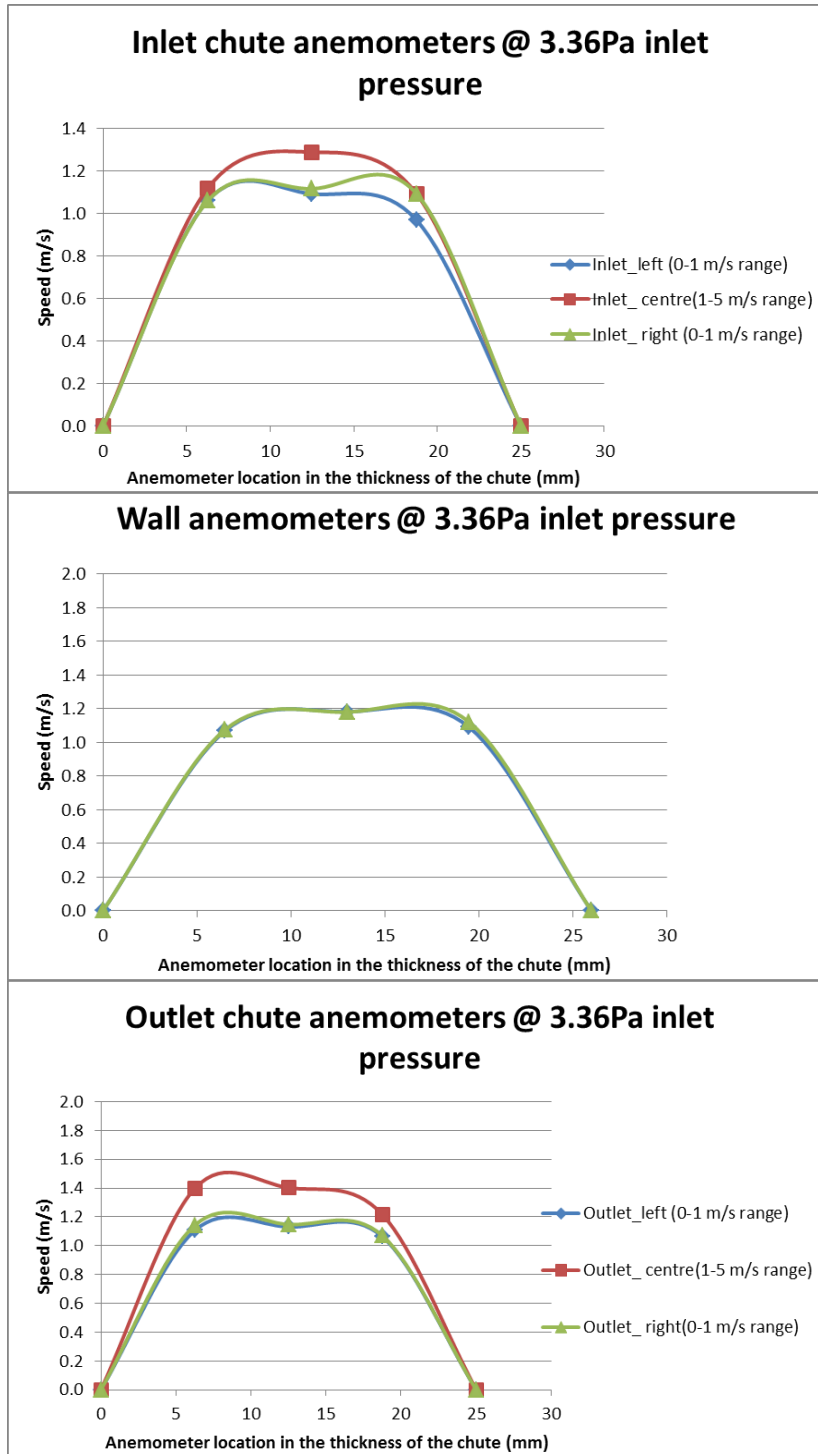


Figure 11 – Air velocity profiles at a pressure differential of 3.5 Pa for a cavity of 25 mm depth at the inlet chute, mid-height (wall) and outlet chute

5.4 Configuration 4: 10 mm Cavity Depth with Drainage Medium (Client C)

In Configuration 4, the drainage medium product of Client C (Open matrix Nylon mesh (10 mm]) bonded to PP² nonwoven sheathing membrane) was enclosed in a 10 mm air space as shown in Figure 12 and in which can also be seen a sectional view (Figure 12 A) of the drainage product as installed in the cavity. Two lengths of the drainage product were installed in the cavity (Figure 12 B) one upstream and the other downstream of the set of three anemometers located at mid-height of the cavity.

Measurements at the inlet and outlet chute and at mid-height (wall) of the cavity space were acquired at 15, 20, 30 and 50 Pa for which the air velocity measurement results are provided, respectively, in Figure 13 to Figure 16.

The air velocity profiles at a pressure differential of 15 Pa and as a function of the depth of the cavity are given in Figure 13. Values for air velocity at mid-height (wall) of the cavity space are, as might be expected, greater than those at either the inlet or outlet chutes given that the depth of the cavity at mid-height is 10 mm as compared to 25 mm at the other control locations. Maximum velocities attained at either the inlet or outlet chute are ca. 0.3-0.4 m/s whereas at the mid-height these are in excess of 0.8 m/s.

The shape of the velocity profiles at the inlet or outlet chutes no longer appears parabolic as the shape of the vertex is considerably attenuated as compared to the results obtained for either the 20 mm or 25 mm cavity space, both for which the flow was unobstructed by the presence of drainage media.

As well, the velocity profiles have been skewed by the presence of the drainage medium as is shown in Figure 12C. For example, a lower velocity was measured where the anemometer aligned with a channel whereas greater velocities were observed when the sensor was aligned with portions of the medium between channels. The velocity obtained when the anemometer was not aligned with a channel was about > 1.5 times as compared to when it was aligned (i.e. ca. 0.5 m/s as compared to 0.85 m/s).

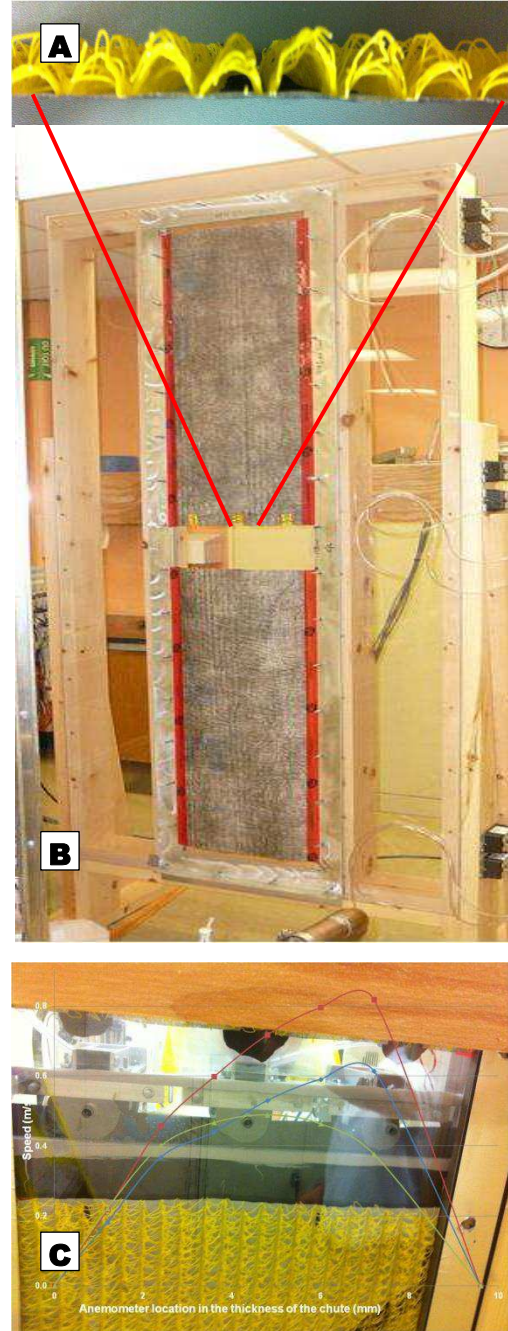


Figure 12 – Configuration 4: 10 mm cavity incorporating drainage medium (Client C); (a) Sectional view of cavity; (B) Drainage medium installed in cavity; (C) Velocity profiles skewed by presence of medium

² PP - polypropylene

The air velocity profiles at a pressure difference of 20 Pa and as a function of the depth of the cavity are given in Figure 14. As was the case for results of air velocity obtained at 15 Pa pressure difference, values for air velocity at mid-height (wall) of the cavity space are, greater than those at either the inlet or outlet chutes given that the depth of the cavity at mid-height is smaller (10 mm) than that of either the inlet or outlet chute (25 mm). Maximum velocities attained at either the inlet or outlet chute are ca. 0.3-0.4 m/s whereas at the mid-height these were ca. 1 m/s as compared to 0.8 m/s obtained at 15 Pa. The shape of the velocity profiles at the inlet or outlet chutes was no different than that obtained at 15 Pa pressure difference. The shape was no longer parabolic and the vertex was attenuated as compared to the results obtained for the cavity space unobstructed by the presence of drainage media.

As can be seen in

Figure 14, the velocity profiles have been skewed by the presence of the drainage medium as was the case for that obtained at 15 Pa. Lower velocities were measured where the anemometer was aligned with a channel (maximum of 0.6 m/s) and the profile has a parabolic shape. Whereas greater velocities (i.e. ca. 0.8-1.0 m/s) were observed when the sensor was aligned with portions of the medium between channels.

The air velocity profiles at a pressure difference of 30 Pa and as a function of the depth of the cavity are given in Figure 15. The same trends as were observed at 15 and 20 Pa are evident for measurements acquired at 30 Pa:

- Air velocity at mid-height (wall) of the cavity was greater than those at either the inlet or outlet chutes (e.g. maximum velocities attained at either the inlet or outlet chute are. > ca 0.4 m/s whereas at the mid-height these were > ca. 1.1 m/s;
- The shape of the velocity profiles at the inlet or outlet chutes is no longer parabolic; but no different than that obtained at a 15 Pa pressure difference;
- The velocity profiles were skewed by the presence of the drainage medium.

The air velocity profiles at a pressure difference of 50 Pa and as a function of the depth of the cavity are given in Figure 16. As was the case for air velocity values obtained at 15, 20 and 30 Pa, the same trends prevailed at 50 Pa; specifically:

- Air velocity at mid-height (wall) was greater than the other control locations (e.g. maximum velocities attained at the inlet or outlet chute are > ca. 0.6 m/s and at mid-height these were > ca. 1.4 m/s;
- The shape of the velocity profiles was not parabolic; but no different than obtained at lower pressures;
- The velocity profiles at mid-height of the cavity was skewed by the presence of the drainage medium; (Values for maximum velocity ranging from ca. 1.1 to 1.4 m/s)

The air velocity profiles in depth of cavity at given pressure differentials for a cavity with a drainage medium (Client C) is given in Figure 17; the increase in air velocities with a corresponding increase in pressure difference is clearly evident for all control locations.

The air velocity as a function of pressure differentials at the cavity centre of the inlet and chute, and mid-height (wall) of cavity with a drainage medium (Client C), is given in Figure 18. Maximum values for air

velocities ranged between ca. 0.3 and > 1.2 m/s for corresponding values of pressure difference of 5 to 50 Pa.

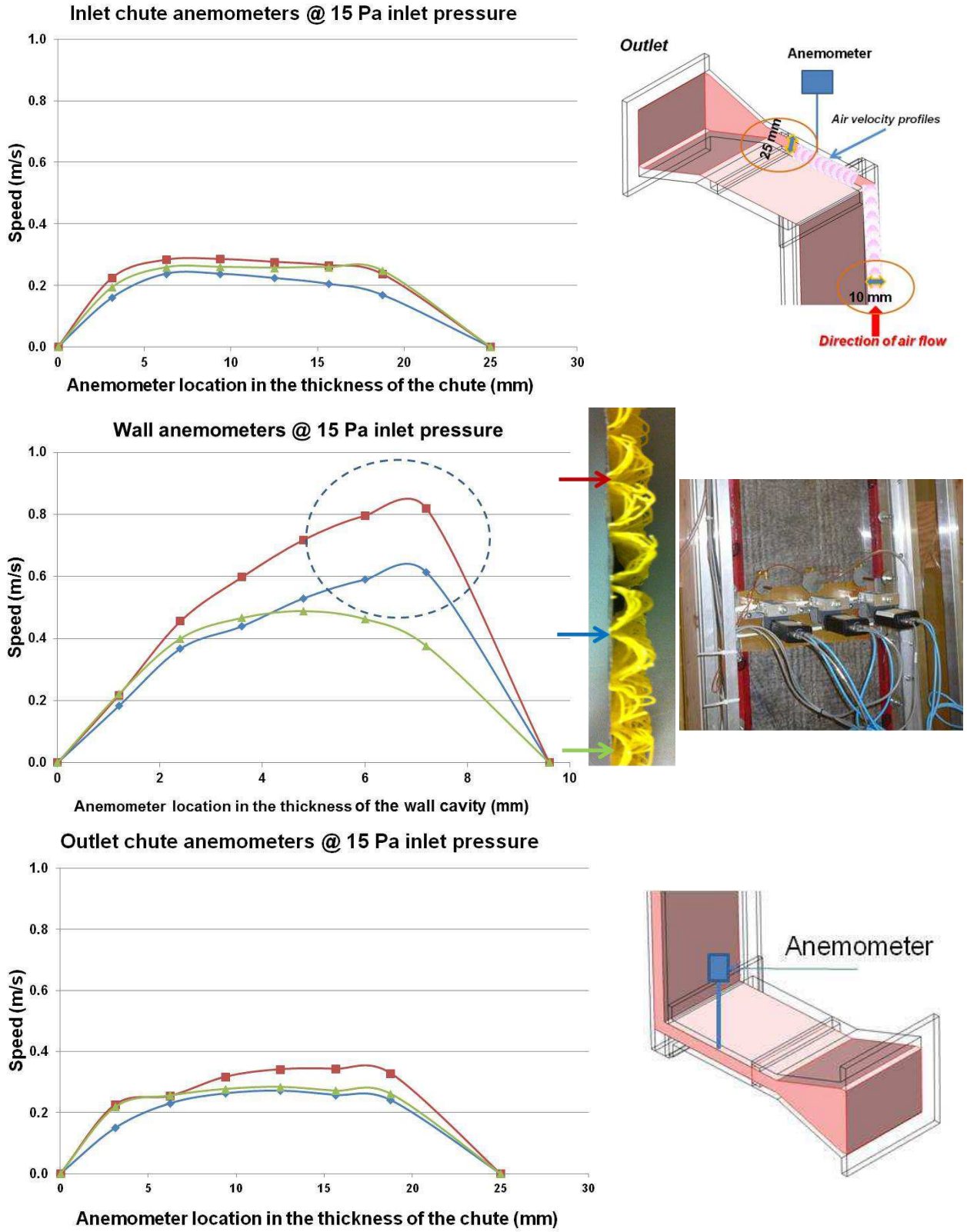


Figure 13 – Air velocity profiles at a pressure differential of 15 Pa for a cavity of 10 mm depth with drainage Medium (Client C) at the inlet chute, mid-height (wall) and outlet chute

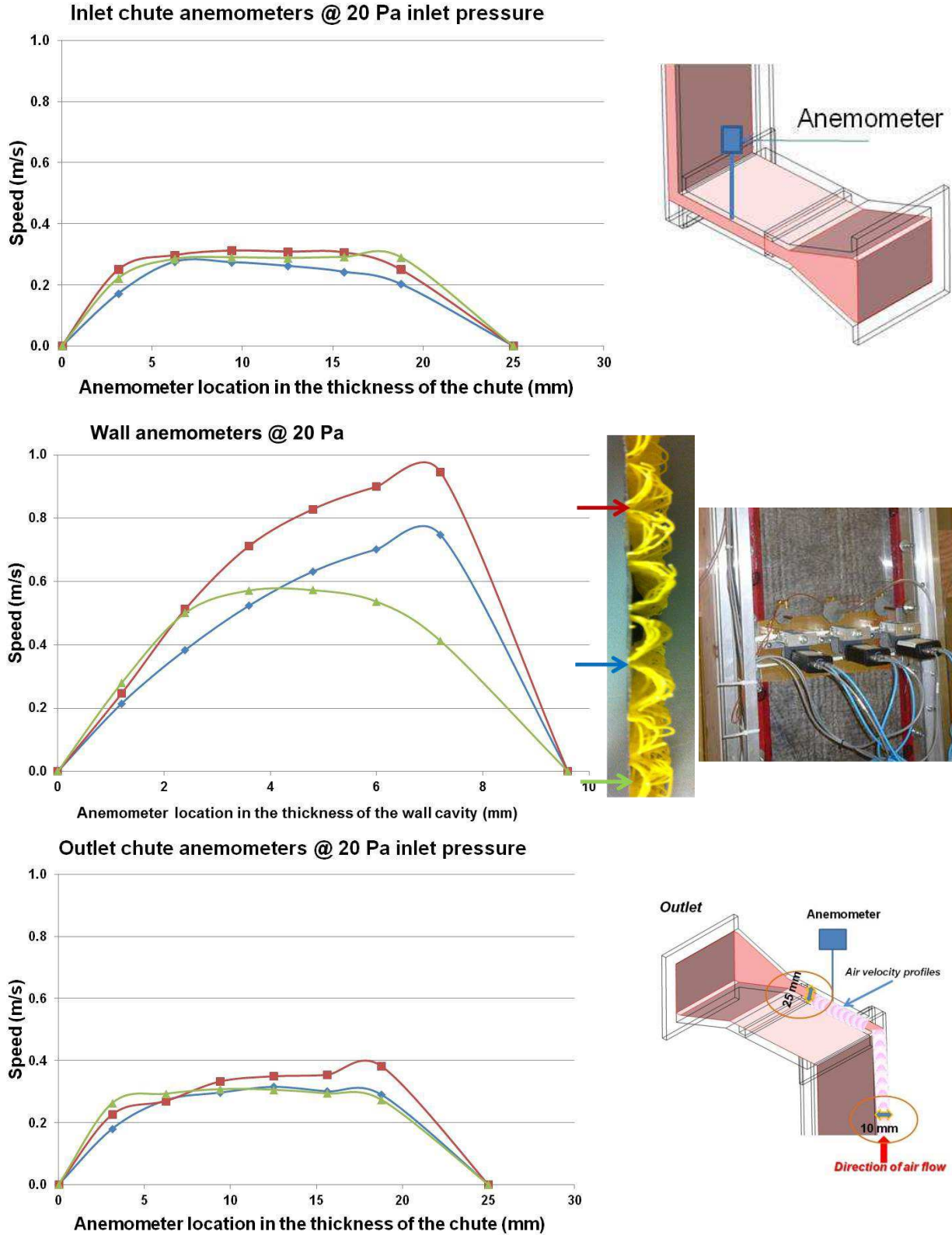


Figure 14 - Air velocity profiles at a pressure differential of 20 Pa for a cavity of 10 mm depth with drainage Medium (Client C) at the inlet chute, mid-height (wall) and outlet chute

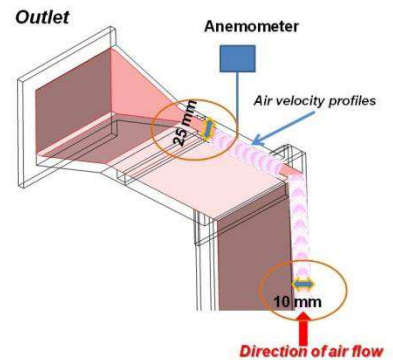
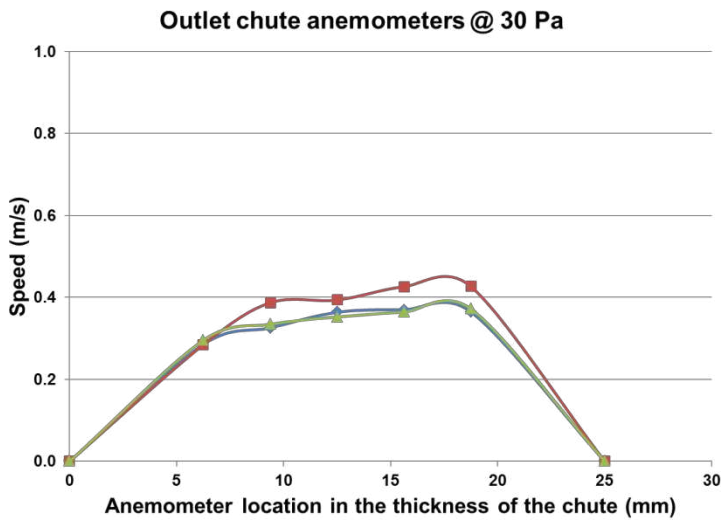
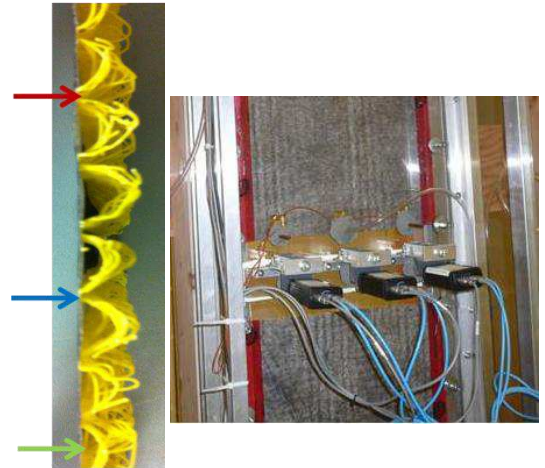
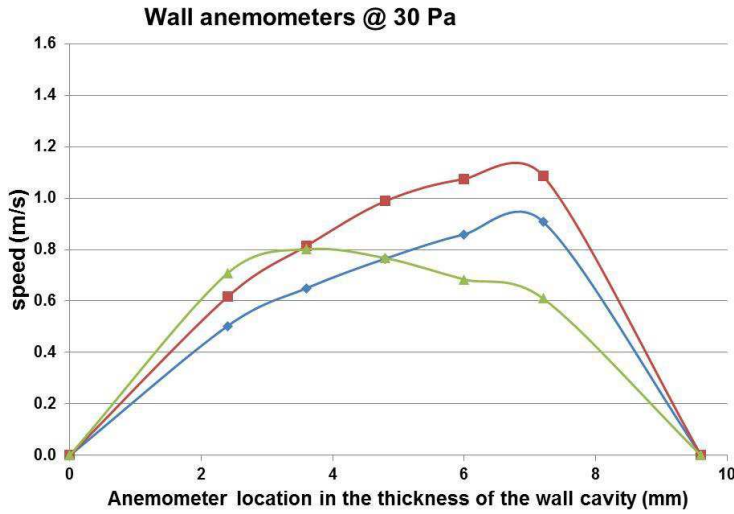
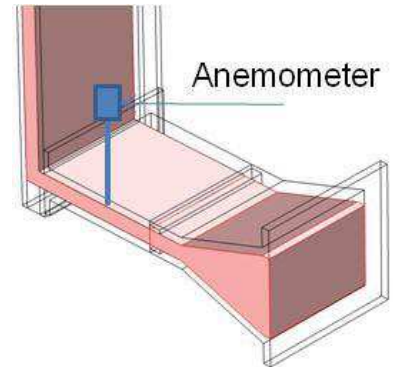
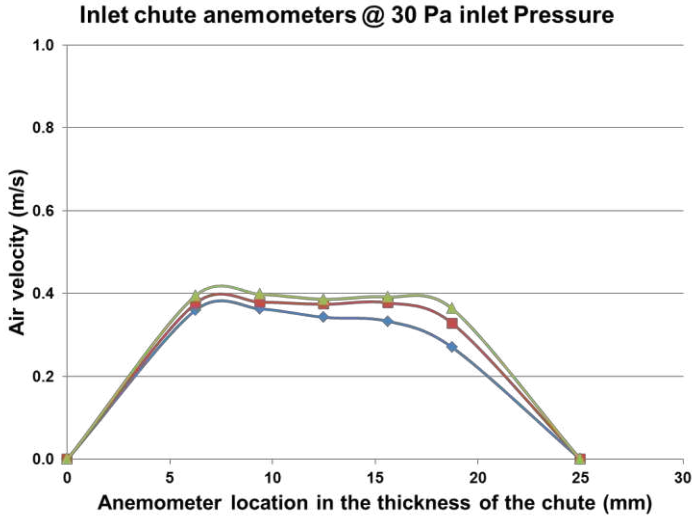


Figure 15 - Air velocity profiles at a pressure differential of 30 Pa for a cavity of 10 mm depth with Drainage Medium (Client C) at the inlet chute, mid-height (wall) and outlet chute

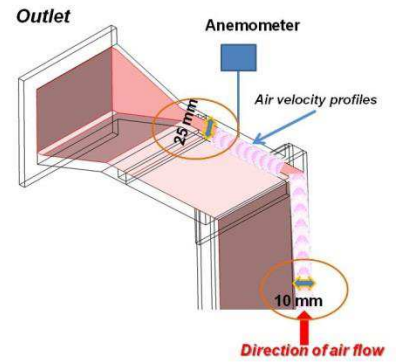
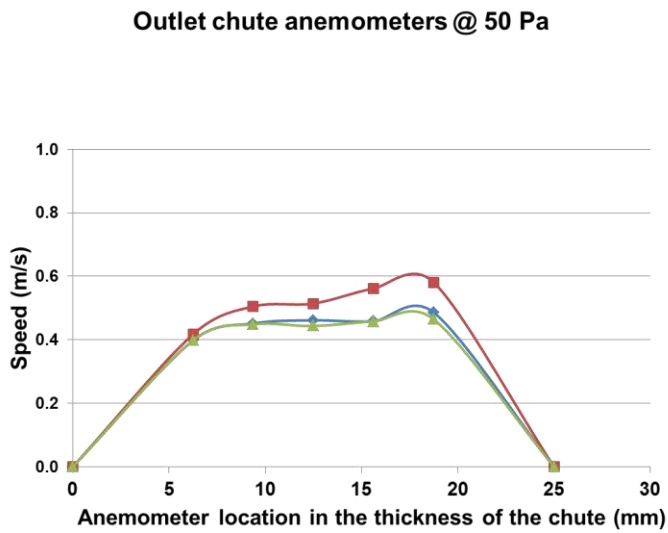
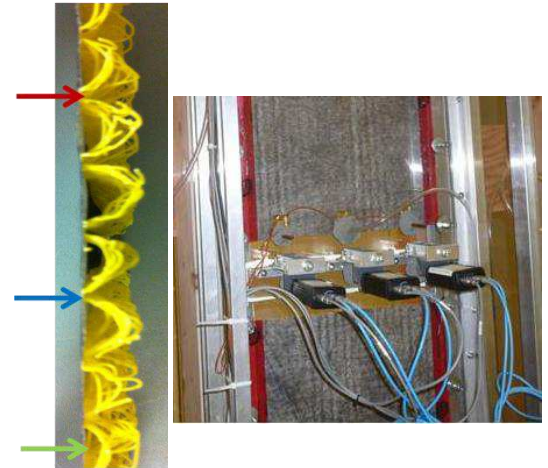
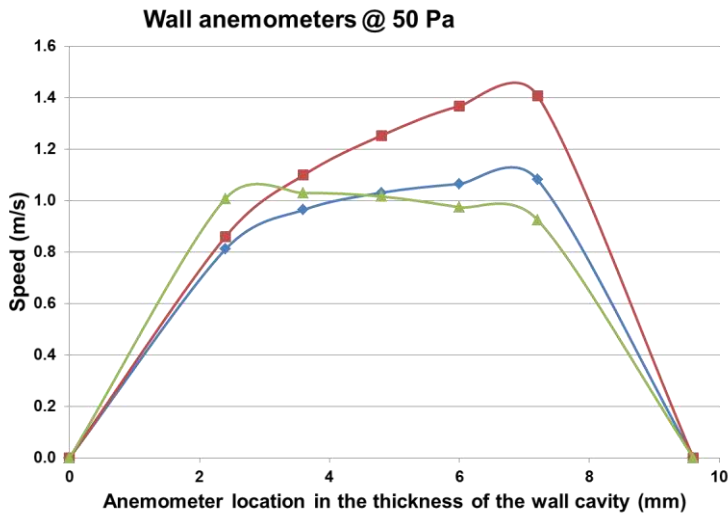
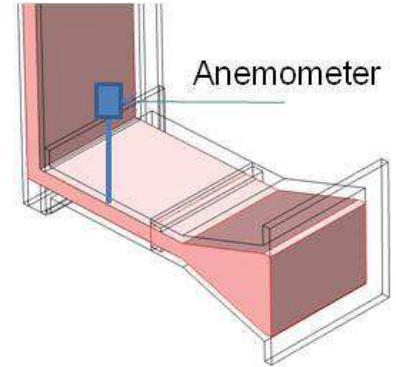
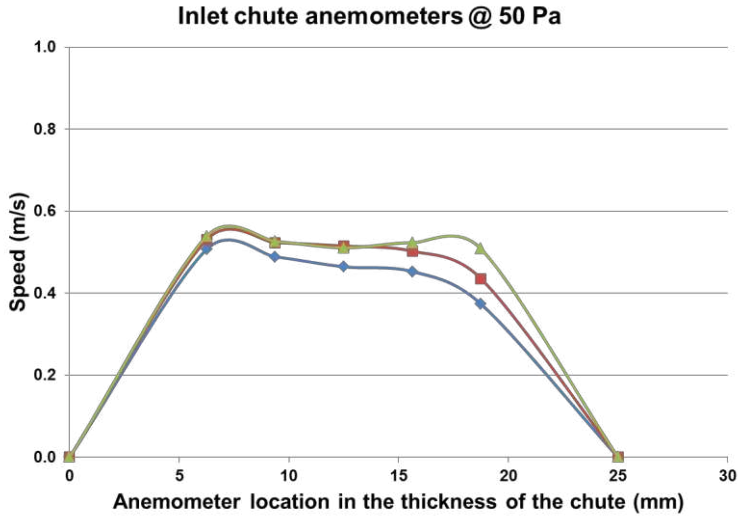


Figure 16 - Air velocity profiles at a pressure differential of 50 Pa for a cavity of 10 mm depth with Drainage Medium (Client C) at the inlet chute, mid-height (wall) and outlet chute

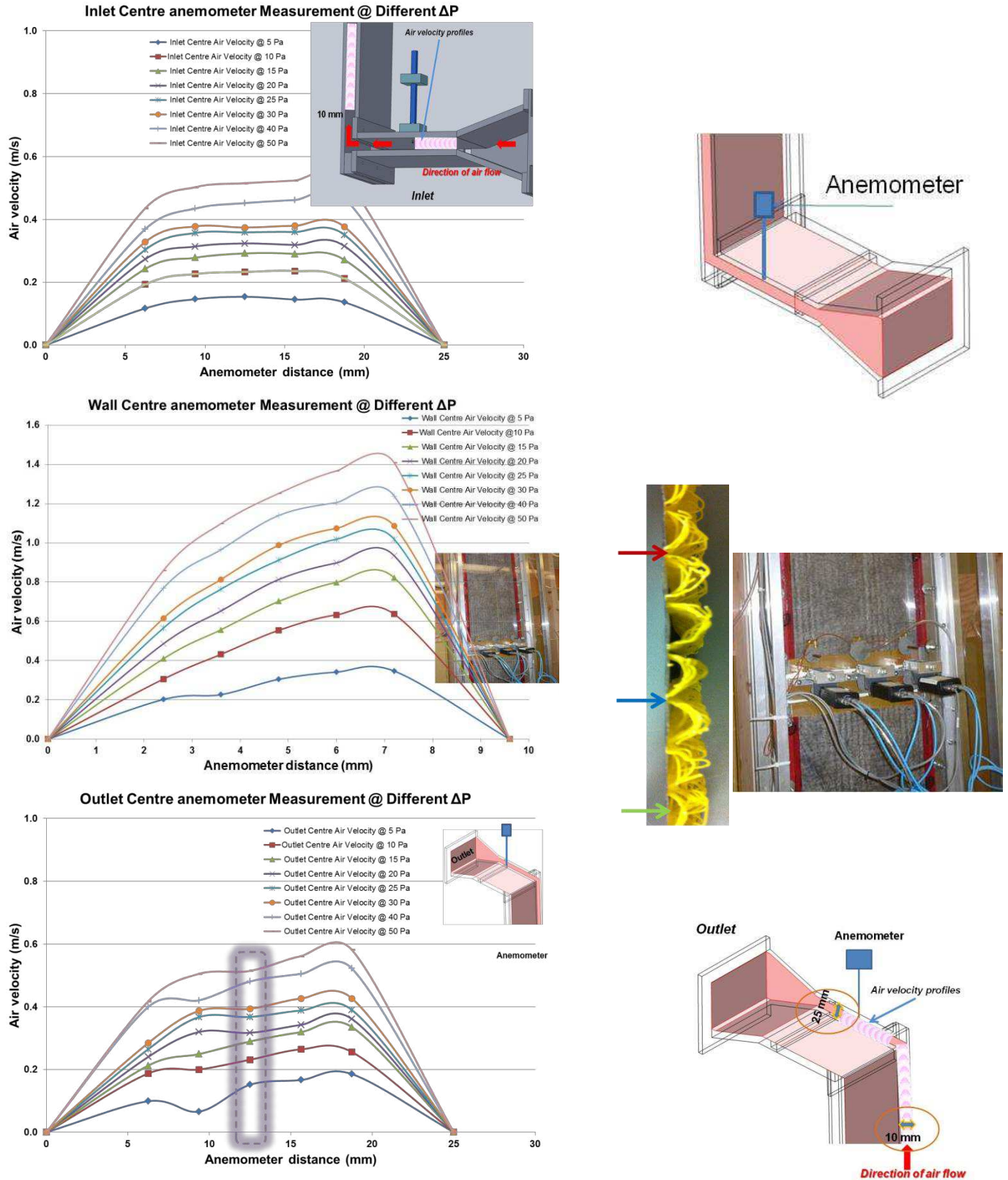


Figure 17 – Air velocity profiles in depth of cavity at given pressure differentials for a cavity of 10 mm depth with Drainage Medium (Client C) at the inlet chute, mid-height (wall) and outlet chute

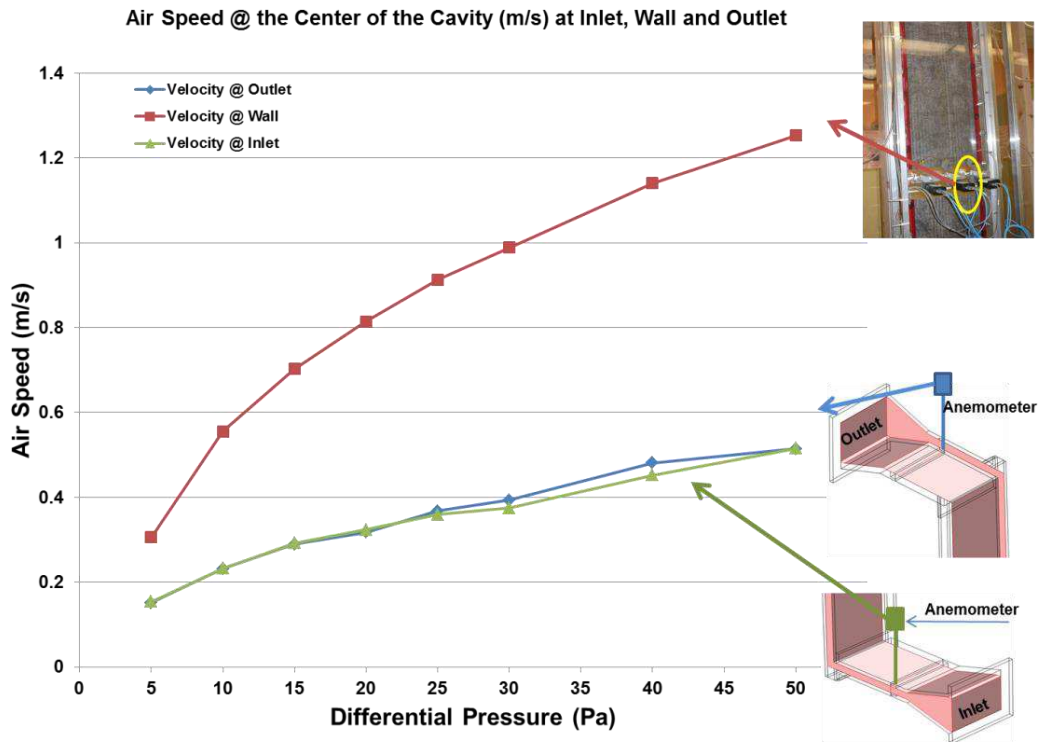
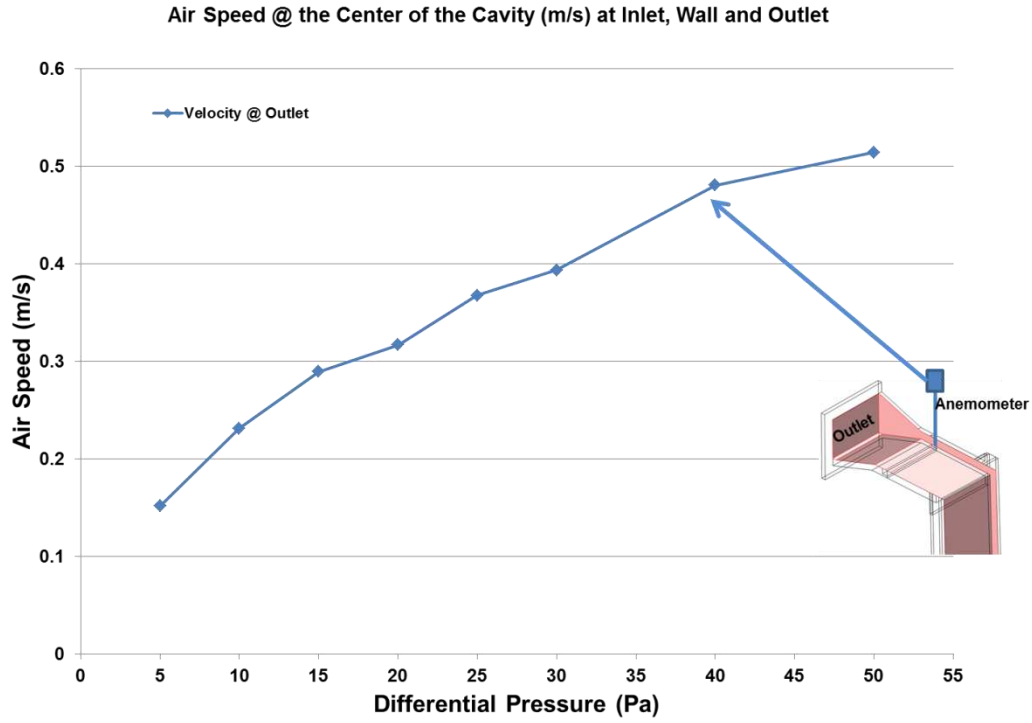


Figure 18- Air velocity as a function of pressure differentials at the cavity centre at the inlet chute, mid-height (wall) and outlet chute for a 10 mm cavity depth with Drainage Medium (Client C)

5.5 Configuration 5: 10 mm Cavity Depth with Drainage Medium (Client G)

A 10 mm drainage mat with a separation fabric comprised the drainage medium product for client G; the product is shown in Figure 19. The drainage product was enclosed in a 10 mm air space. As was fabricated for other similar products, two lengths of the drainage product were installed in the cavity one



upstream and the other downstream of the set of three anemometers located at mid-height of the cavity.

