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Computational Fluid Dynamics (CFD) Applications at the School of Architecture, University of Hawaii: Development of Comfort Assessment & Occupant Comfort Findings

Task 7

Prepared For
Hawaii Natural Energy Institute

Prepared By
Sustainable Design & Consulting LLC, UH Environmental Research and Design Laboratory, UH Sea Grant College Program & HNEI

December 2015

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

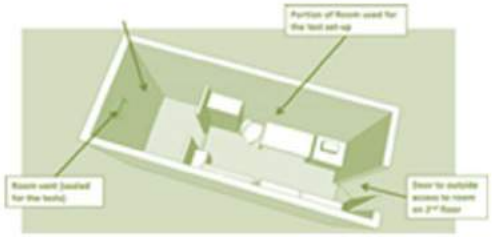
Project Phase 1- 7.C

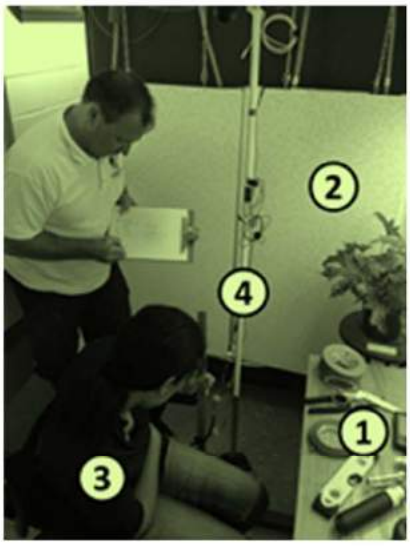
REPORT ON DEVELOPMENT OF COMFORT ASSESSMENT AND ON FINDINGS OF OCCUPANT COMFORT

14

FINAL

December 10, 2015





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ERDL HNEI

Contract # N000-14-13-1-0463

Computational Fluid Dynamics (CFD) Applications at the School of Architecture, University of Hawaii

Project Phase 1 – 7.C

Task 7.C.6: Report on the Development of Comfort Assessment (Phase 3)

Project Deliverable No. 14:

Simulations and Testing of the Effectiveness of Ceiling Fans and Actively Cooled Radiant Panels as Comfort Enhancement Technologies at the ERDL Test Site

Prepared for

Hawaii Natural Energy Institute
School of Ocean and Earth Science and Technology
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- Big Ass Solutions provided one Haiku Fan for use at the test set-up.
- Barcol Air USA, LLC, provided 10 radiant panels and heat rejection rail assemblies

ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
clo	Clothing insulation
CFD	Computational Fluid Dynamics
ERDL	Environmental Design and Research Laboratory, University of Hawaii at Manoa
BRG	Gypsum Ceiling System
HIG	Hawaii Institute of Geophysics
HNEI	Hawaii Natural Energy Institute
HVAC	Heating, Ventilation, and Air Conditioning
met	Metabolic rate
PMV	Predicted Mean Vote
PPD	Predicted Percentage Dissatisfied

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APPENDICES

EXECUTIVE SUMMARY

This report is Project Deliverable 14. The report presents methodology, results and conclusions of simulations and measurements of occupant comfort and the assessment of the performance of several comfort enhancement measure. Project Deliverable 14 is part of a CFD research program which is sponsored by the Hawaii Natural Energy Institute (HNEI). The research program endeavors to develop advanced building modeling skills at the Environmental Design and Research Laboratory (ERDL), University of Hawaii at Manoa.

The present report presents project work in conjunction with Part 3 of this CFD research program. The main objective of Part 3 of the research program is to investigate the use simulations to predict occupant comfort in naturally ventilated spaces by means of comfort improving measures and to provide validation of theoretical predictions through experimental studies.

The research conducted in Part 3 introduces the concept of "comfort islands", which are technologies to increase thermal comfort at the occupant level in warm climates, while leaving the space basically naturally ventilated. The underlying phenomena of comfort islands is lowering the perceived temperature in the space directly adjacent to the occupant. The decrease of perceived temperatures is accomplished by providing radiant cooling and increased air flow over the occupant's body.

Actively cooled radiant surfaces which are placed in close proximity to and around the occupant provide radiant cooling and therefore lower the operative temperature. In addition, the comfort islands can use ceiling fans to lower the perceived temperature for the occupants through increased convective heat loss. The research hypothesis of this research project suggests that the use of comfort islands can provide significant energy reductions in naturally ventilated spaces, compared to full space cooling and ventilation.

This project report, Deliverable 14, summarizes a significant range and scope of research work that was conducted in conjunction with comfort tests and advanced building simulations. The project work was conducted over a period of six months. The research work and results obtained represent a significant contribution to the understanding of convective and radiative cooling and their applications in improving acceptable indoor comfort in spaces that are not fully conditioned.

The research described in the report used a test set-up located in a room on the University of Hawaii Manoa campus, which was converted to a comfort chamber. The test space included one test station, where comfort enhancement measures were installed and one control station, which served as baseline. At the test station one high performance ceiling fan, donated by the company Big Ass Fans, was installed on an adjustable wood support structure. The fan speed could be controlled and the fan blade could be positioned over the test subjects. The test station had one 10-panel array of radiant panels that was suspended from the wooded support structure by means of adjustable chains. Each radiant cooling panel had an individually controlled chilled water supply valve so that the radiant panels could be either actively cooled or remain at ambient temperature. The chilled water was generated outside the comfort

chamber and was piped into the room. The chilled water and panel array was fully instrumented to obtain all pertinent environmental and process parameters.

The comfort tests were conducted over a period of three weeks with about 50 test subjects participating in the tests. All of the test subjects were students and staff of the University of Hawaii. As an incentive, the test subjects were given a gift certificate upon completion of their participation in the tests. The test procedure had subjects sit in the control and test stations while experiencing several alternative comfort enhancement measures. The test subjects reported on their individual comfort experience. The results of the subjective comfort experiences were correlated against environmental data and standard comfort metrics.

The project work included simulations of physical indoor environmental conditions at the test site and simulation of comfort levels predicted for thermal conditions and for the test comfort enhancement measures. The CFD simulation result were validated against measurements of the corresponding parameters at the test site. The research team used a CFD simulation workflow that had been developed and applied in parametric investigations prior to the comfort tests. The data consistency between the CFD simulation results and measured data differed between test scenarios. The boundary conditions of actual comfort test conditions were not known at the time of completion of the CFD part of the study, yet the CFD results provided important conclusions and important learning opportunities for the CFD team. For future comfort simulations the CFD team identified a special purpose software product for human comfort simulations. This software, which was not available, would have avoided considerable effort and trial and error required to customized the general purpose CFD software product available to the research team.

The main conclusion of the research project was the assessment of the performance level of the tested comfort enhancement measures. The best performing measure was identified by applying a ranking procedure using a range of performance criteria. The results of the ranking indicated that the comfort enhancement measures using the ceiling fan alone had the best performance. The comfort enhancement measures using actively radiant panels alone or in combination with a ceiling fan had a lower performance level.

These results suggested that ceiling fans were not only performance effective but also a cost effective method of increasing comfort levels of occupants.

The results of the research work presented in this report, in addition to the technical and scientific results, contributed to the overarching goal of this research program, which is the development of application skills at ERDL in advanced building simulations, measurement and analysis of indoor environment and a better understanding of human comfort in a humid environment. The extensive research work conducted by the ERDL team has served the overall objective of developing skill sets at ERDL and has paved the way for future research and education work in occupant comfort at the University of Hawaii and ERDL.

SECTION 1 - OBJECTIVES

A main objective of the research work was the determination of the effectiveness of comfort enhancement technologies to improve comfort levels for occupants of naturally ventilated spaces. Comfort enhancement in spaces which are not mechanically cooled, ventilated and dehumidified is essential in order gain occupant's acceptance for alternative concepts of space conditioning. Alternative approaches to space conditioning can save significant amounts of energy.

The different objectives of the work presented in this report are as follows:

- Develop protocols for preparing the test equipment and instrumentation of a specifically furnished internal comfort test set-up to carry out experiments on physical indoor environmental parameters and comfort test with human test subjects.
- Prepare and conduct comfort tests with human test subjects using a range of test scenarios to determine the effectiveness of two comfort enhancement technologies at the ERDL test facility.
- Carry out the comfort tests with a larger group of test subjects and obtain test protocols as well as record a significant number of pertinent physical parameters in order to obtain an objective assessment of comfort supporting indoor environmental conditions.
- Carry out data reduction and presentation of the records for further analysis.
- Carry out a comprehensive data analysis, discuss results and come to conclusions on the validation process of the theoretical simulations results against results obtains in tests.
- Develop a ranking procedure by which the level of effectiveness of the comfort enhancing measures is assessed and can be used to select the best alternative.
- Prepare conclusions on where future research work should be directed at ERDL to further investigate energy efficient comfort enhancing measures.
- Develop CFD simulations procedures of indoor environmental conditions and resulting occupant comfort conditions , which can predict the performance of comfort enhancement.
- Perform validation of theoretical CFD predictions with actually measured phenomena in the controlled test environment of a specifically equipped test facility.

SECTION 2 - GENERAL APPROACH

This section describes the approach taken in conducting the CFD comfort simulations and conduction physical measurements at the ERDL test set-up in the HIG building on the University of Hawaii at Manoa (UHM) campus to validate the theoretical results through measurements.

2.1 Description of the Test Facility

The test facility for the comfort tests was located in Room 204 of the Hawaii Institute of Geophysics (HIG) building on the Manoa campus. The room was temporarily converted from an unused, windowless office to a temporary climate chamber. The room was rearranged to hold two test spaces with textile covered partitions as room dividers. The layout of the test site is shown in Figures 2.1.1. through 2.1.3.

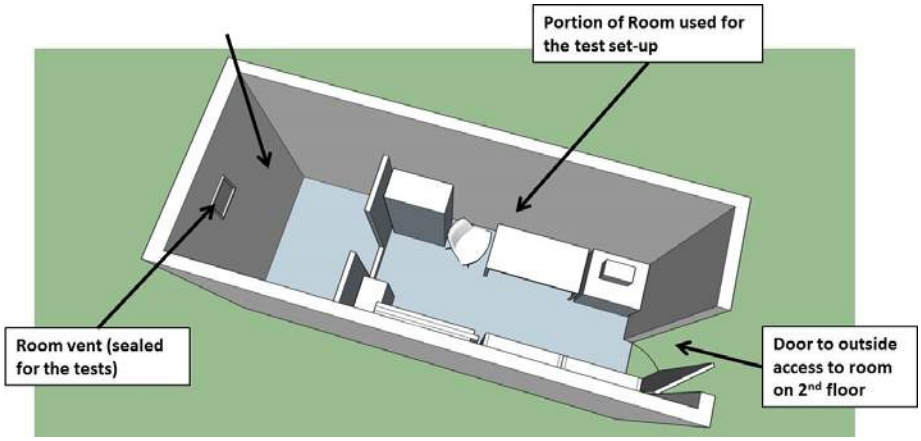


Figure 2.1.1: Configuration of Room HIG 204 prior to tests

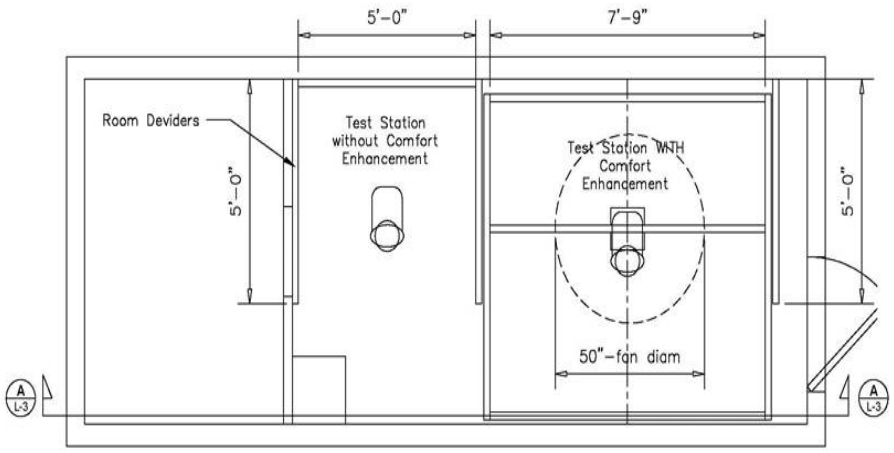


Figure 2.1.2: Layout of the test set-up in HIG 204 – Plan View

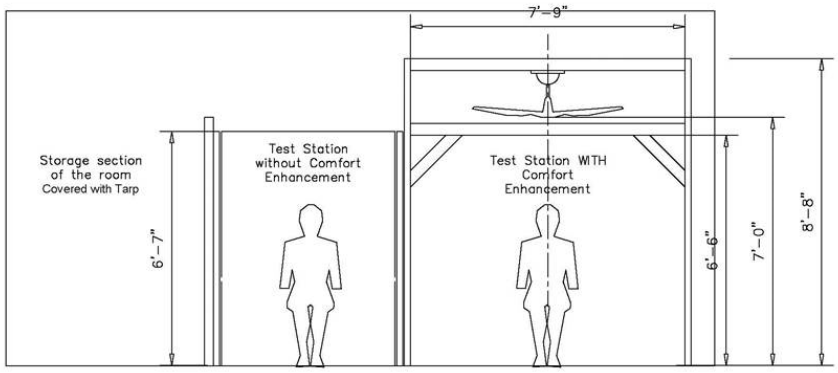


Figure 2.1.2: Layout of the test set-up in HIG 204 – Section A-A

In one of the test spaces, called the "test station", one ceiling fan and a number of actively cooled radiant panels were installed to serve as comfort enhancement measures. The other test space called the "control station" did not have any comfort enhancement. The control station therefore served as the baseline or benchmarking against which performance of the comfort enhancement measures were compared. One comfort measure was a 50-inch high efficiency ceiling fan and the other measure was an array of vertically positioned actively cooled radiant cooling panels which were arranged around the test person.

The contribution to increase comfort generated by the two structural comfort enhancement measures were investigated in the present investigation. Both structural comfort enhancement measures were installed only in the test station of the test set-up. The test set-up and the test equipment is described in detail in Project Deliverable 11.2 "FINAL Report on Comfort Studies – Test set-up".

2.2 Comfort Enhancing Measures – Ceiling Fans

The 50-inch ceiling fan for the test set-up was provided by the company Big Ass Fans (BAF). The ceiling fan was installed on a cross beam of the wooden structure and the ceiling fan was moveable along the cross beam. This provided the flexibility to move the ceiling fan lengthwise along the middle axis of the test station to coincide with the actual sitting position of test subject. Figure 2.2.2 shows the installation of the ceiling fan on the wooded support structure.

The nature of comfort enhancement through the use of a ceiling fan is based on the increased convective heat loss from humans. The increased heat loss is approximated by a perceived temperature drop of the ambient environment. It is important to note that the ambient operative temperature does not change in physical terms since the ambient air and the radiant surfaces are not cooled by the ceiling fan. The effectiveness of the cooling effect through increased air movement past the human body is a function of primarily the speed of the air. The humidity level and temperature of the ambient air are additional parameters; but these parameters cannot be regulated by the ceiling fan. The perception of increased air movement across the human body can be experienced as positive, which is mostly the

cooling effect and a feeling of "freshness", but also as negative in form of "draft". Therefore, human thermal comfort is both a physical as well as a psychological phenomenon.

Figure 2.2.1: Ceiling fan installation

2.3 Comfort Enhancing Measures – Actively Cooled Radiant Panels

A 10-panel array of actively cooled radiant panels was installed at the test station. The panel array surrounded the human test subject on all four sides. The radiant cooled panels were suspended from the wooded support structure, which provided flexibility in their horizontal and vertical positioning. The panels were connected to an external chilled water supply and the chilled water flow through each panel could be individually controlled and metered by a control valve and flow meter, respectively. Figure 2.3.1 shows the installation of the actively cooled panels.

The close proximity of the radiant panels to the test subject was intended to increase the radiant heat loss and therefore lower the operative temperature. Similar to the increased air speed generated by the ceiling fan the main objective of the actively cooled panels was to increase the heat loss and therefore increase the occupant comfort without the need to lower the air temperature in the room.

2.4 Main Parameters for Occupant Comfort

The experience of thermal comfort happens on an individual level and two occupants in a room with the same thermal conditions can feel differently about whether it feels too warm or cold to them, or if they do not perceive any thermal sensation at all. Standards have been developed to provide objective criteria of how humans most likely experience thermal comfort. The six main parameters which are recognized as determining the level of human comfort in spaces can be categorized into two groups, environmental and personal conditions. The four environmental conditions, including air temperature, radiant temperature, relative humidity, air speed, are those parameters which are present in the space, and can therefore be experienced by all occupants. The two personal conditions are metabolic rate and clothing insulation.

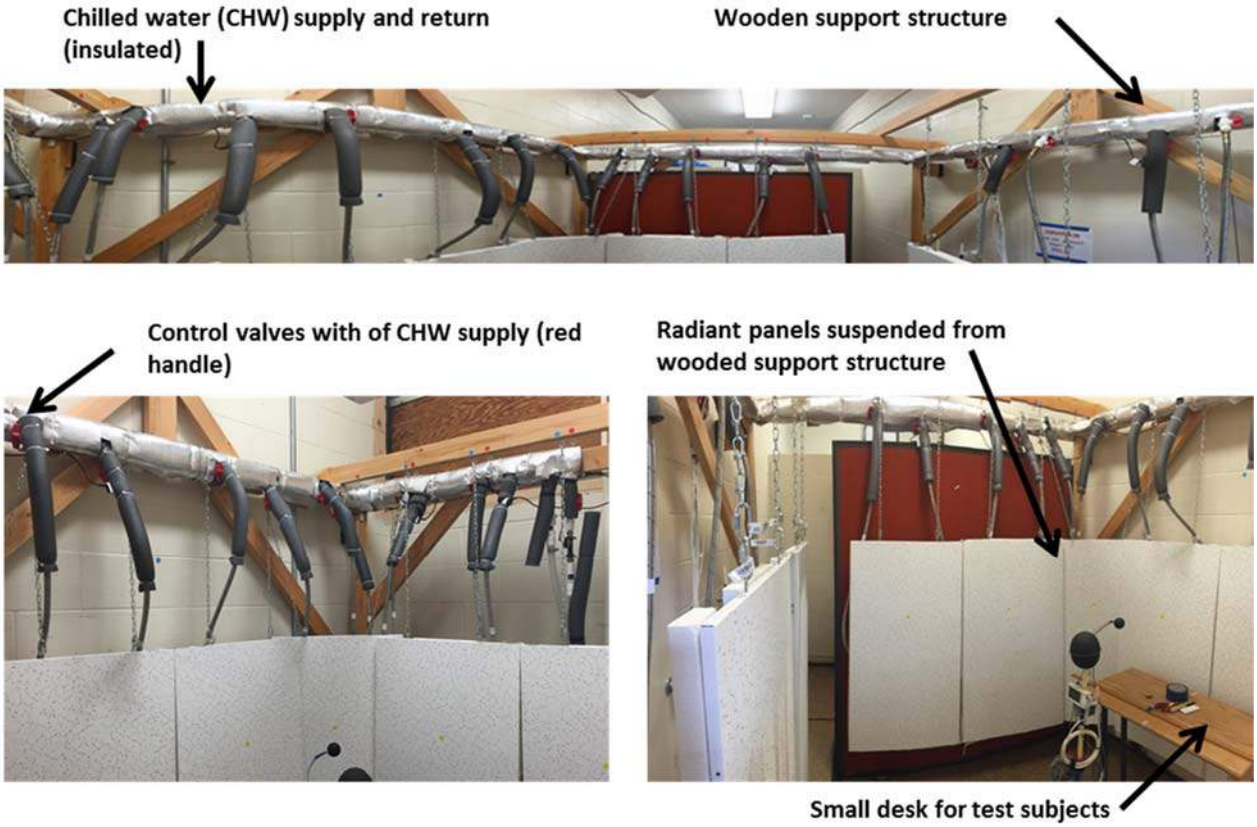


Figure 2.3.1: Installation of radiant panels at the test station

The six parameters which affect human comfort are illustrated in Figure 2.4.1 and are briefly discussed in the following:

Air temperature: Air temperature regulates a significant portion of heat transfer processes since the driving force for sensible heat loss is the difference between the skin temperature and the ambient air temperature. Air temperature is measures by conventional dry bulb temperature.

Radiant temperature: This is the temperature of surfaces of objects to which the human body rejects heat through electromagnetic waves, e.g. through radiation. The total amount of heat that is lost through radiation from the human body is the sum of radiant heat loss to all relevant objects within the line of sight of the human body. In order to make things easier the term "mean radiant temperature" is defined as the aggregated sum of radiant heat flux from objects that affect the body through radiant heat loss. The mean radiant temperature can be measured through a so-called "globe thermometer".

Operative Temperature: Operative temperature is an expression that combines air and radiant temperature into one metric. Operative temperature is quantified as the weighted average of air

and radiant temperature. When values of air and radiant temperatures do not deviate significantly, the operative temperature is simply that statistical mean of the air and radiant temperatures.

Metabolic rate: Metabolic rate, as it related to human comfort assessment, is the level of transformation of chemical energy into heat and mechanical work by metabolic activities within the human body. Metabolic rate is defined in "met" units, with 1 met being the rate generated by a waking person at rest. Tables are available that provide met units for different activities. Examples are sleep and light office work as 0.7 met and 1.1 met, respectively.

Clothing insulation: Clothing insulation is the amount of thermal insulation created by clothing worn by a person. The value of clothing insulation is expressed in "clo" unit and can be determined by adding the value of any particular clothing worn by a person.

Relative humidity: Relative humidity (RH) is expressed as the ratio of the amount of actual water vapor pressures in the air to the amount of water vapor at saturation pressure of air at the specific temperature and pressure. Relative humidity has significance to human comfort in a range of processes, such as impeded ability to reject heat through evaporation at higher RH values to the feeling of itchiness and effects of respiratory system at very low RH values. RH is measured as a percentage.

Air speed: air speed is expressed as the average speed of air measured at points of reference. Higher air speed can lower the perceived temperature, enabling the set point in air conditioned spaces to be increased without the loss of comfort or raising acceptability limit for naturally ventilated spaces.

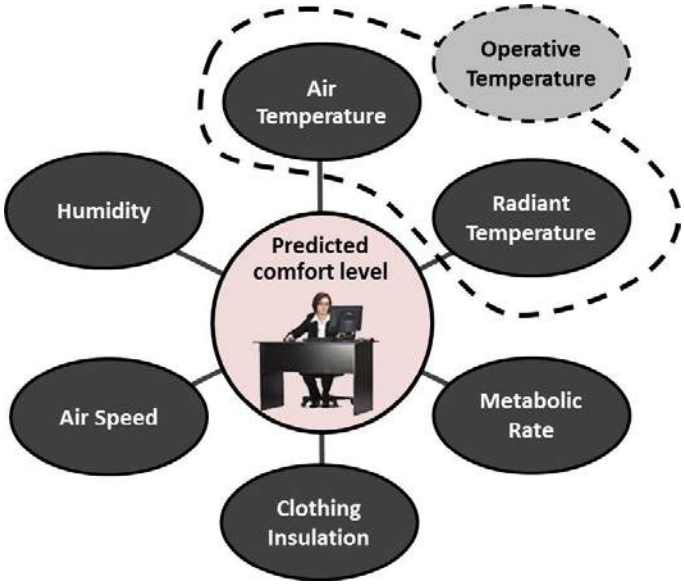


Figure 2.4.1: Main parameters to assess thermal comfort levels

These six comfort parameters can be quantified in physical terms and objective metrics can be assigned. This allows a quantitative description of a combination of these parameters whose results are correlated to the human perception of comfort. There are several standards providing correlations of physical conditions to comfort experienced by humans. All of which are based on probability. Two of these

standards are Fanger's Predicted Mean Value (PMV) approach and the more recent Adaptive Comfort assessment. Both are used in the data analysis in the investigations presented in this report.

2.4 Thermal Comfort Tests with Test Subjects

Tests with human subjects are a reliable way to measure individual comfort levels in prevailing thermal comfort conditions in certain indoor conditions. The results of a sample group of human test subjects is expressed in statistical terms, which serves as the basis to assess the level of comfort dissatisfaction. For the widely used comfort standard ASHRAE 55, unacceptable comfort is defined as more than 20% occupant dissatisfaction.

While varying factors such gender, age and condition of physical activities of the human subjects have been suggested as affecting human thermal responses, these factors were not considered as principal in these investigations. Therefore, although the group of human test subjects who participated in the ERDL comfort tests was non-uniform in terms of gender, age and condition of physical activities, all responses to the comfort test were weighted uniformly.

For the ERDL comfort tests presented in this report, specific procedures followed guidelines by previous comfort tests, but included some unique process steps, in order to accommodate conditions of the ERDL test sites. The procedures used in as well as analysis of results obtained by the comfort test are presented in Section Four of this report.

SECTION 3 - INVESTIGATION OF PHYSICAL INDOOR ENVIRONMENTAL CONDITIONS

This section describes investigations carried out to describe physical environmental conditions at the ERDL test site. These investigations include CFD simulations of heat and mass transfer phenomena and actual measurements of convection and thermal radiation.

3.1 CFD Simulations of Convective and Radiative Heat Transfer at the Test Station

CFD simulations were conducted to quantify convective and radiative heat transfer mechanisms at the test station. The CFD simulations were then compared against actual measured data.

3.1.1 Description of the Test Scenarios

Initial scoping CFD simulations were carried out to define test scenarios and determine thermal conditions which should be maintained during the comfort tests. Due to the high number of independent test parameters the test matrix had to be simplified in order to hold the scope of simulations manageable.

The scenarios used for the CFD simulations represented a combination of values four test parameters:

Ceiling fan speed level (subsequently referred to as “fan speed” or “fan speed level”); considered in four speed levels 1 through 4, where 1 was the lowest speed level.

Radiant panel configurations: the 10-panel array could be individually controlled to allow chilled water flow through selected panels. For the CFD simulations three panel configurations A through C were used (refer to Figure 3.1.1.1 for a description what panels were cooled under the three panel configurations). It should be noted that the horizontal and vertical positions of the panel array were not changed during the tests.

Panel temperature range: Two potential panel surface temperature settings were selected, a “warm” and a “cold” panel temperature.

Room temperature: Two combinations of air and surface (e.g. walls, Floor and ceiling) were selected, with a “warm” and a “warmer” temperature range.

Figure 3.1.1.1 illustrates the four thermal parameters with their selected ranges which were used in the CFD simulation scenarios.

Parameters for Setting Up CFD Simulation Scenarios

		low			high	
ceiling fans:	fans speed	*1*	*2*	*3*	*4*	
Panel configurations						
	configuration	*A*				
Note:						
Panel is cooled						
Panel is NOT cooled		*B*				
		C				
Panel temperature range		warm		cold		
	Temperatures	*1*	*2*			
	{F°}	72	68			
Room temperature		warm			warmer	
	Temperatures	*1*			*2*	
	Air {F°}	80			85	
	Wall {F°}	80			85	
	Floor {F°}	77			82	
	Ceiling {F°}	78			83	

Figure 3.1.1.1.: Parameters used in setting the CFD simuations

Since each simulation required a significant amount of time, two days of running time on average, the test matrix could not include every possible parameter combination. Sixteen combinations of the four parameters were selected as representative in the CFD investigations. These 16 CFD scenarios are presented in Table 3.1.1.1.

Test matrix of CFD simulations:

Instrumentation based = Physical without test person

e.g. testing of physical thermal performance of test set-up

Table 3.1.1.1: Scenarios used in the CFD simuations of physical performance of the test set-up.

Radiant ceiling panels:

objective: test mean radiant temperature

Scenario ID	ceiling fan speed	panel configuration	panel temperature	Room temperature
A1	No fan	A	1	1
A2	No fan	A	1	2
A3	No fan	A	2	1
A4	No fan	A	2	2
A5	No fan	B	1	1
A6	No fan	B	1	2
A7	No fan	B	2	1
A8	No fan	B	2	2
A9	No fan	C	1	1
A10	No fan	C	1	2
A11	No fan	C	2	1
A12	No fan	C	2	2

Ceiling fan:

objective: Test the air velocity distribution of ceiling fans at 43" height

Scenario ID	ceiling fan speed	panel configuration	panel temperature	Room temperature
A13	1 (2)	A	N/A	N/A
A13B	2 (3)	A	N/A	N/A
A14	3 (4)	A	N/A	N/A
A14B	4 (5)	A	N/A	N/A

Note: ceiling fan speed in parentheses indicates the factory speed level of the BAF ceiling fan

3.1.2 Methodology used in the CFD Simulations

The methodology used in these CFD simulations followed the CFD workflow which is described in the report "*Project Deliverable No. 13: Parametric CFD Investigations of Comfort and Environmental Conditions at the ERDL Test Site".*

The CFD simulations reported in project report "*Project Deliverable No. 13"* were repeated for this present report "*Project Deliverable No. 14"* using updated boundary conditions. While the CFD simulation in report "*Project Deliverable No. 13"* could only reply an assumed boundary conditions, the present report "*Project Deliverable No. 14"* used initial scoping test, which were performed during the "shake down testing" of the test set-up. It should be noted however, that the shake down tests did not provide the correct thermal conditions which were eventually obtained during the actual tests. Reasons for the deviation were the presence of test humans and the required long running time of the test equipment.

3.1.3 Presentation of Qualitative CFD Results

Each CFD simulation provided a range of visual representation of the qualitative results in terms of air movement and thermal distribution. These visual depictions of CFD simulation results are presented in **Appendix A.**

Figure 3.1.3.1 through 3.1.3.7 show several samples of visual depictions (shown are images of scenarios A4 and A 13; scenarios without and with ceiling fan operating).

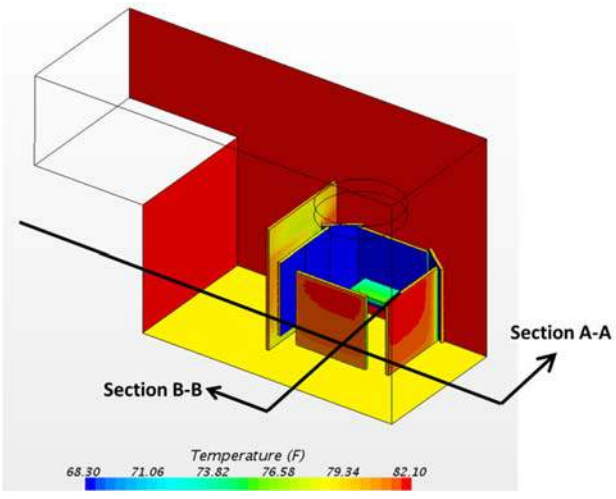


Figure 3.1.3.1: Test set-up isometric view with section definition

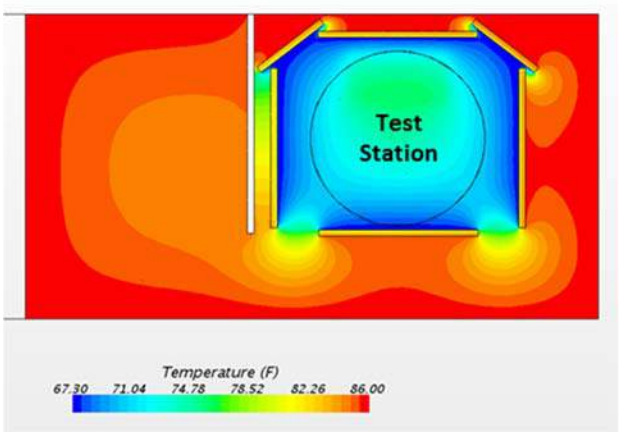


Figure 3.1.3.2: Test set-up plan view, temperature distribution

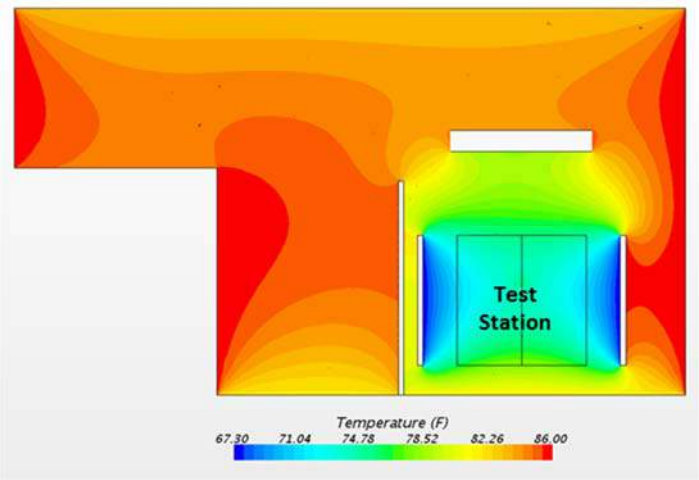


Figure 3.1.3.3: Test set-up plan Section A-A, temperature distribution

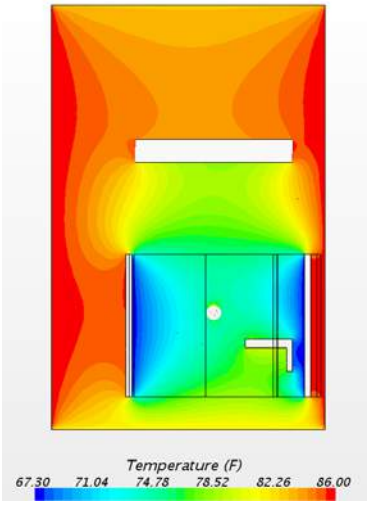


Figure 3.1.3.4: Test set-up plan Section B-B, temperature distribution

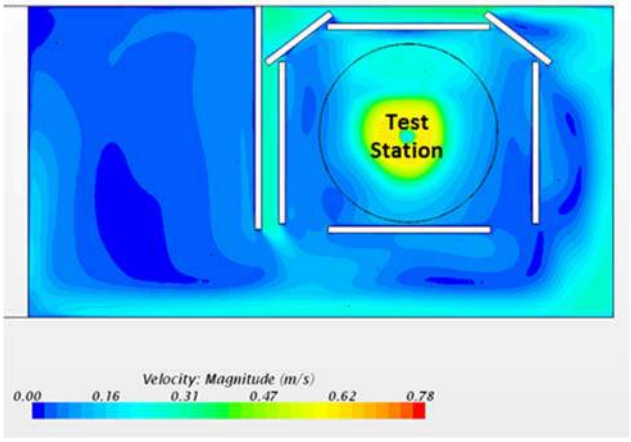


Figure 3.1.3.5: Test set-up plan View, air velocity distribution

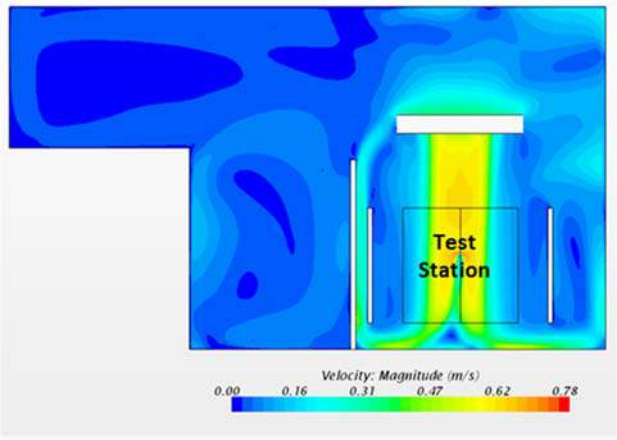


Figure 3.1.3.6: Test set-up plan Section A-A, air velocity distribution

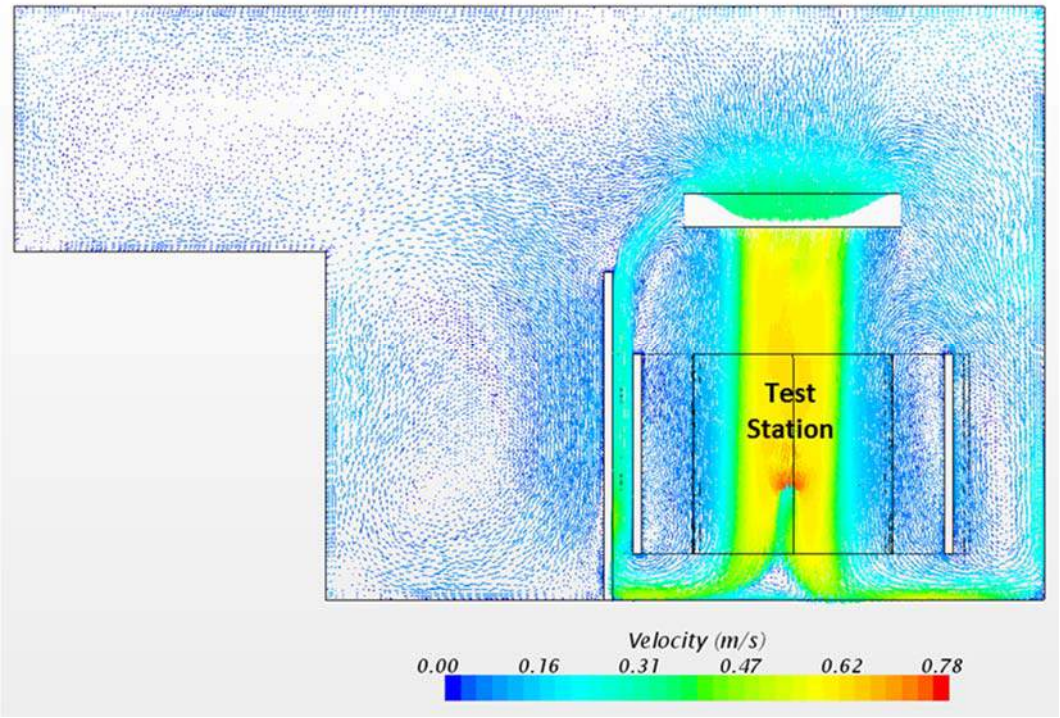


Figure 3.1.3.7: Test set-up plan Section A-A, air velocity distribution, Streamlines

3.2 Air Measurements at Test set-up with Test Person

The assessment of quantitative comfort levels required knowledge of air speeds which were generated by the ceiling fan at different fans speeds used in the comfort tests. This section describes the methodology and results of these air speed measurements.

3.2.1 Methodology

Air speeds around the test person were determined by installing an array of five anemometers in close proximity of a person who was sitting in a chair and in front of the desk in the test station.

Figure 3.2.1.1 and 3.2.1.2 show the locations and elevation of the of the anemometer array for these air movement tests, respectively. Four anemometers were placed at four corners around the shoulders of the test person at the elevation of the shoulders (e.g. Anemometer locations A through D). One additional anemometer was placed above the head of the sitting test person (e.g. Anemometer locations E or 'overhead').

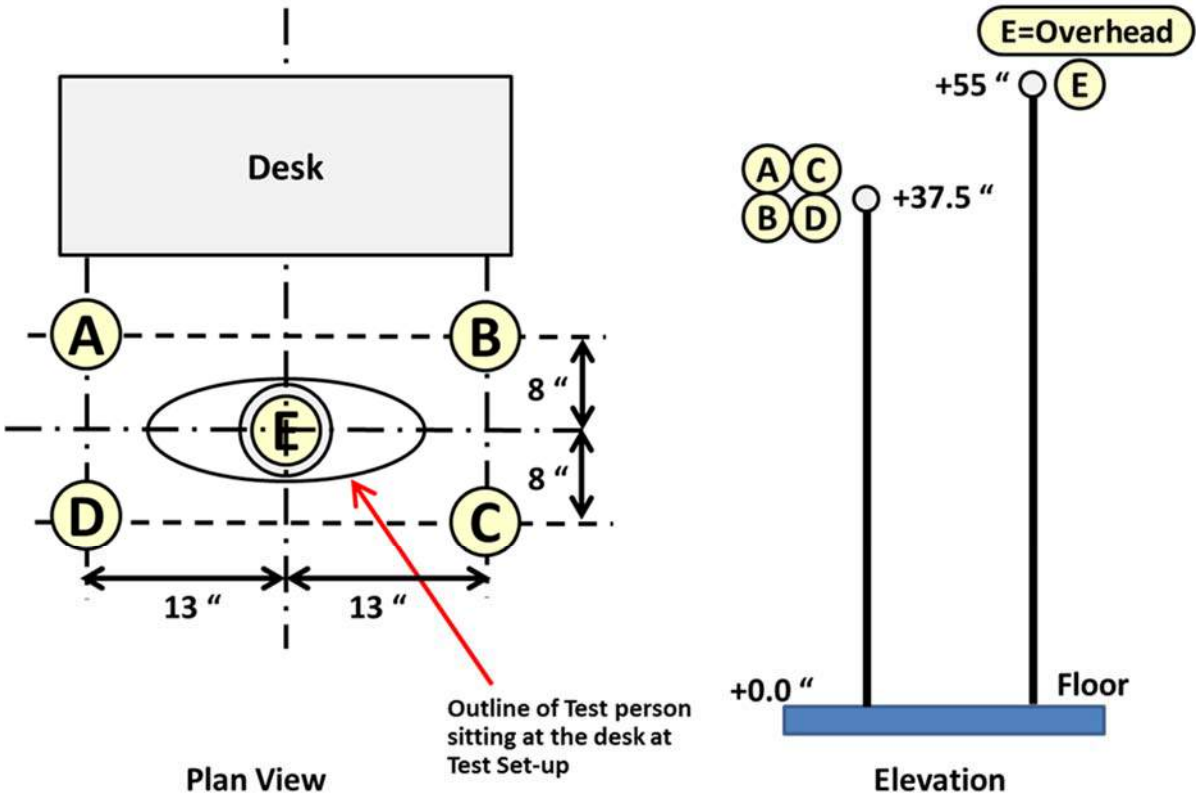


Figure 3.2.1.1: Locations of anemometers during measurements to determine representative air speed at different fan speed levels

Figure 3.2.1.2: The air speed test

Description:

1. Desk used in tests
2. Cooling panels surrounding the desk and test person
3. ERDL team member serving as test person during air movement measurements
4. Anemometer attached to stand (here anemometer at location "A"

At each of the five measurement locations (A though E), three anemometer sensors were used to measure the air speed. Two were identical F-900 anemometers and one was a hand-held Wolfsense anemometer. All three anemometers were placed at a distance of about 1.0 inch of each other. All three anemometers were data logged at 1 second sample intervals. The length of the air speed measurements at each location and each fan speed level was about two minutes. Five fan speed levels were used. Since the fan levels 2 and 3 had been selected for the comfort tests, more tests were conducted for fan speed level 2 and 3 than for fan levels 4 and 5.

3.2.2 Presentation of Measured Air Speed Data

Figures 3.2.2.1 and 3.2.2.2 show examples of measured air speeds. Data records showed fluctuating air speeds values due to turbulence. Figure 3.2.2.1 shows the air speed distribution of the F-900 anemometer No. 2 for the location A and for fan speeds 2 and 3. The figure illustrates the fluctuating air speeds and compares the two fan speed levels that were used in the comfort studies. Figure 3.2.2.2 compares the distributions of air speed of the two F-900 anemometers at that same location and the same fan speed level. The complete data sets of the measurements are presented in **Appendix B**.

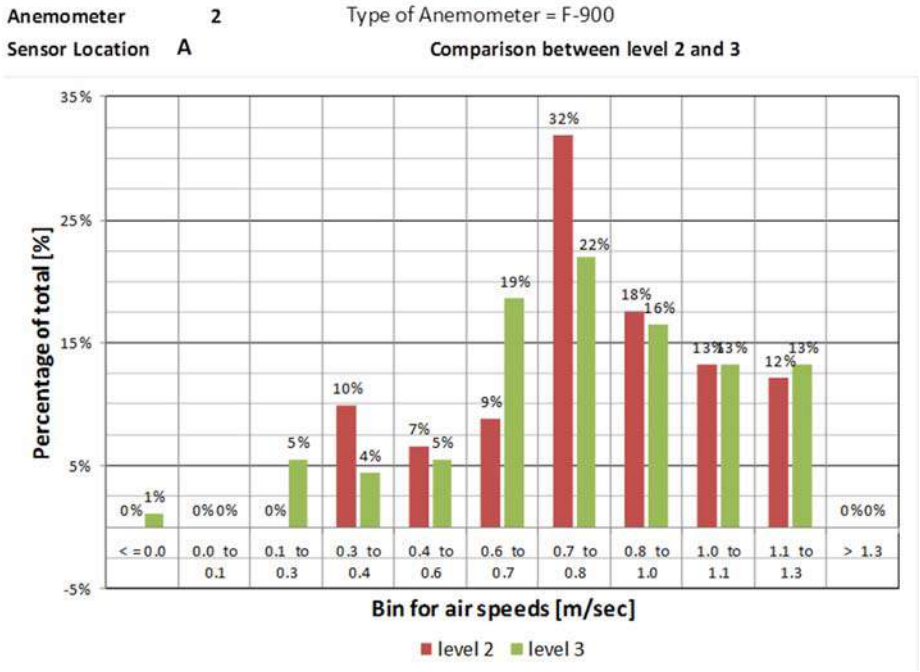


Figure 3.2.2.1: Example of an air speed record measured at the test site, the record describes the distribution of air speeds and compares fan speed levels 2 and 3

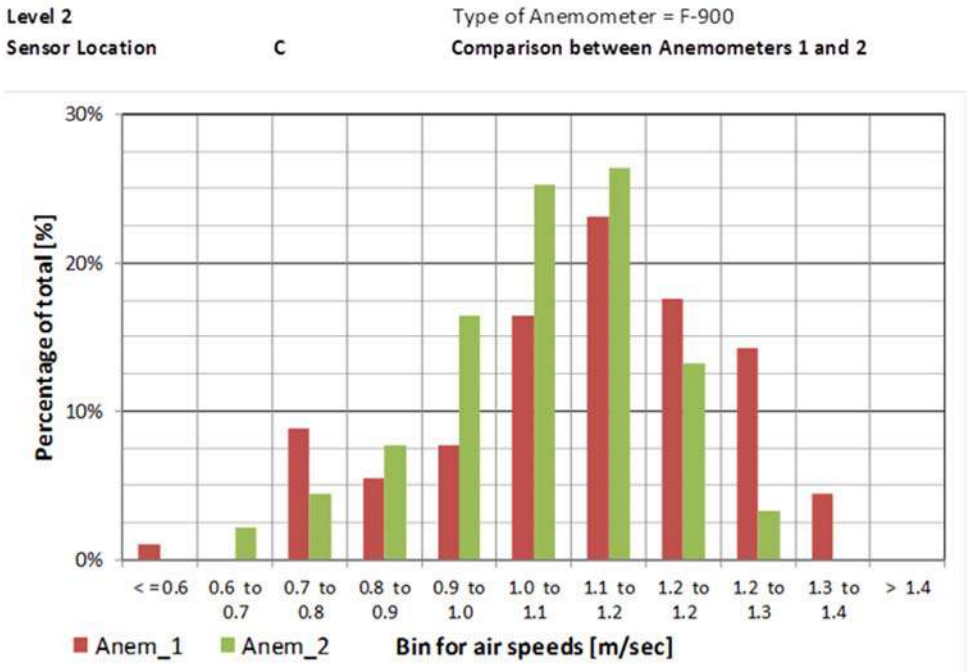


Figure 3.2.2.1: Example of an air speed record measured at the test site, the record describes the distribution of air speeds and compares fan speed levels 2 and 3

3.2.3 Discussion of Results and Conclusions

Figures 3.2.3.1 ad 3.2.3.2 show the resulting air speeds measured at the five locations, A through E (e.g. "Overhead"), at fan speed levels 2 and 3, respectively.

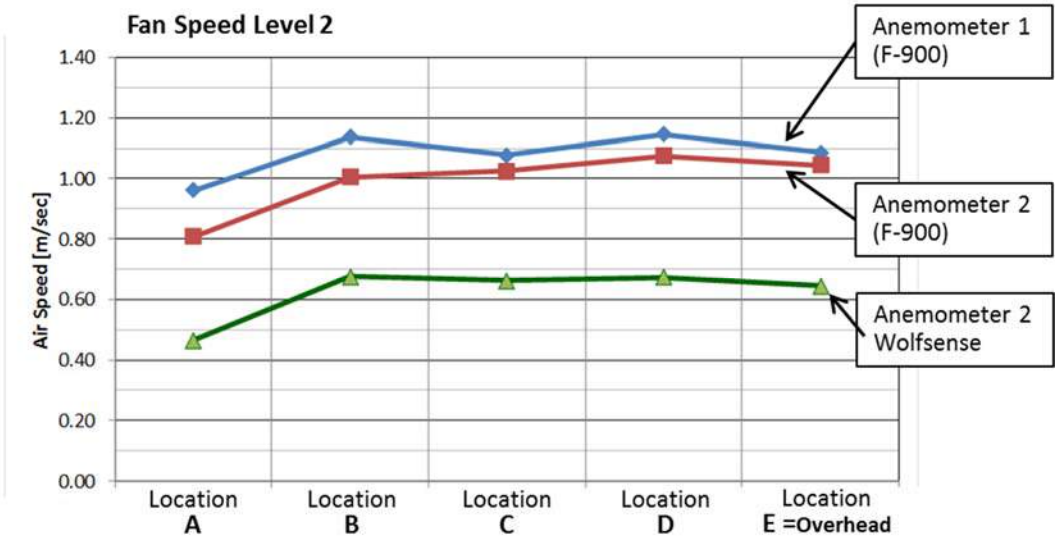


Figure 3.2.3.1: Measured air speeds at the five sampling locations A through E for fans speed level 2

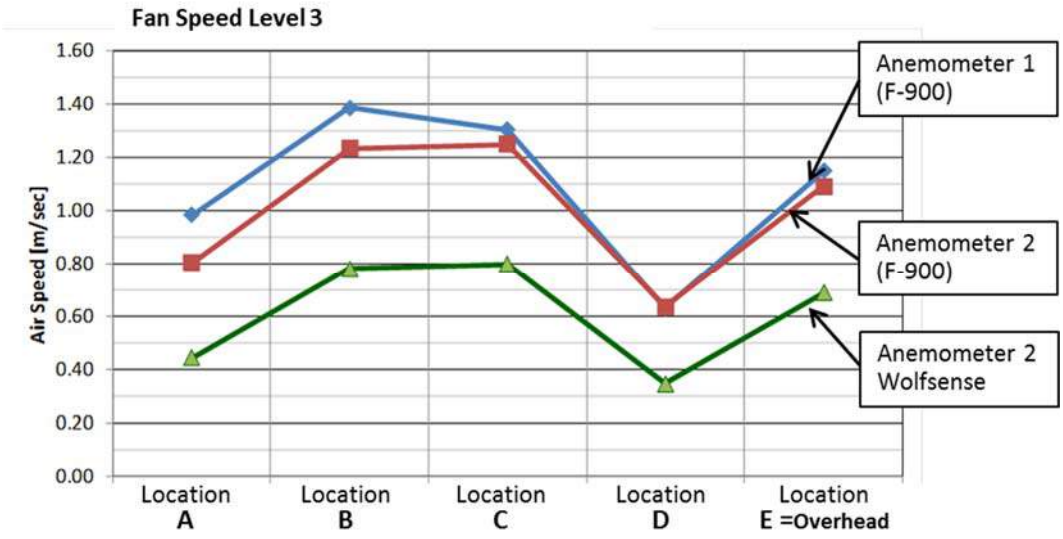


Figure 3.2.3.2: Measured air speeds at the five sampling locations A through E for fans speed level 3

Figures 3.2.3.3 and 3.2.3.4 show comparisons between the sampling locations A through D, which are the locations of anemometers with the same elevation.

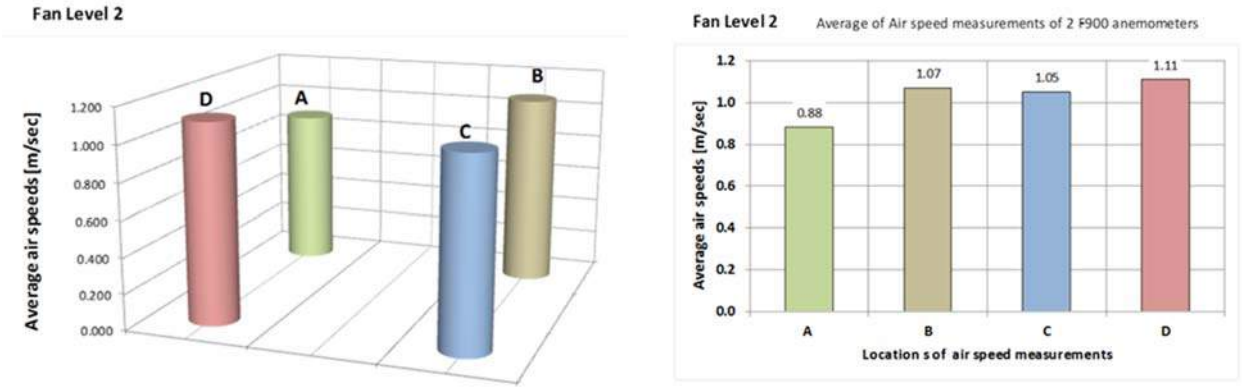


Figure 3.2.3.3: Comparison of air speeds measured at different locations – shown is the average air speed od Anemometers 1 and 2 (F-900 anemometers; for **Fan speed level 2**

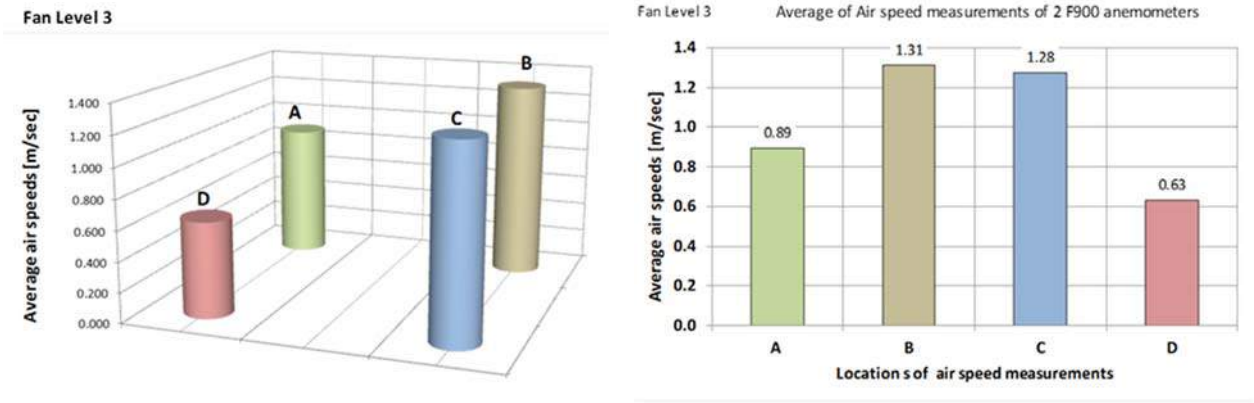


Figure 3.2.3.4: Comparison of air speeds measured at different locations – shown is the average air speed od Anemometers 1 and 2 (F-900 anemometers; for **Fan speed level 3**

Figures 3.2.3.1 and 3.2.3.2 show that the measured air speeds for the two F-900 deviated only slightly. The third anemometer, the Wolfsense anemometer, deviated significantly from the F-900 anemometers. Consequently, it was decided to use the average the measured air speed of the two F-900 anemometers as the representative air speed.

Figures 3.2.3.3 and 3.2.3.4 illustrate that the spatial distribution of the speed speeds was not uniform between the four locations of sample locations A through D, with the same elevations.

The significant difference between the two F-900 and the Wolfsense anemometers, shown in Figures 3.2.3.1 and 3.2.3.2, was further evaluated in Figure 3.2.3.5. Figure 3.2.3.5 suggests that the difference between the averages of F-900 and Wolfsense anemometers followed a somewhat systematic pattern. Table 3.2.3.1 shows that the ratio of the average overhead F-900 and Wolfsense airspeeds were basically constant with a resulting factor of 1.64. Applying an adjustment factor of 1.64 to the Wolfsense air speed data resulted in practically identical air speeds for F-900 and the Wolfsense anemometers. Figure 3.2.2.6 illustrates the good correlation of the average air speeds of the two F-900 anemometers and the ADJUSTED Wolfsense anemometer.

The fact that the Wolfsense anemometer gave a systematic measurement error is an important observation since air speeds leaving the ceiling fan was measured with the Wolfsense anemometer. The air speeds leaving the ceiling fan were used as boundary conditions for modelling the discharge patterns of the ceiling fan, and therefore these boundary conditions were important input values for the CFD simulations. With the Wolfsense measuring approximately 60% of the actually anticipated air speeds, a systematic error was introduced for the CFD simulations. This fact was only identified after the bulk of the CFD investigations had been concluded.

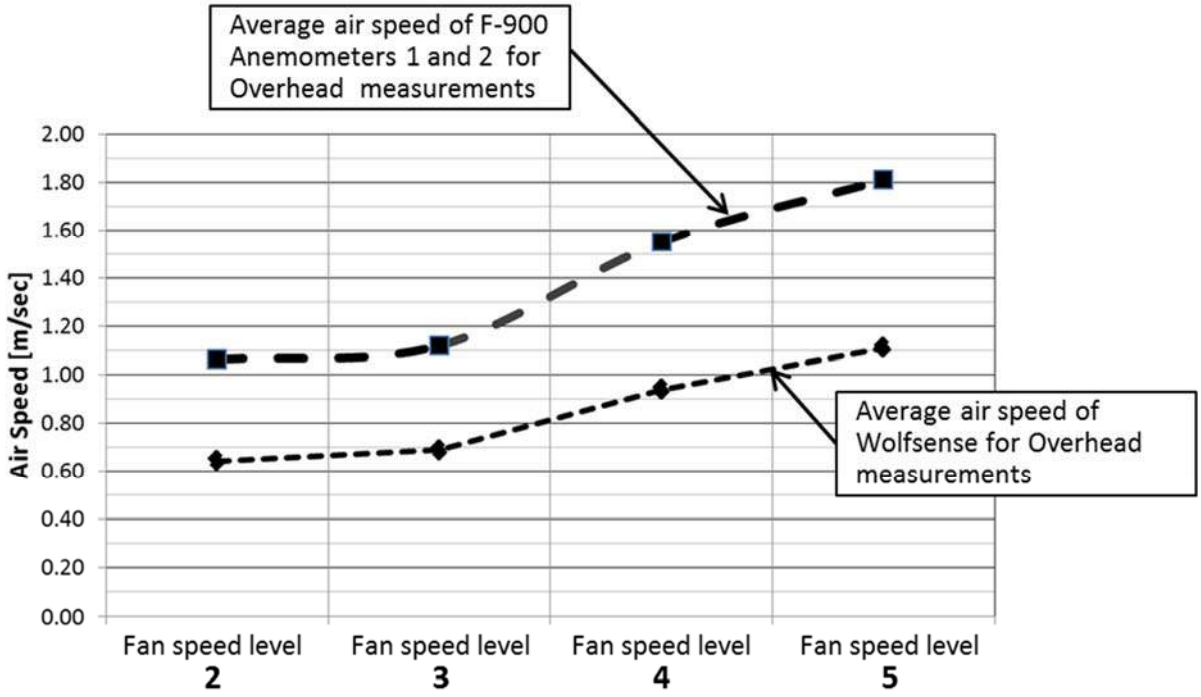


Figure 3.2.3.5: Comparison between overhead averages of F-900 and Wolfsense anemometers

	F-900 Overhead m/sec	Wolfsense Overhead m/sec	Factor [-]	adjusted wolfsense m/sec
Level 2	1.06	0.64	1.65	1.06
Level 3	1.12	0.69	1.63	1.13
Level 4	1.55	0.94	1.65	1.54
Level 5	1.81	1.11	1.63	1.82
			1.64	

Table 3.2.3.1: Adjustment factor for Wolfsense anemometer

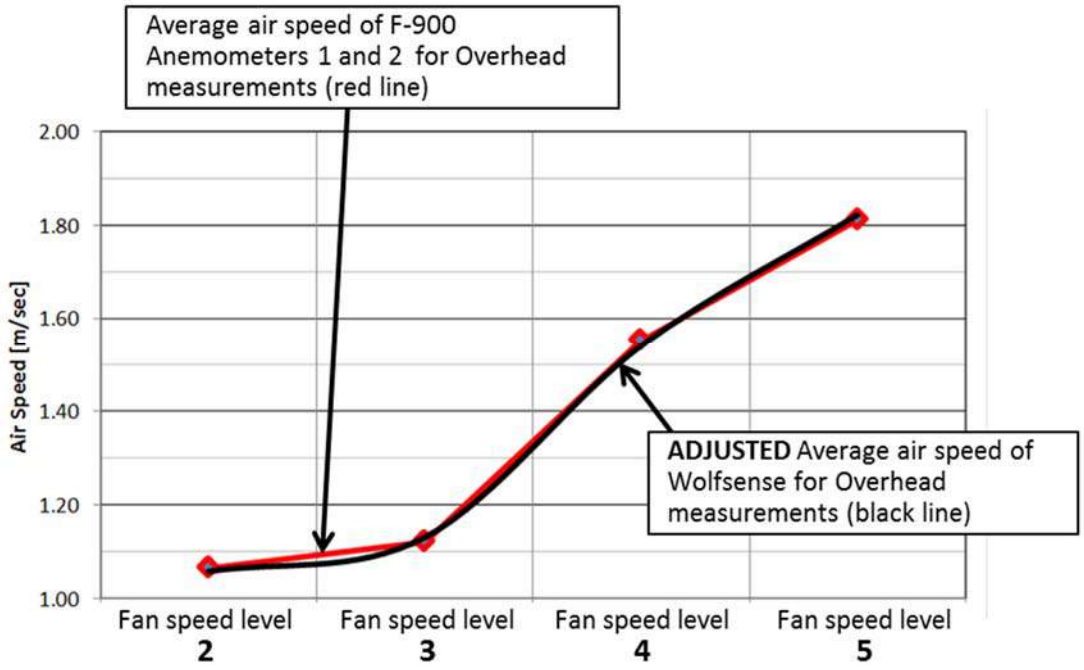


Figure 3.2.3.6: Comparison between average overhead air speeds for F-900 and ADJUSTED Wolfsense anemometers

The representative air speeds which were used in the data analysis of the comfort test are depicted in Figure 3.2.3.7 and in Table 3.2.3.2. The representative air speeds for fan speed levels 2 and 3 were 1.05 and 1.14 m/sec.

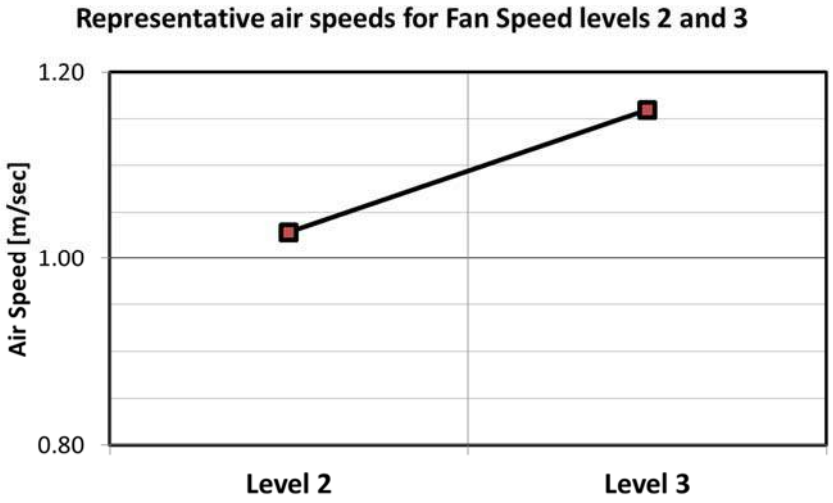


Figure 3.2.3.7: Representative air speed for Fan speed levels 2 and 3 – these air speeds were used in the analysis of the comfort tests

F900 anemometer

Fan level	Overhead [m/sec]	average A to D [m/sec]	Resulting [m/sec]
Level 2	1.06	1.03	**1.05**
Level 3	1.12	1.16	**1.14**
Level 4	1.55		
Level 5	1.81		

Table 3.2.3.2: Air speeds resulting from the ceiling fan at levels 2 and 3 – these air speed value were used in the analysis of the comfort tests

3.3 CFD Simulations and Measurement of Air Movement at Test Set-up Without Test Person

Ceiling fan induced air movement at the test set-up was simulated with CFD and subsequently measured for data validation. Air speeds at four fans speed levels were investigated with CFD simulations. A virtual sensor array was placed at the center location of the test station. The sensor array was used to extract local velocity data from the computational domain. The theoretical simulations were validated with results of actual measurements. For these air movement investigations, no human body was present in the CFD computational domain and during the actual measurements.

3.3.1 Methodology of CFD Simulations

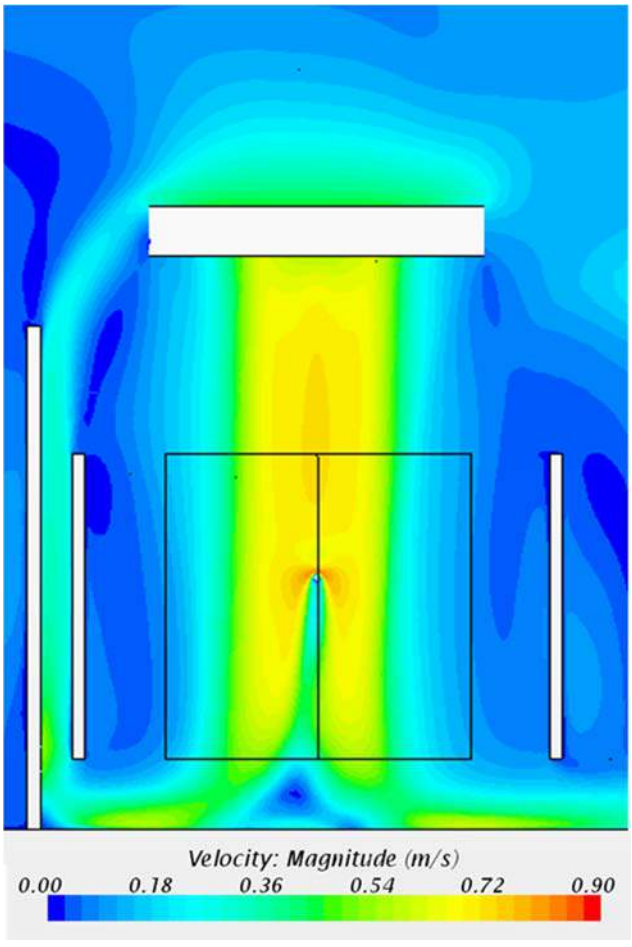
CFD simulations were conducted following the workflow previously developed in project report "*Deliverable 12 – Generic CFD Workflow for Comfort Assessment*" and applied in the CFD simulations reported in project report "*Deliverable 13: Parametric CFD Investigations of Comfort and Environmental Conditions at the ERDL Test Site*". The CFD simulation for this report Deliverable 14 used the identical CFD workflow but updated values of the same types of boundary conditions. The updated values for the boundary conditions were selected on the basis of data obtained during the shake down testing of the test set-up.

The data representation of the CFD air speed simulations was done using both qualitative and quantitative methods. The qualitative presentation included colored velocity contour and streamline images. Two examples are shown in Figure 3.3.1.1. A complete presentation of the CFD air speed investigation can be seen in **Appendix A** under the four scenarios 13 through 14B.

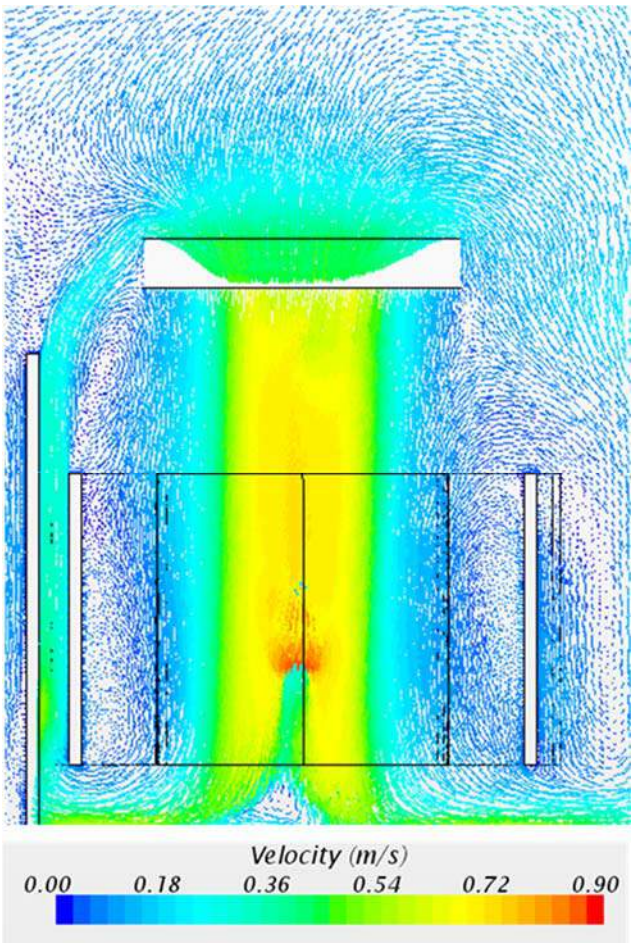
The quantitative data representation of the CFD air speed simulations used a 7 x 7 x7 data grid, which was a 3D array consisting of 343 data nodes within the computational domain. Data of predicted air speeds was extracted for all nodes and reported in an external data set for subsequent analysis.

The 3D 7 x 7 x 7 node array is depicted in Figure 3.3.1.2. Figure 3.3.1.3 shows the dimensions of the 7x7x7 node array with the horizontal and vertical node spacing. Figure 3.3.1.3 also visualizes the location of the anemometers that were used to measure local velocities and provide the data for validation.

While the systematic of the CFD simulation approach and setting remained basically unchanged from the parametric investigation of project report "*Deliverable 13: Parametric CFD Investigations of Comfort and Environmental Conditions at the ERDL Test Site*" the boundary condition of ceiling fan was changed. The changes to the boundary conditions used a more refined resolution of the air speeds downstream of the actual ceiling fan.



Velocity profile – contour map



Velocity profile – contour map with velocity vectors

Figure 3.3.1.1: Example of visual representation of CFD air speed simulation – depicted is Scenario 13B at the center section A-A (see also Appendix A for the complete representation of CFD visual data presentation

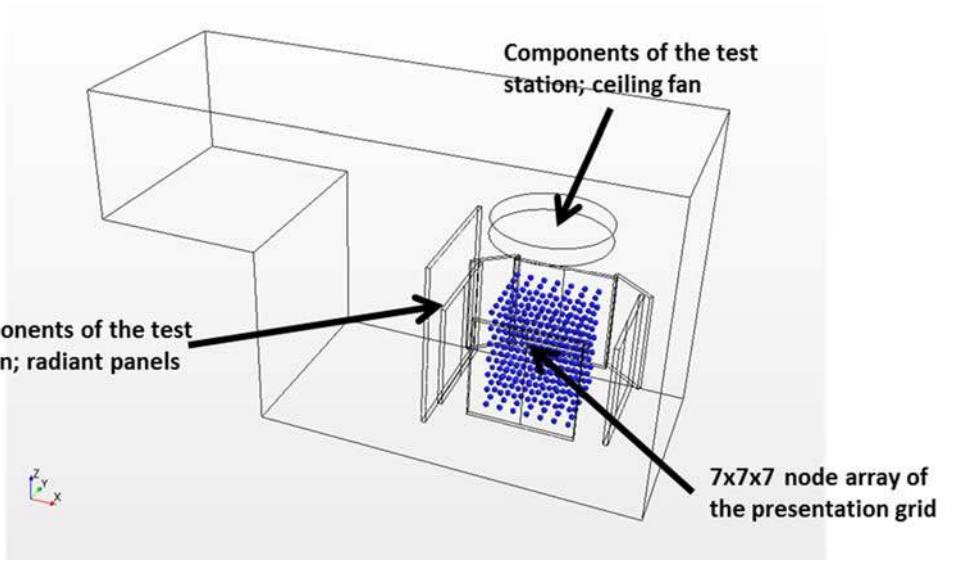


Figure 3.3.1.2: Isometric view of the 7x7x7 presentation grid for data extraction of CFD air speed simulations

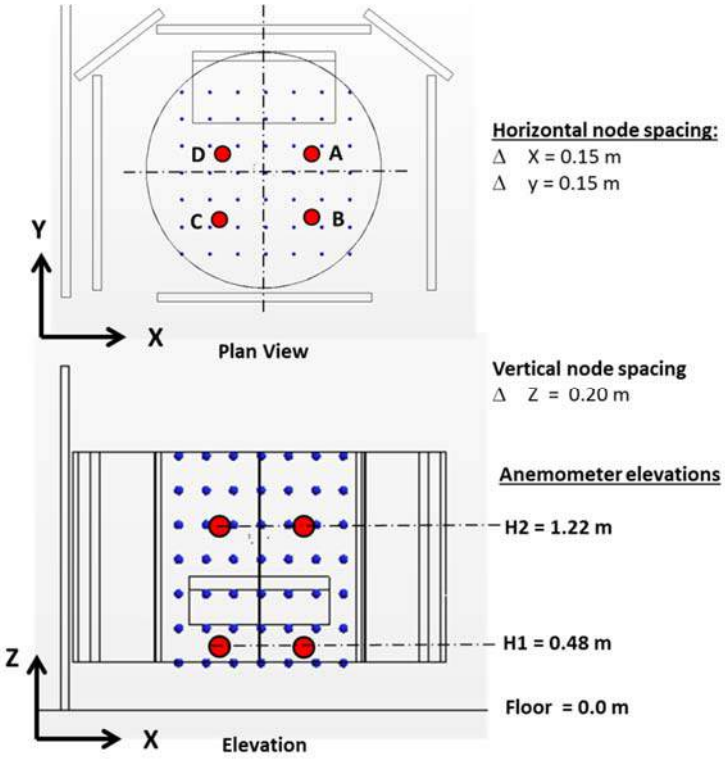


Figure 3.3.1.4: Dimension of the 7x7x7 presentation grid with horizontal and vertical node spacing; also depicted in red circles are the locations of the anemometers for local air speed measurements

3.3.2 Results of CFD Air Movement Simulations

A series of CFD air speed simulations was conducted for four fan speed levels 2 through 5. The data exported from the CFD program for each was imported into EXCEL for further data analysis. In order to obtain representative CFD results for local air speeds at the anemometers locations A through D and at two elevations, 0.46 m and 1.22 m, certain nodes of the 7x7x7 presentation grid were averaged. Figure 3.3.2.1 shows which nodes were used to determine the CFD local air speeds. The resulting averages at these nodes were validated with the measured air speeds at corresponding locations

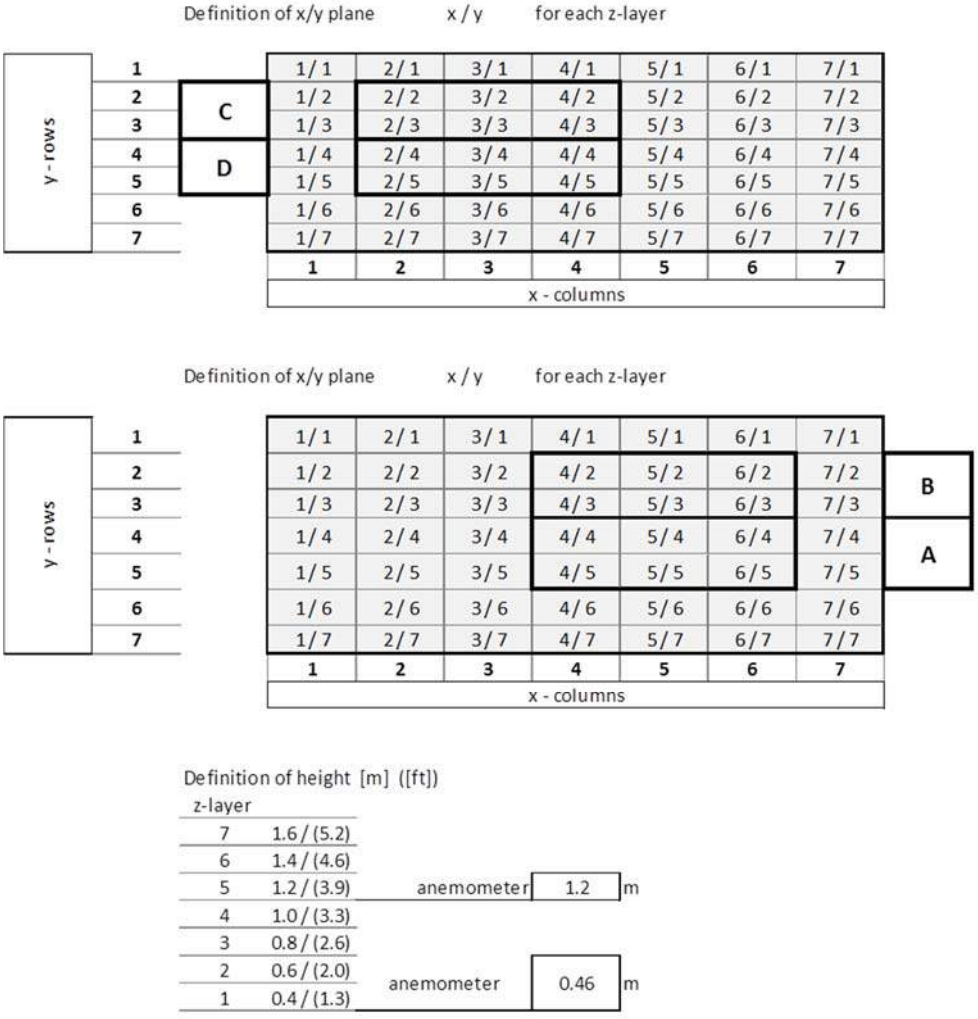


Figure 3.3.2.1: Description of nodes of the presentation grid that were used to determine the CFD air speeds for the anemometer location A through D

Figure 3.3.2.2 shows an example of the data extraction procedure and analysis for the local air speeds derived by the CFD simulations. In the figure the resulting air speed at the elevation of 0.46 m was a weighted mean of the selected nodes at the 0.4 and 0.6 m elevation.

Average for entire z-layers

average	z-ccord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.231	70.0%
Entire z-layer 2	0.6	0.233	30.0%
weighted average	**0.46**	**0.232**	m/sec
stnd. Dev.			
Entire z-layer 1		0.153	
Entire z-layer 2		0.188	

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.231 m/sec

y - rows	x = 1	2	3	4	5	6	7
1	0.115	0.152	0.230	0.195	0.139	0.101	0.080
2	0.144	0.255	0.423	0.429	0.305	0.143	0.094
3	0.177	0.402	0.463	0.452	0.452	0.201	0.109
4	0.229	0.454	0.332	0.346	0.504	0.278	0.132
5	0.209	0.452	0.490	0.495	0.443	0.355	0.184
6	0.178	0.366	0.116	0.042	0.038	0.033	0.042
7	0.085	0.129	0.100	0.093	0.056	0.042	0.047

x - columns

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.233 m/sec

y - rows	x = 1	2	3	4	5	6	7
1	0.083	0.124	0.161	0.183	0.123	0.092	0.063
2	0.092	0.194	0.381	0.439	0.284	0.131	0.079
3	0.137	0.353	0.552	0.560	0.521	0.208	0.098
4	0.168	0.495	0.556	0.534	0.564	0.264	0.126
5	0.154	0.449	0.572	0.575	0.543	0.317	0.160
6	0.186	0.194	0.074	0.043	0.040	0.032	0.039
7	0.139	0.040	0.083	0.075	0.032	0.048	0.052

x - columns

Anemometer position A at 0.46 m elevation

average	z-ccord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.429	70.0%
Entire z-layer 2	0.6	0.507	30.0%
weighted average	**0.46**	**0.452**	m/sec
stnd. Dev.			
Entire z-layer 1		0.039	0.090878
Entire z-layer 2		0.126	0.248428

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.403 m/sec

y - rows	x = 1	2	3	4	5	6	7
1							
2							
3							
4				0.346	0.504	0.278	
5				0.495	0.443	0.355	
6							
7							

x - columns

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.466 m/sec

y - rows	x = 1	2	3	4	5	6	7
1							
2							
3							
4				0.534	0.564	0.264	
5				0.575	0.543	0.317	
6							
7							

x - columns

Figure 3.3.2.2: Example of data analysis for a representative local air speed from the extracted CFD data

For a specific fan speed level and elevation, the local air speeds were obtained. A comparison of averages for the locations A through D is shown in an example in Figure 3.3.2.3. CFD simulation results of air speeds for all four fan speeds levels at the four locations A through D and two elevations are presented in **Appendix C.**

averages for anemometers

Fan speed level 2

	elevation [m]	air speed [m/sec]	% of layer	% of all
Anemometer A	0.46	0.45	195%	185%
Anemometer B	0.46	0.38	163%	154%
Anemometer C	0.46	0.44	190%	180%
Anemometer D	0.46	0.49	214%	202%
Average for z-layer	0.46	**0.23**	100%	95%
Average - all points	N/A	0.24	106%	100%

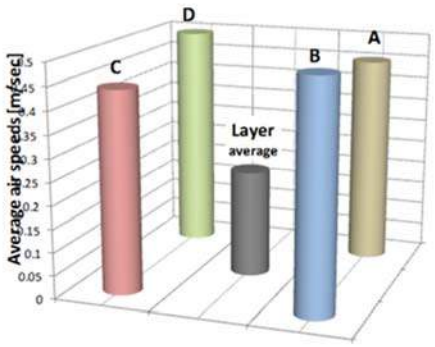


Figure 3.3.2.3: Example of comparison of CFD simulations results of local air speeds – here for fan speed level 2 and an elevation of 0.46 m

3.3.3 Presentations of Measured Air Speeds for CFD Validation

Air speeds at the four locations A through D and two elevations (0.46 m and 1.22 m) for four fan speeds were measured with eight F-900 anemometers. The data record of the anemometer at location D and elevation 0.46 m was later found inconclusive and therefore results for this location were not used in the analysis. Figure 3.3.3.1 and 3.3.3.2 show the four locations and two elevations of the anemometers, respectively. A correlation between CFD simulation and actual measurements is also illustrated in Figure 3.3.1.4. Figure 3.3.3.3 shows the installation of anemometers at the test station.

Figure 3.3.3.3 shows the installation of an anemometer for the measurements. Figure 3.3.3.3 also shows the installation of a globe thermometer which was used to measure the globe temperature at the test station. The globe temperature was used to determine the mean radiant temperature at the test station.

Each data set, comprised of a certain fan speed level, horizontal and vertical location of the anemometer, was used to determine a frequency distribution. As an example, Figure 3.3.3.4 shows the frequency distribution of the data set at Location B, fan speed level 2 and 48-inch elevation. The spread of the air speed measured around the average air speed suggests the inherent turbulence and presence of vortices in the downstream of the ceiling fan. A complete presentation of all result of air speed measurement for the seven anemometer location is presented in **Appendix D.**

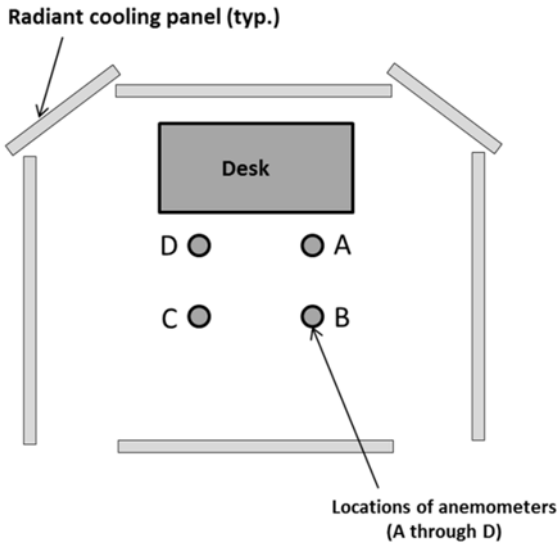


Figure 3.3.3.1: Description of the horizontal location of the four anemometer location

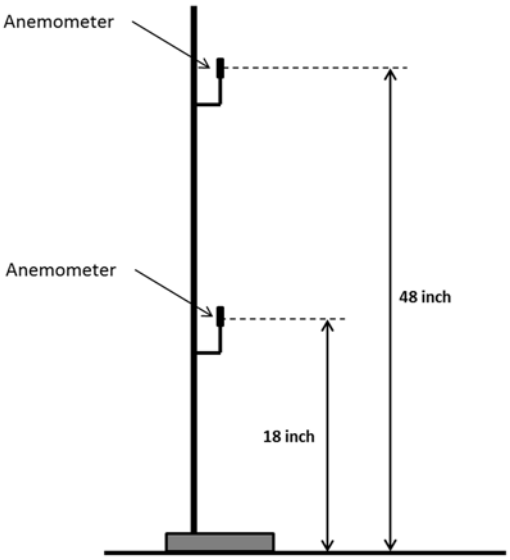


Figure 3.3.3.2: Description of the vertical location (elevation) of the four anemometer location

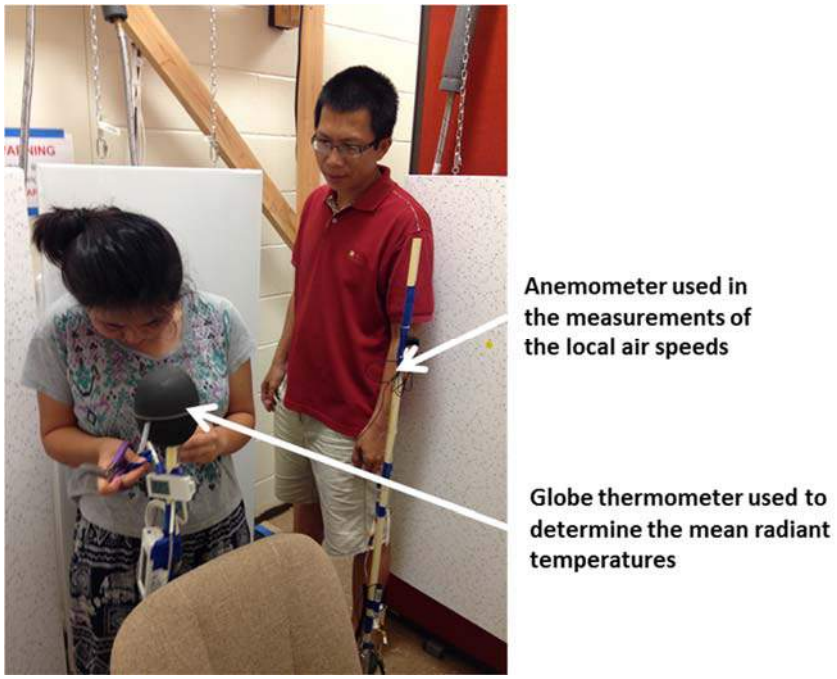


Figure 3.3.3.3:
Photo of showing the installation of the anemometers

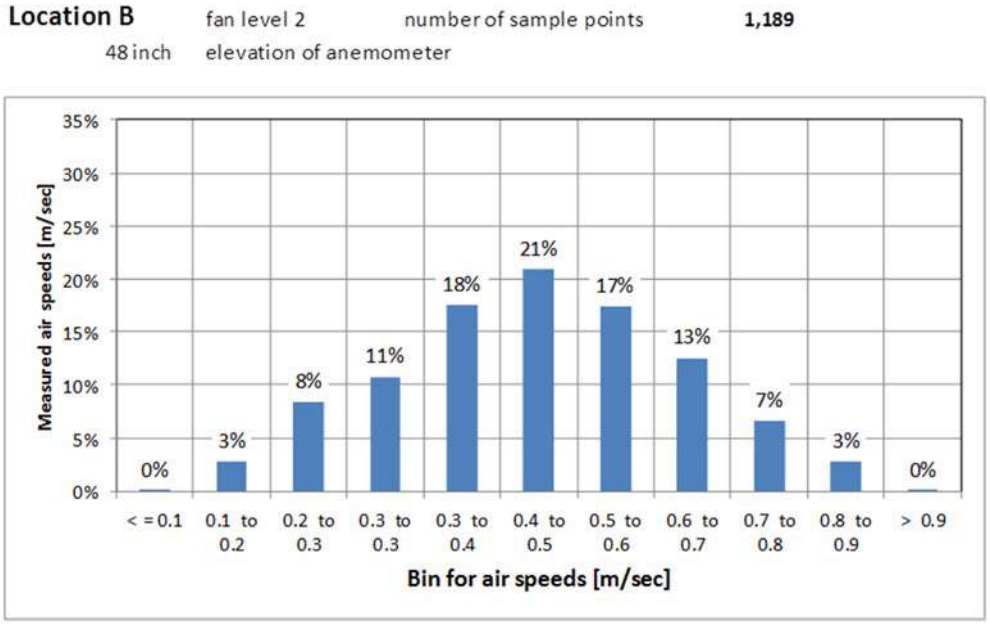


Figure 3.3.3.4: Example of results of air speed measurements at the test station for CFD validation

As an example data set Figure 3.3.3.5 shows a comparison between measured air speed at 0.46 and 1.22 m elevation for a fan speed level 3. The spatial distribution of the locations A through D of the measured air speed indicates that the air stream downstream of the ceiling fan is non-uniform.

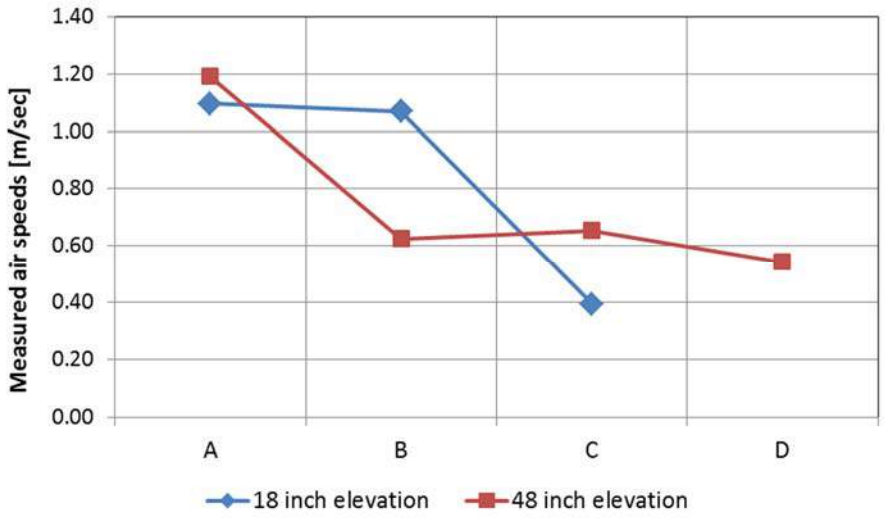


Figure 3.3.3.5: Example of results of air speed measurements at the test station for CFD validation - comparison of air speed measured at one sampling location and two different elevations.

3.3.4 Discussion of Results and Conclusions

The results of the CFD simulations of local air speed against the measured air speeds are compared in Figure 3.3.4.1 and 3.3.4.2. The comparison suggests that the measured air speeds at the same location are consistently larger than the values obtained with the CFD simulation.

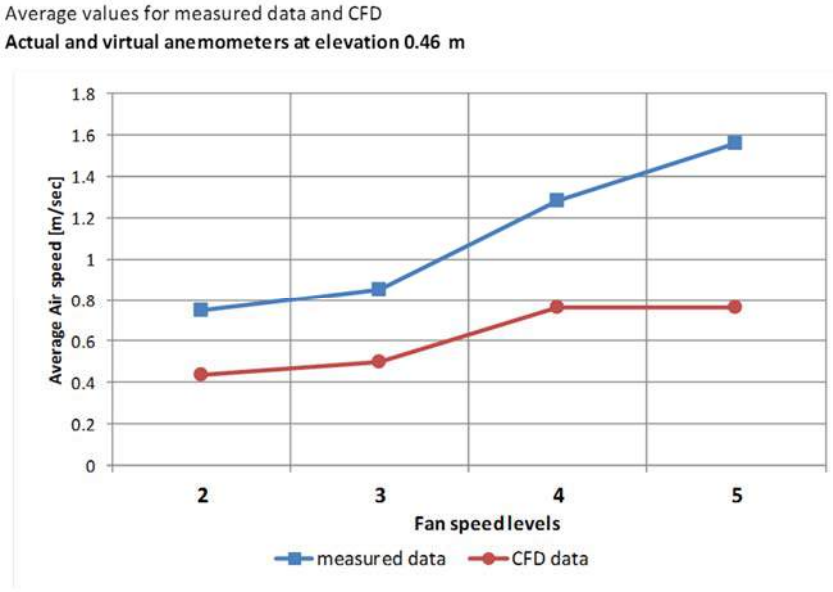


Figure 3.3.4.1:
Comparison of local air speeds between calculated CFD and measured values, for sensors at an elevation of **0.46 m.**

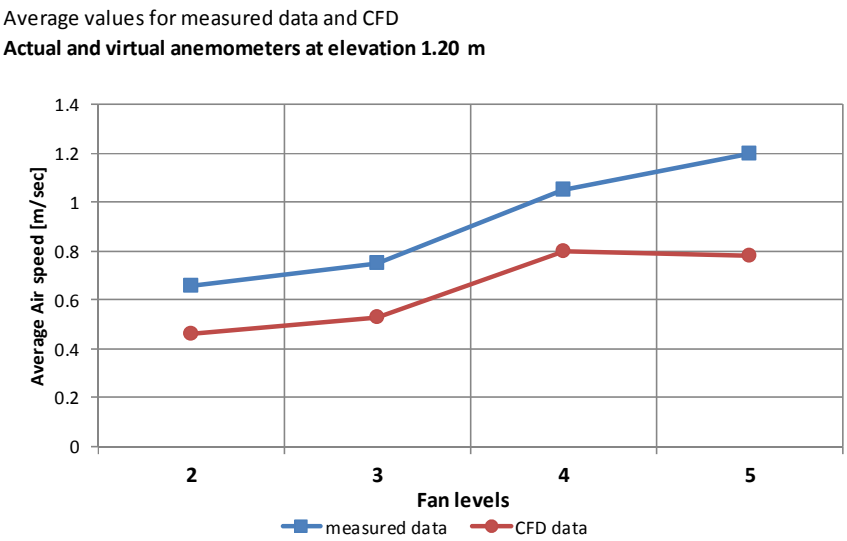


Figure 3.3.4.2:
Comparison of local air speeds between calculated CFD and measured values, for sensors at an elevation of **1.22 m.**

The graphs of measured and CFD calculated air speed curves, however, depict a consistent qualitative pattern where the measured data appear to be larger by somewhat linear factors.

A linear adjustment of the CFD values results was carried out and the results are presented in Tables 3.3.4.1 and 3.3.4.2 and in Figures 3.3.4.3 and 3.3.4.4. For the sensor elevation at 0.46 m the adjustment values in Table 3.3.4.1 suggests that the measured values of the fan speed levels 2 through 4 are 1.7-times the CFD simulation values. Including the fan speed level 5 values results in an average adjustment factor of 1.8. Figure 3.3.4.3 shows that the adjusted values of CFD had good data consistency with the measured data, especially, as indicated before, for the fan speed levels 2 through 4. A corresponding result of data adjustment is obtained for the CFD and measured values when calculated (e.g. CFD simulations) and measured at a sensor elevation of 1.22 m.

As was already discussed in Section 3.2 the Wolfsense anemometer was found to consistently under predict air speed by a significant yet constant factor. Since the Wolfsense anemometer was used to measure the air speed directly downstream of the ceiling fan, which was then used for the CFD boundary conditions, it can be assumed that the CFD simulations result have a systematic, yet linear inaccuracy. It can therefore be stated that the CFD simulated and measured values of local air speeds have a good data consistency in terms of fan speed level dependent pattern, albeit the difference in absolute values.

Adjustments of CFD data
Anemometers at elevation 0.46 m
averages

fan speed level	measured data	CFD data	measured / CFD	Adjusted CFD data
2	0.75	0.44	1.7	0.79
3	0.85	0.5	1.7	0.89
4	1.28	0.76	1.7	1.36
5	1.56	0.76	2.1	1.36
		average	1.8	

Table 3.3.4.1: Adjustment of CFD air speed simulation results – sensor elevation 0.46 m

Adjusted CFD data points with an average and constant correction factors of 1.8
Average values for measured data and CFD
Actual and virtual anemometers at elevation 0.46 m

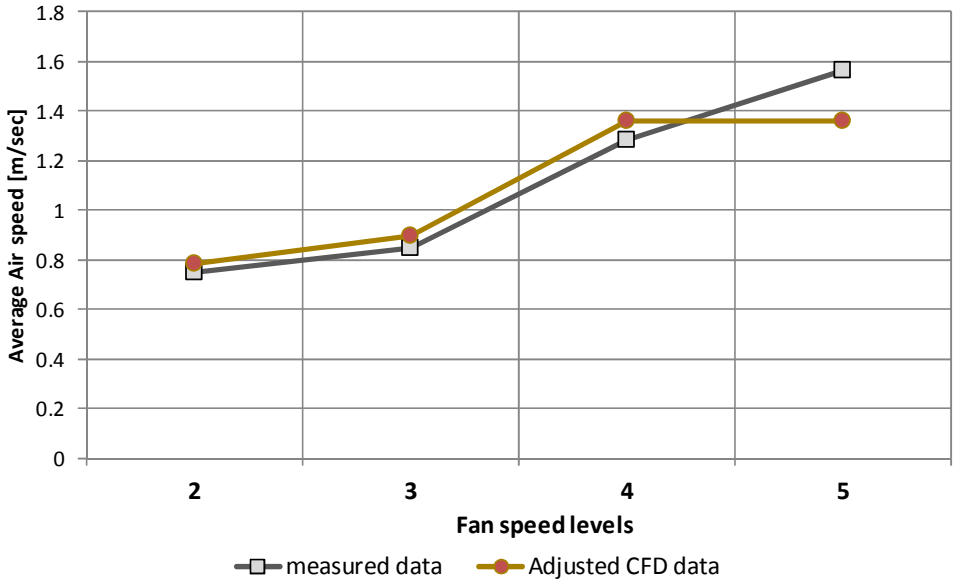


Figure 3.3.4.3: Comparison of ADJUSTED CFD simulation and measured air speeds – at sensor elevation of **0.46 m**

Adjustments of CFD data
Anemometers at elevation 1.20 m
averages

fan speed level	measured data	CFD data	measured / CFD	Adjusted CFD data
2	0.66	0.46	1.4	0.66
3	0.75	0.53	1.4	0.76
4	1.05	0.8	1.3	1.14
5	1.2	0.78	1.5	1.11
		average	1.4	

Table 3.3.4.2: Adjustment of CFD air speed simulation results – sensor elevation **1.22 m**

Adjusted CFD data points with an average and constant correction factors of 1.4
Average values for measured data and CFD
Actual and virtual anemometers at elevation 1.20 m

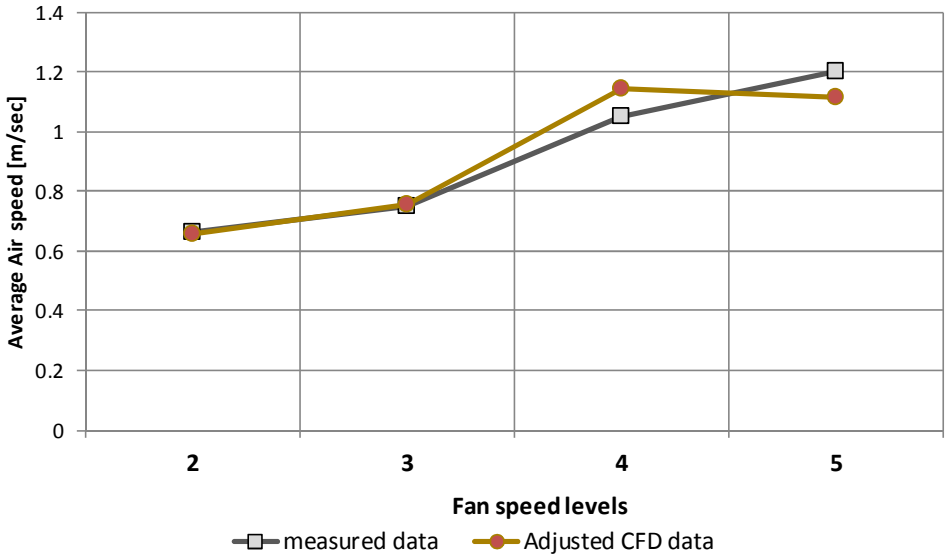


Figure 3.3.4.3: Comparison of ADJUSTED CFD simulation and measured air speeds – at sensor elevation of **1.22 m**

3.4 CFD Simulations and Measurement of Radiant Heat Transfer Without Test Person

Radiant heat loss is the primary physical phenomenon of the comfort enhancing measure with actively cooled radiant panels. Since increased radiant heat loss decreases operating temperature without the need to lower the ambient air temperature energy can be saved for space conditioning.

Radiant heat transfer at the test set-up was simulated with CFD and subsequently measured for data validation. The CFD simulations and measurements were carried without a person sitting inside the tests station. The objective of these test of physical comfort contributing conditions was to validate the CFD simulation approach for thermal performance of the ERDL test set-up.

3.4.1 Methodology of CFD Simulations and Measurements

The rate of radiant heat transfer was investigated with CFD simulations and measured by means of a globe thermometer installed at a center location of the test station.

The CFD simulation determined the radiant heat transfer conditions for a “target” object, which was an inert object of the same dimension as the globe thermometer used in the actual heat transfer tests. The CFD simulation determined the average radiant temperatures that the target object was subjected to by

integrating the radiant temperature over the object surface. Figure 3.4.1.1 shows the "target" object which was placed into the CFD computational domain at the same horizontal and vertical location as the globe thermometer in the measurements.

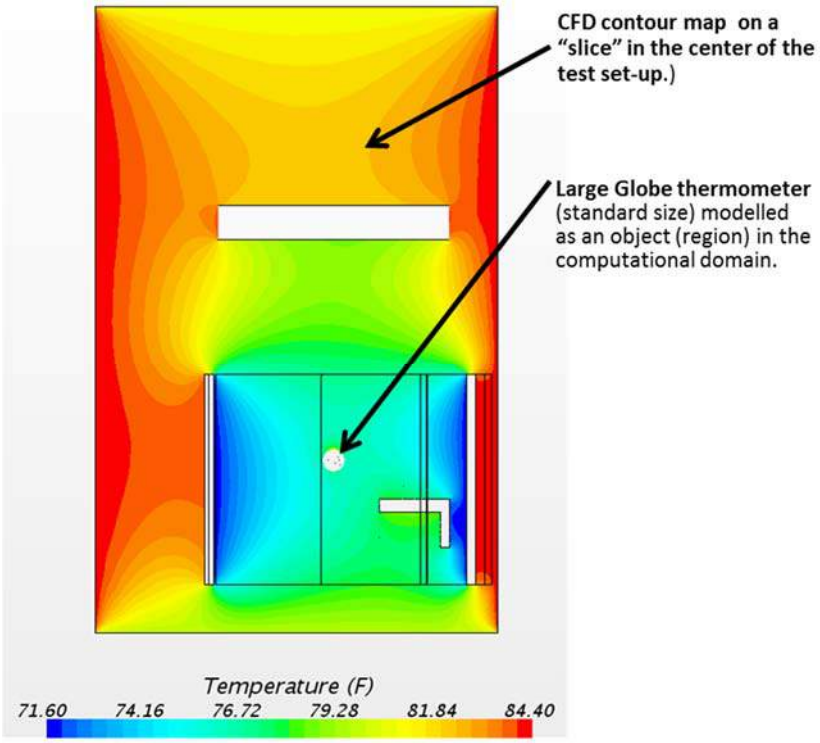


Figure 3.4.1.1:
CFD simulation to detemine the mean radiant temperature

Figures 3.4.1.2 and 3.4.1.3 show the globe thermometer installed at the test set-up. Figure 3.4.1.2 shows the test set-up of globe thermometer which was installed along with the four anemometers for the test series without a person sitting at the test site. Image (A) shows the globe thermometer situated at the center of the test station. Image (B) shows a detail of the globe thermometer installation with one large and one small globe thermometer. The large globe thermometer had standard dimensions of 150 mm and the small a diameter of 50 mm.

The ERDL research team had built several small globe thermometers which were installed at different locations at the test set-up. The small globe thermometers were cost effective and allowed multiple measurements and the use of average measurements allowed more precise temperature assessments. As is known by physical performance, convection over small globe thermometers, affect the measured globe temperature more than for larger globe thermometers. There are standard theoretical adjustments that can be applied to the measurements to compensate for the effect of convective heat transfer to the globe thermometer. The standard ASHRAE adjustment equation was used to calculate the adjustment for the small 50 mm diameter globe thermometer.

In order to validate the theoretical globe thermometer adjustment with experimental data, the two globe thermometers, one small and one large, were used in test measurements and results were compared to the theoretical adjustment. With good data consistency, all globe temperature readings obtained with the small globe thermometer were subsequently adjusted with the theoretical standard correction. Figure 3.4.1.3 shows the infrared (IR) thermometer with which surface temperatures were measured at the test set-up. Surface temperatures of objects and enclosures in clear line-of-sight contribute to the mean radiant temperature.

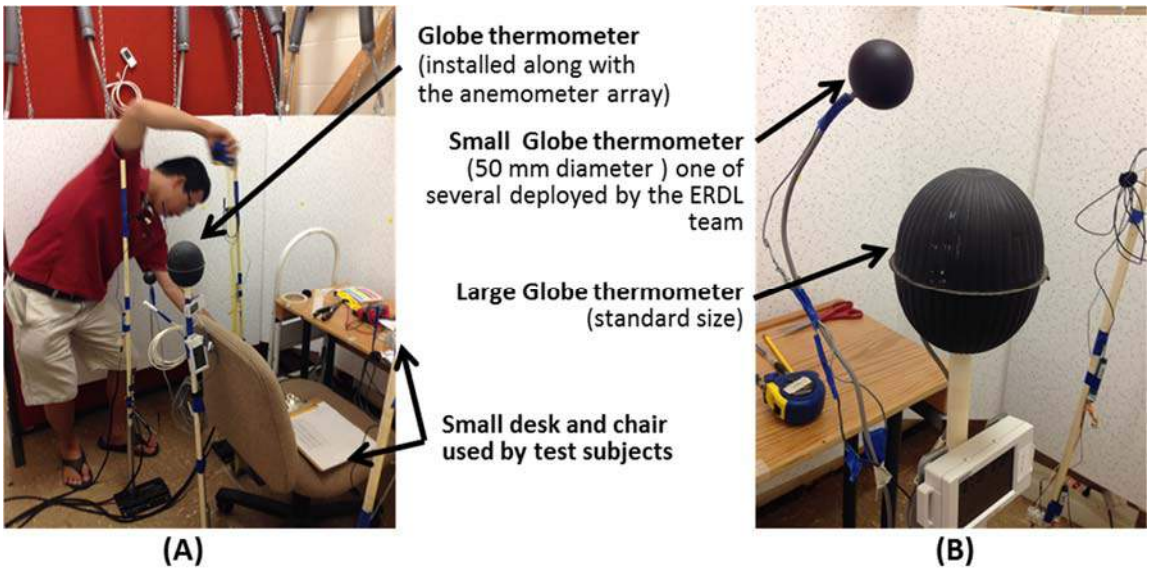


Figure 3.4.1.2: Test set-up with globe thermometer

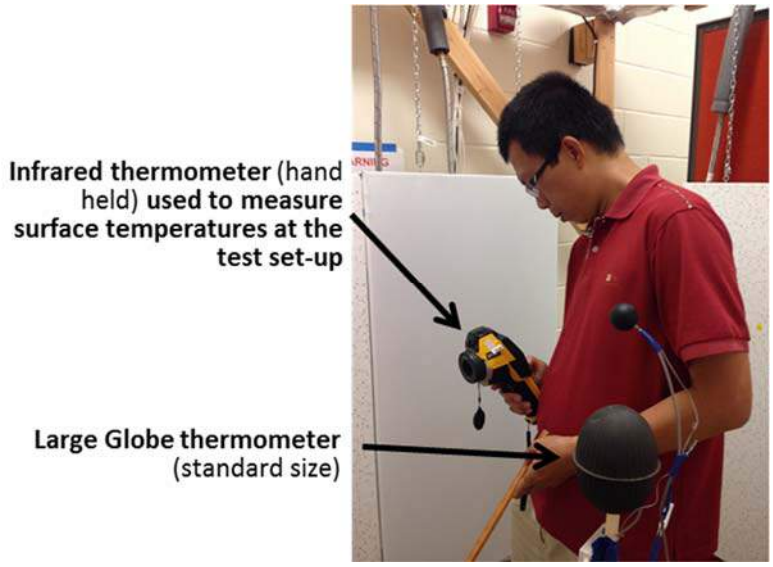


Figure 3.4.1.2: Test set-up with globe thermometer and IR thermometer

3.4.2 Results of Predicted and Measured Temperatures at the Test Site

The results CFD simulations and measured values of temperatures at the test site are presented in Tables 3.4.2.1 and 3.4.2.2, respectively. As was pointed out before the mean radiant temperature was determined by the globe thermometer with the application of a standard correction procedure.

Table 3.4.2.1: Temperatures for scenariosn obtained through CFD simulations

	Simulation		
Scenario ID	Fan speed	Mean Radiant Temperature	Mean Air Temperature
		{°F}	{°F}
A1	*OFF*	76.1	75.1
A2	*OFF*	77.4	77.0
A3	*OFF*	74.9	74.5
A4	*OFF*	75.7	75.8
A5	*OFF*	76.5	76.9
A6	*OFF*	79.9	79.0
A7	*OFF*	76.7	75.6
A8	*OFF*	79.1	78.2
A9	*OFF*	78.8	77.9
A10	*OFF*	82.4	81.7
A11	*OFF*	78.2	77.3
A12	*OFF*	80.0	80.9
A13	2	84.7	84.3
A13B	3	85.0	84.6
A14	4	86.4	85.8
A14B	5	85.5	84.9

Figure 3.4.2.1 shows a comparison between mean radiant temperatures (MRT) obtained by CFD simulations and measurements.

Table 3.4.2.2: Temperatures for scenariosn obtained through measurements

	Measurements						
Scenario ID	Mean Radiant Temperature {F}		Mean Air Temperature {F}		Average Wall Temperature	Average Ceiling Temperature	Average Floor Temperature
	test	control	test	control	{°F}	{°F}	{°F}
A1	78.4	78.4	*NA*	81.0	82.3	79.7	78.9
A2	82.3	85.8	83.2	85.8	84.4	80.8	79.7
A3	77.9	81.1	*NA*	80.9	82.1	79.4	78.9
A4	81.6	86.2	82.5	86.2	84.9	81.3	79.9
A5	79.0	81.4	79.1	81.3	81.4	78.6	78.5
A6	83.4	86.9	84.0	86.9	85.6	82.3	80.5
A7	78.3	81.5	78.5	81.4	81.7	78.8	78.8
A8	82.9	86.8	83.4	86.9	85.7	82.5	80.9
A9	79.2	81.5	79.4	81.4	82.0	79.0	78.7
A10	84.5	87.9	85.1	88.0	86.6	83.2	81.9
A11	79.2	81.4	79.5	81.4	81.4	78.6	79.0
A12	84.3	87.8	84.8	87.9	86.5	83.0	82.2
A13	87.5	87.2	87.7	87.2	85.8	84.3	82.2
A13B	87.8	87.3	87.8	87.1	86.2	84.6	82.2
A14	87.6	87.4	87.7	87.0	86.3	85.4	82.7
A14B	87.5	87.4	87.7	87.9	86.3	85.1	82.5

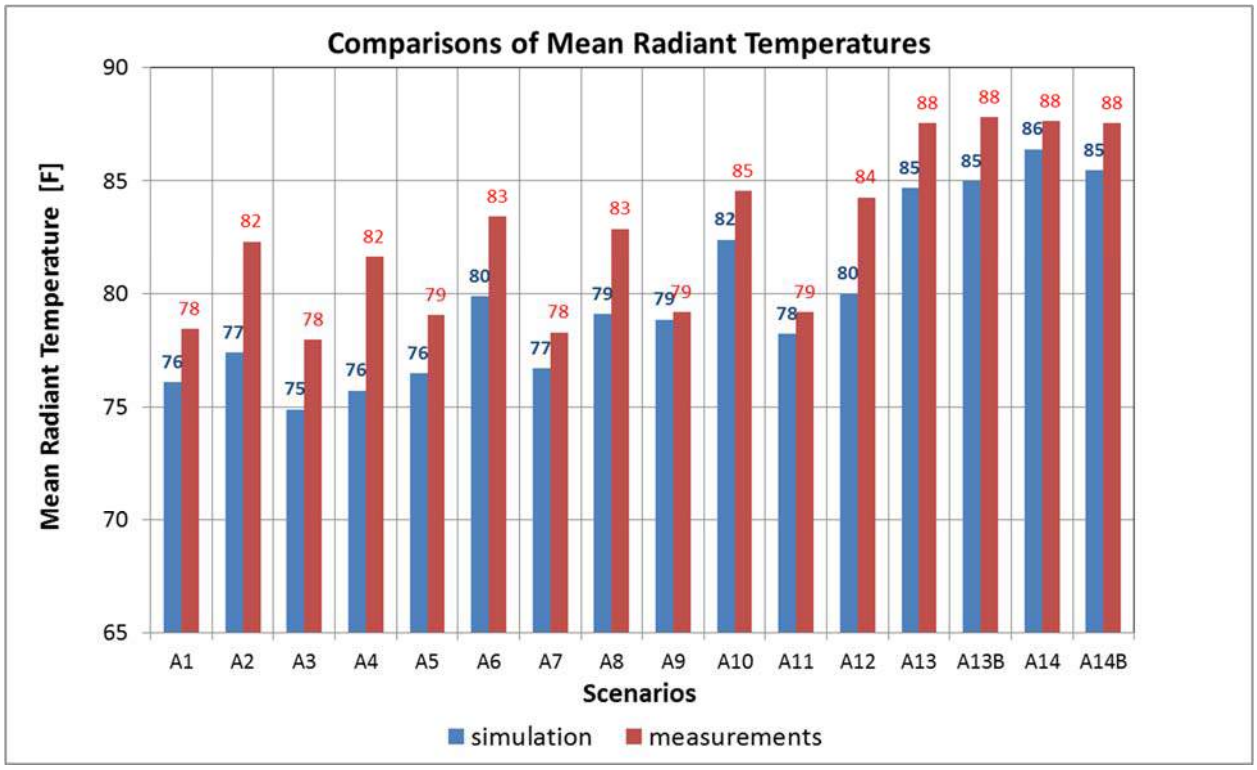


Figure 3.4.2.1: Comparison of MRT values obtained with CFD simulations and measurements

A direct comparison between predicted and measured air and mean radiant temperatures is provided in Figures 3.4.2.2 through 3.4.2.5.

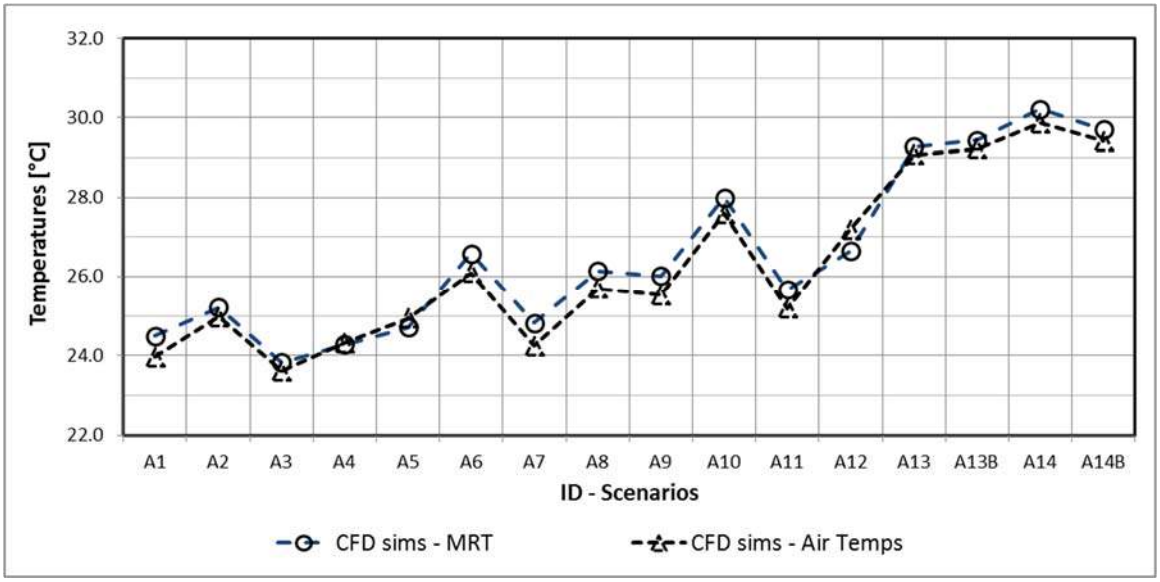


Figure 3.4.2.2: Comparison between CFD simulated and measured air and mean radiant temperatures

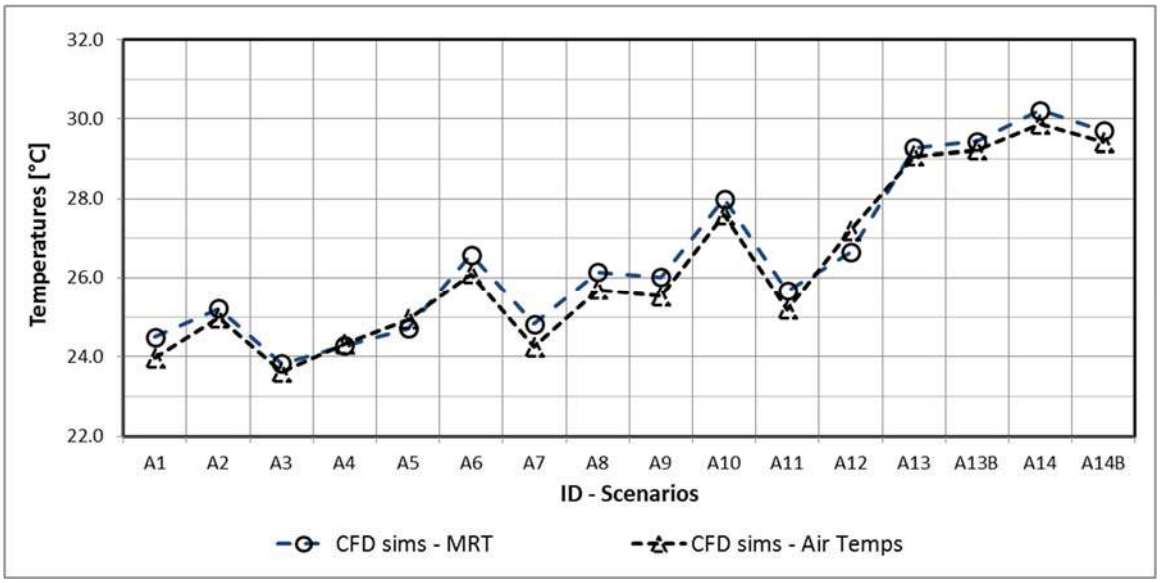


Figure 3.4.2.3: Comparison between CFD simulated air and mean radiant temperatures

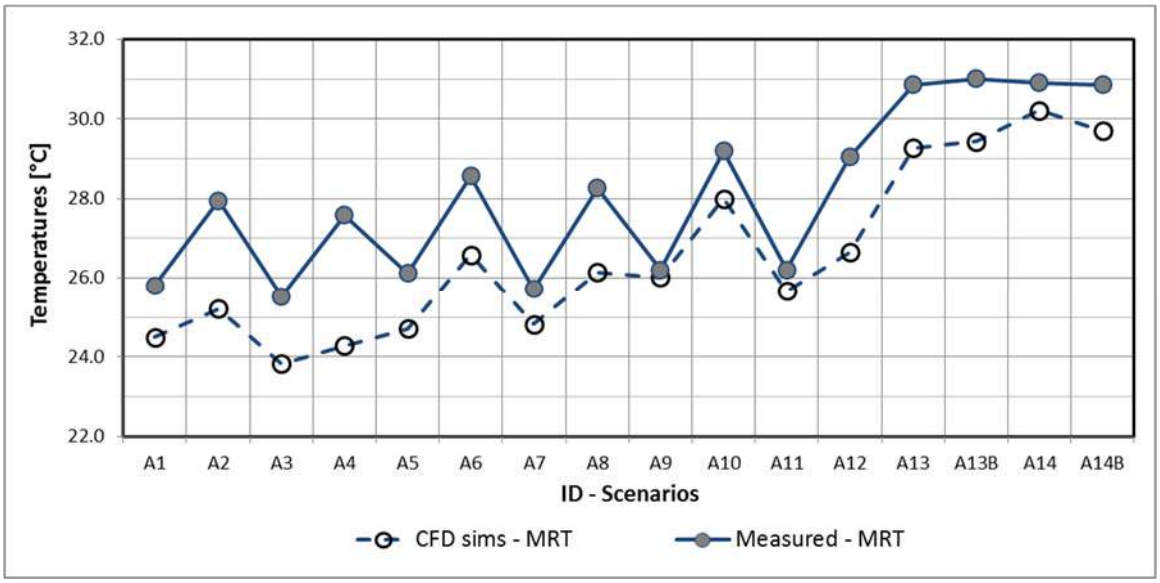


Figure 3.4.2.4: Comparison between CFD simulated and measured mean radiant temperatures

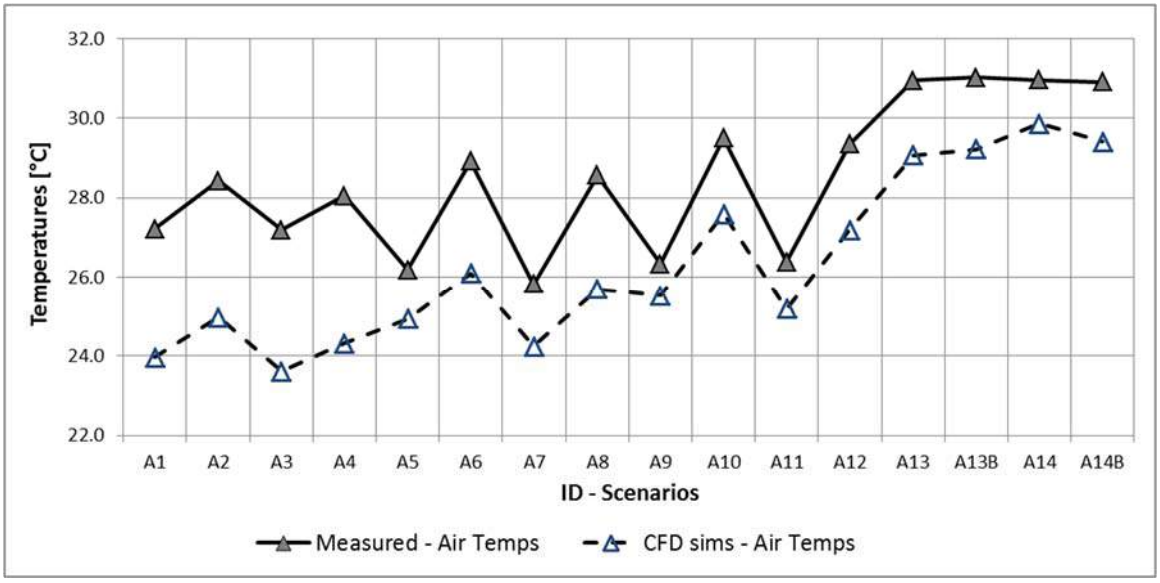


Figure 3.4.2.5: Comparison between CFD simulated and measured air temperatures

3.4.3 Discussion of Results

As shown in Figure 3.4.2.1, the CFD simulation predicted a lower mean radiant temperature than actually measured at the test site.

Figure 3.4.2.2 indicates that the simulated air and mean radiant temperatures for the different "A" scenarios did not differ significantly, while the predicted mean radiant temperatures were either equal of larger than the predicted air temperatures. Figure 3.4.2.3 shows that the measured air and mean radiant temperature also did not differ significantly, however, the mean radiant temperatures were here generally smaller than the air temperatures.

Figure 3.4.3.4 shows that the mean radiant temperatures predicted through simulation are smaller than those measured. Similarly, Figure 3.4.3.5, indicated that the predicted air temperatures are also smaller than the measured temperatures.

Reasons for this data discrepancy cannot be described with the data available.

SECTION 4 - OCCUPANT COMFORT INVESTIGATIONS

This section reports on investigations into increased occupant comfort resulting from the use of comfort enhancing measures. This section presents and discusses result of investigations obtained through tests with human subjects and simulations.

4.1 Comfort Tests with Subjects

The comfort tests were conducted at the ERDL test site over a period of three weeks. A detailed description of the various comfort test procedures is provided in **Appendix E** and of the comfort tests data management in **Appendix F**.

4.1.1 Methodology of Comfort Tests and Surveys

Human Research Preparation and Recruitment

In order to comply with the University of Hawaii regulations, an application was submitted to the internal review board (IRB; Office of Research Compliance, Human Studies Program) to request an exemption from federal regulations pertaining to the protection of human research participants. The team completed an online training required by the IRB. The survey questions were submitted with the application for an exemption to the IRB (see Appendix E for surveys and application). Recruitment of participants was done by word of mouth, posting fliers around the campus and contacting a dozen professors who mentioned the research project to their classes. A ten-dollar gift card was offered as a token of appreciation for the participants.

The Physical Environment for the Comfort Test

Two cubicles were set up in the Hawaiian Institute of Geophysics (HIG) Building, Room 204. Instead of using the ceiling lights installed in the room, lighting was provided by 122-cm (48-inch), 3,800-lumen LED shop lights hung over each desk at height of 152 cm (60”) from floor (76 cm over desk) and along the opposite wall of each cubicle at height of 170 cm (67”). By placing the lights lower than the ceiling fan, a strobing effect of ceiling lights was avoided. The lights were directed at a slight angle toward the wall to reduce glare and provide some indirect light. Room temperature was maintained at a target of 29oC (85oF) using two Vornado ATH1 whole room tower heaters with automatic climate control.

If the relative humidity dropped below 70%, moisture was added by means of steam from an electric kettle. Ventilation was provided by a 12-cm (4.75”) diameter fan installed in the outer wall at a height of 100 cm (8’4”) which provided a ventilation rate of about 1,000 l/m (35 cfm), exceeding the minimum required 570 lpm (20 cfm) ventilation rate specified by ASHRAE 62.1-2013 for an office space occupied by two people. The door to the room was left open 3cm to facilitate the ventilation of the room. Each cubicle was furnished with a small desk, a net-style rolling office chair, and a small potted plant.

The temperature sensors were located so they would not interfere with the participants' movements. The globe thermometer was suspended over the cubicle at a height of 168 cm (66") and the temperature and humidity sensors were hung on the cubicle divider wall at 168 cm (66"). For the test cubicle, this placement was above the panels and was not representative of the conditions the participant experienced while seated in the chair. A further study was conducted to compare the readings from this sensor placement to that which was used in the studies that did not involve human subjects: those sensors had been placed on a stand in the middle of the cubicle at a height of 123 cm (48"). A correction factor was applied to the temperature readings for this study based on this difference.

