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An Inter-program Analysis of Computational Fluid Dynamics Based on PHOENICS and DesignBuilder Software

Aim

The aim of this work is to compare the computational fluid dynamics (CFD) simulation performance provided by DesignBuilder software with a specialist commercial CFD modelling package – Phoenics. Particular emphasis is placed on temperature and velocity fields within a typical built environment space including typical heating, ventilating and air condition (HVAC) components.

Introduction

DesignBuilder is a generic energy simulation program for the built environment for the modelling of energy and comfort in buildings including HVAC plant. It provides results compatible with a number of energy and carbon labelling schemes such as UK Energy Performance Certificates, UK Building Regulation Compliance, UK BREEAM and US Green building Council LEED assessments. It also includes a CFD modelling capability specifically adapted for analysing air movement and ventilation problems within building spaces. The results reported in this document deal with the latter only. Phoenics is a CFD simulation package which is able to solve a wide range of industrial fluid flow problems including fluid flow in free fields, developing and fully-developed flow, flow in pipes and ducts, heat and mass transfer, chemical reaction and combustion. Phoenics is used in this project because of its advantage in dealing with CFD modelling applied to HVAC components, by means of a specialist environment called FLAIR.

The nature of this work is to compare simulation results from four specific heating or cooling scenarios, and verify the DesignBuilder results against those obtained for the same test cases from Phoenics. This work is based on Phoenics version 2009 and DesignBuilder version 2.3.5.020 BETA

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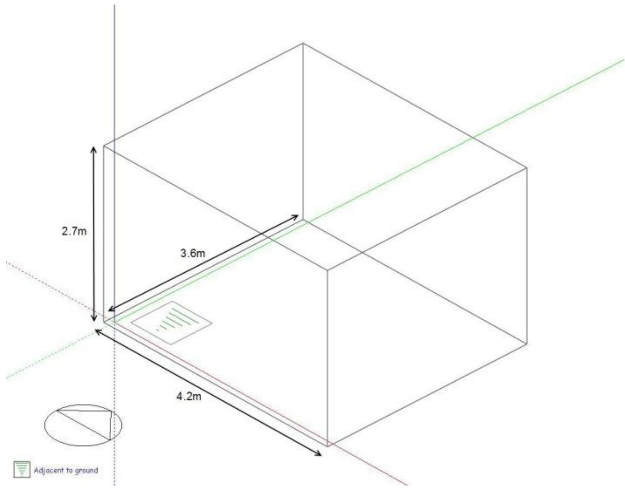
Methodology

Four test cases have been designed for this comparison study represented by four different heating and cooling scenarios in a typical built environment space. All cases are simulated within both software packages under nominally identical numerical settings and boundary conditions. The small number of instances in which identical settings could not be made are identified in the following.

The geometry of the test cases:

All cases comprise a single rectangular room with the size of 4.2m x 3.6m x 2.7m (high). There are two isothermal cases focusing on the air distribution in the room. The other cases concentrate on the natural and mixed convection heat transfer in the room.

For the isothermal cases (A & B), a supply diffuser with an overall dimension of 0.2m x 0.1m is positioned at the centre of the west-facing wall at a distance of 0.2m from the ceiling to the top edge of the diffuser. The discharge angle of the diffuser is 45° upwards from the horizontal. There are two extract grilles located in the north-east and south-east corners of the ceiling, with a distance of 0.2m from the upper edge of the north- and east-facing walls or south- and east-facing walls. The dimensions of the extract grilles are 0.3m x 0.3m.



For the convection cases (C & D), there is a window located in the south-facing wall, at a distance of 0.8m from the floor and 0.2m from the side walls. In case C (natural convection), a single panel radiator with a dimension of 2m x 1m x 0.05m is added to the room, which is located 0.1m in front of the south-facing wall and 0.1m above the floor.

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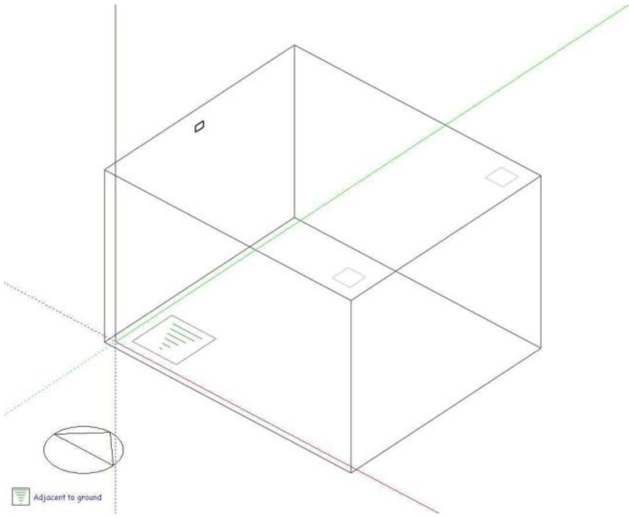
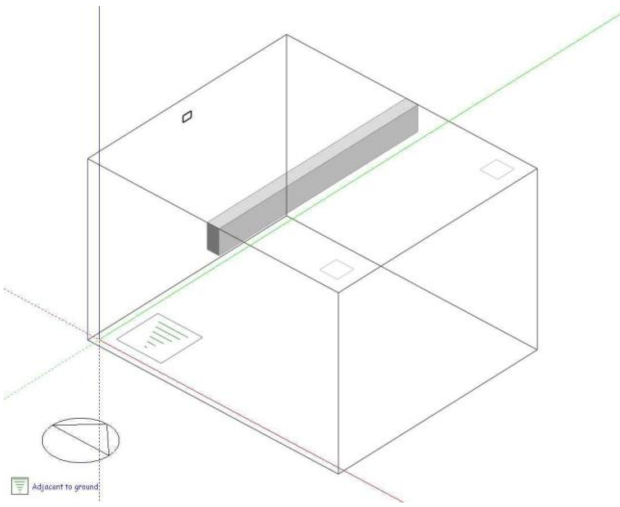
<u>The boundary conditions of the four cases are as follows:</u>

A. Isothermal forced convection with a supply air diffuser, two extract grilles
   Air flow rate = $0.034m^3/s$, discharge velocity = 3.0m/s



B. Isothermal forced convection with supply air diffuser, extract grilles and obstruction to the air flow
   Air flow rate = $0.034m^3/s$, discharge velocity = 3.0m/s
   The obstruction is in the form of a beam which spans the width of the space and is located adjacent to the ceiling equidistant between the east- and west-facing walls. The dimensions of the beam are 3.6m x 0.2m x 0.4m.



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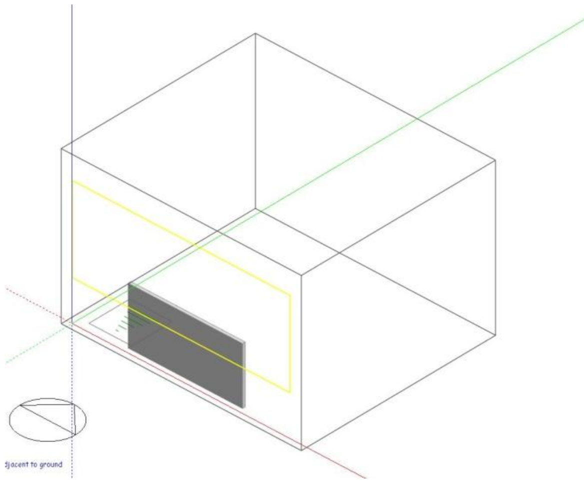
C. Natural convection – winter heating natural convection with radiator located beneath a cold window

Radiator surface temperature = 75°C

Wall/ ceiling/ floor surface temperatures = 17°C

Window surface temperature = 5°C



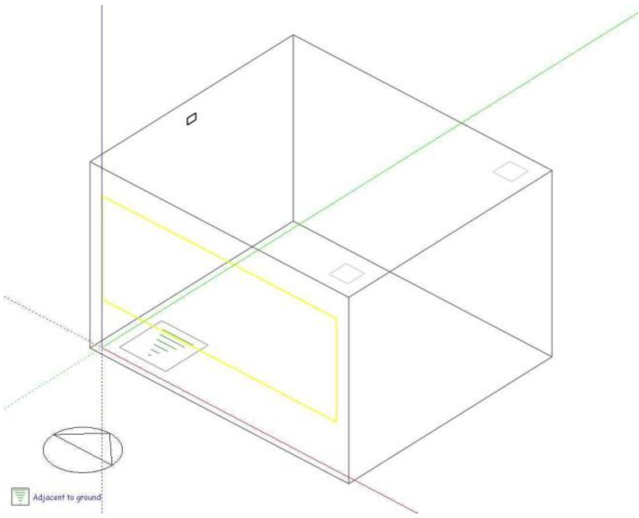
D. Mixed convection – summer cooling mixed convection with supply diffuser and extract grilles

Air flow rate = 0.034m^3/s, discharge velocity = 3.0m/s

Supply air temperature = 17°C

Wall/ ceiling/ floor surface temperatures = 23°C

Window surface temperature = 32°C



Numerical Model setting:

	DesignBuilder	**Phoenics**
Algorithm	Simpler	Simplest
Turbulence model	standard k-e with wall functions	standard k-e with wall functions
Discretisation scheme	first order upwind	first order upwind
Mesh size	0.1m	0.1m

Results:

Cases A and B are isothermal cases; the air is delivered to the room at a mean velocity of 3m/s through a wall mounted diffuser. Only the air velocity distribution is of relevance in these two cases. Velocity profiles developed across the middle of the room, from the west to east wall and perpendicular with the diffuser, are plotted. Plotting in both programs is carried out at each 0.1m increment from the diffuser, from the floor to ceiling level across the room. The average root mean square (RMS) difference of the DesignBuilder results with reference to the Phoenics results of velocity is 0.03 for both cases. The differences in predicted velocity fields are likely to be due ,at least in part, to the slightly different approaches to diffuser discharge velocity calculations. DesignBuilder uses the mean velocity and discharge angle to determine the air distribution from the diffuser, while Phoenics uses either effective area, or throw distance, terminal velocity and a decay constant.

In case B, the RMS difference between the two predictions reduces significantly at a distance of 2.05m from the diffuser and reduces gradually with further distance. The reduction of the RMS differences appears to be due to the significant drop of air velocity arising from the ceiling obstruction in this case.