Measurements at the inlet and outlet chute and at mid-height (wall) of the cavity space were acquired at 5, 10, 15, 20, 25, 30, 40 and 50 Pa for which a selected set of air velocity measurement results are provided, respectively, in Figure 20 to Figure 23.

Figure 19 – Photo of drainage medium product (Client G)

The air velocity profiles at a pressure differential of 10 Pa and as a function of the depth of the cavity are given in Figure 20. Values for air velocity at mid-height (wall) of the cavity space are, as might reasonably be expected, greater than those at either the inlet or outlet chutes given that the depth of the cavity at mid-height is 10 mm as compared to 25 mm at the other control locations. Maximum velocities attained at either the inlet or outlet chute were ca. 0.2 m/s whereas at the mid-height these were ~ 0.4 m/s.; as well, the velocity profiles have been skewed by the presence of the drainage medium.

The air velocity profiles at a pressure differential of 20 Pa and as a function of the depth of the cavity are given in Figure 21; the results at this pressure difference are not tangibly different than those obtained at 10 Pa with the exception that maximum values for air velocity at mid-height of the cavity space and at 20 Pa exceeded that obtained at 10 Pa (i.e. 0.6 m/s at 20 Pa as compared to a. 0.4 m/s at 10 Pa).

The air velocity profiles in depth of cavity at given pressure differentials for a cavity with a drainage medium (Client G) is given in Figure 22; the increase in air velocities with a corresponding increase in pressure difference is clearly evident for all control locations. As well, there was a considerable skew in the results obtained at mid-height cavity space.

The air velocity as a function of pressure differentials at the cavity centre of the inlet and chute, and mid-height (wall) of cavity with a drainage medium (Client G), is given in Figure 23. Maximum values for air velocities are ca. 0.15 and 0.55 m/s for corresponding values of pressure difference of 5 to 50 Pa

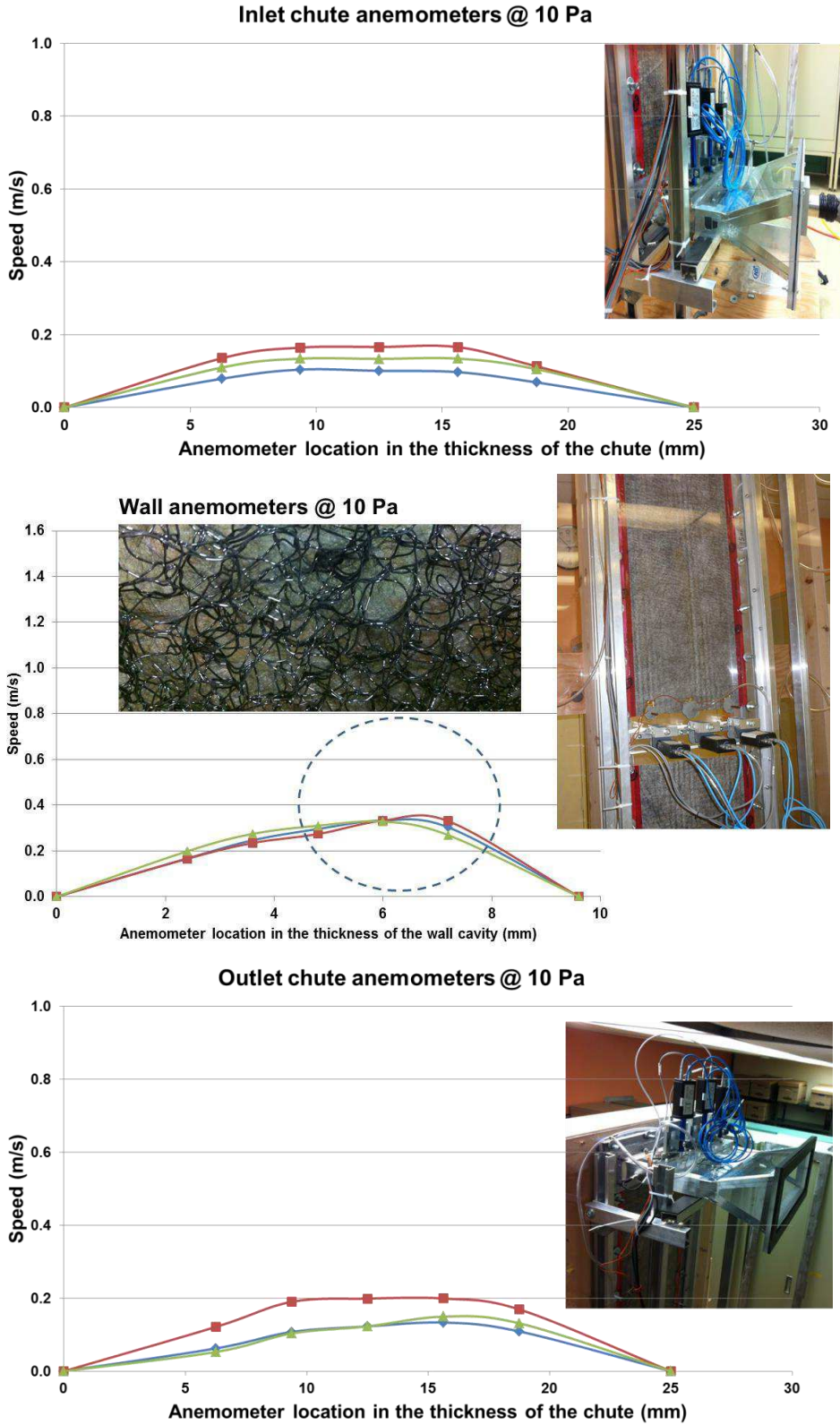


Figure 20 – Air velocity profile measurements at inlet, centre and outlet of air flow apparatus at 10Pa pressure difference and as a function of anemometer distance from edge of air space

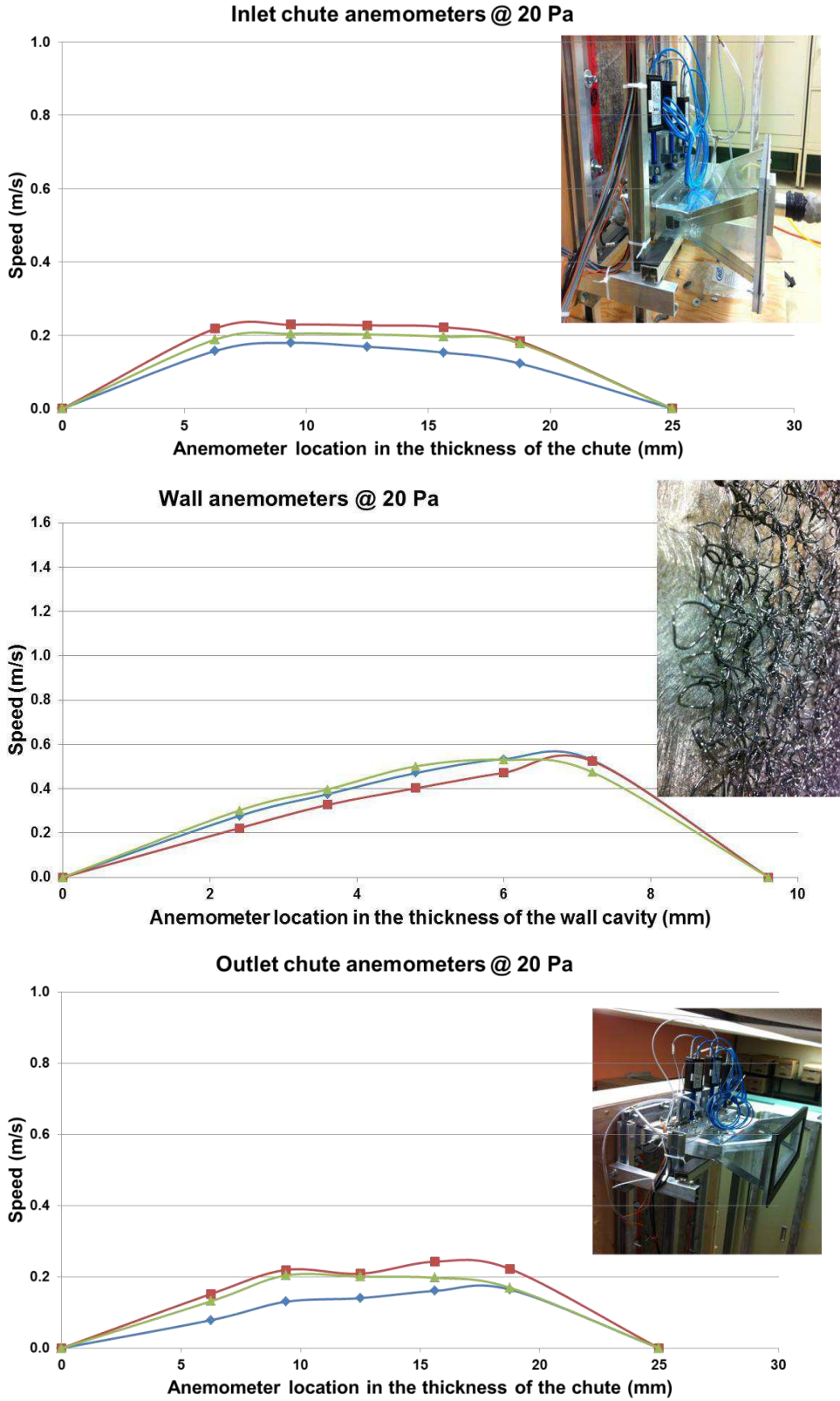


Figure 21 – Air velocity profile measurements at inlet, centre and outlet of air flow apparatus at 20 Pa pressure difference and as a function of anemometer distance from edge of air space

TASK 4 — CHARACTERIZATION OF AIR FLOW WITHIN DRAINAGE CAVITIES

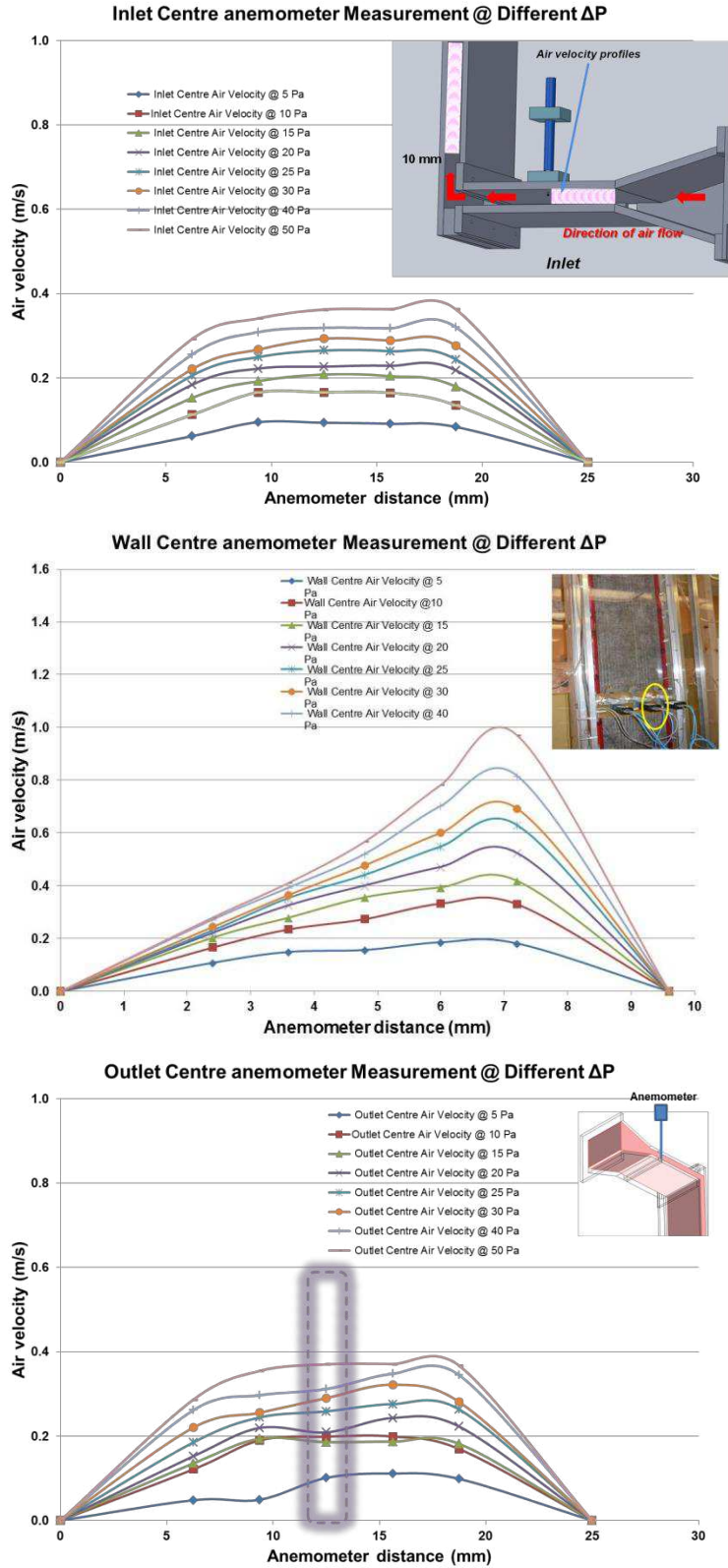


Figure 22 – Air velocity profile measurements at inlet, centre and outlet of air flow apparatus at given pressure differences and as a function of anemometer distance from edge of air space

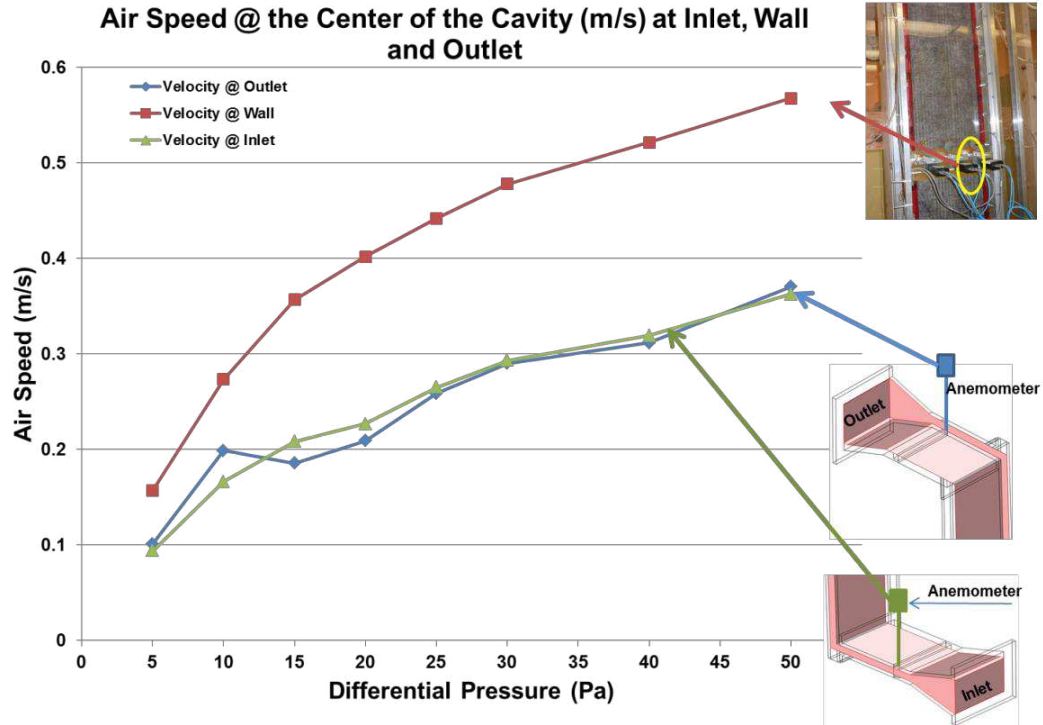


Figure 23 – Air velocity (m/s) at centre of air flow cavity for the inlet, mid-height (wall) and outlet locations of the air flow apparatus

5.6 Configuration 6: 10 mm Cavity Depth with Drainage Medium (Client E)

In this section, results of air flow characterization for the dimpled membrane drainage medium with a mortar screen fabric are given (Client E). The dimpled membrane drainage medium and mesh fabric of 10 mm depth is shown in Figure 24. The screen fabric is a thin layer of non-woven polymeric mesh and is used to restrict mortar from being worked into the openings between adjacent dimples (Figure 24 B).

As can be seen in Figure 24, air might flow between the (i) dimpled membrane and the sheathing membrane (Figure 24C: red arrows), and; (ii) mesh fabric and dimpled membrane (Figure 24 C and D: green arrows). As such, air flow of the dimpled membrane drainage medium was characterized as occurring through both paths and as occurring only between the mesh fabric and dimpled membrane.

Results are first provided for air flow through both paths and thereafter in the subsequent section, for air flow between the parging mesh and dimpled membrane; in the latter instance, the means taken to fabricate the test specimen is also provided.

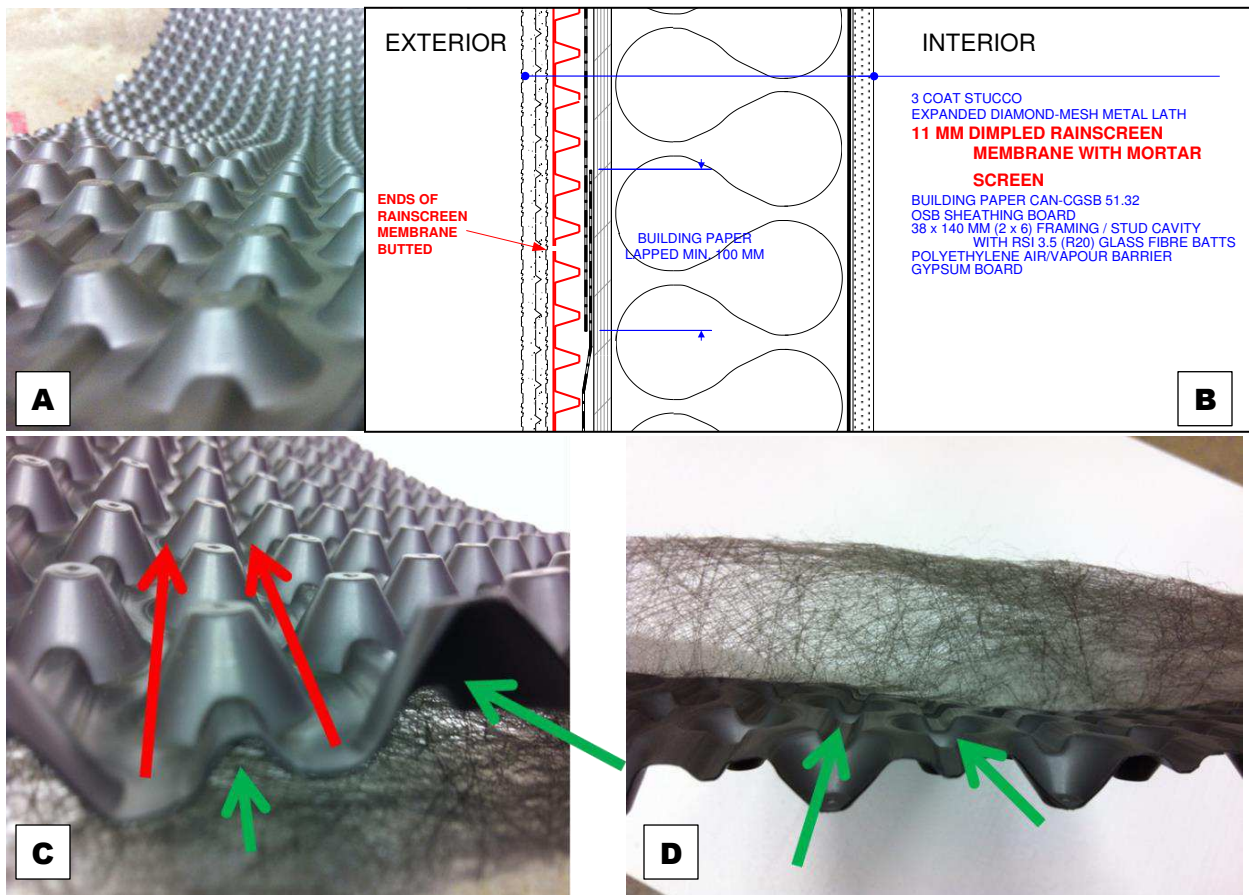


Figure 24 – (a) Dimpled membrane drainage medium (client E) and mesh fabric showing the two paths for air flow (B): red arrows depict flow between dimpled membrane and sheathing membrane whereas green arrows (C) show flow between mesh fabric and dimpled membrane

5.6.1 Measurement of Total Velocity (Interior + Exterior)

The results of air flow characterization tests for the dimpled membrane and for which the air velocity profile measurements at a pressure difference of 10 Pa, are given in Figure 25 and for 20 Pa, in Figure 26. The air velocity profile measurements are provided for the inlet chute, wall (at mid-height of apparatus) and outlet chute of the air flow apparatus. The values provided show the air velocities across the depth of the cavity from each of the three anemometers placed across the width of the cavity.

As is evident for the information provided in the figure, the velocities are greater at the mid-height location (Figure 26: maximum ~ 0.6 m/s at 20 Pa) as compared to either the inlet or outlet (maximum ~ 0.3 m/s) given that the depth of the cavity at mid-height of the apparatus is ~10 mm as compared to 25 mm at the inlet and outlet chutes.

The air velocity profile measurements at the centre of the control volume and at the inlet chute, wall (at mid-height of apparatus) and outlet chute of the apparatus at pressure differences ranging between 5 and 50 Pa are given in Figure 27. The values shown are air velocities across the depth of the control volume. As is shown, for all of the profiles, there is an increase in air velocity with a corresponding increase in pressure difference.

In Figure 28 are shown air velocities as a function of pressure difference at the inlet and outlet chutes and at the mid-height of the apparatus. The values are those taken at the mid-point across the width of the control volume and at mid-depth of the cavity for the inlet chute, mid-height and outlet chute locations of the apparatus. As is evident from the values provided in the figure, the highest velocities occur at the apparatus mid-height upwards of 0.6 m/s as compared to < 0.4 m/s obtained at either the inlet or outlet chutes.

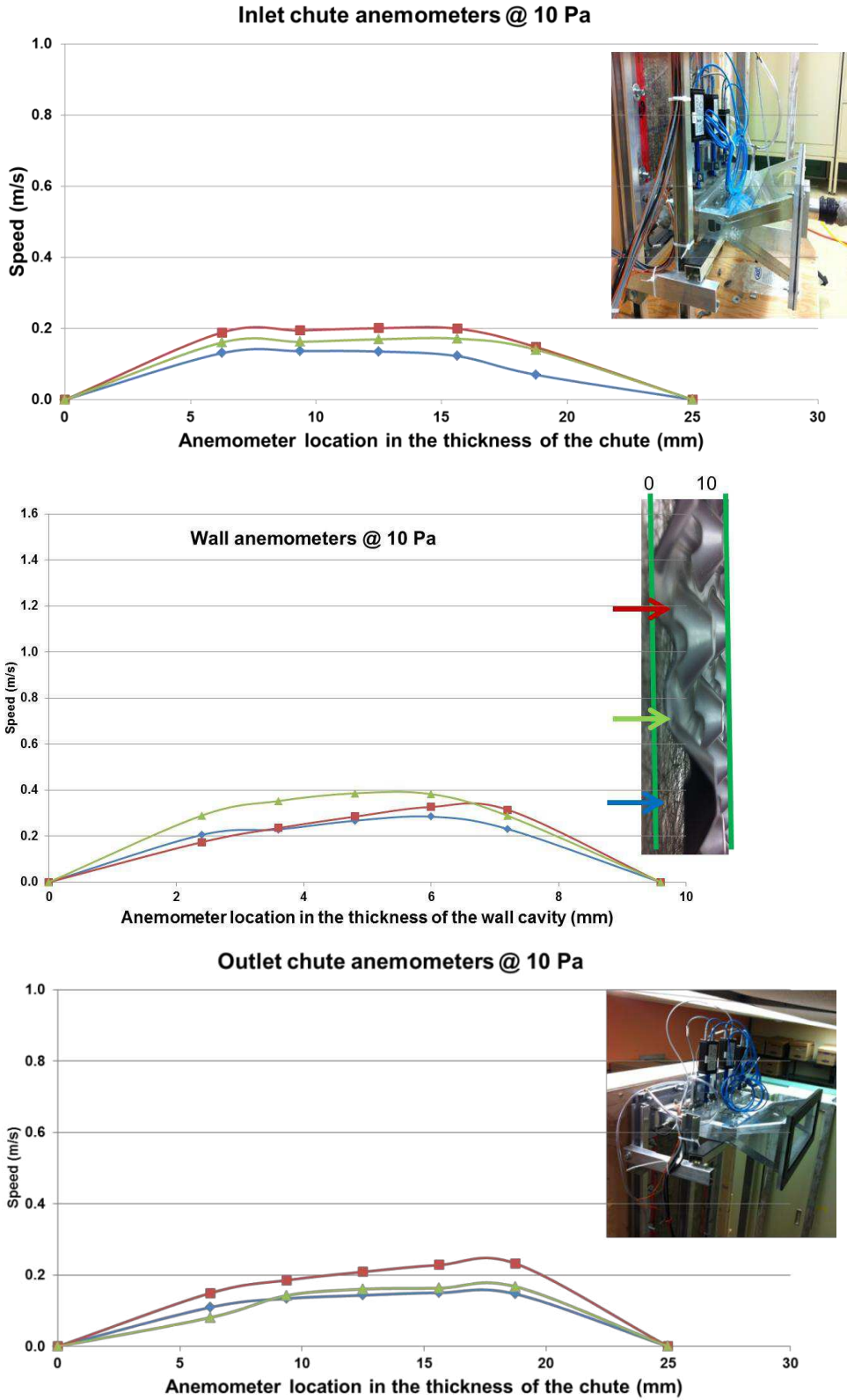


Figure 25 - Air velocity profile measurements across cavity width and depth for the inlet and outlet chutes and the mid-height of (wall) test apparatus at 10Pa pressure difference

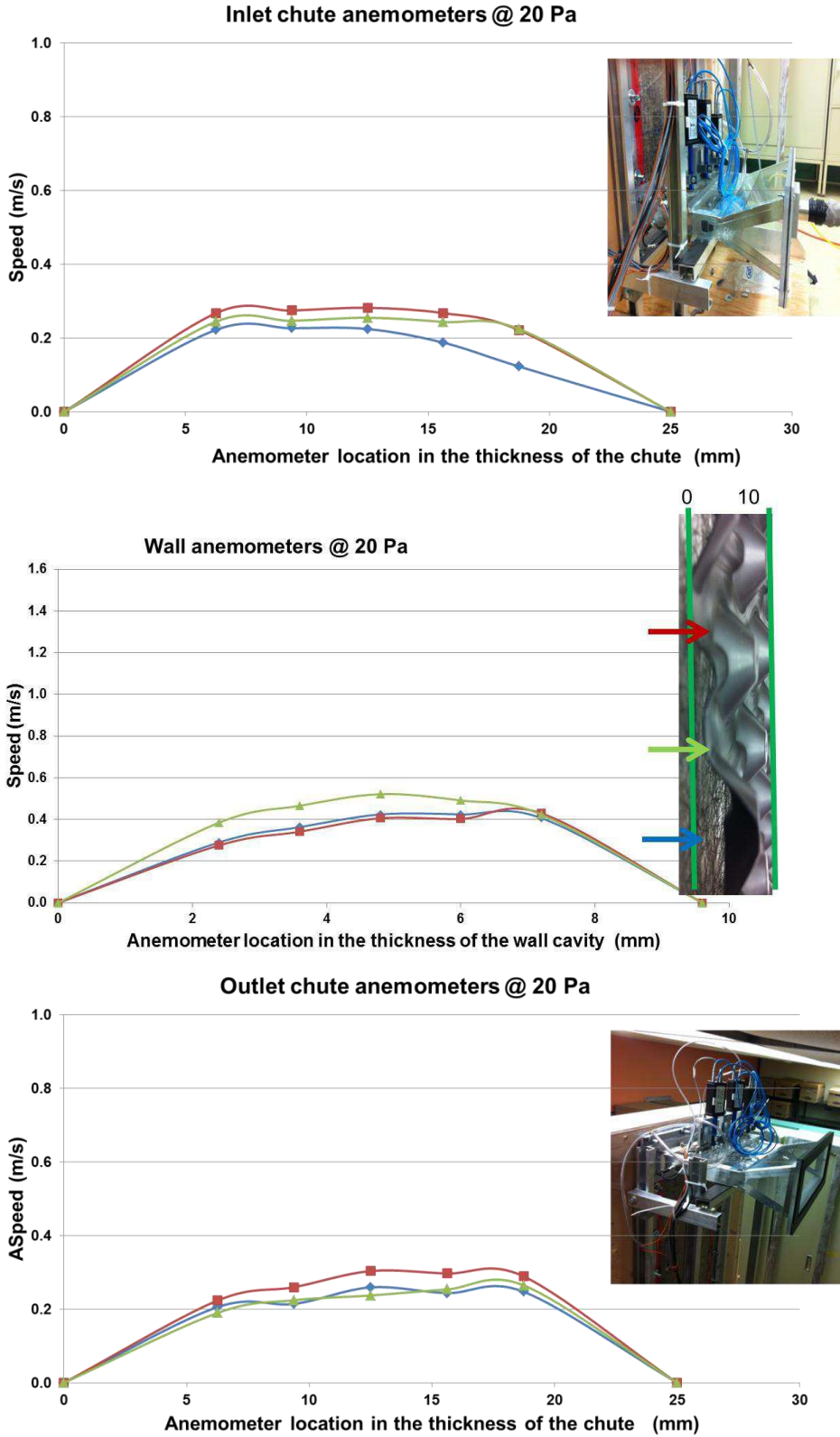


Figure 26 - Air velocity profile measurements across cavity width and depth for the inlet and outlet chutes and the mid-height of (wall) test apparatus at 20 Pa pressure difference

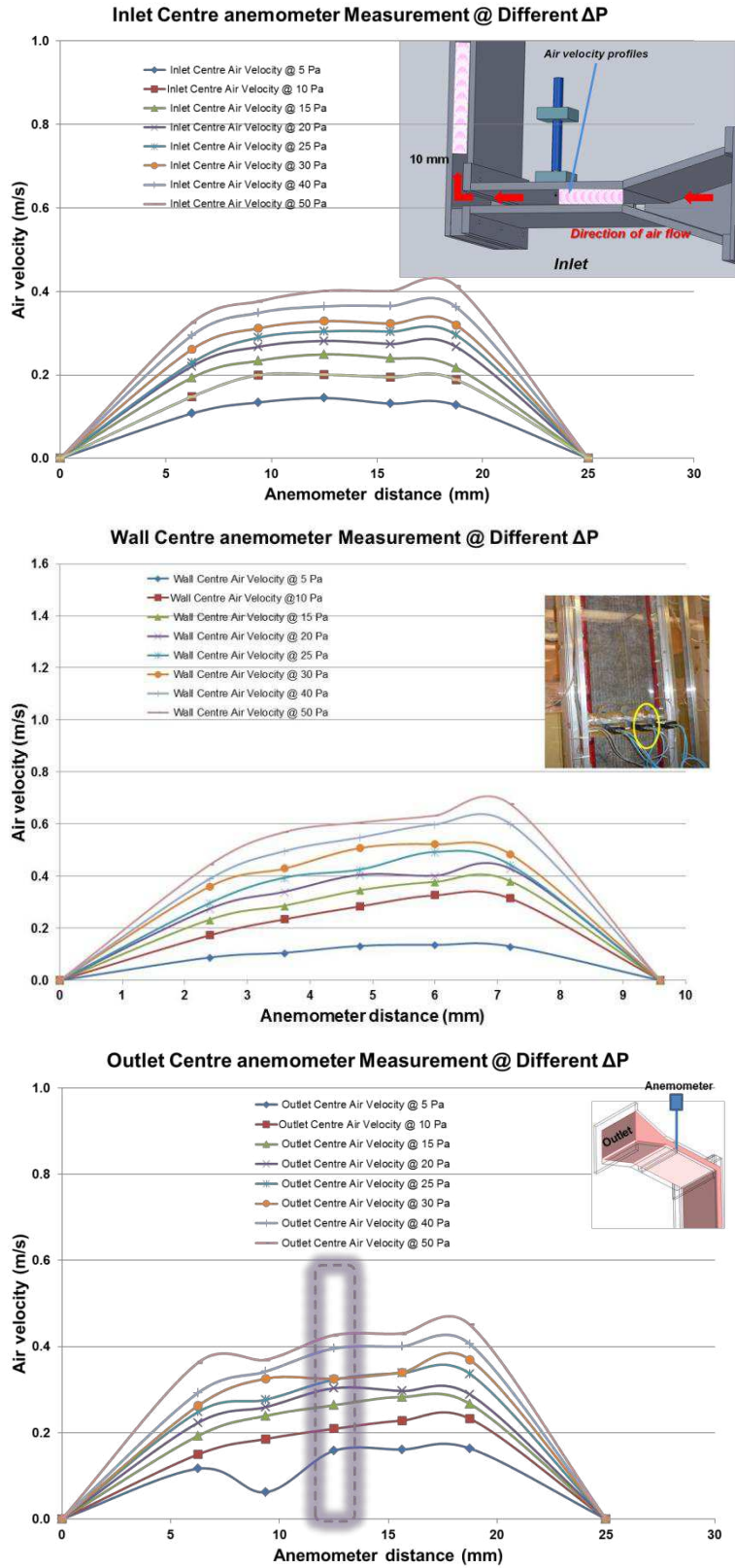


Figure 27 – Air velocity measurements at given pressure differences across depth of cavity for anemometer at mid cavity width at inlet and outlet chutes and mid-height of test apparatus (wall)

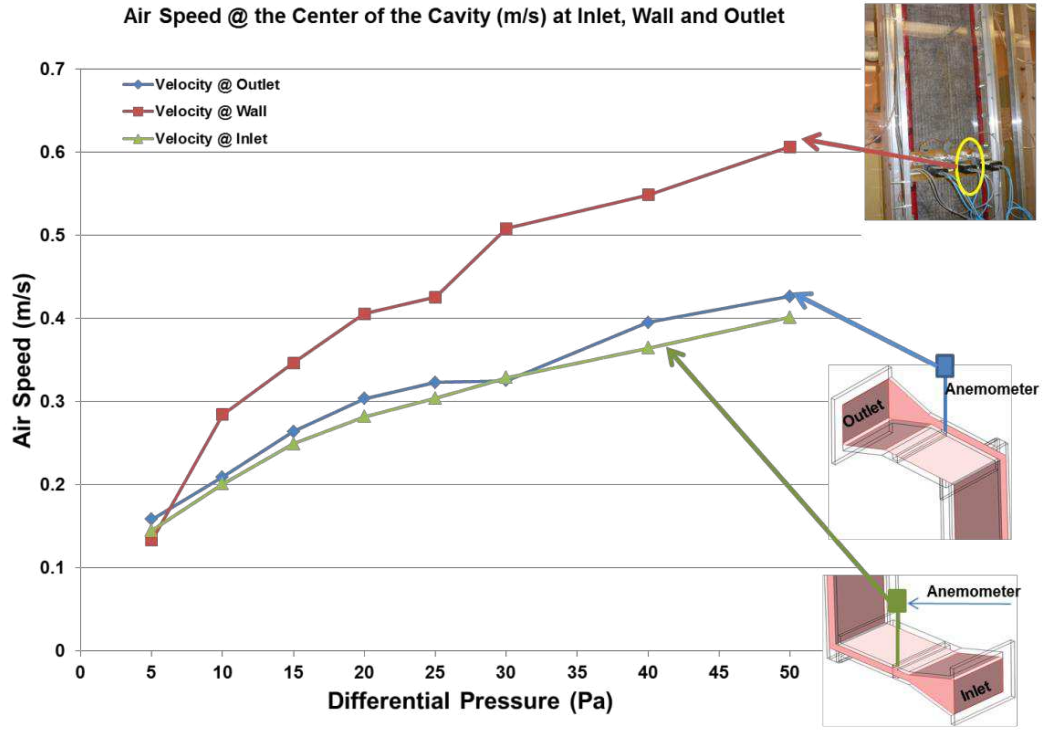


Figure 28 – Air velocity (m/s) at centre of air flow cavity for the inlet, mid-height (wall) and outlet locations of the air flow apparatus

5.6.2 Measurement of Interior Velocity

Results in this section reflect those acquired for air flow between the mortar mesh and dimpled membrane as depicted in figure. The test specimen was fabricated by filling the gaps between adjacent dimples over a length of ~ 100mm at the end portion a membrane panel with silicone sealant.

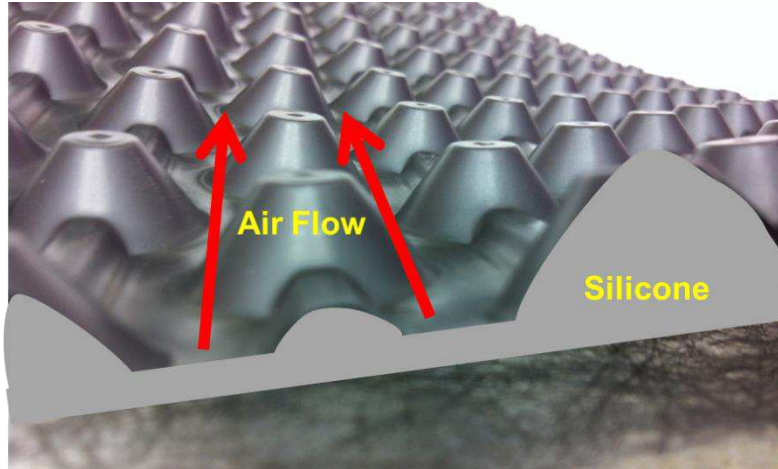
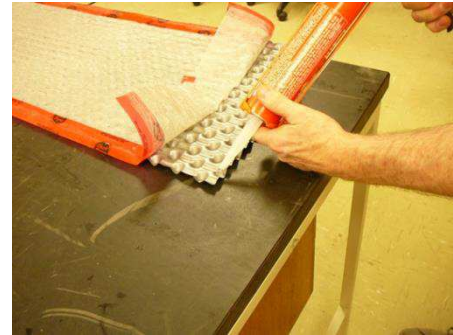


Figure 29 – Dimpled plastic membrane and parging screen fabric showing: (A) flow of air between dimpled membrane and parging fabric; (B) Specimen fabrication



The results of air flow characterization tests for the dimpled membrane and parging screen fabric for which the air velocity profile measurements at a pressure difference of 10 Pa, are given in Figure 30 and for 20 Pa, in Figure 31. The air velocity profile measurements are provided for the inlet chute, wall (at mid-height of apparatus) and outlet chute of the air flow apparatus. The values provided show the air velocities across the depth of the cavity from each of the three anemometers placed across the width of the cavity. As is evident for the information provided in the figure, the velocities are greater at the mid-height location (Figure 25: maximum ~ 0.6 m/s at 20 Pa) as compared to either the inlet or outlet (maximum~ 0.3 m/s) given that the depth of the cavity at mid-height of the apparatus is ~10 mm as compared to 25 mm at the inlet and outlet chutes. The air velocity profile measurements at the centre of the control volume and at the inlet chute, wall (at mid-height of apparatus) and outlet chute of the apparatus at pressure differences ranging between 5 and 50 Pa are given in Figure 32. The values shown are air velocities across the depth of the control volume. As is shown, for all of the profiles, there is an increase in air velocity with a corresponding increase in pressure difference. In Figure 33 are shown air velocities as a function of pressure difference at the inlet and outlet chutes and at the mid-height of the apparatus. The values are those taken at the mid-point across the width of the control volume and at mid-depth of the cavity for the inlet chute, mid-height and outlet chute locations of the apparatus. As is evident from the values provided in the figure, the highest velocities occur at the apparatus mid-height an upwards of 0.6 m/s as compared to < 0.4 m/s obtained at either the inlet or outlet chutes.