Description of Treatments

The "baseline or control" cubicle did not have cooling panels nor or fans. This control space served as a "warm" baseline condition. The "test station" cubicle was equipped with actively cooled radiant panels and one ceiling fan. For logistical reasons, the panels were either being cooled for the entire day of tests or cooling was not used at all that day of tests.

The cooling or no cooling treatments were randomly assigned to days during the two and a half weeks the study was run (Aug 26 – Sept 11, 2015). On days when radiant panels were actively cooled, test subjects experienced cooling panels ON without the ceiling fan running, and cooling panels ON with the ceiling fan on setting speed level 2.

The order in which the test subjects experienced tests conditions was randomly assigned to the appointments. On the days that the panels were not cooled, the two comfort test treatments the test subjects experienced in the test cubicle were the ceiling fan speed levels 2 and 3, which provide average air velocities of 1.05 m/s (207 fpm) and 1.14 m/s (224 fps), respectively. The order of these treatments was randomly assigned to the appointment periods. See Table 4.1.1.1 for the test matrix.

Scenario	Survey	Treatment	Combination	Order
1	1	baseline	1	1
1	2	fan 2	1	1
1	3	fan 3	1	1
2	1	baseline	1	2
2	2	fan 3	1	2
2	3	fan 2	1	2
3	1	baseline	2	1
3	2	panels	2	1
3	3	panels + fan 2	2	1
4	1	baseline	2	2
4	2	panels + fan 2	2	2
4	3	panels	2	2

Table 4.1.1.1: Test matrix

Sequence of activities of test subjects

The sequence of activities of test subjects is described in the following and summarized in Table 4.1.1.2.

Table 4.1.1.2: Sequence of activities by test subjects

Activity No.	Location of Activity	Description of activity	Duration min	Timeline min
1	Team office (HIG 205)	Subjects arrive at team office	0	0
2	Team office (HIG 205)	Subjects acclimate for 10 min; during that 10 min the get introduction and start fill our survey form	10	10
3	Control station	Subject stay at control station for baseline conditions; engages in directed activities	12	22
4	Test station	Subject moves from comfort station to test station; stays at test station during test scenario ("treatment"), subject engages in directed activities	12	34
5	Control station	Holding time at the control station while the test conditions ("treatments") are changed in the test station	2	36
6	Test station	Subject moves from comfort station to test station; stays at test station during test scenario ("treatment"), subject engages in directed activities	12	48
7	Team office (HIG 205)	Test subject is checked out and completes filling out the survey forms	2	50
		Total length of test subject at the tests site	**50**	

Detailed Description of sequence of activities of test subjects during the test runs:

Activity No. 1 – Arriving at the test site: The test subjects arrived at the test site and were directed to the team office which is located in the room adjacent to the room with the test set-up. The team office was not air conditioned but had appropriate thermal conditions. An important indicator of how test subjects experience thermal conditions in the test facility was the level of physical activity and therefore metabolic rate prior to arrival at the test site. On the way to the site test subjects had different means of transportation. Traveling short distances, walking in the shade or through air conditioning, and using elevators did not result in high metabolic rates and heat gain. On the opposite side, walking fast over longer distances (while being on a challenging class schedule),

walking over un-shaded paths and climbing stairs and slopes can significantly increase metabolic rate and heat gain.

Activity No. 2 – Acclimating and Introduction to test Environment: The test subjects arrived at the team office*, next* to the test facility (HIG Room 205) and spent ten minutes in this room. The period of 10 minutes *was* intended as a "cool-off period", since the test subjects had different pre-test metabolic rates and had experienced different heat gains. The acclimation period ensured that test subjects enter the control and test station for the tests with similar pre-test metabolic rates.

During this initial 10 minutes the test subject also signed a consent form, filled out a basic survey form with an identifying test ID and received an introduction of the test procedure. They were offered drinking water and an opportunity to use the restroom.

Activity No. 3 – Baseline tests at the Control station: The test subjects were escorted to the control station (baseline cubicle) in room HIG 204. The test subjects were instructed to only engage in sedentary activities during tests, including sitting quietly, reading or working on their computer. At the end of this activity they were asked to complete the appropriate section of the survey.

Activity No. 4 – First comfort test scenario at the Test Station: The test subjects were asked to move from the control station to the adjacent cubicle, e.g. the test station, where they experienced the first test scenario (e.g. treatment) for that day of testing. There were two days of tests with two different combinations of two test scenarios each. The test subjects were instructed to only engage in sedentary activities during tests, including sitting quietly, reading or working on their computer. At the end of this activity the subjects were asked to complete the appropriate section of the survey.

Activity No. 5 – Brief holding time between comfort tests: While the test conditions were changed from one test scenario to the next one at the test station, the test subjects were asked to quietly wait in the control station. The holding period was short and did not surpass the two minutes. When a change in ceiling fan speed level was made, the two minutes served as a transition time to stabilize the air flow from the ceiling fan when the speed level was changed. At the end of the holding period, the test subjects were asked to again sit in the test section.

Activity No. 6 – Second comfort test scenario at the Test Station: The test subjects were asked to move from the control station to the adjacent cubicle, e.g. the test station, where they experienced the second test scenario (e.g. treatment) for that day of testing. There were two days of tests with two different combinations of two test scenarios each. The test subjects were instructed to only engage in sedentary activities during tests, including sitting quietly, reading or working on their computer. At the end of this activity the subjects were asked to complete the appropriate section of the survey.

Activity No. 7 – Completion and checking out: After the completion of the second comfort tests series of the day, the tests subject returned to the adjacent office (HIG Room 205) and were allowed to ask questions. They were given a $10 gift card as a gesture of appreciation and asked to not discuss the research with others as to avoid creating any bias in potential volunteer participants.

Data acquisition and types of sensors used:

Globe temperature was measured with an Onset TMC20-HD temperature probe incased in a 50-mm (~1.8") celluloid globe, spray-painted matt black. Globe thermometers were suspended from a wire at a height of 168 cm (66") above the desk chair and data was logged using an Onset Hobo UX120-0006M device. Air temperature and humidity was measured with an Onset Hobo UX100-023 logger hung on a partition wall of each cubicle (for the cubicle with panels, it was hung on the partition wall, above and behind the cooling panels) at a height of 168 cm (66"). Outdoor temperature and humidity was measured outside the room out of direct sunlight and data logged by an Onset Hobo UX100-023 device. Carbon dioxide level in the room was monitored with a Telaire 7001 and the signal was acquired by an Onset HOBO UX120-006M. This was located in the baseline cubicle, which was furthest from the ventilation fan and the door. These data were logged in 1-min intervals except for outdoor temperature and humidity which was logged in 15-min intervals.

Flowrate of chilled water supply was through each cooling panel was measured with Grundfos VFS 1-20 vortex flow sensors and signals were acquired with a National Instruments UBB-6341 USB device and a laptop equipped with National Instruments Signal Express software. Scaling and calibration was entered into the software and data was logged in 30-sec intervals. Data processing was completed using Python scripts to insert data into a PostgreSQL database (see Appendix G for data management information and scripts).

Data Management in Database

Survey questions were completed on paper and the responses were manually entered into an electronic spreadsheet. All data was uploaded to a database for subsequent analysis. Average air temperature, globe temperature, and relative humidity were calculated for the 10-min period during which the test subjects were located there before completing the comfort survey. These data were added to a table with the survey responses. (**Appendix F** presents data scripts and other data management procedures).

4.1.2. Results of Comfort Tests and Surveys

This section presents the results of the comfort tests with test subjects.

Outdoor Environmental Conditions: The summer 2015 was a particularly hot summer in Honolulu, so participants of the comfort study were generally acclimated to hot weather conditions. For eight days preceding the start of the study, the daily outdoor high temperature ranged from 27.7 to 31.5 °C (81.9 to 88.6oF) and the relative humidity ranged from 58.6 to 93.4% over that period. Figure 4.1.2.1 shows the prevailing outdoor temperatures and relative humidity during the eight-day period. As a comparison, during the two and a half weeks the comfort tests, the daily high temperature ranged from 27.6 to 31.8oC (81.7 to 89.2oF) and the relative humidity ranged from 55.6 to 90.5%.

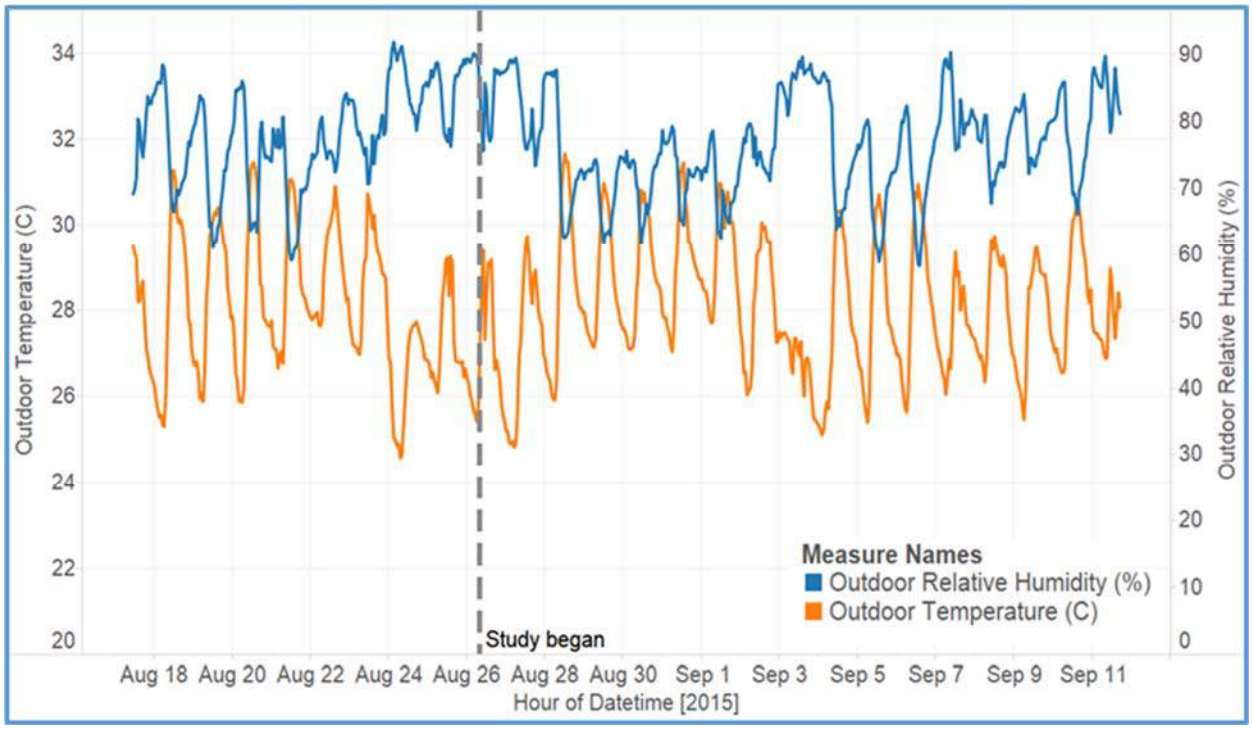


Figure 4.1.2.1: Outdoor temperature (C) and relative humidity (%) before and during the study

Demographic Information of Test Subjects Forty test subjects were recruited and each subject completed three comfort surveys. Of the 40, 26 were female and 14 were male, 25 were under the age of 30, 12 were between 31 and 50, and three were over 50 years old. Once half of the participants experienced the test scenarios (e.g. comfort treatments) with panels being cooled and half without the panels cooled.

Prevailing indoor environmental conditions: During the comfort tests the globe and dry bulb thermometers were installed at distance from center of the test and comfort stations, where the test subjects were sitting during the test runs. These locations of thermometers were selected in order not to interfere with the test subjects. There was a concern that these off-center placements of thermometers could result in potential deviations from thermometers reading at the center of the test and comfort stations. Upon completion of the comfort tests runs selected tests scenarios (e.g. comfort treatments) were run again, but without human subjects present in order to allow data comparisons. The resulting temperatures of both off-center locations were correlated to those gathered in the center of the control station and test station at a height of 122 cm (48”). It was found that only the test scenarios with cooling panels showed differences in temperature between the sensor locations, so only these temperatures were adjusted with a correction factor. Table 4.1.2.1 shows the average and range of environmental conditions participants experienced in the different treatments (with applicable correction factors applied).

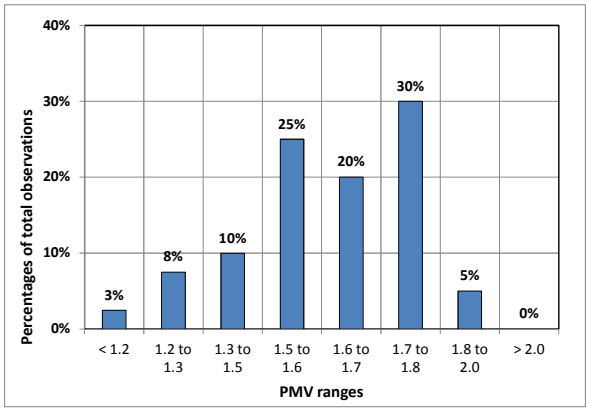
Table 4.1.2.1: Average, minimum and maximum indoor environmental conditions for various test scenarios

	Treatment				
	Baseline	Fan 2	Fan 3	Panels	Panels + Fan 2
Relative Humidity Avg (%)	69.1	73.0	72.7	75.5	75.8
RH Min (%)	63.5	68.6	68.3	71.9	72.0
RH Max (%)	75.4	76.7	76.7	78.7	78.8
Air Temperature Avg °C (°F)	29.8 (85.7)	29.6 (85.2)	29.6 (85.4)	27.8 (82.0)	28.5 (83.4)
Temperature Min °C (°F)	29.2 (84.6)	29.0 (84.2)	29.3 (84.8)	27.2 (81.0)	28.0 (82.4)
Temperature Max °C (°F)	30.7 (87.2)	29.9 (85.9)	30.0 (86.0)	28.3 (83.0)	29.4 (84.9)
Globe Temperature Avg °C (°F)	29.3 (84.7)	29.6 (85.3)	29.6 (85.3)	28.7 (83.7)	29.2 (84.6)
Globe Temp Min °C (°F)	28.4 (83.2)	29.3 (84.8)	29.3 (84.8)	27.9 (82.2)	28.4 (83.2)
Globe Temp F Max °C (°F)	30.0 (85.9)	30.0 (86.0)	30.0 (86.0)	29.6 (85.3)	30.0 (86.0)
Air Velocity Avg (m/s)	0.00	1.05	1.14	0.00	1.05
CO_2 Avg (ppm)	418.7	468.9	466.8	450.5	435.6
CO_2 Min (ppm)	321.5	321.6	321.6	331.4	331.4
CO_2 Max (ppm)	589.7	574.7	580.6	519.0	525.0

Presentation of results of comfort tests: For the four comfort test scenarios and the baseline condition, a range of parameters was measured and obtained through the surveys. These parameters were used to quantify the level of comfort experienced by the test subjects. The detailed presentation of results is presented in **Appendix G**. Selected results are summarized in Table 4.1.2.2 and Figures 4.1.2.2 through 4.1.2.10. These figures allow a direct comparison of average values between the four tests scenarios and the baseline case. The frequency distribution of selected parameters provides an indication of the data spread.

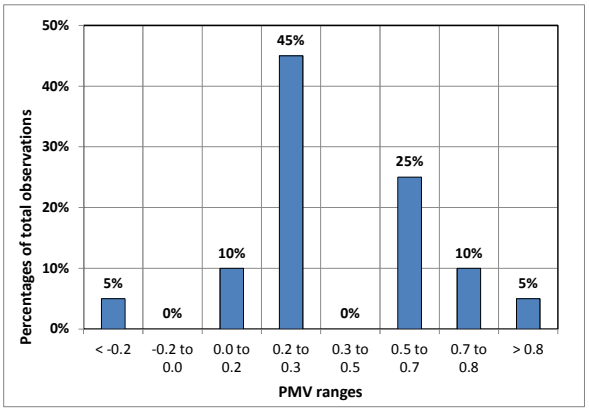
Table 4.1.2.2: Results of the comfort tests

Averages of values:		Baseline - Control Tests	Test with Fan at Level 2	Test with Fan at Level 3	Test with Radiant Panels NO Fan	Test with Radiant Panels and Fans at Level 2
PMV	[-]	1.62	0.37	0.35	1.18	0.27
Temperature perception WARMER than or EQUAL to PMV prediction	[%]	33%	35%	15%	10%	25%
Temperature perception COLDER than PMV predicti	[%]	68%	65%	85%	90%	75%
Percentage of conforming general comfort (PPD)	[%]	0%	60%	60%	5%	55%
Percentage of NON-conforming general comfort (PP	[%]	100%	40%	40%	95%	45%
Thermal sensation value >>>	[-]	1.40	-0.10	-0.55	0.15	-0.50
description >>>>		Closer to Slightly warm than Warm	Closer to Neutral than Slightly cool	Closer to Neutral than Slightly cool	Closer to Neutral than Slightly warm	Closer to Neutral than Slightly cool
Thermal acceptance value >>>	[-]	0.40	1.95	2.20	1.25	2.00
description >>>>		Closer to Neutral than Slightly acceptable	Closer to Moderately acceptable than Slightly acceptable	Closer to Moderately acceptable than Highly acceptable	Closer to Slightly acceptable than Moderately acceptable	Closer to Moderately acceptable than Moderately acceptable
Air movement acceptance value >>>	[-]	-0.10	1.60	1.65	0.20	1.80
description >>>>		Closer to Neutral than Slightly unacceptable	Closer to Moderately acceptable than Slightly acceptable	Closer to Moderately acceptable than Slightly acceptable	Closer to Neutral than Slightly acceptable	Closer to Moderately acceptable than Slightly acceptable
Air movement preference value >>>	[-]	0.90	0.20	-0.10	0.90	0.05
description >>>>		Closer to Want MORE air movement than Want No change	Closer to Want No change than Want MORE air movement	Closer to Want No change than Want LESS air movement	Closer to Want MORE air movement than Want No change	Closer to Want No change than Want MORE air movement
Numerical assessment of adaptive comfort:						
Conformant with adaptive comfort 80% criterion	[%]	100%	100%	100%	100%	100%
NOT Conformant with adaptive comfort 80% criterion	[%]	0%	0%	0%	0%	0%
All values are averages:						
Middle (e.g. expected) value of comfort standard	°C	26.5	26.6	26.6	26.5	26.5
Upper limit WITHOUT correction for air motion:	°C	30.0	30.1	30.1	30.0	30.0
Upper limit WITH correction for air motion:	°C	30.1	32.1	32.2	30.0	32.0
Correction of upper limit due to air movement	°C	No correction	2.0	2.1	No correction	2.0
Applicable upper limit	°C	30.1	32.1	32.2	30.0	32.0
Operative temperature	°C	29.6	29.6	29.6	28.2	30.1
Absolute deviation from middle	°C	3.0	3.1	3.0	1.7	3.6
Percentage of deviation from applicable upper lim	[%]	85%	56%	53%	50%	65%



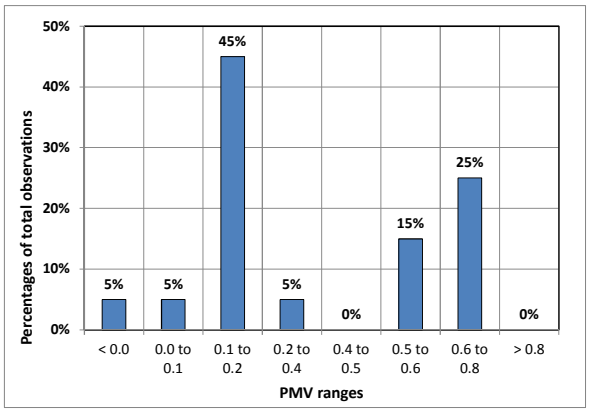
Baseline - Control Tests:

Average PMV: 1.62



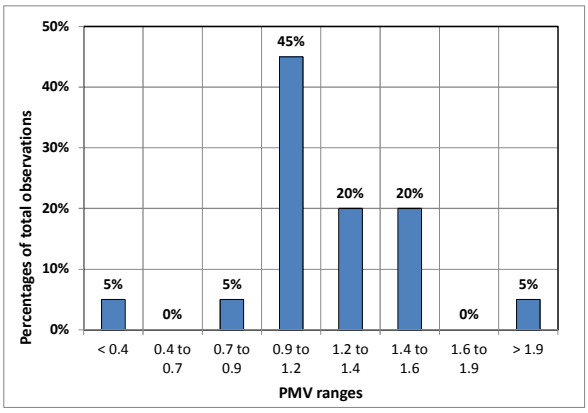
Test with Fan at Level 2

Average PMV: 0.37



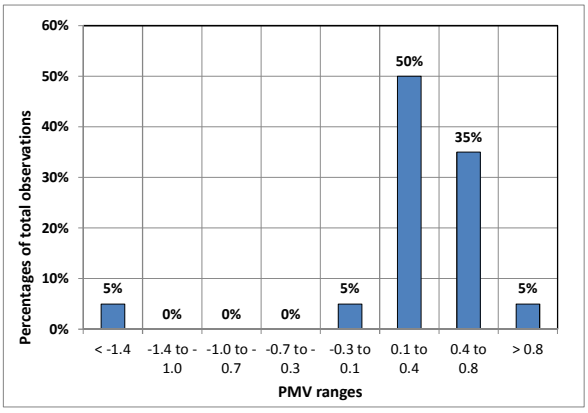
Test with Fan at Level 3

Average PMV: 0.35



Test with Radiant Panels NO Fan

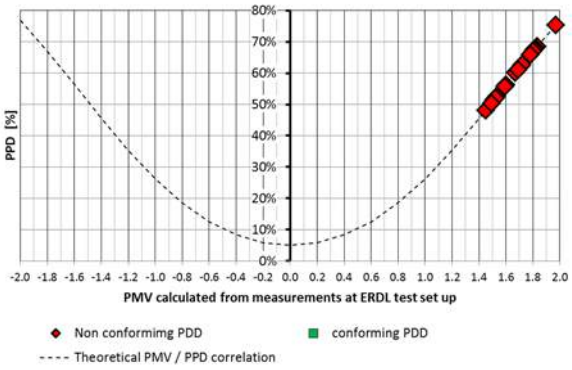
Average PMV: 1.18



Test with Radiant Panels and Fans at Level 2

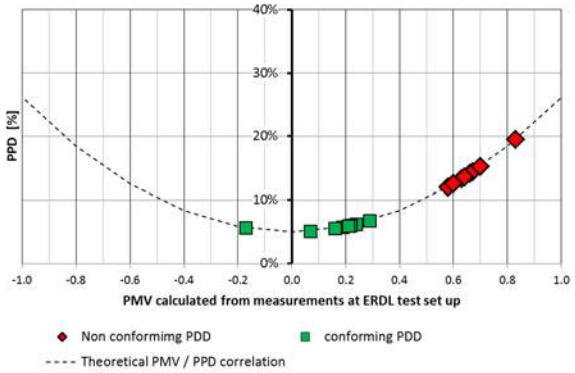
Average PMV: 0.27

Figure 4.1.2.2: PMV results of all test scenarios



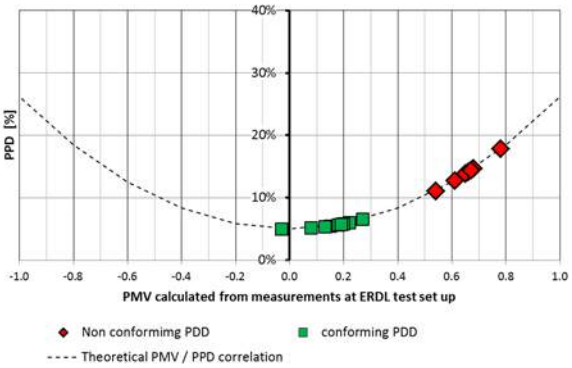
Baseline - Control Tests:

% PPD conforming general comfort	0%
% PPD NON-conforming general comfort	100%



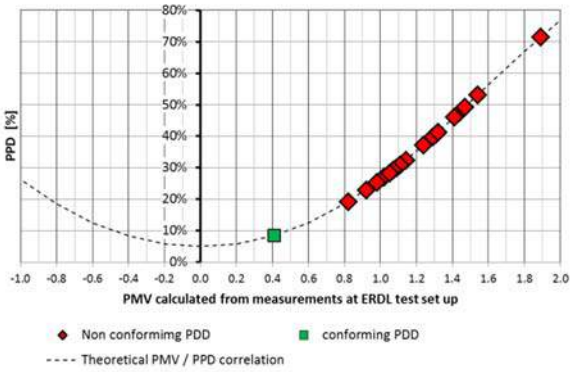
Test with Fan at Level 2

% conforming general comfort	60%
% NON-conforming general comfort	40%



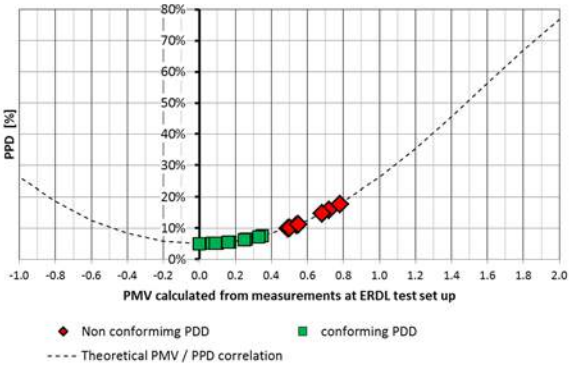
Test with Fan at Level 3

% conforming general comfort	60%
% NON-conforming general comfort	40%



Test with Radiant Panels NO Fan

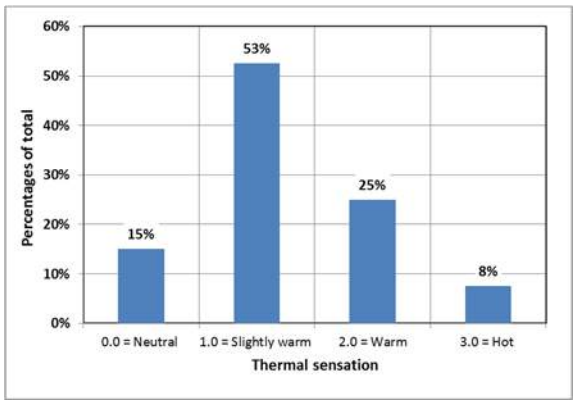
% conforming general comfort	5%
% NON-conforming general comfort	95%



Test with Radiant Panels and Fans at Level 2

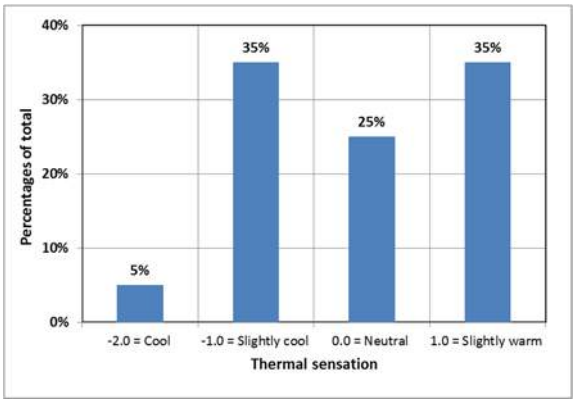
% conforming general comfort	
% NON-conforming general comfort	

Figure 4.1.2.3: PMV and PPD results of all test scenarios



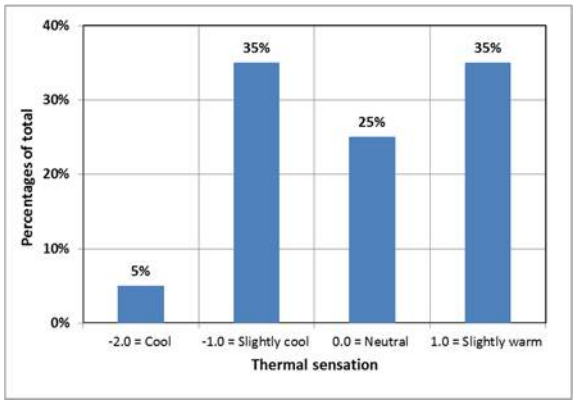
Baseline - Control Tests:

Average Thermal Sensation = 1.4



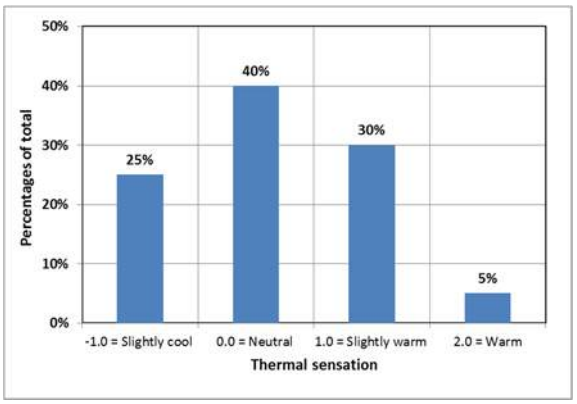
Test with Fan at Level 2

Average Thermal Sensation = - 0.1



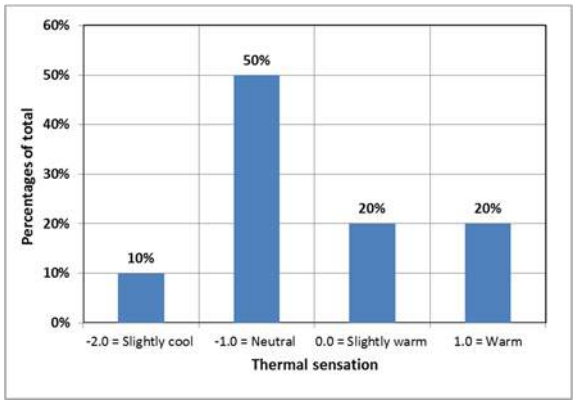
Test with Fan at Level 3

Average Thermal Sensation = - 0.55



Test with Radiant Panels NO Fan

Average Thermal Sensation = 1.25



Test with Radiant Panels and Fans at Level 2

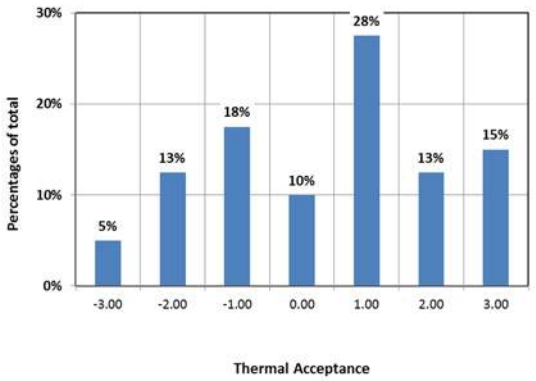
Average Thermal Sensation = - 0.50

Scales for Thermal sensation:

Thermal sensation	Value
Hot	3
Warm	2
Slightly warm	1
Neutral	0
Slightly cool	-1
Cool	-2
Cold	-3

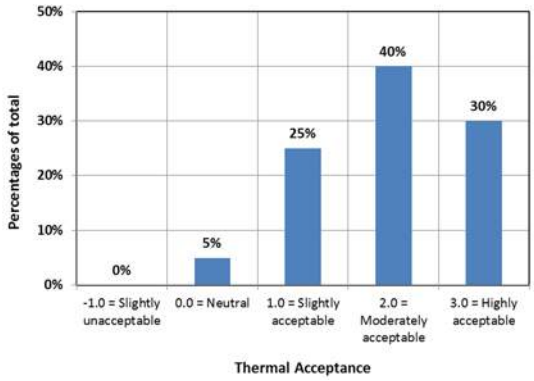
Thermal sensation

Figure 4.1.2.4: Thermal Sensation results of all test scenarios



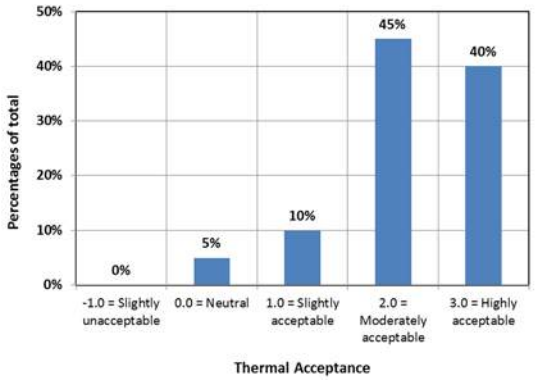
Baseline - Control Tests:

Average Thermal Acceptance = - 0.1



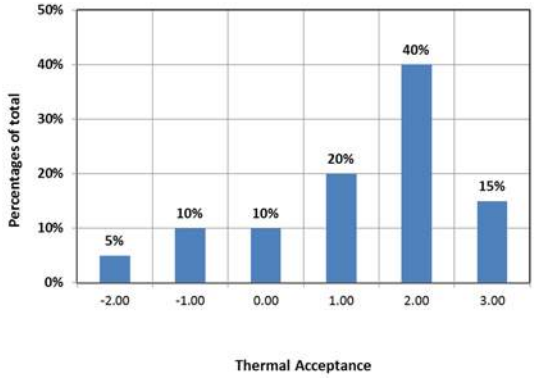
Test with Fan at Level 2

Average Thermal Acceptance = 1.95



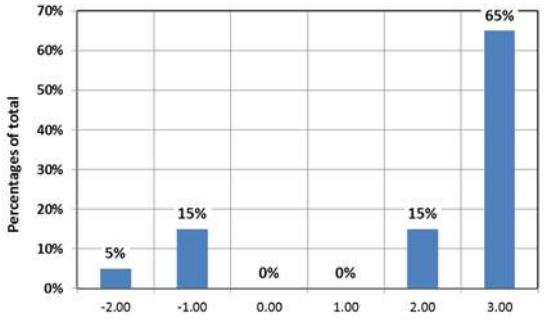
Test with Fan at Level 3

Average Thermal Acceptance = 2.20



Test with Radiant Panels NO Fan

Average Thermal Acceptance = 1.25



Test with Radiant Panels and Fans at Level 2

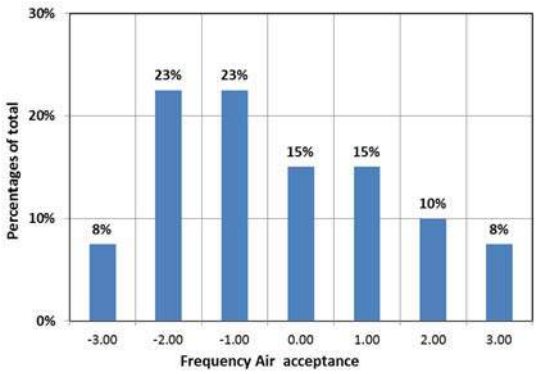
Average Thermal Acceptance = 2.0

Scales for Thermal sensation:

Thermal Acceptance	Value
Highly acceptable	3
Moderately acceptable	2
Slightly acceptable	1
Neutral	0
Slightly unacceptable	-1
Moderately unacceptable	-2
Highly unacceptable	-3

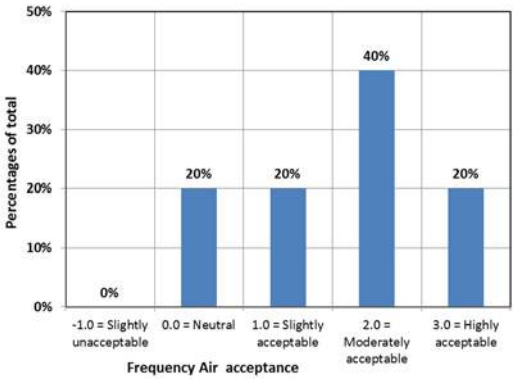
Thermal Acceptance

Figure 4.1.2.5: Thermal Acceptance results of all test scenarios



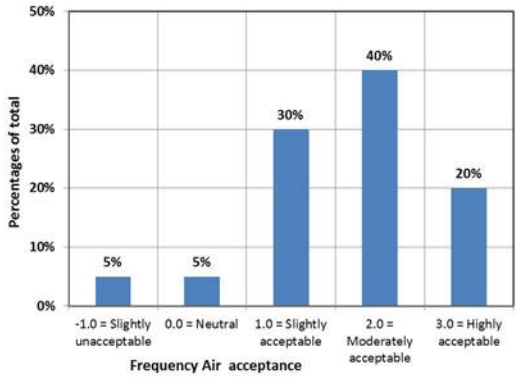
Baseline - Control Tests:

Average Air movement Acceptance = - 0.1



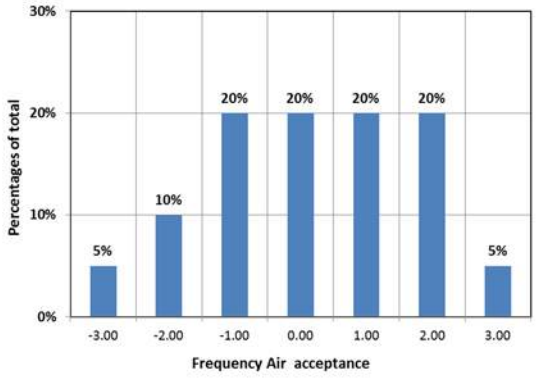
Test with Fan at Level 2

Average Air movement Acceptance = 1.60



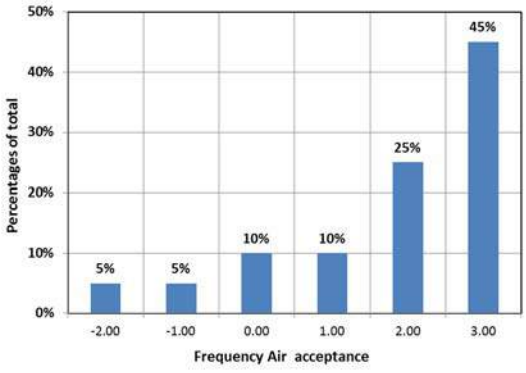
Test with Fan at Level 3

Average Air movement Acceptance = 1.65



Test with Radiant Panels NO Fan

Average Air movement Acceptance = 0.2



Test with Radiant Panels and Fans at Level 2

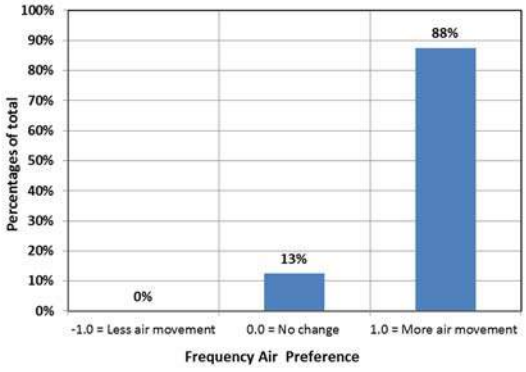
Average Air movement Acceptance = 1.8

Scales for Thermal sensation:

Air Movement Acceptance	Value
Highly acceptable	3
Moderately acceptable	2
Slightly acceptable	1
Neutral	0
Slightly unacceptable	-1
Moderately unacceptable	-2
Highly unacceptable	-3

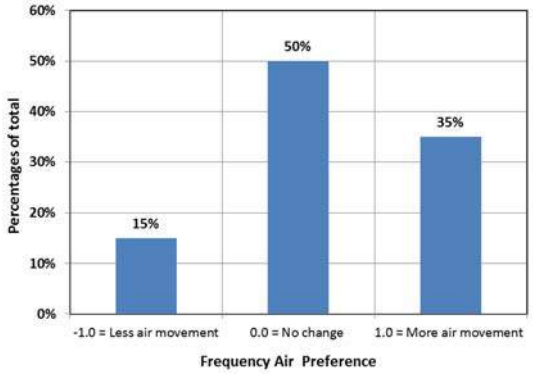
Air movement Acceptance

Figure 4.1.2.5: Thermal Acceptance results of all test scenarios



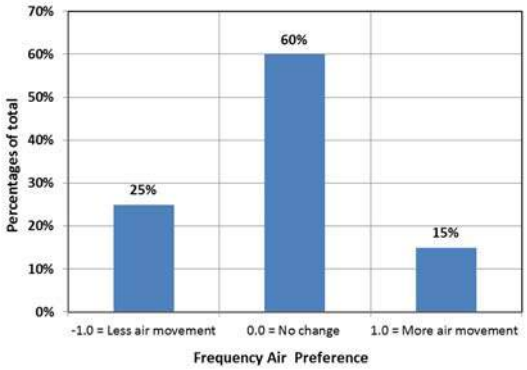
Baseline - Control Tests:

Average Air movement Preference= - 0.1



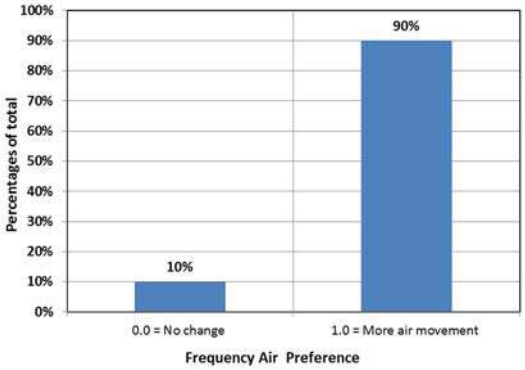
Test with Fan at Level 2

Average Air movement Preference= 0.2



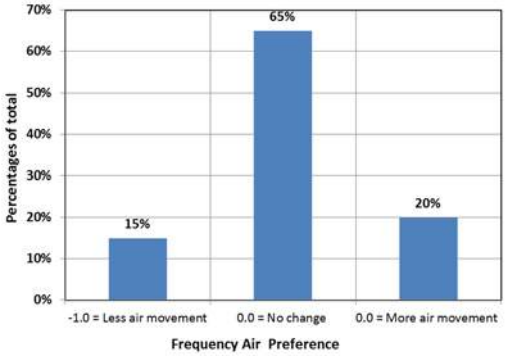
Test with Fan at Level 3

Average Air movement Preference= -0.1



Test with Radiant Panels NO Fan

Average Air movement Preference= 0.9



Test with Radiant Panels and Fans at Level 2

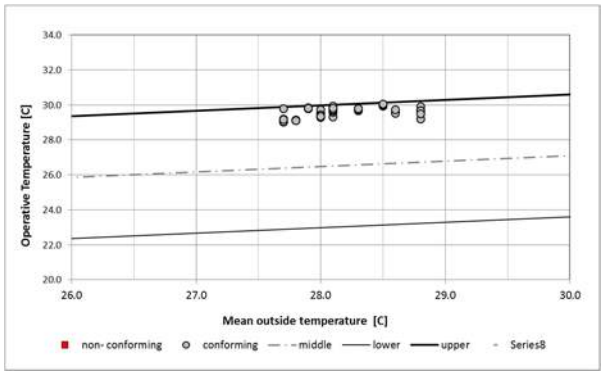
Average Air movement Preference= 0.1

Scales for Air Movement Preference:

Air movement Preference	Value
Prefer More air movement	1
Prefer No change	0
Prefer Less air movement	-1

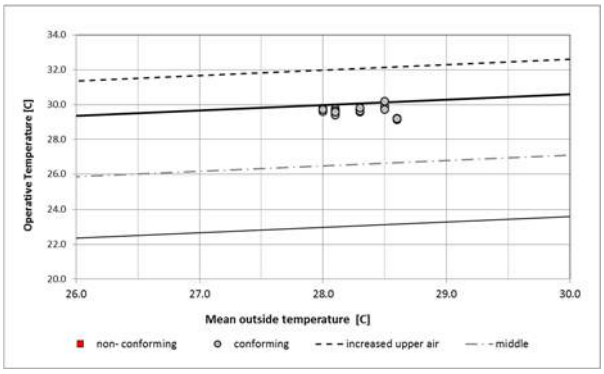
Air movement Preference

Figure 4.1.2.6: Thermal Acceptance results of all test scenarios



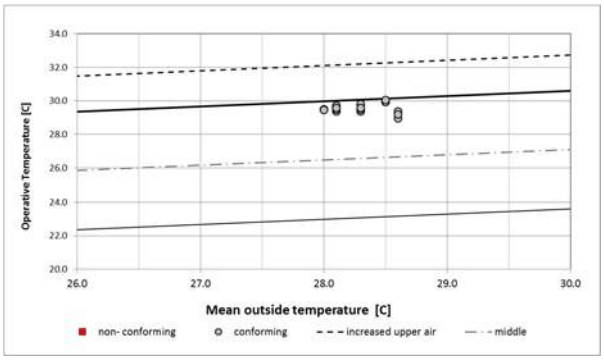
Baseline - Control Tests:

Adaptive comfort



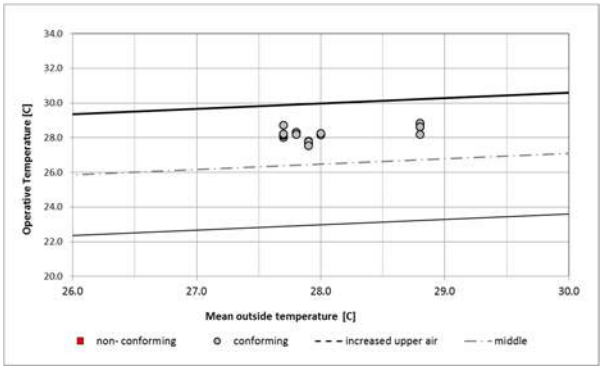
Test with Fan at Level 2

Adaptive comfort



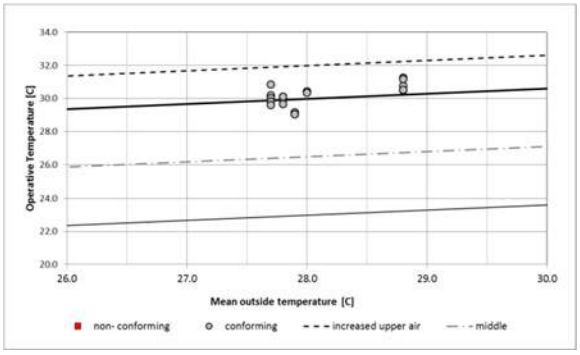
Test with Fan at Level 3

Adaptive comfort



Test with Radiant Panels NO Fan

Adaptive comfort



Test with Radiant Panels and Fans at Level 2

Adaptive comfort

Adaptive comfort

Figure 4.1.2.7: Summary of adaptive comfort plots for all test scenarios

Figures 4.1.2.8 through 4.1.2.11 show the definition of adaptive comfier parameters. Figures 4.1.2.12 through shows the result of applying the parameters.

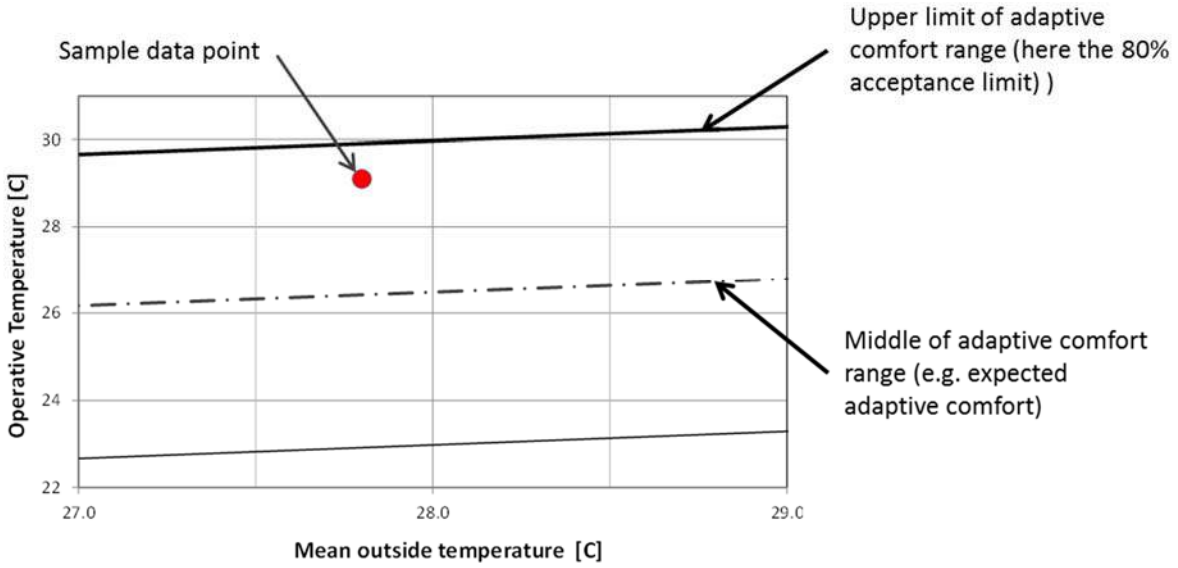


Figure 4.1.2.8: Adaptive comfort definition with air movement smaller than or equal to 0.3 m/s

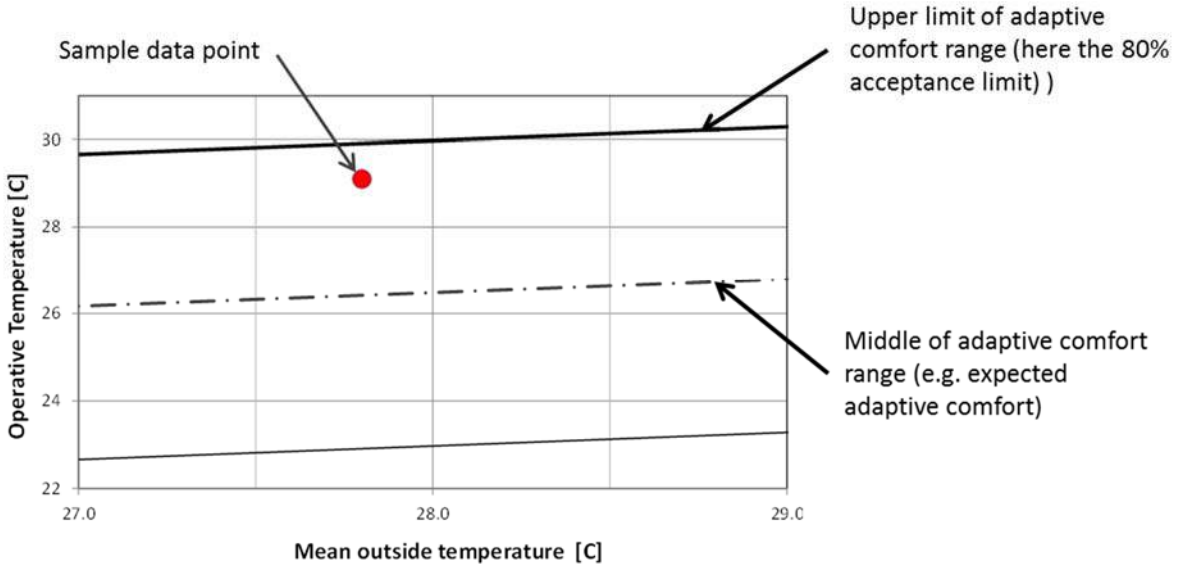
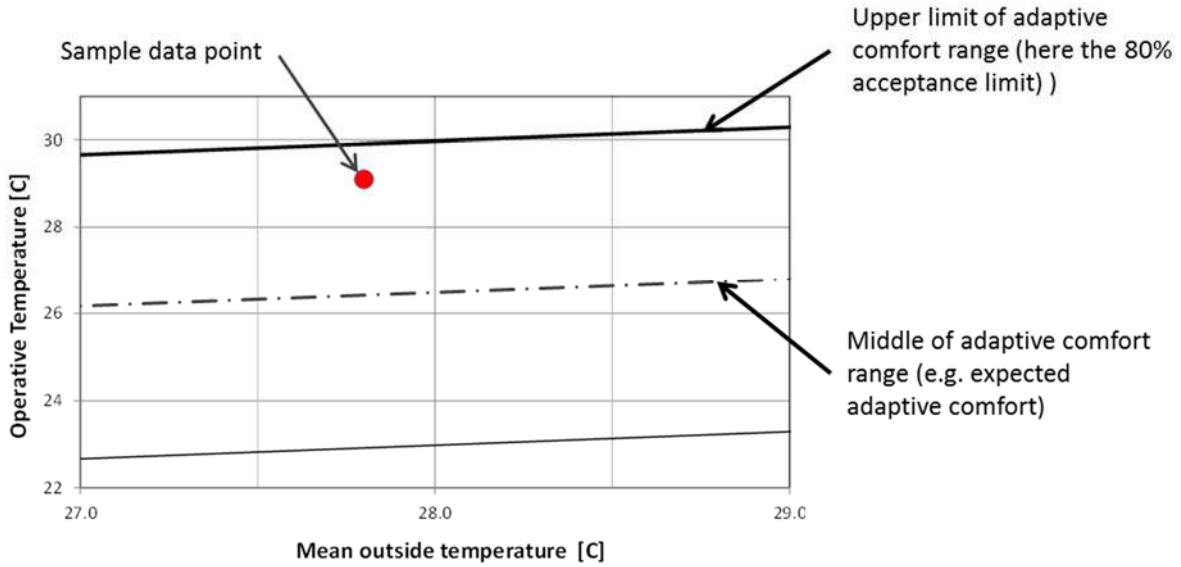
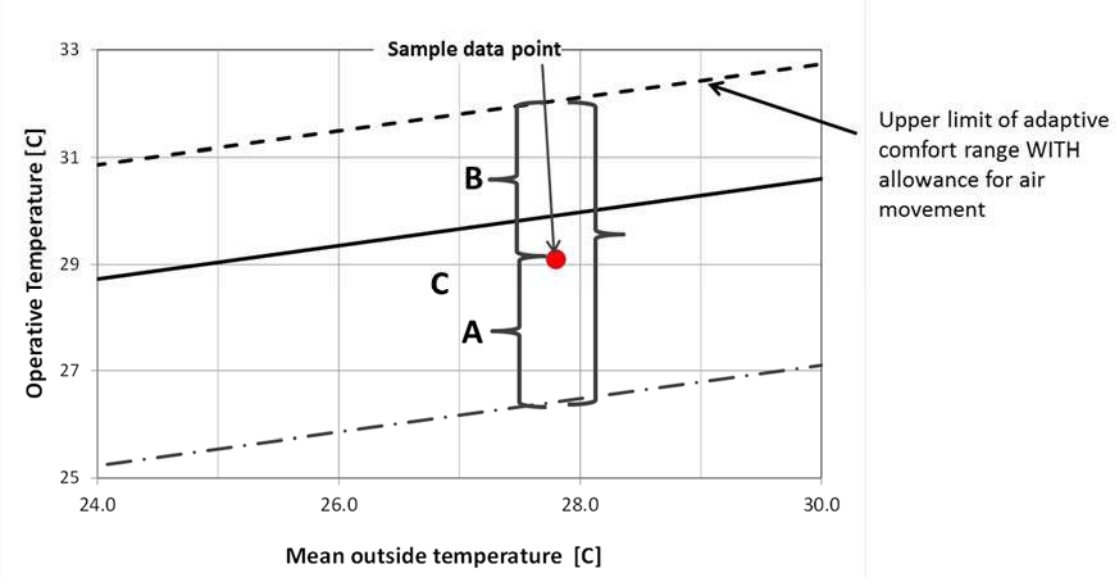


Figure 4.1.2.9: Adaptive comfort definition with air movement larger than 0.3 m/s and therefore with an allowance for air movement



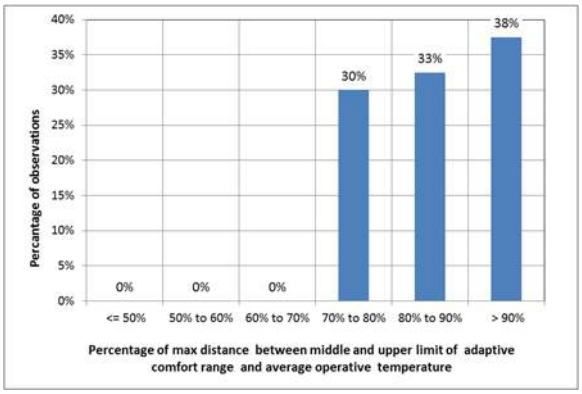
A = Deviation of operative temperature from middle of adaptive comfort range (in °C)
B = Approach of operative temperature to upper comfort range (in °C)
C = Distance between upper limit of adaptive comfort range and middle of range (in °C)

Figure 4.1.2.10: Percentage of deviation of operative temperature from middle of range relative to distance of upper limit to middle of comfort range A/C (in %)



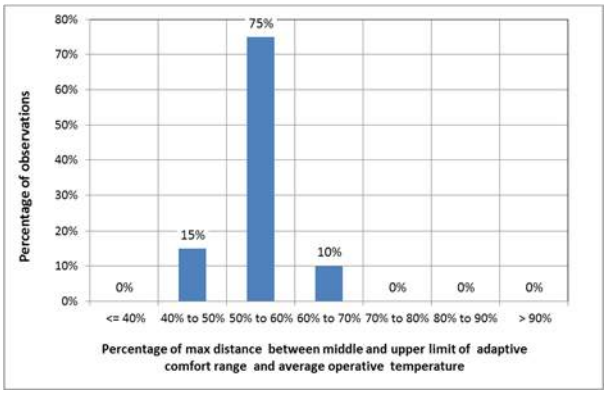
A = Deviation of operative temperature from middle of adaptive comfort range (in °C)
B = Approach of operative temperature to upper comfort range (in °C)
C = Distance between upper limit of adaptive comfort range and middle of range (in °C)

Figure 4.1.2.10: Percentage of deviation of operative temperature from middle of range relative to distance of upper limit to middle of comfort range A/C (in %)



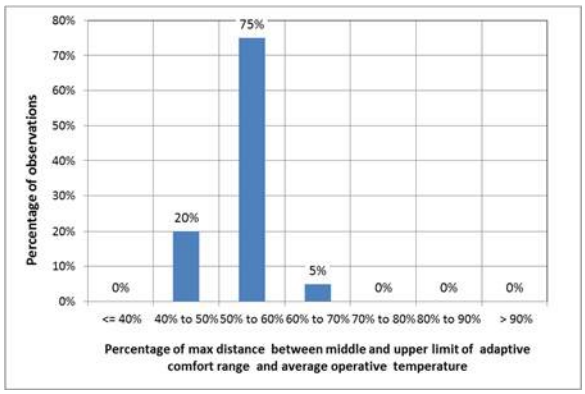
Baseline - Control Tests:

Average Portion of Total Distance = 87%



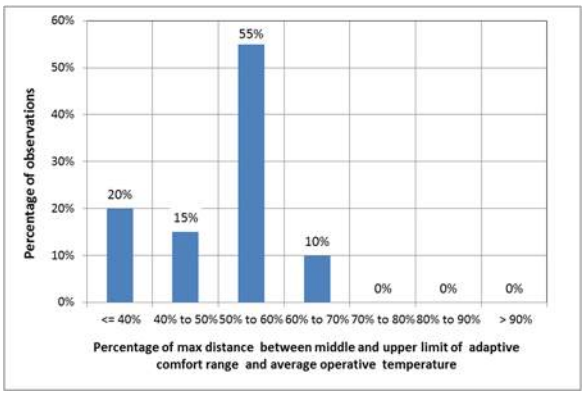
Test with Fan at Level 2

Average Portion of Total Distance = 56%



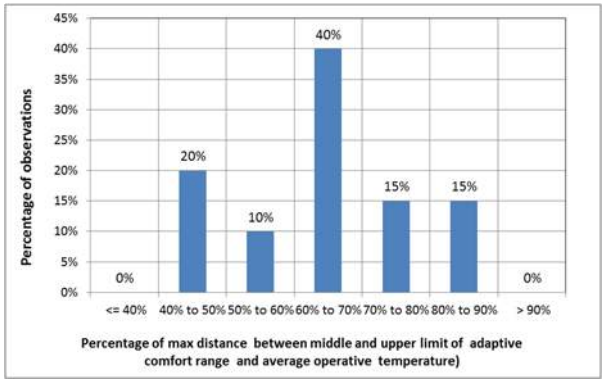
Test with Fan at Level 3

Average Portion of Total Distance = 53%



Test with Radiant Panels NO Fan

Average Portion of Total Distance = 50%



Test with Radiant Panels and Fans at Level 2

Average Portion of Total Distance = 65%

Proportion of distance between upper limit of adaptive comfort range (80%) occupied by average operative temperature

Proportion of distance from middle of range

Figure 4.1.2.11: Average Portion of Total Distance

4.1.3 Ranking the Performance of Comfort Enhancement Measures

A discussion of the results of the comfort test can best be accomplished by determining what comfort enhancement measures performed best in regard to increasing occupant comfort.

For this purpose, a ranking procedure was created and applied to the comfort tests results. The ranking procedures involved a two tiered ranking method. In the first tier a particular overall weight is assigned to each ranking criterion, where the sum of all overall weights for all criteria is 100% or unity. In the second tier of ranking alternative comfort enhancement measures (e.g. alternatives) ranking factors were assigned for each ranking criterion. The product of overall weight and ranking factor determined the resulting rank for each ranking criteria; and the sum of all resulting ranks was the overall rank of the alternative. The alternative with the highest rank was defined as having the best performance

Figure 4.1.3.1 illustrates the methodology of assigning the overall weights. As can be seen in Figure 4.1.3.1 there are four ranking criteria groups with several sub criteria. First the group ranking is assigned with the sum equal to 100%. The different sub criteria area also assigned with relative rankings adding up to 100%.

Once the overall weights were assigned, individual ranking factors were determined for each ranking criterion and for each of the four comfort enhancement measure alternatives and the baseline case. The result is the overall rank of the alternative measured by their multiple to the baseline control tests (benchmarking).

The results of the ranking procedure are presented in Figure 4.1.3.2.

Ranking group and individual criteria	Group ranking	Criterion ranking	Overall weight
PMV	**30%**		
PMV value		50%	**15%**
Ratio of conforming to non conforming		50%	**15%**
Adaptive comfort conformance assessment	**25%**		
Percentage of operative temperature deviation from applicable upper limit		100%	**25%**
Response to thernal conditions	**30%**		
Temperature perception		15%	**5%**
Thermal sensation		25%	**8%**
Thermal acceptance		60%	**18%**
Response to air movement conditions	**15%**		
Air movement acceptance		60%	**9%**
Air movement preference		40%	**6%**
sums	**100%**		**100%**

Figure 4.1.3.1:
Definition of ranking criteria and assigning of overall weights; the figure shows two levels of ranking, the first level is the group level and the second level is the criterion ranking.

				Bechmarking			Scenarios with different "Comfort Island" measures											
				Baseline - Control Tests			Test with Fan at Level 2			Test with Fan at Level 3			Test with Radiant Panels NO Fan			Test with Radiant Panels and Fans at Level 2		
Ranking group and individual criteria	Group ranking	Criterion ranking	Overall weight	value	criterion rank factor	overall rank	value	criterion rank factor	overall rank	value	criterion rank factor	overall rank	value	criterion rank factor	overall rank	value	criterion rank factor	overall rank
PMV	**30%**																	
PMV value		50%	**15%**	1.62	19%	3%	0.37	81%	12%	0.35	82%	12%	1.18	41%	6%	0.27	86%	13%
Ratio of conforming to non conforming		50%	**15%**	0.0	0%	0%	1.5	75%	11%	1.5	75%	11%	0.1	3%	0%	1.2	61%	9%
Adaptive comfort conformance assessment	**25%**																	
Percentage of operative temperature deviation from applicable upper limit		100%	**25%**	0.9	15%	4%	0.6	44%	11%	0.5	47%	12%	0.5	50%	13%	0.7	35%	9%
Response to thernal conditions	**30%**																	
Temperature perception		15%	**5%**	2.1	21%	1%	1.9	19%	1%	5.7	57%	3%	9.0	90%	4%	3.0	30%	1%
Thermal sensation		25%	**8%**	1.40	53%	4%	-0.10	97%	7%	-0.55	82%	6%	0.15	95%	7%	-0.50	83%	6%
Thermal acceptance		60%	**18%**	0.4	13%	2%	2.0	65%	12%	2.2	73%	13%	1.3	42%	8%	2.0	67%	12%
Response to air movement conditions	**15%**																	
Air movement acceptance		60%	**9%**	0.10	3%	0%	1.60	53%	5%	1.65	55%	5%	0.20	7%	1%	1.80	60%	5%
Air movement preference		40%	**6%**	0.9	10%	1%	0.2	80%	5%	-0.1	90%	5%	0.9	10%	1%	0.1	95%	6%
sums	**100%**		**100%**			**15%**			**64%**			**67%**			**39%**			**62%**
relative value of ranking									**4.3**			**4.6**			**2.7**			**4.2**
Rank by results									**2**			**1**			**4**			**3**

Figure 4.1.3.2: Ranking of comfort enhancement measures

Figure 4.1.3.3 illustrates the procedure of determining the criterion ranking factor. The procedure involved selecting a suitable full range of numerical values which included all numerical values of criteria for alternatives. This full range was determined by LOWER and UPPER limits of values to be ranked. All of the applicable values of alternatives had to be situated within that range. As an example from the numbers presented in Figure 4.1.3.2; the thermal acceptance was assigned a LOWER and UPPER limit of 0 and 3, respectively. The example scenario "test with Fan at (speed) level 2" lists a value of 2.2 which resulted in a criterion ranking factor of 73%. The value of 73% was obtained by the following linear relationship, 2.2/3*100% = 73%. The 73% criterion factor was then multiplied with the overall weight of 18%, which resulted in an overall rank for that ranking criterion of 13%.

The sum of the overall ranks of all ranking criteria for an alternative determined the overall ranks for that alternative. The higher the sum of all criteria overall ranks were, the higher the overall rank of the alternative. The relative rank of the alternatives was calculated by dividing the overall rank of the alternative by the overall rank of the baseline. For example, with the overall rank of the baseline being 15% the scenario "test with Fan at (speed) level 2" has a value of 4.3 (e.g. 64%/15%=4.3).

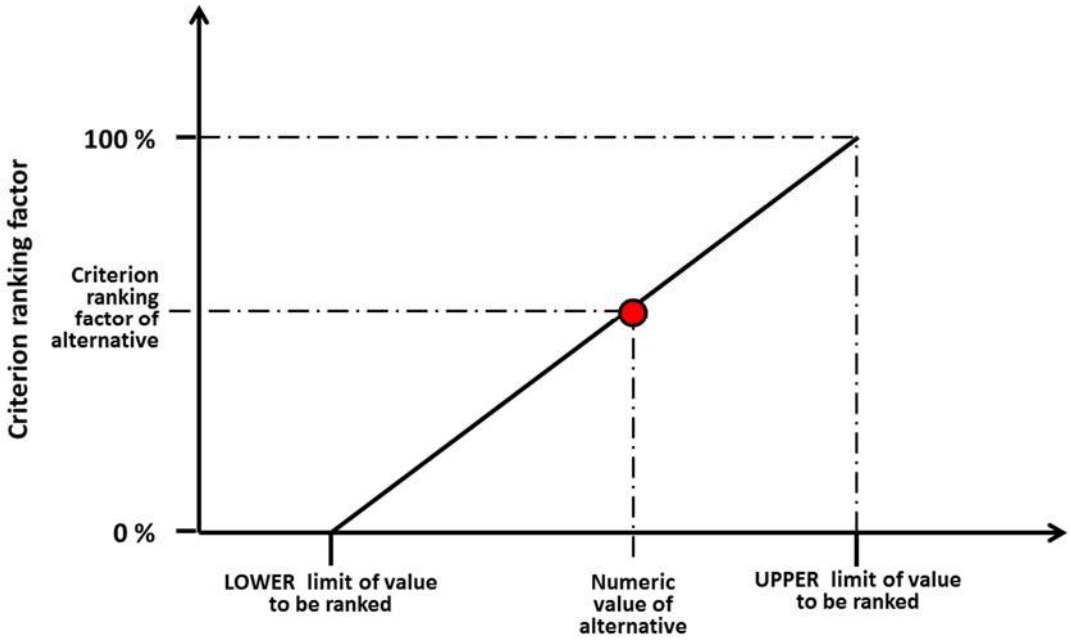


Figure 4.1.3.3: Definition of Criterion ranking factor

4.1.4 Discussion of Results and Scenario Ranking

The ranking results of the performance test scenarios is presented in Table 4.1.4.1. The most effective test scenario alternative of comfort enhancement measures was scenario "*Fan at Speed Level 3*" and the least effective scenario was "*Radiant Panels NO Fan*".

Table 4.1.4.1: Performance Ranking of comfort enhancement measures

Comfort enhancement alternative	**Rank of performance of increasing comfort level**
Fan at Speed Level 3	1
Fan at Speed Level 2	2
Radiant Panels and Fan at Speed Level 2	3
Radiant Panels NO Fan	4

The ranking of the result of the comfort tests suggests that both scenarios with only the fan in operation have the highest rank, followed by the combination of cooling panels and fans and the scenario with only the cooling panel. The physical method of using a fan to increase air movement over the body (or better skin) results in a higher convective heat loss due to an increased convective heat transfer coefficient which in turn increases due to a thinner boundary layer. The physical method of using actively cooled radiant panels results in the lowering of the radiant temperatures of adjacent surfaces and therefore in the lowering of the operative temperature. Both physical methods of increasing air movement over the skin and lowering the radiant temperatures of adjacent surfaces result in the same occupant perception of having a lower operative temperature.

Considering the scope of investigation of the present comfort tests, it can be suggested that the cost benefit ratio of using a ceiling fan is higher than installing an elaborate chilled water system with actively radiant panels. However, observation during the experiments indicated that the relative warm side walls and ceiling that surrounded the test station kept the mean radiant temperature higher than anticipated from initial scoping tests and CFD heat transfer simulations. Furthermore, all heat transfer simulations did not include the heat output of the test subject.

Future tests should consider the installation of a radiant barrier to shield the test station from unwanted radiant heat gain from the walls and ceiling.

4.2 Validation of CFD Comfort Simulations

The section presents the results of CFD comfort simulations and compares the CFD comfort simulations with comfort levels obtained from the comfort tests with test subjects.

4.2.1 Methodology

The work flow of simulating comfort with CFD was established and then used for parametric studies in the scope of work for the project reports Deliverable 12 and 13, respectively. The work flow procedure is described in detail in these reports and a description is not repeated here.

Due to logistics, the comfort simulations had to be completed prior to the comfort test at the ERDL test site. Therefore, boundary conditions established by the actual comfort tests were not known at the time of the simulations. The CFD team decided to carry out the comfort simulations with an anticipated range of environmental and heat transfer conditions at the test site. In doing so the CFD team made it possible to validate selected comfort simulations with actual comfort test, provided both had comparable boundary conditions.

4.2.2 Results of Comfort Simulations and validation

The results of the comfort simulations are presented in **Appendix H**. A total of 19 comfort simulations were carried out. The average individual duration of CFD runs was approximately 24 hours.

The basic work flow to determine the PMV value of the simulated environmental conditions used a hybrid method. The determination of the convective and radiative heat losses was determined with CFD simulations and the estimate of the evaporative heat loss was determined using the standard PMV procedure.

Since the convective and radiative heat losses were of primary importance, the calculated values of CFD and PMV procedures are compared in Table 4.2.2.1. The corresponding data comparisons of Table 4.2.2.1 are also shown n Figures 4.2.2.1 through 4.2.2.3.

Figures 4.2.2.1 and 4.2.2.2 indicate that for both the CFD simulations and the hybrid PMV procedure, radiant heat losses are higher than convective heat losses. Figure 4.2.2.3 shows a better data consistency for radiant heat losses between the CFD simulations and the PMV hybrid procedure.

Table 4.2.2.1: Comparison between convective and radiant heat losses obtain by simulations and PMV procedure

	CFD - heat transfer simulations			**Results with our PMV analysis**	
Scenarios	CFD sims - Heat loss Convection	CFD sims - Heat loss Radiation		PMV cals - Heat loss Convection	PMV cals - Heat loss Radiation
	W	**W**		**W**	**W**
B1	5.4	37.1		21.6	39.6
B2	4.0	33.6		15.7	37.3
B3	5.4	36.4		21.6	37.9
B4	2.7	31.2		50.0	35.6
B5	5.4	34.9		23.7	41.5
B6	5.7	31.0		20.3	32.7
B9	2.7	30.8		20.5	31.4
B10	0.7	30.8		18.2	32.3
B11	0.7			16.4	37.6
B12	4.4	28.2		13.5	29.7
B13	0.6	31.4		8.9	37.0
B14	0.1	34.6		10.4	40.8
B15	1.2	31.0		4.5	37.8
B16	1.4	34.1		4.7	42.0
B17	0.8	29.9		9.4	34.0
B18	0.9	32.6		10.6	36.7
B19	2.2	29.2		4.0	34.6
B20	1.5	32.0		5.0	37.7

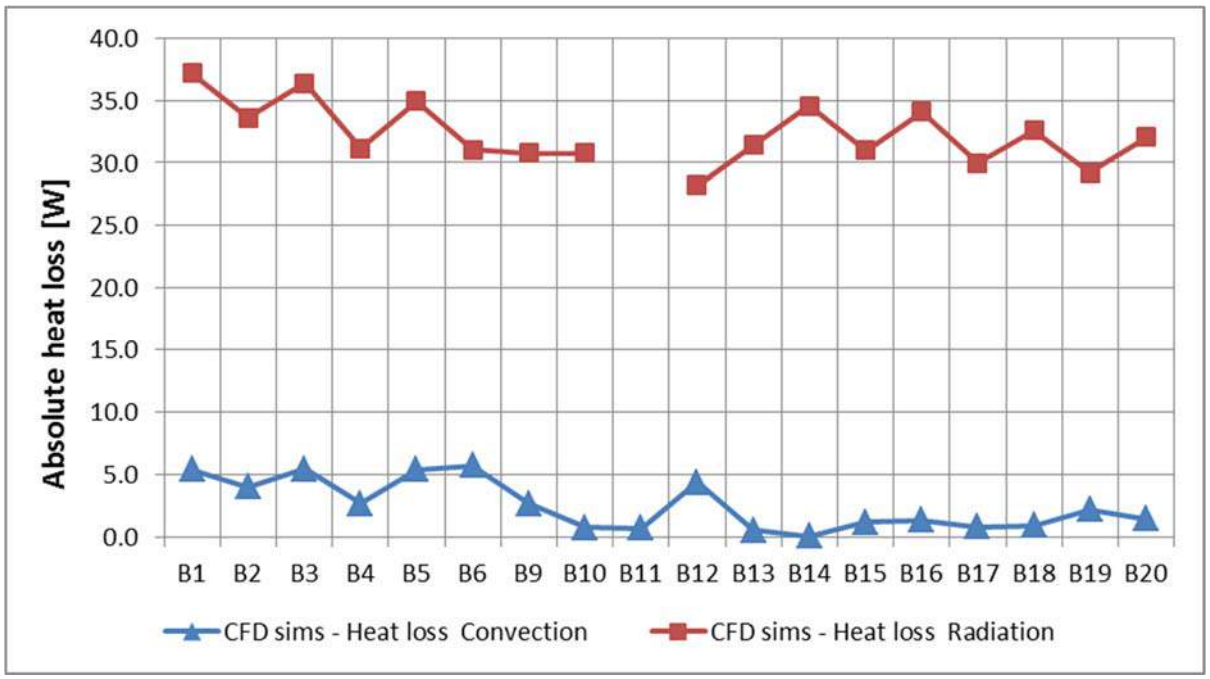


Figure 4.2.2.1: Convective and radiative heat losses obtained by simulations

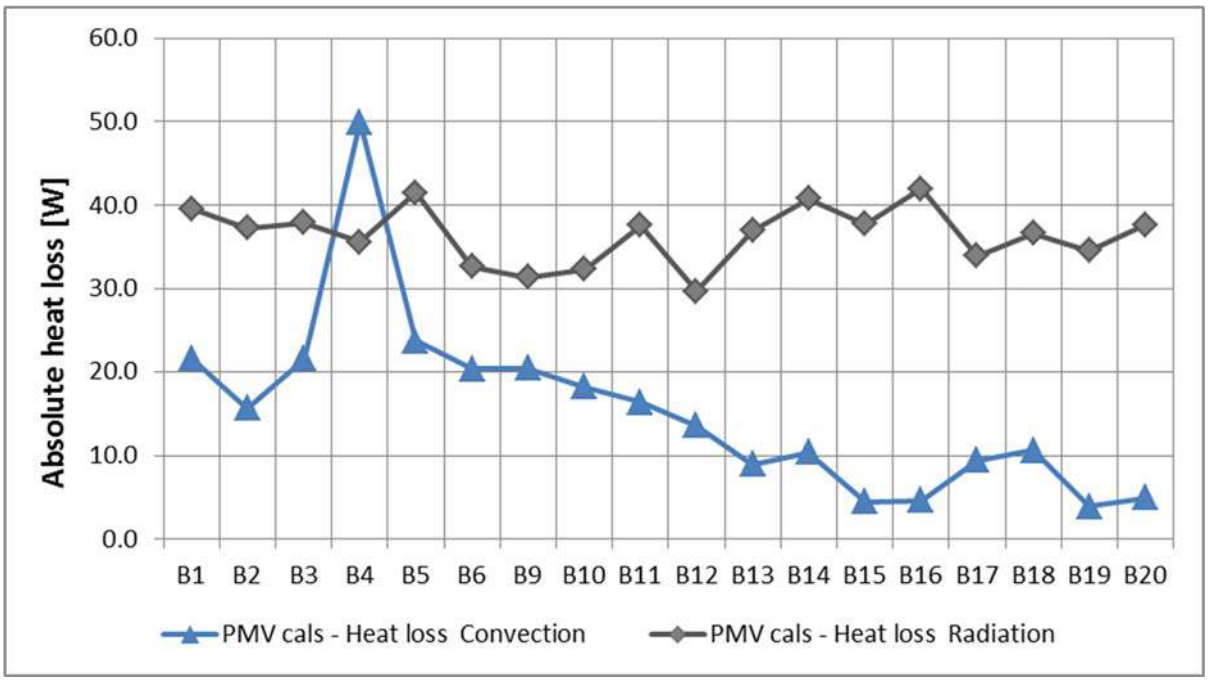


Figure 4.2.2.2: Convective and radiative heat losses obtained by hybrid PMV procedure

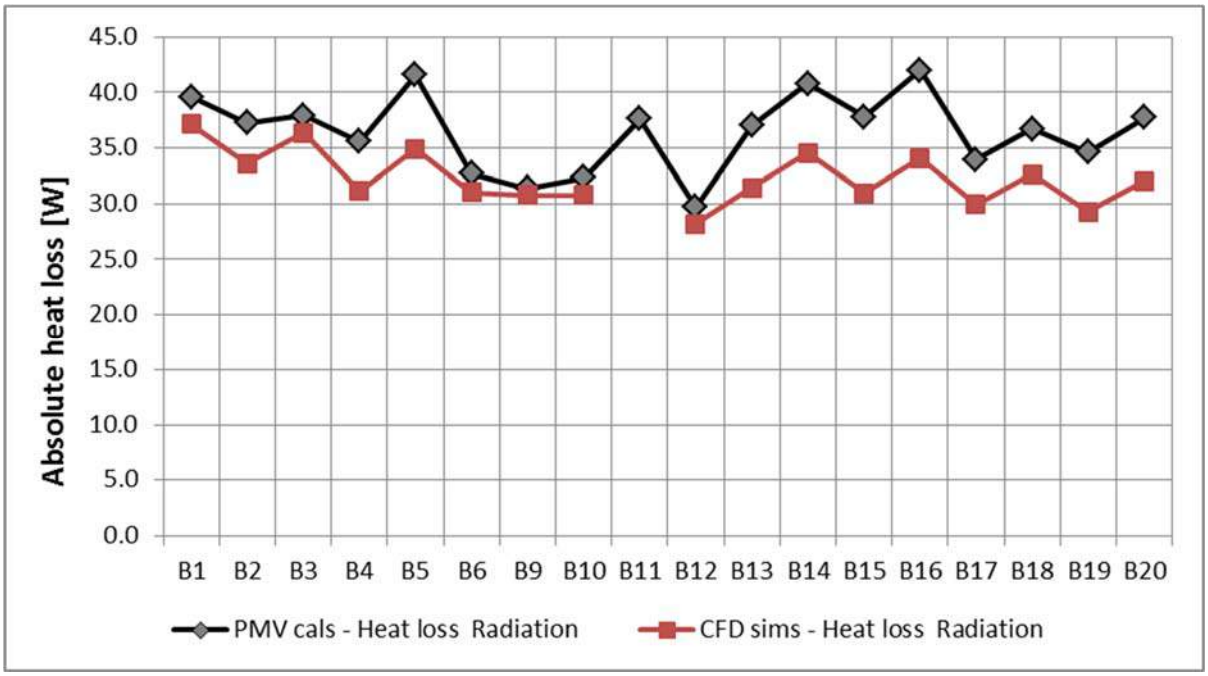


Figure 4.2.2.3: Radiative heat losses obtained by CFD simulation and hybrid PMV procedure

Out of the 19 comfort simulations only three resembled actual environmental conditions during the comfort tests, however the environmental conditions differed not insignificantly. The three cases that could be used for validation purposes of comfort simulations are as follows.

Case No.	Comfort simulation cases	PMV obtained in sims	Average of test cases	Average PMV measured
1	B2	0.89	Only radiant panels and NO fans	1.18
2	B10	0.96	Fan and speed level 2	0.37
3	B13	1.24	Panels and fan at speed level 2	0.27

While the case No. 1, showed a reasonable data consistency between comfort simulations and cases No. 2 and 3 deviated significantly.

4.2.3 Discussion of Results

The quality of data consistency between PMV values obtained through comfort simulations and PMV based on averaged measured data was negatively affected by the fact that the comfort simulations were conducted before the comfort tests. As a result, boundary conditions of numeric comfort simulations and measurements of corresponding physical parameters were not consistent.

In general, the comfort simulations showed a better data consistency between predicted (e.g. simulation) and measured PMV for the case where the radiant heat loss was the predominant heat loss occurrence. For cases where convective heat loss was increased by the ceiling fan operation, the resulting comfort simulations compared to the measured comfort levels to a lesser degree.

A concise explanation of the data deviation for cases with significant convective is not attempted at this point.

SECTION 5 – GENERAL CONCLUSIONS

This section presents main conclusions of this project report, Deliverable 14:

The scope of the comfort investigations presented in this project report was a significant effort that was carried out by the entire ERDL research team over a period of half a year, from March through September 2015.

The type of work presented in this report covered a wide range of research activities, and the main activities are listed below:

- Select a test site among alternative locations to carry out comfort investigations.
- Design and outfit the test facilities to allow testing of comfort enhancement measures and benchmarking against a baseline without such enhancement measures
- Design and construct custom fitted test equipment to carry out the comfort investigations with test subjects as well as carry out investigations of physical properties that are relevant to indoor comfort.
- Install, maintain and operate a large array of sensors to measure physical indoor environmental parameters. These physical parameters were used to correlate subjective comfort experiences of test subject. The objective values obtained were then used to rank the comfort enhancement measures and identify the measure with the best performance.
- Develop and operate a comprehensive data acquisition and management system, including operating of signal processing and creation and maintenance of databases for all test results.
- Develop and execute a suitable procedure for the comfort investigations, including development of the comfort survey, obtaining agency permission to conduct the comfort tests, inviting a significant number of participating test subjects, and preparing the logistic prerequisites for effective and productive test runs.
- Develop and apply a procedure to rank the comfort enhancement measure alternatives in order to determine the overall best performance.
- Carry out CFD simulations to predict thermal and air flow performance of the test set up. Due to logistics requirements all of the CFD simulations had to be conducted before the actual performance of the test set up was known. This resulted in the fact that important parameters of boundary conditions for the CFD simulations had to be predicted and could not be based on the actual steady state conditions at the test site. This represented a challenge and was responsible for certain data deviations between predicted and measured conditions.

- Carry out comfort simulations with the available CFD software STAR-CCM+, which had no occupant comfort functionality, such as a comfort wizard. The CFD research team faced significant challenges to model air movement induced by a rotational body (e.g. ceiling fan) without access to large and sophisticated multidimensional CFD models. These types of CFD models typically require significant computational resources. The CFD team solved the computational challenge by using an approximation where a cylinder of the same dimensions as the ceiling fan was substituted for the rotating ceiling fan, and used the approximate defined discharge air patterns as a boundary condition.
- The CFD research team also was faced with the fact that the CFD software offered an occupant comfort functionality which was custom made for applications in the automobile and aerospace industry. Communications with the CFD software support revealed that the "comfort wizard" could not be used for the comfort simulations at the test site.
- Summarizing, the efforts that were required to obtain the results presented in this project report were extraordinary, in scope, commitment of resources and sophistication.

Challenges and Lessons Learned

As a general remark: The project was not short of challenges and the ERDL research team worked diligently to solve the many problems; sometimes using creative and innovative ways to build prototypes and thus avoid buying equipment that was out-of-budget.

One of the main challenges of the work presented in this report was the wide scope and numerous types of research tasks and support activities that had to be planned, managed and carried out. Basically all of the ERDL research resources were engaged, including staff and student help. The fact that all research was performed diligently and enthusiastically and that work tasks were seamlessly coordinated and managed made this tremendous work effort possible. Important research results were obtained which can be directly applied to a better understanding of providing comfort in the built environment.

In the next section, the more detailed challenges and lessons learned are described.

Providing the test space: An initial challenge faced by the ERDL team was finding an appropriate space to conduct the tests. Efficient logistics required a space location close to the ERDL laboratory in order to allow short walks from the ERDL laboratory. Safety and security were additional concerns since equipment and instrumentation needed to be secured from tampering and theft. After a lengthy search that involved several candidate spaces the room HIG 204 next the ERDL laboratory which is located in room HIG 205 was made available for the tests. The space is an older storage room with the dimension of about 8 by 25 feet and a high 10 feet ceiling. A part of the room was separated from the usable space

by an internal 6 feet high separating wall, which left a tight room for two cubicles; one, the "test station", with comfort enhancement measures, and second, the "control station", without measures.

The nature of "comfort islands" is an approach of providing increased thermal comfort locally and not uniformly in a space. Comfort islands are envisioned to work best in larger spaces. The tight dimensions of the test space in HIG with the test subjects sitting in a small space while experiencing different levels of "dis-comfort" might have somewhat affected the results of the subjective comfort tests results. To what degree the tight spaces may have affected the outcome of the comfort tests cannot be expressed quantitatively at this time. It is very likely that a larger, preferable naturally ventilated test space without tight enclosure and perhaps daylight and a view would be better suited as a future test site. In addition, the test subjects needed to pass through the tight test set-up of the test station in order to access the comfort station. This was deemed to be a less than optimal solution.

The ERDL team improves the appearance of the tight test site by adding attractive lighting and some green plants. This was well received by the test subjects and future comfort test should allow for such improvements of the visual appearance.

Installing the comfort enhancement measures:

Actively cooled radiant panels: A significant challenge was installing the actively cooled radiant panels and supplying the panels with a sufficient quantity of chilled water. This comfort improvement using cooled surfaces which are located close to and surrounding the occupant as a way to lower the operative temperature without the need to air condition the entire space, is an innovative measure. This approach to improve the thermal comfort by of providing cold surfaces without dehumidifying the indoor air has not been tested before. Therefore, the prototype installation needed new design and construction methods. At the same time, available equipment had to be used in order to reduce the costs and effort of fabricating sophisticated equipment parts. The result was an innovative and integrated cooling system consisting of commercially available radiant panels and a chilled water supply.

The original project scope included the testing of phase change material (PCM) which was incorporated into gypsum boards. For initial scoping tests, the ERDL team mounted one PCM containing gypsum boards on a wooden frame and installed a heat conduction copper tubing meander with aluminum plates on the back surface. It was envisioned that the copper tube meander would readily remove heat from the PCM panels to provide cold surface temperature suitable as radiant cooling panels. The scoping test revealed that the heat removal efficiency of the copper pipe meander was not effective and resulted in a significant temperature difference between the PCM panel surface and the chilled water. Apparently, the mounting of the copper pipe mender to the PCM board was insufficient and resulted in heat transfer below expectations. As a consequence, the originally planned investigation of PCM containing gypsum boards was no longer

pursued. Instead of the PCM panels, commercially available radiant panels were bought. These panels were installed in a vertical position instead of the typical horizontal alignment.

Chilled water supply: The chilled water generation also provided the team with a significant challenge. Commercially available chilled water units, with the relatively low flow rate of the test set-up, were too expensive and their procurement time was too long. Instead of a direct water chiller, cooling of the chilled water supply for the radiant panels used an indirect method. In this indirect method, chilled water ran through an air-to-water heat exchanger. In the heat exchanger, the water was cooled with chilled air from a typical AC-window unit. This method of generating sufficient quantities and the low temperatures needed by the radiant panels was successful, although a lot of effort was required to fine-tune the system and add components such as recycling of the chilled air.

Determining the ceiling induced air flow at the test site:

The nature of comfort improvement through increased air movement is based on air passing over the body, which increases the convective heat loss and thereby decreases the perceived operative temperature.

In order to allow a quantitative correlation of increased air movement downstream of the ceiling fan and the thermal sensation of the test subject, the air speed needed to be measured for the fan speeds used in the comfort tests. The measurements of air flow were carried out with two types of hot wire anemometers, an F-900 anemometer and a Wolfsense anemometers. By design the hot wire measurement could only determine the absolute air speed. The directional vector of the air movement could not be measured. Established indoor thermal comfort standards, such as the ASHRAE 55 standard, only use the velocity of the air stream, and not their direction, to determine increases of thermal comfort. For certain aspects of the investigations, a directional resolution of the air movement would have been advantageous. The establishment of reliable boundary condition of the ceiling fan CFD model as well as the resulting 3D-flow regime of the air movement used in validating the CFD results, would have benefitted greatly from the knowledge of directional air velocity information.

Determining air flow characteristics for comfort tests: The ceiling-induced air movement measure at the test site was needed for the different fan speed levels in order to correlate thermal experiences of test subjects with air speed. The measurement of air flow around a person was measured at five locations with a test person sitting inside the test station. For these measurements the air speed was cross checked with the two types of anemometers. It was revealed that the Wolfsense Anemometer constantly showed a consistently lower air speed than the average of two F-900 anemometers. The fact of erroneous air speed measurements of the Wolfsense anemometer was significant since the Wolfsense anemometer was used to determine the boundary conditions of the ceiling fan model for the CFD simulation. For future air flow tests, a precise calibration of anemometers will be required.

The ceiling induced air speeds around a test person were obtained for four fan speed levels. The air speed measured revealed a non-symmetric air flow pattern around the person. The determination of the effect that a symmetric or asymmetric air flow pattern has on perceived thermal comfort was beyond the scope of these investigations. A more detailed knowledge of such air flow patterns effect would however be of great value. For the present investigations, the representative air speed per fan speed level was a non-weighted average of all five anemometer readings. Two of the fan speed levels, 2 and 3, were selected for the comfort tests with ceiling fans in operation.

Determining the air flow characteristics for CFD simulation validation: The air flow measurements for CFD validation were carried out without a person sitting at the test station. An array of eight anemometers were installed which showed a non-symmetric air flow patterns. For the validation of CFD air flow simulations a directional resolution of the air flow pattern would be of great value. For future investigations a high precision directional anemometer (e.g. 3D) should be used.

Determining the radiant heat transfer characteristics: Radiant heat transfer characteristics of the actively cooled radiant panel array were measured with a globe thermometer. While the radiant heat loss from a human to the radiant panels were an important thermal characteristic of the comfort tests, the radiant heat transfer measurements were conducted without a test subject sitting at the test station. The human body, however, generates and rejects a considerable amount of heat. This addition of heat by the human body and its effect on the thermal performance could not be considered, and this could have affected the results in these tests. For future comfort tests, the use of an instrumented manikin, which can precisely replicate and measure the thermal experience of the human body, would be highly recommended. The significant costs of renting a thermal manikin was, however, was cost prohibitive and far exceeded the allocated budget of the present comfort tests. Future use of instrumented manikins and custom made comfort software would be a valuable contribution to increase our understanding of indoor comfort.

CFD simulations of indoor environmental conditions at the test site: The CFD software STAR-CCM+ was used for the simulations. This software was the same that was used for the other two parts of the present research program, which investigated air flow inside and around buildings. The comfort simulations included modelling air flow that was induced by a ceiling fan, which requires significantly more sophistication than modelling air flow inside and around buildings due to natural wind. After scoping tests, it was decided to model the ceiling fan not as a body of rotation but as a CFD region with a certain discharge air pattern. This CFD simulation methodology was developed and used for parametric CFD simulations in the two previous project reports, project Deliverables 12 and 13.

Using this methodology, however, requires a good knowledge of velocity vectors of the air flow leaving the imaginary CFD body that models the ceiling fan. For the investigation of this report the absolute air speed and not the directional air speed was measured at a location downstream of the ceiling in order to determine the values for the CFD boundary conditions. The directional patterns of

the air flow vectors, a required input variable for the CFD simulations, was assumed, following samples given in the literature (see project Deliverable 13 for more details and literature reference). In addition, the air flow was measured with the Wolfsense anemometer, which was found to yield erroneous measurement values.

While considering data discrepancies between theoretical predictions and actual measurements of air movement at the test site, the CFD simulations provided nevertheless important and valuable results. A comparison between CFD simulation results and measured air flows indicated consistent data trends, where the air flow values obtained by CFD simulations were below measured values but consistently followed the measured data trends with offsets by a constant factor. It can be concluded that measured values of the air speed downstream of the ceiling which were used to establish the boundary conditions of the CFD model of the ceiling fan were too low. Therefore, the magnitude of the CFD airflow simulations should have been consistently too low, since they depend on the boundary conditions. The observed consistent data trends between simulated and measured values suggests that the basic methodology of CFD air flow simulation workflow was suitable. With corrected boundary conditions for the ceiling fan the data consistency between simulated and measured air speeds at corresponding locations should be much better.

The CFD simulation for heat transfer rates yielded good validation results for the radiative heat transfer. The CFD simulation of the convective heat transfer resulted in diverging simulations and measurement results. The reasons of the deviation of these simulated and measured results likely included several phenomena whose determination was beyond the scope of this research project. One likely contributing reason was the erroneous boundary condition of the CFD ceiling fan which would produce distorted convective heat loss results of the CFD simulations.

CFD comfort simulations: The CFD comfort investigations were carried out with the CFD software STAR-CCM+. This software offered an occupant comfort wizard which the software vendor suggested as suitable for the present comfort simulations in indoor spaces. In the course of the project work the CFD team concluded that the STAR-CCM+ comfort wizard could not be used to simulation comfort at the test site. Consequently, the CFD team developed a project specific simulation workflow. The results of the comfort simulations indicated a reasonable data consistency between simulated and measured values for the test scenario where radiant heat transfer was the predominant mans of heat loss. For test scenarios where increased air flow induced by the ceiling fan was the governing mode of heat loss, data consistency was less.

In hindsight, the CFD team recognized that developing a customized approach for STAR-CCM+ was a perhaps too demanding task that yielded good initial results but could not be developed to an advanced level in the short time of the investigations. For future project involving comfort simulations, a dedicate software product should be used that has been tested and validated for thermal simulation applications in the built environment. The CFD team had started communications with a vendor of a specialized comfort simulation software, but shifting simulation

software products during the final month of this research project was considered not feasible and was also beyond the project budget.

One aspect that hampered the quality of results of CFD simulations was the fact that the CFD simulations had to start and be completed before the tests-up had passed final shake-down. The thermal performance of the test set-up under steady state, and therefore under the conditions eventually used during the comfort test, was not known when the thermal boundary conditions were selected for the CFD simulations. It is evident that CFD boundary conditions that were different from the actual test conditions would unavoidably yield diverging results. In such, a certain level of data inconsistency between simulation and measured results could be not ruled out. For future comfort test involving CFD simulations, the steady state conditions of the tests should be known at the time when the boundary conditions are formulated. As was mentioned, in this research project logistics dictated that the CFD simulations were started and completed before the test set-up operated at test conditions.

Ranking of the performance of comfort enhancement measures tested: Perhaps the most important conclusion of the present comfort study was the assessment of which comfort enhancement measure investigated in the tests showed the highest comfort improvement. For the determination of the most effective measure, a two tiered ranking approach was developed and applied to the five test scenarios. Ranking criteria were categorized in four groups. Three of these groups contained sub categories of ranking criteria. Using group and sub categories, overall weights was defined for each ranking criterion. The sum of all overall weights was unity (e.g. 100%) and therefore the ranking was a relative comparison between all ranking criteria and ultimately between the alternative comfort enhancement categories. For each of the four comfort enhancement measures as well as the baseline condition, ranking factors were selected that best defined the performance of the alternatives to the ranking criteria. The best alternative achieved the highest ranking value. The comparison of the results of the four comfort enhancement measures to the baseline condition produced the final relative improvement factor.

The results of the ranking showed that using a **ceiling fan had the largest positive impact on occupant comfort**, where a higher fan speed level and therefore higher local air speed yielded a higher comfort satisfaction. The use of the actively cooled radiant panels alone or in conjunction with a low setting of the ceiling fan resulted in lower improvements of comfort satisfaction. Since the effort to install and operate an actively chilled radiant panel array versus using a ceiling fan alone is significantly higher, ceiling fans should be the preferred comfort enhancement measures for comfort islands.

These conclusions should, however, not be interpreted as ruling out the use of actively cooled surfaces as a comfort enhancement measure in otherwise unconditioned spaces. The conclusions are only valid for the conditions of the present tests. The ERDL team concluded that using radiant barriers that would shield some of the higher radiant heat gains from warm walls and ceiling could

have significantly improved the performance of the radiant panels. More testing in the future, reducing the limiting factors mentioned above, may render actively cooled panel arrays as a suitable and potentially effective comfort enhancement measures.

REFERENCES

There are no references quoted in this report.

APPENDICES

The following Appendices are attached to this report:

Appendix A - Presentation of Qualitative Post processing For Scenarios A 1 through A 14 (110 pages)

Appendix B - Summary of Air Measurements WITH a Test Person (29 pages)

Appendix C - Summary of Results of CFD Air Speed Simulations (26 pages)

Appendix D - Summary of Air Speed Measurements without a Test Person (27 pages)

Appendix E - Surveys, IRB Application and Approval, Test Procedure (14 pages)

Appendix F - Data Management (19 pages)

Appendix G - Results of Comfort Tests (31 pages)

Appendix H - Results of CFD Simulations of Comfort Scenarios (12 pages)

APPENDIX A

Presentation of Qualitative Post processing For Scenarios A 1 through A 14

(110 pages)

Description of CFD Simulation methodology and scope

Test matrix

Test matrix of CFD simulations:

Instrumentation based = Physical without test person

e.g. testing of physical performance:

Panels:

objective: test mean radiant temperature

Scenario ID	ceiling fan speed	panel configuration	panel temperature	Room temperature
A1	No fan	A	1	1
A2	No fan	A	1	2
A3	No fan	A	2	1
A4	No fan	A	2	2
A5	No fan	B	1	1
A6	No fan	B	1	2
A7	No fan	B	2	1
A8	No fan	B	2	2
A9	No fan	C	1	1
A10	No fan	C	1	2
A11	No fan	C	2	1
A12	No fan	C	2	2

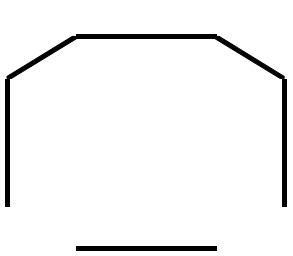
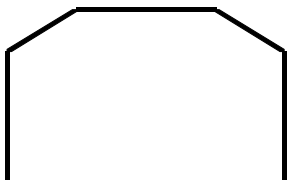
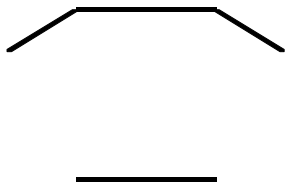
ceiling fans:

objective: Test the air velocity distribution of ceiling fans at 43" height

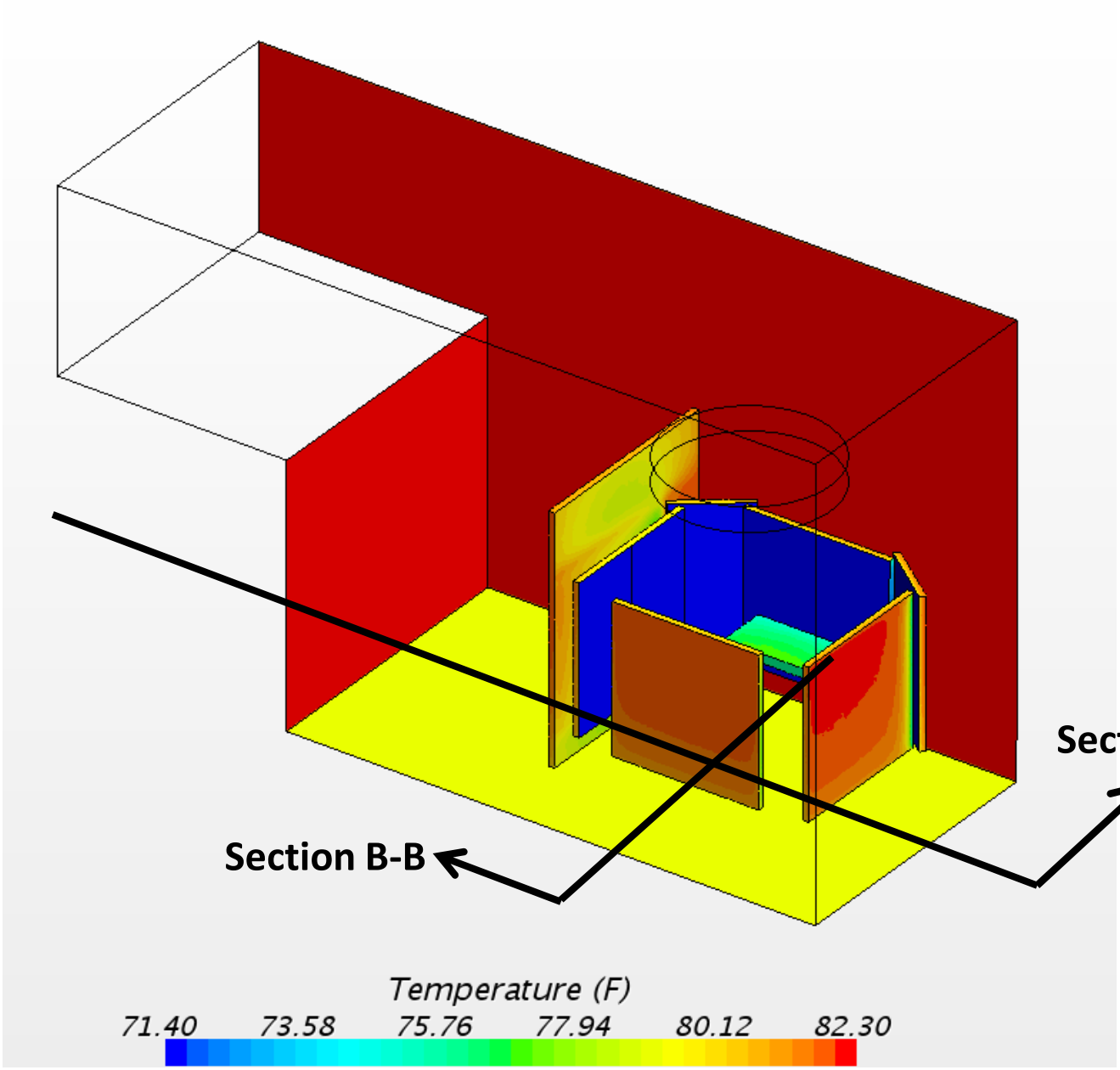
Scenario ID	ceiling fan speed	panel configuration	panel temperature	Room temperature
A13	2	A	N/A	N/A
A14	4	A	N/A	N/A

Description of CFD Simulation methodology and scope

Test parameters

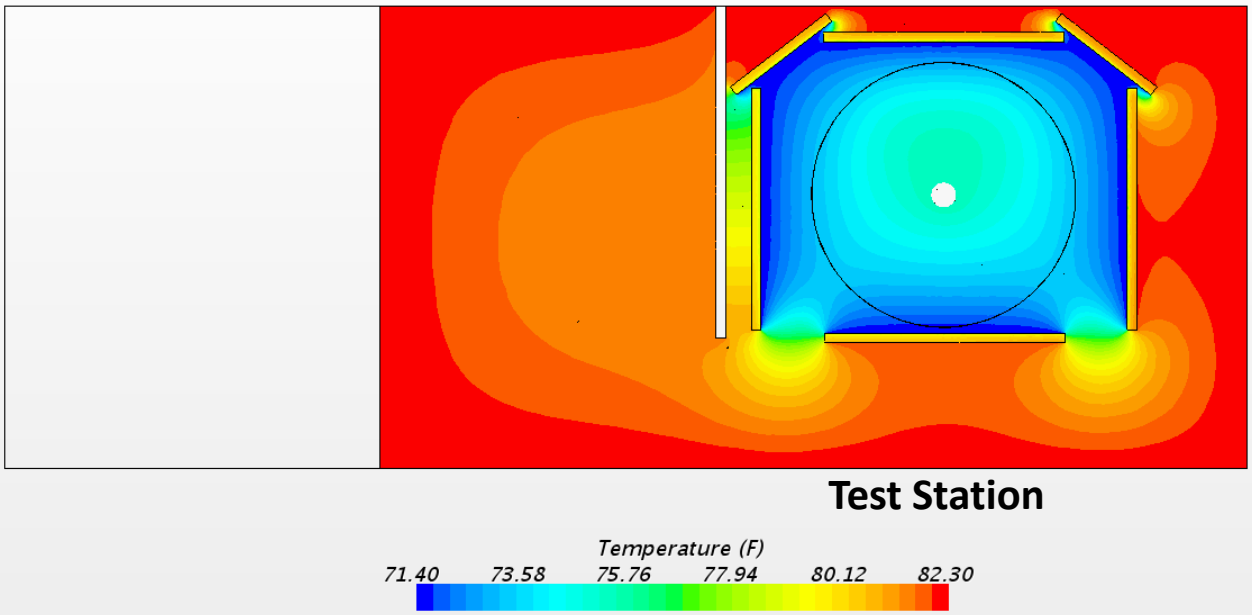
Parameters for Setting Up Test Scenarios						
			low			high
ceiling fans:	fans speed		*1*	*2*	*3*	*4*
Panel configurations						
	configuration		*A* 			
			B 			
			C 			
Panel temperature range			warm		cold	
	Temperatures		*1*	*2*		
	{F°}		72	68		
Room temperature			warm		warmer	
	Temperatures		*1*		*2*	
	Air	{F°}	80		85	
	Wall	{F°}	80		85	
	Floor	{F°}	77		82	
	Ceiling	{F°}	78		83	

Presentation of Qualitative Post processing For Scenarios A 1

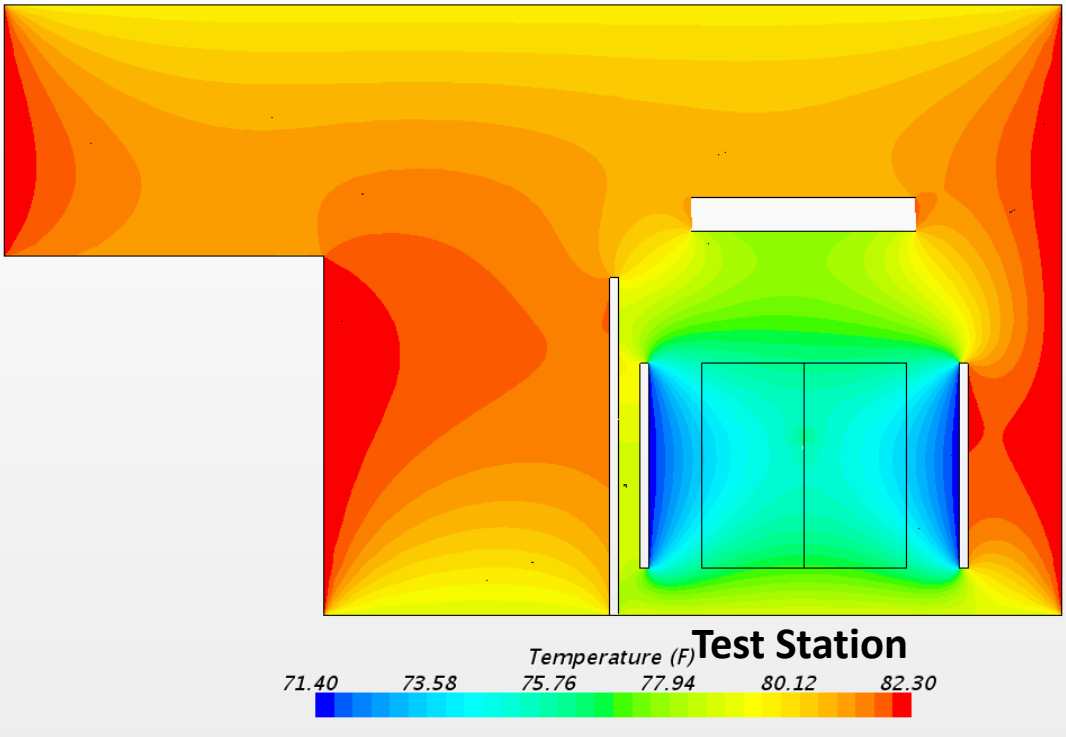


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 1

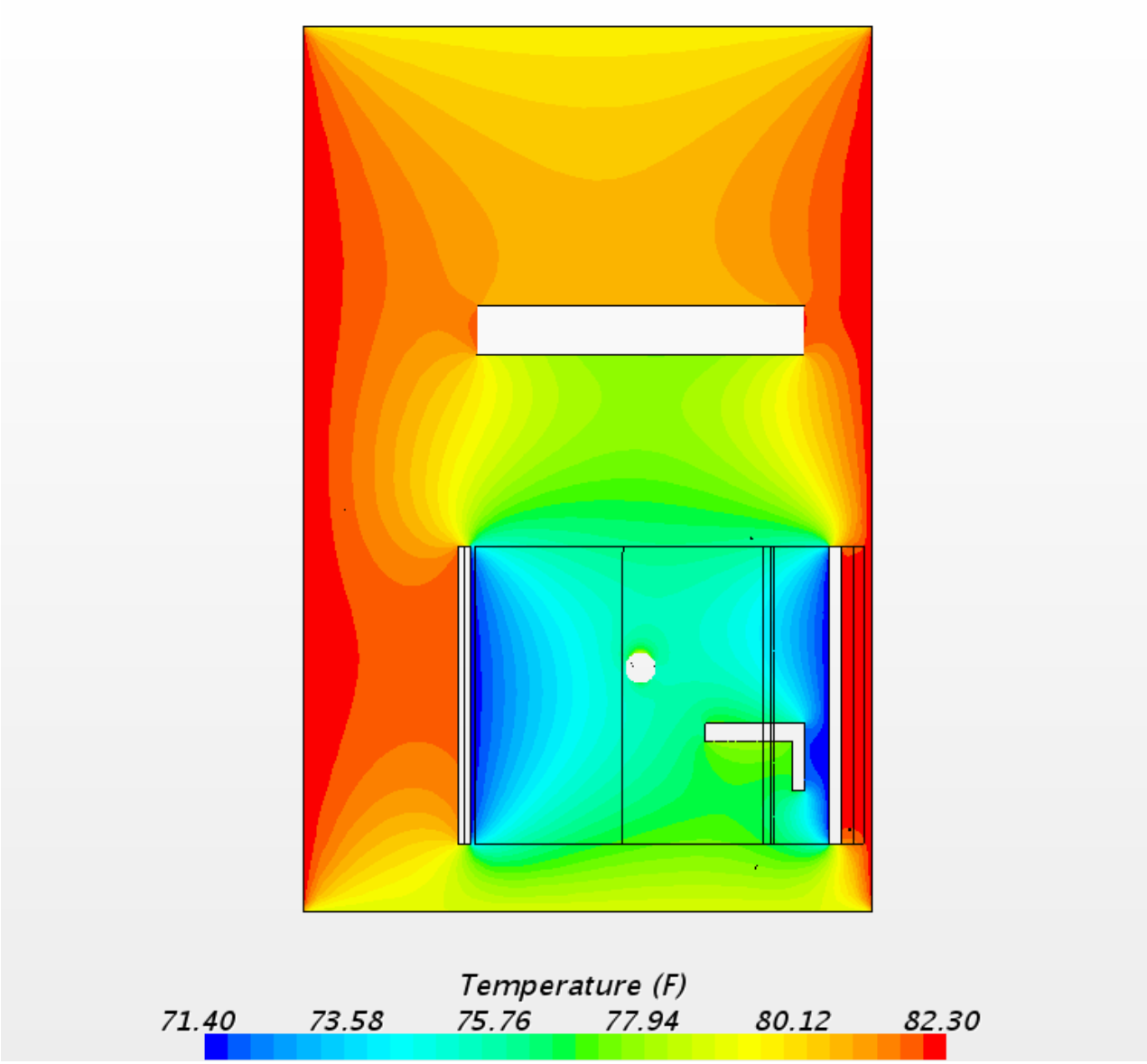


Test Set-up - Plan View



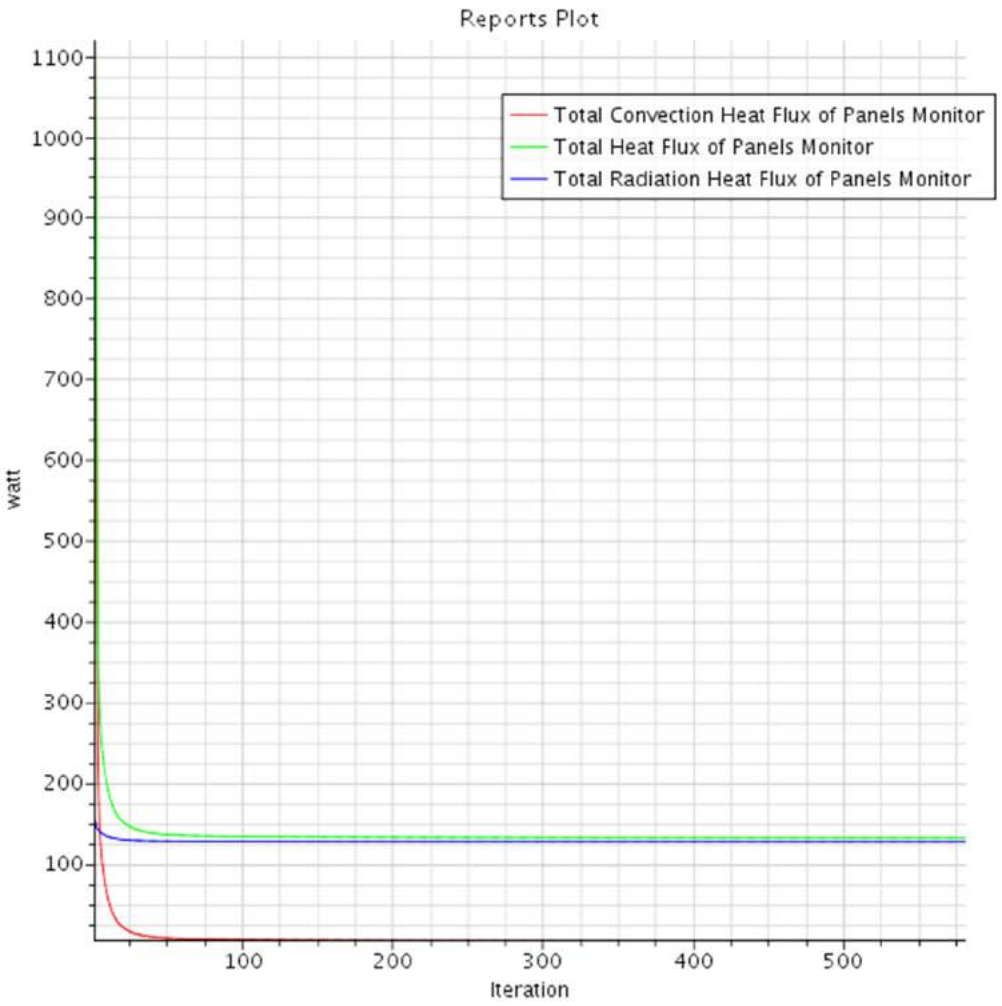
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 1



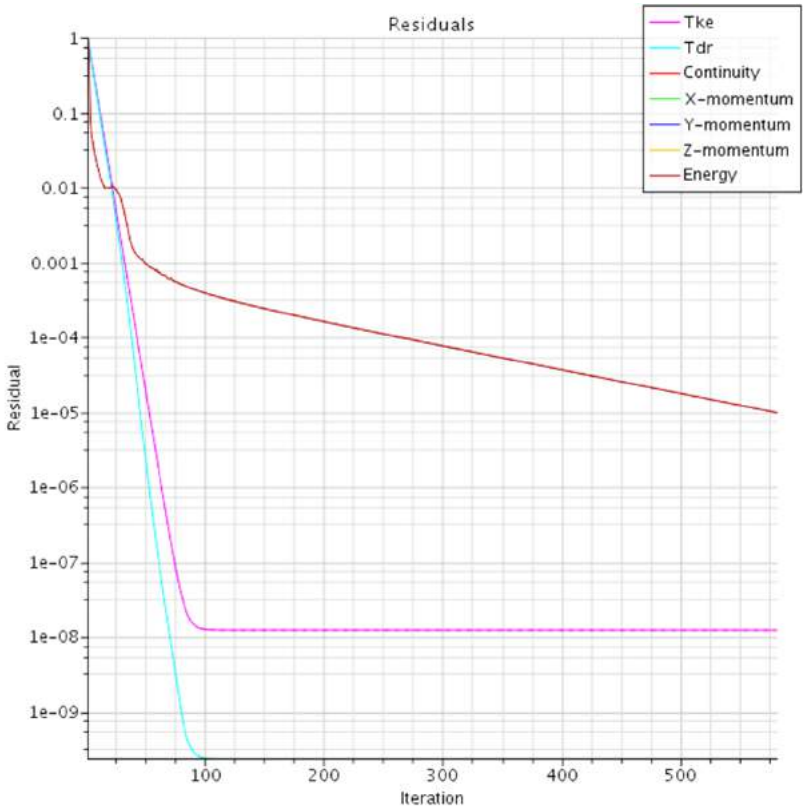
Test Set-up - Section B-B

Presentation of Qualitative Post processing For Scenarios A 1

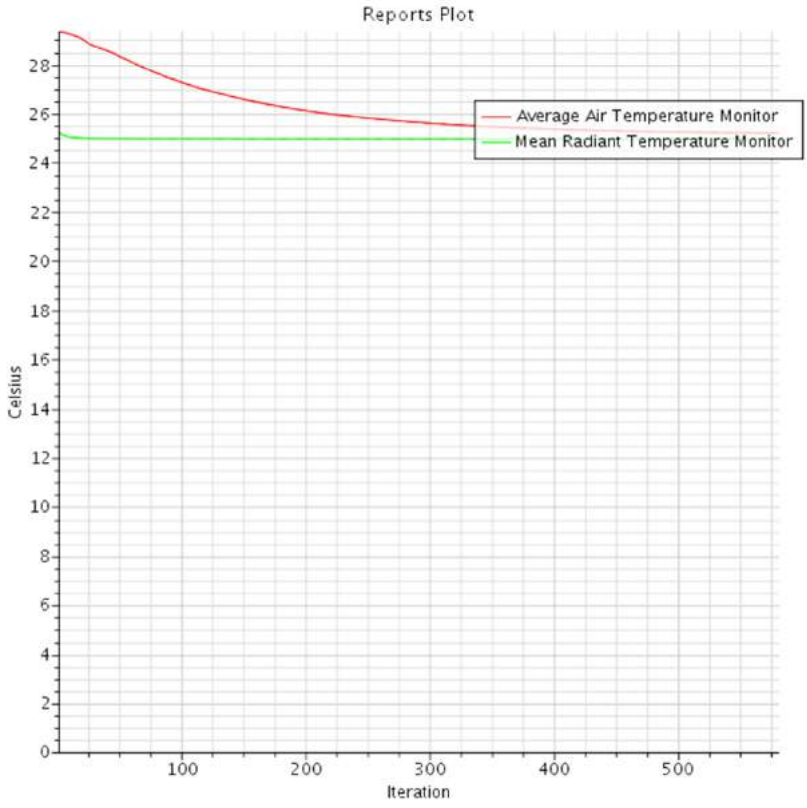


Heat Flux

Presentation of Qualitative Post processing
For Scenarios A 1

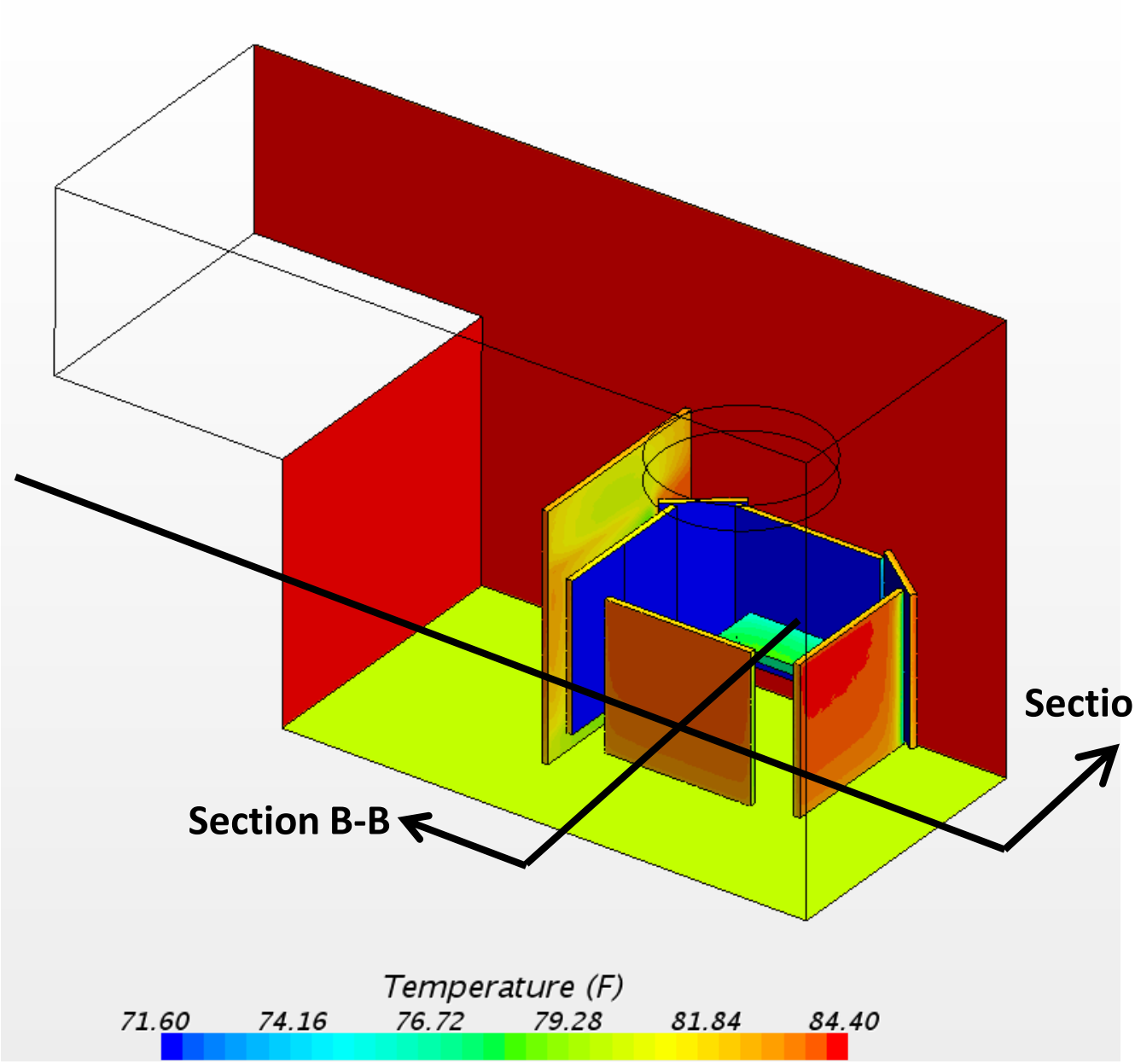


Convergence - Residuals



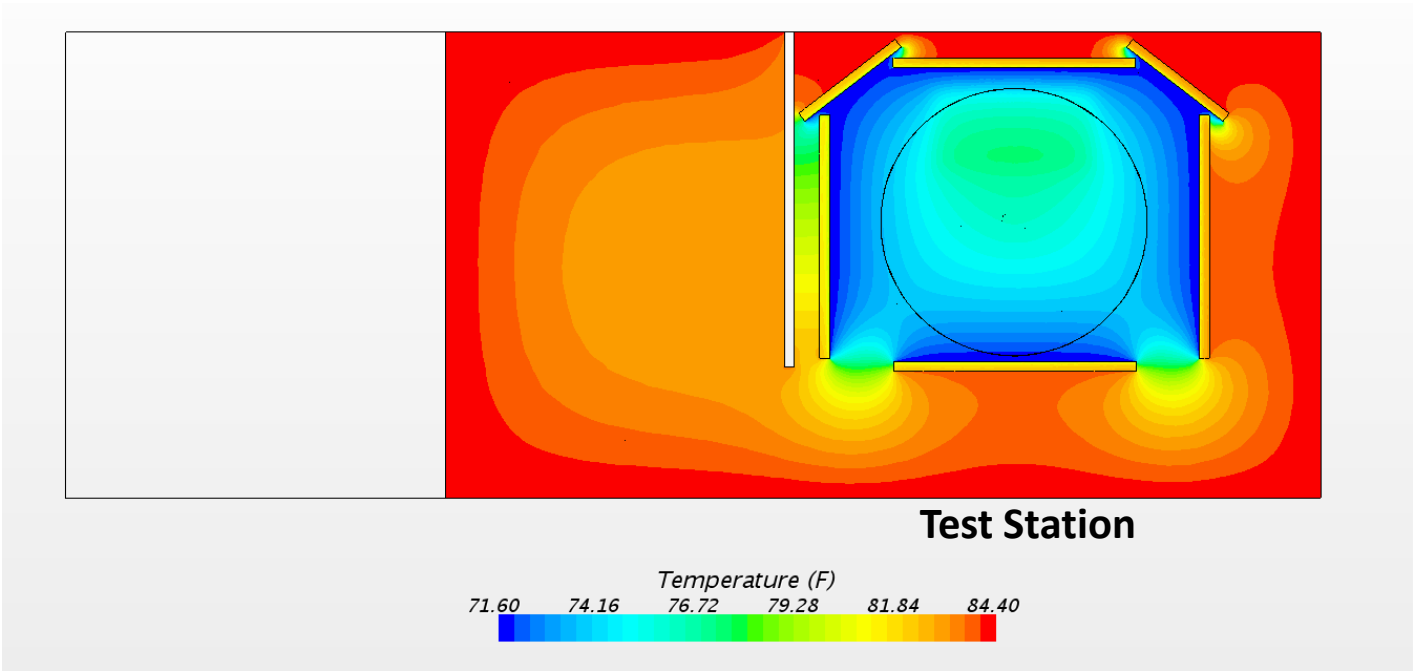
Convergence - Temperature

Presentation of Qualitative Post processing For Scenarios A 2

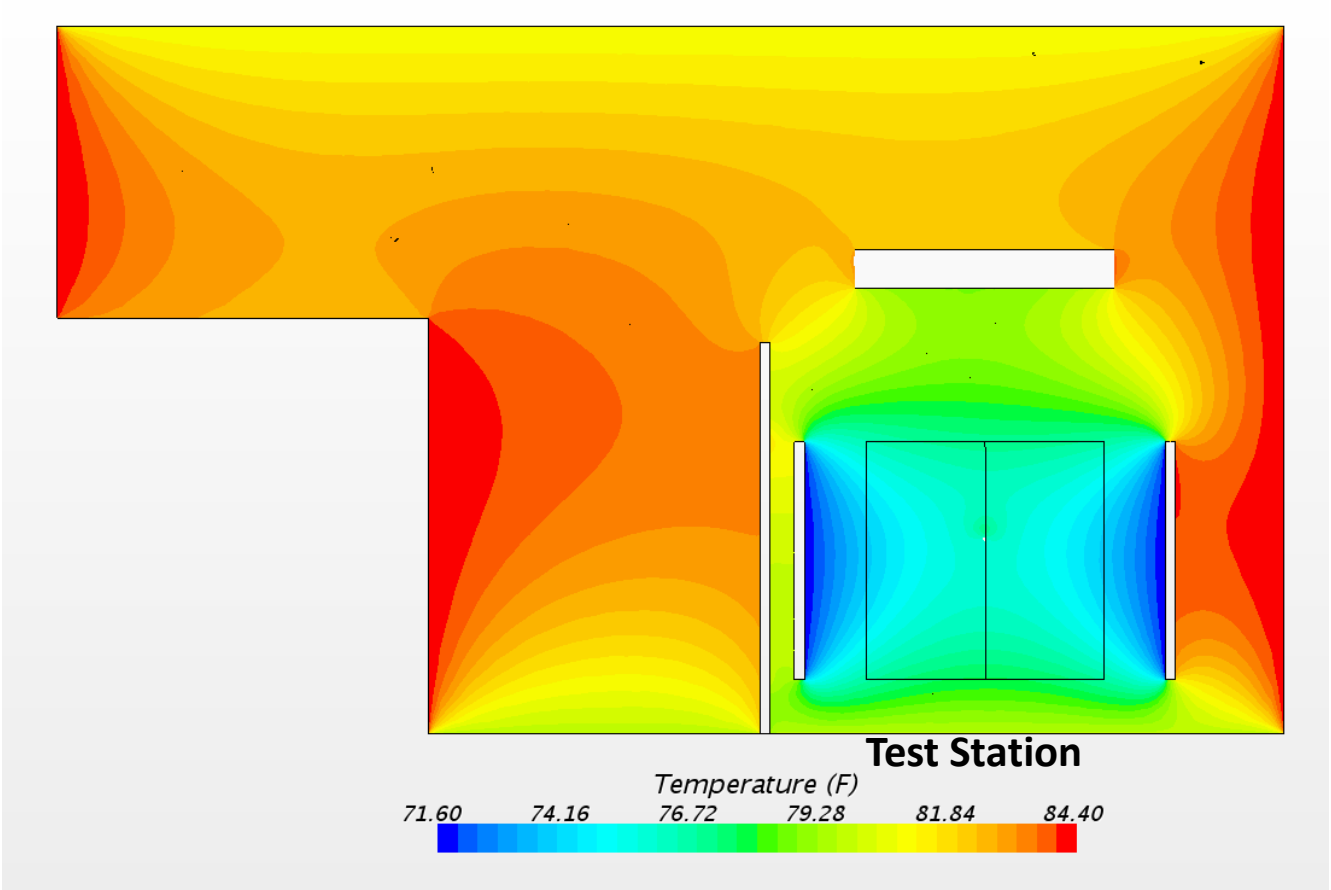


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 2

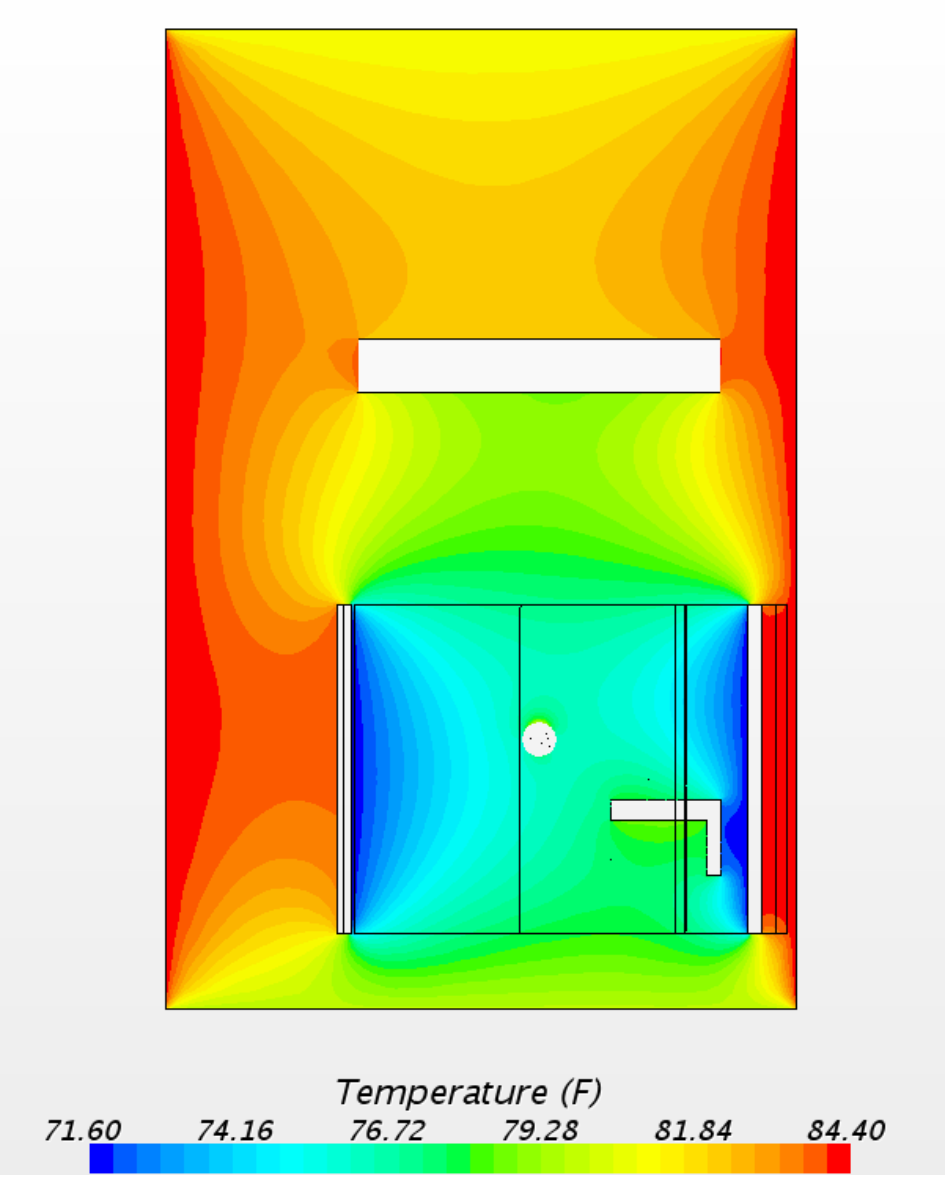


Test Set-up - Plan View



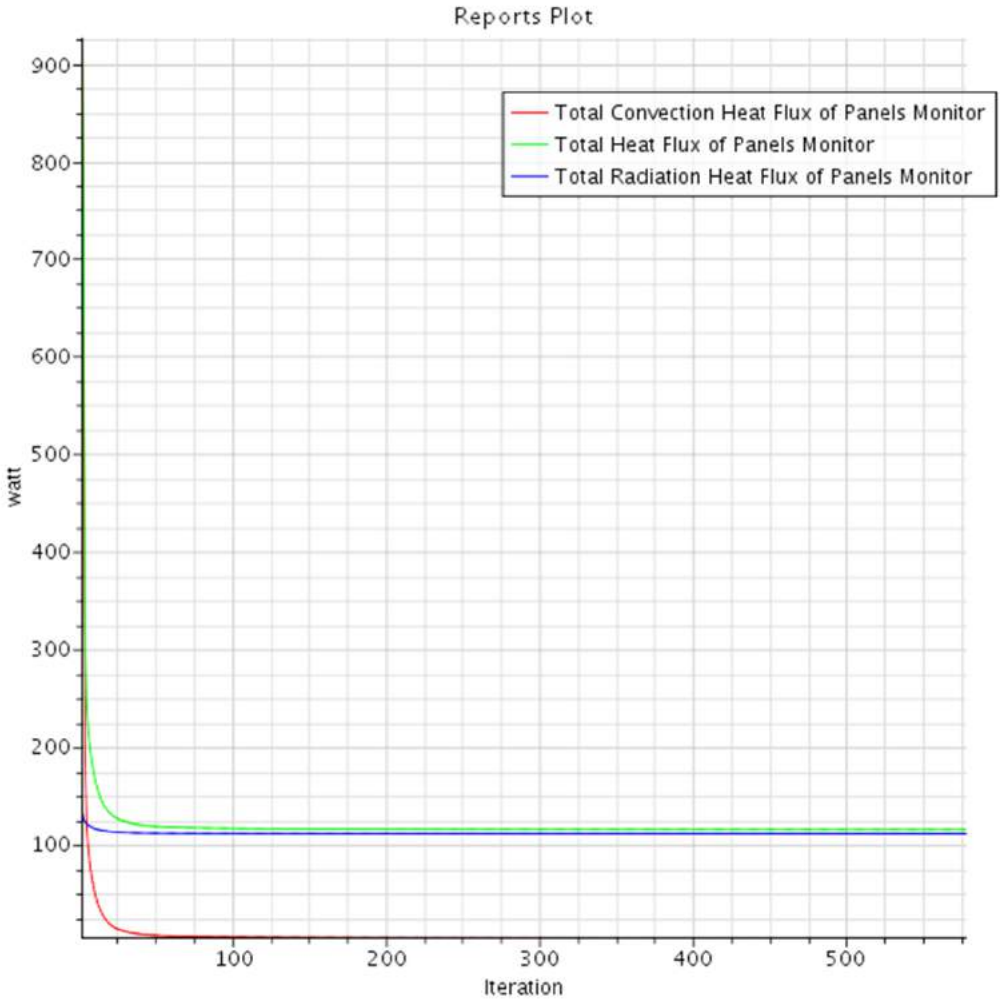
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 2