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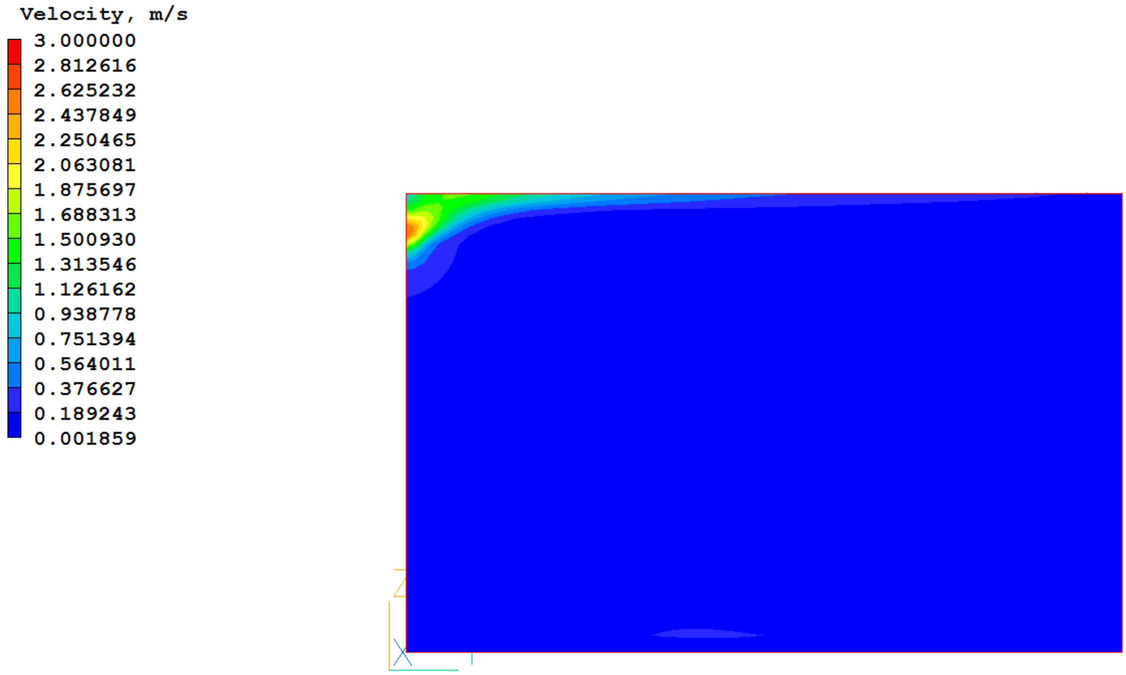
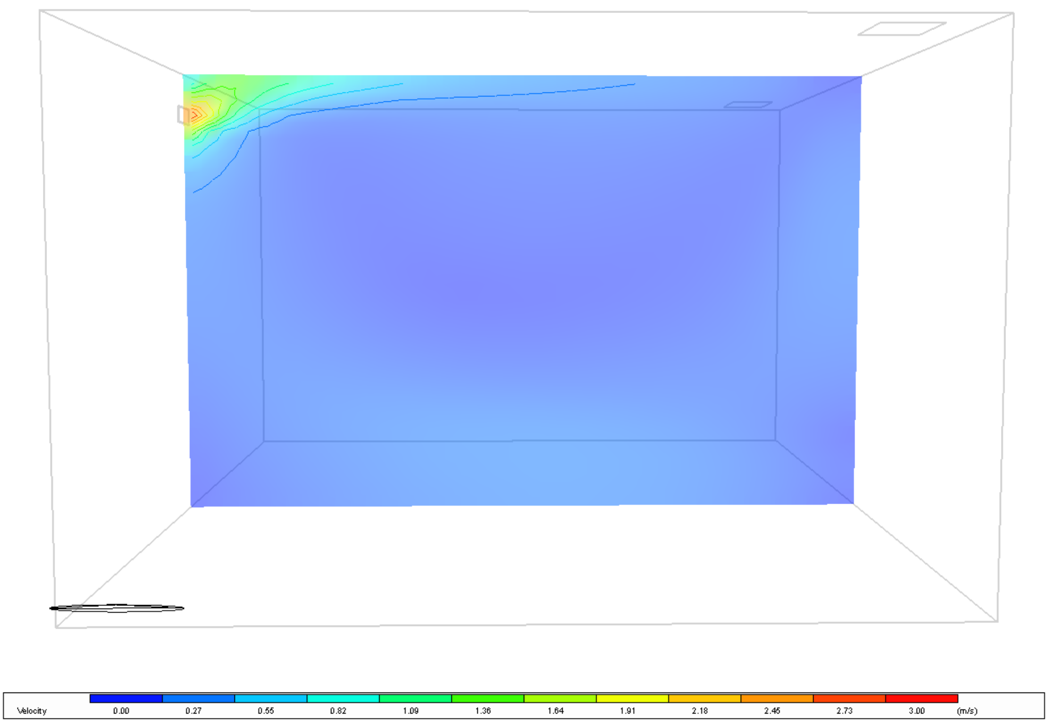
Velocity contours of case A from Phoenics (west to east plane)



Velocity contours of case A from DesignBuilder (west to east plane)



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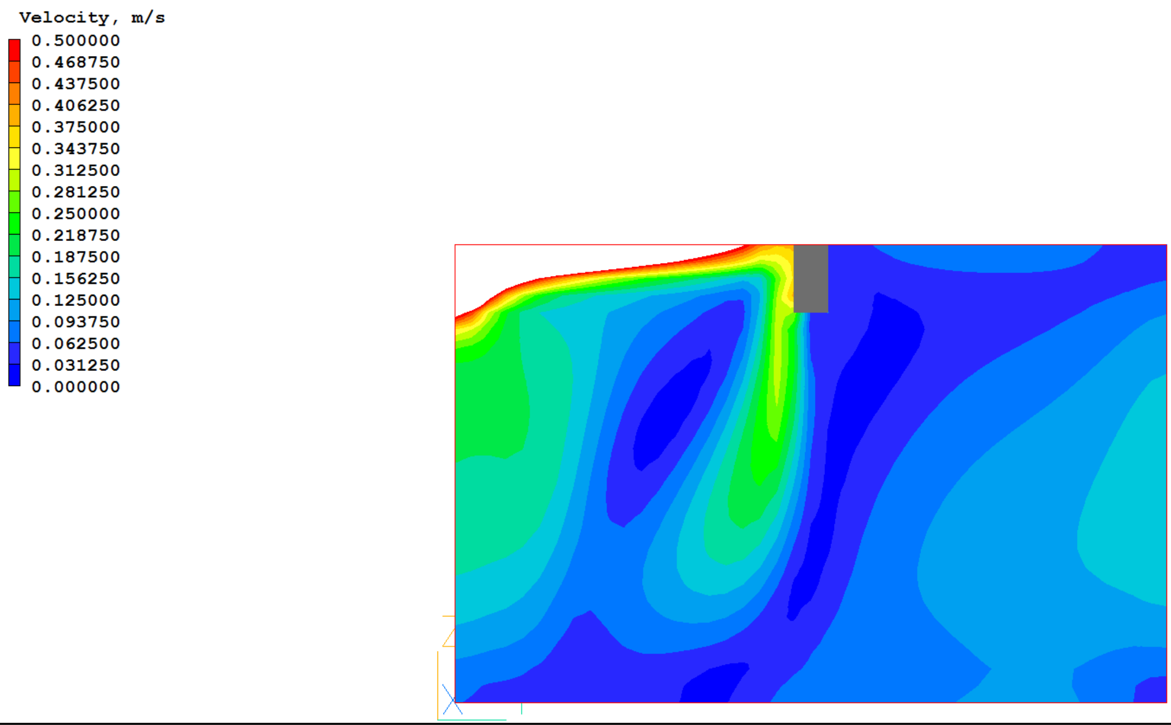
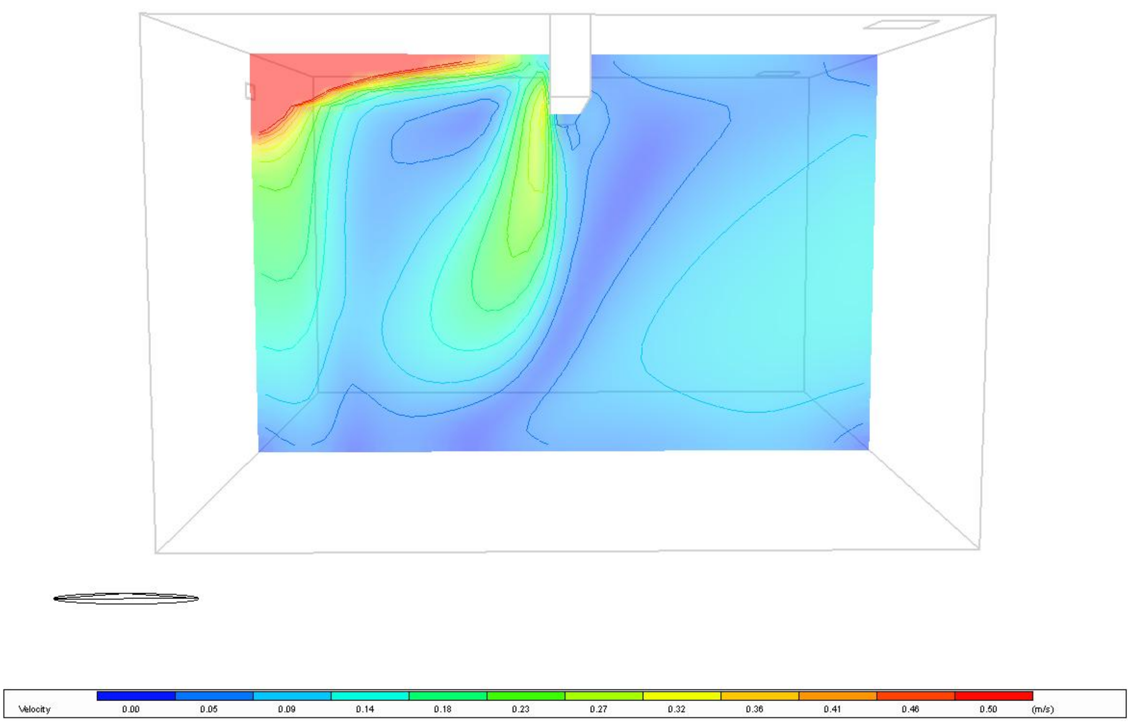
Velocity contours of case B from Phoenics (west to east plane)



Velocity contours of case B from DesignBuilder (west to east plane)



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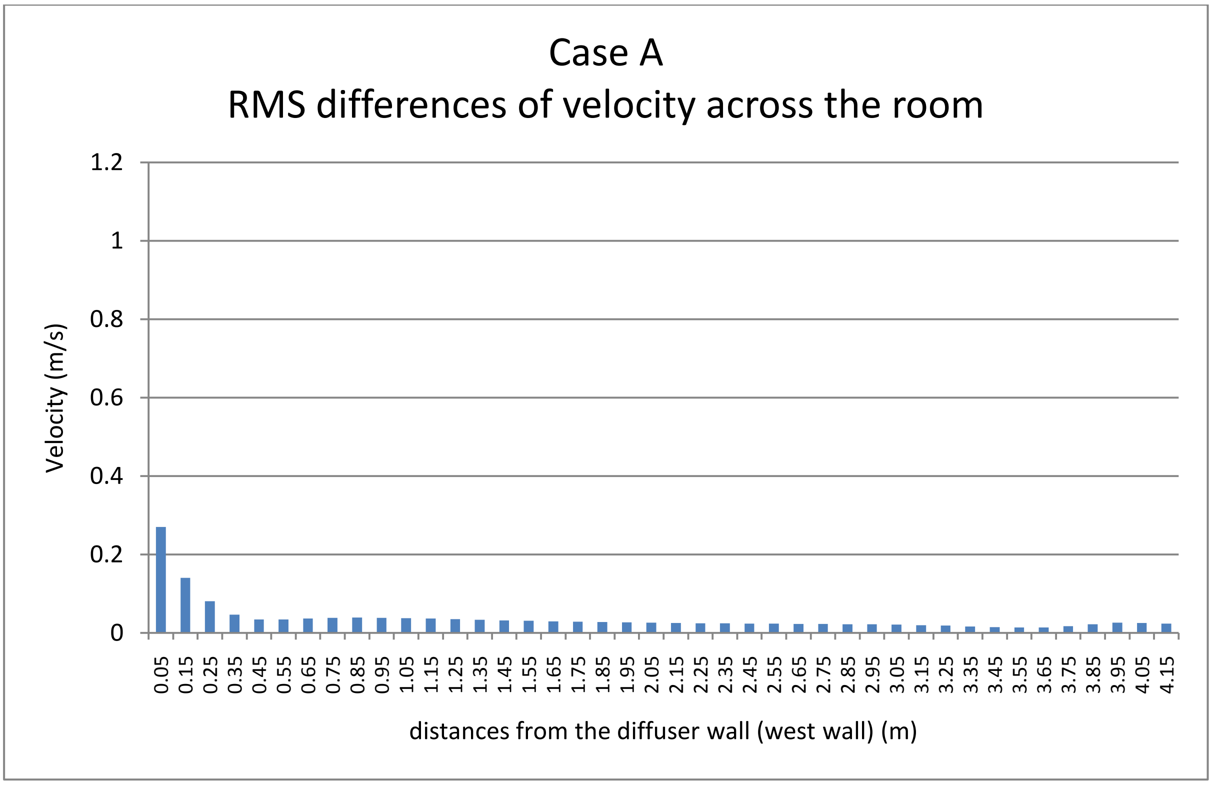