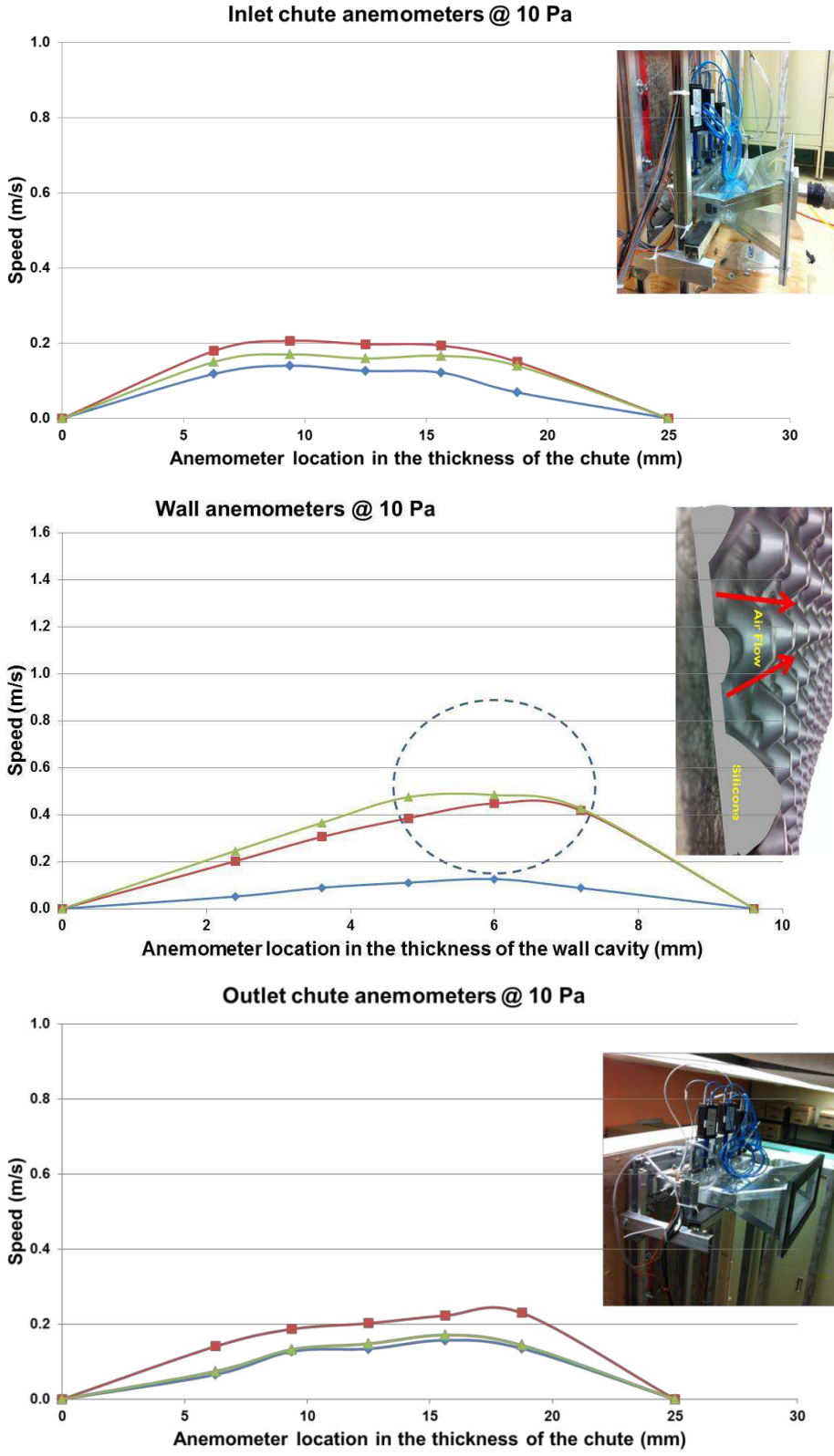


Figure 30 - Air velocity profile measurements at inlet, centre and outlet of air flow apparatus as a function of anemometer distance from edge of air space

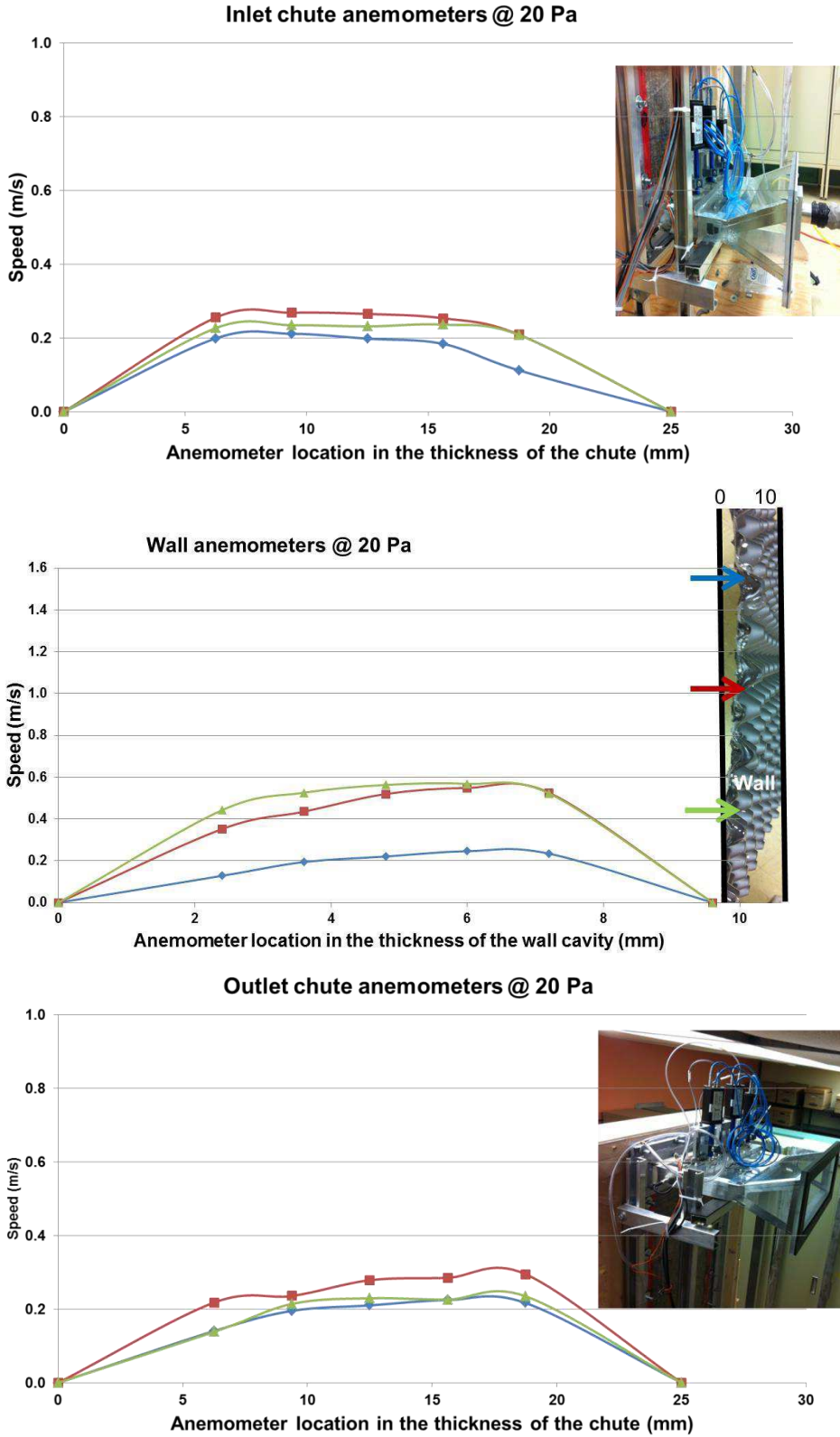


Figure 31 – Air velocity profile measurements at inlet, centre and outlet of air flow apparatus at a pressure difference of 20 Pa and as a function of anemometer distance from edge of air space

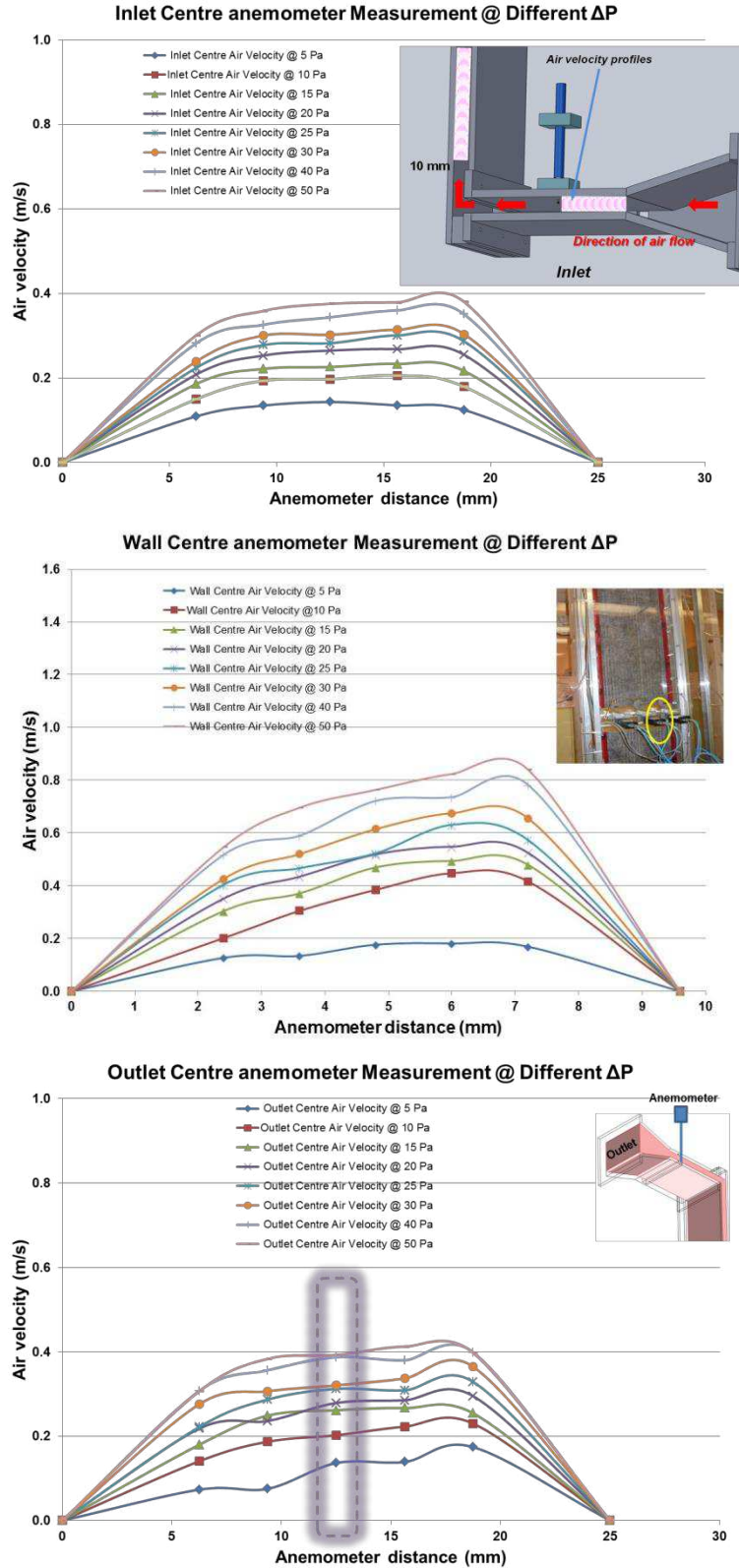


Figure 32 – Air velocity profile measurements at inlet, centre and outlet of air flow apparatus at given pressure differences and as a function of anemometer distance from edge of air space

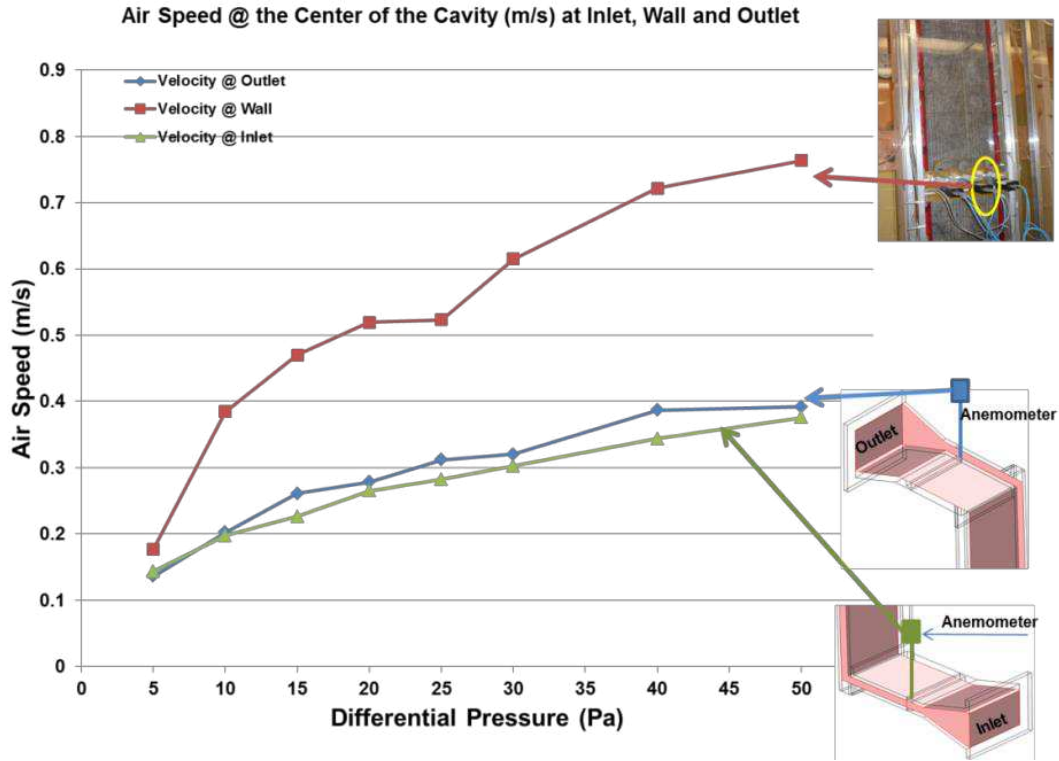


Figure 33 – Air velocity (m/s) at centre of air flow cavity for the inlet, mid-height and outlet locations of the air flow apparatus

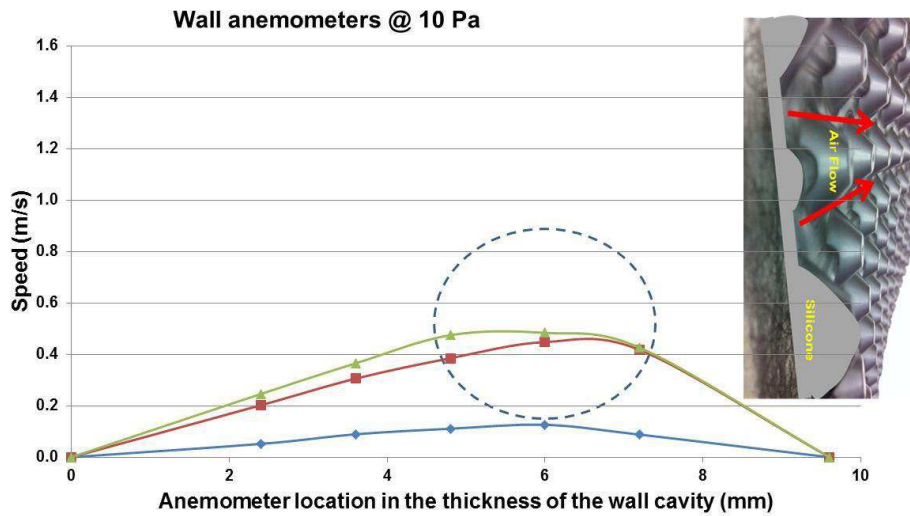


Figure 34 - Air velocity profile measurements mid-height of cavity space air at a pressure difference of 10 Pa and as a function of anemometer depth in cavity.

5.7 Configuration 7: 4 mm Cavity Depth with Drainage Medium (Client I)

The results of air flow characterization for the asphalt impregnated corrugated paper drainage medium (client I) are given in this section. The asphalt impregnated corrugated paper drainage medium of 4 mm depth is shown in Figure 34. The board was less than 10 mm thick and as such to ensure that the overall depth of the test specimen be maintained at 10 mm, the corrugated paper drainage medium was secured to a 6 mm thick XPS panel as depicted in the Figure 35.

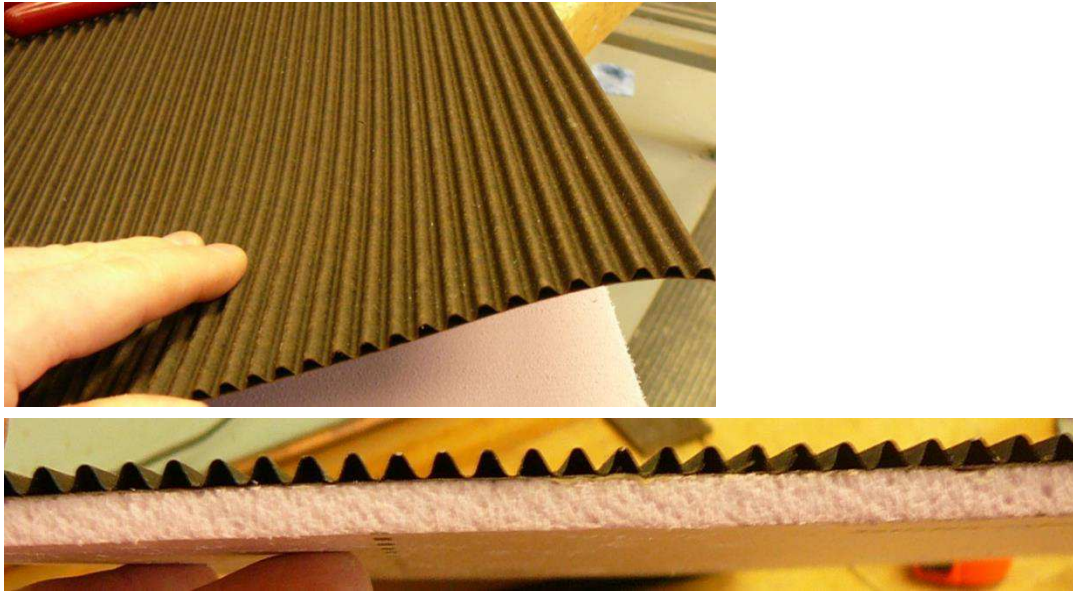


Figure 35 – Corrugated asphalt impregnated paper drainage medium of 4 mm depth (Client I); (a) board ; (b) Corrugated paper drainage medium affixed to 6 mm thick XPS panel to permit testing in 10mm deep cavity

The results of air flow characterization tests for which the air velocity profile measurements at the inlet chute, wall (at mid-height of apparatus) and outlet chute of the air flow apparatus at a pressure difference of 10 Pa, are given in Figure 36. The values provided show the air velocities across the depth of the cavity from each of the three anemometers placed across the width of the cavity.

As is evident for the information provided in the figure, the velocities are greater at the mid-height location as compared to either the inlet or outlet given that the depth of the cavity at mid-height of the apparatus is 4 mm as compared to 25 mm at the inlet and outlet chutes.

The air velocity profile measurements at the centre of the control volume and at the inlet chute, wall (at mid-height of apparatus) and outlet chute of the apparatus at pressure differences ranging between 5 and 50 Pa are given in Figure 37. The values shown are air velocities across the depth of the control volume. Evidently, greater velocities arise due to higher pressure differences.

In Figure 38 are shown air velocity as a function of pressure difference at the inlet and outlet. The values are those taken at the mid-point across the width of the control volume and at mid-depth of the cavity for the inlet chute, mid-height and outlet chute locations of the apparatus. As is evident from the values provided in the figure, the highest velocities occur at the apparatus mid-height upwards of 0.5 m/s as compared to < 0.2 m/s obtained at either the inlet or outlet chutes.

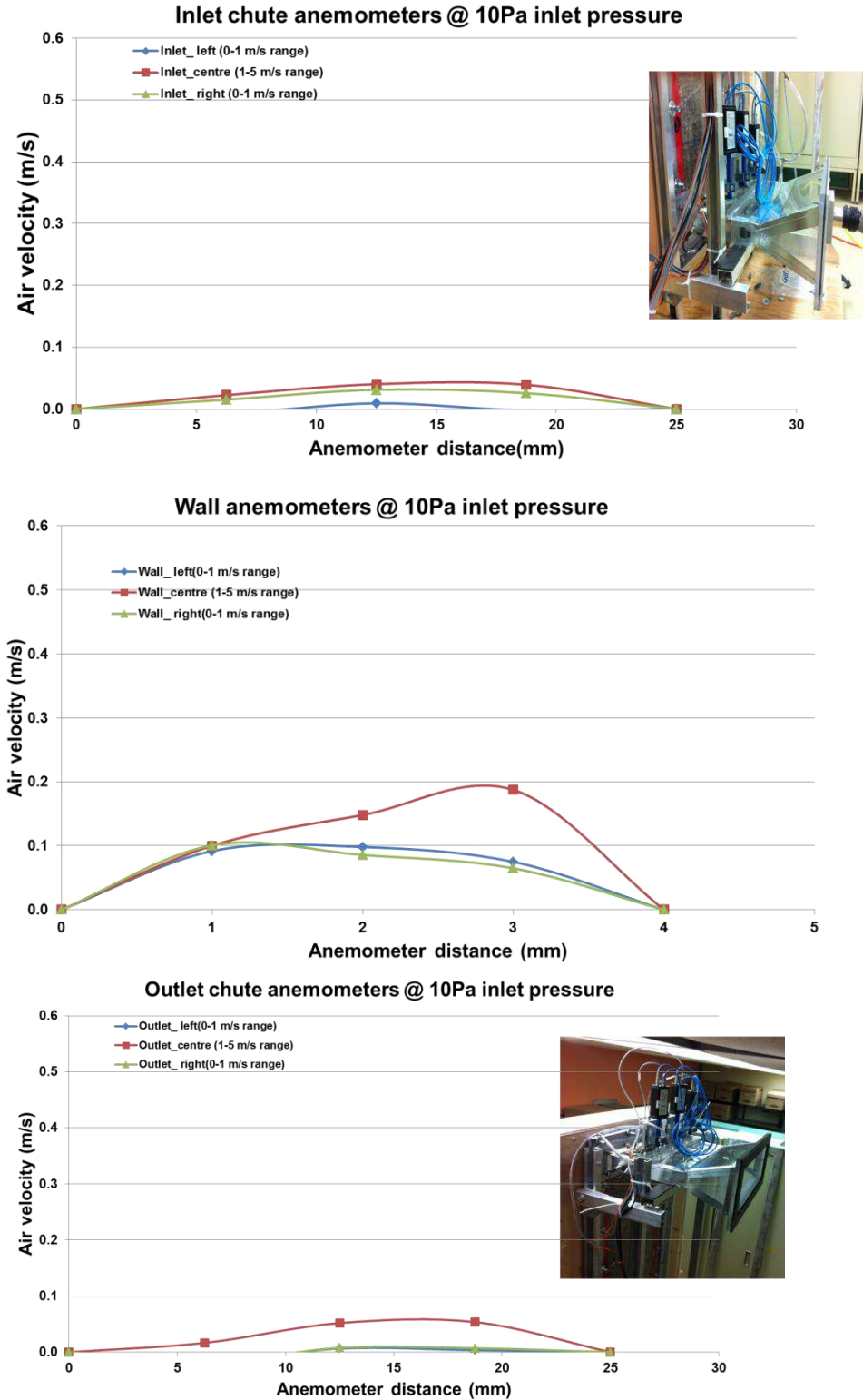


Figure 36 – Air velocity profile measurements at inlet, centre and outlet of air flow apparatus as a function of anemometer distance from edge of air space

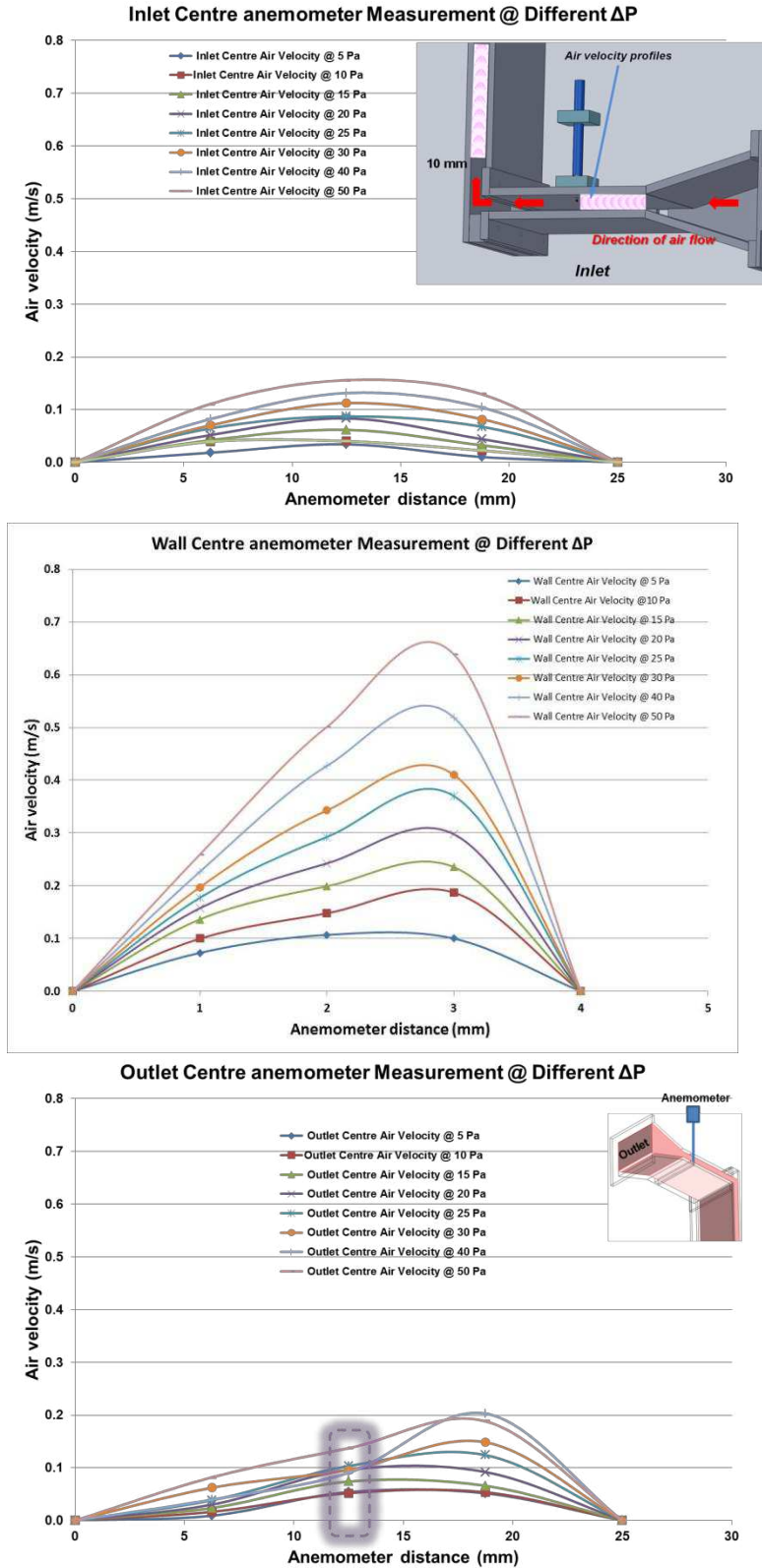


Figure 37 – Air velocity profile measurements at inlet, centre and outlet of air flow apparatus at given pressure differences and as a function of anemometer distance from edge of air space

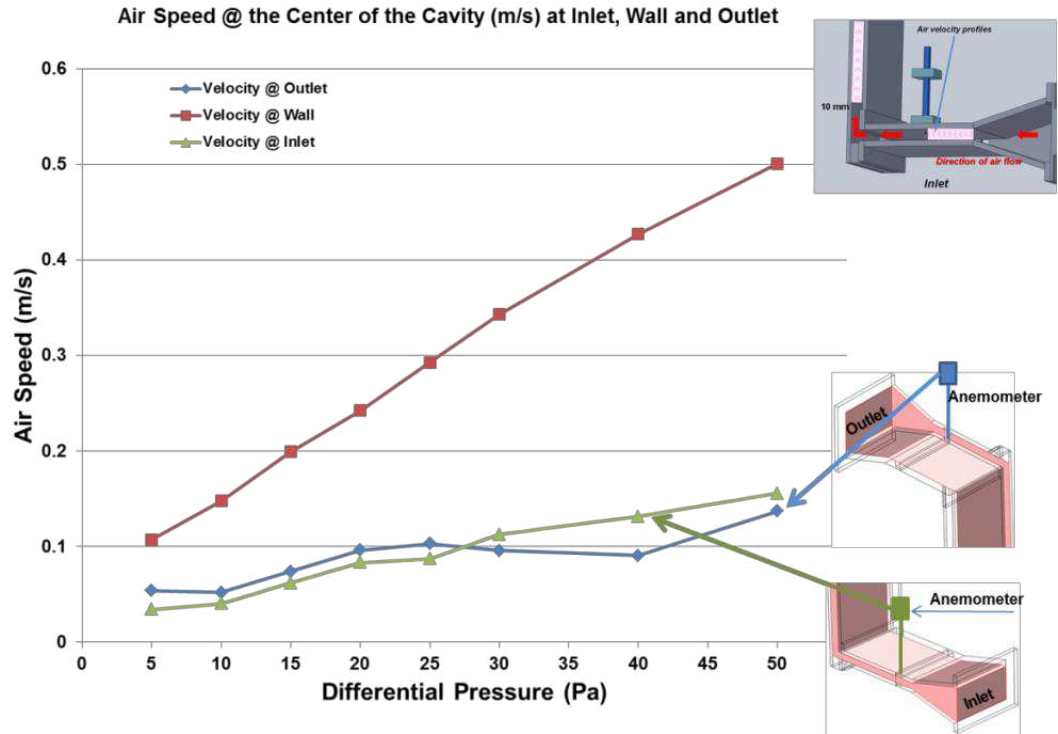


Figure 38 – Air velocity (m/s) at centre of air flow cavity for the inlet, mid-height and outlet locations of the air flow apparatus

6. Summary

A cavity air flow characterization apparatus was designed and fabricated with the intent of acquiring data on air flow through clear unobstructed cavities as well as cavities incorporating various types of drainage media. Use of the computational fluid dynamic portion of a metaphysics simulation model (hygIRC-C) was used in the design. The model predictions on air flow were subsequently benchmarked using the data derived from the use of this apparatus. The use of the simulation model likewise permitted selection of appropriate air velocity sensors and their location in the apparatus.

The prototype, once fabricated, and the sensors calibrated, was first commissioned for use for the air flow characterisation of three depths of clear cavity (i.e. 10, 20 and 25 mm depth). Thereafter, air flow characterization tests were undertaken on cavities incorporating several different drainage media.

The results of the tests helped to benchmark the hygrothermal model hygIRC-C. As well, they formed the basis of a method to characterize permeability to air of such type of drainage media. The air permeability is known to affect the capability of such products to permit drying within cavities and as such, represents an important test parameter to evaluate when evaluating the moisture performance of wall assemblies that include drainage media.

Appendix 1 – List of Task Reports

Report	Reference
Task 1	M. Armstrong and B. Di Lenardo (2014), Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads – Task 1 – Wall Assembly Specifications; Client Report A1-000030.01; National Research Council Canada; Ottawa, ON; 52 pgs.
Task 2	P. Mukhopadhyaya, D. van Reenen and S. Bundalo-Perc (2014), Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads – Task 2 – Building Component Hygrothermal Properties Characterization; Client Report A1-000030.02; National Research Council Canada; Ottawa, ON; 58 pgs.
Task 3	H. H. Saber, W. Maref, and G. Ganapathy, (2015) Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads – Task 3 –Hygrothermal Model Benchmarking; Client Report A1-000030.04; National Research Council Canada; Ottawa, ON; 63 pgs.
Task 4	W. Maref, H. H. Saber and G. Ganapathy (2015), Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads – Task 4 – Characterization of Air Flow within Drainage Cavities; Client Report A1-000030.05; National Research Council Canada; Ottawa, ON; 115 pgs.
Task 5	Steven M. Cornick and Khaled Abdulghani (2013), Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads – Task – Defining Exterior Environmental Loads; Client Report A1-000030.03; National Research Council Canada; Ottawa, ON; 99 pgs.
Task 5	T. Moore and M. Nicholls (2015), Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads – Task 5 – Characterization of Water Entry to, Retention and Dissipation from Drainage Components; Client Report A1-000030.06; National Research Council Canada; Ottawa, ON; 43 pgs.
Task 6	H. H. Saber (2015) Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads – Task 6 – Hygrothermal Performance of NBC-Compliant Reference Wall for Selected Canadian Locations; Client Report A1-000030.07; National Research Council Canada; Ottawa, ON; 59 pgs. H. H. Saber (2015) Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads – Task 6 – Hygrothermal Performance of Wall Assemblies Incorporating Drainage Components for Selected Canadian Locations; Client Report A1-000030.08; National Research Council Canada; Ottawa, ON; 167 pgs. H. H. Saber (2015) Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads – Task 6 – Hygrothermal Performance of Wall Assemblies Incorporating Drainage Components: Results for wall components having Medium Resistant (MR) Mould Growth Sensitivity Class; Client Report A1-000030.10; National Research Council Canada; Ottawa, ON; 85 p.
Task 7	M. A. Lacasse (2015) Performance Evaluation of Proprietary Drainage Components and Sheathing Membranes when Subjected to Climate Loads – Task 7 – Summary Report on Experimental and Modelling Tasks and Recommendations; Client Report A1-000030.09; National Research Council Canada; Ottawa, ON; 43 pgs.

