**MEASUREMENT OF THERMAL CONDUCTIVITY OF SMALLER
THERMAL INSULATION SPECIMENS USING STANDARD HEAT
FLOW METER APPARATUS**

A thesis submitted to
the Faculty of Graduate and Postdoctoral Affairs
in Partial Fulfillment of the requirements for the degree

Masters of Applied Science

by

Graziela Girardi

Department of Civil and Environmental Engineering
Carleton University

Ottawa-Carleton Institute of Civil and Environmental Engineering

May, 2013

©2013 Graziela Girardi

Library and Archives
Canada

Published Heritage
Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et
Archives Canada

Direction du
Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence

ISBN: 978-0-494-94671-8

Our file Notre référence

ISBN: 978-0-494-94671-8

NOTICE:

The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:

L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protègent cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

Abstract

Thermal insulation is used to maintain comfortable temperatures inside buildings and reduce energy loss to the external environment. A variety of materials have been used as thermal insulation, and new products are constantly being developed. The thermal properties of these materials must be assessed to determine appropriate applications. The American Society for Testing and Materials (ASTM) developed the Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus (ASTM C518), which specifies that the test should be conducted on a sample that is at least 300 x 300 mm. When an insulation manufacturer develops a new product, usually, a small quantity of an experimental product is produced and samples with the minimum size required for heat flow meter tests are not always available. It is also not feasible to build a new apparatus or modify an existing apparatus, with different size heat flow sensors, every time a different size sample needs to be tested. The research reported in this thesis examined a new method for testing thermal conductivity using smaller samples of six commercial insulation material, and correlate results to testing of the standard size samples. The tests were carried out using the heat flow meter apparatus, and results were subsequently analyzed using the finite element modelling tool, HEAT3.

Acknowledgements

I would like to thank my supervisor Dr. Ehab Zalok for this opportunity, and for his support and patience along this process.

Special thanks go to my co-supervisor at NRC, Dr. Phalguni Mukhopadhyaya, he taught me to think critically and helped me go through this research motivating me with wise words. Thank you for your time!

I would like to thank all NRC staff from building M-24. Special thanks to Mr. Gordon Sherrer for his laboratory support that allowed the experimental tests to be completed. I am also grateful for Mr. David Van Reenen who helped me to understand and use Heat3 model.

I would like to thank my friends at Carleton University for their support and motivation, especially Sabah Ali, and Omar Abdelalim.

Finally, I would like to express my gratitude to my fiancé, Iman Faris, family and friends for their support and tolerance as I put in innumerable long days at work and too many nights and weekends in front of a laptop.

Table of Contents

Abstract	ii
Acknowledgements	iii
Table of Contents	iv
List of Tables	vii
List of Figures	ix
Nomenclature	xi
Chapter 1: Introduction	1
1.1 Introduction.....	1
1.2 Study Goals and Specific Objectives.....	2
1.3 Contribution of the Study.....	3
1.4 Organization of Thesis.....	3
Chapter 2: Background and Literature Review	5
2.1 Introduction.....	5
2.2 Heat Transfer Mechanisms	5
2.2.1 Conduction Heat Transfer	7
2.2.2 Convection Heat Transfer	8
2.2.3 Radiation Heat Transfer	8
2.3 Thermal Performance and Insulating Material	9
2.3.1 Thermal Insulation Materials	12
2.4 Thermal Conductivity (k)	16
2.4.1 Thermal Resistance	24

2.4.2 Thermal Conductivity Measurement.....	25
2.4.3 Techniques for Thermal Conductivity Measurement.....	26
2.4.4 Use of the Guarded Hot Plate Apparatus to Measure Thermal Conductivity.....	29
2.4.5 Use of Heat Flow meter Apparatus to Measure Thermal Conductivity...	30
2.5 Measuring Thermal Conductivity of Smaller Specimens.....	32
2.6 Thermal Modelling	38
2.7 Summary.....	44
Chapter 3: Experimental Work	46
3.1 Test Materials.....	46
3.2 Test Apparatus and Methods	47
3.2.1 Heat Flow Meter Apparatus	47
3.2.2 Thermal Conductivity Measurements Using the Heat Flow Meter	49
3.2.3 Calibration of the Heat Flow Meter Apparatus.....	50
3.2.4 Data Acquisition System	50
3.2.5 Environmental Conditions.....	52
3.2.6 Specimen Preparation.....	52
3.2.7 Sensitivity Analysis.....	55
3.2.8 Test Procedure.....	56
3.3 Tests Results and Discussion	57
3.3.1 200 x 200 mm Specimens	58
3.3.2 150 x 150 mm Specimens	61
3.3.3 100 x 100 mm Specimens	63

3.3.4 50 x 50 mm Specimens	66
3.3.5 Summary	68
Chapter 4: Modelling	70
4.1 Data Input.....	70
4.2 Simulation Output.....	73
4.3 Sensitivity Analysis	74
4.4 Results and Discussion	76
4.4.1 200 x 200 mm Specimens	76
4.4.2 150 x 150 mm Specimens	78
4.4.3 100 x 100 mm Specimens	79
4.4.4 50 x 50 mm specimens	80
4.4.5 Summary	82
Chapter 5: Conclusions and Recommendations	83
5.1 Conclusions.....	83
5.2 Recommendations for Future Work.....	85
References	86
Appendix A. Thermal Conductivity of Small Specimen with 25 and 12.5 mm thickness.	91

List of Tables

Table 2.1. Characteristics of common insulation materials [13].	15
Table 2.2. Blowing Agent types [20].....	18
Table 2.3. Standard techniques for measuring thermal conductivity.....	28
Table 3.1. Type, density and thickness of insulation materials.	47
Table 3.2. Number of samples tested for each sample size, per thickness.	54
Table 3.3 Repeatability of thermal conductivity tests	55
Table 3.4. Thermal conductivity of intact 300 x 300 mm specimens (k) and masked 200 x 200 mm specimens (k_o), 12.5 and 25 mm thick.....	59
Table 3.5. Measured (k) and derived (k') thermal conductivities of intact 300 x 300 mm specimens and masked 200 x 200 mm specimens, with 12.5 and 25 mm thicknesses.....	60
Table 3.6. Thermal conductivity of intact 300 x 300 mm specimens (k) and masked 150 x 150 mm specimens (k_o), 12.5 and 25 mm thick.....	62
Table 3.7. Measured (k) and derived (k') thermal conductivities of intact 300 x 300 mm specimens and masked 150 x 150 mm specimens, with 12.5 and 25 mm thicknesses.....	63
Table 3.8. Thermal conductivity of intact 300 x 300 mm specimens (k) and masked 100 x 100 mm specimens (k_o), 12.5 and 25 mm thick.....	64
Table 3.9. Measured (k) and derived (k') thermal conductivities of intact 300 x 300 mm specimens and masked 100 x 100 mm specimens, with 12.5 and 25 mm thicknesses.....	65
Table 3.10. Thermal conductivity of intact 300 x 300 mm specimens (k) and masked 50 x 50 mm specimens (k_o), 12.5 and 25 mm thick.....	67
Table 3.11. Measured (k) and derived (k') thermal conductivities of intact 300 x 300 mm specimens and masked 50 x 50 mm specimens, with 12.5 and 25 mm thicknesses.....	68
Table 4.1 Thermal conductivity values measured using intact specimens	73

Table 4.2. Measured and simulated heat flow (q) for specimens with 200 x 200 mm, 25 mm thickness.	77
Table 4.3. Measured and simulated heat flow (q) for specimens with 200 x 200 mm, 12.5 mm thickness.	77
Table 4.4. Measured and simulated heat flow (q) for specimens with 150 x 150 mm, 25 mm thickness.	78
Table 4.5. Measured and simulated heat flow (q) for specimens with 150 x 150 mm, 12.5 mm thickness.	79
Table 4.6. Measured and simulated heat flow (q) for specimens with 100 x 100 mm, 25 mm thickness.	80
Table 4.7. Measured and simulated heat flow (q) for specimens with 100 x 100 mm, 12.5 mm thickness.	80
Table 4.8. Measured and simulated heat flow (q) for specimens with 50 x 50 mm, 25 mm thickness.....	81
Table 4.9. Measured and simulated heat flow (q) for specimens with 50 x 50 mm, 12.5 mm thickness.	81

List of Figures

Figure 2.1. Physics of heat transfer mechanisms [6].	7
Figure 2.2. Heat loss from a typical house with no insulation [9].	10
Figure 2.3. Effect of insulation in a typical house [9].	11
Figure 2.4. (a) Polystyrene (cellular) insulation [11]; (b) Fiberglass (fibrous) insulation [8].	13
Figure 2.5. (a) Flake/granular insulation [11]; (b) Reflective insulation [11].	14
Figure 2.6. Schematic diagram showing heat flow through mass insulation [18].	17
Figure 2.7. Effect of moisture content on the thermal conductivity of insulation [16]. ...	20
Figure 2.8. Comparison of the relative variations of k with mean operating temperatures [22].	21
Figure 2.9. Thermal conductivity versus density for various insulation materials [18]. ..	22
Figure 2.10. Effect of mass density on thermal conductivity for two values of ΔT [16]. ..	23
Figure 2.11. R-values of various insulation materials [3].	24
Figure 2.12. Commonly used methods for measuring thermal conductivity [26].	27
Figure 2.13. Schematic diagram of the guarded hot plate apparatus [31].	30
Figure 2.14. Schematic diagram of the heat flow meter apparatus [35].	31
Figure 2.15. Diagram of Fujino's guarded hot plate apparatus [43].	35
Figure 2.16 Diagram of Muklopadhyaya's heat flow meter apparatus [44].	36
Figure 2.17. Relationship between thermal conductivity measured using intact vs. masked specimens [44].	37
Figure 3.1. Heat flow meter apparatus showing test specimen between two heat flux transducers [35].	48
Figure 3.2. Cold and hot plate thermocouple location.	48
Figure 3.3. EPS mask with cut out.	53

Figure 3.4. EPS mask with the material insert.....	53
Figure 3.5. Test specimens (LDGF, EPS, XPS, ISO, PUR, HDGF).	54
Figure 3.6. Heat flow meter masked specimen set up.	56
Figure 3.7. Heat flow meter test set up.	57
Figure 3.8. Thermal conductivity of masked 200 x 200 mm and intact 300 x 300 mm specimens, 12.5 and 25 mm thick.....	59
Figure 3.9. Thermal conductivity of masked 150 x 150 mm and intact 300 x 300 mm samples, 12.5 and 25 mm thick.....	61
Figure 3.10. Thermal conductivity of masked 100 x 100 mm and intact 300 x 300 mm samples, 12.5 and 25 mm thick.....	64
Figure 3.11. Thermal conductivity of masked 50 x 50 mm and intact 300 x 300 mm samples, 12.5 and 25 mm thick.....	66
Figure 4.1 Test assembly	71
Figure 4.2. Material database library	71
Figure 4.3 Boundary condition	72
Figure 4.4 Temperature output as shown in the post-processor window.	74
Figure 4.5 Heat flow output as shown in the post-processor window.	74
Figure 4.6. a) Scenario 1: model simulated with no gap and b) Scenario 2: model simulated with 1 mm gap.....	75
Figure 4.7. a) Scenario 3: model simulated with 0.7 mm gap and b) Scenario 4: model simulated with 0.5 mm gap.....	75

Nomenclature

ρ – density, kg/m^3

k or λ , – thermal Conductivity, $W/(mK)$

σ - Stefan-Boltzmann constant, $5.67 \times 10^{-8} W/m^2 K^4$

A – metering area, m^2

A_t – total metering area, m^2

C – thermal conductance, $W/(m^2 K)$

C_i - specific heat, $J/kg K$

E – heat flux transducer output, V

k_0 – thermal conductivity of the reference material, $W/(mK)$

h_c – surface coefficient of heat transfer, $W/(m^2 K)$

L – separation between the hot and cold plate assemblies during testing, m

L_0 – thickness of the reference material, m

m – mass of the specimen, kg

Q – heat flow rate in the metered area, W

q – heat flux (heat flow rate, Q , through area, A), W/m^2

R – thermal resistance, $m^2 K/W$

ΔT – temperature difference across the specimen, $T_h - T_c$

t – thickness, m

T - temperature, $^{\circ}C$ or K

T_h – hot surface temperature, K

T_c – cold surface temperature, K

T_m - mean temperature, K , $(T_h + T_c)/2$

S – calibration factor of the heat flux transducer, $(W/m^2)/V$

Chapter 1: Introduction

1.1 Introduction

In times of high energy prices and concern about impacts of energy usage on the environment, use of thermal insulation materials to reduce the energy consumption is of particular importance. Thermal insulation is one of the most effective energy conservation measures for cooling and heating buildings, limiting energy consumption by reducing both heat loss or gain and hence the heating and cooling period [1]. Effective insulation improves the conservation of existing energy and allows the use of simpler heating and cooling systems. Therefore, manufacturers and end users are constantly searching for new, more energy-efficient and cost-effective building insulation materials.

Thermal performance of a new insulation product is primarily assessed based on its thermal properties, including thermal conductivity or thermal resistance. Most measurements of thermal conductivity or thermal resistance of building insulations, other than pipe insulation, are now made using a guarded hot plate apparatus or a heat flow meter apparatus [2]. These methods require samples 300 – 600 mm in length and width, and 20 – 200 mm in thickness. When an insulation manufacturer/researcher develops a new product, samples of such sizes are often not available. It is also not feasible to build a new apparatus or modify an existing apparatus every time a different size sample needs to

be tested. Manufacturers need to acquire data rapidly and with sufficient accuracy to make informed decisions in a timely manner. Consequently, an alternative method of measuring the thermal conductivity of small insulation samples is needed.

The present study tested a new method for measuring thermal conductivity of smaller samples of building insulation materials. Results of the new method were verified to measurements made using larger samples of the same materials, in compliance with ASTM C518, the Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus. The results were also compared to thermal conductivity of the smaller samples predicted by the modelling software tool, HEAT3. Based on the experimental and modelling results, simplified empirical calculation methods were developed.

1.2 Study Goals and Specific Objectives

The goal of the present study is to develop and determine the accuracy of a new method aimed at measuring thermal conductivity of smaller specimens of thermal insulation materials, using the heat flow meter apparatus. Various test materials and samples of different sizes and thicknesses were used. The specific objectives are as follow:

- develop a test method for measuring the thermal conductivity values of small insulation specimens,
- verify the accuracy of the new methodology by comparing the results to measurements made for larger samples of the same materials by the standard test methodology specified in ASTM C518, and

- evaluate the new methodology by comparing the results to thermal conductivities predicted using a mathematical model based on HEAT3 software.

1.3 Contribution of the Study

The methodology proposed for determining thermal conductivity of smaller specimens will be useful by manufacturers developing new insulation materials, particularly foams. The methodology can be used to analyze different types, sizes, and thicknesses of insulation materials that were not examined in the present study.

The experimental tests were validated by using the finite element modelling which is specifically applicable to smaller specimens. The validation extended the use of models for examining thermal properties of insulation materials, and demonstrated that the 3-D heat transfer analysis was accurate for predicting heat transfer at specified temperatures.

1.4 Organization of Thesis

This thesis is organized into six chapters.

- Chapter 1 (Introduction): introduces the problem, explains the study goals and objectives.
- Chapter 2 (Background and Literature Review): reviews the literature on thermal properties of insulation materials, with a particular focus on methodologies used for measuring thermal conductivity of composite materials.
- Chapter 3 (Experimental Work): describes the methodology used to determine thermal conductivity of smaller specimens using a heat flow meter apparatus, and re-

ports on the thermal conductivity values determined for a variety of insulation materials using the new methodology with smaller specimens.

- Chapter 4 (Modelling): describes the HEAT3 modelling tool used, and discusses the results of the scenarios simulated to validate the experimental results.
- Chapter 5 (Conclusion and Recommendations): presents the conclusions from this study and recommendations for future work.

Chapter 2: Background and Literature Review

Chapter 2 provides an introduction to thermal insulation, heat transfer mechanisms, and thermal conductivity measurements, and reviews results of previous studies related to thermal conductivity measurement of small specimens.

2.1 Introduction

Insulation material is defined as a material, or combination of materials, which provides resistance to the flow of heat [3]. The materials can usually be adapted to a variety of sizes, shapes, and surfaces. Thermal insulation materials are specifically designed to conserve energy by reducing heat loss or gain; to control surface temperatures for personnel protection and comfort; and to increase efficiency of heating, ventilating, and cooling in commercial, residential and industrial installations [3]. To understand the properties of insulation materials and the various approaches to insulating a building, it is necessary to understand the mechanisms of heat transfer.

2.2 Heat Transfer Mechanisms

Heat transfer is the transmission of energy from one region to another, as a result of a temperature gradient. For example, a difference of temperature between the interior of a

building and the exterior environment, or between different parts of a building, will result in a transfer of heat from the warmer to the cooler area. The rate at which heat flows between the two locations is called the rate of heat transfer. The variables that control the rate of heat transfer are temperature difference, material, area, air-flow, air gaps, thickness or distance.

