INVESTIGATIONS ON THERMAL PERFORMANCE OF BUILDING ELEMENTS

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INVESTIGATIONS ON THERMAL PERFORMANCE OF BUILDING ELEMENTS

Major Project Report

Submitted in partial fulfillment of the requirements

For the Degree of

Master of Technology in Mechanical Engineering (Thermal Engineering)

By

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Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Thermal Engineering at Nirma University and has not been submitted elsewhere for a degree or diploma.

2. Due acknowledgement has been made in the text to all other material used.

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Undertaking for Originality of the Work

I, **Vimal S. Patel**, Roll No.**11MMET13**, give undertaking that the Major Project entitled " **Investigation on Thermal Performance of Bulding Elements**" submitted by me, towards the partial fulfillment of requirements for degree of **Master technology in Mechanical Engineering (Thermal Engineering)** of Nirma university,Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will resul in severe disciplinary action.

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This is to certify that the Major Project Report entitled "**Investigations on Thermal Performance of Building Elements**" submitted by **Mr.Vimal S. Patel(11MMET13)**, towards the partial fulfillment of the requirements for the award of Degree of **Master of Technology in Mechanical Engineering (Thermal Engineering)** of Institute of Technology, Nirma University, Ahmedabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination.The result embodied in this major project, to the best of our knowledge, has not been submitted to any other University or Institution for award of any degree.

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Abbreviations

GHB	=	Guarded Hot Box
ISO	=	The International Organization for Standardization
Q	=	Heat Flow Rate [W]
U	=	Thermal transmitance [W/(m^{2}K)]
A	=	Area perpendicular to heat flow [m^2]
$\triangle$T	=	Temperature difference [K]

Abstract

A large amount of heat loss through building envelopes takes place via inhomogeneous components such as windows, doors, and thermal bridges. This loss can be approximated by measuring in laboratory the actual thermal transmittance of these components with the use of a Guarded Hot Box (GHB). It is necessary for design guidance and research to look into the performance of materials and constructions and for verification of simulation models.

A detailed literature review pertaining to the design and technical specifications of a Guarded Hot Box was carried out. Based on the same, the dimensions and details of the proposed Guarded Hot Box was worked out. The CFD analysis to study the air flow pattern inside the Guarded Hot Box was done using FLUENT software. The CFD results indicate that for a fairly uniform velocity and pressure profile the suitable position of the air circulation fan is on the front wall (side) in the Guard box as well as in the Cold box. For the Metering box, the suitable position of the air circulation fan is observed to be at the centre of the side wall.

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Chapter 1

Introduction

A large amount of heat loss through building envelopes takes place via inhomogeneous components such as windows, doors, and Building Wall. This loss can be approximated by measuring in lab the actual thermal transmittance of these components with the use of a hot box. It is necessary for Design guidance, for research into the performance of materials and constructions and for verification of simulation models.

Data on the thermal transmission properties of insulants and insulated structures are needed for various purposes including judging compliance with regulations and specifications, for design guidance, for research into the performance of materials and constructions and for verification of simulation models. Many thermal insulating materials and systems are such that the heat transfer through them is a complex combination of conduction, convection and radiation.

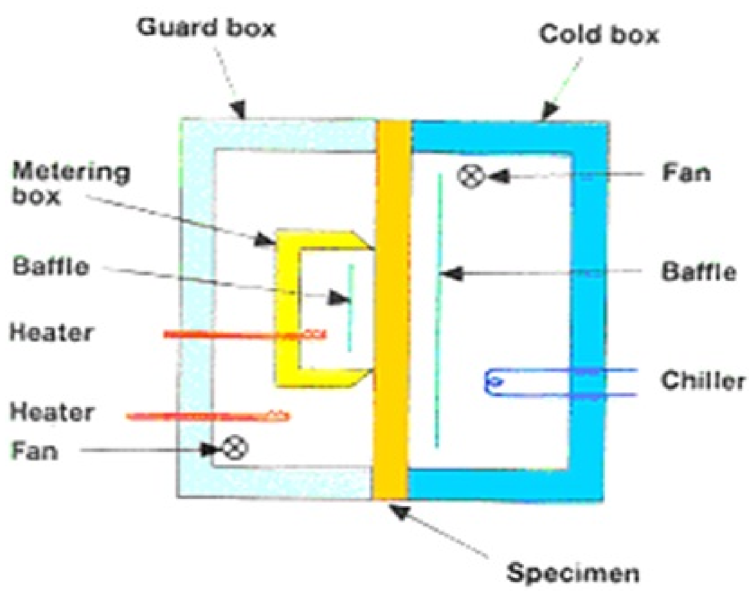

Figure 1.1: Schematic diagram of guarded hot box[1]

The methods described in this report the total amount of heat transferred from one side of the specimen to the other for a given temperature difference, irrespective of the individual modes of heat transfer, and the test results can therefore be applied to situations when that is the property required. However, the thermal transmission properties often depend on the specimen itself and on the boundary conditions, specimen dimensions, direction of heat transfer, temperatures, temperature differences, air velocities, and relative humidity. In consequence, the test conditions must replicate those of the intended application, or be evaluated if the result is to be meaningful.

It should also be borne in mind that a property can only be assessed as useful to characterize a material, product or system if the measurement of the steady-state thermal transmission properties of the specimen and the calculation or interpretation of the thermal transmission characteristics represent the actual performance of the product or system. Further, a property can only be characteristic of a material, product or system if the results of a series of measurements on a number of specimens from several samples provide sufficient reproducibility.

The design and operation of the guarded hot box is a complex subject. It is essential that the designer and user of such apparatus has a thorough background knowledge of heat transfer, and has experience of precision measurement techniques. Many different designs of the calibrated and the guarded hot box exist worldwide conforming to national standards. Continuing research and development is in progress to improve apparatus and measurement techniques. Also the variation of structures to be tested may be so great, and the requirements for test conditions so different.

1.1 Overview of the Guarded Hot Box

Today, hot boxes are reliable instruments for various types of measurements. However, their history dates to the first attempts of mumaw, who in the early 70s used this device to test large and highly thermal resistant wall sections. Soon after, the potential benefit of this apparatus in the field of inhomogeneous materials testing drew the attention of those investigating window systems. Another popular application of this measurement system is in research on building materials.

This test method establishes the principles for the design of a hot box apparatus and the minimum requirements for the determination of the steady state thermal performance of building assemblies when exposed to controlled laboratory conditions. This method is also used to measure the thermal performance of a building material at standardized test conditions such as those required in material Specifications and Practice.

Figure 1.2: Photograph of guarded hot box apparatus[1]

This test method is used for large homogeneous or non-homogeneous specimens. This test method applies to building structures or composite assemblies of building materials for which it is possible to build a representative specimen that fits the test apparatus.

In an ideal hotbox test of a homogenous material there is no temperature difference on either the warm or cold specimen faces to drive a flanking heat flow. In addition, there would be no temperature differences that would drive heat across the boundary of the metering chamber walls. However, experience has demonstrated that maintaining a perfect guard/ metering chamber balance is not possible and small corrections are needed to accurately characterize all the heat flow paths from the metering chamber. To gain this final confidence in the test result, it is necessary to benchmark the overall result of the hot box apparatus by performing measurements on specimens having known heat transfer values and comparing those results to the expected values.Heat flow rate is define bu following equation.

Heat flow rate, $Q = UA\triangle T$

where,

Q=Heat flow rate [W]

U=Thermal transmitance [$W/(m^2K)$]

A=Area perpendicular to heat flow [m^2]

$\triangle$T=Temperature difference [K]

This test method is intended for use at conditions typical of normal building applications. The naturally occurring outside conditions in temperate zones range from approximately −48 to 85°C and the normal inside residential temperatures is approximately 21°C. Building materials used to construct the test specimens shall be pre-conditioned, if necessary, based upon the material's properties and their potential variability. The preconditioning parameters shall be chosen to accurately reflect the test samples intended use and shall be documented in the report. Practice C870 may be used as a guide for test specimen conditioning. The general principles of the hot box method can be used to construct an apparatus to measure the heat flow through industrial systems at elevated temperatures. Detailed design of that type of apparatus is beyond the scope of this method.

This test method permits operation under natural or forced convective conditions at the specimen surfaces. The direction of airflow motion under forced convective conditions shall be either perpendicular or parallel to the surface.

The hot box apparatus, when constructed to measure heat transfer in the horizontal direction, is used for testing walls and other vertical structures. When constructed to measure heat transfer in the vertical direction, the hot box is used for testing roof, ceiling, floor, and other horizontal structures. Other orientations are also permitted. The same apparatus may be used in several orientations but may require special design capability to permit repositioning to each orientation. Whatever the test orientation, the apparatus performance shall first be verified at that orientation with a specimen of known thermal resistance in place.

This test method does not permit intentional mass transfer of air or moisture through the specimen during measurements. Air infiltration or moisture migration can alter the net heat transfer. Complicated interactions and dependence upon many variables, coupled with only a limited experience in testing under such conditions, have made it inadvisable to include this type testing in this standard.

1.2 Scope

This test method establishes the principles for the design of a hot box apparatus and the minimum requirements for the determination of the steady state thermal performance of building assemblies when exposed to controlled laboratory conditions. This method is also used to measure the thermal performance of a building material at standardized test conditions such as those required in material Specifications.

This test method is used for large homogeneous or non-homogeneous specimens. This test method applies to building structures or composite assemblies of building materials for which it is possible to build a representative specimen that fits the test apparatus. The dimensions of specimen projections or recesses are controlled by the design of the hot box apparatus. Some hot boxes are limited to planar or nearly planar specimens. However, larger hot boxes have been used to characterize projecting skylights and attic sections.

According to International Standard lays down the principles for the design of the apparatus and minimum requirement that shall be met for determination of the laboratory steady-state thermal transmission properties of building components and similar components for industrial use. It does not, however, specify a particular design since requirements vary, particularly in terms of size, and also to a lesser extent in terms of operating conditions.

According to International Standard describes also the apparatus, measurement technique and necessary data reporting. Special components, for example windows, need additional procedures which are not included in this International Standard. Also excluded are measurements of the effect on heat flow of moisture transfer or redistribution but consideration shall be given in the design and operation of the equipment as to the possible effect of moisture transfer on the accuracy and the relevance of test results. The properties which can be measured are thermal transmittance and thermal resistance. Two alternative methods are included: the calibrated hot box method and the guarded hot box method. Both are suitable for vertical specimens such as walls and for horizontal specimens such as ceilings and floors. The apparatus can be sufficiently large to study full-scale components.

A properly designed and operated hot box apparatus is directly analogous to the test method guarded hot plate for testing large specimens exposed to air induced temperature differences. The operation of a hot box apparatus requires a significant number of fundamental measurements of temperatures, areas and power. The equipment performing these measurements requires calibration to ensure that the data are accurate. During initial setup and periodic verification testing, each measurement system and sensor is calibrated against a standard traceable to a national standards laboratory. If the hot box apparatus has been designed, constructed and operated in the ideal manner, no further calibration or adjustment would be necessary. As such, the hot box is considered a primary method and the uncertainty of the result is analyzed by direct evaluation of the component measurement uncertainties of the instrumentation used in making the measurements.

In order to ensure an acceptable level of result uncertainty, persons applying this test method must possess a knowledge of the requirements of thermal measurements and testing practice and of the practical application of heat transfer theory relating to thermal insulation materials and systems. Detailed operating procedures, including design schematics and electrical drawings, shall be available for each apparatus to ensure that tests are in accordance with this test method.

This test method permits operation under natural or forced convective conditions at the specimen surfaces. The direction of airflow motion under forced convective conditions shall be either perpendicular or parallel to the surface.

The hot box apparatus also is used for measurements of individual building assemblies that are smaller than the metering area. Special characterization procedures are required for these tests.

The hot box has been used to investigate the thermal behavior of non-homogeneous building assemblies such as structural members, piping, electrical outlets, or construction defects such as insulation voids.

1.3 Principle

The guarded hot box apparatus is intended to reproduce conventional boundary conditions of a specimen between two fluids, usually atmospheric air, each at uniform temperature.

The specimen is placed between a hot and a cold chamber in which environmental temperatures are known. Measurements are made at steady-state of air and surface temperatures and of the power input to the hot side chamber. From these measurements the thermal transfer properties of the specimen are calculated. Heat exchange at the surfaces of the test specimen involves both convective and radiative components. The former depends upon air temperature and air velocity, and the latter depends upon the temperatures and the total hemispherical emittances of specimen surfaces and of surfaces "seen" by the test specimen surface. The effects of the heat transfer by convection and radiation are combined in the concept of an "environmental temperature" and a surface heat transfer coefficient.

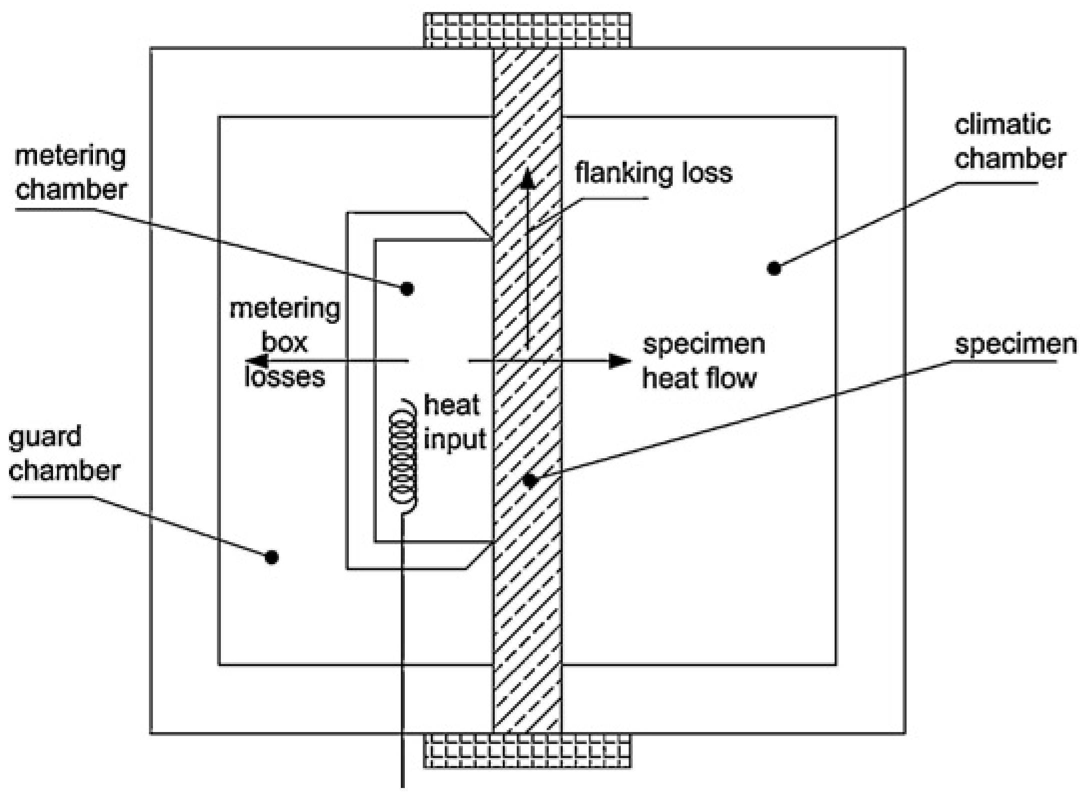

Figure 1.3: Schematic diagram of guarded hot box[1]

Thermal transmittance is defined between two environmental temperatures, and therefore suitable temperature measurements are required to enable these to be determined. This is particularly important with test specimens of low thermal resistance for which the surface coefficients of heat transfer form a significant fraction of the total resistance. In case of test specimens with a moderate to high thermal resistance, it may be sufficient to record air temperatures only during a test, if it can be shown that the difference in air and radiant temperatures on either side of the test specimen is so small that the accuracy requirements are met.

A special situation arises when the hot box has a radiant panel, close to the warm side of the specimen, as heat supply. In this case the radiant component will be more dominant in the heat transfer to the specimen surface. This method with radiant panel can be used to measure the thermal resistance of the specimen but is not suitable for direct measurements of the thermal transmittance, at conventional surface coefficients.