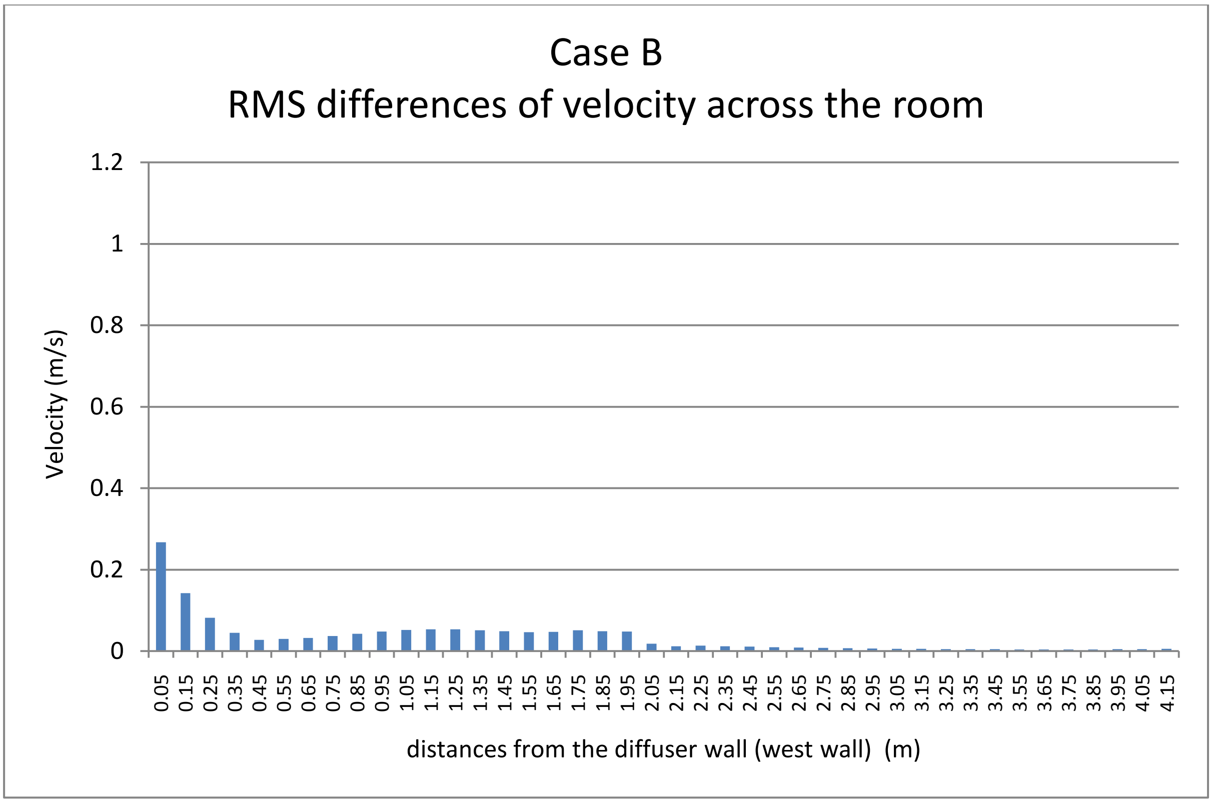

Case C is a natural convective heat transfer case with a radiator fixed beneath a cold window on the south wall. Both the air velocity and temperature distributions within the space are considered in this case. Results are plotted at every 0.1m away from the source, (i.e. the radiator) from south to north over the full height of the room, perpendicular with the radiator surface. The radiator is fixed at 0.15m away from the window.

The average RMS difference between temperature and velocity predictions from DesignBuilder are 0.13 and 0.01 (across the entire room) with respect to the Phoenics results, respectively. The results taken from 0.2m away from the radiator (i.e. 0.35m away from the window) to the end of the room (north wall) yield a relatively low RMS difference of 0.23 or less. In addition, the details of temperature comparison between both programs at three representative locations (close to the south wall/window/radiator, middle of the room, close to the north wall) demonstrate a reasonably good agreement between Phoenics and DesignBuilder simulations on natural convective heat transfer in an upward direction (from floor to ceiling).

For the velocity measurement, the average RMS difference across the whole measurement plane is relatively low, only 0.01.

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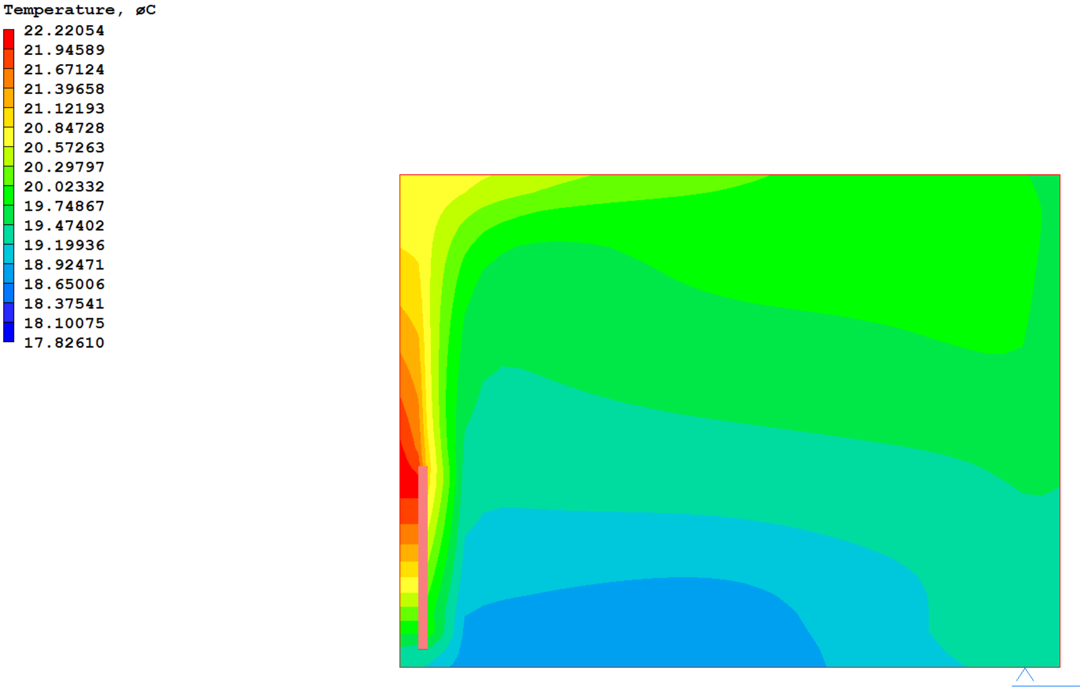
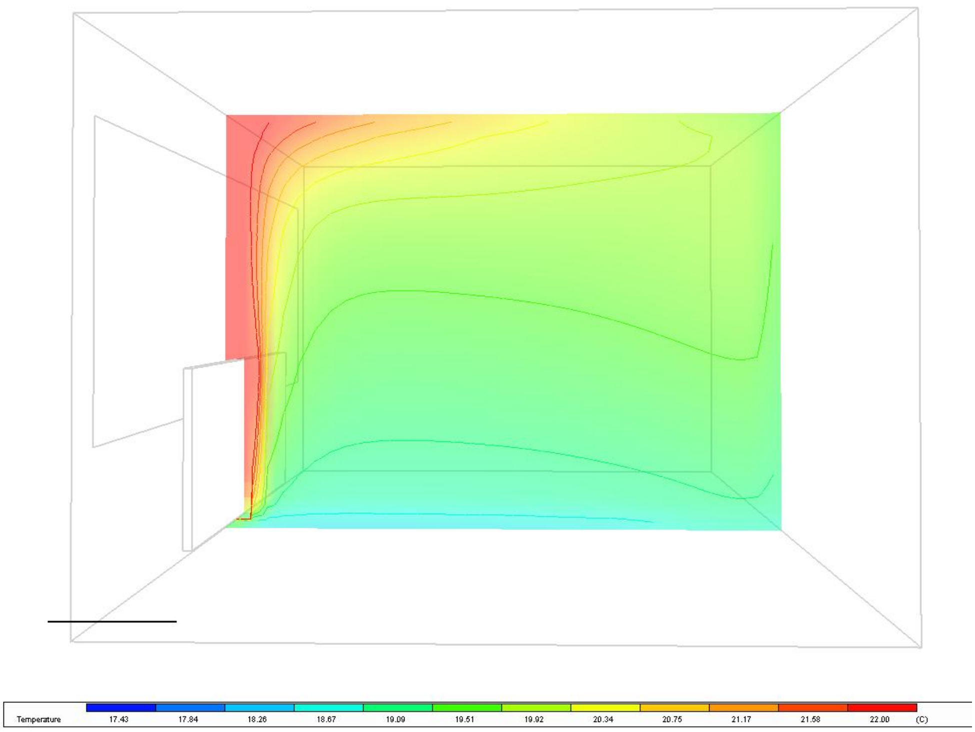
Temperature contours of case C from Phoenics (south to north plane)



Temperature contours of case C from DesignBuilder (south to north plane)



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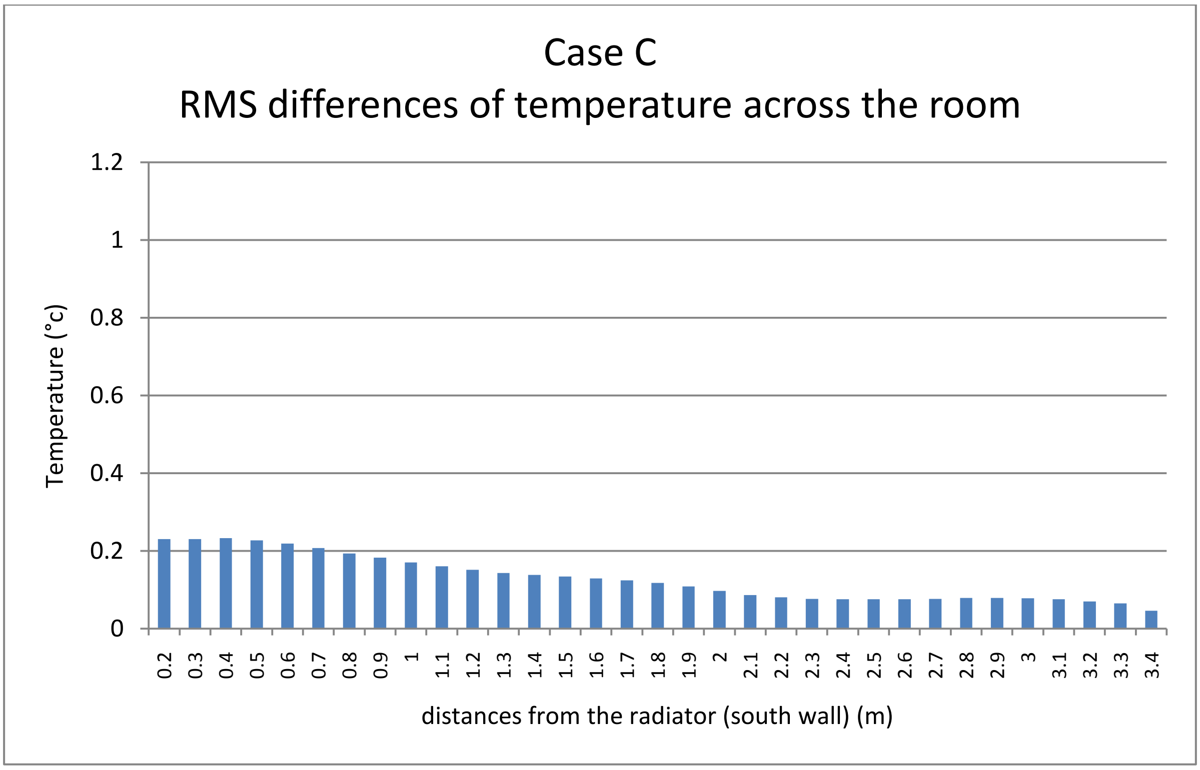