The transfer of heat from a hot to a cold location will continue as long as there is a difference in temperature. Once the two locations reach the same temperature, thermal equilibrium is established, and the heat transfer stops. The rate of heat transfer is directly proportional to the surface area through which the heat is being conducted [4], more heat will be lost from a home through a large window than through a small window of the same composition and thickness. The rate of heat transfer is inversely proportional to the thickness of the wall it is passing through, i.e., heat is transferred more rapidly through a thin wall than through a thick wall when subjected to the same temperature difference [5].

The application of the principles of insulation to building design requires understanding the different modes of heat transfer that influence heat gains and losses in buildings. Three basic mechanisms control the insulating capacity of conventional thermal insulation materials: conduction, convection, and radiation (Figure 2.1).

Figure 2.1. Physics of heat transfer mechanisms [6].

2.2.1 Conduction Heat Transfer

Conduction is the most significant means of heat transfer in solid materials. Conduction is the process by which heat flows through or along a material, or between two solids materials that are in contact. Conduction occurs as hot, rapidly moving or vibrating atoms and molecules transfer some of their energy as heat to neighboring atoms and molecules [5].

Whenever a temperature gradient exists in a solid medium, heat flows from the higher to the lower temperature region. The rate at which heat is transferred by conduction, q (W), is proportional to the temperature gradient, dT/dx , times the area, A (m^2), through which heat is transferred,

$$\dot{q} \propto A \frac{dT}{dx}$$

where T is the local temperature in Kelvin (K), and x is the distance, in meters (m), in the direction of heat flow in watts (W). The actual rate of heat flow depends on the thermal conductivity, k (W/mK), which is a physical property of the medium. For conduction

through a homogeneous medium, the rate of heat transfer is calculated using Equation 2.1, known as Fourier's law.

$$q = -kA \frac{dT}{dx} \quad (2.1)$$

2.2.2 Convection Heat Transfer

Heat transfer by convection occurs in liquids and gases. Differences in density, due to variations in temperature cause movement of the liquid or gas resulting in the transfer of heat. There has to be a temperature difference, or no heat transfer occurs. Convection heat also transfer occurs at the surfaces of walls, floors, and roofs, when the surface is warmer or cooler than the adjacent air. The rate of transfer increases, if air movement is enhanced, for example, by wind or a fan [6]. The rate of heat transfer by convection between a surface and a fluid can be calculated from Equation 2.2.

$$\dot{q}_c = h_c A \Delta T \quad (2.2)$$

Where $\dot{q}_c$ is the rate of heat transfer by convection in watts (W), A is the heat transfer area in square meters (m^2), ΔT is the difference between the surface temperature and a temperature of the fluid at some specified location, (K), and $\bar{h}_c$ is the surface coefficient of heat transfer, (W/m^2K).

2.2.3 Radiation Heat Transfer

In heat transfer by radiation, heat is emitted from a body and transmitted through space as energy. All bodies emit radiant energy, and the rate of emission depends on the

temperature of the body and on the nature of its surface. Radiation is the only form of heat transfer that can occur in the absence of a medium, i.e., in a vacuum. Thermal radiation is based on the emission of electromagnetic radiation, which carries energy away from a surface [7]. The quantity of energy leaving a surface as radiant heat depends on the absolute temperature and the nature of the surface. A perfect radiator or blackbody emits radiant energy from its surface at a rate $\dot{q}$ given by Equation 2.3.

$$\dot{q} = \sigma A_s (T_s^4) \quad (2.3)$$

Where $\dot{q}$ is the heat transfer per unit time (W), σ is the Stefan-Boltzmann constant, and is equal to 5.6703×10^{-8} (W/m²K⁴), T is the temperature in Kelvin (K), and A is the area (m²) of the emitting body.

2.3 Thermal Performance and Insulating Material

Thermal insulation is used to minimize radiative, convective, and conductive heat transfer. Insulation helps to maintain a comfortable indoor living environment by maintaining steady temperatures and, at the same time, reducing energy consumption [8]. The main purpose of insulation is to create a thermal barrier around the building, over the roof, on the walls, and beneath the floor to resist heat transfer. This helps to reduce the amount of heat gained on a warm day and the amount of heat loss on a cold day. Figure 2.2, illustrates the different ways heat air is lost in a house. Since the majority of heat is lost or gained through the roof and the exposed walls, these areas are the most fundamental places to insulate in order to create a comfortable and energy efficient home.

Figure 2.2. Heat loss from a typical house with no insulation [9].

In a house with insulation, heat flow through its boundaries is limited to an extent that depends on the capacity of the material to conduct heat. Effective insulation prevents heat from being transmitted through the roof and walls. The interior remains relatively cool in the summer and warm in the winter, compared to the exterior environment, because most heat transfer is blocked by the insulation barrier. Thus, the interior temperature can be kept comfortable with less heating and cooling energy [10].

On a hot day, the temperature of the roof and walls increases, until they start to emit heat to the interior of the building. Materials with the capacity to store heat, such as concrete and brick, can remain warm during the night, continuing to make the building inte-

rior uncomfortably hot. The opposite happens during cold weather where heat from the interior of the house is absorbed by the roof and walls and emitted to the exterior environment, so that the interior temperature can eventually match the cold exterior temperature.

Figure 2.3. Effect of insulation in a typical house [9].

The effectiveness of insulation as a heat barrier is determined by many factors, most importantly by its thermal conductivity. This value denotes the resistance against heat transfer across the material. Thermal conductivity is the property used in the industry to compare different types of insulation. However, other factors, such as cost, safety, and feasibility of the product are also considered in choosing insulation for a specific use [10].

2.3.1 Thermal Insulation Materials

A variety of insulation materials is available, with different applications, and can be divided into four main groups [11]:

- cellular insulation,
- fibrous insulation,
- flake/granular insulation, and
- reflective insulation.

Cellular Insulation

Cellular insulation is composed of small individual cells either closed-cell or open-cell. The material is in the form of extended flexible or rigid boards, and is used in roofs, walls, and under floors. Cellular insulation has the advantage of low density, low heat capacity, and relatively high compressive strength. Examples of cellular insulations are polystyrene, polyisocyanurate (polyiso), polyurethane, and foam rubber [11]. All of these materials are produced in rigid sheet form (Figure 2.4a), and some can be sprayed into the cavities of walls.

Fibrous Insulation

Fibrous insulation, such as rock wool, sheep's wool, and glass fiber (Figure 2.4b) is commonly used for insulating attics and walls. These materials are generally manufactured in blanket rolls or rigid sheets. Fibrous insulations are composed of small diameter

fibers that finely divide the air space. The fibers might be perpendicular or parallel to the surface being insulated, and might or might not be bonded together. Fibrous materials have high porosity (~90%). Mineral wool is a common fibrous insulation used at temperatures below 700°C, and fiberglass is often used at temperatures below 200°C [12].

Figure 2.4. (a) Polystyrene (cellular) insulation [11]; (b) Fiberglass (fibrous) insulation [8].

Granular/Flake Insulation

Granular/flake insulation is an open cell material, consisting of small nodules containing air pockets, or small flakes that divide the air, and is commonly used in attics (Figure 2.5a). Granular/flake insulation is not considered to be true cellular material, as gas can be transferred between the spaces. This insulation is produced in the form of loose fill/pourable material, which can be combined with a binder and fibers to make rigid insulation. Examples are expanded vermiculite, perlite, and cellulose [12].

Reflective Insulation

Reflective insulation is a thermal insulating coating that provides a radiant barrier (Figure 2.5b). Instead of reducing conductive heat flow, it reduces radiant heat flow. Reflective insulation only works when there is an air gap between the heat source and the reflective surface because when an air gap exists in a building's shell, heat moves across the gap via radiation [12]. This type of insulation is added to surfaces, such as ceilings, to lower heat transfer to and from those surfaces.

Figure 2.5. (a) Flake/granular insulation [11]; (b) Reflective insulation [11].

Thermal insulation materials are heterogeneous in nature, so some variation in properties must be expected. The primary goal is to ensure that the material performs at the level it was originally designed for, based on the assumption that all properties remain

unchanged. However, actual performance can be affected by the manufacturing process, packing, handling, transportation, installation, time, and the environment.

Characteristics of three types of insulation and their associated properties such as density, and thermal conductivity are shown in Table 2.1.

Table 2.1. Characteristics of common insulation materials [13].

	Property	
	Density ρ (kg/m ³)	Thermal Conductivity (W/mK)
Cellular		
Expanded polystyrene	16 - 35	0.032-0.037
Extruded polystyrene	20 - 33	0.024-0.026
Polyisocyanurate	24 - 55	0.021-0.027
Polyurethane	27 - 49	0.021-0.033
Fibrous		
Low density glass fiber	12 - 56	0.033-0.040
High density glass fiber	66 - 150	0.031-0.043
Rockwool	40 - 200	0.036-0.045
Granular/flake		
Vermiculite	64 - 130	0.063-0.068
Perlite	32 - 176	0.040-0.060

2.4 Thermal Conductivity (k)

All materials have thermodynamic properties which are used in the evaluation of the materials and in heat energy calculations [15]. Thermal conductivity is the property that determines the ability of a material to transfer heat. The heat conduction equation is directly used to determine the thermal conductivity of materials, according to Fourier's law [14], Equation 2.1, thermal conductivity (W/mK) is defined in Equation 2.4.

$$k = \frac{Q\Delta_x}{A\Delta_T} \quad (2.4)$$

Thermal conductivity is a measure of the rate at which heat flows through a material when there is a temperature difference between its surfaces, i.e., the quantity of heat passing through the material, per unit of time, per unit area, at a temperature difference. Thermal conductivity is expressed as watts per metre thickness of material for a temperature gradient of one Kelvin (W/mK).

The thermal conductivity value depends on the medium and varies with aging effects, density, moisture content, and temperature [16].

Structure of Insulation

Most insulation materials presently used in buildings have two basic structures: a continuous body of gas that contains a dispersion of solid particles or fibres; and a con-

tinuous matrix of solid material with a random dispersion of gas-filled cavities [17]

(Figure 2.6).

When a small amount of opaque solid material is distributed throughout an air space, it inhibits heat transfer by convection and radiation while contributing little to conduction, thereby raising the value of the thermal resistance of the space. Solids such as glass, rock and plastic that provide little resistance to heat flow can be used in this way to produce good insulation [19].

Figure 2.6. Schematic diagram showing heat flow through mass insulation [18].

The closed-cell type of insulation can have gases other than air in the cells and thus can have resistances higher than are possible for air-filled materials. The closed-cells are filled up by the captive gaseous blowing agent(s) during the manufacturing process of the foam [20]. The thermal conductivity of the blowing agent is usually lower than air. In effect, the presence of blowing agents inside the closed-cell reduces the air conduction component of thermal conductivity significantly depending on the type of blowing agent used in the closed-cell foam insulation [20] (Table 2.2).

Table 2.2. Blowing Agent types [20]

Blowing Agent	Thermal Conductivity [k_{gas} @ 25 (°C) mW/mK]
CFC-11	8.7
HCFC-22	11
HFC – 134a	12
Hydrocarbon c- C5	15
Air	26

Aging Effects

Thermal conductivity of the closed-cell foam insulation, due to the presence of captive blowing agents inside the close-dell, increases over time as air diffuses into and blowing agents(s) diffuses out of the closed-cells [17].

The rate at which this diffusion (also called aging) occurs depends on a number of parameters such as properties of foam, geometry and structure of the cells, expose con-

ditions, density of material, and manufacturing process. Gases with large molecules such as Freon-11 may take years to diffuse out of high quality urethane foam, but carbon dioxide can diffuse out of the same foam in only a few days and air may diffuse into the cells in a matter of weeks [20]. This aging process slows down with the time and almost reaches to an equilibrium state after a certain time. The fully aged value of resistance should be used for buildings expected to have a life span of many decades [20]. Open cell insulations contain only air and are not subject to this aging effect.

Moisture

Moisture in a material is usually measured by weight and expressed as a percentage of the weight of the material when completely dry, or as a percentage of the weight of the saturation content the maximum amount that the material can hold. The higher the moisture content of the material, the greater the thermal conductivity value (Figure 2.7).

The saturation moisture content and the percentage increase in the k value due to saturation, vary considerably for different materials. Thermal insulation is typically advertised using its thermal conductivity in a dry state. In practice, however, thermal conductivity values should be relevant to the range of moisture content that is likely to predominate in the material when used in a structure. The thermal conductivity value is usually determined for material stored at 22°C under normal atmospheric conditions. Thermal conductivity values of insulation materials are typically below 0.060 W/m.K at 10°C. The

lower the thermal conductivity value, the better the insulation performance of the material [21].

Figure 2.7. Effect of moisture content on the thermal conductivity of insulation [16].

Temperature

Temperature is another factor influencing the rate of heat flow through a material. The conductivity of a material changes with variation in mean temperature, temperature difference, and direction of heat flow. All of these factors must be considered in the determination of the thermal conductivity of an insulating material. Thermal conductivities can be considerably greater at high temperatures than at low temperatures [22], however; the variation in thermal conductivity over the range of temperatures commonly occurring

in buildings is comparatively small and the values measured at normal atmospheric temperatures are generally used when considering structural insulation.

A comparison of the relative variations of thermal conductivity with mean operating temperatures for different samples of insulation materials is illustrated in Figure 2.8. It can be seen that the thermal conductivity values of all insulation materials are affected in varying degrees with operating temperature. In all cases, however, a higher temperature leads to higher thermal conductivity values [22].

Figure 2.8. Comparison of the relative variations of k with mean operating temperatures [22].

Density

Density of the material affects its thermal conductivity. Dense materials generally have higher thermal conductivity and, therefore, are poor insulators compared to lightweight materials [18] (Figure 2.9). The thermal conductivity (k) of Glass Fiber A decreases sharply from 0.4 to 0.25 when the density increases from 8 to 16 kg m^{-3} . However, when the density reaches 24 kg m^{-3} the density does not have a big effect on the thermal conductivity value. Glass Fiber B exhibits a similar, but more gradual, change in thermal conductivity as the density increases. In contrast, density has only a small effect on the thermal conductivity of Cellulosic, and no significant effect on the thermal conductivity of Extruded Polystyrene or the Polyurethane.

Figure 2.9. Thermal conductivity versus density for various insulation materials [18].

Heat is more easily transferred across a flake or fiber insulation containing a few large air spaces than across a material with many small air spaces. Thus, for a given mean temperature and temperature difference, there is an optimum density at which a material is most efficient in reducing heat flow [19]. Therefore, conductivity decreases with increasing density until the lowest conductivity is reached, then increases with further increases in density as per Figure 2.10. The density at which conductivity is lowest depends on temperature. Therefore, determining the mass density and temperature at which the minimum thermal conductivity is achieved is important in selecting the insulation material.

Figure 2.10. Effect of mass density on thermal conductivity for two values of ΔT [16].

2.4.1 Thermal Resistance

Thermal resistance is the ability of a specific insulation material to resist heat transfer at a given thickness, and is expressed as an R-value in the building and construction industry. The R-value is the most effective measure for comparing the performance of different materials and thicknesses. The higher the R-value the more effective the insulation (Figure 2.11).

Figure 2.11. R-values of various insulation materials [3].

Increasing thickness provides a proportional increase in thermal resistance. The thermal resistance of a material is calculated as per Equation 2.5.

$$R = \frac{t}{k} \quad (2.5)$$

where t is the thickness (m), and k is the thermal conductivity (W/m.K).

2.4.2 Thermal Conductivity Measurement

Standard measurements of thermal conductivity were initiated in the late 1920s and early 1930s, but methods of determining thermal conductivity were first developed during the 19th century. Zarr and Kumaran [23] summarized the work of early thermal conductivity researchers, such as Péclet, Forbes, Christiansen, Hencky. Péclet proposed three methods for determining thermal conductivity, using a sphere, pipe section, or vertical slab. Forbes developed a slab method for determining negative temperatures, by measuring the thickness of the ice layer formed on one surface of the specimen, while the other side was exposed to a freezing mixture. Christiansen built a comparative instrument that was later developed into a heat flow meter (HFM) apparatus. It contained three relatively thick copper plates with drilled holes for thermometers. Two specimens were placed between the plates – a reference material with known thermal conductivity and a test material for which thermal conductivity was to be measured. Thermal conductivity, k , of the test specimen was calculated using Equation 2.6.

$$k = k_0 \frac{L(T_3 - T_2)}{L_0(T_2 - T_1)} \quad (2.6)$$

where k_0 = thermal conductivity of the reference material, L and L_0 = thicknesses of the test and reference materials, respectively, and, T_3, T_2, T_1 = temperatures of copper plates, starting from the hot plate.

Schmidt measured thermal conductivity using a heat flow transducer with low thermal resistance and compensating rubber strips of approximately the same resistance as the transducer [23]. Hencky modified the design by adding a layer with thermal resistance comparable to that being measured. The same technique is being used eighty years later, because the physical principles involved remain practically unchanged. However, more precise instruments have been developed to improve the precision and accuracy for a wider range of materials and testing conditions.