Appendix 2 – Pressure Measurements & Uncertainty

Configuration 1: 10 mm wall Air Cavity Depth

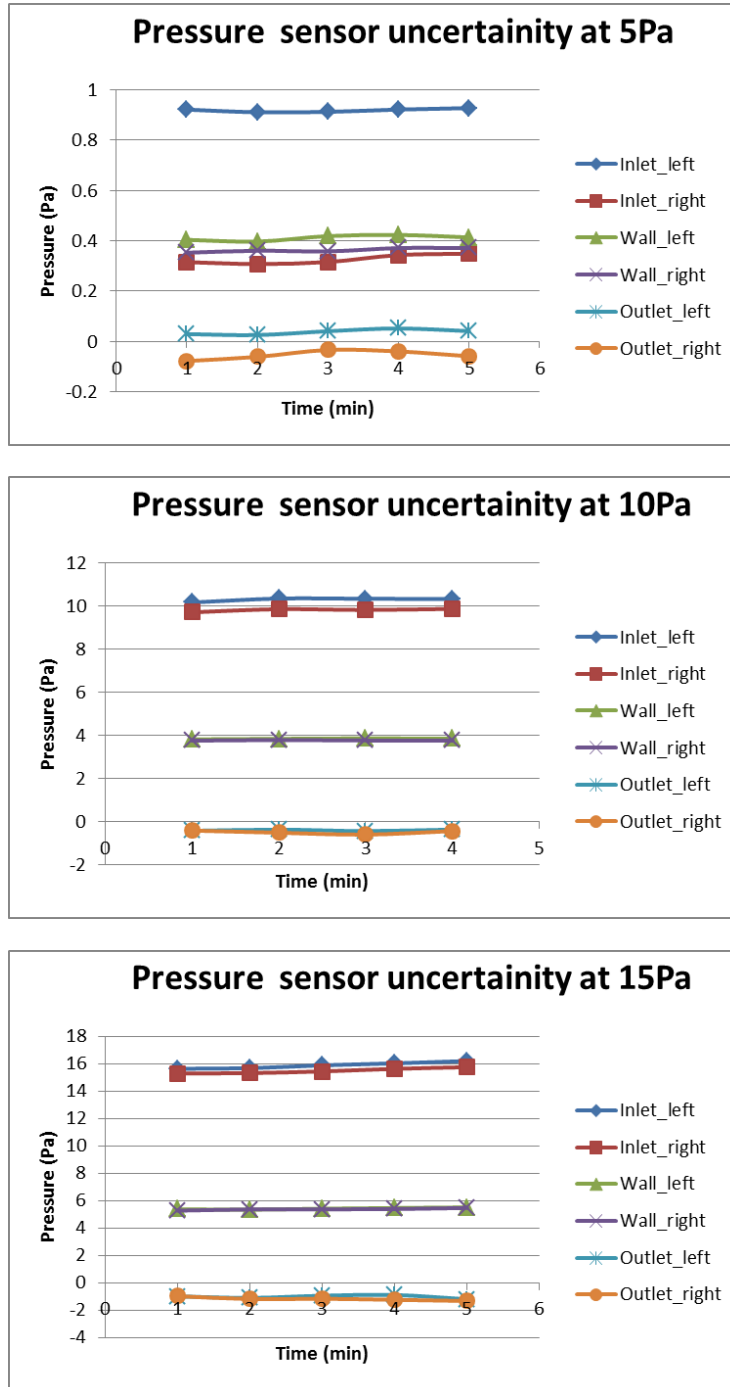


Figure 39 - Pressure sensor uncertainty at given pressure differentials for sensors located at the inlet, mid-height of cavity (middle) and outlet for 10 mm wall air cavity

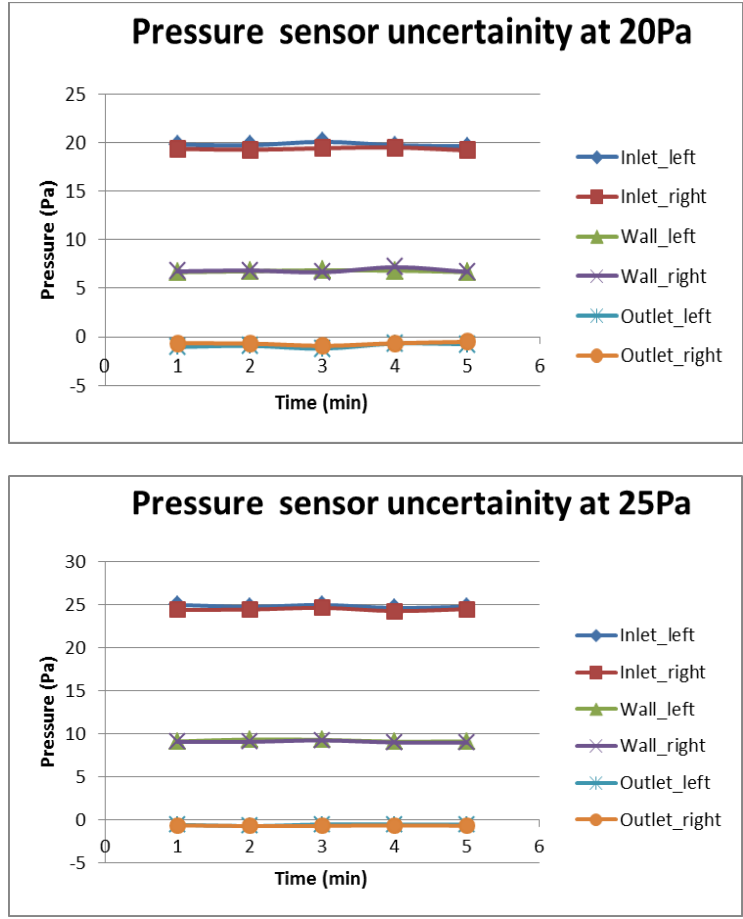


Figure 40 - Pressure sensor at uncertainty at given pressure differentials for sensors located at the inlet, mid-height of cavity (middle) and outlet for 10 mm wall air cavity

Configuration 2: 20 mm wall Air Cavity Depth

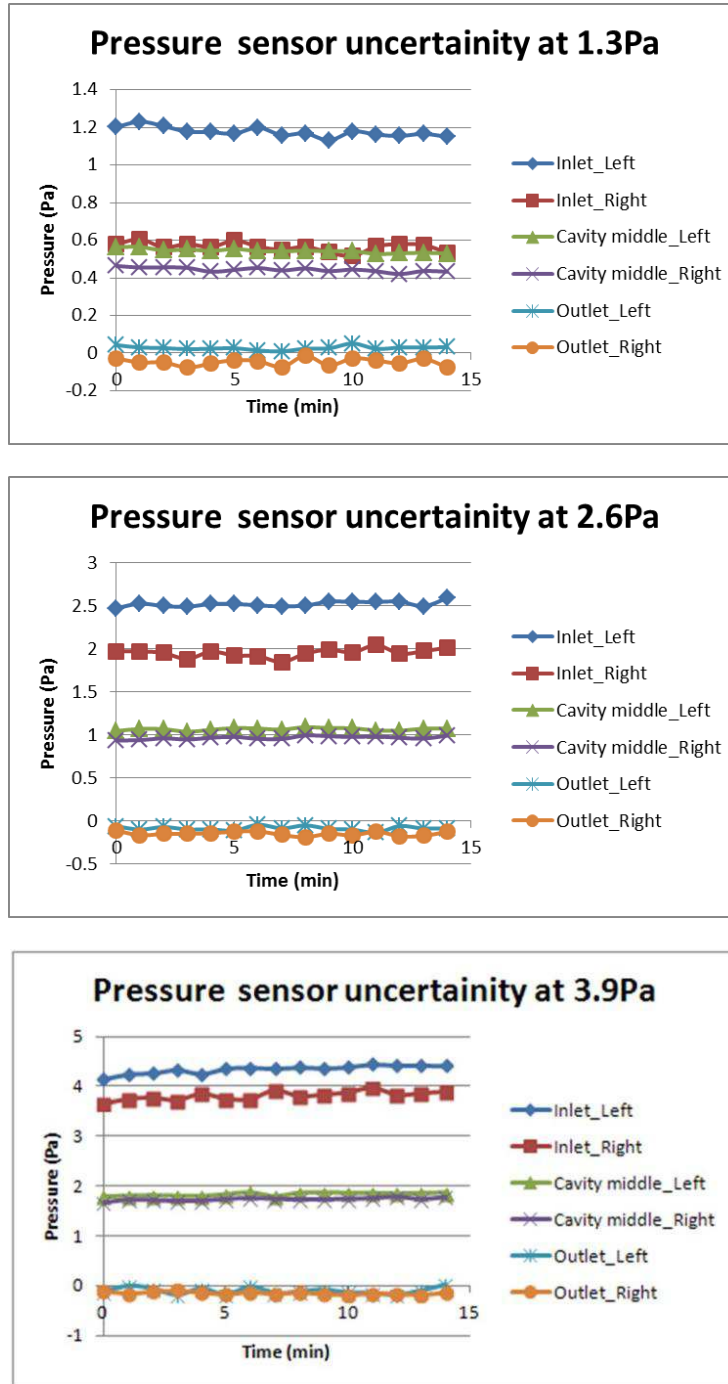


Figure 41 - Pressure sensor uncertainty at given pressure differentials for sensors located at the inlet, mid-height of cavity (middle) and outlet for 20 mm wall air cavity

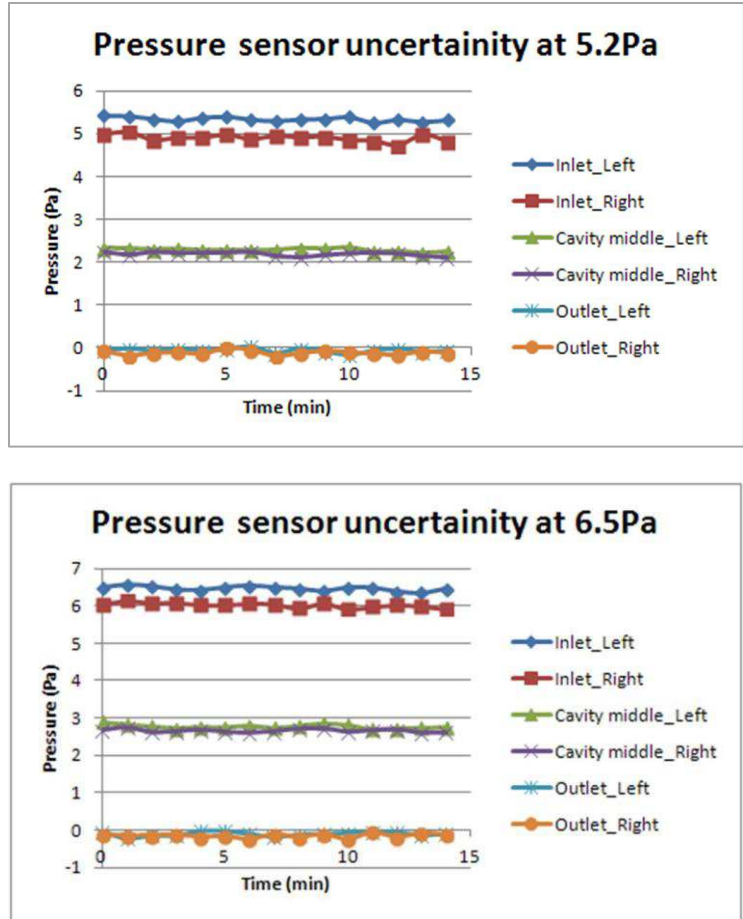


Figure 42 – Pressure sensor uncertainty at given pressure differentials for sensors located at the inlet, mid-height of cavity (middle) and outlet for 20 mm wall air cavity

Configuration 3: 25 mm wall Air Cavity Depth

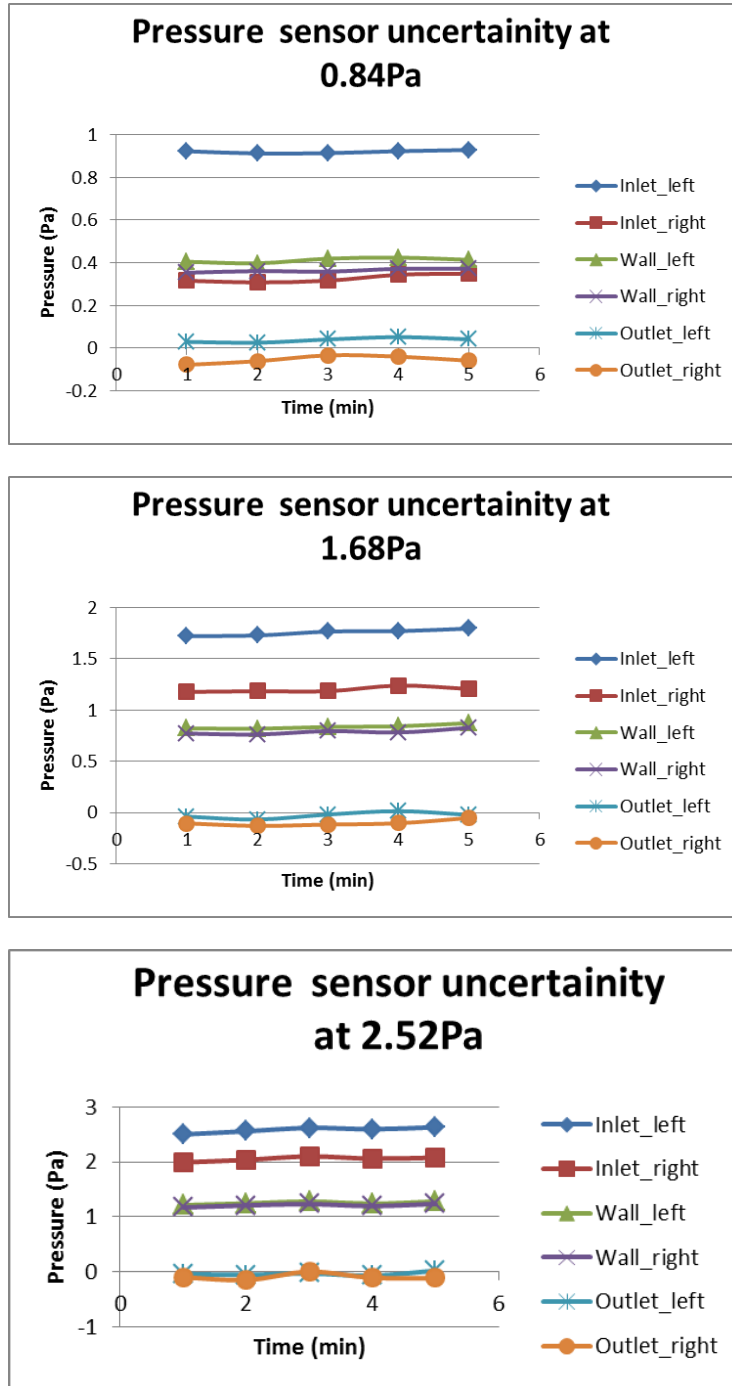


Figure 43 - Pressure sensor uncertainty for a cavity of 25 mm depth at given pressure differentials for sensors located at the inlet, mid-height of cavity (middle) and outlet for 25 mm wall air cavity

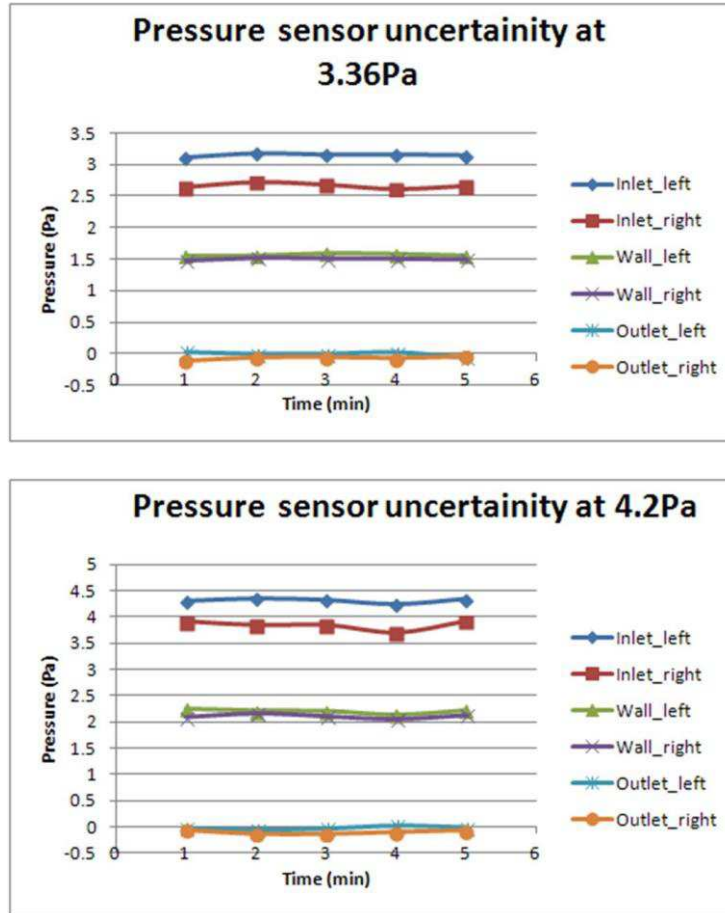


Figure 44 - Pressure sensor uncertainty for a cavity of 25 mm depth at given pressure differentials for sensors located at the inlet, mid-height of cavity (middle) and outlet for 25 mm wall air cavity

Appendix 3 – Air Velocity Measurements

Configuration 1: 10 mm Wall Air Cavity – 5 Pa

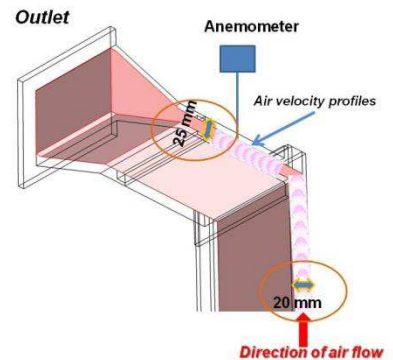
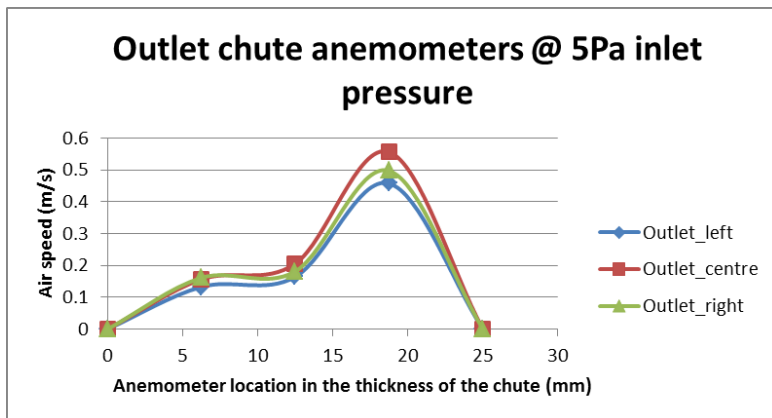
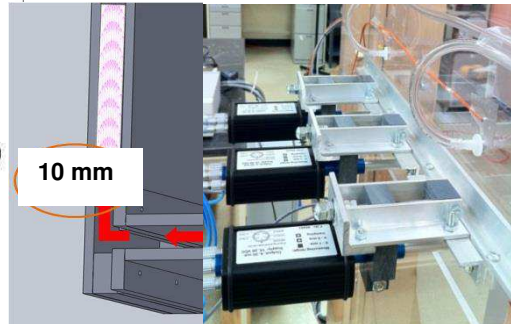
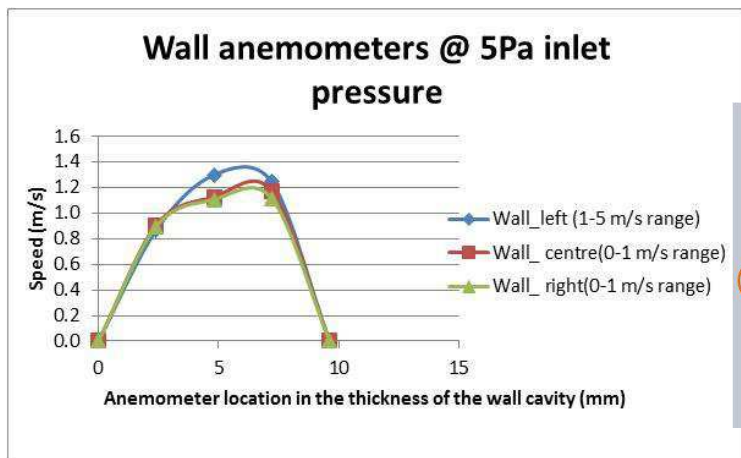
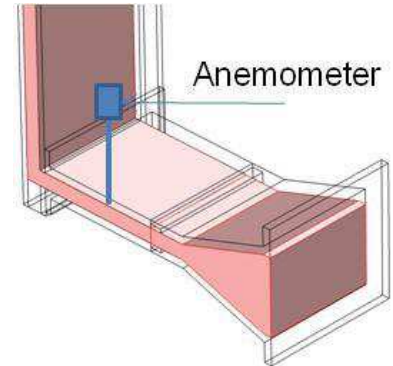
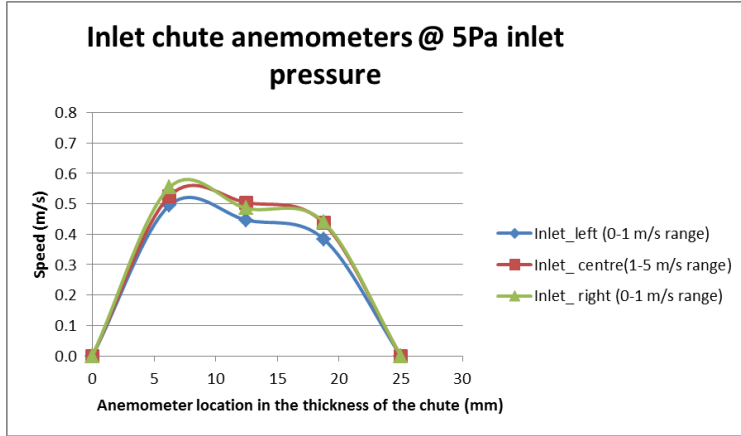


Figure 45 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 5 Pa and cavity depth of 10 mm

Configuration 1: 10 mm Wall Air Cavity – 10Pa

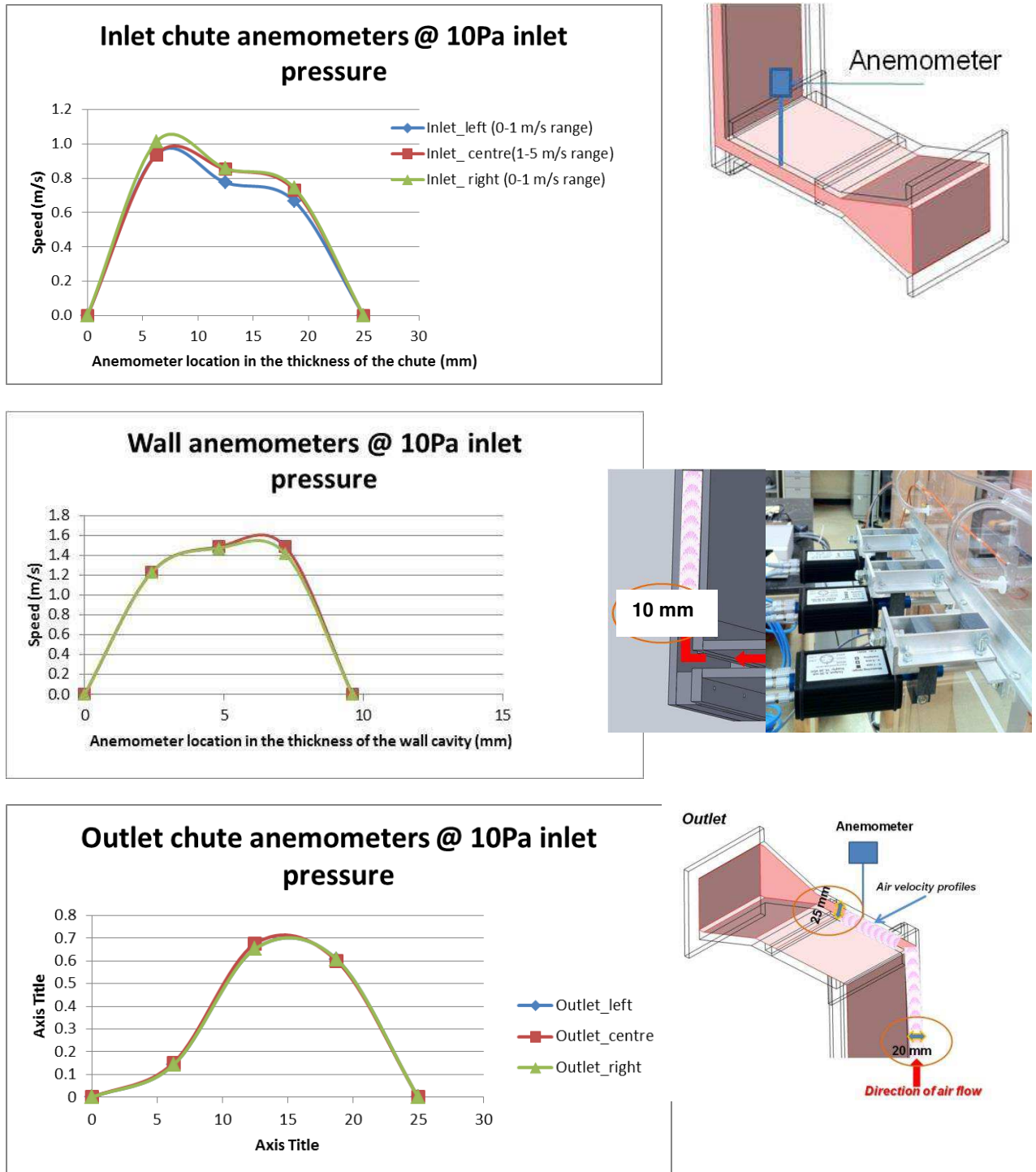


Figure 46 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 10 Pa and cavity depth of 10 mm

Configuration 1: 10 mm Wall Air Cavity – 15 Pa

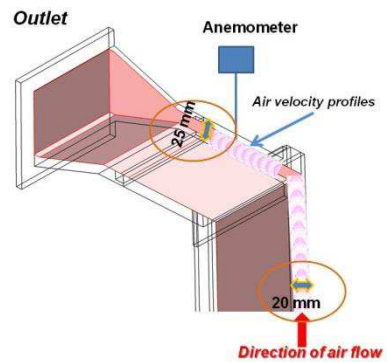
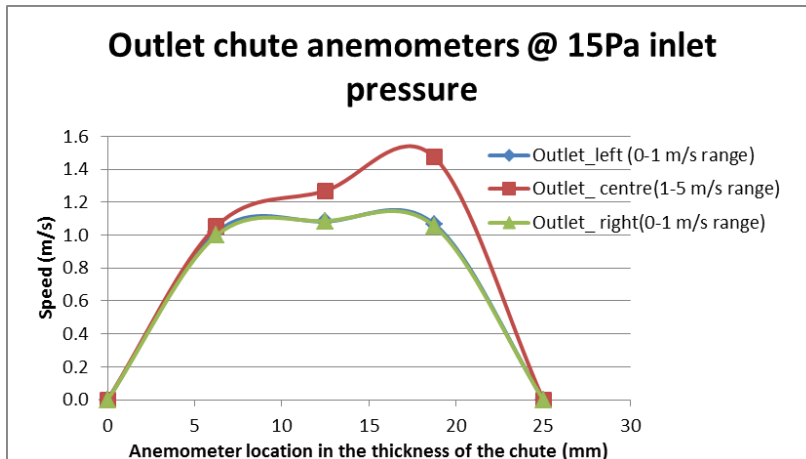
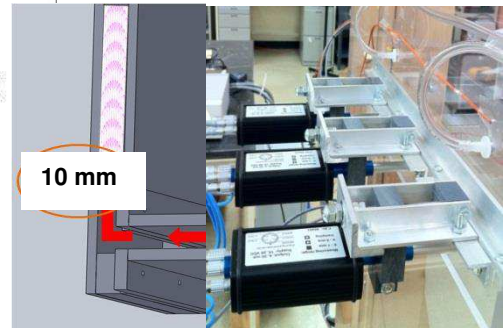
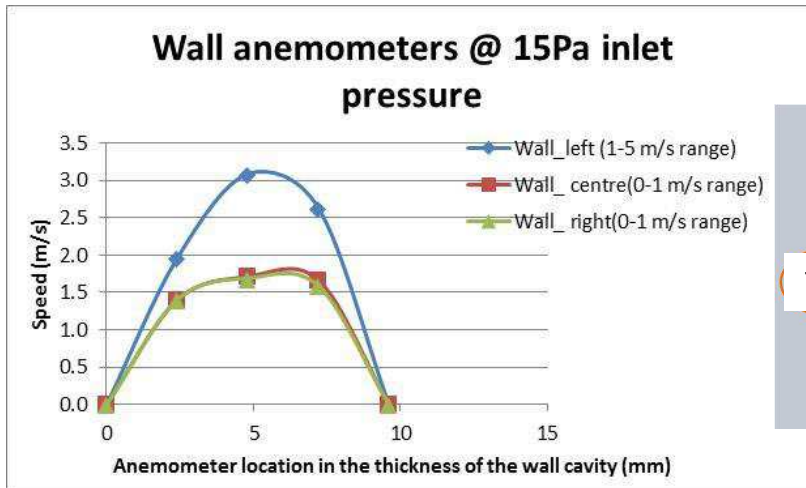
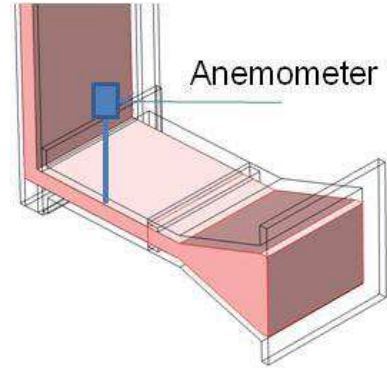
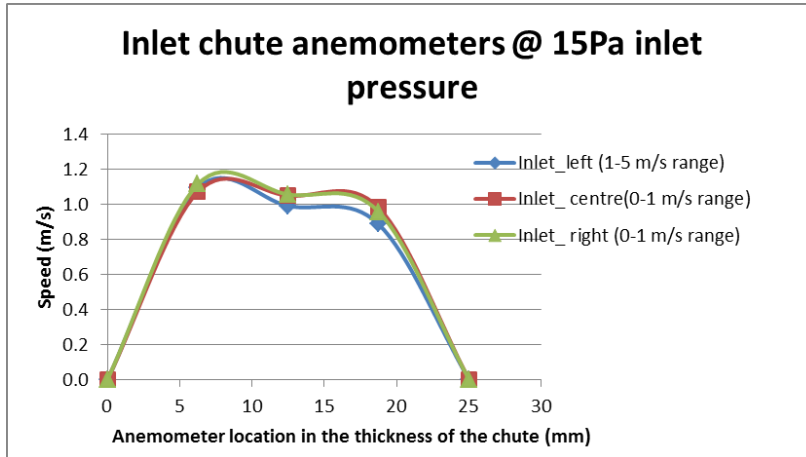


Figure 47 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 15 Pa and cavity depth of 10 mm

Configuration 1: 10 mm Wall Air Cavity – 20 Pa

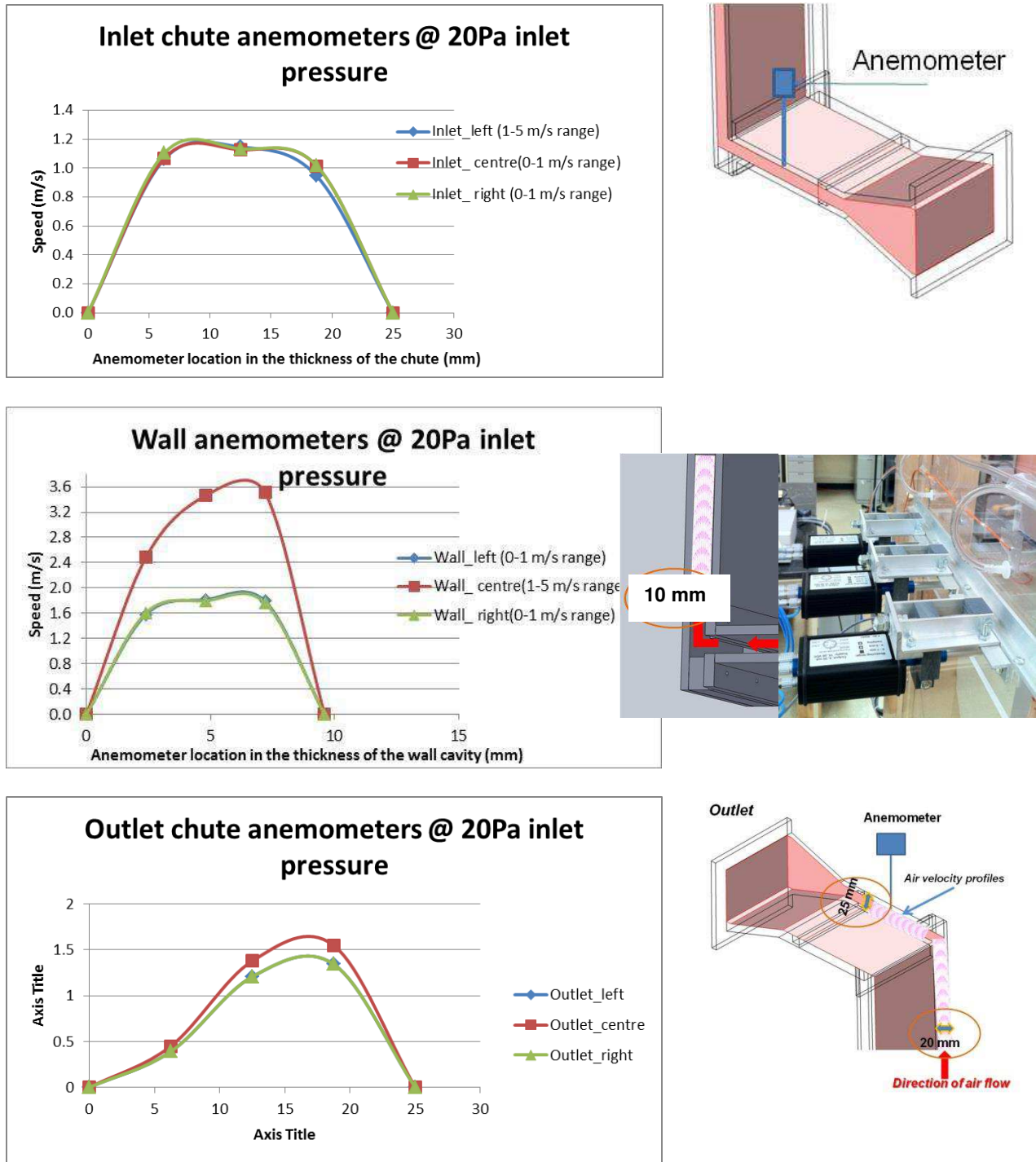


Figure 48 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 20 Pa and cavity depth of 10 mm

Configuration 1: 10 mm Wall Air Cavity – 25 Pa

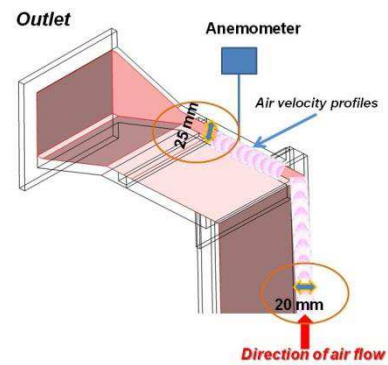
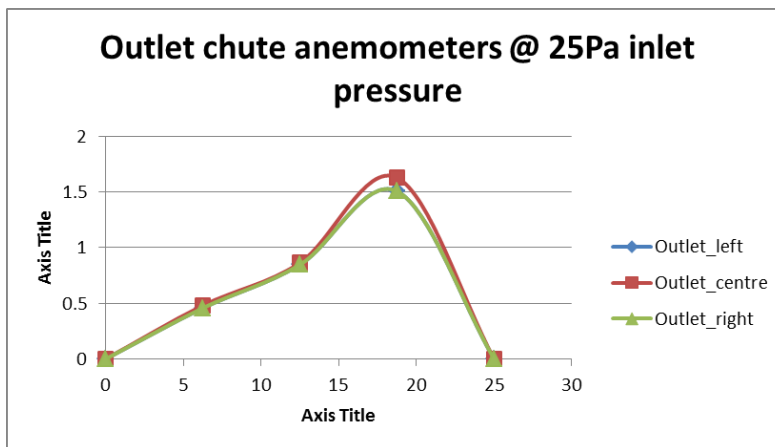
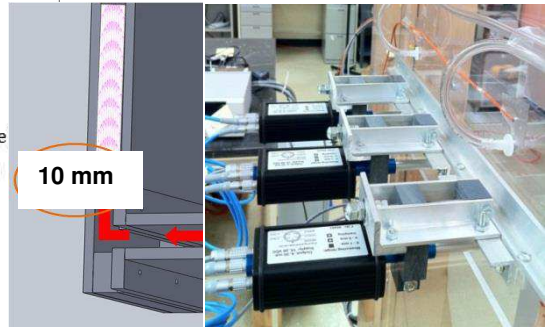
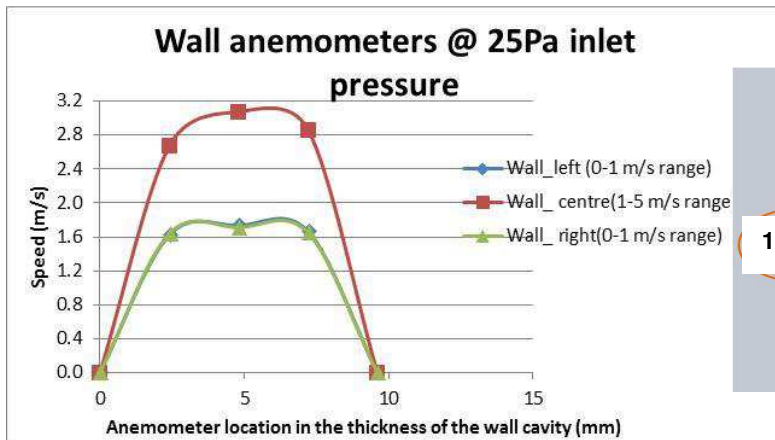
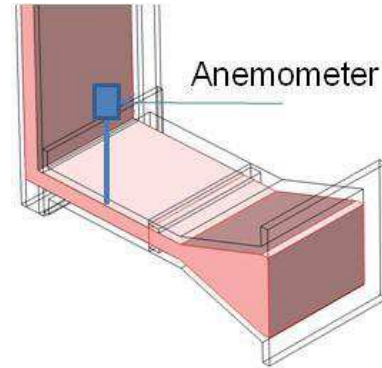
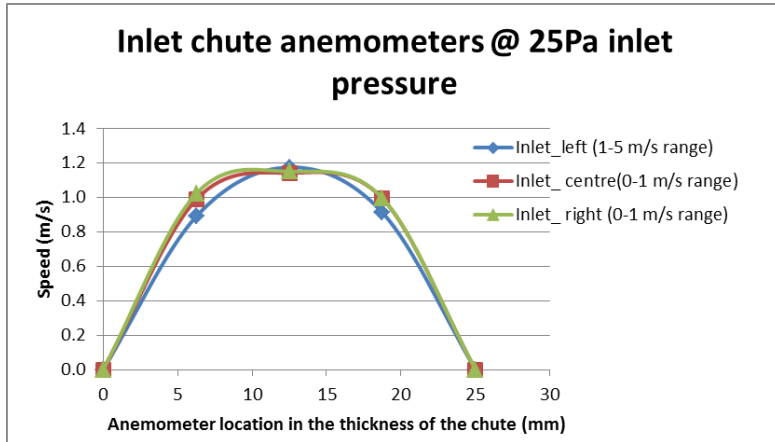


Figure 49 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 25 Pa and cavity depth of 10 mm

Configuration 2: 20 mm Wall Air Cavity – 1.3 Pa

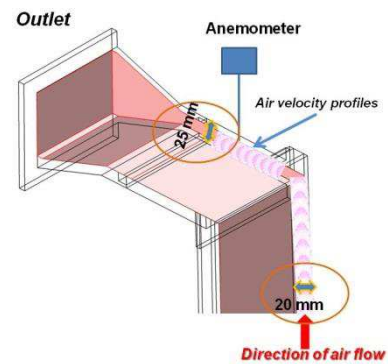
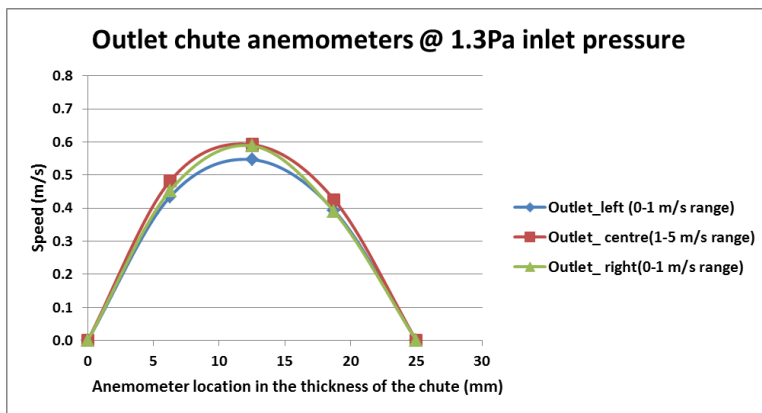
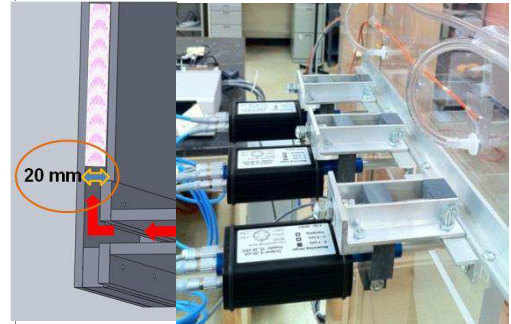
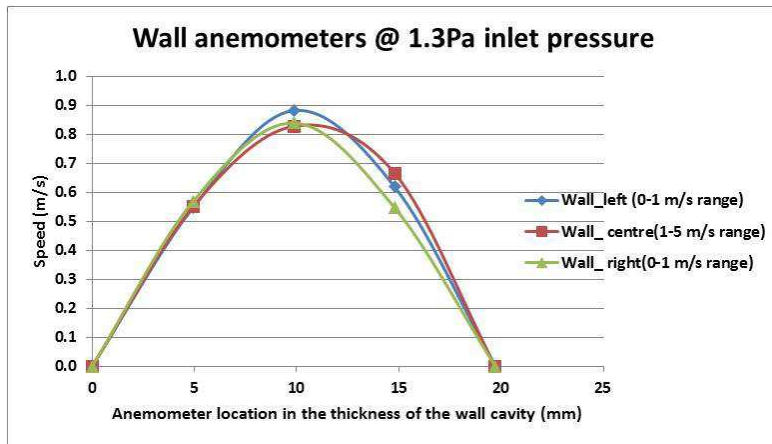
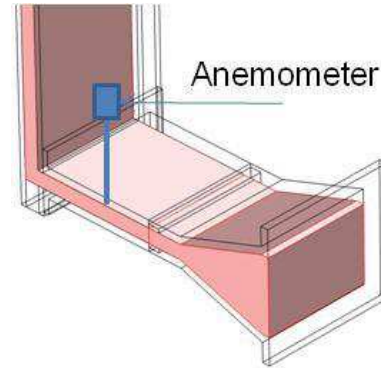
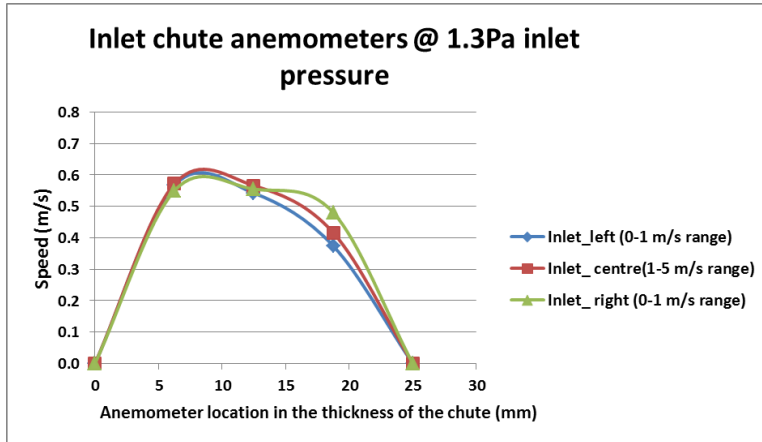