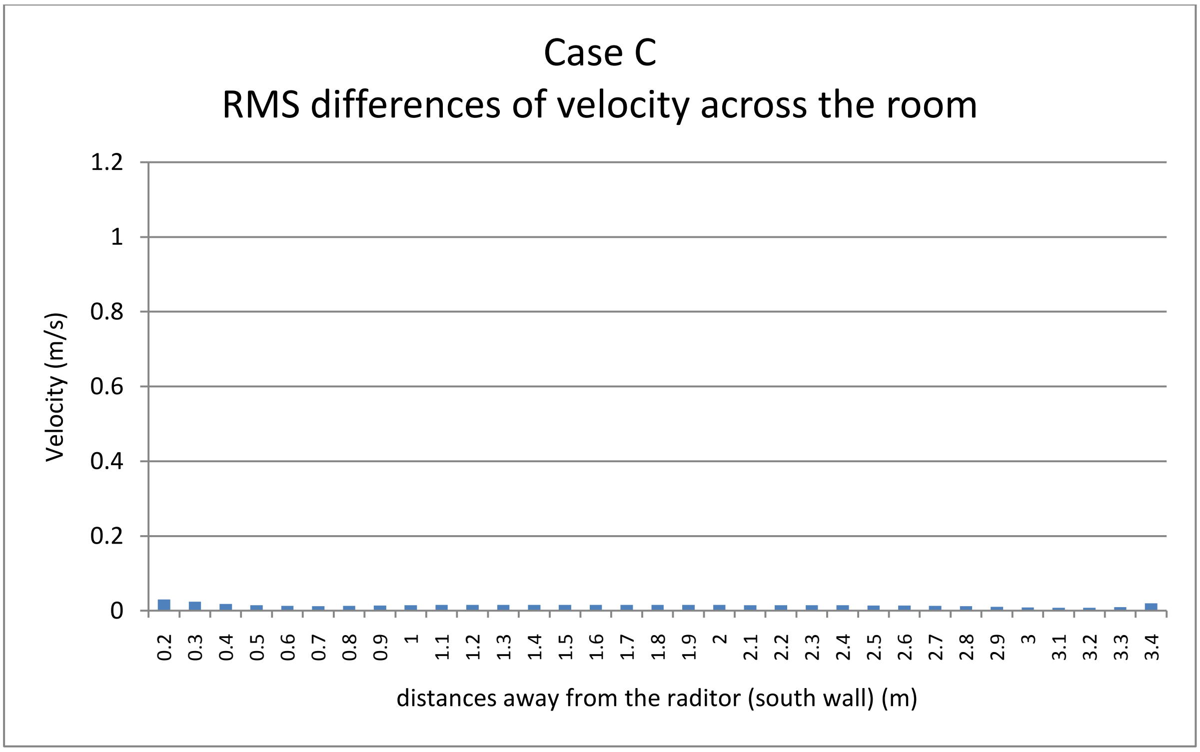

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Case D represents a summer cooling scenario with mixed convection heat transfer within the space. There are two sources applied in this case, including a wall mounted diffuser on the west wall and a warm window surface on the south wall. Therefore, all relevant parameters are plotted in two directions, from south to north and west to east according to the centreline of the room, at increments of 0.1m away from the sources. The average RMS differences in the prediction of temperatures across the room are 0.07 (from south to north direction) and 0.06 (from west to east direction), while the average RMS differences in the prediction of velocity are 0.03 (from south to north direction) and 0.06 (from west to east direction). All RMS differences in this case are all below 0.07, representing a high level of agreement between the DesignBuilder and Phoenics simulations.

The difference in the prediction of velocity arising next to the diffuser outlet (RMS = 0.27), and is similar to case A and B likely to be due, again, to slightly different velocity calculation approaches for the diffuser model used in both programs.

Differences in temperature prediction are thought to be due, in part, to possible differences in the temperature wall functions adopted by the different programs.

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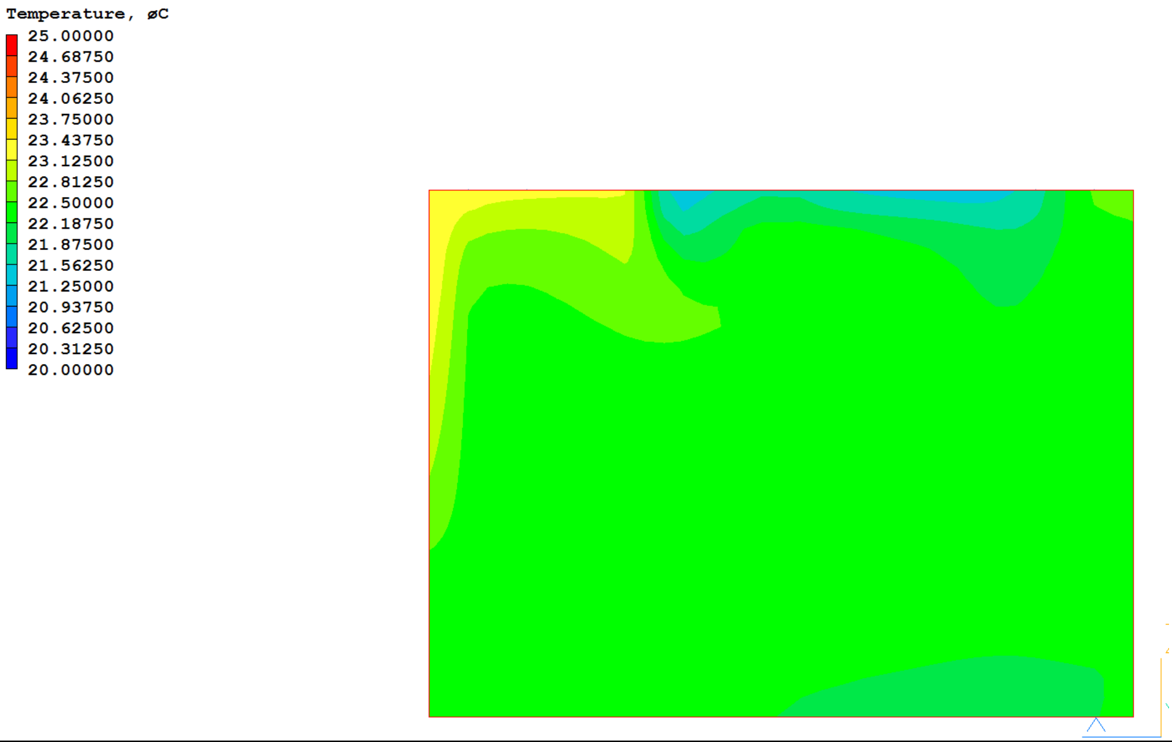
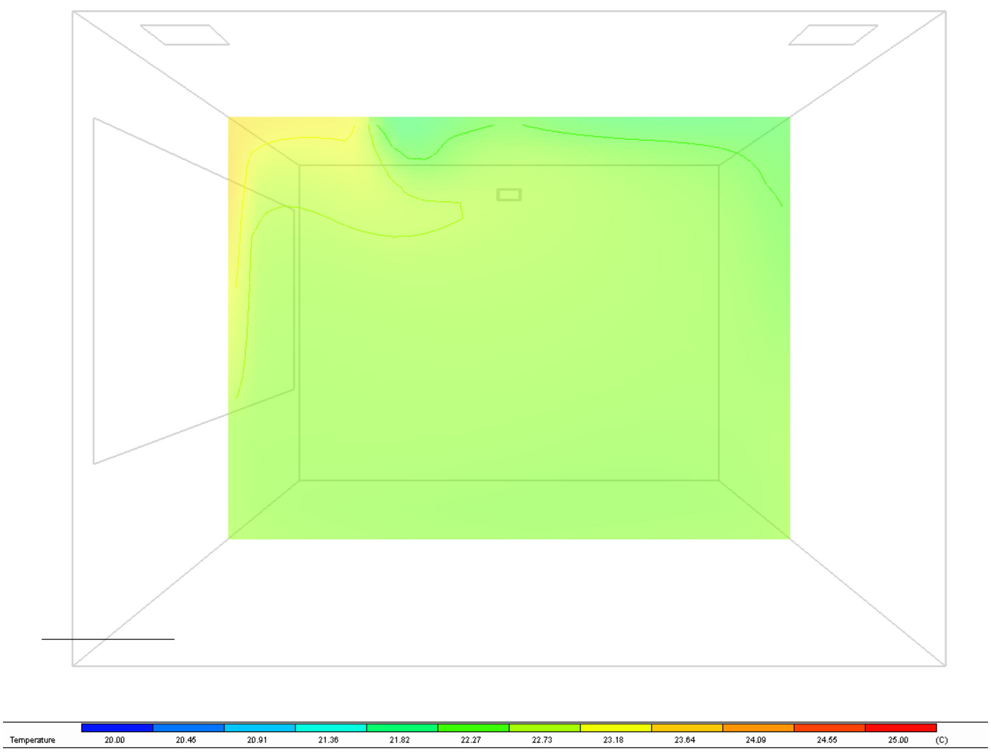
Temperature contours of case D from Phoenics (south to north plane)



Temperature contours of case D from DesignBuilder (south to north plane)



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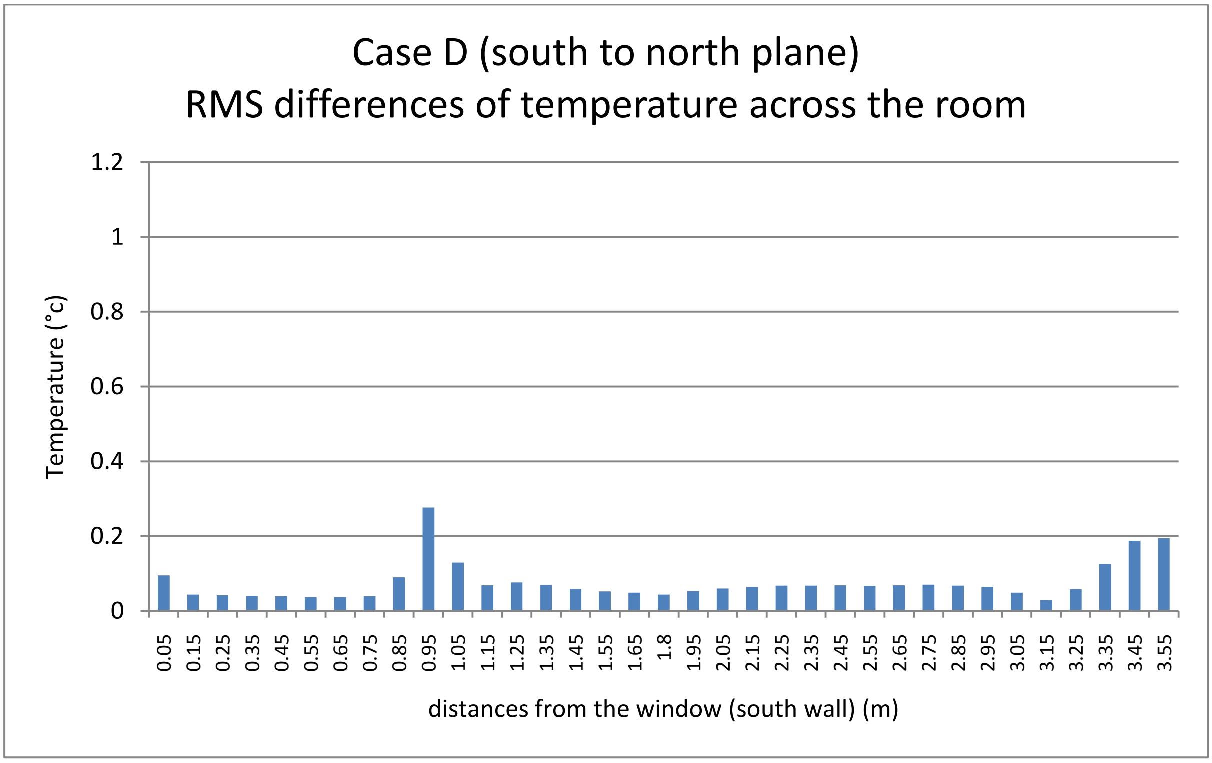