2.4.3 Techniques for Thermal Conductivity Measurement

Today, a number of methods and types of equipment are used to evaluate thermal transmission properties. The methods can be categorized as either steady-state or transient (dynamic) methods [24]. In general, thermal conductivity is measured by steady-state techniques, which apply to situations where the temperature of the material remains constant over time. Steady state signals are constant, so analysis is straightforward [24]. Under steady-state conduction, the quantity of heat passing into an object is equal to that being released. Some transient techniques can also be modified for measuring thermal conductivity [25].

Thermal properties range widely, so no single measurement method can be used to characterize all materials (Figure 2.12). The type of material, range of thermal properties, sample size and shape, and operational temperature range determine the method and equipment used. The heat flow meter and guarded hot plate are usually used to measure k -values of low conductivity materials [25], such as insulations and foams. Other meth-

ods, such as the laser flash, give more accurate results for highly conductive ceramics, metals, or diamond composites [25].

Figure 2.12. Commonly used methods for measuring thermal conductivity [26].

There are two types of guarded hot plate techniques used to measure thermal conductivity of insulation materials, and the standards used to measure thermal conductivity of insulation materials are summarized in Table 2.3.

The first type, represented by ASTM C177 [27], ISO 8302:1991 [28], DINEN 12939 [29], and JIS A 1412-1 [30] is an absolute method, where the apparatus is constructed so that thermal conductivity is directly obtained from measurement of electrical power, temperatures, and sample dimensions [31]. The other type, represent-

ed by ASTM C518 [32], ISO 8301:1991 [33], and DINEN 12667 [34], incorporates one or more heat flux meters in a stack of plates calibrated against standard samples.

Table 2.3. Standard techniques for measuring thermal conductivity.

Standard	Description
ASTM C177	Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded-Hot-Plate Apparatus
ASTM C518	Standard Test Method for Steady-State Thermal transmission Properties by Means of the Heat Flow Meter Apparatus
DINEN 12667/12939	European Standard for Measurements of Insulating Materials Using the Heat Flow Meter Method or the Guarded Hot Plate Technique
ISO 8301/8302	Standard Test Technique for Measurements of Insulating Materials Using the Heat Flow Meter/Guarded Hot Plate Method
JIS A 1412-1:1999	Test Method For Thermal Resistance And Related Properties Of Thermal Insulations - Guarded Hot Plate

2.4.4 Use of the Guarded Hot Plate Apparatus to Measure Thermal Conductivity

The guarded hot plate apparatus is used to determine the steady state heat transfer properties, thermal conductivity, and thermal resistance of flat slab specimens, in accordance with International Standards (ISO) 8302 and ASTM C-177 [31]. It is designed for use in test laboratories, manufacturing processes, and quality control procedures, for a wide range of materials with low and intermediate thermal conductivity, including rubber, plastics, mineral and glass fibers, cellular rubber, polyurethane, and polystyrene.

The guarded hot plate apparatus consists of a flat, electrically heated, metering section, surrounded on all sides by a guard. The heater, controlled using differential thermocouples, supplies a planar heat source over the hot face of the specimen. The most common measurement configuration is a symmetrical arrangement, where the heater assembly is sandwiched between two specimens. The schematic diagram of the guarded hot plate is shown in Figure 2.13. In the single-sided configuration, the heat flow passes through one specimen, and the back of the main heater acts as a guard plate, creating an adiabatic environment [36].

Figure 2.13. Schematic diagram of the guarded hot plate apparatus [31].

2.4.5 Use of Heat Flow meter Apparatus to Measure Thermal Conductivity

The heat flow meter apparatus is a widely used and versatile method of measuring steady state thermal transmission. The method is based on a simple operation and provides accurate results for flat, homogeneous materials with low thermal conductivities under moderate temperature conditions [35]. The heat flow meter apparatus consists of two isothermal plate assemblies, and one or more heat flux transducers. The sample is sandwiched between the hot and cold surface assemblies, which provide steady-state, one-dimensional heat flux through the specimens (Figure 2.14). The metered section is defined by ASTM C518 as the portion of the test specimen (or auxiliary insulation) through which the heat input flows under ideal conditions [37]. The heat transferred through the specimen is equal to the power supplied to the metered section. Temperature

is monitored at each surface, using thermocouples. Steady-state is achieved when temperature and voltage readings become constant.

Figure 2.14. Schematic diagram of the heat flow meter apparatus [35].

The heat flow meter apparatus is usually located in an environmentally controlled chamber, and is used to determine the thermal conductivity of thermal insulations used in building construction.

Deviations from the idealized measurements using the heat flow meter apparatus can be considerable, due to non-homogeneity of specimens, temperature differences between the metered section and the guard, and temperature differences between the outer edge of the assembly, and the surrounding controlled environment. Any heat propagating routes that result in lateral heat flow within the apparatus, rather than heat flow through the specimen along the direction of temperature gradient, affect the results. Specific configurations for standardized measurements with maximum accuracy are recommended by the ASTM C518. The linear dimension of the metered section must be precisely determined, and the temperature along the surface plate of the hot surface assembly in the lateral direction must be constant, with less than 2% temperature variation across the specimen

[38]. The gap between the metered section and the primary guard must be not more than 5% of the metered section area, to provide lateral thermal resistance. Despite these precautions, experimental error can be considerable, because thermal properties are sensitive to many environmental factors, such as temperature, moisture, and pressure [38]. The results can also vary significantly among tests using apparatuses with different specifications. Thus, each apparatus must be calibrated periodically.

2.5 Measuring Thermal Conductivity of Smaller Specimens

In the late 1990s, Flynn and Gorthala designed a small guarded hot plate apparatus for determining the thermal conductivity of smaller specimens, 100 to 300 mm² in area, and up to 13 mm thick [39][40]. The apparatus was intended to be useful to manufacturers for characterizing insulation materials and polymers, particularly experimental products that are only available in very small sample sizes. The work was conducted under a Small Business Innovative Research (SBIR) Phase I contract from the National Institute of Standards and Technology (NIST). The goal was a single-sided guarded hot plate that was much smaller than any other device available, for measuring materials with very low thermal conductivity. Flynn and Gorthala favored an absolute measurement approach and noted the general lack of calibration standards for highly insulating materials. The meter and guard on the cold plate side of the small guarded hot plate apparatus were designed to incorporate a heat flux meter. Ceramic materials, including BeO, AlN, Si, or polycrystalline diamond, were considered for the meter and guard plates to provide electrical insula-

tion. The surfaces of the plates were to be treated, so that they had high emittance or matched emittance corresponding to the end use of the material being tested. The apparatus was designed to cover a temperature range of at least -40 to 10°C , in an environment of air, selected gases, or vacuum. The primary conductivity range was designed to be from 0.02 to 0.05 W/mK , and if possible, from less than 0.005 to 0.35 W/mK . The design goals were less than 5% error in accuracy ($< 2\%$ near 25°C), and less than 2% error in repeatability ($< 0.5\%$ near 25°C).

Flynn and Gorthala [39, 40] noted that constructing a small guarded hot plate apparatus required serious correction, especially regarding heat flow across the gap. The sample thickness should be scaled down in proportion to the lateral dimensions which was an apparent contradiction to the stated goal of allowing samples up to 13 mm thick. They also expressed skepticism about using air as a calibration standard. The prototype was to be built, if a Phase II SBIR contract was awarded. However, there is no evidence in the literature to indicate that the apparatus was actually built and tested.

Miller et al. [41] developed a hot plate method using air as a standard reference material, for the steady-state measurement of the thermal conductivity of small samples with thermal conductivity on the order of air. Heat flow through the test sample was designed to be essentially one-dimensional, but no attempt was made to use heated guards to block the flow of heat from the hot plate to the surroundings. Miller et al. stated that, since large correction factors must be applied to account for guard imperfections when sample di-

mensions are small, it was preferable to simply measure and correct for heat that flows from the heater disc to directions other than into the sample. Experimental measurements made with a prototype apparatus, combined with extensive computational modelling of heat transfer in the apparatus, showed that sufficiently accurate measurements could be obtained to allow determination of the thermal conductivity of low thermal conductivity materials. The technique required a standard reference material with relatively low thermal conductivity, such as Glass Fiberboard SRM 1450c, which has a thermal conductivity of about 0.033 W/mK at room temperature. The thickness of this material is 25 mm; however, its layered structure might not lend itself to machining into small, well-characterized samples. Expanded polystyrene, EPS SRM 1453 [42], is another standard reference material with similar thermal conductivity and similar problems for machining into samples ~4 mm in thickness.

Fujino [43] developed a guarded hot plate apparatus [43] for measuring the thermal conductivity of polymer specimens smaller (≤ 200 mm) and thicker than recommended by the JIS [30] and ASTM C-177 [20], within 10% accuracy (Figure 2.15).

The thermal conductivity of such polymers ranges from 0.2 to 0.6 W/mK. Three experimental apparatuses were built, appropriate for specimens 50 x 50, 100 x 100, and 200 x 200 mm² in area. The major concerns were the influence of specimen size, the difference in temperature between the main and guard heaters, and effect of the gap on thermal conductivity measurements. In a test apparatus suitable for specimens of 50 mm x 50

mm², the gap affects the measurement of thermal conductivity, and the temperature difference of the heat source, ΔT_g , has a direct influence on deviation in the thermal conductivity data. Fujino compared results from his apparatus with results from the standard apparatus, and found thermal conductivity measurements within 4% of the standard results. A 50 x 50 mm² in area specimen was sufficient to determine thermal conductivity ranging from 0.2 to 0.6 W/mK. However, the gap did affect the measurement, and the long term effect of thermal contact resistance considerably increased thermal conductivity.

Figure 2.15. Diagram of Fujino's guarded hot plate apparatus [43].

Mukhopadhyaya et al. [44] developed a method, using an existing heat flow meter apparatus and following ASTM C518, to assess the thermal conductivity of new biobased polyurethane (PU), closed-cell, foam insulations using smaller size samples. The size of the foam specimen was 70 x 70 x 12 mm. The heat flow meter had a metering area of 150

x 150 mm, and the smaller specimen was masked with a larger piece of insulation (Figure 2.16). Standard size specimens (300 mm x 300 mm) are called "intact", and smaller specimens are "masked".

Figure 2.16 Diagram of Muklopadhyaya's heat flow meter apparatus [44].

The results showed close correlation between the new method and the standard method with 300 x 300 mm specimens (Figure 2.17) [44]. The range of the thermal conductivity was 0.024-0.028 W/m.K for the masked specimens versus 0.025-0.04 W/m.K for the intact specimens. This relationship could be used to derive the thermal conductivity of biofoam materials from masked thermal conductivity measurements with small specimens.

Figure 2.17. Relationship between thermal conductivity measured using intact vs. masked specimens [44].

Masson et al. [45] developed a rapid method for measuring thermal conductivity of new foams, using temperature-modulated differential scanning calorimetry (MDSC). The method determines thermal conductivity values from heat capacity measurements on cylindrical samples ≤ 2 g in weight, and is the basis for ASTM E1952, "Thermal Conductivity and Thermal Diffusivity by Modulated Differential Scanning Calorimetry" (MDSC) [46]. ASTM E1952 methods were applied to thermal insulating foams used in construction applications, and the results demonstrated that MDSC provides excellent repeatability and good reproducibility. However, a comparison of established values of thermal conductivity for six insulating foams to values determined by ASTM E1952 showed that the ASTM E1952 method was inaccurate. Two sources of errors were identified: 1) the use of nitrogen as a purge gas, and 2) the use of an equation that inaccurately

relates the measured heat capacity to thermal conductivity. The method needs to be tested using purge gases with lower thermal conductivity and other numerical models.

2.6 Thermal Modelling

The term, model, from Latin *modulus* or measure is a representation of reality that retains its salient features [47]. Modelling often involves approximating the real geometry as an ideal geometry, e.g., assuming perfect planar, cylindrical, or spherical surfaces; fitting a set of points to a given interpolation function and its domain; approximating material properties, such as constant values, isotropic values, reference material values, extrapolated values. In the case of heat transfer equations, modeling involves neglecting some contributions, linearizing some terms, assuming the media are a continuum, and discretization [47].

Modelling material properties introduces uncertainties, because density, thermal conductivity, thermal capacity, emissivity, and so on, depend on the base materials, their impurity contents, applied bulk and surface treatments, actual temperatures, effects of aging, etc. Most of the times, material properties are modelled as uniform in space and constant in time for each material, but, the worthiness of this model and the right selection of the constant-property values, requires insight [48].

Thermal problems are mathematically stated as a set of restrictions that the model solution must verify. Some of the restrictions are given explicitly, such as data; some are implicit, including assumed data and equations [49]. Both the explicit boundary condi-

tions and the implicit equations (algebraic, differential, or integral) are subject to uncertainties from the assumed geometry, material properties, and external interactions [49]. In modeling a physical system, numerical methods are not just approximations based on differential equations; they are approximations of real behaviour. There is no exact model or an exact solution to a physical problem, just an attempt at sufficient accuracy to achieve the purpose [48].

Numerical solutions are generally used to solve practical heat transfer problems, as well as mass and momentum transfer problems, because analyses using partial differential equations are not solvable analytical, except for very simple configurations [49]. Numerical methods transform the continuous problem to a discrete problem. Thus, rather than providing a continuous solution that is valid for every point in space and time, and every value of the parameters, numerical methods yield discrete solutions that are valid for discrete points in space and time, and for discrete values of the parameters [50]. Despite these limitations, the numerical approach has two crucial advantages.

- It can provide a solution to any practical problem, however complicated, not just steady, one-dimensional, constant-property ideal models.
- The discretization can be refined as much as is desired, although there are costs in computing time and required memory.

Numerical approaches transform the continuous problem, which can be written as $PDE(T)=F$, indicating that a partial differential operator applied to the temperature field should equal the force-field imposing the thermal non-equilibrium, to a discrete problem.

For each time step, there is a set of N algebraic equations, involving unknown temperatures at N selected points in the system, a set of known applied stimuli at N points, and a set of $N*N$ coefficients [49]. Numerical methods differ in the way they resolve this system of algebraic equations, but follow a general baseline. The problem can be generally stated in Equation 2.7.

$$PDE(T(\vec{x}, t)) = 0, BC(T(\vec{x}_0, t)) = 0, IC(T(\vec{x}_0, t)) = 0 \quad (2.7)$$

where PDE , BC and IC represent functionals related to the partial differential equation, boundary conditions, and initial conditions, respectively.

Several numerical methods have been developed, each with its own advantages and complexities. Simple methods like the finite difference method, can be developed from scratch for every new problem, but become too cumbersome in complex cases. The standard finite element method demands more effort to develop, but can be routinely applied to a variety of complex cases.

The most common numerical method is the differential method. Differential methods solve the heat equation, rather than the integral energy equation, and are used for the numerical analysis of heat transfer. The most commonly used differential methods are:

- Finite differences,
- Finite elements, and
- Boundary elements.

Finite Difference Method (FDM)

In the finite difference method (FDM), invented by Courant et al. in 1929 [50], the partial differential equation (PDE) is discretized term by term, substituting each derivative with its truncated Taylor expansion [50]. The minimum order for time derivatives is a linear approach, usually advanced in time as per Equation 2.8.

$$\partial T / \partial t \approx T \left((t + \Delta T) - T(t) / \Delta T \right) \quad (2.8)$$

The FDM can be also viewed as a discretized mesh, with the PDE integrated at each finite volume. A nodal point is assigned to each finite volume, and an unknown temperature is attributed to each nodal point [50]. The FDM yields a highly structured system of equations, particularly when a regular mesh is used, which has advantages and disadvantages. The main advantage is the simple formulation of the method – it is the most basic numerical method for solving PDEs. The disadvantage is that FDM demands a simple geometry with a structured grid, and becomes complicated in systems with non-rectangular, non-cylindrical, or non-spherical geometries.

FDM starts by establishing a mesh of nodes in the domain, i.e., a set of points in space, where the function is to be computed. There should be a node where the function is sought; at least one node at each boundary or singularity, plus a few others for better resolution [51]. Although not mandatory, it is advisable to use a regular mesh to simplify the coding. A material element and a thermal inertia are ascribed to each node. A thermal conductance is assigned to each pair of nodes. The finite difference discretization of the

PDE provides the energy balance for every generic (internal) node. The energy balance must be set aside for each special (interface) node, which are the most characteristic data in a problem. A regular spatial mesh is used, such as a square mesh of size h in 2D, and derivatives are approximated by finite differences, centred in the node, or from one side (forward or backward) [51]. For example, the Laplace operator is approximated at every standard internal node (marked by its x -step position, i , and its y -step position, j), using centred differences as per Equation 2.9.

$$\nabla^2 T_{i,j} \approx \frac{1}{h^2} (T_{i-1,j} + T_{i+1,j} + T_{i,j-1} + T_{i,j+1} - 4T_{i,j}) \quad (2.9)$$

This simple discretization becomes cumbersome when applied to boundary nodes, if the geometry is not rectangular. Thus, for boundary nodes that have only a fraction f of an h -step in the North-South-East-West neighbour, the Laplace operator should be approximated as per Equation 2.10.

$$\nabla^2 T_{i,j} \approx \frac{2}{h^2} \left(\frac{1/f_W}{f_W + f_E} T_{i-1,j} + \frac{1/f_E}{f_W + f_E} T_{i+1,j} + \frac{1/f_S}{f_S + f_N} T_{i,j-1} + \frac{1/f_N}{f_S + f_N} T_{i,j+1} - \frac{f_S f_N + f_W f_E}{f_S f_N f_W f} \Delta T_{i,j} \right) \quad (2.10)$$

This becomes even more awkward, because for a regular mesh in an irregular domain, a mesh refinement does not include all previous nodes in the boundary.