Chapter 2

Literature Review

2.1 Previous Studies

Thermal transmittance measurement with the hot box method, by F. Asdrubali, G. Baldinelli [1], at University of Perugia, Industrial Engineering Department, Via Duranti, 67, Perugia 06125, Italy, in 6 March 2011, Carried out the experimental evaluation of inhomogeneous components thermal transmittance has been carried out through the hot box method, following three different standards. All the tests were executed in an apparatus designed and produced at the University of Perugia to meet all requirements of EN ISO 8990, ASTM C1363-05, and GOST 26602.1-99. The preliminary measurements underlined that a long and detailed calibration procedure is needed both for the European and American Standards, with the aim of properly defining the hot box characteristics. Data obtained from this process remained valid for all samples tested in the same apparatus. As far as the Russian Standard, no calibration is needed for the chambers, but each sample had to be deeply analyzed to define the thermally homogenous zones before proceeding to the actual measurement.

Analysis of a thermal bridge in a guarded hot box testing facility,by K. Martin, [2], at Department of Thermal Engineering – University of the Basque Country (UPV/EHU), Alameda Urquijo s/n, 48013 Bilbao, Spain, in 13 March 2012, Carried out with the aim of analyzing the real behavior of TBs, a series of tests in steady and dynamic state have been carried out in a guarded hot box facility. To this end two similar samples have been built in the LCCE, one containing the pillar TB and the other without it. The test conducted in accordance with the standard EN ISO 8990 for the homogeneous wall agrees very fairly with the numerical calculation carried out with FLUENT software, with an error lower than 2%. This error is under the uncertainties of each method.

Thermal insulation -Determination of steady-state thermal transmission properties -Calibrated and guarded hot Box, by ISO-8990,[3], First Edition,1994, Carried out the test results shall be compared with the tentative estimate stated. In the case of significant divergences, the specimen shall be carefully inspected to locate any discrepancy from its specifications, and then the tentative estimate shall be repeated with the findings of the inspection. If inexplicable differences still exist between tentative estimates and measured data, the alternative possibilities of oversimplified computation procedures and of test errors shall be investigated. EN ISO 8990 seem in terms of procedures definition and methodology of heat exchange definition.it treat the sample as a “black box” and calculate the total heat transfer that passes through the survey itself without considering (and being affected by), the different parts that constitute the component under test.

Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus, by ASTM-C1363-11,[4], Carried out the heat balance in a hot box Apparatus,Provides a general overview of the heat balance within a hot box apparatus.Estimating the Metering Box wall loss,describes the physics of the metering box wall loss. Also describes the characterization tests required to determine the heat flow through the metering box walls in relation to the metering box wall transducer output. Estimating the Flanking Loss,defines the concept of the flanking loss. Also describes methods for modeling and model verification of the flanking loss in a hot box apparatus.Preliminary Hot Box Characterization,Outlines the initial testing required for the initial setup of the metering box wall transducers.Using the Hot Box to determine the Heat Transfer through Specimens Smaller Than the Metering Area,explains how to use a surround panel to measure the thermal resistance of specimens smaller than the metering area of the hot box.Determination of the environmental temperature in the Hot Box environment,describes how to calculate the environmental temperature in both chambers of the hot box. These values are used to determine the thermal resistance of all specimens.

Comparing different approaches to in measurement of building components thermal resistance,by Giuseppe Desogus, Salvatore Mura,[5], at University of Cagliari, Department of Architecture, Via Corte d’Appello 87, 09124 Cagliari, Italy, in 30 May 2011, Carried out On the one hand the differences between the results of the two methods are so small that either of them could be useful in evaluating the in situ R-value of a building envelope and satisfying the requirements for practical applications. Each of these two methods has obviously its own advantages.Thus, if the correct environmental conditions are available, the best way to evaluate the in situ R-value of buildings is by direct measurement with a heat-flux meter. Otherwise, if the conditions are not ideal, the use of the other two methods is still possible, but the estimation of building energy performance will be clearly less precise.

A simple dynamic measurement technique for comparing thermal insulation performances of anisotropic building materials,by Bulent Yesilata, Paki Turgut,[6], at Harran University, Mechanical Engineering Department, 63300 Sanliurfa, Turkey, in 30 November 2006, carried out the dynamic adiabatic technique described here is found to be functional and robust for first estimation of thermal insulation performances of complex structured (i.e. inhomogeneous, anisotropic, layered) flat specimens. The thermal conditions in hot and cold spaces can easily be arranged and changed to examine various internal and external environment effects on thermal behavior. Although testing time is quiet long due to low effective thermal conductivity of specimens, maintaining the required cold space conditions during this time are easy. The thermal insulation performances of rubberized concrete specimens are compared with that of the ordinary one to demonstrate the measurement and evaluation procedures of the technique. It is found that the insulation performance is improved as much as 14.7% by addition of circular rubber matrix into the ordinary concrete. More work and tests are necessary to increase the utilization and standardization of the proposed technique.

Thermal properties of building materials evaluated by a dynamic simulation of a test cell,by G. Leftheriotis, P. Yianoulis,[7], at Department of Physics, University of Patras, Patras 26500, Greece, in 25 May 2000, carried out a procedure has been developed for the measurement of thermal properties of building materials based on the dynamic simulation of a test cell.The test cell presented here is constructed in a way that enables calculation of thermal properties from simple temperature measurements, without the need for measurement of input and output power.The limited thermal mass of the test cell combined with indoor testing, enables accurate estimation of thermal properties in short testing times.

A rational approach to the harmonisation of the thermal properties of building materials,by J.A. Clarke, P.P. Yaneske,[8], at Department of Mechanical Engineering, University of Strathclyde, Glasgow, UK,in 16 February 2009, carried out the major sets of material thermo-physical properties were gathered, organised and conflated as a function of the expected reliability of the underlying test procedures.With regard to the thermal performance of materials, the guarded hot-plate and heat flow meter methods continue to be the basis for measurement standards with the aim of determining heat transfer properties in the steady state for materials of either low-tomedium thermal resistance or of medium-to-high thermal resistance, with a further subdivision of the latter by thickness [32–34].

Analysis of two main LNG CCS (cargo containment system) insulation boxes for leakage safety using experimentally defined thermal properties,by Sung Woong Choi, Jeong U. Roh, Moo Sun Kim, Woo Il Lee,[9], at School of Mechanical and Aerospace and Engineering, Seoul National University, Seoul 151-742, Republic of Korea,in 10 April 2012, carried out The experimental tests conducted in this study indicate that the thermal conductivity decreases as the environmental temperature decreases. Considering the cryogenic temperature of LNG insulation boxes the insulation materials used for the LNG CCS box are superior insulation materials as they have low thermal conductivity ratings. They used two main LNG CCS models to estimate the thermal distribution of a CCS box and two systems of tanks with superior insulation characteristics based on steady-state thermal analyses. Of the two systems leakage through glass wool is more likely to occur for the GTT Mark III system.

Thermal properties of a variable cavity wall, by D.P. Aviram , A.N. Fried, J.J. Roberts,[10],at Faculty of Technology, School of Civil Engineering, Kingston University, Penrhyn Road, Kingston upon Thames, Surrey KTI 2EE, UK,in 23 May 2000, carried out within the experimental range of aspect ratio and boundary conditions increasing the cavity aspect ratio was found to reduce the magnitude of convective 4ow velocity. It is postulated that the reason for increased thermal resistance at higher aspect ratios is linked to the lower magnitude of convective 4ows. The lower intensity of air circulation produces lower heat exchange between the hot and cold cavity walls.Over the aspect ratio range tested, 4ow regimes were found to change from turbulent to laminar with transition in between. This was observed experimentally and by computational models.A meandering 4ow pattern, which increased in frequency as the aspect ratio increased was observed in the cavity. It is indicative of a highly complex three-dimensional 4ow.The presence of mortar joints increases heat losses through the wall and produces an undulating 4ow pattern within the cavity.The resistance of the air cavity, measured by Nusselt number, was found to increase by 66% over the aspect ratios tested.

A methodology for experimental evaluations of low-e barriers thermal properties: Field tests and comparison with theoretical models, by G. Baldinelli,[11],at University of Perugia, Industrial Engineering Department, Via Duranti, 67, Perugia 06125, Italy,in 13 October 2009, carried out the experimental approach proposed for the evaluation of low-e insulators installed on vertical walls makes it possible to define the stationary and dynamic properties of these solutions under real outdoor conditions. The possibility of verifying the entire wall without the low-e material permits the precise definition of the thermophysical properties of all the other components, guaranteeing, therefore, that the differential measurement could underline the performance of the low-e panel alone. The same approach could be used if the radiant panel is installed in horizontal walls. The in situ campaigns demonstrated that ISO 6946 represents a good approximation of the low-e material and air gap behavior in stationary conditions, provided that the total emittance is defined accurately.

Investigation of thermal performance of reflective insulations for different applications, by Hamed H. Saber,[12],at Institute for Research in Construction, National Research Council Canada, Bldg. M-24, 1200 Montreal Road, Ottawa, Ontario, Canada,in 15 December 2011, carried out the numerical simulations were conducted to address the thermal performance of different types of reflective insulations. The present model was used to explore the possibility of using the ASTM C-518 test method for measuring the effective R-value of sample stack with reflective insulations. In the first phase of this study, the predictions of the present model were compared with the CCHRC's test data that were obtained using FOX-314 heat flow meter in accordance of ASTM C-518 test method. Results showed that the predicted R-values were consistently 6.8e9.1% higher than the R-values derived from the test data. To understand why the predicted R-values were consistently higher than the measured ones, two tests were conducted at NRC for EPS sample stack with and without aluminum foil using the same test method and same test conditions as in reference but with different heat flow meter.

Reduced linear state model of hollow blocks walls, validation using hot box measurements, by Y. Gao, J.J. Roux, C. Teodosiu, L.H. Zhao,[13], at School of Municipal and Environmental Engineering, Harbin Institute of Technology, 92 West Da-Zhi Street, Harbin 150001, China,in 30 March 2004, carried out the traditional method based on multi-layers onedimensional heat flow (by using hypothetical equivalent thickness of materials) to predict heat loss through building envelopes under dynamic conditions is not very precise in the case of hollow blocks walls. Consequently, complex three-dimensional heat transfer computations are indispensable to properly describe the thermal behaviour of hollow blocks. Unfortunately, this approach leads generally to linear state models defined by high-order matrixes. Numerical treatment of such complicated models is almost prohibitory because it necessitates judicious algorithm implementation and important computation time.

Experimental and numerical thermal analysis of a balcony board with integrated glass fibre reinforced polymer GFRP elements, by Karim Ghazi Wakili, Hans Simmler, Thomas Frank,[14],at Swiss Federal Laboratories for Materials Testing and Research (Empa), CH-8600 Duebendorf, Switzerland, in 4 May 2006, carried out a novel system of thermally interrupted balcony boards containing glass fibre reinforced elements analyzed both experimentally and numerically resulted to be a thermally more favourable solution than its statically equivalent conventional boards. This was achieved by using the glass fibre reinforced plastic elements which replace the compression rods and simultaneously allow a reduction of the diameter of the tensile rods, which in turn reduces the additional heat loss, i.e. the linear thermal transmittance of the whole building detail.

Static and dynamic thermal characterisation of a hollow brick wall: Tests and numerical analysis,by J.M. Sala, A. Urresti, K. Martin, I. Flores, A. Apaolaza,[15],at Thermal Engineering Department, Universidad del Paı´s Vasco (UPV/EHU), Alda. Urquijo s/n, 48013 Bilbao, Spain,in 2 February 2008, carried out in calculating the energy demands for buildings and particularly for bioclimatic systems, it is very important to characterise the thermal inertia of walls. For this reason, a calibrated hot-box unit is adjusted for static and dynamic thermal characterisation of different types of wall, using 2 m 2 m samples. Numerical analysis is carried out to obtain the thermal performance of a wall, in stationary and dynamic frameworks. Dynamic tests are carried out on the basis of the measurement of the surface temperatures of the wall and determination of the thermal resistance of the interior and exterior air layers. On determining these values, and using a triangular signal in the air temperature of the cold chamber, the surface temperatures of the sample are measured throughout the period and the heat flow is calculated.

In situ measuring and evaluating the thermal resistance of building construction, by Changhai Peng, Zhishen Wu,[16],at IIUSE, Southeast University, Nanjing 210096, PR China,in 30 May 2008, carried out Based on the discussions mentioned above, the following conclusions can be made: On the one hand, the differences between the results of the three methods are so small that any of them could be used to evaluate the in situ R-value of buildings and to satisfy the requirements of practical projects. Certainly, each of these three methods has its own advantages. For instance, the synthetic temperature method only requires measuring the heat-flow rate on the inside surface of the building construction and both the synthetic indoor and outdoor temperatures. And the surface temperature method just requires testing the heat-flow rate on the inside surface of building envelopes and both the inside and outside surface temperatures of building construction. However, the frequency response method introduced in this paper only relates to the mean synthetic indoor and outdoor temperatures as well as the average of the inside surface temperatures of the building envelopes. In other words, it is not involved with the heatflow rate, which is difficult to measure. In fact, one of main test errors of in situ measuring the thermal resistance of building construction comes from heat-flow meters, including from these instruments themselves and from measuring operation. In practice, heat-flow meters need to be plastered on the surface or embedded in specimens. In this case, since the heat condition on the surface is altered, it will lead to the change of temperature fields in the specimen and around the heat-flow meter. All of these will result in the difference between the test results and the real cases. This is so-called the measure error of heat-flow meters.

2.2 Summary of Literature Review

Table 2.1: Summary of literature review

Configuration	**Nature of Work**	**Observations**	**Author Name**	**Journal Name/References**
Calibrated hot box,Thermal transmittance, Experimental methodologies, Uncertainties	Thermal transmittance measurements with the hot box method	Thermal Transmittance, Experimental methodologies	F. Asdrubali G. Baldinelli [43]	Energy and Buildings, (2011)
Testing,Guarded hot box Simulation, Dynamic regime, Thermal inertia	Analysis of a thermal bridge in a guarded hot box testing facility	Test methodology, and Testing facility	K. Martin [50]	Energy and Buildings, (2012)
Thermal insulation,Thermal transmittance	Determination of steady-state thermal transmission properties	Design Criteria, Test Procedure	ISO-8990	International Standard First edition (1994-09-01)
Standard Test Method	Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus	Principal and Test Procedure	ASTM-C1363	ASTM-C1363 (2011)
Building envelope, Energy efficiency, Measurement of thermal transmittance	Comparing different approaches to in situ measurement of building components thermal resistance	Energy efficiency, Measurement of thermal transmittance	Giuseppe Desogus, Salvatore Mura [43]	Energy and Buildings, (2011)
Measurement methods, Thermal properties, Adiabatic-box technique, Anisotropy	A simple dynamic measurement technique for comparing thermal insulation performances of anisotropic building materials	Measurement methods, Thermal properties	Bulent Yesilata, Paki Turgut [39]	Energy and Buildings, (2006)

Table 2.2: Summary of literature review

Configuration	Nature of Work	Observations	Author Name	Journal Name/References
Thermal properties, Calibration of the test cell	Thermal properties of building materials evaluated by a dynamic simulation of a test cell	Thermal properties,Testing procedure	G. Leftheriotis, P. Yianoulis [69]	Solar Energy, (2000)
Material thermo-physical properties, Test methods	A rational approach to the harmonisation of the thermal properties of building materials	Test methods	J.A. Clarke, P.P. Yaneske [44]	Building and Environment, (2009)
Perlite, Plywood, Polyurethane foam, LNG (liquefied natural gas)	Analysis of two main LNG CCS (cargo containment system) insulation boxes for leakage safety using experimentally defined thermal properties	Thermal conductivity of insulation materials,Test methods	Sung Woong Choi et al. [37]	Applied Ocean Research, (2012)
Thermal properties and Construction of the variable cavity wall	Thermal properties of a variable cavity wall	Thermal properties, Test methods	D.P. Aviram, A.N. Fried, J.J. Roberts [36]	Building and Environment, (2000)
Low-e thermal insulators, Radiant barriers, Dynamic model, Emittance, Thermal resistance, Computational fluid dynamics	A methodology for experimental evaluations of low-e barriers thermal properties: Field tests and comparison with theoretical models	Computational fluid dynamics, Dynamic model	G. Baldinelli [45]	Building and Environment, (2009)

Table 2.3: Summary of literature review

Configuration	Nature of Work	Observations	Author Name	Journal Name/References
Reflective insulation, Low emissivity materials, ASTM C-518 test method, ASTM C-1363 test method, Heat transfer by convection, Conduction and radiation, Flat and sloped roofing systems	Investigation of thermal performance of reflective insulations for different applications	Heat transfer by convection, Conduction and radiation	Hamed H. Saber [52]	Energy and Buildings, (2011)
Model reduction,Hollow blocks numerical model, Experimental validation	Reduced linear state model of hollow blocks walls, validation using hot box measurements	Numerical approach, Experimental set-up	Y. Gao et al. [36]	Energy and Buildings, (2004)
Balcony board, Thermal analysis, Linear thermal transmittance, Reinforcement rods, Hot box	Experimental and numerical thermal analysis of a balcony board with integrated glass fibre reinforced polymer GFRP elements	Thermal analysis, Energy efficiency	Karim Ghazi Wakili et al. [39]	Energy and Buildings, (2006)
Calibrated hot-box test, Dynamic thermal characteristics, Wall transient heat flow, Response factors, Conduction transfer coefficients	Static and dynamic thermal characterisation of a hollow brick wall: Tests and numerical analysis	Wall transient heat flow, Tests and numerical analysis	J.M. Sala et al. [40]	Energy and Buildings, (2008)
Measuring, Evaluating, Thermal resistance, Building construction	In situ measuring and evaluating the thermal resistance of building construction	Thermal resistance,Test methods	Changhai Peng, Zhishen Wu [40]	Energy and Buildings, (2008)

2.3 Objective of Present Study

An exhaustive literature review was conducted related to the construction and performance of Guarded Hot Box.