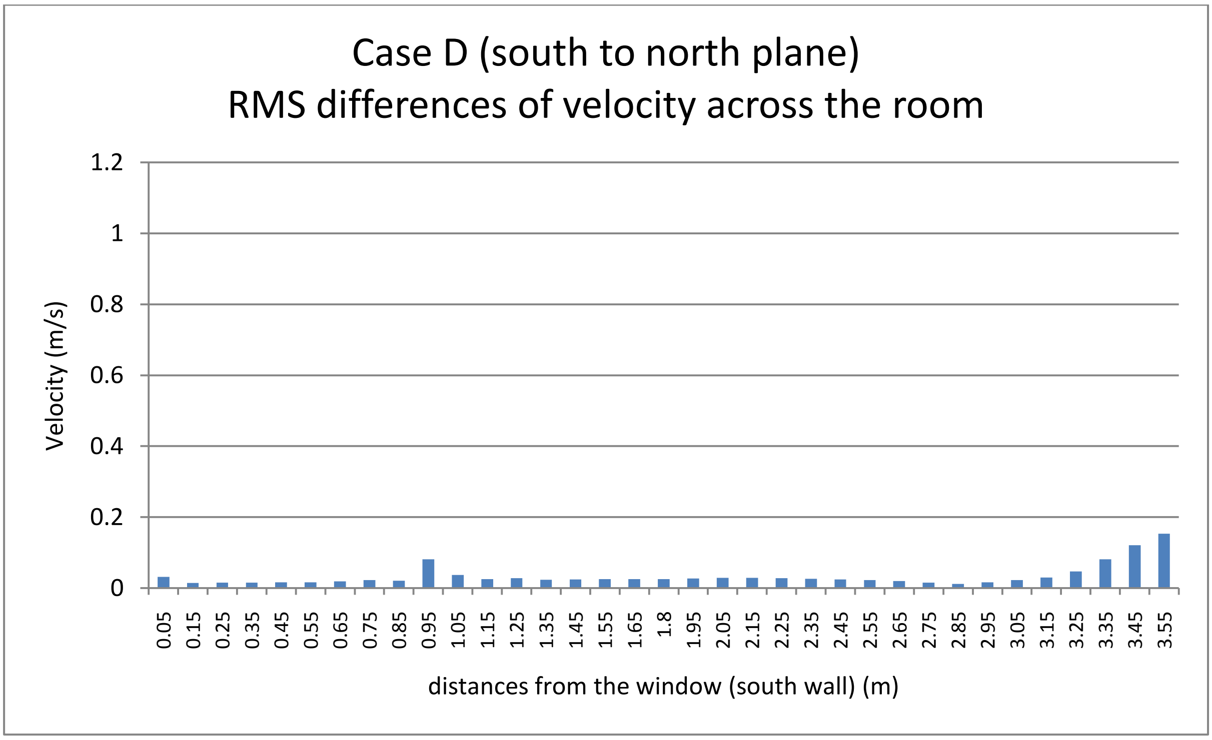

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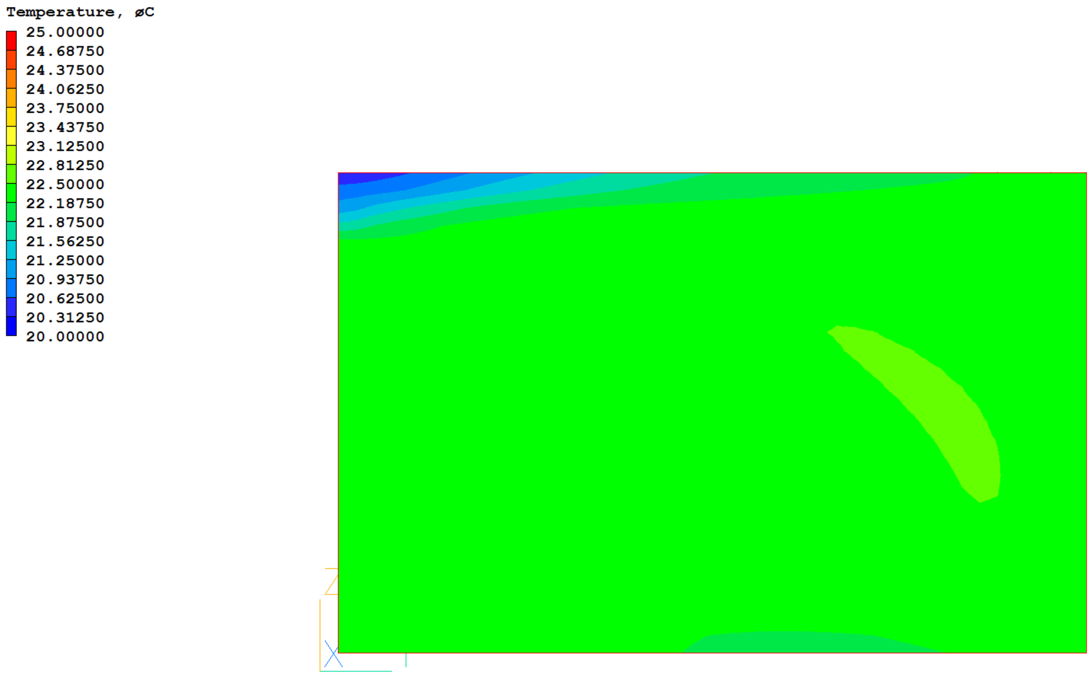
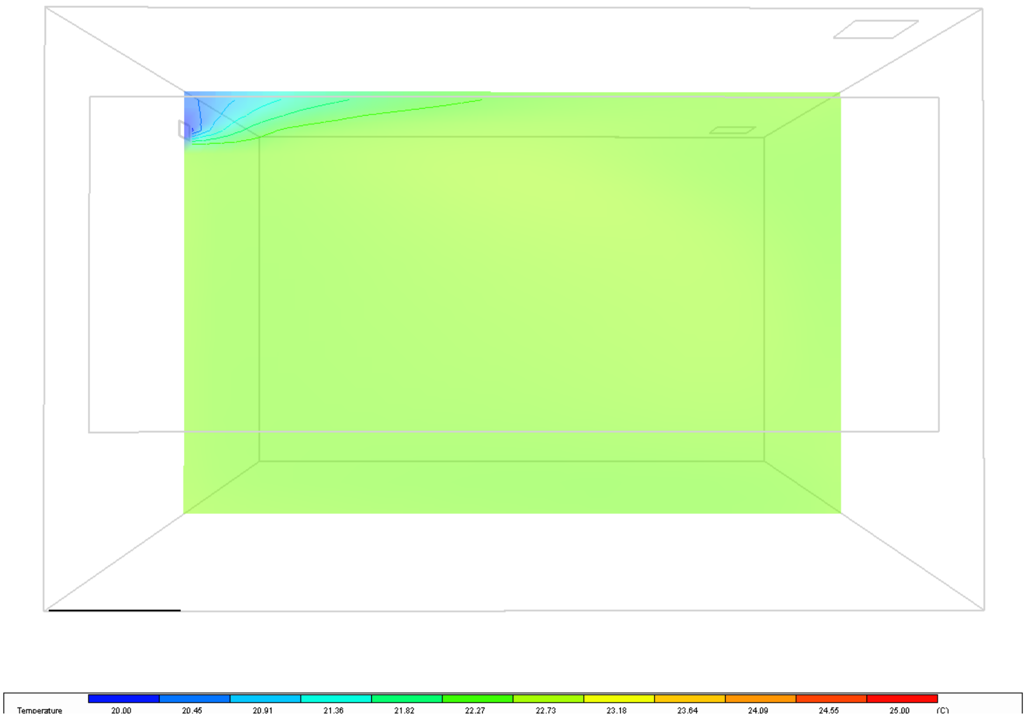
Temperature contours of case D from Phoenics (west to east plane)



Temperature contours of case D from DesignBuilder (west to east plane)



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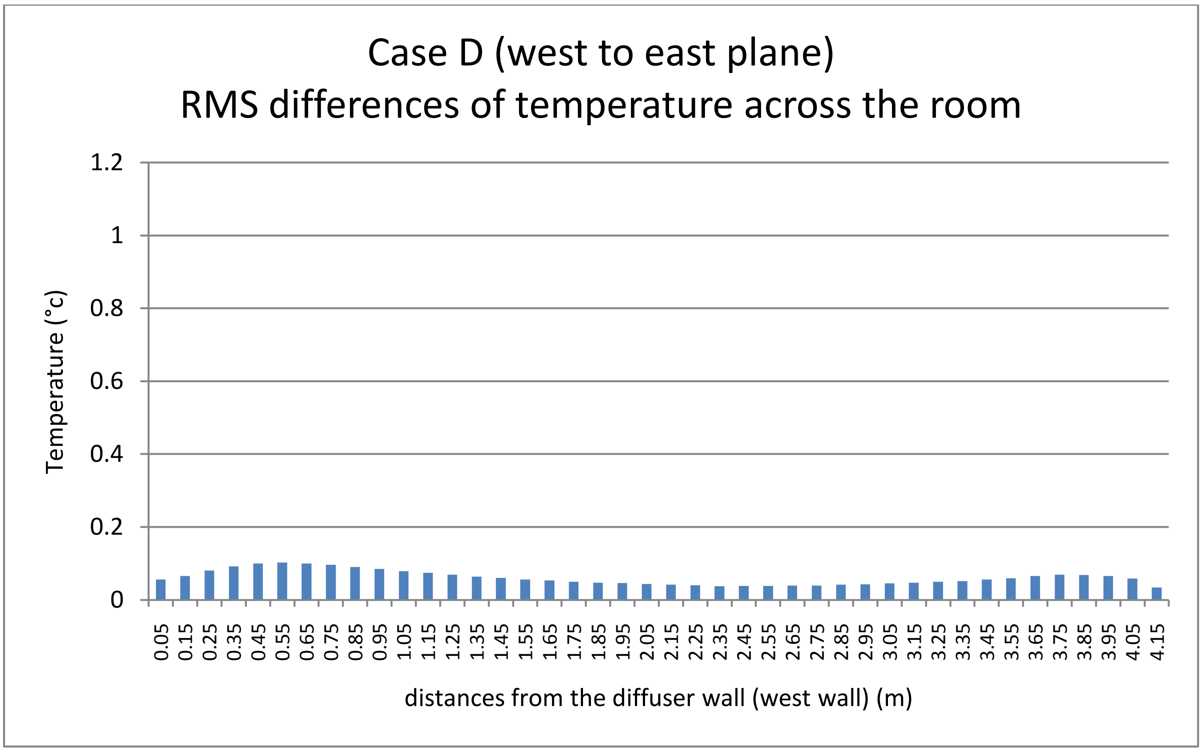

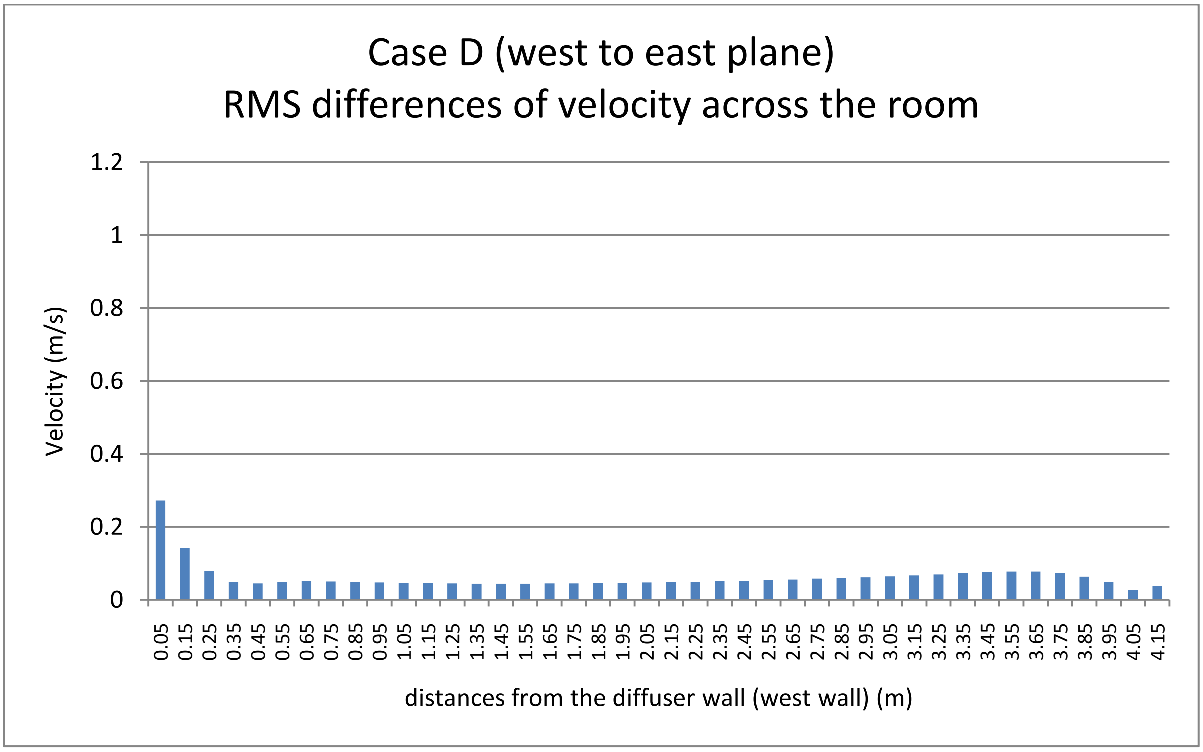

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Discussion

Small differences in the prediction of velocity and temperature fields are thought to be largely due to the different diffuser models used and possible differences in temperature wall function, respectively.