Finite Elements

The finite elements method (FEM), also known as finite element analysis (FEA) was invented by Courant in 1943. FEM is based on the premise that an approximate solution

to any complex engineering problem can be reached by subdividing the problem into smaller, more manageable, finite elements [51]. Using finite elements, complex partial differential equations that describe the behaviour of structures can be reduced to a set of linear equations that are easily solved using the standard techniques of matrix algebra.

In the simplest FEM formulation, 2D spatial domains are discretized in triangles, and the base functions are chosen as linear unitary local functions, i.e., zero outside of their associated element [51]. The subsystem in FEM is a mass between nodal points at the corners, in contrast to the subsystem in FDM, which is a mass around the nodal point.

Standard algorithms exist for meshing any irregular domain. The procedure is well developed because the approximation is by integration, which with suitable base functions, can be done locally in each element without any directionality, rather than by differentiation, which is a directional operation based on all neighbour elements. The task is massive, but simple, which is ideal for computers. Thus, FEM is the preferred numerical method for non-singular engineering problems, particularly for multidisciplinary computations, such as mechanical, thermal, fluid-dynamic, or electrical [52].

Typical commercial FEM packages include ABAQUS, ANSYS, FEMLAB, HEAT3, and MSC/NASTRAN. These packages usually cover a wide spectrum of possibilities, e.g., material properties and heat sources that vary with time.

Boundary Elements

Because a given set of boundary and initial conditions uniquely defines the solution in the domain, the value of the function at any point in the interior can be expressed as a sole contribution of boundary values. This is achieved mathematically by the Green-Stokes-Gauss-divergence theorem [52], which is the foundation of the boundary elements method (BEM). In BEM, first the full solution of the function and derivatives at the boundary points are computed by a kind of finite-element method, in which the base functions are the fundamental solutions of the PDE at the boundary nodes. A set of algebraic equations are then solved at the nodes. Finally, if needed, the value at any internal point is directly computed by a quadrature, without interpolation. The problem with the boundary element method is that local integration within the boundary is more involved than in standard FEM, because there are singular points that require more elaborate computations [53] other drawback is that the BEM only applies to regions of constant properties. The great advantage of BEM is that, for bulky domains, the number of nodes significantly decreases which explains its frequent use in external fluidmechanics and geomechanics [53].

2.7 Summary

Rising energy prices and increasing pressure to conserve energy and protect the environment emphasize the importance of developing innovative thermal insulating foams for building applications [11]. This goal requires a rapid and accurate method for measur-

ing thermal conductivity of new products. Most measurements of the thermal conductivity or thermal resistance of building insulations are currently made using a guarded hot plate apparatus or heat flow meter apparatus. Both methods are applicable to a wide variety of materials, but require specimens around 300–600 mm in length and width, and 20–200 mm in thickness. Such large samples are often unavailable for innovative insulations in the process of development.

The present study used an alternative method for rapidly measuring thermal conductivity of smaller insulation samples. Using smaller specimens, rather than standard size, might provide more rapid and less costly measurements of thermal conductivity. The new method tested and reported herein uses a heat flow meter apparatus, and is based on methodology developed by Mukhopadhyaya et al. [44]. The experimental results were validated by numerical modelling, using the HEAT3 software.

Chapter 3: Experimental Work

The objective of this research was to develop and test new methodology for determining the thermal conductivity of smaller insulation specimens. Thermal conductivity tests were conducted on six insulation materials using the standard heat flow meter apparatus (300 mm x 300 mm) following ASTM Standard test method C518, and results from the new methodology with smaller specimens were verified with the results obtained from full-size specimens.

3.1 Test Materials

Six types of aged insulation materials of two different thicknesses that are commonly used for residential, commercial, and industrial applications were procured from the storage of National Research Council Canada (NRC). The aged (about 5 years or more) insulations were used in this study to isolate the aging effect from the experimental results.

The density and thickness of insulation materials used in this study are shown in Table 3.1. It is to be noted that insulation materials have the same density for both thicknesses except for high density glass fibre where two slightly different density boards.

Table 3.1. Type, density and thickness of insulation materials.

Insulation Material	Specimen Thickness	Density
	mm	ρ (kg/m ³)
Expanded Polystyrene (EPS)	12.5 / 25	22
Extruded Polystyrene (XPS)	12.5 / 25	25
Polyurethane (PUR)	12.5 / 25	39
Polyisocyanurate (ISO)	12.5 / 25	29
High Density Glass Fiber (HDGF)	25	135
High Density Glass Fiber (HDGF)	12.5	118
Low Density Glass Fiber (LDGF)	12.5 / 25	11

3.2 Test Apparatus and Methods

3.2.1 Heat Flow Meter Apparatus

The heat flow meter at the NRC laboratory was used to measure the thermal conductivity of the insulation materials. The heat flow meter measures the steady state thermal transmission by establishing steady state heat flux in one dimension through a flat slab test specimen held between two parallel plates at constant, but different, temperatures. The plate assemblies are rigid to maintain flatness and uniform thickness of the specimens. Figure 3.1, shows the test specimen between two plates (hot and cold) embedded with heat flux transducers. The Top plate is the cold surface, and the bottom plate is the hot surface. Fluid baths are connected to the plates to maintain the desired temperatures. The plate assemblies provide isothermal surfaces in contact with both sides of the speci-

men, and a heat flux transducer is attached to both plate assemblies to measure heat flow through specimen surfaces.

Figure 3.1. Heat flow meter apparatus showing test specimen between two heat flux transducers [35].

The plates are 300 x 300 mm in width and length. Figure 3.2 shows the metering area, 150 x 150 mm, defined by the sensor of the heat flux transducer, and the location of the thermocouples. The remainder of the plates is the guard area. The metering area of the heat flow meter is usually not more than 25% of the total plate surface area [35].

Figure 3.2. Cold and hot plate thermocouple location.

3.2.2 Thermal Conductivity Measurements Using the Heat Flow Meter

The conventional heat flow meter technique assumes one-dimensional heat conduction. The method works well for determining thermal conductivity of thin thermal insulators, as long as the requirement that one-dimensional heat flow with negligible lateral losses is maintained [38]. Heat flow is perpendicular to the plate surfaces. The test specimen of given thickness is sandwiched between the hot and cold plates. The plates are maintained at different constant temperatures, giving a temperature difference of ΔT (K). A thin heat flux transducer, with negligible thermal resistance, relative to that of the specimen, is placed in series with the test specimen at the hot and/or cold plate. At equilibrium condition, the heat flux transducer output Q (V), is measured and the apparent thermal conductivity, k_{app} , is calculated using Equation 3.1.

$$k_{app} = NQl/\Delta T \quad (3.1)$$

where N is a calibration factor for a particular set of conditions ($\text{W m}^{-2} \text{V}^{-1}$). N is obtained by calibrating the apparatus with an appropriate transfer standard of known thermal resistance, measured under the same conditions used for the test specimen.

As described in Chapter 2, the heat flow meter method uses Fourier's law of heat conduction to calculate thermal conductivity and thermal resistance. Equation 3.2 represents the heat conduction equation, as outlined in the standard test method (ASTM C518), for practical applications as,

$$k_{app} = q \times l / (\Delta T) \quad (3.2)$$

Where k_{app} = apparent thermal conductivity, a function of the average temperature of the test specimen (W/m.K), q = heat flow rate (W), l = thickness of test specimen (m), ΔT = hot surface temperature – cold surface temperature (K).

3.2.3 Calibration of the Heat Flow Meter Apparatus

One of the challenges of measuring heat flow across a material is to accurately calibrate the heat flux transducer. Accurate measurement of the thickness of the material is also of particular concern, especially for light materials and/or smaller specimens. These factors are important, because lateral heat losses or gains can be significant under all testing conditions, even under identical conditions of a plate temperature, temperature gradient, specimen thickness, heat flow direction, and apparatus orientation. In the present study, the heat flow meter was routinely calibrated by the NRC personnel following the standard practice described in ASTM C518 (section 6) [32].

3.2.4 Data Acquisition System

Data from the heat flow meter were collected and analyzed, according to the following routine.

- 1) Data acquisition is done using the Keithley Scanner [54] and the software, Agilent HP-Vee Pro, version 8.0 [55], a graphical dataflow programming software development for automated test, measurement, data analysis and reporting.

- 2) Based on the scan interval configured in the application (e.g., 2 min between scans), the software cues the Keithley 706 Scanner, to “begin scanning” the configured contacts.
- 3) The Scanner is a type of multi-plexer, which closes and opens the contacts of individual electrical circuits, consisting of sets of electrical contacts. Each of the 20 circuits is located on one of the ten Model 7064 20-Channel L₀ Voltage Scanner “I/O Cards,” located in the back of the scanner chassis.
- 4) The lead wires of the resistance temperature detectors (RTD), thermocouple, or heat flux transducer measurement instrument, located in the heat flow-meter plates, are attached to one of the contact pairs of the I/O “channel” that corresponds to the contact pair in the scanner/card. When a specific circuit is closed, an electrical path is opened between the appropriate set of electrical contacts and the respective measurement instrument.
- 5) Upon contact closure of a particular circuit, the corresponding set of contacts passes either an electrical resistance or an electrical voltage, representing the temperature at the surface of the plate, or the flux of heat passing through the test specimen, to the other side of the contact pair, i.e., opens the I/O channel.
- 6) One set of ends of each of the 20 contact pairs is connected together, forming one wire that is connected to one measurement terminal of the digital multi-meter (2000 DMM). The other set of ends is also connected together, forming one wire that is connected to the 2000 DMM’s other measurement terminal.

- 7) The progression of contact closures is configured by the data acquisition program and executed by the scanner. Electrical values representing resistances, e.g. temperatures measured by RTDs, or voltages provided by the thermocouples and the heat flux transducer, are read in rapid succession. The Agilent HP-Vee Pro software records the thermal measurements at the configured scan rate and reports the results as averages.

3.2.5 Environmental Conditions

The selected test specimens of the various insulation materials were kept in a humidity and temperature controlled room at 22°C temperature and 50% RH for over 24 hours prior to the test as prescribed in the ASTM C518 test method. Tests were conducted in a room with controlled temperature around $22 \pm 1^\circ\text{C}$.

3.2.6 Specimen Preparation

Full size (300 x 300 mm) specimens were tested to establish the thermal resistance of each material. Thereafter, smaller specimens were cut from the center of the tested sample (Figure 3.3).

Figure 3.3. EPS mask with cut out.

Expanded polystyrene or EPS ($300 \times 300 \times 12.5$ and 25 mm) was used as mask to measure the thermal conductivity of smaller specimens. EPS board is a material sufficiently homogeneous and stable. EPS board is also used as a standard reference material for calibration of heat flow meter. To reduce, or eliminate, lateral flow (2-D flow), it is recommended that the physical and thermal properties of the mask material should be as similar as those of the test specimen (masked specimen). Figure 3.4 shows the EPS mask with the material insert.

Figure 3.4. EPS mask with the material insert.

A total of 144 samples were used in this study. Three parameters were investigated in the experimental tests: material type, thickness and size. The number of specimens and the materials tested are shown in

Table 3.2. Three specimen sizes were within the metering area (150 x 150 mm) of the heat flow meter and one specimen size (200 x 200 mm) was beyond the metering area of the heat flow meter. Figure 3.5, shows the specimens sizes.

Table 3.2. Number of samples tested for each sample size, per thickness.

Material	# of Samples per thickness - Size (mm)				
	300 x 300	200 x 200	150 x 150	100 x 100	50 x 50
EPS	8	1	1	1	1
XPS	8	1	1	1	1
PUR	8	1	1	1	1
ISO	8	1	1	1	1
HDGF	8	1	1	1	1
LDGF	8	1	1	1	1
Total	48	6	6	6	6

Figure 3.5. Test specimens (LDGF, EPS, XPS, ISO, PUR, HDGF).

3.2.7 Sensitivity Analysis

Sensitivity analysis was conducted to determine the number of specimens to be tested for each parameter under investigation. As per Section 7.2.1 of ASTM C518 [32], one specimen can be used to measure thermal characteristics of insulation materials. Nevertheless, tests were conducted on multiple specimens using Polyurethane (PUR), which belongs to the foam insulation family, and High Density Glass Fiber (HDGF) from the fibrous insulation family. Three 200 x 200 x 25 mm and three 150 x 150 x 25 mm specimens of PUR and HDGF were tested. The results showed a variance less than 1% between 200 x 200 mm HDGF specimens, and less than 2% between 150 x 150 mm specimens (Table 3.3). The variance for PUR specimens of both sizes was less than 2%. These variance values are in compliance with Section 10 (Precision and Bias) of ASTM C518. The standard states that, "The accuracy of a test result refers to the closeness of agreement between the observed value and an accepted reference value." In the present case, the accepted variance value would be 2.8% for High Density Glass Fiber, and $\pm 5\%$ for foams. Therefore, only one specimen was tested for each case considered in the present study.

Table 3.3 Repeatability of thermal conductivity tests

Thermal conductivity (W/m.k)				
Specimen	PUR		HDGF	
	200 x 200 mm	150 x 150 mm	200 x 200 mm	150 x 150 mm
R1	0.0260	0.0274	0.0343	0.0348
R2	0.0262	0.0275	0.0343	0.0342
R3	0.0257	0.0265	0.0340	0.0337

3.2.8 Test Procedure

The procedure for determining thermal resistance of the specimens followed the standard specified by ASTM C518.

- 1) Remove the specimen from the humidity room and measure its thickness.
- 2) Insert the intact sample in the heat flow meter.
- 3) Measure the distance between the plates.
- 4) Adjust the temperature, so the temperatures of the plates are maintained within 22 °C for these measurements.
- 5) Measure thermal resistance after steady state conditions is reached.

Figure 3.6 shows the specimen set up in the HFM and Figure 3.7 shows the final heat flow meter set up.

Figure 3.6. Heat flow meter masked specimen set up.

Figure 3.7. Heat flow meter test set up.

3.3 Tests Results and Discussion

Thermal conductivities were compared for intact (k) and smaller masked samples (k_o) (Figures 3.8-3.11). The results were used to generate empirical equations relating intact and masked samples, which were then used to calculate derived thermal conductivities (k') (Table 3.4-3.1). It is to be noted that the equations derived from this study are different from the previous similar study done by Mukhophyaya et al. primarily due to the change of mask material (ISO to EPS).

3.3.1 200 x 200 mm Specimens

Thermal conductivities were compared for masked 200 x 200 mm specimens and intact 300 x 300 mm specimens, with 12.5 and 25 mm thicknesses (Figure 3.8, Table 3.4). Regression analysis was used, rather than a straight line approach, to investigate the relationship between the thermal conductivities and find the equation that fits the data. The curve was selected based on the R^2 value that best fit the data including only the experimental data point, and excluding the points at $x=0$ and $y=0$. A Regression analysis showed a significant correlation between the thermal conductivities of masked and intact samples for both thicknesses: $y=9.31x^2+0.4493x+0.0083$ ($R^2=0.9963$) for specimens with 12.5 mm thickness, and $y=-8.4251x^2+1.4907x+0.0066$ ($R^2=0.9978$) for specimens with 25 mm thickness. The equation shown on Figure 3.8, for specimens with 25 mm thickness, has a negative sign for the x^2 coefficient (Example: $-8.425 x^2$); it is negative due to the polynomial curve been concave. The difference between the thermal conductivities of masked (k_0) and intact (k) specimens of ISO and LDGF was 1.34% and 1.3%, respectively (Table 3.4). The difference between thermal conductivities of masked and intact specimens of HDGF was 1.05%. The thermal conductivities of masked and intact specimens were similar for XPS, EPS and HDGF, with variances less than 1%. When measuring thermal conductivity when the same material is used as the intact part and the mask, it is expected that the variance should be zero. However, in the case of EPS (Table 3.4) the calculated value of the variance, 0.02% and -0.53%, is due to the gap between the sample and the mask

Figure 3.8. Thermal conductivity of masked 200 x 200 mm and intact 300 x 300 mm specimens, 12.5 and 25 mm thick.

Table 3.4. Thermal conductivity of intact 300 x 300 mm specimens (k) and masked 200 x 200 mm specimens (k_o), 12.5 and 25 mm thick.