Based on the literature reviewed the dimensions and details of a Guarded Hot Box was worked out conforming to existing international standards.

The literature reviewed suggest that there is scope to work on the proper positioning of the fan unit for air circulation within the Guarded Hot Box such that the flow pattern over the specimen is fairly uniform and unaffected by the wall of the box. This may be Studied using commercially available softwares such as ANSYS FLUENT.

Chapter 3

Design of a Guarded Hot Box

The main aim of the design is to create a guarded hot box apparatus with minimum losses. In this regards,the setup is proposed for future experimentation with considerations to the existing standards such as ISO 8990 and ASTM C 1363.

3.1 Design Requirements

The size of the apparatus shall be commensurate with the intended use, taking the following points into consideration. The metered area shall be big enough to provide a representative test area. For modular components the metered area should preferably span exactly an integral number of modules. The ratio of metered area to perimeter of the metered area influences accuracy in both types of boxes because one-dimensional heat flow cannot be maintained at the perimeter of the metered area. These error heat flows at the perimeter of the metered area, measured as a fraction of the metered heat flow, will increase with decreasing metered area. Imbalance heat flow Q, in the guarded hot box is due to nonuniformities both in surface coefficients and air temperatures close to the periphery of the metered area. An amount of heat enters the specimen through the nose of the metering box in the guarded hot box. Deviation from one-dimensional heat flow is caused by the finite thickness of the nose seal. Both edge insulation and edge boundary conditions affect peripheral losses, for the guarded hot box and flanking losses, for the calibrated hot box. All these problems are made more complex by nonhomogeneities in the specimen close to the perimeter of the metered area.

In general, the size of the metering box determines the minimum size of other elements of the apparatus. The depth of the metering box should not be greater than that strictly necessary to maintain desired boundary conditions (desired boundary layer thickness, etc.) and to accommodate its equipment. The emittance of surfaces which have radiative exchange with the specimen surfaces can be either high or low. High emissivity (0.8 or greater) will in most cases be typical of actual use of building and industrial components. The low emissivity environment requires a greater convective component, such as higher velocities, to achieve conventional surface coefficients. This produces a substantial change in the distribution of the surface coefficient which can give better temperature uniformity, but this situation can produce an artificial thermal behaviour substantially different from actual use. In particular, it is unsuitable for specimens with permeable surfaces.

3.2 Metering Box

The metering box is generally constructed on hot side of the apparatus, The all walls of the metering box are generated from a sandwich structure composed of two panels of wood (0.019m each) with a middle layer of expanded polystyrene (0.240 m).The metering box have inside dimension are, height-1m, length-1m, and 0.37m wide. And the metering box have outside dimension are, height-1.556m, length-1.556m, and 0.648m wide. The all walls of the metering box are constructed from same materials of sandwich structure.

The support panel will divided the two rooms of the hot-box apparatus, the metering and climatic chamber. The insulation of the box wall shall be chosen considering the intended range of specimen resistance and temperature difference so that an error in the evaluation of the metering box losses does not affect the determination of the specimen heat flow by more than 0.5 %. Box walls shall be thermally uniform to aid in achieving uniform temperatures inside the box and to aid in determining the heat flow through the walls using a thermopile or other type of heat flow sensor. In addition, it shall be recalled that hot spots, such as heaters, fans, etc., can affect the uniformity of the temperatures inside the box, owing to their local radiative exchanges with the box walls.

The box walls, perimeter seal and specimen shall form an air- and water-vapour-tight enclosure to avoid errors due to air and moisture transfer. In the guarded hot box configuration, the metering box is held against the specimen to provide an airtight joint The width of the gasket on the nose of the box shall not exceed 2 % of the metering width or 20 mm.

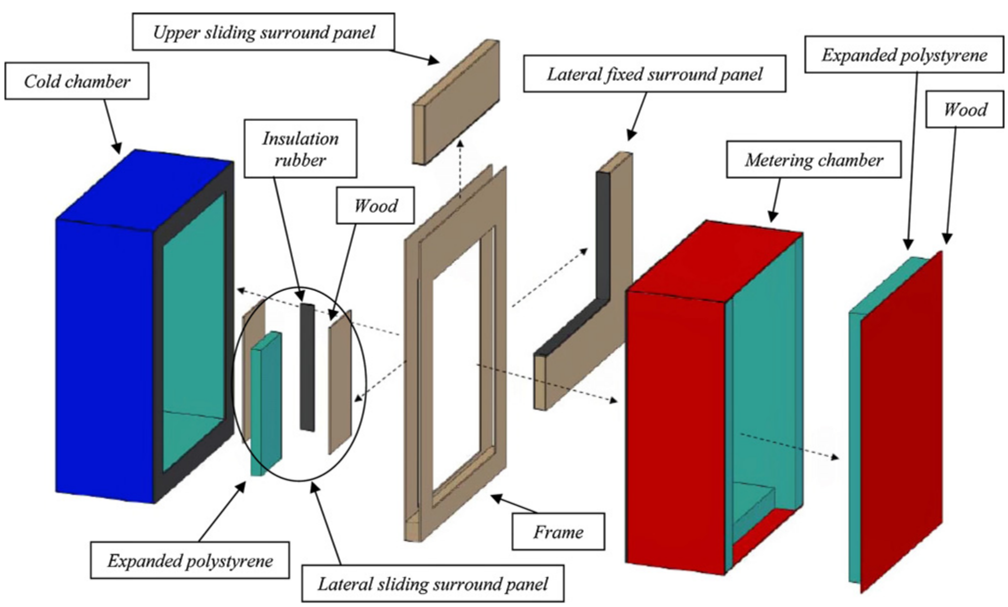

Figure 3.1: Schematic diagram of guarded hot box[1]

3.3 Guard Box

The guard box is generally constructed on hot side of the appratus,The all walls of the guard box are generated from a sandwich structure composed of two panels of wood (0.019m each) with a middle layer of expanded polystyrene (0.240 m).The guard box have inside dimension are, height-2.7m, length-2m, and 1m wide. And the guard box have outside dimension are, height-3.256m, length-2.556m, and 1.278m wide. The all walls of the guard box are constructed from same materials of sandwich structure.

In the guarded hot box the metering box is placed inside a guard box. The purpose of this guard box is to establish such air temperature and surface coefficients around the metering box that heat flow through the metering box walls and imbalance heat flow in the surface of the specimen from metered to guard area is minimized.The requirements concerning emissivity, shielding of heaters, and temperature stability are in principle the same for the guard box as for the metering box. Temperature uniformity shall be such that the influence on imbalance error will be smaller than 0.5 % of the heat flow through the metered area of the specimen. Circulating fan will normally be needed to avoid stagnant air in the guard box.

3.4 Support Panel or Specimen Frame

The support panel was designed to be flexible and able to host standard samples like doors and windows. It is mainly made of a rigid frame of four parts, which are movable thanks to some pistons or with any mechanisum. It is also possible to substitute the four parts of the support panel which, as previously mentioned, allows for the possibility to host alternatively different semples.Thanks to the mechanisum,it is possible to adjust samples whose dimensions are slightly different from the standard ones and to seal the whole panel.

The support panel is a sandwich structure composed of two panels of wood (0.019m each) with a middle layer of expanded polystyrene (0.240 m). The support panel divides the two rooms of the hot-box apparatus, the metering and climatic chamber. The two rooms have the same dimensions: 2.700m high; 2.000m long; and 1m wide. The height and length were determined by the dimensions of the support panel. The width was determined as the result of a compromise of the needs to create a uniform climate in both rooms and have enough space to host all the instrumentations and probes. The walls of both rooms are made of the same materials of the support panel.

3.5 Cold Side Chamber or Climate Chamber

The Climate chamber is generally constructed on cold side of the apparatus,The all walls of the cold box are generated from a sandwich structure composed of two panels of wood (0.019m each) with a middle layer of expanded polystyrene (0.240 m).The cold box have inside dimension are,height-2.7m,length-2m, and 1m wide. And the cold box have outside dimension are,height-3.256m,length-2.556m, and 1.278m wide. The all walls of the cold box are constructed from same materials of sandwich structure.

The chamber walls should be constructed to reduce the load of the refrigeration equipment and prevent moisture condensation. The inside surfaces of the chamber shall have an emittance in accordance with the desired radiative heat exchange. The requirements concerning emittance, shielding of heaters, temperature stability and temperature uniformity are in principle the same as for the metering box. For fine tuning of the cold side temperature, electric resistance heaters in the outlet from the evaporator are often useful. As mentioned under the metering box, a baffle may also be advantageous to achieve uniform air distribution. Air flow direction corresponding to natural convection is suggested. Motors, fans, evaporators and heaters shall be radiation-shielded. Air velocities should be adjustable to meet the required surface coefficients of the test and should be measured. In simulating natural conditions for building components, the range can be from 0.1 m/s to 10 m/s.

3.6 Temperature Measurements

The sensors for the measurement of air temperature and specimen surface temperature should be evenly spaced over the specimen area and located opposite each other on the hot and cold side. Surface temperatures of the equipment "seen" by the specimen shall be investigated to calculate the mean radiant temperature.

The number of sensors for air temperature and surface temperature measurement shall be at least two per square metre and not less than nine, unless other information on the temperature distribution is available. Air and surface temperature differences over the specimen and surface temperature differences over the metering box walls can be determined by differential measurement in order to improve accuracy.

3.7 Instrumentation

In guarded hot box method there are various types of instruments are used which are described as under.

3.7.1 Heater

During the tests, the individual temperatures inside the two rooms are kept constant thanks to a heating system for the hot room and a cooling system for the cold room. The heating system is made of a 50m long, S-shaped, heating wire disposed inside the hot room,it is located at a few centimetres away from the wider vertical wall. The heating power of the wire is 50 W. Due to a PID control system, the wire can switch on and off automatically. It is possible to maintain the internal temperature of the hot room as constant with a tolerance lower than 0.2°C.

In guarded hot box measurements technique there are two heaters are required.

3.7.2 Air-conditioning system

The cold room is equipped with an air-cooled compression refrigerator, placed on top of the rooms. The refrigerator's evaporator is made of copper pipes and aluminum cooling fins, and is equipped with a fan and thermostatic valve, cooling directly the air inside the room. The operating temperatures of the cold room vary from -10 to $+20$°C. For this reason, the cold room is also equipped with a heating wire in order to return to desired temperature if the room becomes too cold.

3.7.3 Air circulation fans

The air circulation within the Guarded Hot Box is created by a fan. For the present study, the following selection was done:

1. Air velocity - 0.1 m/s to 10 m/s
2. Outer diameter of fan - 304.8 mm
3. Fan wing length - 110 mm
4. Number of wings - 07

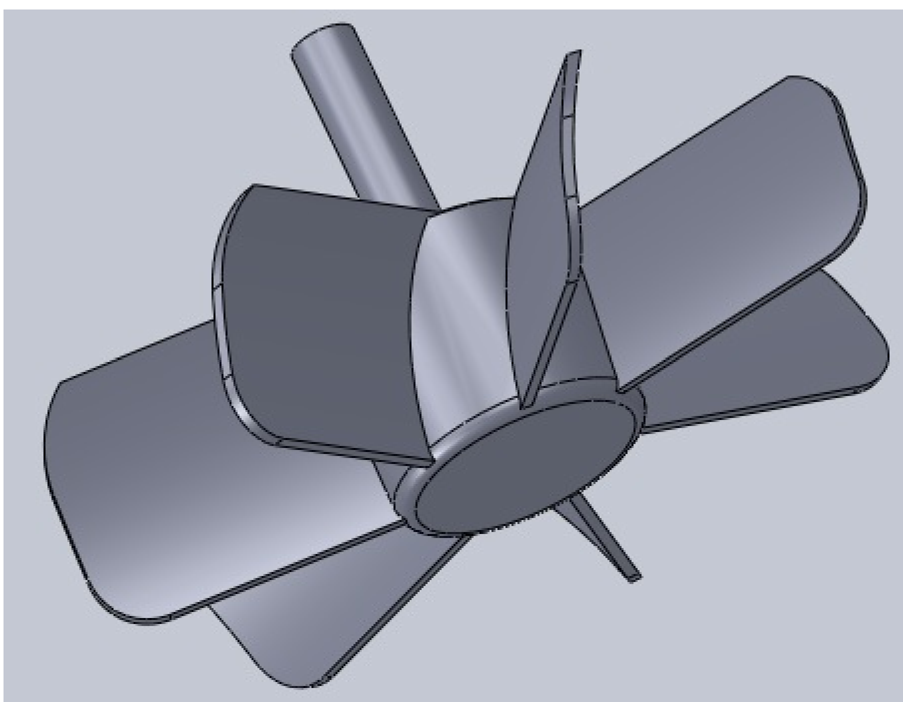

Figure 3.2: Schematic diagram of fan

When testing in a vertical position, the circulation resulting from natural convection can be sufficient to ensure temperature uniformity and the desired surface coefficients. When air movement is due to natural convection, the distance between specimen and baffle should be larger than the boundary layer thickness or no baffle should be used. When it is impossible to achieve the desired conditions with natural convection, circulating fans should be installed. If the fan motors are installed inside the metering box, then their power consumption shall be measured and added to the consumption of the heaters. If only the fans are inside the metering box, the shaft power shall be determined and added to the heater power: this shall be done with an accuracy such that the error on specimen heat flow is less than 0.5 %.

3.7.4 Thermocouples

For temperature measurements, T-thermocouples made of a junction copper (+) and constantan (−) were selected. The temperature range is from −200°C to +400°C, the sensitivity is 48.2V/°C. Total number of thermocouples were installed inside the hot and cold chambers and differential thermocouples were needed to assess the temperature differences between the metering chamber and the external ambient are approximately 150 thermocouples.

These measurements shall be made with sensors chosen and applied to the surface in such a way that the sensors do not change the temperature at the measuring point.This requirement can be met by thermocouples of wire diameter less than 0.25 mm, with junctions and at least 100 mm of adjoining wire in thermal contact with the surface, along the most isothermal path, using cement or tape of emissivity close to that of the surface.

In the case of nonhomogeneous specimens, the indicated number of sensors will not ensure reliable mean surface temperatures. For moderately inhomogeneous specimens, supplementary sensors shall be applied to each region of varying temperature. The mean surface temperature of each region shall then be weighted proportionally to the area of that region to obtain the mean surface temperature of the specimen.For very inhomogeneous specimens, this is not possible. In this case, specimen thermal resistance, cannot be measured as only the thermal transmittance, based on the environmental temperature difference across the specimen can be defined.