In all four test cases, the temperature and velocity distributions across the room predicted by DesignBuilder compare favourably with those simulated by Phoenics.. The average RMS differences in the prediction of velocity across the room in each individual case is equal to, or less than, 0.06. The accuracy of a typical air velocity meter is about +/- 3% to 5% of the reading. In cases A, B & D, the air is delivered to the room at 3m/s from the diffuser outlet and hence the maximum acceptable range of errors is about 0.09 to 0.15 m/s (apart from the velocity measurement next to the diffuser outlet at 0.05m over the maximum range of errors; all other measurements at further locations are within or below the this range). Thus the predictions from both programs agree to within a reasonable tolerance for practical measurement.

For temperatures, the average RMS difference in predictions between the two programs in case C and D across the centreline of the room are 0.13 in case C, and 0.07 (south to north) and 0.06 (west to east) in case D. The accuracy of typical air temperature sensor for room air is 0.2K for a high-specification sensor. The calculated RMS differences in prediction for temperature from these two programs are, therefore, practically within the minimum range of uncertainty that might be expected from practical measurements.

Conclusion

In this inter-program comparison exercise, the relatively low RMS differences between predicted results from the two programs considered in four contrasting built environment test cases suggest that the CFD modelling capability of DesignBuilder software is comparable with a high-exposure specialist CFD package.

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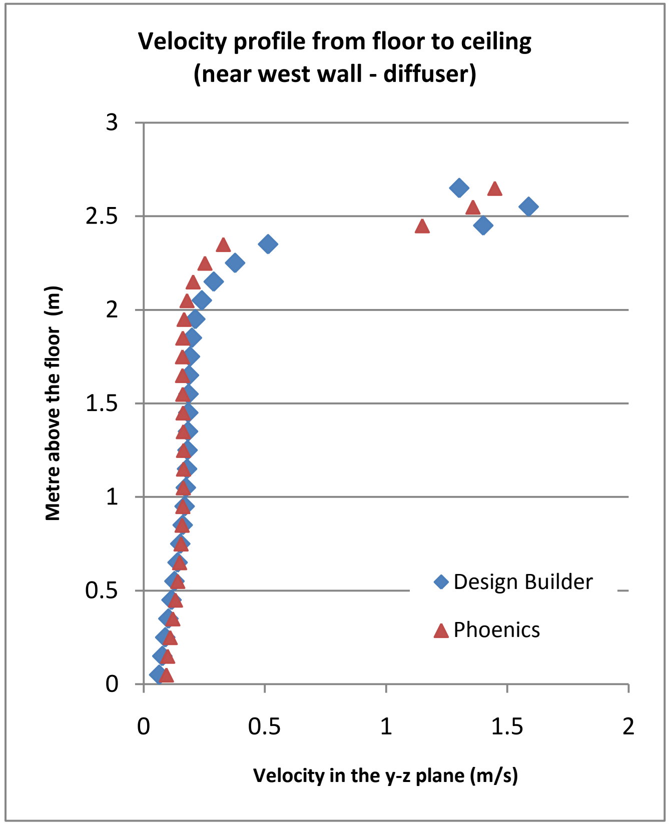
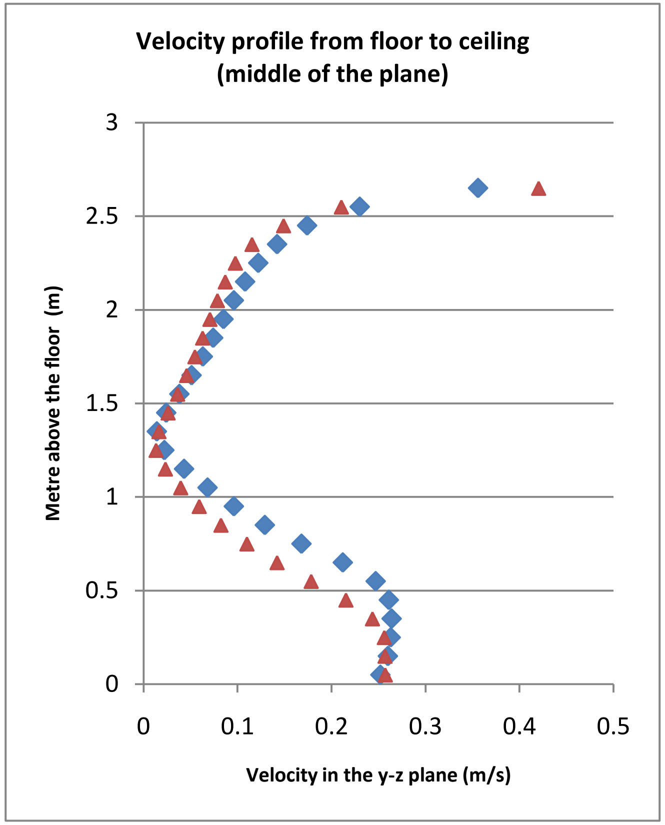
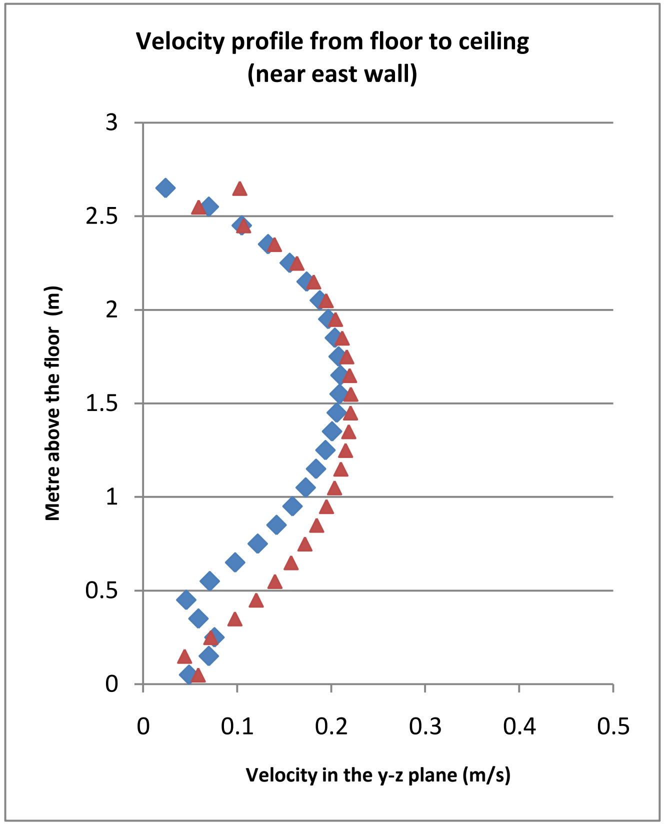
Appendix

Case A Velocity profiles







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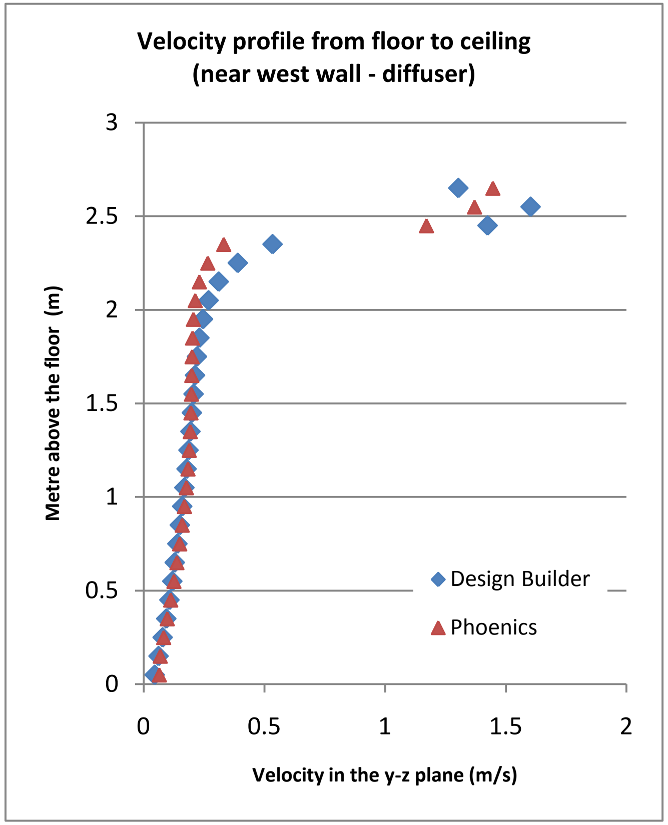
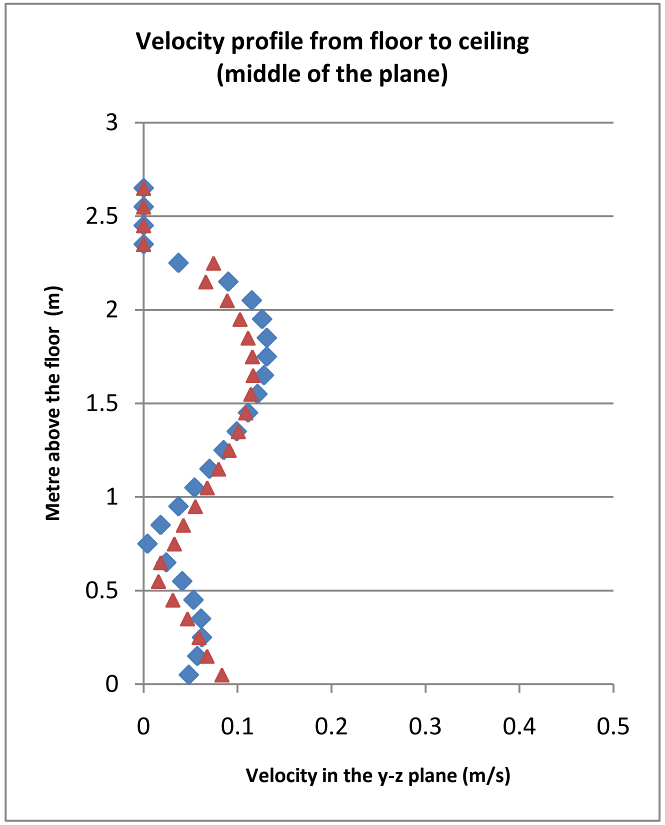
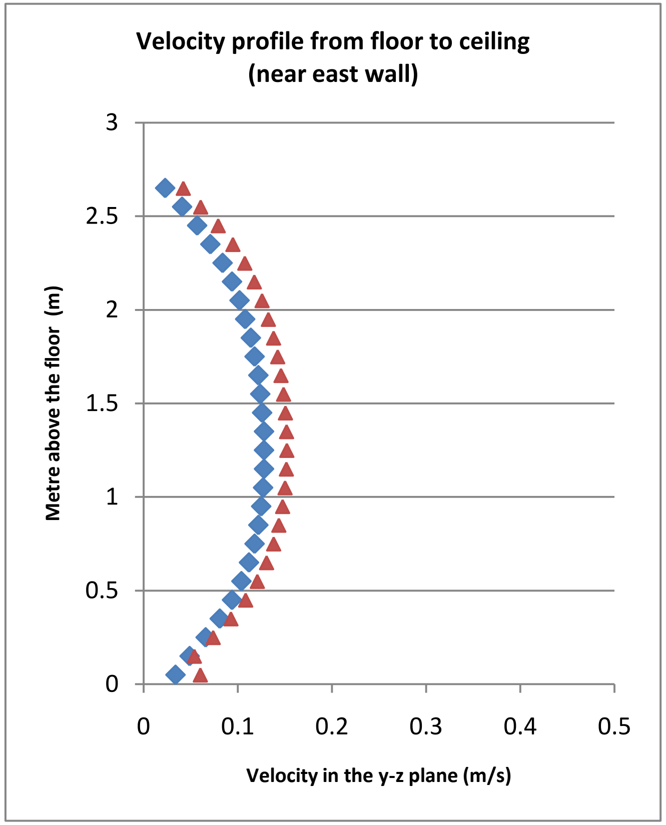
Case B Velocity profiles