Size (mm)	Thermal conductivity (W/m.k)					
	12.5 mm thickness			25 mm thickness		
	300 x 300	200 x 200		300 x 300	200 x 200	
Material	k	k_o	Variance %	k	k_o	Variance %
EPS	0.03360	0.03360	0.02	0.03473	0.03455	-0.53
XPS	0.02897	0.02896	-0.01	0.02935	0.02910	-0.85
PUR	0.02723	0.02697	-0.95	0.02574	0.02536	-1.47
ISO	0.02629	0.02591	-1.44	0.02599	0.02526	-2.80
HDGF	0.03514	0.03420	-2.67	0.03463	0.03407	-1.62
LDGF	0.03894	0.03812	-2.09	0.03823	0.03853	0.79

Thermal conductivity values (k') for 200 x 200 mm masked specimens were derived from the empirical equation and the thermal conductivity of intact specimens (k) (Table 3.5). The variance between the derived values and measured values for intact 300 x 300 mm specimens ranged from -1.43% to 1.18% for 12.5 mm thick materials, and from -1.18% to 1.08% for 25 mm thick materials. EPS, HDGF, and LDGF had smaller variances for specimens with 25 mm thickness than XPS, PUR, and ISO. The ISO specimen with 25 mm thickness had the highest variance (1.18%), and LDGF had the lowest (0.27%). For 12.5 mm thick specimens, HDGF had the highest variance (1.43%), and PUR had the lowest (0.06%). The difference in variances between 12.5 and 25 mm thicknesses was 1% for PUR and ISO, and less than 1% for the other materials. HDGF was the only material with slightly different densities, and the variance differed by 0.78% between the two thicknesses. Thus, there was a correlation between the values derived from the empirical formula and values from experimental observations.

Table 3.5. Measured (k) and derived (k') thermal conductivities of intact 300 x 300 mm specimens and masked 200 x 200 mm specimens, with 12.5 and 25 mm thicknesses.

Thermal conductivity (W/m.k)						
Size (mm)	12.5 mm thickness			25 mm thickness		
	300 x 300	200 x 200		300 x 300	200 x 200	
Material	k	Variance %	k'	k	Variance %	k'
EPS	0.03360	1.18	0.03400	0.03473	0.31	0.03484
XPS	0.02897	0.74	0.02919	0.02935	1.02	0.02964
PUR	0.02723	0.06	0.02724	0.02574	1.12	0.02546
ISO	0.02629	-0.18	0.02624	0.02599	-1.18	0.02567
HDGF	0.03514	-1.43	0.03464	0.03463	-0.65	0.03441
LDGF	0.03894	0.32	0.03907	0.03823	0.27	0.03833

3.3.2 150 x 150 mm Specimens

Thermal conductivities were compared for masked 150 x 150 mm specimens and intact 300 x 300 mm specimens, with 12.5 and 25 mm thicknesses (Figure 3.9, Table 3.6). Regression analysis showed a significant correlation between the thermal conductivities of masked and intact samples for both thicknesses. For specimens with 12.5 mm thickness $y = 32.572x^2 - 9469x + 0.0288$ ($R^2 = 0.9912$), and for specimens with 25 mm thickness $y = 8.8317x^2 + 0.5726x + 0.0046$ ($R^2 = 0.9947$). The difference between variances for the two thicknesses was highest for LDGF (1.31%), indicating that thickness affected results for the masked samples. The other insulation materials had small differences between variances of the two thicknesses.

Figure 3.9. Thermal conductivity of masked 150 x 150 mm and intact 300 x 300 mm samples, 12.5 and 25 mm thick.

Table 3.6. Thermal conductivity of intact 300 x 300 mm specimens (k) and masked 150 x 150 mm specimens (k_o), 12.5 and 25 mm thick.

Thermal conductivity (W/m.k)						
Size (mm)	12.5 mm thickness			25 mm thickness		
	300 x 300	150 x 150		300 x 300	150 x 150	
Material	k	k_o	Variance %	k	k_o	Variance %
EPS	0.03360	0.0336	0.12	0.03473	0.03467	-0.18
XPS	0.02897	0.0294	1.46	0.02935	0.02998	2.15
PUR	0.02723	0.0265	-2.62	0.02574	0.02654	-3.09
ISO	0.02629	0.0269	2.47	0.02599	0.02632	1.26
HDGF	0.03514	0.0343	-2.26	0.03463	0.03371	-2.65
LDGF	0.03894	0.0375	-3.71	0.03823	0.03731	-2.41

Thermal conductivity values (k') for 150 x 150 mm masked specimens were derived from the empirical equation and the thermal conductivity of intact specimens (k) (Table 3.7). The variance between the derived values and measured values for intact 300 x 300 mm specimens ranged from -2.32% to 0.61% for 12.5 mm thick materials, and -2% to 1.22% for 25 mm thick materials. EPS, XPS, and LDGF specimens with 12.5 mm thickness had variances less than 1%. EPS, PUR, and LDGF specimens with 25 mm thickness had variances as low as 1%. The difference in variances between 12.5 and 25 mm thicknesses was highest for PUR and ISO -2.97% and 1.67% respectively, indicating that thickness slightly affected predicted thermal conductivity. HDGF was the only material with slightly different densities, and the variance differed by 0.74% between the two thicknesses, indicating no significant effect on thermal conductivity predictions. Thus, there was a very close correlation between the values derived from the empirical formula and values from experimental observations.

Table 3.7. Measured (k) and derived (k') thermal conductivities of intact 300 x 300 mm specimens and masked 150 x 150 mm specimens, with 12.5 and 25 mm thicknesses.

Size (mm)	Thermal conductivity (W/m.k)					
	12.5 mm thickness			25 mm thickness		
	300 x 300	150 x 150		300 x 300	150 x 150	
Material	k	k'	Variance %	k	k'	Variance %
EPS	0.03360	0.03381	0.61	0.03473	0.03506	0.95
XPS	0.02897	0.02911	0.47	0.02935	0.02970	1.22
PUR	0.02723	0.02659	-2.32	0.02574	0.02557	0.65
ISO	0.02629	0.02693	2.45	0.02599	0.02579	-0.78
HDGF	0.03514	0.03470	-1.26	0.03463	0.03394	-2.00
LDGF	0.03894	0.03909	0.38	0.03823	0.03825	0.07

3.3.3 100 x 100 mm Specimens

Thermal conductivities were compared for masked 100 x 100 mm specimens and intact 300 x 300 mm specimens, with 12.5 and 25 mm thicknesses (Figure 3.10, Table 3.8).. PUR had the highest variation between thermal conductivity of masked and intact specimens of both thicknesses, followed by LDGF and ISO. The respective variances were 4.81%, 4.41% and 2.12%. For XPS, ISO and HDGF, the variances were less than 2%. Regression analysis showed a significant correlation between the thermal conductivities of masked and intact samples for both thicknesses: $y=454.3x^2-27.176x+0.4327$ ($R^2=0.9906$) for specimens with 12.5 mm thickness; $y=-20.498x^2+3.50561x-0.0619$ ($R^2=0.9927$) for specimens with 25 mm thickness. The line fit to data for specimens with 12.5 mm thickness was somewhat curved, but the line fit to data for 25 mm thick specimens was linear. Despite the relatively high variances of PUR, ISO, XPS, the high R^2

values indicated strong correlations between measured and predicted thermal conductivity for both thicknesses.

Figure 3.10. Thermal conductivity of masked 100 x 100 mm and intact 300 x 300 mm samples, 12.5 and 25 mm thick.

Table 3.8. Thermal conductivity of intact 300 x 300 mm specimens (k) and masked 100 x 100 mm specimens (k_o), 12.5 and 25 mm thick.

Thermal conductivity (W/m.k)						
Size (mm)	12.5 mm thickness			25 mm thickness		
	300 x 300	100 x 100		300 x 300	100 x 100	
Material	k	k _o	Variance %	k	k _o	Variance %
EPS	0.03360	0.03412	1.57	0.03473	0.03469	-0.09
XPS	0.02897	0.03218	11.08	0.02935	0.03218	9.65
PUR	0.02723	0.03163	16.19	0.02574	0.03020	21.00
ISO	0.02629	0.03007	14.41	0.02599	0.03028	16.53
HDGF	0.03514	0.03418	-2.72	0.03463	0.03417	-1.33
LDGF	0.03894	0.03519	-9.61	0.03823	0.03624	-5.20

The variance between derived thermal conductivity values (k') for 100 x 100 mm masked specimens and thermal conductivity of intact specimens (k) ranged from -1.94% to 1.34% for 25 mm thick samples, and from -1.58% to 2.28% for 12.5 mm thick samples (Table 3.9). The variance for EPS and LDGF specimens with 25 mm thickness was less than 1%. ISO and HDGF had the highest variance for specimens with 25 mm thickness (1.9%). ISO and LDGF had variances as low as 0.1% for specimens with 12.5 mm thickness, and EPS had the highest variance for specimens with 12.5 mm thickness (2.28%). XPS and ISO had variances of 2.4% and 1.99%, respectively, for both thicknesses. As for larger masked samples, HDGF was the only material with slightly different densities between thicknesses, and the variance differed by 0.33%, indicating no significant effect on thermal conductivity predictions. Thus, there was a close correlation between the values derived from the empirical formula and values from experimental observations.

Table 3.9. Measured (k) and derived (k') thermal conductivities of intact 300 x 300 mm specimens and masked 100 x 100 mm specimens, with 12.5 and 25 mm thicknesses.

Size (mm)	Thermal conductivity (W/m.k)					
	12.5 mm thickness			25 mm thickness		
	300 x 300	100 x 100		300 x 300	100 x 100	
Material	k	k'	Variance %	k	k'	Variance %
EPS	0.03360	0.03437	2.28	0.03473	0.03508	0.99
XPS	0.02897	0.02863	-1.19	0.02935	0.02970	1.21
PUR	0.02723	0.02764	1.53	0.02574	0.02529	1.34
ISO	0.02629	0.02630	0.05	0.02599	0.02548	-1.94
HDGF	0.03514	0.03459	-1.58	0.03463	0.03397	-1.91
LDGF	0.03894	0.03898	0.10	0.03823	0.03824	0.04

3.3.4 50 x 50 mm Specimens

The predicted thermal conductivities of masked 50 x 50 mm specimens of 25 mm thick materials were fairly well correlated with thermal conductivity measurements for intact specimens (Figure 3.11): $y = -2339.1x^2 + 167.44x - 2.9585$ ($R^2 = 0.94$). However, predicted and measured values were poorly correlated for 12.5 mm thick samples: $y = 491.59x^2 - 29.659x + 0.4731$ ($R^2 = 0.53$). The latter correlation was not strong enough to provide reliable values. Variance between measured thermal conductivity of masked (k_0) and intact (k) samples were highest for XPS, PUR and ISO samples of both thicknesses. When both thicknesses were compared, the difference between variances was 15.78%, -5.74%, and 3.36% for PUR, HDGF, and ISO, respectively (Table 3.10). The difference between variances was less than 1.6% for EPS, XPS and LDGF.

Figure 3.11. Thermal conductivity of masked 50 x 50 mm and intact 300 x 300 mm samples, 12.5 and 25 mm thick.

Table 3.10. Thermal conductivity of intact 300 x 300 mm specimens (k) and masked 50 x 50 mm specimens (k_o), 12.5 and 25 mm thick.

Size (mm)	Thermal conductivity (W/m.k)					
	12.5 mm thickness			25 mm thickness		
	300 x 300	50 x 50		300 x 300	50 x 50	
Material	k	k_o	Variance %	k	k_o	Variance %
EPS	0.03360	0.03354	-0.18	0.03473	0.03502	0.85
XPS	0.02897	0.03395	17.21	0.02935	0.03395	15.69
PUR	0.02723	0.03220	18.26	0.02574	0.03346	34.04
ISO	0.02629	0.03300	25.50	0.02599	0.03349	28.86
HDGF	0.03514	0.03311	-5.78	0.03463	0.03461	-0.05
LDGF	0.03894	0.03520	-9.60	0.03823	0.03492	-8.65

Variance between derived thermal conductivity values (k') and values measured for intact 300 x 300 mm specimens (k) are shown in ranged from -14.64% to 13.21% for 12.5 mm thick materials, and from -5.35% to 5.35% for 25 mm thick materials (Table 3.11). For specimens with 25 mm thickness, EPS had the highest variance (5.35%), and HDGF had the lowest (0.23%). HDGF had the highest variance for 12.5 mm thick specimens (14.64%), and LDGF had the lowest (-1.86%). XPS, ISO and HDGF had variances of more than 12% when both thicknesses were compared, but the same variances were less than 3.5% for the other materials. HDGF was the only material with slightly different densities between the two thicknesses, and the variance difference was 14.41%. From these observations, it is evident that thermal conductivity measurements using 50 x 50 mm specimens were more reliable for materials with 25 mm thickness than with 12.5 mm thicknesses.

Table 3.11. Measured (k) and derived (k') thermal conductivities of intact 300 x 300 mm specimens and masked 50 x 50 mm specimens, with 12.5 and 25 mm thicknesses.

Thermal conductivity (W/m.k)						
Size (mm)	12.5 mm thickness			25 mm thickness		
	300 x 300	50 x 50		300 x 300	50 x 50	
Material	k	k'	Variance %	k	k'	Variance %
EPS	0.03360	0.03134	6.72	0.03473	0.03659	5.35
XPS	0.02897	0.03280	13.21	0.02935	0.03007	2.48
PUR	0.02723	0.02778	2.05	0.02574	0.02521	1.01
ISO	0.02629	0.02968	12.91	0.02599	0.02558	-1.57
HDGF	0.03514	0.03000	-14.64	0.03463	0.03471	0.23
LDGF	0.03894	0.03822	-1.86	0.03823	0.03620	-5.31

3.3.5 Summary

The correlations varied more as specimens became smaller, but the relationships were still highly significant, indicating that it is possible to accurately derive the thermal conductivity value (k') from the value measured using the masked sample (k_o). In general, thermal conductivity measurements for masked specimens 200 x 200 mm, 150 x 150 mm, and 100 x 100 mm were closely correlated with measurements for intact 300 x 300 mm specimens of the same materials.

Measurements using the smallest masked specimens tested (50 x 50 mm) did not provide reliable results, particularly for the thinner materials (Figure 3.11), because the thermal conductivity measurements were more representative of the mask material than the sample material. Thus, 50 x 50 mm is too small a sample size for accurate assessment of thermal conductivity using the heat flow meter with a metering area 150 x 150 mm.

It is also recommended that this test methodology may not be applicable for any new specimens with unknown thermal conductivity beyond the range of thermal conductivity data ($0.025 \text{ W/mK} - 0.034 \text{ W/mK}$) that were used to generate the best fit curve in this study.

Chapter 4: Modelling

Chapter 4 presents a three-dimensional analysis, using HEAT3, version 6.1 [56], of heat transfer through different size specimens of the six experimental insulation materials. HEAT3 is a finite element-based, finite volume method for solving transient and steady-state heat conduction. In the present study, numerical simulations were compared to experimental results.

4.1 Data Input

Several types of data were entered into the HEAT3 program to simulate the test conditions and calculate heat flows. Data input included, but was not limited to:

Geometrical definition

The test assembly was described with three different materials (Figure 4.1):

- The mask (Area I)
- The air gap (Area II)
- The test specimen (Area III)

Figure 4.1 Test assembly

Type of Material

Materials were selected from the material database library (Figure 4.1).

Figure 4.2. Material database library

Boundary Conditions

Boundary conditions were the temperatures of the cold and hot plates (13°C and 35°C, respectively), and heat flow at the four edges of the specimen. All the four edges were considered to be completely insulated, so heat flow was assumed to be zero (Figure 4.3).

Figure 4.3 Boundary condition

Thermal Conductivity of Material

The experimentally determined thermal conductivity values of intact 300 x 300 mm mask and these thermal conductivity values were used as input (Table 4.1). The thermal conductivity of the air (0.024 W/mk) is also required as input.

Table 4.1 Thermal conductivity values measured using intact specimens

Material	Size sample 300 x 300 mm	
	12.5 mm Thickness	25 mm Thickness
	k (W/mK)	k (W/mK)
EPS	0.03360	0.03473
XPS	0.02897	0.29350
PU	0.02723	0.02574
PI	0.02629	0.02599
HDGF	0.03514	0.03462
LDGF	0.03894	0.03823
AIR	0.00240	0.00240

Mesh

The FEM divides a continuum into discrete elements. This subdivision is called discretization. In FEM, the individual elements are connected by a topological map, usually called a mesh. The finite element interpolation functions are built on the mesh, which ensures compatibility of the interpolation. The mesh used in the HEAT3 model had the smallest cell dimensions ($dx = 0.0002$ m, $dy = 0.0005$ m, $dz = 0.0023$ m). The total number of computational cells was 183,001.

4.2 Simulation Output

The simulation output is: Heat flow (W/m^2) and Surface temperature ($^{\circ}\text{C}$). The Typical post-processor output is shown in Figure 4.4, and Figure 4.5.

Figure 4.4 Temperature output as shown in the post-processor window.

Figure 4.5 Heat flow output as shown in the post-processor window.

4.3 Sensitivity Analysis

Four scenarios were used to validate the results of model simulations, using thermal conductivities measured for masked smaller specimens of the six types of insulation (Figure 4.6 and Figure 4.7).

- Scenario 1 assumed that there was no gap between the specimen and the EPS mask.
- Scenario 2 assumed a 1 mm gap between the specimen and the mask.
- Scenario 3 assumed a 0.7 mm gap between the specimen and the mask.
- Scenario 4 assumed a 0.5 mm gap between the specimen and the mask.