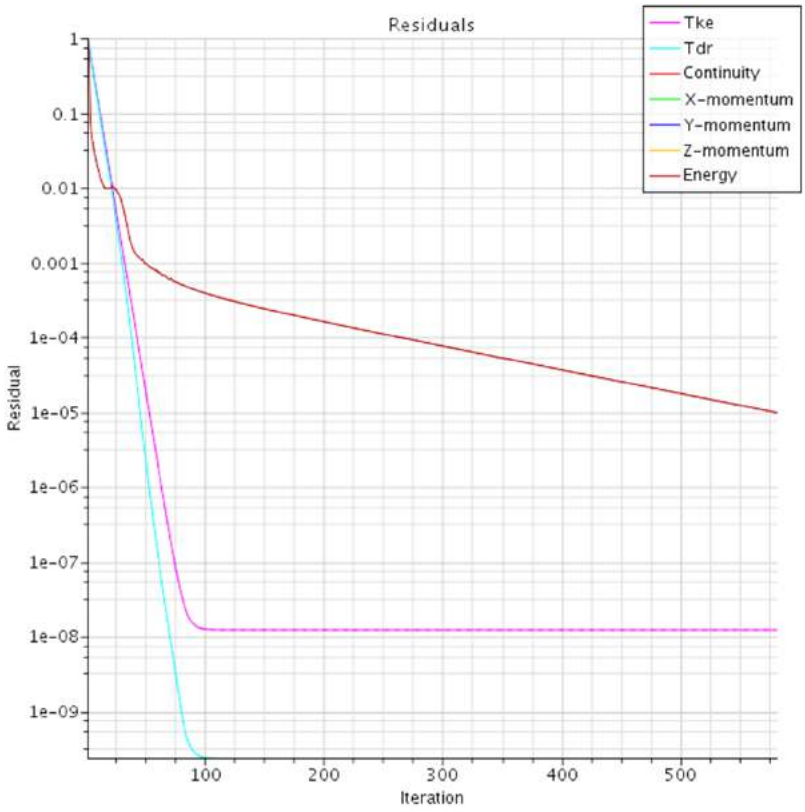
Test Set-up - Section B-B

Presentation of Qualitative Post processing For Scenarios A 2

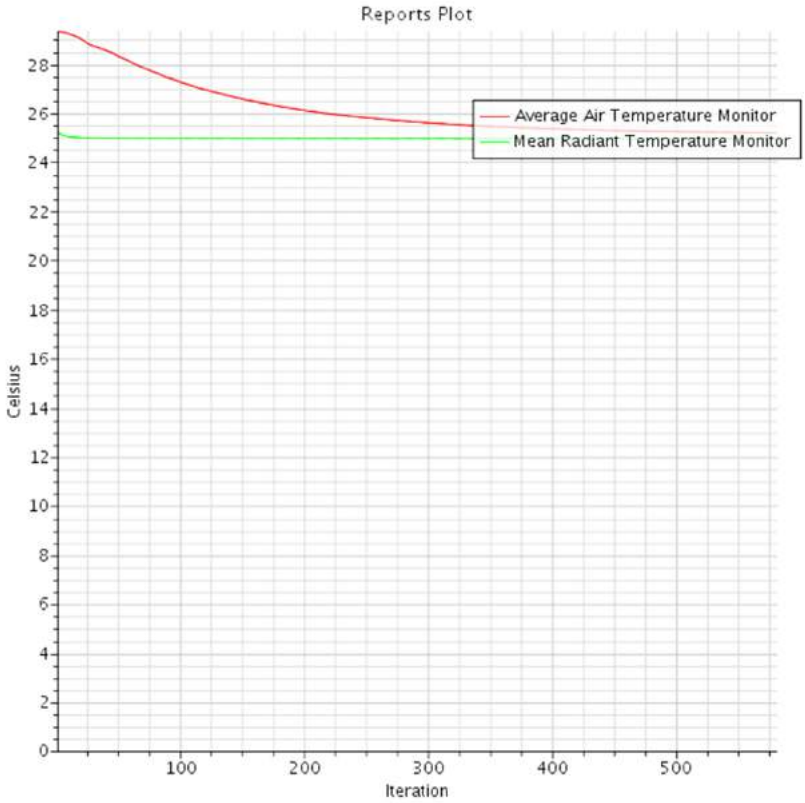


Heat Flux

Presentation of Qualitative Post processing
For Scenarios A 2

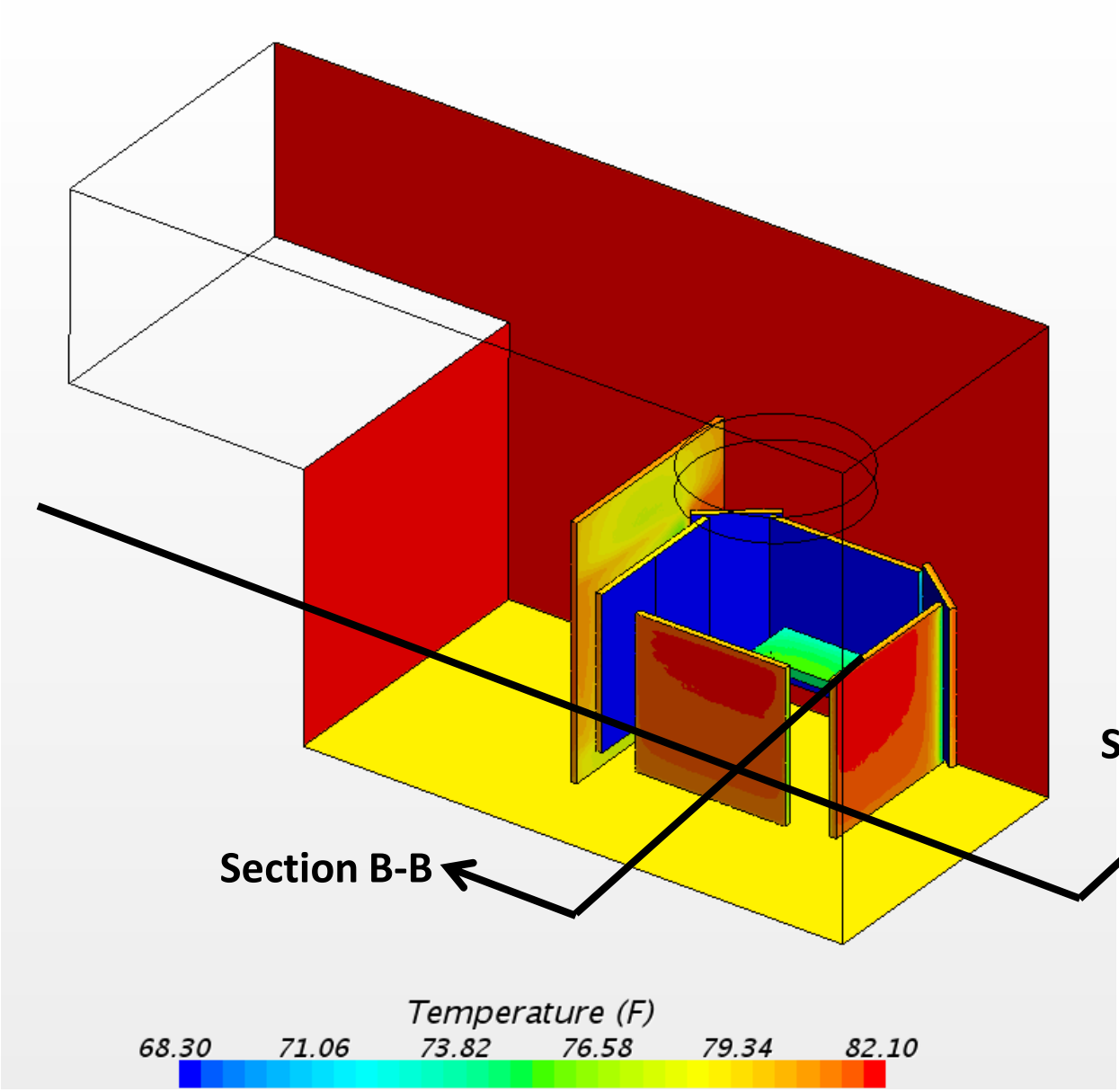


Convergence - Residuals



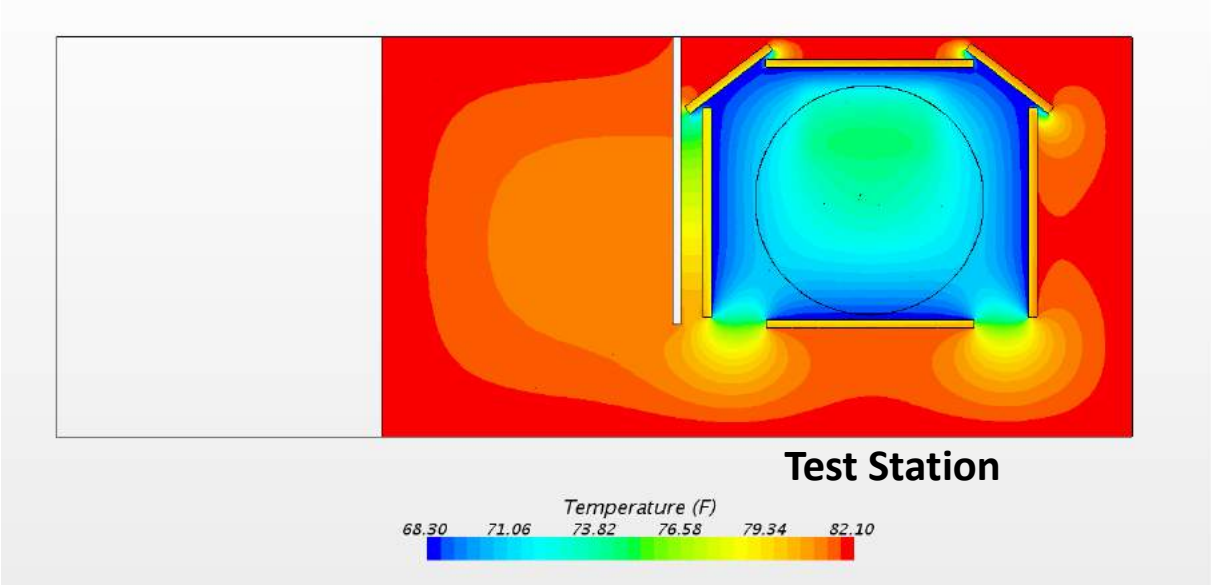
Convergence - Temperature

Presentation of Qualitative Post processing For Scenarios A 3

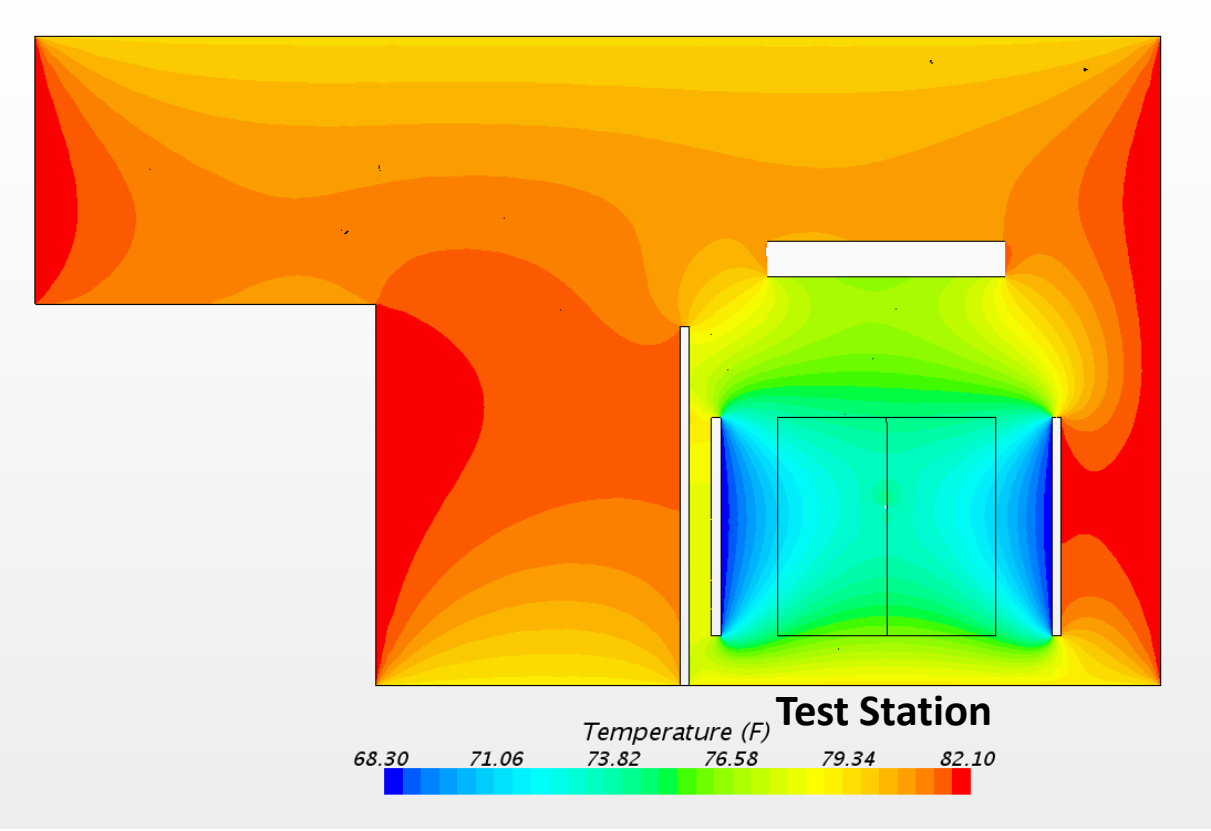


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 3

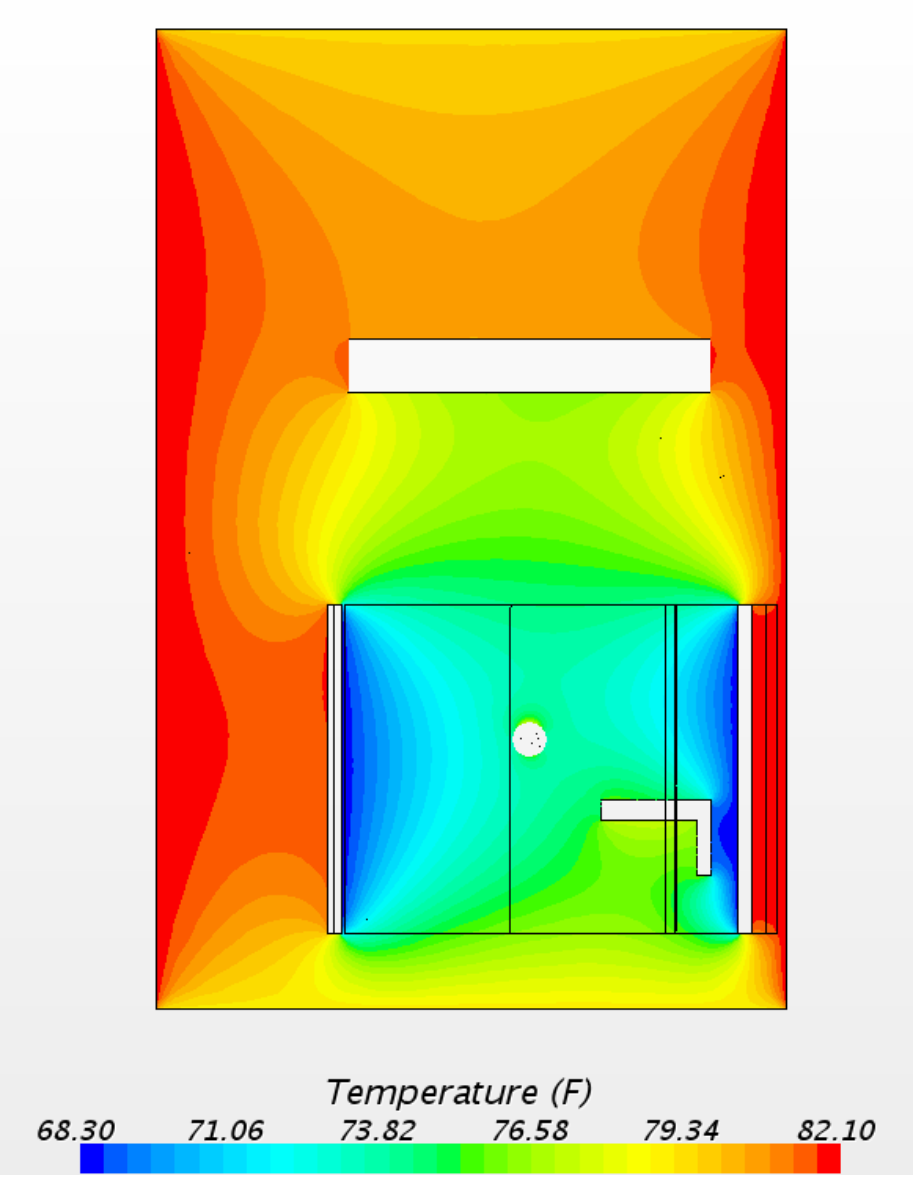


Test Set-up - Plan View



Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 3



Test Set-up - Section B-B

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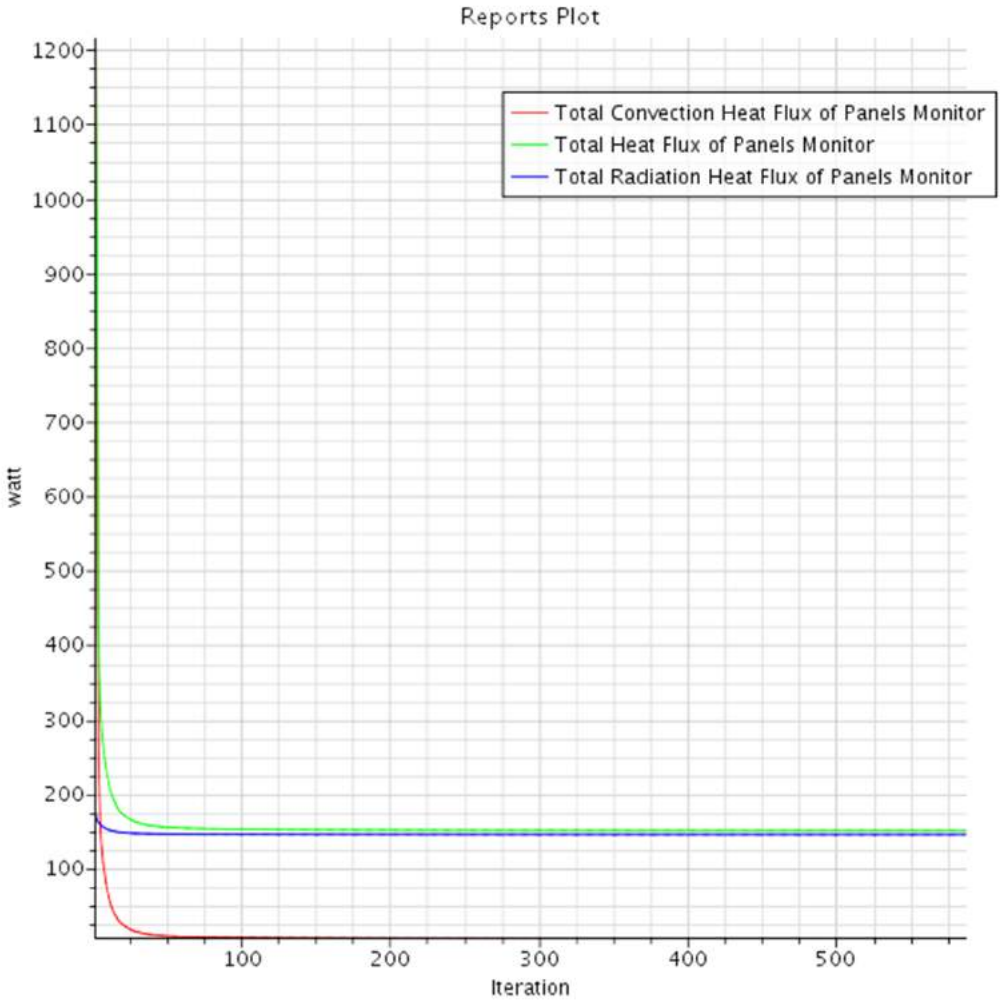
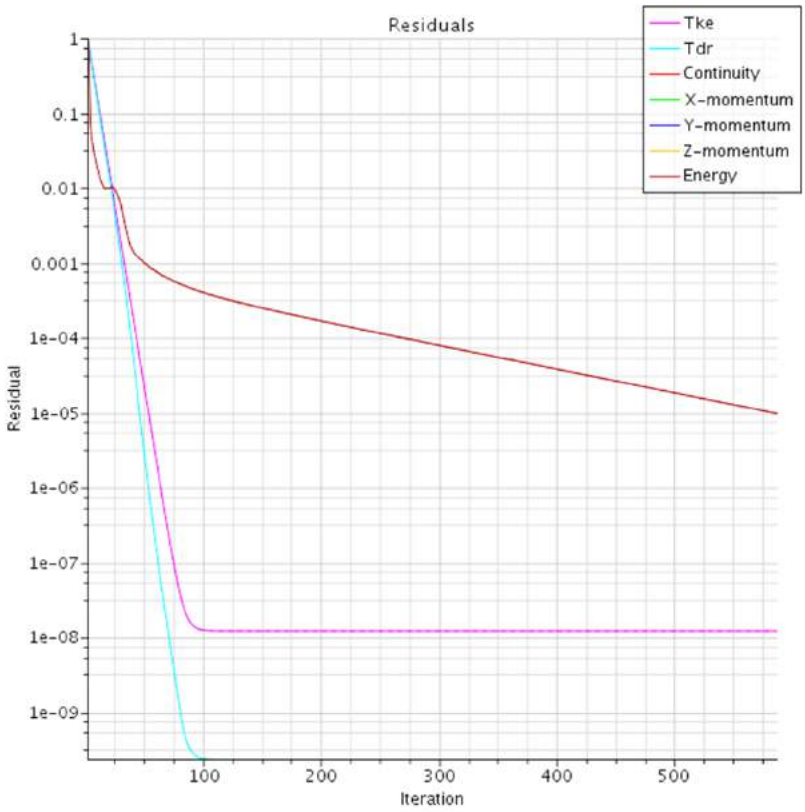
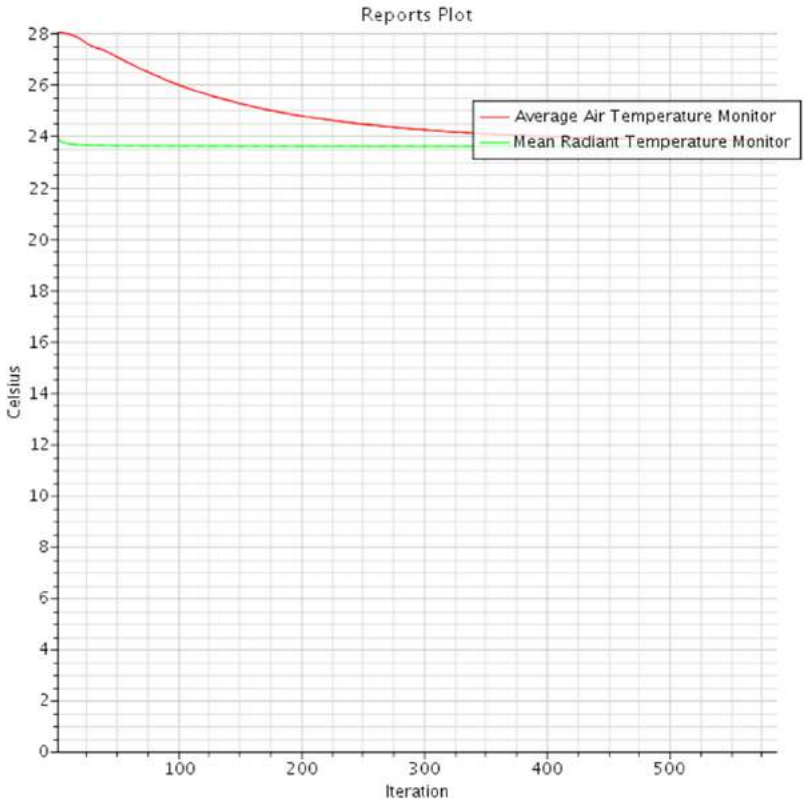


Heat Flux

Presentation of Qualitative Post processing
For Scenarios A 3

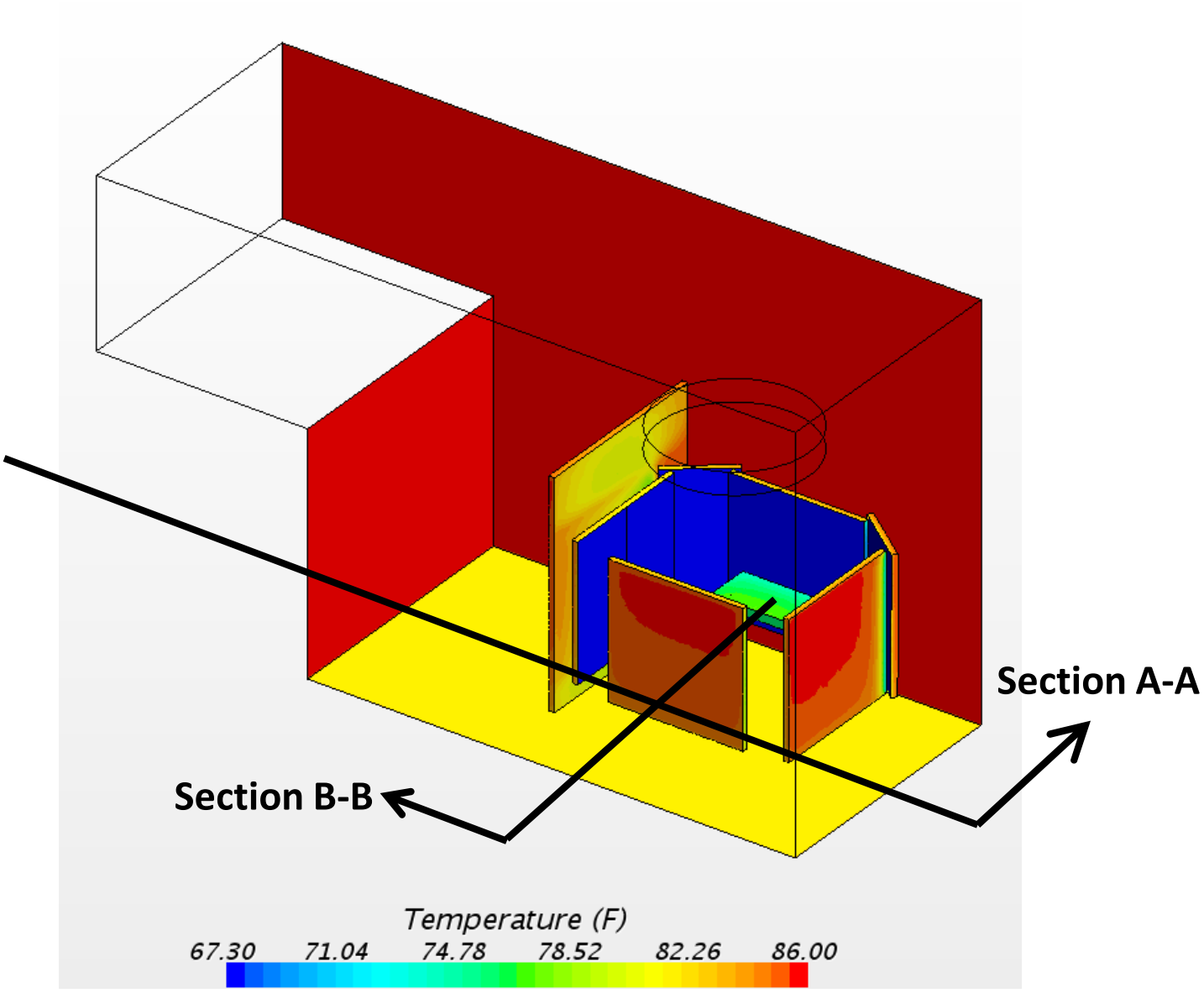


Convergence - Residuals



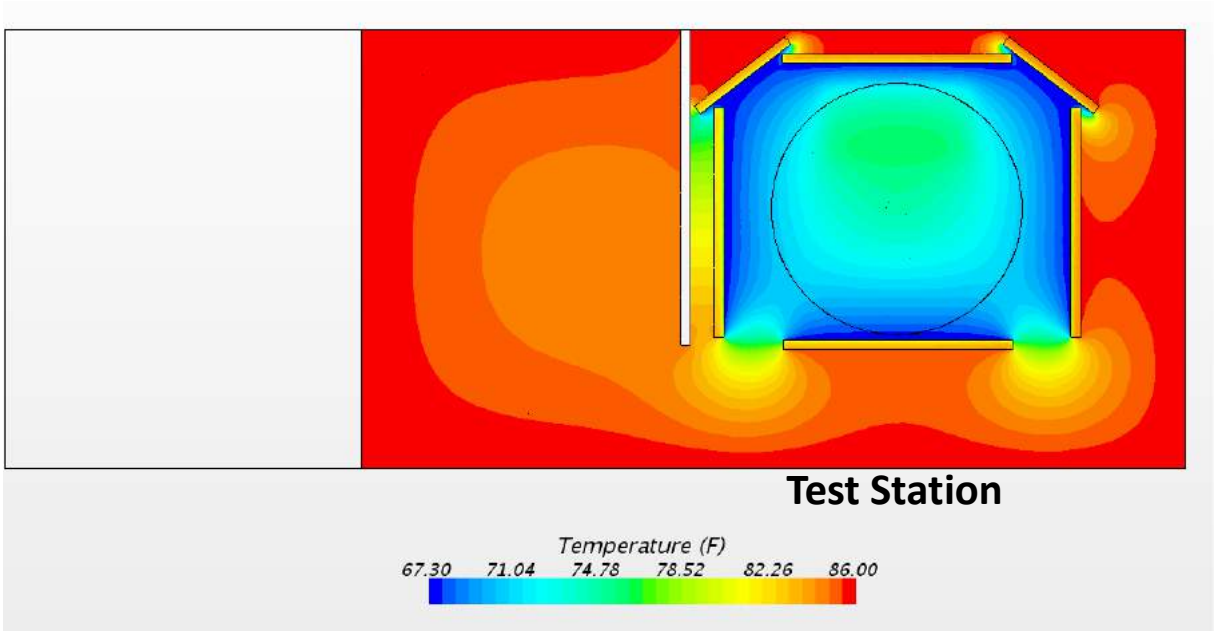
Convergence - Temperature

Presentation of Qualitative Post processing For Scenarios A 4

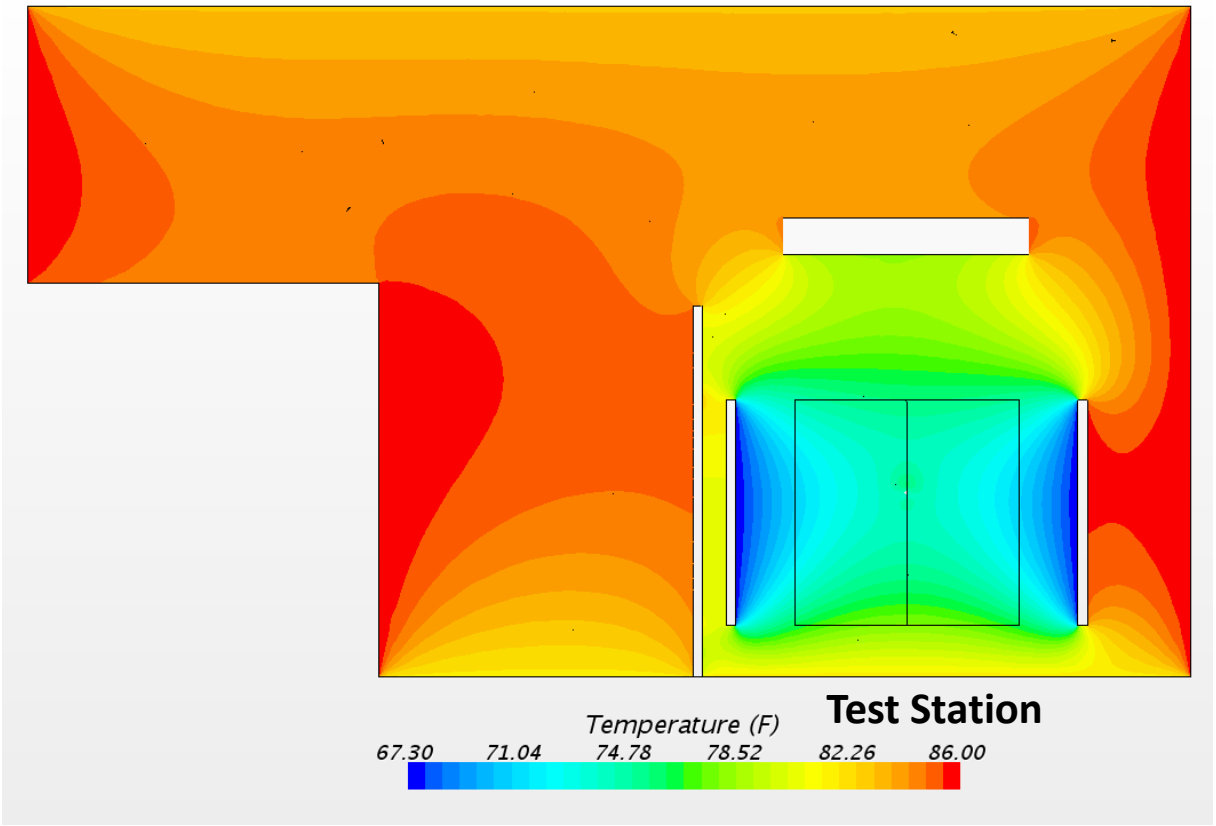


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 4



Test Set-up - Plan View



Test Set-up - Section A-A

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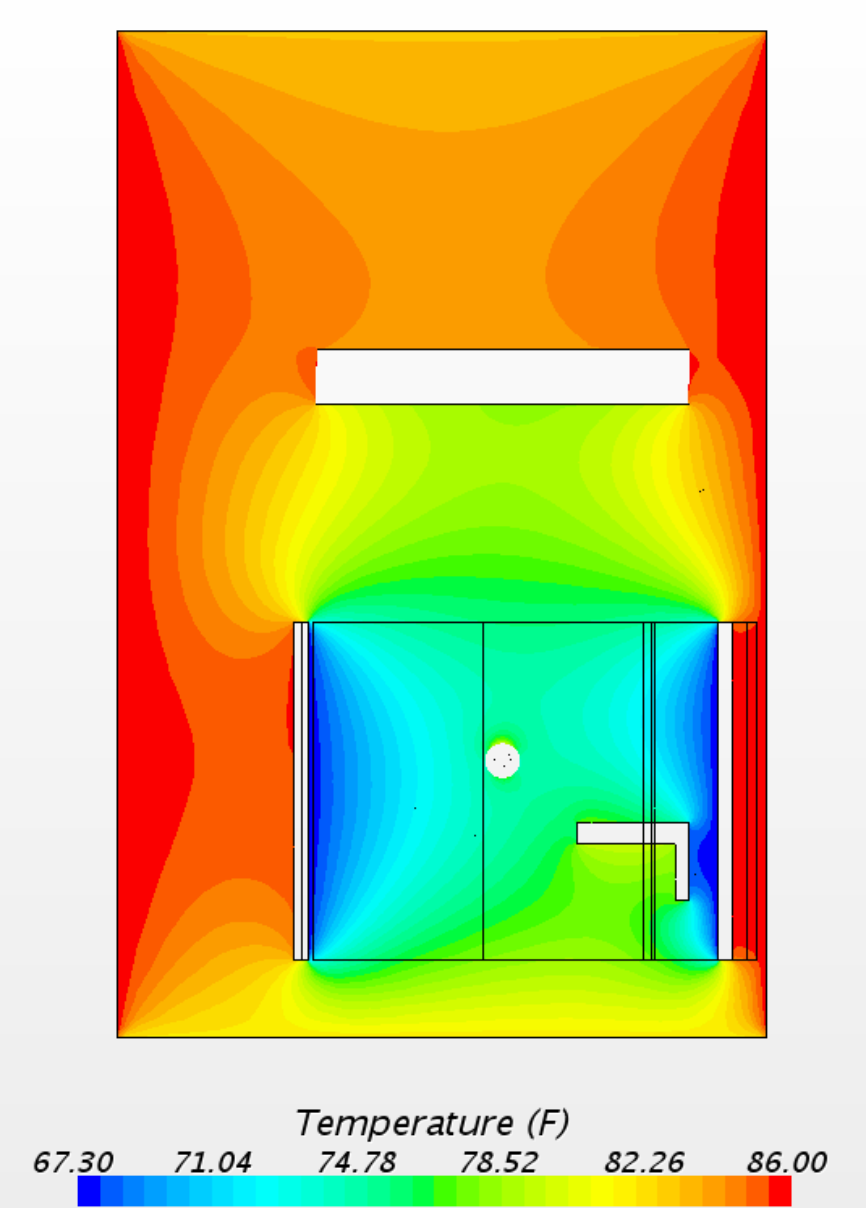

Test Set-up - Section B-B

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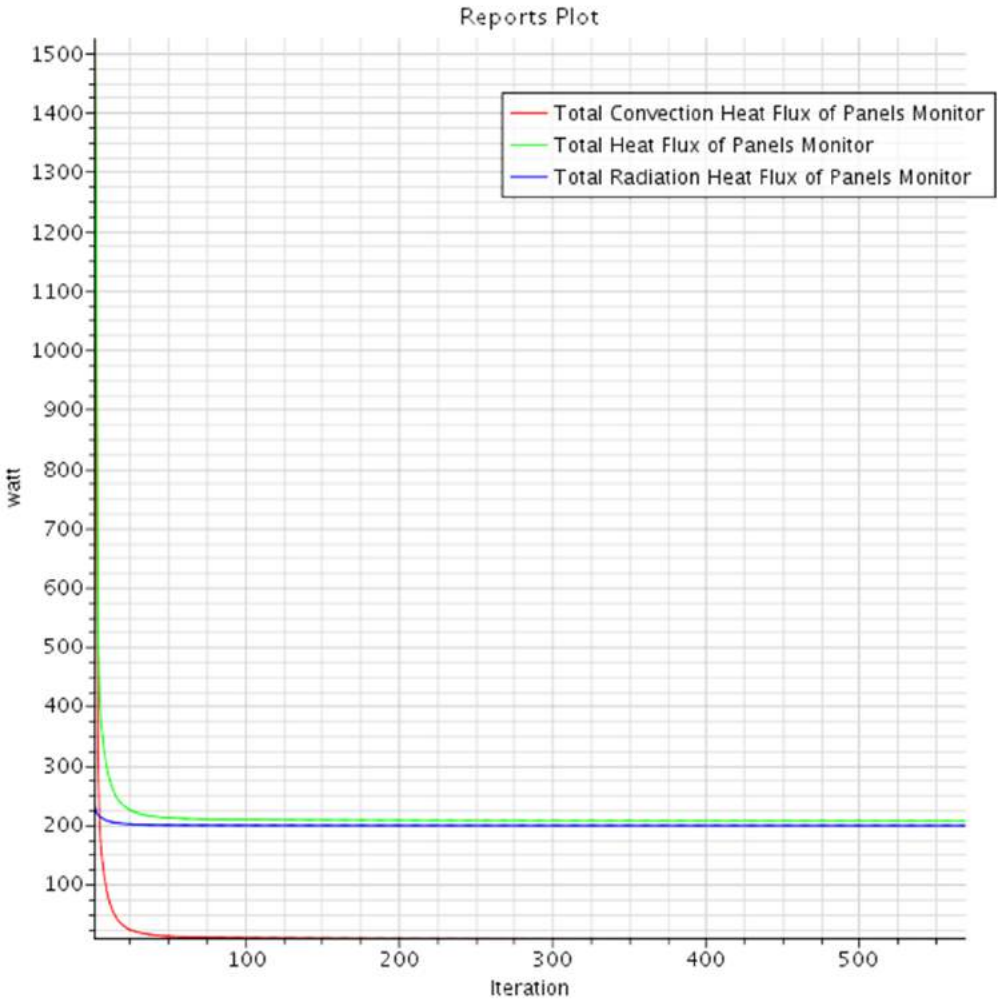
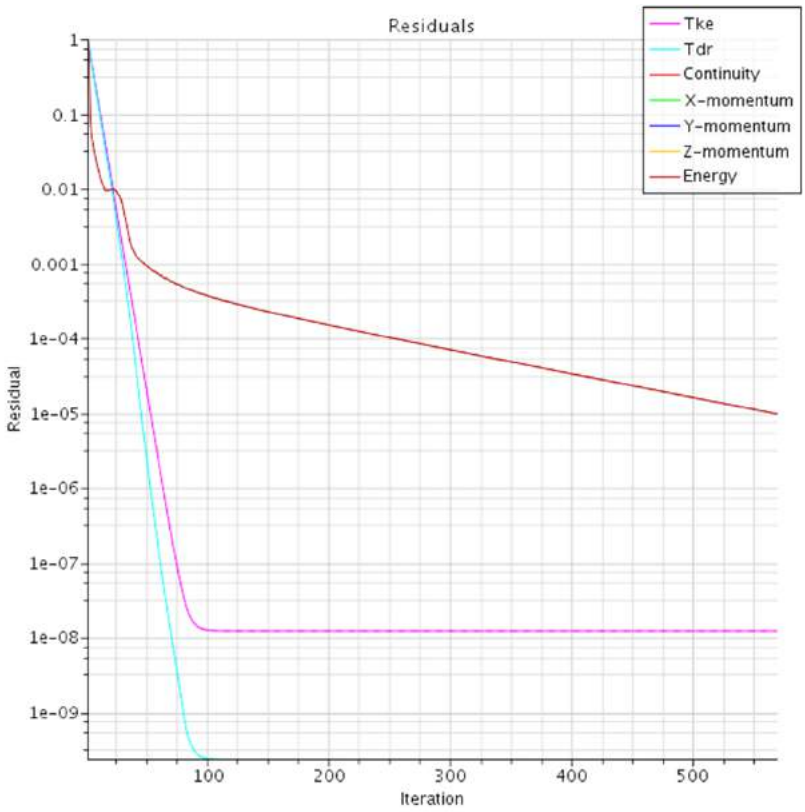
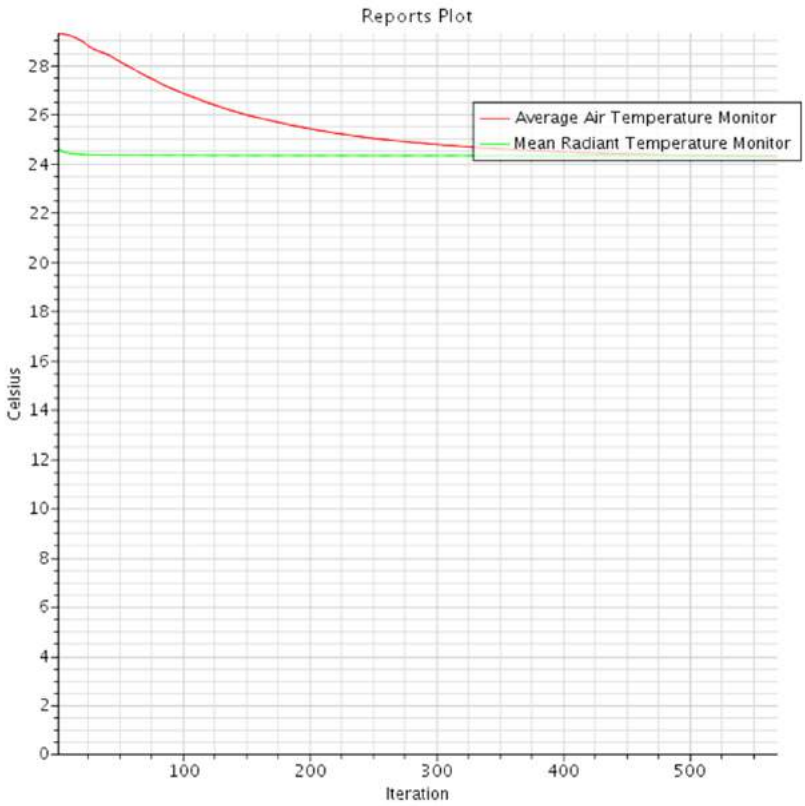


Heat Flux

Presentation of Qualitative Post processing For Scenarios A 4

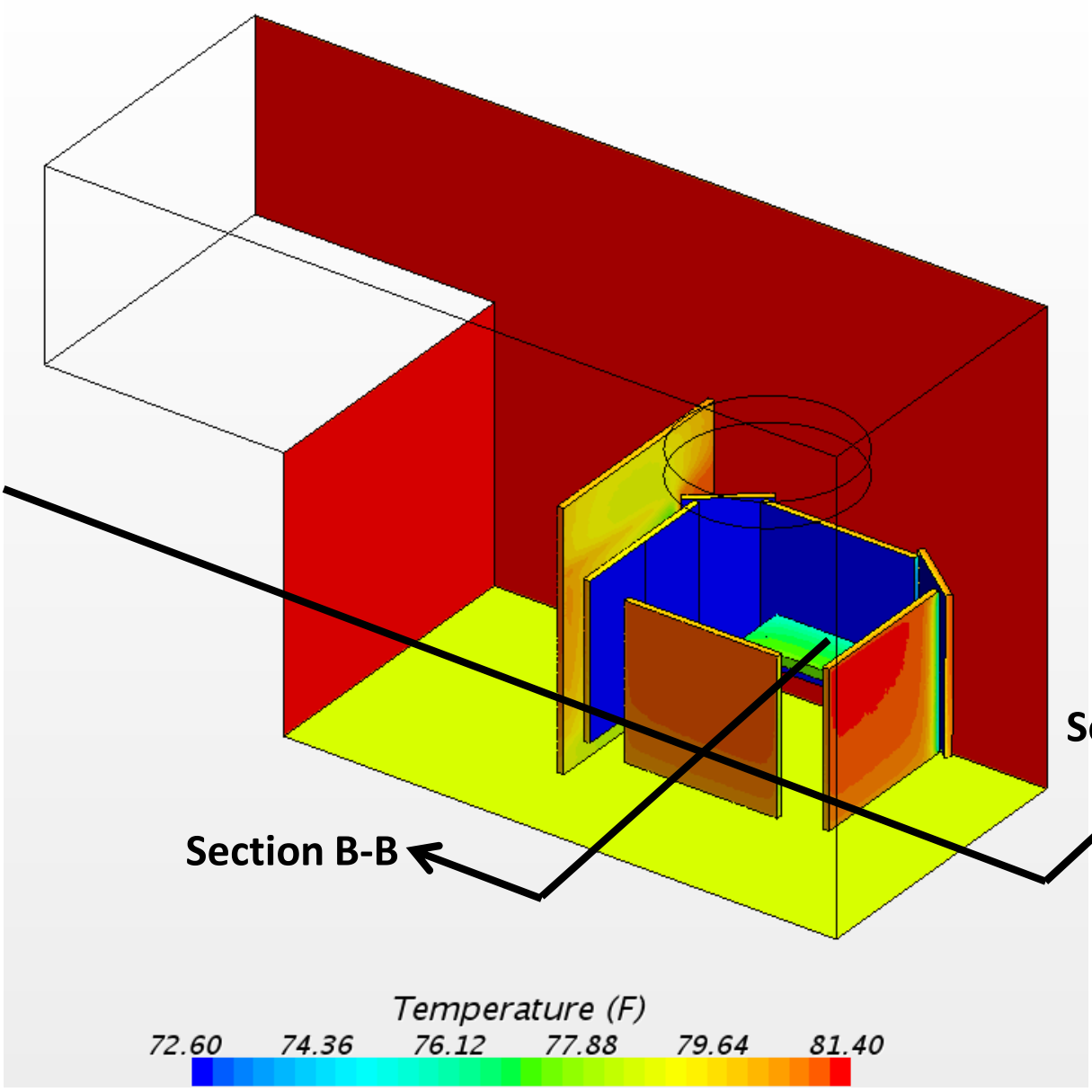


Convergence - Residuals



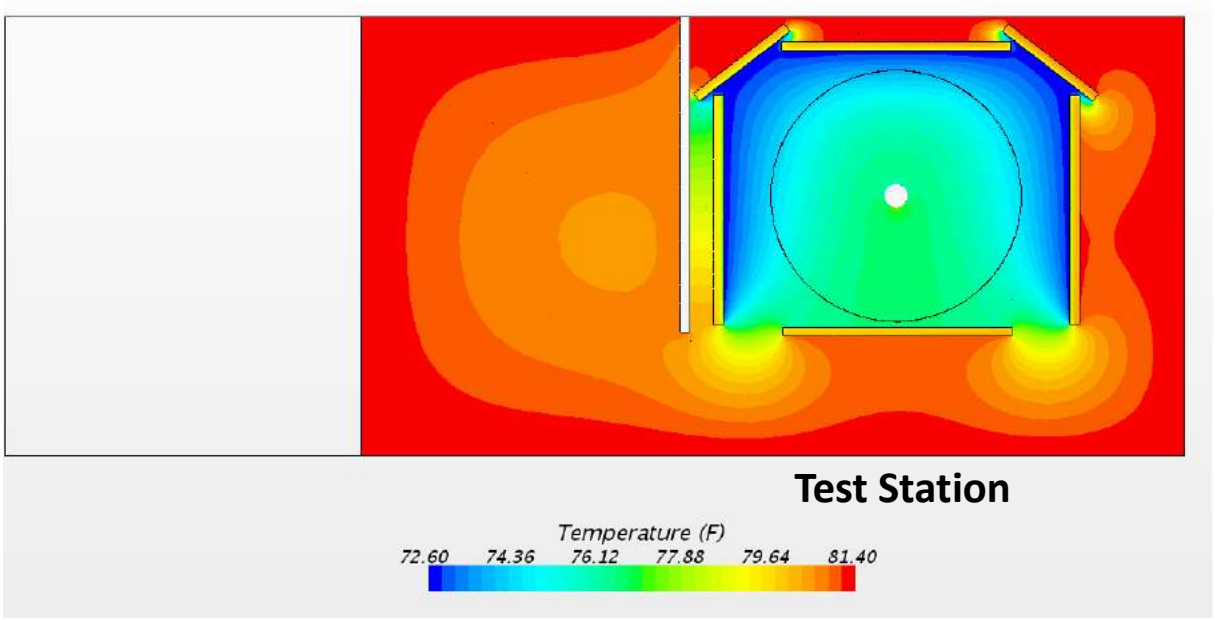
Convergence - Temperature

Presentation of Qualitative Post processing For Scenarios A 5

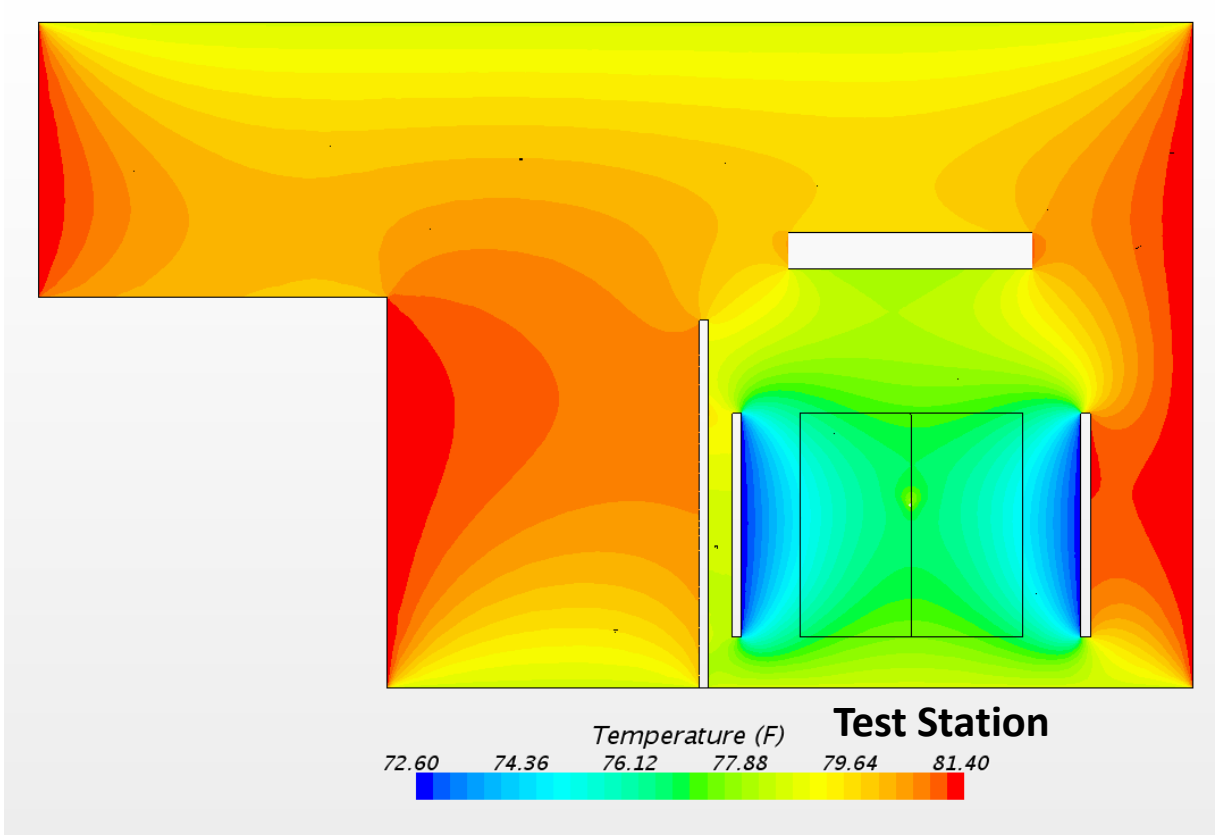


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 5

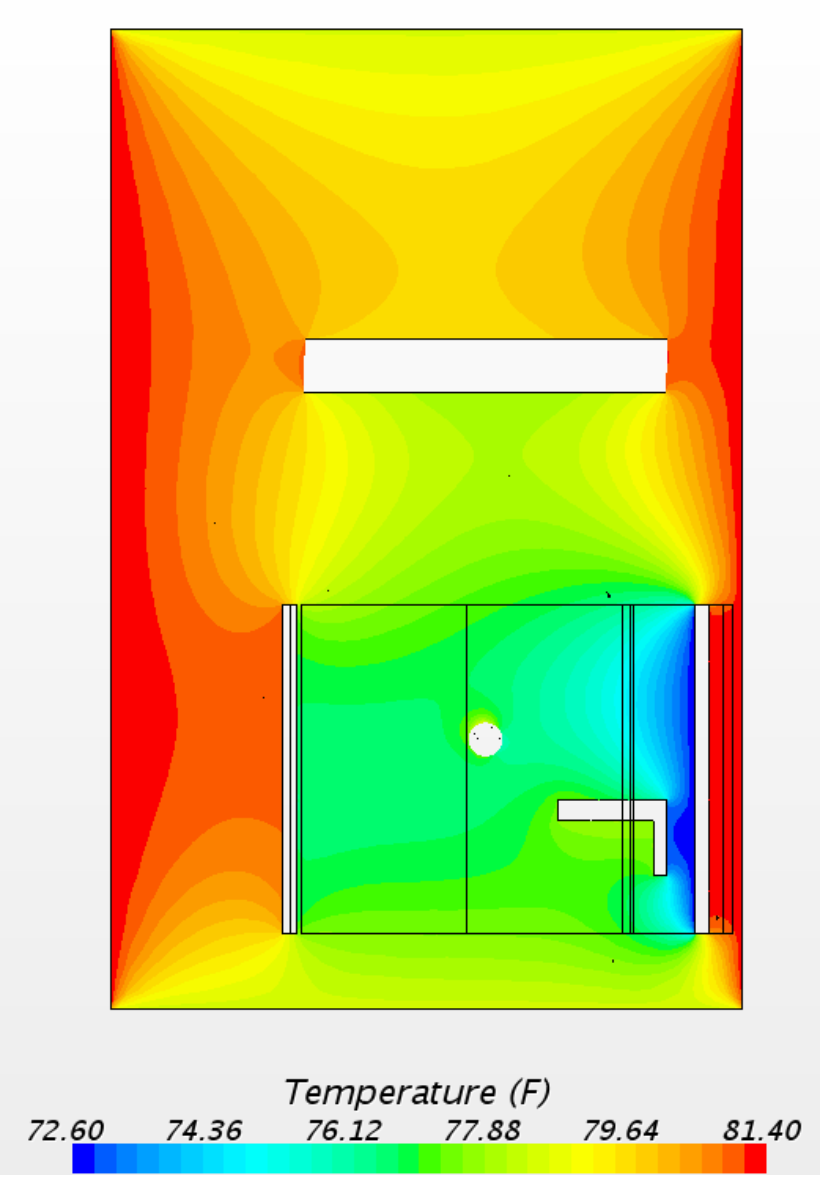


Test Set-up - Plan View



Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 5



Test Set-up - Section B-B

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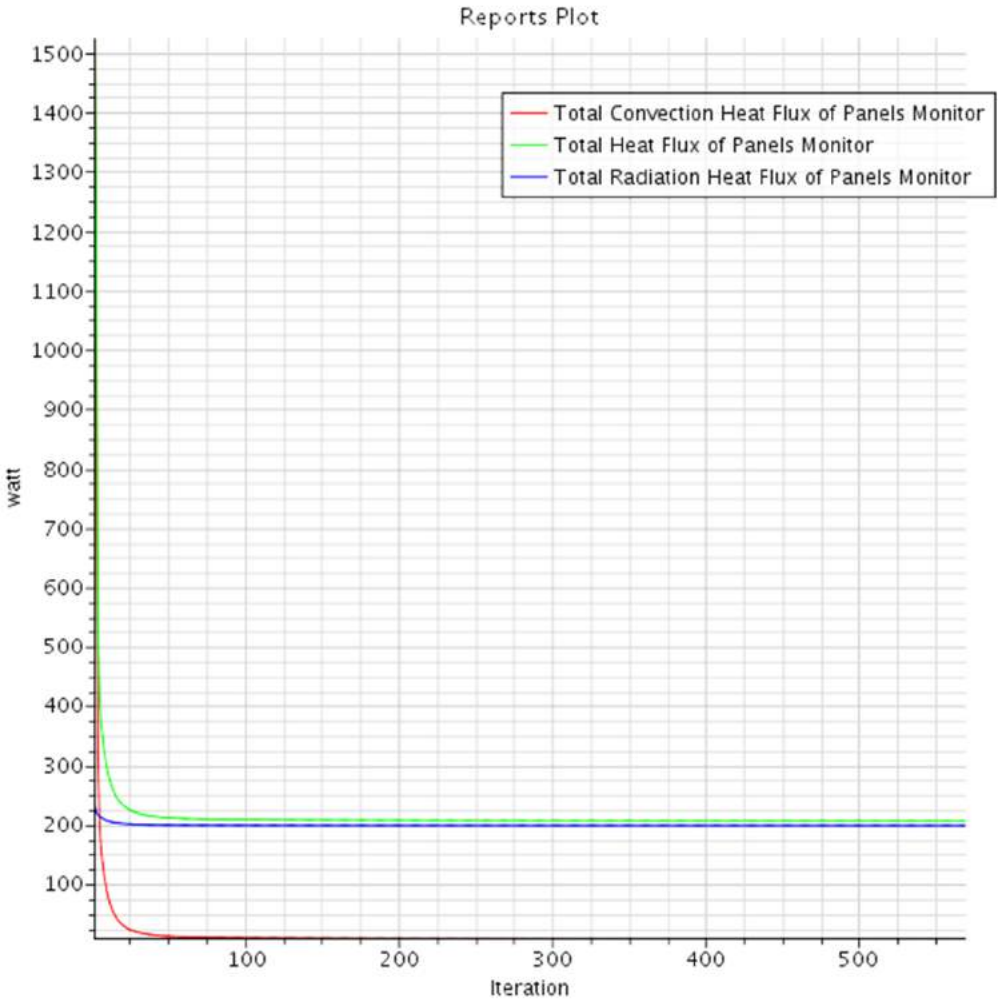
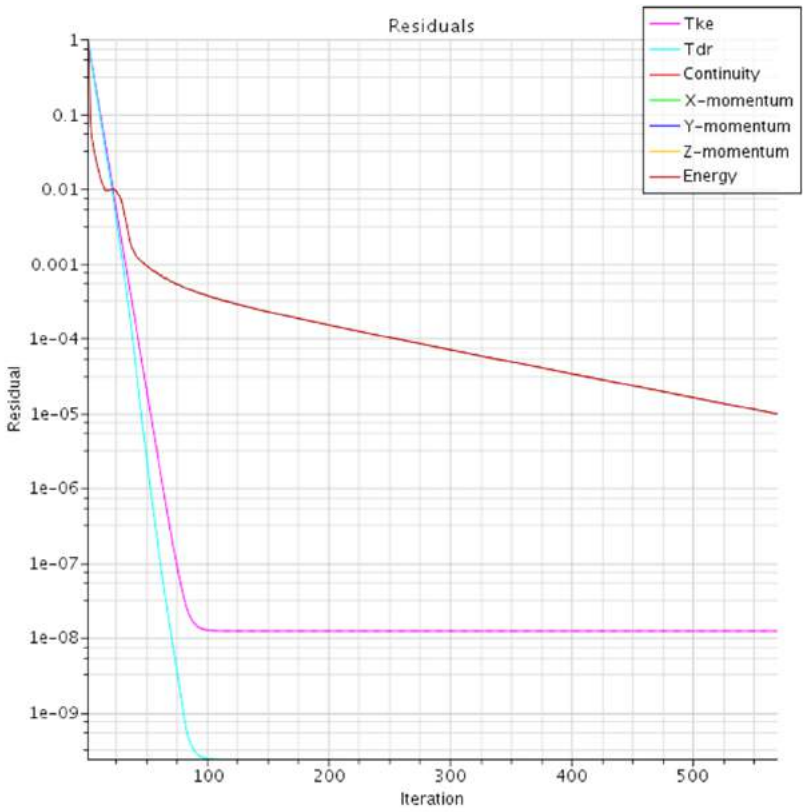
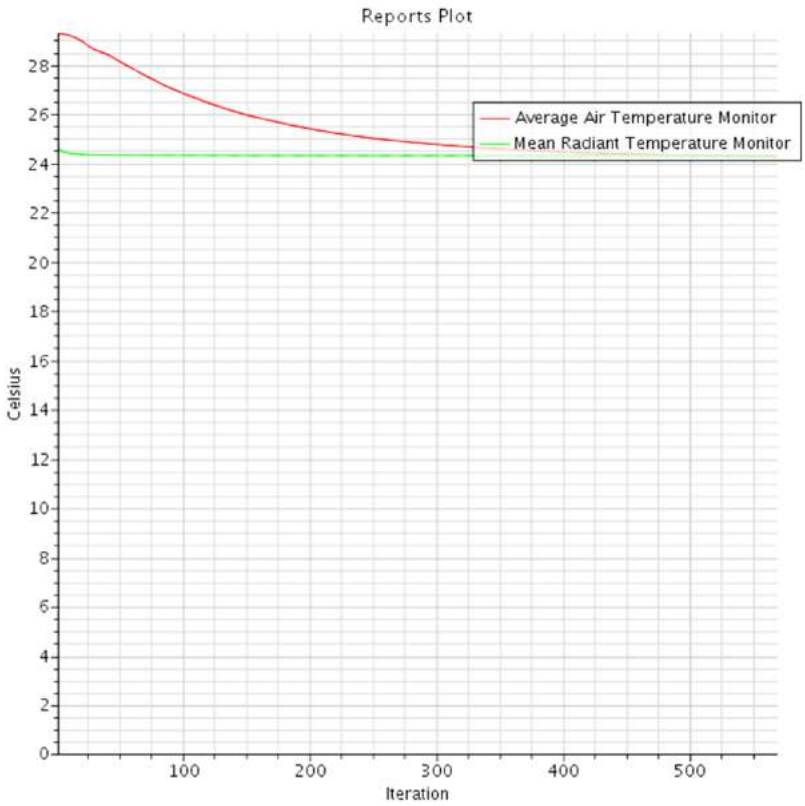


Heat Flux

Presentation of Qualitative Post processing For Scenarios A 5

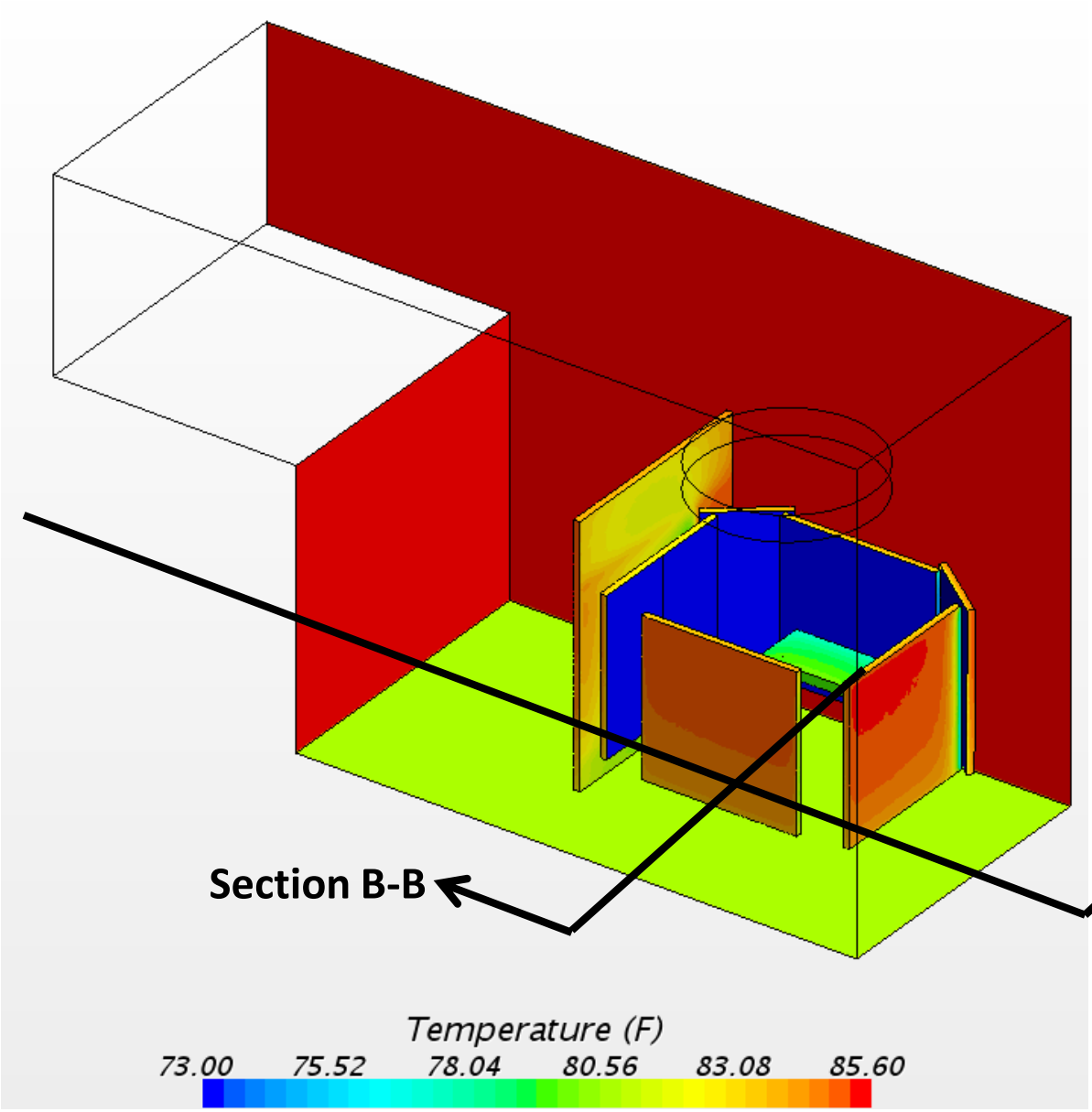


Convergence - Residuals



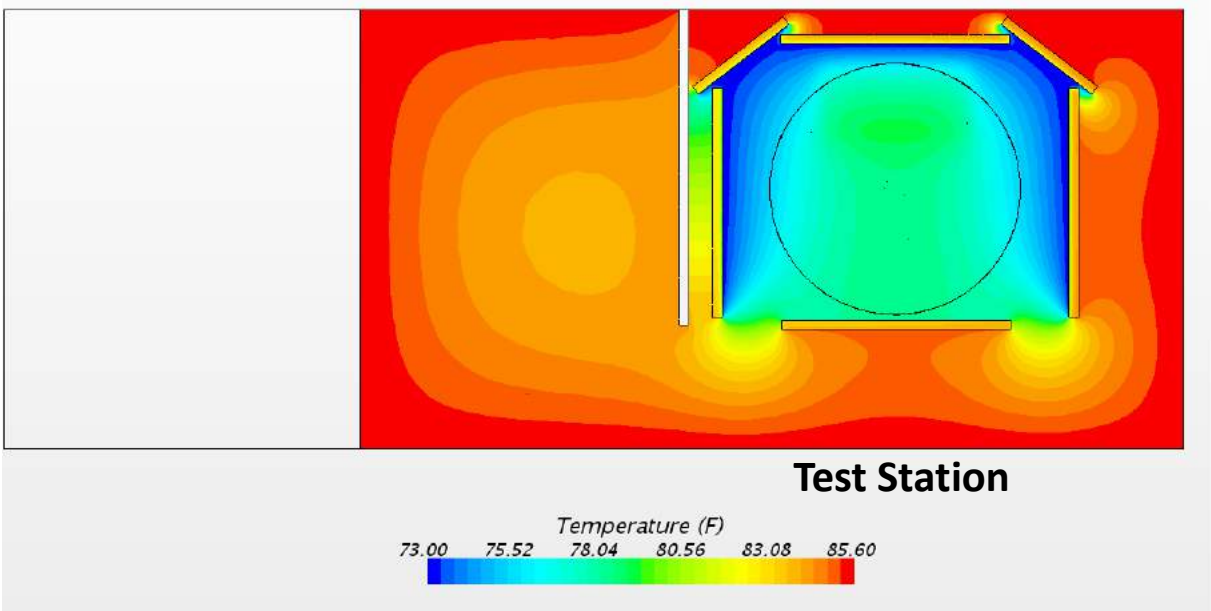
Convergence - Temperature

Presentation of Qualitative Post processing For Scenarios A 6

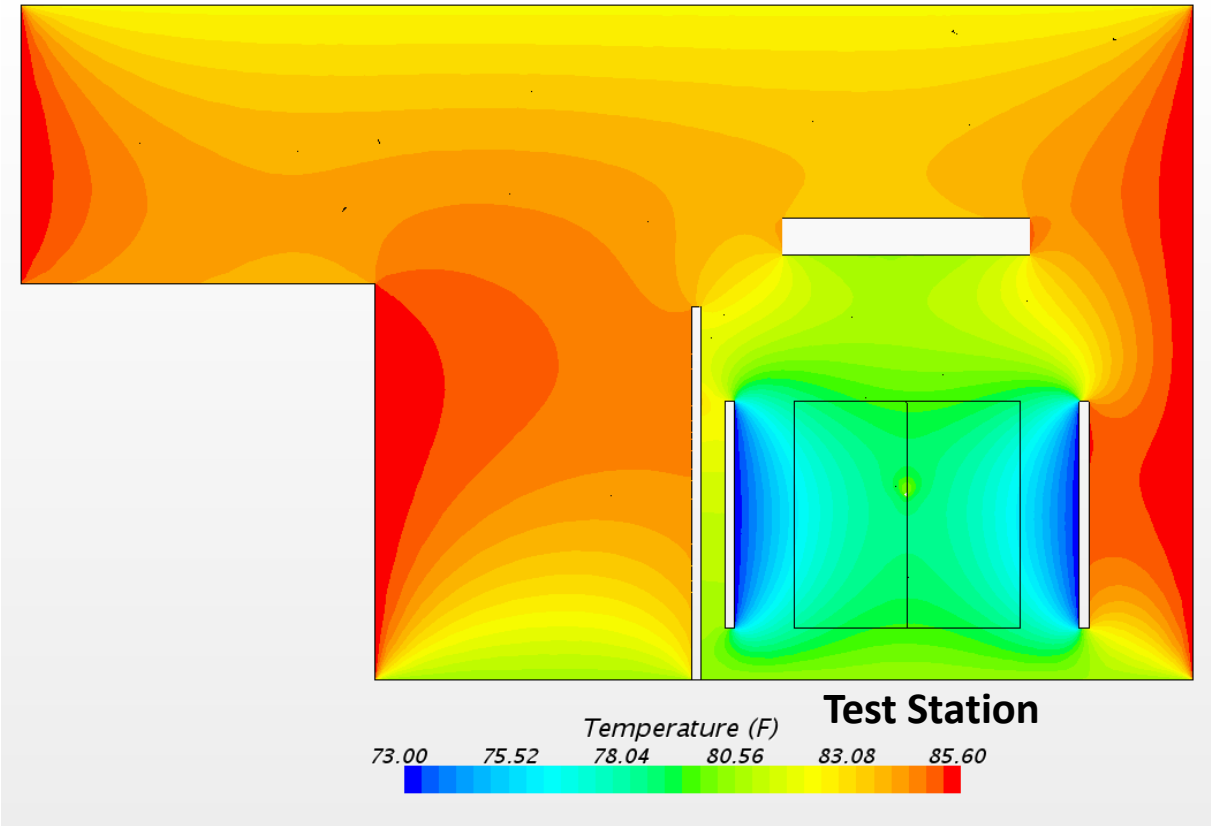


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 6

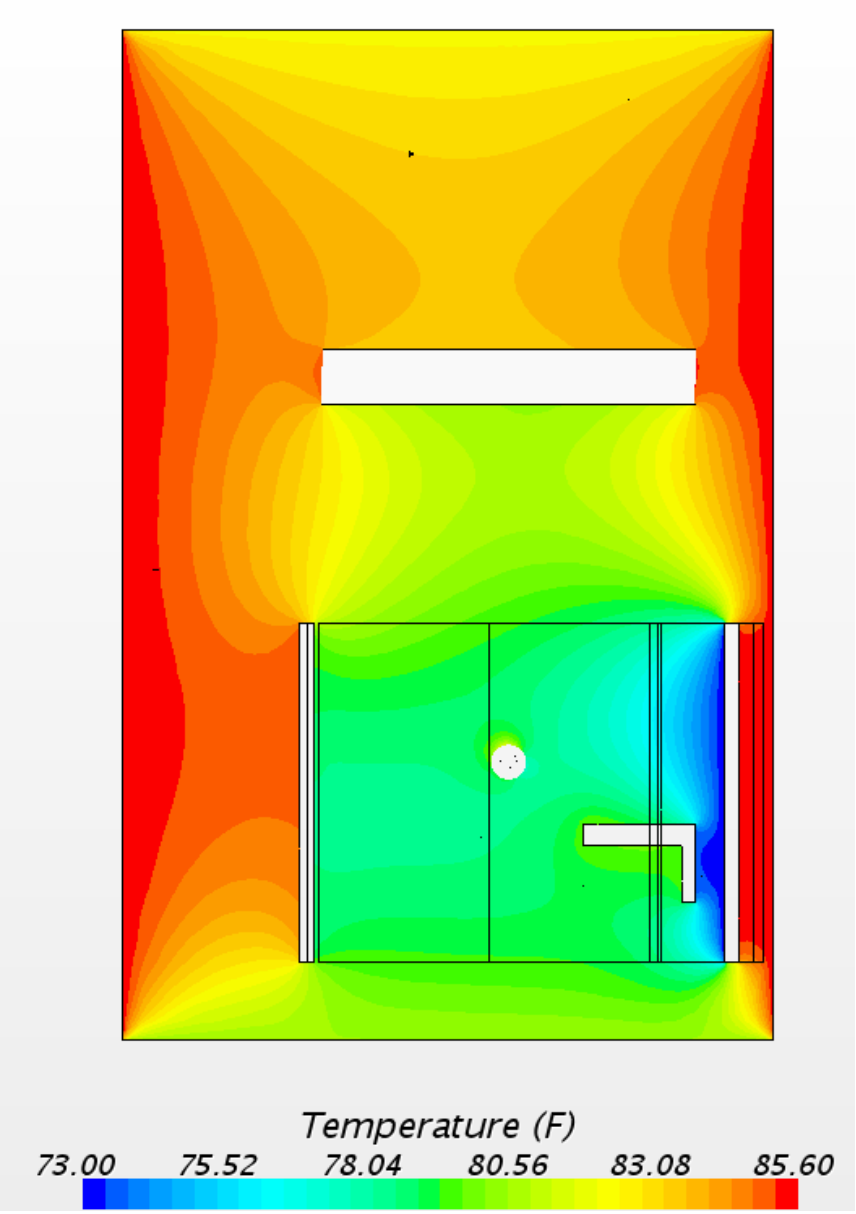


Test Set-up - Plan View



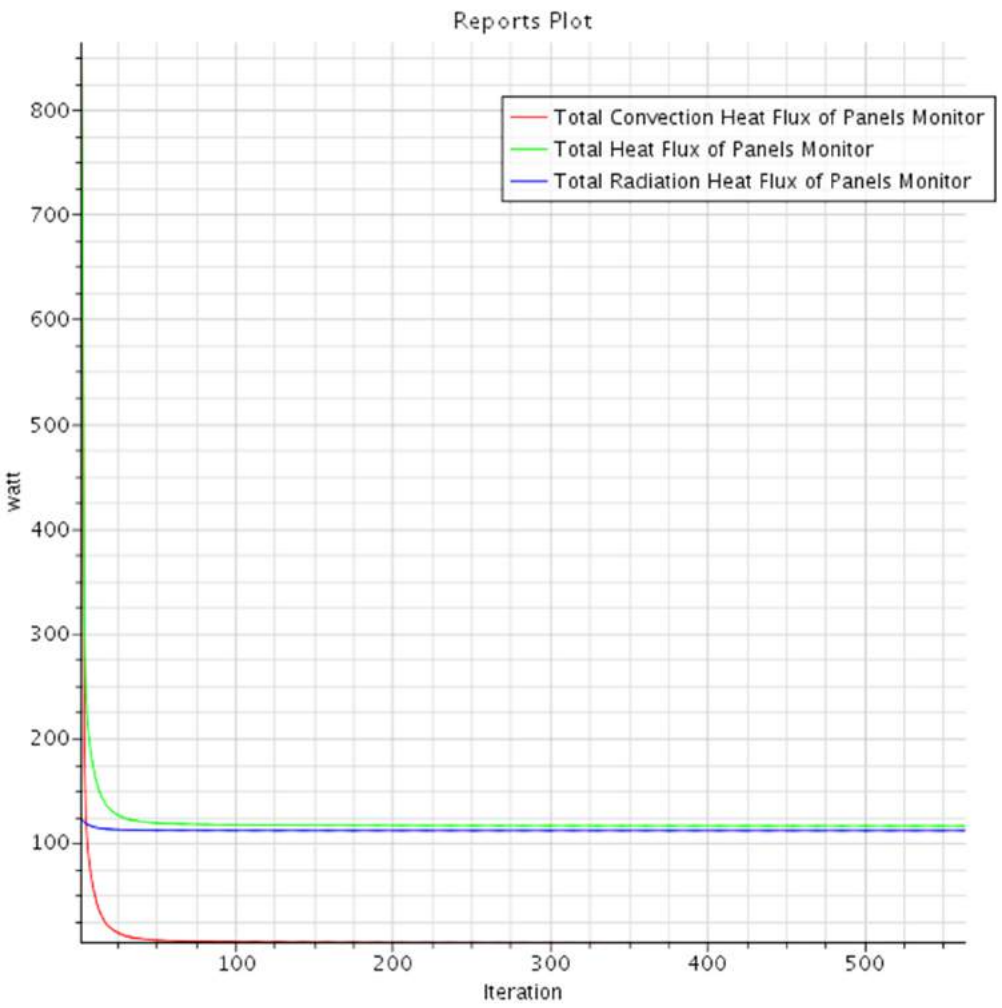
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 6



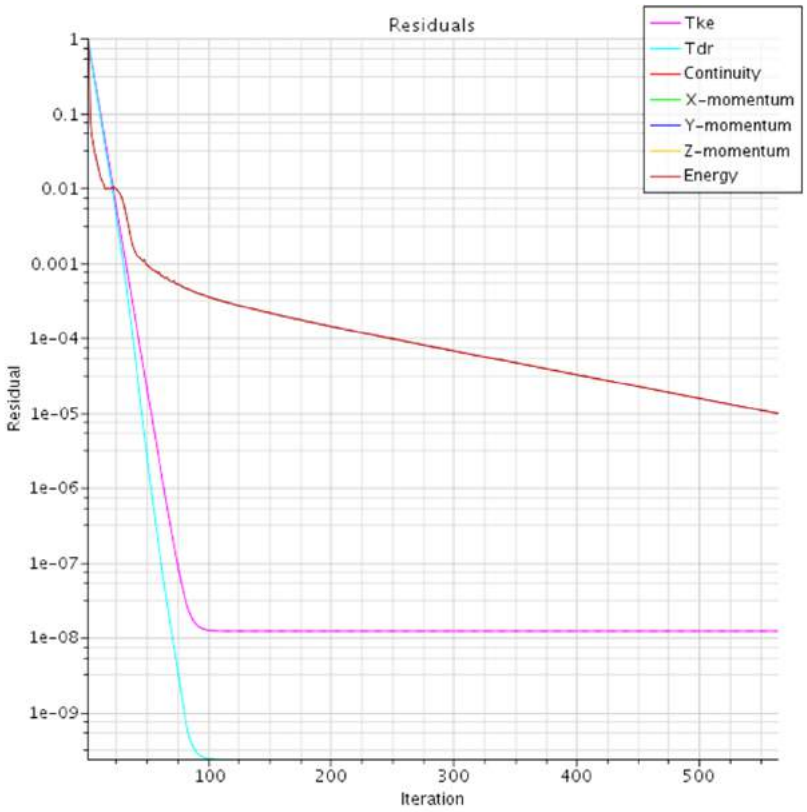
Test Set-up - Section B-B

Presentation of Qualitative Post processing For Scenarios A 6

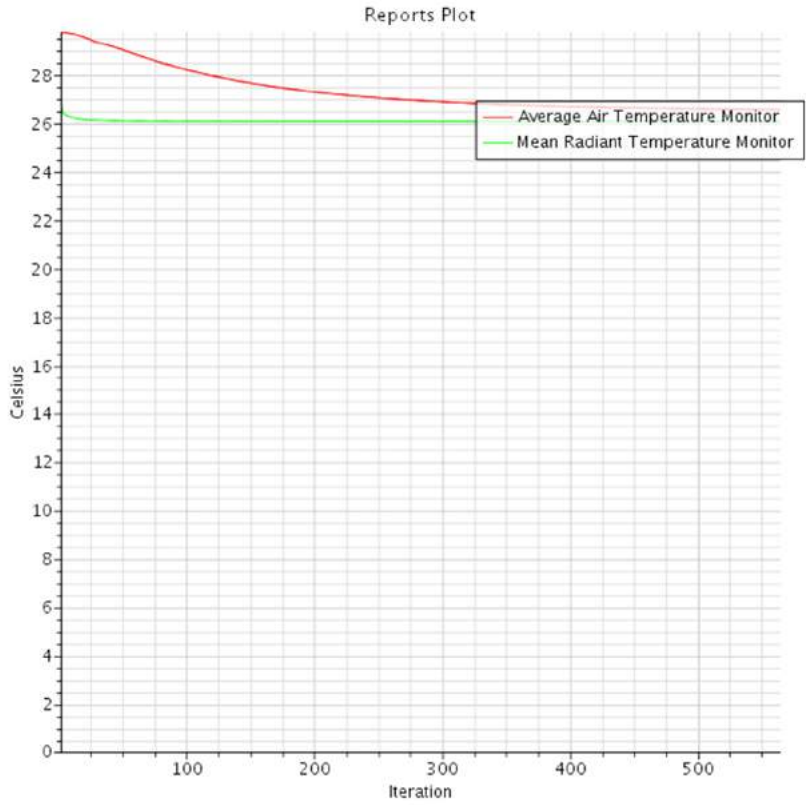


Heat Flux

Presentation of Qualitative Post processing For Scenarios A 6

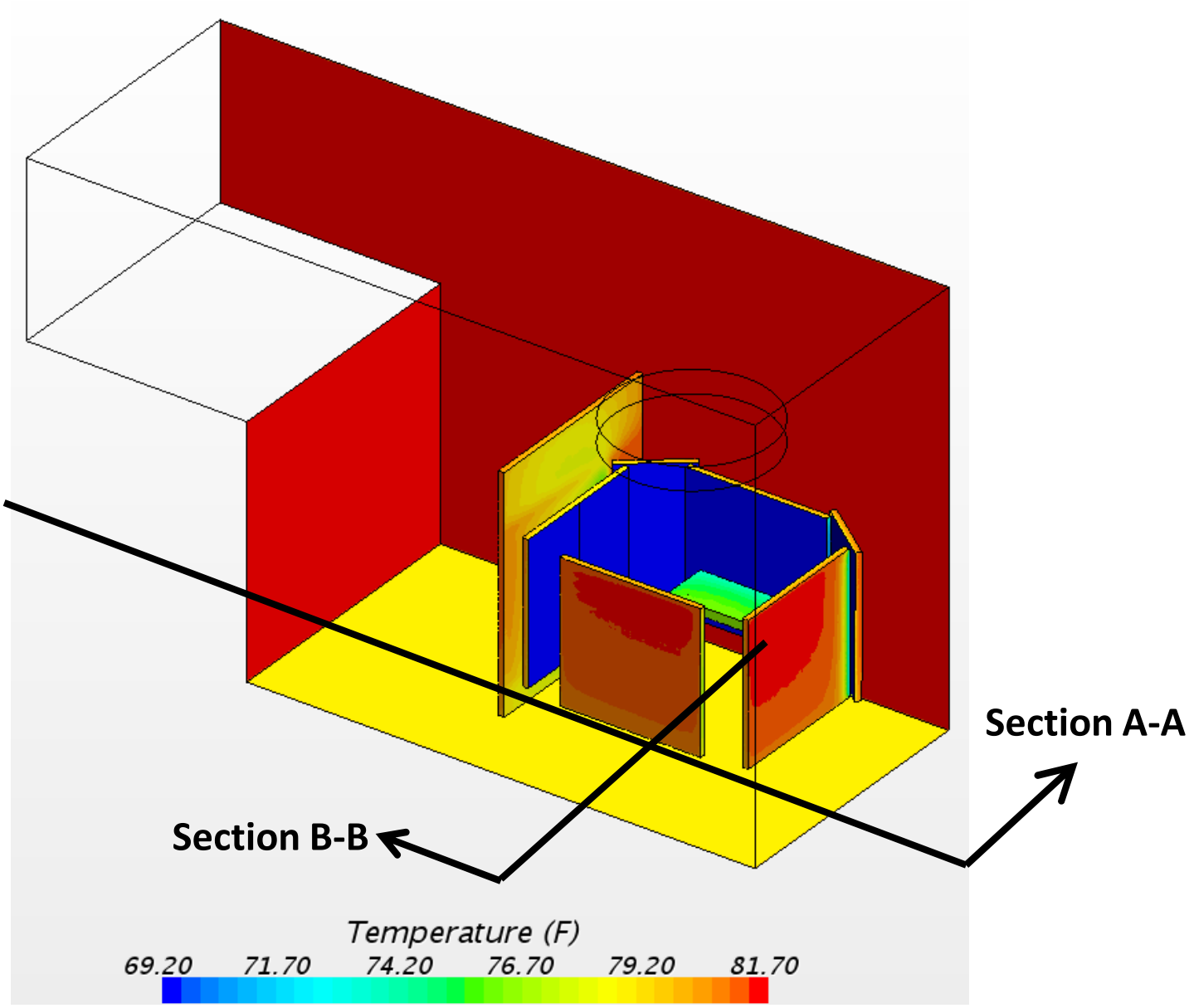


Convergence - Residuals



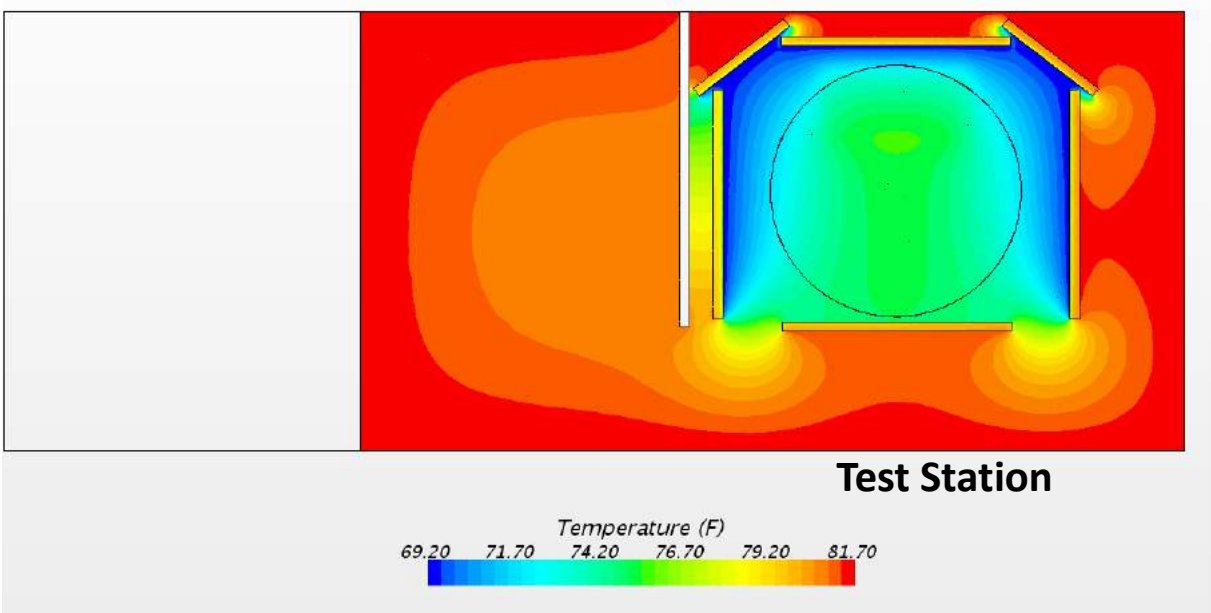
Convergence - Temperature

Presentation of Qualitative Post processing For Scenarios A 7

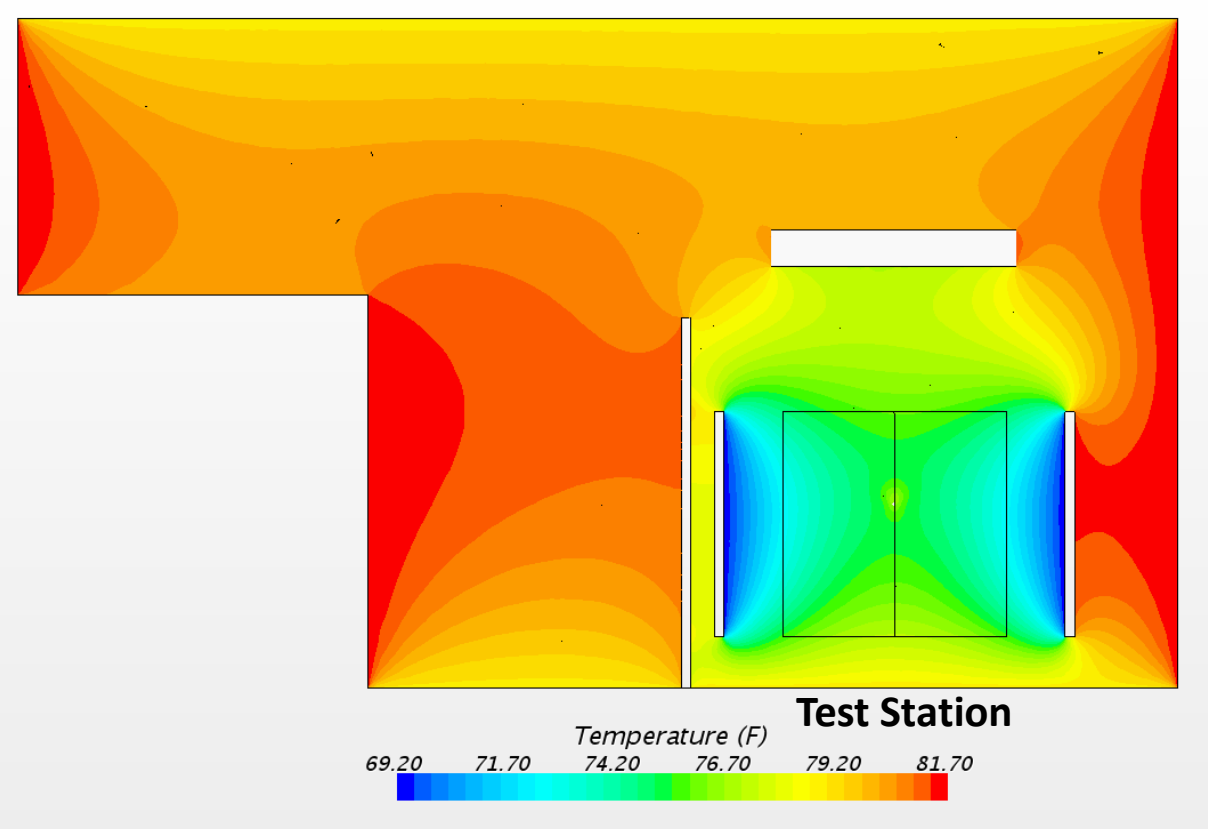


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 7

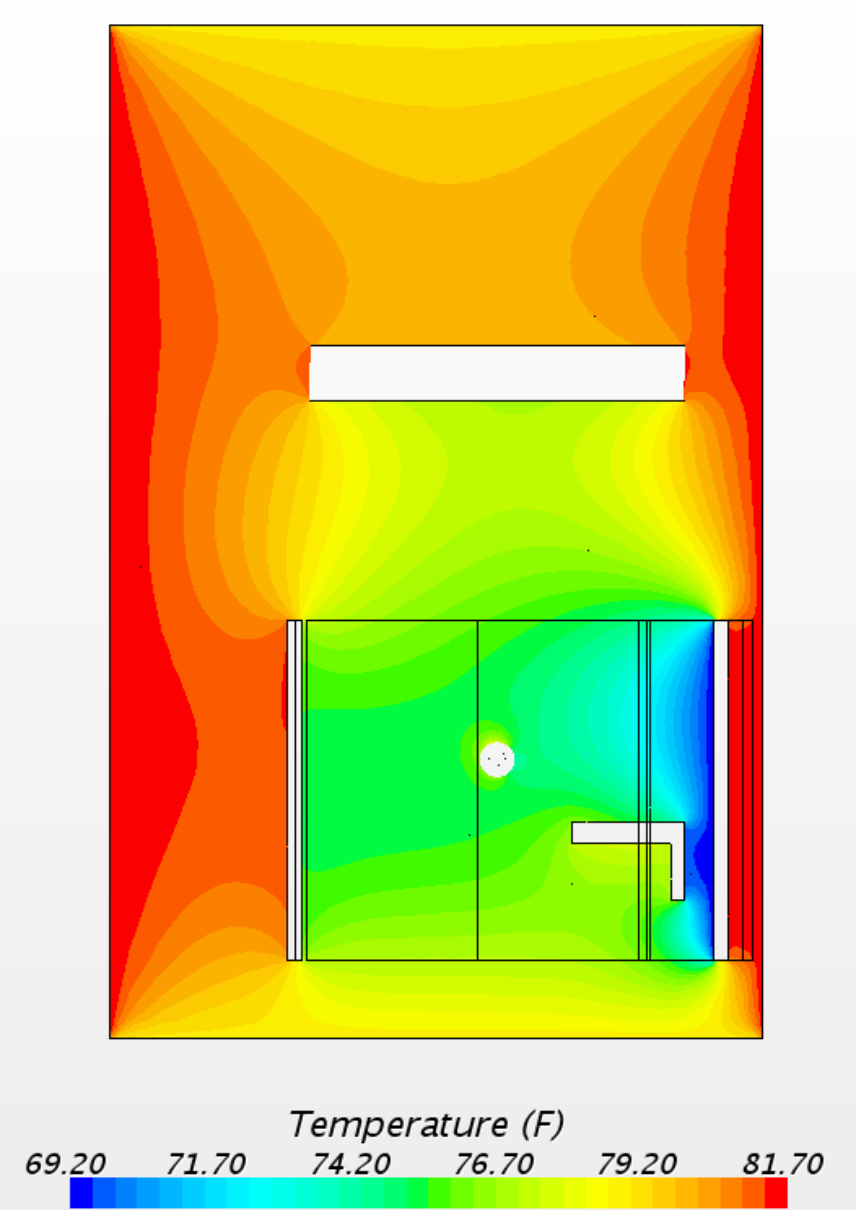


Test Set-up - Plan View



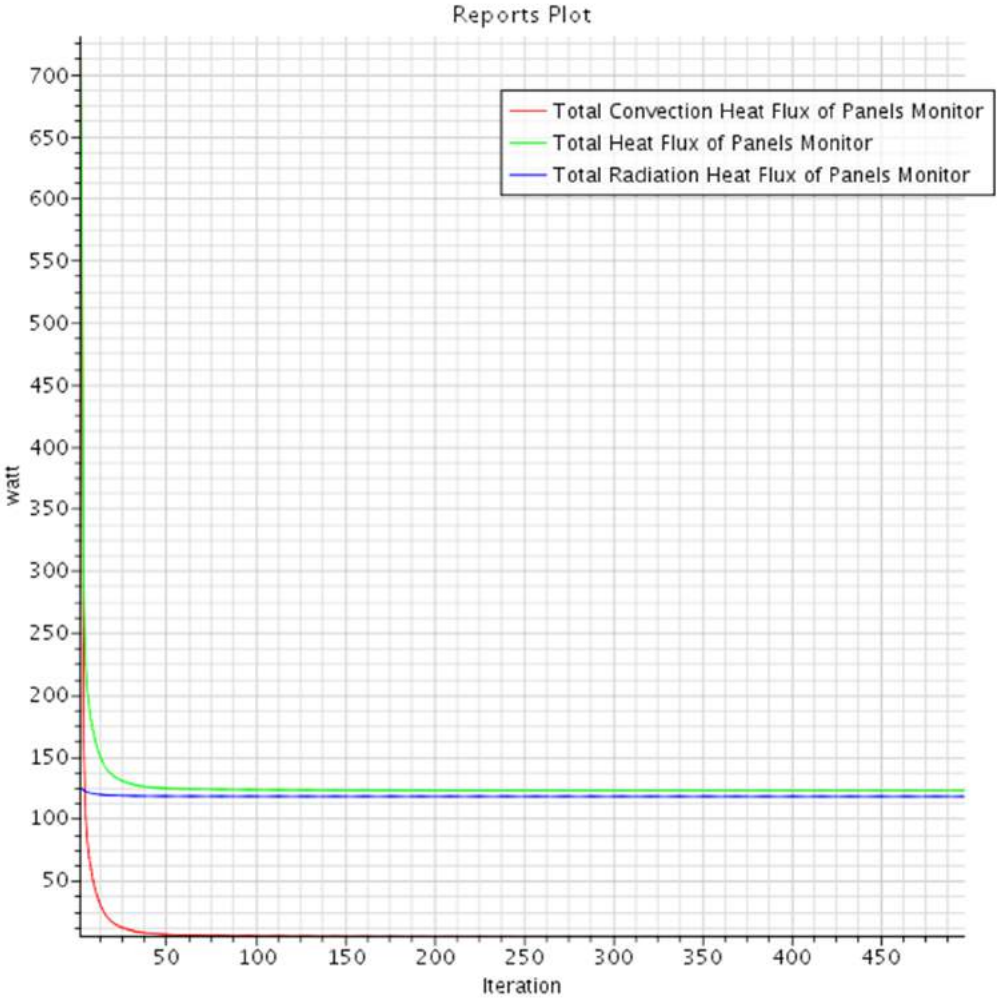
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 7



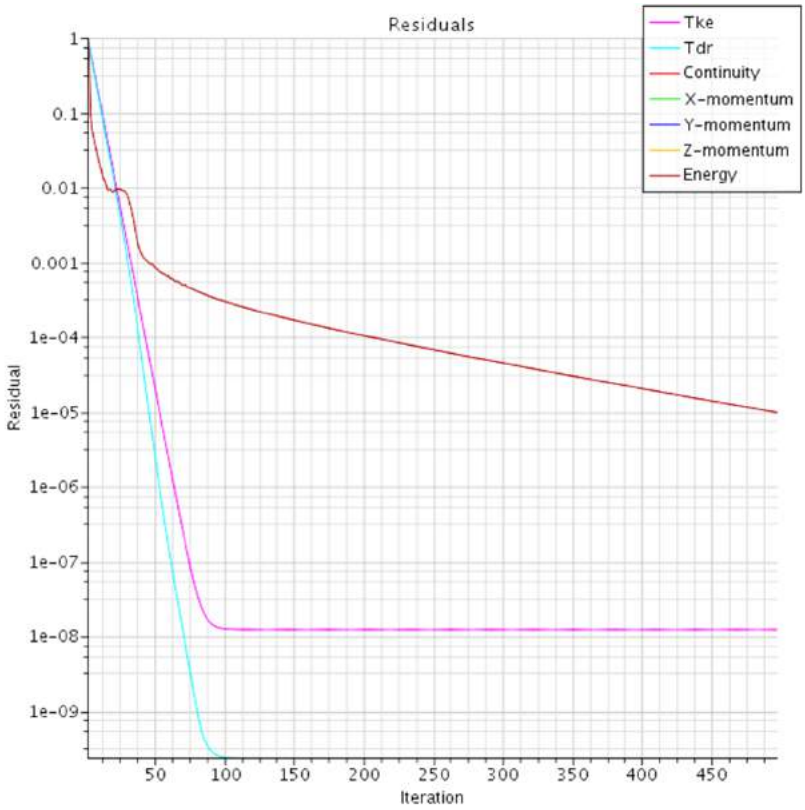
Test Set-up - Section B-B

Presentation of Qualitative Post processing For Scenarios A 7

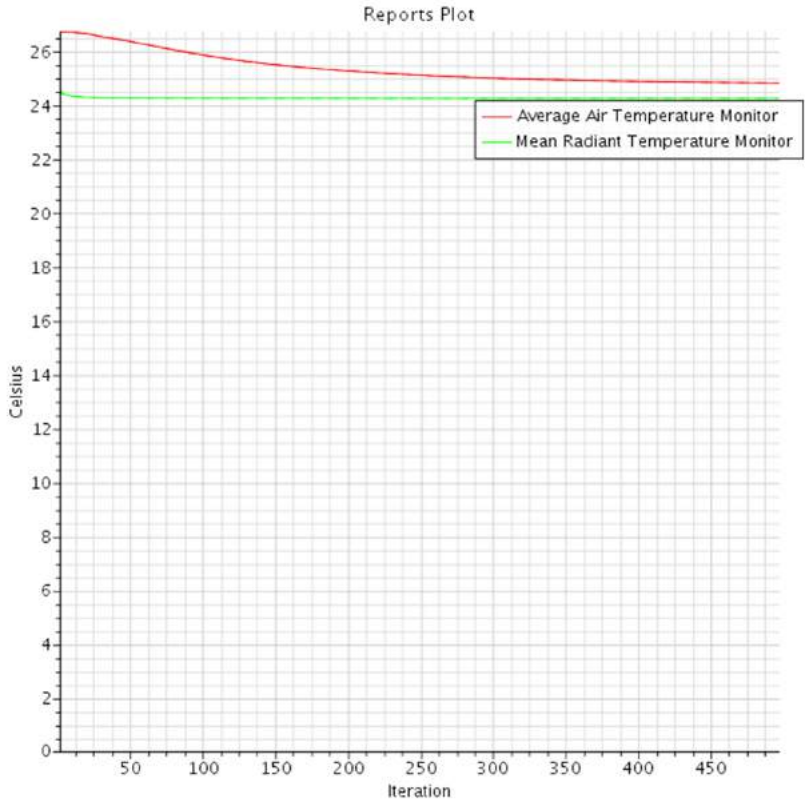


Heat Flux

Presentation of Qualitative Post processing
For Scenarios A 7

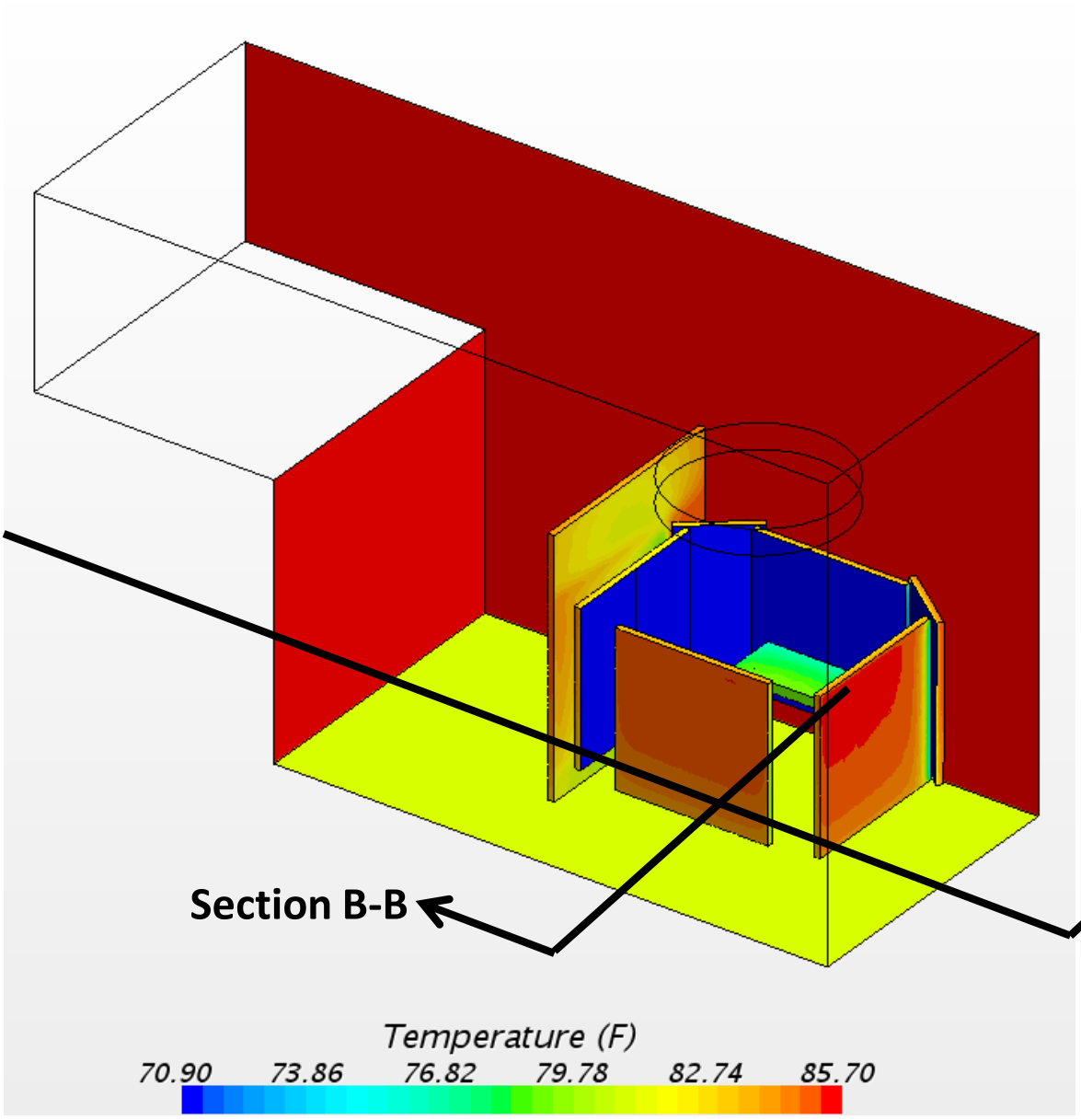


Convergence - Residuals



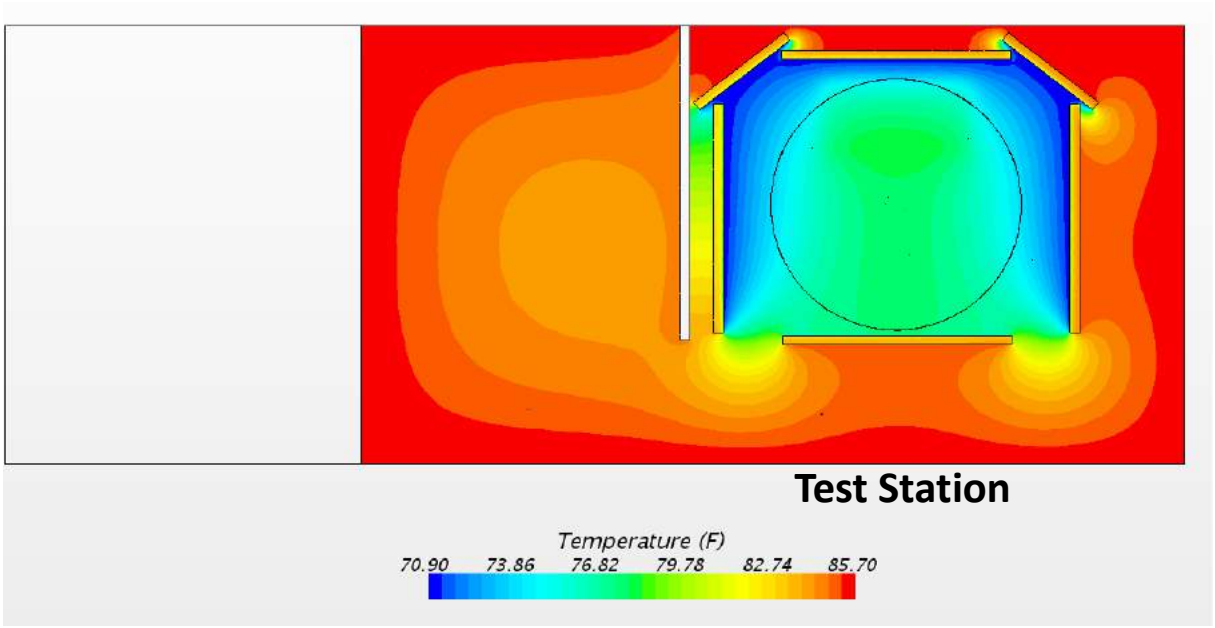
Convergence - Temperature

Presentation of Qualitative Post processing For Scenarios A 8

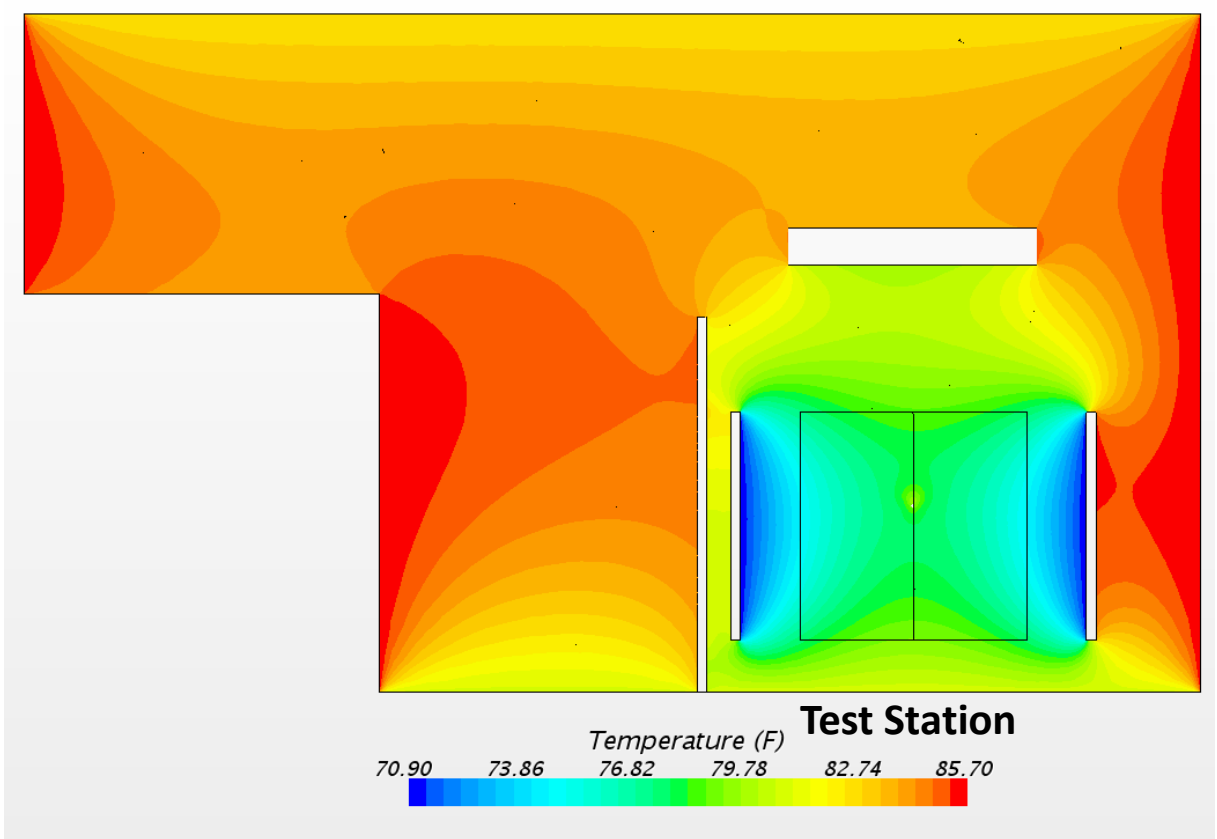


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 8

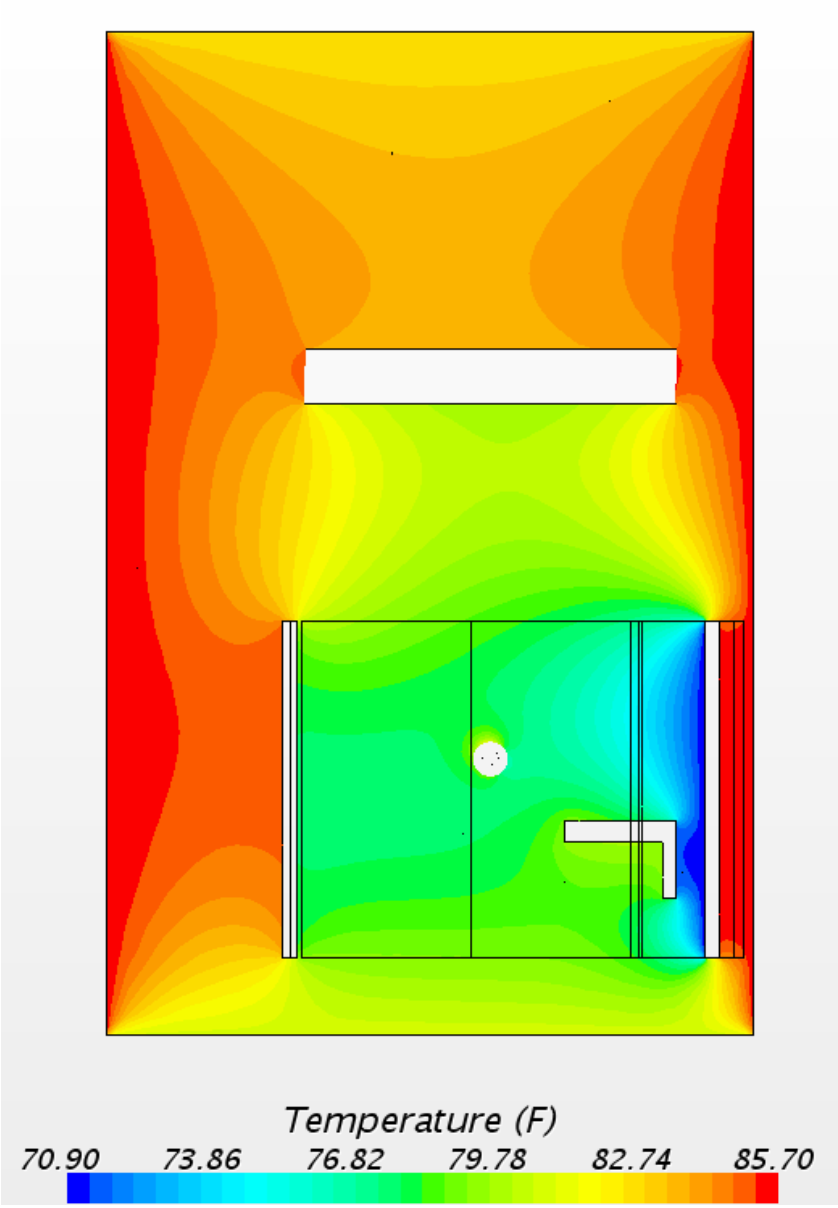


Test Set-up - Plan View



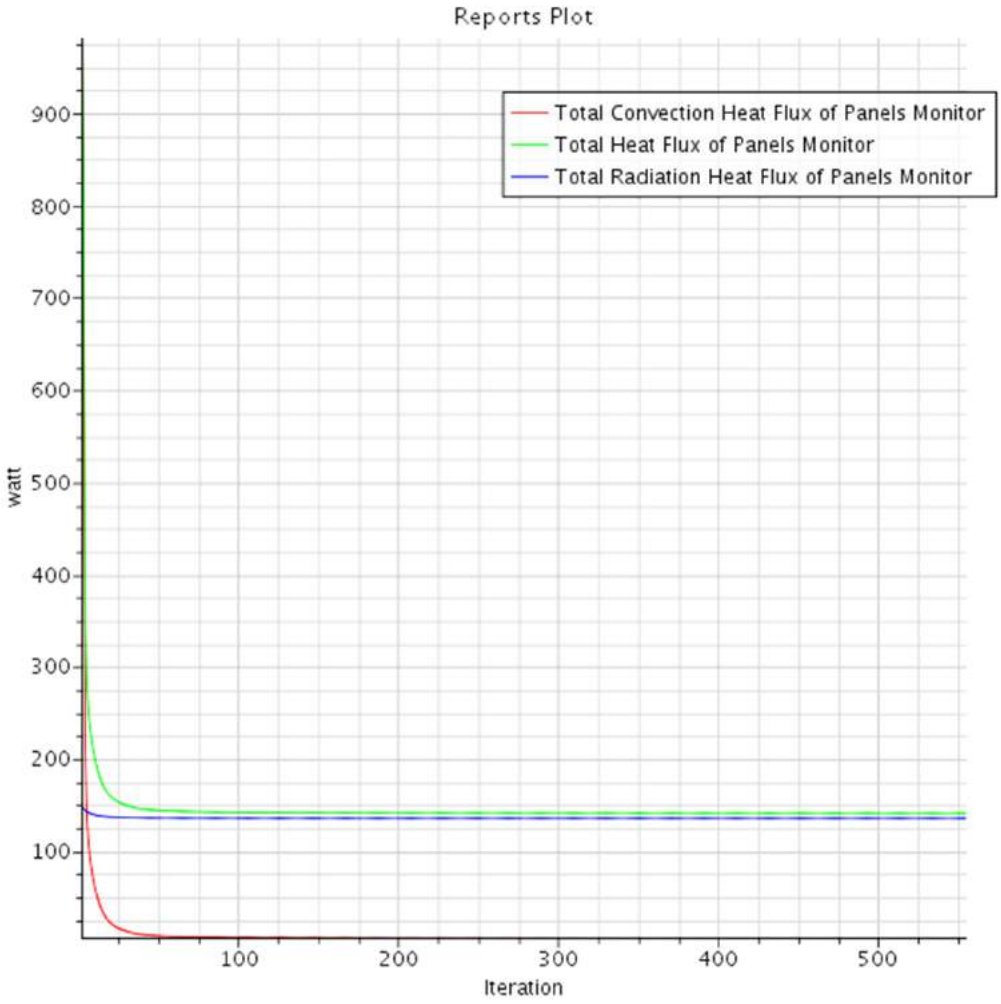
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 8