Figure 50 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 1.3 Pa and cavity depth of 20 mm

Configuration 2: 20 mm Wall Air Cavity – 2.6 Pa

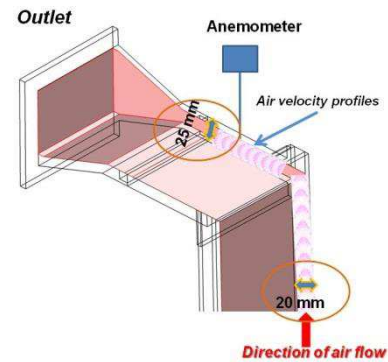
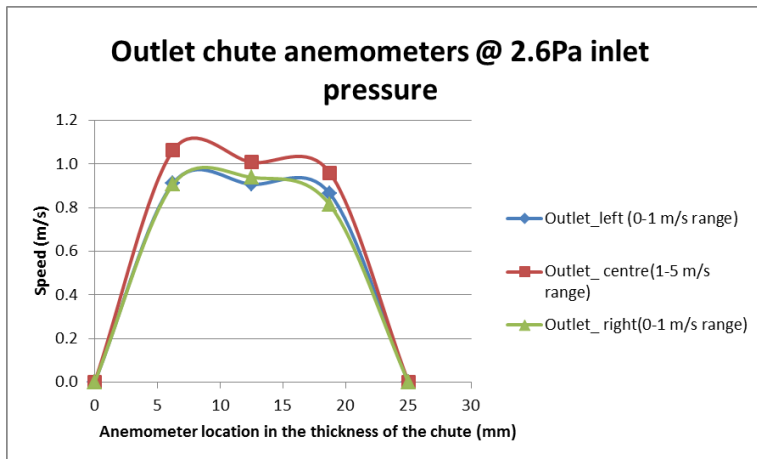
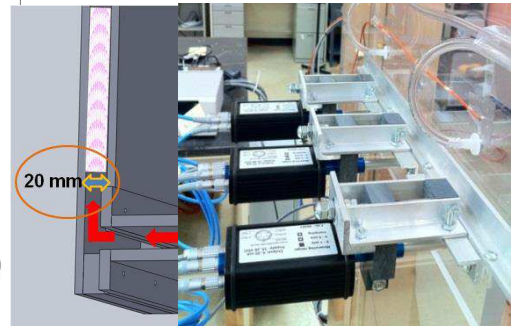
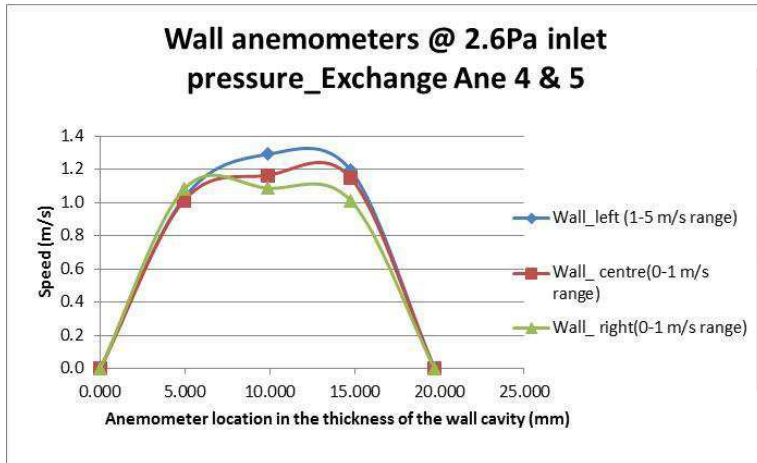
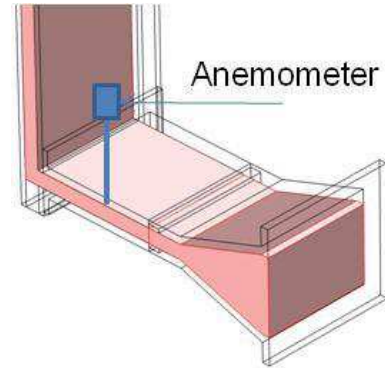
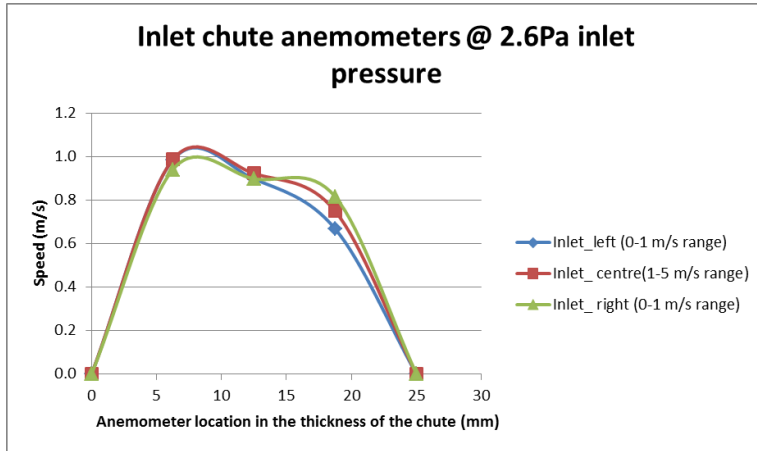


Figure 51 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 2.6 Pa and cavity depth of 20 mm

Configuration 2: 20 mm Wall Air Cavity – 3.9 Pa

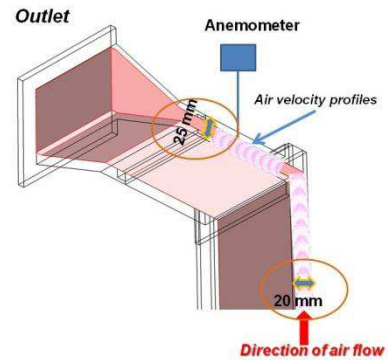
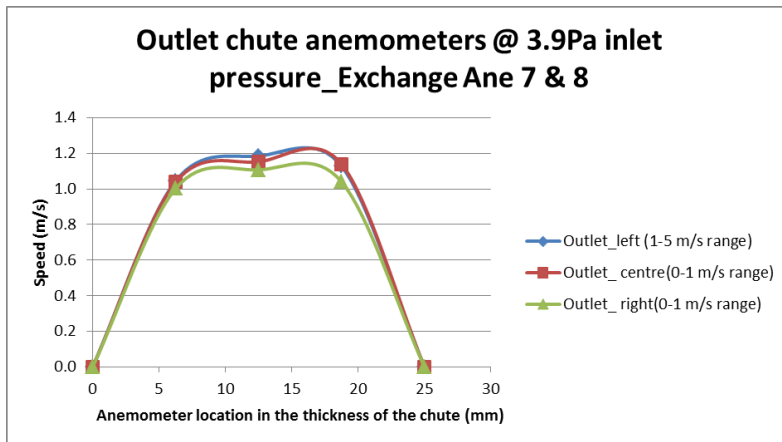
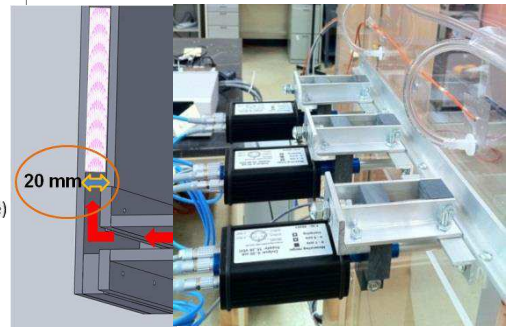
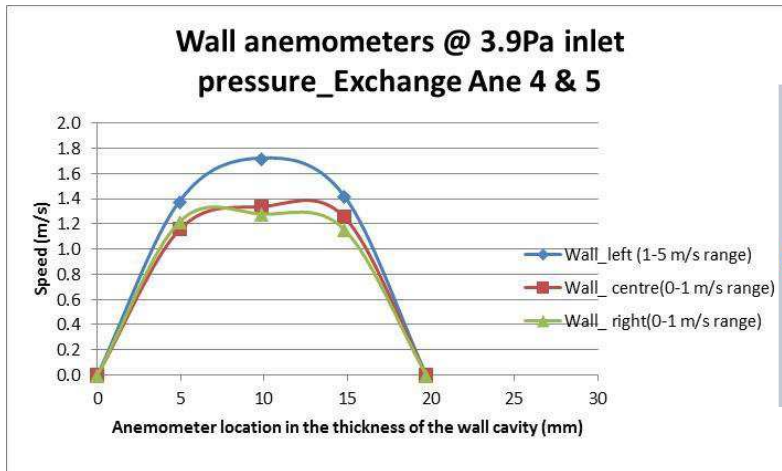
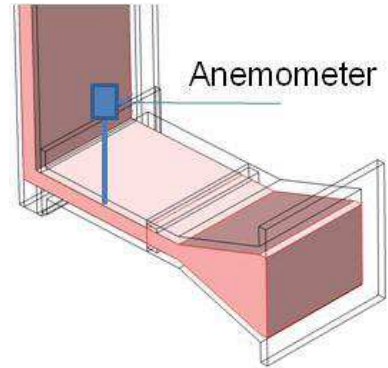
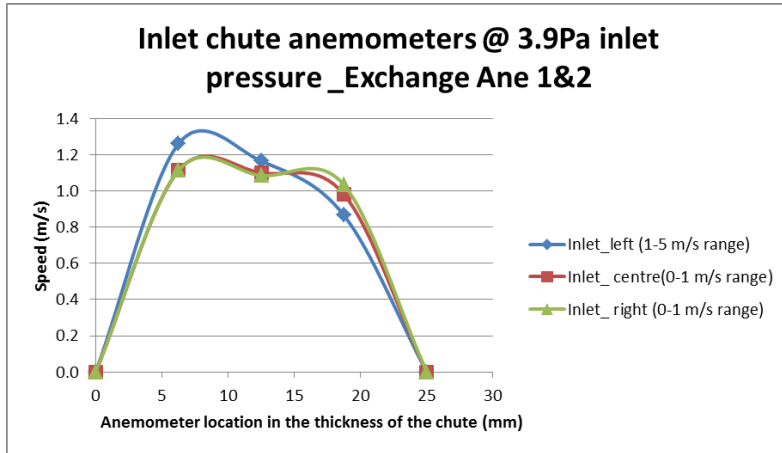


Figure 52 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 3.9 Pa and cavity depth of 20 mm

Configuration 2: 20 mm Wall Air Cavity – 5.2 Pa

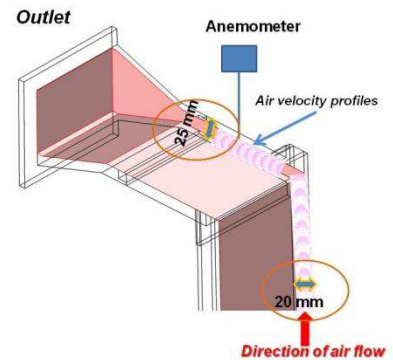
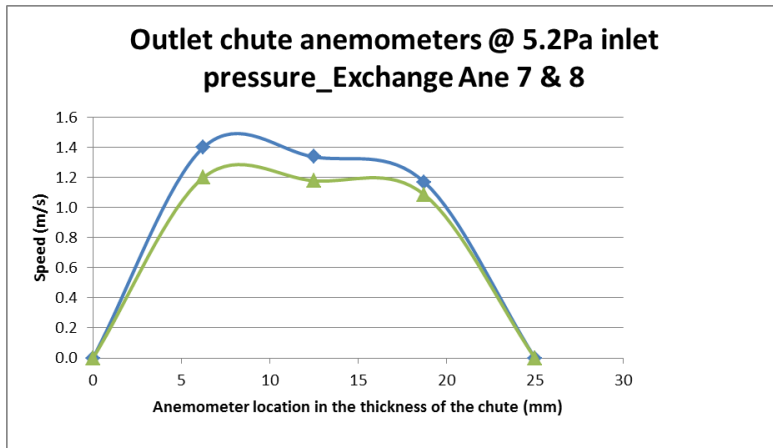
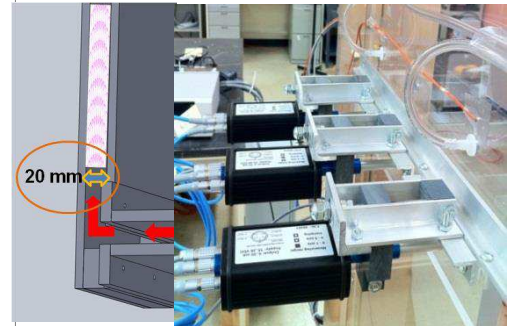
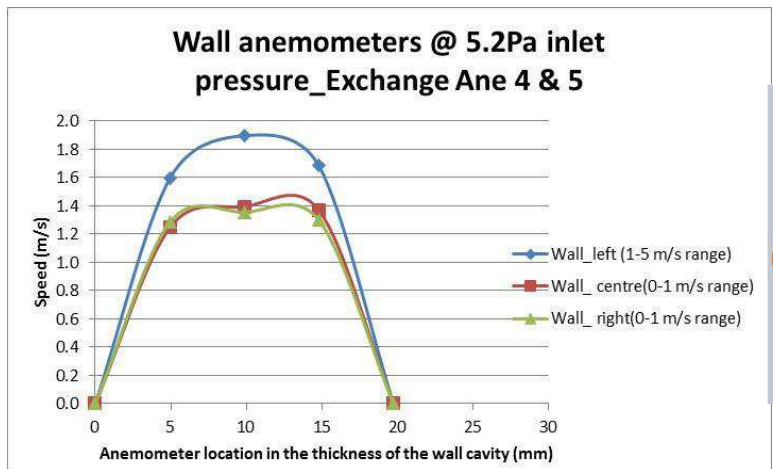
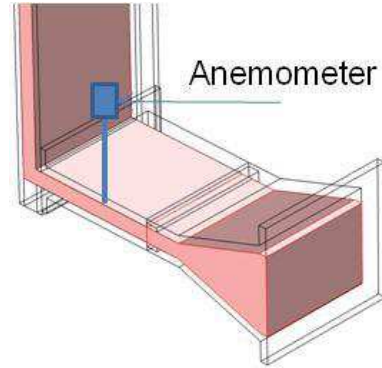
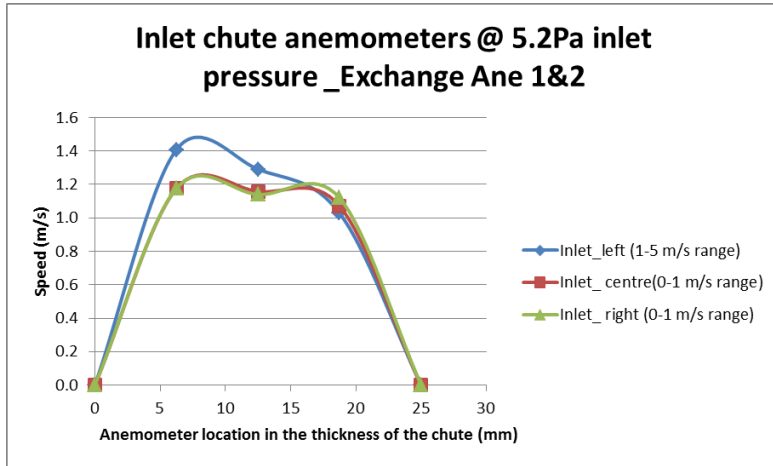


Figure 53 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 5.2 Pa and cavity depth of 20 mm

Configuration 2: 20 mm Wall Air Cavity – 6.5Pa

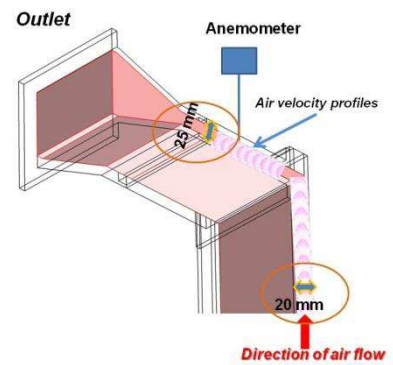
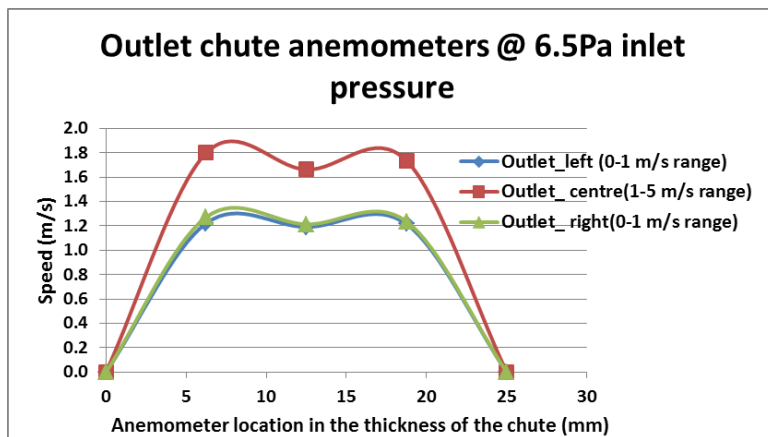
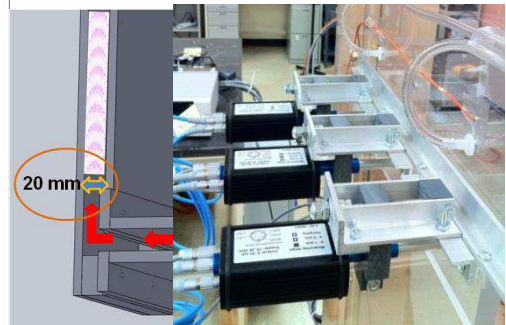
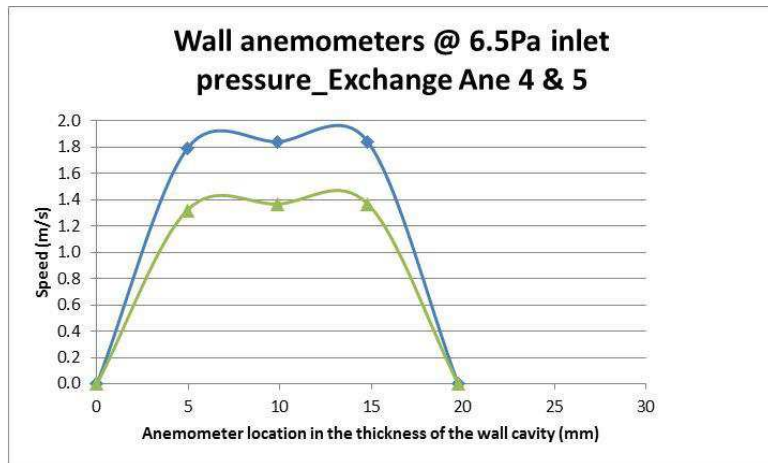
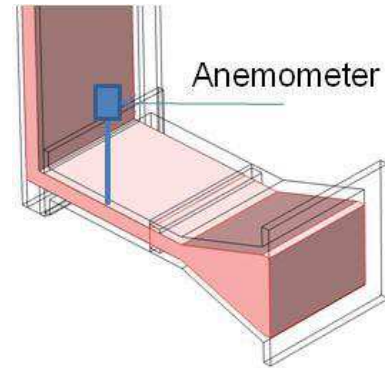
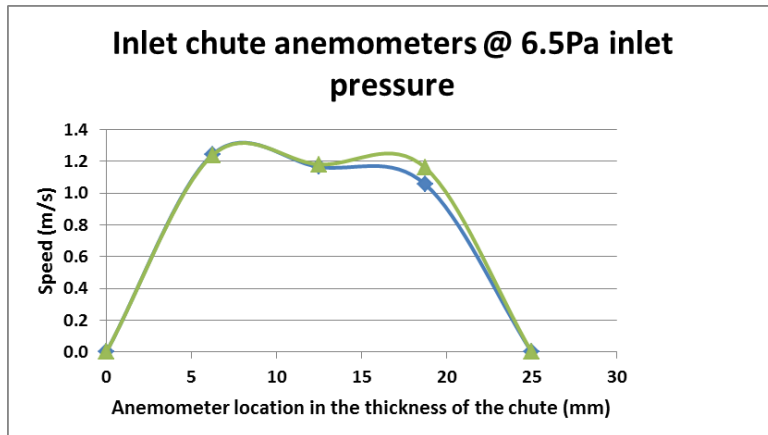


Figure 54 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 6.5 Pa and cavity depth of 20 mm

Configuration 3: 25 mm Wall Air Cavity – 0.84Pa

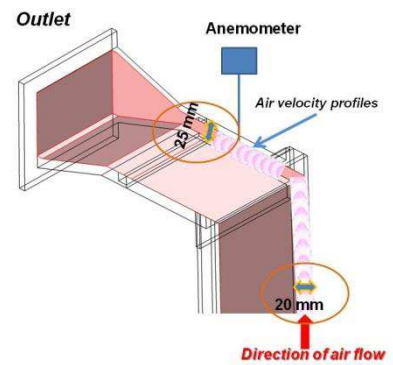
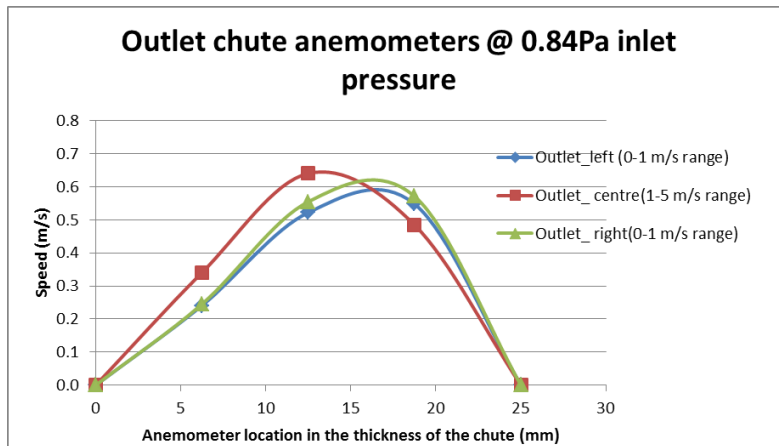
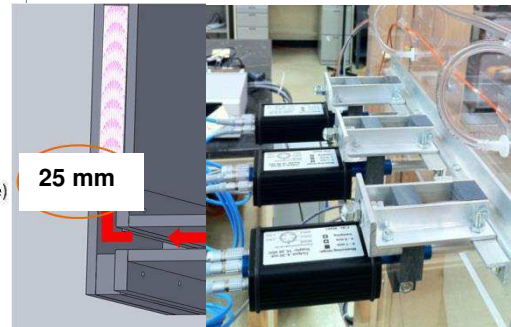
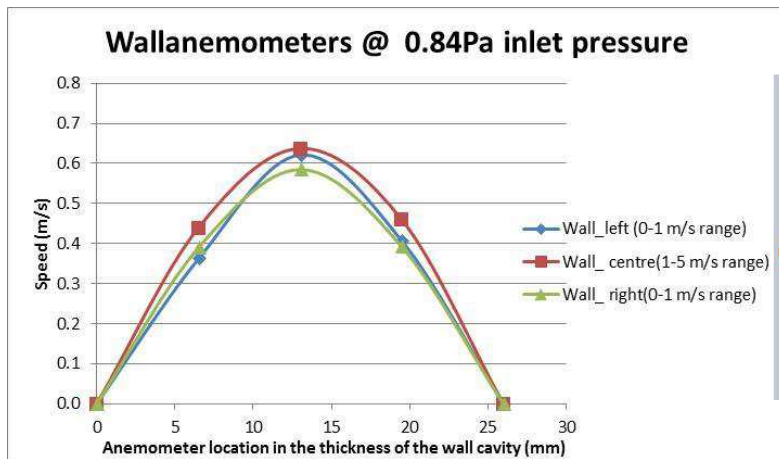
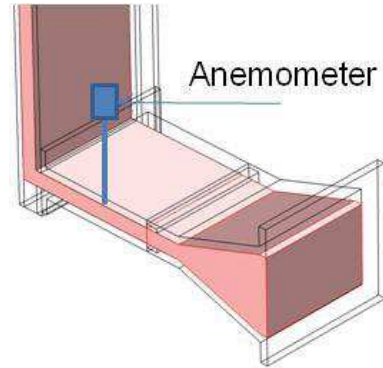
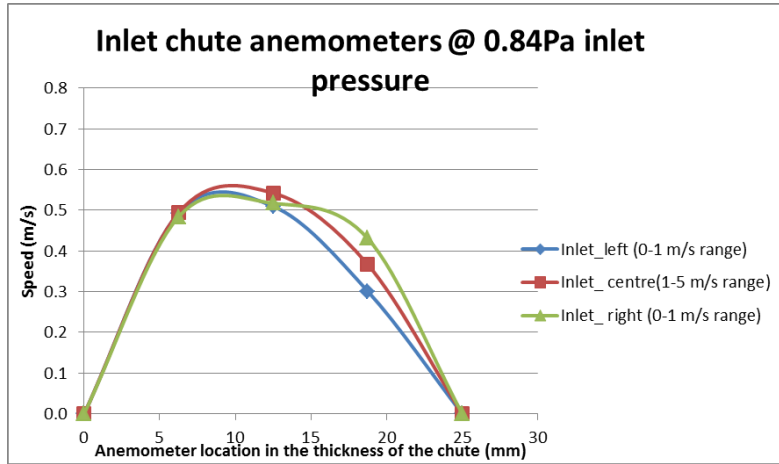


Figure 55 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 0.84 Pa and cavity depth of 25 mm

Configuration 3: 25 mm Wall Air Cavity – 1.68Pa

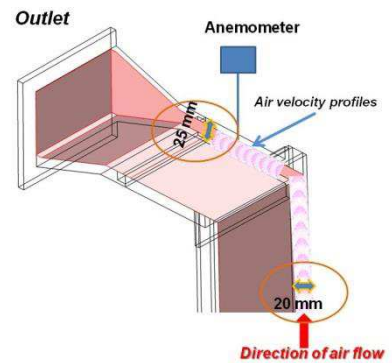
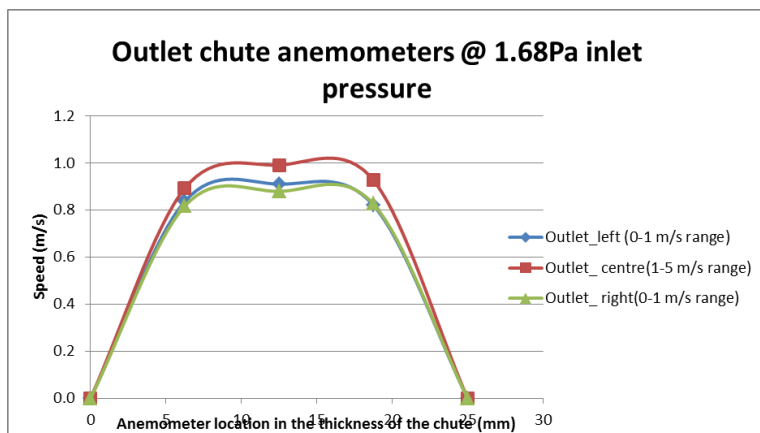
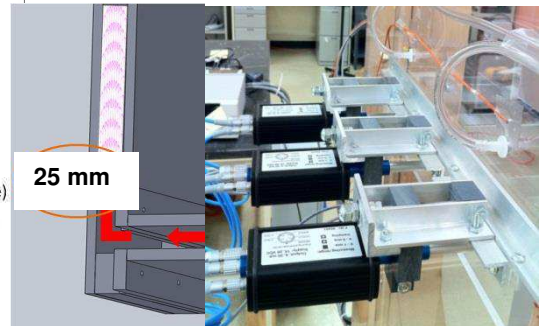
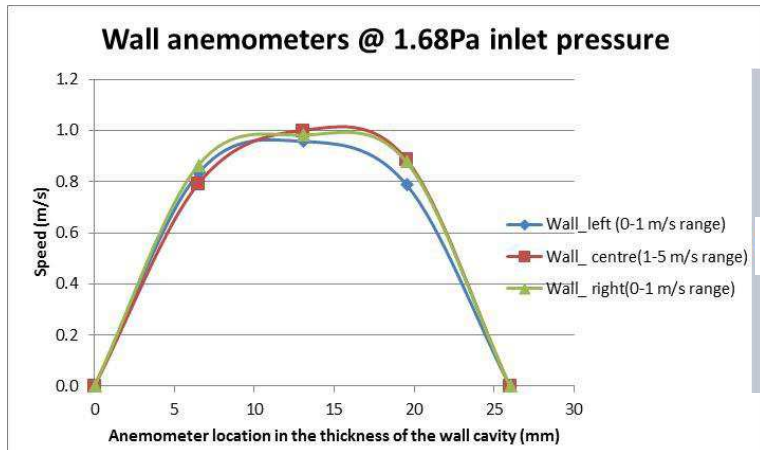
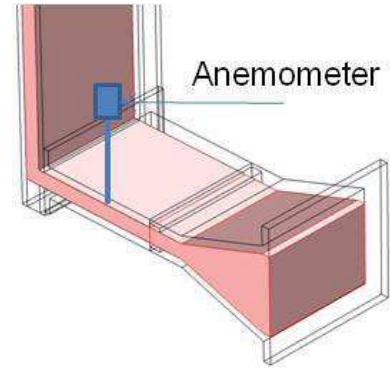
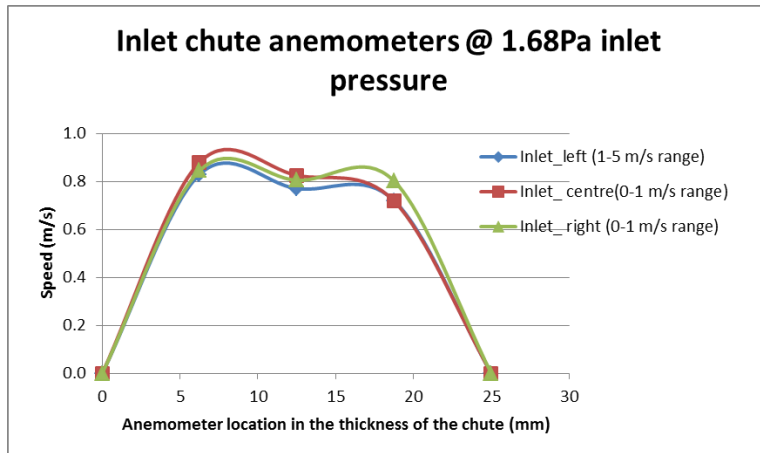


Figure 56 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 1.68 Pa and cavity depth of 25 mm

Configuration 3: 25 mm Wall Air Cavity – 2.52Pa

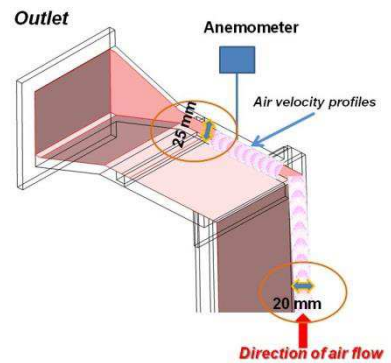
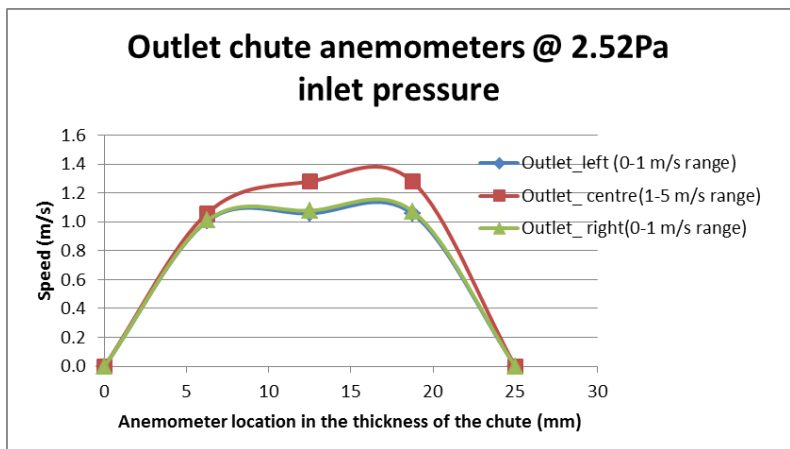
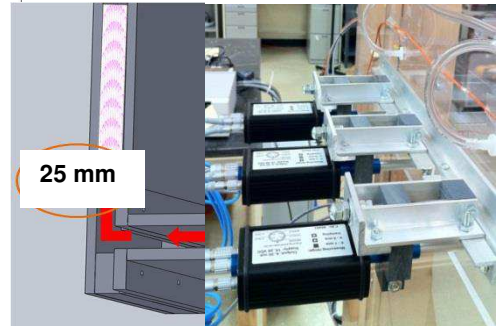
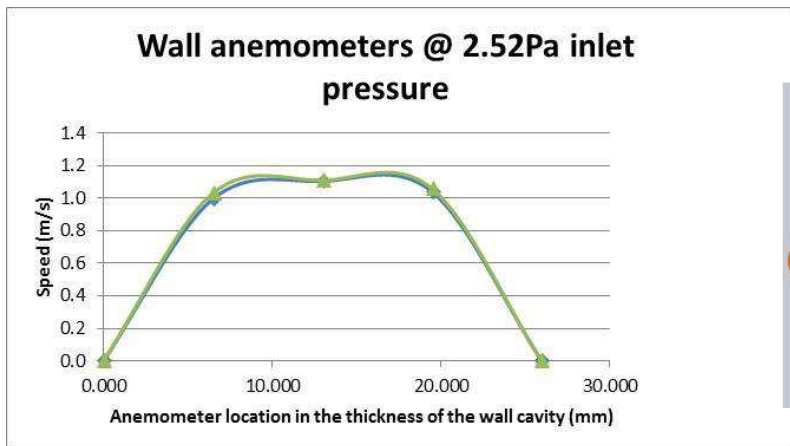
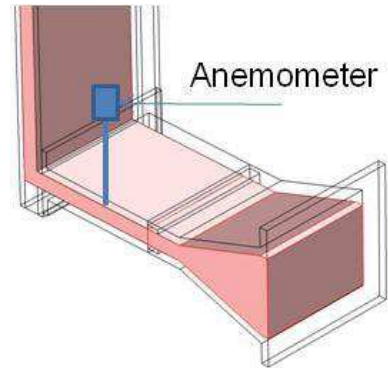
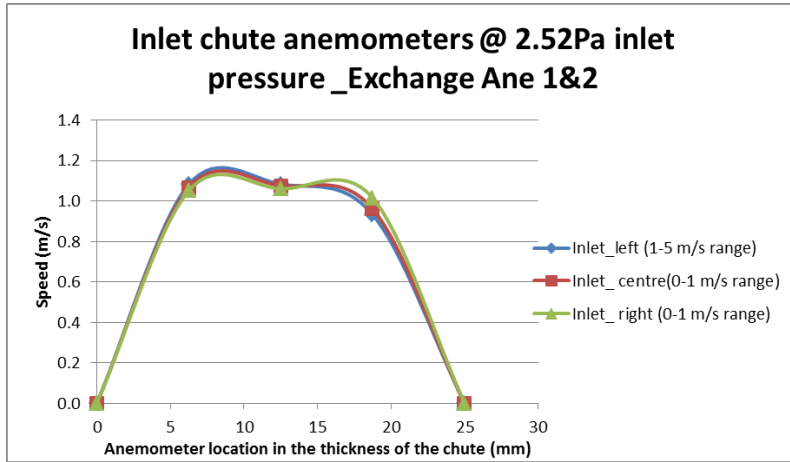


Figure 57 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 2.52 Pa and cavity depth of 25 mm

Configuration 3: 25 mm Wall Air Cavity – 3.36Pa

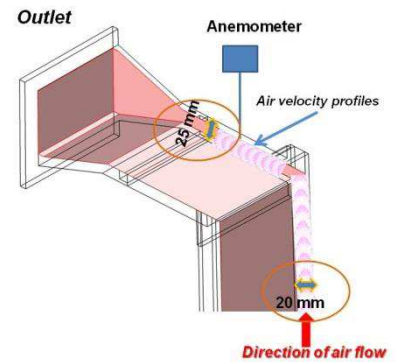
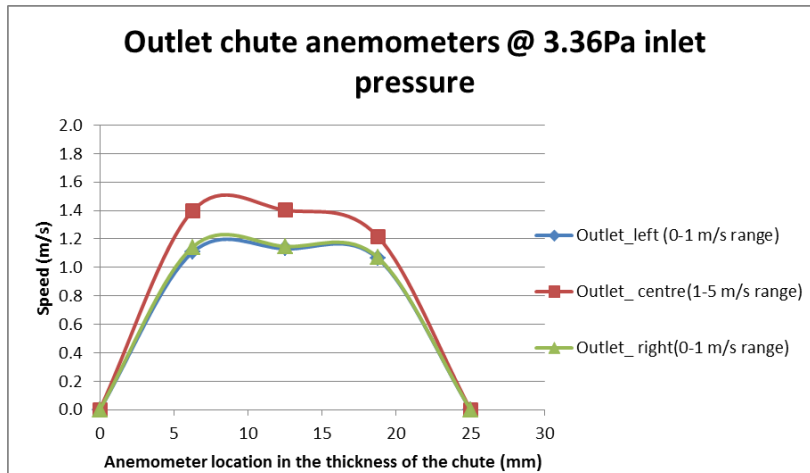
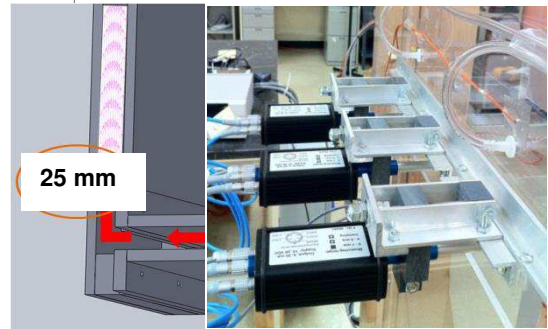
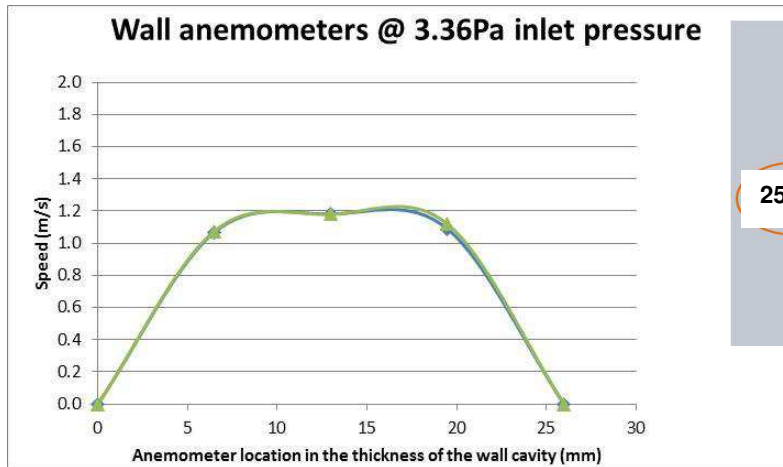
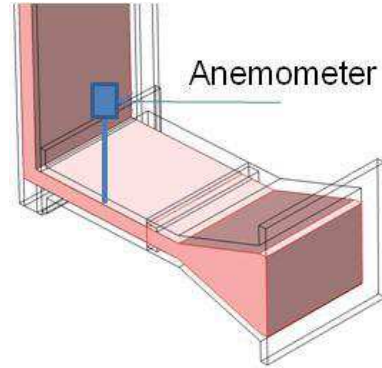
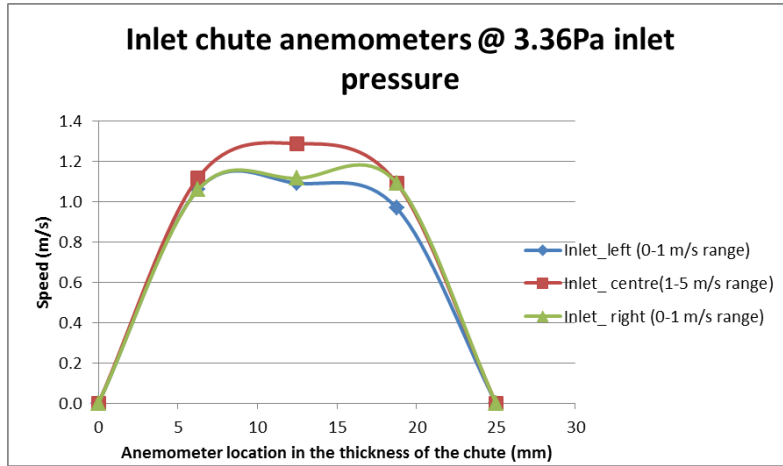