Figure 4.6. a) Scenario 1: model simulated with no gap and b) Scenario 2: model simulated with 1 mm gap.

Figure 4.7. a) Scenario 3: model simulated with 0.7 mm gap and b) Scenario 4: model simulated with 0.5 mm gap.

This study was aimed to optimize the air gap size between the mask and test specimen. One hundred ninety-two steady-state simulations were carried out using HEAT3,

based on the four scenarios, four sample sizes (200 x 200 mm, 150 x 150 mm, 100 x 100 mm, and 50 x 50 mm), and two thicknesses of the six insulation materials.

4.4 Results and Discussion

Heat flows predicted using HEAT3 with the four scenarios were compared to heat flows measured using masked small specimens of the six insulation materials (Table 4.2–4.9).

4.4.1 200 x 200 mm Specimens

As per Equation 2.4 the heat flow (Q) for specimen 12.5 mm thickness should be double of specimens with 25 mm thickness. However, in few cases, it was noticed that surface resistance of the material affected this correlation. LDGF had the highest variance of the six materials (Table 4.2 and Table 4.3). Variance between experimental and simulated measurements was less than 1% for EPS, XPS, PUR, ISO, and HDGF in all gap scenarios. Although variance increased with increasing the gap size, differences between scenarios were small, indicating that a gap up to 1 mm does not have a significant effect on heat flow measurements using masked 200 x 200 mm samples.

Table 4.2. Measured and simulated heat flow (q) for specimens with 200 x 200 mm, 25 mm thickness.

Measured		Simulated - HEAT3							
Masked		No Gap		0.5 mm Gap		0.7 mm Gap		1 mm Gap	
q (W/m ²)		q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)
EPS	29.56	29.78	0.75	29.79	0.79	29.81	0.87	29.84	0.94
XPS	25.13	25.06	-0.20	25.07	-0.23	25.07	-0.25	24.89	-0.96
PUR	21.85	21.78	-0.31	21.92	0.33	21.77	-0.34	21.74	-0.49
ISO	21.80	21.84	0.17	21.77	-0.15	21.76	-0.20	21.72	-0.38
HDGF	29.08	29.15	0.24	29.17	0.30	29.20	0.40	28.96	-0.42
LDGF	33.92	34.02	0.29	34.21	0.85	34.40	1.41	34.67	2.20

Table 4.3. Measured and simulated heat flow (q) for specimens with 200 x 200 mm, 12.5 mm thickness.

Measured		Simulated - HEAT3							
Masked		No Gap		0.5 mm Gap		0.7 mm Gap		1 mm Gap	
q (W/m ²)		q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)
EPS	57.82	58.15	0.57	58.13	0.53	58.18	0.62	58.25	0.74
XPS	51.81	51.73	-0.15	51.58	-0.44	51.45	-0.68	51.49	-0.61
PUR	44.25	44.57	0.74	44.47	0.52	44.32	0.17	44.40	0.36
ISO	45.25	45.45	0.44	45.34	0.22	45.20	-0.11	45.27	0.06
HDGF	59.00	59.10	0.18	58.91	-0.16	58.82	-0.32	58.81	-0.33
LDGF	67.3	66.86	-0.65	66.61	-1.01	66.56	-1.09	66.51	-1.19

4.4.2 150 x 150 mm Specimens

In comparisons of measured and simulated heat flow for masked 150 x 150 mm specimens with 25 mm thickness, LDGF had the highest variances of the six materials, greater than 1% for all gap scenarios (Table 4.4). Results for XPS and PUR also showed variances greater than 1% in the scenario with a 1 mm gap, and HDGF had variances greater than 1% for simulations with 0.7 mm and 1 mm gaps. Variances for EPS and ISO were less than 1% for all gap scenarios.

Comparison of measured and simulated heat flows for 150 x 150 mm specimens with 12.5 mm thickness resulted in variance less than 0.5% for all materials and gap scenarios (Table 4.5). Heat flow measurements predicted by the model were quite consistent among the four scenarios indicating a minimal effect of gap size.

Table 4.4. Measured and simulated heat flow (q) for specimens with 150 x 150 mm, 25 mm thickness.

Measured		Simulated - HEAT3							
Masked		No Gap		0.5 mm Gap		0.7 mm Gap		1 mm Gap	
q (W/m ²)		q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)
EPS	29.87	30.04	0.56	30.08	0.73	30.09	0.74	30.13	0.87
XPS	25.96	25.81	-0.60	25.78	-0.70	25.76	-0.79	25.60	-1.40
PUR	22.88	22.67	-0.91	22.63	-1.09	22.54	-1.49	22.52	-1.57
ISO	22.84	22.82	-0.09	22.80	-0.20	22.84	-0.04	22.67	-0.75
HDGF	29.08	28.87	-0.72	28.84	-0.83	28.72	-1.24	28.67	-1.41
LDGF	32.09	31.61	-1.50	31.58	-1.60	31.40	-2.17	33.12	3.19

Table 4.5. Measured and simulated heat flow (q) for specimens with 150 x 150 mm, 12.5 mm thickness.

	Measured		Simulated - HEAT3							
	Masked	q (W/m ²)	No Gap		0.5 mm Gap		0.7 mm Gap		1 mm Gap	
			q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)
EPS	57.93	57.93	58.02	0.15	58.03	0.18	58.06	0.22	58.11	0.27
XPS	45.79	45.79	45.75	-0.07	45.91	0.25	45.78	-0.01	45.73	-0.12
PUR	50.81	50.81	50.95	0.28	50.95	0.29	50.86	0.12	50.79	-0.03
ISO	48.06	48.06	48.09	0.08	48.12	0.14	48.01	-0.09	47.94	-0.25
HDGF	59.22	59.22	59.19	-0.05	59.11	-0.19	59.07	-0.24	59.01	-0.35
LDGF	64.08	64.08	64.18	0.16	64.07	0.01	64.08	0.01	64.01	-0.10

4.4.3 100 x 100 mm Specimens

Comparison of measured and simulated heat flow for 100 x 100 mm specimens with 25 mm thickness showed variances less than 1% for EPS, XPS, PUR, ISO and LDGF for all scenarios calculated and a variance of -2.43% for HDGF for scenario with 1mm gap.(Table 4.6). It also observed that greater gap size resulted in greater variance.

Results for specimens with 12.5 mm thickness had variances below 1% for EPS, XPS, ISO, HDGF and LDGF in all four scenarios (Table 4.7). PUR had variances greater than 1% for all simulations with a gap.

Table 4.6. Measured and simulated heat flow (q) for specimens with 100 x 100 mm, 25 mm thickness.

Measured		Simulated - HEAT3							
Masked		No Gap		0.5 mm Gap		0.7 mm Gap		1 mm Gap	
q (W/m ²)		q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)
EPS	31.41	31.46	0.20	31.55	0.40	31.64	0.70	31.69	0.90
XPS	27.6	27.61	0.05	27.59	-0.02	27.57	-0.08	27.46	-0.48
PUR	25.89	25.91	0.08	25.67	-0.85	25.65	-0.93	25.64	-0.97
ISO	25.90	25.89	-0.04	25.89	-0.04	25.84	-0.23	25.81	-0.35
HDGF	29.34	29.30	-0.16	29.27	-0.25	29.26	-0.29	28.63	-2.43
LDGF	31.02	30.98	-0.14	31.13	0.35	31.16	0.43	31.18	0.49

Table 4.7. Measured and simulated heat flow (q) for specimens with 100 x 100 mm, 12.5 mm thickness.

Measured		Simulated - HEAT3							
Masked		No Gap		0.5 mm Gap		0.7 mm Gap		1 mm Gap	
q (W/m ²)		q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)
EPS	58.84	58.95	0.18	58.95	0.19	58.97	0.23	58.99	0.25
XPS	54.45	54.72	0.51	54.59	0.26	54.61	0.30	54.62	0.33
PUR	51.96	52.06	0.20	51.31	-1.24	51.33	-1.21	51.37	-1.13
ISO	51.88	51.98	0.19	51.84	-0.07	51.86	-0.04	51.89	0.03
HDGF	59.84	59.83	0.01	59.69	-0.24	59.73	-0.18	59.71	-0.22
LDGF	60.86	60.53	-0.54	61.06	0.34	61.09	0.39	61.06	0.34

4.4.4 50 x 50 mm specimens

Comparison of measured and simulated heat flow for masked 50 x 50 mm specimens with 25 mm thickness showed the highest variance for HDGF (-2.44%) with a 1 mm gap

(Table 4.8). XPS with a 1 mm gap also had a variance greater than 1%, while EPS, PUR, ISO, and LDGF had variances less than 1% for all gap scenarios.

Comparison for specimens with 12.5 mm thickness, variances were less than 1% for all gap scenarios (Table 4.9).

Table 4.8. Measured and simulated heat flow (q) for specimens with 50 x 50 mm, 25 mm thickness.

Measured		Simulated - HEAT3							
Masked		No Gap		0.5 mm Gap		0.7 mm Gap		1 mm Gap	
q (W/m ²)		q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)
EPS	33.23	33.45	0.66	33.48	0.75	33.52	0.87	33.54	0.93
XPS	29.26	29.44	0.62	29.36	0.33	29.42	0.52	28.91	-1.21
PUR	29.26	29.35	0.31	29.09	-0.58	29.10	-0.55	29.07	-0.65
ISO	28.82	28.81	-0.03	28.78	-0.14	29.02	0.69	28.77	-0.17
HDGF	29.75	29.57	-0.62	29.54	-0.72	29.48	-0.91	29.03	-2.44
LDGF	30.13	30.06	-0.23	30.03	-0.32	29.97	-0.52	30.31	0.61

Table 4.9. Measured and simulated heat flow (q) for specimens with 50 x 50 mm, 12.5 mm thickness.

Measured		Simulated - HEAT3							
Masked		No Gap		0.5 mm Gap		0.7 mm Gap		1 mm Gap	
q (W/m ²)		q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)	q (W/m ²)	Variance (%)
EPS	57.95	58.07	0.22	58.08	0.23	58.11	0.27	58.14	0.32
XPS	56.87	56.83	-0.06	56.7	-0.30	56.82	-0.08	56.78	-0.14
PUR	55.59	55.36	-0.41	55.22	-0.66	55.35	-0.43	55.32	-0.48
ISO	56.7	56.68	-0.03	56.54	-0.27	56.67	-0.04	56.64	-0.11
HDGF	57.63	57.81	0.32	57.68	0.09	57.8	0.30	57.76	0.24
LDGF	60.87	61.02	0.25	60.88	0.03	61.01	0.24	60.95	0.14

4.4.5 Summary

Results of heat flow simulations using the four gap scenarios were similar to each other and to the experimental results. The results were also fairly consistent for the two thicknesses. A gap up to 1 mm did not significantly affect simulated heat flows, indicating that small gaps between sample and masking materials should not affect thermal conductivity measurements using smaller specimens of insulation when considering only heat conduction.

It has been observed that simulated results of the heat flow for the EPS specimens also had variations, between 0.15% to 0.75% (less than 1%), when compared to EPS masked from the experimental results; these variations are well within experimental tolerance of the ASTM C518 test results.

Close agreement between experimental data and model predictions indicate that the masked smaller specimens provide accurate measures of heat flow through all of the insulation materials tested.

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

The primary goal of the research described in this thesis was to establish a new methodology for measuring thermal conductivity of small insulation specimens (200 x 200 mm; 150 x 150 mm; 100 x 100 mm; 50 x 50 mm), using a heat flow meter apparatus (300 x 300 mm) with metering area of 150 x 150 mm and smaller specimens. The new method used smaller specimens inserted in a mask made of insulation with known thermal conductivity. The new method was tested on six insulation materials of two thicknesses (12.5 mm and 25 mm). The empirical data were used to generate equations relating thermal conductivity (k) measured according to the standard method (ASTM C518) with standard size samples (300mm x 300mm) to thermal conductivity (k_o) measured with the smaller masked samples.

Based on the research reported in this thesis, the following conclusions can be drawn on the assessment of thermal conductivity using smaller specimens:

1. The new method can be used to accurately measure thermal conductivity for a variety of insulation materials with different thicknesses, using samples down to 100mm x 100mm.

2. It has been observed that samples with 50 mm x 50 mm are too small for accurate assessment of thermal conductivity using a heat flow meter (300 x 300 mm) with a metering area 150 x 150 mm and did not provide reliable thermal conductivity values.
3. From the simulation results with no gap and with gap (1 mm, 0.7 mm and 0.5mm), it can be noticed that a gap between the mask and the smaller specimen does not significantly influence the variance between the experimental tests and the modelling simulation.
4. Experimental data and model predictions indicate that the masked smaller specimens provide accurate measures of heat flow through all of the insulation materials tested.

The suggested methodology allows measurement of thermal conductivity for insulation materials when large samples are not available, e.g., smaller specimens of new materials are being produced experimentally in a laboratory. Furthermore, the same test can be carried out to assess the thermal conductivity of smaller insulation specimens, collected from existing building envelopes, to study the long-term insulation performance.

Application of this method will accelerate the assessment of thermal conductivity of the new insulation materials and will expedite the introduction of the next generation of insulation material.

5.2 Recommendations for Future Work

Following verification of the new methodology using smaller specimens of insulation should be carried out.

- Different mask material for smaller specimens should be applied to study the effect of the mask on the thermal conductivity for smaller specimens.
- The proposed new methodology must go through further verification/ investigation in different laboratories and critical peer review before adopting it as a standard test method in the future

References

1. Stazi, F., Di Perna, C., and Munafo, P., 2009, Durability of 20-year-old insulation and assessment of various types of retrofitting to meet new energy regulations, *Energy Building* 41, pp. 721 – 731.
2. Bolaturk, A., 2006, Determination of Optimum Insulation Thickness for Building Walls With Respect to Various Fuels and Climate Zones in Turkey, *Appl. Therm. Eng.*, 26, pp. 1301-1309.
3. Mohammad, S. A., 2005, Performance Characteristics and Practical Application of Common Building Thermal Insulation Materials, *Building and Environment* 40, pp. 353-366.
4. Cengel, Heat Transfer, 2nd edition, McGraw-Hill, New York City, NY, 2003.
5. Jijji, L. M., 2009, Heat Conduction, Springer, pp. 1-23.
6. Kern, D., 1950, Process Heat Transfer, McGraw-Hill, New York City, pp. 2-104.
7. Kreith, F., Manglik, R. M., and Bohn, M., 2011. Principles of heat transfer. Stamford, Cengage Learning, pp. 10-25.
8. Houston, R. L. and Korpela, S. A., Heat Transfer through Fiberglass Insulations, in *Proceeding of the 7 International Heat Transfer Conference – Munich*, Washington: Hemisphere Publ. Co., Vol.2, pp. 322-334.
9. Insulation Malta, http://www.insulationsmalta.com/Why_to_insulate.htm, accessed: September 2012.
10. Hasan, A., 1999, Optimizing Insulation Thickness for Buildings Using Life Cycle Cost, *Applied Energy* 63, pp. 115-124.
11. Frawley, E., Thermal testing of innovative building insulations, 2009, MASc. Thesis Dublin Institute of Technology.
12. Powell, Frank J., Matthews, Stanley L. III. Committee C-16 on Thermal Insulation, Dallas, TX, 2-6 Dec. 1984.
13. Kumaran, M. K., Lackey, J. C., Normandin, N., Tariku, F., Van Reenen, D., 2004, A Thermal and Moisture Transport Property Database for Common Insulating Materials

- Used in Canada, Institute for Research in Construction, National Research Council Canada, Ottawa, Canada.
14. Tye, R., 1969, Thermal Conductivity, Vol. 1, Academic Press, New York.
 15. De Ponte, F., and Klarsfeld, S., 1990, What Property Do We Measure – Considerations on a Decade of ISO/TC 163, Journal of Thermal Insulation, Vol. 13, pp. 160-190.
 16. Pratt, A. W., 1968, Heat Transmission in Low Conductivity Materials, in Thermal Conductivity, R. P. Tye, ed., Academic Press, New York, pp. 301-300.
 17. Shirtliffe, C. J., 2005, Thermal Resistance of Building Insulation, Canadian Building Digests, NRC-IRC publications.
 18. Strother E. and Turner W., 1990, “Thermal Insulation Building guide,” pp 8-12.
 19. Shirtliffe, C. J., 1980, Effect of Thickness on the Thermal Properties of Thick Specimens of Low-Density Thermal Insulation, ASTM STP 718, Philadelphia: ASTM, pp. 36-50.
 20. Mukhopadhyaya, P., Kumaran, M. K., 2008, Long-Term Thermal of Closed-cell Foam Insulation: Research Update from Canada, 3rd Global Insulation Conference and Exhibition, Barcelona, Spain, pp.1-12.
 21. Guyer, E. C., and Brownwell D. L., 1999, Handbook of Applied Thermal Design, Taylor & Francis, Philadelphia, Part 3, Chapter 1, pp. 2 and 3.
 22. Abdou, A. A., Budaiwi, I. M., 2005, Comparison of Thermal Conductivity Measurements of Building Insulation Materials under Various Operating Temperatures, Journal of Building Physics, Vol. 29, No. 2, Sage Publications, pp. 171-184
 23. Zarr, R.R., A History of Testing Heat Insulators at the National Institute of Standards and Technology. ASHRAE Transactions, 2001. 107 Pt. 2(2): p. 111.
 24. Zarr, R.R., Kumaran, M.K., and Lagergren, E.S., 2002, NIST/NRC-Canada Interlaboratory comparison of Guarded Hot Plate Measurements, U.S Government printing office, Washington, DC.
 25. Powell, F. J., and Matthews, S. L., Thermal insulation: materials and systems / a conference sponsored by ASTM Committee C-16 on Thermal Insulation, Dallas, TX, 2-6 Dec. 1984.
 26. Roder, H. M, Perkins R. A, and De Castro, C. A. N, and Laesecke, A., 2000, Absolute Steady-State Thermal Conductivity Measurements by Use of a Transient Hot-Wire System. Journal of Research of the National Institute of Standards and Technology, , Vol. 105, No. 2, p. 221.
 27. ASTM C177, 2004, Standard Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Guarded Hot Plate Apparatus.