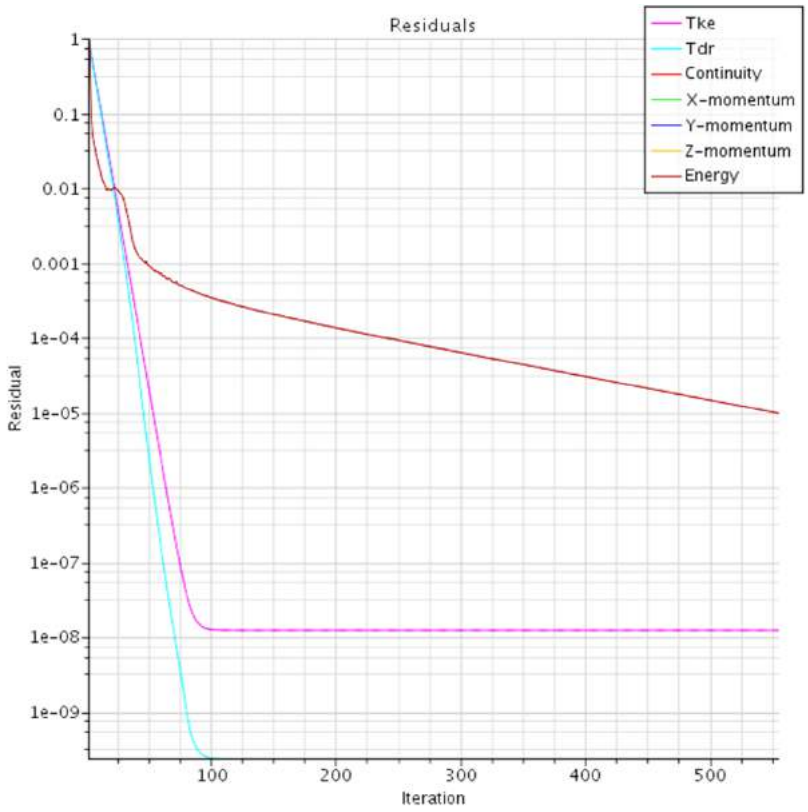
Test Set-up - Section B-B

Presentation of Qualitative Post processing For Scenarios A 8

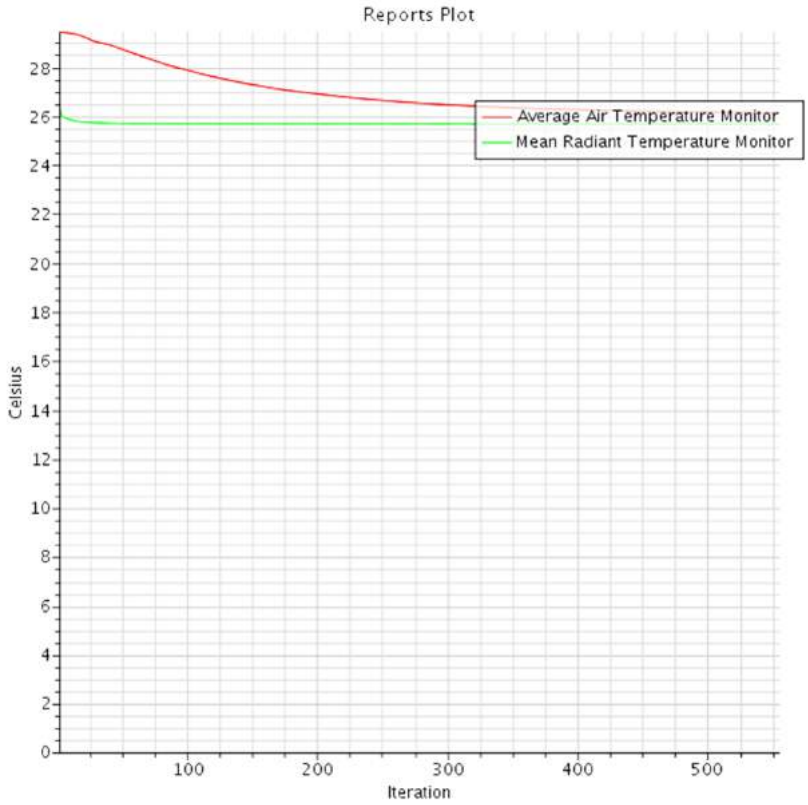


Heat Flux

Presentation of Qualitative Post processing
For Scenarios A 8

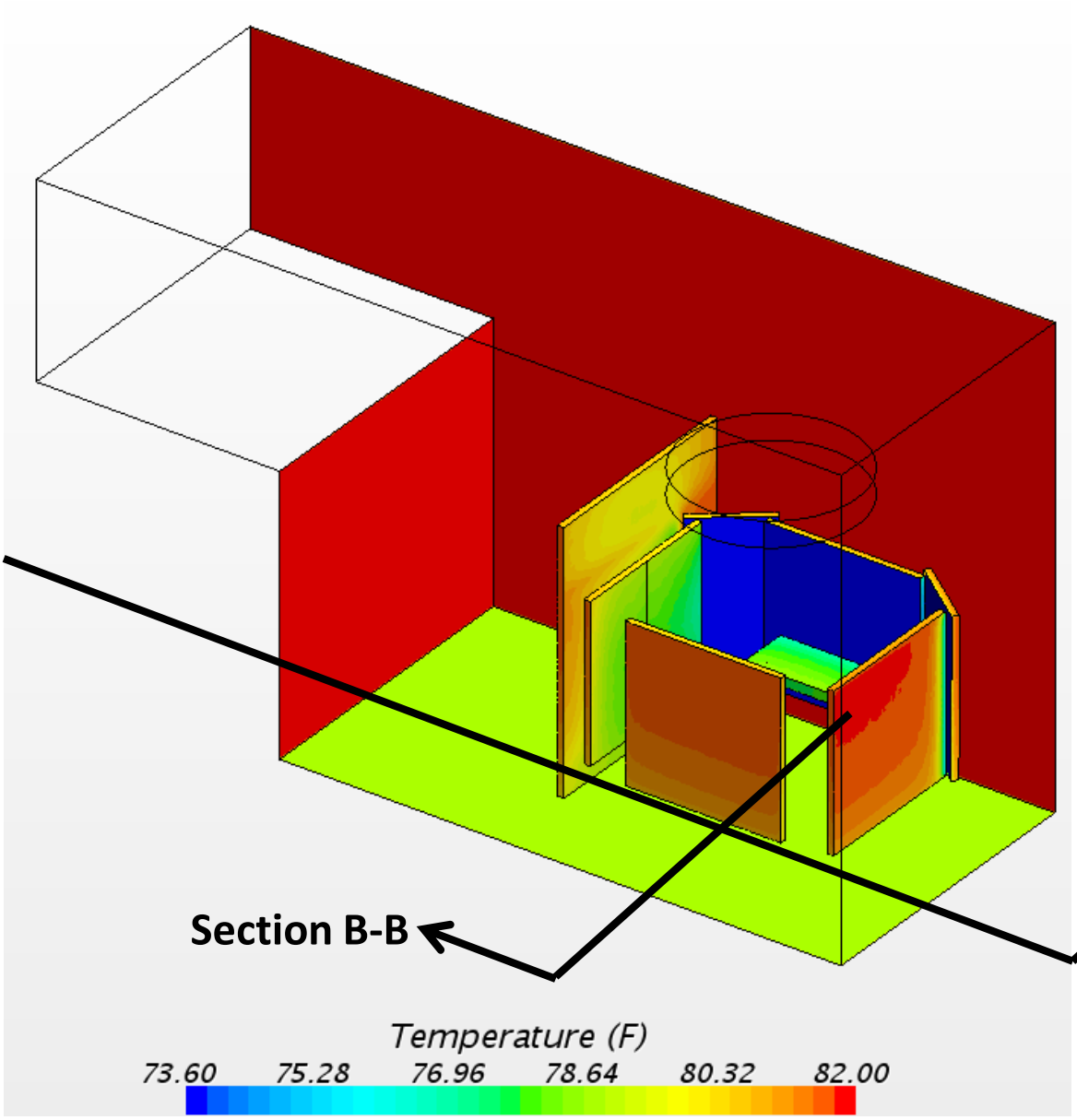


Convergence - Residuals



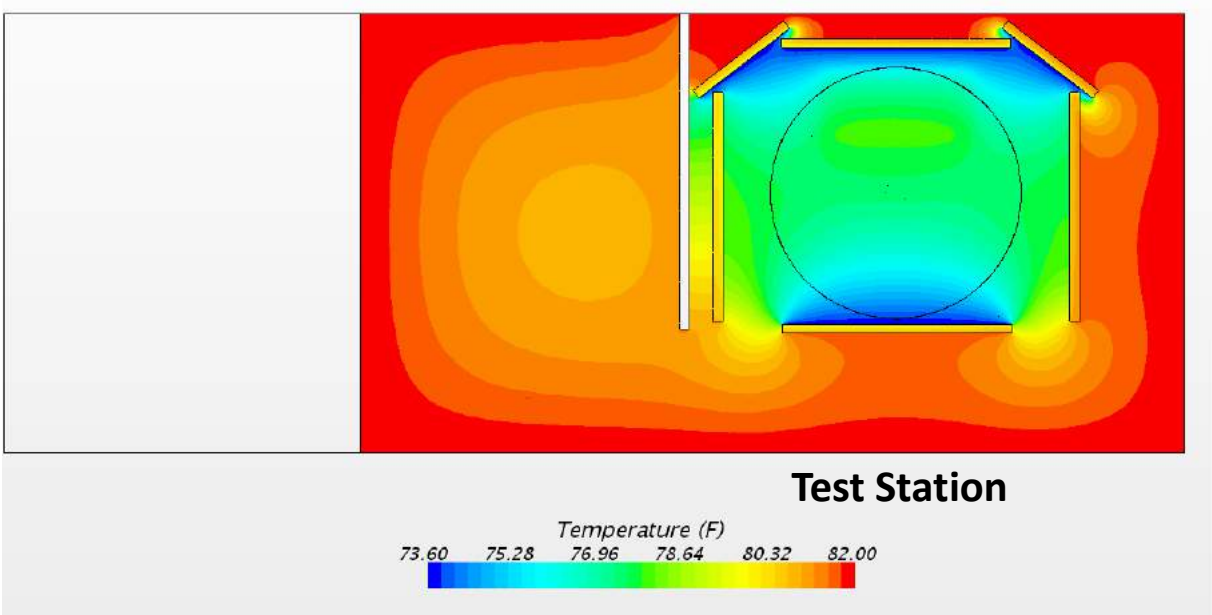
Convergence - Temperature

Presentation of Qualitative Post processing For Scenarios A 9

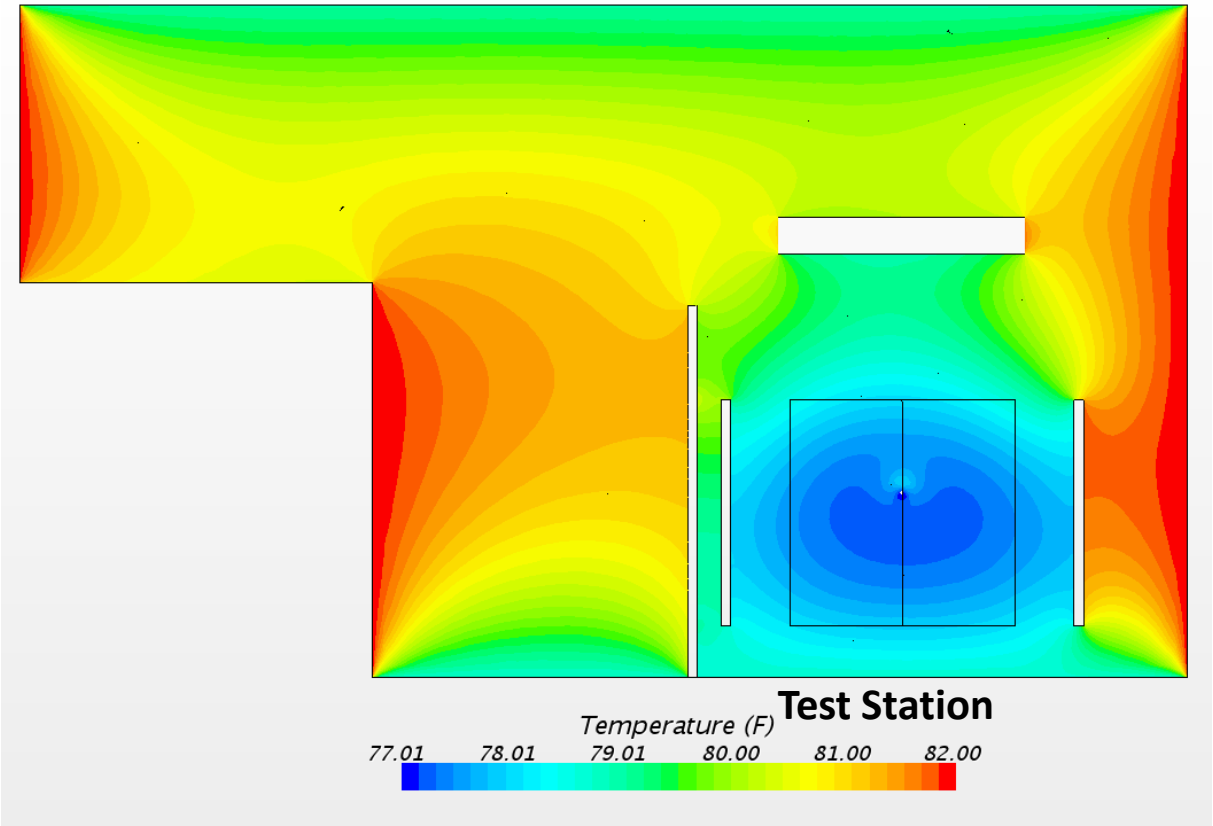


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 9

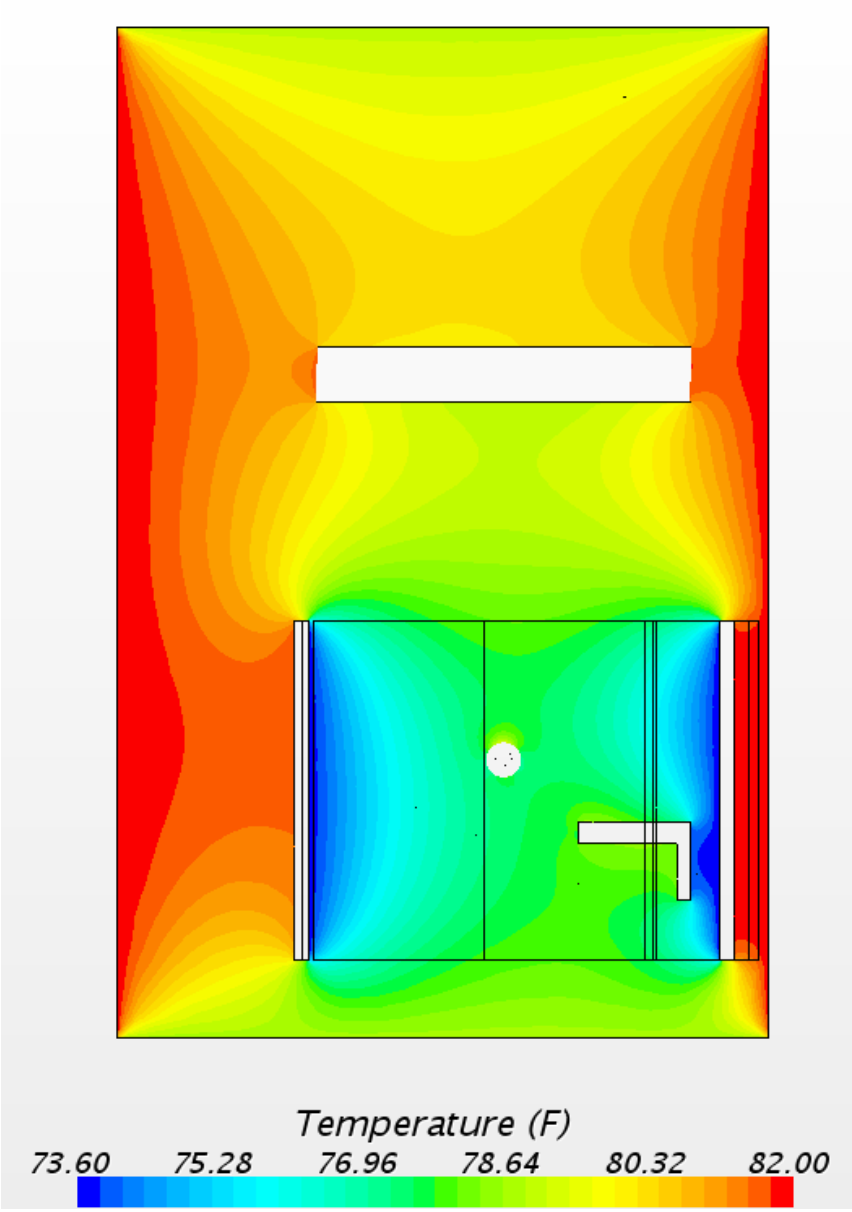


Test Set-up - Plan View



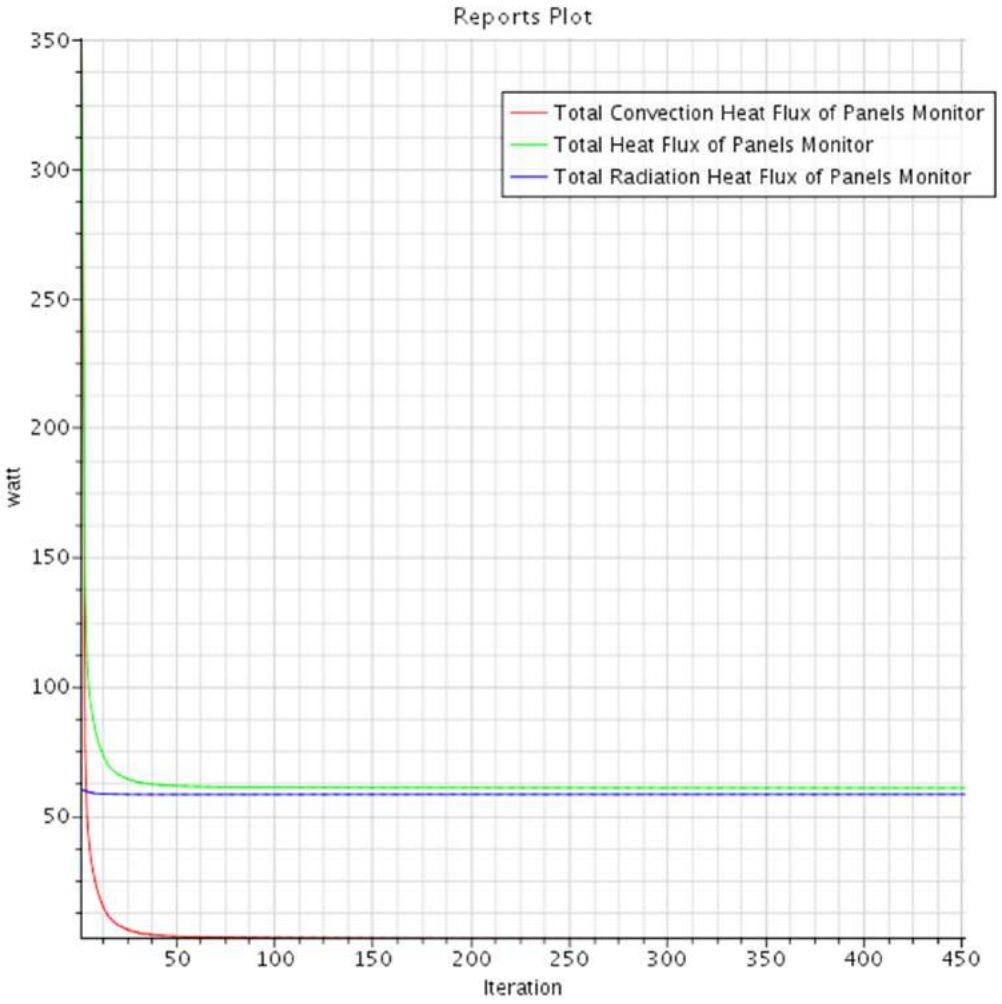
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 9



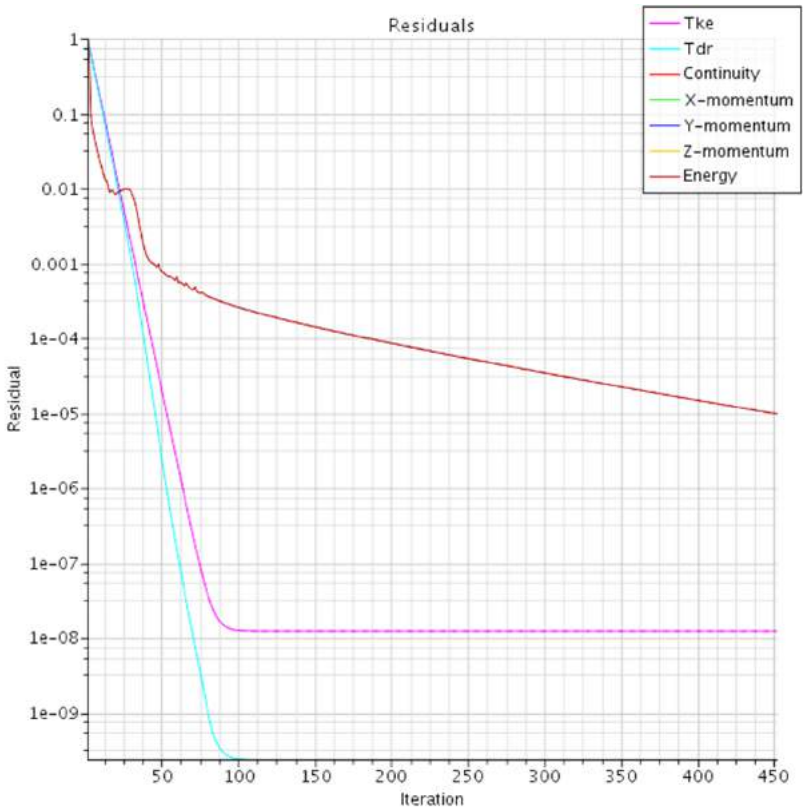
Test Set-up - Section B-B

Presentation of Qualitative Post processing For Scenarios A 9

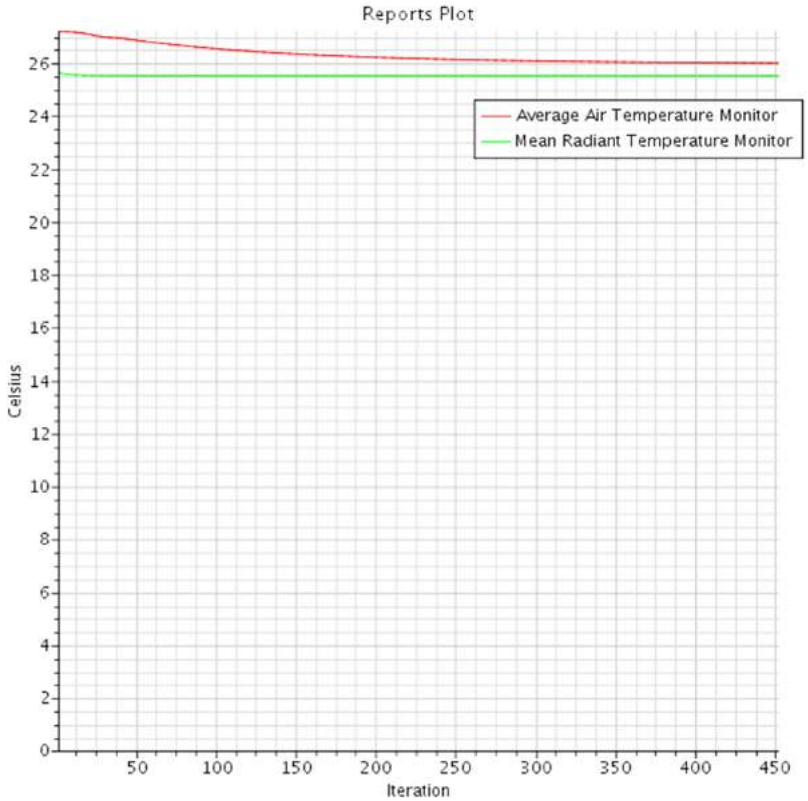


Heat Flux

Presentation of Qualitative Post processing For Scenarios A 9

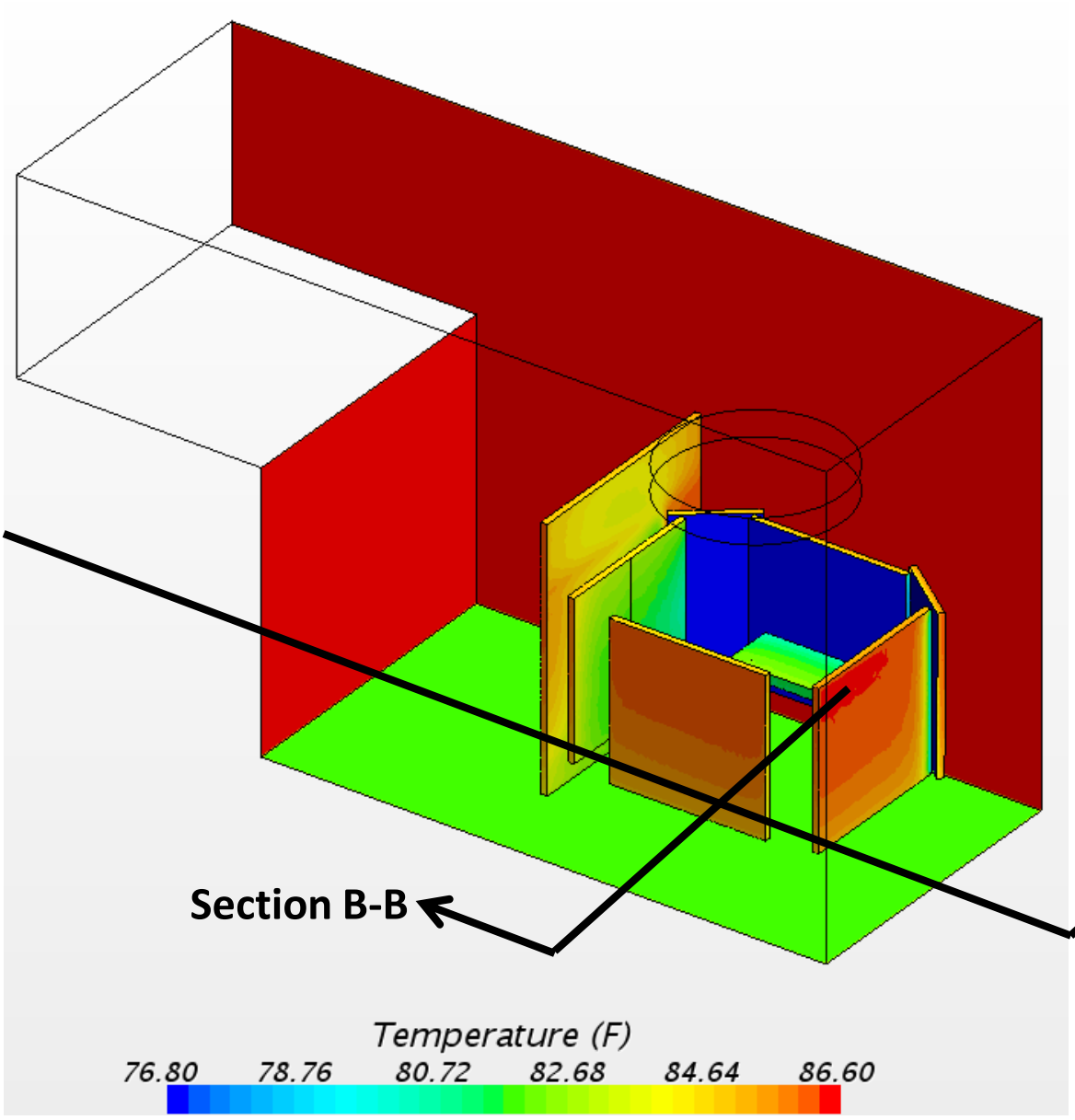


Convergence - Residuals



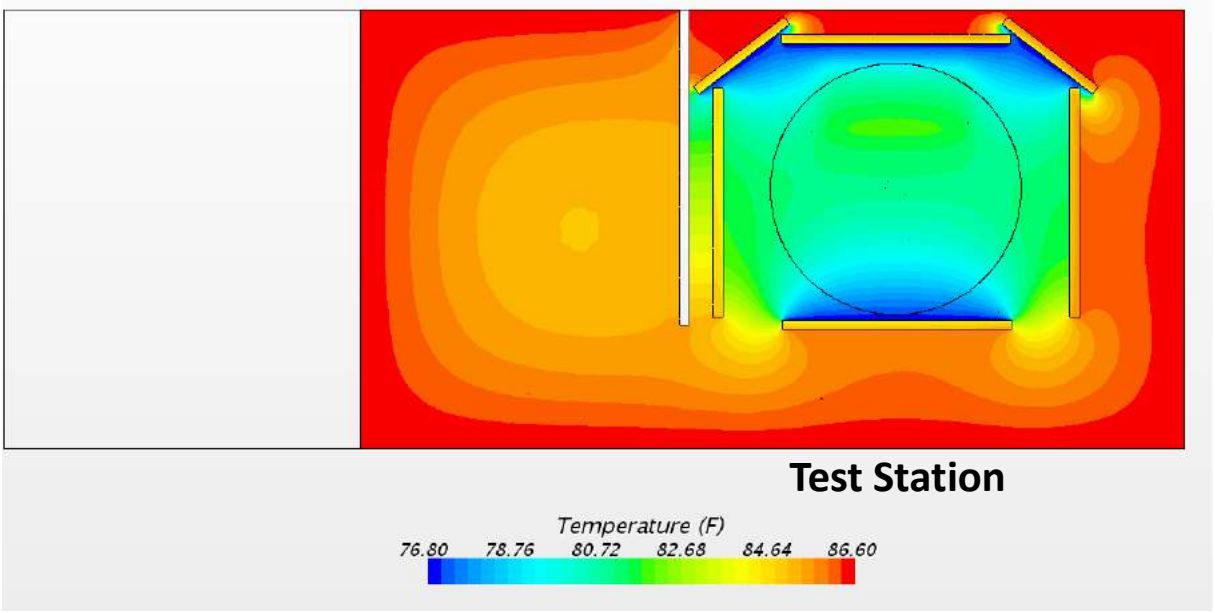
Convergence - Temperature

Presentation of Qualitative Post processing For Scenarios A 10

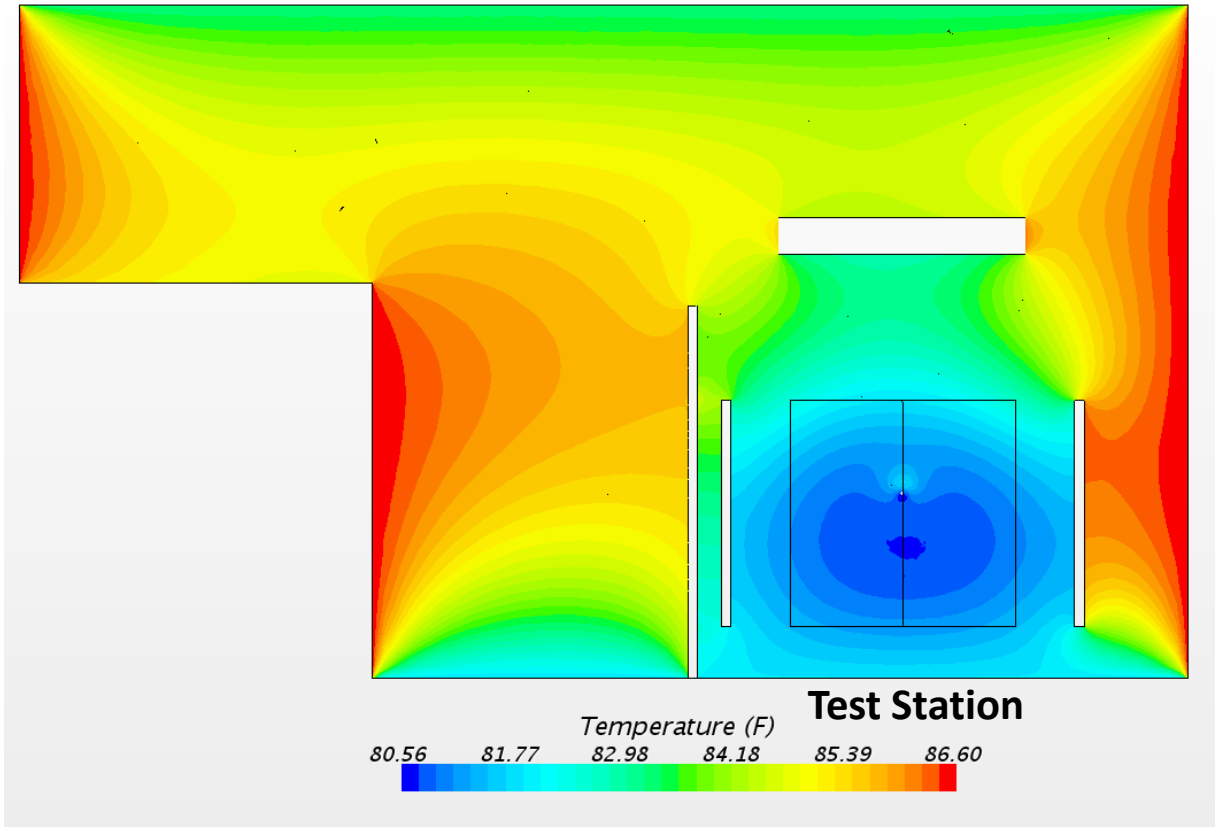


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 10

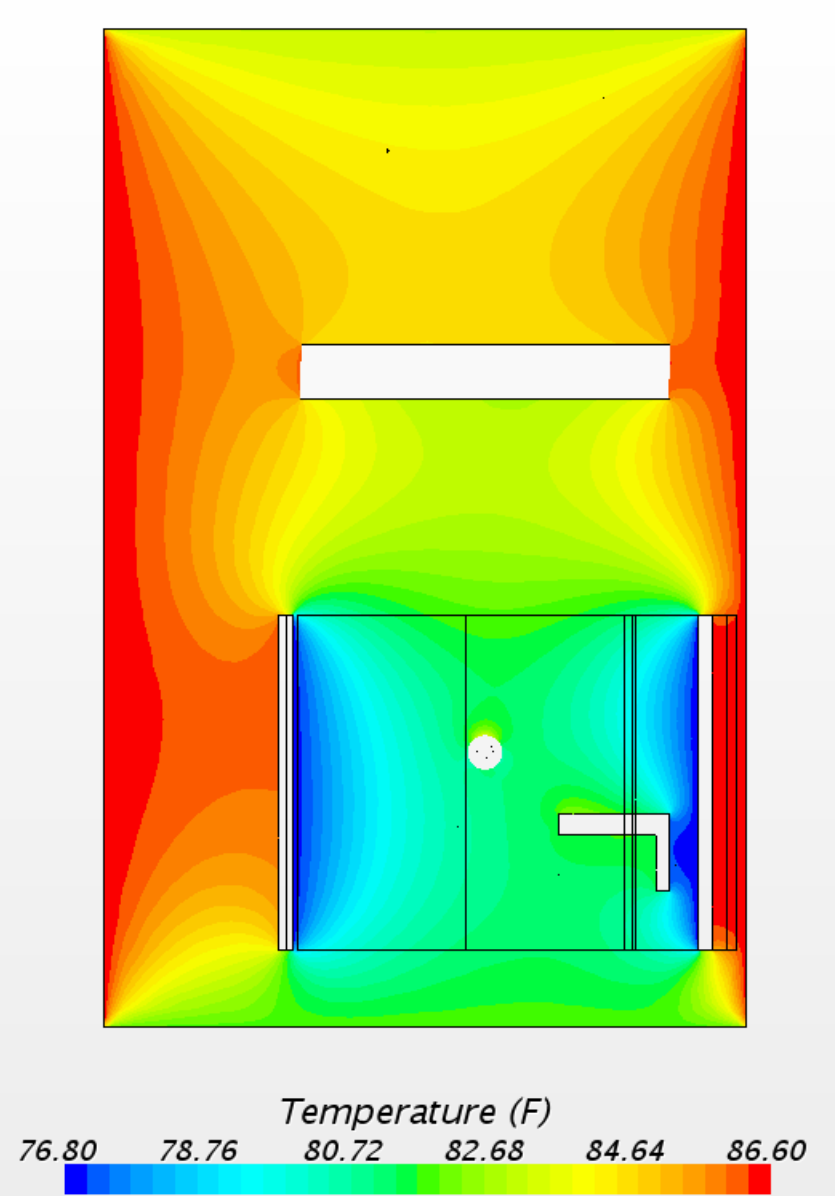


Test Set-up - Plan View



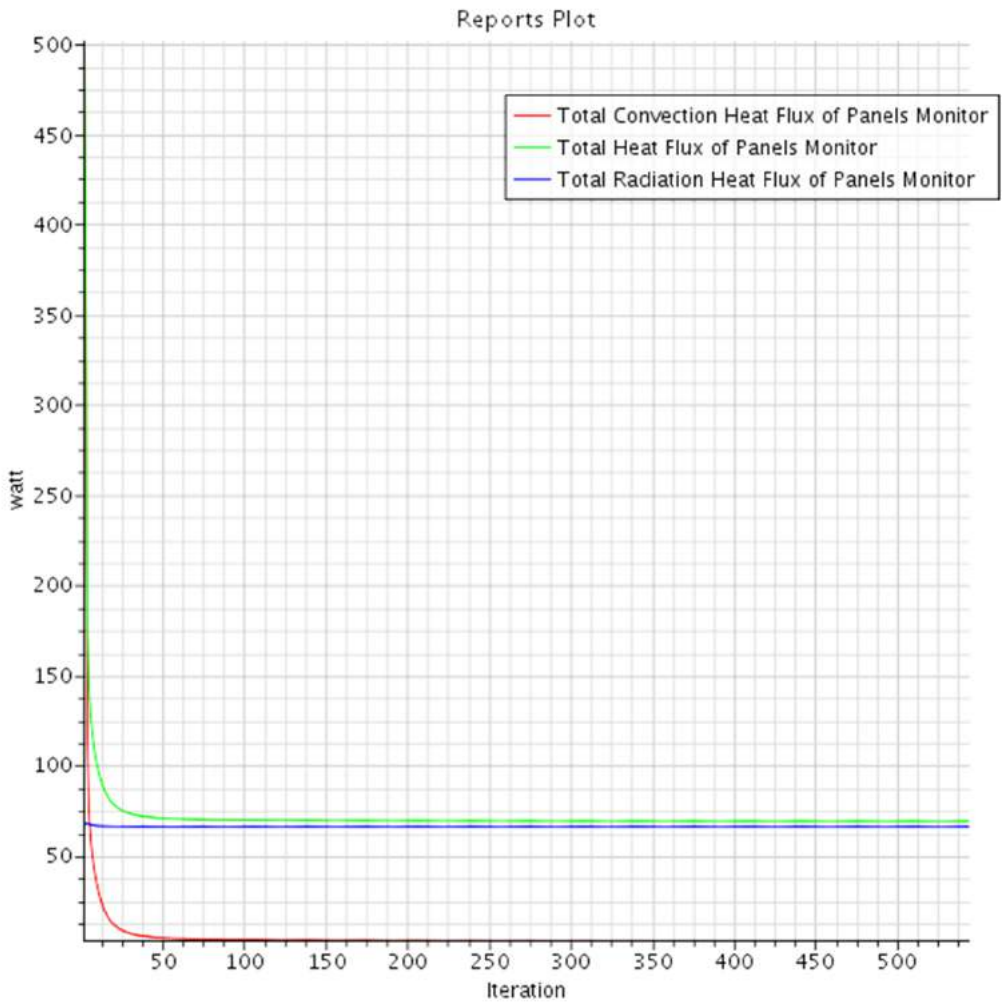
Test Set-up - Section A-A

Presentation of Qualitative Post processing
For Scenarios A 10



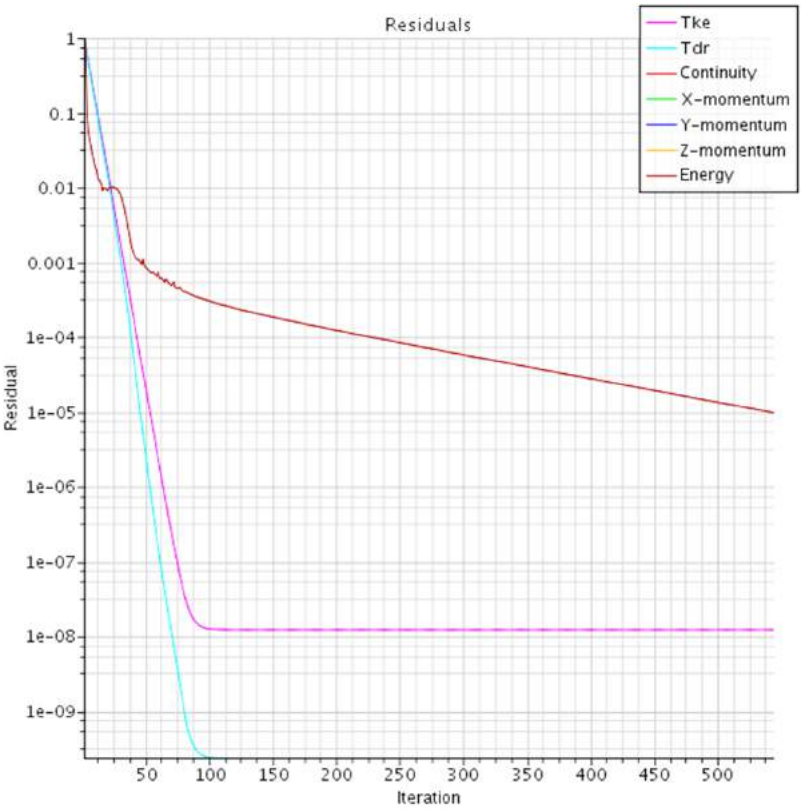
Test Set-up - Section B-B

Presentation of Qualitative Post processing For Scenarios A 10

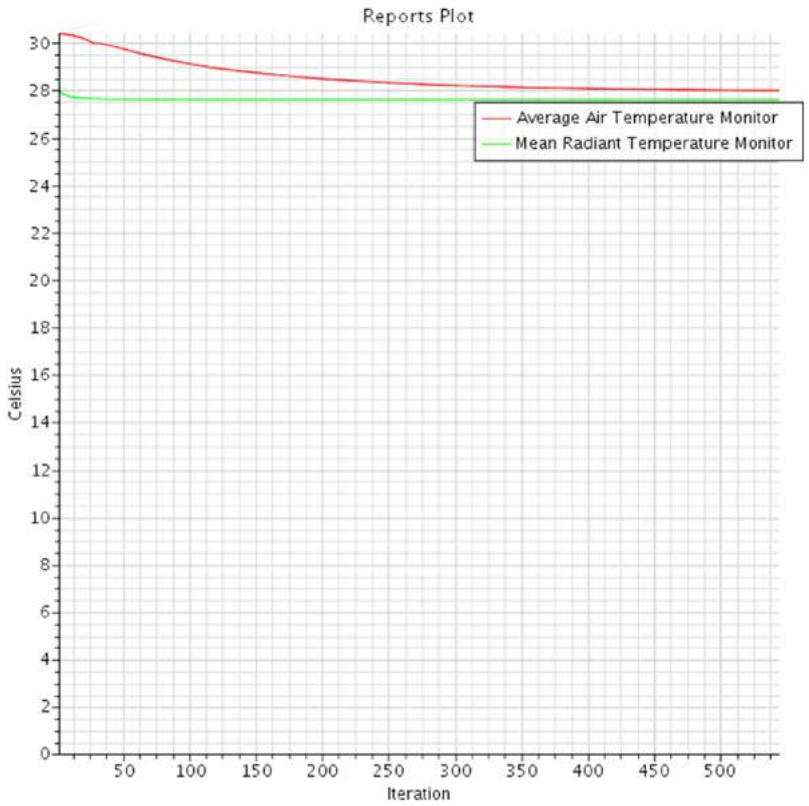


Heat Flux

Presentation of Qualitative Post processing
For Scenarios A 10

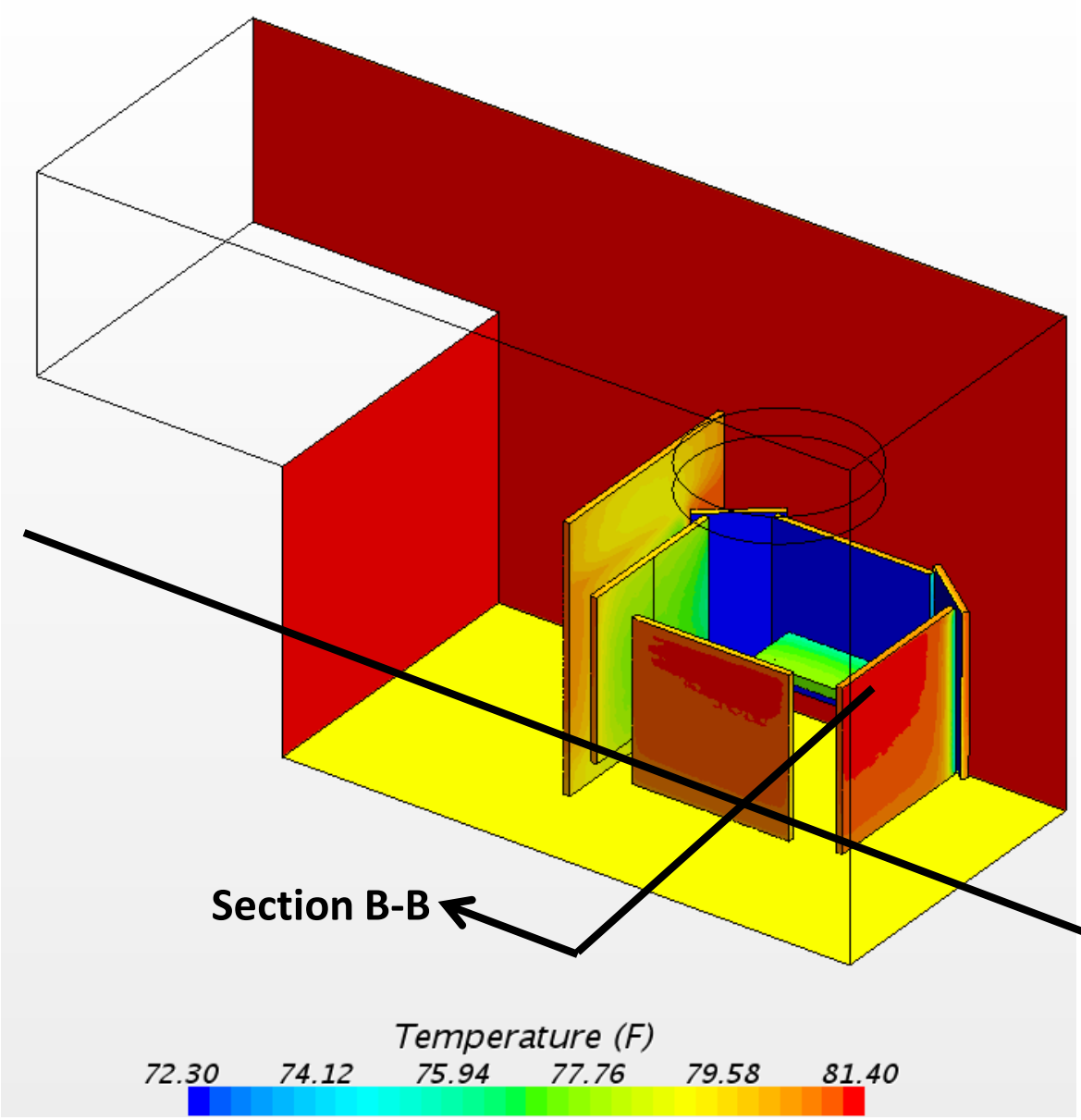


Convergence - Residuals



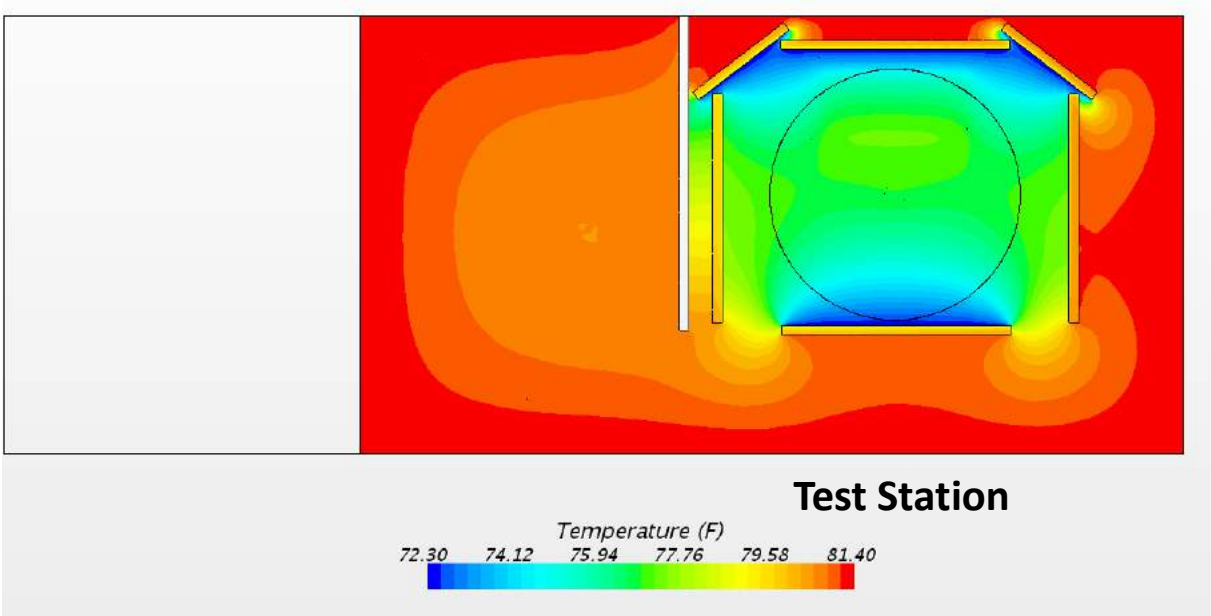
Convergence - Temperature

Presentation of Qualitative Post processing For Scenarios A 11

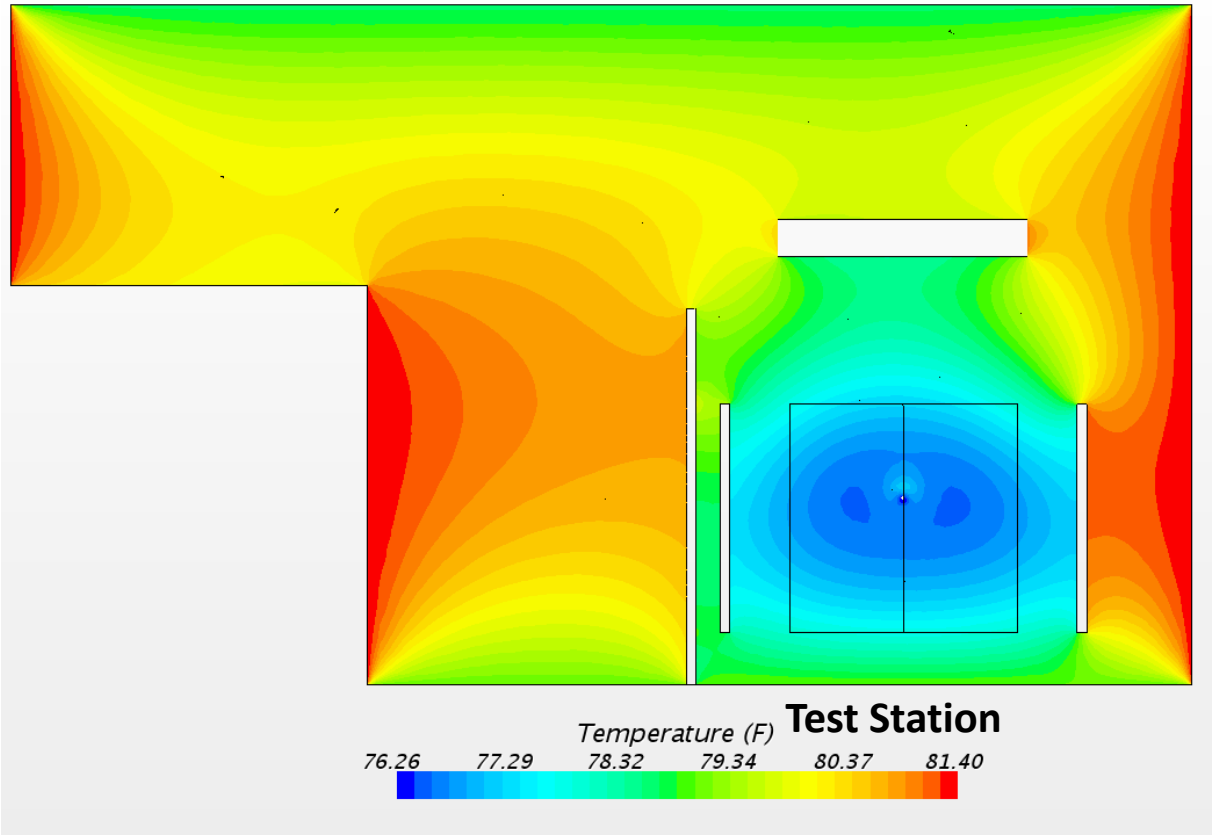


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 11

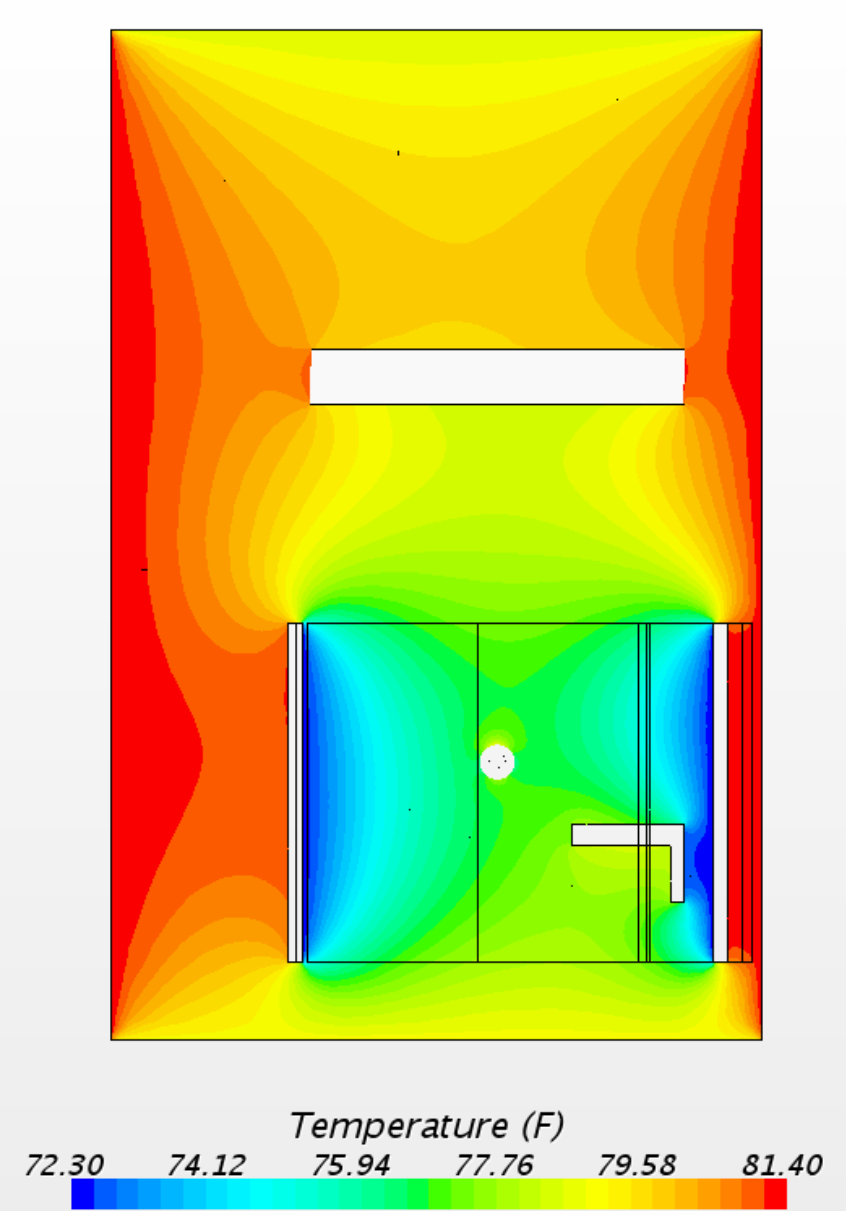


Test Set-up - Plan View



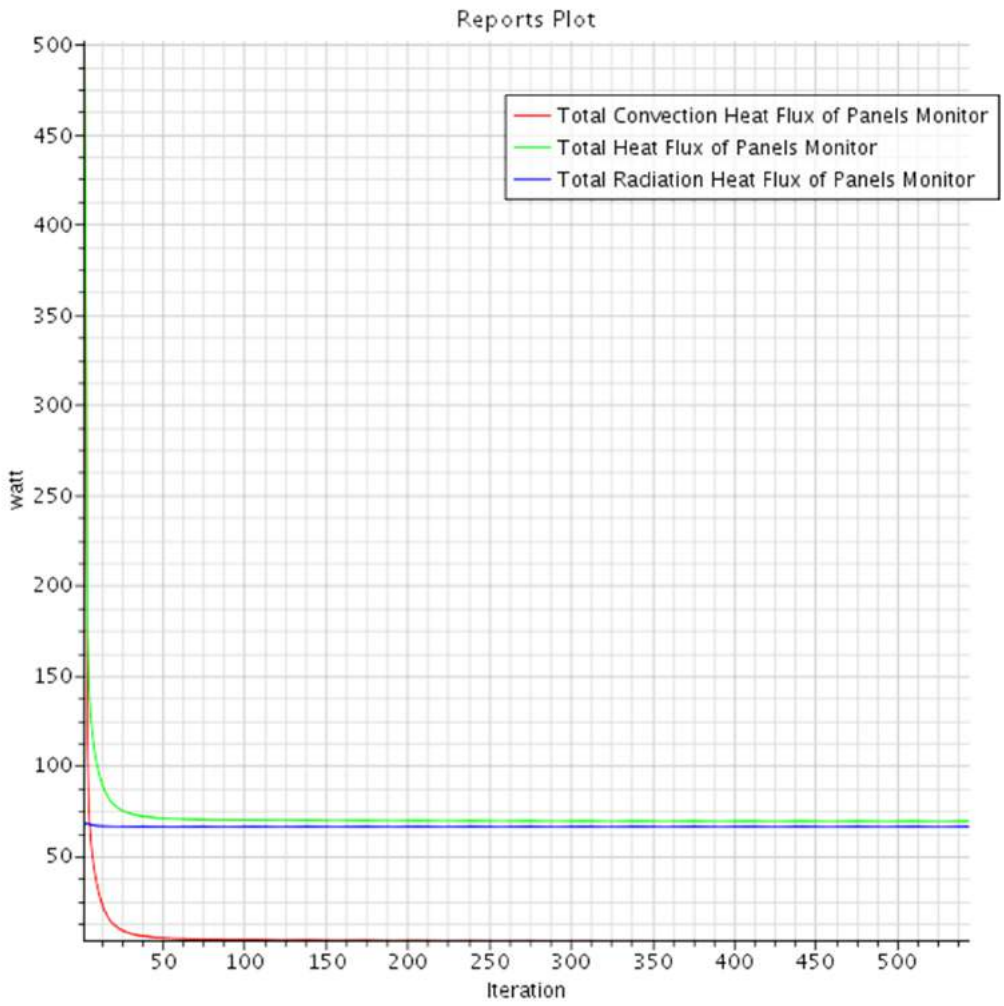
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 11



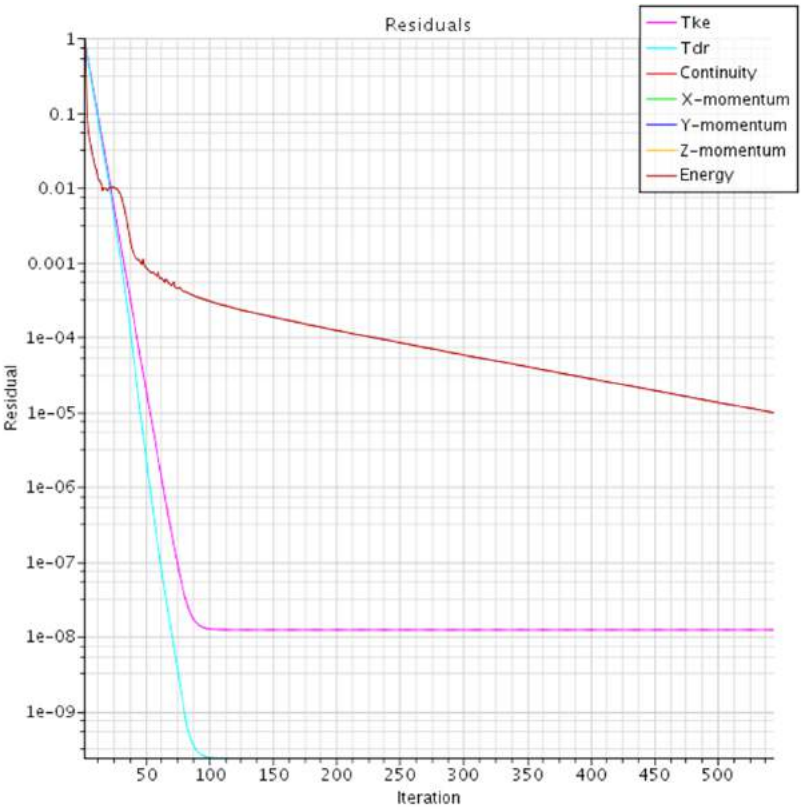
Test Set-up - Section B-B

Presentation of Qualitative Post processing For Scenarios A 11

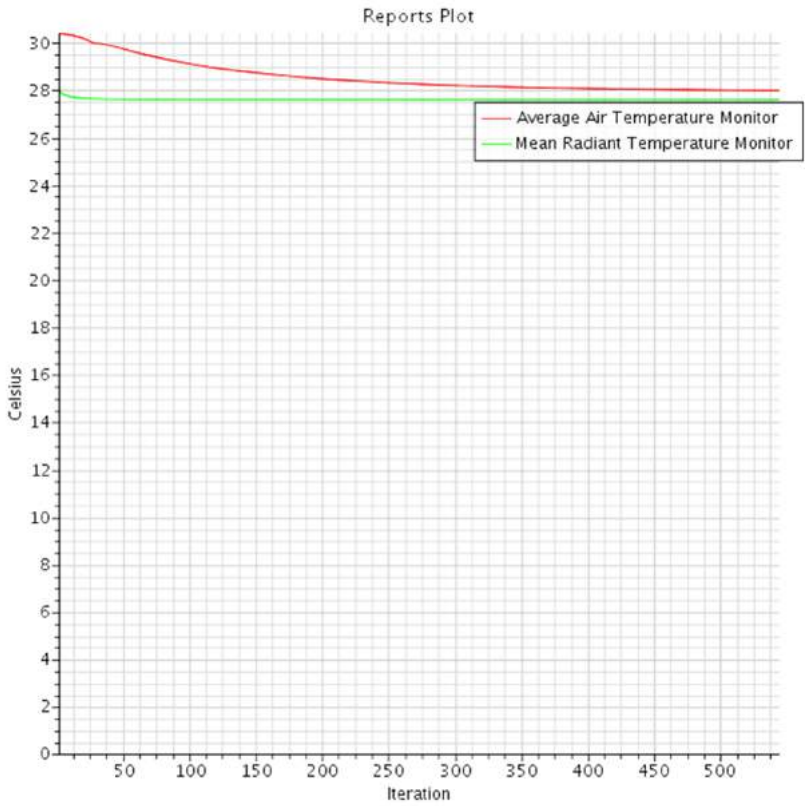


Heat Flux

Presentation of Qualitative Post processing
For Scenarios A 11

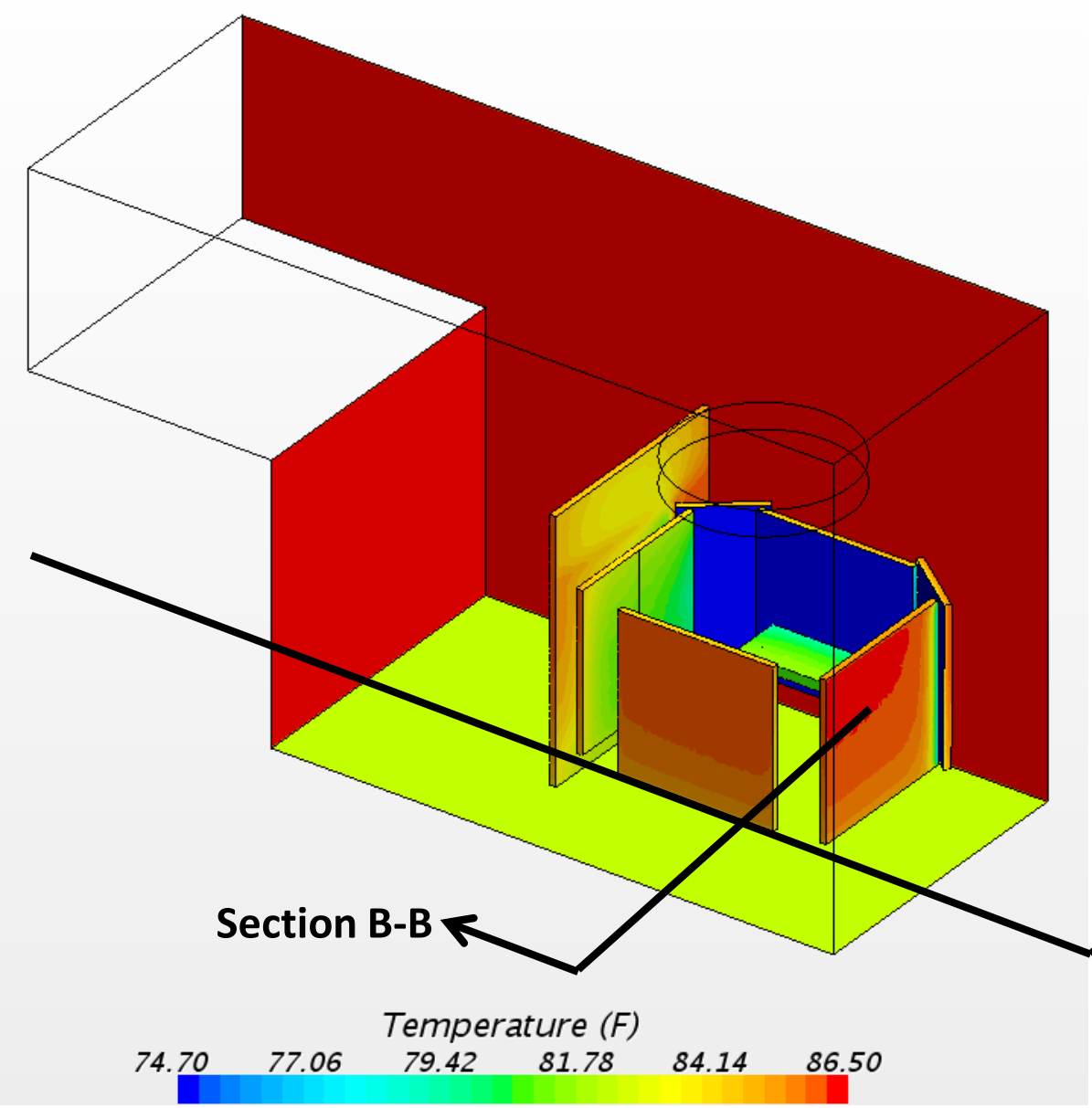


Convergence - Residuals



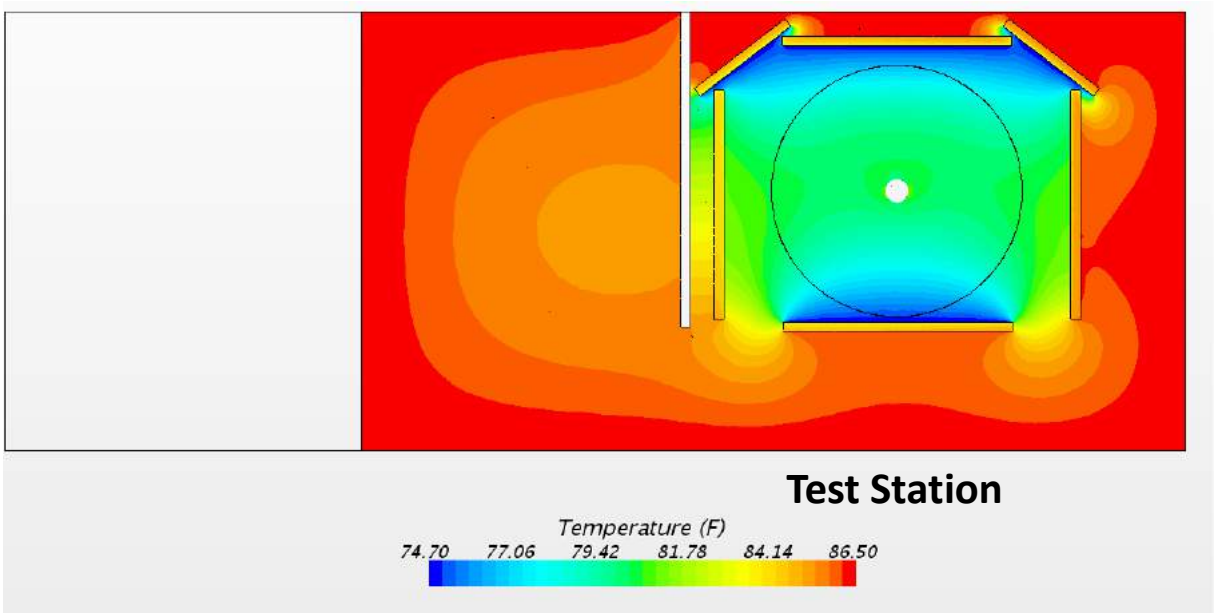
Convergence - Temperature

Presentation of Qualitative Post processing
For Scenarios A 12

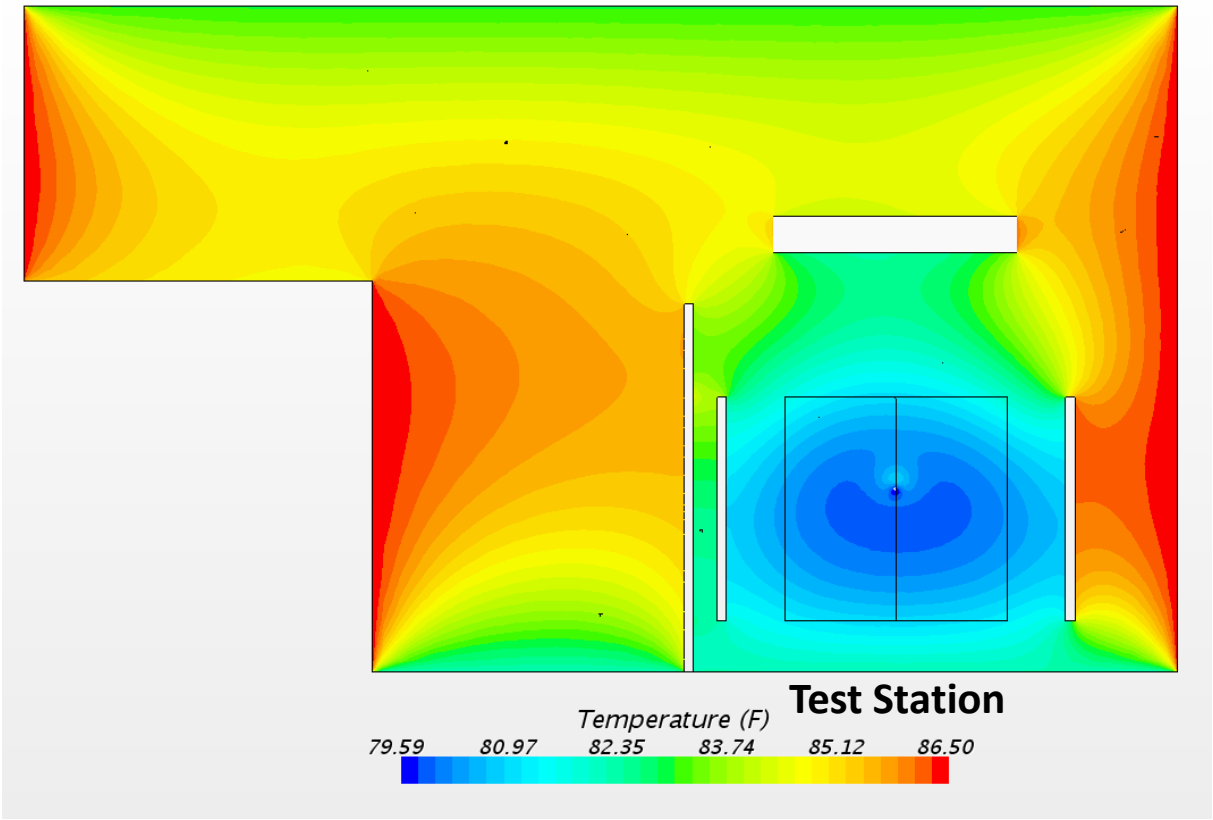


Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 12

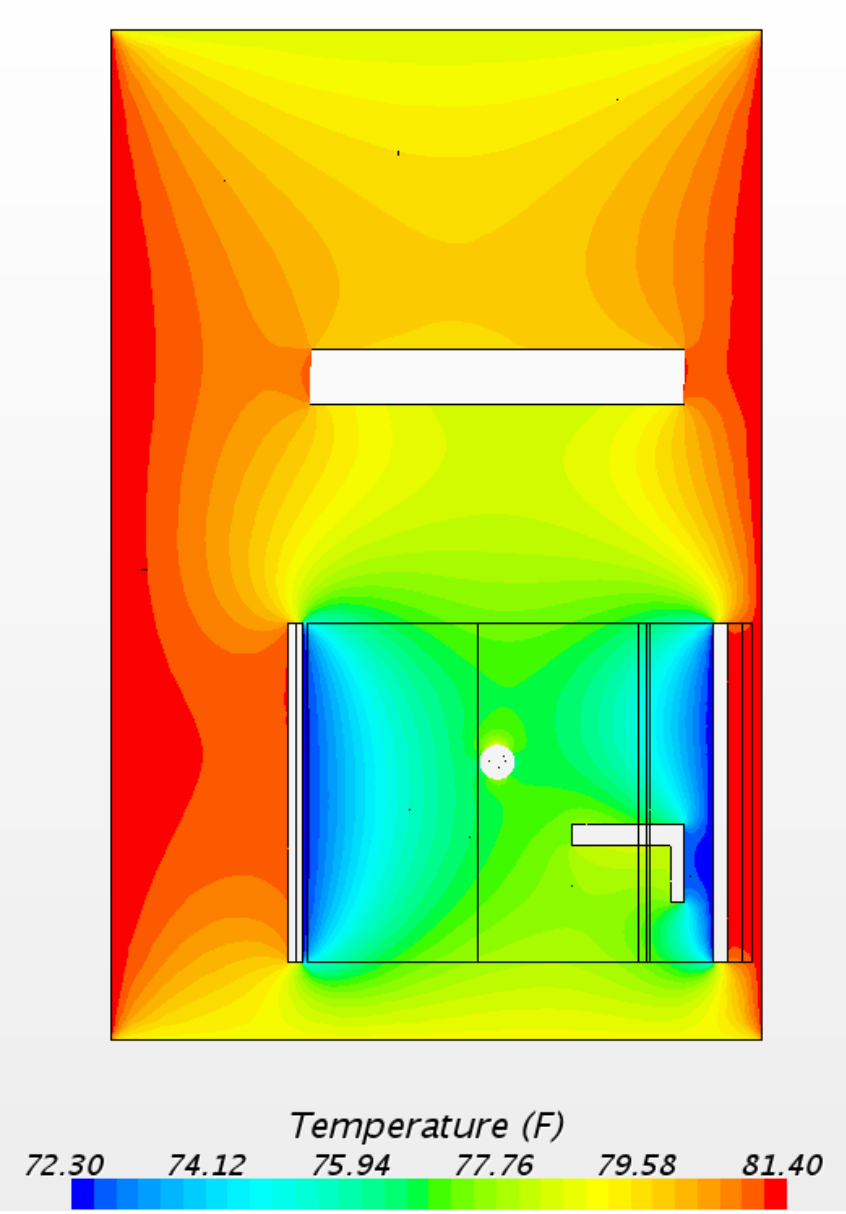


Test Set-up - Plan View



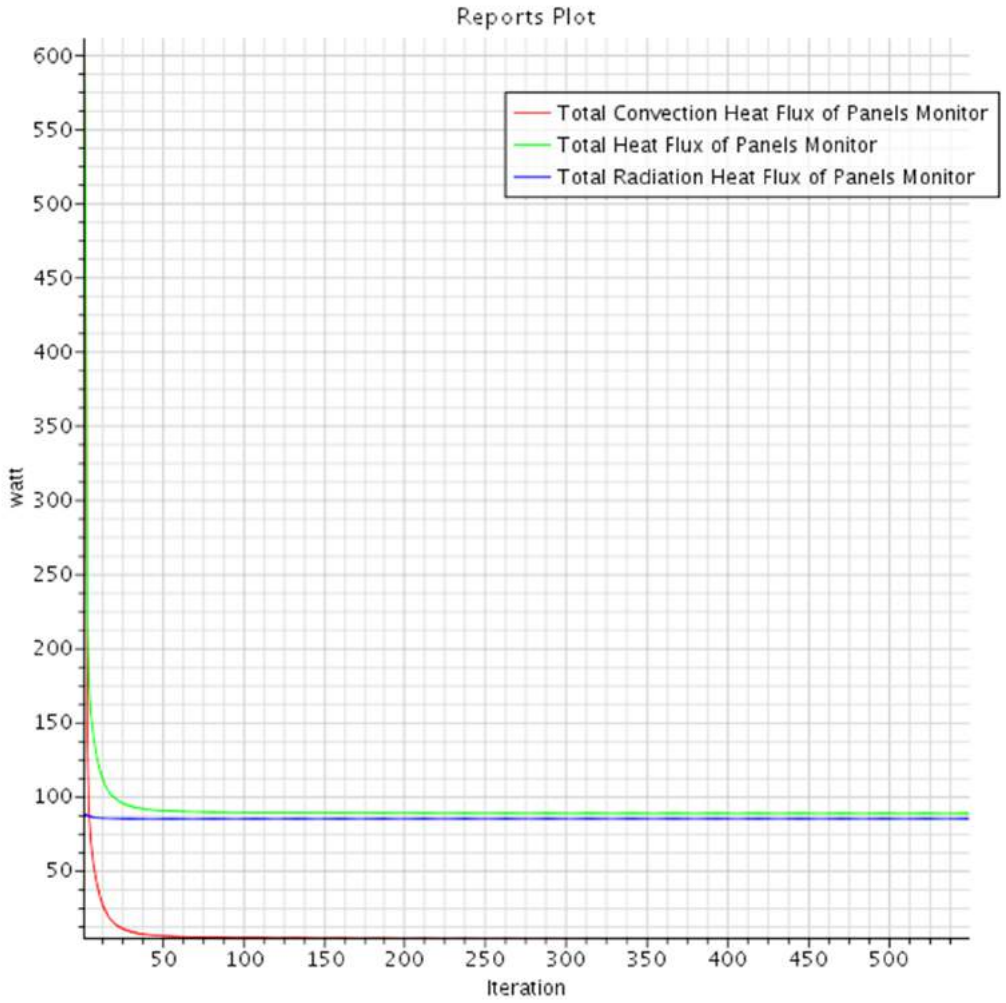
Test Set-up - Section A-A

Presentation of Qualitative Post processing
For Scenarios A 12



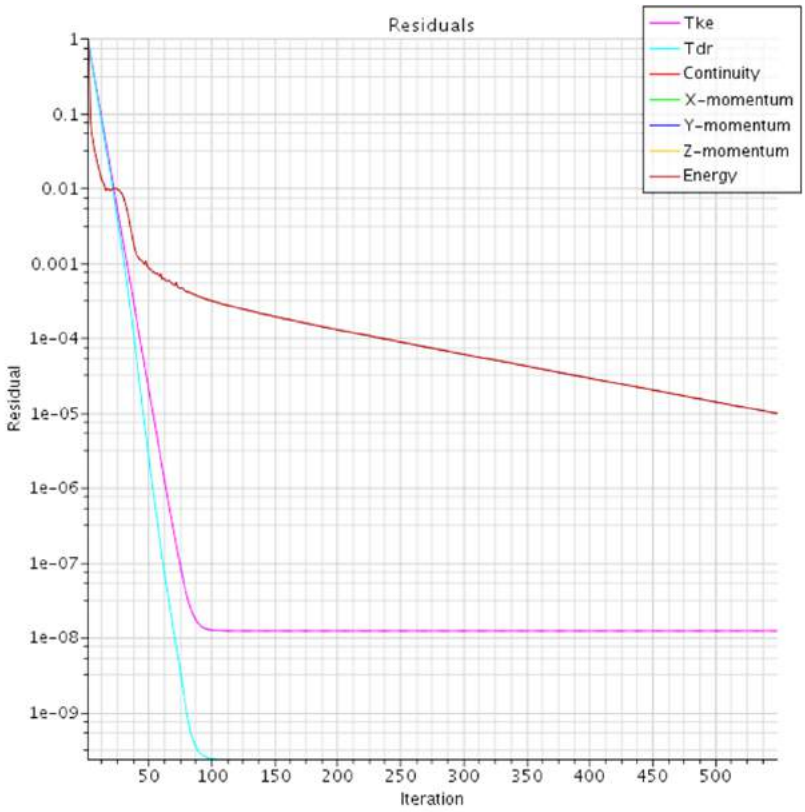
Test Set-up - Section B-B

Presentation of Qualitative Post processing For Scenarios A 12

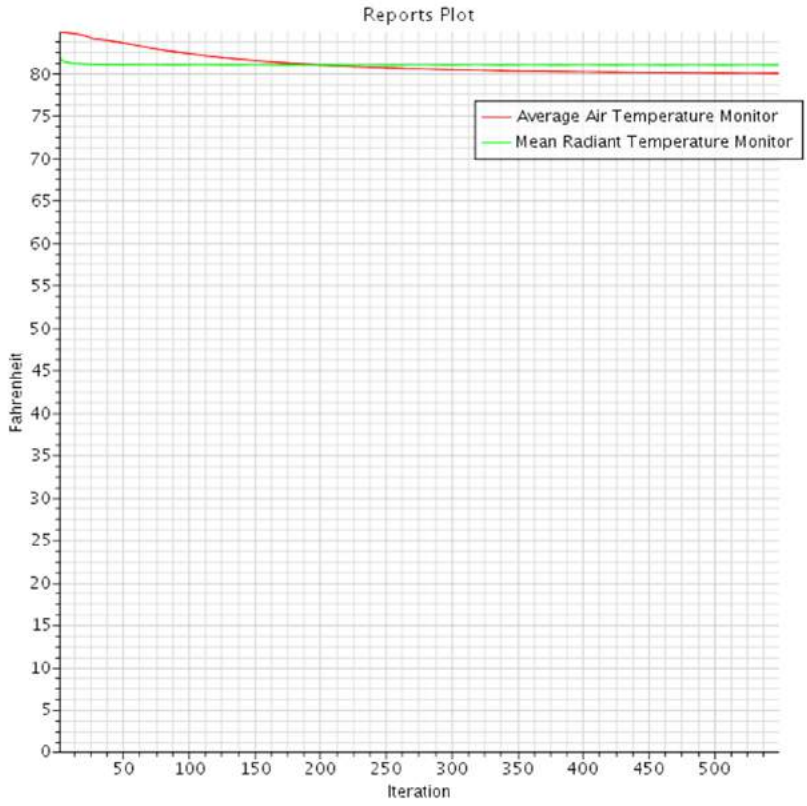


Heat Flux

Presentation of Qualitative Post processing
For Scenarios A 12

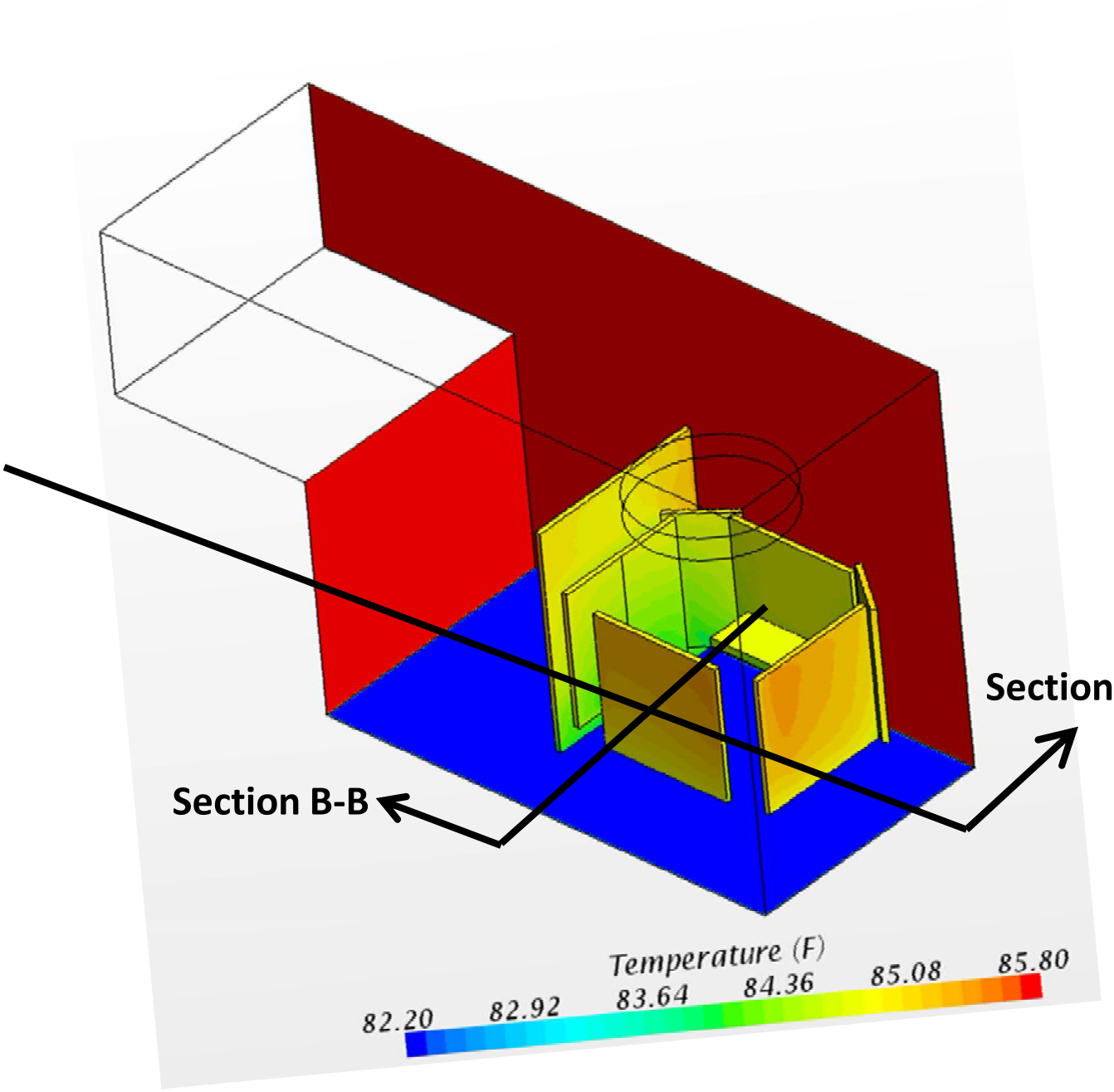


Convergence - Residuals



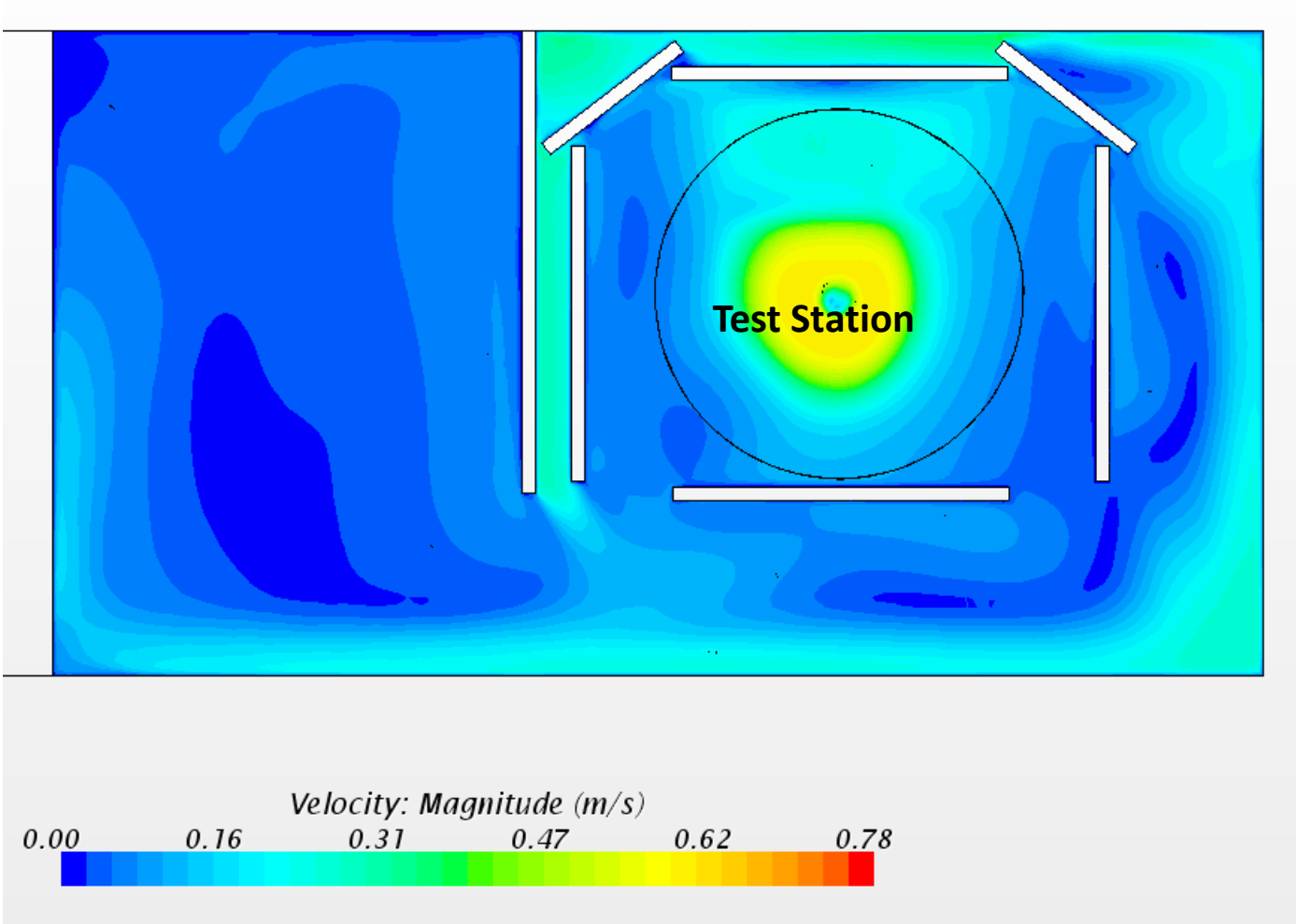
Convergence - Temperature

Presentation of Qualitative Post processing
For Scenarios A 13



Test Set-up - Iso-metric View

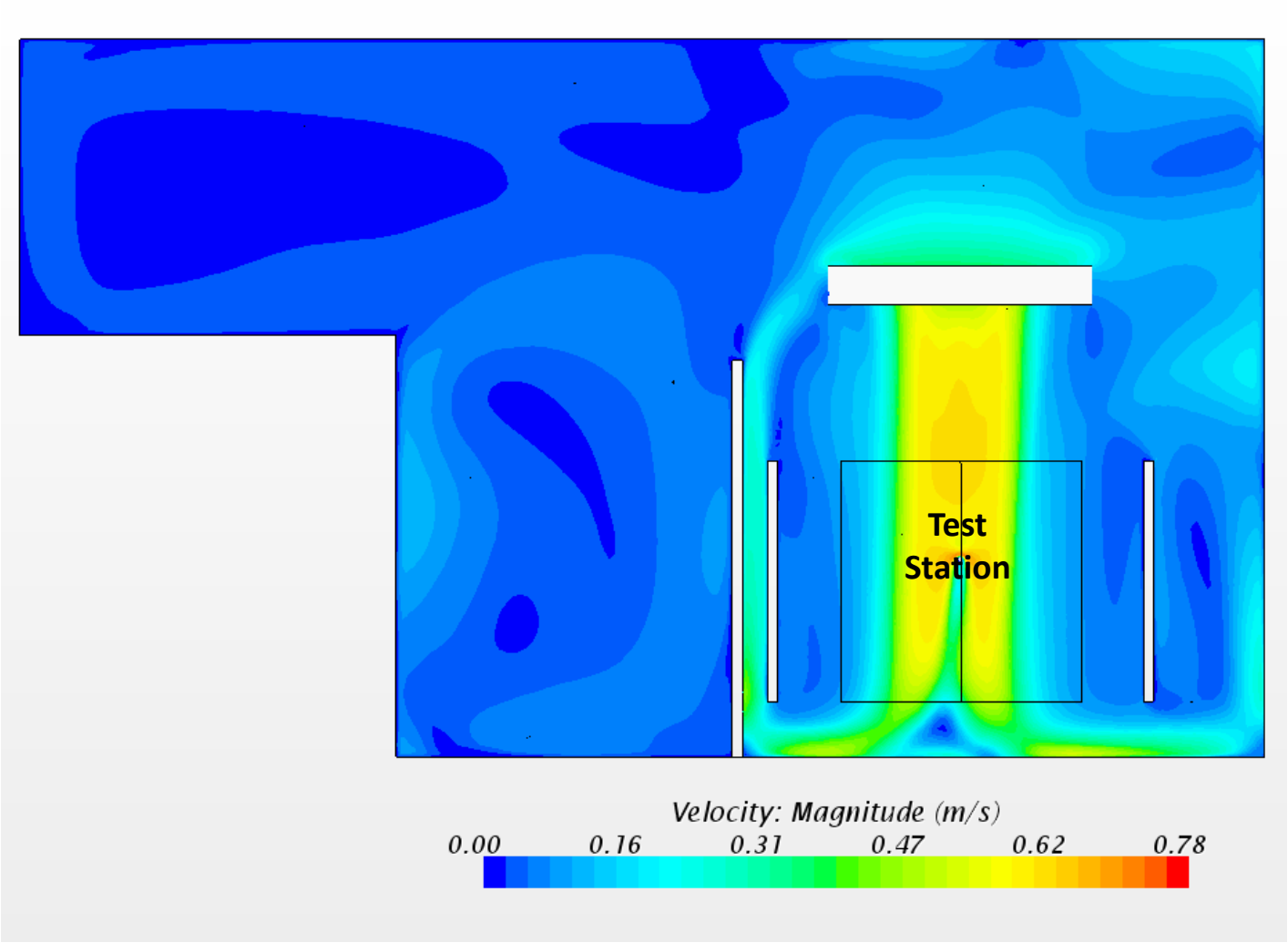
Presentation of Qualitative Post processing
For Scenarios A 13



Test Set-up - Plan View

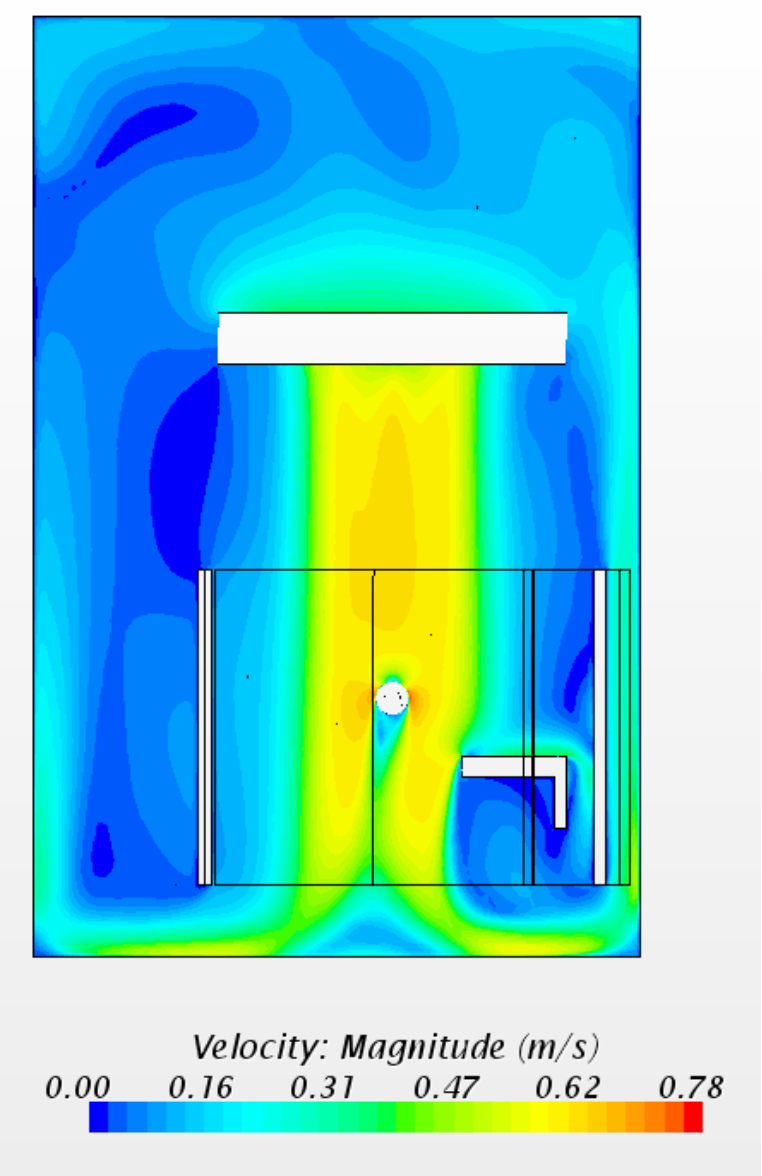
Test Set-up - Section A-A

Presentation of Qualitative Post processing
For Scenarios A 13



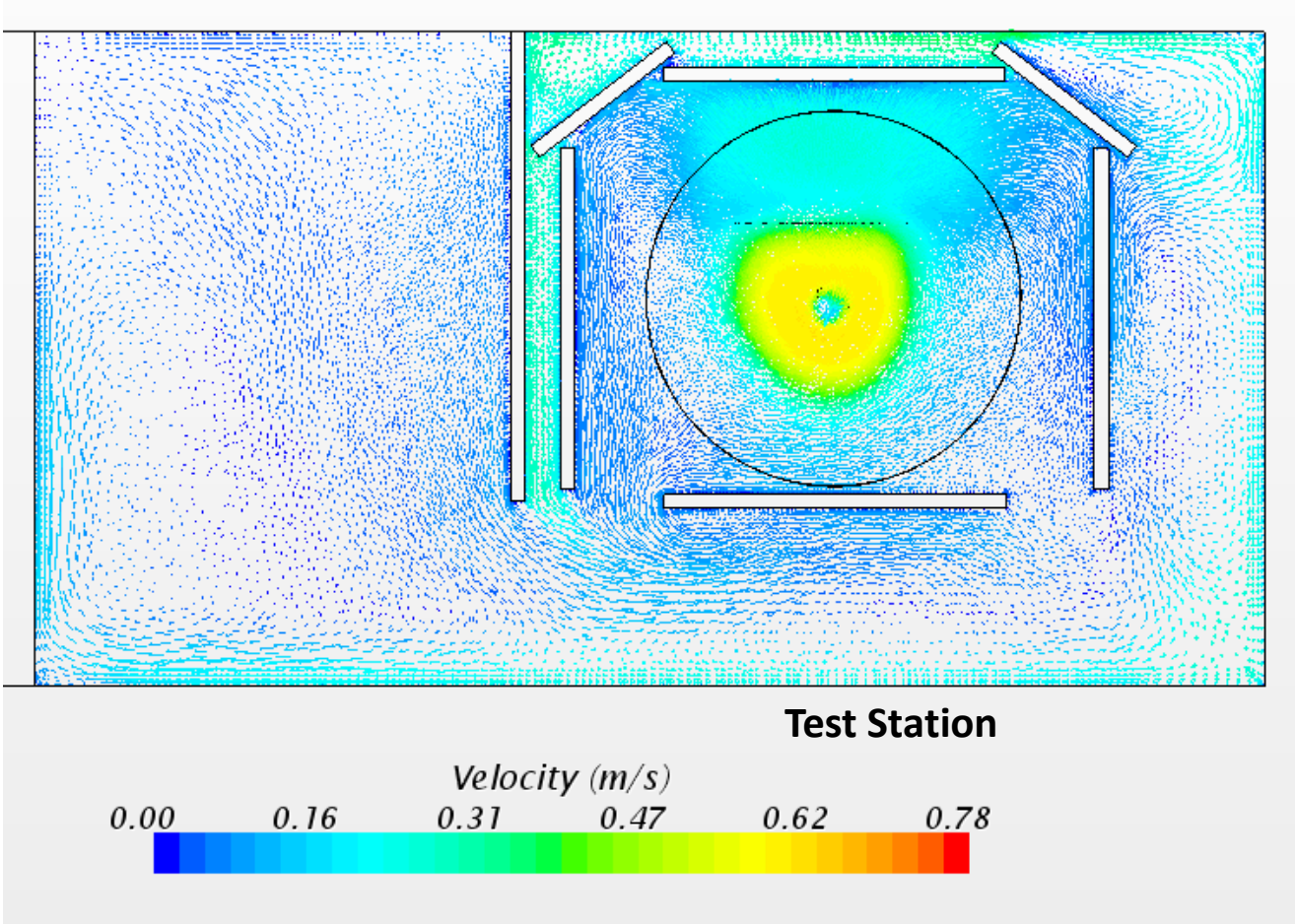
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 13



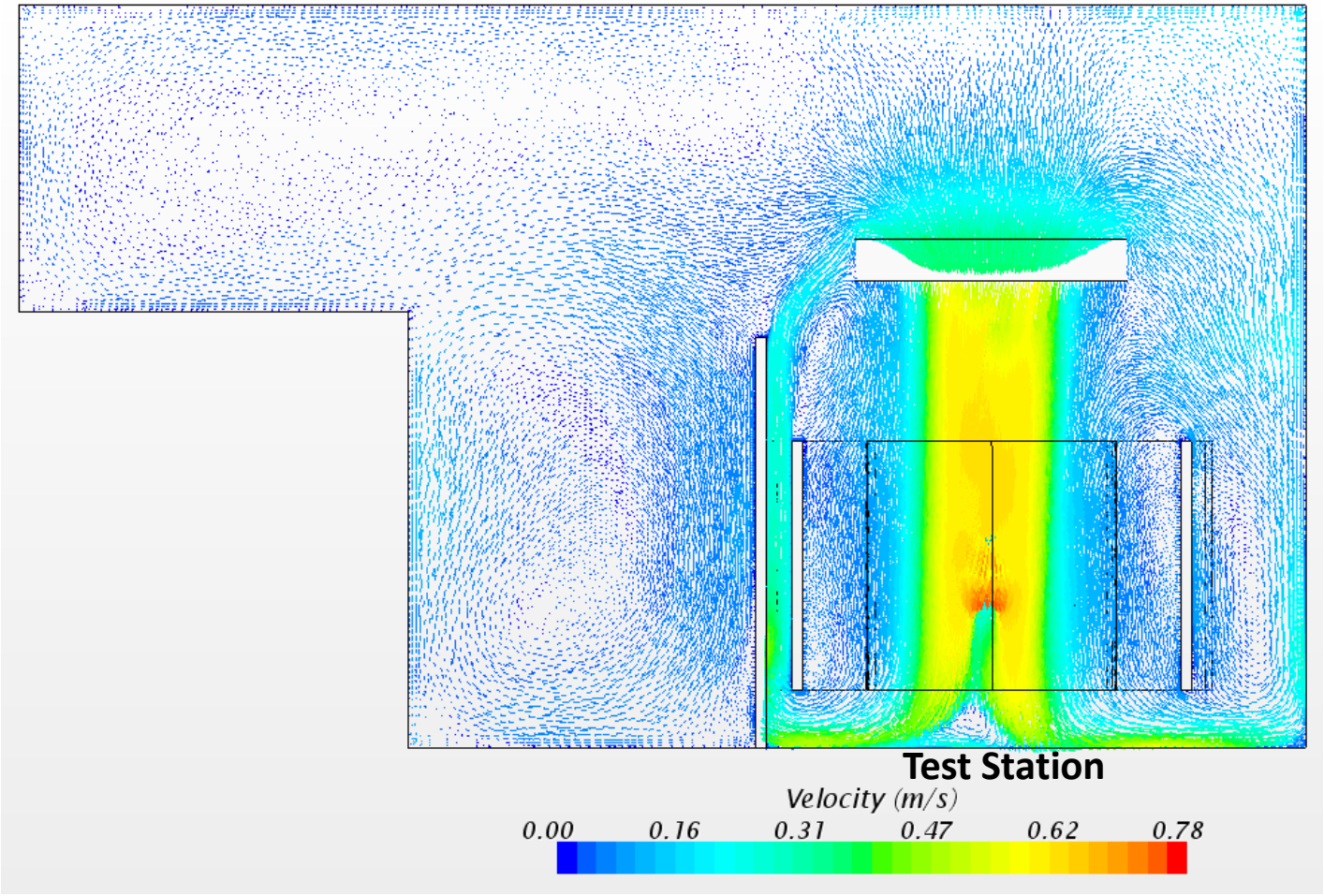
Test Set-up - Section B-B

Presentation of Qualitative Post processing
For Scenarios A 13



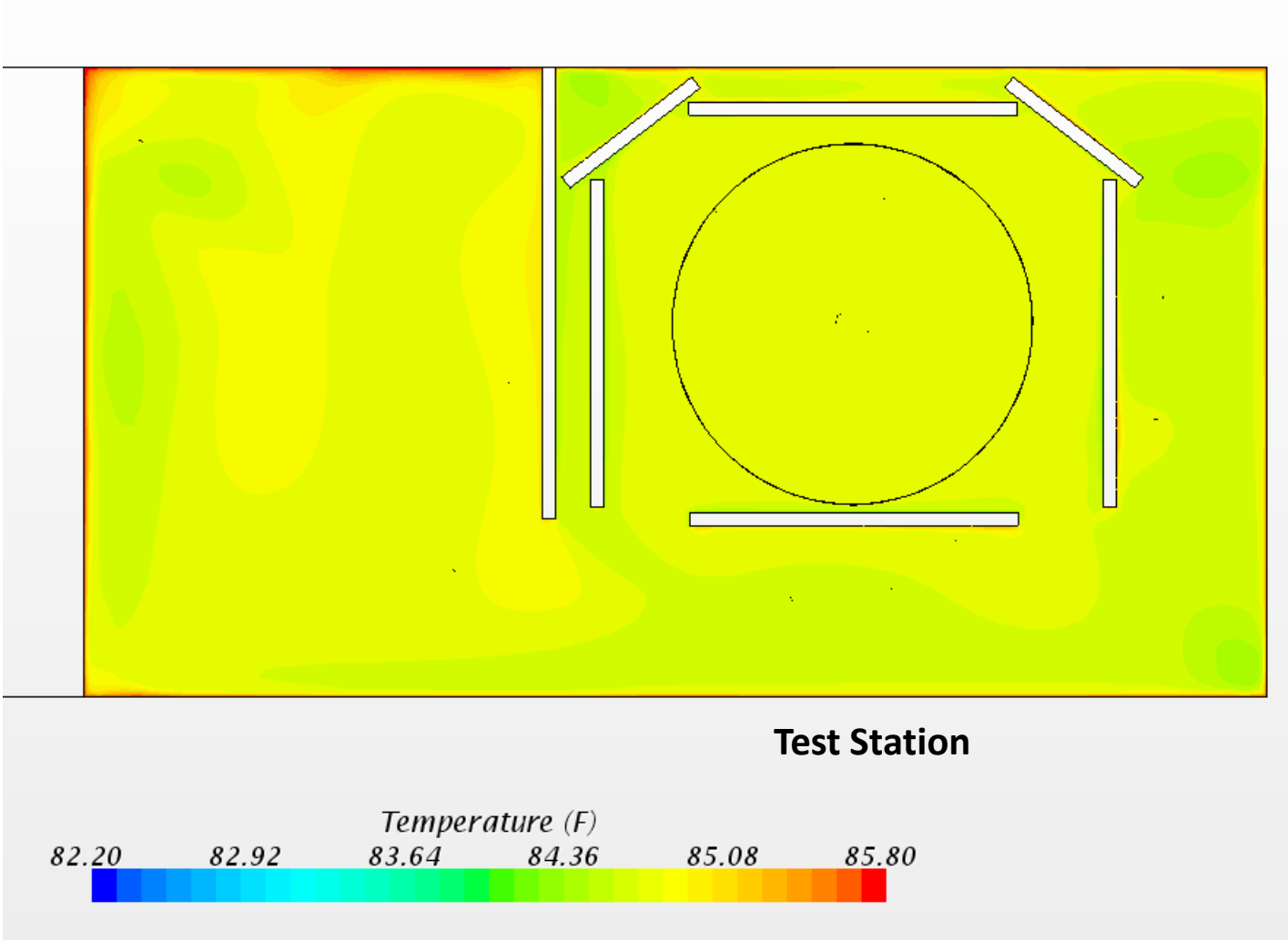
Test Set-up - Plan View

Presentation of Qualitative Post processing
For Scenarios A 13



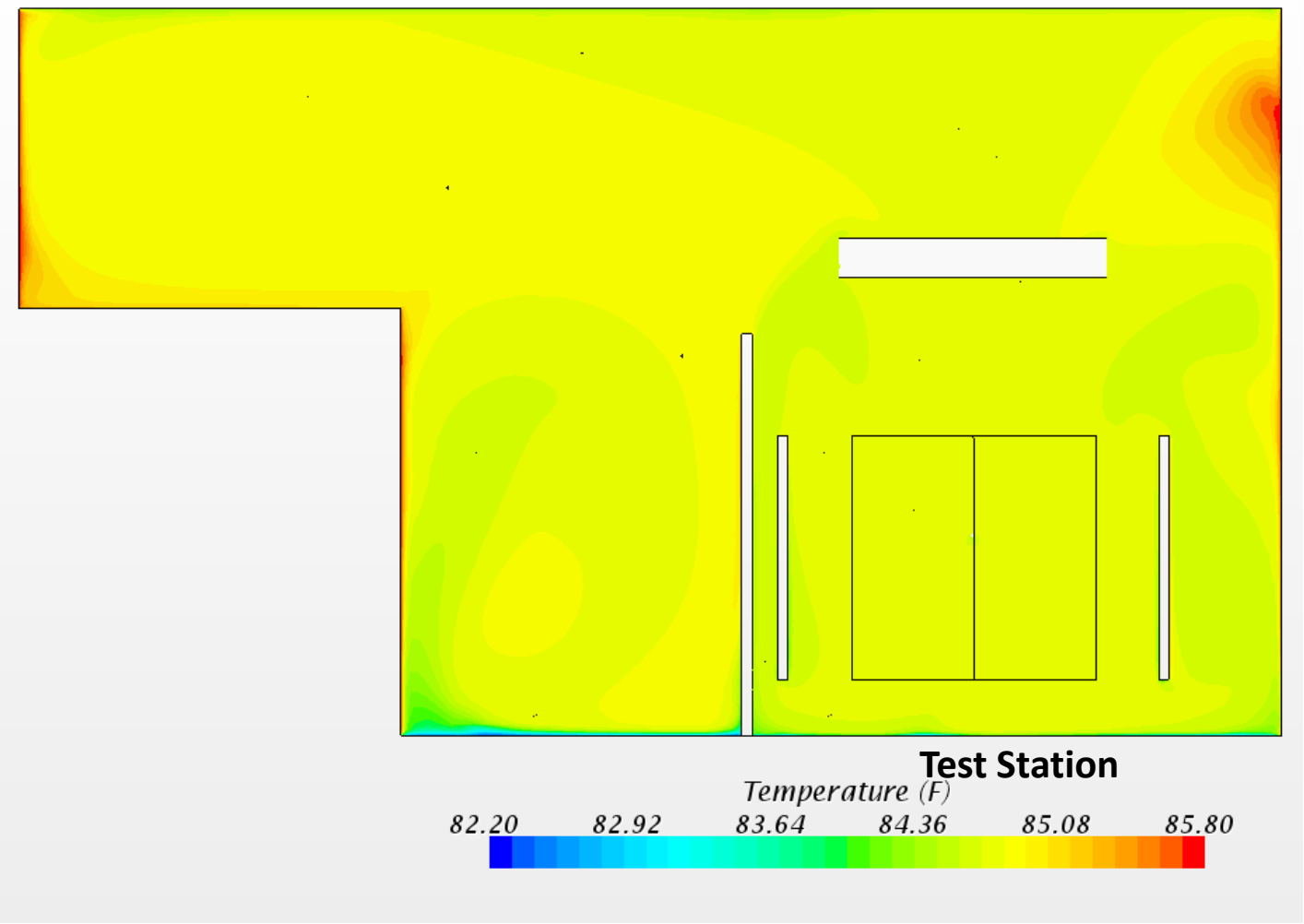
Test Set-up - Section A-A

Presentation of Qualitative Post processing
For Scenarios A 13



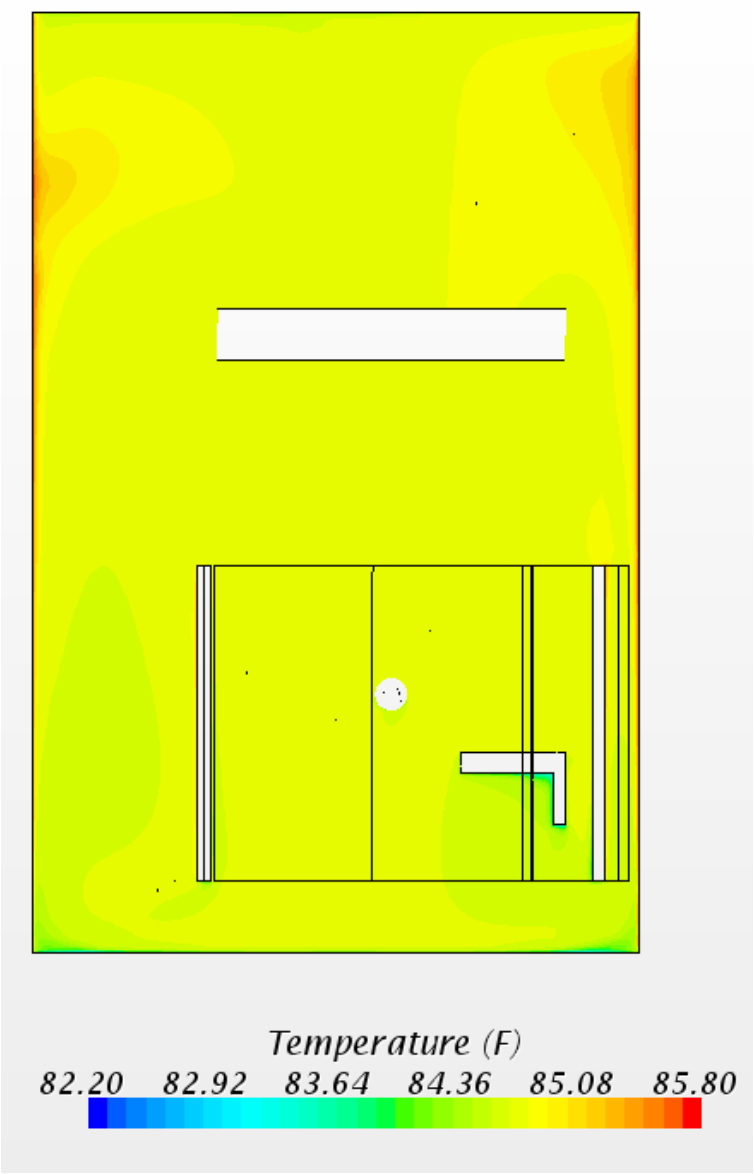
Test Set-up - Plan View

Presentation of Qualitative Post processing
For Scenarios A 13



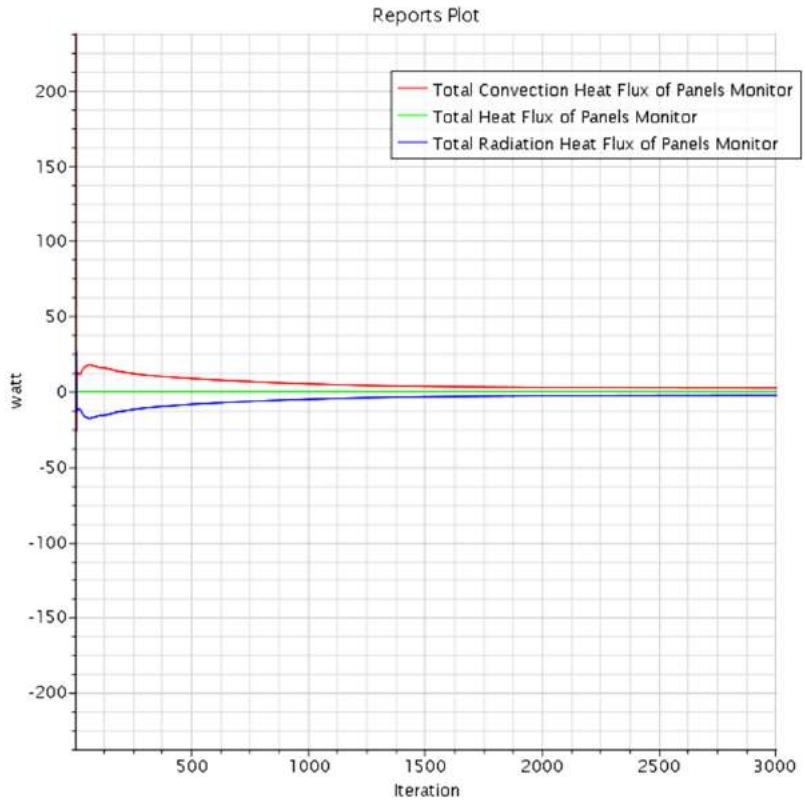
Test Set-up - Section A-A

Presentation of Qualitative Post processing
For Scenarios A 13

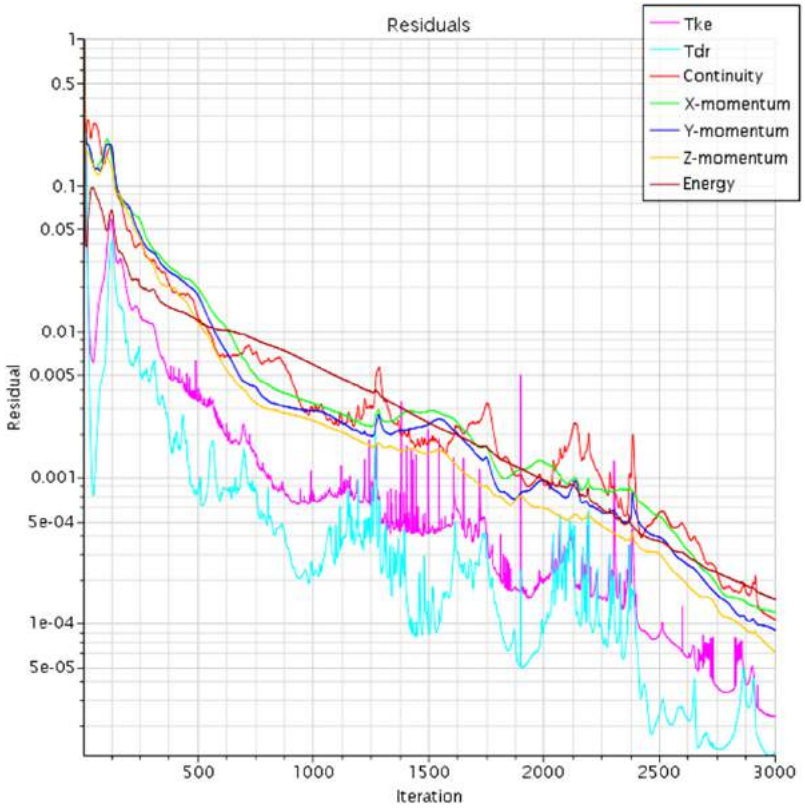


Test Set-up - Section B-B

Presentation of Qualitative Post processing
For Scenarios A 13

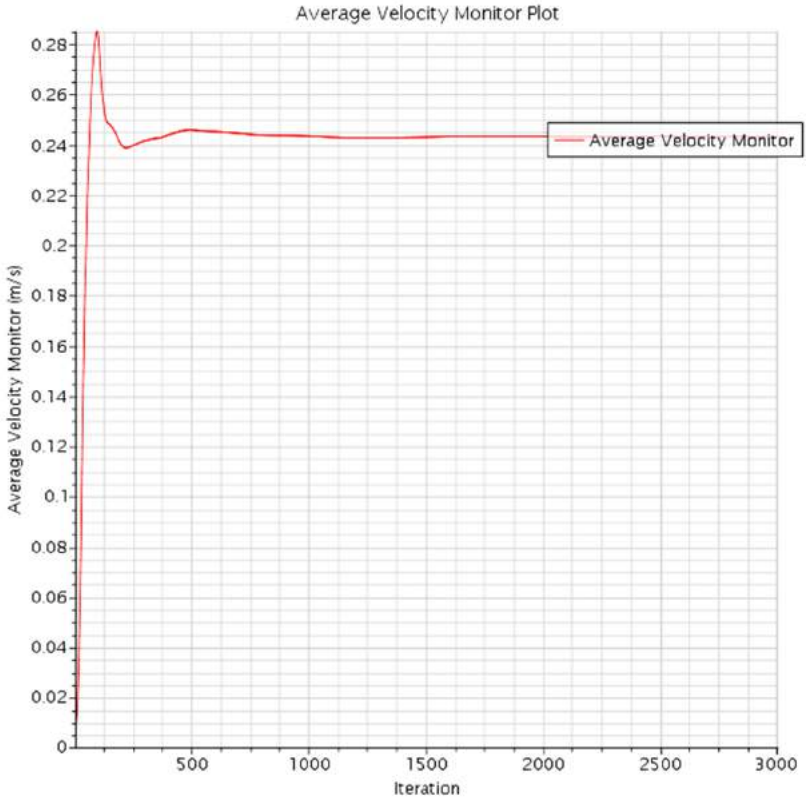


Heat Flux

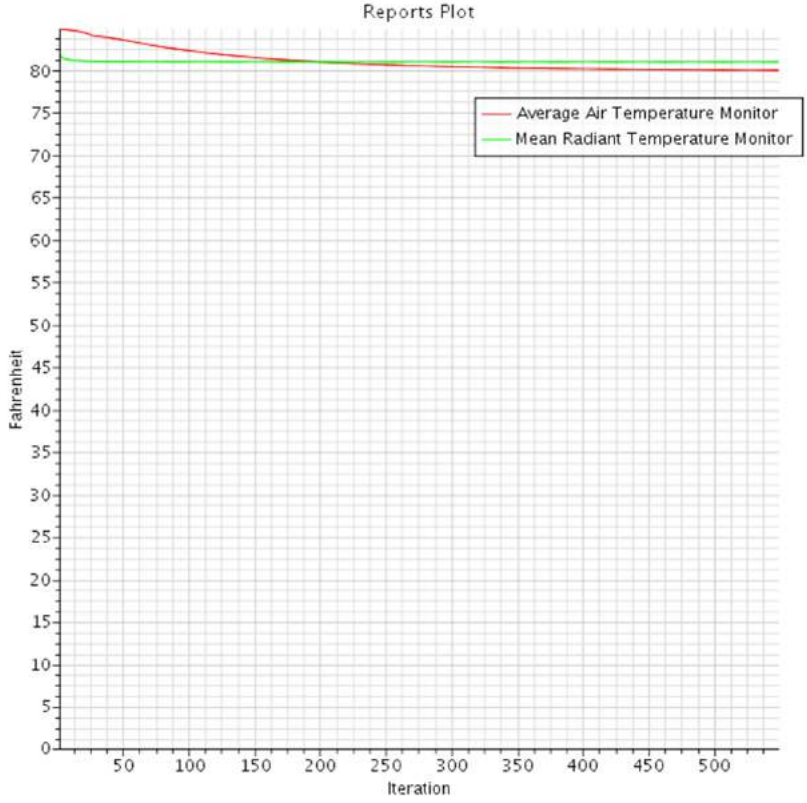


Convergence - Residuals

Presentation of Qualitative Post processing For Scenarios A 13

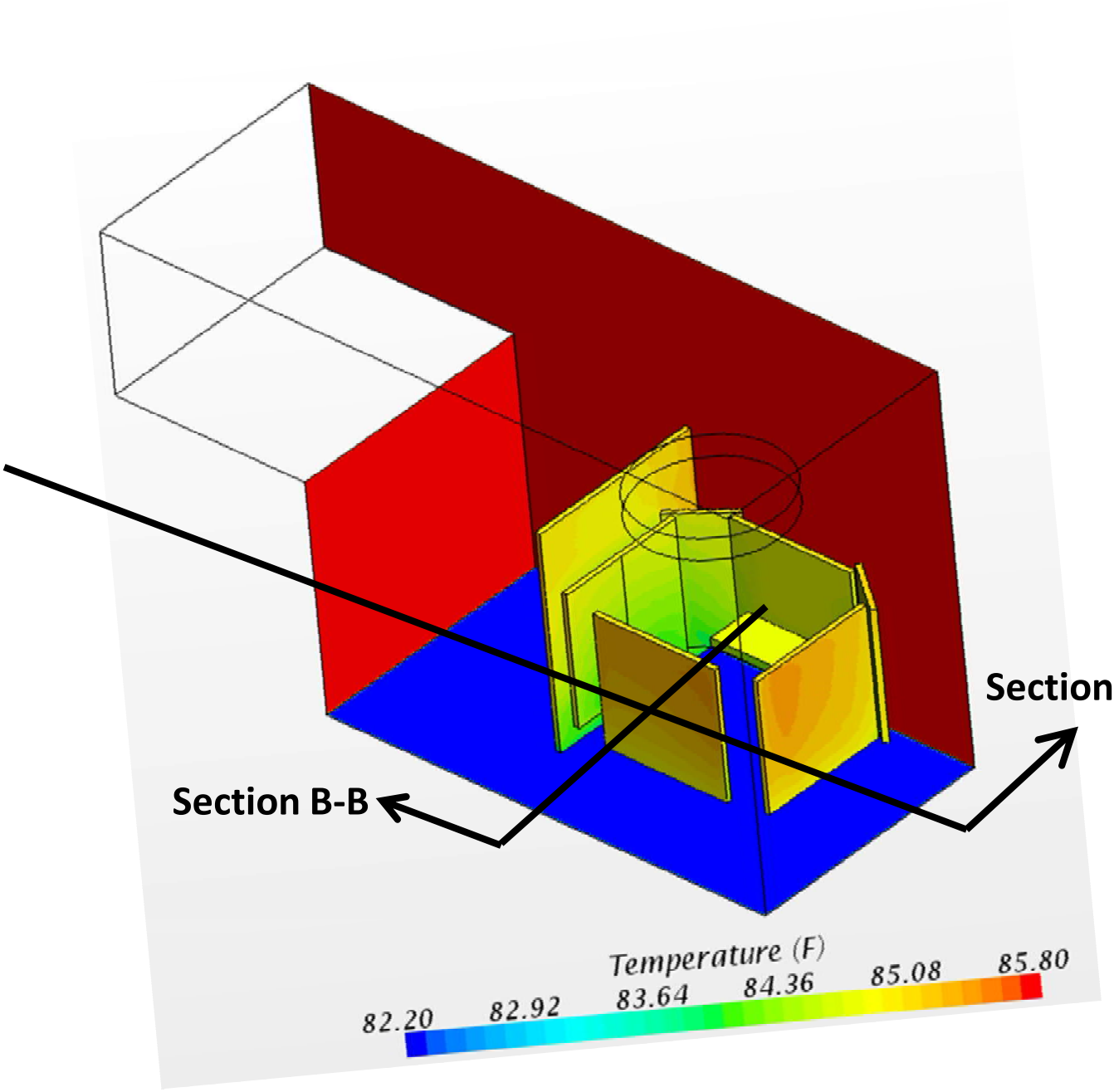


Convergence - Average Velocity Monitor



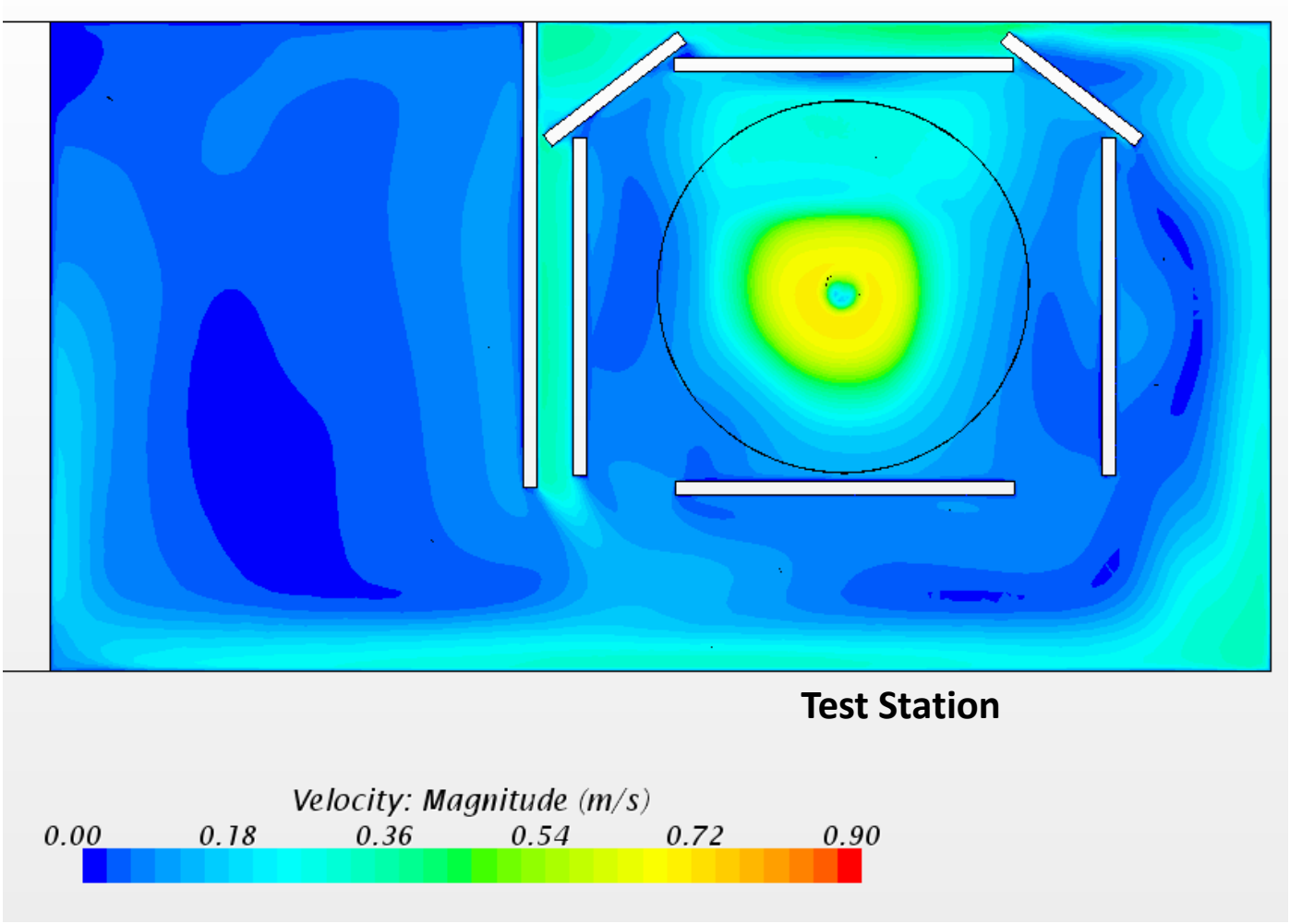
Convergence - Temperature

Presentation of Qualitative Post processing
For Scenarios A 13-B



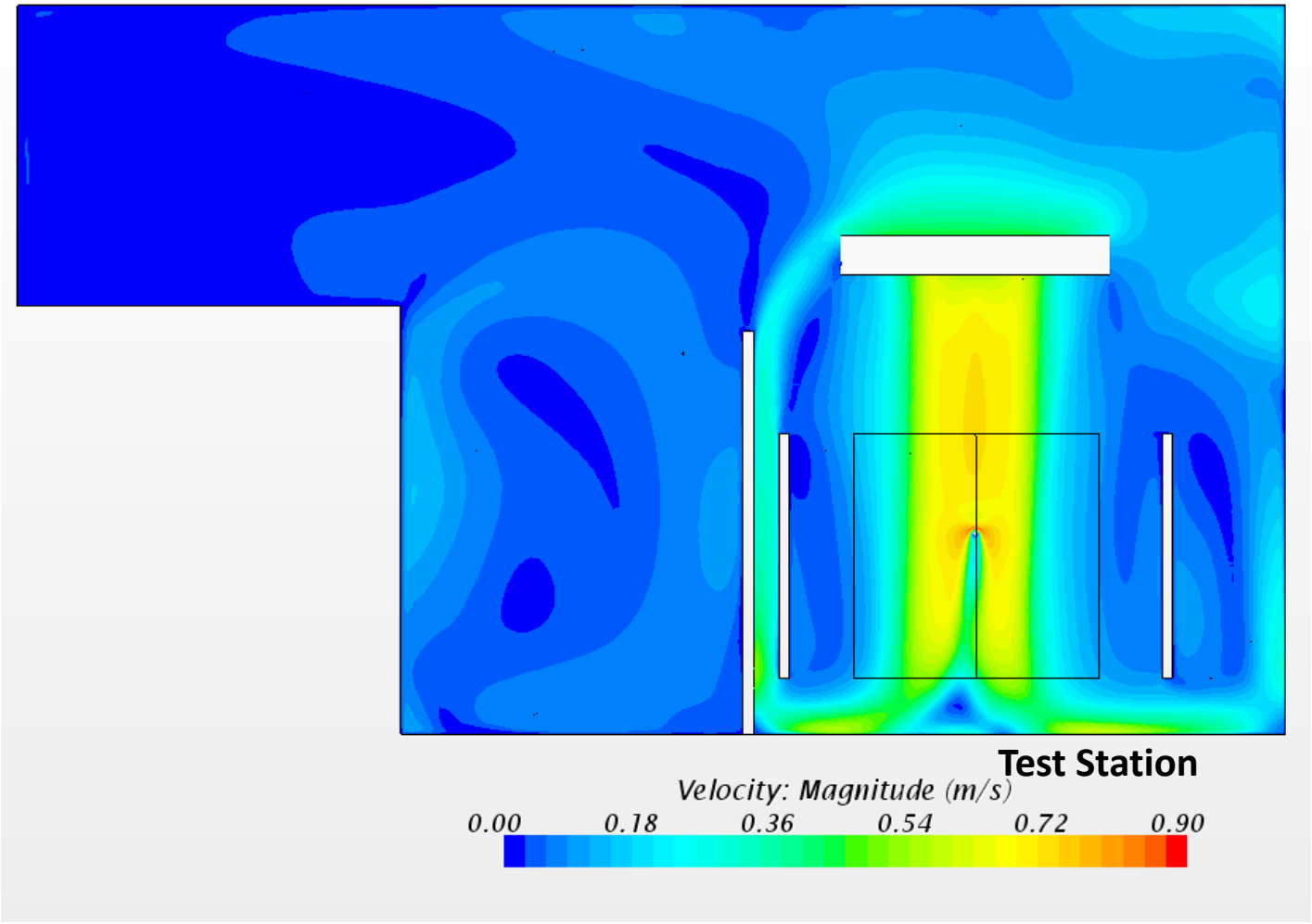
Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 13-B