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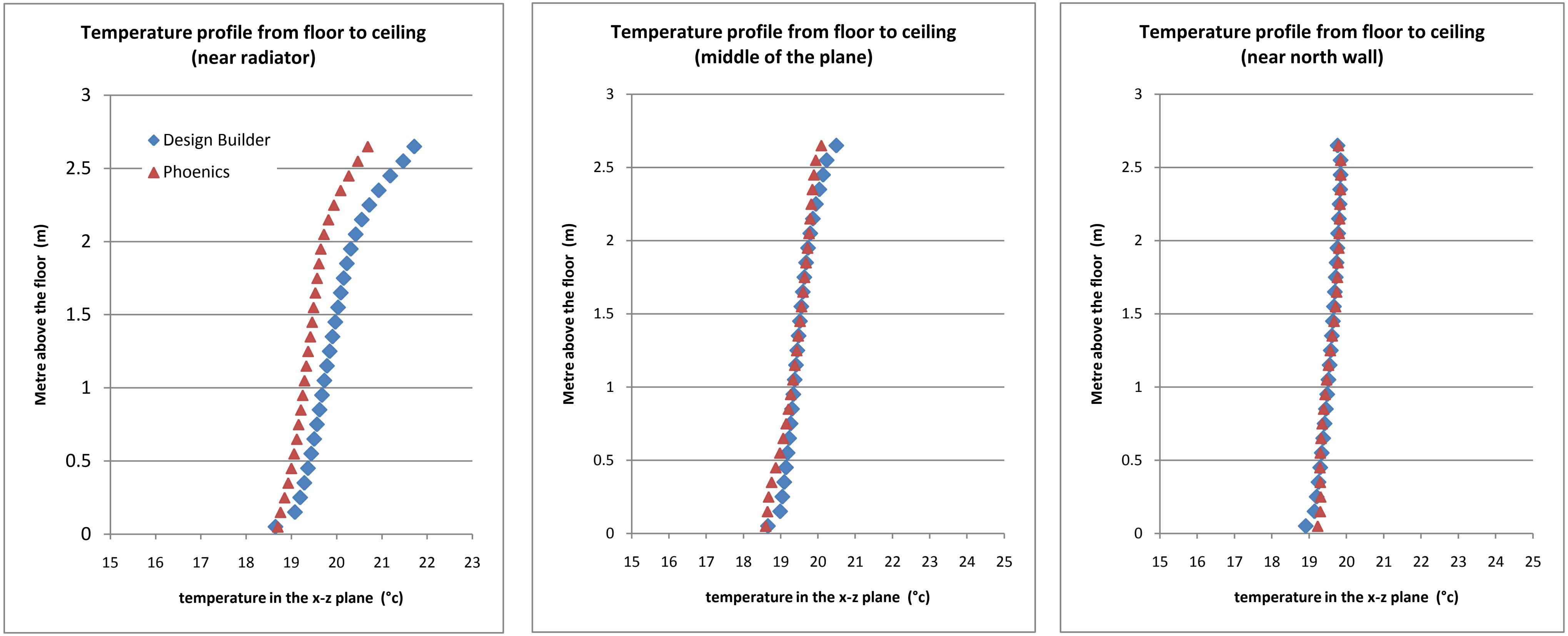
Case C Temperature profiles



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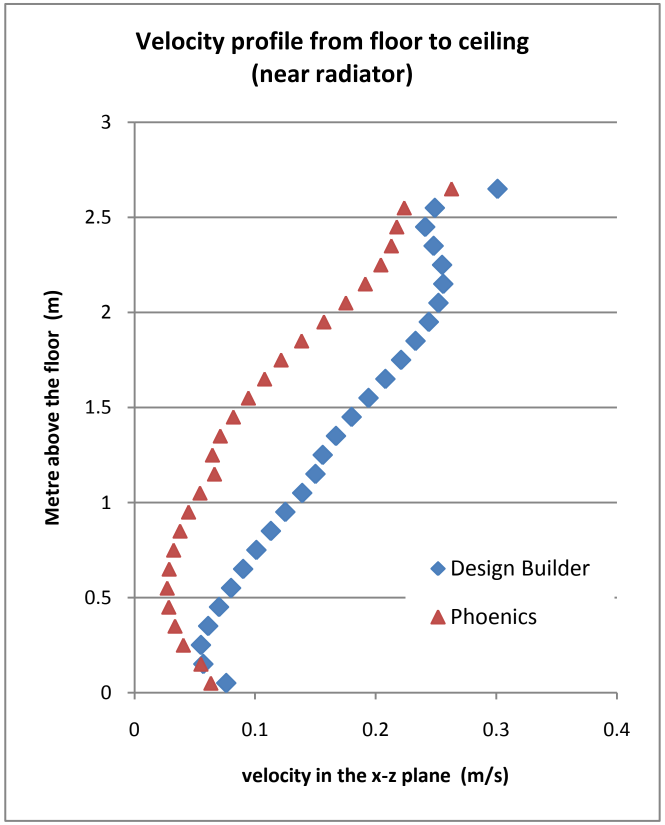
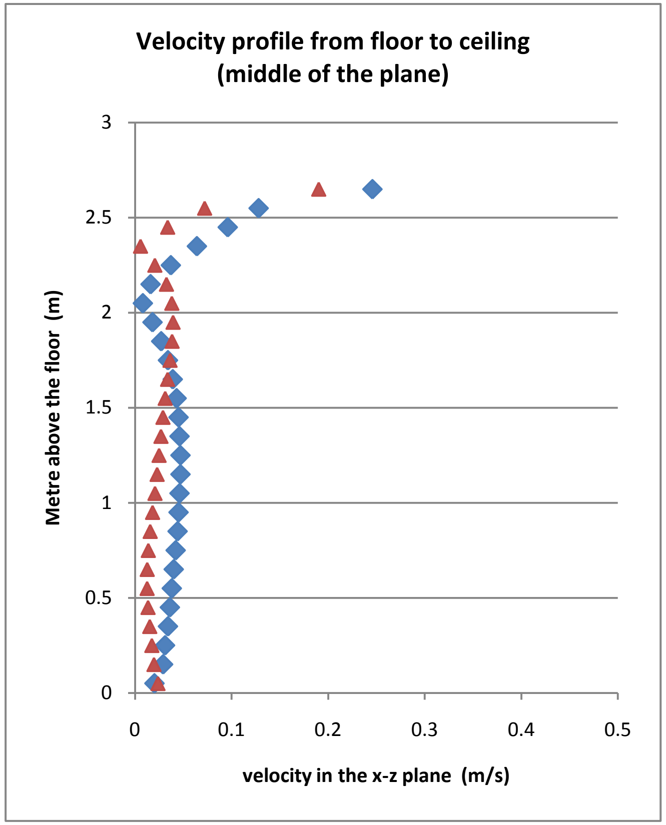
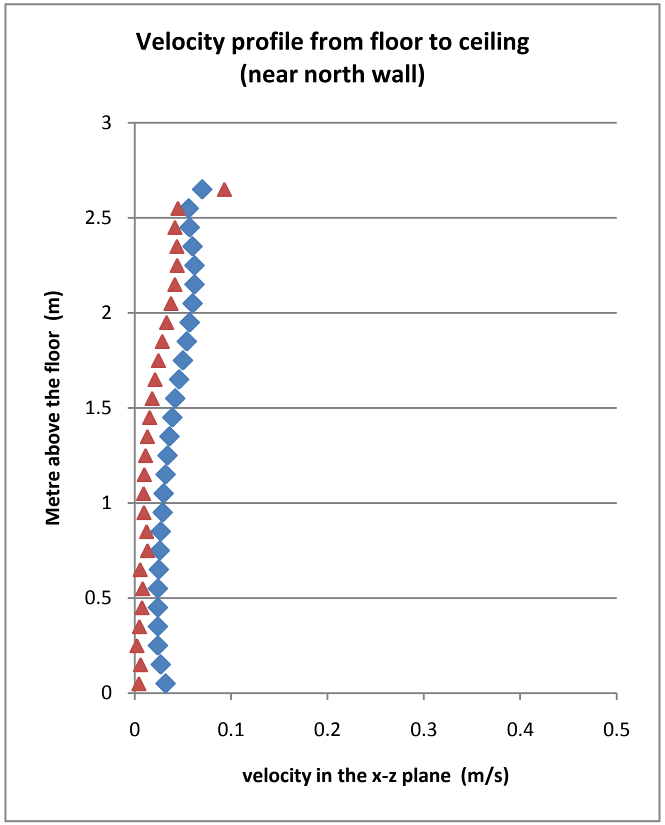
Case C Velocity profiles







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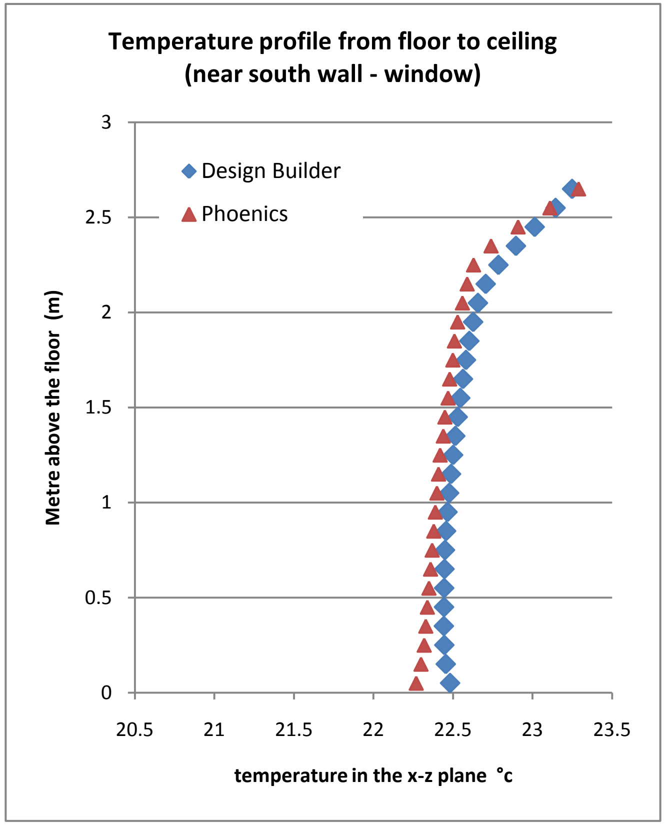
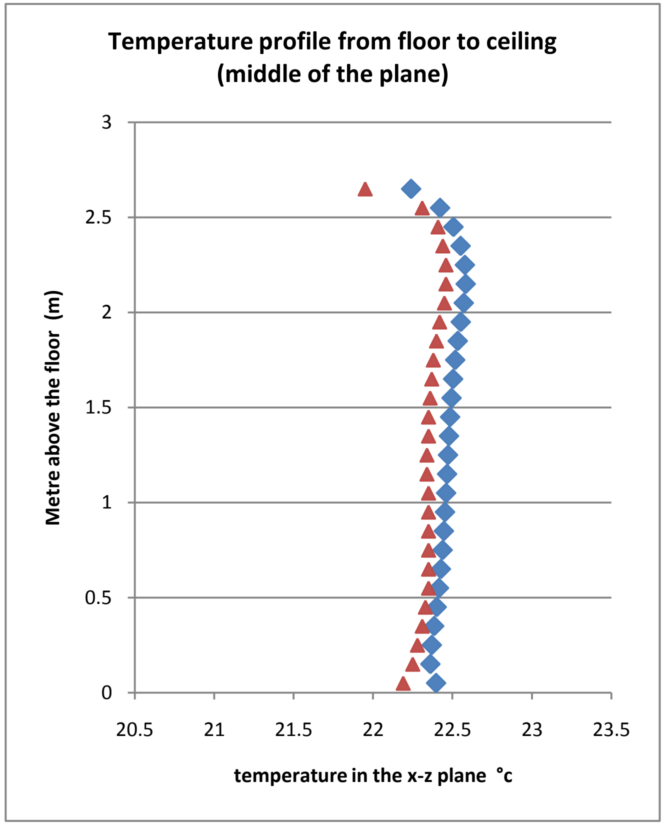
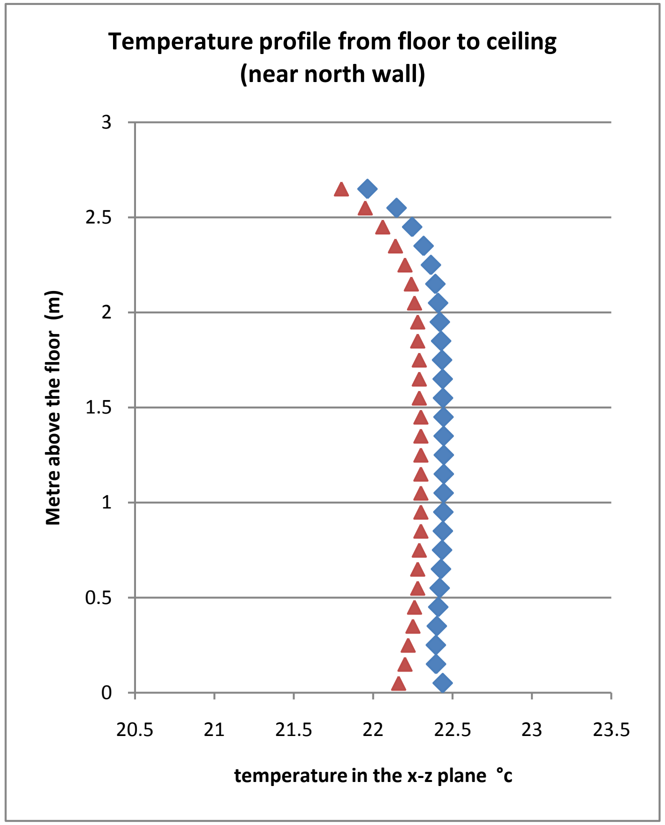
Case D Temperature profiles (south to north wall)