28. ISO 8302:1991, 1991, Thermal Insulation-Determination of Steady-State Thermal Resistance and Related Properties- Guarded Hot Plate Apparatus.
29. DINEN 12939, 1996, European Standard for Measurements of Insulating Materials Using the Guarded Hot Plate Technique.
30. JIS A 1412-1, 1999, Test Method for Thermal Resistance and Related Properties of Thermal Insulations, Part 1: Guarded Hot Plate Apparatus, Japanese Standards Association, Tokyo.
31. Zarr, R. R., and Filliben J. J., 2002, International Comparison of Guarded Hot Plate Apparatus Using National and Regional Reference Materials, NIST TN 1444.
32. ASTM C 518, 2004, Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus.
33. ISO 8301:1991, 1991, Thermal Insulation-Determination of Steady-State Thermal Resistance and Related Properties-Heat Flow Meter Apparatus.
34. DINEN 12667, 2001, European Standard for Measurements of Insulating Materials Using the Heat Flow Meter Method.
35. Bomberg, M., and Solvason, R., 1985, Discussion of Heat Flow Meter Apparatus and Transfer Standards Used for Error Analysis, in Guarded Hot Plate and Heat Flow Meter Methodology, STM STP 879,
36. C. J. Shirliffe and R. P. Tye, eds., American Society for Testing and Materials, Philadelphia, pp. 140-153.
37. Hahn, M. H., Robinson, H. E., and Flynn, D. R., 1974, Robinson Line-Heat-Source Guarded Hot Plate Apparatus, Heat Transmission Measurements in Thermal Insulations, ASTM SIP 544, R. P. Tye, ed., American Society for Testing and Materials, pp. 167-192.
38. Marcus, M., and Reading, M., Method and Apparatus for Thermal Conductivity Measurements, US Patent 5,334,994, August 8, 1994.
39. Flynn, D. R., and Gorthala, R., 1997, Thermal Design of A Miniature Guarded Hot Plate Apparatus, in Insulation Materials: Testing and Applications, ASTM STP 1320, R.R.Z. R.S. Graves, ed., American Society for Testing and Materials, West Conshohocken, PA.
40. Flynn, D. R., and Gorthala, R., 1996, Design of a Subminiature Guarded Hot Plate Apparatus, in Thermal Conductivity, R.B.D. Kenneth Earl Wilkes, Ronald S. Graves, Editor.
41. Miller, R., and Kuczmarski, M., 2009, Method for Measuring Thermal Conductivity of Small samples Having Very Low Thermal Conductivity, NASA Center for Aerospace Information (CASI) 7115 Standard Drive Hanover, MD 21076-1320.

42. Miller, R., and Kuczmarski, M., Method and Apparatus for Measuring Thermal Conductivity of Small, Highly Insulating Specimens, US Patent 8,220,989 B1, July 17, 2012.
43. Fujino, J., and Honda, T., 2007, Study on Guarded Hot Plate Apparatus for Measurement of Thermal Conductivity of Small Polymer Specimens, Thermal Engineering Heat Transfer Summer Conference collocated with the ASME 2007 InterPACK, Volume 3, July 8-12, Vancouver, British Columbia, Canada.
44. Mukhopadhyaya, P., Ngo, T., Ton-That, M., Masson, J. F., and Sherrer, G., 2011, Hygrothermal Properties of Biobased Polyurethane Foam Insulation for Building Envelope Construction, 9th Nordic Symposium on Building Physics, Finland, pp. 1-8.
45. Masson, J.F., Bundalo-Perc, S. Mukhopadhyaya, P., 2012, On the accuracy of ASTM E 1952 for the thermal conductivity of foams used as building insulation, National Research Canada, Ottawa.
46. ASTM E1952, 2011, Standard Test Method for Thermal Conductivity and Thermal Diffusivity by Modulated Temperature Differential Scanning Calorimetry.
47. Martinez. I. H., Heat Conduction Modelling, <http://webserver.dmt.upm.es/~isidoro/>, accessed: January, 2012.
48. Irons, B. M., and Ahmad, S., 1980, Techniques of Finite Elements, John Wiley, New York.
49. Asad, A. S., and Rama, S., 2004, Finite Element Heat Transfer and Structural Analysis, Proceedings of the WSEAS/IASME Int. Conference on Heat and Mass Transfer, Corfu, Greece, pp. 112-120.
50. Lewis, R. W., Morgan, K., Thomas, H. R., and Seetharamu, K. N., 1996, The Finite Element Analysis for Heat Transfer Analysis, John Wiley New York, pp. 1-80.
51. Wang, B. L., and Tian, Z. H., 2005, Application of Finite Element – Finite Difference Method to the Determination of Transient Temperature Field in Functionally Graded Materials, Finite Element Analyses. Design, 41, pp. 335-349.
52. Blomberg, T., 1996, Heat conduction in two and three dimensions. Computer modelling of Building Physics Applications, Department of Building Physics, Lund University, Sweden. ISBN 91-88722-05-8.
53. Paris, F., and Cañas, J., 1997, Boundary Element Method: Fundamentals and Applications, Oxford University Press, Oxford.
54. Keithley, 1991, Model 706 Scanner Instruction Manual, http://www.artisan-tg.com/info/Keithley_706_Manual.pdf access: September, 2012.
55. Agilent Technologies, <http://www.home.agilent.com>, access: September 2012.

56. Blomberg, T., 1994a, HEAT3 - A three-dimensional heat transfer computer program. Manual for HEAT3, Department of Building Physics, Lund University, Lund, Sweden. CODEN:LUTVDG/(TVBH-7169)

Project :	Thermal Conductivity of small specimens													
Material :	Extruded polystyrene													
Specimen :	EPS_INS_EPS_200x200 mm													
Thickness :	0.02562 m													
12" HFM station B2														
Date	Time	T hp	T h	T c	T cp	d t	T m	Q h	Q c	Q avg	R	C	Eh	Ec
15-May-11	21:00	36.0580	34.6419	12.6388	11.1588	22.0030	23.6404	29.4415	29.8891	29.6633	0.7417	1.3482	1.0296	1.0185
15-May-11	22:00	36.0561	34.6408	12.6412	11.1580	21.9996	23.6410	29.4755	29.8840	29.6797	0.7412	1.3491	1.0308	1.0183
15-May-11	23:00	36.0581	34.6412	12.6424	11.1577	21.9987	23.6418	29.4281	29.9069	29.6675	0.7415	1.3486	1.0291	1.0191
16-May-11	00:00	36.0539	34.6395	12.6388	11.1566	22.0007	23.6392	29.4308	29.8898	29.6603	0.7418	1.3481	1.0292	1.0185
16-May-11	01:00	36.0533	34.6399	12.6413	11.1569	21.9985	23.6406	29.4362	29.8847	29.6604	0.7417	1.3483	1.0294	1.0183
16-May-11	02:00	36.0597	34.6410	12.6421	11.1583	21.9990	23.6416	29.4509	29.8713	29.6611	0.7417	1.3483	1.0299	1.0178
16-May-11	03:00	36.0557	34.6389	12.6420	11.1585	21.9969	23.6405	29.4385	29.8785	29.6585	0.7417	1.3483	1.0295	1.0181
16-May-11	04:00	36.0617	34.6451	12.6436	11.1629	22.0015	23.6443	29.4626	29.8681	29.6654	0.7417	1.3483	1.0304	1.0177
16-May-11	05:00	36.0589	34.6432	12.6430	11.1625	22.0002	23.6431	29.4274	29.9067	29.6671	0.7416	1.3485	1.0291	1.0191
16-May-11	06:00	36.0638	34.6475	12.6470	11.1664	22.0005	23.6472	29.4529	29.8698	29.6613	0.7417	1.3482	1.0300	1.0178
16-May-11	07:00	36.0684	34.6542	12.6518	11.1724	22.0024	23.6530	29.4610	29.8724	29.6667	0.7417	1.3483	1.0303	1.0179
16-May-11	08:00	36.0696	34.6569	12.6556	11.1747	22.0012	23.6562	29.4139	29.8978	29.6559	0.7419	1.3479	1.0287	1.0188

All input in S.I.				EPS_INS_EPS_200x200 mm					
Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)	Dt	Tm	R	R/L	C	K
34.6	12.6	29.66	0.0256	22.0	23.6	0.74	28.9	1.348	0.0345

BTU Calculation									
Th (F)	Tc (F)	Q BTU*H/FT2	Thickness (Inches)	Dt	Tm	R	R/L	C	K
94.4	54.8	9.40	1.01	39.6	74.6	4.2	4.2	0.237	0.2395

Project : Thermal Conductivity of small specimens														
Material : Extruded polystyrene														
Specimen : EPS_INS_EPS_150x150 mm														
Thickness = 0.02560 m														
12"HFM station B2														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
16-May-11	21:00	36.0897	34.6433	12.6568	11.1661	21.9864	23.8501	29.5652	29.9653	29.7752	0.7384	1.3542	1.0339	1.0217
16-May-11	22:00	36.0641	34.6441	12.6553	11.1689	21.9888	23.8497	29.5367	29.9601	29.7644	0.7388	1.3536	1.0330	1.0219
16-May-11	23:00	36.0710	34.6475	12.6551	11.1670	21.9924	23.8513	29.5653	30.0234	29.7944	0.7382	1.3547	1.0339	1.0230
17-May-11	00:00	36.0688	34.6476	12.6594	11.1703	21.9881	23.8535	29.5225	29.9963	29.7594	0.7389	1.3534	1.0324	1.0221
17-May-11	01:00	36.0869	34.6445	12.6562	11.1672	21.9883	23.8504	29.5363	30.0025	29.7694	0.7386	1.3539	1.0329	1.0223
17-May-11	02:00	36.0897	34.6478	12.6553	11.1684	21.9925	23.8515	29.5507	30.0027	29.7767	0.7386	1.3539	1.0334	1.0223
17-May-11	03:00	36.0637	34.6432	12.6544	11.1685	21.9888	23.8488	29.5203	29.9869	29.7536	0.7390	1.3531	1.0324	1.0218
17-May-11	04:00	36.0687	34.6469	12.6540	11.1661	21.9929	23.8505	29.5285	30.0063	29.7684	0.7388	1.3535	1.0326	1.0225
17-May-11	05:00	36.0679	34.6446	12.6527	11.1633	21.9918	23.8486	29.5864	30.0248	29.8056	0.7379	1.3563	1.0347	1.0231
17-May-11	06:00	36.0649	34.6413	12.6574	11.1670	21.9840	23.8493	29.5375	29.9819	29.7597	0.7387	1.3537	1.0330	1.0218
17-May-11	07:00	36.0760	34.6503	12.6646	11.1760	21.9857	23.8575	29.5712	29.9967	29.7840	0.7382	1.3547	1.0341	1.0221
17-May-11	08:00	36.0754	34.6538	12.6644	11.1782	21.9894	23.8591	29.5411	30.0063	29.7737	0.7386	1.3540	1.0331	1.0225

All input in S.I.						EPS_INS_EPS_150x150 mm							
T _h		T _c		Q		Thickness							
(C)		(C)		(W/M2)		(Meter)							
34.6		12.7		29.77		0.0256							
D _t		T _m		R		R/L		C		K			
22.0		23.7		0.74		28.8		1.354		0.03467			

BTU Calculation													
T _h		T _c		Q		Thickness							
(F)		(F)		BTU/h/FT2		(Inches)							
94.4		54.8		9.44		1.01							
D _t		T _m		R		R/L		C		K			
39.6		74.6		4.2		4.2		0.238		0.2404			

Project : Thermal Conductivity of small specimens														
Material : Extruded polystyrene														
Specimen : EPS_INS_EPS_100x100 mm														
Thickness = 0.02575 m														
12"HFM station B2														
Date	Time	T hp	T h	T c	T cp	d t	T m	Q h	Q c	Q avg	R	C	E h	E c
17-May-11	21:00	36.3970	34.9786	12.9713	11.4929	22.0074	23.9750	29.4288	29.8989	29.6639	0.7419	1.3479	1.0294	1.0191
17-May-11	22:00	36.3959	34.9807	12.9730	11.4902	22.0077	23.9768	29.3961	29.9192	29.6577	0.7421	1.3476	1.0283	1.0198
17-May-11	23:00	36.3974	34.9816	12.9755	11.4923	22.0081	23.9785	29.4215	29.9167	29.6691	0.7417	1.3482	1.0292	1.0197
18-May-11	00:00	36.3972	34.9808	12.9728	11.4902	22.0080	23.9768	29.3858	29.9344	29.6601	0.7420	1.3477	1.0279	1.0203
18-May-11	01:00	36.3957	34.9786	12.9735	11.4894	22.0050	23.9761	29.4177	29.9130	29.6654	0.7418	1.3481	1.0291	1.0195
18-May-11	02:00	36.3964	34.9790	12.9717	11.4891	22.0073	23.9754	29.3995	29.8982	29.6488	0.7423	1.3472	1.0284	1.0190
18-May-11	03:00	36.3960	34.9811	12.9693	11.4878	22.0118	23.9752	29.3952	29.8981	29.6471	0.7425	1.3468	1.0283	1.0190
18-May-11	04:00	36.3963	34.9798	12.9735	11.4899	22.0084	23.9766	29.4137	29.8931	29.6534	0.7421	1.3475	1.0289	1.0189
18-May-11	05:00	36.3969	34.9817	12.9739	11.4908	22.0078	23.9778	29.4043	29.8953	29.6498	0.7423	1.3472	1.0286	1.0189
18-May-11	06:00	36.3998	34.9797	12.9725	11.4893	22.0073	23.9761	29.4250	29.8826	29.6538	0.7421	1.3474	1.0293	1.0185
18-May-11	07:00	36.4048	34.9863	12.9772	11.4942	22.0091	23.9817	29.4320	29.9082	29.6701	0.7418	1.3481	1.0296	1.0194
18-May-11	08:00	36.4046	34.9892	12.9757	11.4927	22.0135	23.9824	29.3920	29.9070	29.6495	0.7425	1.3469	1.0282	1.0193

All input in S.I.						EPS_INS_EPS_100x100 mm							
Th		Tc		Q		Thickness							
(C)		(C)		(W/M2)		(Meter)							
35.0		13.0		29.66		0.0257							
Dt		Tm		R		R/L		C		K			
22.0		24.0		0.74		28.8		1.348		0.034698			

BTU Calculation											
Th		Tc		Q		Thickness					
(F)		(F)		BTU/h/FT2		(Inches)					
95.0		55.4		9.40		1.01					
Dt		Tm		R		R/L		C		K	
39.6		75.2		4.2		4.2		0.237		0.2408	

Project : Thermal Conductivity of small specimens

Material : Extruded polystyrene

Specimen : EPS_INS_EPS_50x50 mm

12"HFM station B2

Thickness = 0.02557 m

Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
18-May-11	21:00	36.4100	34.9706	13.0095	11.5038	21.9612	23.9901	29.8590	30.3378	30.0984	0.7297	1.3705	1.0444	1.0340
18-May-11	22:00	36.4079	34.9677	13.0138	11.5087	21.9540	23.9908	29.8542	30.3058	30.0800	0.7299	1.3701	1.0443	1.0329
18-May-11	23:02	36.4107	34.9707	13.0130	11.5089	21.9577	23.9919	29.9040	30.3126	30.1083	0.7293	1.3712	1.0460	1.0331
19-May-11	00:02	36.4073	34.9686	13.0115	11.5075	21.9571	23.9901	29.8711	30.3249	30.0980	0.7295	1.3707	1.0449	1.0336
19-May-11	01:02	36.3983	34.9624	13.0029	11.4985	21.9595	23.9826	29.8472	30.3126	30.0799	0.7300	1.3698	1.0440	1.0331
19-May-11	02:02	36.3986	34.9600	13.0011	11.4925	21.9589	23.9806	29.8484	30.3029	30.0756	0.7301	1.3696	1.0441	1.0328
19-May-11	03:02	36.3974	34.9568	12.9981	11.4916	21.9587	23.9774	29.8621	30.3273	30.0947	0.7297	1.3705	1.0445	1.0336
19-May-11	04:02	36.3904	34.9557	12.9969	11.4941	21.9588	23.9763	29.8107	30.3060	30.0584	0.7306	1.3688	1.0427	1.0329
19-May-11	05:02	36.3982	34.9554	12.9976	11.4916	21.9577	23.9765	29.8769	30.2907	30.0838	0.7299	1.3701	1.0450	1.0324
19-May-11	06:02	36.3931	34.9568	12.9986	11.4919	21.9580	23.9776	29.8044	30.3072	30.0558	0.7308	1.3688	1.0425	1.0329
19-May-11	07:02	36.3943	34.9572	12.9985	11.4943	21.9607	23.9788	29.8461	30.2809	30.0635	0.7305	1.3690	1.0440	1.0321
19-May-11	08:02	36.3984	34.9588	12.9974	11.4894	21.9614	23.9781	29.8591	30.3448	30.1020	0.7296	1.3707	1.0444	1.0342

All input in S.I.