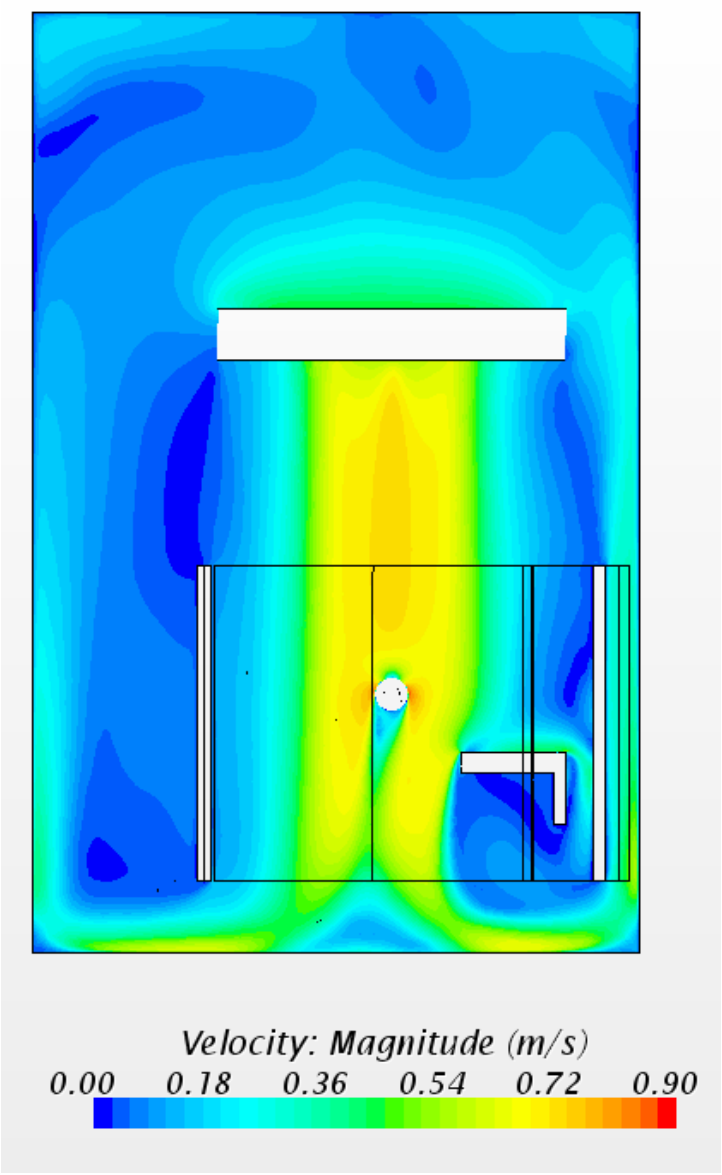
Test Set-up - Plan View

Presentation of Qualitative Post processing For Scenarios A 13-B



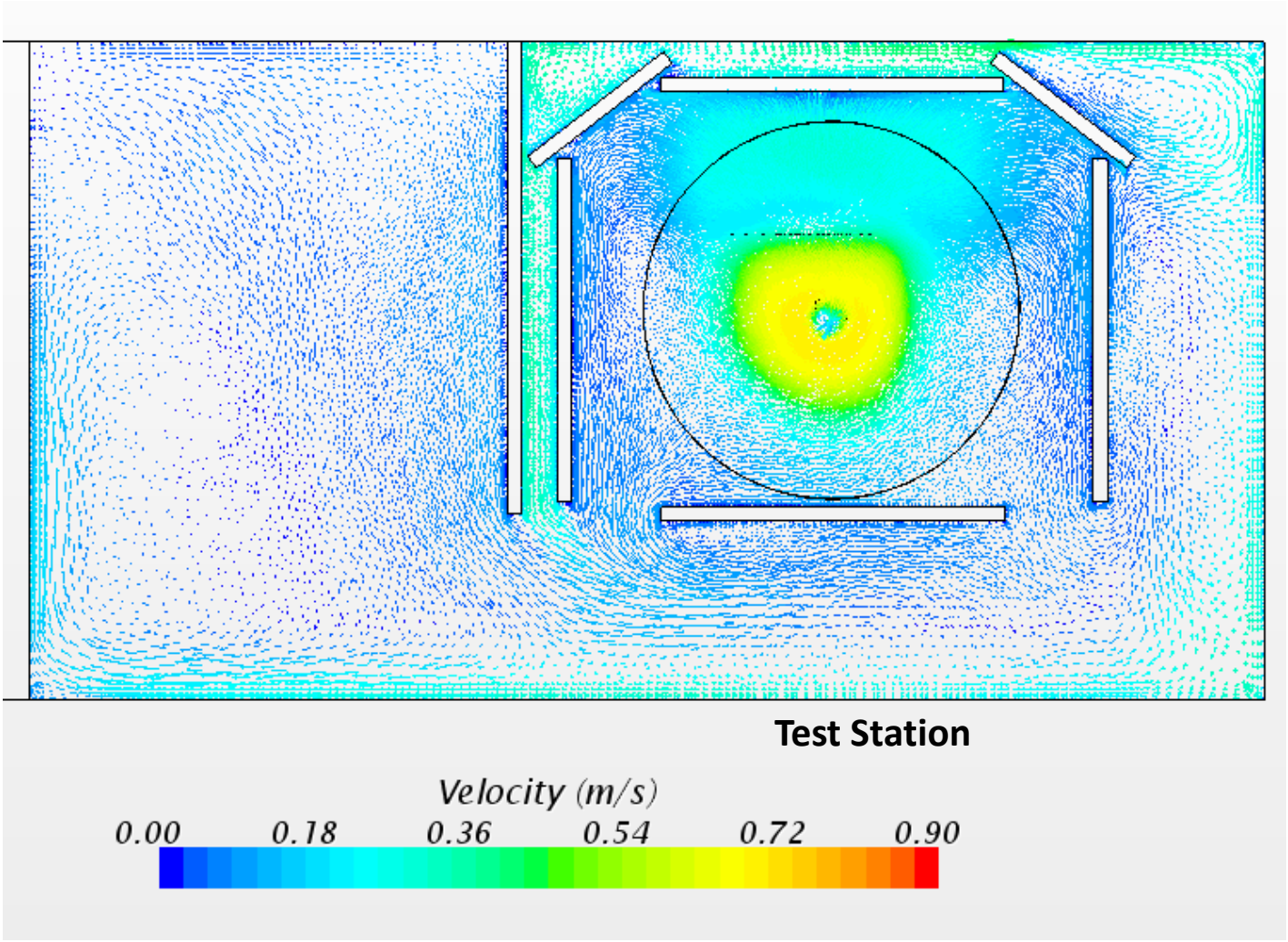
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 13-B



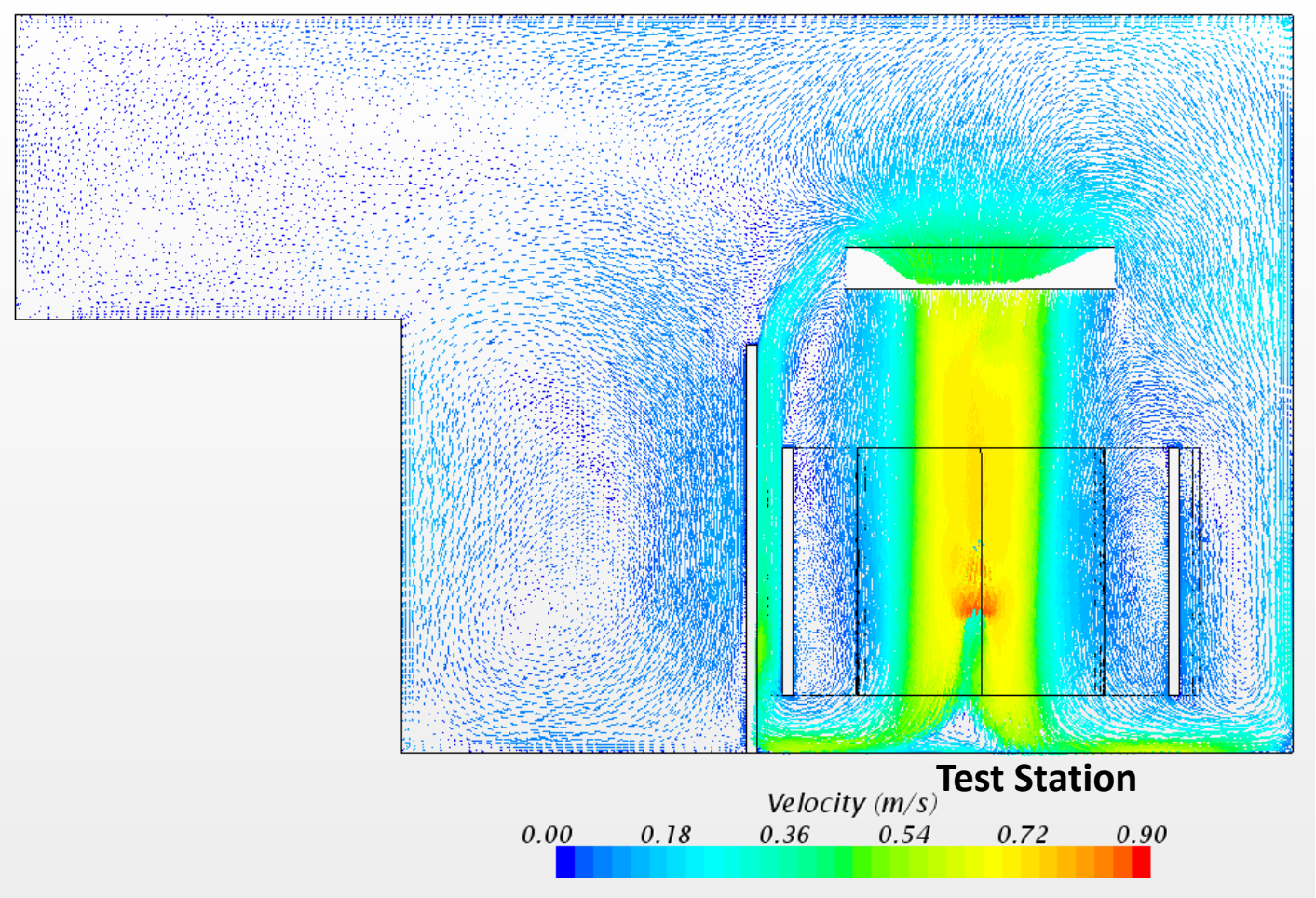
Test Set-up - Section B-B

Presentation of Qualitative Post processing For Scenarios A 13-B



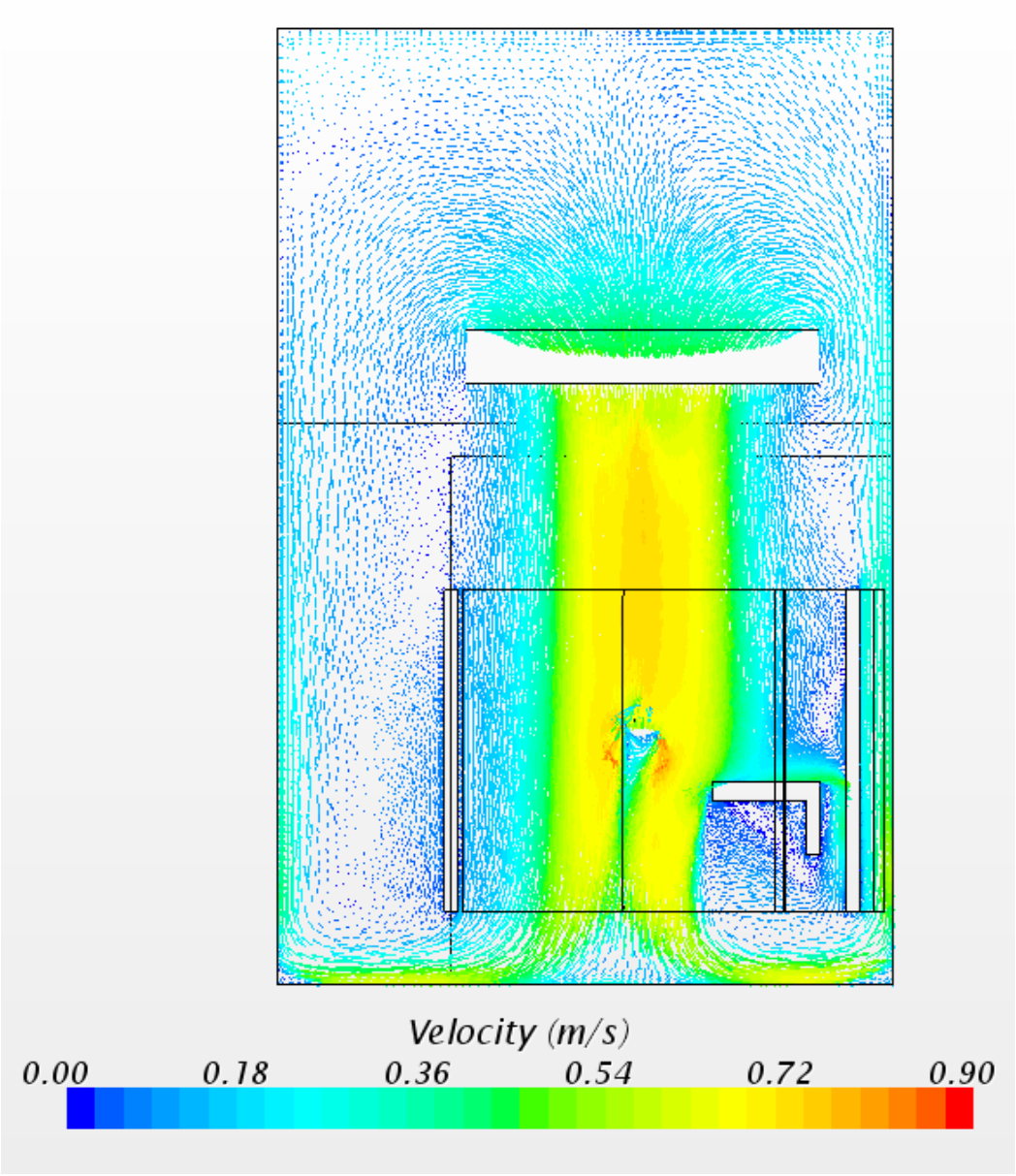
Test Set-up - Plan View

Presentation of Qualitative Post processing For Scenarios A 13-B



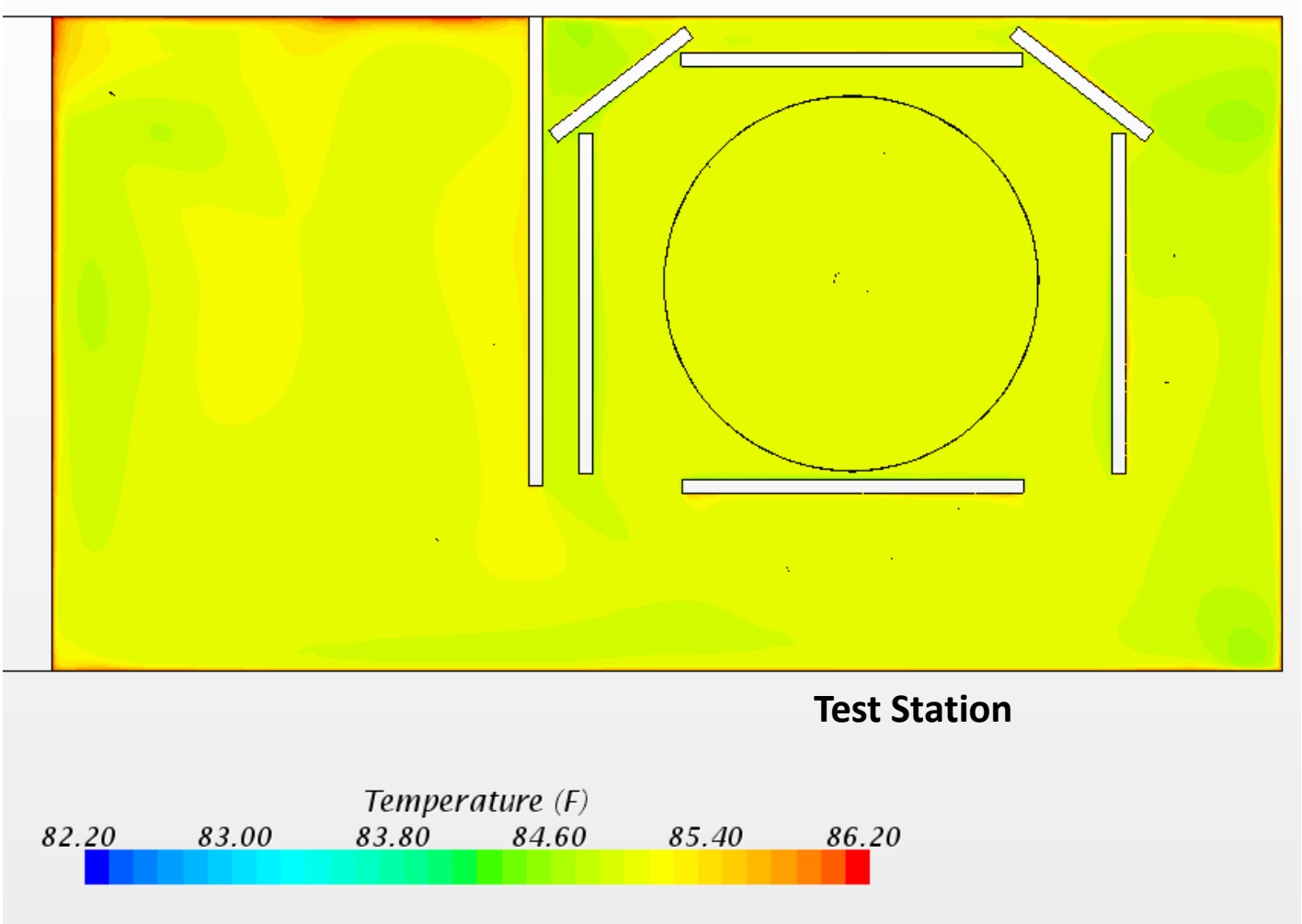
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 13-B



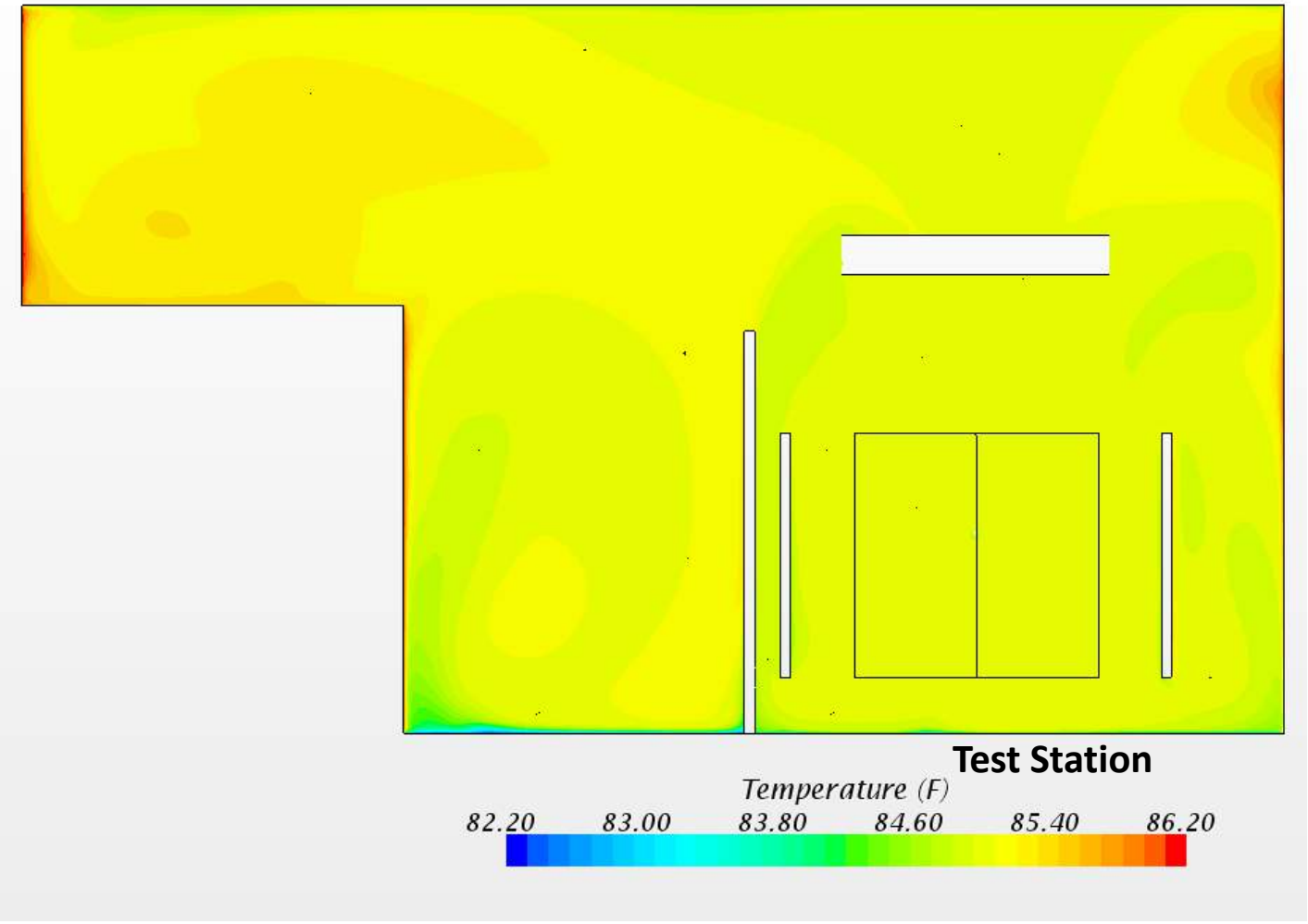
Test Set-up - Section B-B

Presentation of Qualitative Post processing
For Scenarios A 13-B



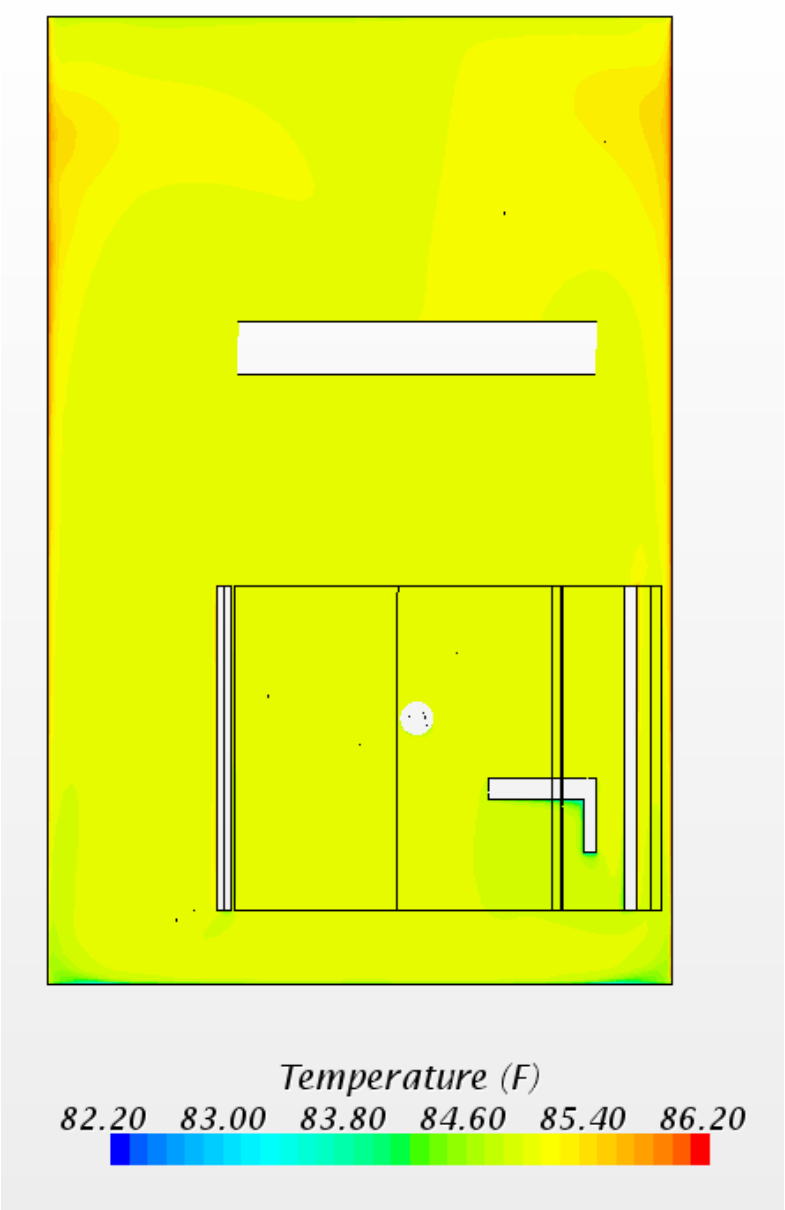
Test Set-up - Plan View

Presentation of Qualitative Post processing
For Scenarios A 13-B



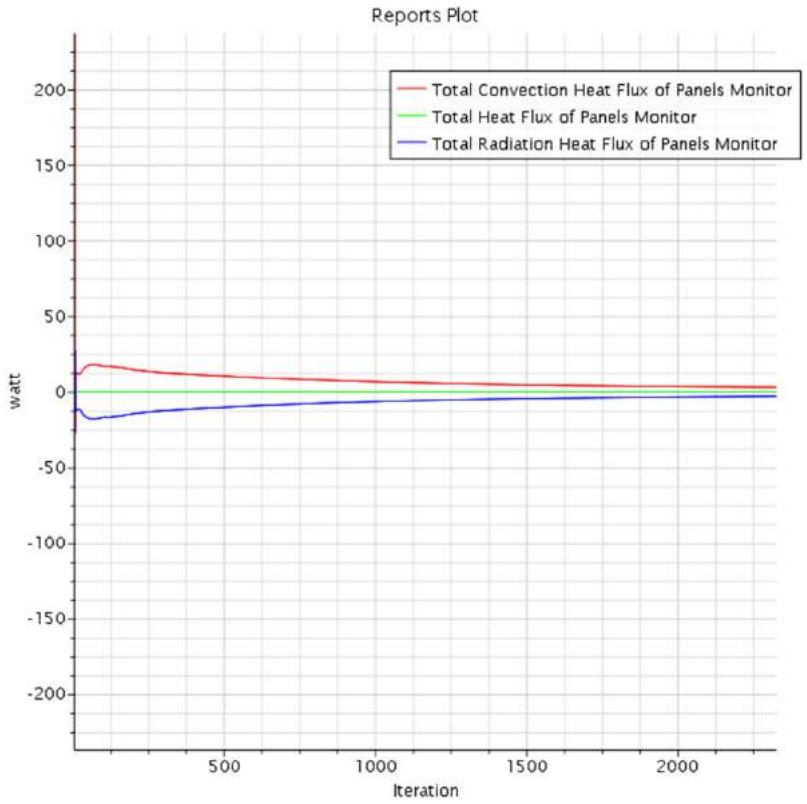
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 13-B

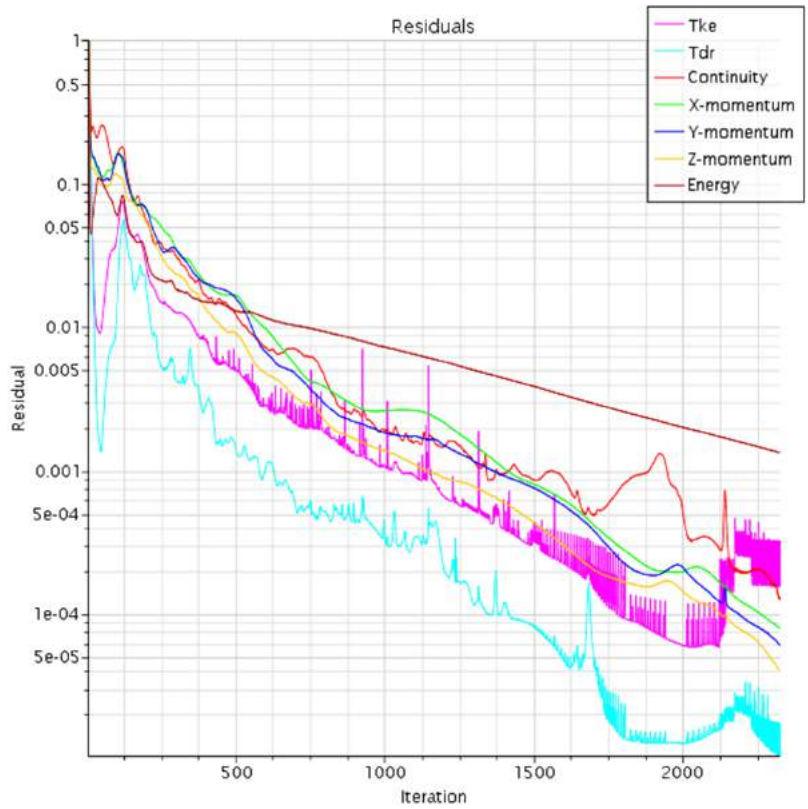


Test Set-up - Section B-B

Presentation of Qualitative Post processing
For Scenarios A 13-B

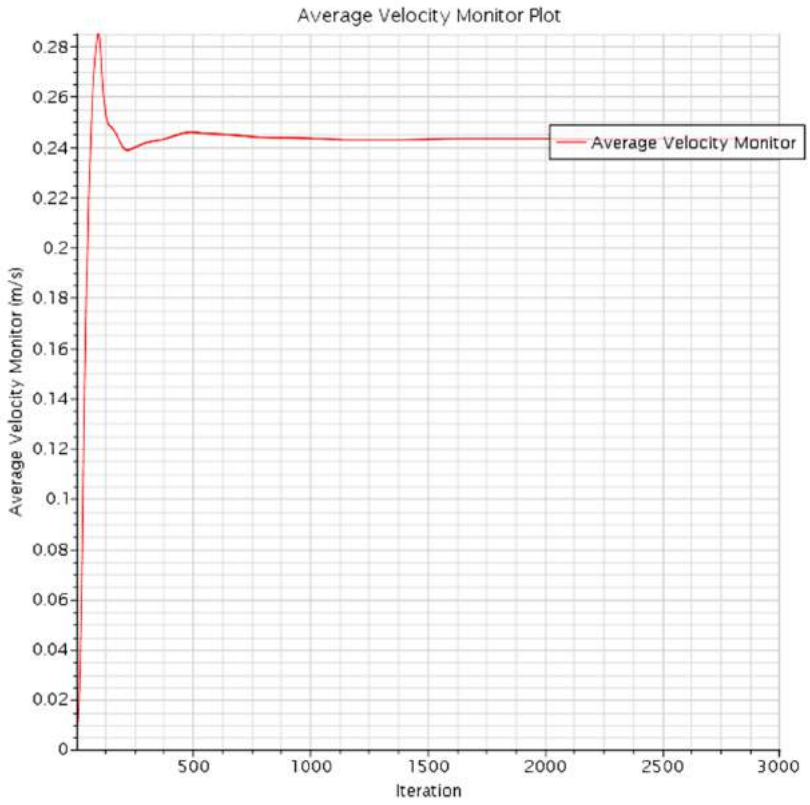


Convergence - Heat Flux

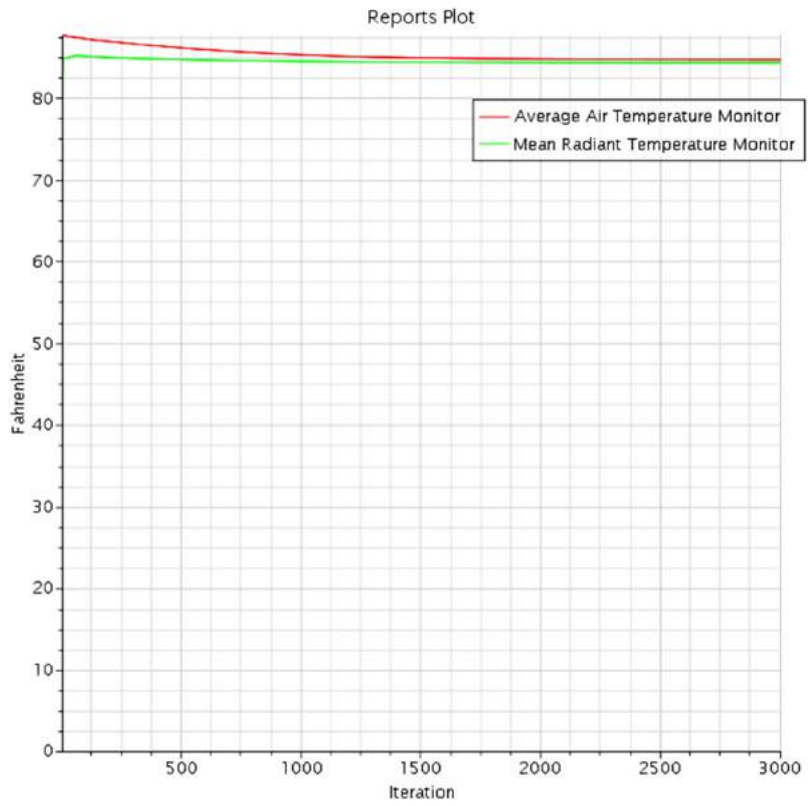


Convergence - Residuals

Presentation of Qualitative Post processing For Scenarios A 13-B

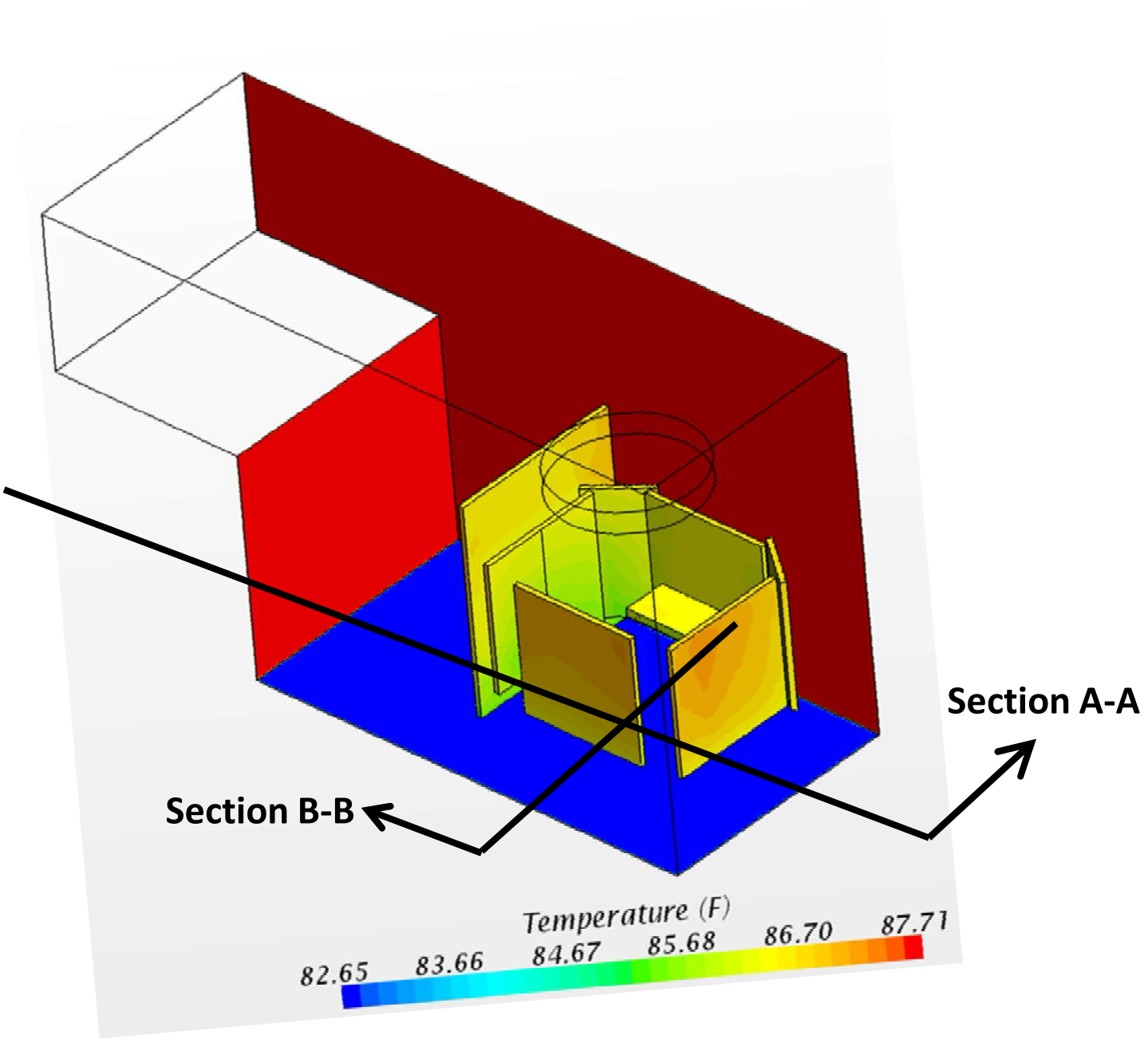


Convergence - Average Velocity Monitor



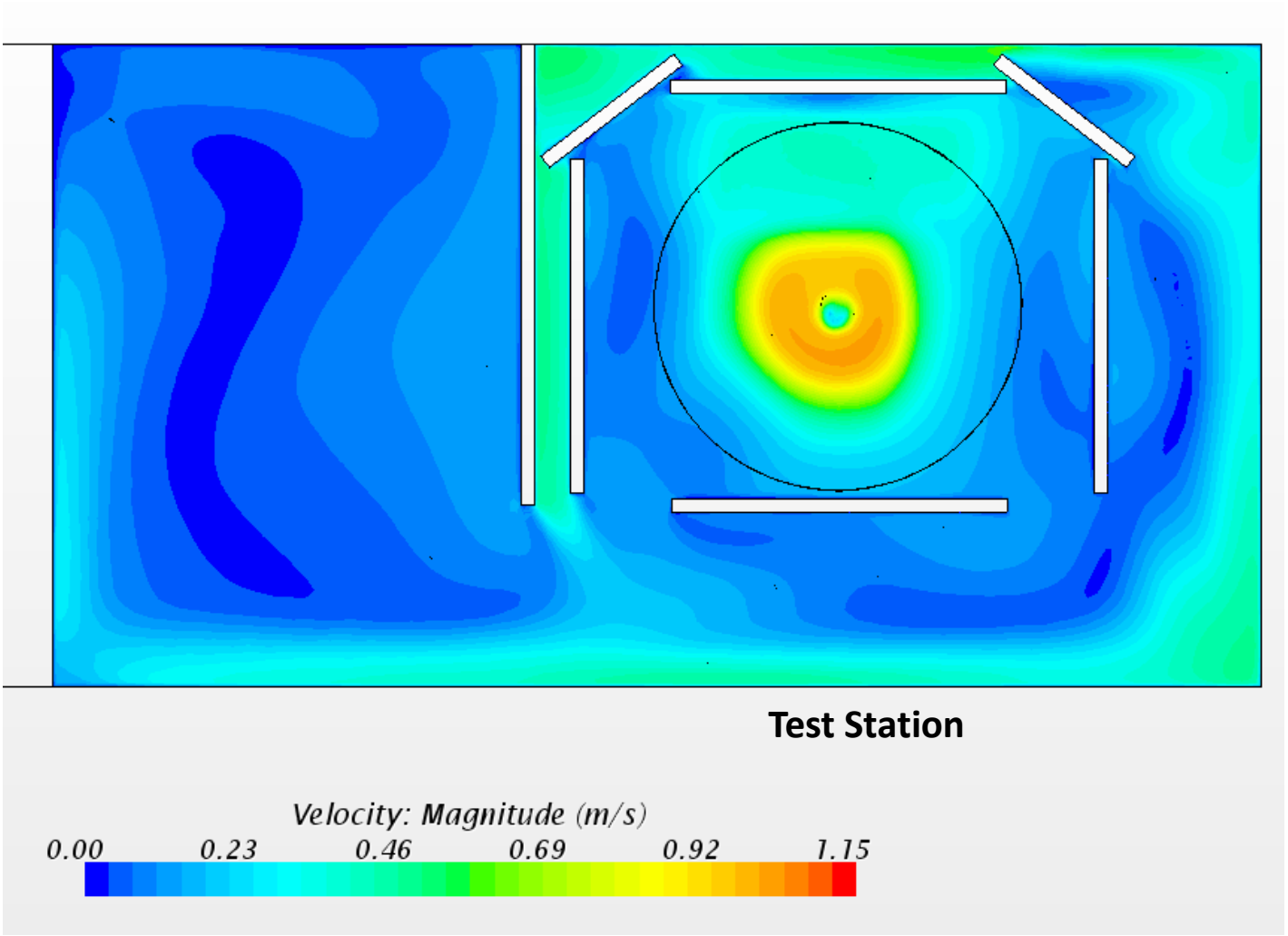
Convergence - Temperature

Presentation of Qualitative Post processing
For Scenarios A 14



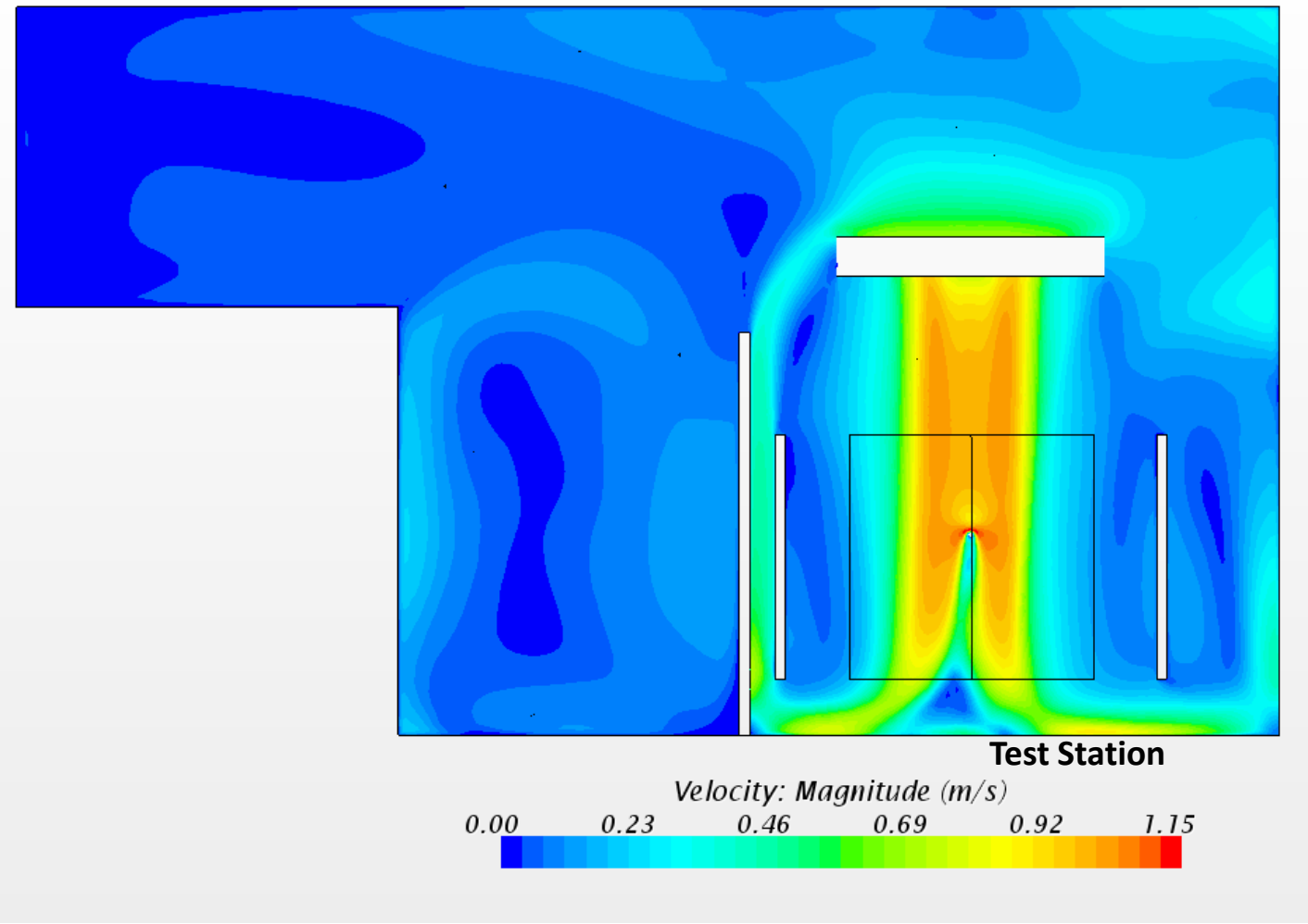
Test Set-up - Iso-metric View

Presentation of Qualitative Post processing For Scenarios A 14



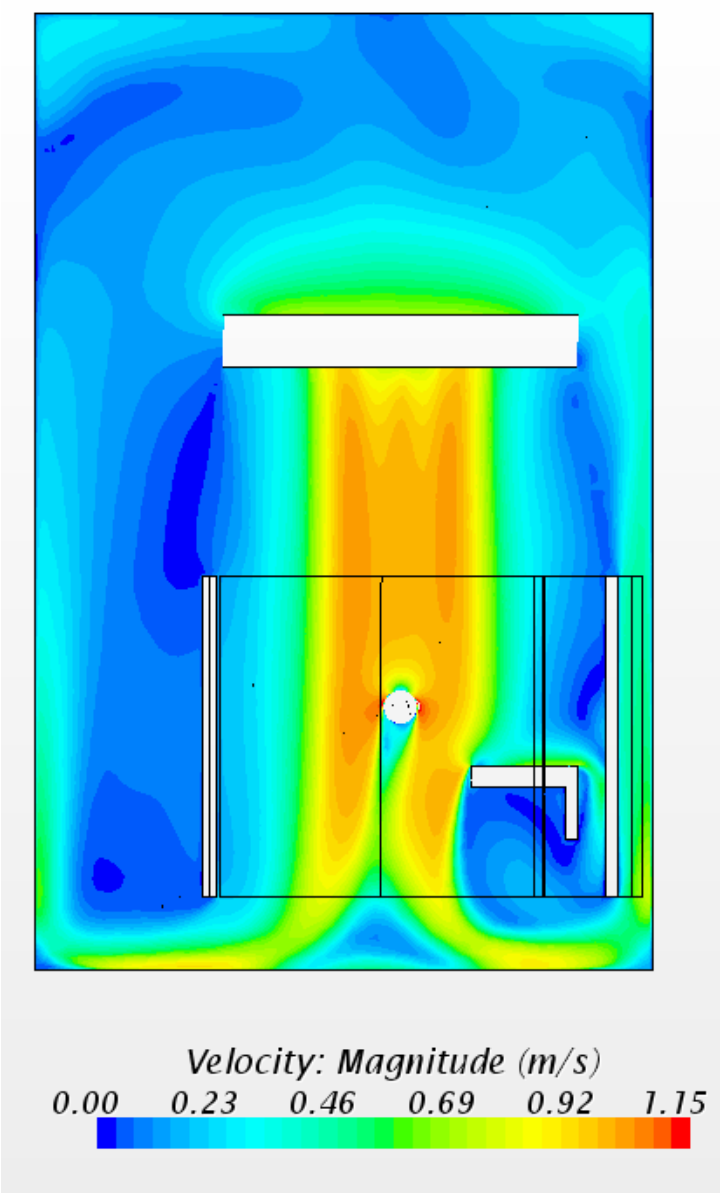
Test Set-up - Plan View

Presentation of Qualitative Post processing
For Scenarios A 14



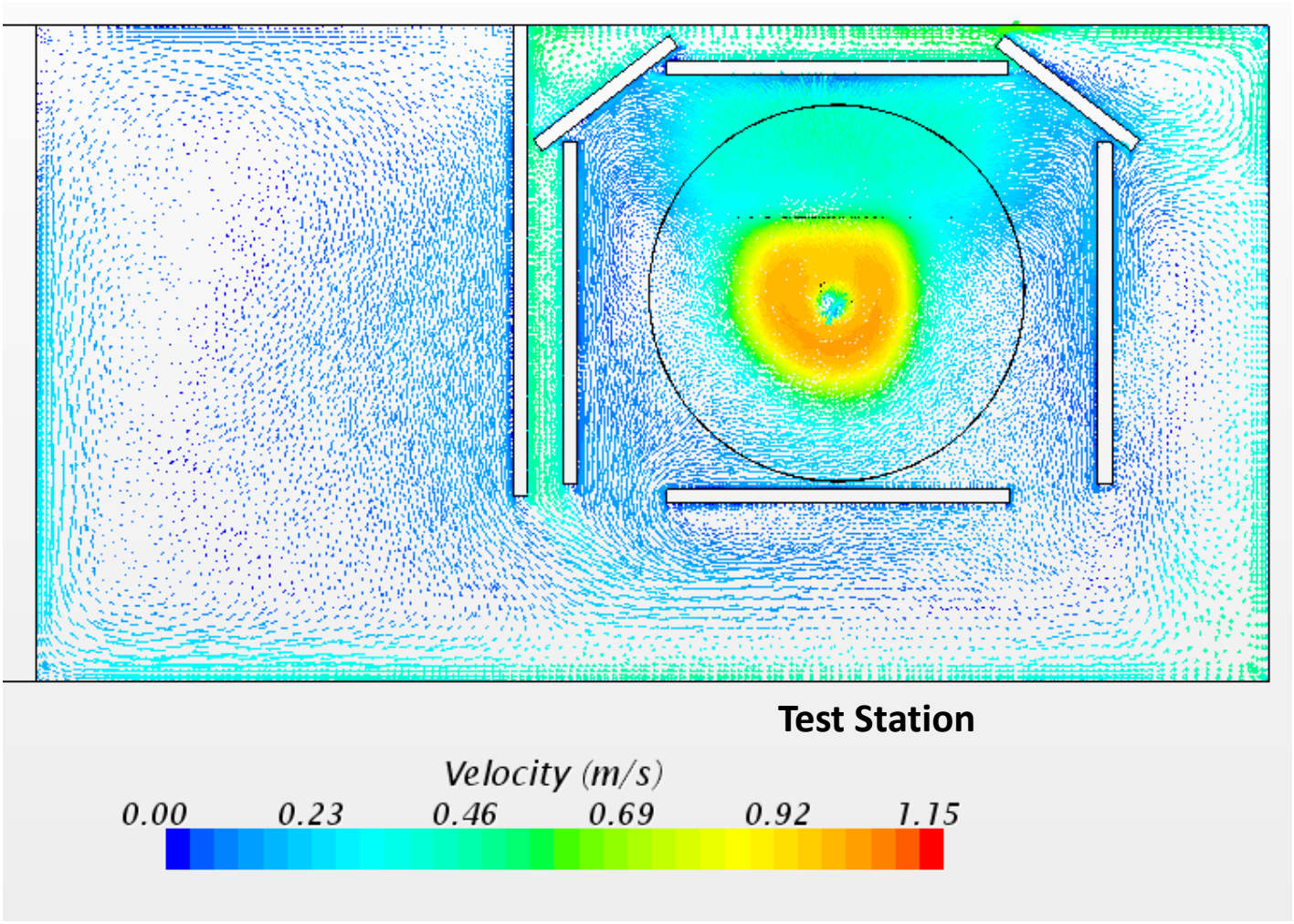
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 14



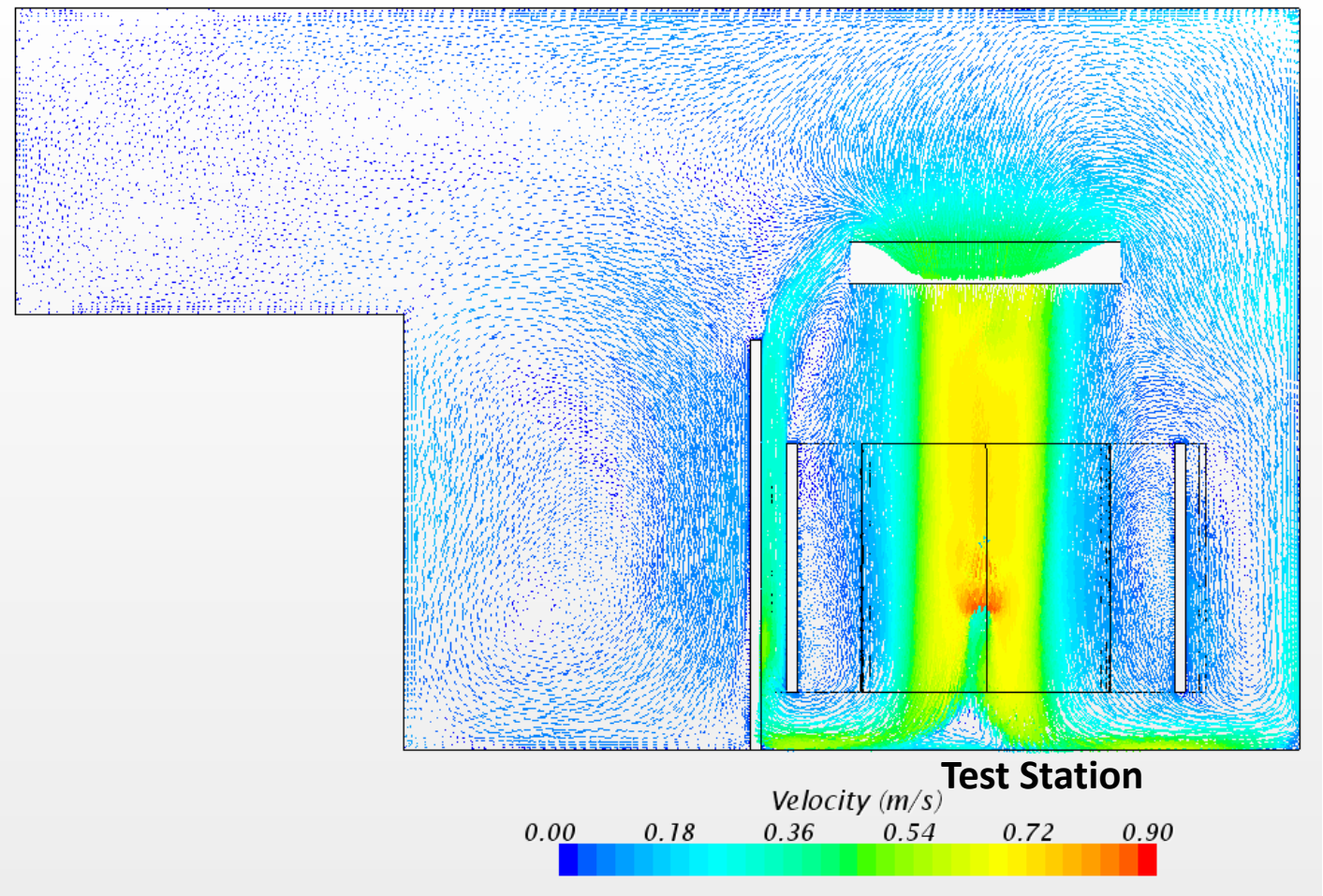
Test Set-up - Section B-B

Presentation of Qualitative Post processing
For Scenarios A 14



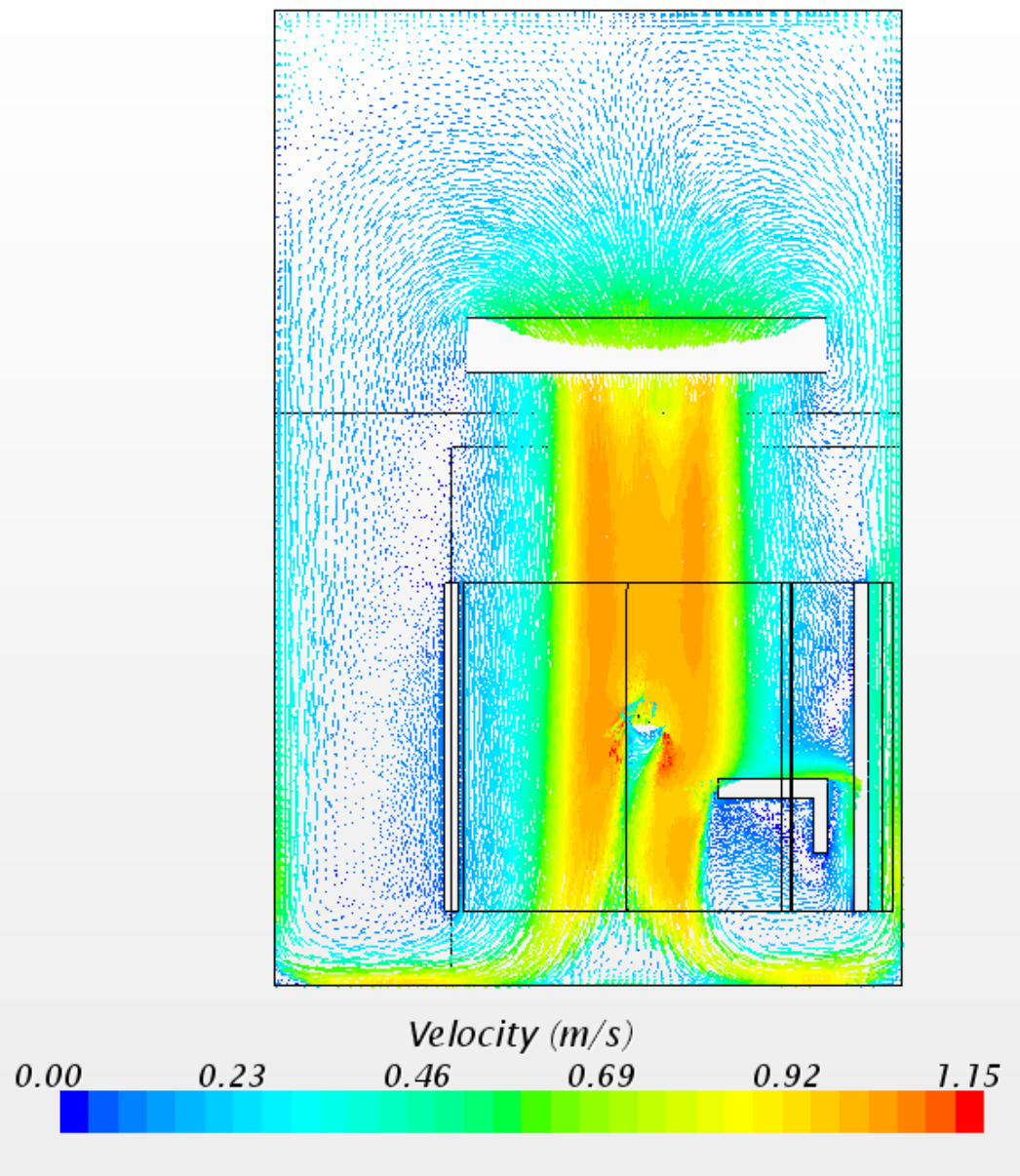
Test Set-up - Plan View

Presentation of Qualitative Post processing
For Scenarios A 14



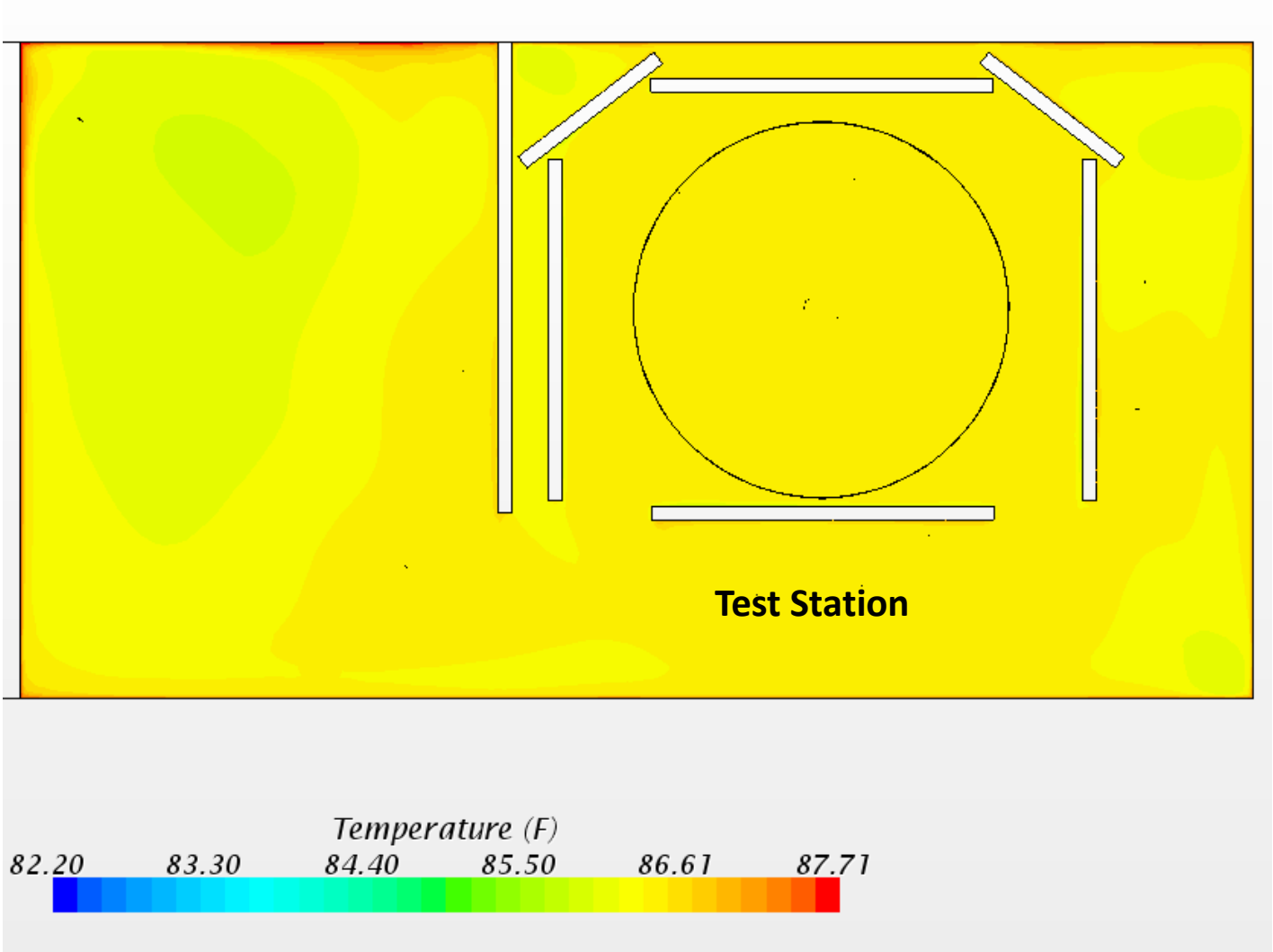
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 14



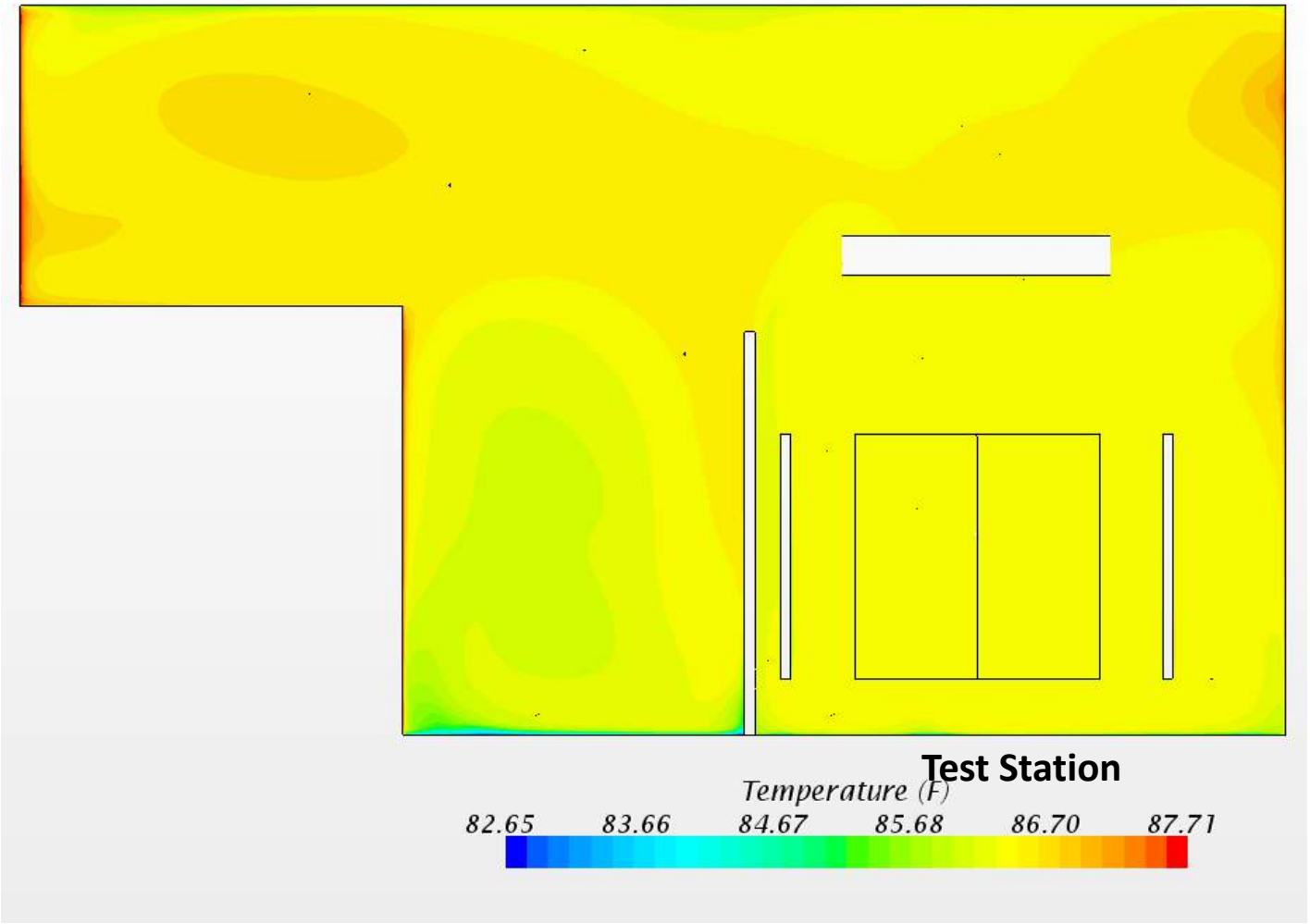
Test Set-up - Section B-B

Presentation of Qualitative Post processing
For Scenarios A 134



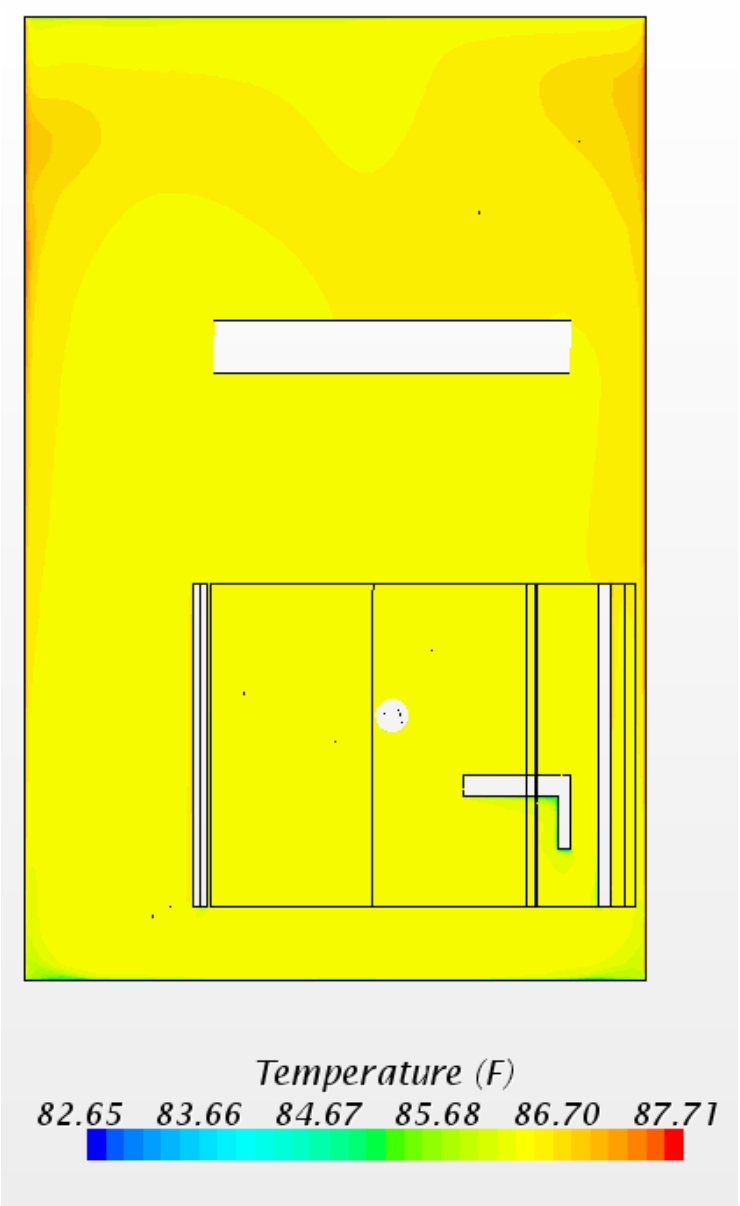
Test Set-up - Plan View

Presentation of Qualitative Post processing
For Scenarios A 14



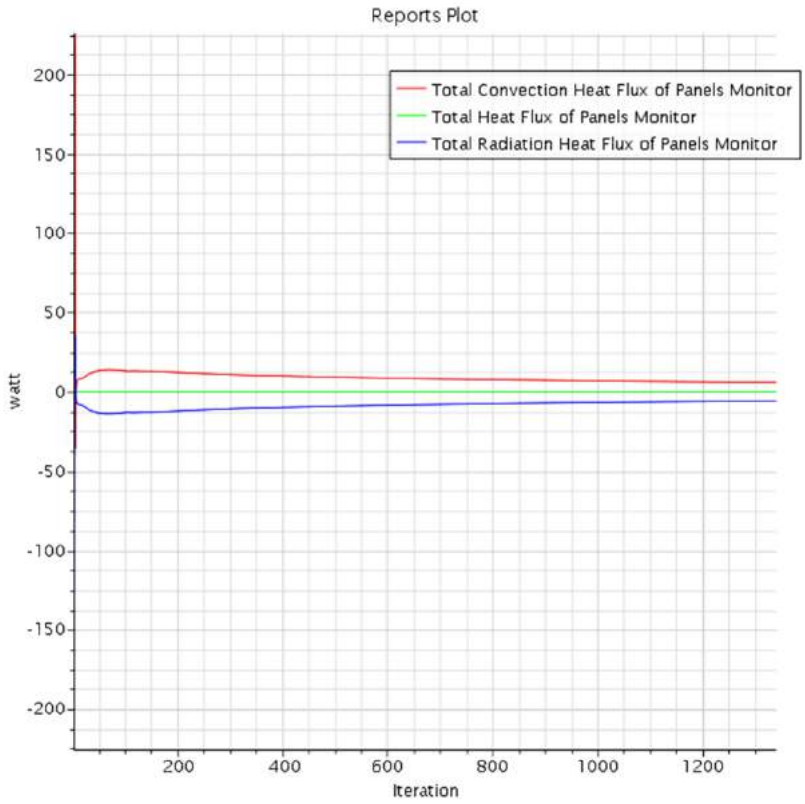
Test Set-up - Section A-A

Presentation of Qualitative Post processing
For Scenarios A 14

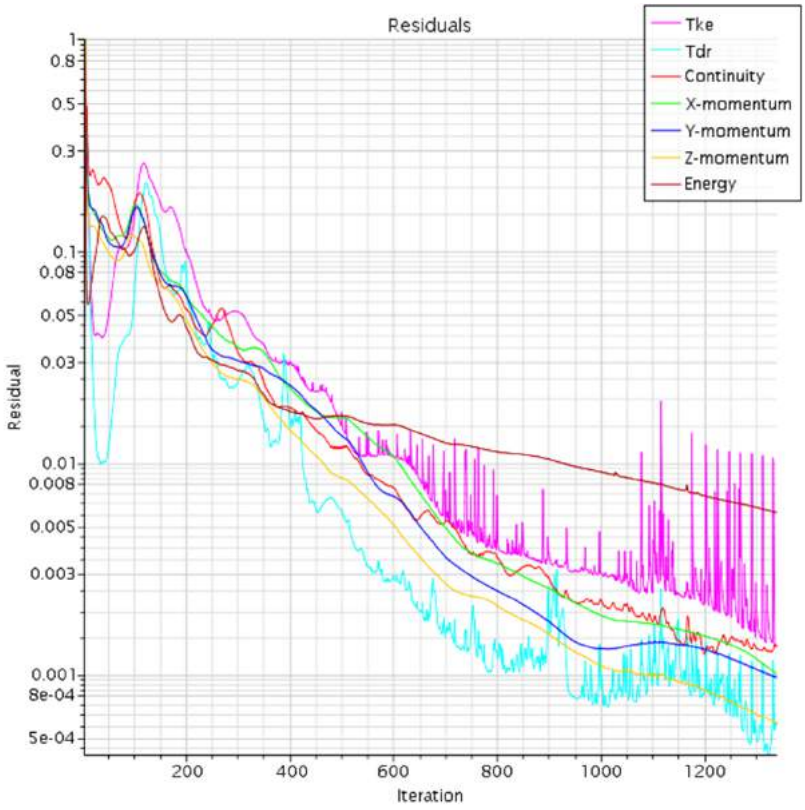


Test Set-up - Section B-B

Presentation of Qualitative Post processing
For Scenarios A 14

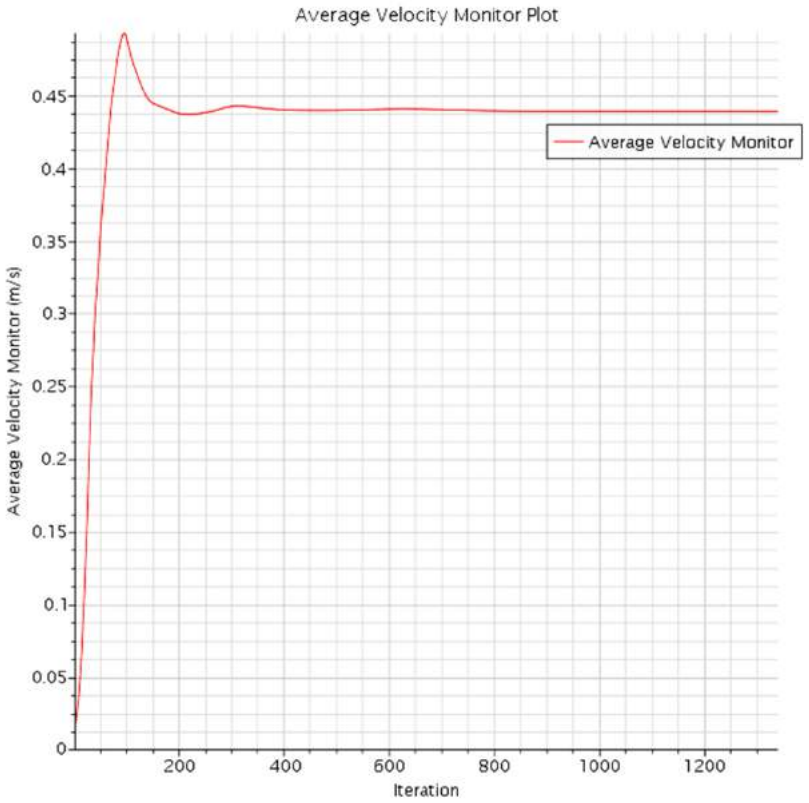


Convergence - Heat Flux

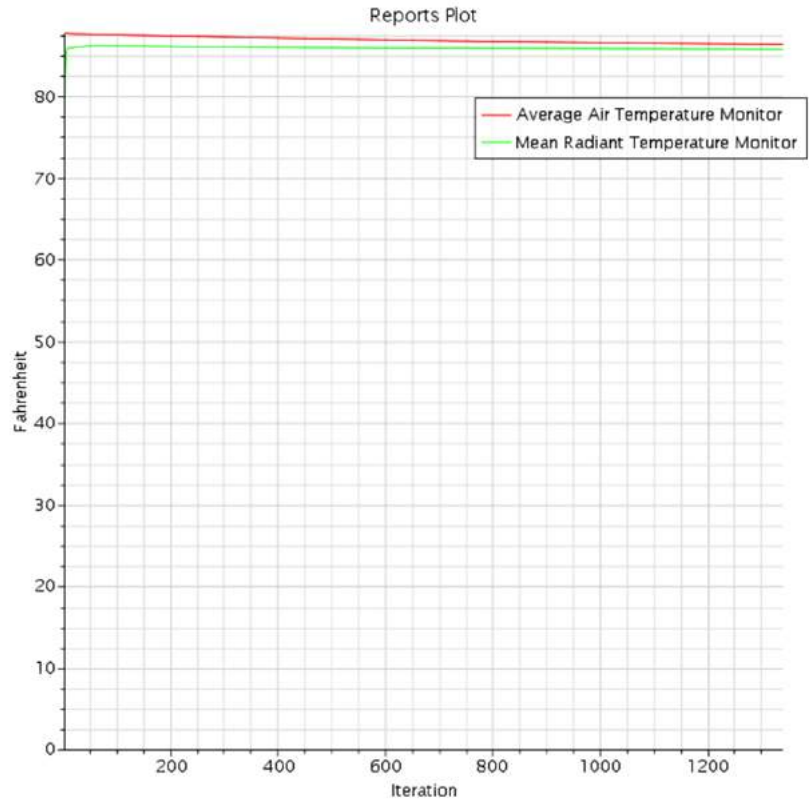


Convergence - Residuals

Presentation of Qualitative Post processing For Scenarios A 14

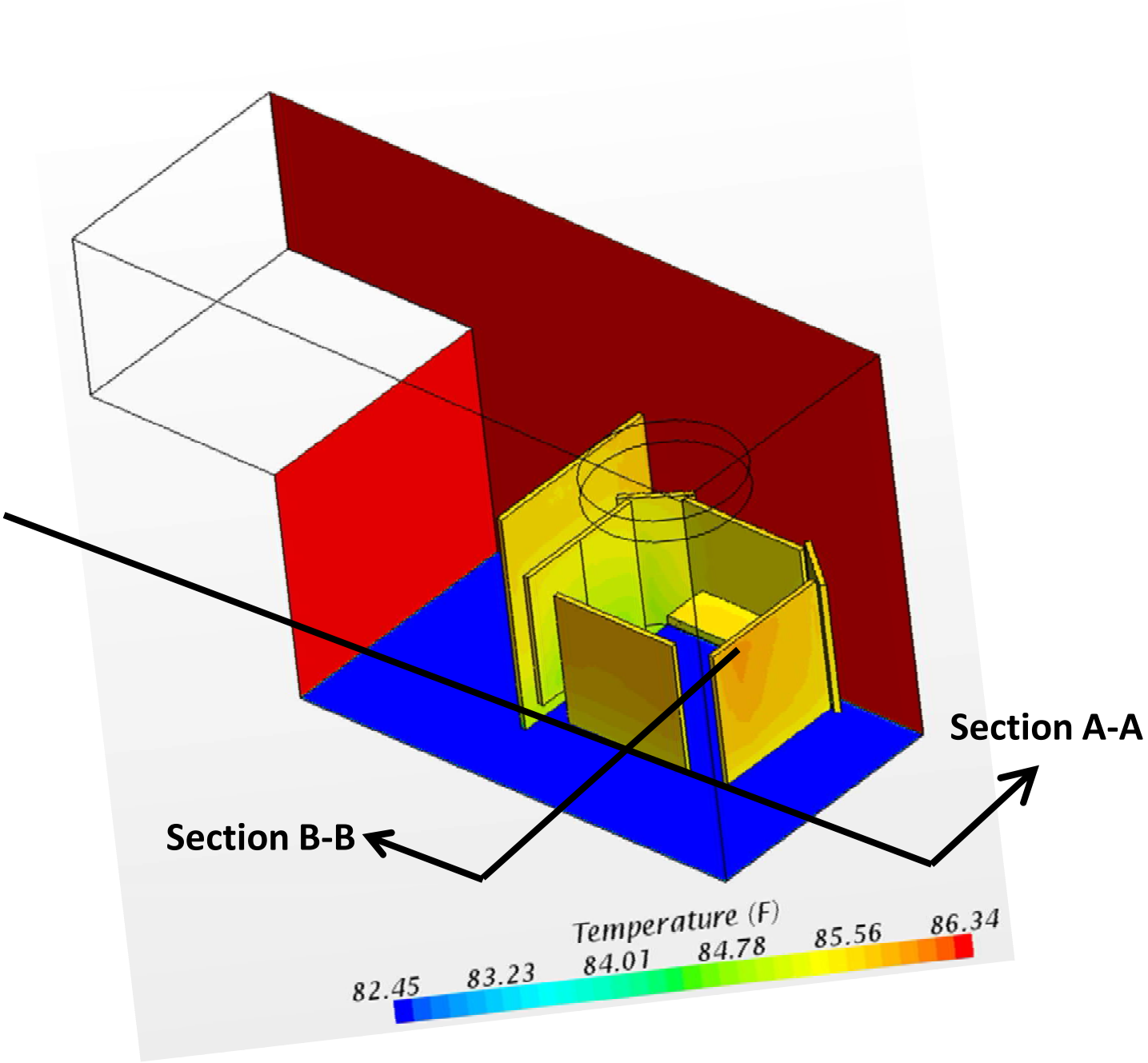


Convergence - Average Velocity Monitor



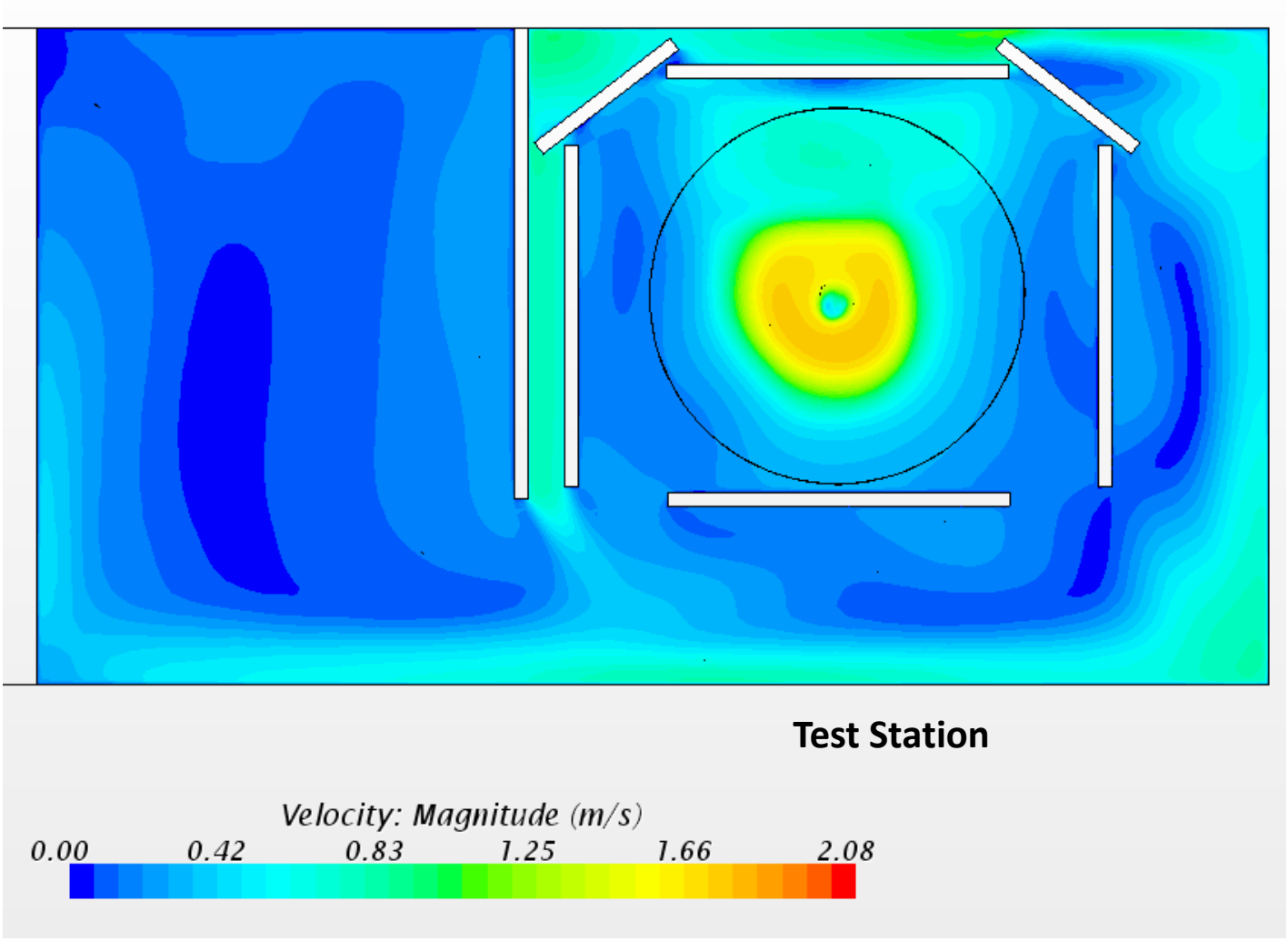
Convergence - Temperature

Presentation of Qualitative Post processing For Scenarios A 14-B



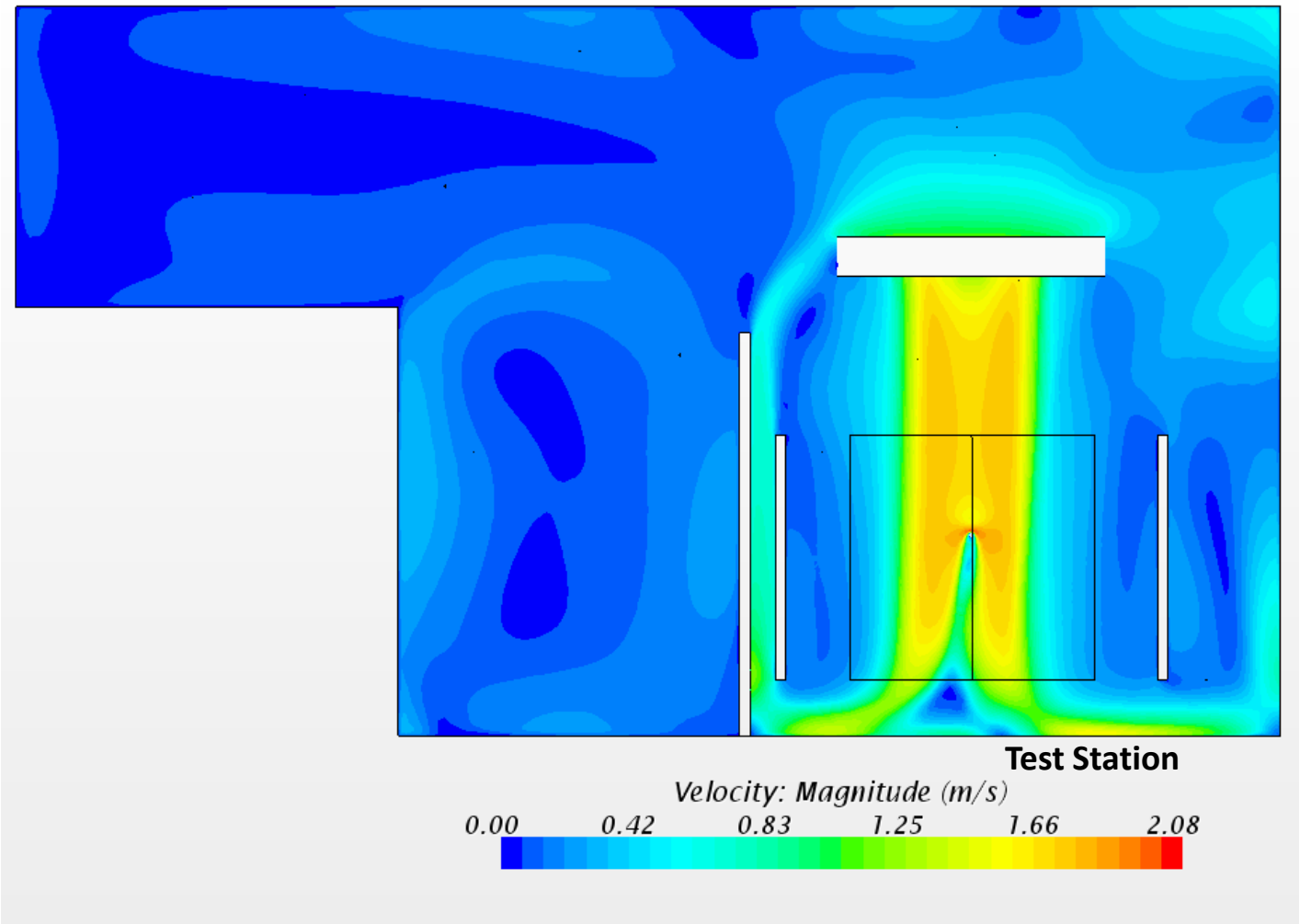
Test Set-up - Iso-metric View

Presentation of Qualitative Post processing
For Scenarios A 14-B



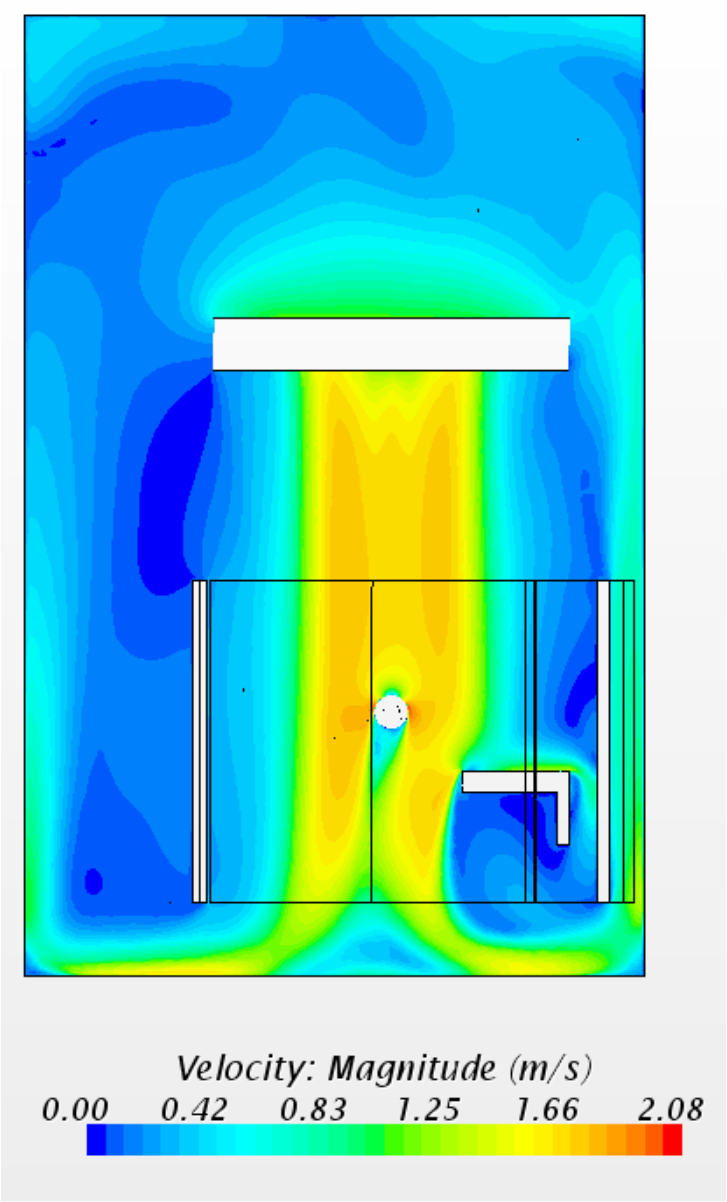
Test Set-up - Plan View

Presentation of Qualitative Post processing
For Scenarios A 14-B



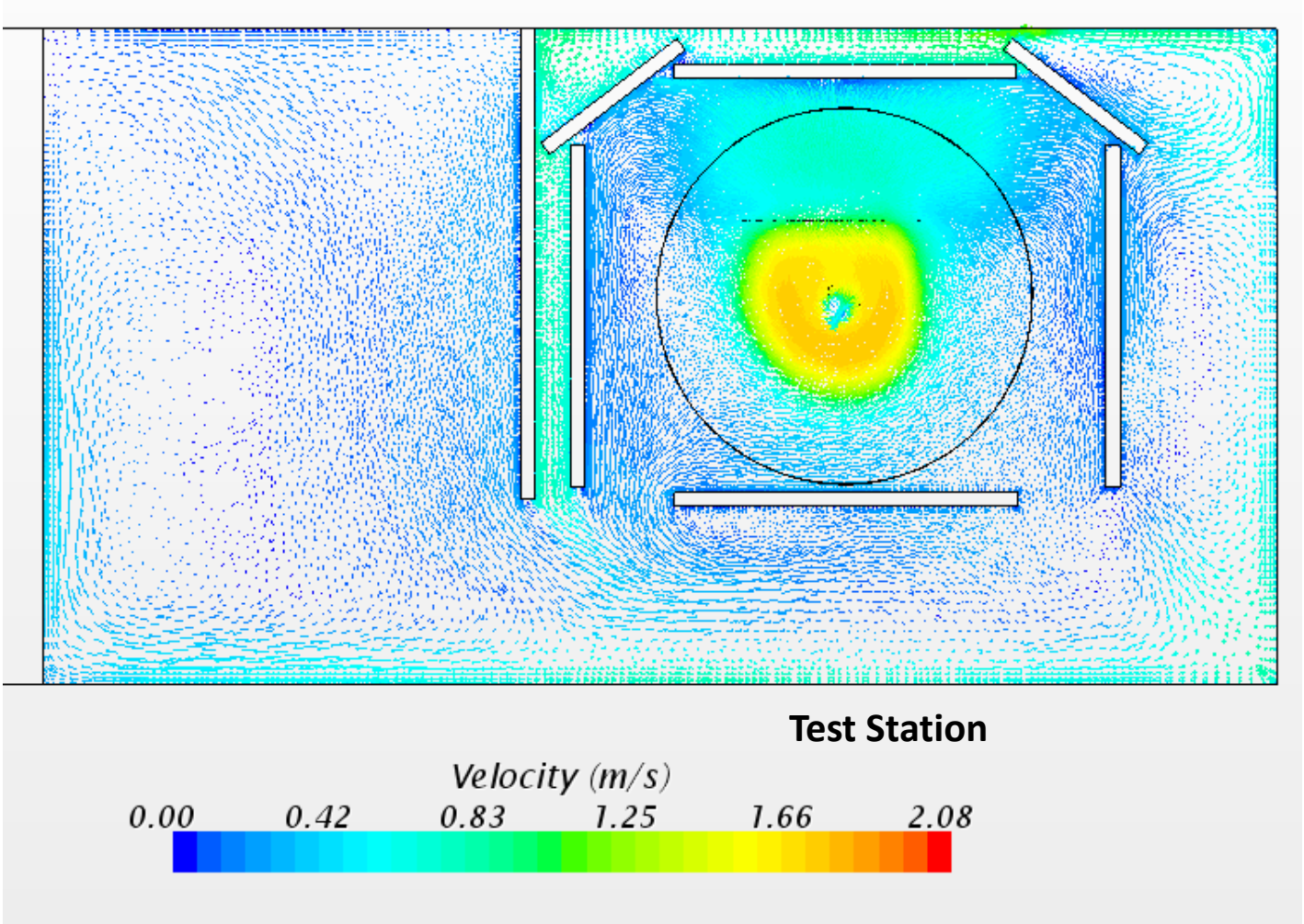
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 14-B



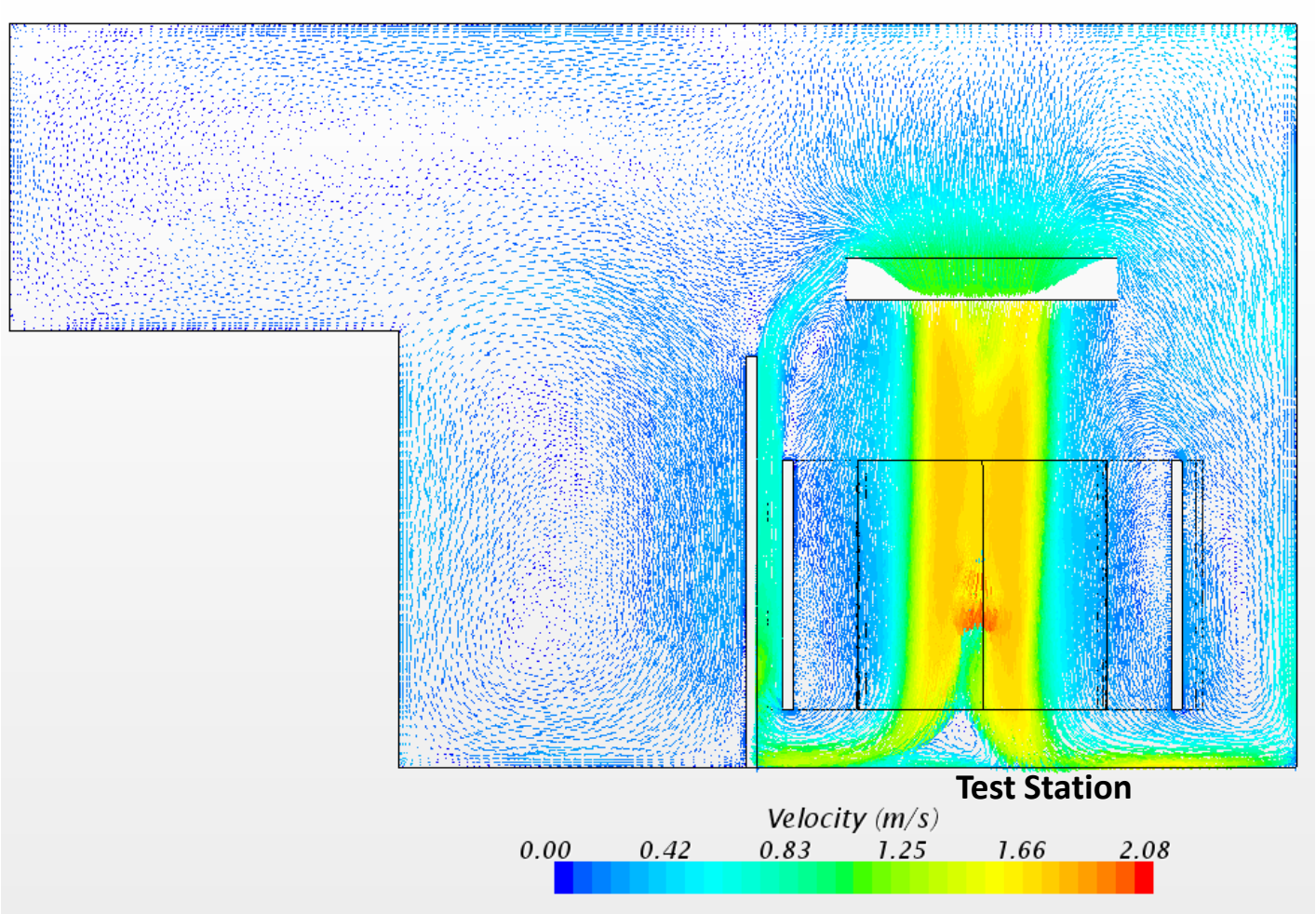
Test Set-up - Section B-B

Presentation of Qualitative Post processing
For Scenarios A 14-B



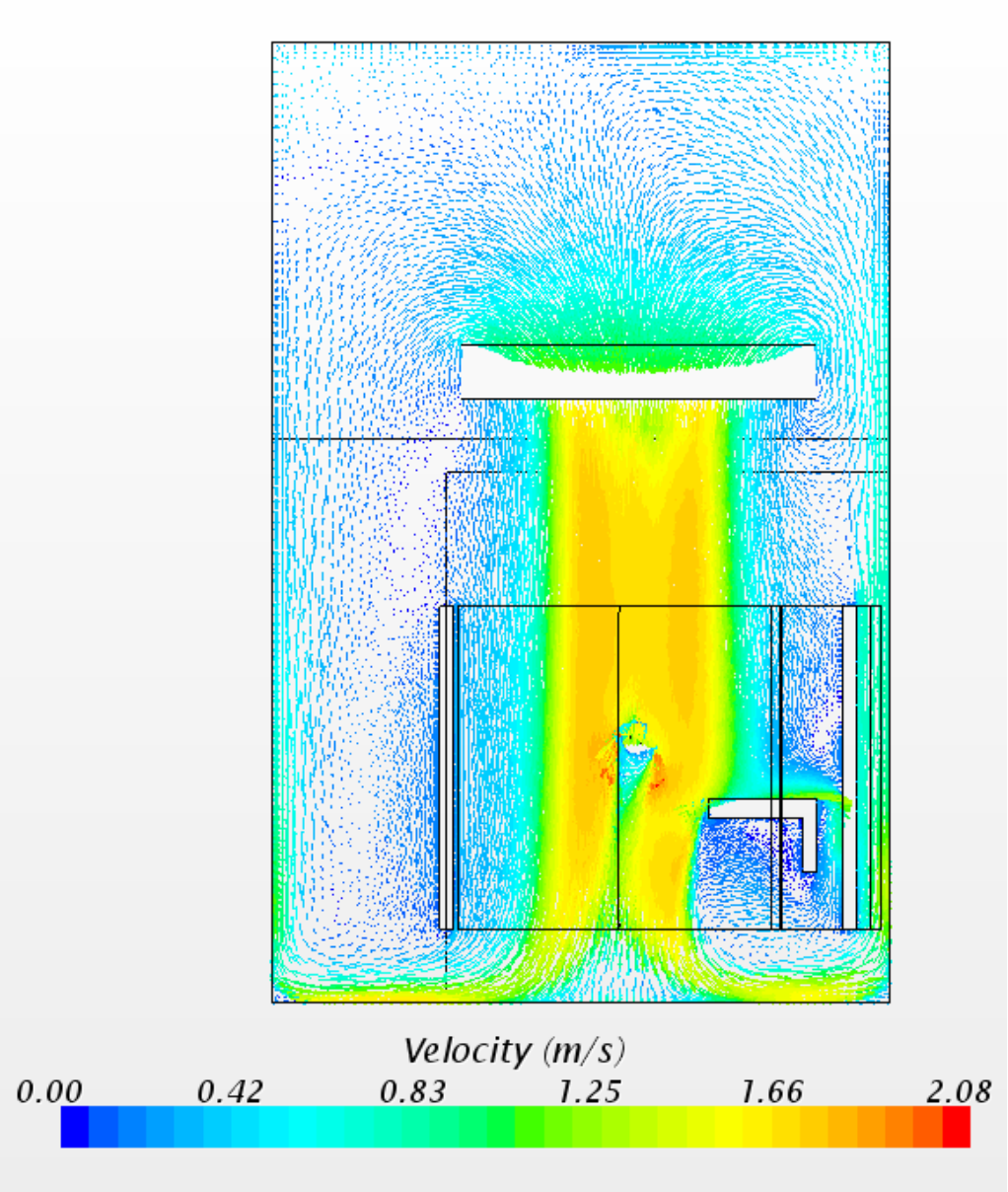
Test Set-up - Plan View

Presentation of Qualitative Post processing
For Scenarios A 14-B



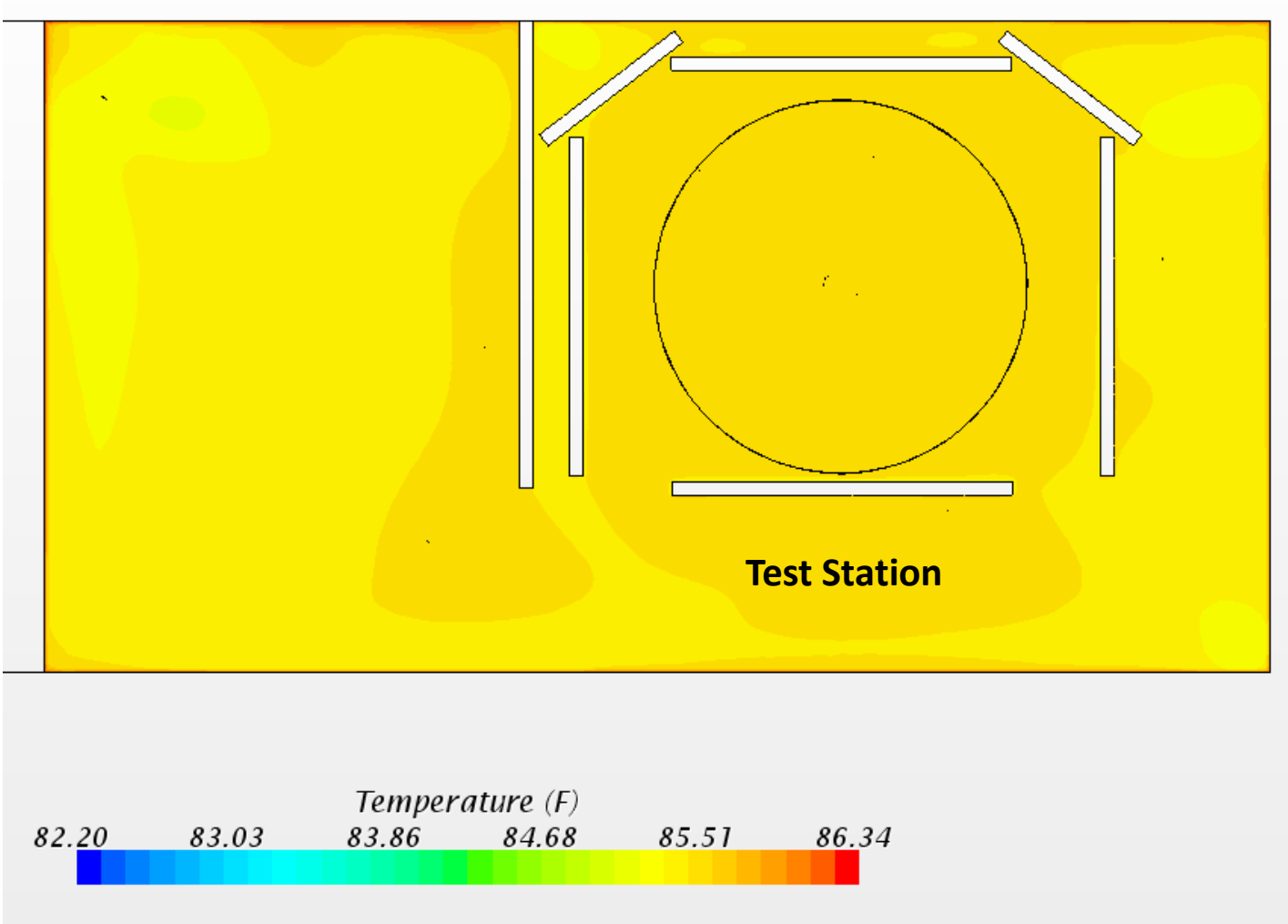
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 14-B



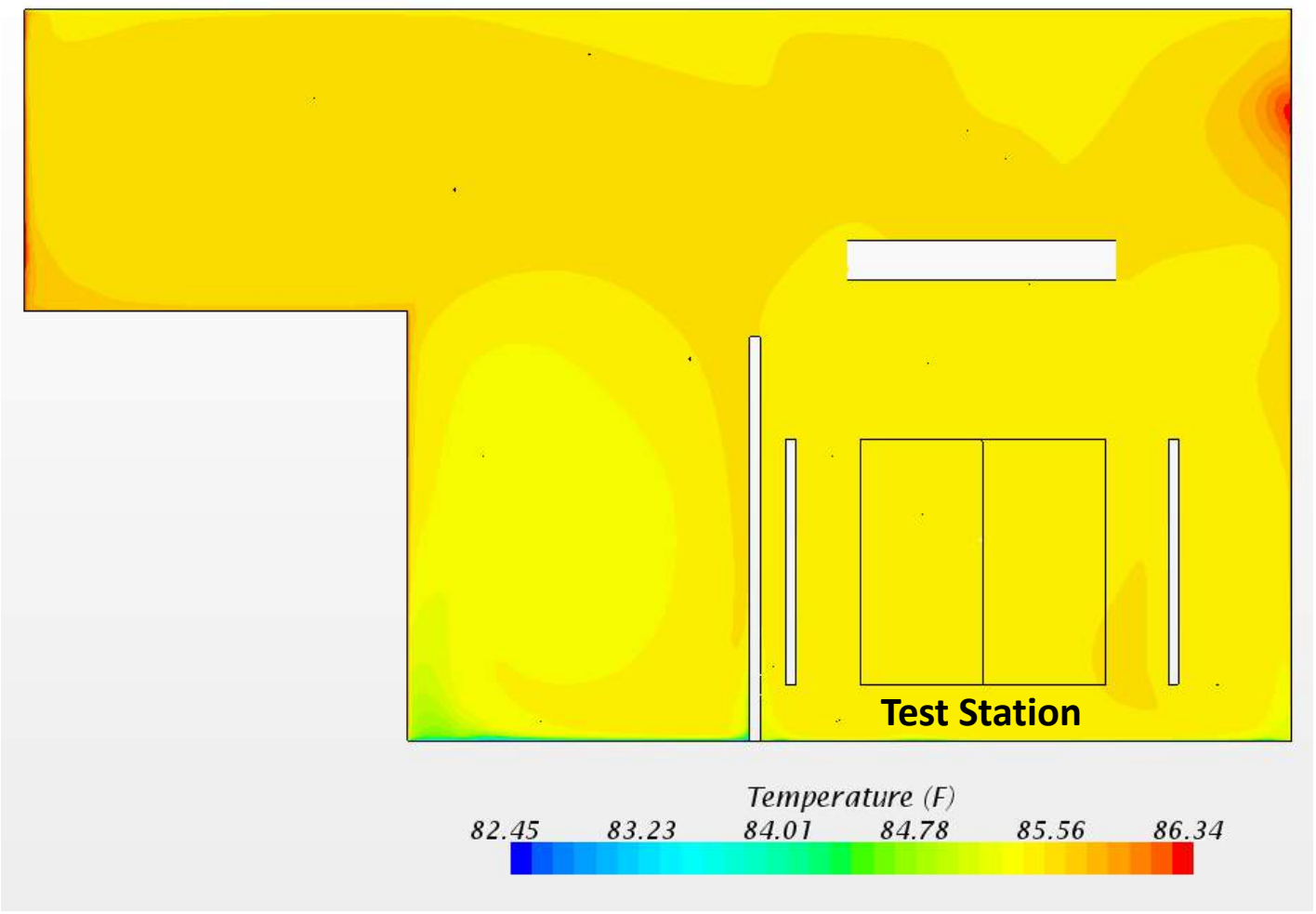
Test Set-up - Section B-B

Presentation of Qualitative Post processing
For Scenarios A 14-B



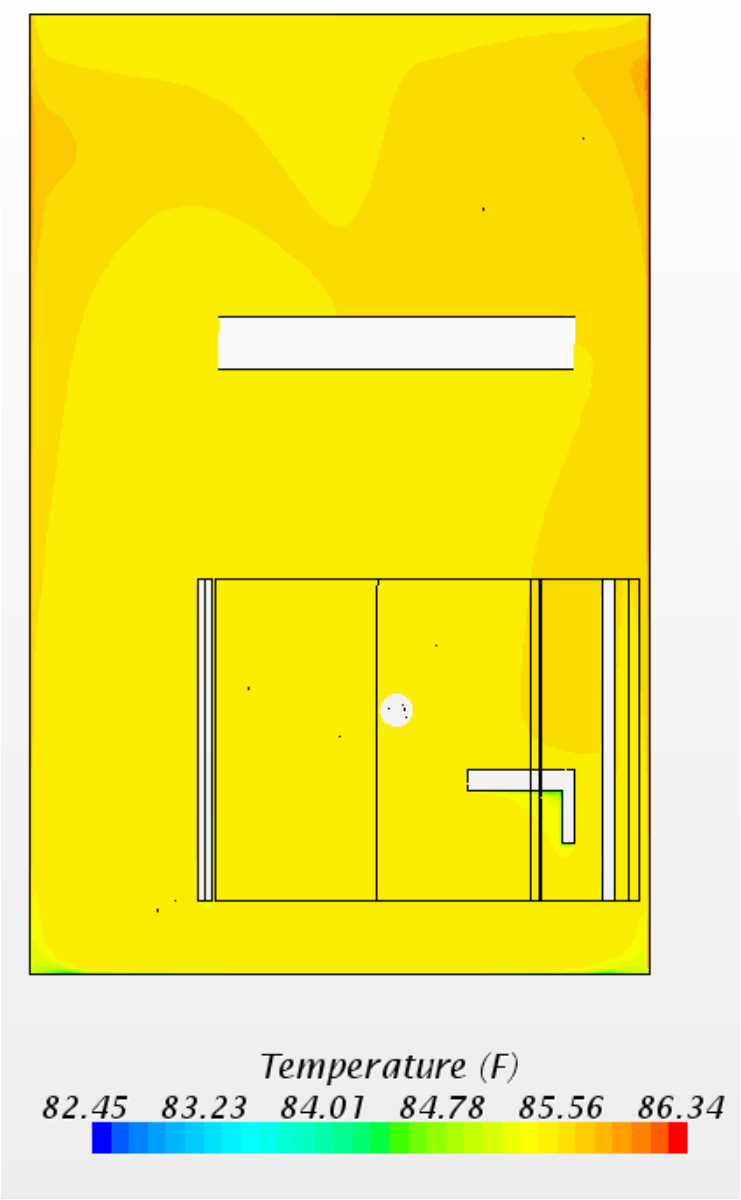
Test Set-up - Plan View

Presentation of Qualitative Post processing
For Scenarios A 14-B



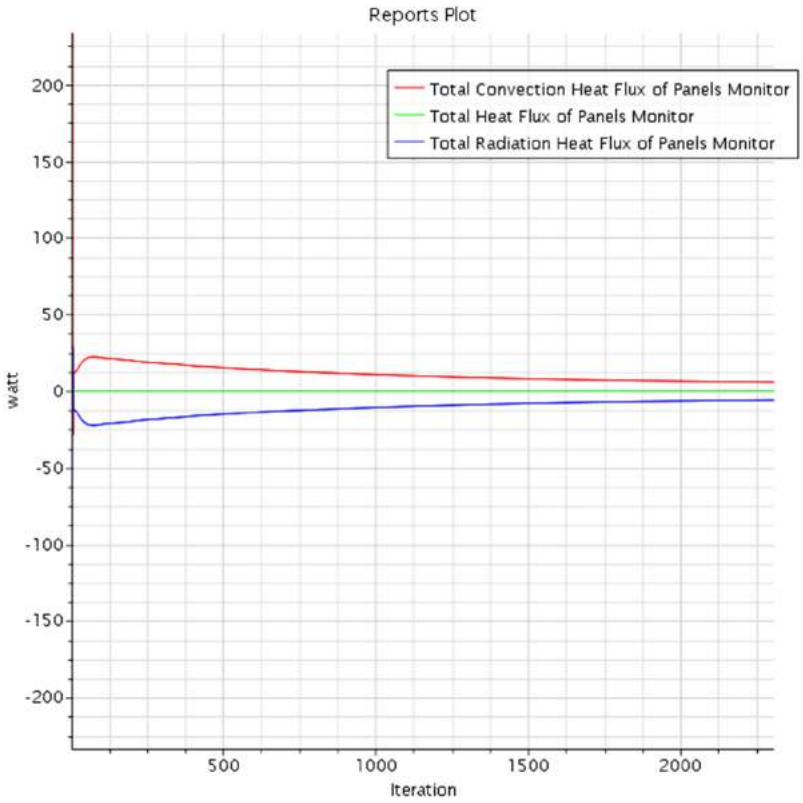
Test Set-up - Section A-A

Presentation of Qualitative Post processing For Scenarios A 14-B

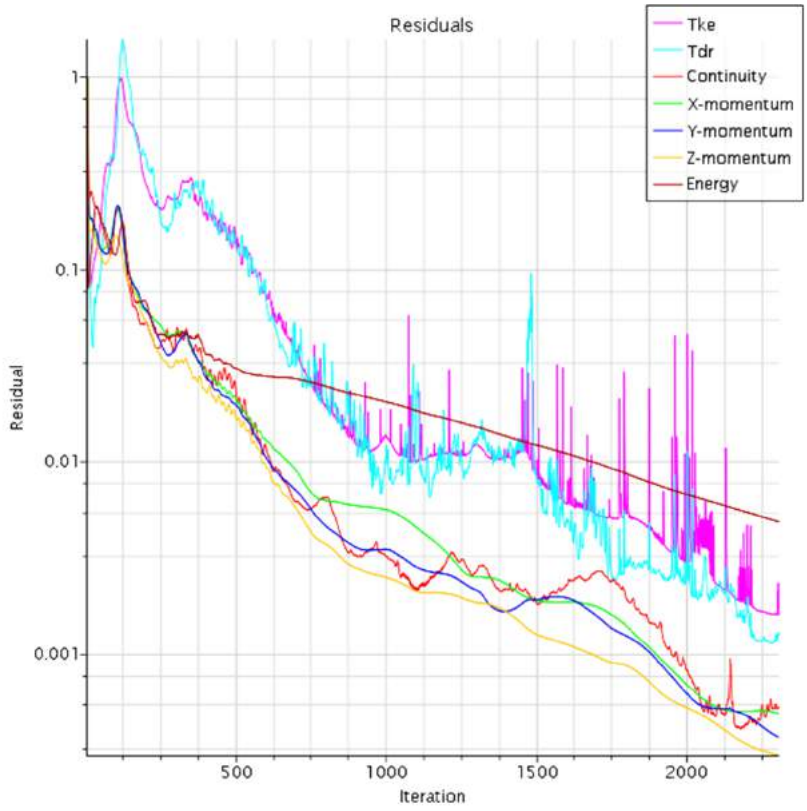


Test Set-up - Section B-B

Presentation of Qualitative Post processing
For Scenarios A 14-B

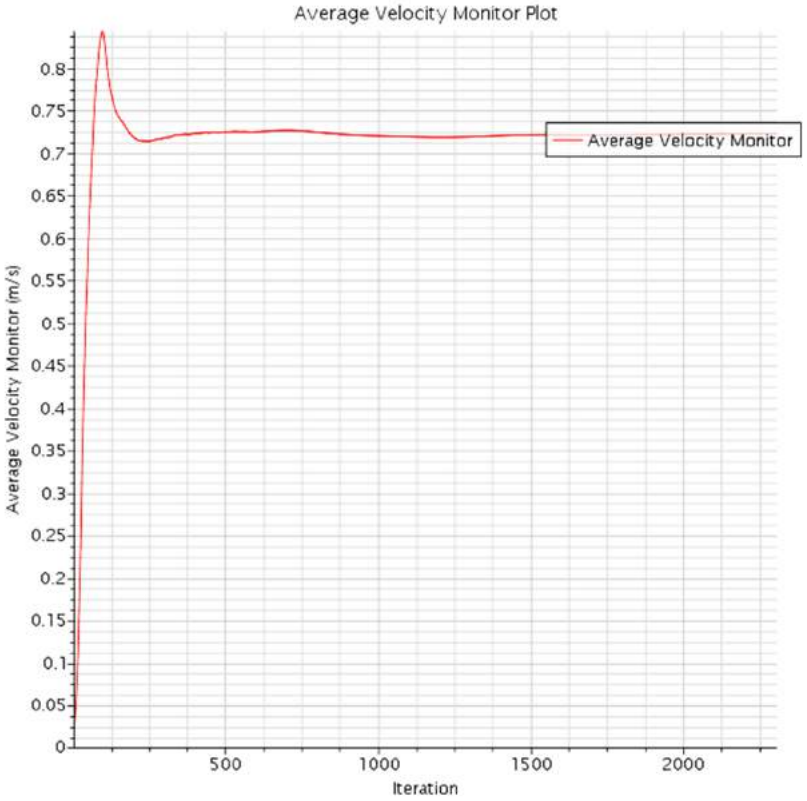


Convergence - Heat Flux

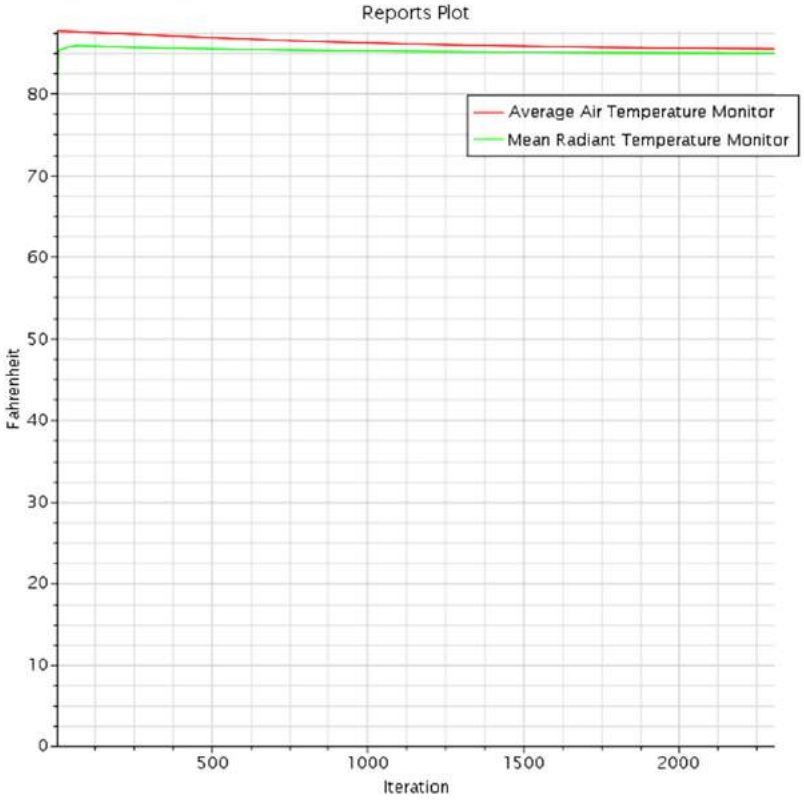


Convergence - Residuals

Presentation of Qualitative Post processing For Scenarios A 14-B



Convergence - Average Velocity Monitor



Convergence - Temperature

APPENDIX B

Summary of Air Measurements WITH a Test Person

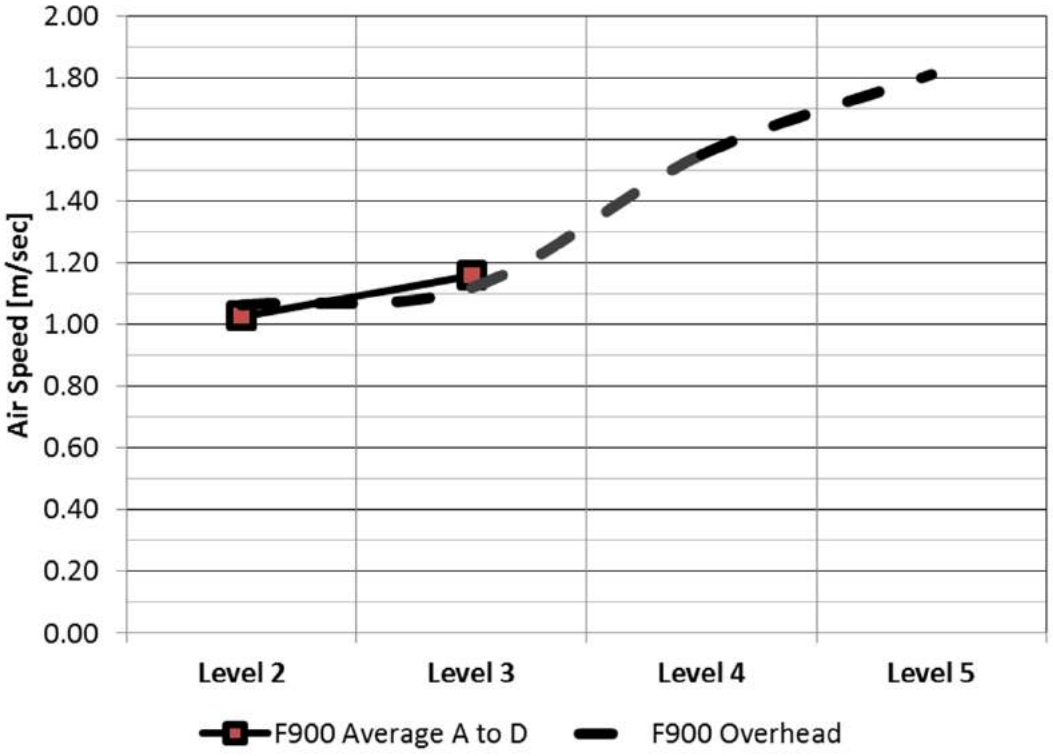
(29 pages)

APPENDIX B

Summary of Air Measurements WITH a Test Person

These air speed measurements were conducted in order to determine a representative air speed around the test person for the different fan level setting.