Figure 58 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 3.36 Pa and cavity depth of 25 mm

Configuration 3: 25 mm Wall Air Cavity – 4.2Pa

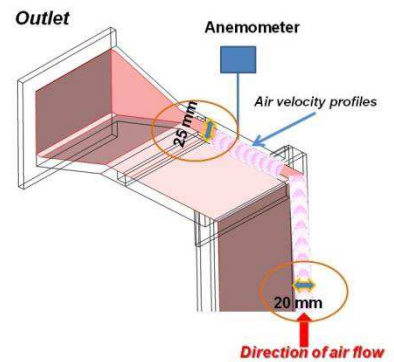
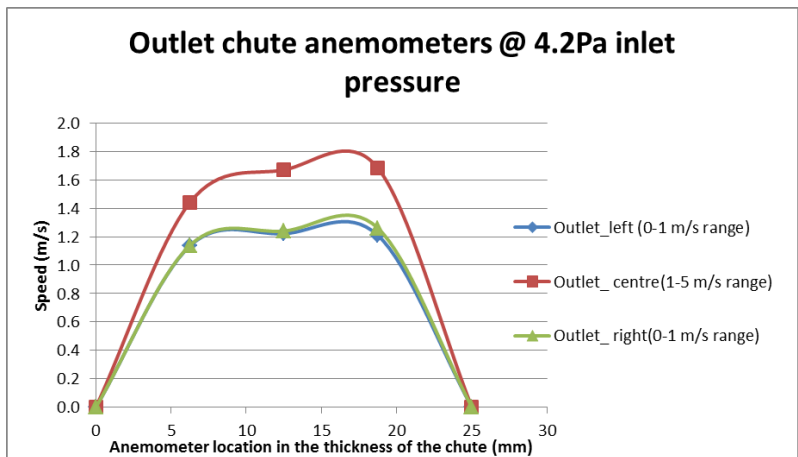
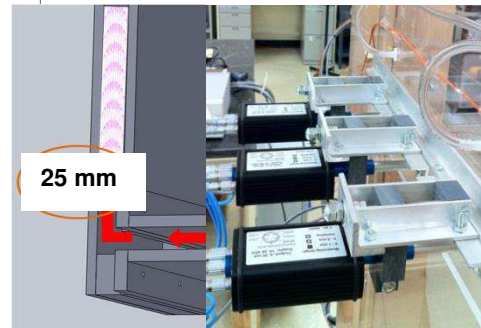
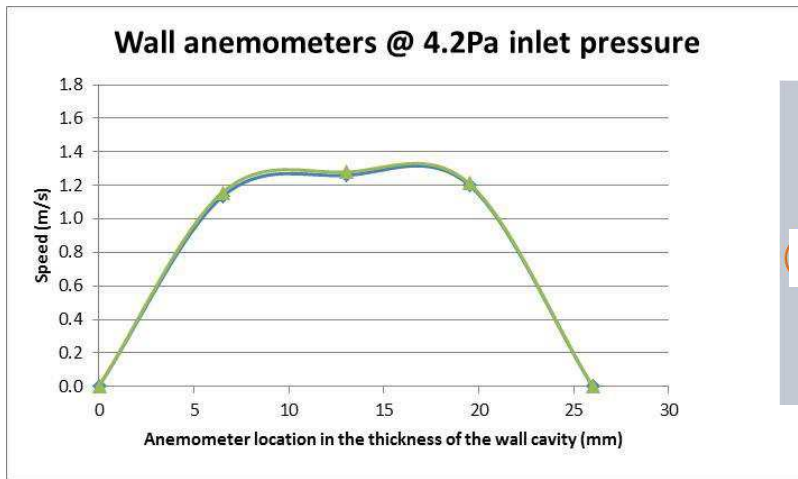
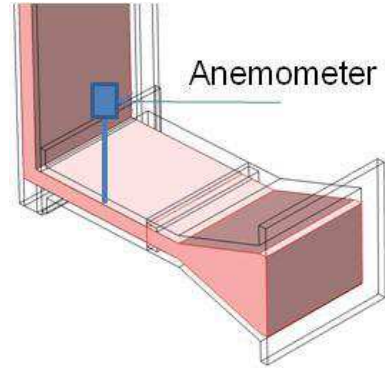
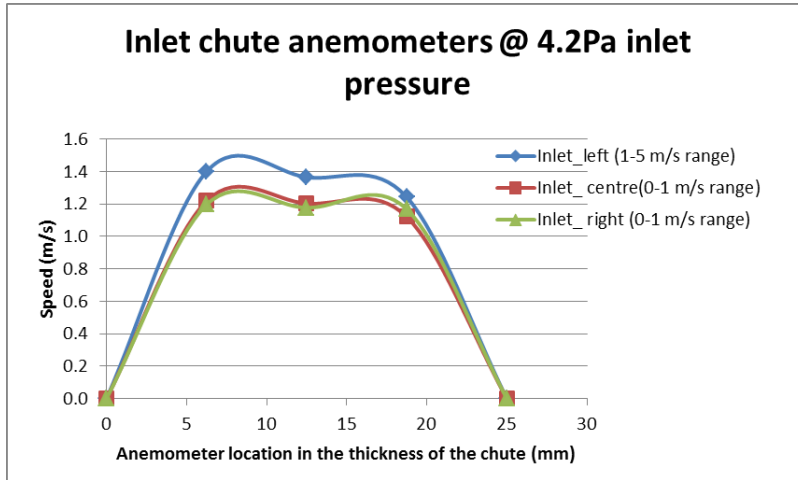


Figure 59 – Air velocity profiles at the inlet chute, mid-height (wall) and outlet chute for a pressure differential of 4.2 Pa and cavity depth of 25 mm

Configuration 4: 10 mm Wall Cavity Depth with Drainage Medium (Client C) – 5Pa

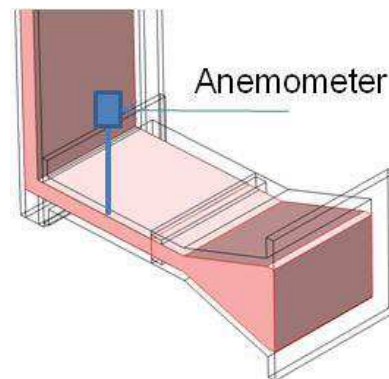
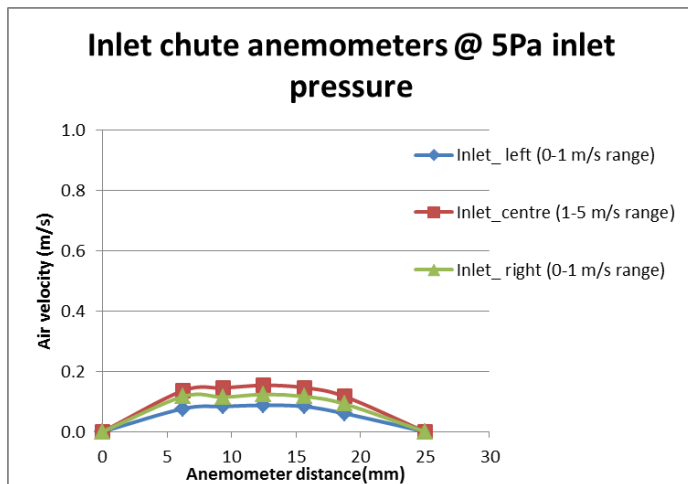
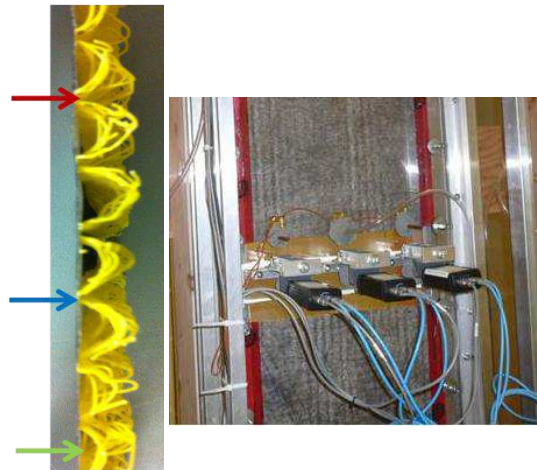
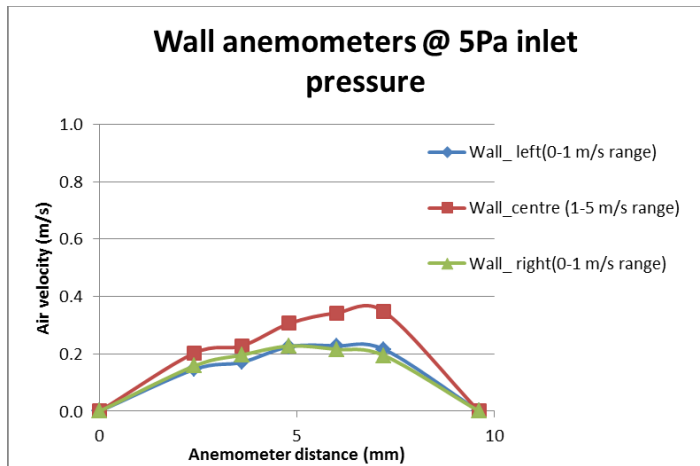
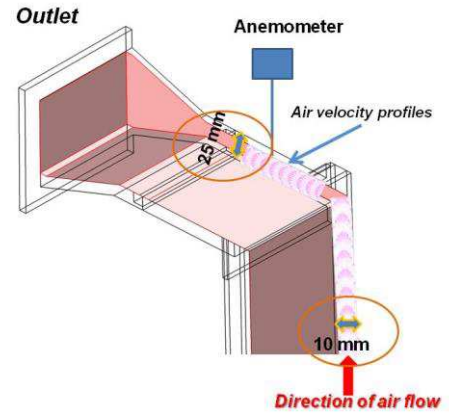
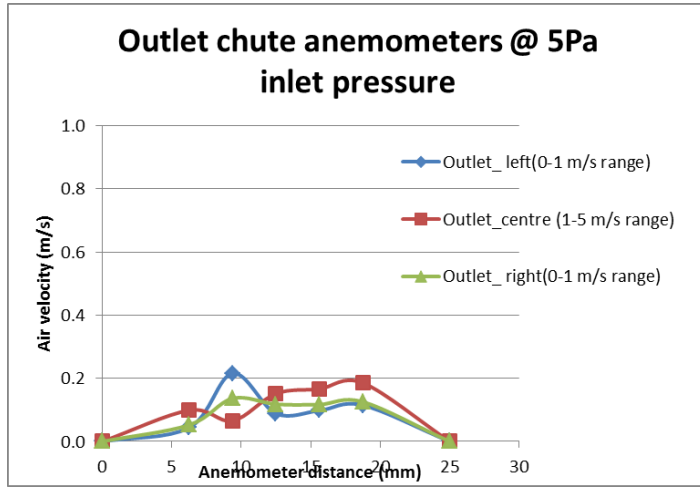


Figure 60 – Air velocity profiles at a pressure differential of 5 Pa for a cavity of 10 mm depth with drainage Medium (Client C) at the inlet chute, mid-height (wall) and outlet chute

Configuration 4: 10 mm Wall Cavity Depth with Drainage Medium (Client C) – 10Pa

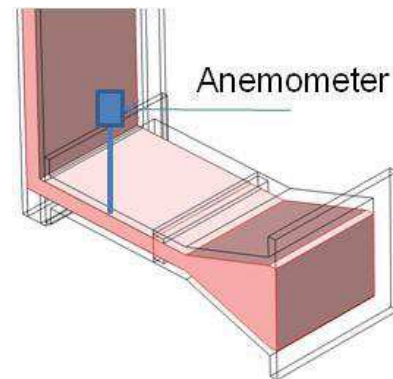
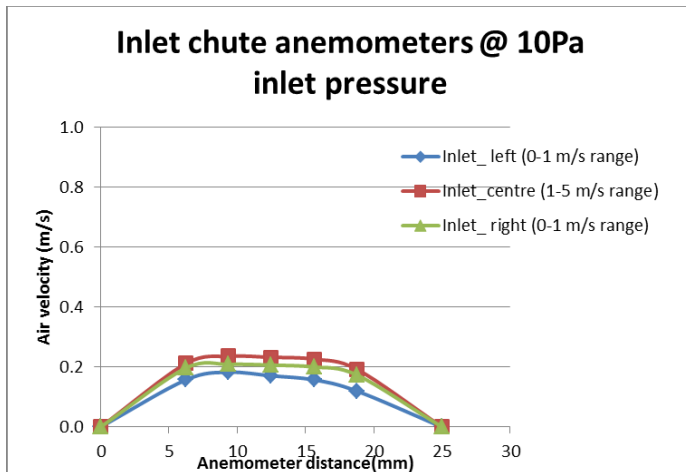
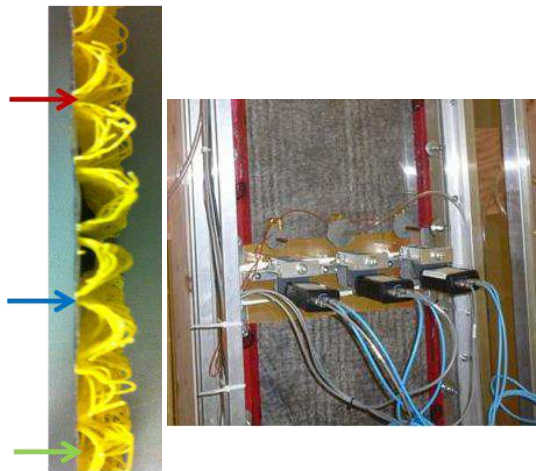
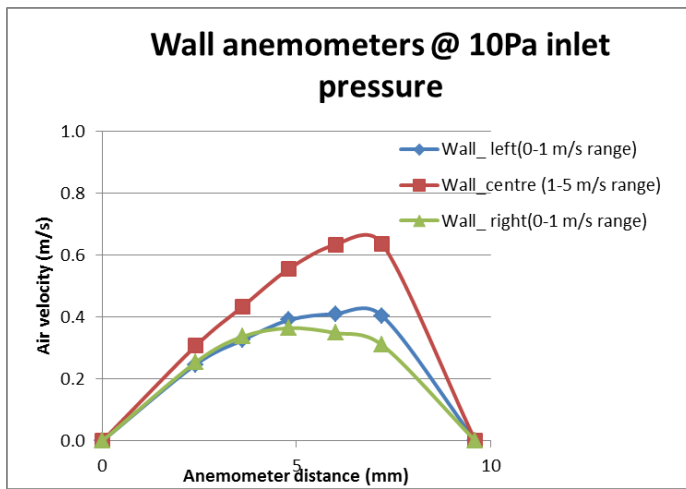
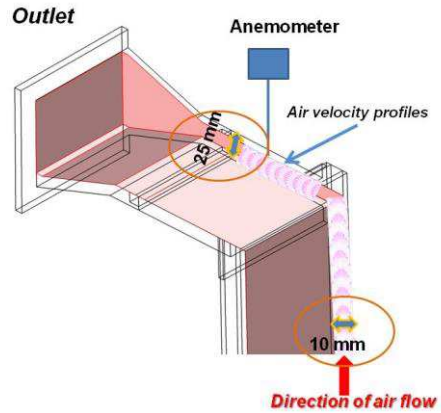
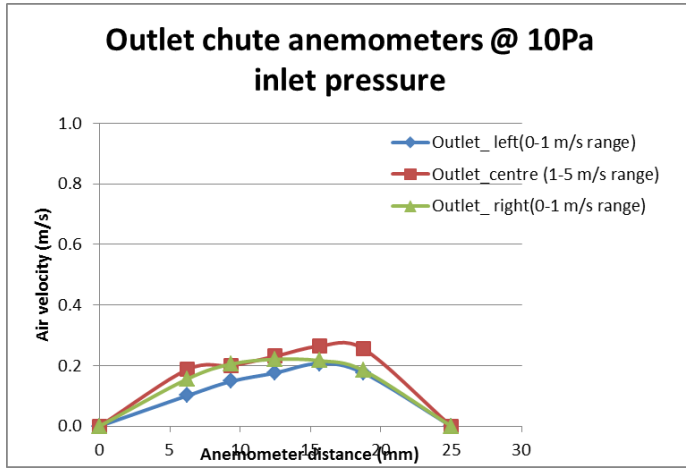


Figure 61 – Air velocity profiles at a pressure differential of 10 Pa for a cavity of 10 mm depth with drainage Medium (Client C) at the inlet chute, mid-height (wall) and outlet chute

Configuration 4: 10 mm Wall Cavity Depth with Drainage Medium (Client C) – 15Pa

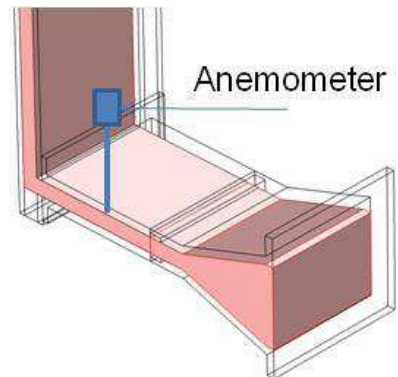
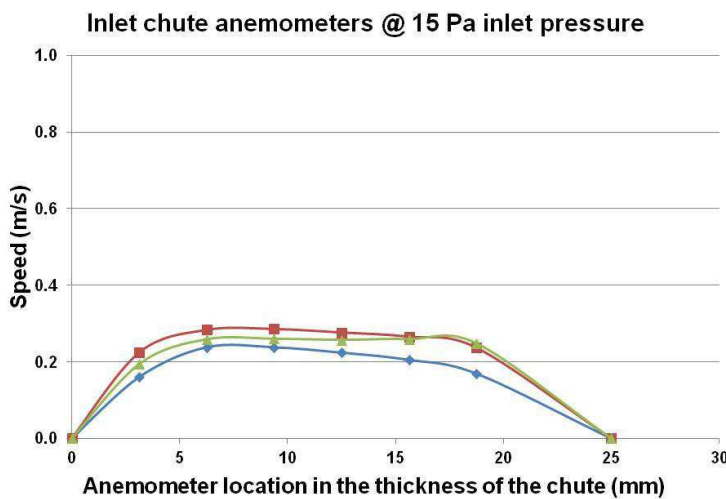
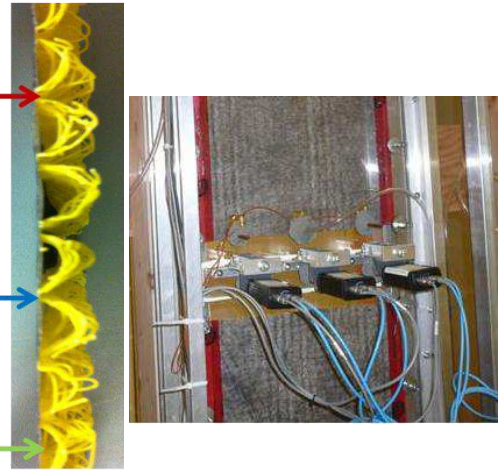
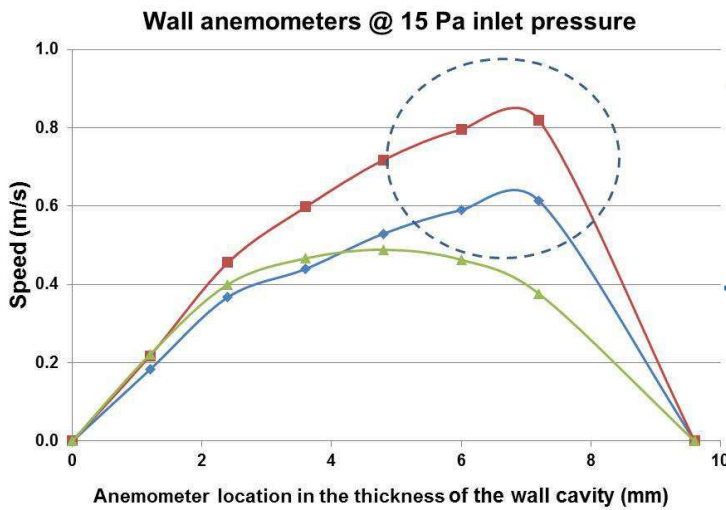
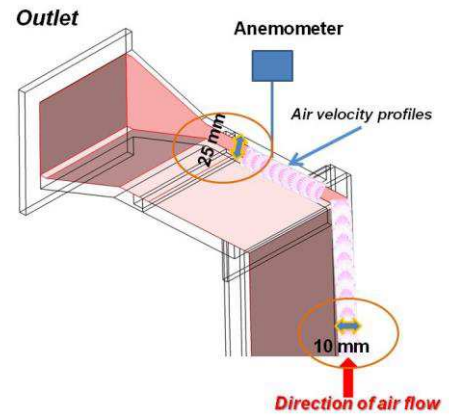
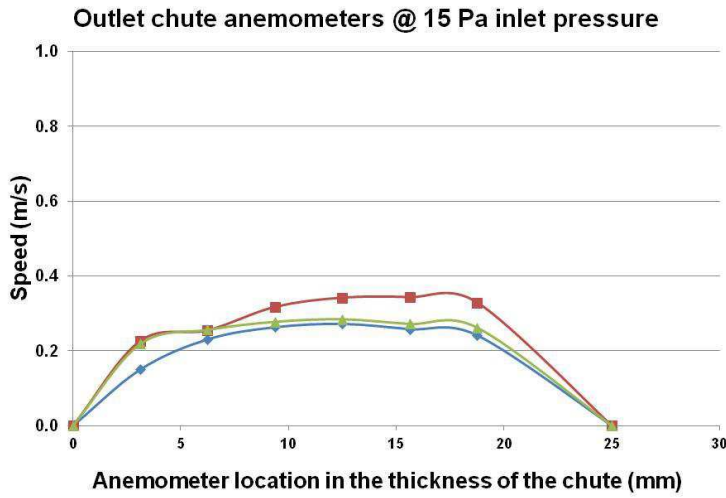


Figure 62 – Air velocity profiles at a pressure differential of 15 Pa for a cavity of 10 mm depth with drainage Medium (Client C) at the inlet chute, mid-height (wall) and outlet chute

Configuration 4: 10 mm Wall Cavity Depth with Drainage Medium (Client C) – 25Pa

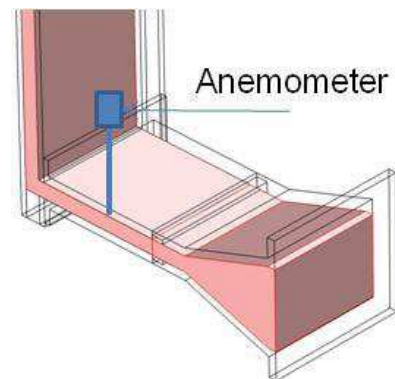
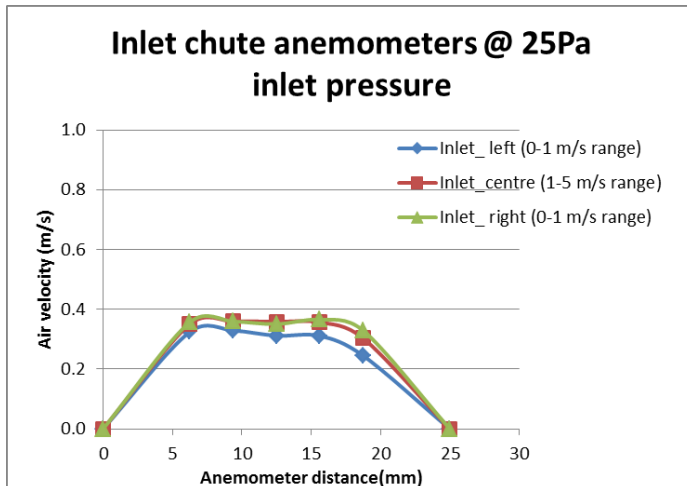
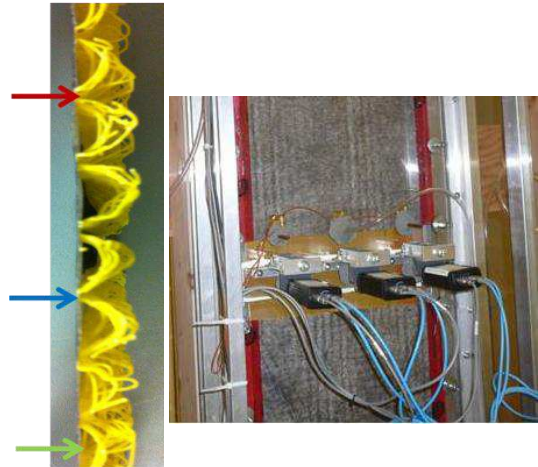
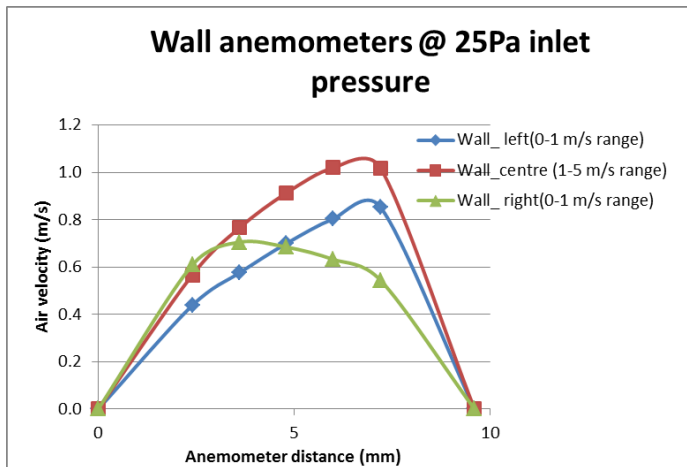
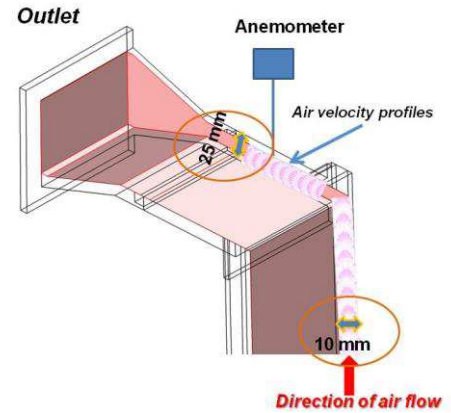
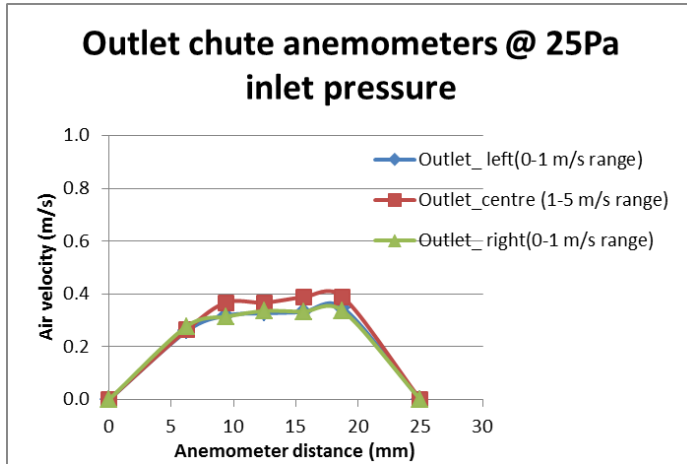


Figure 63 – Air velocity profiles at a pressure differential of 25 Pa for a cavity of 10 mm depth with drainage Medium (Client C) at the inlet chute, mid-height (wall) and outlet chute

Configuration 4: 10 mm Wall Cavity Depth with Drainage Medium (Client C) – 40Pa

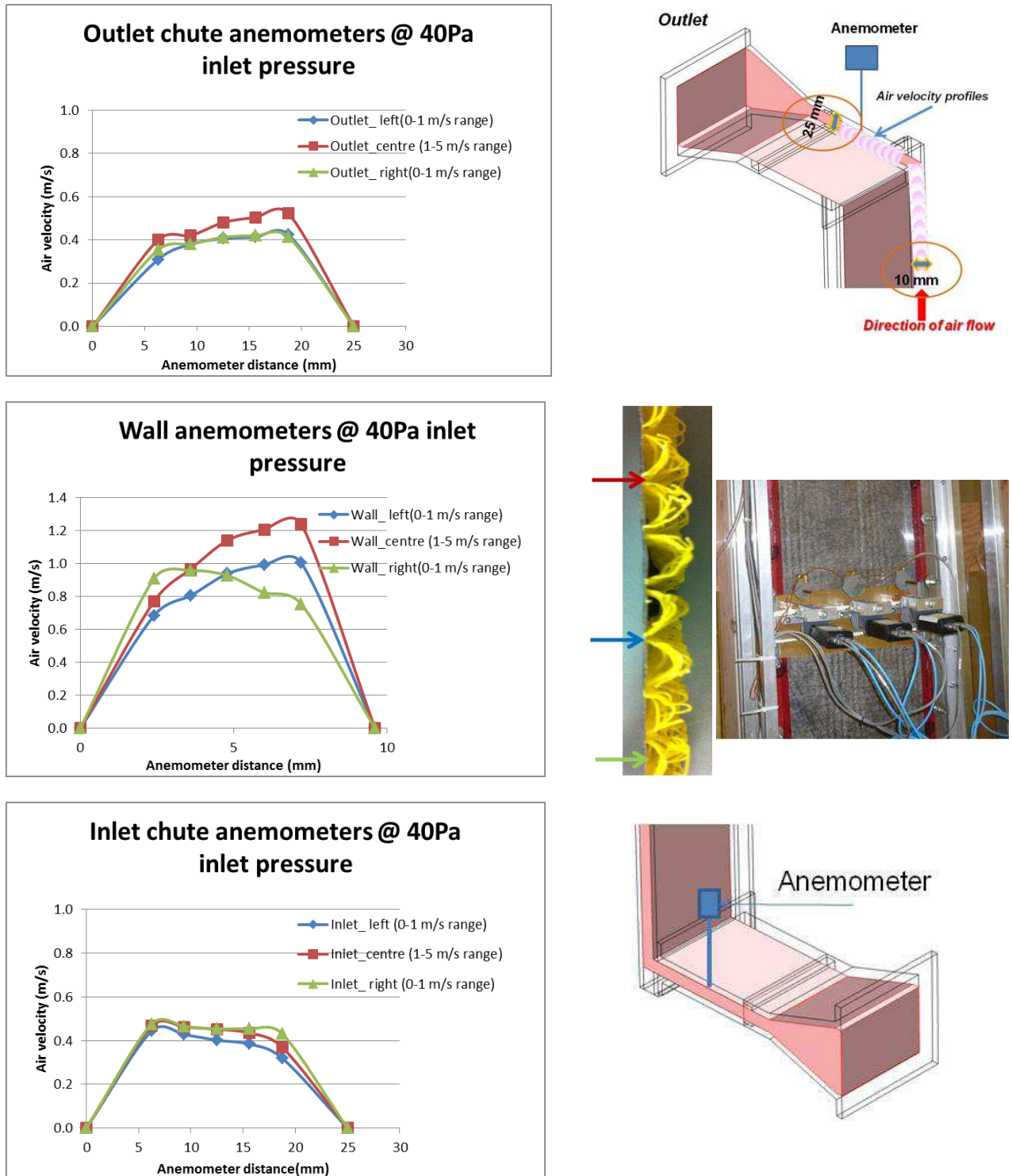


Figure 64 – Air velocity profiles at a pressure differential of 40 Pa for a cavity of 10 mm depth with drainage Medium (Client C) at the inlet chute, mid-height (wall) and outlet chute

Configuration 5: 10 mm Wall Cavity Depth with Drainage Medium (Client G) – 5Pa

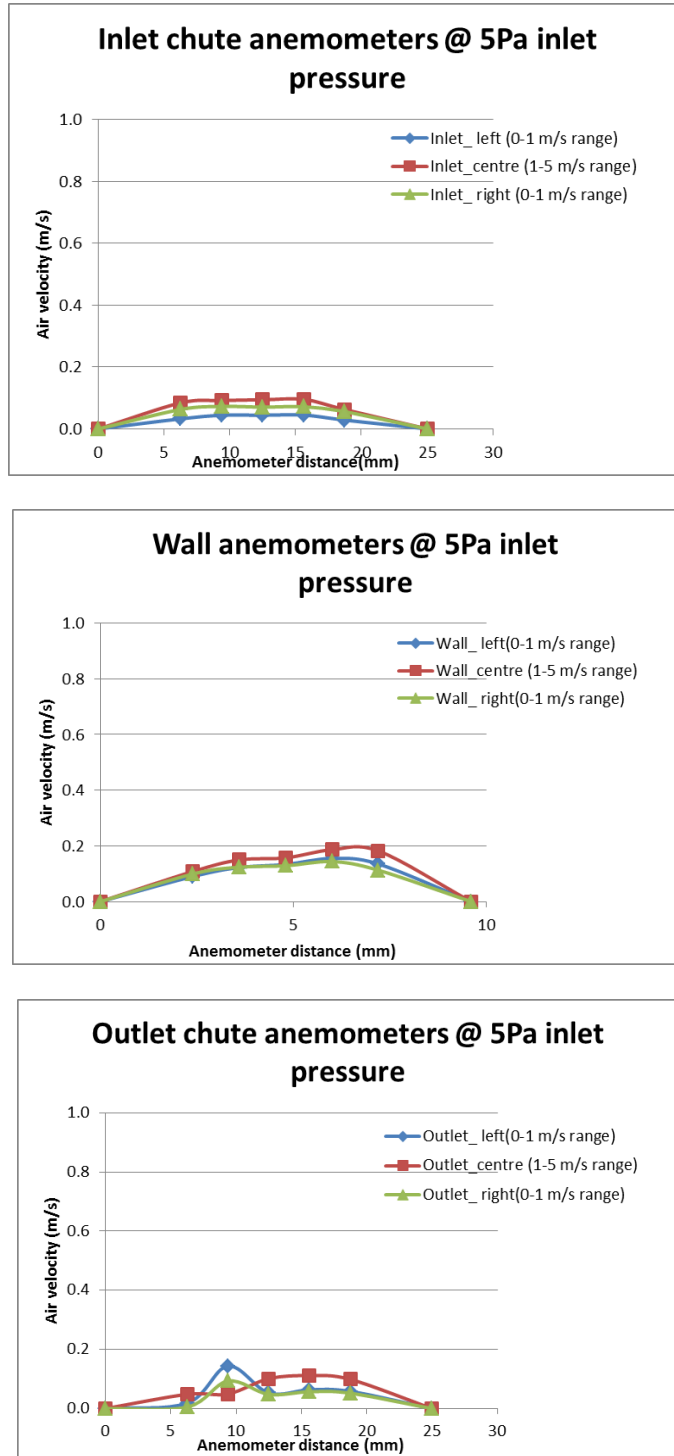


Figure 65 – Air velocity profiles at a pressure differential of 5 Pa for a cavity of 10 mm depth with drainage Medium (Client G) at the inlet chute, mid-height (wall) and outlet chute

Configuration 5: 10 mm Wall Cavity Depth with Drainage Medium (Client G) – 15Pa

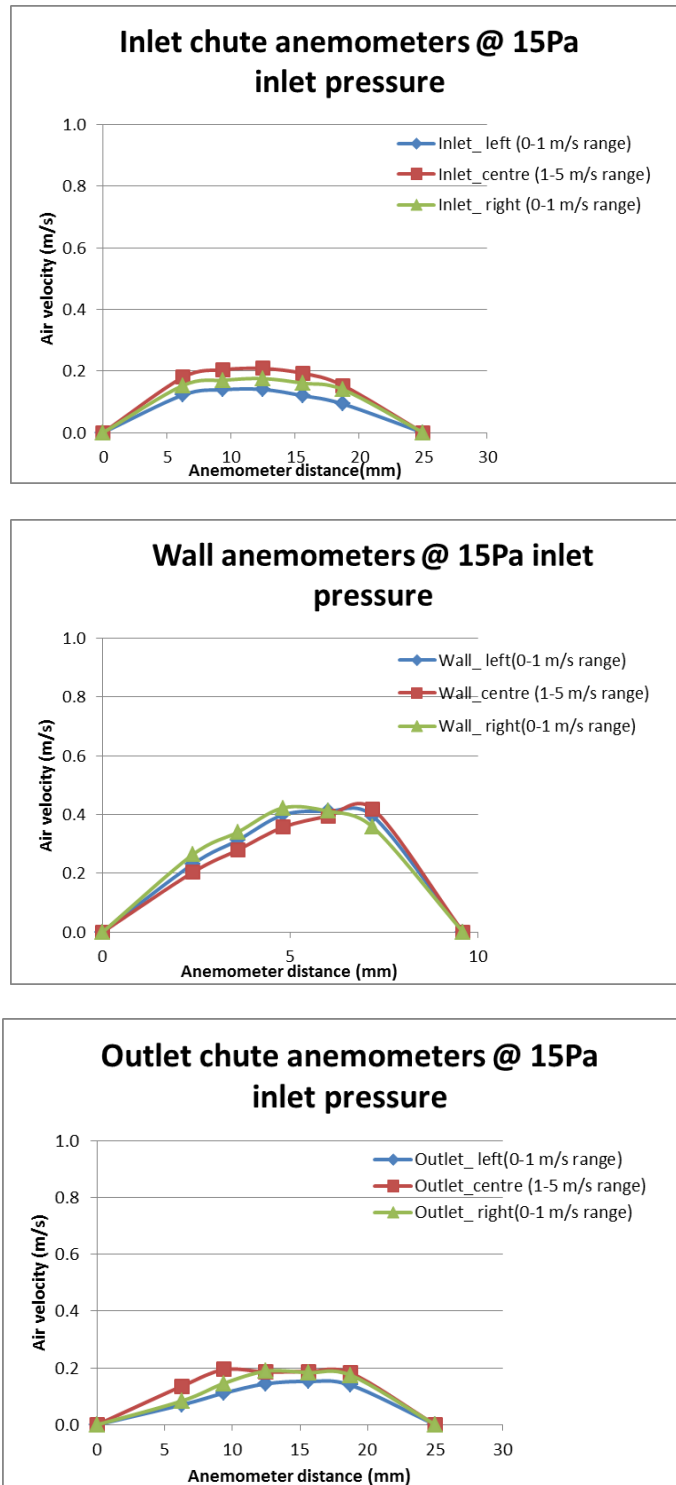


Figure 66 – Air velocity profiles at a pressure differential of 15 Pa for a cavity of 10 mm depth with drainage Medium (Client G) at the inlet chute, mid-height (wall) and outlet chute