3.7.5 Heat flux sensors

Heat flux sensors used for monitoring heat flow through the metering box. It is located on the speciment surface and box wall surface.

Each sensors are located per 0.25 m^2surface.

There are four heat flux sensors are required for the guarded hot box apparatus.

3.7.6 PLC controller system

The control system is based on a PLC and can be configured with up to 1024 digital and 128 analogue inputs and outputs, with automatic start-up in case of power failure. The measuring system consists of a data acquisition system,The equipment is provided with a 96-channel data acquisition system. The system is controlled by an external PC and includes analogue input and output modules, module supports, standard network technology and RS232 series for data transmission.

All acquired data are transferred to a PC, with the option of selecting the time step of the acquisitions; it is also possible to visualize and save the acquired data.

3.8 Design Summary for the Guarded Hot Box

The designed Guarded Hot Box specifications finalised of the basis of various literature and standards reviewed are as following:

Dimensions of guard box:

- length - 2000 mm
- height - 2700 mm
- width - 1000 mm
- volume - 4.9×10^9 mm^3

Dimensions of metering box:

- length - 1000 mm
- height - 1000 mm
- width - 370 mm
- volume - 0.5×10^9 mm^3

Dimensions of cold box:

- length - 2000 mm
- height - 2700 mm
- width - 1000 mm
- volume - 5.4×10^9 mm^3

Temperature sensors:

- sensivity of sensor - 48.2 V/°C
- number of sensors required - 150

- junctions of sensor - copper (+) and constantan (−)
- temperature range - −200°C to +400°C

Heater:

- coil length - 50 m
- required power - 50 W
- number of heater - 02

Air-conditioning system:

- material of evoporator pipe - copper
- number of air-conditioning - 01

Heat flux sensor:

- number of heat flux sensors required - 04
- location - on the surface of the box wall and speciment wall per 0.25 m^2 surface.

Air circulation fan:

- air velocity - 0.1 m/s to 10 m/s
- outer dia. of fan - 304.8 mm
- fan wing length - 110 mm
- number of wings - 07

Chapter 4

CFD Analysis of Guarded Hot Box

4.1 Introduction

Computational Fluid Dynamics (CFD) is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problem that involve fluid flow. All of CFD, in one or another form, is based on fundamental governing equations of fluid dynamics.

1. Law of conservation of mass
2. Law of conservation of momentum
3. Law of conservation of energy

The set of equations which describe the processes of momentum, heat and mass transfer are known as Navier Stoke's equations. Various solution methods are used in CFD codes. The most common in this technique, is known as the finite volume technique. The region of interest is divided into small sub-regions called control volumes. Now the equations are discretized and solved iteratively for each control volumes. So finally approximation of the value of each variable at specific point throughout the domain can be obtained. The stepwise procedure for doing CFD work are shown in Figure 4.1.

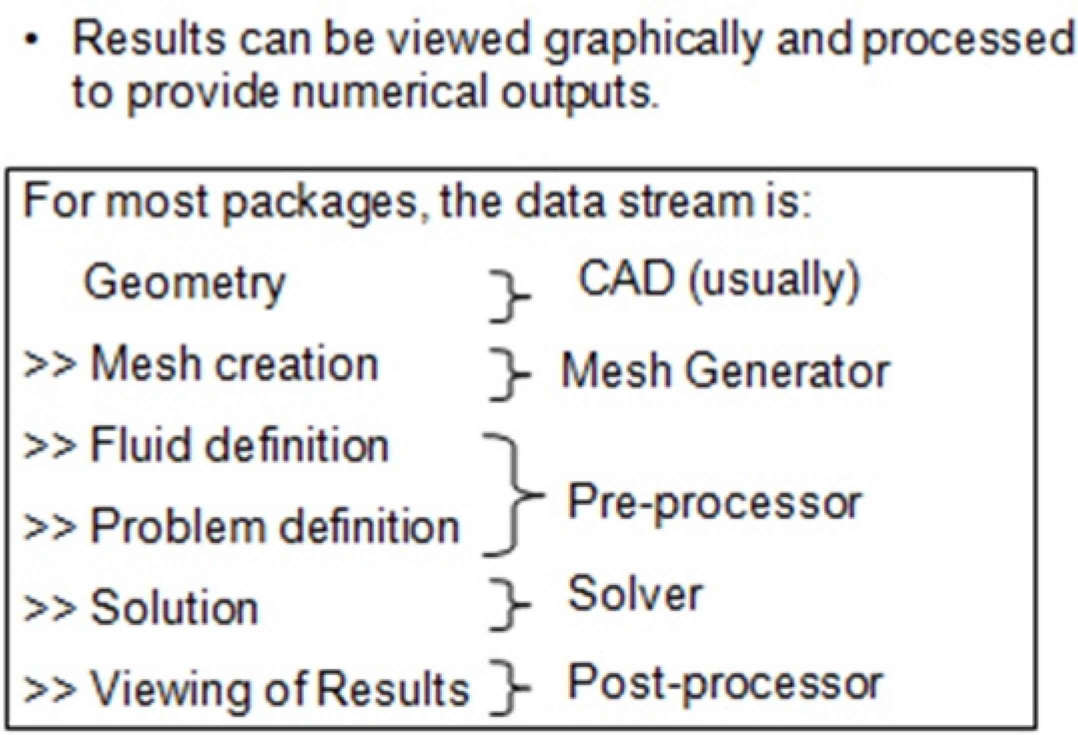

Figure 4.1: Stepwise procedure for doing CFD

Pre-Processing is the step where the modeling goals are determined and computational grid is created. In the second step numerical models and boundary conditions are set to start up the solver, Solver runs until the convergence is reached. When solver is terminated, the results are examined which is the post-processing part.

Some simplifying assumptions are required before applying the conventional Navier-Stokes and Energy equations to the model. The major assumptions are as following.

(1) Steady state flow and heat transfer

(2) Incompressible fluid

(3) Laminar flow

(4) Uniform wall heat flux

(5) Constant solid and fluid properties (thermophysical properties)

4.2 Geometry Creation

The geometry for the Guarded Hot Box was created using Gambit software.

The hardware utilised for this application was a computer having 64 bit processor and 4 GB Ram.

The Guarded Hot Box geometry included that of various components such as Fan, Guard box, Metering box, Cold box.

4.2.1 Grid generation

There are two ways of generating a mesh. Gambit calls them 'top down' or 'bottom-up' in the user manuals. These instructions are bottom-up. The vertices are created upon which the edges will be built upon. Connecting edges will create a face. Connecting faces will create a volume (3D). Once the face or volume is created, a mesh can be generated on it.

4.3 Mesh Generation

Altair HyperMesh,authorized by Nirma University is a high-performance finite element preprocessor to prepare even the largest models, starting from import of CAD geometry to exporting an analysis run for variousdisciplines.

HyperMesh enables engineers to receive high quality meshes with maximum accuracy in the shortest time possible. A complete set of geometry editing tools helps to efficiently prepare CAD models for the meshing process. Meshing algorithms for shell and solid elements provide full level of control, or can be used in automatic mode. Altair's BatchMeshing technology meshes hundreds of files precisely in the background to match user-defined standards. HyperMesh offers the biggest variety of solid meshing capabilities in the market, including domain specific methods such as SPH, NVH or CFD meshing.

An long list of CAD formats ensures a high level of CAD interoperability. Altair's connector technology automatically assembles individual parts with their Finite Element representation. HyperMesh is entirely customizable. A extensive API library can be used to automate repeating tasks or do complicated math operations for model generation.

Minimum Element Size: 2 mm

Maximum Element Size: 32 mm

Type of Grid: Tetrahedral grid

Name of Solver: K-epsilon

4.3.1 Mesh

In Figure: 4.2, 4.3 and 4.4 are shown that the meshing of the guard box, cold box and metering box respectively.

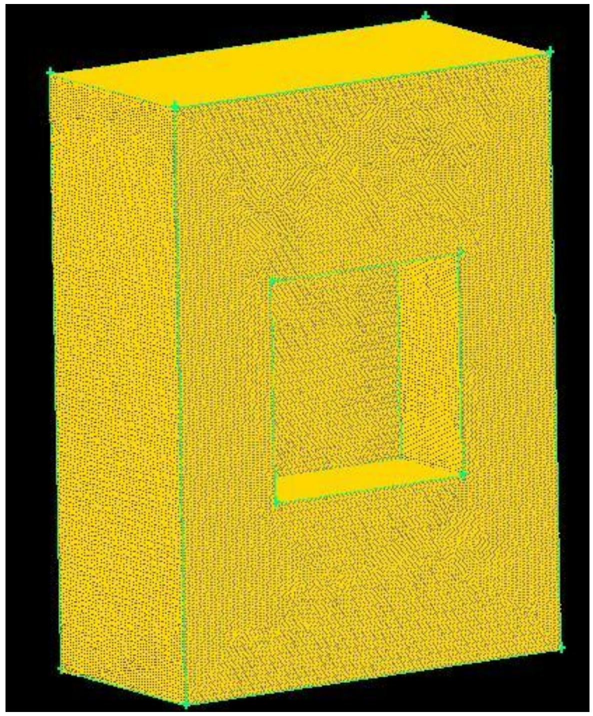

Figure 4.2: Mesh for guard box

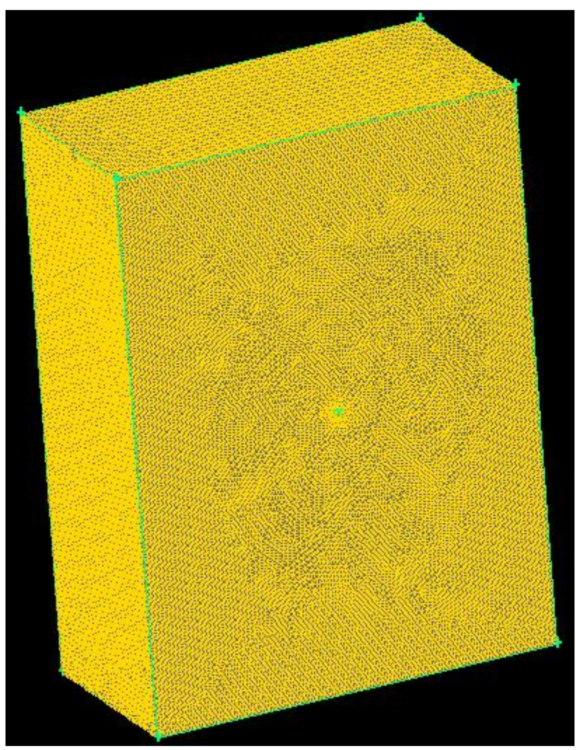

Figure 4.3: Mesh for cold box

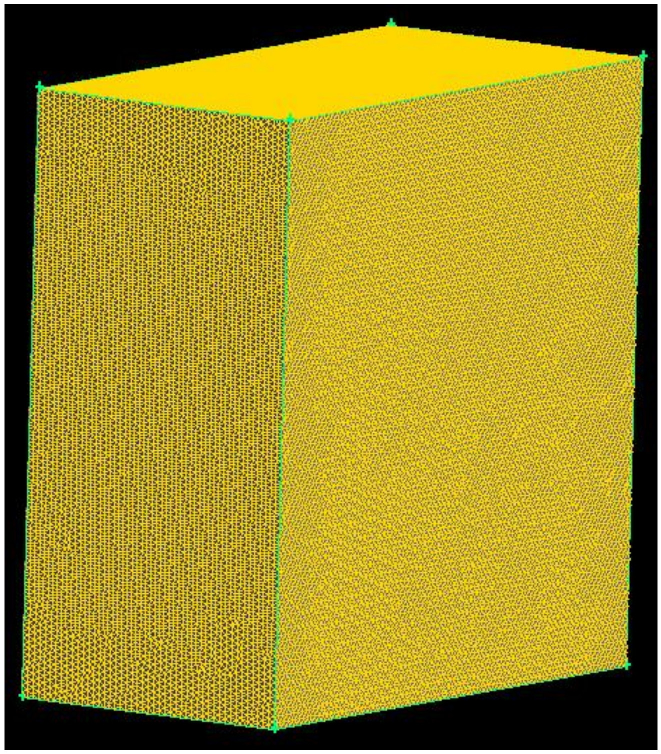

Figure 4.4: Mesh for metering box

The dynamic mesh model in FLUENT can be used to model flows where the shape of the domain is changing with time due to motion on the domain boundaries. The motion can be a prescribed motion or an unprescribed motion where the subsequent motion is determined based on the solution at the current time (e.g., the linear and angular velocities are calculated from the force balance on a solid body).

The update of the volume mesh is handled automatically by FLUENT at each time step based on the new positions of the boundaries. To use the dynamic mesh model, we need to provide a starting volume mesh and the description of the motion of any moving zones in the model. FLUENT allows we have to describe the motion using either boundary problems or user-defined functions (UDFs). FLUENT expects the description of the motion to be specified on either face or cell zones.

If the model contains moving and non-moving regions, It is needed to identified these regions by grouping them into their respective face or cell zones in the starting volume mesh that generated.

Furthermore, regions that are deforming due to motion on their adjacent regions must also be grouped into separate zones in the starting volume mesh. The boundary between the various regions need not be conformal. It can use the non conformal or sliding interface capability in FLUENT to connect the various zones in the final model. In Table 4.1, 4.2 and 4.3 are shown that the element size and number of elements where obtained on different positions which are described in below table.

Table 4.1: Elements detail of guard box

Name of Position	Element Size	Number of Elements
Top(centre)	23	30,96,568
Front Side(centre)	23	28,45,983
Side Wall(centre)	23	26,37,942
Top(sample side)	23	29,87,362
Front Side(side)	23	28,63,852
Side Wall(sample side)	23	28,64,956
Side Wall(lower corner)	23	28,98,447
Side Wall(upper corner)	23	29,10,726

Table 4.2: Elements detail of metering box

Name of Position	Element Size	Number of Elements
Top(centre)	11	28,29,316
Front Side(centre)	11	31,47,204
Side Wall(centre)	11	29,87,537
Top(sample side)	11	28,68,493
Front Side(side)	11	30,34,813
Side Wall(sample side)	11	28,64,710
Side Wall(lower corner)	11	28,49,885
Side Wall(upper corner)	11	28,77,032

Table 4.3: Elements detail of cold box

Name of Position	Element Size	Number of Elements
Top(centre)	24	31,78,902
Front Side(centre)	24	31,50,791
Side Wall(centre)	24	31,22,609
Top(sample side)	24	30,85,099
Front Side(side)	24	31,49,211
Side Wall(sample side)	24	30,66,087
Side Wall(lower corner)	24	30,56,753
Side Wall(upper corner)	24	30,71,319

4.3.2 Grid independence test

The model is tested for grid-independence to give proper resolution to the region where large gradients of fluid flow characteristic is predicted. The optimum grid system has the meshing resolution. The model in this study uses a total number of grid 37, 00,000. A grid independence test was carried out by doubling the grid size for the Stenter with the dimension discussed earlier.

The fine grid mesh for the x , y-directions and z-direction is adopted to properly resolve the velocity .The meshing along the surface of entrance region a relatively T- grid system has taken.

The reasons for the T-grid discretization for the z-direction are with the exception of the inlet region, are small compared to the gradients occurring in other directions and the CPU time as well as the memory storage required increases dramatically as the number of grid nodes is increased.

Further more comparison with standard numerical results, indicates that the finer the mesh size, the higher the numerical accuracy.

4.4 Fluid Definition and Problem Solving

FLUENT allows choosing either of two numerical methods:

- Segregated solver
- Coupled solver

The two numerical methods employ a similar discretization process (finite volume), but the approach used to linearize and solve the discretized equation is different.

4.4.1 Segregated method

Using this approach, the governing equations are solved sequentially (i.e., segregated from one another). Because the governing equations are non-linear (and coupled), several iterations of the solution loop must be performed before a converged solution is obtained. Each iteration consists of the steps illustrated below:

1. Fluid properties are updated, based on the current solution. (if the calculation has just begun, the fluid properties will be updated based on the initialized solution).

2. The momentum equations are each solved in turn using current values for pressure and face mass fluxes, in order to update the velocity field.