Resulting airspeeds of Fan levels 2 and 3 which are used in the comfort analysis



F900 anemometer

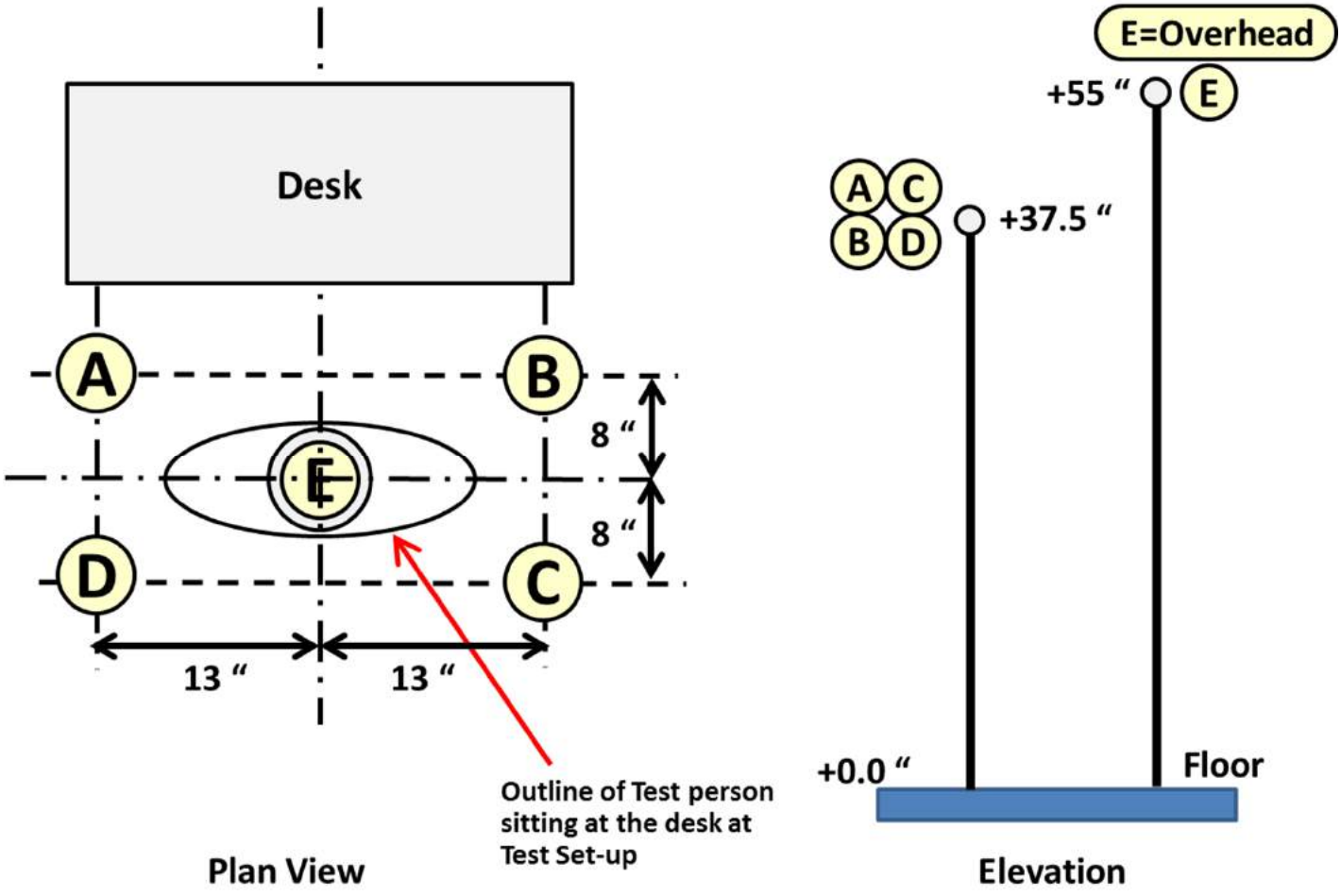
Fan level	Overhead [m/sec]	average A to D [m/sec]	Resulting [m/sec]
Level 2	1.06	1.03	**1.05**
Level 3	1.12	1.16	**1.14**
Level 4	1.55		
Level 5	1.81		

Test set up

Description:

1. = Desk used in tests
2. = Cooling panels surrounding the desk and test person
3. = ERDL team member serving as test person during air movement measurements
4. = Anemometers attached to stand (here anemometer location “A”

Test set up



Locations of anemometers during measurements to determine representative air speed at different fan speed levels

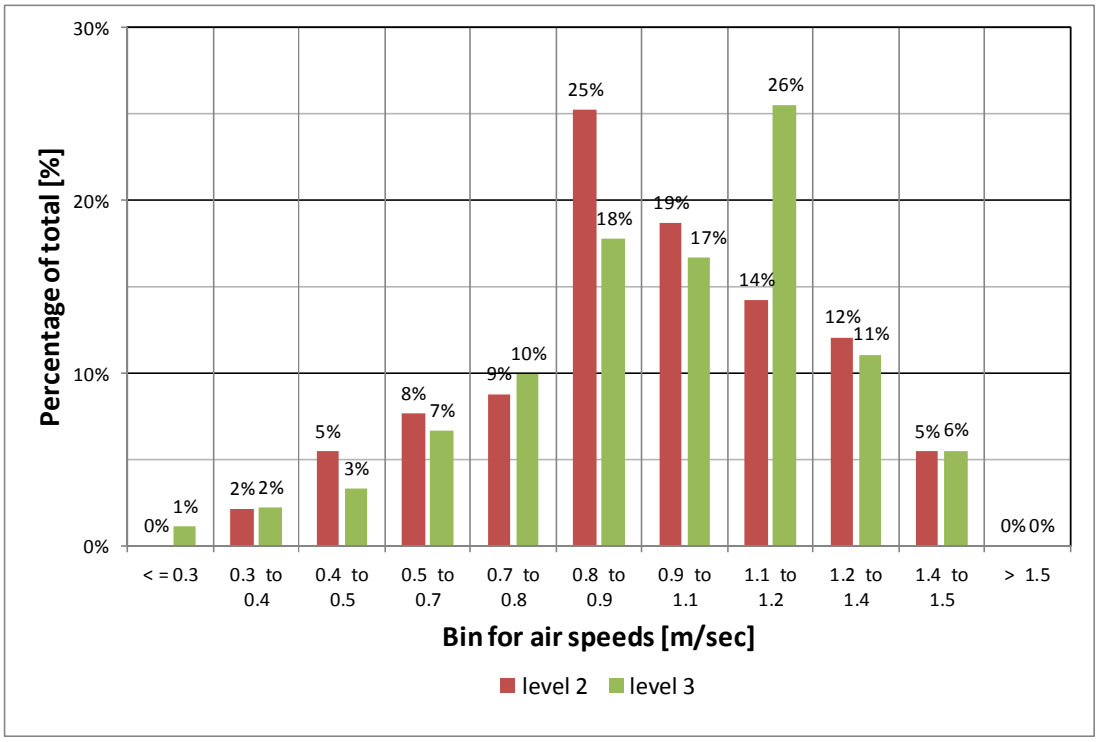
APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 2 and 3

Fan Level 2 = “level 2” Fan Level 3 = “level 3”

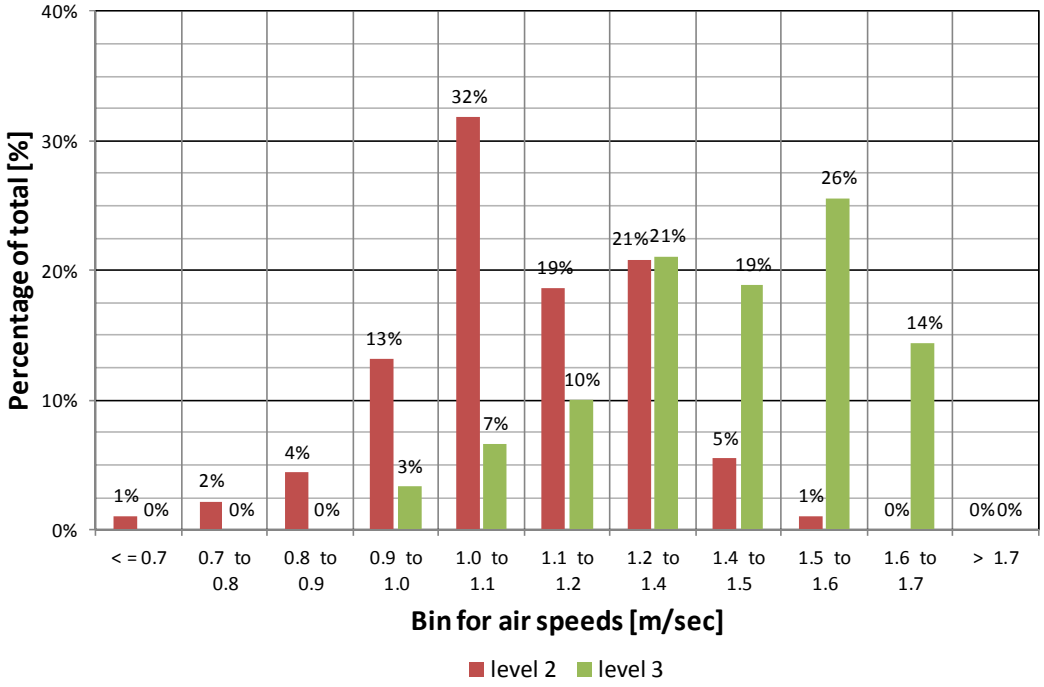
Anemometer No. 1 Type of Anemometer = F-900

Sensor Location A **Comparison between level 2 and 3**



Anemometer No. 1 Type of Anemometer = F-900

Sensor Location B **Comparison between level 2 and 3**



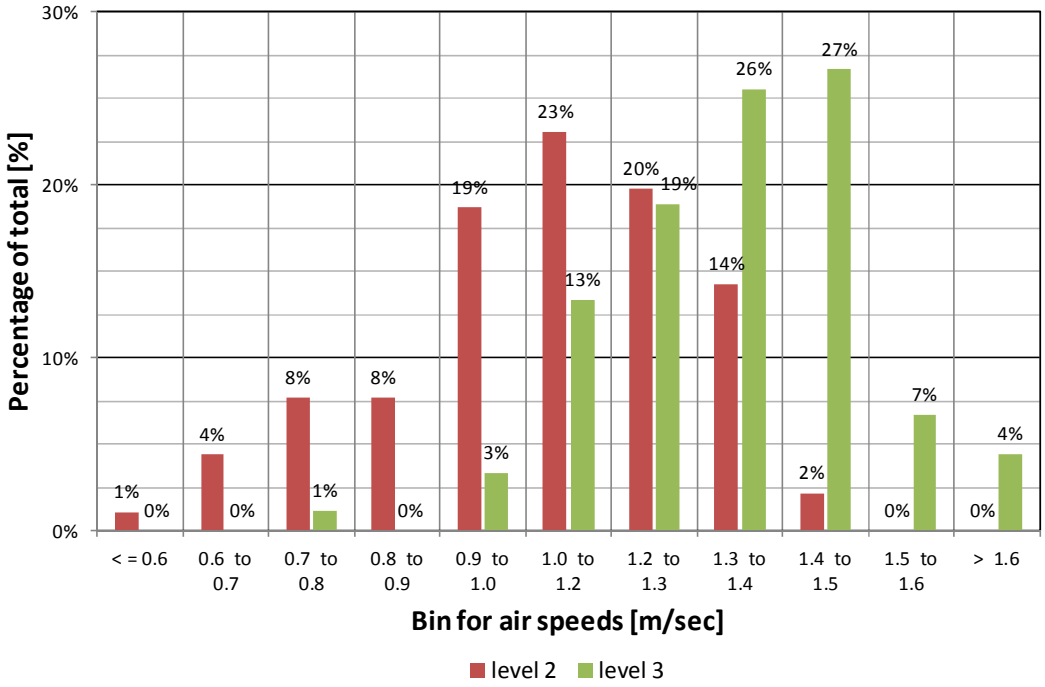
APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 2 and 3

Fan Level 2 = “level 2” Fan Level 3 = “level 3”

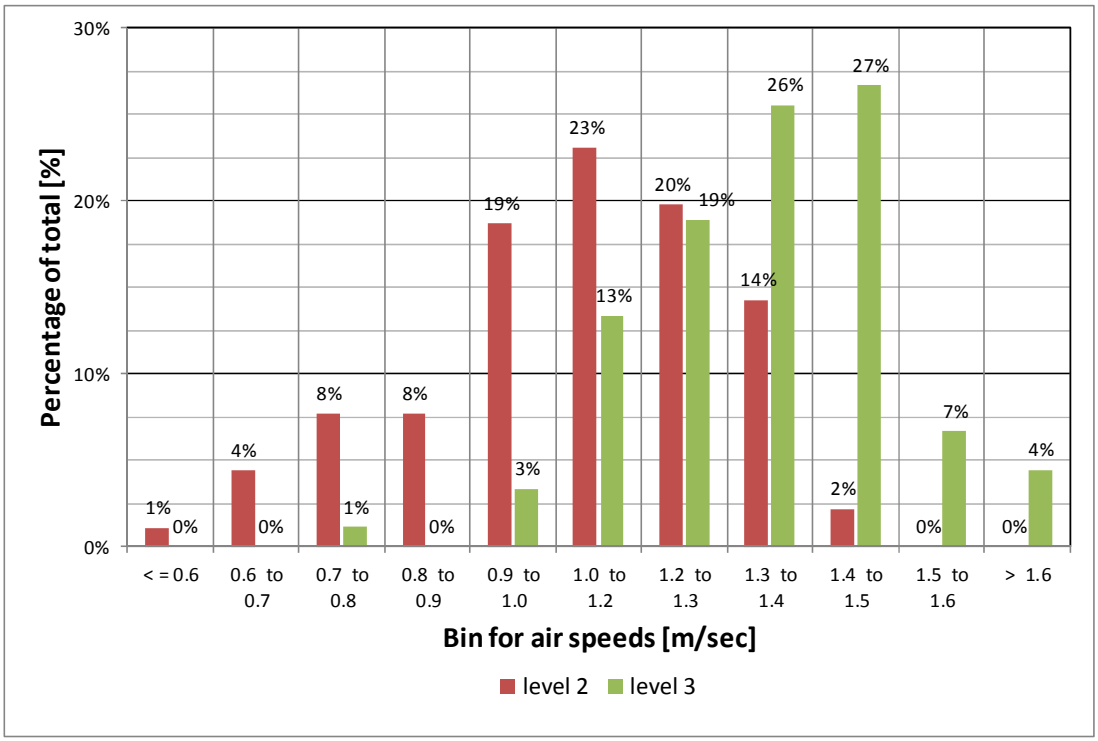
Anemometer No. 1 Type of Anemometer = F-900

Sensor Location **C** **Comparison between level 2 and 3**



Anemometer No. 1 Type of Anemometer = F-900

Sensor Location **D** **Comparison between level 2 and 3**



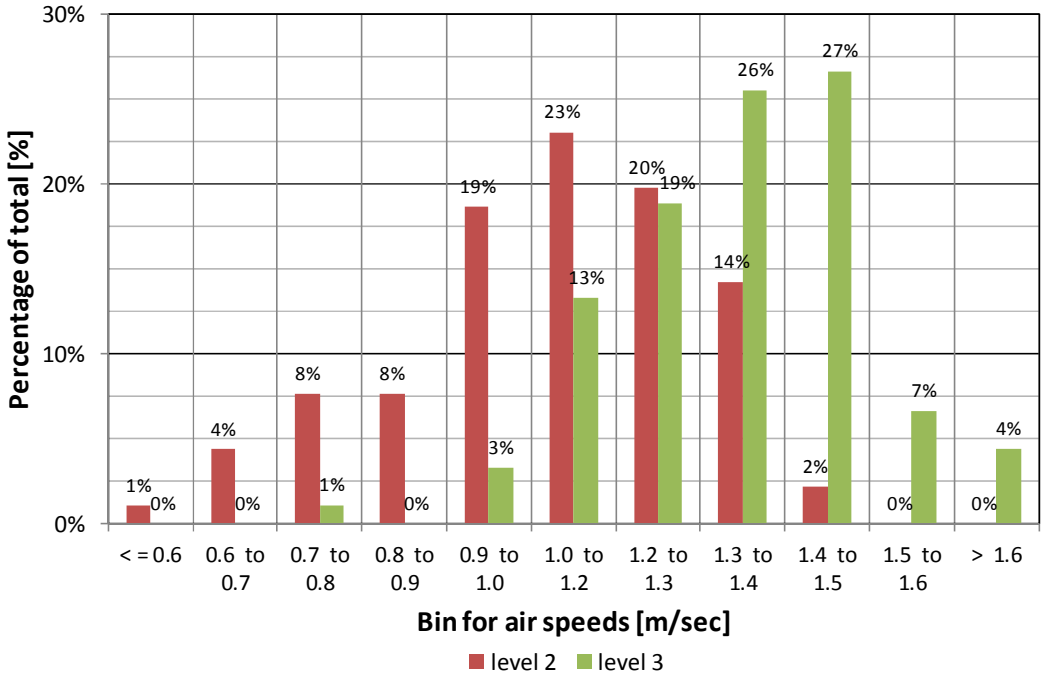
APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 2 and 3

Fan Level 2 = “level 2” Fan Level 3 = “level 3”

Anemometer No. 1 Type of Anemometer = F-900

Sensor Location **OverHead** **Comparison between level 2 and 3**



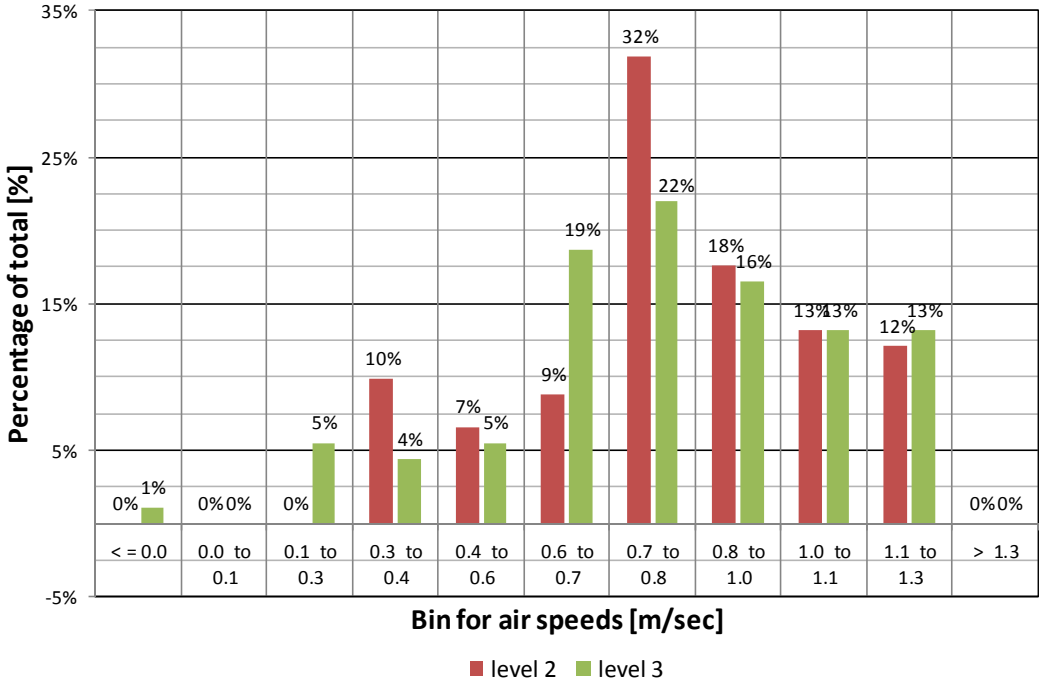
APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 2 and 3

Fan Level 2 = “level 2” Fan Level 3 = “level 3”

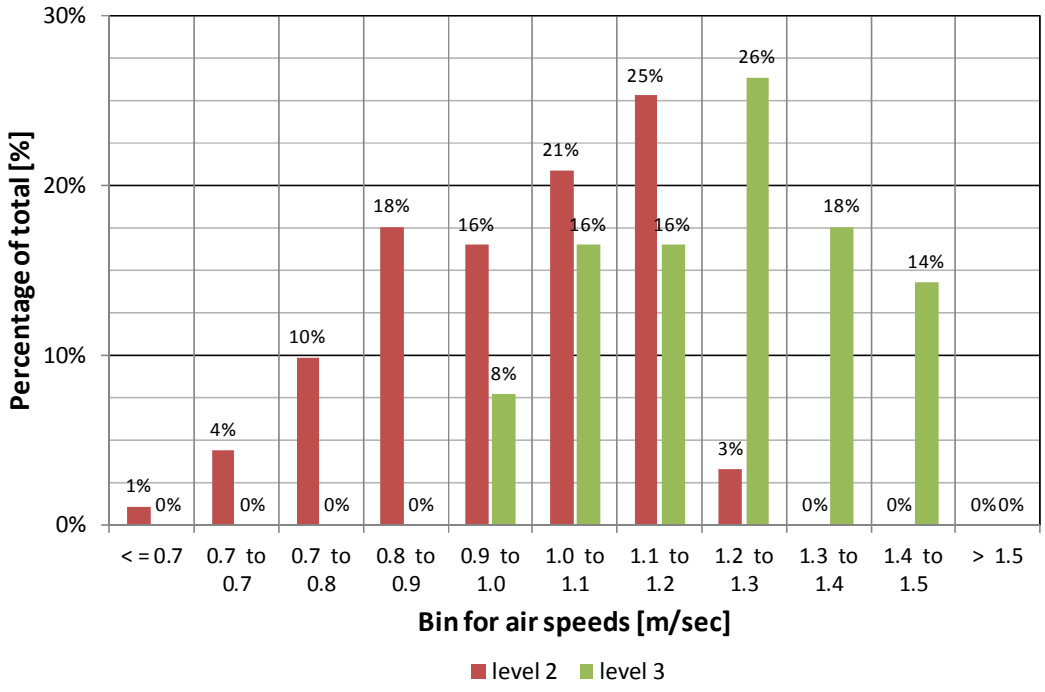
Anemometer **2** Type of Anemometer = F-900

Sensor Location **A** **Comparison between level 2 and 3**



Anemometer **2** Type of Anemometer = F-900

Sensor Location **B** **Comparison between level 2 and 3**



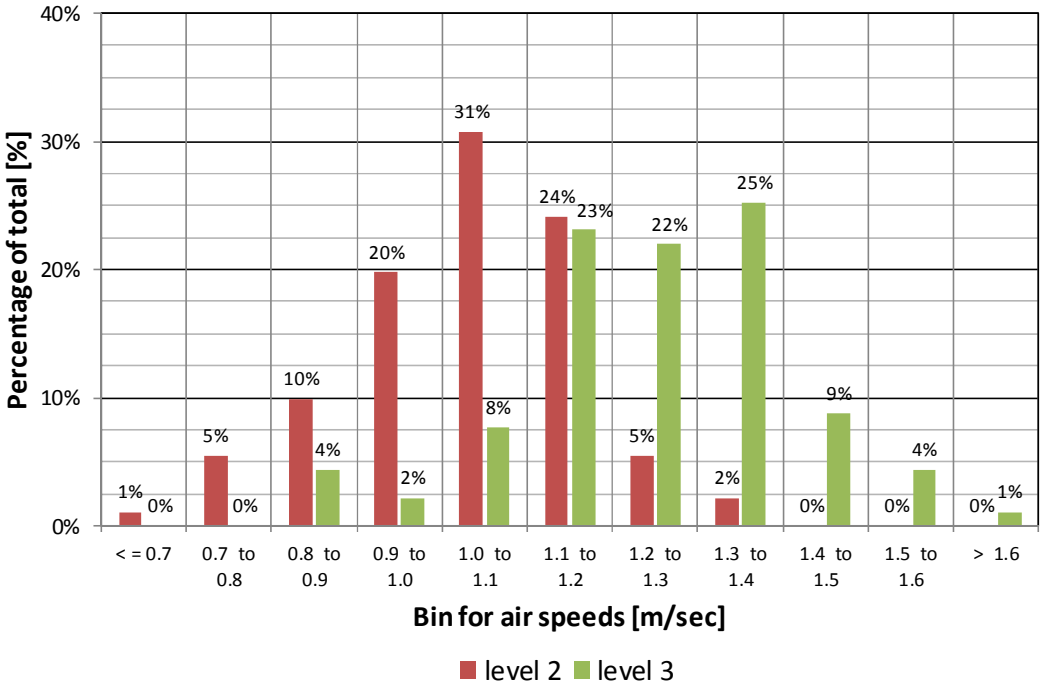
APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 2 and 3

Fan Level 2 = “level 2” Fan Level 3 = “level 3”

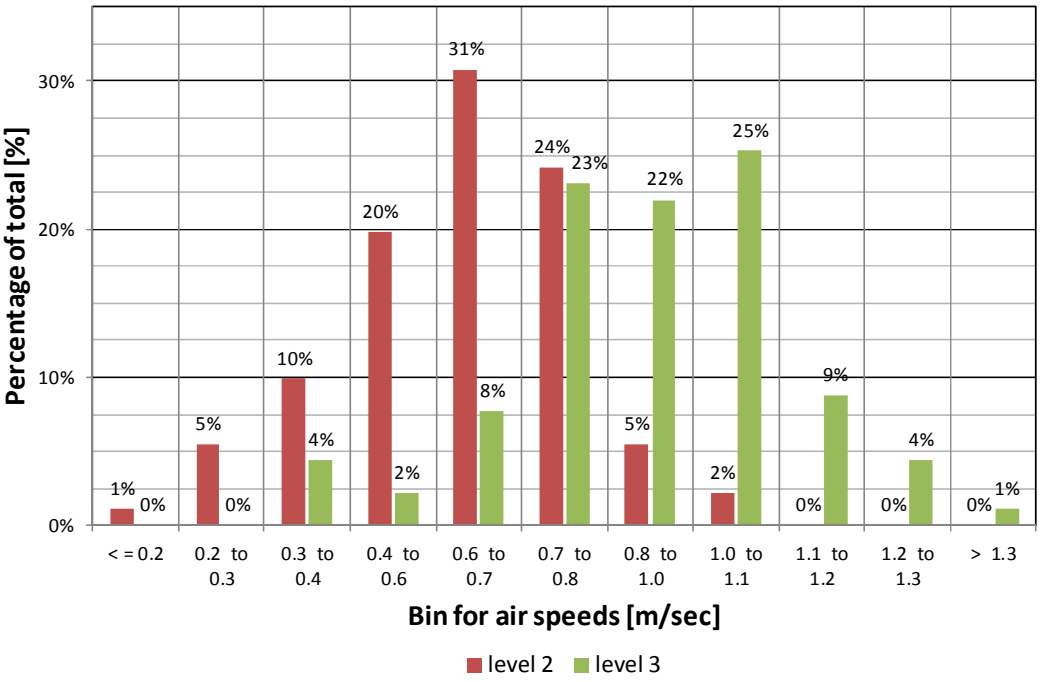
Anemometer **2** Type of Anemometer = F-900

Sensor Location **C** **Comparison between level 2 and 3**



Anemometer **2** Type of Anemometer = F-900

Sensor Location **D** **Comparison between level 2 and 3**



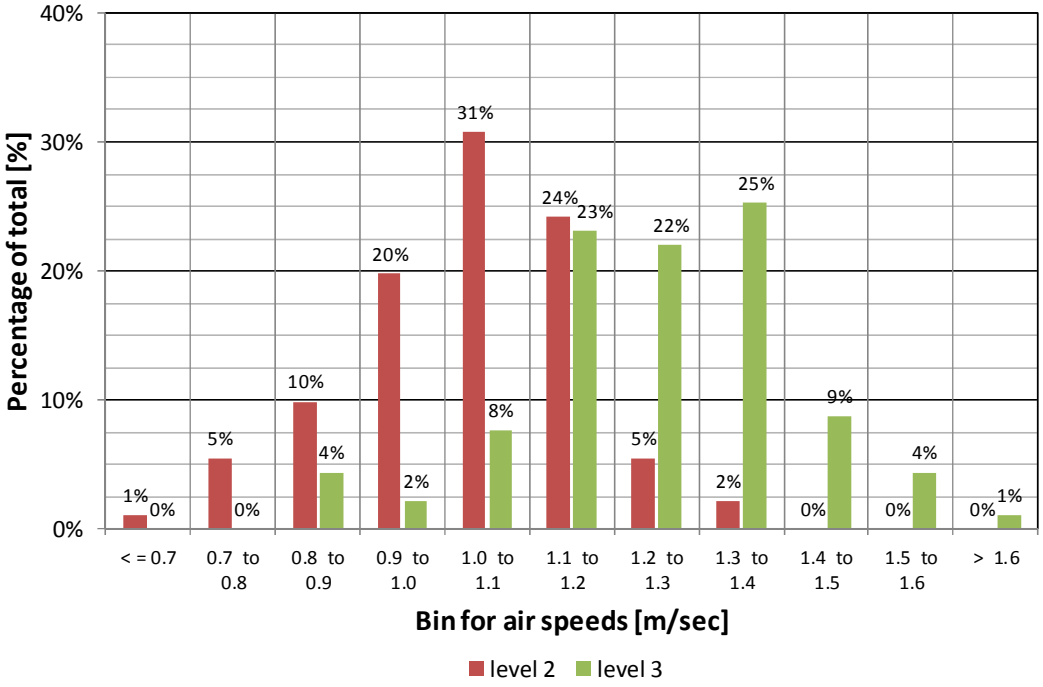
APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 2 and 3

Fan Level 2 = “level 2” Fan Level 3 = “level 3”

Anemometer **2** Type of Anemometer = F-900

Sensor Location **OverHead** **Comparison between level 2 and 3**



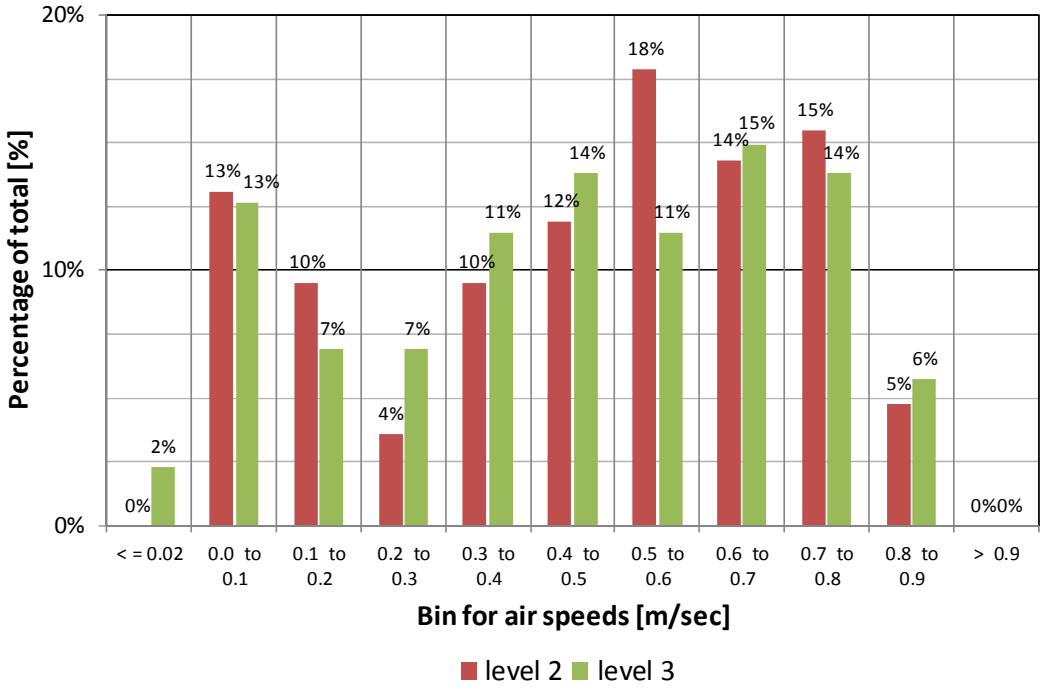
APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 2 and 3

Fan Level 2 = “level 2” Fan Level 3 = “level 3”

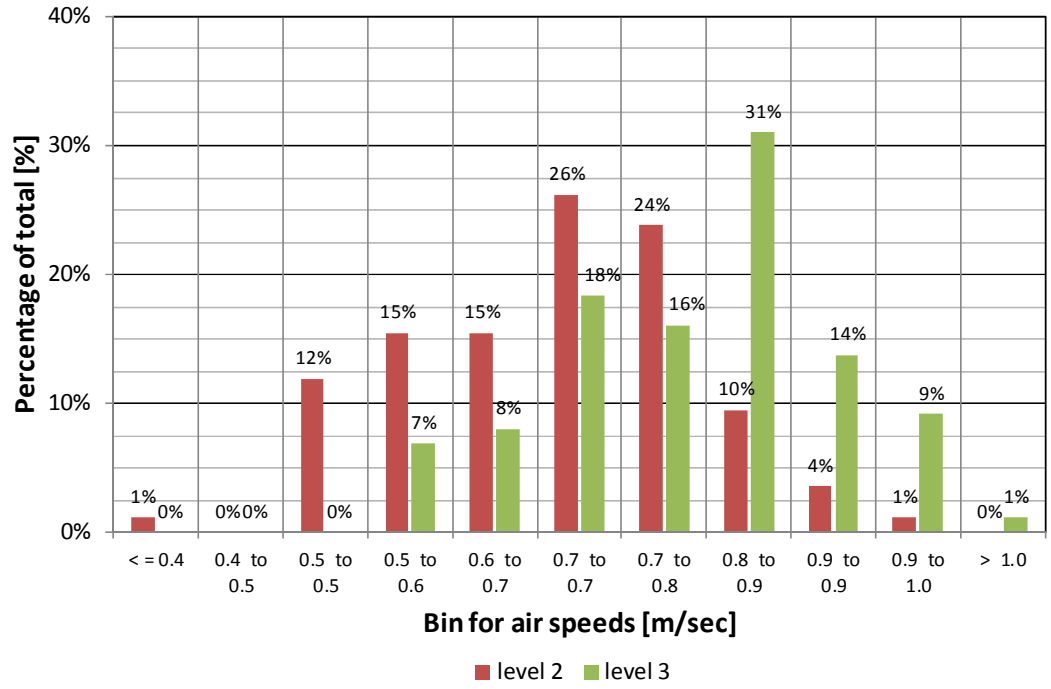
Wolfsense

Sensor Location A **Comparison between level 2 and 3**



Wolfsense

Sensor Location B **Comparison between level 2 and 3**



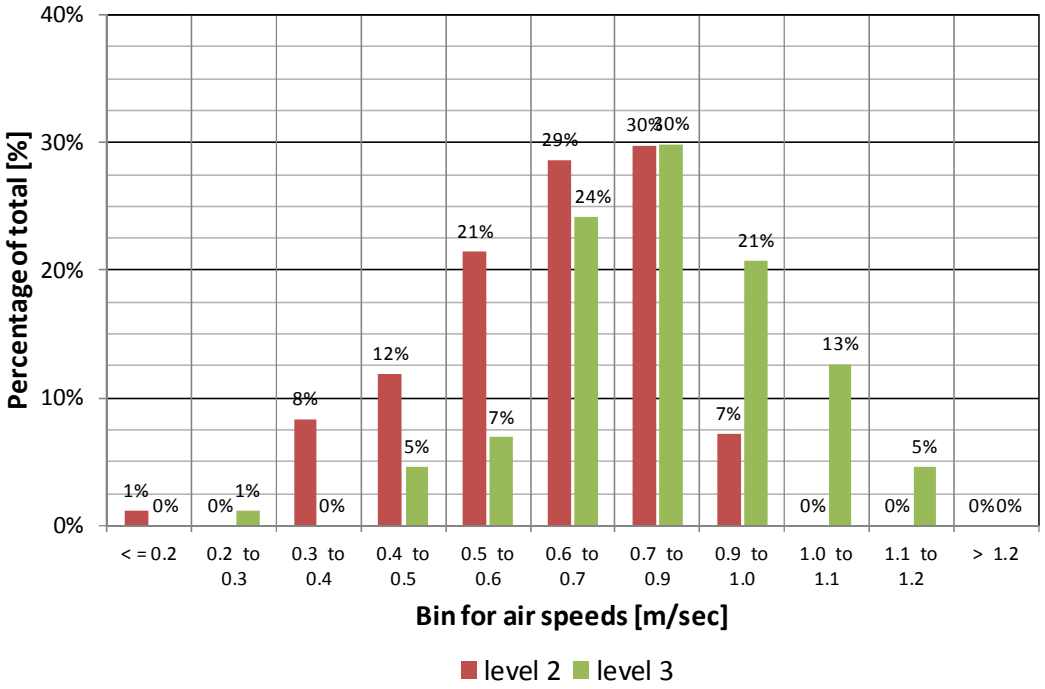
APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 2 and 3

Fan Level 2 = “level 2” Fan Level 3 = “level 3”

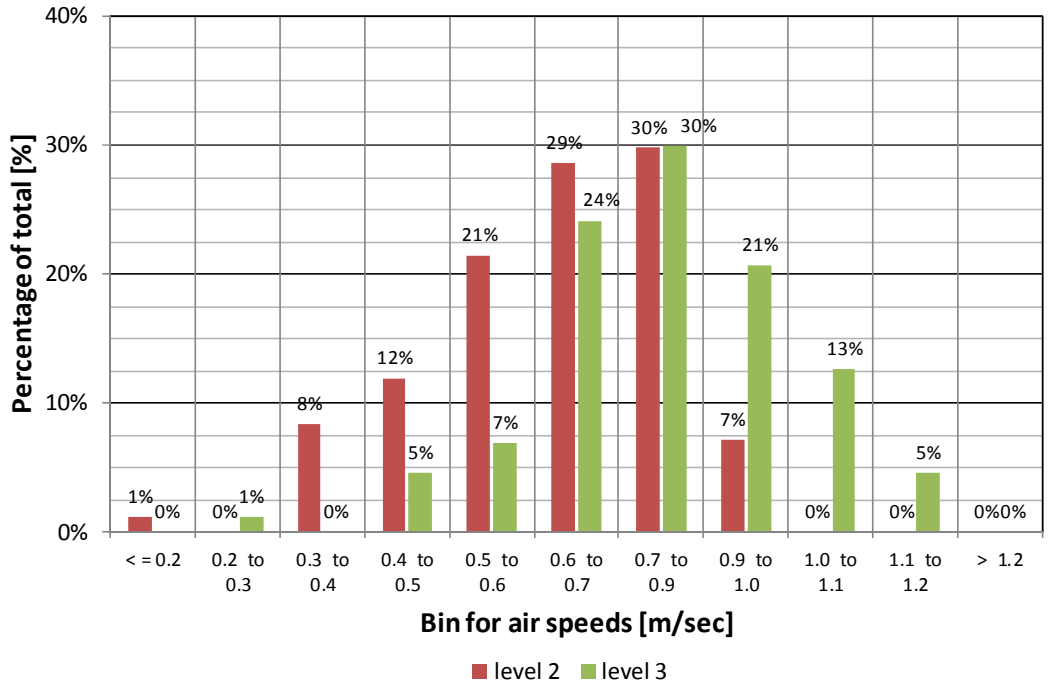
Wolfsense

Sensor Location C **Comparison between level 2 and 3**



Wolfsense

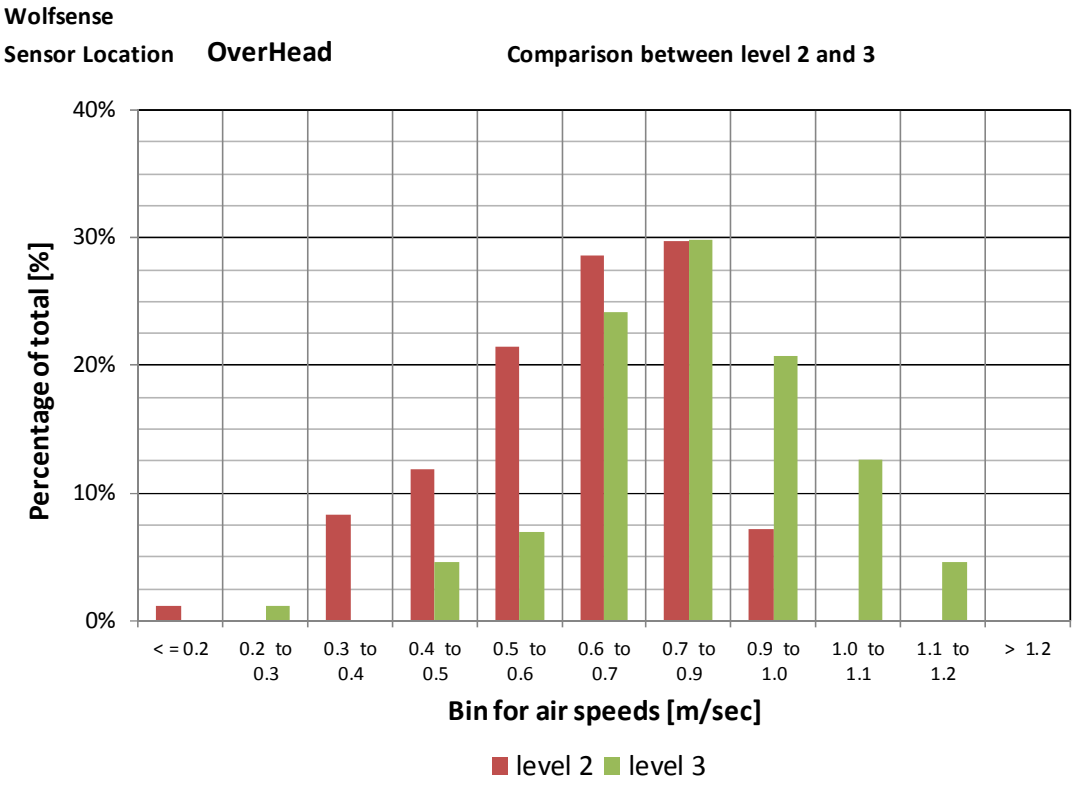
Sensor Location D **Comparison between level 2 and 3**



APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 2 and 3

Fan Level 2 = “level 2” Fan Level 3 = “level 3”



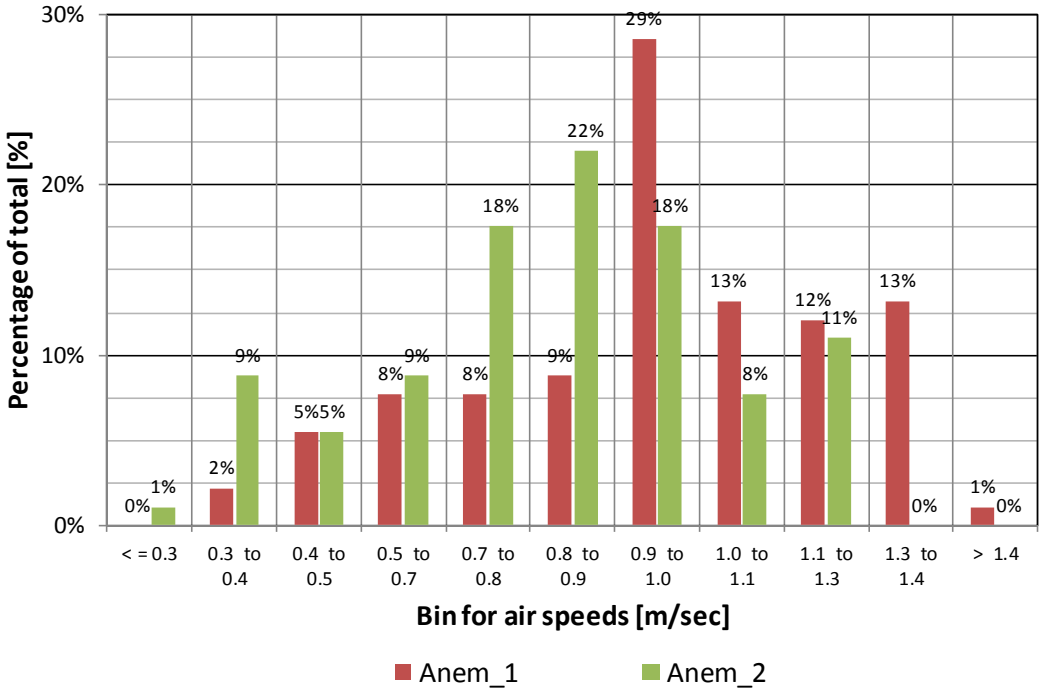
APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 2

Fan Level 2 = “level 2”

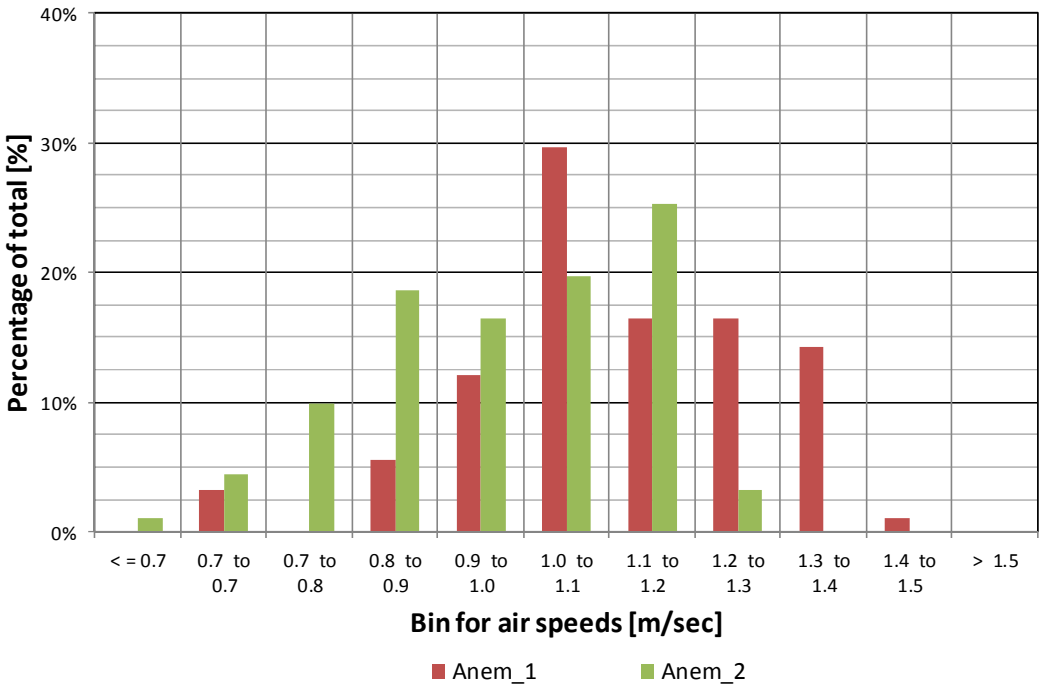
Level 2

Sensor Location **A** **Comparison between Anim 1 and 2**



Level 2

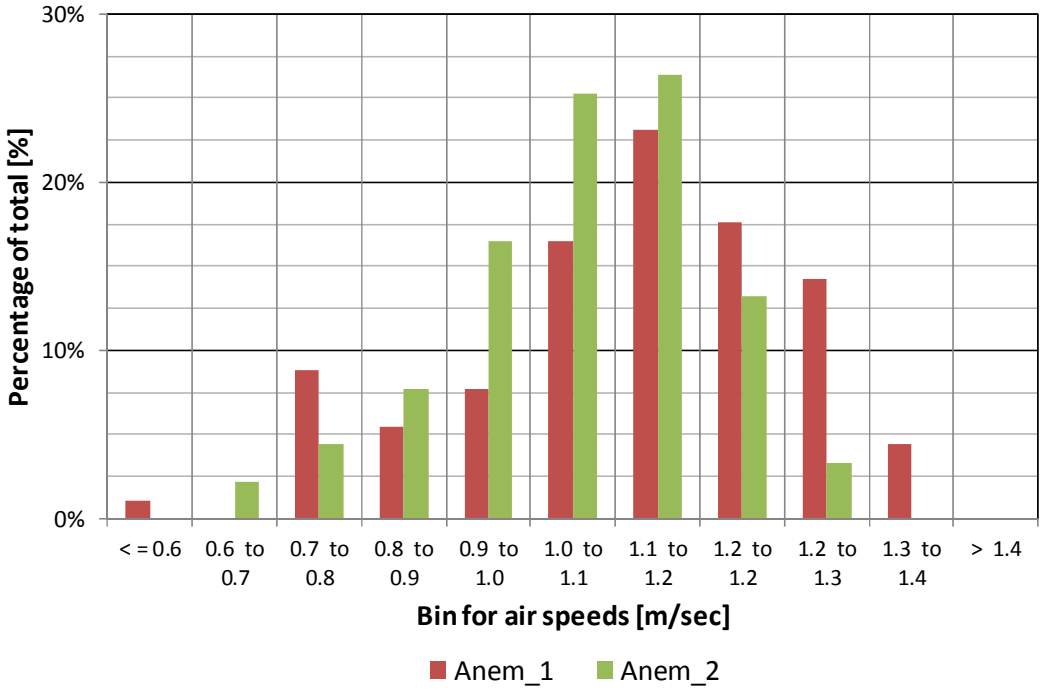
Sensor Location **B** **Comparison between Anim 1 and 2**



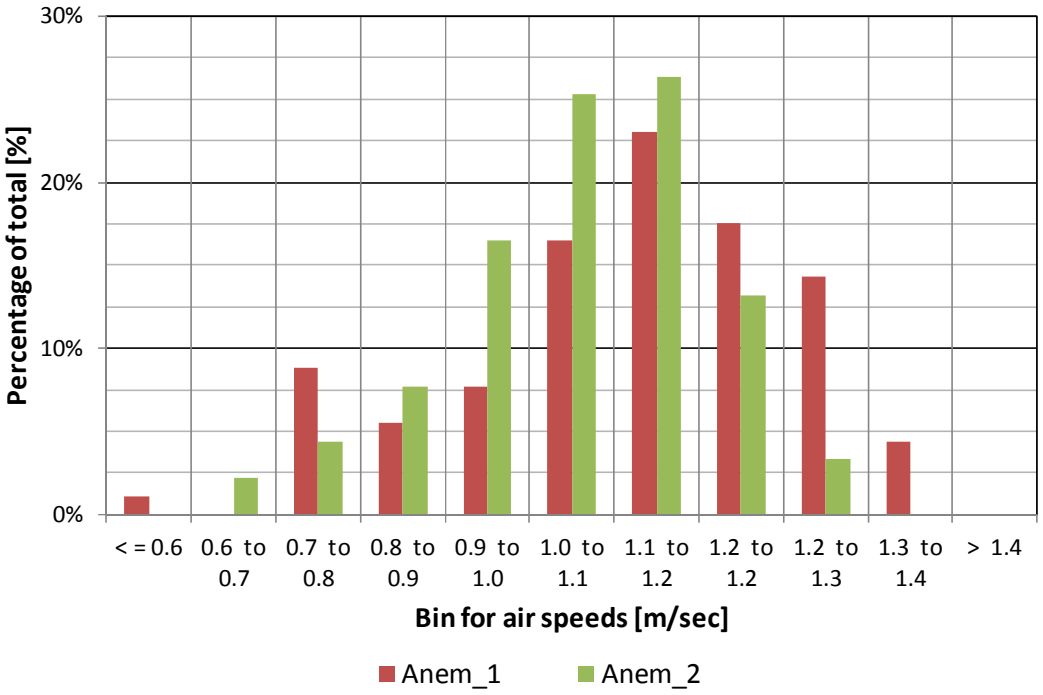
Fan Levels 2

Fan Level 2 = “level 2”

Level 2
Sensor Location C **Comparison between Anim 1 and 2**



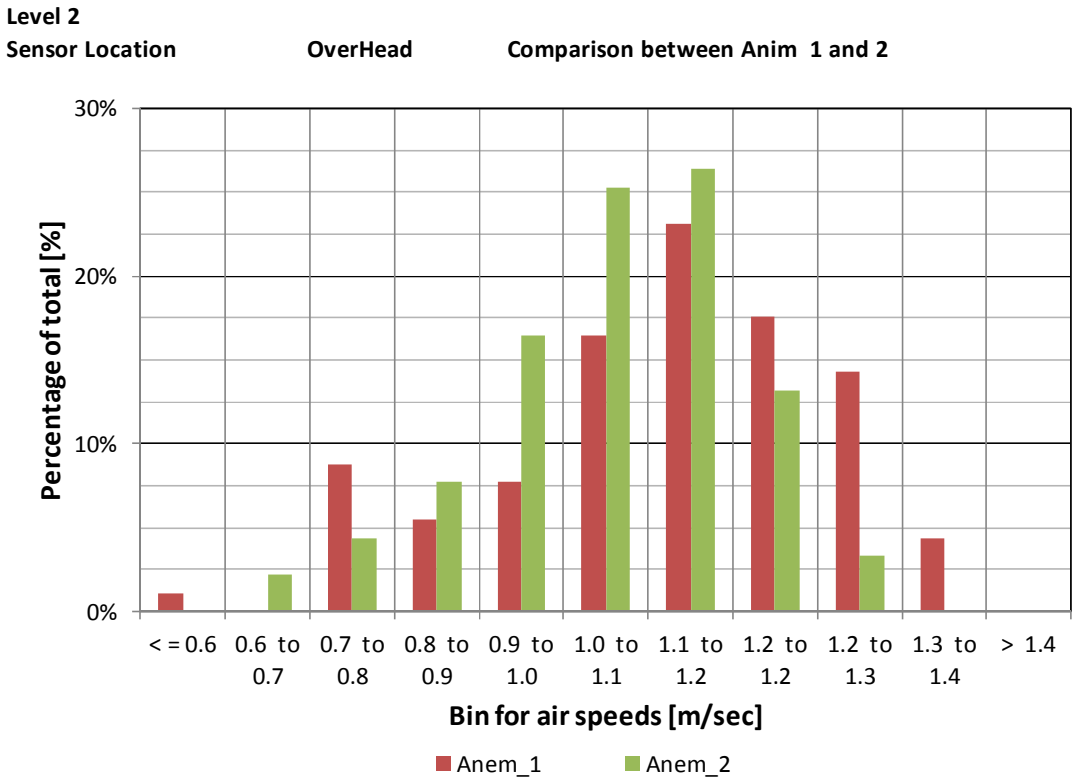
Level 2
Sensor Location D **Comparison between Anim 1 and 2**



APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 2

Fan Level 2 = “level 2”



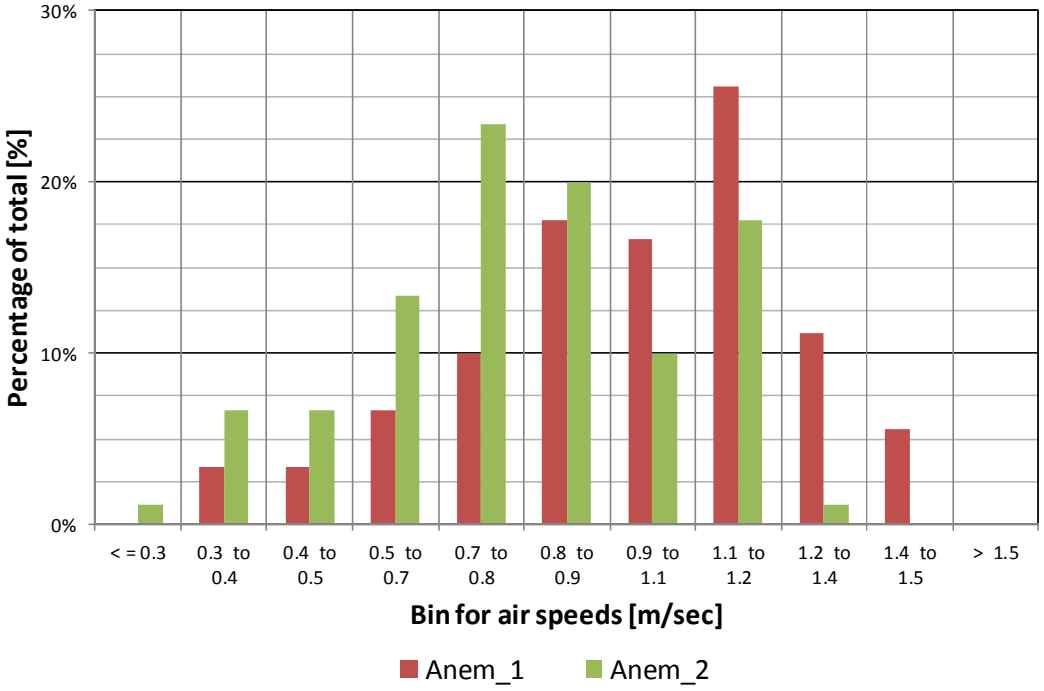
APPENDIX C: Summary of Air Measurements WITH a Test Person

Fan Levels 3

Fan Level 3 = “level 3”

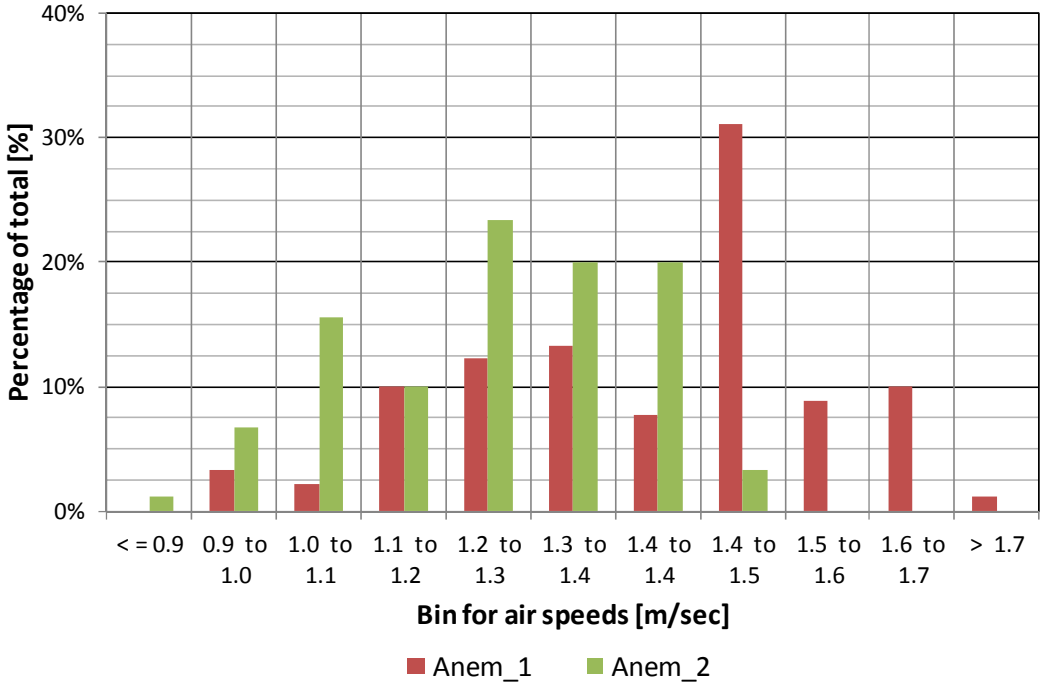
level 3

Sensor Location A **Comparison between Anim 1 and 2**



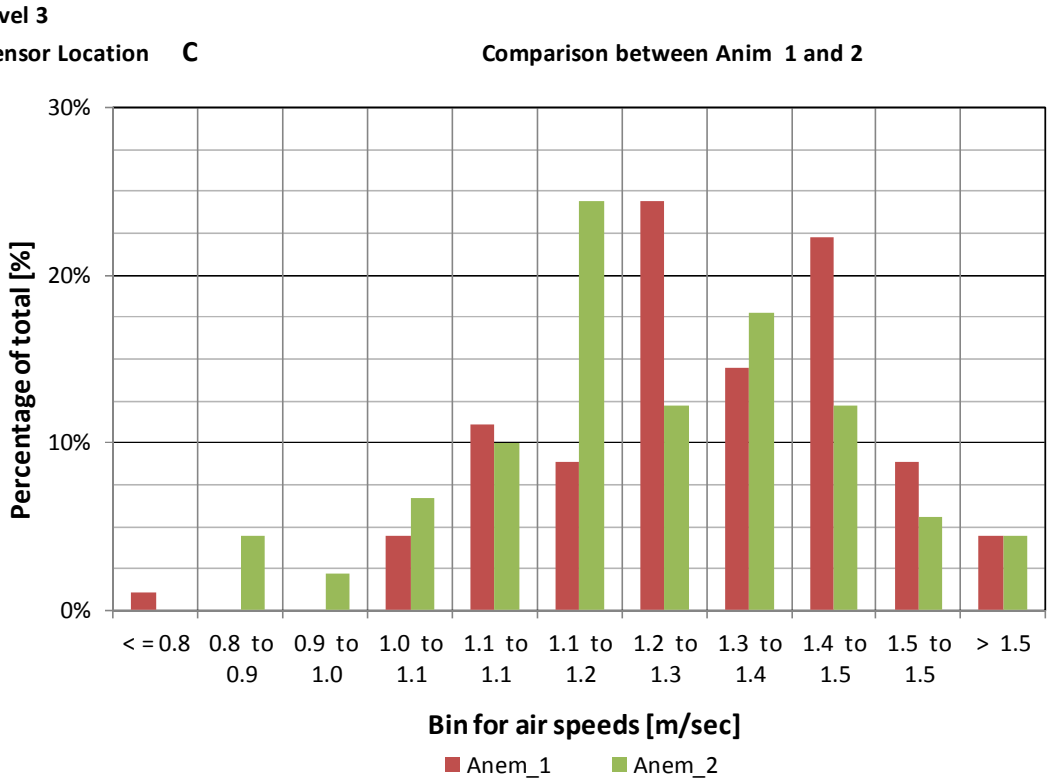
level 3

Sensor Location B **Comparison between Anim 1 and 2**



Fan Levels 3

Fan Level 3 = “level 3”



APPENDIX C: Summary of Air Measurements WITH a Test Person

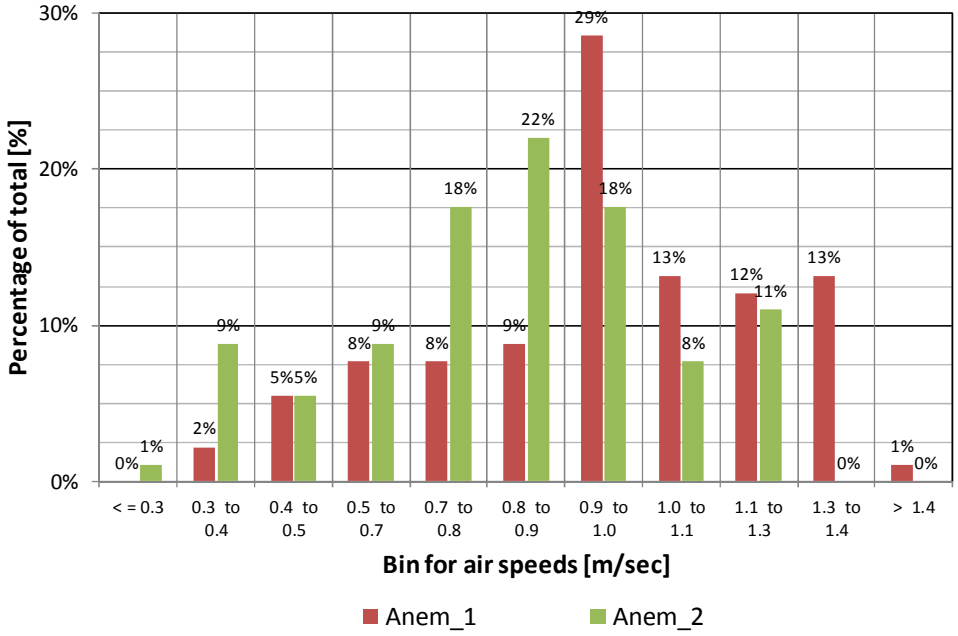
Comparison between Anemometers 1 and 2

Type of Anemometer = F-900

Fan level 2

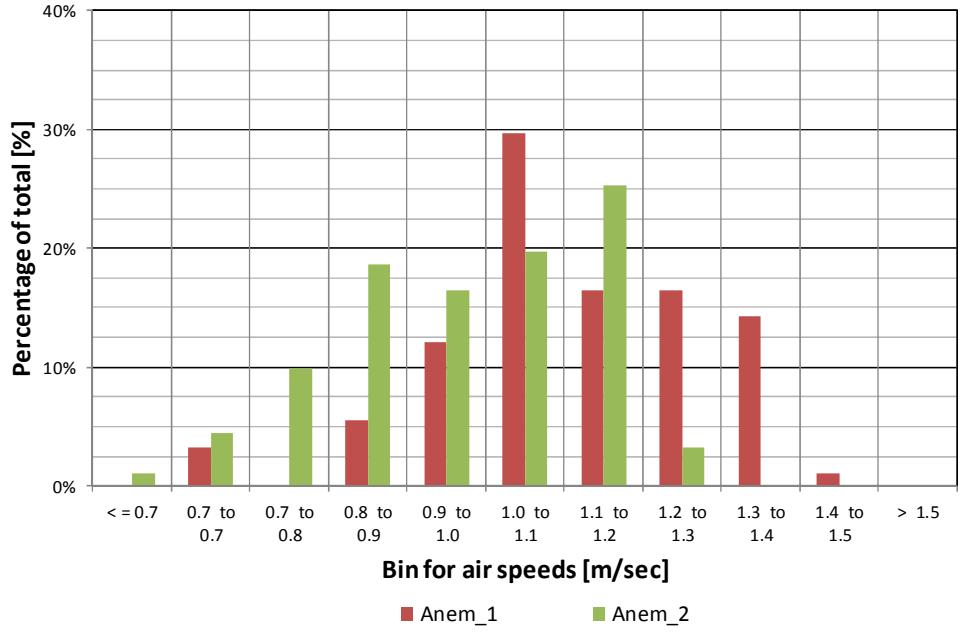
Level 2 Type of Anemometer = F-900

Sensor Location **A** **Comparison between Anemometers 1 and 2**



Level 2 Type of Anemometer = F-900

Sensor Location **B** **Comparison between Anemometers 1 and 2**



APPENDIX C: Summary of Air Measurements WITH a Test Person

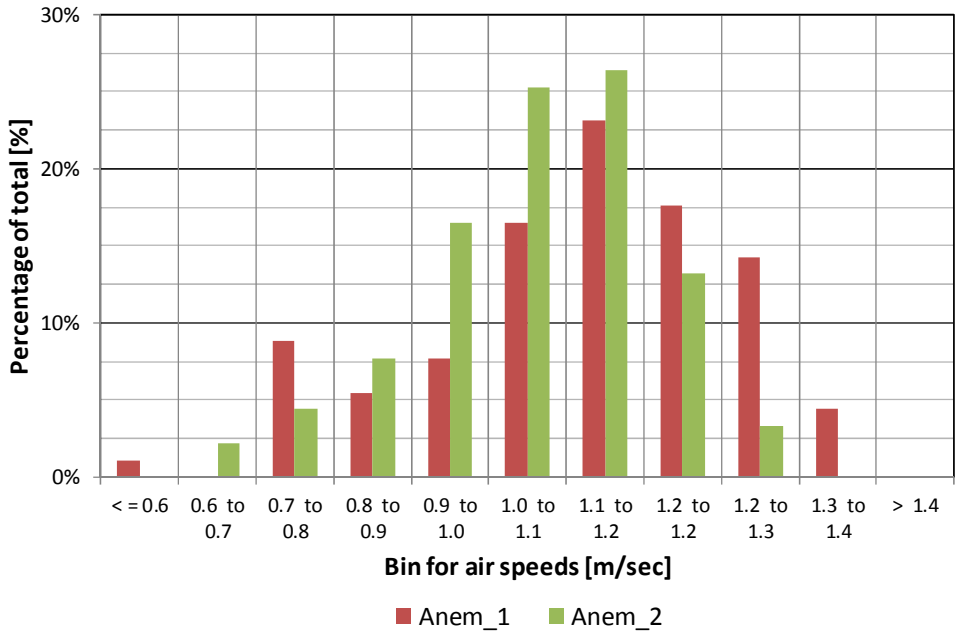
Comparison between Anemometers 1 and 2

Type of Anemometer = F-900

Fan level 2

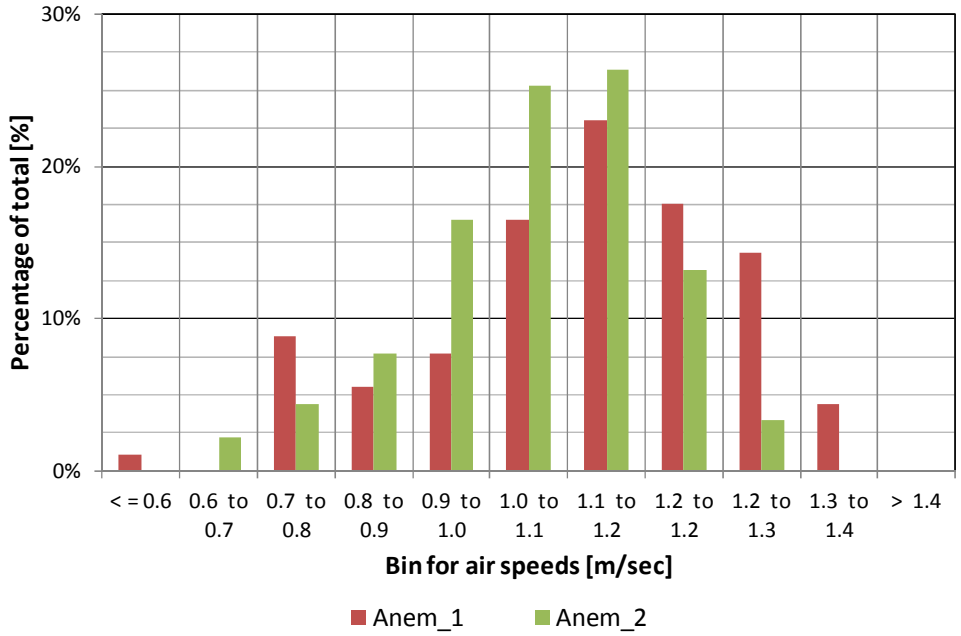
Level 2 Type of Anemometer = F-900

Sensor Location **C** **Comparison between Anemometers 1 and 2**



Level 2 Type of Anemometer = F-900

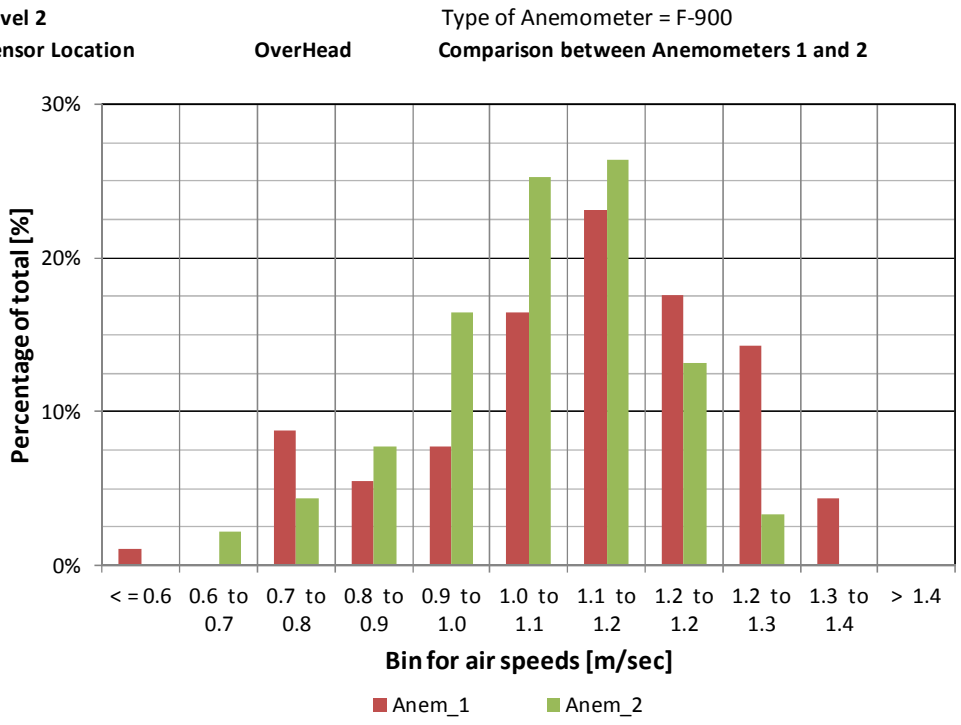
Sensor Location **D** **Comparison between Anemometers 1 and 2**



Comparison between Anemometers 1 and 2

Type of Anemometer = F-900

Fan level 2



APPENDIX C: Summary of Air Measurements WITH a Test Person

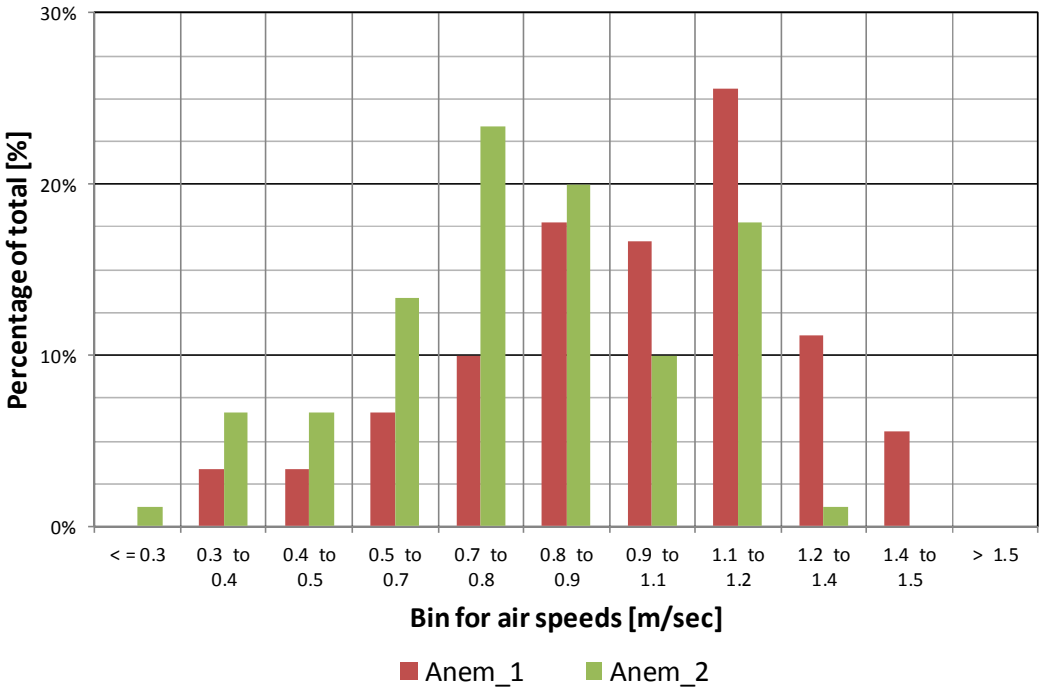
Comparison between Anemometers 1 and 2

Type of Anemometer = F-900

Fan level 3

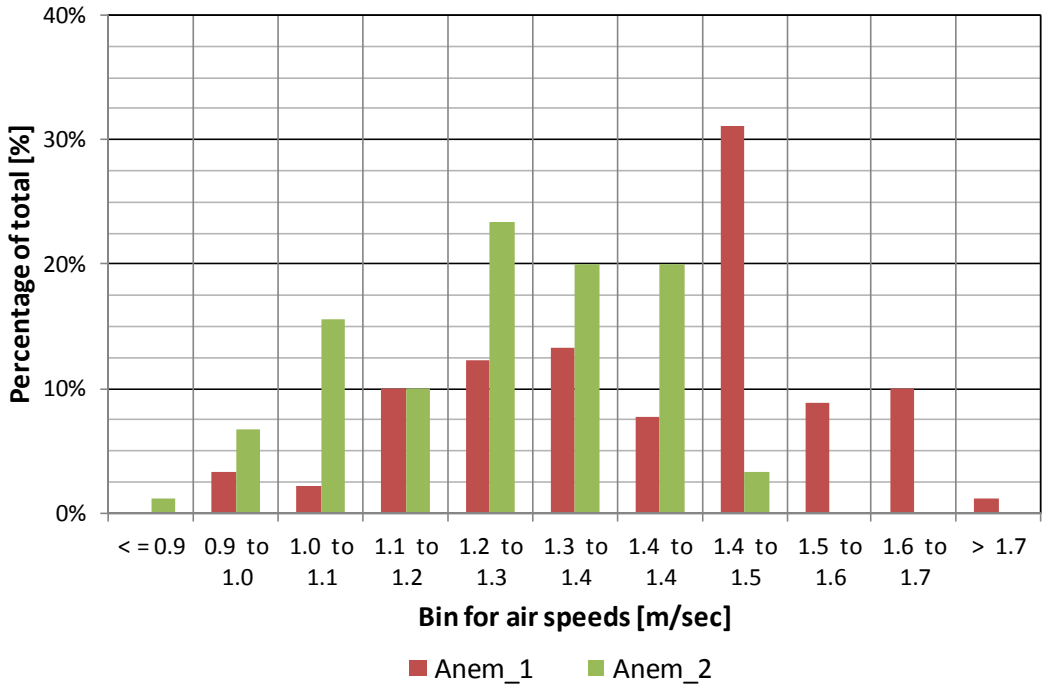
level 3 Type of Anemometer = F-900

Sensor Location A **Comparison between Anim 1 and 2**



level 3 Type of Anemometer = F-900

Sensor Location B **Comparison between Anim 1 and 2**



APPENDIX C: Summary of Air Measurements WITH a Test Person

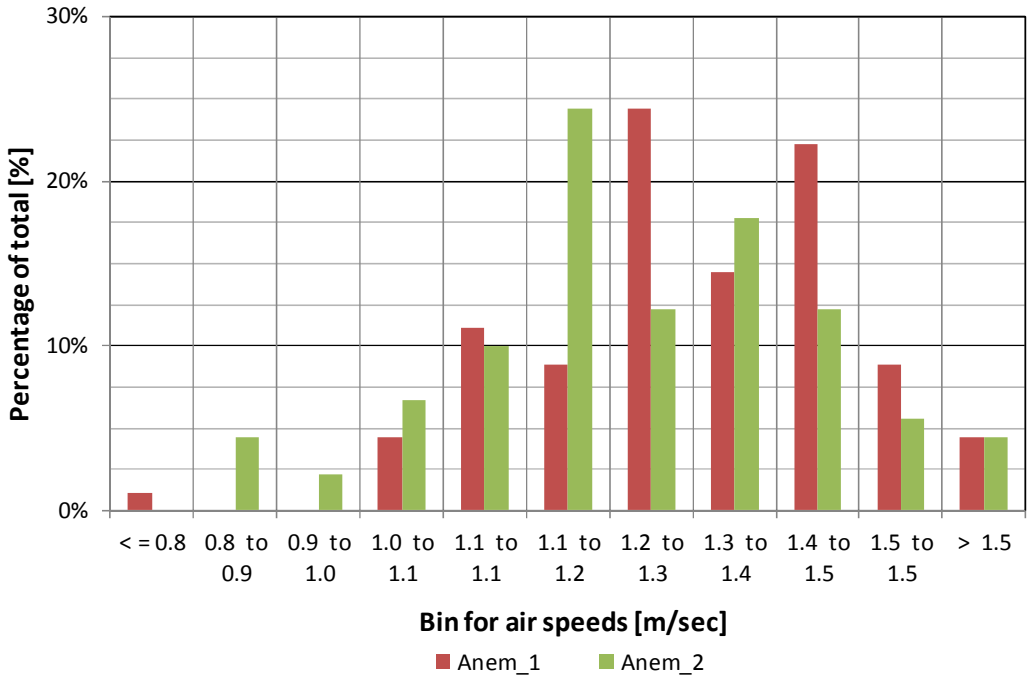
Comparison between Anemometers 1 and 2

Type of Anemometer = F-900

Fan level 3

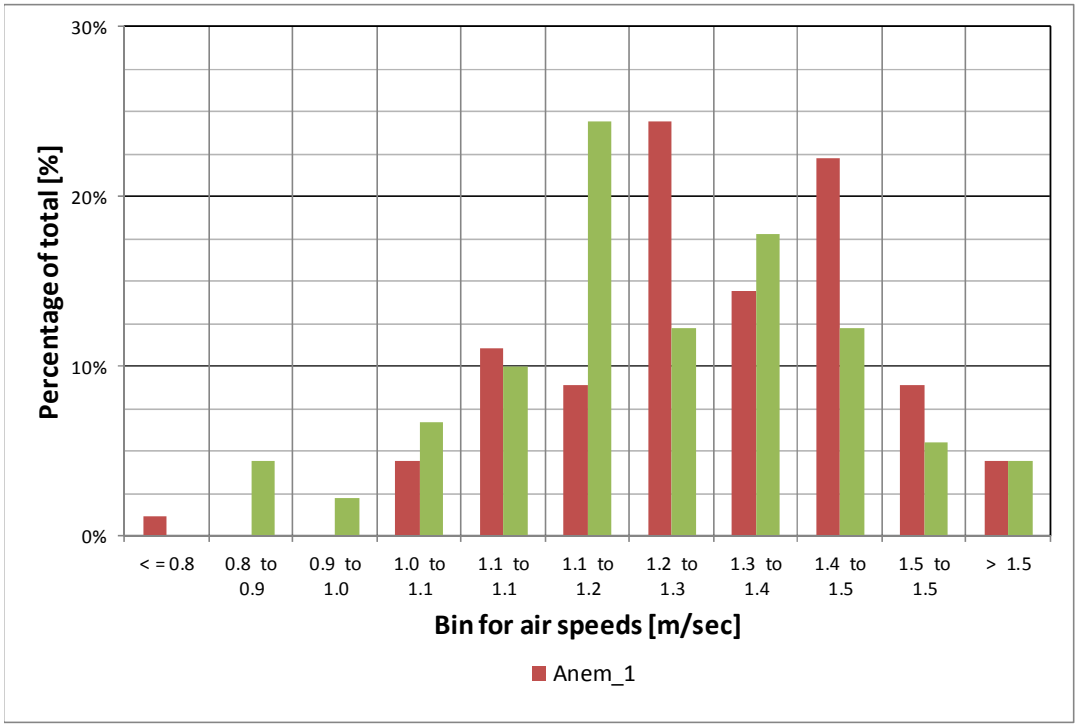
level 3 Type of Anemometer = F-900

Sensor Location C **Comparison between Anim 1 and 2**



level 3 Type of Anemometer = F-900

Sensor Location D **Comparison between Anim 1 and 2**



APPENDIX C: Summary of Air Measurements WITH a Test Person

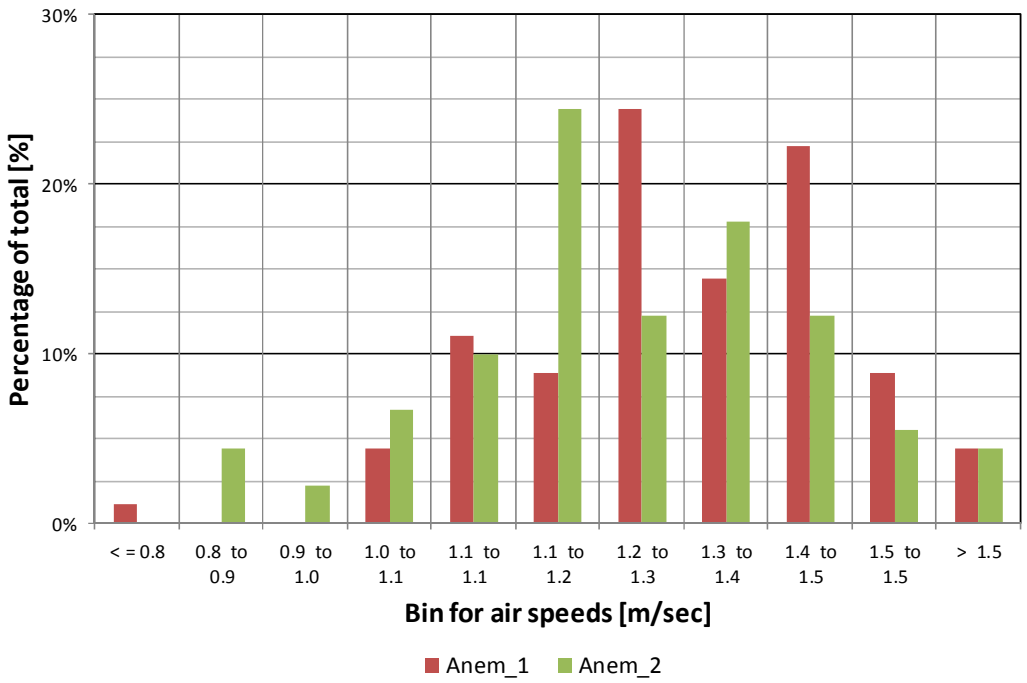
Comparison between Anemometers 1 and 2

Type of Anemometer = F-900

Fan level 3

level 3 Type of Anemometer = F-900

Sensor Location **OverHead** **Comparison between Anim 1 and 2**



APPENDIX C: Summary of Air Measurements WITH a Test Person

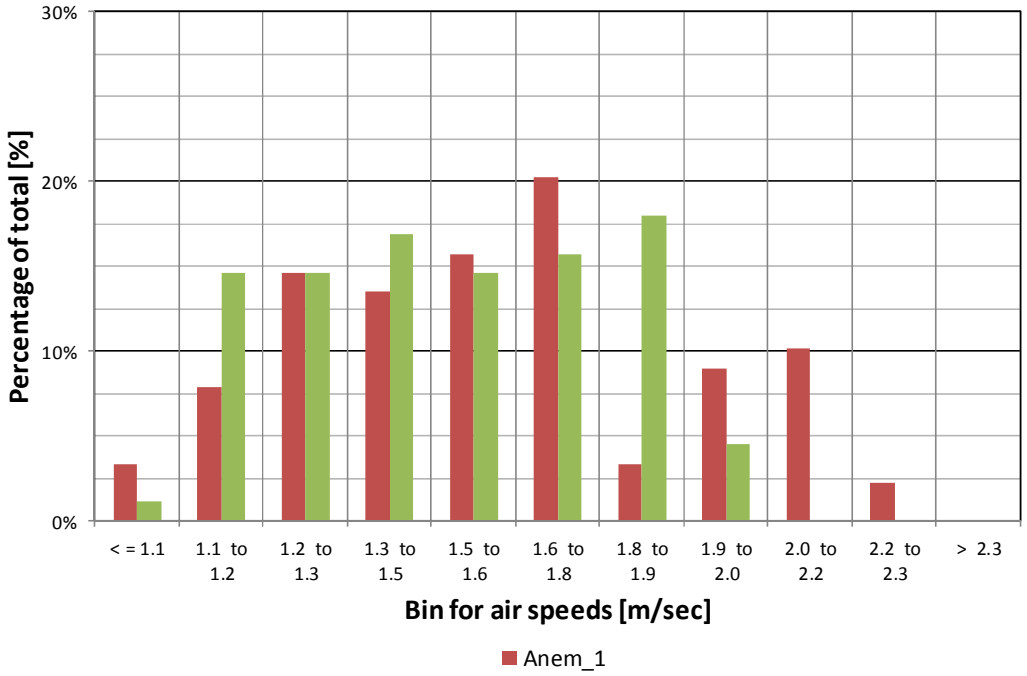
Comparison between Anemometers 1 and 2

Type of Anemometer = F-900

Fan level 4 - Measurement only at Overhead

Level 4 Type of Anemometer = F-900

Sensor Location **OverHead** **Comparison between Anim 1 and 2**



APPENDIX C: Summary of Air Measurements WITH a Test Person

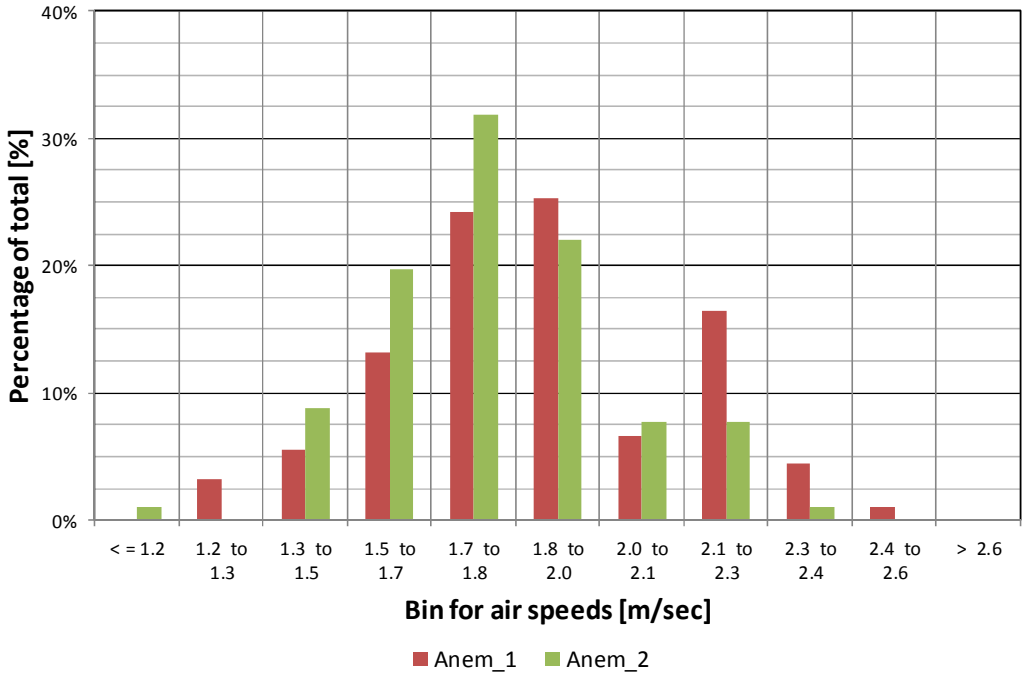
Comparison between Anemometers 1 and 2

Type of Anemometer = F-900

Fan level 5 - Measurement only at Overhead

level 5 Type of Anemometer = F-900

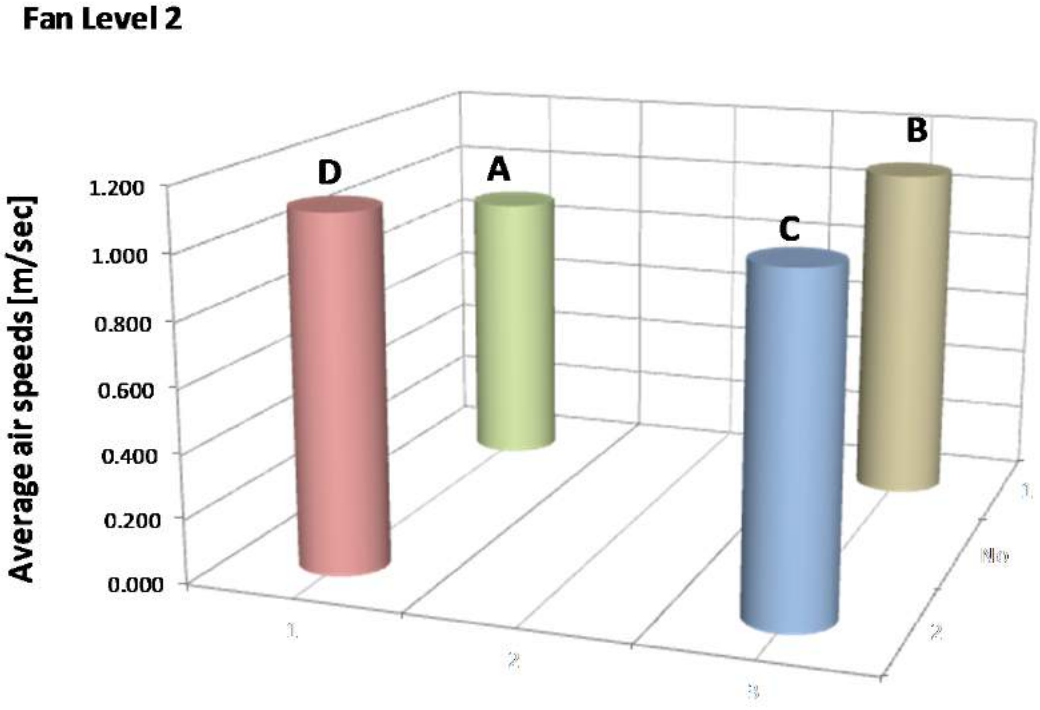
Sensor Location **OverHead** **Comparison between Anim 1 and 2**

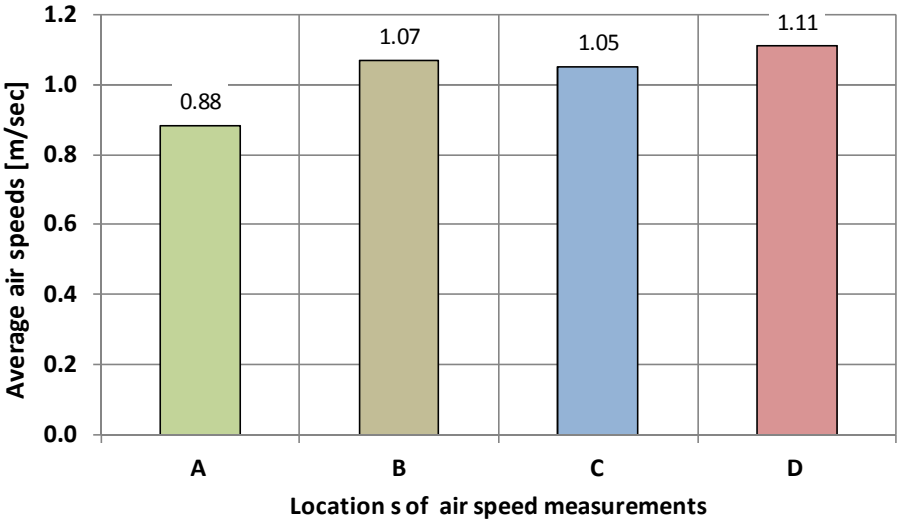


APPENDIX C: Summary of Air Measurements WITH a Test Person

Averages for Levels 2 and 3

Type of Anemometer = F-900

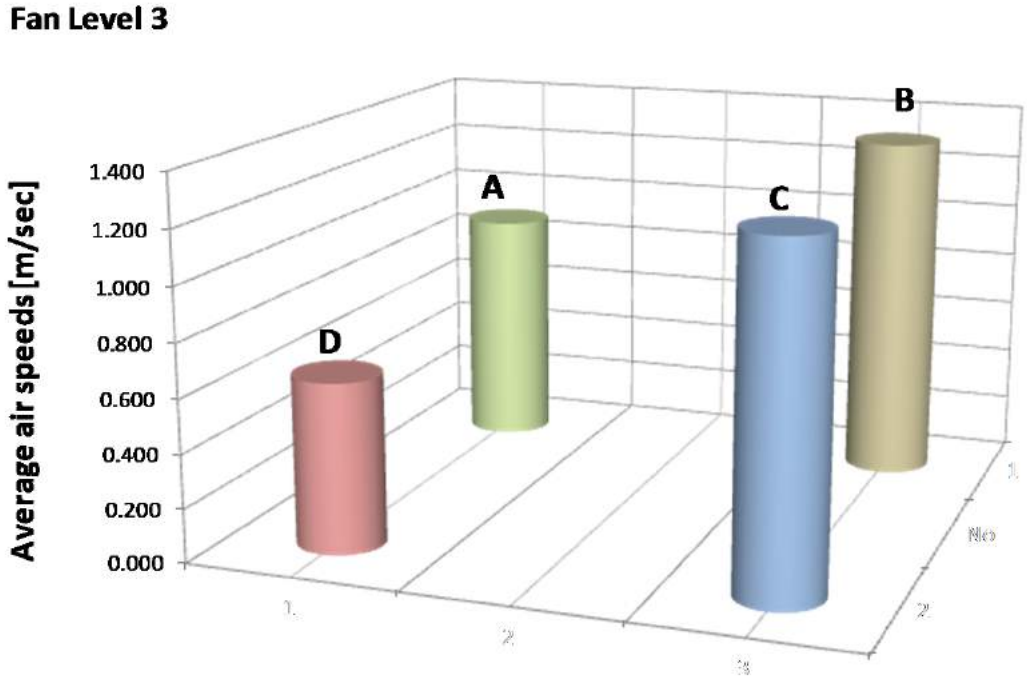




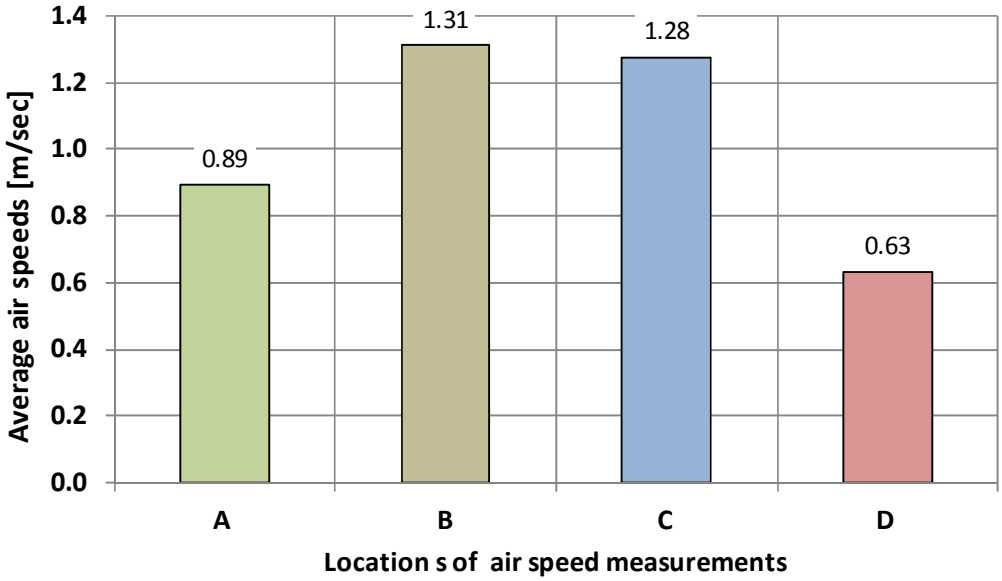
APPENDIX C: Summary of Air Measurements WITH a Test Person

Averages for Levels 2 and 3

Type of Anemometer = F-900



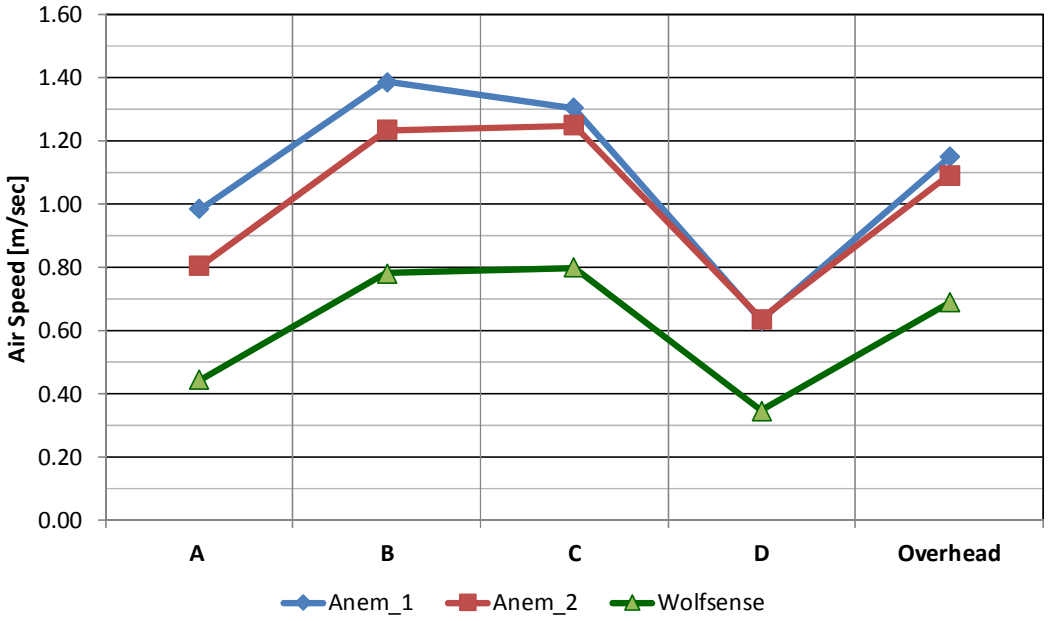
Fan Level 3 Average of Air speed measurements of 2 F900 anemometers



Comparisons od F-900 Anemometers and Wolfsense

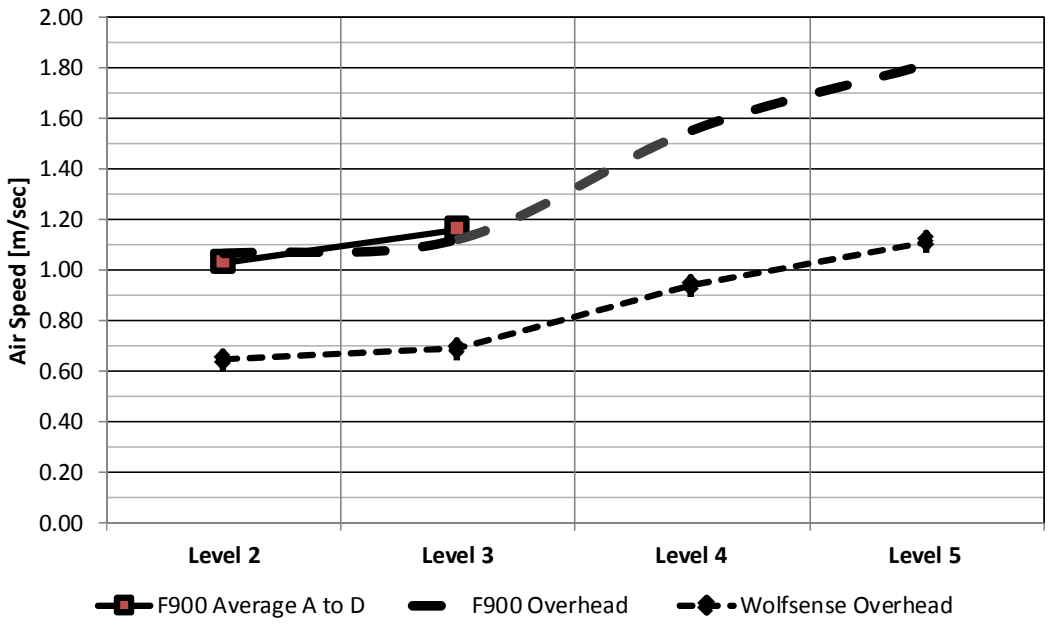
Level 2 **Comparison between types of Anemometers versus Location of Sensors**

Level 3 **Comparison between types of Anemometers versus Location of Sensors**



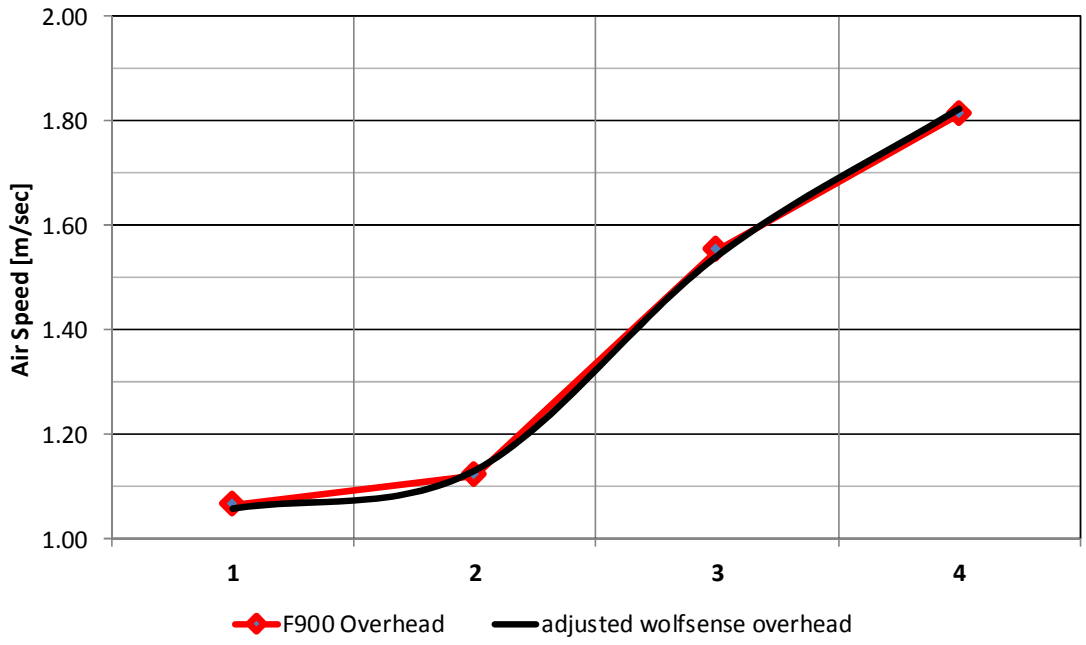
Comparisons od F-900 Anemometers and Wolfsense

Level 2 to 5 **Comparison between types of Anemometers versus Location of Sensors**



Level 2 to 5 **Comparison between F-900 Anemometers and Adjusted Wolfsense**

Only Overhead measurements considerd



APPENDIX C

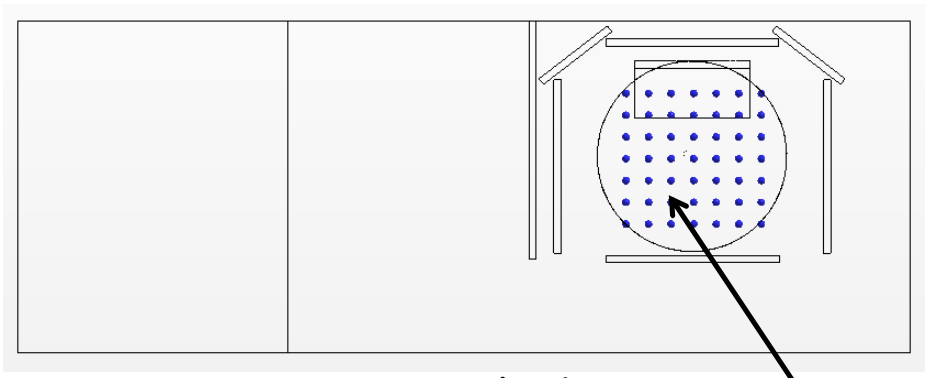
Summary of Results of CFD Air Speed Simulations

(26 pages)

APPENDIX C

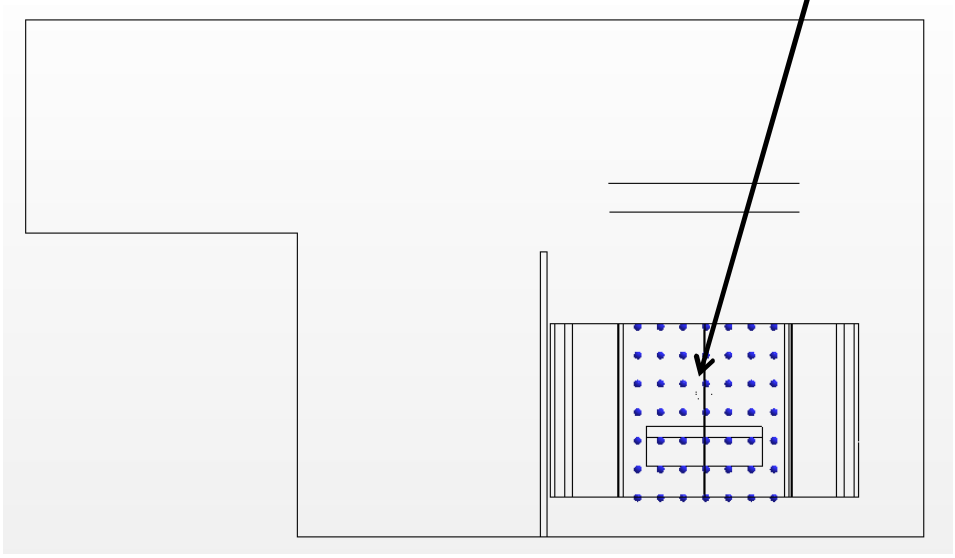
Summary of Results of CFD air speed simulations

Overview of data representation for CFD air speed simulations



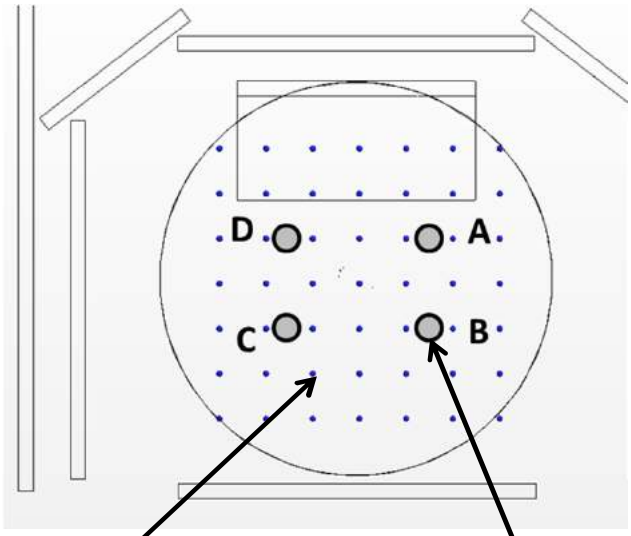
Test set-up - Plan View

7 x 7 x 7 data representation grid



Test set-up - Section

Indication of anemometer locations A through D superimposed on the presentation grid



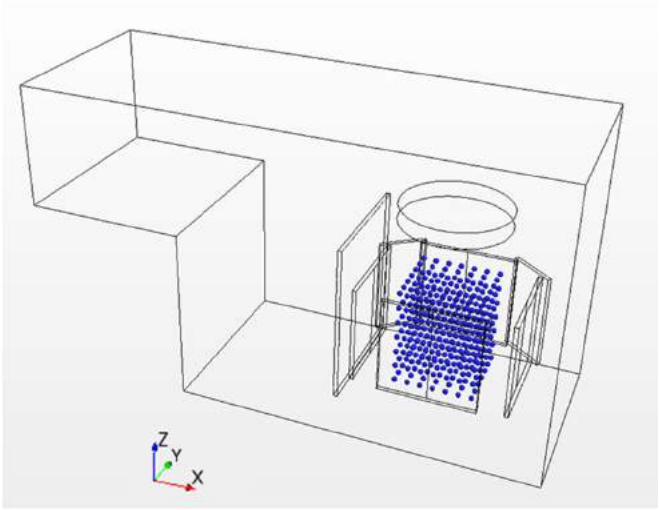
7 x 7 x 7 data representation grid

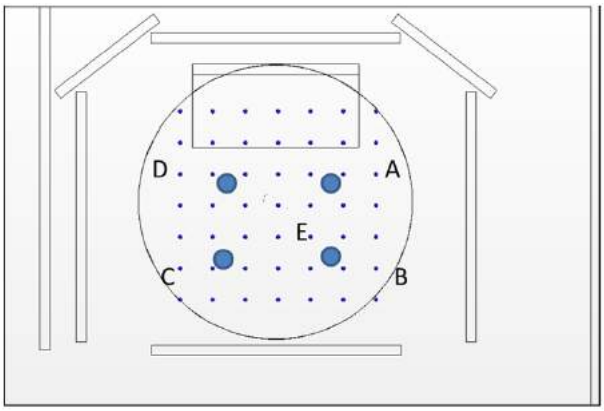
Locations of anemometers A through D with which the CFD results are validated

Definition of 7 x 7 x 7 presentation grid

Elevation of actual anemometers for measurements

height 1	18.0	inches
	0.46	m
height 2	48.0	inches
	1.22	m





rows
7
6
5
4
3
2
1

Definition of 7 x 7 x 7 presentation grid

Definition of x/y plane x / y for each z-layer

y - rows									
	1		1 / 1	2 / 1	3 / 1	4 / 1	5 / 1	6 / 1	7 / 1
	2	C	1 / 2	2 / 2	3 / 2	4 / 2	5 / 2	6 / 2	7 / 2
	3		1 / 3	2 / 3	3 / 3	4 / 3	5 / 3	6 / 3	7 / 3
	4	D	1 / 4	2 / 4	3 / 4	4 / 4	5 / 4	6 / 4	7 / 4
	5		1 / 5	2 / 5	3 / 5	4 / 5	5 / 5	6 / 5	7 / 5
	6		1 / 6	2 / 6	3 / 6	4 / 6	5 / 6	6 / 6	7 / 6
	7		1 / 7	2 / 7	3 / 7	4 / 7	5 / 7	6 / 7	7 / 7
			1	2	3	4	5	6	7
			x - columns						

Definition of x/y plane x / y for each z-layer

y - rows								
1	1 / 1	2 / 1	3 / 1	4 / 1	5 / 1	6 / 1	7 / 1	
2	1 / 2	2 / 2	3 / 2	4 / 2	5 / 2	6 / 2	7 / 2	B
3	1 / 3	2 / 3	3 / 3	4 / 3	5 / 3	6 / 3	7 / 3	
4	1 / 4	2 / 4	3 / 4	4 / 4	5 / 4	6 / 4	7 / 4	A
5	1 / 5	2 / 5	3 / 5	4 / 5	5 / 5	6 / 5	7 / 5	
6	1 / 6	2 / 6	3 / 6	4 / 6	5 / 6	6 / 6	7 / 6	
7	1 / 7	2 / 7	3 / 7	4 / 7	5 / 7	6 / 7	7 / 7	
	1	2	3	4	5	6	7	
	x - columns							

Definition of height [m] ([ft])

z-layer				
7	1.6 / (5.2)			
6	1.4 / (4.6)			
5	1.2 / (3.9)	anemometer	1.2	m
4	1.0 / (3.3)			
3	0.8 / (2.6)			
2	0.6 / (2.0)	anemometer	0.46	m
1	0.4 / (1.3)			

Presentation of results for Fan speed **Level 2 – elevation 0.46 m**

Average for entire z-layers

average	z-ccord.	vel.	weight
	m	m/sec	[%]
Entire z-layer 1	0.4	0.231	70.0%
Entire z-layer 2	0.6	0.233	30.0%
weighted average	**0.46**	**0.232**	m/sec
stnd. Dev.			
Entire z-layer 1		0.153	
Entire z-layer 2		0.188	

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.231 m/sec

y - rows								
	1	0.115	0.152	0.230	0.195	0.139	0.101	0.080
	2	0.144	0.255	0.423	0.429	0.305	0.143	0.094
	3	0.177	0.402	0.463	0.452	0.452	0.201	0.109
	4	0.229	0.454	0.332	0.346	0.504	0.278	0.132
	5	0.209	0.452	0.490	0.495	0.443	0.355	0.184
	6	0.178	0.366	0.116	0.042	0.038	0.033	0.042
	7	0.085	0.129	0.100	0.093	0.056	0.042	0.047
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.233 m/sec

y - rows								
	1	0.083	0.124	0.161	0.183	0.123	0.092	0.063
	2	0.092	0.194	0.381	0.439	0.284	0.131	0.079
	3	0.137	0.353	0.552	0.560	0.521	0.208	0.098
	4	0.168	0.495	0.556	0.534	0.564	0.264	0.126
	5	0.154	0.449	0.572	0.575	0.543	0.317	0.160
	6	0.186	0.194	0.074	0.043	0.040	0.032	0.039
	7	0.139	0.040	0.083	0.075	0.032	0.048	0.052
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position A at 0.46 m elevation

average	z-ccord.	vel.	weight
	m	m/sec	[%]
Entire z-layer 1	0.4	0.429	70.0%
Entire z-layer 2	0.6	0.507	30.0%
weighted average	**0.46**	**0.452**	m/sec
stnd. Dev.			
Entire z-layer 1		0.039	0.090878
Entire z-layer 2		0.126	0.248428

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.403 m/sec

y - rows								
	1							
	2							
	3							
	4				0.346	0.504	0.278	
	5				0.495	0.443	0.355	
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.466 m/sec

y - rows								
	1							
	2							
	3							
	4				0.534	0.564	0.264	
	5				0.575	0.543	0.317	
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Presentation of results for Fan speed **Level 2 – elevation 0.46 m**

Anemometer position B at 0.46 m elevation

average	z-ccord.	vel.	weight
	m	m/sec	[%]
Entire z-layer 1	0.4	0.368	70.0%
Entire z-layer 2	0.6	0.402	30.0%
weighted average	**0.46**	**0.378**	m/sec

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.330 m/sec

y - rows	x - columns 1	2	3	4	5	6	7
1							
2				0.429	0.305	0.143	
3				0.452	0.452	0.201	
4							
5							
6							
7							

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.357 m/sec

y - rows	x - columns 1	2	3	4	5	6	7
1							
2				0.439	0.284	0.131	
3				0.560	0.521	0.208	
4							
5							
6							
7							