Configuration 5: 10 mm Wall Cavity Depth with Drainage Medium (Client G) – 25Pa

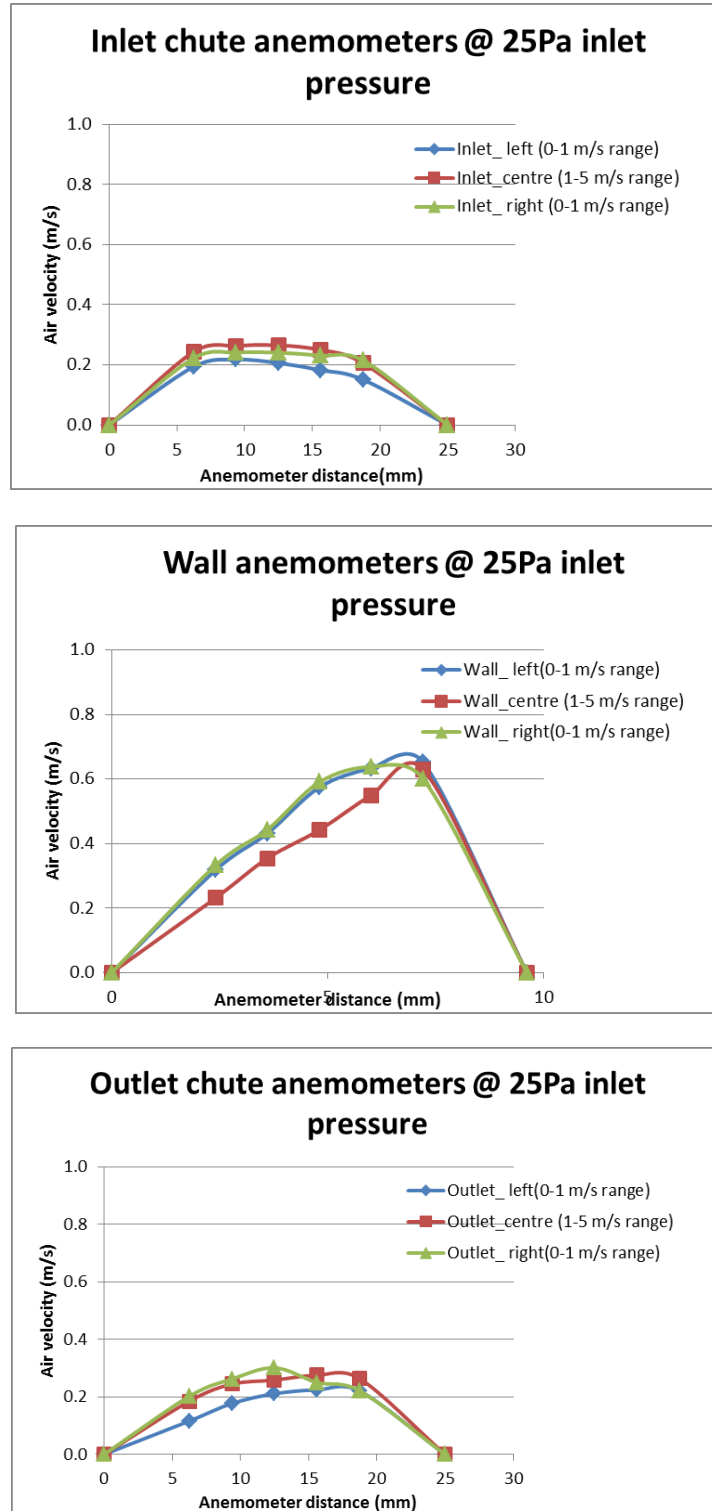


Figure 67 – Air velocity profiles at a pressure differential of 25 Pa for a cavity of 10 mm depth with drainage Medium (Client G) at the inlet chute, mid-height (wall) and outlet chute

Configuration 5: 10 mm Wall Cavity Depth with Drainage Medium (Client G) – 30Pa

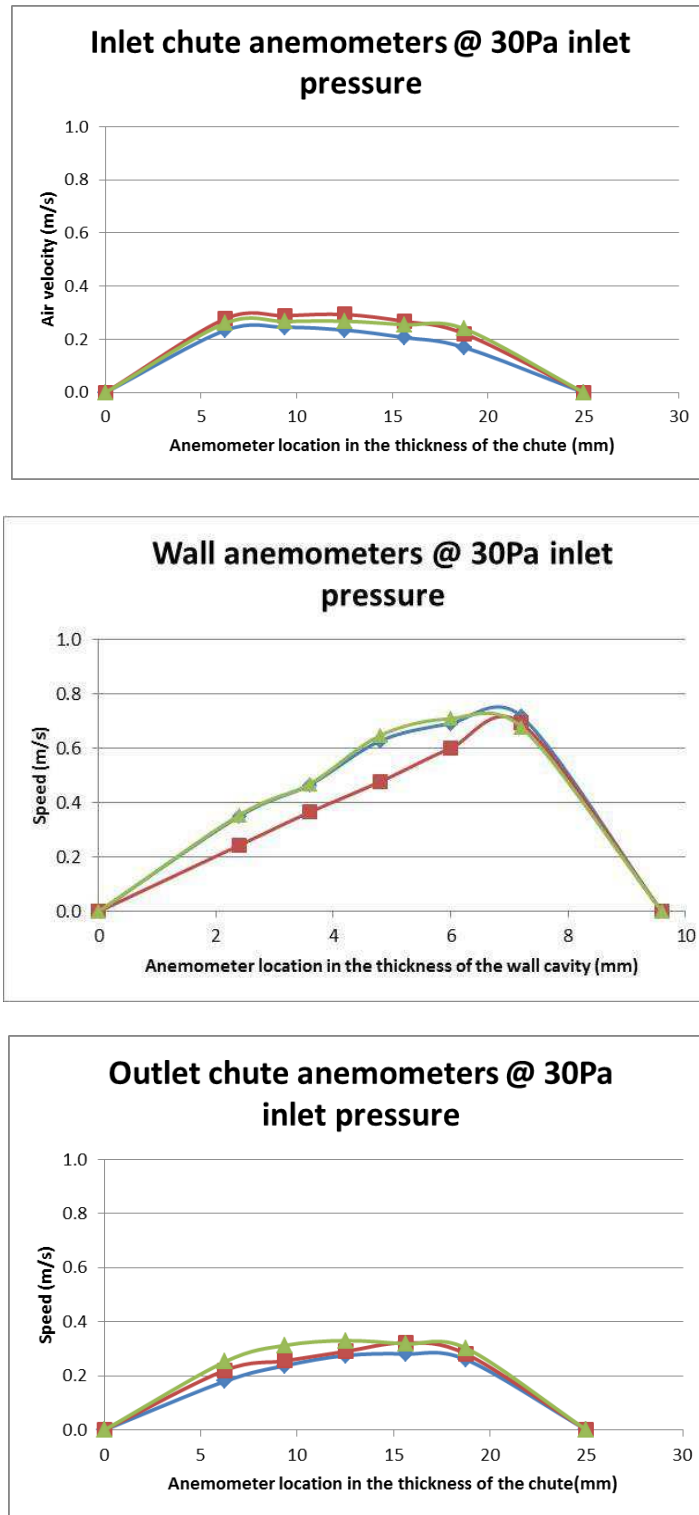


Figure 68 – Air velocity profiles at a pressure differential of 30 Pa for a cavity of 10 mm depth with drainage Medium (Client G) at the inlet chute, mid-height (wall) and outlet chute

Configuration 5: 10 mm Wall Cavity Depth with Drainage Medium (Client G) – 40Pa

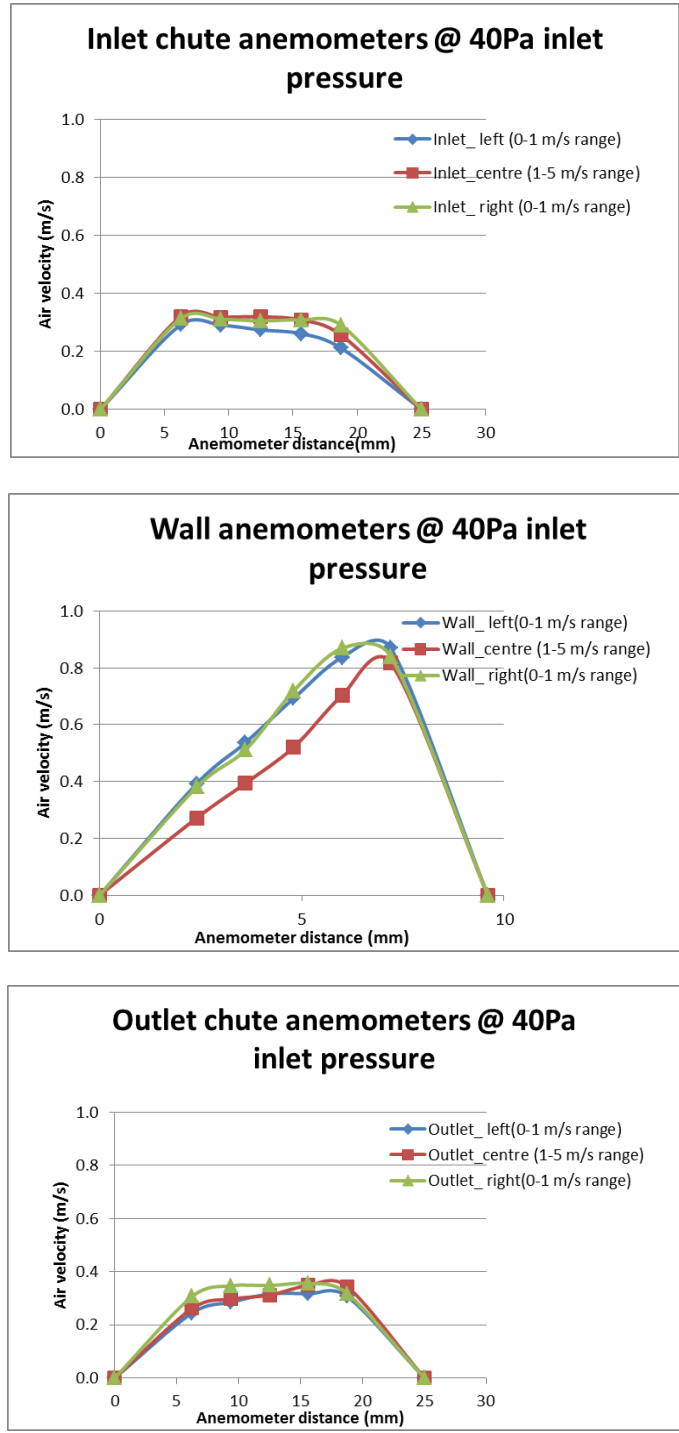


Figure 69 – Air velocity profiles at a pressure differential of 40 Pa for a cavity of 10 mm depth with drainage Medium (Client G) at the inlet chute, mid-height (wall) and outlet chute

Configuration 5: 10 mm Wall Cavity Depth with Drainage Medium (Client G) – 50Pa

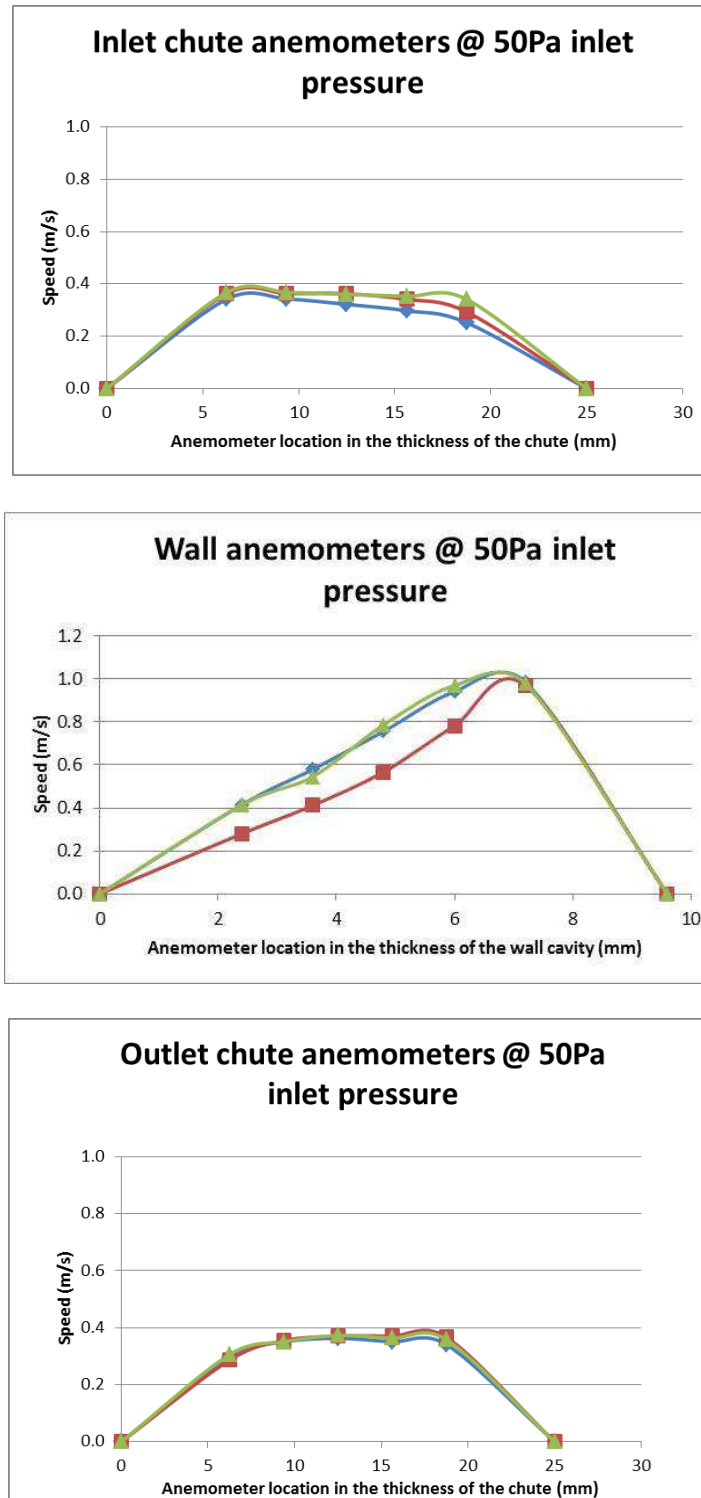


Figure 70 – Air velocity profiles at a pressure differential of 50 Pa for a cavity of 10 mm depth with drainage Medium (Client G) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 5Pa

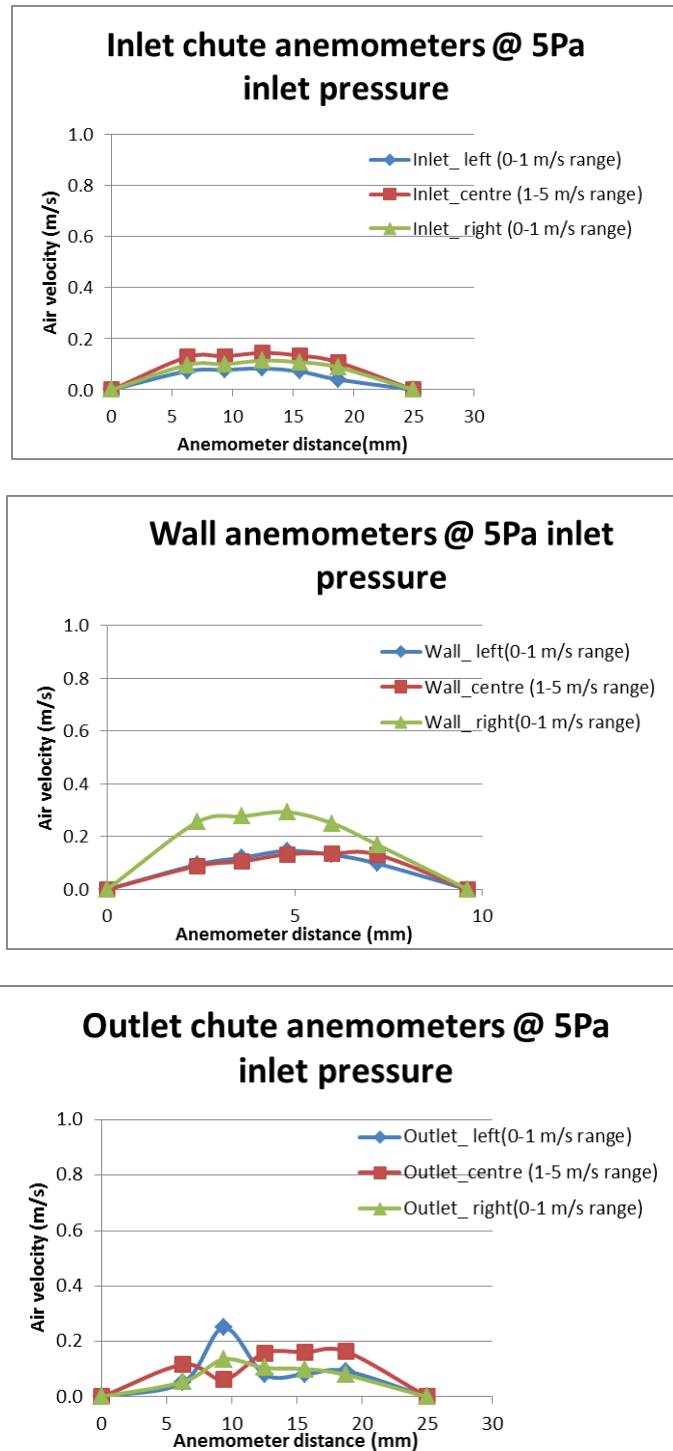


Figure 71 – Total Air velocity profiles at a pressure differential of 5 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 15Pa

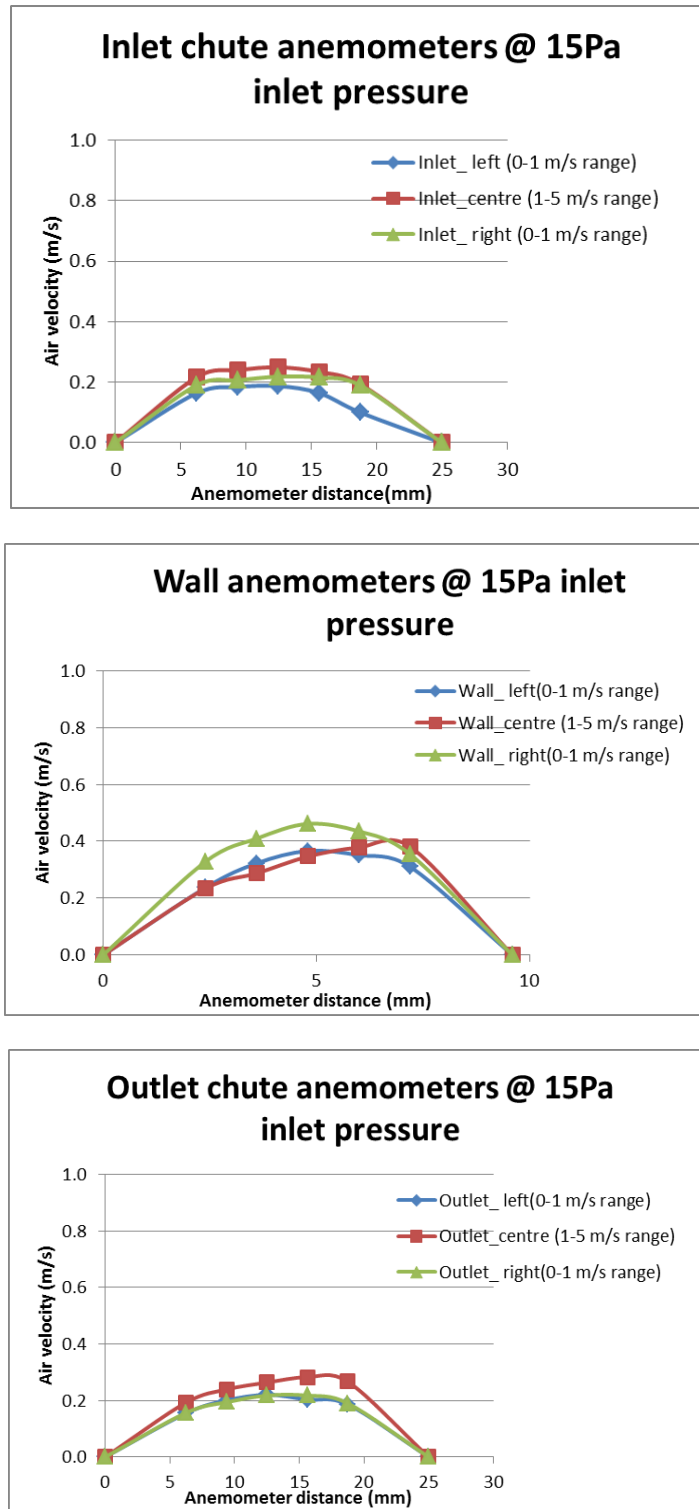


Figure 72 – Total Air velocity profiles at a pressure differential of 15 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 25Pa

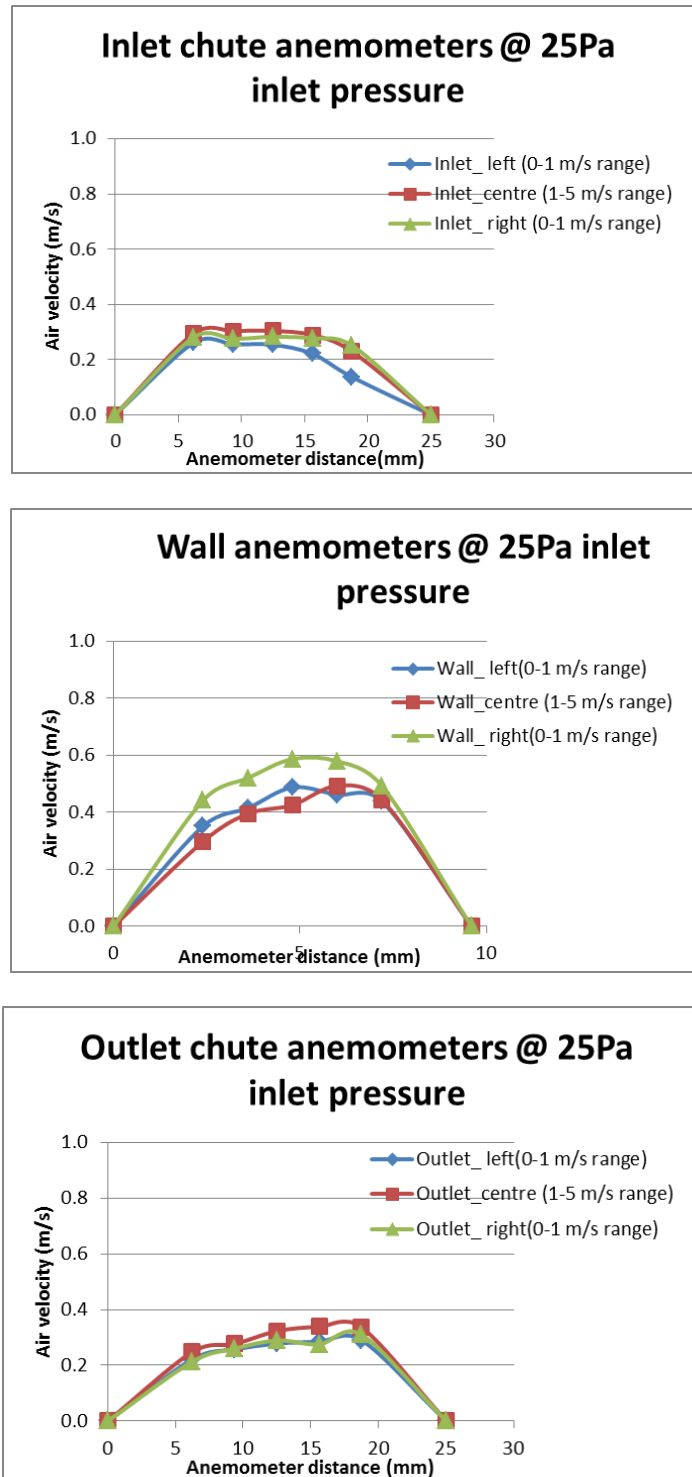


Figure 73 – Total Air velocity profiles at a pressure differential of 25 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 30Pa

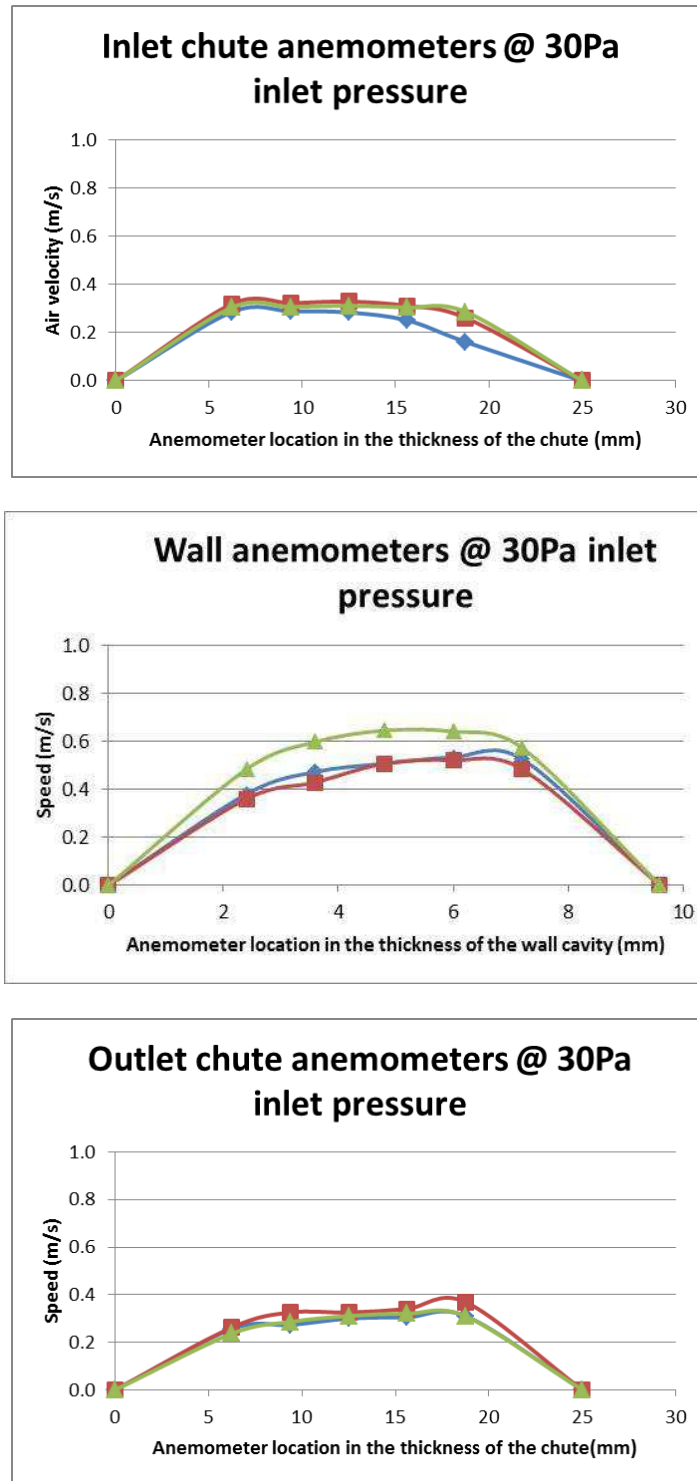


Figure 74 – Total Air velocity profiles at a pressure differential of 30 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 40Pa

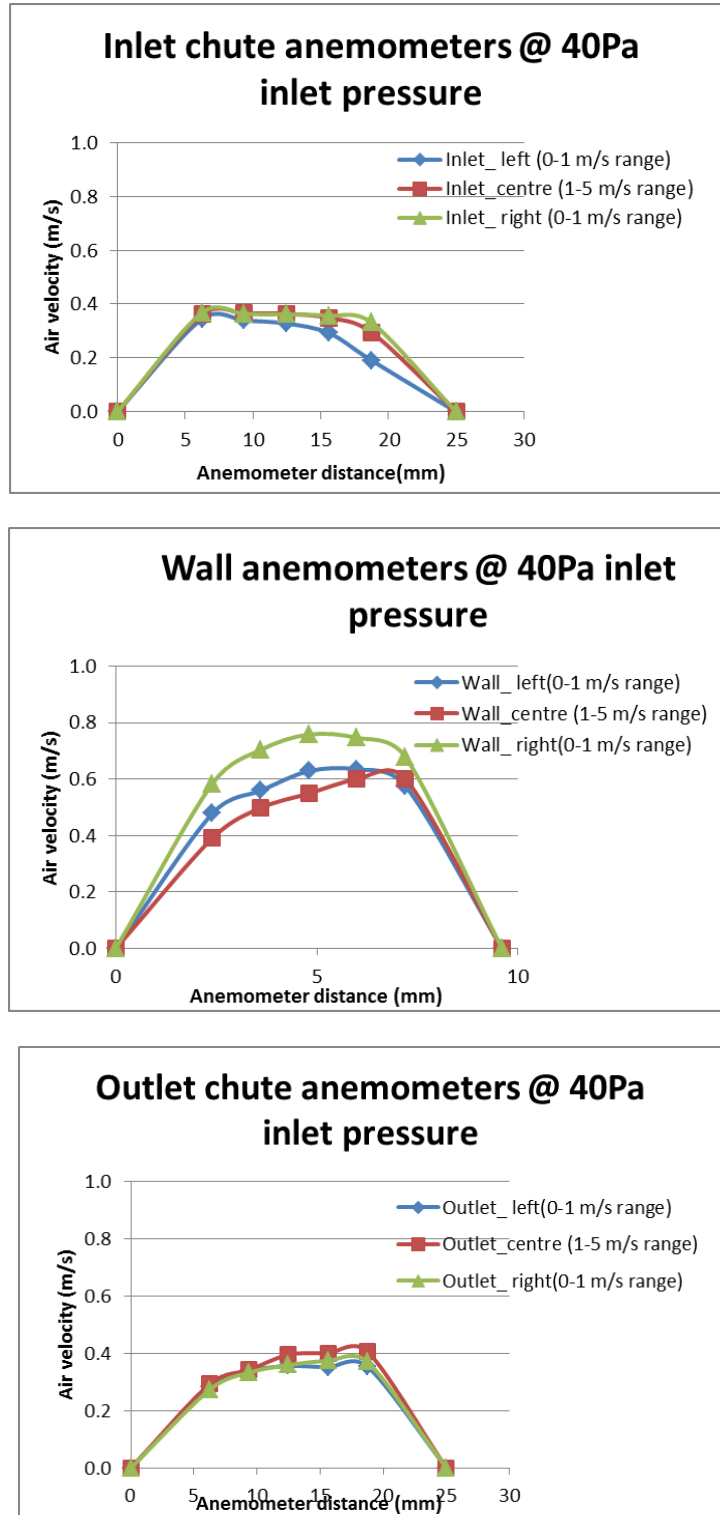


Figure 75 – Total Air velocity profiles at a pressure differential of 40 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 50Pa

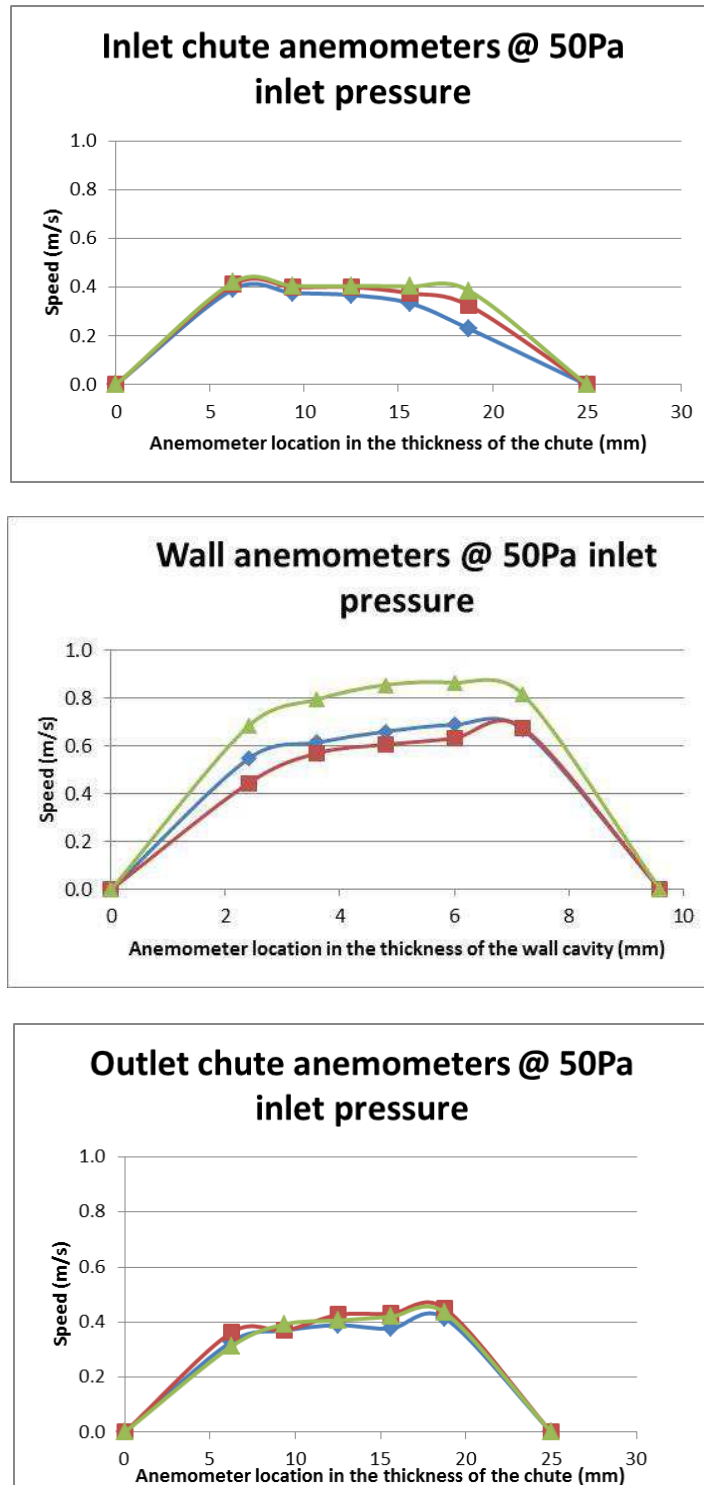


Figure 76 – Total Air velocity profiles at a pressure differential of 50 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 5Pa

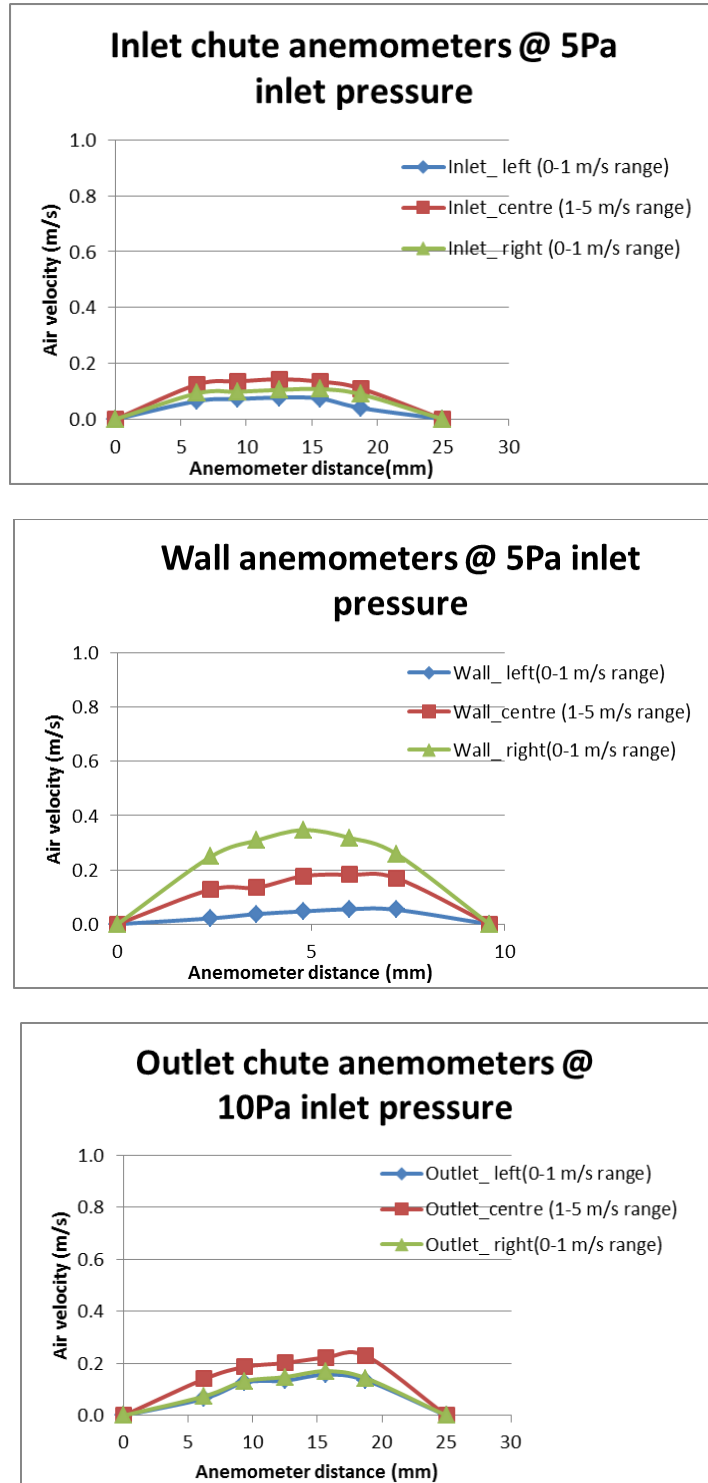


Figure 77 – Interior Air velocity profiles at a pressure differential of 5 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 15Pa