3. Since the velocities obtained in step 2 may not satisfy the continuity equation locally, a “Poisson-type” equation for the pressure correction is derived from the continuity equation is then solved to obtain the necessary corrections to the pressure and velocity fields and the face mass fluxes such that continuity.

4. Where appropriate, equations for scalars such as turbulence, energy, species and radiation are solved using the previously updated values of the other variables.

5. When inter-phase coupling is to be included, the source terms in the appropriate continuous phase equations may be updated with a discrete phase trajectory calculation.

These steps are continued until the convergence criteria are met.

4.4.2 Coupled method

The coupled solver solves the governing equations of continuity, momentum and (where appropriate) energy and species transport simultaneously (i.e., coupled together). Governing equations for additional scalar will be solved sequentially (i.e., segregated from one another and from the coupled set) using the procedure described for the segregated solver. Because the governing equations are non-linear (and coupled), several iterations of the solution loop must be performed before a converged solution is obtained. Each iteration consists of the steps outlined below:

1. Fluid properties are updated, based on the current solution. (if the calculation has just begun, the fluid properties will be updated based on the initialized solution).

2. The continuity, momentum and (where appropriate) energy and species equations are solved simultaneously.

3. Where appropriate, equations for scalars such as turbulence and radiation are solved using the previously updated values of the other variables.

4. When interphase coupling is to be included, the source terms in the appropriate continuous phase equations may be updated with a discrete phase trajectory calculation.

5. A check for convergence of the equation set is made.

These steps are continued until the convergence criteria are met.

FLUENT's segregated solver has taken, which is an implicit solver. The unknown value for a given variable is computed from a set of linear equations, each of which is written for a single cell in the domain. Relaxation factors have direct impact on convergence.

Generally default values are used, but if convergence problems occur, then these values are modified. Decreasing these factors gradually helps in convergence. Using segregated solver approach, the governing equations are solved sequentially. Several methods like SIMPLE, SIMPLEC, SIMPLER and PISO are available for this purpose.

4.4.3 Boundary condition

Boundary condition for the guarded hot box are as following:

At inlet- mass flow rate: 2.4 kg/s

At outlet- pressure outlet: 1000 pascal

In figure 4.5, 4.6, and 4.7 are shown that the shaded geometry of the guard box, cold box and metering box with boundary condition.

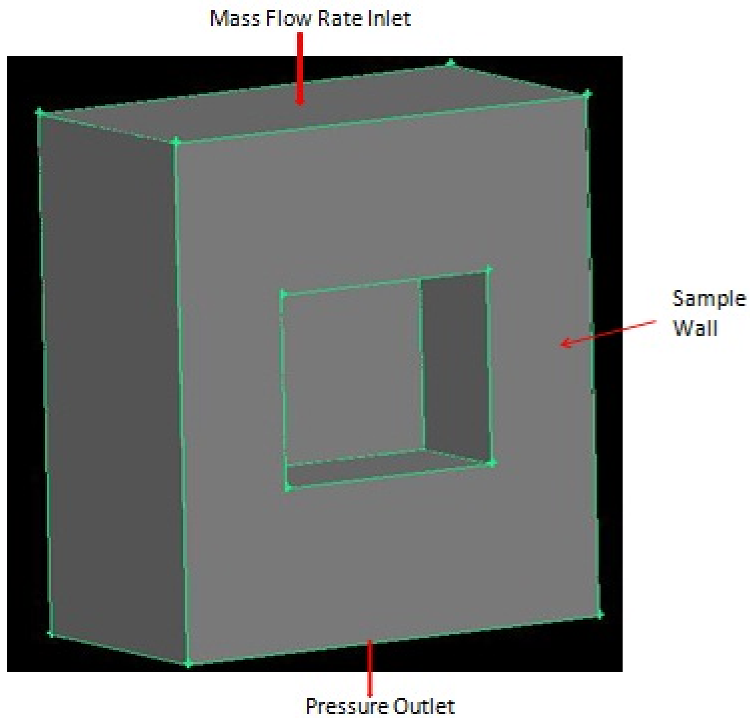

Figure 4.5: Guard box with boundary condition

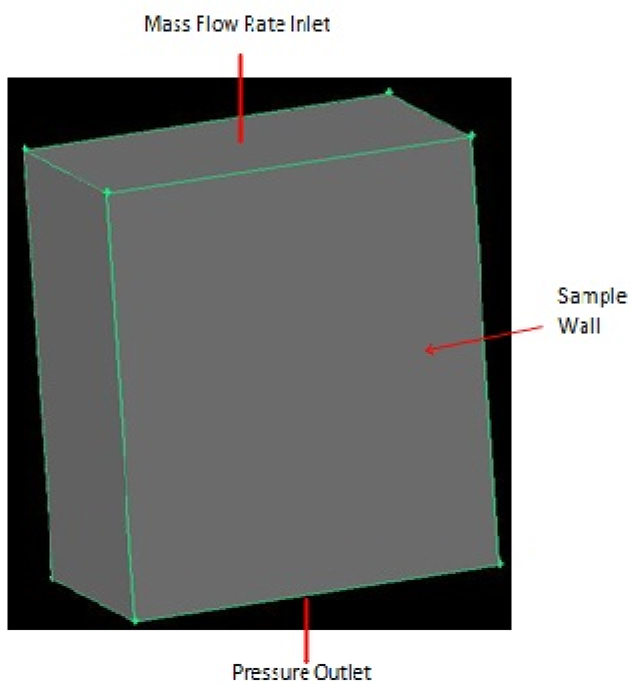

Figure 4.6: Cold box with boundary condition

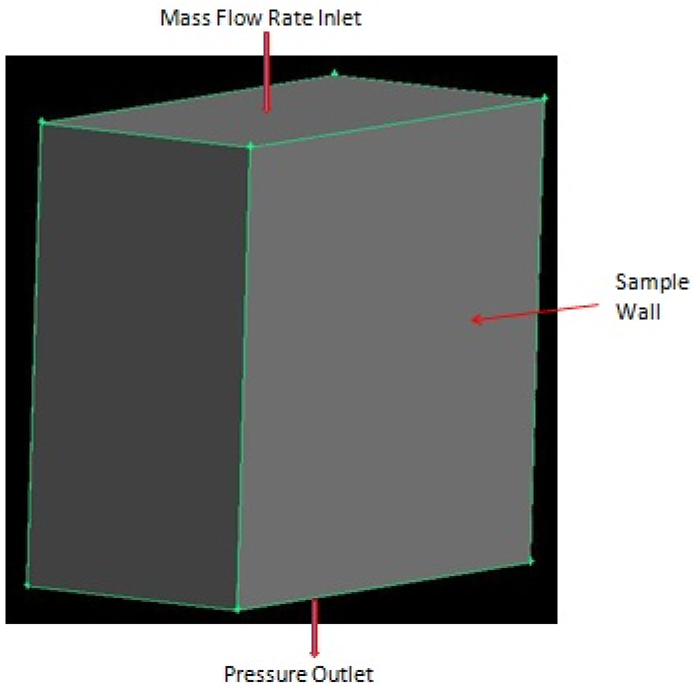

Figure 4.7: Metering box with boundary condition

For the present problem we have used Segregated solver with turbulence K- ϵ model and have given inlet and turbulent and viscosity ratio are 2% and first order upwind differencing method.

4.5 Input Parameters

The input parameters for Guard box, Metering box, and Cold box analysis are as following:

Parameters for guard box

Mass flow rate inlet: 2.4 kg/s

Pressure outlet: 1000 Pascal

Fan speed: 500 RPM, 1000 RPM, 1500 RPM, 2000 RPM

Parameters for metering box

Mass flow rate inlet: 2.4 kg/s

Pressure outlet: 1000 Pascal

Fan speed: 500 RPM, 1000 RPM, 1500 RPM, 2000 RPM

Parameters for cold box

Mass flow rate inlet: 2.4 kg/s

Pressure outlet: 1000 Pascal

Fan speed: 500 RPM, 1000 RPM, 1500 RPM, 2000 RPM

4.6 Problem Solving Steps

The following steps where involved in solving the problem:

1. Creating the geometry model and meshing it.

2. Starting the appropriate solver for 2D or 3D modeling.

3. Importing the grid and checking it.

4. Selecting the solver formulation.

5. Choosing the basic equation to solved: laminar or turbulent (or in viscid), chemical species or reaction, heat transfer models, etc. Also identifying additional models needed: fans, heat exchangers, porous media, etc.

6. Specifying the material properties.

7. Specifying the boundary properties.

8. Adjusting the solution control parameter.

9. Initializing the flow field.

10. Calculating a solution.

11. Examining the results.

12. Saving the results.

13. If necessary, refining the grid or considering revisions to the numerical or physical.

Type Formulation in this Implicit we have simpliestTurbulence model called as standard k-ε model ,these iteration are performed under various relaxation factor in Pressure is 0.3, Pressure –velocity coupling is SIMPLE, Discretization is First order upwind scheme, Momentum is 0.5 and Convergence criteria is Continuity equation 0.0001, Turbulence kinetic energy is 0.6, Momentum equations 0.0001, Turbulence dissipation rate: 0.6, Turbulence kinetic energy 0.001

High velocity shown by yellow colour, High pressure shown by dark yellow colour.

Material used here is Air, and type is fluid, Specified boundary conditions are mass flow inlet and pressure outlet, Density of air 0.7785 kg/m3 and viscosity 0.00002551kg/ms.

Chapter 5

Results and Discussion

The results obtained from the CFD analysis of the Guarded Hot Box using FLUENT software as described in the previous chapter are presented here, The activity table for the analysis undertaken is shown in Table 5.1.

Table 5.1: Activity table of CFD work undertaken

Name of Box	Fan Position	Fan Speed (RPM)			
Guard Box	Top (centre)	500	1000	1500	2000
	Top (sample side)	500	1000	1500	2000
	Front (centre)	500	1000	1500	2000
	Front (side)	500	1000	1500	2000
	Side Wall (centre)	500	1000	1500	2000
	Side Wall (sample side)	500	1000	1500	2000
	Side Wall (lower corner)	500	1000	1500	2000
	Side Wall (upper corner)	500	1000	1500	2000
Metering Box	Top (centre)	500	1000	1500	2000
	Top (sample side)	500	1000	1500	2000
	Front (centre)	500	1000	1500	2000
	Front (side)	500	1000	1500	2000
	Side Wall (centre)	500	1000	1500	2000
	Side Wall (sample side)	500	1000	1500	2000
	Side Wall (lower corner)	500	1000	1500	2000
	Side Wall (upper corner)	500	1000	1500	2000
Cold Box	Top (centre)	500	1000	1500	2000
	Top (sample side)	500	1000	1500	2000
	Front (centre)	500	1000	1500	2000
	Front (side)	500	1000	1500	2000
	Side Wall (centre)	500	1000	1500	2000
	Side Wall (sample side)	500	1000	1500	2000
	Side Wall (lower corner)	500	1000	1500	2000
	Side Wall (upper corner)	500	1000	1500	2000

5.1 Velocity and Pressure Distribution in the Guard Box

The CFD results for the velocity and pressure distribution in the guard box for various fan positions are shown in Figure 5.1 to 5.8. The results are also summarised in Table 5.2.

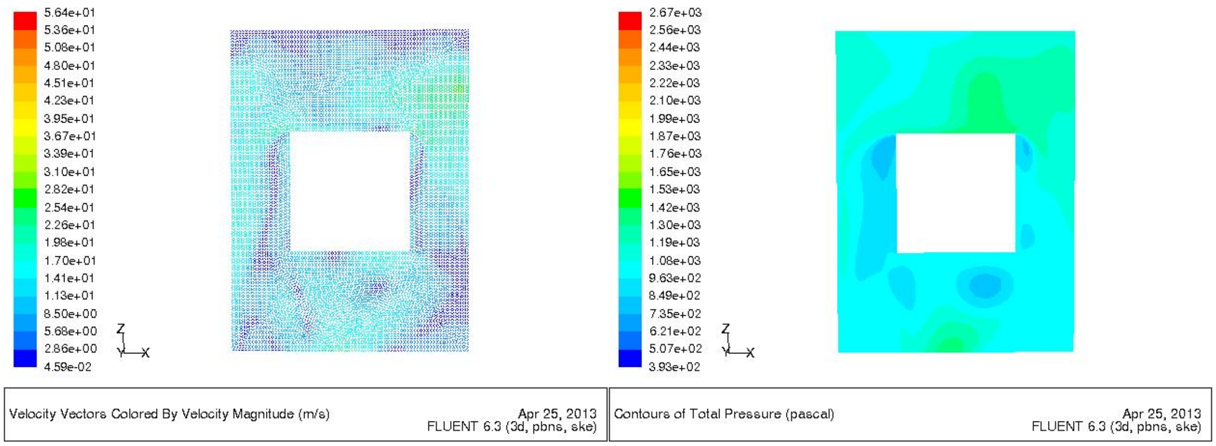

Figure 5.1: The velocity and total pressure distribution in the guard box for the position of fan at top(centre) wall

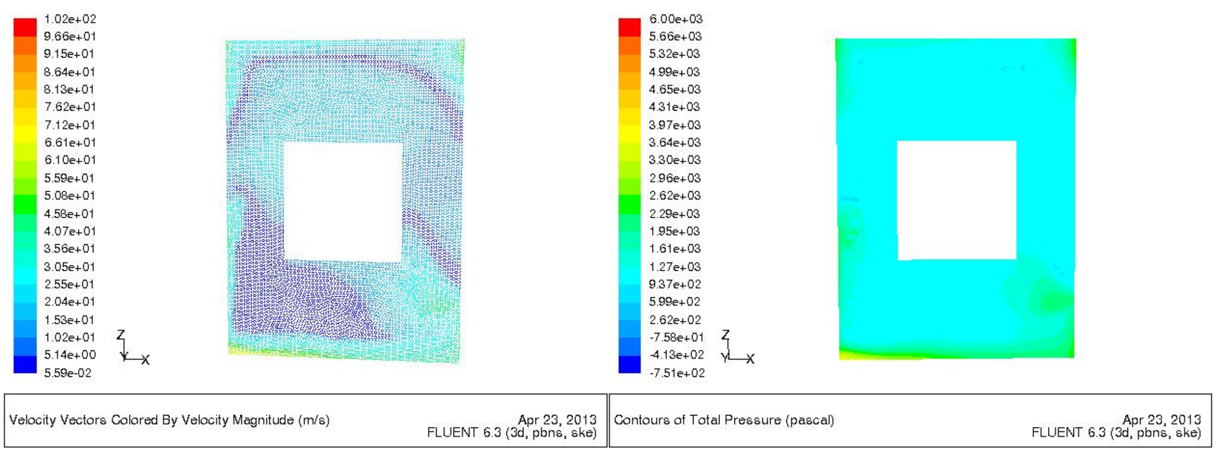

Figure 5.2: The velocity and total pressure distribution in the guard box for the position of fan at top(sample side) wall

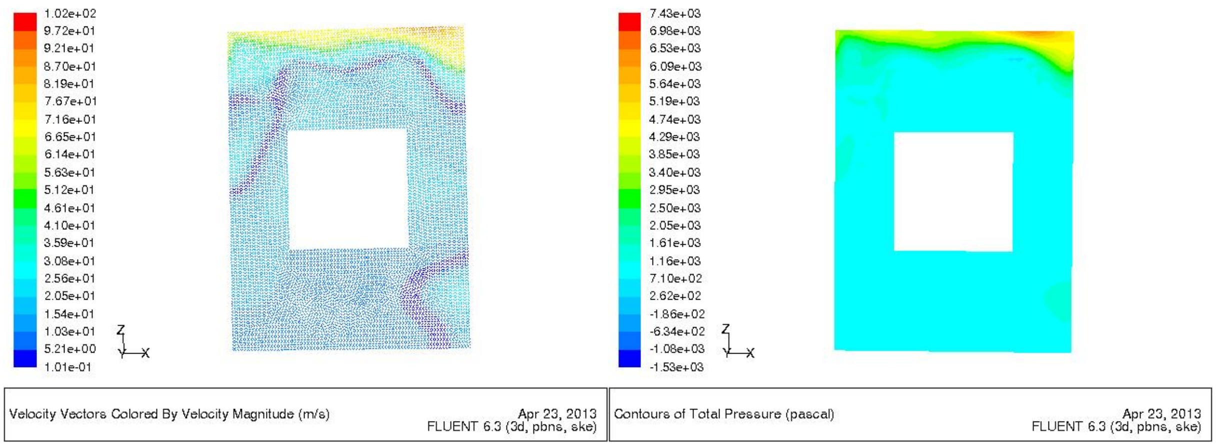

Figure 5.3: The velocity and total pressure distribution in the guard box for the position of fan at front side(centre) wall