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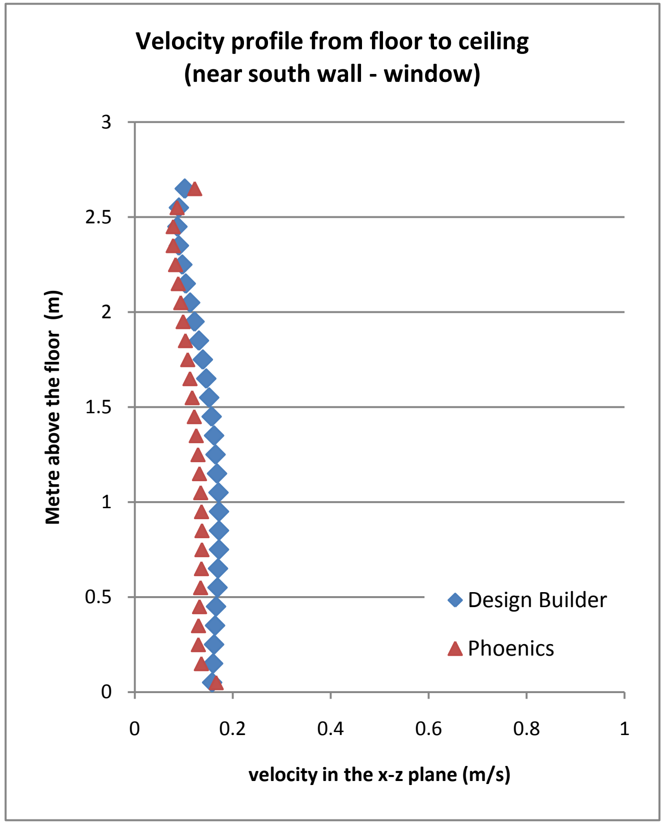
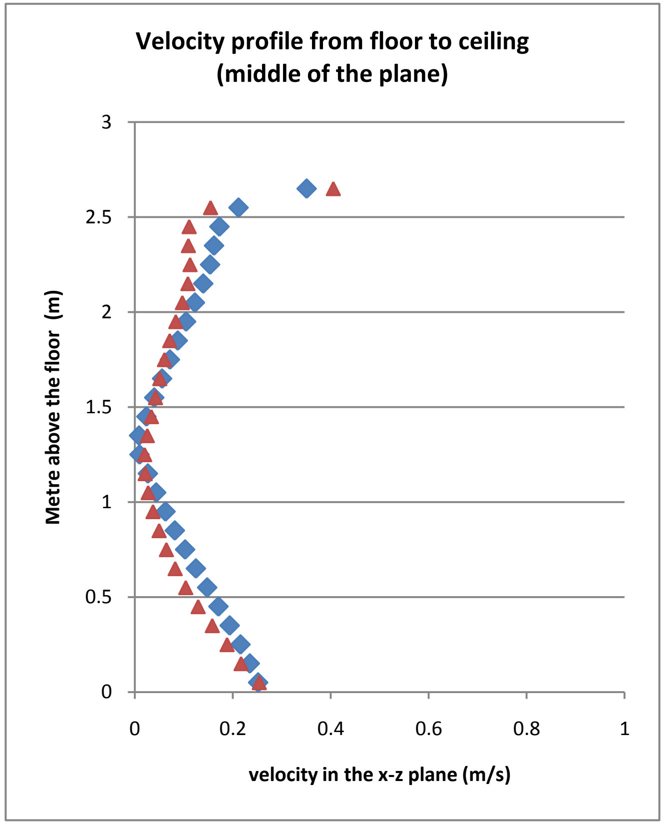
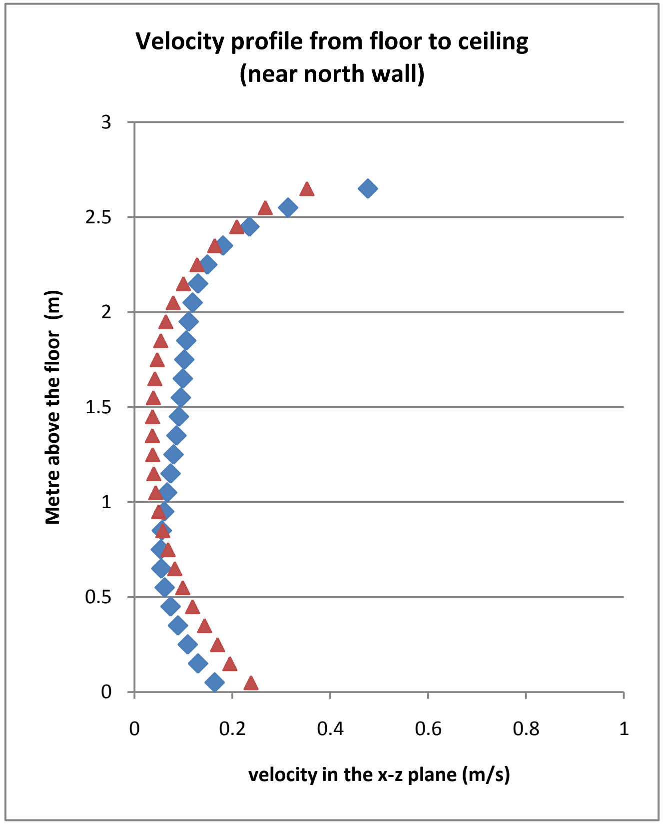
Case D Velocity profiles (south to north wall)







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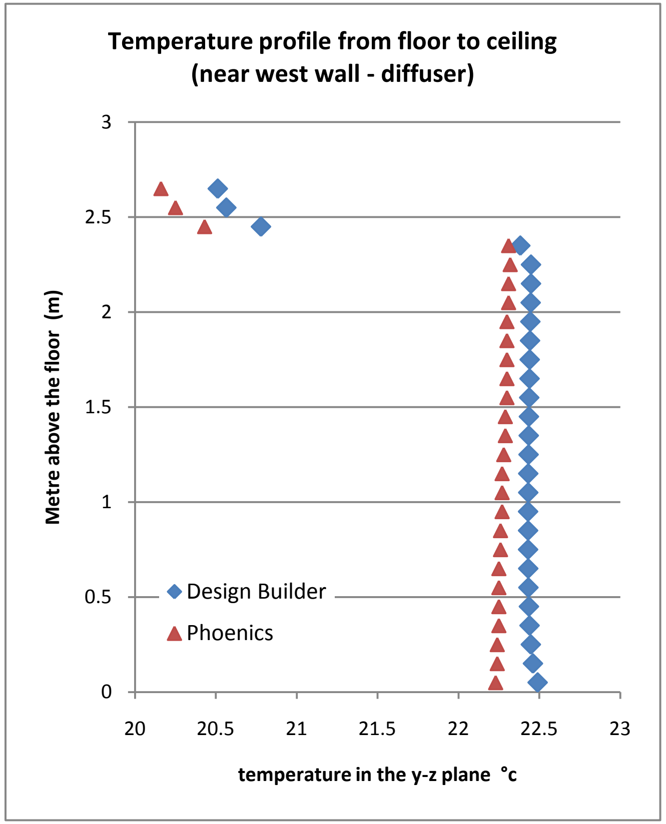
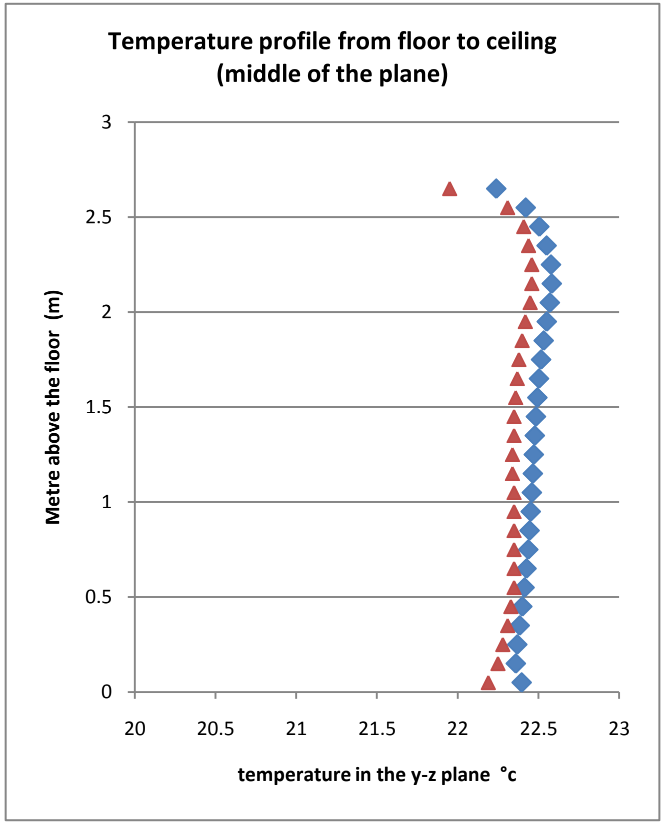
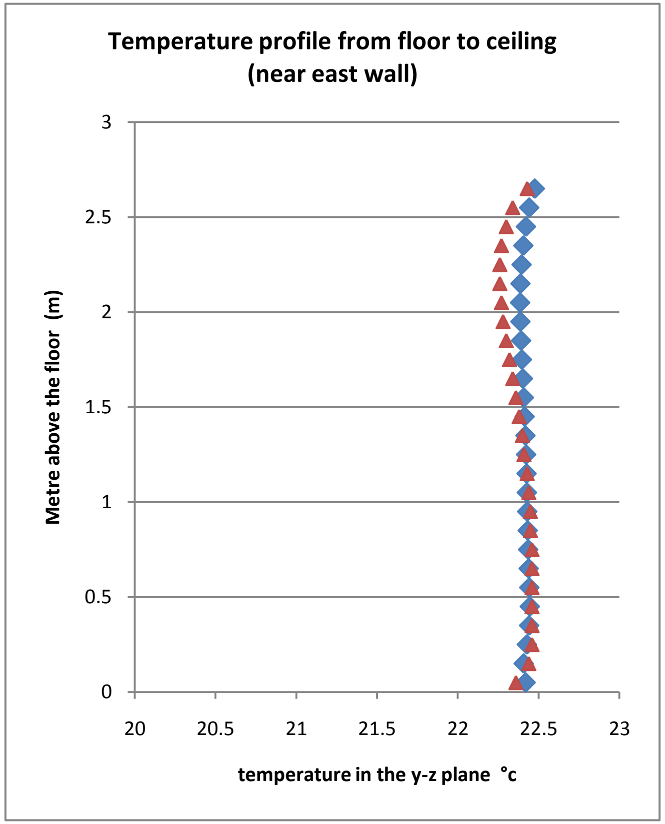
Case D Temperature profiles (west to east wall)







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Case D Velocity profiles (west to east wall)