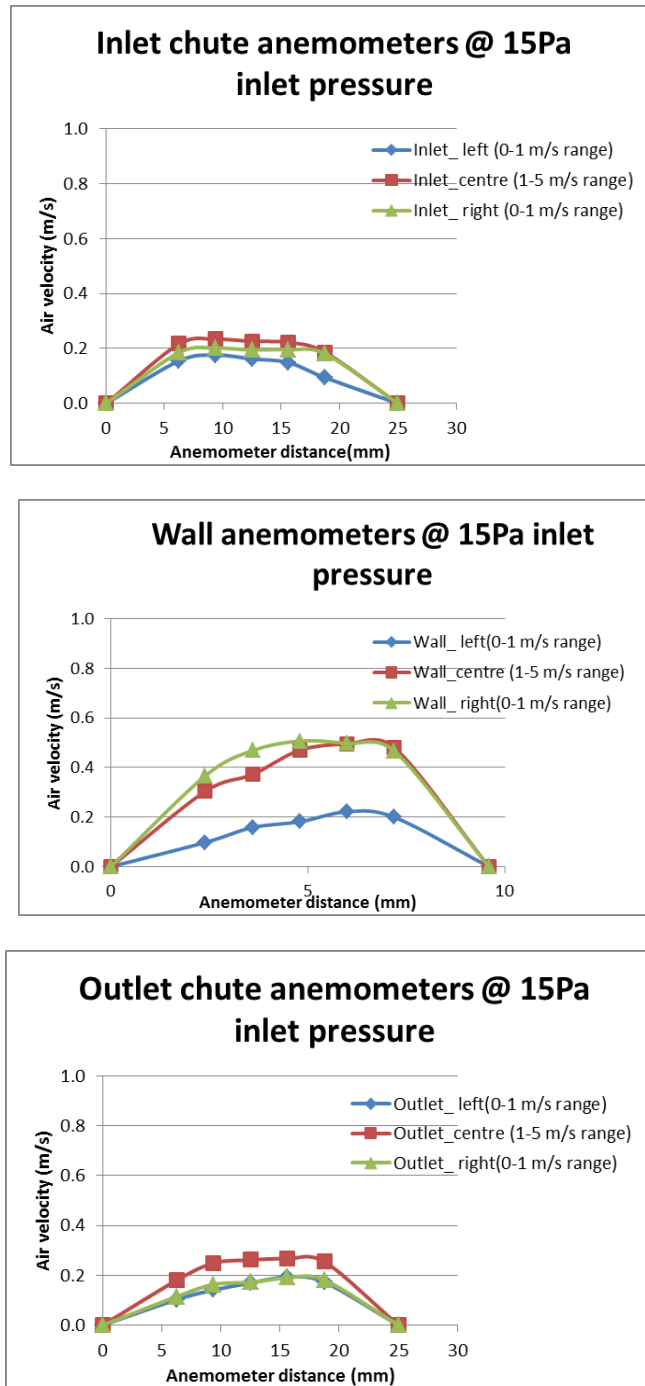


Figure 78 – Interior Air velocity profiles at a pressure differential of 15 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 25Pa

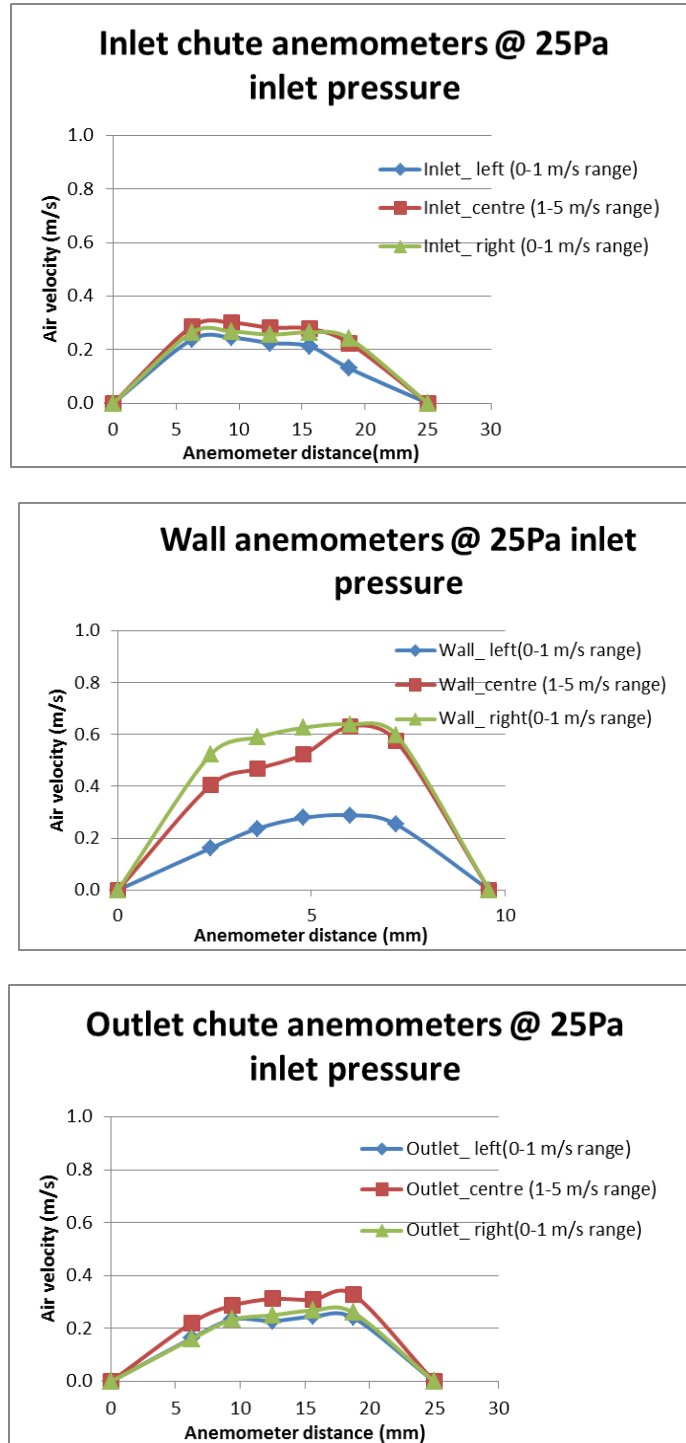


Figure 79 – Interior Air velocity profiles at a pressure differential of 25 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 30Pa

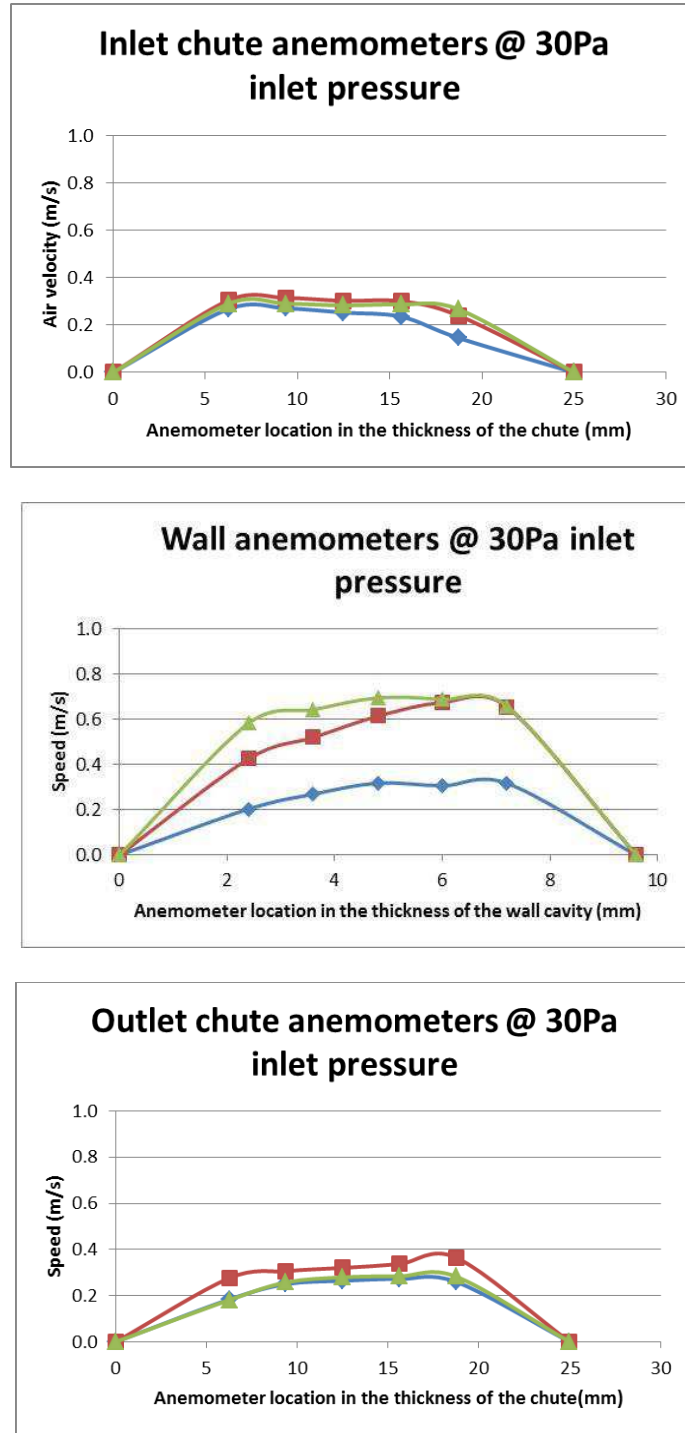


Figure 80 – Interior Air velocity profiles at a pressure differential of 30 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 40Pa

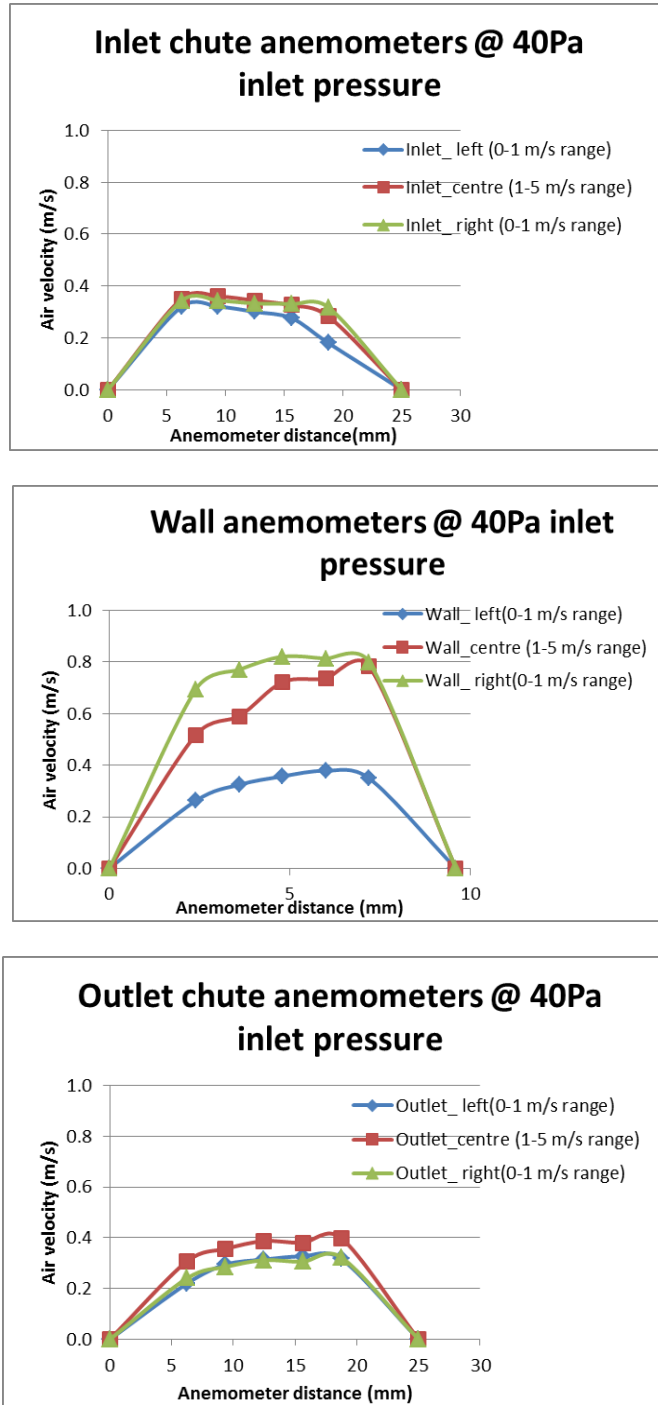


Figure 81 – Interior Air velocity profiles at a pressure differential of 40 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 6: 10 mm Wall Cavity Depth with Drainage Medium (Client E) – 50Pa

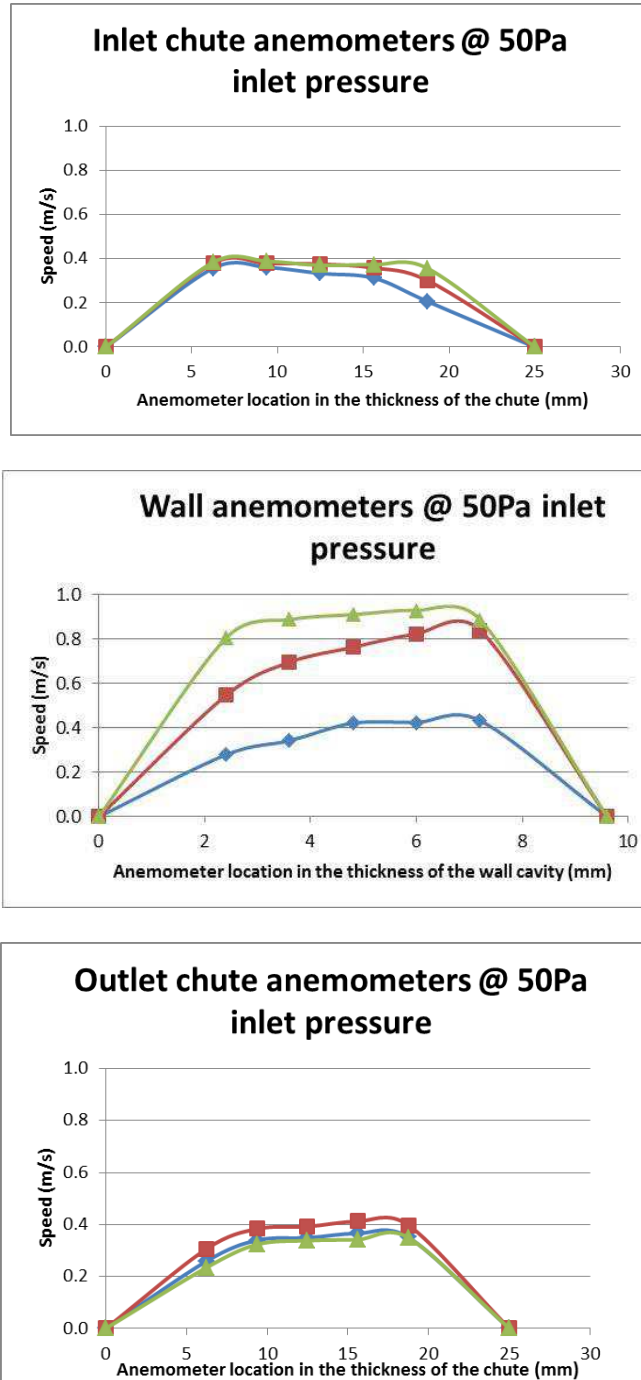


Figure 82 – Interior Air velocity profiles at a pressure differential of 50 Pa for a cavity of 10 mm depth with drainage Medium (Client E) at the inlet chute, mid-height (wall) and outlet chute

Configuration 7: 4 mm Wall Cavity Depth with Drainage Medium (Client I) – 5Pa

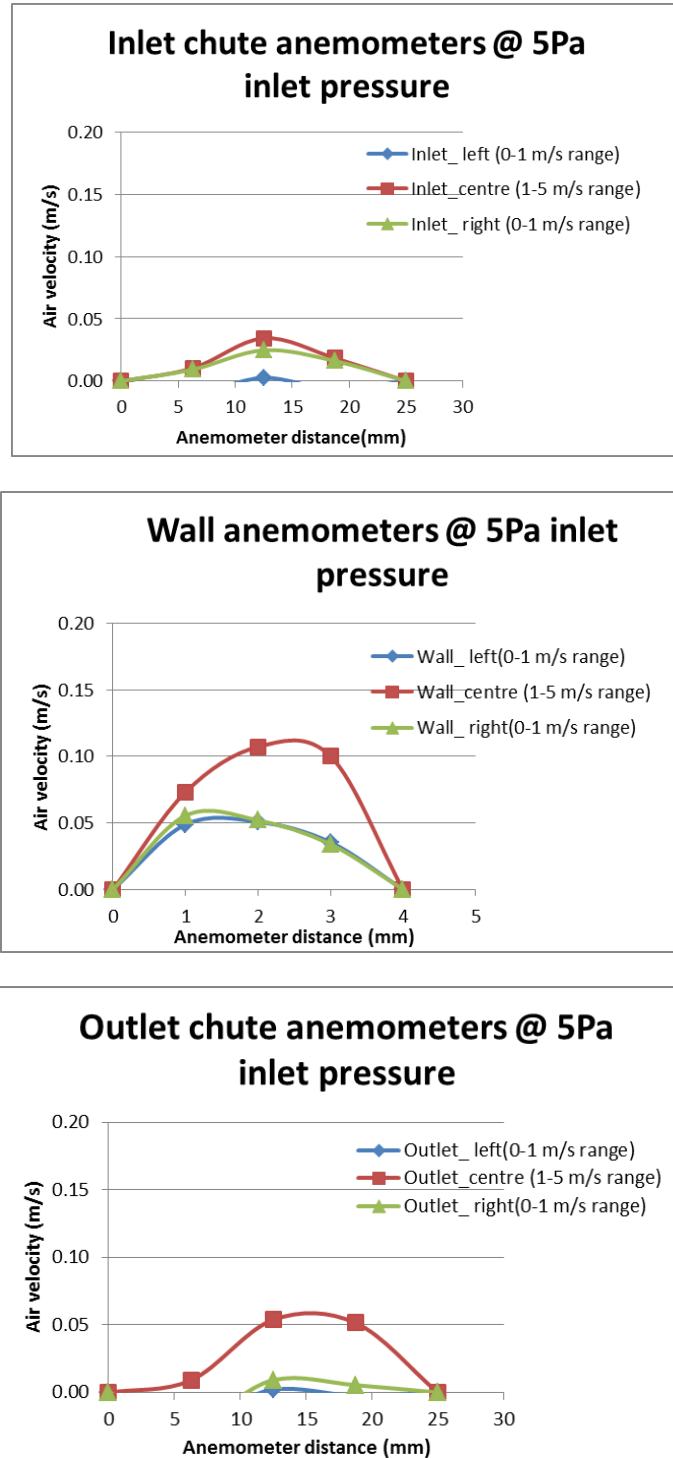


Figure 83 – Total Air velocity profiles at a pressure differential of 5 Pa for a cavity of 4 mm depth with drainage Medium (Client I) at the inlet chute, mid-height (wall) and outlet chute

Configuration 7: 4 mm Wall Cavity Depth with Drainage Medium (Client I) – 15Pa

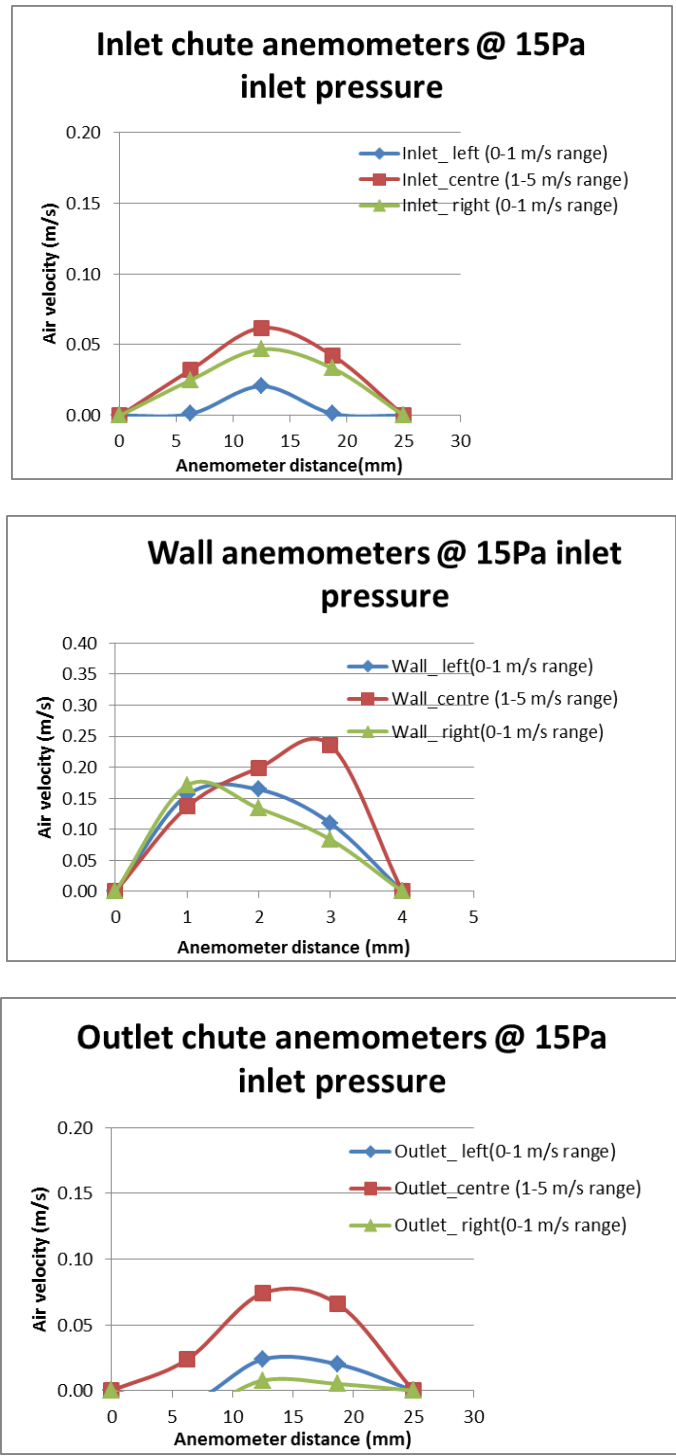


Figure 84 – Total Air velocity profiles at a pressure differential of 15 Pa for a cavity of 4 mm depth with drainage Medium (Client I) at the inlet chute, mid-height (wall) and outlet chute

Configuration 7: 4 mm Wall Cavity Depth with Drainage Medium (Client I) – 20Pa

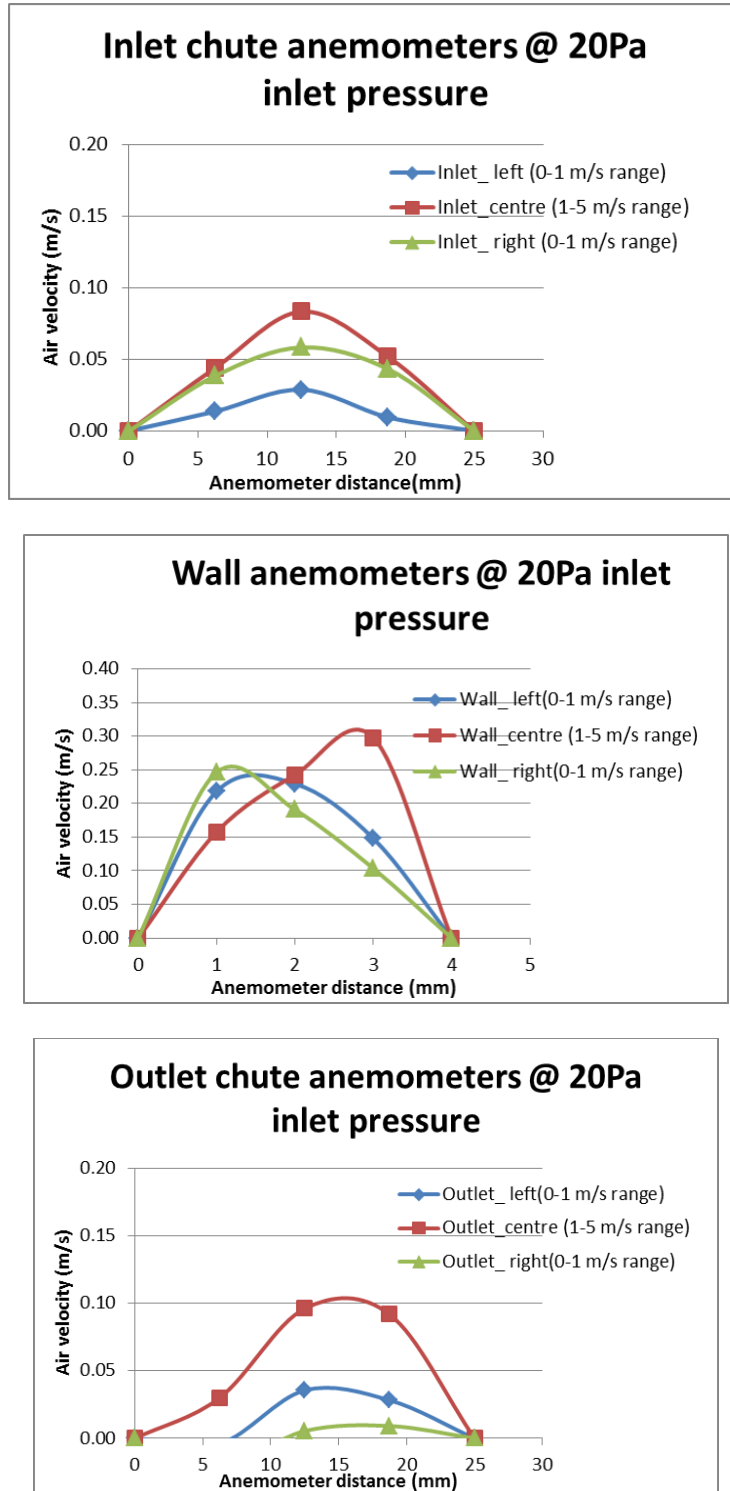


Figure 85 – Total Air velocity profiles at a pressure differential of 20 Pa for a cavity of 4 mm depth with drainage Medium (Client I) at the inlet chute, mid-height (wall) and outlet chute

Configuration 7: 4 mm Wall Cavity Depth with Drainage Medium (Client I) – 25Pa

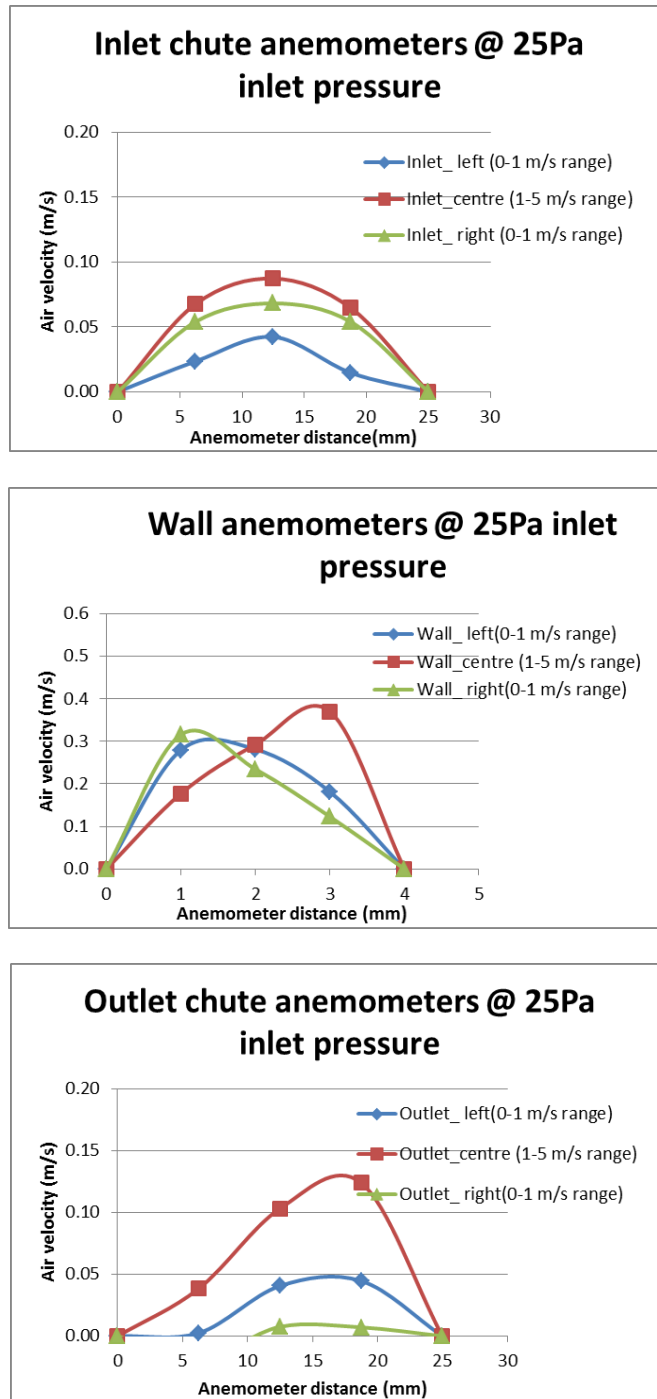


Figure 86 – Total Air velocity profiles at a pressure differential of 25 Pa for a cavity of 4 mm depth with drainage Medium (Client I) at the inlet chute, mid-height (wall) and outlet chute

Configuration 7: 4 mm Wall Cavity Depth with Drainage Medium (Client I) – 30Pa

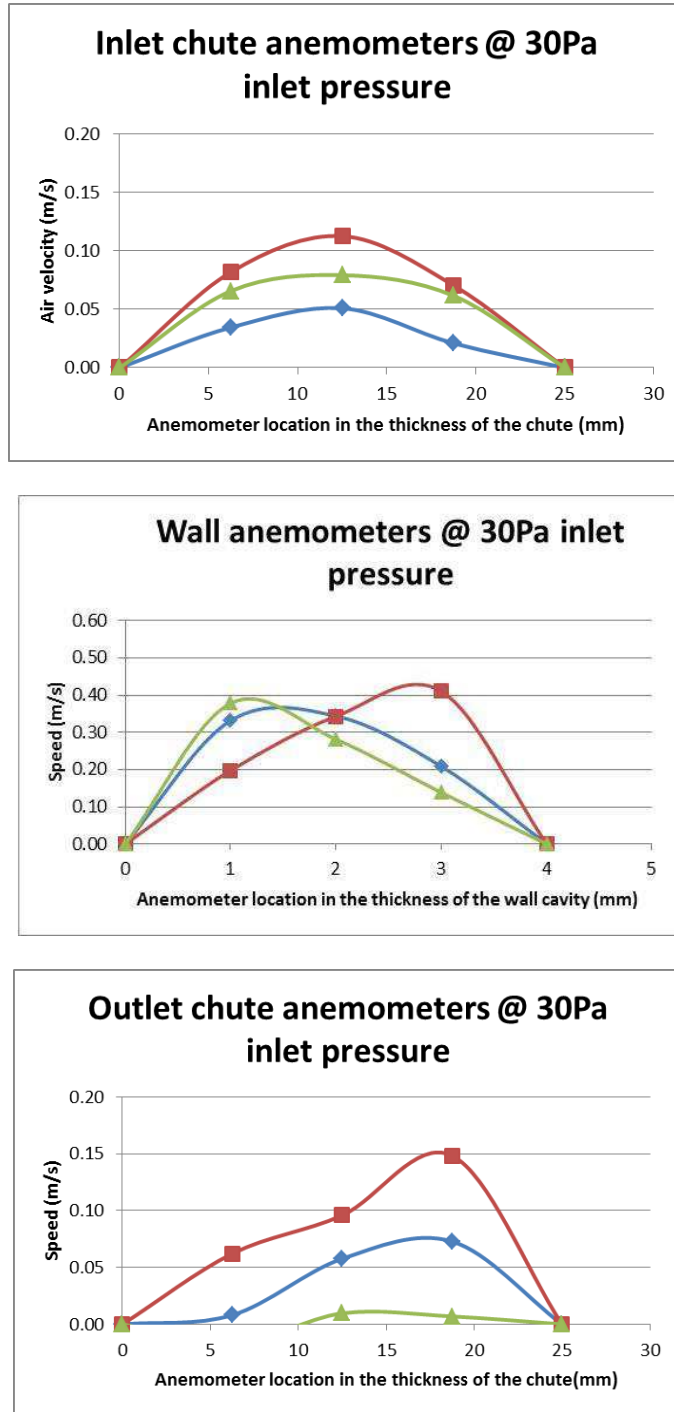


Figure 87 – Total Air velocity profiles at a pressure differential of 1 30 Pa for a cavity of 4 mm depth with drainage Medium (Client I) at the inlet chute, mid-height (wall) and outlet chute

Configuration 7: 4 mm Wall Cavity Depth with Drainage Medium (Client I) – 40Pa

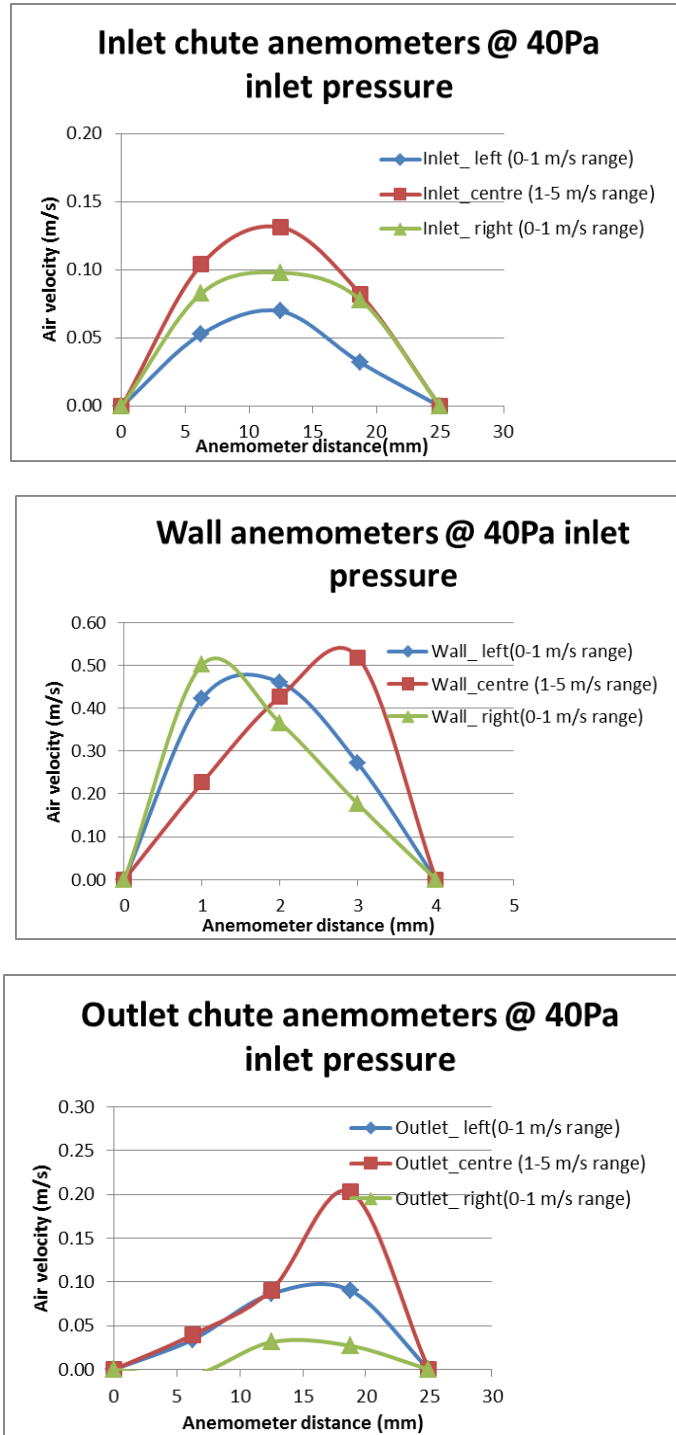


Figure 88 – Total Air velocity profiles at a pressure differential of 40 Pa for a cavity of 4 mm depth with drainage Medium (Client I) at the inlet chute, mid-height (wall) and outlet chute

Configuration 7: 4 mm Wall Cavity Depth with Drainage Medium (Client I) – 50Pa

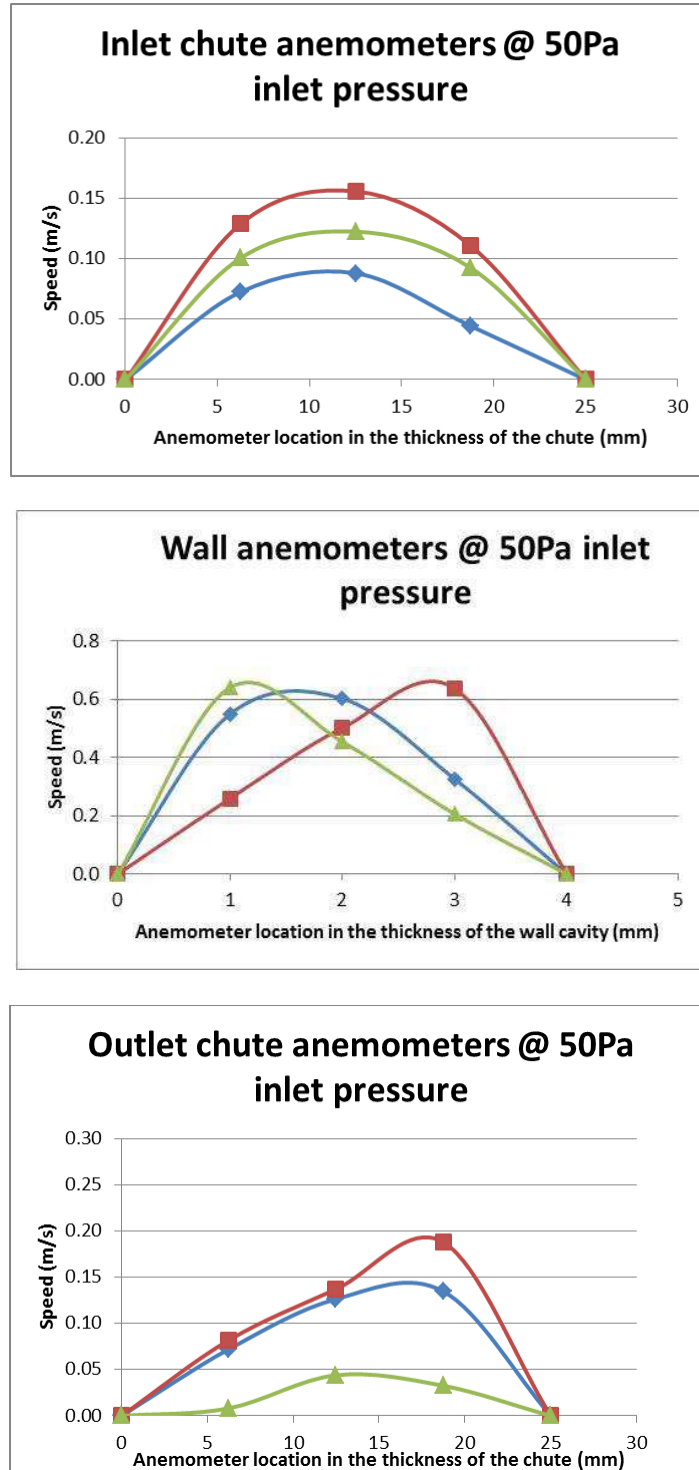


Figure 89 – Total Air velocity profiles at a pressure differential of 1 50 Pa for a cavity of 4 mm depth with drainage Medium (Client I) at the inlet chute, mid-height (wall) and outlet chute