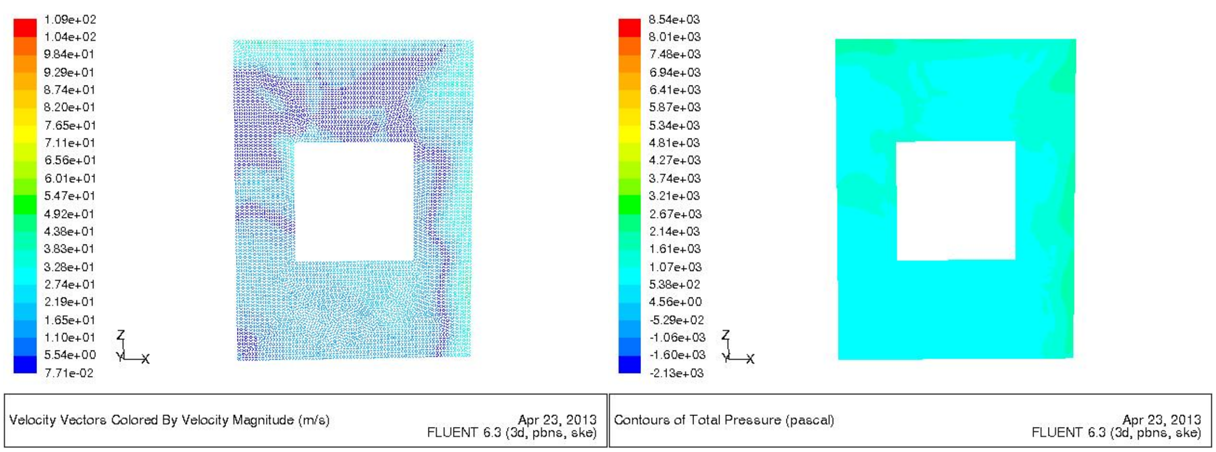

Figure 5.4: The velocity and total pressure distribution in the guard box for the position of fan at front side(side) wall

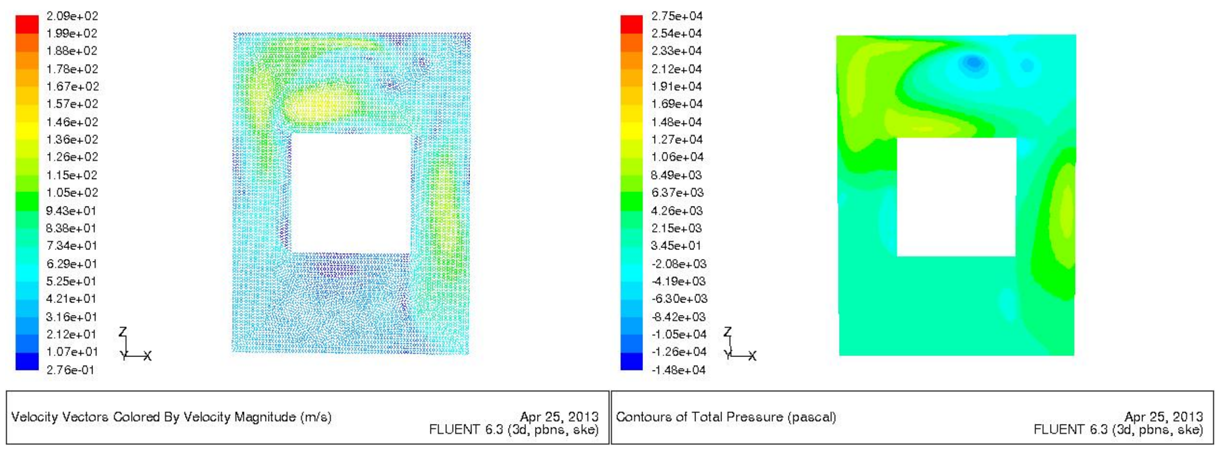

Figure 5.5: The velocity and total pressure distribution in the guard box for the position of fan at side wall(centre) wall

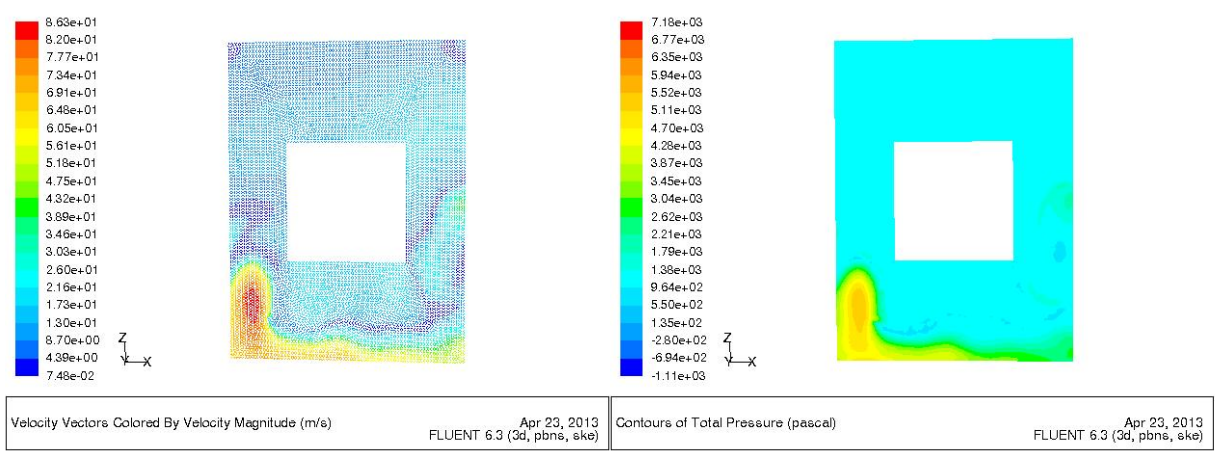

Figure 5.6: The velocity and total pressure distribution in the guard box for the position of fan at side wall(sample side) wall

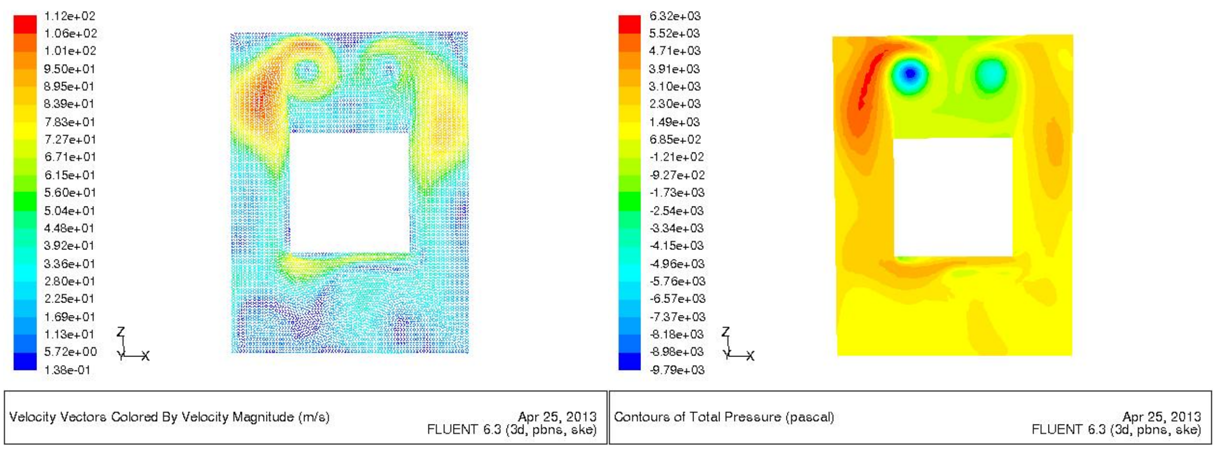

Figure 5.7: The velocity and total pressure distribution in the guard box for the position of fan at side wall(lower corner) wall

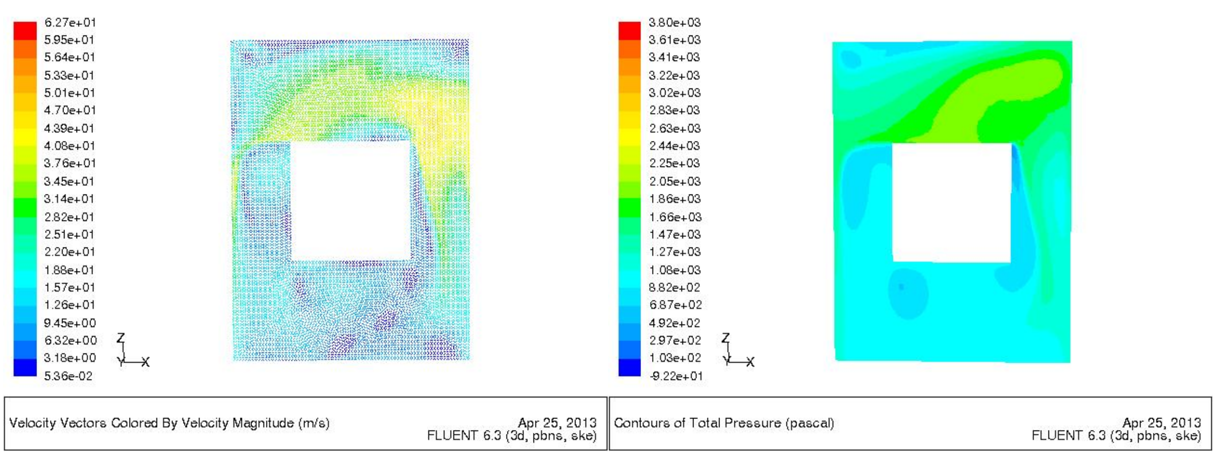

Figure 5.8: The velocity and total pressure distribution in the guard box for the position of fan at side wall(upper corner) wall

5.2 Velocity and Pressure Distribution in the Cold Box

The CFD results for the velocity and pressure distribution in the cold box for various fan positions are shown in Figure 5.9 to 5.16. The results are also summarised in Table 5.2.

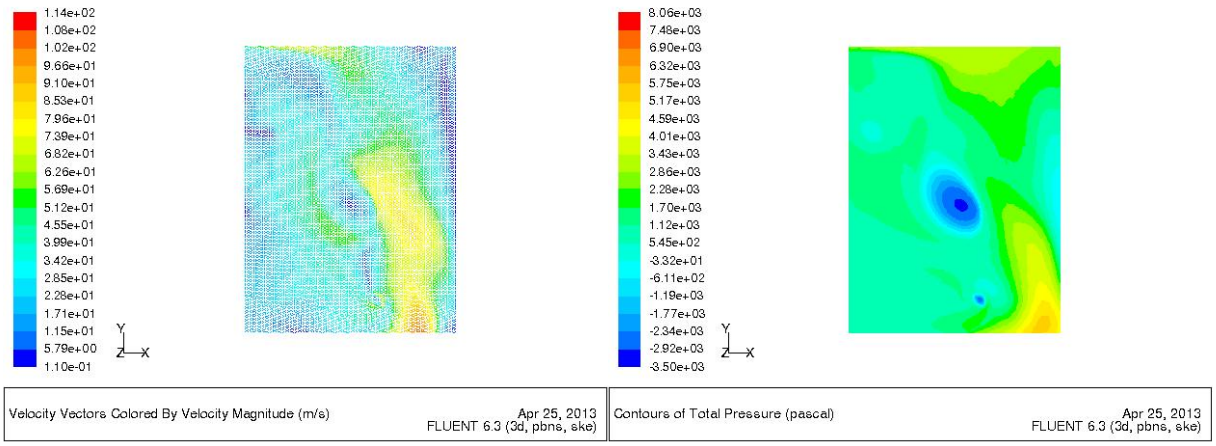

Figure 5.9: The velocity and total pressure distribution in the cold box for the position of fan at top (centre) wall

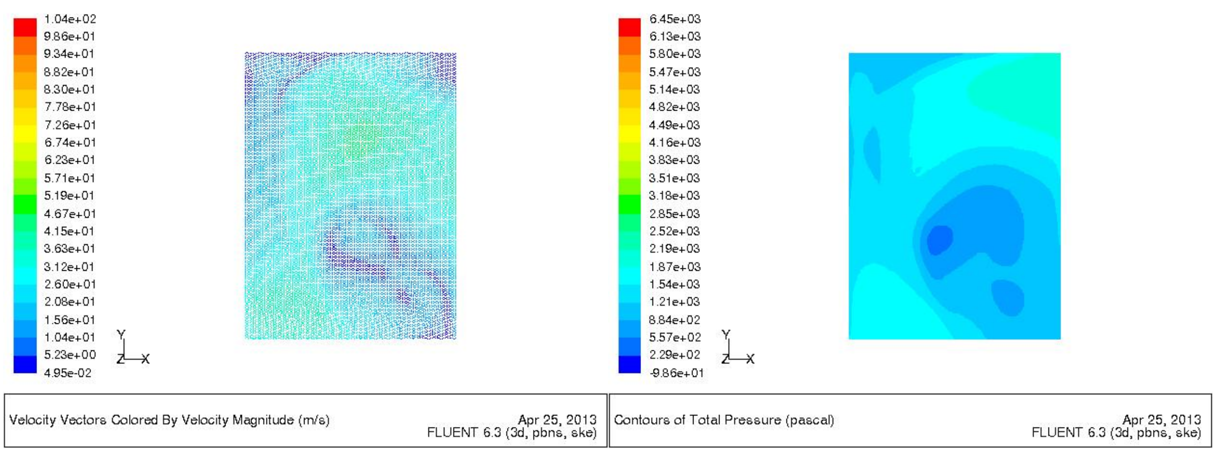

Figure 5.10: The velocity and total pressure distribution in the cold box for the position of fan at top (sample side) wall

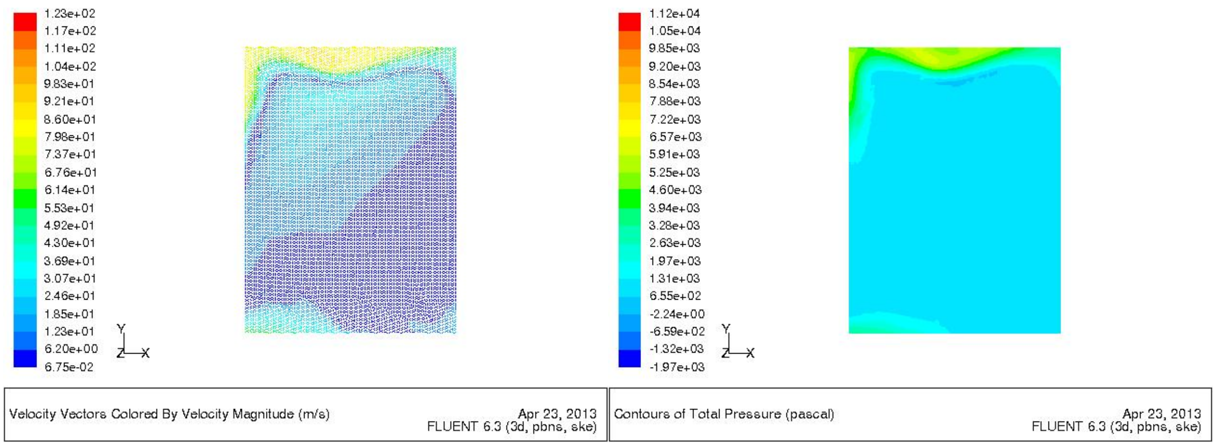

Figure 5.11: The velocity and total pressure distribution in the cold box for the position of fan at front side (centre) wall