Anemometer position C at 0.46 m elevation

average	z-ccord.	vel.	weight
	m	m/sec	[%]
Entire z-layer 1	0.4	0.434	70.0%
Entire z-layer 2	0.6	0.457	30.0%
weighted average	**0.46**	**0.441**	m/sec

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.404 m/sec

y - rows	x - columns 1	2	3	4	5	6	7
1							
2		0.255	0.423	0.429			
3		0.402	0.463	0.452			
4							
5							
6							
7							

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.413 m/sec

y - rows	x - columns 1	2	3	4	5	6	7
1							
2		0.194	0.381	0.439			
3		0.353	0.552	0.560			
4							
5							
6							
7							

Presentation of results for Fan speed **Level 2 – elevation 0.46 m**

Anemometer position D at 0.46 m elevation

average	z-coord. m	vel. m/sec	weight [%]	
Entire z-layer 1	0.4	0.473	70.0%	
Entire z-layer 2	0.6	0.547	30.0%	
weighted average	**0.46**	**0.495**	m/sec	

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells **0.428** m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
y = 1							
y = 2							
y = 3							
y = 4		0.454	0.332	0.346			
y = 5		0.452	0.490	0.495			
y = 6							
y = 7							

x - columns

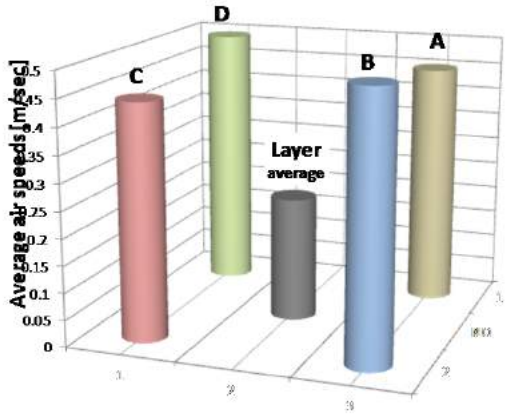
z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells **0.530** m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
y = 1							
y = 2							
y = 3							
y = 4		0.495	0.556	0.534			
y = 5		0.449	0.572	0.575			
y = 6							
y = 7							

x - columns

averages for anemometers
Fan speed level 2

	elevation [m]	air speed [m/sec]	% of layer	% of all
Anemometer A	0.46	0.45	195%	185%
Anemometer B	0.46	0.38	163%	154%
Anemometer C	0.46	0.44	190%	180%
Anemometer D	0.46	0.49	214%	202%
Average for z-layer	0.46	**0.23**	100%	95%
Average - all points	N/A	0.24	106%	100%



Presentation of results for Fan speed **Level 2 – elevation 1.20 m**

Average for entire z-layers

average	z-ccord.	vel.
	m	m/sec
Entire z-layer	1.2	0.167

z-layer 5 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.251 m/sec

y - rows								
	1	0.040	0.084	0.134	0.167	0.143	0.105	0.079
	2	0.082	0.135	0.312	0.415	0.288	0.138	0.090
	3	0.124	0.323	0.583	0.606	0.558	0.201	0.106
	4	0.151	0.479	0.605	0.316	0.596	0.238	0.112
	5	0.126	0.377	0.593	0.594	0.559	0.199	0.107
	6	0.095	0.211	0.408	0.476	0.340	0.135	0.093
	7	0.069	0.093	0.145	0.193	0.125	0.091	0.076
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position A at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer A	1.2	0.461

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.417 m/sec

y - rows								
	1							
	2							
	3							
	4				0.316	0.596	0.238	
	5				0.594	0.559	0.199	
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position B at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer B	1.2	0.414

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.368 m/sec

y - rows								
	1							
	2				0.415	0.288	0.138	
	3				0.606	0.558	0.201	
	4							
	5							
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position C at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer C	1.2	0.448

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.396 m/sec

y - rows								
	1							
	2		0.135	0.312	0.415			
	3		0.323	0.583	0.606			
	4							
	5							
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Presentation of results for Fan speed **Level 2 – elevation 1.20 m**

Anemometer position D at 1.20 m elevation

average	z-coord.	vel.
	m	m/sec
Anemometer D	1.2	0.530

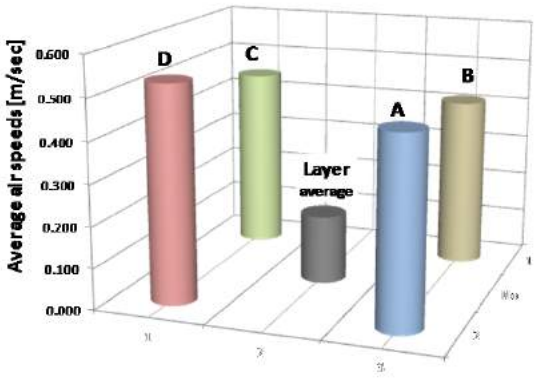
z-layer 1 **1.2** **m elevation** **velocity data in m/sec**

average of shaded cells **0.494 m/sec**

y - rows		x - columns						
		1	2	3	4	5	6	7
	1							
	2							
	3							
	4		0.479	0.605	0.316			
	5		0.377	0.593	0.594			
	6							
	7							

Fan level 2
averages for anemometers

	elevation [m]	air speed [m/sec]	% of layer	% of all
Anemometer A	1.2	0.46	276%	188%
Anemometer B	1.2	0.41	248%	169%
Anemometer C	1.2	0.45	269%	183%
Anemometer D	1.2	0.53	318%	216%
Average for z-layer	1.2	0.17	100%	68%
Average - all points	N/A	0.24	147%	100%



Presentation of results for Fan speed **Level 3 – elevation 0.46 m**

Average for entire z-layers

average	z-ccord.	vel.	weight
	m	m/sec	[%]
Entire z-layer 1	0.4	0.272	70.0%
Entire z-layer 2	0.6	0.276	30.0%
weighted average	**0.46**	**0.273**	m/sec
stnd. Dev.			
Entire z-layer 1		0.168	
Entire z-layer 2		0.209	

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.272 m/sec

y - rows								
	1	0.144	0.187	0.281	0.262	0.192	0.139	0.113
	2	0.185	0.313	0.462	0.492	0.405	0.191	0.129
	3	0.231	0.455	0.509	0.487	0.518	0.255	0.145
	4	0.289	0.497	0.417	0.401	0.563	0.350	0.179
	5	0.273	0.503	0.555	0.546	0.461	0.421	0.238
	6	0.279	0.375	0.080	0.054	0.043	0.028	0.026
	7	0.125	0.120	0.117	0.097	0.063	0.052	0.057
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.276 m/sec

y - rows								
	1	0.101	0.146	0.198	0.252	0.174	0.133	0.091
	2	0.131	0.251	0.434	0.513	0.401	0.177	0.105
	3	0.189	0.443	0.612	0.624	0.604	0.262	0.126
	4	0.216	0.549	0.631	0.615	0.634	0.329	0.167
	5	0.220	0.514	0.639	0.639	0.589	0.400	0.219
	6	0.269	0.155	0.046	0.052	0.046	0.048	0.041
	7	0.117	0.086	0.102	0.064	0.041	0.063	0.062
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position A at 0.46 m elevation

average	z-ccord.	vel.	weight
	m	m/sec	[%]
Entire z-layer 1	0.4	0.478	70.0%
Entire z-layer 2	0.6	0.575	30.0%
weighted average	**0.46**	**0.508**	m/sec
stnd. Dev.			
Entire z-layer 1		0.036	0.074484
Entire z-layer 2		0.123	0.213331

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.457 m/sec

y - rows								
	1							
	2							
	3							
	4				0.401	0.563	0.350	
	5				0.546	0.461	0.421	
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.534 m/sec

y - rows								
	1							
	2							
	3							
	4				0.615	0.634	0.329	
	5				0.639	0.589	0.400	
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Presentation of results for Fan speed **Level 3 – elevation 0.46 m**

Anemometer position B at 0.46 m elevation

average	z-ccord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.431	70.0%
Entire z-layer 2	0.6	0.481	30.0%
weighted average	**0.46**	**0.446**	m/sec

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.391 m/sec

y - rows	1	2	3	4	5	6	7
1							
2				0.492	0.405	0.191	
3				0.487	0.518	0.255	
4							
5							
6							
7							

x - columns

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.430 m/sec

y - rows	1	2	3	4	5	6	7
1							
2				0.513	0.401	0.177	
3				0.624	0.604	0.262	
4							
5							
6							
7							

x - columns

Anemometer position C at 0.46 m elevation

average	z-ccord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.481	70.0%
Entire z-layer 2	0.6	0.525	30.0%
weighted average	**0.46**	**0.494**	m/sec

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.453 m/sec

y - rows	1	2	3	4	5	6	7
1							
2		0.313	0.462	0.492			
3		0.455	0.509	0.487			
4							
5							
6							
7							

x - columns

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.479 m/sec

y - rows	1	2	3	4	5	6	7
1							
2		0.251	0.434	0.513			
3		0.443	0.612	0.624			
4							
5							
6							
7							

x - columns

Presentation of results for Fan speed **Level 3 – elevation 0.46 m**

Anemometer position D at 0.46 m elevation

average	z-coord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.525	70.0%
Entire z-layer 2	0.6	0.615	30.0%
weighted average	**0.46**	**0.552**	m/sec

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells **0.487** m/sec

y - rows	1	2	3	4	5	6	7
1							
2							
3							
4		0.497	0.417	0.401			
5		0.503	0.555	0.546			
6							
7							

x - columns

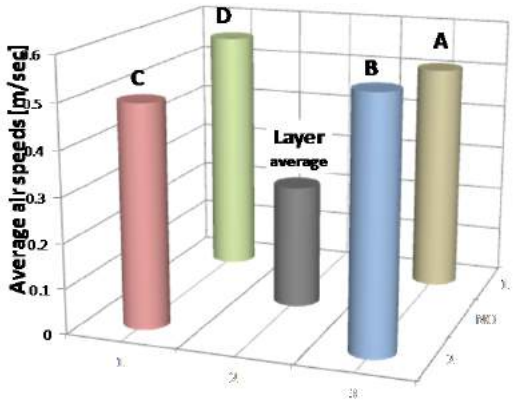
z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells **0.598** m/sec

y - rows	1	2	3	4	5	6	7
1							
2							
3							
4		0.549	0.631	0.615			
5		0.514	0.639	0.639			
6							
7							

x - columns

averages for anemometers
Level 3

	elevation [m]	air speed [m/sec]	% of layer	% of all
Anemometer A	0.46	0.51	186%	173%
Anemometer B	0.46	0.45	164%	153%
Anemometer C	0.46	0.49	181%	169%
Anemometer D	0.46	0.55	202%	189%
Average for z-layer	0.46	0.27	100%	93%
Average - all points	N/A	0.29	107%	100%



Presentation of results for Fan speed **Level 3 – elevation 1.22 m**

Average for entire z-layers

average	z-ccord.	vel.
	m	m/sec
Entire z-layer	1.2	0.231

z-layer 5 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.305 m/sec

y - rows	x = 1	2	3	4	5	6	7
1	0.065	0.103	0.170	0.231	0.211	0.143	0.105
2	0.121	0.197	0.393	0.480	0.397	0.198	0.118
3	0.190	0.416	0.649	0.679	0.630	0.275	0.135
4	0.224	0.535	0.680	0.370	0.667	0.297	0.139
5	0.189	0.435	0.660	0.668	0.620	0.253	0.129
6	0.115	0.263	0.470	0.529	0.406	0.176	0.109
7	0.087	0.144	0.225	0.259	0.166	0.118	0.094

x - columns

Anemometer position A at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer A	1.2	0.525

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.479 m/sec

y - rows	x = 1	2	3	4	5	6	7
1							
2							
3							
4				0.370	0.667	0.297	
5				0.668	0.620	0.253	
6							
7							

x - columns

Anemometer position B at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer B	1.2	0.492

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.443 m/sec

y - rows	x = 1	2	3	4	5	6	7
1							
2				0.480	0.397	0.198	
3				0.679	0.630	0.275	
4							
5							
6							
7							

x - columns

Anemometer position C at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer C	1.2	0.523

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.469 m/sec

y - rows	x = 1	2	3	4	5	6	7
1							
2		0.197	0.393	0.480			
3		0.416	0.649	0.679			
4							
5							
6							
7							

x - columns

Presentation of results for Fan speed **Level 3 – elevation 1.22 m**

Anemometer position D at 1.20 m elevation

average	z-coord.	vel.
	m	m/sec
Anemometer D	1.2	0.596

z-layer 1 **1.2** m elevation velocity data in m/sec

average of shaded cells 0.558 m/sec

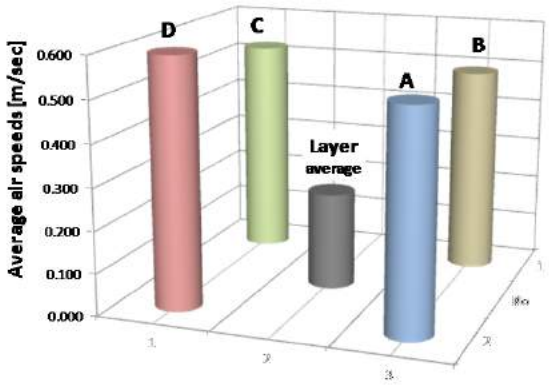
y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
y = 1							
y = 2							
y = 3							
y = 4		0.535	0.680	0.370			
y = 5		0.435	0.660	0.668			
y = 6							
y = 7							

x - columns

Fan level 3

averages for anemometers

	elevation [m]	air speed [m/sec]	% of layer	% of all
Anemometer A	1.2	0.525	227%	179%
Anemometer B	1.2	0.492	213%	168%
Anemometer C	1.2	0.523	226%	179%
Anemometer D	1.2	0.596	257%	204%
Average for z-layer	1.2	0.231	100%	79%
Average - all points	N/A	0.293	126%	100%



Presentation of results for Fan speed **Level 4 – elevation 0.46 m**

Average for entire z-layers

average	z-ccord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.410	70.0%
Entire z-layer 2	0.6	0.413	30.0%
weighted average	**0.46**	**0.411**	m/sec
stnd. Dev.			
Entire z-layer 1		0.257	
Entire z-layer 2		0.312	

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.410 m/sec

y - rows		x - columns 1	2	3	4	5	6	7
	1	0.217	0.285	0.436	0.392	0.283	0.207	0.169
	2	0.285	0.516	0.753	0.790	0.662	0.289	0.190
	3	0.362	0.741	0.701	0.661	0.809	0.386	0.212
	4	0.460	0.789	0.403	0.476	0.847	0.525	0.256
	5	0.412	0.796	0.808	0.844	0.751	0.655	0.348
	6	0.396	0.625	0.145	0.081	0.070	0.046	0.052
	7	0.187	0.200	0.178	0.155	0.096	0.076	0.077

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.413 m/sec

y - rows		x - columns 1	2	3	4	5	6	7
	1	0.152	0.220	0.296	0.364	0.255	0.203	0.145
	2	0.193	0.369	0.670	0.797	0.619	0.267	0.162
	3	0.282	0.692	0.907	0.889	0.928	0.386	0.188
	4	0.326	0.862	0.887	0.845	0.948	0.474	0.238
	5	0.312	0.795	0.950	0.964	0.923	0.586	0.308
	6	0.405	0.256	0.078	0.078	0.071	0.069	0.059
	7	0.206	0.111	0.154	0.111	0.061	0.092	0.093

Anemometer position A at 0.46 m elevation

average	z-ccord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.715	70.0%
Entire z-layer 2	0.6	0.853	30.0%
weighted average	**0.46**	**0.756**	m/sec
stnd. Dev.			
Entire z-layer 1		0.065	0.09111
Entire z-layer 2		0.190	0.222948

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.683 m/sec

y - rows		x - columns 1	2	3	4	5	6	7
	1							
	2							
	3							
	4				0.476	0.847	0.525	
	5				0.844	0.751	0.655	
	6							
	7							

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.790 m/sec

y - rows		x - columns 1	2	3	4	5	6	7
	1							
	2							
	3							
	4				0.845	0.948	0.474	
	5				0.964	0.923	0.586	
	6							
	7							

Presentation of results for Fan speed **Level 4 – elevation 0.46 m**

Anemometer position B at 0.46 m elevation

average	z-ccord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.662	70.0%
Entire z-layer 2	0.6	0.724	30.0%
weighted average	**0.46**	**0.680**	m/sec

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.600 m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
1							
2				0.790	0.662	0.289	
3				0.661	0.809	0.386	
4							
5							
6							
7							

x - columns

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.648 m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
1							
2				0.797	0.619	0.267	
3				0.889	0.928	0.386	
4							
5							
6							
7							

x - columns

Anemometer position C at 0.46 m elevation

average	z-ccord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.729	70.0%
Entire z-layer 2	0.6	0.791	30.0%
weighted average	**0.46**	**0.748**	m/sec

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.694 m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
1							
2		0.516	0.753	0.790			
3		0.741	0.701	0.661			
4							
5							
6							
7							

x - columns

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.721 m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
1							
2		0.369	0.670	0.797			
3		0.692	0.907	0.889			
4							
5							
6							
7							

x - columns

Presentation of results for Fan speed **Level 4 – elevation 0.46 m**

Anemometer position D at 0.46 m elevation

average	z-coord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.809	70.0%
Entire z-layer 2	0.6	0.901	30.0%
weighted average	**0.46**	**0.837**	m/sec

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells **0.686** m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
1							
2							
3							
4		0.789	0.403	0.476			
5		0.796	0.808	0.844			
6							
7							

x - columns

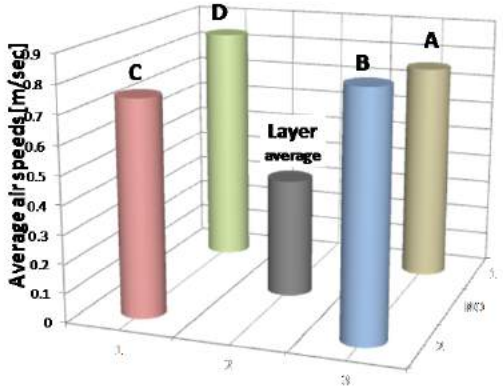
z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells **0.884** m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
1							
2							
3							
4		0.862	0.887	0.845			
5		0.795	0.950	0.964			
6							
7							

x - columns

averages for anemometers
Level 4

	elevation [m]	air speed [m/sec]	% of layer	% of all
Anemometer A	0.46	0.76	184%	172%
Anemometer B	0.46	0.68	165%	155%
Anemometer C	0.46	0.75	182%	170%
Anemometer D	0.46	0.84	204%	191%
Average for z-layer	0.46	**0.41**	100%	94%
Average - all points	N/A	0.44	107%	100%



Presentation of results for Fan speed **Level 4 – elevation 1.22 m**

Average for entire z-layers

average	z-ccord.	vel.
	m	m/sec
Entire z-layer	1.2	0.349

z-layer 5 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.457 m/sec

y - rows								
	1	0.091	0.155	0.259	0.349	0.319	0.221	0.166
	2	0.179	0.284	0.580	0.725	0.587	0.299	0.186
	3	0.287	0.623	0.998	1.022	0.973	0.404	0.209
	4	0.340	0.830	1.003	0.508	1.011	0.426	0.209
	5	0.286	0.656	0.996	0.982	0.955	0.358	0.192
	6	0.172	0.387	0.719	0.819	0.592	0.254	0.163
	7	0.133	0.222	0.321	0.373	0.239	0.176	0.141
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position A at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer A	1.2	0.776

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.707 m/sec

y - rows								
	1							
	2							
	3							
	4				0.508	1.011	0.426	
	5				0.982	0.955	0.358	
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position B at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer B	1.2	0.742

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.668 m/sec

y - rows								
	1							
	2				0.725	0.587	0.299	
	3				1.022	0.973	0.404	
	4							
	5							
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position C at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer C	1.2	0.790

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.706 m/sec

y - rows								
	1							
	2		0.284	0.580	0.725			
	3		0.623	0.998	1.022			
	4							
	5							
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Presentation of results for Fan speed **Level 4 – elevation 1.22 m**

Anemometer position D at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer D	1.2	0.893

z-layer 1 **1.2** **m elevation** **velocity data in m/sec**

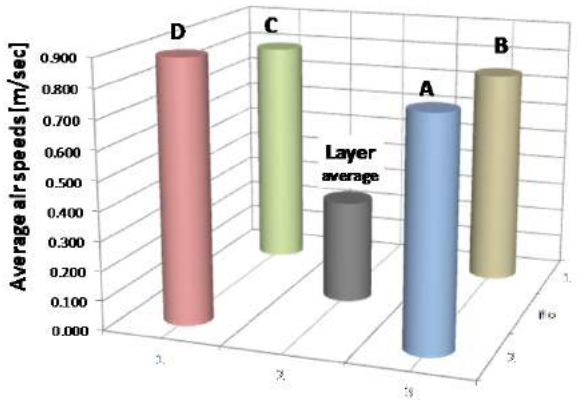
average of shaded cells **0.829 m/sec**

y - rows								
	1							
	2							
	3							
	4		0.830	1.003	0.508			
	5		0.656	0.996	0.982			
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Fan level 4

averages for anemometers

	elevation [m]	air speed [m/sec]	% of layer	% of all
Anemometer A	1.2	0.78	222%	177%
Anemometer B	1.2	0.74	213%	169%
Anemometer C	1.2	0.79	226%	180%
Anemometer D	1.2	0.89	256%	203%
Average for z-layer	1.2	0.35	100%	80%
Average - all points	N/A	0.44	126%	100%



Presentation of results for Fan speed **Level 5 – elevation 0.46 m**

Average for entire z-layers

average	z-ccord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.410	70.0%
Entire z-layer 2	0.6	0.413	30.0%
weighted average	**0.46**	**0.411**	m/sec
stnd. Dev.			
Entire z-layer 1		0.257	
Entire z-layer 2		0.312	

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.410 m/sec

y - rows								
	1	0.217	0.285	0.436	0.392	0.283	0.207	0.169
	2	0.285	0.516	0.753	0.790	0.662	0.289	0.190
	3	0.362	0.741	0.701	0.661	0.809	0.386	0.212
	4	0.460	0.789	0.403	0.476	0.847	0.525	0.256
	5	0.412	0.796	0.808	0.844	0.751	0.655	0.348
	6	0.396	0.625	0.145	0.081	0.070	0.046	0.052
	7	0.187	0.200	0.178	0.155	0.096	0.076	0.077
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.413 m/sec

y - rows								
	1	0.152	0.220	0.296	0.364	0.255	0.203	0.145
	2	0.193	0.369	0.670	0.797	0.619	0.267	0.162
	3	0.282	0.692	0.907	0.889	0.928	0.386	0.188
	4	0.326	0.862	0.887	0.845	0.948	0.474	0.238
	5	0.312	0.795	0.950	0.964	0.923	0.586	0.308
	6	0.405	0.256	0.078	0.078	0.071	0.069	0.059
	7	0.206	0.111	0.154	0.111	0.061	0.092	0.093
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position A at 0.46 m elevation

average	z-ccord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.715	70.0%
Entire z-layer 2	0.6	0.853	30.0%
weighted average	**0.46**	**0.756**	m/sec
stnd. Dev.			
Entire z-layer 1		0.065	0.09111
Entire z-layer 2		0.190	0.222948

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.683 m/sec

y - rows								
	1							
	2							
	3							
	4				0.476	0.847	0.525	
	5				0.844	0.751	0.655	
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.790 m/sec

y - rows								
	1							
	2							
	3							
	4				0.845	0.948	0.474	
	5				0.964	0.923	0.586	
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Presentation of results for Fan speed **Level 5 – elevation 0.46 m**

Anemometer position B at 0.46 m elevation

average	z-ccord.	vel.	weight
	m	m/sec	[%]
Entire z-layer 1	0.4	0.662	70.0%
Entire z-layer 2	0.6	0.724	30.0%
weighted average	**0.46**	**0.680**	m/sec

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.600 m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
1							
2				0.790	0.662	0.289	
3				0.661	0.809	0.386	
4							
5							
6							
7							

x - columns

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.648 m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
1							
2				0.797	0.619	0.267	
3				0.889	0.928	0.386	
4							
5							
6							
7							

x - columns

Anemometer position C at 0.46 m elevation

average	z-ccord.	vel.	weight
	m	m/sec	[%]
Entire z-layer 1	0.4	0.729	70.0%
Entire z-layer 2	0.6	0.791	30.0%
weighted average	**0.46**	**0.748**	m/sec

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells 0.694 m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
1							
2		0.516	0.753	0.790			
3		0.741	0.701	0.661			
4							
5							
6							
7							

x - columns

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells 0.721 m/sec

y - rows	x = 1	x = 2	x = 3	x = 4	x = 5	x = 6	x = 7
1							
2		0.369	0.670	0.797			
3		0.692	0.907	0.889			
4							
5							
6							
7							

x - columns

Presentation of results for Fan speed **Level 5 – elevation 0.46 m**

Anemometer position D at 0.46 m elevation

average	z-coord. m	vel. m/sec	weight [%]
Entire z-layer 1	0.4	0.809	70.0%
Entire z-layer 2	0.6	0.901	30.0%
weighted average	**0.46**	**0.837**	m/sec

z-layer 1 **0.4** m elevation velocity data in m/sec
average of shaded cells **0.686** m/sec

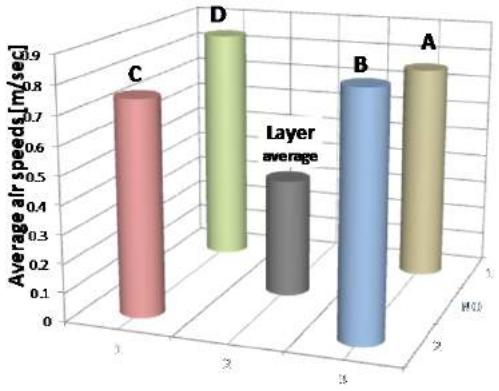
y - rows	x - columns 1	2	3	4	5	6	7
1							
2							
3							
4		0.789	0.403	0.476			
5		0.796	0.808	0.844			
6							
7							

z-layer 2 **0.6** m elevation velocity data in m/sec
average of shaded cells **0.884** m/sec

y - rows	x - columns 1	2	3	4	5	6	7
1							
2							
3							
4		0.862	0.887	0.845			
5		0.795	0.950	0.964			
6							
7							

averages for anemometers
Level 5

	elevation [m]	air speed [m/sec]	% of layer	% of all
Anemometer A	0.46	0.76	184%	172%
Anemometer B	0.46	0.68	165%	155%
Anemometer C	0.46	0.75	182%	171%
Anemometer D	0.46	0.84	204%	191%
Average for z-layer	0.46	**0.41**	100%	94%
Average - all points	N/A	0.44	107%	100%



Presentation of results for Fan speed **Level 5 – elevation 1.22 m**

Average for entire z-layers

average	z-ccord.	vel.
	m	m/sec
Entire z-layer	1.2	0.349

z-layer 5 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.446 m/sec

y - rows								
	1	0.091	0.155	0.259	0.349	0.319	0.221	0.166
	2	0.179	0.284	0.580	0.725	0.587	0.299	0.186
	3	0.287	0.623	0.998	1.022	0.973	0.404	0.209
	4	0.340	0.830	1.003	0.000	1.011	0.426	0.209
	5	0.286	0.656	0.996	0.982	0.955	0.358	0.192
	6	0.172	0.387	0.719	0.819	0.592	0.254	0.163
	7	0.133	0.222	0.321	0.373	0.239	0.176	0.141
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position A at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer A	1.2	0.675

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.622 m/sec

y - rows								
	1							
	2							
	3							
	4				0.000	1.011	0.426	
	5				0.982	0.955	0.358	
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position B at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer B	1.2	0.742

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.668 m/sec

y - rows								
	1							
	2				0.725	0.587	0.299	
	3				1.022	0.973	0.404	
	4							
	5							
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Anemometer position C at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer C	1.2	0.790

z-layer 1 **1.2** m elevation velocity data in m/sec
average of shaded cells 0.706 m/sec

y - rows								
	1							
	2		0.284	0.580	0.725			
	3		0.623	0.998	1.022			
	4							
	5							
	6							
	7							
		1	**2**	**3**	**4**	**5**	**6**	**7**
		x - columns						

Presentation of results for Fan speed **Level 5 – elevation 1.22 m**

Anemometer position D at 1.20 m elevation

average	z-ccord.	vel.
	m	m/sec
Anemometer D	1.2	0.893

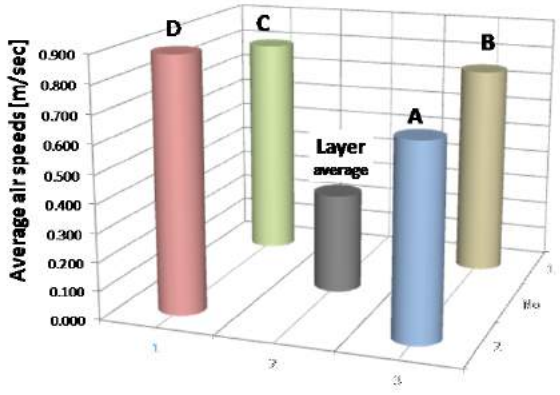
z-layer 1 1.2 m elevation velocity data in m/sec

average of shaded cells 0.745 m/sec

y - rows								
	1							
	2							
	3							
	4		0.830	1.003	0.000			
	5		0.656	0.996	0.982			
	6							
	7							
		1	2	3	4	5	6	7
		x - columns						

Fan level 5
averages for anemometers

	elevation [m]	air speed [m/sec]	% of layer	% of all
Anemometer A	1.2	0.675	193%	154%
Anemometer B	1.2	0.742	213%	169%
Anemometer C	1.2	0.790	226%	180%
Anemometer D	1.2	0.893	256%	204%
Average for z-layer	1.2	0.349	100%	80%
Average - all points	N/A	0.438	126%	100%



APPENDIX D

Summary of Air Speed Measurements

without a Test Person

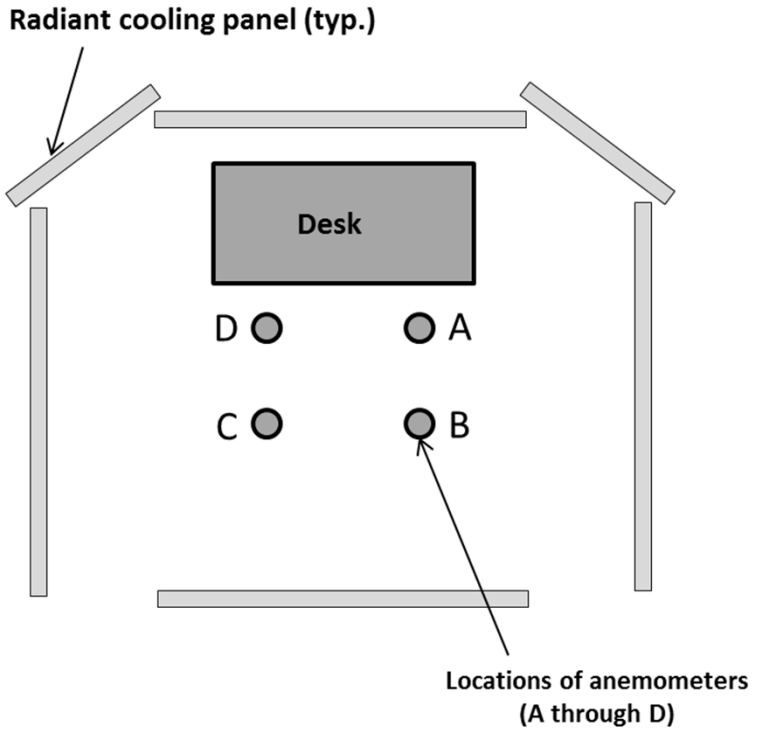
(27 pages)

APPENDIX D

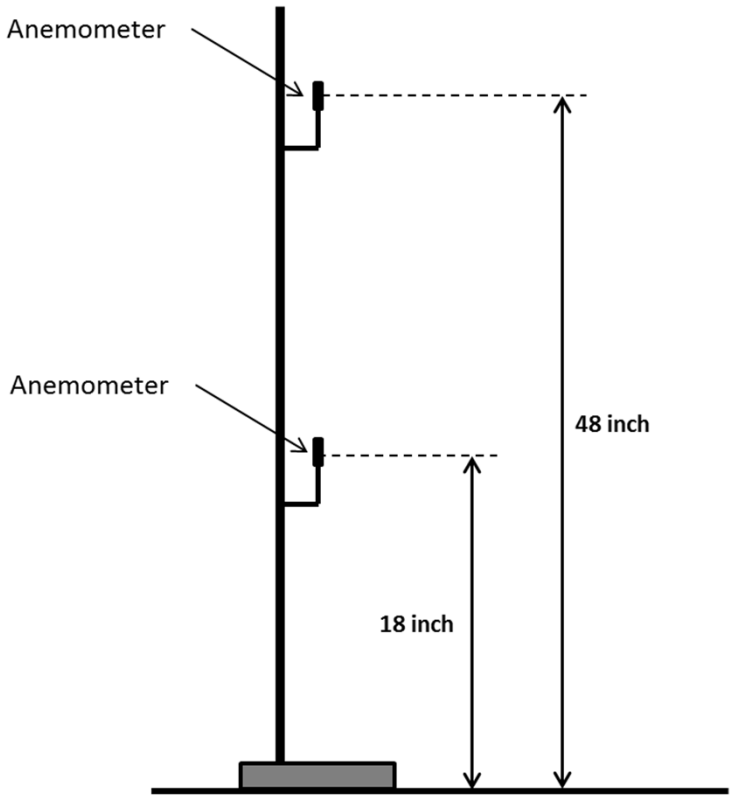
Summary of Air Speed Measurements without a Test Person

These measurement values will be used to validate results of CFD air speed simulations

Overview of Test set-up – Plan view
The air speed was measured at the locations A through D and at two elevations



Overview of Test set-up – Plan view
The air speed was measured at the locations A through D and at two elevations

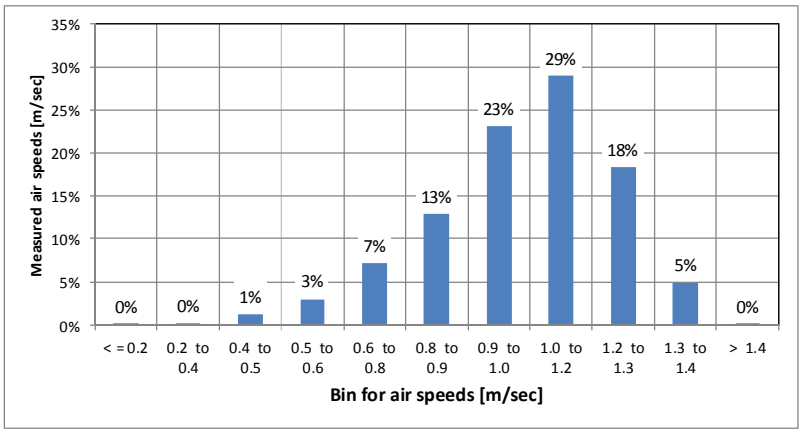


Summary of Air Measurements without a Test Person

Fan Level 2

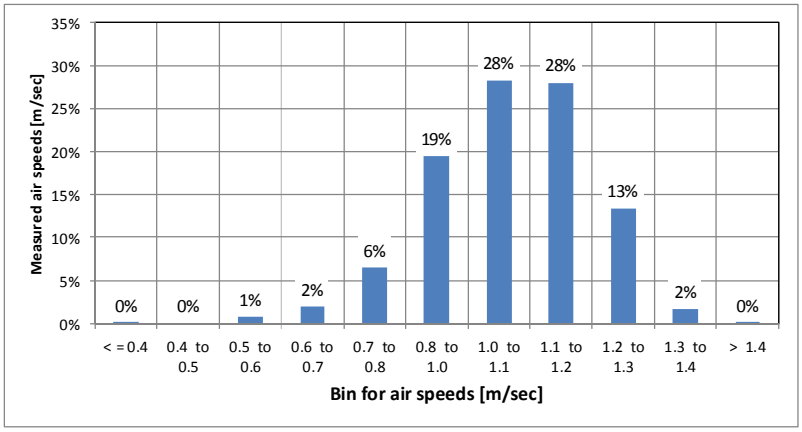
Fan Level 2 = “level 2”

Location A fan level 2 number of sample points **1,189**
18 inch elevation of anemometer



average	1.01	[m/sec]
median	1.04	[m/sec]
skewness	-0.72	[-]

Location A fan level 2 number of sample points **1,189**
48 inch elevation of anemometer



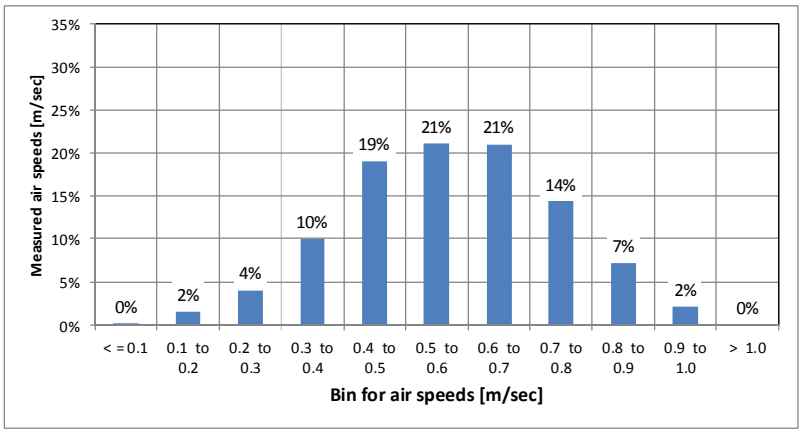
average	1.03	[m/sec]
median	1.04	[m/sec]
skewness	-0.49	[-]

Summary of Air Measurements without a Test Person

Fan Level 2

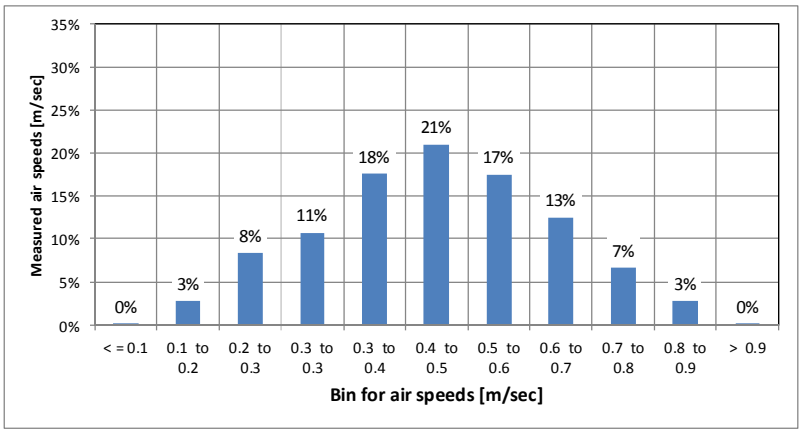
Fan Level 2 = “level 2”

Location B fan level 2 number of sample points **1,189**
18 inch elevation of anemometer



average	0.82	[m/sec]
median	0.82	[m/sec]
skewness	-0.11	[-]

Location B fan level 2 number of sample points **1,189**
48 inch elevation of anemometer



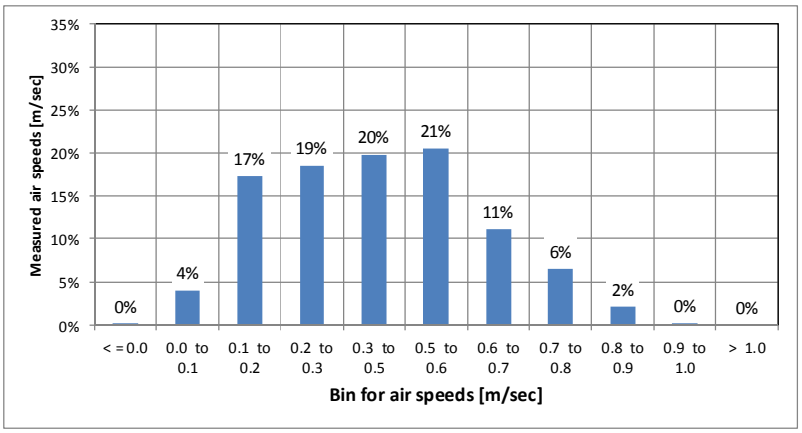
average	0.47	[m/sec]
median	0.48	[m/sec]
skewness	-0.04	[-]

Summary of Air Measurements without a Test Person

Fan Level 2

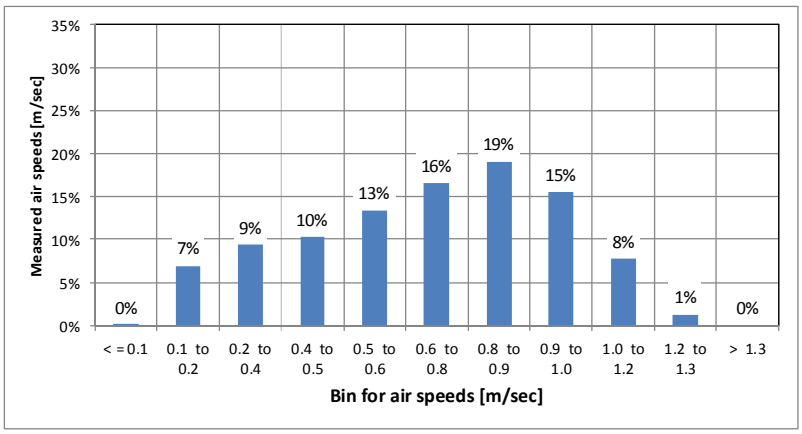
Fan Level 2 = “level 2”

Location C fan level 2 number of sample points **1,189**
18 inch elevation of anemometer



average	0.41	[m/sec]
median	0.40	[m/sec]
skewness	0.24	[-]

Location C fan level 2 number of sample points **1,189**
48 inch elevation of anemometer



average	0.48	[m/sec]
median	0.48	[m/sec]
skewness	-0.26	[-]

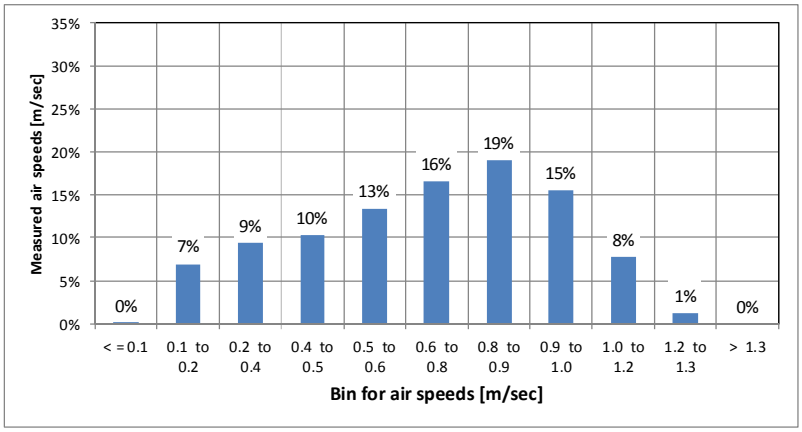
Summary of Air Measurements without a Test Person

Fan Level 2

Fan Level 2 = “level 2”

Location D fan level 2 number of sample points **1,189**

48 inch elevation of anemometer



average	0.67	[m/sec]
median	0.71	[m/sec]
skewness	-0.26	[-]

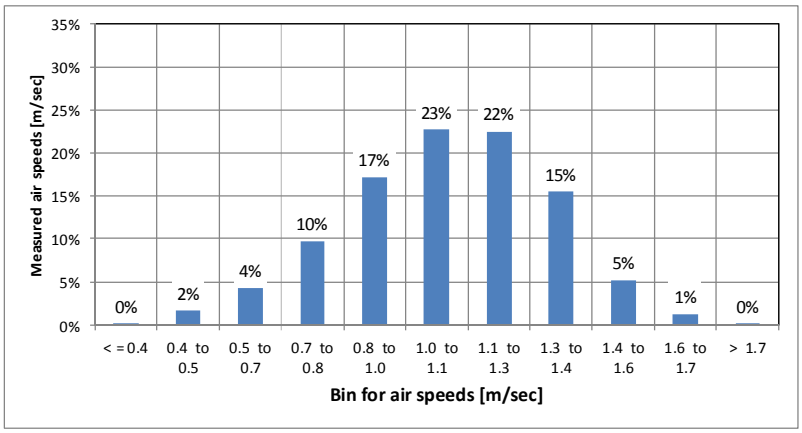
Summary of Air Measurements without a Test Person

Fan Level 3

Fan Level 3 = “level 3”

Location A **fan level 3** **number of sample point** **1189**

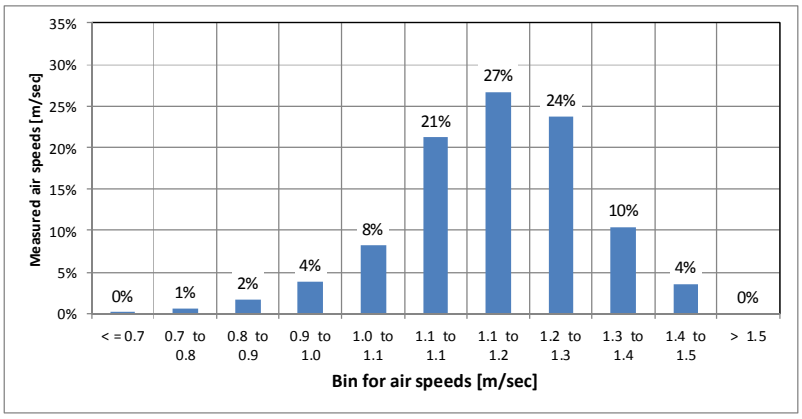
18 inch elevation of anemometer



average	1.10	[m/sec]
median	1.11	[m/sec]
skewness	-0.21	[-]

Location A fan level 3 number of sample points **1,189**

48 inch elevation of anemometer



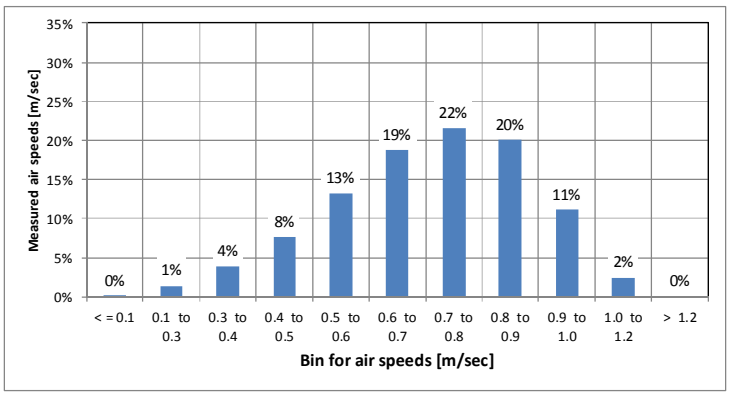
average	1.19	[m/sec]
median	1.19	[m/sec]
skewness	-0.46	[-]

Summary of Air Measurements without a Test Person

Fan Level 3

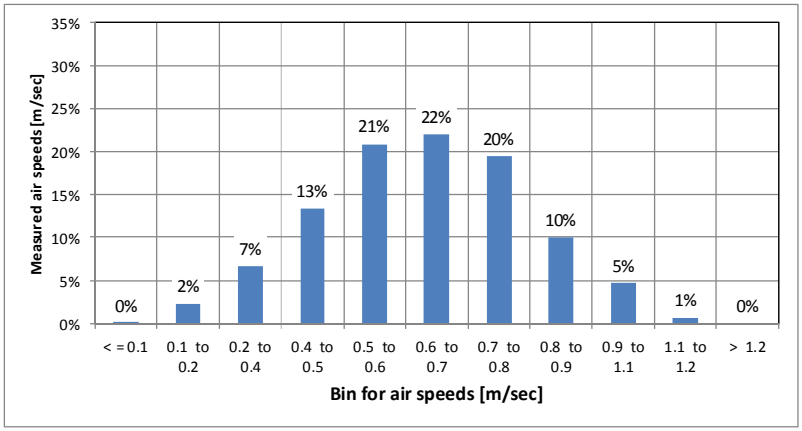
Fan Level 3 = “level 3”

Location B fan level 3 number of sample points **1,189**
18 inch elevation of anemometer



average	1.07	[m/sec]
median	1.07	[m/sec]
skewness	-0.33	[-]

Location B fan level 3 number of sample points **1,189**
48 inch elevation of anemometer



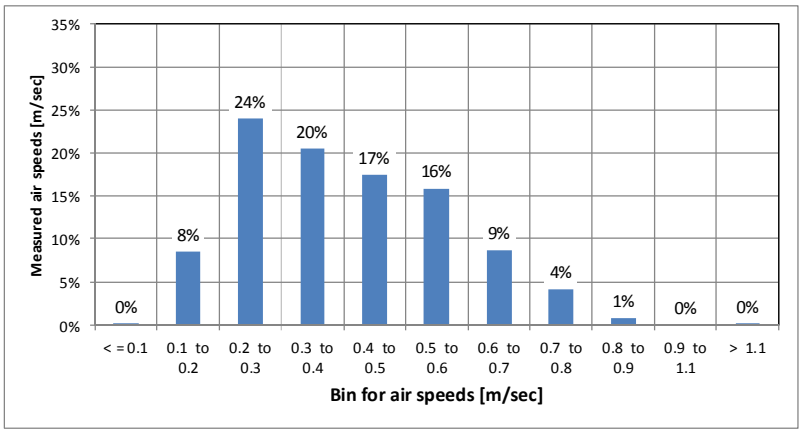
average	0.63	[m/sec]
median	0.62	[m/sec]
skewness	0.00	[-]

Summary of Air Measurements without a Test Person

Fan Level 3

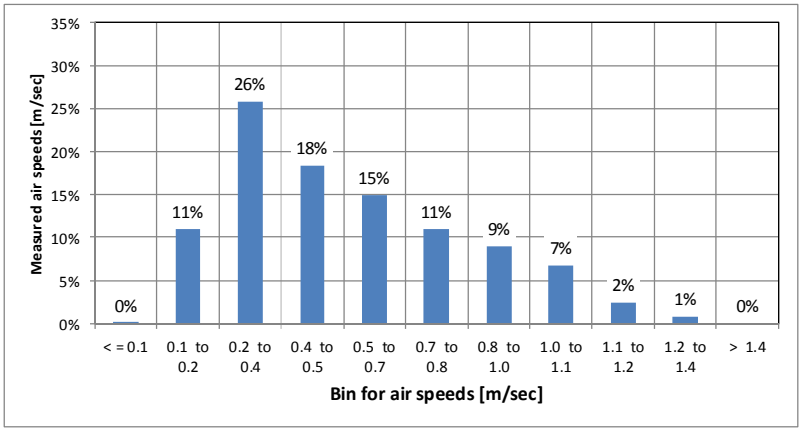
Fan Level 3 = “level 3”

Location C fan level 3 number of sample points **1,189**
18 inch elevation of anemometer



average	0.39	[m/sec]
median	0.37	[m/sec]
skewness	0.46	[-]

Location C fan level 3 number of sample points **1,189**
48 inch elevation of anemometer



average	0.65	[m/sec]
median	0.65	[m/sec]
skewness	0.66	[-]

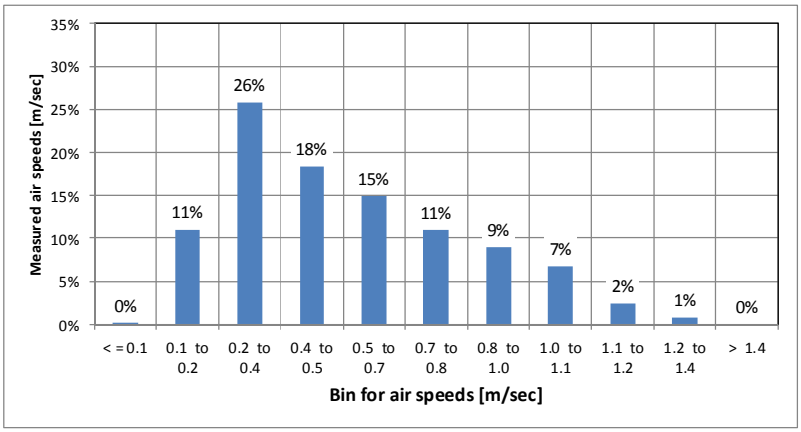
Summary of Air Measurements without a Test Person

Fan Level 3

Fan Level 3 = “level 3”

Location D fan level 3 number of sample points **1,189**

48 inch elevation of anemometer



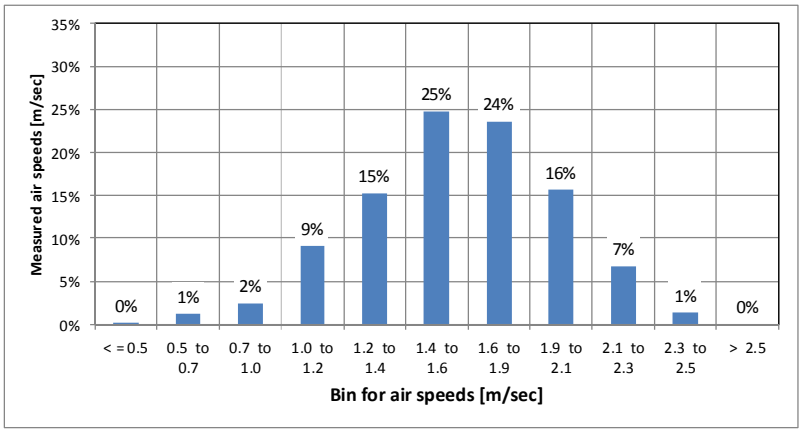
average	0.54	[m/sec]
median	0.48	[m/sec]
skewness	0.66	[-]

Summary of Air Measurements without a Test Person

Fan Level 4

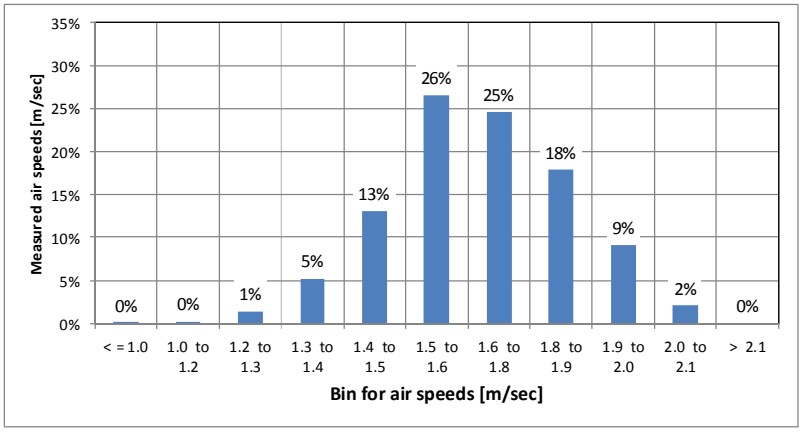
Fan Level 4= “level 4”

Location A fan level 4 number of sample points **1,391**
18 inch elevation of anemometer



average	1.62	[m/sec]
median	1.62	[m/sec]
skewness	-0.21	[-]

Location A fan level 4 number of sample points **1,391**
48 inch elevation of anemometer



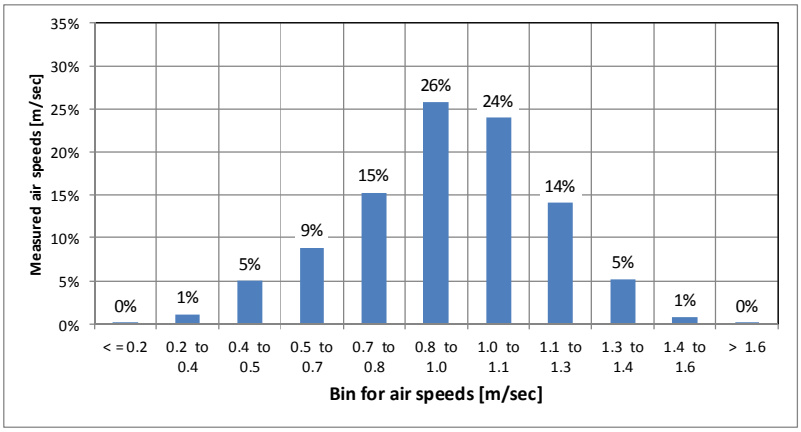
average	1.66	[m/sec]
median	1.65	[m/sec]
skewness	-0.11	[-]

Summary of Air Measurements without a Test Person

Fan Level 4

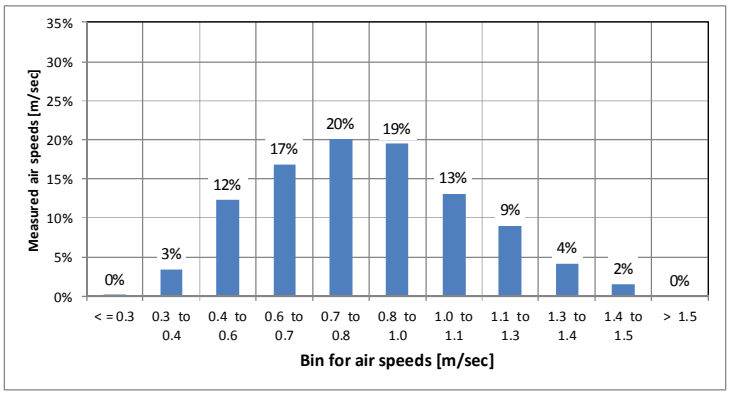
Fan Level 4= “level 4”

Location B fan level 4 number of sample points **1,391**
18 inch elevation of anemometer



average	1.53	[m/sec]
median	1.53	[m/sec]
skewness	-0.28	[-]

Location B fan level 4 number of sample points **1,391**
48 inch elevation of anemometer



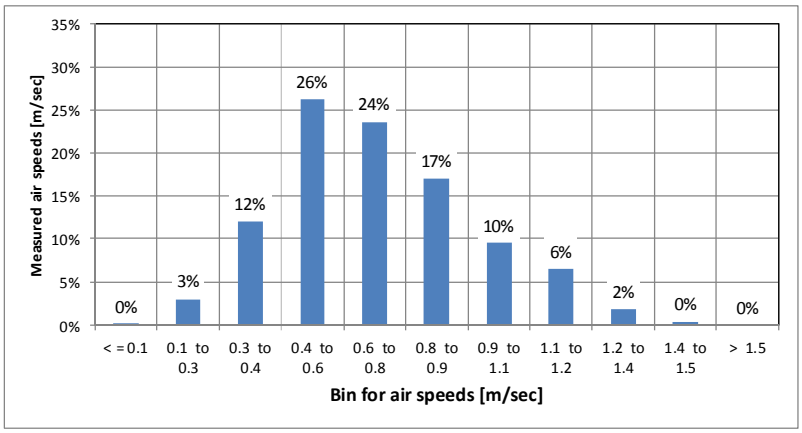
average	0.84	[m/sec]
median	0.83	[m/sec]
skewness	0.25	[-]

Summary of Air Measurements without a Test Person

Fan Level 4

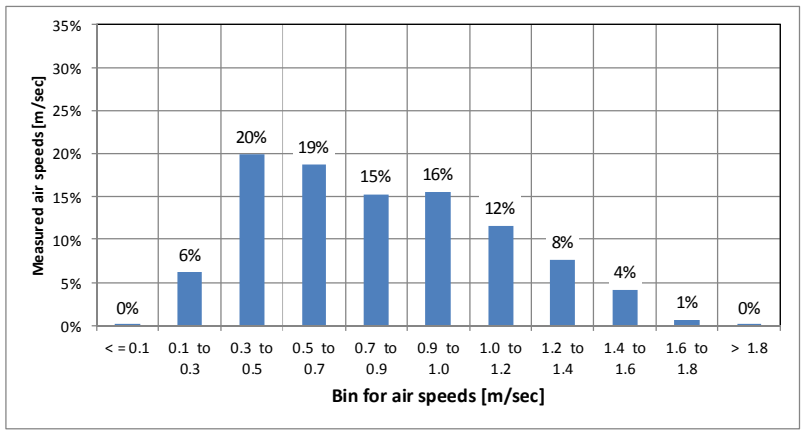
Fan Level 4= “level 4”

Location C fan level 4 number of sample points **1,391**
18 inch elevation of anemometer



average	0.68	[m/sec]
median	0.64	[m/sec]
skewness	0.49	[-]

Location C fan level 4 number of sample points **1,391**
48 inch elevation of anemometer



average	0.92	[m/sec]
median	0.92	[m/sec]
skewness	0.39	[-]

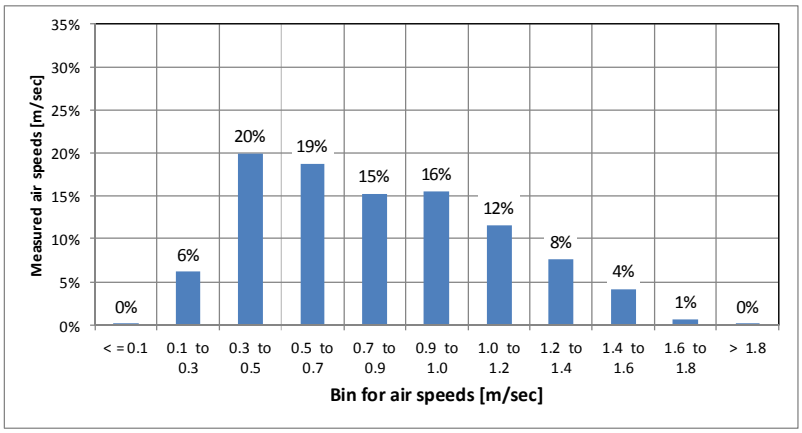
Summary of Air Measurements without a Test Person

Fan Level 4

Fan Level 4= “level 4”

Location D fan level 4 number of sample points **1,391**

48 inch elevation of anemometer



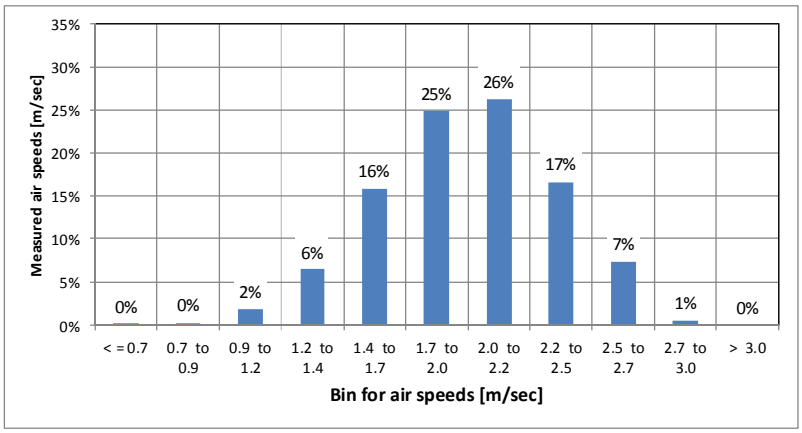
average	0.77	[m/sec]
median	0.73	[m/sec]
skewness	0.39	[-]

Summary of Air Measurements without a Test Person

Fan Level 5

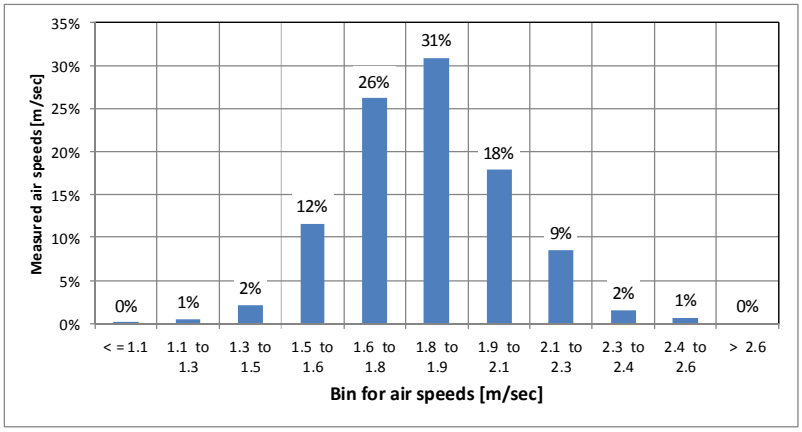
Fan Level 5 = “level 5”

Location A fan level 5 number of sample points **1,167**
18 inch elevation of anemometer



average	1.96	[m/sec]
median	1.97	[m/sec]
skewness	-0.17	[-]

Location A fan level 5 number of sample points **1,167**
48 inch elevation of anemometer



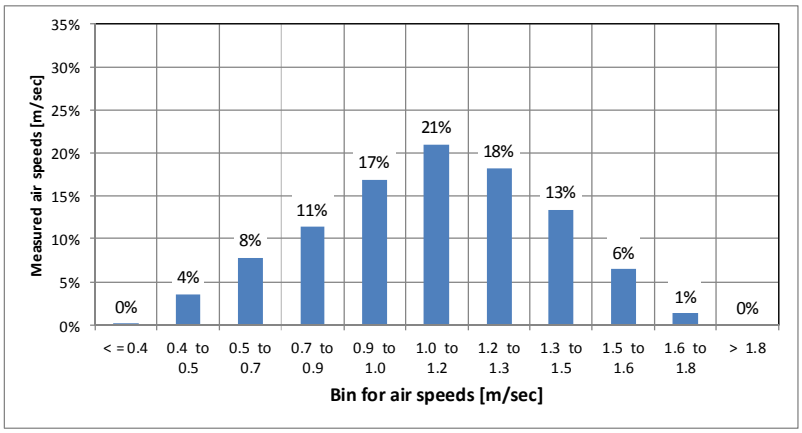
average	1.83	[m/sec]
median	1.82	[m/sec]
skewness	0.20	[-]

Summary of Air Measurements without a Test Person

Fan Level 5

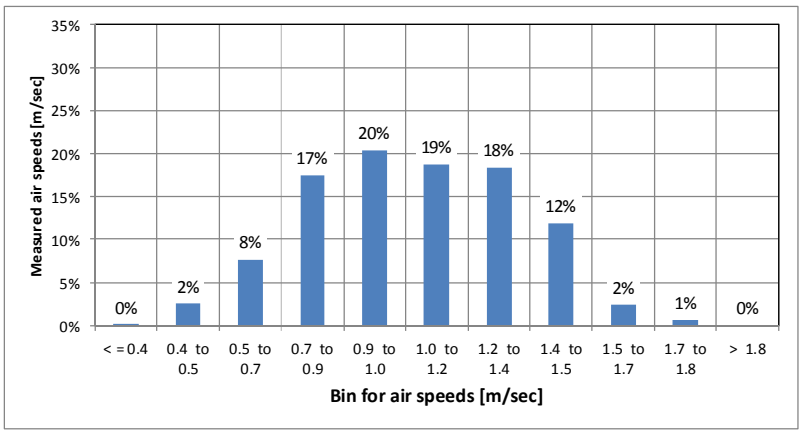
Fan Level 5 = “level 5”

Location B fan level 5 number of sample points **1,167**
18 inch elevation of anemometer



average	1.83	[m/sec]
median	1.83	[m/sec]
skewness	-0.15	[-]

Location B fan level 5 number of sample points **1,167**
48 inch elevation of anemometer



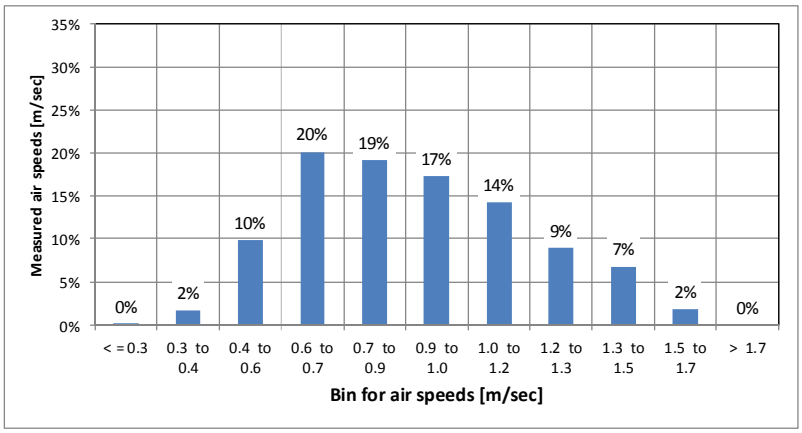
average	1.05	[m/sec]
median	1.04	[m/sec]
skewness	0.06	[-]

Summary of Air Measurements without a Test Person

Fan Level 5

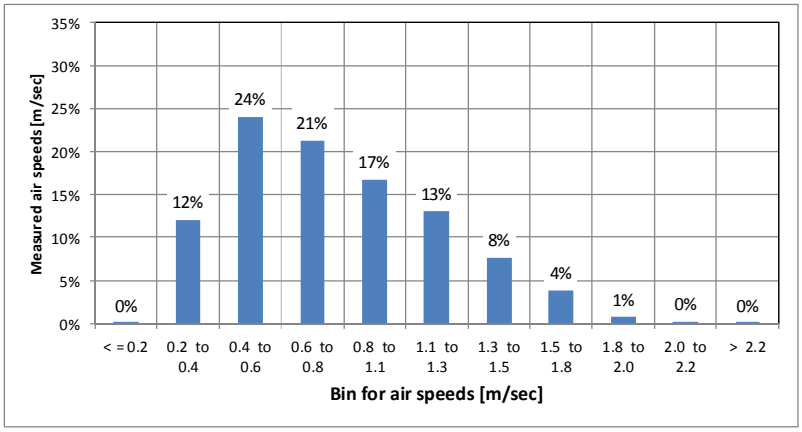
Fan Level 5 = “level 5”

Location C fan level 5 number of sample points **1,167**
18 inch elevation of anemometer



average	0.89	[m/sec]
median	0.86	[m/sec]
skewness	0.36	[-]

Location C fan level 5 number of sample points **1,167**
48 inch



average	1.11	[m/sec]
median	1.11	[m/sec]
skewness	0.64	[-]

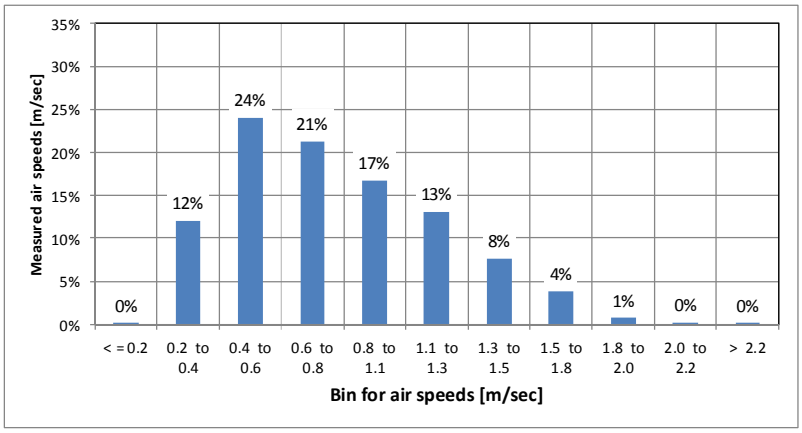
Summary of Air Measurements without a Test Person

Fan Level 5

Fan Level 5 = “level 5”

Location D fan level 5 number of sample points **1,167**

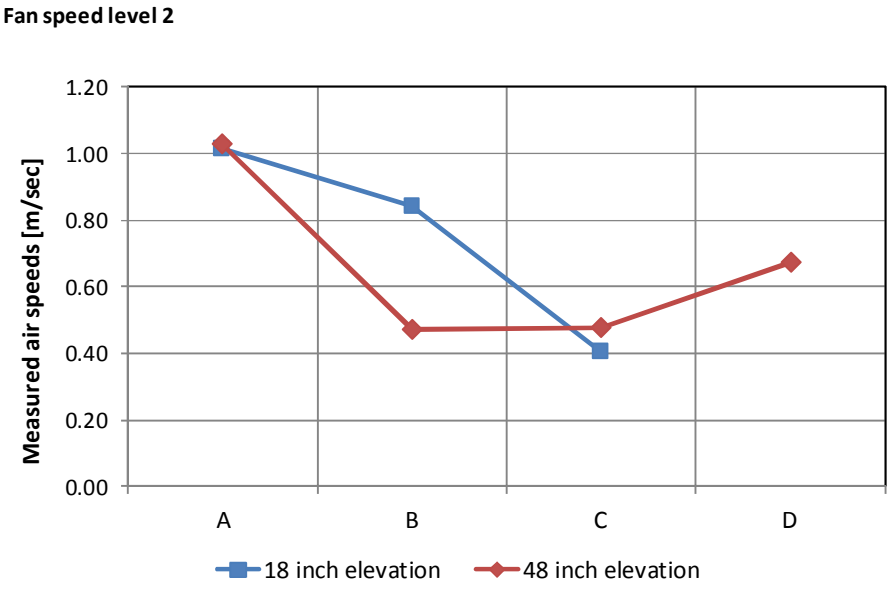
48 inch elevation of anemometer



average	0.82	[m/sec]
median	0.74	[m/sec]
skewness	0.64	[-]

Summary of Air Measurements without a Test Person

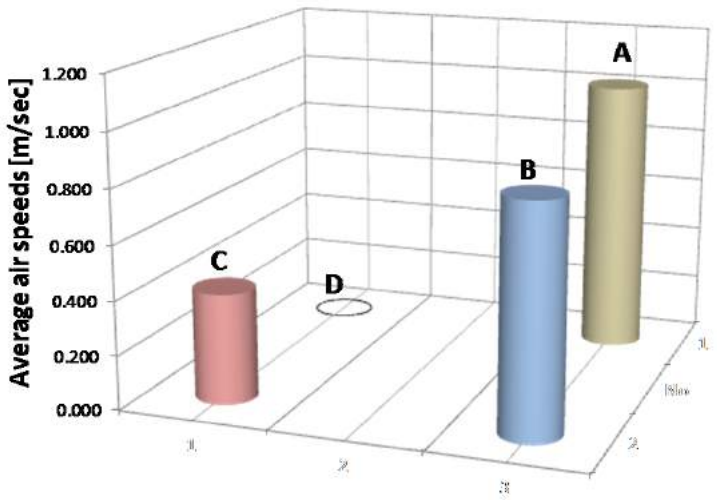
Fan Speed Level 2



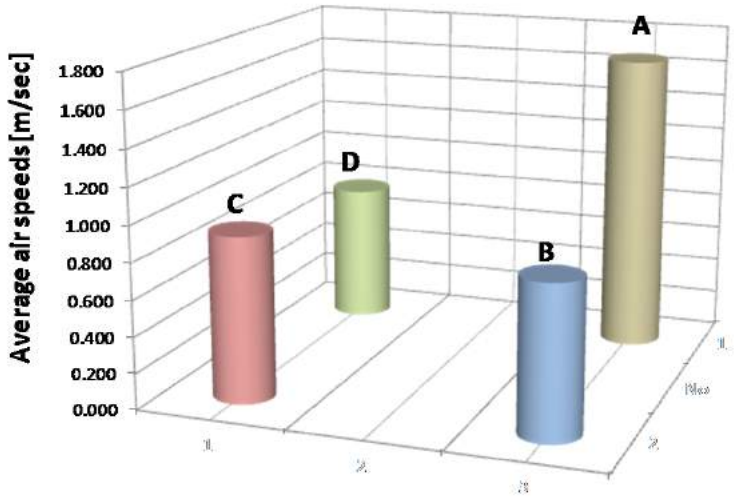
Summary of Air Measurements without a Test Person

Fan Speed Level 2

Fan speed level 2 sensor elevation 18 inch elevation

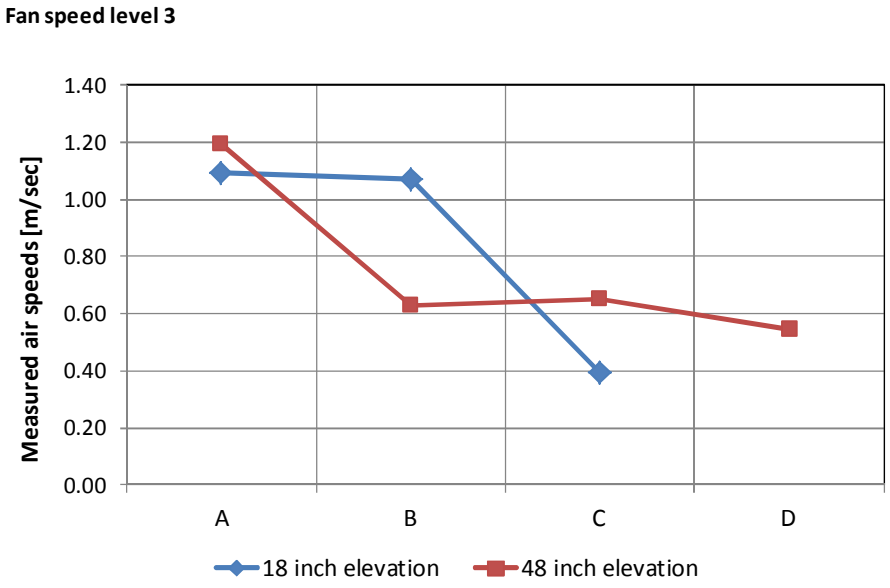


Fan speed level 2 sensor elevation 48 inch elevation



Summary of Air Measurements without a Test Person

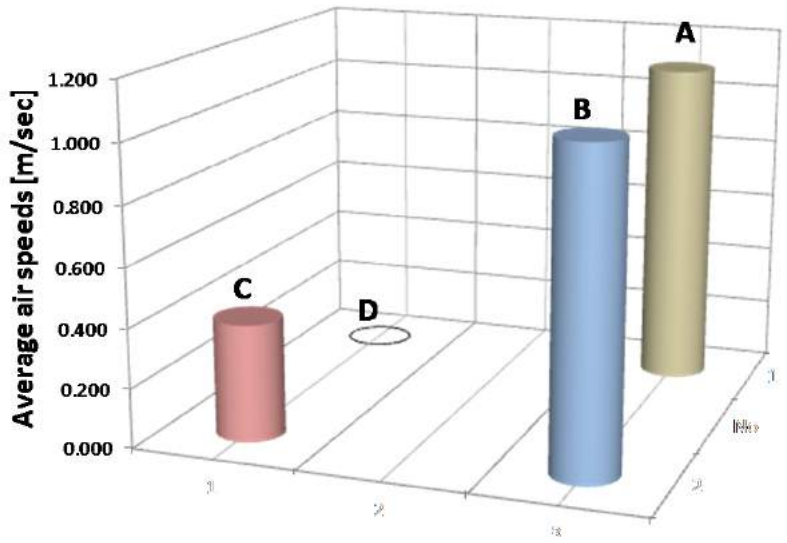
Fan Speed Level 3



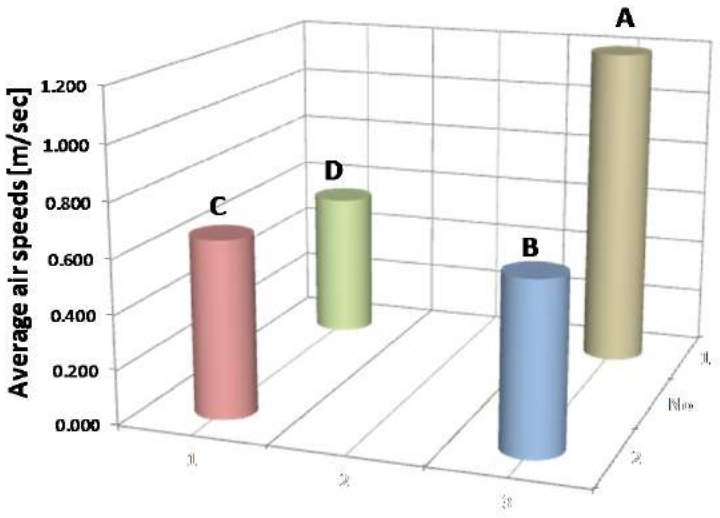
Summary of Air Measurements without a Test Person

Fan Speed Level 3

Fan speed level 3 sensor elevation **18 inch elevation**

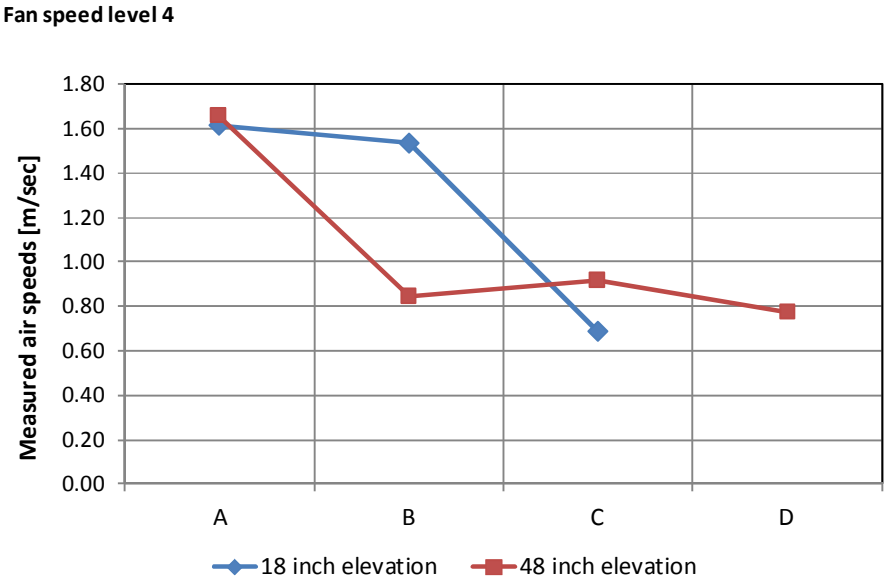


Fan speed level 3 sensor elevation **48 inch elevation**



Summary of Air Measurements without a Test Person

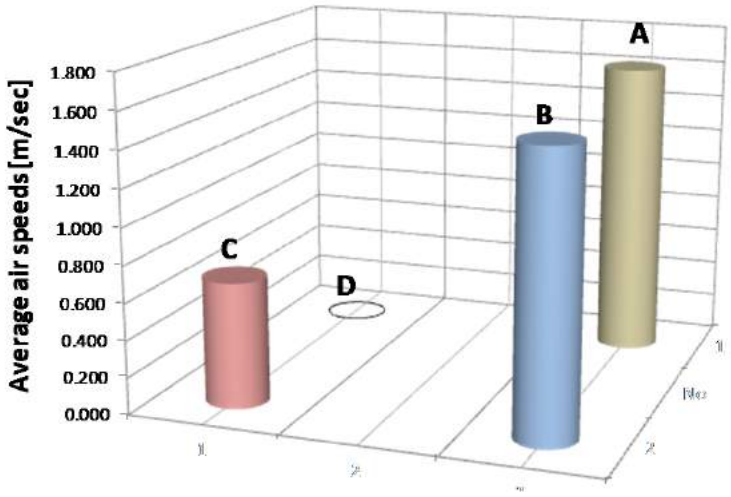
Fan Speed Level 4



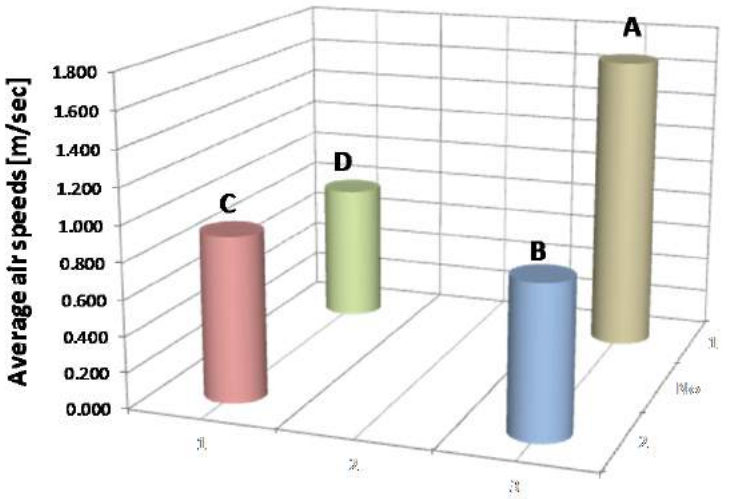
Summary of Air Measurements without a Test Person

Fan Speed Level 4

Fan speed level 4 sensor elevation **18 inch elevation**

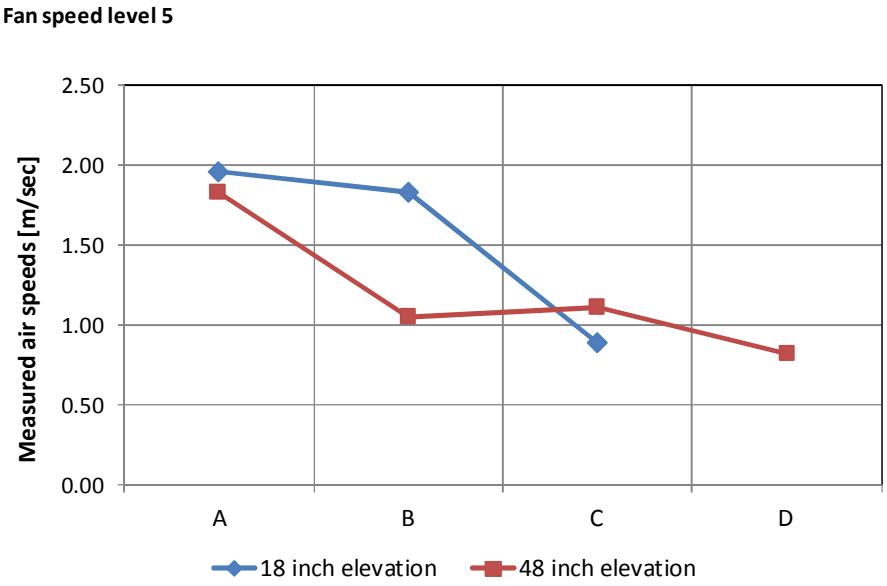


Fan speed level 4 sensor elevation **48 inch elevation**



Summary of Air Measurements without a Test Person

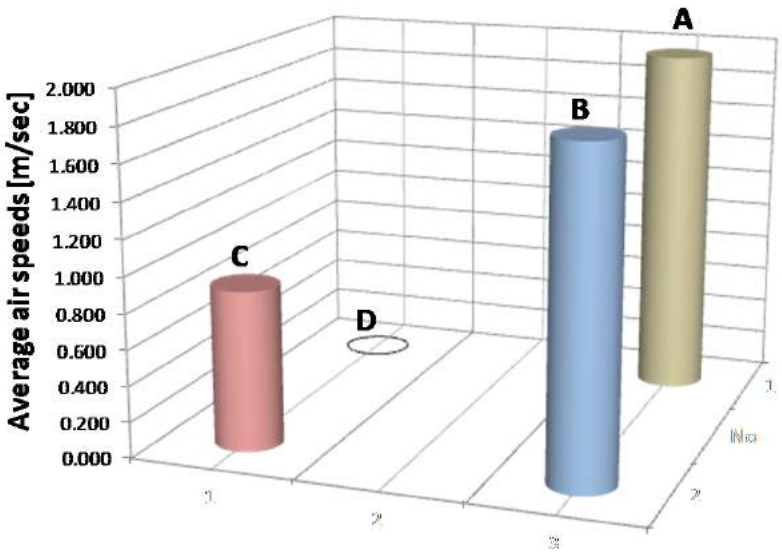
Fan Speed Level 5



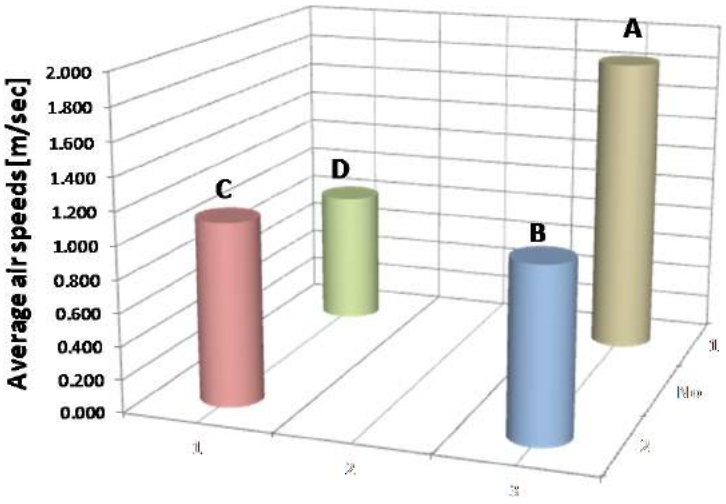
Summary of Air Measurements without a Test Person

Fan Speed Level 5

Fan speed level 5 sensor elevation 18 inch elevation



Fan speed level 5 sensor elevation 48 inch elevation



APPENDIX E

Surveys, IRB Application and Approval, Test Procedure

(14 pages)

APPENDIX E: Surveys, IRB Application and Approval

Part 1 (background information)

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UNIVERSITY OF HAWAI'I

Thermal Comfort Research: HIG 204

This survey will take 2-3 minutes of your time to complete.
The research team expects that around 100 people will take part in this project.
Completing the survey will be considered as your consent to participate in this study.

Thank you for your cooperation!

1.1. Please provide us with your study ID/ number.

1.2. What is the time right now?

1.3. How would you describe the field of work/study that you do?

- ○ Science/Technology/Engineering
- ○ Design/Architecture/Planning
- ○ Environment/Ecology
- ○ Administration/Management/Supervision
- ○ Other

1.4. What is your age?

- 30 or under
- 31-50
- Over 50

1.5. What is your gender?

- Female
- Male

1.6. What kind of activities did you perform BEFORE you came here? (Please check all that apply).

- Sleeping/resting
- Seated, resting
- Seated, reading
- Seated, writing and typing
- Standing, relaxed
- Standing, light work
- Standing, heavy work
- Walking, level surface
- Walking, inclined surface
- Walking fast on inclined surface, or Running
- Biking or skateboarding
- Driving, automobile or motorbike
- Driving, heavy automobile or equipment
- Cooking
- House cleaning
- Heavy machinery or labor work
- Exercise, light and easy
- Exercise, heavy and strenuous
- Dancing
- Tennis
- Basketball
- Wrestling or heavy workout

1.7. Please enter your height (feet and inches)

1.8. Please enter your weight (lbs).

1.9. How much of your daily activities are spent in active (moving) or sedentary (sitting) work?

- ◯ Mostly sedentary (I hardly leave my desk)
- ◯ Equal time spent in indoor work at my desk computer and on outdoor activities through the day
- ◯ Mostly active (almost all of my work or study requires physical activity)

1.10. Please mark in the list below all the garments you are wearing now (Choose one or multiple options).

Upper Body garments

- ◯ Short-sleeved shirt or blouse
- ◯ Long-sleeved shirt or blouse
- ◯ Sweater or jacket
- ◯ Dress
- ◯ Tie

Lower Body garments

- ◯ Shorts
- ◯ Skirt
- ◯ Trousers or pants or long skirt

Footwear

- ◯ Socks
- ◯ Sandals or open-toed shoes
- ◯ Shoes, sneakers, or boots

Mahalo

.

Thank you for participating in this Survey!!

Part 2 **(Comfort Survey)**

2.1. Please provide us with your study ID/ number.

2.2. What is the time right now?

TEMPERATURE

2.3. RIGHT NOW: How acceptable is the temperature?

	Highly acceptable (+3)	Moderately acceptable (+2)	Slightly acceptable (+1)	Neutral (0)	Slightly unacceptable (-1)	Moderately unacceptable (-2)	Highly unacceptable (-3)
Please choose one	○	○	○	○	○	○	○

2.4. You feel (please mark on the scale)?

	Hot	Warm	Slightly warm	Neutral	Slightly cool	Cool	Cold
Please choose one	○	○	○	○	○	○	○

2.5. You would prefer to be?

	Cooler	No change	Warmer
Please choose one	○	○	○

AIR MOVEMENT

2.6. RIGHT NOW: How acceptable is the air movement?

	Highly acceptable (+3)	Moderately acceptable (+2)	Slightly acceptable (+1)	Neutral (0)	Slightly unacceptable (-1)	Moderately unacceptable (-2)	Highly unacceptable (-3)
Please choose one	○	○	○	○	○	○	○

2.7. Do you have the ceiling fan turned on to achieve this air movement?

- ◯ Yes
- ◯ No

2.8. You would prefer:

	More air movement	No change	Less air movement
Please choose one	◯	◯	◯

2.9. What kind of activities did you perform DURING this experiment? (Please check all that apply).

- ◯ Seated, resting
- ◯ Seated, reading, no typing
- ◯ Seated, writing and typing
- ◯ Seated, browsing the internet, no typing
- ◯ Seated, browsing the internet and typing
- ◯ Seated, watching videos or songs

Mahalo

.

Thank you for participating in this Survey!!

CHS# _____

Application for Exempt Status for Human Subjects Research
University of Hawaii - Human Studies Program

Please type the information below. Thank you.

Researcher name: **Aarthi Padmanabhan**

Researcher email: Aarthi@hawaii.edu

Researcher phone: (808) 222-5254

Department: School of Architecture

Campus: UH Manoa

Status: ☐ Faculty

☐ Student
☐ Masters ☐ Ph.D. ☒ Postdoctoral Research Fellow
Other:

Name of student's Faculty Advisor: Eileen Peppard

Advisor email: epeppard@hawaii.edu

Advisor phone: (808) 956-2861

Title of Research Project: RADIANT COOLING FOR THE TROPICS: Thermal Comfort and Design Parameters

Signatures

I certify that the Information in this application is accurate and complete.

Researcher: _____ Date: 1-7-2015

I have reviewed and approved this application:
[*Advisor: Please check student's application for the following required documents in this application*]

☒ 'Description of Project' questions answered
☒ Informed consent(s)/ assent(s)/ informational flyer(s), if applicable
☒ Surveys/ questionnaires, if applicable
☒ Online Training Requirement

Advisor: _____ Date: 1-7-2015
(for student research)

This box for Human Studies Program Use Only:

Exempt Request: ☐ *Approved* ☐ *Not Approved* *Exempt Category* _____

Training: ☐ PI ☐ Advisor, if applicable Is this study involving? ☐DOH ☐ DOE

Reviewer comments / recommendations:

Approved by: _____ **Date:** _____

Application for Exempt Status for Human Subjects Research

University of Hawaii - Human Studies Program

1960 East-West Road, Biomedical Building B-104, Honolulu, HI 96822, (808) 956-5007, uhirb@hawaii.edu

Aloha! Most research involving human subjects at the University of Hawaii must be approved by the UH Human Studies Program. Some research may be exempt from certain Federal requirements. Please read and follow all instructions carefully when filling out this application. For more information, please go to the Human Studies Program website at www.hawaii.edu/irb or contact our office with any questions. Underlined words are defined in the Glossary on page 5.

I. Is Your Project "Research"?

To determine if your project qualifies as research, please answer the question below.

If you answer "Yes" to the following question, your project meets the federal definition of research. Please answer Section II to determine of your project is human subjects research. If you answer "No", your project does not meet the federal definition of research. No application is required.	
1. Is your project a systematic investigation, including research development, testing and evaluation, designed to develop or contribute to generalizable knowledge? (Underlined words are defined in the Glossary on page 5.)	☒ Yes ☐ No

II. Is Your Project "Human Subjects" Research?

To determine if your project qualifies as human subjects research, please answer the questions below.

If you answer "Yes" to either of the following 2 questions, your project does not require Human Studies Program review and approval and you do not need to complete or submit this application.	
1. Does your project involve **only** the analysis of publicly available data? Examples include census data, large public survey data sets with no individual identifiers, and public information available on the internet.	☐ Yes ☒ No
2. Is this a UH class project (whether individual or group) from which the data will only be submitted to your instructor for a class grade and will not be published, presented at an academic conference, given to an agency as a formal report, and will not be used in future research or to qualify for a graduate degree (e.g. Master's or Doctoral dissertation)?	☐ Yes ☒ No
If your answer to the following questions is "Yes" for both 1 and 2, or both 1 and 3, please complete Section III of this form. If you answer "No" for 1, 2, and 3 below, your project does not require Human Studies Program review and approval and you do not need to complete or submit this application.	
1. Does your research involve obtaining information about living individuals?	☒ Yes ☐ No
2. Will the information be obtained through intervention or interaction with these individuals?	☒ Yes ☐ No
3. Will your research involve access to private information from which individuals can be identified directly or indirectly through a link or code? This includes access to existing data that identifies individuals but these individuals will not be contacted in your research project.	☐ Yes ☒ No

III. Categories of Exemption

Complete all the categories below that apply to your research. If a category does not apply to your study, check "Not Applicable" (N/A). If your research does not meet the requirements for any of the six categories below, please complete and submit the standard Application for a New Study available on the Human Studies Program website at www.hawaii.edu/irb under "Forms".

Research on Educational Practices (Federal Category 1)	☒ N/A
Your research will take place in an established or commonly accepted K-12 educational setting, involving normal educational curriculum (appearing as normal classroom activities).	☐ Yes
If Yes, complete **Section IV** and **Section V** of this application.	

Research Involving Surveys or Interviews (Federal Category 2)	☐ N/A
1. Your research will involve the use of educational tests, surveys or interviews for participants ages 18 and older. (educational tests may include cognitive, diagnostic, aptitude, and achievement tests)	☒ Yes
2. Your survey/interview research will involve only adult participants (18 and older) who would **not** be considered part of a vulnerable population. (for definitions, see glossary on page 5)	☒ Yes
3. The research data that you collect (including field notes) will be recorded in such a manner that if participants can be identified, they would not be at risk of damage to their reputation, financial standing, employability, or criminal and civil liability **or** this data will be recorded anonymously (so that participants cannot be identified, either directly or through identifiers linked to them).	☒ Yes
If you answered "Yes" to 1, 2 and 3, complete **Section IV** and **Section V** of this application.	

Research Involving Public Observation (Federal Category 2)	☒ N/A
Your research will involve observation of human subjects in a public setting where there is no expectation of privacy.	☐ Yes
If Yes, complete **Section IV** of this application.	

Research Involving Public Officials (Federal Category 3)	☒ N/A
Your research will involve surveying or interviewing elected or appointed public officials (or candidates for public office).	☐ Yes
If Yes, complete **Section IV** and **Section V** of this application.	

Research Involving the Use of Existing Data (Federal Category 4)	☒ N/A
1. Your research will involve the study of existing data, documents, records, pathological specimens, or diagnostic specimens.	☐ Yes
2. You will record the information in such a manner that participants cannot be identified either directly or through identifiers linked to the participants, **or** the sources of these data are publicly available.	☐ Yes
If you answered Yes to 1 and 2, complete **Section IV** of this application.	

Research Involving Public Benefit or Service Program Evaluation (Federal Category 5)	☒ N/A
Your research will evaluate, study or otherwise examine a public benefit or service program at the request of a department or agency head. (IRB approval is required to perform research under this category.)	☐ Yes
If Yes, complete **Section IV** and **Section V** of this application.	

Research Involving Taste and Food Quality (Federal Category 6)	☒ N/A
Your research will involve an evaluation of taste and food quality, or a consumer acceptance assessment.	☐ Yes
If Yes, Complete S**ection IV** and **Section V** of this application.	

IV. Description of Project

Please attach 1-2 typed pages answering questions 1 through 6. Provide your answers as separate responses to each question.
(Do **not** attach a master's proposal or contract/grant.)

1. Briefly describe the purpose and objectives of your research in non-technical language.

2. Briefly describe your research design and methods.

3. For research being conducted as "educational curriculum," describe how the activity being studied is part of "normal" educational practice.

4. If you are using existing data, describe the source(s), the extent to which individuals are identified, and how you have access to the data.

5. If your research will be observational, describe how the observations will be recorded (e.g., audio, video, field notes). If you are planning to audio the participants, please see Section IV.

    a. If your project involves videotaping, please fill out an application for non-exempt review.

6. Describe your participant population (e.g., age, as special needs, etc…). How will you identify, contact and recruit participants? How many participants do you intend to involve in your research? How will you explain your research to participants?

V. Attachments

1. Please provide a consent form to be given to research participants. Examples can be found on the Human Studies Program website under "Forms".
    a. If audio recordings will be a part of the research records, there must be a clear description in the consent form of:
        i. how the recordings will be used including any uses beyond this research project,
        ii. how the recordings will be stored,
        iii. and what will be done with the recordings when the project is complete. A separate consent form, or yes/no checkbox on the main consent form must be provided so that participants can agree or refuse to be recorded.
    b. If applicable, include language in the consent form that describes how the data or recordings are likely to be used for future research purposes.

2. For research involving minors (ages 17 and younger), you must provide the following:
    a. A parent/guardian consent form for their child to participate in research that includes space for a signature and date.
    b. A way of obtaining assent or refusal to participate from the child(ren) that is understandable to them. If the participants are 5 to 11 years old, please provide an oral assent script with an explanation of how you will explain the project to them and obtain their assent or refusal to participate. If the participants are 12 to 17 years old, please provide a written assent form that includes space for a signature and date.

3. Attach a copy of all survey instruments and interview guides. If draft instruments are submitted, final drafts must be submitted for final Human Studies Program approval before use.

4. If you are using recruitment flyers, or advertisements, please provide copies of these as well. Examples can be found on the Human Studies Program website.

5. Attach a copy of your CITI training completion report. See Human Studies Program website under "Training" for instructions on how to complete the training. Your application will not be reviewed until training requirement has been met.

Approval of this Exempt Application is valid for the entire life of the research project and does not need to be renewed annually. However, any changes in the procedures or instruments must be prospectively approved by the Human Studies Program, a process which can occur via email to uhirb@hawaii.edu for Exempt projects. Once the study is complete, please notify the Human Studies Program also by email to uhirb@hawaii.edu.

If you have questions, or you are unsure whether your research project is Exempt, please call the Human Studies Program office at (808) 956-5007, or send an inquiry by email to uhirb@hawaii.edu.

VI. How to Submit Your Application:

Please provide Human Studies Program with this application (typed and signed on page 1), a description of the project, and all relevant documents listed in Section V.

- **Email to**: uhirb@hawaii.edu. Subject line: "Exempt Application". A signed application is required. To convert your signed application to an e-file, please scan.

VII. Glossary

Assent A child's affirmative agreement to participate in research. Mere failure to object should not, absent affirmative agreement, be construed as assent.

Application Form (these forms are found on the Human Studies Program website under "Forms at www.hawaii.edu/irb).

- **Application for Exempt Status for Human Subjects Research** Use this application to determine if and to apply for Human Studies Program approval as an exempt study.
- **Application for New Approval of a Study Involving Human Subjects** Use this application for research that is not exempt.

Consent Form A document which explains a research study (including a description of any procedures, the potential benefits and risks of participation, etc.) to potential research participants. Most consent forms require a signature and date of the participant. By signing the consent form, a participant asserts his or her voluntary agreement to participate in a study. Examples of consent forms are available on the Human Studies Program website at www.hawaii.edu/irb.

Educational Curriculum Includes teaching, curriculum development and other activities consistent with the process of formal education. To K-12 classroom participants, this research will look like normal classroom practice.

Educational Setting A school, classroom, and other locations where formal education is typically conducted.

Exempt Research Under federal regulations, specific categories of research can be designated as exempt from certain regulatory requirements as well as initial and continuing review by the IRB. Research at UH must be approved as exempt by the UH Human Studies Program.

Existing Data Data that has been previously compiled for research or non-research purposes, such as school records or census information. Existing data may include data sets, interview notes or audio or video tapes. (Note: to qualify for exempt status, the data must exist at the time of the application)

Generalizable Knowledge When study results are intended to answer a research question, to draw conclusions about a specific premise (or hypothesis), or to apply study results beyond the specific focus of the research (the research data or study participants), they are considered to be generalizable. Study results that will be published (in a scholarly journal, book, or on-line), placed in a library (such as a masters or doctoral dissertation), or presented at an academic meeting are considered to be generalizable.

Human Subject A human subject is a living individual about whom a researcher, whether professional or student, obtains data through intervention or interaction, or obtains identifiable private information about them.

Informed Consent The process by which a person voluntarily agrees to participate in research based on adequate knowledge and understanding of the research project.

Identifiable Data Data that can be used to identify individual research participants. Identifiers include but are not limited to names, addresses, phone numbers, social security numbers, geocodes, and images (but not voices). Identifiers may also include codes that can be used to link an individual's identity with information about them.

Private Information Information that an individual would reasonably expect to not be shared without the individual's permission. Private information may also refer to observed behavior about a person in a setting in which the person would not expect to be observed for research purposes without permission.

Public Benefit or Service Program A government agency or program established to provide services to eligible members of the public (e.g. WIC, Veterans Affairs, etc.) Research must be supervised by the agency in charge of the public benefit or service program. Please contact the Human Studies Program office if you believe your project may qualify under this category.

Vulnerable populations Children, prisoners, pregnant women, physically or mentally disabled persons, or economically or educationally disadvantaged persons.

Office of Research Compliance
Human Studies Program

UNIVERSITY of HAWAI'I MĀNOA

April 29, 2014

TO: Aarthi Padmanabhan
Principal Investigator
School of Architecture

FROM: Denise A. Lin-DeShetler, MPH, MA
Director

SUBJECT: CHS #22109- "Identification of Thermal Comfort Issues and Parameters For Design: UHM Outreach College at Sinclair Library"

This letter is your record of the Human Studies Program approval of this study as exempt.

On April 29, 2014, the University of Hawai'i (UH) Human Studies Program approved this study as exempt from federal regulations pertaining to the protection of human research participants. The authority for the exemption applicable to your study is documented in the Code of Federal Regulations at 45CFR 46.101(b)(Exempt Category 2).

Exempt studies are subject to the ethical principles articulated in The Belmont Report, found at http://www.hawaii.edu/irb/html/manual/appendices/A/belmont.html.

Exempt studies do not require regular continuing review by the Human Studies Program. However, if you propose to modify your study, you must receive approval from the Human Studies Program prior to implementing any changes. You can submit your proposed changes via email at uhirb@hawaii.edu. (The subject line should read: Exempt Study Modification,) The Human Studies Program may review the exempt status at that time and request an application for approval as non-exempt research.

In order to protect the confidentiality of research participants, we encourage you to destroy private information which can be linked to the identities of individuals as soon as it is reasonable to do so. Signed consent forms, as applicable to your study, should be maintained for at least the duration of your project.

This approval does not expire. However, please notify the Human Studies Program when your study is complete. Upon notification, we will close our files pertaining to your study.

If you have any questions relating to the protection of human research participants, please contact the Human Studies Program at 956-5007 or uhirb@hawaii.edu. We wish you success in carrying out your research project.

1960 East-West Road
Biomedical Sciences Building B104
Honolulu, Hawai'i 96822
Telephone: (808) 956-5007
Fax: (808) 956-8683

APPENDIX E : Research Procedure

F.1 Experimental Setup

Prepare the HIG 204 room environment and sensors:

1. Air temperature, radiant temperature, and relative humidity (RH), and carbon dioxide concentration (CO2) set to 1-min logging interval.
2. No anemometers were used during experiment with participants.
3. Outdoor air temperature and RH set to 15-min logging interval.
4. CO2 sensor set to 1-min logging and placed within control cubicle.
5. Target room temperature = 29.4^{o}C (85^{o}F), target room RH = 70%.
6. Run the DAC logger at 1 hz and test the flow sensors and temp data on the panels.
7. Arrange plants, chairs, etc. neatly within the room.
8. Turn on heaters: set to 31-31.7^{o}C (88-89^{o}F) to achieve the target of 29.4^{o}C (85^{o}F). Keep fan on at low speed to circulate air. Heaters must be turned on a day in advance of the study to achieve a stable temperature.
9. Adjust LED lights position and tilt within the control and test cubicles. keep one overhead light on in the room at the end of the day to maintain the plants.

F.2 Recruit, inform, and prepare for participants

1. Schedule appointments via email. Give them days and time-slots from which to choose, this illicites a more decisive response then asking them to offer time slots first.
2. Send 1-day and 1-hour reminders to the volunteer participant regarding the appointment for the experiment.
3. No food allowed. Water will be provided (make sure to have sufficient cups).
4. Notes on heaters and light switches: “DO NOT TURN ME OFF!”
5. Remove fan remote control from the room.
6. Cover or mask the LCD readout on the data loggers.
7. Remind participants to dress for “warm” weather.
8. If any health issues, please notify immediately so as to help prepare accordingly.
9. Please bring laptop/phone/tablet as needed, you can charge and work on anything (use internet, watch movies/videos, or work on your project or paper or research).
10. Not allowed to leave the desk during the 40 minutes of the study while in room HIG 204.

F.3 Experimental Protocol

1. Pre-cool the water in the cooler of the chiller unit. Set the Johnson Controls to 18.9^{o} C (66^{o} F) and plug the chiller recirculation pump into this (not the room recirculation pump).

2. Set DAQs to 1 hz data (do not record yet) and run so flowrates can be seen. Use remote desktop app on smart phone to view flowrates.
3. Open valves from chiller unit to test cubicle and allow time to purge air from pipes and for panels to cool. Use the return valves to regulate flow and open supply valves to full. Open and close the bypass valve to jolt air bubbles out of the system, then close the bypass valve. Check the DAQ readings for flowrates and adjust return valves so flowrates are all in the range of 1.5-1.9 l/min.
4. Change DAQ resolution to 0.03333 hz (two readings per minute) and start recording.
5. Consent form: ask the participant to sit in HIG 205 and sign and date the form.
6. Offer bathroom break and drinking water before and after the experiment.
7. Determine the order and combination of treatments of the experiment from the random assignment, out of total four scenarios: Scenario 1 (Fan 2 then Fan 3), Scenario 2 (Fan 3 then Fan 2), Scenario 3 (Panels only then Panels+Fan 2), and Scenario 4 (Panels+Fan2 then Panels only).
8. Determine and make note of the study ID for the participant (101 through 140).
9. Use the appropriate data sheet, and make note of pre-conditions, start time, end time, and time the different sections within the testing phase.
10. Pre-HIG 204: Ask participants to complete Part 1 of survey (background information, clothing, and activity level). In our database, this is referred to as survey "0". Ask participants to fill out Part 2 (the comfort survey) three times while inside HIG 204: once in the baseline cubicle (survey 1), and twice in the treatment cubicle (surveys 2 and 3).
11. At the end of the study: Make sure that they are offered water, then a gift card if available (if not, make a note regarding volunteer/extra credit purpose), then thank them for their time (initial participants also given a research flyer to post around campus or within department). Remind for participant to not discuss any details about the study with peers or colleagues.
12. Turn off the chiller, close valves to test cubicle and turn off all supply valves to panels (this seems to prevent a lot of air entering system). Put chiller unit away. Turn off DAQs and download all the Hobo sensors. Run the python scripts to move the data to the database on the server. This is the driver.py and the adaseed.py scripts. When the server was down and we could not push the data, we ran only the driver.py script. This created a lot of 2-minute csv files from the logs. These can be combined by opening a command prompt in the folder and typing: copy *.csv allfiles.csv Then removed the last line, save the file and upload to whatever database is being used.