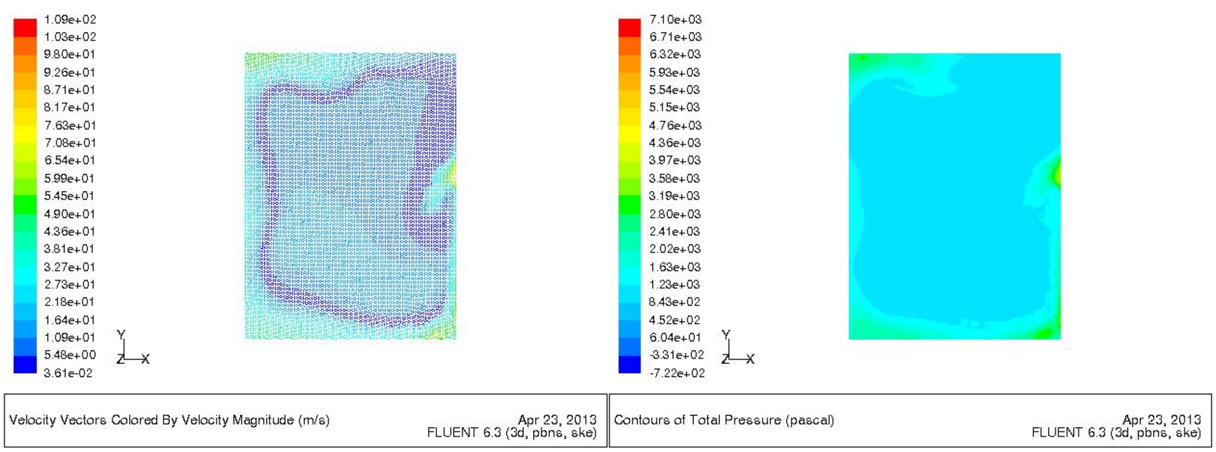

Figure 5.12: The velocity and total pressure distribution in the cold box for the position of fan at front side (side) wall

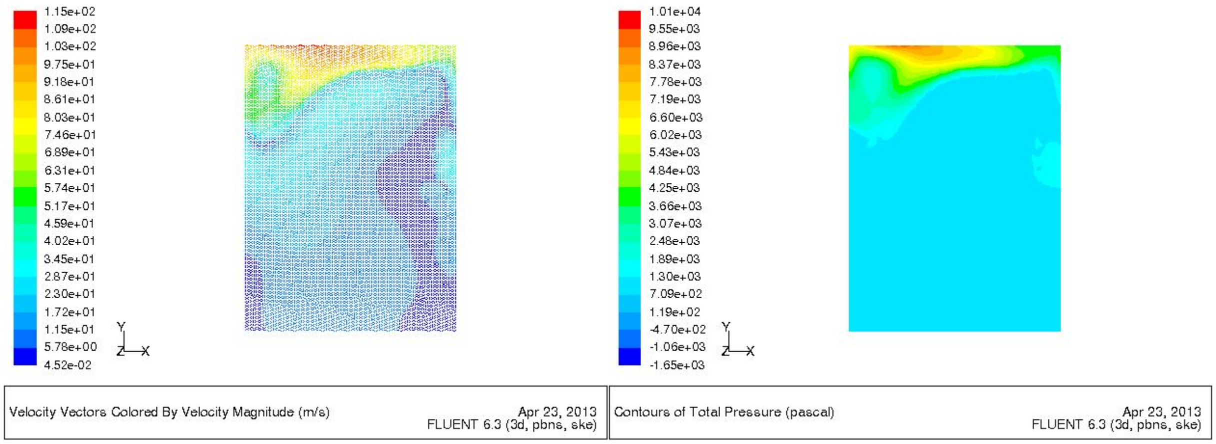

Figure 5.13: The velocity and total pressure distribution in the cold box for the position of fan at side wall (centre) wall

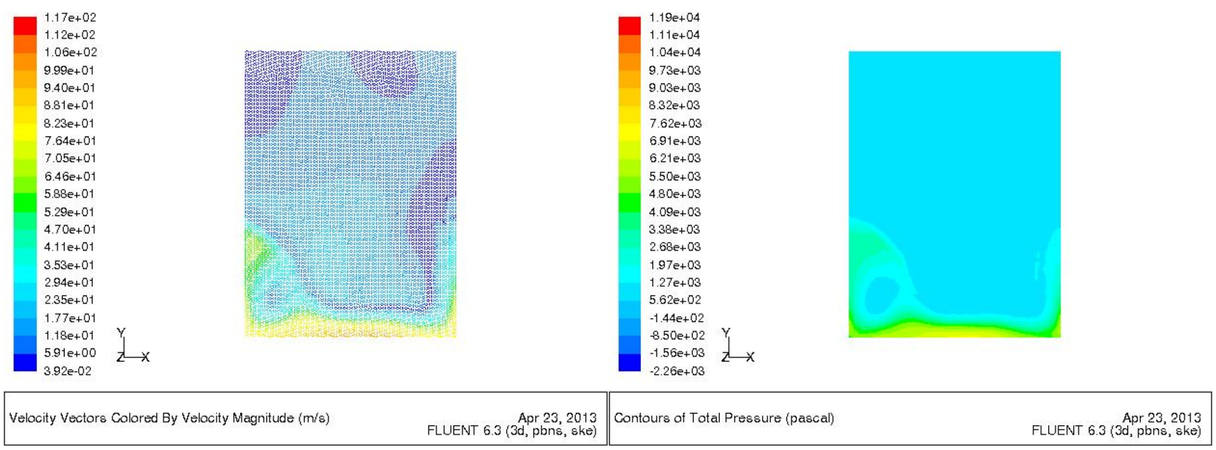

Figure 5.14: The velocity and total pressure distribution in the cold box for the position of fan at side wall (sample side) wall

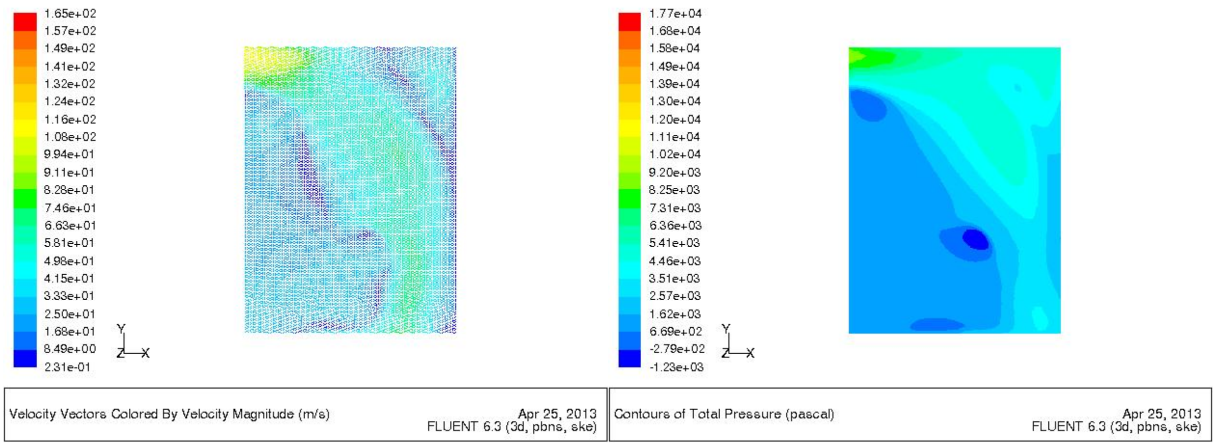

Figure 5.15: The velocity and total pressure distribution in the cold box for the position of fan at side wall (lower corner) wall

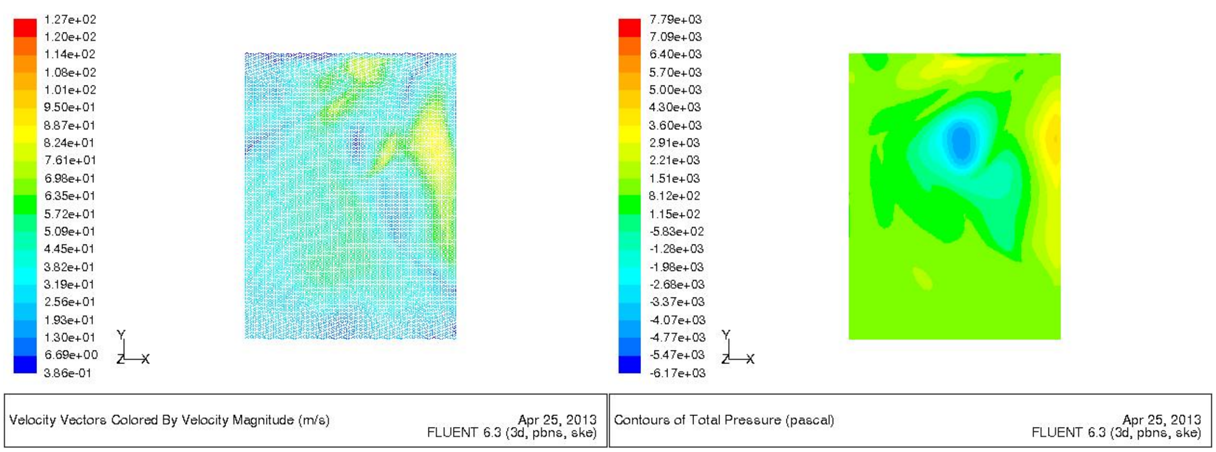

Figure 5.16: The velocity and total pressure distribution in the cold box for the position of fan at side wall (upper corner) wall

5.3 Velocity and Pressure Distribution in the Metering Box

The CFD results for the velocity and pressure distribution in the metering box for various fan positions are shown in Figure 5.17 to 5.24. The results are also summarised in Table 5.2.

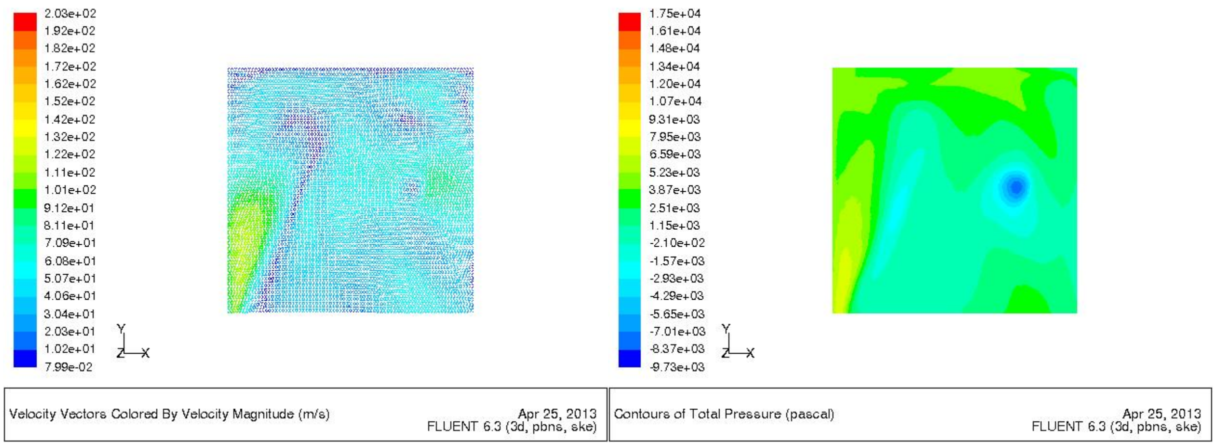

Figure 5.17: The velocity and total pressure distribution in the metering box for the position of fan at top (centre) wall

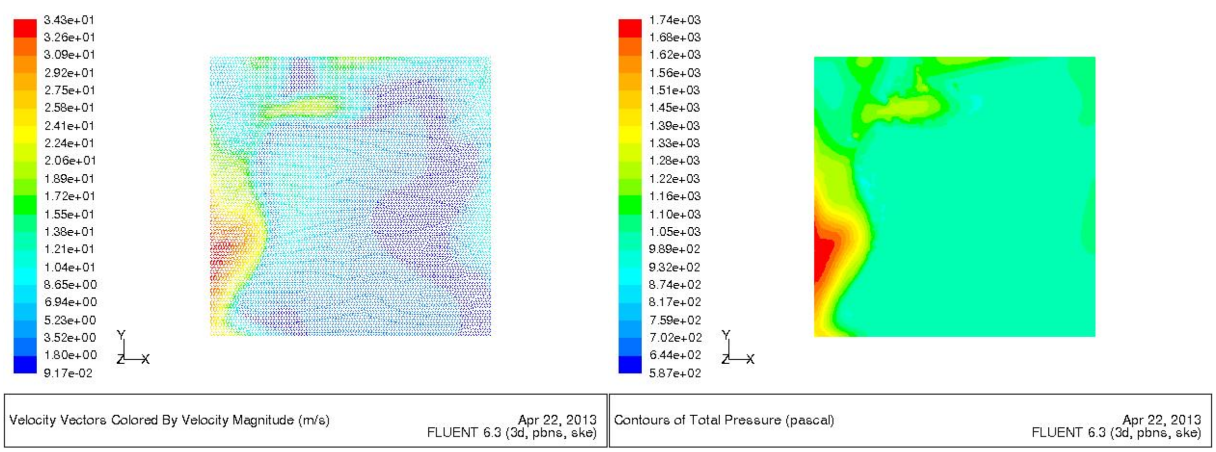

Figure 5.18: The velocity and total pressure distribution in the metering box for the position of fan at top (sample side) wall

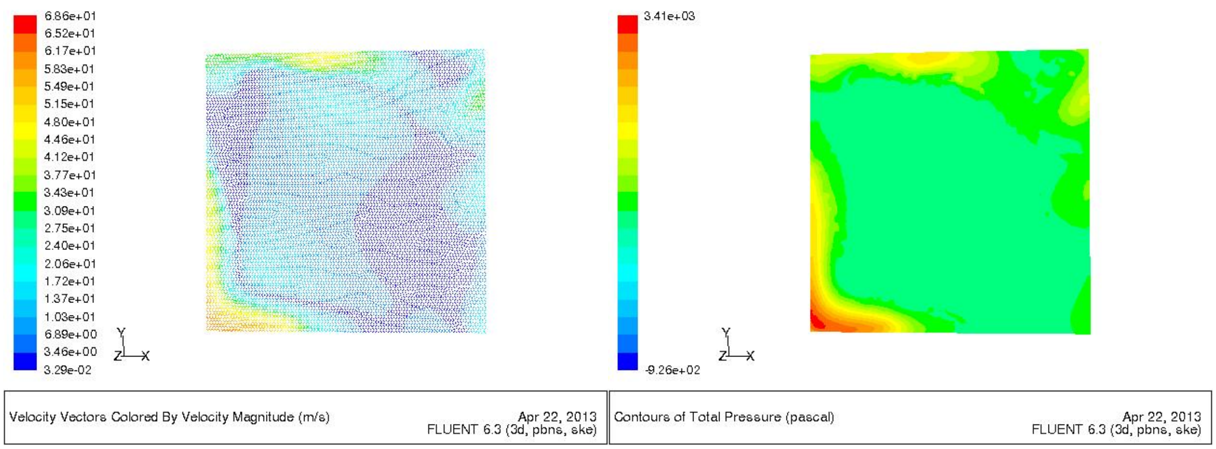

Figure 5.19: The velocity and total pressure distribution in the metering box for the position of fan at front side (centre) wall