APPENDIX F

Data Management

(17 pages)

APPENDIX F: Data Management

G.1. Tables in "radiantpanels" database

1. "comfort_sensor_data": included data from HOBO sensors and DAQ sensors
2. "comfort_scenarios": lists the combination of scenario, survey #, and treatment
3. "survey_data": lists the answers the subjects gave on the comfort surveys and also holds the averages for the environmental conditions of the space for the ten minutes preceding the time the survey was taken
4. "survey_subject_info": lists the demographic information of the subjects

G.2. Instructions for handling data from Hobo sensors

1. In Excel, use Tableau plugin to reshape data to 3 columns: timestamp, sensor ID, value
2. Make sure there are no duplicate data
3. Delete the header row
4. Save as csv file
5. In the folder with all the files, open command promt
6. Use this command: `copy *.csv allfiles.csv` (or you can give it another name)
7. Open the csv and delete the last line (a bit of text that says SUB)
8. Upload it to the table "comfort_sensor_data"

G.3. Python scripts to convert SignalExpress files to CSVs, reshape the data, and push to the database

G.3.1. driver.py

Open a command line from the comfort survey folder and type `python driver.py` This is call on the NISignalExpressUtility which follows.

```
import NISignalExpressUtility
import os
import time
import datetime
import shutil
import csv
from GrundfosUtility import convert_output
from DataFiles import __data__
from ConvertedCSVs import __converted__
from ReshapedCSVs import __reshaped__
from CalibratedCSVs import __calibrated__
from Output import __output__
from NISignalExpressUtility import move_to_output
from NISignalExpressUtility import network_share_auth
data_location = os.path.dirname(os.path.abspath(__data__.__file__)) #DataFile
converted_location = os.path.dirname(os.path.abspath(__converted__.__file__))
reshaped_location = os.path.dirname(os.path.abspath(__reshaped__.__file__))
calibrated_location = os.path.dirname(os.path.abspath(__calibrated__.__file__))
output_location = os.path.dirname(os.path.abspath(__output__.__file__))
archive_location = os.path.join(os.path.dirname(__file__), 'archive')

print "data: ", data_location
print "converted: ", converted_location
```

```
print "reshaped: ", reshaped_location
print "calibrated: ", calibrated_location
print "output: ", output_location

pattern = '%d.%m.%Y %H:%M:%S'


#if in archive, ignore it
#if not in archive, add it to archive and process it


while 1:
    print "Processing current data"
    #check that file was created an hour ago
    now = datetime.datetime.now().strftime(pattern)
    current_epoch = int(time.mktime(time.strptime(now, pattern)))

    data_folders_locations = []
    #get folders in DataFiles folder
    for folder_name in os.listdir(data_location):
        if ".py" not in folder_name:
            archived = False
            with open('archive.csv', 'rb') as archivefile:
                archivereader = csv.reader(archivefile)
                for archiveditem in archivereader:
                    try:
                        if folder_name == archiveditem[0]:
                            archived = True
                    except:
                        print "Error: Blank archive file"
            if not archived:
                try:
                    tdms_path = os.path.join(data_location, folder_name,
                                             os.listdir(os.path.join(data_location, fol
der_name))[0])
                    create_time = os.path.getctime(tdms_path)
                    if current_epoch - 120 > create_time:
                        with open('archive.csv', 'a') as archivefile:
                            archivewriter = csv.writer(archivefile)
                            archivewriter.writerow([folder_name])
                        NIExtract = NISignalExpressUtility.NISignalExpressUtility(
                            os.path.join(data_location, folder_name),
                            converted_location,
                            reshaped_location, calibrated_location)
                        print "Extracted " + folder_name
                        NIExtract.convert_to_csv()
                        print "Converted " + folder_name
                        NIExtract.reshape_csv()
                        print "Reshaped " + folder_name
                        NIExtract.calibrate_output()
                        print "Calibrated " + folder_name
                except Exception as e:
                    print "File " + folder_name + " not ready for processing"
    move_to_output()
    for files in os.listdir(converted_location):
        if ".csv" in files:
            os.remove(os.path.join(converted_location, files))

    for files in os.listdir(reshaped_location):
        if ".csv" in files:
            os.remove(os.path.join(reshaped_location, files))
```

```
84.
85.     for files in os.listdir(calibrated_location):
86.         if ".csv" in files:
87.             os.remove(os.path.join(calibrated_location, files))
88.     time.sleep(60)
```

G.3.2. NIExpressUtility

This is called by the driver.py, you don't have to run it.

```
1.  #-------------------
2.  # Author: Christian A. Damo
3.  # file name: NISignalExpressUtility.py
4.  # rev. by: Reed Shinsato
5.  # rev. date: 2014-07-11
6.  #-------------------
7.  #
8.  # Patch Notes: Cleaned up class
9.  #
10. #-------------------
11. """
12.     This script convertes .tdms files from NISignalExpress into .csv files.
13.     Then, it pushes the .csv files to a server with a specified ip.
14. """
15.
16. # Import Libraries
17. from nptdms import TdmsFile
18. from contextlib import contextmanager
19. import os
20. import datetime
21. import csv
22.
23. def separatefiles():
24.     #dataFolder = "CalibratedCSVs"
25.     #uniqueid = ["temp", "flow"]
26.     homeDir = os.path.dirname(os.path.abspath(__file__))
27.     dataFileDir = os.path.join(homeDir, "CalibratedCSVs")
28.     tempFileDir = os.path.join(homeDir, "ADASEED", "CalibratedFlow") #CalibratedTempera
    ture
29.     flowFileDir = os.path.join(homeDir, "ADASEED", "CalibratedFlow")
30.     csvFiles = []
31.     #list all files in the directory
32.     #print "datafileDir =" + dataFileDir
33.     currentDirFiles = os.listdir(dataFileDir)
34.     #print currentDirFiles
35.     #get all csvs in the directory
36.     for filename in currentDirFiles:
37.         if ".csv" in filename:
38.             csvFiles.append(filename)
39.     #print csvFiles
40.     for csvFile in csvFiles:
41.         #create two output file names
42.         name = csvFile
43.         newName = name.split('.')
44.         tempName = list(newName)
45.         flowName = list(newName)
46.         tempName.insert(1, "_temp.")
47.         newTempName = ''.join(tempName)
48.         flowName.insert(1, "_flow.")
49.         newFlowName = ''.join(flowName)
50.         tempFilePath = os.path.join(tempFileDir, newTempName)
```

```
        flowFilePath = os.path.join(flowFileDir, newFlowName)
        csvFilePath = os.path.join(dataFileDir, csvFile)
       # print "asdjfl" + tempFilePath
        #print flowFilePath
        with open(csvFilePath, "rb") as inputFile:
            reader = csv.reader(inputFile)
            with open(tempFilePath, "wb") as outputT:
                with open(flowFilePath, "wb") as outputF:
                    outputTwriter = csv.writer(outputT)
                    outputFwriter = csv.writer(outputF)
                    for row in reader:
                        if "Temp" in row[3]:
                            outputTwriter.writerow(row)
                        elif "Flow" in row[3]:
                            outputFwriter.writerow(row)
                        elif "Anem" in row[3]:
                            outputFwriter.writerow(row)

def move_to_output():
    #dataFolder = "CalibratedCSVs"
    #uniqueid = ["temp", "flow"]
    homeDir = os.path.dirname(os.path.abspath(__file__))
    dataFileDir = os.path.join(homeDir, "CalibratedCSVs")
    outputFileDir = os.path.join(homeDir, "ADASEED", "CalibratedFlow") #CalibratedTempe
rature
    csvFiles = []
    #list all files in the directory
    #print "datafileDir =" + dataFileDir
    currentDirFiles = os.listdir(dataFileDir)
    #print currentDirFiles
    #get all csvs in the directory
    for filename in currentDirFiles:
        if ".csv" in filename:
            csvFiles.append(filename)
    #print csvFiles
    for csvFile in csvFiles:
        #create two output file names
        name = csvFile
        outputFilePath = os.path.join(outputFileDir, name)
        csvFilePath = os.path.join(dataFileDir, csvFile)
       # print "asdjfl" + tempFilePath
        #print flowFilePath
        with open(csvFilePath, "rb") as inputFile:
            reader = csv.reader(inputFile)
            with open(outputFilePath, "wb") as output:
                outputwriter = csv.writer(output)
                for row in reader:
                    if "Temp" in row[3]:
                        outputwriter.writerow(row)
                    elif "Flow" in row[3]:
                         outputwriter.writerow(row)
                     elif "Anem" in row[3]:
                         outputwriter.writerow(row)


#dictionary for tacking on a sensor name & location to a corresponding port
notes = {'Dev1ai0':"Temperature_1",
         'Dev1ai1':"Flow_1",
         'Dev1ai2':"Temperature_2",
         'Dev1ai3':"Flow_2",
         'Dev1ai4':"Temperature_3",
```

```
         'Dev1ai5':"Flow_3",
         'Dev1ai6':"Temperature_5",
         'Dev1ai7':"Flow_5",
         'Dev1ai8':"Temperature_4",
         'Dev1ai9':"Flow_4",
         'Dev1ai10':"Flow_6",
         'Dev1ai11':"Temperature_7",
         'Dev1ai12':"Flow_8",
         'Dev1ai13':"Temperature_8",
         'Dev1ai14':"Flow_7",
         'Dev1ai15':"Temperature_6",
         'Dev2ai0':"Temperature_9",
         'Dev2ai8':"Flow_9",
         'Dev2ai1':"Temperature_10",
         'Dev2ai9':"Flow_10",
         'Dev2ai2':"Temperature_Main",
         'Dev2ai10':"Flow_Main",
         'Dev2ai11':"Flow_Main_Return",
         'Dev2ai3':"Temperature_Main_Return",
         'Dev2ai12':"Anem_3",
         'Dev2ai5':"Anem_2",
         'Dev2ai13':"Anem_4",
         'Dev2ai4':"Anem_1",
         'Dev2ai6':"Anem_5",
         'Dev2ai14':"Anem_6",
         'Dev2ai7':"Anem_7",
         'Dev2ai15':"Anem_8"}


# Create Classes
class GroupChannel:
    """
        This class holds the group and channel names from a metafile.
    """
    def __init__(self, meta_filename):
        print
        self._channel_type = ""
        self._start_time = datetime.datetime.now()
        self._meta_filename = meta_filename
        self._group_name = ""
        self._channel_names = []
        self.__get_group_name(self._meta_filename)
        # self.__str__()

    def __str__(self):
        print "\nCalling GroupChannels __str__()"
        print "Type: ", self._channel_type
        print "Start: ", self._start_time
        print "Group Name: ", self._group_name
        print "Channel Names: \n\n", self._channel_names

    def __get_start_and_names(self, meta_filename, temp_names):
        """
            This function stores the start time and channel names
        """
        # Check the meta_file for " ", which is the line of the channel names.
        # Check the meta_file for "Log start time", which holds the start time.
        meta_file = open(meta_filename)
        for line in meta_file:
            if line[0] == " ":
```

```
                temp_names.append(line)
            if "Log start time" in line:
                self._start_time = self.__start_convert_to_datetime_object(line)
        meta_file.close()

    def __start_convert_to_datetime_object(self, line):
        """
            This function turns the given line into a datetime object.
        """
        # Find each element of the given line
        # Turn the elements into a datetime object
        # Return the datetime object
        line = line.split(" ")
        date = line[3]
        date = date.split("/")
        year = int(date[2])
        day = int(date[1])
        month = int(date[0])
        time = line[4]
        time = time[:-1]
        time = time.split(":")
        hour = int(time[0])
        minute = int(time[1])
        second = time[2].split(".")
        second = int(second[0])
        begin_time = datetime.datetime(year, month, day, hour, minute, second)
        return begin_time

    def __get_group_name(self, meta_filename):
        """
            This functions determines the group_name
        """
        # Get the start time and channel names
        # Determine the timestamp
        # Store the channel names
        # Determine the data type
        # Create the group name
        temp_names = []
        self.__get_start_and_names(meta_filename, temp_names)
        for line in temp_names:
            temp_line = line.split("-")
            timestamp = temp_line[0]
            timestamp = timestamp[5: -1]
            channel_name = temp_line[-1]
            channel_name = channel_name[1: -1]
            self._channel_names.append(channel_name)
            data_type = temp_line[1]
            data_type = data_type[1: -1]
            self._channel_type = data_type
            self._group_name = (timestamp + " - " + data_type +
                                " - " + "All Data")

    def return_group_name(self):
        """
            This function returns the group name.
        """
        # Retunr group_name
        return self._group_name

    def return_channel_names(self):
        """
```

```
            This function returns the channel names.
        """
        # Return channel_names
        return self._channel_names

    def return_start_time(self):
        """
            This function returns the start time.
        """
        # Return start_time
        return self._start_time

class NISignalExpressUtility:
    def __init__(self, data_location = os.path.dirname(\
        os.path.abspath(__file__)), csv_location = os.path.dirname(\
        os.path.abspath(__file__)), reshaped_location = os.path.dirname(\
        os.path.abspath(__file__)), calibrated_location = os.path.dirname(\
        os.path.abspath(__file__))):
        self._data_location = data_location
        self._csv_location = csv_location
        self._reshaped_location = reshaped_location
        self._calibrated_location = calibrated_location
        self._meta_voltage_filename = (os.path.join(self._data_location,\
            "Voltage_meta.txt"))
        self._meta_current_filename = (os.path.join(self._data_location,\
            "Current_meta.txt"))
        self._tdms_voltage_filename = (os.path.join(self._data_location,\
            "Voltage.tdms"))
        self._tdms_current_filename = (os.path.join(self._data_location,\
            "Current.tdms"))
        self._channel_names = []
        self._tdms_filenames = []
        self._GroupChannels = []
        self._tdms_to_csv_filename = str(os.path.split(data_location)[-1]) +\
            "_converted.csv"
        self._reshaped_filename = str(os.path.split(data_location)[-1]) +\
            "_reshaped.csv"
        self._converted_to_csv = False

    def __check_for_group_channels(self, tdms_filename, tdms_filenames,\
            meta_filename, channel_names, GroupChannels):
        """
            This function creates the GroupChannels.
        """
        # Create a tdms object
        # Create a GroupChannel object
        # Add to the list of channel_names
        # Add to the list of tdms_filenames
        # Add to the list of GroupChannels
        tdms_file = TdmsFile(tdms_filename)
        TypeGroupChannel = GroupChannel(meta_filename)
        type_channel_names = TypeGroupChannel.return_channel_names()
        channel_names.append(type_channel_names)
        tdms_filenames.append(tdms_file)
        GroupChannels.append(TypeGroupChannel)

    def __tdms_to_csv_file(self, channel_names, tdms_filenames,
                           GroupChannels):
        """
            This function will convert .tdms files into .csv files
        """
```

```
        # Get the data from the .tdms file
        #    Create a channel object from a tdms object
        #    Get the data from the channel
        #    Get the time from the channel
        # Clean up the channel_names to be a single array
        # Save the data into the output file
        #    Save the timestamp using delta from the start_time
        #    Save the data in a row relative to the channel_id column

        datas = []
        times = []
        for channel_names_index in range(0, len(channel_names)):
            for channel_name in channel_names[channel_names_index]:
                channel = (tdms_filenames[channel_names_index].
              object(GroupChannels[channel_names_index].
              return_group_name(), channel_name))
                data = channel.data
                datas.append(data)
                times = channel.time_track()

        temp_channel_names = []
        for channel_names_index in range(len(channel_names)):
            for name in channel_names[channel_names_index]:
                temp_channel_names.append(name)

        channel_names = []
        channel_names = temp_channel_names


        converted_file = open(os.path.join(self._csv_location,\
            self._tdms_to_csv_filename),"wb")
        writer = csv.writer(converted_file)

        new_row = list(channel_names)
        new_row.insert(0, "timestamp")
        writer.writerow(new_row)

        #iterates through each time element
        for times_index in range(len(times)):
            #created delta object
            delta = datetime.timedelta(seconds = times[times_index] + 1)
            #creates the actual printed time
            current_time = GroupChannels[0].return_start_time() + delta
            #creates new line with time as element 0
            new_row = [current_time]
            #iterating through the datas list
            for datas_index in range(len(datas)):
                data = datas[datas_index][times_index]
                new_row.append(data)
            writer.writerow(new_row)
            #print new_row
            #print len(new_row)
            #raw_input("Press Enter to continue...")
        converted_file.close()


    def reshape_csv(self):
        """
            This function reshapes the data to a specific table format.
        """
        # Find the correct input file
```

```
        # Create an output file
        # Write the header
        # Clean up the channel_names
        # Write the output row with the correct format
        #    Add time to the output row
        #        Add the channel_names to the row
        #        Add the data to the row
        #        Write the row with [time, channel_names, data]
        if self._converted_to_csv == True:
            channel_names = list(self._channel_names)
            input_file = (open(os.path.join(self._csv_location,\
                self._tdms_to_csv_filename), "r"))
            reader = csv.reader(input_file)

            reshaped_file = (open(os.path.join(self._reshaped_location,\
                self._reshaped_filename), "wb"))
            writer = csv.writer(reshaped_file)

            reader.next()
            new_row = ["datetime", "position", "value"]
            writer.writerow(new_row)

            temp_channel_names = []
            for channel_names_index in range(len(channel_names)):
                for names in channel_names[channel_names_index]:
                    temp_channel_names.append(names)
            channel_names = []
            channel_names = temp_channel_names
            new_channel_names = []
            for name in channel_names:
                name = name.split("_")
                name = name[1] + name[2]
                new_channel_names.append(name)

            for row in reader:
                current_time = row[0]
                row = row[1:]
                for new_channel_names_index in range(len(new_channel_names)):
                    new_row = []
                    new_row.append(current_time)
                    new_row.append(new_channel_names[new_channel_names_index])
                    new_row.append(float(row[new_channel_names_index]))
                    writer.writerow(new_row)

            input_file.close()
            reshaped_file.close()

    def convert_to_csv(self):
        """
            This function extracts the tdms data to the correct format.
        """
        # Check for voltage and current group channels
        # Convert the tdms files to csv
        # Reshape the csv files to the correct format
        files_found_voltage = True
        files_found_current = True
        try:
            self.__check_for_group_channels(self._tdms_voltage_filename,\
                self._tdms_filenames, self._meta_voltage_filename,\
                self._channel_names, self._GroupChannels)
        except:
```

```
            print "Note: No Voltage Files"
            files_found_voltage = False
        try:
            self.__check_for_group_channels(self._tdms_current_filename,\
                self._tdms_filenames, self._meta_current_filename,\
                self._channel_names, self._GroupChannels)
        except:
            print "Note: No Current Files"
            files_found_current = False

        if files_found_current == True or files_found_voltage == True:
            self.__tdms_to_csv_file(self._channel_names, self._tdms_filenames,\
                self._GroupChannels)
            self._converted_to_csv =  True

    def add_calibration(self, sensor_id, premultiplier,
                        preoffset, multiplier, offset):
        """
            This function adds a calibration to NICalibrate.csv.
        """
        # Open the calibration file
        # Check if the sensor_id is in the calibration file
        # Delete the calibration for the sensor_id
        # if it is in the calibration file
        # Append the new calibration to the calibration file
        calibration_filename = "NICalibrate.csv"
        delete_id = False
        sensor = str(sensor_id)
        with open(calibration_filename, "r") as calibration_file:
            for row in csv.reader(calibration_file):
                if sensor in row:
                    delete_id = True

        if delete_id == True:
            self.delete_calibration(sensor_id)

        with open(calibration_filename, "a") as calibration_file:
            row = (str(sensor_id) + "," +\
                   str(premultiplier) + "," +\
                   str(preoffset) + "," +\
                   str(multiplier) + "," +\
                   str(offset) + "\n")
            calibration_file.write(row)


    def delete_calibration(self, sensor_id):
        """
            This function deletes a calibration from NICalibrate.csv.
        """
        # Copy NICalibrate.csv into a temp.csv
        # skipping the sensor_id to be deleted
        # Delete the old calibration file NICalibrate.csv
        # Rename temp.csv into the new calibration file NICalibrate.csv
        calibration_filename = "NISignalExpressCalibrate.csv"
        temp_filename = "temp.csv"
        sensor = str(sensor_id)
        with open(temp_filename, "wb") as temp_file:
            with open(calibration_filename, "r") as calibration_file:
                for row in csv.reader(calibration_file):
                    if sensor not in row:
                        csv.writer(temp_file).writerow(row)
```

```
477.
478.         os.remove(calibration_filename)
479.         os.rename(temp_filename, calibration_filename)
480.
481.
482.     def __calibrate_value(self, sensor_id, value):
483.         """
484.             This function calibrates the value of the senor_id.
485.         """
486.         # Open the calibration file
487.         # Check if the sensor_id of the calibration file
488.         # to determine the multipliers and offsets
489.         # Return the value with calibration
490.         calibration_filename = "NISignalExpressCalibrate.csv"
491.         calibration_file = open(calibration_filename, "r")
492.         reader = csv.reader(calibration_file)
493.
494.         value = float(value)
495.
496.         premultiplier = 1.0
497.         preoffset = 0.0
498.         multiplier = 1.0
499.         offset = 0.0
500.
501.         row = reader.next()
502.         for row in reader:
503.             if row[0] == str(sensor_id):
504.                 premultiplier = float(row[1])
505.                 preoffset = float(row[2])
506.                 multiplier = float(row[3])
507.                 offset = float(row[4])
508.
509.         value = multiplier * ((premultiplier * value) + preoffset) + offset
510.
511.         calibration_file.close()
512.         return value
513.
514.     def clean_folder(self, folder_location):
515.         """
516.             This function deletes all the output files created.
517.         """
518.         folder_files_list = os.listdir(folder_location)
519.
520.         for folder_files in folder_files_list:
521.             if ".py" not in folder_files:
522.                 try:
523.                     os.remove(os.path.join(folder_location, folder_files))
524.                 except:
525.                     pass
526.
527.     def calibrate_output(self):
528.         """
529.             This function calibrates the output for given callibrations.
530.         """
531.         # Find the correct input file
532.         # Create a output file for the calibrated values
533.         # Write the header row
534.         # Go through each input row and callibrate the value of the row
535.         # Write the callibrated row to the output file
536.
537.         input_file = (open(os.path.join(self._reshaped_location,\
```

```
            self._reshaped_filename), "r"))
        reader = csv.reader(input_file)

        output_filename = str(self._reshaped_filename).replace(".csv",\
            "_calibrated.csv")
        output_file = (open(os.path.join(self._calibrated_location,\
            output_filename), "wb"))
        writer = csv.writer(output_file)
        new_row = reader.next()
        new_row.append('comments')
        writer.writerow(new_row)

        for row in reader:
            value = self.__calibrate_value(row[1], row[2])
            new_row = [row[0], row[1], round(value,5), notes[row[1]]]
            writer.writerow(new_row)

        input_file.close()
        output_file.close()
```

G.3.3. ADASEED . py

Open a command line from the ADASEED folder and type `python adaseed.py` to run this. If you have problems, such as the server was down and data is being uploaded to a different computer, you can go to the folder with the processed files (folder called calibratedflow; there will be a separate csv for each 2-min log) and combine them with this command: `copy *.csv allfiles.csv`, open text file and delete last line and it's ready for upload to postgresql.

```
#!/usr/bin/env python
'''''
This script is designed to gather data and input them into a PostgreSQL
database.

9/18/2014: Modified to be re-purposed for Radiant Panels data collection.
           EGauge components will be disabled from the script.

           Outputs for this script will be modified to talk to the server API.
           It will push all reshaped data files up into the server, where
           another script will handle shifting the data into the database.
'''
import datetime
import time
from Hobowarebin import HobowareUtility
import os
import xmlrpclib

__author__ = "Christian A. Damo"
__copyright__ = "Copyright 2014 School of Architecture, University of Hawaii at Manoa"

__credits__ = ["Christian A. Damo", "Reed Shinsato"]
__version__ = "0.01"
__maintainer__ = "Eileen Peppard"
__email__ = "epeppard@hawaii.edu"
__status__ = "Prototype"

key = PASSKEY
```

```
28.
29. def push_temperature():
30.     temp_dir = os.path.join(os.path.dirname(os.path.abspath(__file__)), "CalibratedTemp
    erature")
31.     server = xmlrpclib.ServerProxy("IPADDRESS")
32.     #if there ARE files to process, then for each file do the following
33.     for files in os.listdir(temp_dir):
34.         with open(os.path.join(temp_dir, files), "rb") as handle:
35.             binary_data = xmlrpclib.Binary(handle.read())
36.         server.radiantpaneltemperature_push(binary_data, os.path.split(files)[1], key)

37.         os.remove(os.path.join(temp_dir, files))
38.
39. def push_flow():
40.     flow_dir = os.path.join(os.path.dirname(os.path.abspath(__file__)), "CalibratedFlow
    ")
41.     server = xmlrpclib.ServerProxy("IPADDRESS")
42.     #if there ARE files to process, then for each file do the following
43.     for files in os.listdir(flow_dir):
44.         with open(os.path.join(flow_dir, files), "rb") as handle:
45.             binary_data = xmlrpclib.Binary(handle.read())
46.         server.radiantpanelflow_push(binary_data, os.path.split(files)[1], key)
47.         os.remove(os.path.join(flow_dir, files))
48.
49. def process_hobo_files():
50.         '''''
51.     given:  nothing
52.     return: nothing, but carries out the entire processing of the hobo files
53.             when they are saved to the ADASEED>hobo folder. Reshapes the raw
54.              file to a csv, then edits the output by reshaping to eshape and
55.              finally inserting it into the database.
56.         '''
57.
58.      #connect to the API
59.     server = xmlrpclib.ServerProxy("IPADDRESS")
60.     #get the files in the ADASEED>hobo directory
61.     hobo_files = hobo.get_hobo_files()
62.     #if there's no files to process, tell the user there isn't any and end the function

63.     if len(hobo_files) == 0:
64.         print "At "+str(datetime.datetime.now())+" there were no data collected from th
    e Hobo Network\n"
65.         return 0
66.     #if there ARE files to process, then for each file do the following
67.     for hobo_file in hobo_files:
68.         #inform the user you're processing a particular file
69.         print 'processing '+hobo_file
70.         #extract the data from the raw hobo shaped file
71.         output_filename = hobo.extract_data(hobo_file)
72.         #edit the file to do something, look at the HoboUtility comments
73.         output_filename = hobo.edit_output(output_filename)
74.         #once the file is in an eshape go ahead and push it up to the server
75.         with open(output_filename, "rb") as handle:
76.             binary_data = xmlrpclib.Binary(handle.read())
77.         server.kuykendall_push(binary_data, os.path.split(output_filename)[1]\
78.                                    , key)
79.         #delete all the hobo meta files
80.         hobo.clean_folder()
81.
82. try:
83.     #display greeting
```

```
84.     print ''
85.     print '                    *****    Welcome to the    *****'
86.     print '"Automatic Data Acquisition System for Energy and Environmental Data"'
87.     print '                                (ADASEED)\n'
88.
89.     #instance Classes
90.     hobo = HobowareUtility.HobowareUtility()
91.
92.     #check for directories used by this script
93.     if not os.path.exists('hobo'):
94.         #generate the hobo folder if it doesnt exist
95.         os.makedirs('hobo')
96.
97.     if not os.path.exists('extracted'):
98.         os.makedirs('extracted')
99.
100.    if not os.path.exists('edited'):
101.        os.makedirs('edited')
102.
103.    if not os.path.exists('archive\hobo'):
104.        #generate the archieve folder if it doesn't exist
105.        os.makedirs('archive\hobo')
106.
107.    #wait for the user so that they can make sure everything is in working order
108.    raw_input('Press Enter to start "ADASEED"...')
109.
110.    #get time now and store as 'from' time for use in the "except" block.
111.    old_time = datetime.datetime.now()
112.    from_str = str(old_time)[:-9]+'00'
113.
114.    #let the user know that we're starting the session
115.    print 'Your session has started at '+from_str
116.    print 'Hit control-c to end session'
117.
118.    #start looping
119.    while 1:
120.        #wait every 1 minute
121.        time.sleep(60)
122.
123.        push_temperature()
124.        push_flow()
125.
126.
127.except KeyboardInterrupt:
128.    #this block of code basically carries out the same sequence of commands
129.    #in the while loop above
130.    #let the user know wer're finishing up
131.    print 'Ending the "Automatic Data Acquisition System for Energy and Environmental D
    ata"\n'
132.    #process any hobo files
133.    push_temperature()
134.
135.    push_flow()
136.    #let the user manually end the program so that they can read
137.    #any outputs that were created.
138.    raw_input('Press Enter to quit "ADASEED"...')
```

G.4. Postgresql queries to make calcutions

--put clo factor into table for all survey data

```
UPDATE "survey_data" SET clo_factor = "survey_subject_info".clo_factor
FROM survey_subject_info
WHERE survey_data.subject_id = survey_subject_info.subject_id
```

--correct any sensor_id name mistakes from HOBO data

```
UPDATE comfort_sensor_data SET sensor_id = 'Globe_1_control'
WHERE sensor_id = ' Globe_1_control)';
UPDATE comfort_sensor_data SET sensor_id = 'Temp_cooler'
WHERE sensor_id = ' Temp_cooler';
UPDATE comfort_sensor_data SET sensor_id = 'Globe_2_test'
WHERE sensor_id = 'Globe_2_test)';
UPDATE comfort_sensor_data SET sensor_id = 'Temp_ACreturn'
WHERE sensor_id = 'Temp_Acreturn';
UPDATE comfort_sensor_data SET sensor_id = 'OutdoorHumidity'
WHERE sensor_id = 'OutdoorHumidity_HIG';
UPDATE comfort_sensor_data SET sensor_id = 'OutdoorTemp'
WHERE sensor_id = 'OutdoorTemp_HIG';
```

--view to calculate average temperatures for 10-min periods before a survey was taken

```
SELECT survey_data.datetime,
comfort_sensor_data.sensor_id,
avg(comfort_sensor_data.value) AS avg
FROM (comfort_sensor_data
JOIN survey_data ON ((comfort_sensor_data.datetime = survey_data.datetime)))
WHERE ((comfort_sensor_data.datetime >= (survey_data.datetime -
'00:10:00'::interval)) AND (comfort_sensor_data.datetime <=
survey_data.datetime))
GROUP BY survey_data.datetime, comfort_sensor_data.sensor_id;
```

--select the average temperature, humidity, and globe temp from the 10-min average view (above)

```
UPDATE survey_data SET temp_f_avg = view_10min_averages_minute.avg
FROM view_10min_averages_minute
WHERE survey_data.datetime = view_10min_averages_minute.datetime
AND survey_data.survey_id = 1
AND view_10min_averages_minute.sensor_id = 'RoomTemp_control';

UPDATE survey_data SET temp_f_avg = view_10min_averages_minute.avg
FROM view_10min_averages_minute
WHERE survey_data.datetime = view_10min_averages_minute.datetime
AND survey_data.survey_id = 2
AND view_10min_averages_minute.sensor_id = 'RoomTemp_test';

UPDATE survey_data SET temp_f_avg = view_10min_averages_minute.avg
FROM view_10min_averages_minute
WHERE survey_data.datetime = view_10min_averages_minute.datetime
AND survey_data.survey_id = 3
AND view_10min_averages_minute.sensor_id = 'RoomTemp_test';

UPDATE survey_data SET rh_pct_avg = view_10min_averages_minute.avg
FROM view_10min_averages_minute
WHERE survey_data.datetime = view_10min_averages_minute.datetime
AND survey_data.survey_id = 1
AND view_10min_averages_minute.sensor_id = 'Humidity_control';
```

```
UPDATE survey_data SET rh_pct_avg = view_10min_averages_minute.avg
FROM view_10min_averages_minute
WHERE survey_data.datetime = view_10min_averages_minute.datetime
AND survey_data.survey_id = 2
AND view_10min_averages_minute.sensor_id = 'Humidity_test';

UPDATE survey_data SET rh_pct_avg = view_10min_averages_minute.avg
FROM view_10min_averages_minute
WHERE survey_data.datetime = view_10min_averages_minute.datetime
AND survey_data.survey_id = 3
AND view_10min_averages_minute.sensor_id = 'Humidity_test';

--because the timestamps for globe have seconds and the survey data does not:
UPDATE survey_data SET globe_temp_f_avg = view_10min_averages_minute.avg
FROM view_10min_averages_minute
WHERE date_trunc('minute', survey_data.datetime) = date_trunc('minute',
view_10min_averages_minute.datetime)
AND survey_data.survey_id = 1
AND view_10min_averages_minute.sensor_id = 'Globe_1_control';

UPDATE survey_data SET globe_temp_f_avg = view_10min_averages_minute.avg
FROM view_10min_averages_minute
WHERE date_trunc('minute', survey_data.datetime) = date_trunc('minute',
view_10min_averages_minute.datetime)
AND survey_data.survey_id = 2
AND view_10min_averages_minute.sensor_id = 'Globe_2_test';

UPDATE survey_data SET globe_temp_f_avg = view_10min_averages_minute.avg
FROM view_10min_averages_minute
WHERE date_trunc('minute', survey_data.datetime) = date_trunc('minute',
view_10min_averages_minute.datetime)
AND survey_data.survey_id = 3
AND view_10min_averages_minute.sensor_id = 'Globe_2_test';
```

--add Celsius temps to table

```
UPDATE survey_data SET temp_c_avg = round((((temp_f_avg) - 32) * 5 /
9)::numeric, 3);
UPDATE survey_data SET globe_temp_c_avg = round((((globe_temp_f_avg) - 32) * 5
/ 9)::numeric, 3);
```

--add fan settings and if panels are running to table

```
UPDATE radiant_panels SET scenario = 'fan-4' where (radiant_panels.datetime >= '2015-07-24 14:20:00'::timestamp
without time zone) AND (radiant_panels.datetime <= '2015-07-24 14:44:00'::timestamp without time zone);
UPDATE radiant_panels SET scenario = 'fan-3' where ((radiant_panels.datetime >= '2015-07-24 15:56:00'::timestamp
without time zone) AND (radiant_panels.datetime <= '2015-07-24 16:17:00'::timestamp without time zone));
UPDATE survey_data SET panels = 0 WHERE scenario_id = 1;
UPDATE survey_data SET panels = 0 WHERE scenario_id = 2;
UPDATE survey_data SET panels = 1 WHERE scenario_id = 3;
UPDATE survey_data SET panels = 1 WHERE scenario_id = 4;
UPDATE radiant_panels SET scenario = 'fan-2' where ((radiant_panels.datetime >= '2015-07-24 15:27:00'::timestamp
without time zone) AND (radiant_panels.datetime <= '2015-07-24 15:47:00'::timestamp without time zone));
UPDATE radiant_panels SET scenario = 'fan-5' where ((radiant_panels.datetime >= '2015-07-24 14:57:00'::timestamp
without time zone) AND (radiant_panels.datetime <= '2015-07-24 15:17:00'::timestamp without time zone));
```

--fill in column for air velocity in survey data table using average velocities Manfred calculated

```
UPDATE survey_data SET air_velocity_mps = 0
FROM "public".comfort_scenarios
WHERE comfort_scenarios.treatment like 'baseline' AND
survey_data.scenario_id = comfort_scenarios.scenario AND
survey_data.survey_id = comfort_scenarios.survey;

UPDATE survey_data SET air_velocity_mps = 0
FROM "public".comfort_scenarios
WHERE comfort_scenarios.treatment like 'panels' AND
survey_data.scenario_id = comfort_scenarios.scenario AND
survey_data.survey_id = comfort_scenarios.survey;

UPDATE survey_data SET air_velocity_mps = 1.05
FROM "public".comfort_scenarios
WHERE comfort_scenarios.treatment like 'fan 2' AND
survey_data.scenario_id = comfort_scenarios.scenario AND
survey_data.survey_id = comfort_scenarios.survey;

UPDATE survey_data SET air_velocity_mps = 1.05
FROM "public".comfort_scenarios
WHERE comfort_scenarios.treatment like 'panels + fan 2' AND
survey_data.scenario_id = comfort_scenarios.scenario AND
survey_data.survey_id = comfort_scenarios.survey;

UPDATE survey_data SET air_velocity_mps = 1.14
FROM "public".comfort_scenarios
WHERE comfort_scenarios.treatment like 'fan 3' AND
survey_data.scenario_id = comfort_scenarios.scenario AND
survey_data.survey_id = comfort_scenarios.survey;
```

--these scripts correct the temps from sensors placed outside the center of the cubicle, based on data collected on 9/22/15

```
UPDATE survey_data SET globe_temp_f_avg_corrected = (globe_temp_f_avg) - 1.444
WHERE treatment = 'panels';
UPDATE survey_data SET temp_f_avg_corrected = (temp_f_avg) - 0.675
WHERE treatment = 'panels';
UPDATE survey_data SET globe_temp_f_avg_corrected = (globe_temp_f_avg) - 0.582
WHERE treatment = 'panels + fan 2';
UPDATE survey_data SET temp_f_avg_corrected = (temp_f_avg) + 1.247
WHERE treatment = 'panels + fan 2';
```

--when all is done, the others can be filled with the same data as before so we have a complete set:

```
UPDATE survey_data SET globe_temp_f_avg_corrected = globe_temp_f_avg
WHERE globe_temp_f_avg_corrected is NULL;
UPDATE survey_data SET temp_f_avg_corrected = temp_f_avg
WHERE temp_f_avg_corrected is NULL;
```

--view of average environmental conditions for the study:

~~-- this was taken into Tableau and the min, max and mean were calculated for each "treatment; for "baseline" choose the control sensor, for others choose the test sensors; date had to be truncated to the minute because the seconds did not match.~~

```
~~SELECT
"public".survey_data.treatment,
"public".comfort_sensor_data.sensor_id,
date_trunc('minute'::text, comfort_sensor_data.datetime) AS date_trunc,
Avg("public".comfort_sensor_data."value") AS "avg"~~
```

~~FROM (survey_data JOIN comfort_sensor_data ON ((date_trunc('minute'::text, survey_data.datetime) = date_trunc('minute'::text, comfort_sensor_data.datetime))))~~
~~WHERE (((comfort_sensor_data.datetime >= (survey_data.datetime - '00:10:00'::interval)) AND (comfort_sensor_data.datetime >= survey_data.datetime)) AND (((((comfort_sensor_data.sensor_id)::text ~~ 'CO2'::text) OR ((comfort_sensor_data.sensor_id)::text ~~ 'Globe%'::text)) OR ((comfort_sensor_data.sensor_id)::text ~~ 'Humidity%'::text)) OR ((comfort_sensor_data.sensor_id)::text ~~ 'RoomTemp%'::text)))~~
~~GROUP BY survey_data.treatment, comfort_sensor_data.sensor_id, date_trunc('minute'::text, comfort_sensor_data.datetime)~~
~~ORDER BY comfort_sensor_data.sensor_id~~

APPENDIX G

Results of Comfort Tests

(31 pages)

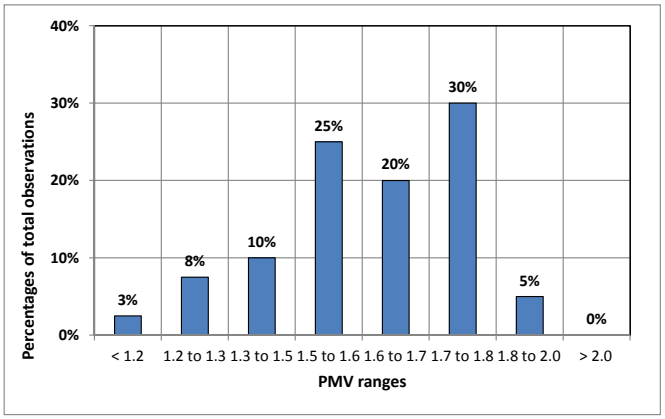
Summary of comfort test results:

Averages of values:		Baseline - Control Tests	Test with Fan at Level 2	Test with Fan at Level 3	Test with Radiant Panels NO Fan	Test with Radiant Panels and Fans at Level 2
PMV	[-]	1.62	0.37	0.35	1.18	0.27
Temperature perception WARMER than or EQUAL to PMV prediction	[%]	33%	35%	15%	10%	25%
Temperature perception COLDER than PMV prediction	[%]	68%	65%	85%	90%	75%
Percentage of conforming general comfort (PPD)	[%]	0%	60%	60%	5%	55%
Percentage of NON-conforming general comfort (PPD)	[%]	100%	40%	40%	95%	45%
Thermal sensation value >>>	[-]	1.40	-0.10	-0.55	0.15	-0.50
description >>>>		Closer to Slightly warm than Warm	Closer to Neutral than Slightly cool	Closer to Neutral than Slightly cool	Closer to Neutral than Slightly warm	Closer to Neutral than Slightly cool
Thermal acceptance value >>>	[-]	0.40	1.95	2.20	1.25	2.00
description >>>>		Closer to Neutral than Slightly acceptable	Closer to Moderately acceptable than Slightly acceptable	Closer to Moderately acceptable than Highly acceptable	Closer to Slightly acceptable than Moderately acceptable	Closer to Moderately acceptable than Moderately acceptable
Air movement acceptance value >>>	[-]	-0.10	1.60	1.65	0.20	1.80
description >>>>		Closer to Neutral than Slightly unacceptable	Closer to Moderately acceptable than Slightly acceptable	Closer to Moderately acceptable than Slightly acceptable	Closer to Neutral than Slightly acceptable	Closer to Moderately acceptable than Slightly acceptable
Air movement preference value >>>	[-]	0.90	0.20	-0.10	0.90	0.05
description >>>>		Closer to Want MORE air movement than Want No change	Closer to Want No change than Want MORE air movement	Closer to Want No change than Want LESS air movement	Closer to Want MORE air movement than Want No change	Closer to Want No change than Want MORE air movement
Numerical assessment of adaptive comfort:						
Conformant with adaptive comfort 80% criterion	[%]	100%	100%	100%	100%	100%
NOT Conformant with adaptive comfort 80% criterion	[%]	0%	0%	0%	0%	0%
All values are averages:						
Middle (e.g. expected) value of comfort standard	°C	26.5	26.6	26.6	26.5	26.5
Upper limit WITHOUT correction for air motion:	°C	30.0	30.1	30.1	30.0	30.0
Upper limit WITH correction for air motion:	°C	30.1	32.1	32.2	30.0	32.0
Correction of upper limit due to air movement	°C	No correction	2.0	2.1	No correction	2.0
Applicable upper limit	°C	30.1	32.1	32.2	30.0	32.0
Operative temperature	°C	29.6	29.6	29.6	28.2	30.1
Absolute deviation from middle	°C	3.0	3.1	3.0	1.7	3.6
Percentage of deviation from applicable upper limit	[%]	85%	56%	53%	50%	65%

				Bechmarking			Scenarios with different "Comfort Island" measures											
				Baseline - Control Tests			Test with Fan at Level 2			Test with Fan at Level 3			Test with Radiant Panels NO Fan			Test with Radiant Panels and Fans at Level 2		
Ranking group and individual criteria	Group ranking	Criterion ranking	Overall weight	value	criteria rank	overall rank	value	criteria rank	overall rank	value	criteria rank	overall rank	value	criteria rank	overall rank	value	criteria rank	overall rank
PMV	**30%**																	
PMV value		50%	**15%**	1.62	19%	3%	0.37	81%	12%	0.35	82%	12%	1.18	41%	6%	0.27	86%	13%
Ratio of conforming to non conforming		50%	**15%**	0.0	0%	0%	1.5	75%	11%	1.5	75%	11%	0.1	3%	0%	1.2	61%	9%
Adaptive comfort conformance assessment	**25%**																	
Percentage of operative temperature deviation from applicable upper limit		100%	**25%**	0.9	15%	4%	0.6	44%	11%	0.5	47%	12%	0.5	50%	13%	0.7	35%	9%
Response to thernal conditions	**30%**																	
Temperature perception		15%	**5%**	2.1	21%	1%	1.9	19%	1%	5.7	57%	3%	9.0	90%	4%	3.0	30%	1%
Thermal sensation		25%	**8%**	1.40	53%	4%	-0.10	97%	7%	-0.55	82%	6%	0.15	95%	7%	-0.50	83%	6%
Thermal acceptance		60%	**18%**	0.4	13%	2%	2.0	65%	12%	2.2	73%	13%	1.3	42%	8%	2.0	67%	12%
Response to air movement conditions	**15%**																	
Air movement acceptance		60%	**9%**	0.10	3%	0%	1.60	53%	5%	1.65	55%	5%	0.20	7%	1%	1.80	60%	5%
Air movement preference		40%	**6%**	0.9	10%	1%	0.2	80%	5%	-0.1	90%	5%	0.9	10%	1%	0.1	95%	6%
sums	**100%**		**100%**			**15%**			**64%**			**67%**			**39%**			**62%**
relative value of ranking									**4.3**			**4.6**			**2.7**			**4.2**
Rank by results									**2**			**1**			**4**			**3**

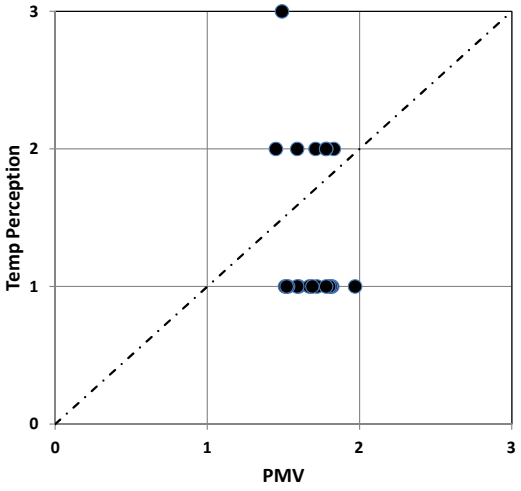
Summary of results for Baseline Scenario

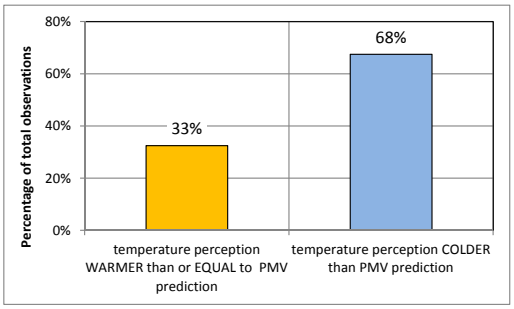
Frequency distribution of PMV



average PMV **1.62**

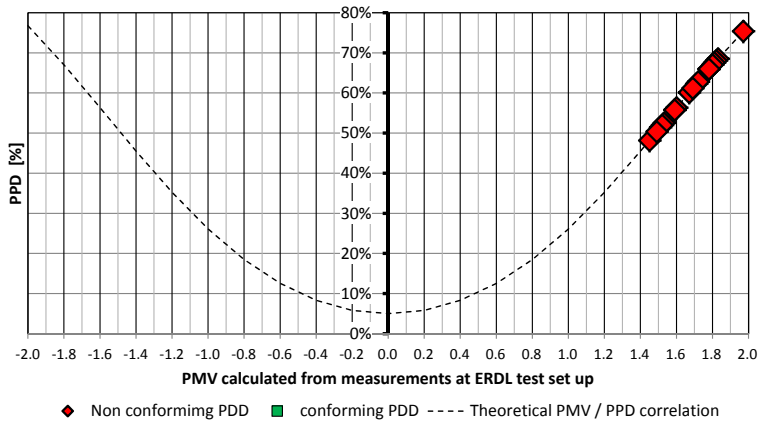
Correlation Temp Perception and PMV





temperature perception WARMER than or EQUAL to PMV prediction	33%
temperature perception COLDER than PMV prediction	68%

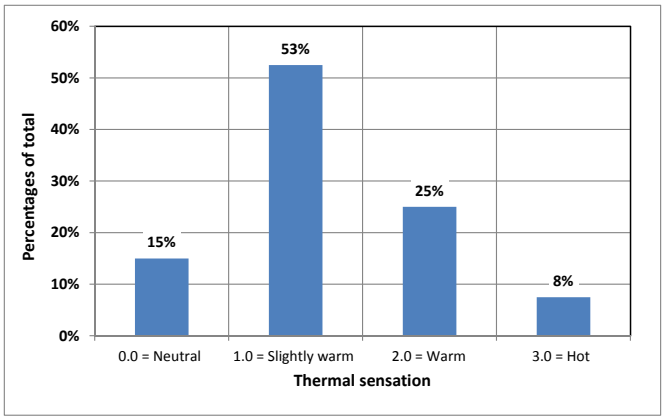
Graph of PMV versus PDD



Number of conforming and non-conforming measurements :

	Percental of total
Number of conforming general PPD:	0%
Number of NON-conforming general PPD	100%
sum	0%

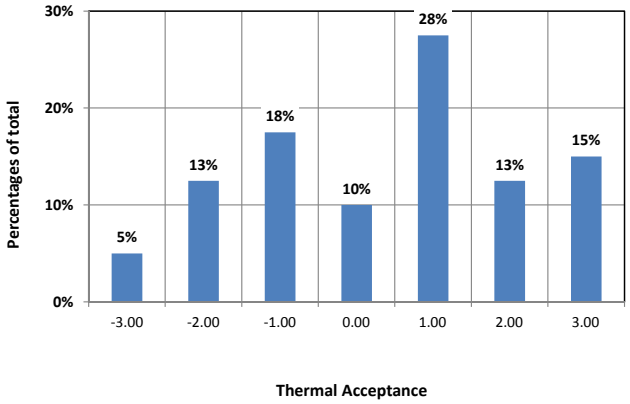
Frequency distribution of thermal sensation (or perception)



Average **1.40**

Hot	3
Warm	2
Slightly warm	1
Neutral	0
Slightly cool	-1
Cool	-2
Cold	-3

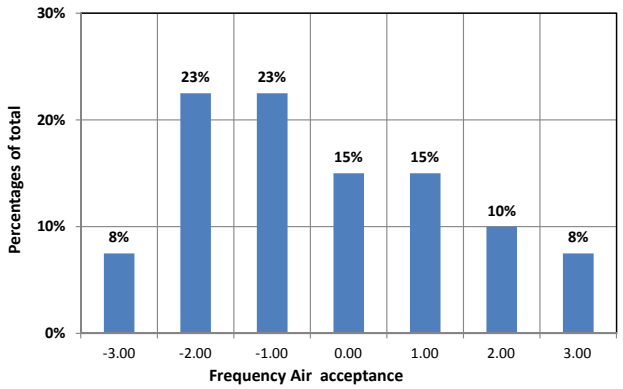
Frequency distribution of thermal acceptance



-3.0 = Highly unacceptable
-2.0 = Moderately unacceptable
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

Average **0.4**

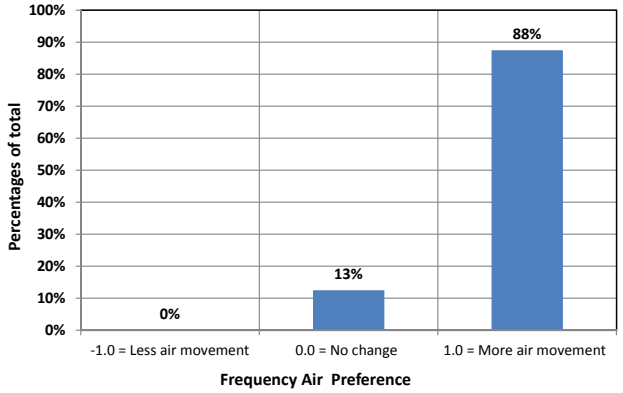
Frequency distribution of air movement acceptance



Average **-0.1**

-3.0 = Highly unacceptable
-2.0 = Moderately unacceptable
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

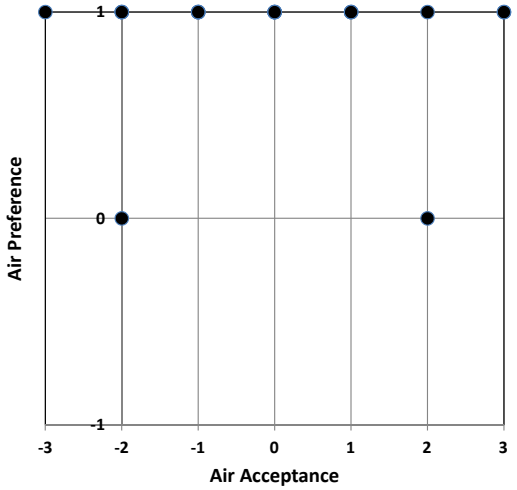
Frequency distribution of air movement preference



Average **0.9**

-1.0 = Less air movement
0.0 = No change
1.0 = More air movement

Correlation between air acceptance and air preference

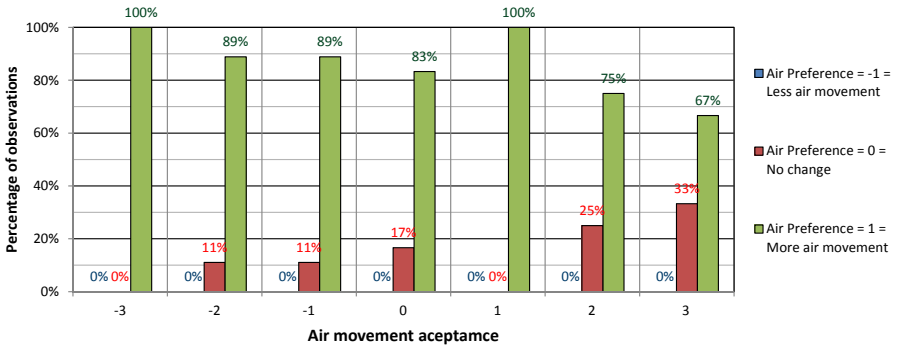


Legend:

Air movement acceptance:
-3.0 = Highly unacceptable
-2.0 = Moderately unacceptable
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

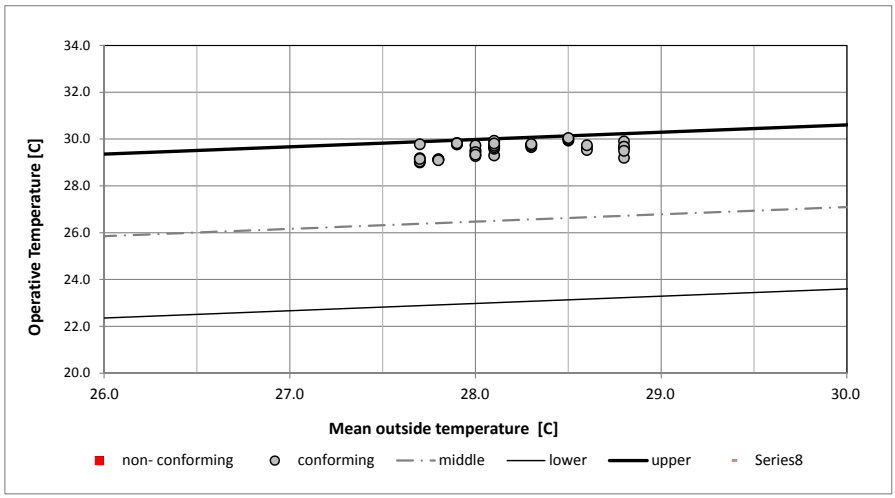
Air Preference
-1.0 = Less air movement
0.0 = No change
1.0 = More air movement

Percentage of Air Preference per Air Acceptance

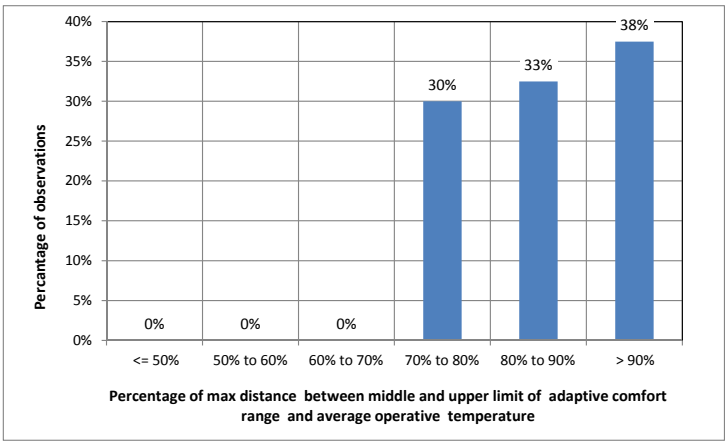


Air movement acceptance:
-3.0 = Highly unacceptable
-2.0 = Moderately unacceptable
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

Adaptive comfort: Baseline Cionditions

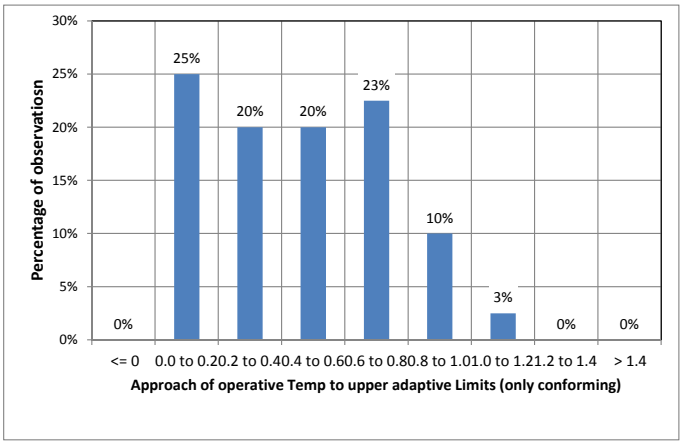


Number of test observations **inside** the 80% conformance limit:	100%
Number of test observations **outside** the 80% conformance limit:	0%



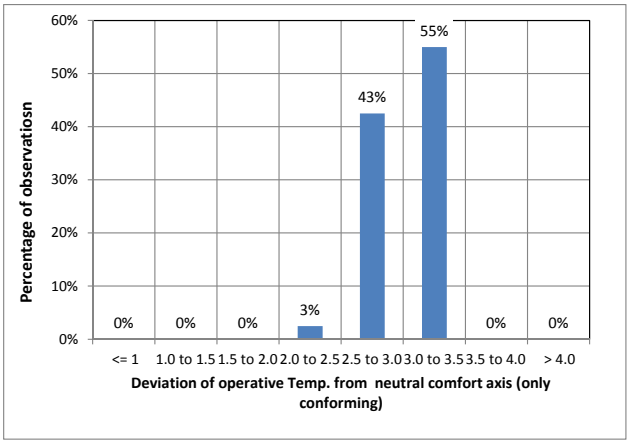
Proportion of distance between upper limit of adaptive comfort range (80%) occupied by average operative temperature

Average	87%
Max	98%
Min	71%



Approach of operative Temp to upper adaptive Limits (only conforming)

Average	0.47	C
Max	1.03	C
Min	0.08	C

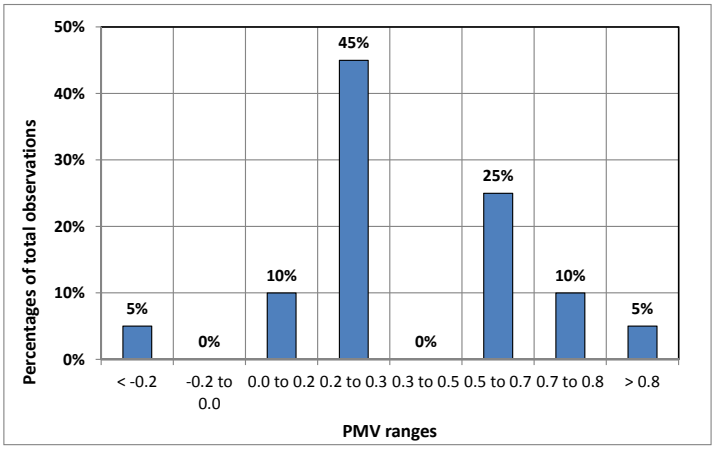


Deviation of operative Temp. from neutral comfort axis

Average	3.03	C
Max	3.42	C
Min	2.47	C

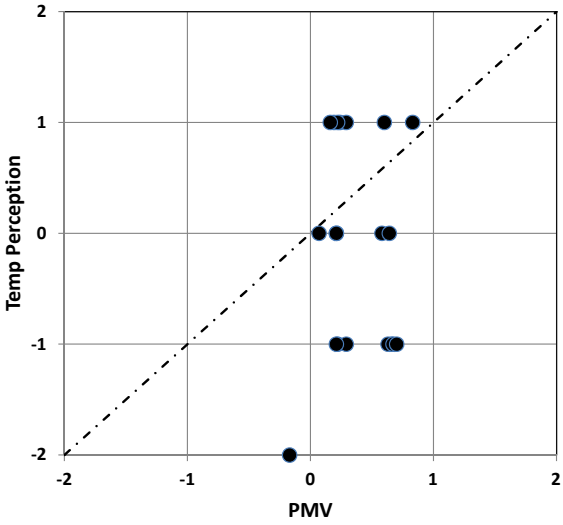
Summary of results for Fan at Speed 2 scenario

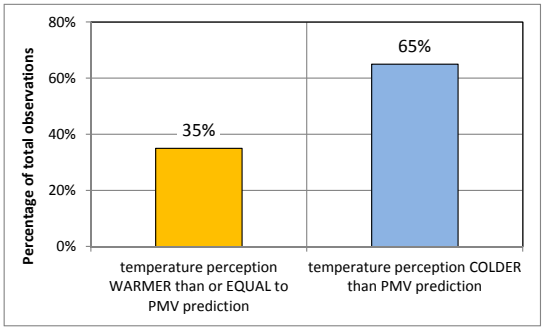
Frequency distribution of PMV



Average	0.37
Max	0.83
Min	-0.17

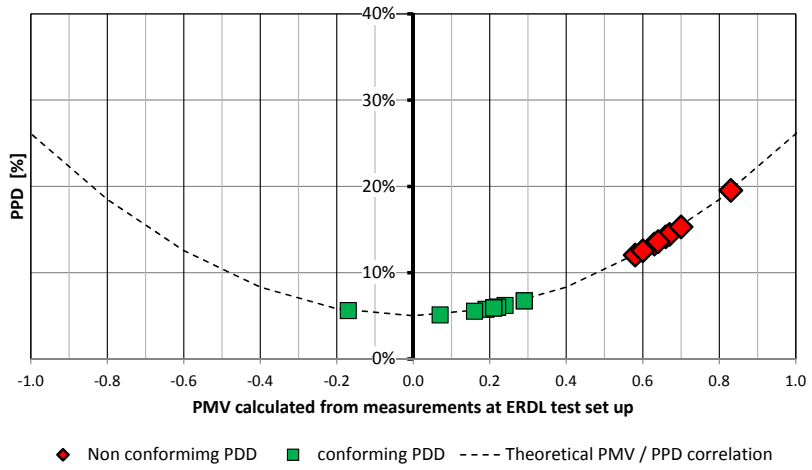
Correlation Temp Perception and PMV





temperature perception WARMER than or EQUAL to PMV prediction	35%
temperature perception COLDER than PMV prediction	65%

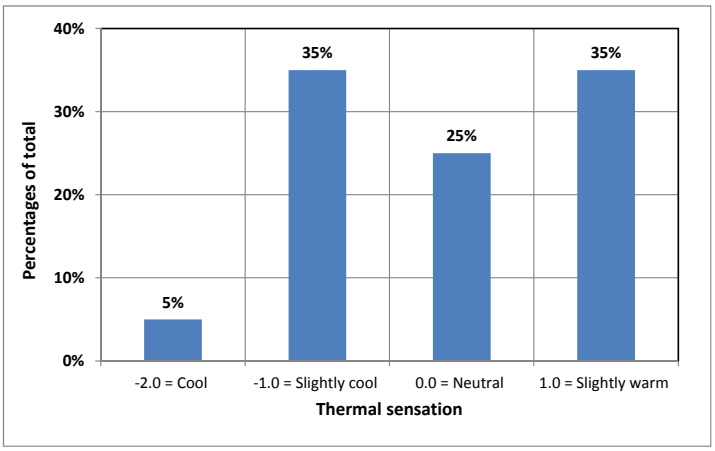
Graph of PMV versus PDD



Number of conforming and non-conforming measurements :

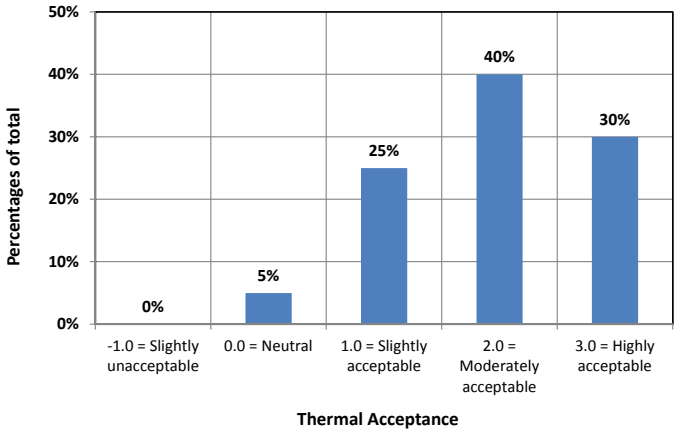
	Percental of total
Number of conforming general PPD:	60%
Number of NON-conforming general PPD	40%
sum	100%

Frequency distribution of thermal sensation (or perception)



Average	-0.10
Max	1.00
Min	-2.00

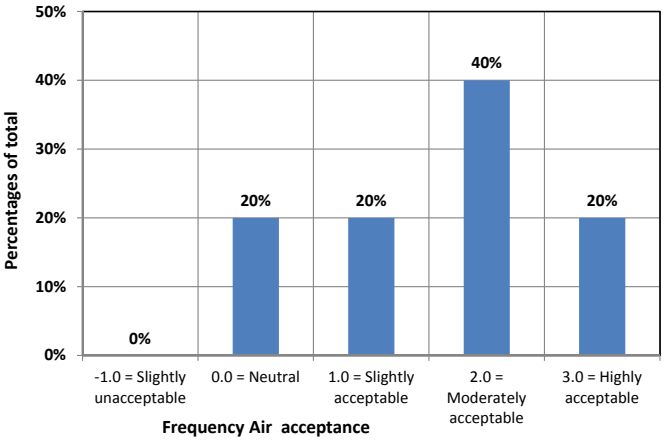
Frequency distribution of thermal acceptance



Average	1.95
Max	3.00
Min	0.00

Average 2.0

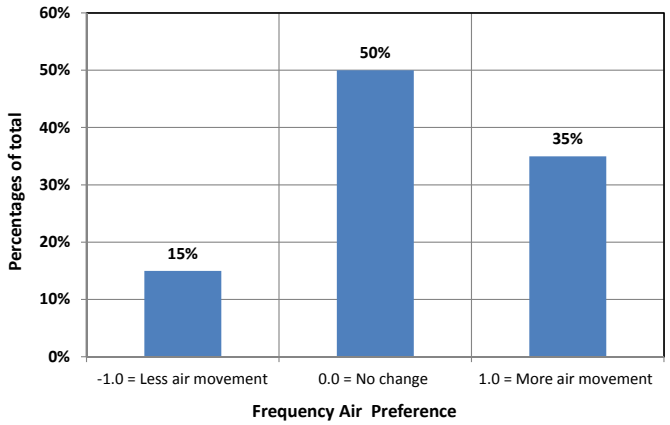
Frequency distribution of air movement acceptance



Average	1.60
Max	3.00
Min	0.00

Average 1.6

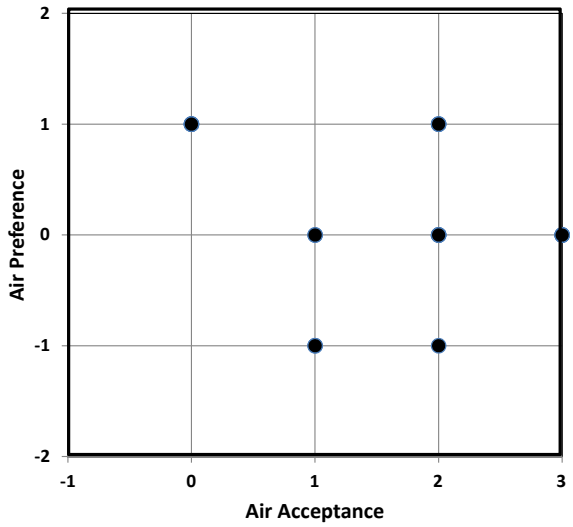
Frequency distribution of air movement preference



Average	0.20
Max	0.00
Min	0.00

Average **0.2**

Correlation between air acceptance and air preference

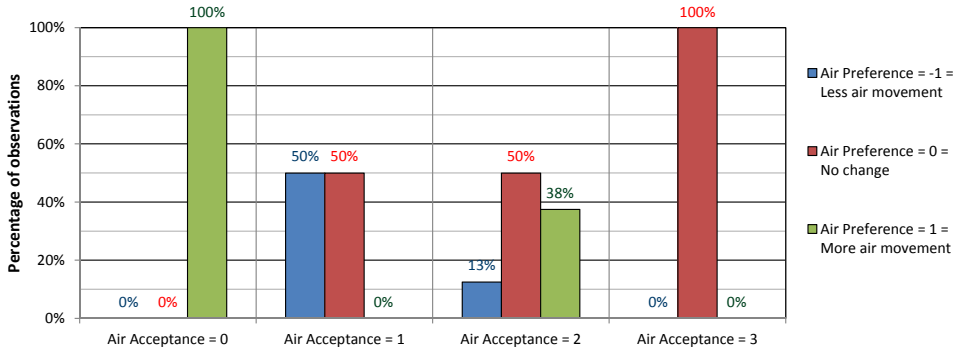


Legend:

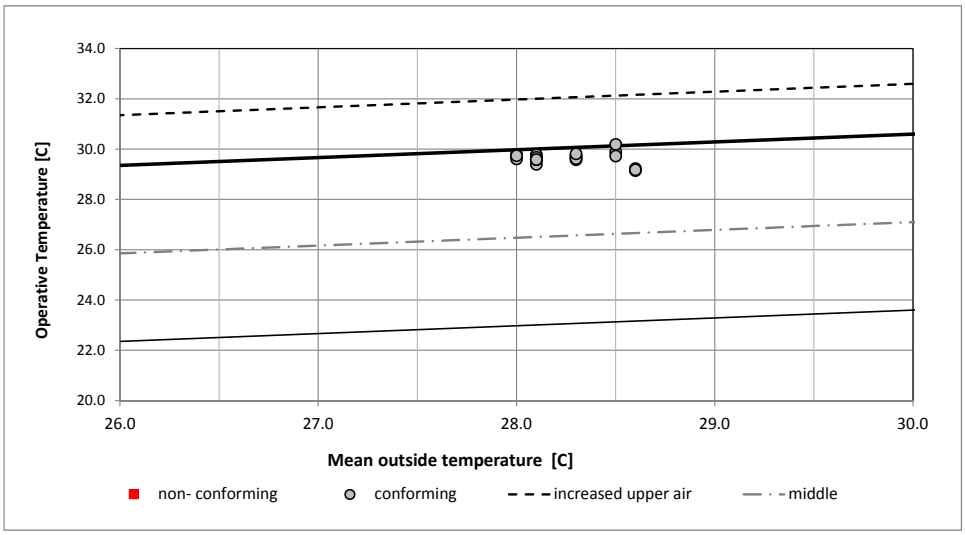
Air Acceptance:
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

Air Preference
-1.0 = Less air movement
0.0 = No change
1.0 = More air movement

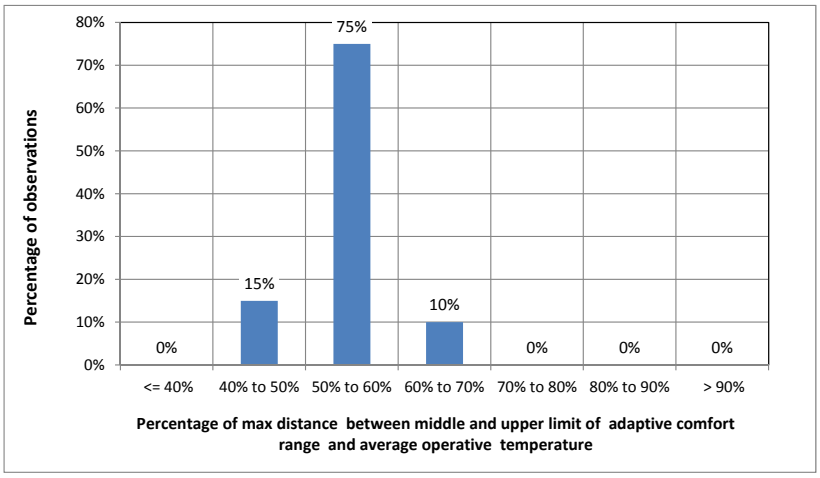
Percentage of Air Preference per Air Acceptance



Adaptive comfort: Fans Level 2

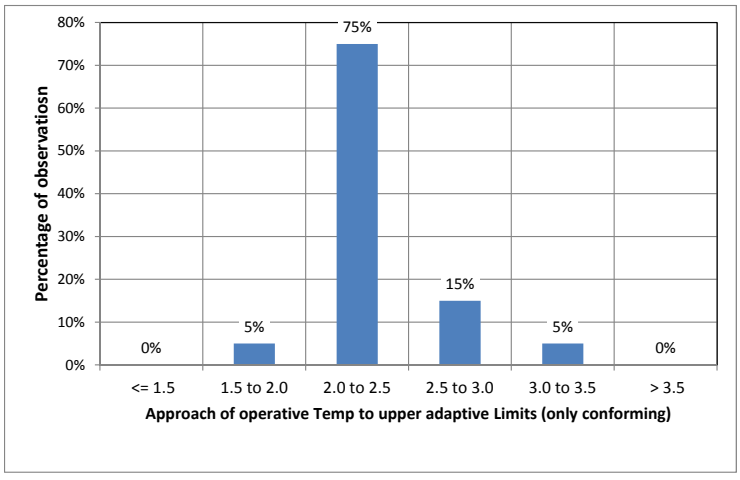


Number of test observations **inside** the 80% conformance limit:	100%
Number of test observations **outside** the 80% conformance limit:	0%



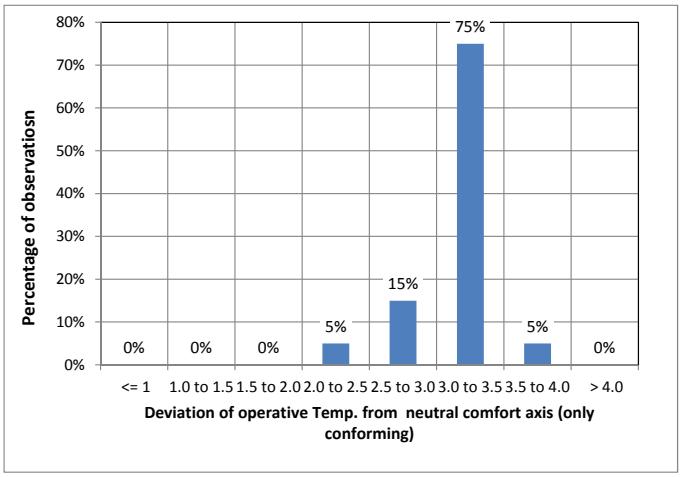
Proportion of distance between upper limit of adaptive comfort range (80%) occupied by average operative temperature

Average	56%
Max	65%
Min	45%



Approach of operative Temp to upper adaptive Limits (only conforming)

Average	2.44	C
Max	3.02	C
Min	1.94	C

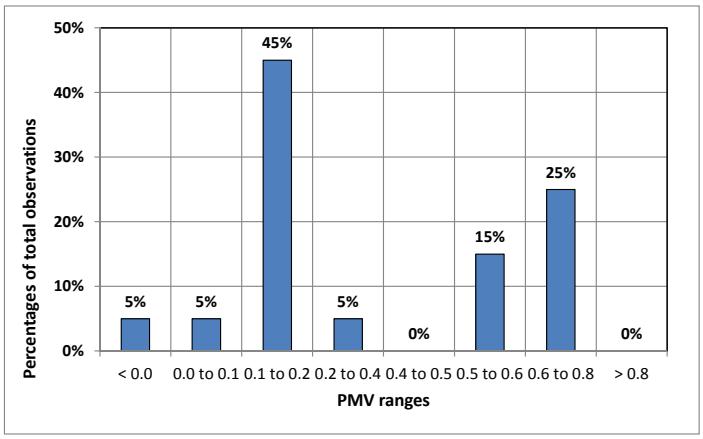


Deviation of operative Temp. from neutral comfort axis

Average	3.06	C
Max	3.56	C
Min	2.48	C

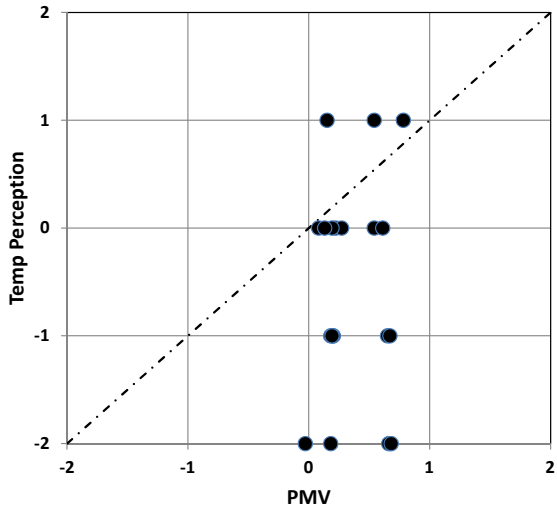
Summary of results for Fan at Speed 3 scenario

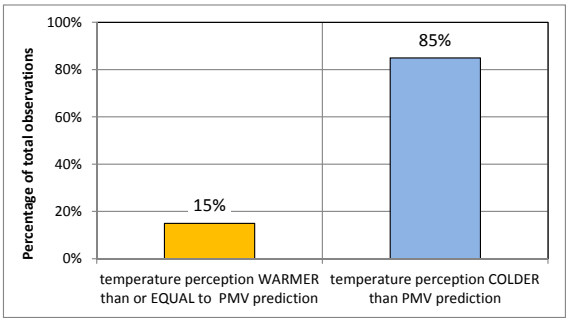
Frequency distribution of PMV



Average	0.35
Max	0.78
Min	-0.03

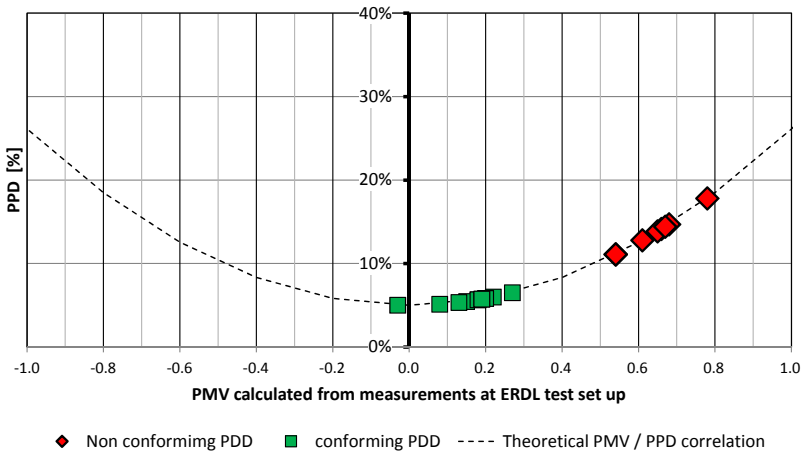
Correlation Temp Perception and PMV





temperature perception WARMER than or EQUAL to PMV prediction	15%
temperature perception COLDER than PMV prediction	85%

Graph of PMV versus PDD

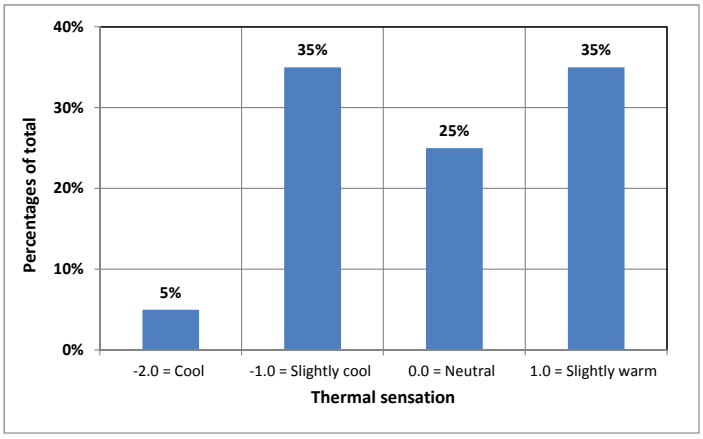


Number of conforming and non-conforming measurements :

	Percental of total
Number of conforming general PPD:	60%
Number of NON-conforming general PPD	40%
sum	100%

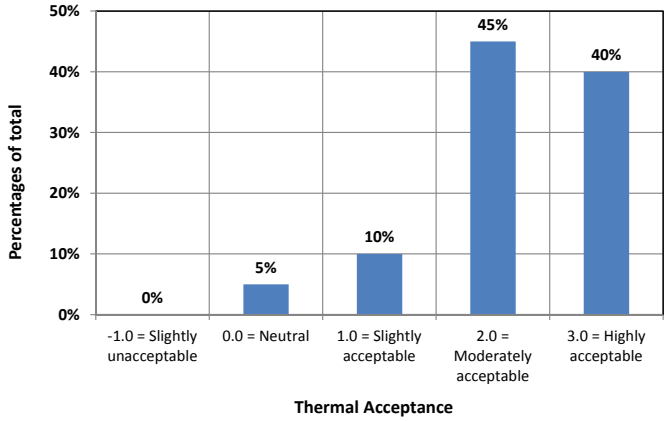
0

Frequency distribution of thermal sensation (or perception)



Average	-0.55
Max	1.00
Min	-2.00

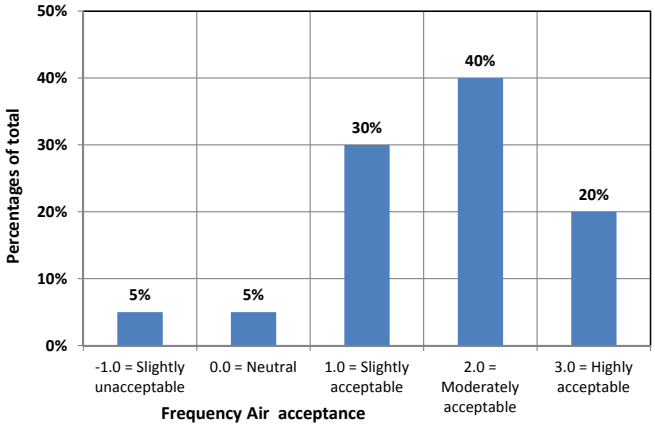
Frequency distribution of thermal acceptance



Average	2.20
Max	3.00
Min	0.00

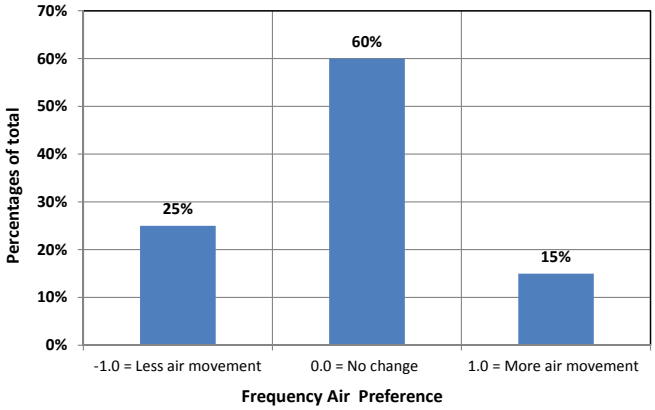
Average 2.2

Frequency distribution of air movement acceptance



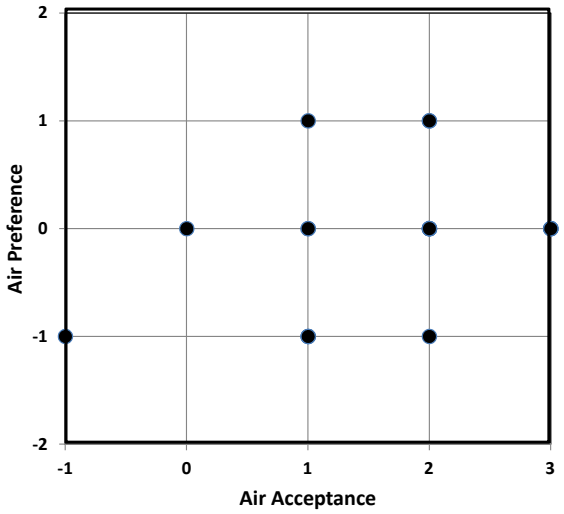
Average	1.65
Max	3.00
Min	-1.00

Frequency distribution of air movement preference



Average **-0.1**

Correlation between air acceptance and air preference

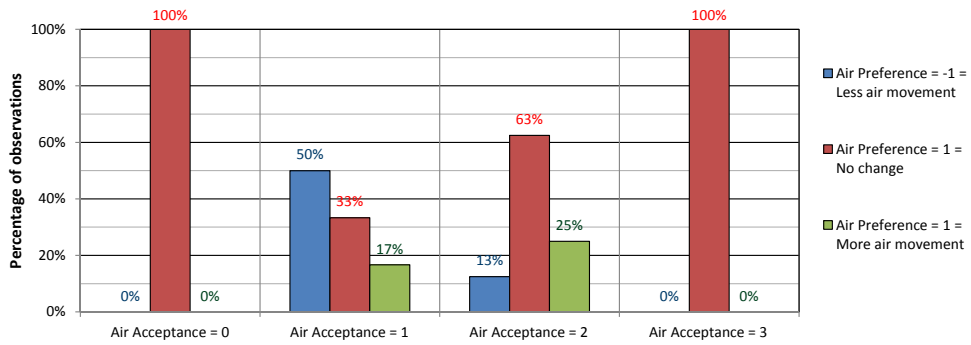


Legend:

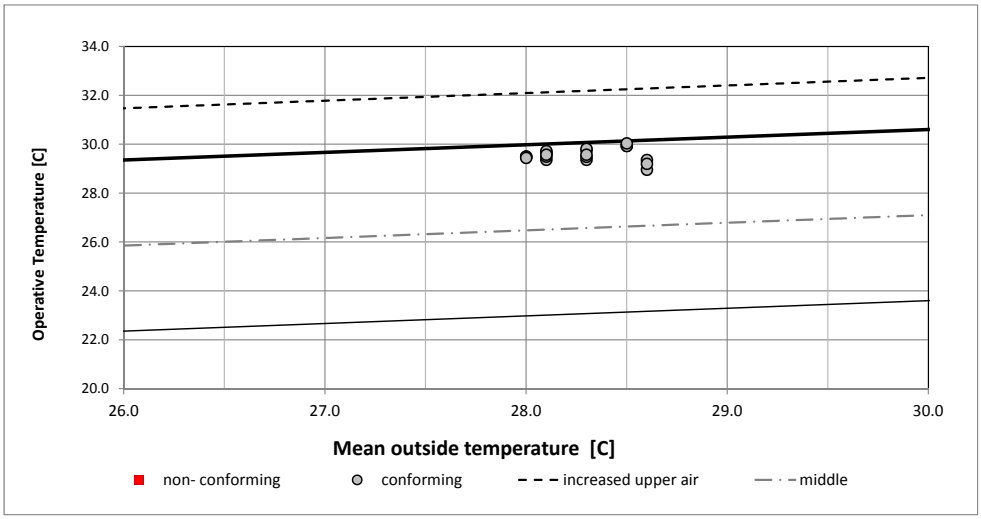
Air Acceptance:
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

Air Preference
-1.0 = Less air movement
0.0 = No change
1.0 = More air movement

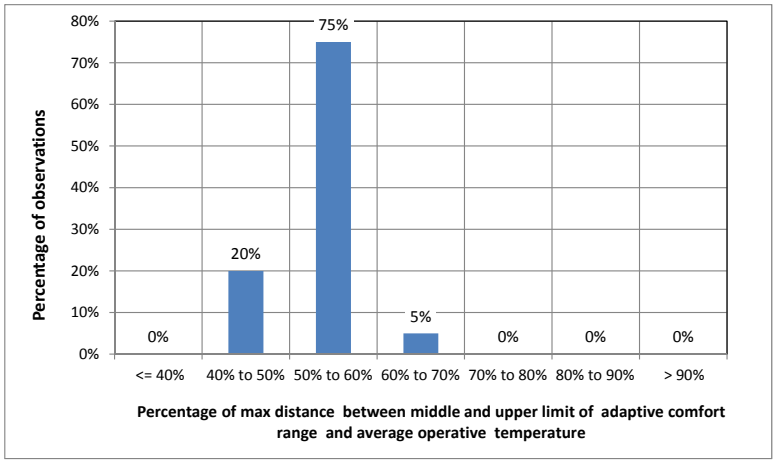
Percentage of Air Preference per Air Acceptance



Adaptive comfort: Fans Level 3

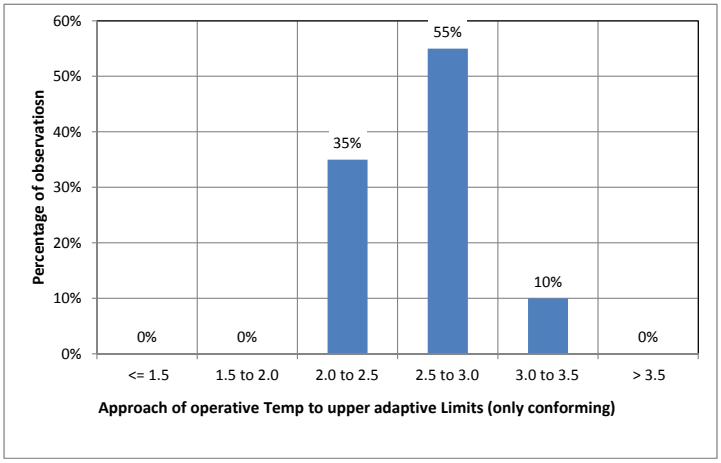


Number of test observations **inside** the 80% conformance limit:	100%
Number of test observations **outside** the 80% conformance limit:	0%



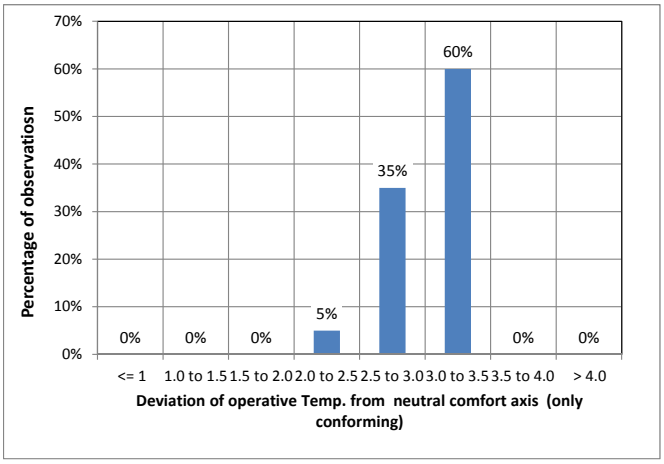
Proportion of distance between upper limit of adaptive comfort range (80%) occupied by average operative temperature

Average	53%
Max	61%
Min	41%



Approach of operative Temp to upper adaptive Limits (only conforming)

Average	2.61	C
Max	3.32	C
Min	2.21	C

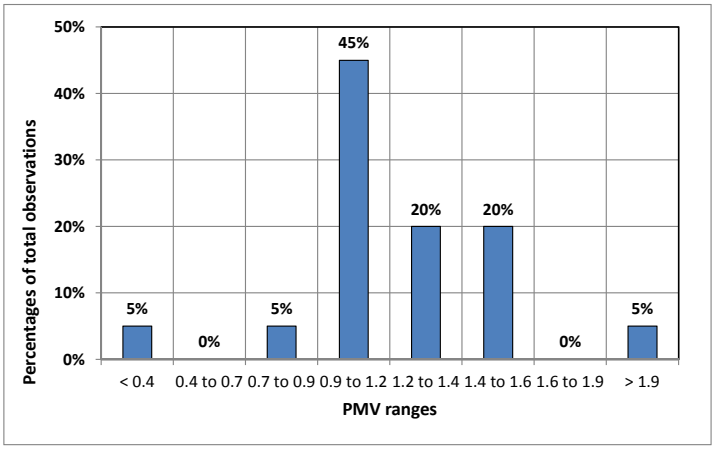


Deviation of operative Temp. from neutral comfort axis

Average	3.00	C
Max	3.41	C
Min	2.30	C

Summary of results for Panel ONLY scenario

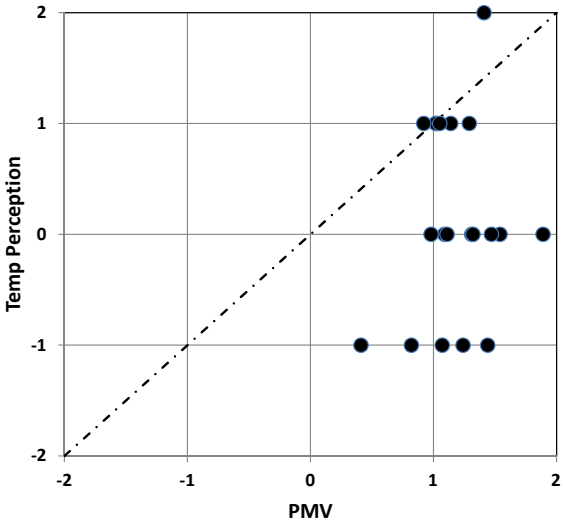
Frequency distribution of PMV

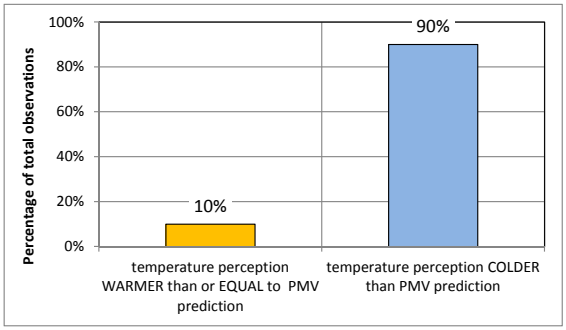


Average	1.18
Max	1.89
Min	0.41

average PMV **1.18**

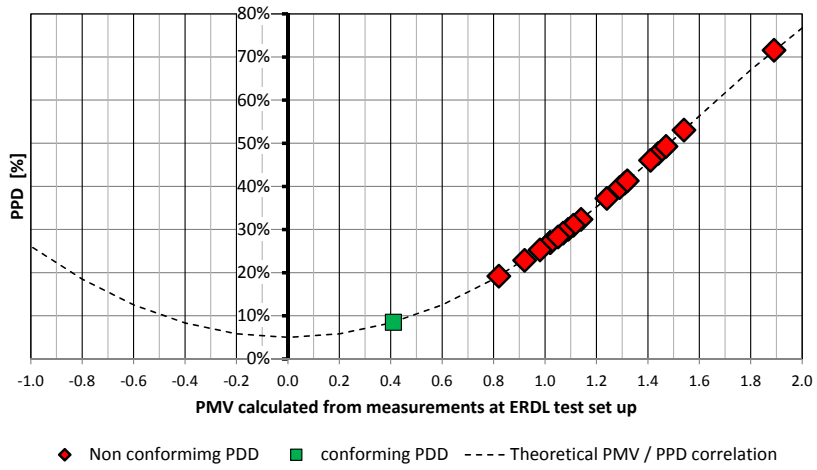
Correlation Temp Perception and PMV





temperature perception WARMER than or EQUAL to PMV prediction	10%
temperature perception COLDER than PMV prediction	90%

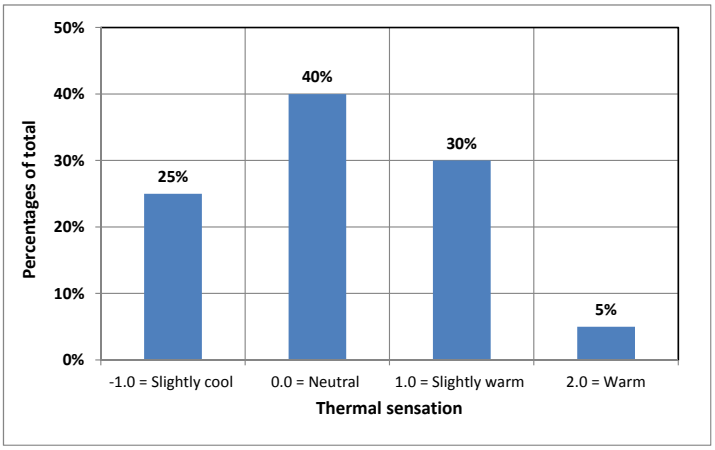
Graph of PMV versus PDD



Number of conforming and non-conforming measurements :

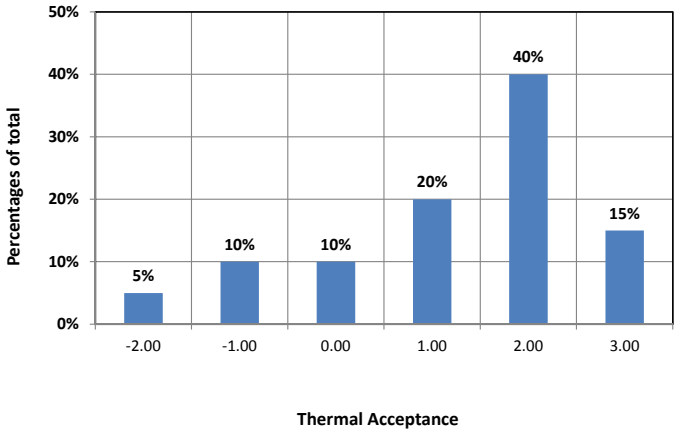
	Percental of total
Number of conforming general PPD:	5%
Number of NON-conforming general PPD	95%
sum	100%

Frequency distribution of thermal sensation (or perception)



Average	0.15
Max	2.00
Min	-1.00

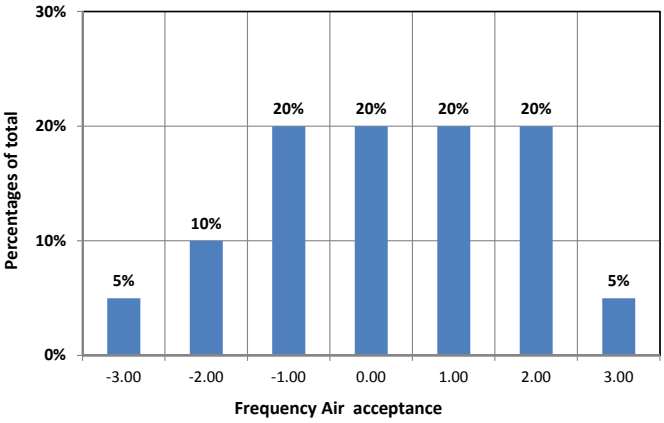
Frequency distribution of thermal acceptance



Average	1.25
Max	3.00
Min	-2.00

-2.0 = Moderately unacceptable
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

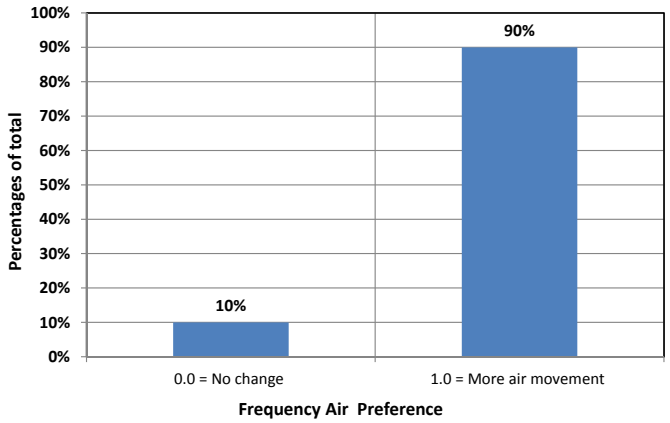
Frequency distribution of air movement acceptance



Average	0.20
Max	3.00
Min	-3.00

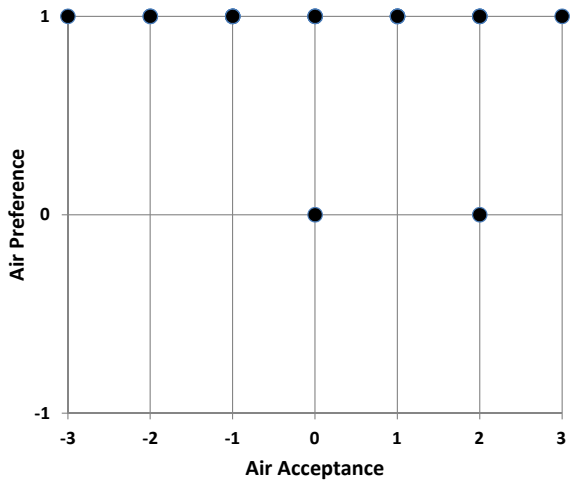
-3.0 = Highly unacceptable
-2.0 = Moderately unacceptable
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

Frequency distribution of air movement preference



Average 0.9

Correlation between air acceptance and air preference

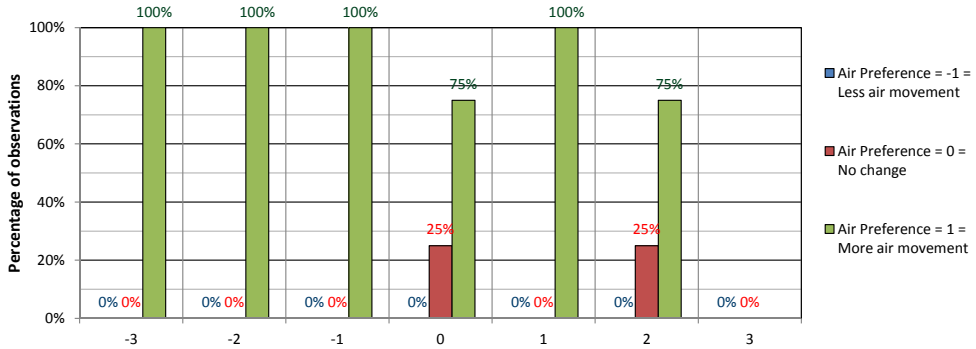


Legend:

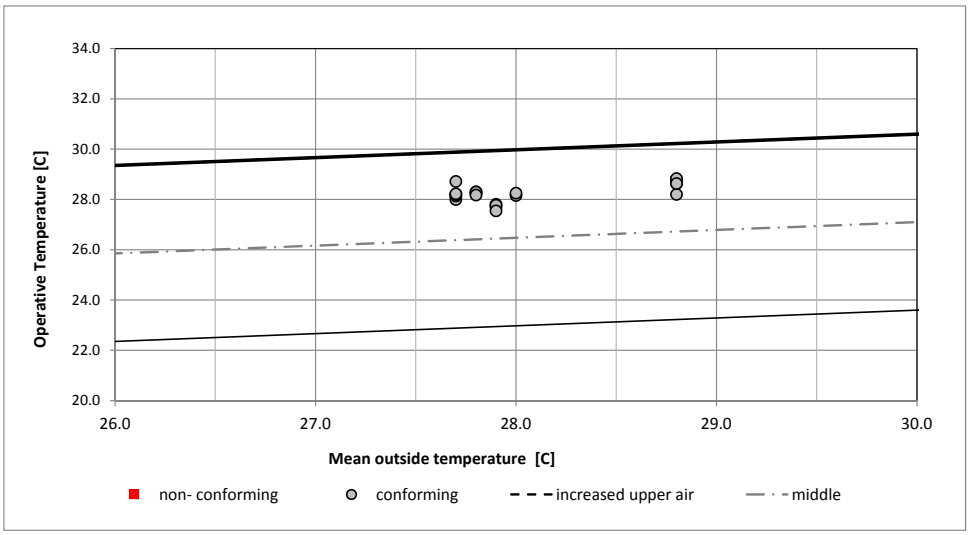
Air Acceptance:
-3.0 = Highly unacceptable
-2.0 = Moderately unacceptable
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

Air Preference
0.0 = No change
1.0 = More air movement

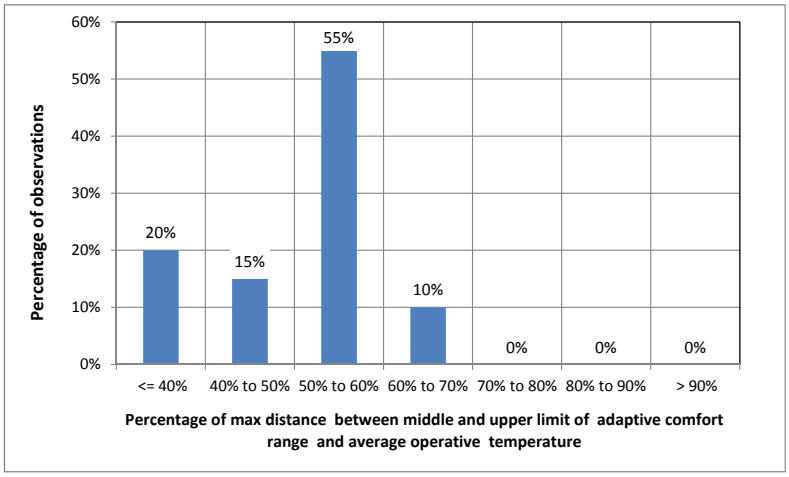
Percentage of Air Preference per Air Acceptance



Adaptive comfort: ONLY Panels

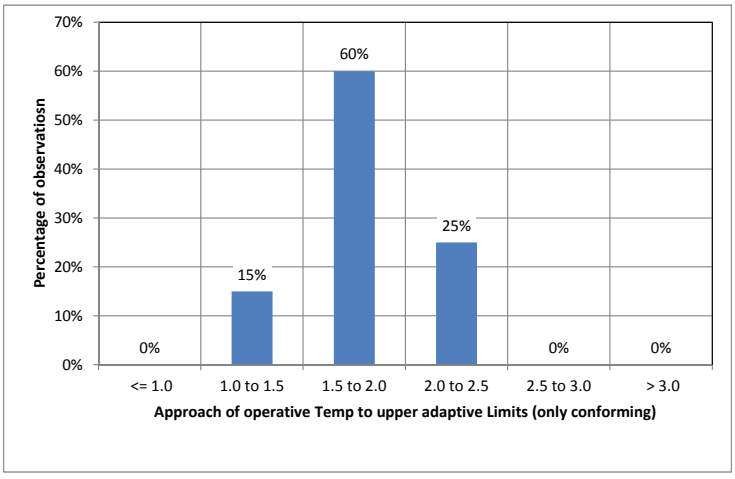


Number of test observations **inside** the 80% conformance limit:	100%
Number of test observations **outside** the 80% conformance limit:	0%



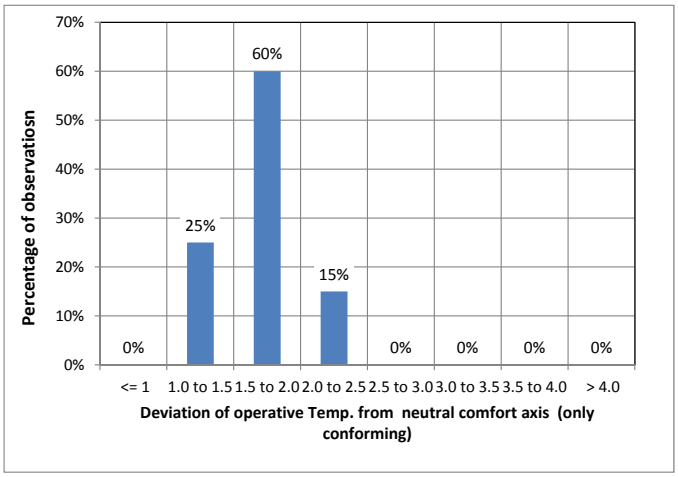
Proportion of distance between upper limit of adaptive comfort range (80%) occupied by average operative temperature

Average	50%
Max	67%
Min	31%



Approach of operative Temp to upper adaptive Limits (only conforming)

Average	1.77	C
Max	2.40	C
Min	1.17	C

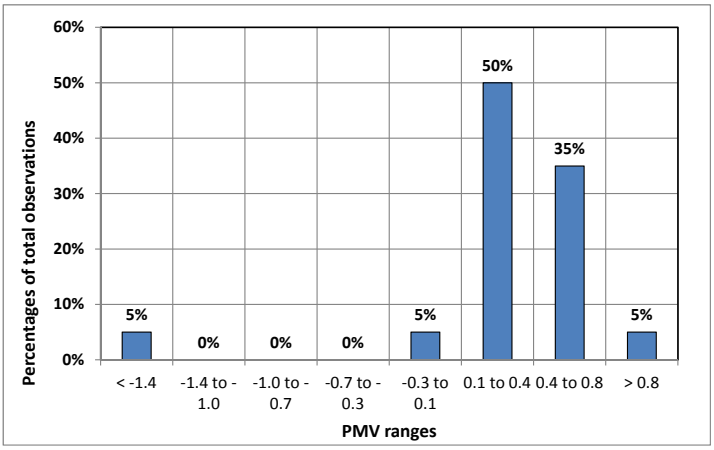


Deviation of operative Temp. from neutral comfort axis

Average	1.73	C
Max	2.33	C
Min	1.10	C

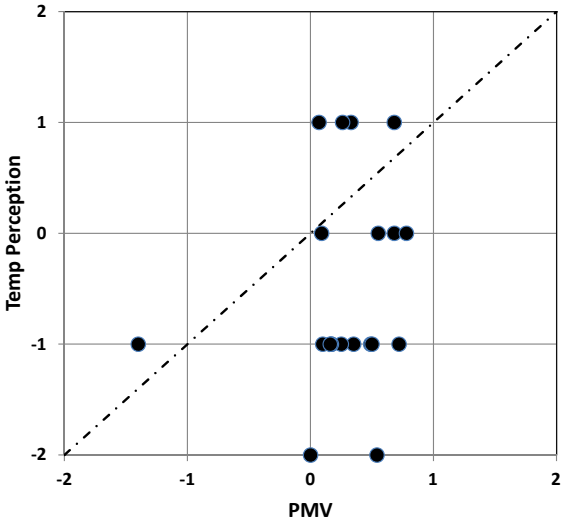
Summary of results for Panel And Fans at Speed 2 scenario

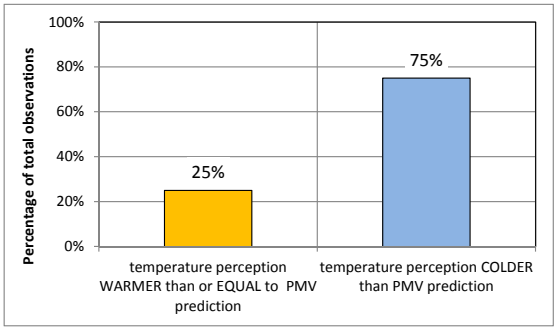
Frequency distribution of PMV



PMV	0.27
Max	0.78
Min	-1.40

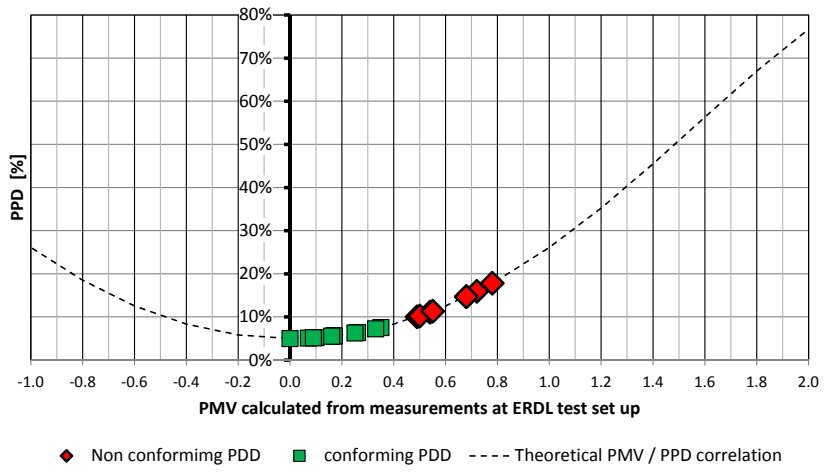
Correlation Temp Perception and PMV





temperature perception WARMER than or EQUAL to PMV prediction	25%
temperature perception COLDER than PMV prediction	75%

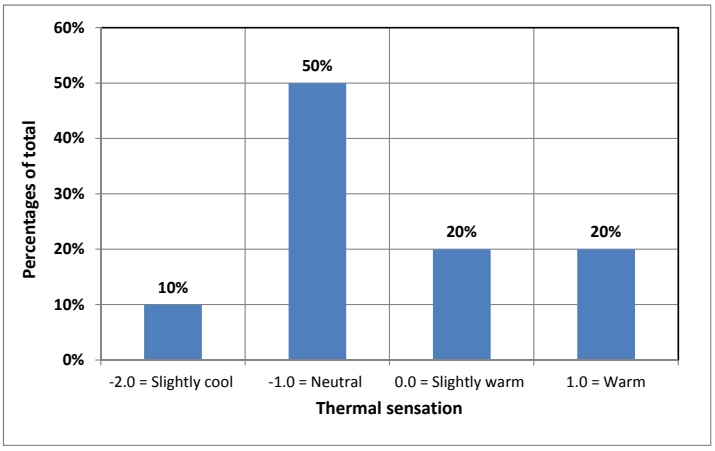
Graph of PMV versus PDD



Number of conforming and non-conforming measurements :

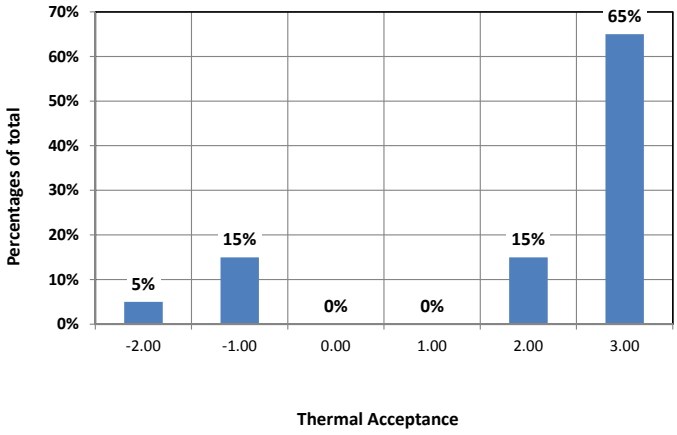
	Percental of total
Number of conforming general PPD:	55%
Number of NON-conforming general PPD	45%
sum	100%

Frequency distribution of thermal sensation (or perception)



Average	-0.50
Max	1.00
Min	-2.00

Frequency distribution of thermal acceptance

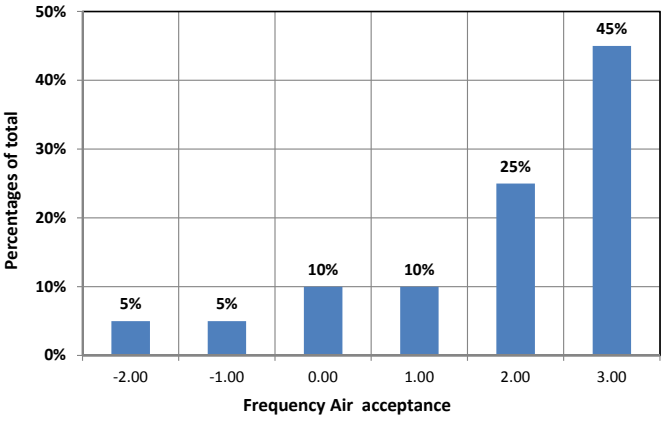


Average	2.00
Max	3.00
Min	-2.00

-2.0 = Moderately unacceptable
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

Average 2.0

Frequency distribution of air movement acceptance

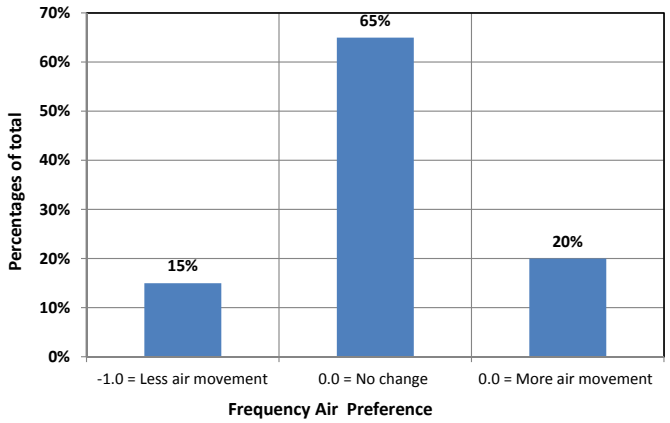


Average	1.80
Max	3.00
Min	-2.00

-2.0 = Moderately unacceptable
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

Average 1.8

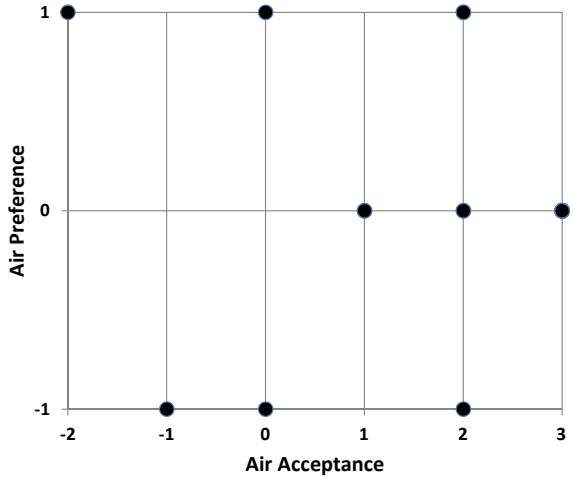
Frequency distribution of air movement preference



Average	0.1

Average

Correlation between air acceptance and air preference



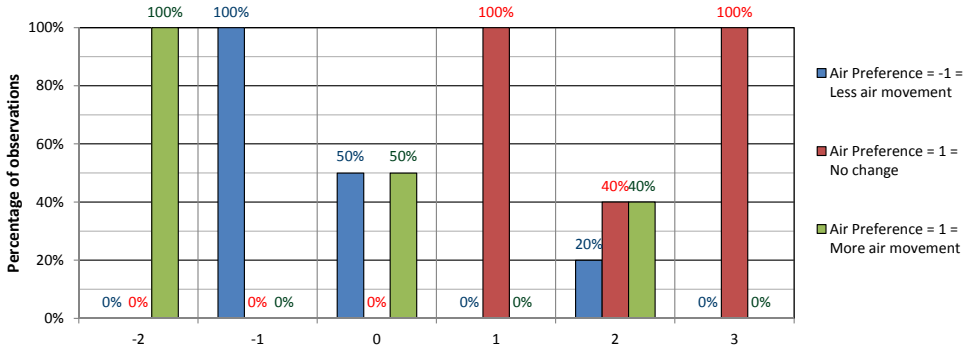
Legend:

Air Acceptance:

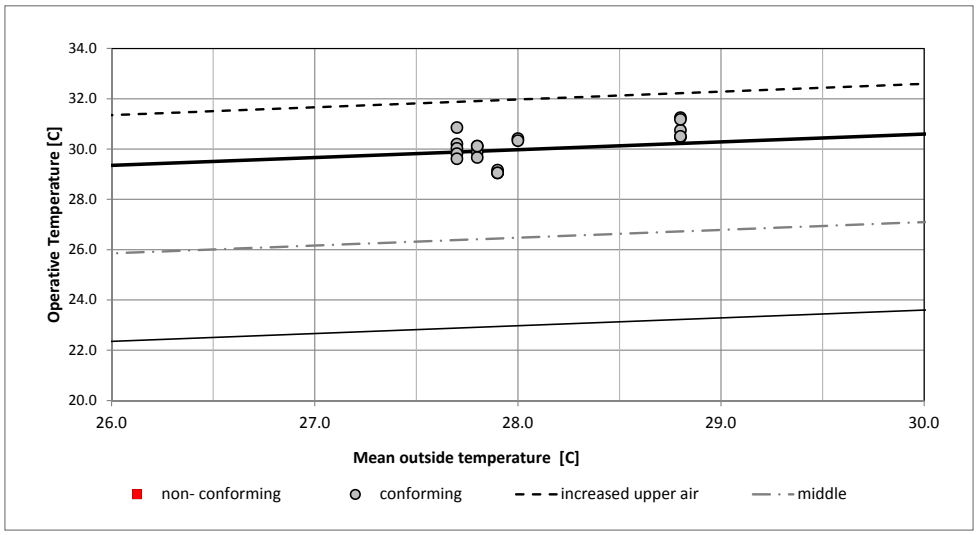
-2.0 = Moderately unacceptable
-1.0 = Slightly unacceptable
0.0 = Neutral
1.0 = Slightly acceptable
2.0 = Moderately acceptable
3.0 = Highly acceptable

Air Preference
-1.0 = Less air movement
0.0 = No change

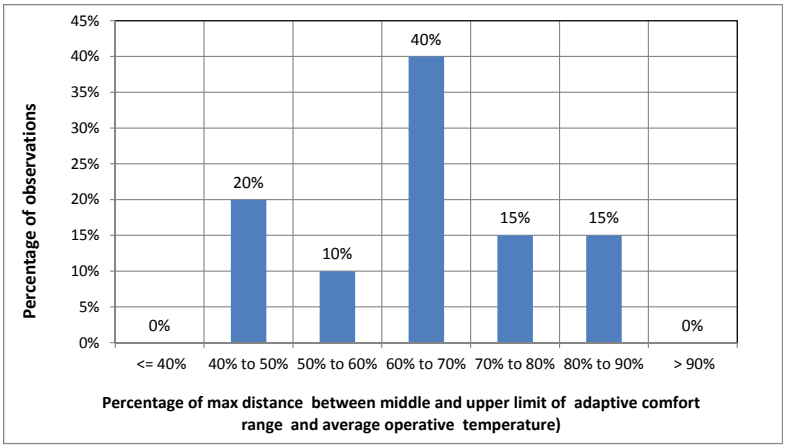
Percentage of Air Preference per Air Acceptance



Adaptive comfort: Panels and Fan Level 2

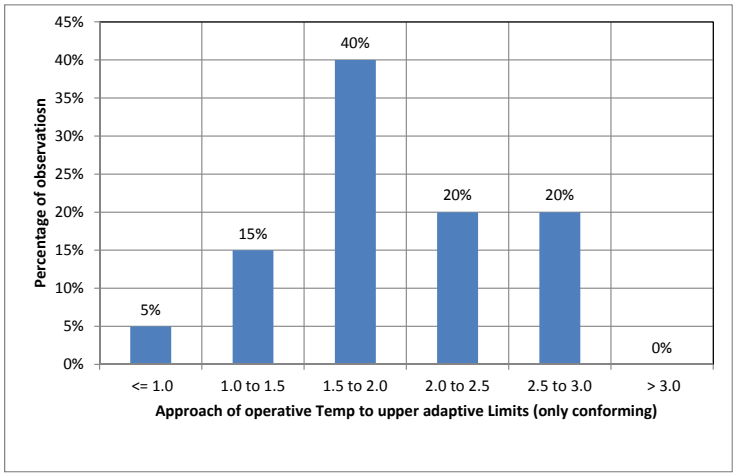


Number of test observations **inside** the 80% conformance limit:	100%
Number of test observations **outside** the 80% conformance limit:	0%



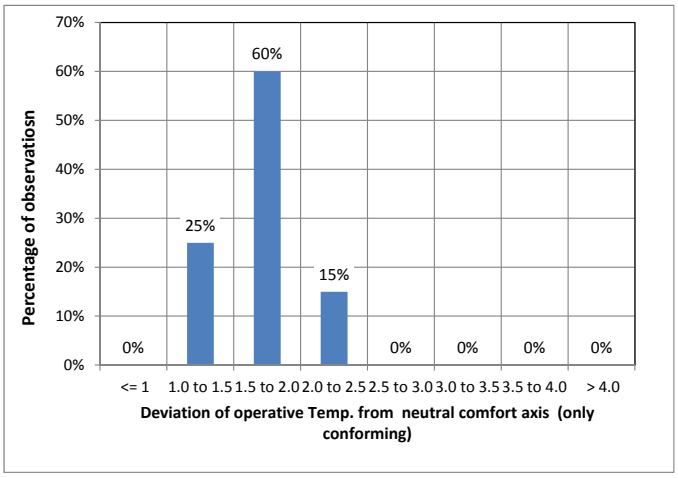
Proportion of distance between upper limit of adaptive comfort range (80%) occupied by average operative temperature

Average	65%
Max	82%
Min	47%



Approach of operative Temp to upper adaptive Limits (only conforming)

Average	1.92	C
Max	2.90	C
Min	0.97	C



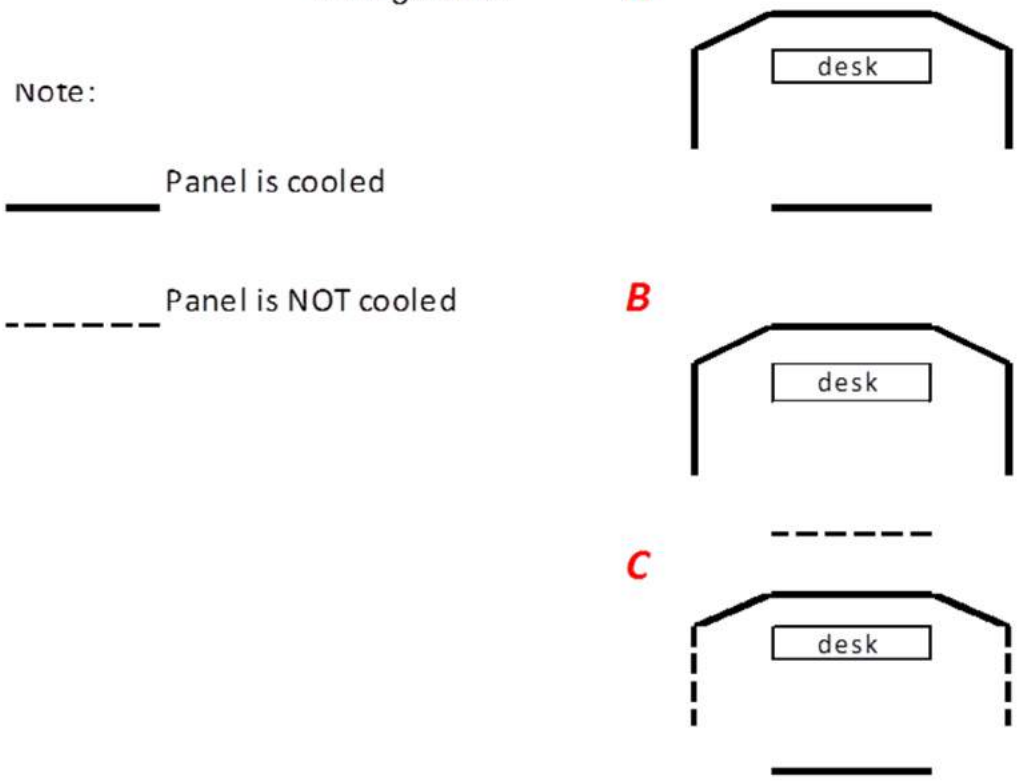
Deviation of operative Temp. from neutral comfort axis

Average	3.58	C
Max	4.53	C
Min	2.60	C

Appendix H

Results of CFD simulations of Comfort Scenarios

Parameters for Setting Up CFD Simulation Scenarios						
			low			high
ceiling fans:	fans speed		1	2	3	4
Panel configurations						
	configuration		A			
Note:						
Panel is cooled						
Panel is NOT cooled			B			
			C			
Panel temperature range			warm		cold	
	Temperatures		1	2		
	{F°}		72	68		
Room temperature			warm			warmer
	Temperatures		1			2
	Air	{F°}	80			85
	Wall	{F°}	80			85
	Floor	{F°}	77			82
	Ceiling	{F°}	78			83



Test matrix of CFD simulations:

Comfort based = Physical without test person

e.g. testing comfort response

Only Panels:

objective: Test comfort sensation of test person

approach: rund CFD simulations with dummy

Scenario ID	ceiling fan speed	panel configuration	panel temperature	Room temperature	PMV	PDD
B1	No fan	**A**	1	1	0.48	10%
B2	No fan	**A**	1	2	0.87	21%
B3	No fan	**B**	1	1	0.55	11%
B4	No fan	**B**	1	2	-0.28	7%
B5	No fan	**C**	1	1	0.62	13%
B6	No fan	**C**	1	2	0.84	20%

Only ceiling fans:

objective: Test comfort sensation of test person

approach: rund CFD simulations with dummy

	ceiling fan speed	panel configuration	panel temperature	Room temperature	PMV	PDD
B9	1	**A**	room temp	1	0.89	22%
B10	2	A	room temp	1	0.96	25%
B11	3	**A**	room temp	1	0.82	19%
B12	4	A	room temp	1	1.32	21%

Combined ceiling fan and panels:

objective: Test comfort sensation of test person

approach: rund CFD simulations with dummy

	ceiling fan speed	panel configuration	panel temperature	Room temperature	PMV	PDD
B13	2	**A**	1	2	1.24	37%
B14	2	**A**	2	2	1.00	26%
B15	4	**A**	1	2	1.45	48%
B16	4	**A**	2	2	1.26	38%
B17	2	**B**	1	2	1.34	43%
B18	2	**B**	2	2	1.06	29%
B19	4	**B**	1	2	1.62	57%
B20	4	**B**	2	2	1.31	41%

Test Scenario B1

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	27
Mean radiant temperature	{C}	26
Relative air velocity	{m/s}	0.03
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.30
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.33
Total heat transfer coefficient of skin	{W/m2.K}	7.62
Total heat transfer coefficient of clothing	{W/m2.K}	6.89
Skin temperature	{C}	34.1
Clothing temperature	{C}	30.7
Vapor pressure of air	{kPa}	2.496

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	13.5	21.6
Heat loss by radiation (R)	24.7	39.6
Heat loss from vapor difussion through skin (Edif)	8.6	13.8
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	3.4	5.4
Convective heat loss from respiration (Cres)	0.6	0.9
Total Heat Loss	**50.8**	**81.3**

Heat Load	**7.3**
PMV	**0.48**
PPD (%)	**9.8**

Test Scenario B2

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	28
Mean radiant temperature	{C}	26
Relative air velocity	{m/s}	0.04
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.10
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.35
Total heat transfer coefficient of skin	{W/m2.K}	7.45
Total heat transfer coefficient of clothing	{W/m2.K}	6.73
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.1
Vapor pressure of air	{kPa}	2.691

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	9.8	15.7
Heat loss by radiation (R)	23.3	37.3
Heat loss from vapor difussion through skin (Edif)	8.0	12.8
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	3.2	5.1
Convective heat loss from respiration (Cres)	0.5	0.7
Total Heat Loss	**44.8**	**71.6**

Heat Load	**13.4**
PMV	**0.87**
PPD (%)	**21.1**

Test Scenario B3

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	27.1
Mean radiant temperature	{C}	25.9
Relative air velocity	{m/s}	0.03
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.30
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.33
Total heat transfer coefficient of skin	{W/m2.K}	7.63
Total heat transfer coefficient of clothing	{W/m2.K}	6.89
Skin temperature	{C}	34.1
Clothing temperature	{C}	30.8
Vapor pressure of air	{kPa}	2.510

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	58.2	93.0

Skin	{W/m2}	{W}
Heat loss by convection (C)	13.5	21.6
Heat loss by radiation (R)	23.7	37.9
Heat loss from vapor difussion through skin (Edif)	8.6	13.7
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	3.4	5.4
Convective heat loss from respiration (Cres)	0.6	0.9
Total Heat Loss	49.7	79.5

Heat Load	8.5
PMV	0.55
PPD (%)	11.4

Test Scenario B4

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.8
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	23.3
Mean radiant temperature	{C}	25.7
Relative air velocity	{m/s}	0.03
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.81
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.31
Total heat transfer coefficient of skin	{W/m2.K}	8.12
Total heat transfer coefficient of clothing	{W/m2.K}	7.34
Skin temperature	{C}	34.1
Clothing temperature	{C}	29.9
Vapor pressure of air	{kPa}	2.002

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	104.7
Total Heat Generation	58.2	104.7

Skin	{W/m2}	{W}
Heat loss by convection (C)	27.8	50.0
Heat loss by radiation (R)	19.8	35.6
Heat loss from vapor difussion through skin (Edif)	10.1	18.2
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	3.9	7.0
Convective heat loss from respiration (Cres)	0.9	1.6
Total Heat Loss	62.4	112.4

Heat Load	-4.3
PMV	-0.28
PPD (%)	6.6

Test Scenario B5

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.8
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	27
Mean radiant temperature	{C}	26
Relative air velocity	{m/s}	0.03
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.28
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.34
Total heat transfer coefficient of skin	{W/m2.K}	7.62
Total heat transfer coefficient of clothing	{W/m2.K}	6.88
Skin temperature	{C}	34.1
Clothing temperature	{C}	30.9
Vapor pressure of air	{kPa}	2.532

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	104.7
Total Heat Generation	**58.2**	**104.7**

Skin	{W/m2}	{W}
Heat loss by convection (C)	13.2	23.7
Heat loss by radiation (R)	23.1	41.5
Heat loss from vapor difussion through skin (Edif)	8.5	15.3
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	3.4	6.0
Convective heat loss from respiration (Cres)	0.5	1.0
Total Heat Loss	**48.7**	**87.6**

Heat Load	**9.5**
PMV	**0.62**
PPD (%)	**13.1**

Test Scenario B6

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	28
Mean radiant temperature	{C}	27
Relative air velocity	{m/s}	0.04
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.26
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.36
Total heat transfer coefficient of skin	{W/m2.K}	7.62
Total heat transfer coefficient of clothing	{W/m2.K}	6.89
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.1
Vapor pressure of air	{kPa}	2.589

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	12.7	20.3
Heat loss by radiation (R)	20.4	32.7
Heat loss from vapor difussion through skin (Edif)	8.3	13.3
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	3.3	5.3
Convective heat loss from respiration (Cres)	0.5	0.8
Total Heat Loss	**45.3**	**72.4**

Heat Load	**12.9**
PMV	**0.84**
PPD (%)	**19.9**

Test Scenario B9

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	28
Mean radiant temperature	{C}	27
Relative air velocity	{m/s}	0.06
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.26
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.37
Total heat transfer coefficient of skin	{W/m2.K}	7.63
Total heat transfer coefficient of clothing	{W/m2.K}	6.90
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.2
Vapor pressure of air	{kPa}	2.596

Metabolism	{W/m2}	{W}
Metabolic heat generation	**58.2**	**93.0**
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	12.8	20.5
Heat loss by radiation (R)	19.6	31.4
Heat loss from vapor difussion through skin (Edif)	**8.3**	**13.3**
Heat loss from sweating (Ersw)	**0.0**	**0.0**
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	**3.3**	**5.3**
Convective heat loss from respiration (Cres)	**0.5**	**0.8**
Total Heat Loss	**44.5**	**71.2**

Heat Load	**13.6**
PMV	**0.89**
PPD (%)	**21.75**

Test Scenario B10

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	28
Mean radiant temperature	{C}	27
Relative air velocity	{m/s}	0.06
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.19
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.37
Total heat transfer coefficient of skin	{W/m2.K}	7.56
Total heat transfer coefficient of clothing	{W/m2.K}	6.83
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.3
Vapor pressure of air	{kPa}	2.657

Metabolism	{W/m2}	{W}
Metabolic heat generation	**58.2**	**93.0**
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	11.3	18.2
Heat loss by radiation (R)	20.2	32.3
Heat loss from vapor difussion through skin (Edif)	**8.1**	**13.0**
Heat loss from sweating (Ersw)	**0.0**	**0.0**
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	**3.2**	**5.2**
Convective heat loss from respiration (Cres)	**0.5**	**0.8**
Total Heat Loss	**43.4**	**69.4**

Heat Load	**14.8**
PMV	**0.96**
PPD (%)	**24.64**

Test Scenario B11

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	28
Mean radiant temperature	{C}	26
Relative air velocity	{m/s}	0.06
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.12
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.35
Total heat transfer coefficient of skin	{W/m2.K}	7.47
Total heat transfer coefficient of clothing	{W/m2.K}	6.75
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.1
Vapor pressure of air	{kPa}	2.666

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	58.2	93.0

Skin	{W/m2}	{W}
Heat loss by convection (C)	10.2	16.3
Heat loss by radiation (R)	23.5	37.6
Heat loss from vapor difussion through skin (Edif)	8.1	13.0
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	3.2	5.2
Convective heat loss from respiration (Cres)	0.5	0.8
Total Heat Loss	45.5	72.9

Heat Load	12.6
PMV	0.82
PPD (%)	19.32

Test Scenario B12

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	29
Mean radiant temperature	{C}	28
Relative air velocity	{m/s}	0.08
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.33
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.40
Total heat transfer coefficient of skin	{W/m2.K}	7.73
Total heat transfer coefficient of clothing	{W/m2.K}	6.98
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.7
Vapor pressure of air	{kPa}	2.868

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	58.2	93.0

Skin	{W/m2}	{W}
Heat loss by convection (C)	8.5	13.5
Heat loss by radiation (R)	18.6	29.7
Heat loss from vapor difussion through skin (Edif)	7.5	12.0
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	3.0	4.8
Convective heat loss from respiration (Cres)	0.4	0.6
Total Heat Loss	37.9	60.7

Heat Load	20.2
PMV	1.32
PPD (%)	41.42

Test Scenario B13

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	30
Mean radiant temperature	{C}	27
Relative air velocity	{m/s}	0.06
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.03
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.37
Total heat transfer coefficient of skin	{W/m2.K}	7.39
Total heat transfer coefficient of clothing	{W/m2.K}	6.68
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.5
Vapor pressure of air	{kPa}	2.947

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	5.6	8.9
Heat loss by radiation (R)	23.1	37.0
Heat loss from vapor difussion through skin (Edif)	7.2	11.6
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	2.9	4.7
Convective heat loss from respiration (Cres)	0.3	0.5
Total Heat Loss	**39.2**	**62.8**

Heat Load	**18.9**
PMV	**1.24**
PPD (%)	**37.03**

Test Scenario B14

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	29
Mean radiant temperature	{C}	26
Relative air velocity	{m/s}	0.07
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.27
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.35
Total heat transfer coefficient of skin	{W/m2.K}	7.62
Total heat transfer coefficient of clothing	{W/m2.K}	6.88
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.2
Vapor pressure of air	{kPa}	2.877

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	6.5	10.4
Heat loss by radiation (R)	25.5	40.8
Heat loss from vapor difussion through skin (Edif)	7.5	11.9
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	3.0	4.8
Convective heat loss from respiration (Cres)	0.4	0.6
Total Heat Loss	**42.8**	**68.6**

Heat Load	**15.3**
PMV	**1.00**
PPD (%)	**26.12**

Test Scenario B15

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	31
Mean radiant temperature	{C}	27
Relative air velocity	{m/s}	0.11
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.97
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.38
Total heat transfer coefficient of skin	{W/m2.K}	8.34
Total heat transfer coefficient of clothing	{W/m2.K}	7.54
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.7
Vapor pressure of air	{kPa}	3.163

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	2.8	4.5
Heat loss by radiation (R)	23.6	37.8
Heat loss from vapor difussion through skin (Edif)	**6.6**	**10.5**
Heat loss from sweating (Ersw)	**0.0**	**0.0**
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	**2.7**	**4.4**
Convective heat loss from respiration (Cres)	**0.2**	**0.4**
Total Heat Loss	**36.0**	**57.5**

Heat Load	**22.2**
PMV	**1.45**
PPD (%)	**48.19**

Test Scenario B16

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	31
Mean radiant temperature	{C}	26
Relative air velocity	{m/s}	0.12
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	4.16
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.35
Total heat transfer coefficient of skin	{W/m2.K}	8.52
Total heat transfer coefficient of clothing	{W/m2.K}	7.69
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.5
Vapor pressure of air	{kPa}	3.121

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	2.9	4.7
Heat loss by radiation (R)	26.2	42.0
Heat loss from vapor difussion through skin (Edif)	**6.7**	**10.7**
Heat loss from sweating (Ersw)	**0.0**	**0.0**
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	**2.8**	**4.4**
Convective heat loss from respiration (Cres)	**0.3**	**0.4**
Total Heat Loss	**38.9**	**62.2**

Heat Load	**19.3**
PMV	**1.26**
PPD (%)	**38.22**

Test Scenario B17

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	30
Mean radiant temperature	{C}	27
Relative air velocity	{m/s}	0.07
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.11
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.38
Total heat transfer coefficient of skin	{W/m2.K}	7.49
Total heat transfer coefficient of clothing	{W/m2.K}	6.77
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.7
Vapor pressure of air	{kPa}	2.963

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	5.9	9.4
Heat loss by radiation (R)	21.2	33.9
Heat loss from vapor difussion through skin (Edif)	7.2	11.5
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	2.9	4.7
Convective heat loss from respiration (Cres)	0.3	0.5
Total Heat Loss	**37.6**	**60.1**

Heat Load	**20.6**
PMV	**1.34**
PPD (%)	**42.60**

Test Scenario B18

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	30
Mean radiant temperature	{C}	27
Relative air velocity	{m/s}	0.07
Relative humidity	{%}	60

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	3.29
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.37
Total heat transfer coefficient of skin	{W/m2.K}	7.66
Total heat transfer coefficient of clothing	{W/m2.K}	6.92
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.5
Vapor pressure of air	{kPa}	2.492

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	6.6	10.6
Heat loss by radiation (R)	22.9	36.7
Heat loss from vapor difussion through skin (Edif)	8.6	13.8
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	3.4	5.4
Convective heat loss from respiration (Cres)	0.4	0.6
Total Heat Loss	**42.0**	**67.1**

Heat Load	**16.2**
PMV	**1.06**
PPD (%)	**28.60**

Test Scenario B19

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	31
Mean radiant temperature	{C}	27
Relative air velocity	{m/s}	0.11
Relative humidity	{%}	70

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	4.04
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.39
Total heat transfer coefficient of skin	{W/m2.K}	8.44
Total heat transfer coefficient of clothing	{W/m2.K}	7.62
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.9
Vapor pressure of air	{kPa}	3.215

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	2.5	4.0
Heat loss by radiation (R)	21.6	34.6
Heat loss from vapor difussion through skin (Edif)	6.4	10.3
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	2.7	4.3
Convective heat loss from respiration (Cres)	0.2	0.3
Total Heat Loss	**33.4**	**53.5**

Heat Load	**24.7**
PMV	**1.62**
PPD (%)	**57.24**

Test Scenario B20

Input		
Clothing	{clo}	0.57
Skin area	{m2}	1.6
Metabolic rate	{met}	1
External work	{met}	0
Air temperature	{C}	31
Mean radiant temperature	{C}	27
Relative air velocity	{m/s}	0.11
Relative humidity	{%}	60

Clothing thermal resistance (Rcl)	{m2.K/W}	0.08835
Clothing area factor (fcl)	n/a	1.107
Convective heat transfer coefficient (hc)	{W/m2.K}	4.06
Radiative heat transfer coefficient (hr)	{W/m2.K}	4.38
Total heat transfer coefficient of skin	{W/m2.K}	8.43
Total heat transfer coefficient of clothing	{W/m2.K}	7.62
Skin temperature	{C}	34.1
Clothing temperature	{C}	31.7
Vapor pressure of air	{kPa}	2.699

Metabolism	{W/m2}	{W}
Metabolic heat generation	58.2	93.0
Total Heat Generation	**58.2**	**93.0**

Skin	{W/m2}	{W}
Heat loss by convection (C)	3.1	5.0
Heat loss by radiation (R)	23.6	37.7
Heat loss from vapor difussion through skin (Edif)	8.0	12.8
Heat loss from sweating (Ersw)	0.0	0.0
Respiration	{W/m2}	{W}
Evaporative heat loss from respiration (Eres)	3.2	5.1
Convective heat loss from respiration (Cres)	0.2	0.4
Total Heat Loss	**38.1**	**61.0**

Heat Load	**20.0**
PMV	**1.31**
PPD (%)	**40.73**