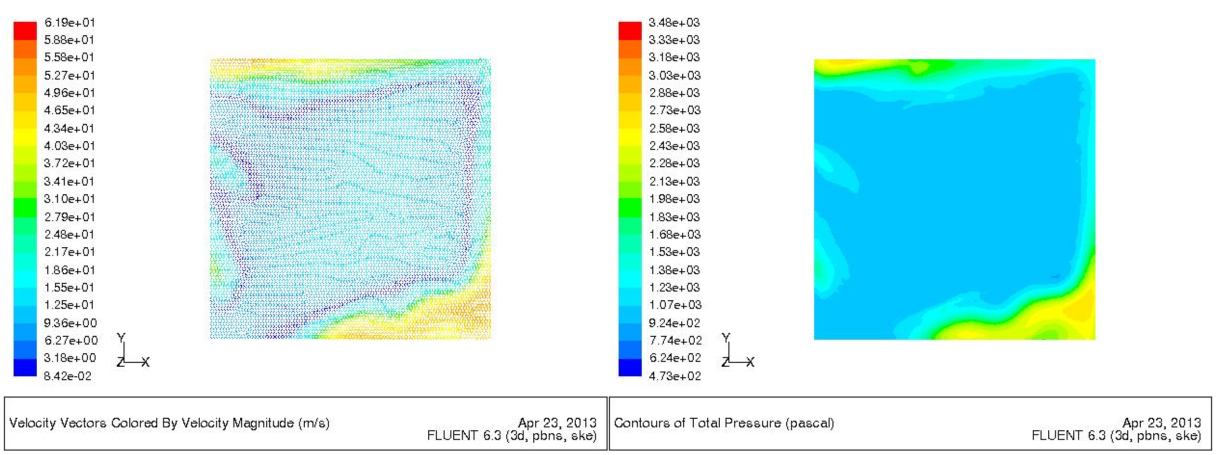

Figure 5.20: The velocity and total pressure distribution in the metering box for the position of fan at front side (side) wall

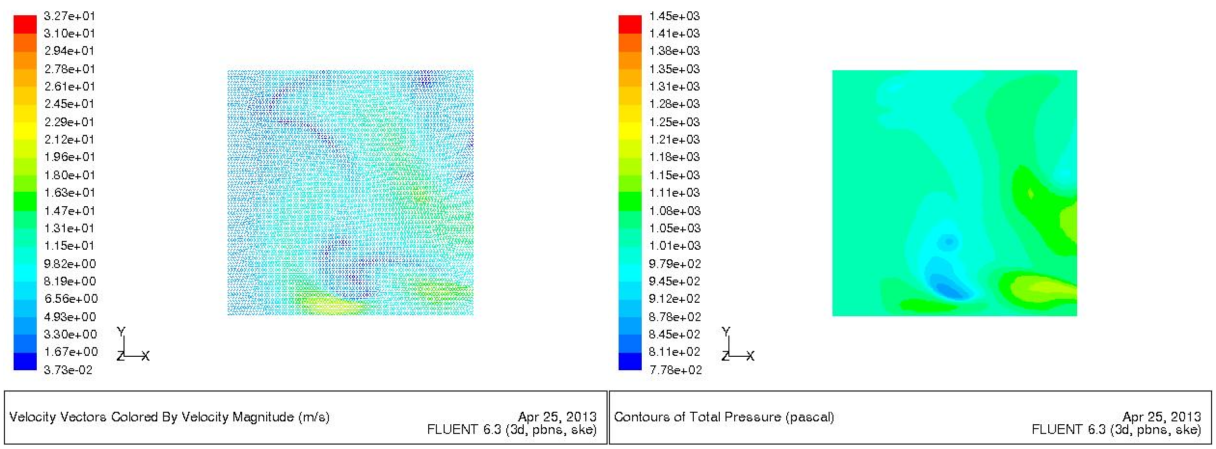

Figure 5.21: The velocity and total pressure distribution in the metering box for the position of fan at side wall (centre) wall

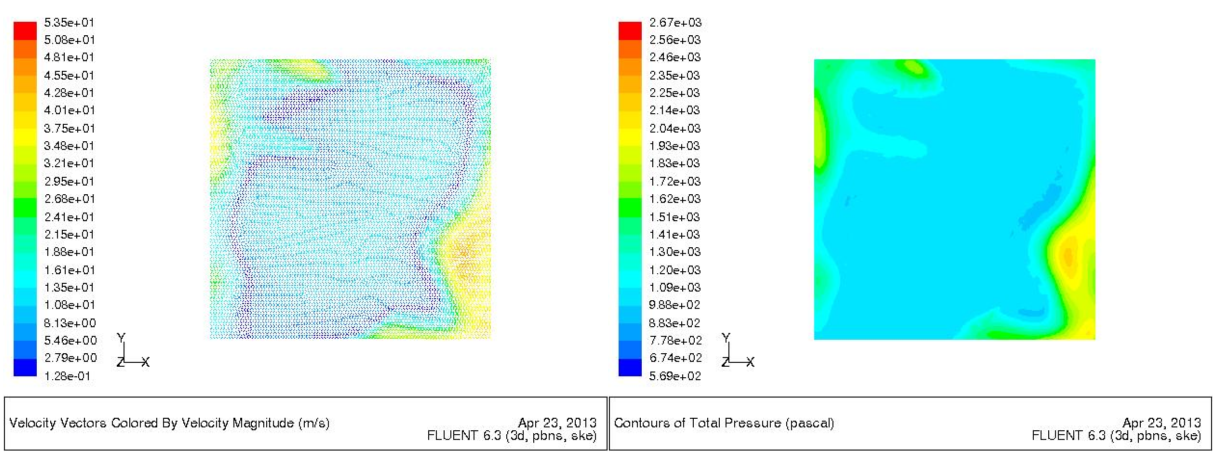

Figure 5.22: The velocity and total pressure distribution in the metering box for the position of fan at side wall (side) wall

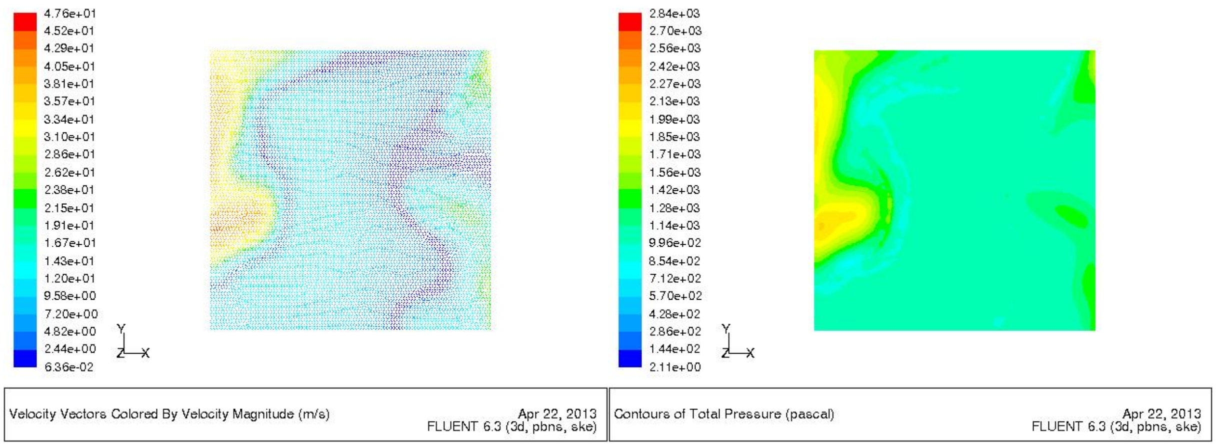

Figure 5.23: The velocity and total pressure distribution in the metering box for the position of fan at side wall (lower corner) wall

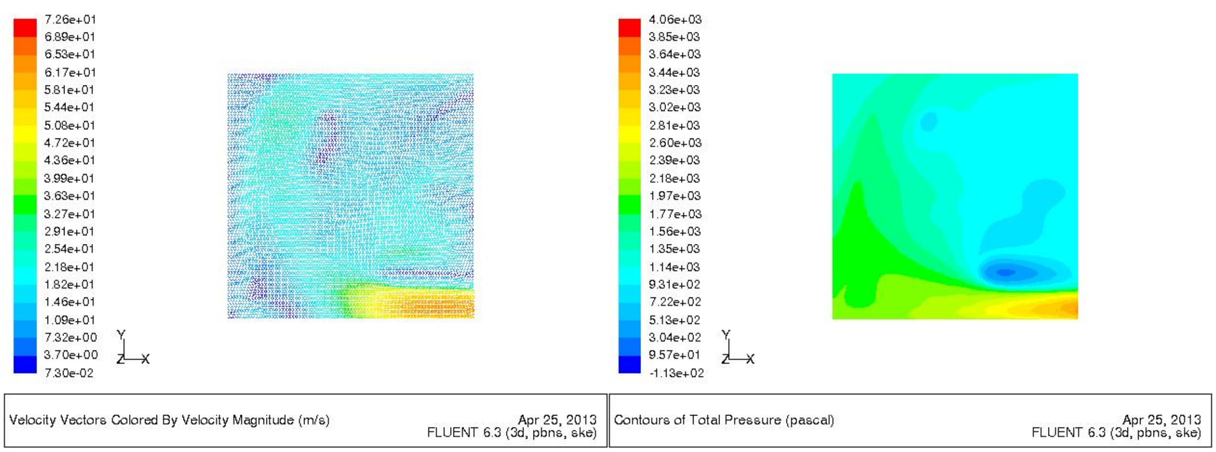

Figure 5.24: The velocity and total pressure distribution in the metering box for the position of fan at side wall (upper corner) wall

Table 5.2: Results of guarded hot box

		Total Pressure (pascal) on Sample wall			**Velocity Magnitude (m/s) on Sample wall**		
Fan Position	**Fan Speed (RPM)**	**Guard Box**	**Metering Box**	**Cold Box**	**Guard Box**	**Metering Box**	**Cold Box**
Top (centre)	500	1075.44	2637.65	2246.27	0.0074	0.1346	0.0904
	1000	939.90	2245.68	1168.12	0.0149	0.2693	0.1808
	1500	1123.18	1070.73	1089.82	0.0224	0.4040	0.2712
	2000	1070.28	1031.25	5774.65	0.0298	0.5387	0.3617
Top (sample side)	500	4232.59	1146.65	1413.26	0.0186	0.0278	0.0912
	1000	1199.15	1227.20	1101.55	0.0373	0.0557	0.1824
	1500	2109.88	1140.93	1368.32	0.0560	0.0826	0.2736
	2000	1597.69	2437.92	1327.61	0.0746	0.1115	0.3648
Front (centre)	500	1269.47	1144.43	1363.09	16.1710	10.3946	16.3848
	1000	1213.38	1059.73	1334.46	15.0601	7.0221	14.6835
	1500	1194.66	1127.20	1207.46	14.0965	12.3429	13.0503
	2000	1346.39	1078.82	1396.80	16.9162	7.3389	18.5843
Front (side)	500	1222.74	1136.95	1546.53	15.0719	12.6123	20.9332
	1000	1208.05	1120.47	1407.51	13.7946	12.0732	16.7707
	1500	1371.86	1144.05	1416.05	17.6253	11.5749	17.1150
	2000	1115.88	1178.39	1176.31	12.7046	14.2557	12.6332
Side Wall (centre)	500	1118.77	1051.58	3827.36	0.0074	0.0285	0.0791
	1000	3411.10	1020.50	2551.44	0.0149	0.0571	0.1582
	1500	1944.91	1027.89	2439.19	0.0224	0.0857	0.2375
	2000	1262.34	1046.14	1271.74	0.0299	0.1143	0.3164
Side Wall (sample side)	500	1238.52	1320.99	382.32	0.0599	0.0277	0.0799
	1000	2815.21	2043.51	1134.41	0.1199	0.0554	0.1599
	1500	1354.86	1298.30	4656.43	0.1799	0.0831	0.2399
	2000	1260.66	1024.98	3374.28	0.23999	0.1108	0.3199
Side Wall (lower corner)	500	1118.77	1135.97	1682.51	0.0074	0.0236	0.0832
	1000	2683.85	1606.50	1766.71	0.1228	0.0472	0.1664
	1500	1535.76	1385.92	2534.06	0.1843	1.4951	0.2496
	2000	1827.13	1131.05	3076.65	0.2457	0.0945	0.3328
Side Wall (upper corner)	500	1504.98	1842.55	2827.02	0.0586	0.0308	0.0824
	1000	2276.66	1546.42	1151.06	0.1172	0.0616	0.1649
	1500	1671.32	1103.13	3808.87	0.1758	0.0924	0.2474
	2000	2581.64	1144.73	2177.90	0.2344	0.1232	0.3299

5.4 Discussion

Based on the results summarised in Table 5.2, and shown in Figure 5.1 to Figure 5.24, it is observed that for a uniform velocity and pressure profile the suitable position of the air circulation fan is on the front wall (side) in the Guard box as well as in the Cold box, and for the Metering box, the suitable position of the air circulation fan is observed to be at the centre of the side wall.

The suitable position of the air circulation fan for the Guard box and Cold box are nearly same, but incase of Metering box the suitable position of the air circulation fan is different becaus of the volume of this box is smaller then the Guard box and Cold box.

For the Guard box, the uniform velocity pattern is observed in the Fig-5.4.

For the Cold box, the uniform velocity pattern is observed in the Fig-5.12.

For the Metering box, the uniform velocity pattern is observed in the Fig-5.21.

Chapter 6

Conclusions & Future Work

6.1 Conclusions

The following conclusions may be drawn from the present study:

1. A detailed literature review pertaining to the design and technical specifications of a Guarded Hot Box was carried out. Based on the same, the dimensions and details of the proposed Guarded Hot Box was worked out.
2. The CFD analysis to study the air flow pattern inside the Guarded Hot Box was done using FLUENT software.
3. The CFD results indicate that for a fairly uniform velocity and pressure profile the suitable position of the air circulation fan is on the front wall (side) in the Guard box as well as in the Cold box.
4. For the Metering box, the suitable position of the air circulation fan is observed to be at the centre of the side wall.

6.2 Future Work

The present study can be extended for the following work:

1. Further analysis using fans of different sizes.
2. Practical (experimental) verification of the CFD results.

Bibliography

[1] F. Asdrubali G. Baldinelli,"Thermal transmittance measurement with the hot box method". Energy and Buildings, vol. 43, pp. 1618-1626, 2011

[2] K. Martin,"Analysis of a Thermal bridge in a Guarded hot box testing facility". Energy and Buildings, vol. 50, pp. 139-149, 2012

[3] ISO-8990,"Thermal insulation Determination of steady-state thermal transmission properties Calibrated and guarded hot Box". First Edition,1994

[4] ASTM-C1363,"Standard Test Method for Thermal Performance of Building Materials and Envelope Assemblies by Means of a Hot Box Apparatus".

[5] Giuseppe Desogus, Salvatore Mura,"Comparing different approaches to in measurement of building components thermal resistance". Energy and Buildings, vol. 43, pp. 2613-2620, 2011

[6] Bulent Yesilata, Paki Turgut,"A simple dynamic measurement technique for comparing thermal insulation performances of anisotropic building materials". Energy and Buildings, vol. 39, pp. 1027-1034, 2007

[7] G. Leftheriotis, P. Yianoulis,"Thermal properties of building materials evaluated by a dynamic simulation of a test cell".Solar Energy,vol. 69, pp. 295-304, 2000

[8] J.A. Clarke, P.P. Yaneske,"A rational approach to the harmonisation of the thermal properties of building materials".Building and Environment, vol. 44, pp. 2046-2055, 2009

[9] Sung Woong Choi et al,"Analysis of two main LNG CCS (cargo containment system) insulation boxes for leakage safety using experimentally defined thermal properties".Applied Ocean Research, vol. 37, pp. 72-89, 2012

[10] D.P. Aviram, A.N. Fried, J.J. Roberts,"Thermal properties of a variable cavity wall".Building and Environment, vol. 36, pp. 1057-1072, 2000

[11] G. Baldinelli,"A methodology for experimental evaluations of low-e barriers thermal properties: Field tests and comparison with theoretical models". Building and Environment, vol. 45, pp. 1016-1024, 2009

[12] Hamed H. Saber,"Investigation of thermal performance of reflective insulations for different applications".Building and Environment, vol. 52, pp. 32-44, 2011

[13] Y. Gao et al,"Reduced linear state model of hollow blocks walls, validation using hot box measurements".Energy and Buildings, vol. 36, pp. 1107-1115, 2004

[14] Karim Ghazi Wakili et al,"Experimental and numerical thermal analysis of a balcony board with integrated glass fibre reinforced polymer GFRP elements".Energy and Buildings, vol. 39, pp. 76-81, 2006

[15] J.M. Sala et al,"Static and dynamic thermal characterisation of a hollow brick wall: Tests and numerical analysis".Energy and Buildings, vol. 40, pp. 1513-1520, 2008

[16] Changhai Peng, Zhishen Wu,"In situ measuring and evaluating the thermal resistance of building construction".Energy and Buildings, vol. 40, pp. 2076-2082, 2008