EPS_INS_EPS_50x50 mm

Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)
35.0	13.0	30.08	0.0256
Dt	Tm	R	R/L
22.0	24.0	0.73	28.6

C	K
1.370	0.03502

BTU Calculation

Th (F)	Tc (F)	Q BTU*H/FT2	Thickness (Inches)		
94.9	55.4	9.54	1.01		
Dt	Tm	R	R/L	C	K
39.5	75.2	4.1	4.1	0.241	0.2428

Project : Thermal Conductivity of small specimens

Material : Extruded polystyrene

Specimen : EPS_INS_XPS_200x200mm

12"HFM station in Room 121

Thickness = 0.02550 m

Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
11-Dec-11	21:00	36.2448	35.0288	13.0060	11.7430	22.0227	24.0174	25.0776	25.1742	25.1259	0.8765	1.1409	0.8777	0.8586
11-Dec-11	22:00	36.2520	35.0342	13.0054	11.7417	22.0288	24.0198	25.0888	25.1882	25.1385	0.8763	1.1411	0.8781	0.8591
11-Dec-11	23:00	36.2413	35.0270	13.0046	11.7393	22.0223	24.0158	25.0345	25.2296	25.1321	0.8763	1.1412	0.8762	0.8605
12-Dec-11	00:00	36.2436	35.0280	13.0048	11.7412	22.0232	24.0164	25.0609	25.1814	25.1211	0.8767	1.1406	0.8771	0.8588
12-Dec-11	01:00	36.2484	35.0302	13.0026	11.7399	22.0275	24.0164	25.0991	25.1749	25.1370	0.8763	1.1411	0.8784	0.8586
12-Dec-11	02:00	36.2443	35.0295	13.0042	11.7401	22.0253	24.0169	25.0274	25.1929	25.1102	0.8772	1.1400	0.8759	0.8592
12-Dec-11	03:00	36.2429	35.0279	13.0053	11.7412	22.0226	24.0166	25.0464	25.1962	25.1213	0.8767	1.1407	0.8766	0.8593
12-Dec-11	04:00	36.2492	35.0323	13.0037	11.7398	22.0286	24.0180	25.0775	25.1958	25.1366	0.8764	1.1410	0.8777	0.8593
12-Dec-11	05:00	36.2513	35.0342	13.0064	11.7423	22.0278	24.0203	25.0888	25.2103	25.1496	0.8759	1.1417	0.8781	0.8598
12-Dec-11	06:00	36.2411	35.0250	13.0027	11.7396	22.0223	24.0138	25.0786	25.2057	25.1422	0.8759	1.1416	0.8777	0.8597
12-Dec-11	07:00	36.2446	35.0267	13.0037	11.7402	22.0229	24.0152	25.0972	25.1754	25.1363	0.8762	1.1413	0.8783	0.8586
12-Dec-11	08:00	36.2500	35.0344	13.0035	11.7387	22.0309	24.0189	25.0697	25.2256	25.1476	0.8761	1.1414	0.8774	0.8603

All input in S.I.

EPS_INS_XPS_200x200mm

T _h (C)	T _c (C)	q (W/M2)	Thickness (Meter)		
35.0	13.0	25.13	0.0255		
D _t	T _m	R	R/L	C	k
22.0	24.0	0.88	34.4	1.141	0.02910

BTU Calculation

Th (F)	Tc (F)	q BTU*H/FT2	Thickness (Inches)		
95.1	55.4	7.97	1.00		
Dt	Tm	R	R/L	C	k
39.6	75.2	5.0	5.0	0.201	0.2018

Project : Thermal Conductivity of small specimens															
Material : Extruded polystyrene															
Specimen : EPS_INS_XPS_150x150mm															
Thickness = 0.02545 m															
12" HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
7-Dec-11	21:00	36.2594	35.0084	12.9652	11.6738	22.0432	23.9868	26.0502	25.9084	25.9793	0.8485	1.1785	0.9116	0.8835	
7-Dec-11	22:00	36.2551	35.0047	12.9628	11.6724	22.0418	23.9838	26.0479	25.9063	25.9771	0.8485	1.1785	0.9115	0.8835	
7-Dec-11	23:02	36.2531	35.0021	12.9611	11.6689	22.0410	23.9816	26.0449	25.9123	25.9786	0.8485	1.1786	0.9114	0.8837	
8-Dec-11	00:02	36.2464	34.9991	12.9587	11.6679	22.0404	23.9789	25.9627	25.9055	25.9341	0.8499	1.1766	0.9086	0.8834	
8-Dec-11	01:02	36.2566	35.0053	12.9587	11.6670	22.0466	23.9820	26.0551	25.9027	25.9789	0.8487	1.1783	0.9118	0.8833	
8-Dec-11	02:02	36.2587	35.0062	12.9615	11.6698	22.0447	23.9839	26.0754	25.9081	25.9918	0.8482	1.1790	0.9125	0.8835	
8-Dec-11	03:04	36.2547	35.0065	12.9609	11.6674	22.0457	23.9837	25.9801	25.9139	25.9470	0.8497	1.1769	0.9092	0.8837	
8-Dec-11	04:04	36.2504	35.0010	12.9603	11.6695	22.0407	23.9807	26.0152	25.8997	25.9574	0.8491	1.1777	0.9104	0.8832	
8-Dec-11	05:04	36.2527	35.0031	12.9568	11.6648	22.0463	23.9800	26.0250	25.9185	25.9717	0.8489	1.1780	0.9107	0.8839	
8-Dec-11	06:04	36.2450	34.9977	12.9578	11.6671	22.0399	23.9778	25.9684	25.9013	25.9349	0.8498	1.1767	0.9088	0.8833	
8-Dec-11	07:04	36.2537	35.0007	12.9574	11.6651	22.0433	23.9791	26.0688	25.9110	25.9899	0.8482	1.1790	0.9123	0.8836	
8-Dec-11	08:04	36.2447	34.9931	12.9512	11.6612	22.0419	23.9721	26.0501	25.8809	25.9655	0.8489	1.1780	0.9116	0.8826	

All input in S.I.															
EPS_INS_XPS_150x150mm															
Th		Tc		q		Thickness									
(C)		(C)		(W/M2)		(Meter)									
35.0		13.0		25.97		0.0255									
Dt		Tm		R		R/L		C		k					
22.0		24.0		0.85		33.4		1.178		0.02998					

BTU Calculation															
Th		Tc		q		Thickness									
(F)		(F)		[BTU*h/FT2]		(Inches)									
95.0		55.3		8.23		1.00									
Dt		Tm		R		R/L		C		k					
39.7		75.2		4.8		4.8		0.207		0.2079					

Project : Thermal Conductivity of small specimens															
Material : Extruded polystyrene															
Specimen : EPS_INS_XPS_100x100mm															
Thickness = 0.02562 m															
12"HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
12-Dec-11	21:00	36.3190	34.9906	13.0225	11.6435	21.9680	24.0065	27.5535	27.6694	27.6114	0.7956	1.2569	0.9640	0.9434	
12-Dec-11	22:00	36.3188	34.9921	13.0180	11.6397	21.9742	24.0050	27.5312	27.6612	27.5962	0.7963	1.2558	0.9633	0.9431	
12-Dec-11	23:00	36.3160	34.9879	13.0165	11.6372	21.9714	24.0022	27.5409	27.6586	27.5997	0.7961	1.2561	0.9636	0.9430	
13-Dec-11	00:00	36.3135	34.9854	13.0157	11.6386	21.9698	24.0005	27.5481	27.6341	27.5911	0.7963	1.2558	0.9638	0.9422	
13-Dec-11	01:00	36.3151	34.9879	13.0161	11.6383	21.9718	24.0020	27.5363	27.6301	27.5832	0.7966	1.2553	0.9634	0.9420	
13-Dec-11	02:00	36.3100	34.9838	13.0135	11.6343	21.9703	23.9986	27.4892	27.6640	27.5766	0.7967	1.2551	0.9618	0.9432	
13-Dec-11	03:00	36.3162	34.9851	13.0145	11.6338	21.9705	23.9998	27.5980	27.6929	27.6455	0.7948	1.2583	0.9656	0.9442	
13-Dec-11	04:00	36.3135	34.9841	13.0146	11.6341	21.9695	23.9994	27.5596	27.6607	27.6102	0.7957	1.2567	0.9642	0.9431	
13-Dec-11	05:00	36.3108	34.9808	13.0122	11.6343	21.9685	23.9965	27.5818	27.6509	27.6164	0.7955	1.2571	0.9650	0.9428	
13-Dec-11	06:00	36.3067	34.9818	13.0088	11.6298	21.9729	23.9953	27.5056	27.6391	27.5724	0.7969	1.2548	0.9624	0.9423	
13-Dec-11	07:00	36.3093	34.9800	13.0100	11.6291	21.9700	23.9950	27.5679	27.6642	27.6161	0.7956	1.2569	0.9645	0.9432	
13-Dec-11	08:00	36.3075	34.9811	13.0110	11.6326	21.9702	23.9961	27.5180	27.6470	27.5825	0.7966	1.2554	0.9628	0.9426	

All input in S.I.						EPS_INS_XPS_100x100mm							
Th		Tc		q		Thickness							
(C)		(C)		(W/M2)		(Meter)							
35.0		13.0		27.60		0.0256							
Dt		Tm		R		R/L		C		k			
22.0		24.0		0.80		31.1		1.256		0.03218			

BTU Calculation													
Th		Tc		q		Thickness							
(F)		(F)		[BTU*h/FT2]		(Inches)							
95.0		55.4		8.75		1.01							
Dt		Tm		R		R/L		C		k			
39.5		75.2		4.5		4.5		0.221		0.2231			

Project : Thermal Conductivity of small specimens														
Material : Extruded polystyrene														
Specimen : EPS_INS_XPS_50x50mm														
Thickness = 0.02550 m														
12" HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	dt	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
13-Dec-11	21:00	36.4185	35.0085	13.0289	11.5580	21.9796	24.0187	29.1195	29.3421	29.2308	0.7520	1.3299	1.0187	1.0002
13-Dec-11	22:00	36.4199	35.0045	13.0268	11.5557	21.9776	24.0157	29.1970	29.3254	29.2612	0.7511	1.3314	1.0214	0.9996
13-Dec-11	23:00	36.4196	35.0077	13.0286	11.5568	21.9791	24.0181	29.1614	29.3356	29.2485	0.7515	1.3307	1.0201	0.9999
14-Dec-11	00:00	36.4253	35.0081	13.0265	11.5567	21.9816	24.0173	29.2518	29.3210	29.2864	0.7506	1.3323	1.0233	0.9995
14-Dec-11	01:00	36.4231	35.0091	13.0266	11.5564	21.9825	24.0179	29.1969	29.3351	29.2660	0.7511	1.3313	1.0214	0.9999
14-Dec-11	02:00	36.4213	35.0071	13.0267	11.5561	21.9804	24.0169	29.2146	29.3293	29.2720	0.7509	1.3317	1.0220	0.9997
14-Dec-11	03:00	36.4174	35.0029	13.0266	11.5557	21.9763	24.0148	29.2042	29.3462	29.2752	0.7507	1.3321	1.0216	1.0003
14-Dec-11	04:00	36.4198	35.0055	13.0253	11.5555	21.9802	24.0154	29.1976	29.3334	29.2655	0.7511	1.3314	1.0214	0.9999
14-Dec-11	05:00	36.4136	35.0023	13.0260	11.5558	21.9763	24.0141	29.1466	29.3282	29.2374	0.7517	1.3304	1.0196	0.9997
14-Dec-11	06:00	36.4154	34.9994	13.0237	11.5538	21.9757	24.0115	29.2246	29.3063	29.2654	0.7509	1.3317	1.0223	0.9989
14-Dec-11	07:00	36.4105	34.9953	13.0228	11.5533	21.9725	24.0091	29.2057	29.3244	29.2651	0.7508	1.3319	1.0217	0.9996
14-Dec-11	08:00	36.4199	35.0005	13.0243	11.5534	21.9763	24.0124	29.2925	29.3538	29.3232	0.7495	1.3343	1.0247	1.0006

All input in S.I.				EPS_INS_XPS_50x50mm			
T _h		T _c		q		Thickness	
(C)		(C)		(W/M2)		(Meter)	
35.0		13.0		29.27		0.0255	
Dt		T _m		R		R/L	
22.0		24.0		0.75		29.5	
						C	
						1.332	
						k	
						0.03395	

BTU Calculation							
T _h		T _c		q		Thickness	
(F)		(F)		(BTU*h/FT2)		(Inches)	
95.0		55.4		9.28		1.00	
Dt		T _m		R		R/L	
39.6		75.2		4.3		4.2	
						C	
						0.235	
						k	
						0.2354	

Project: Thermal Conductivity of small specimens														
Material: Polyurethane														
Specimen: EPS_INS_PUR_200x200mm														
Thickness = 0.02563 m														
12"HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	dt	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
14-Dec-11	21:00	36.0894	35.0329	12.9623	11.8638	22.0706	23.9976	21.8579	21.9474	21.9026	1.0077	0.9923	0.7652	0.7488
14-Dec-11	22:00	36.0868	35.0298	12.9589	11.8634	22.0709	23.9943	21.8457	21.8948	21.8703	1.0092	0.9908	0.7648	0.7471
14-Dec-11	23:00	36.0854	35.0319	12.9575	11.8613	22.0743	23.9947	21.7713	21.8936	21.8324	1.0111	0.9890	0.7622	0.7470
15-Dec-11	00:00	36.0803	35.0270	12.9557	11.8600	22.0713	23.9914	21.7772	21.8846	21.8309	1.0111	0.9891	0.7624	0.7467
15-Dec-11	01:00	36.0898	35.0362	12.9596	11.8644	22.0766	23.9979	21.7850	21.8743	21.8296	1.0113	0.9888	0.7627	0.7464
15-Dec-11	02:00	36.0933	35.0394	12.9616	11.8653	22.0778	24.0005	21.7884	21.9100	21.8492	1.0105	0.9896	0.7628	0.7476
15-Dec-11	03:00	36.0868	35.0344	12.9604	11.8629	22.0740	23.9974	21.7525	21.9027	21.8276	1.0114	0.9888	0.7616	0.7473
15-Dec-11	04:00	36.0849	35.0325	12.9606	11.8657	22.0719	23.9966	21.7404	21.8923	21.8163	1.0118	0.9884	0.7611	0.7470
15-Dec-11	05:00	36.0951	35.0406	12.9611	11.8642	22.0795	24.0008	21.8076	21.8939	21.8508	1.0105	0.9896	0.7635	0.7470
15-Dec-11	06:00	36.0906	35.0350	12.9587	11.8634	22.0764	23.9969	21.8260	21.8797	21.8528	1.0103	0.9898	0.7641	0.7465
15-Dec-11	07:00	36.0933	35.0365	12.9590	11.8607	22.0775	23.9977	21.8330	21.8962	21.8646	1.0098	0.9903	0.7644	0.7471
15-Dec-11	08:00	36.0898	35.0350	12.9593	11.8623	22.0757	23.9971	21.8140	21.8817	21.8478	1.0105	0.9896	0.7637	0.7466

All input in S.I.						EPS_INS_PUR_200x200mm									
T _h		T _c		q		Thickness									
(C)		(C)		(W/M2)		(Meter)									
35.0		13.0		21.85		0.0256									
Dt		T _m		R		R/L		C		k					
22.1		24.0		1.01		39.4		0.990		0.02536					

BTU Calculation															
T _h		T _c		q		Thickness									
(F)		(F)		BTU*h/FT2		(Inches)									
95.1		55.3		6.93		1.01									
Dt		T _m		R		R/L		C		k					
39.7		75.2		5.7		5.7		0.174		0.1759					

Project : Thermal Conductivity of small specimens															
Material : Polyurethane															
Specimen : EPS_INS_PUR_150x150mm															
Thickness = 0.02548 m															
12" HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
15-Dec-11	19:00	36.0979	34.9851	13.0282	11.8780	21.9570	24.0066	23.0886	22.9780	23.0333	0.9533	1.0489	0.8082	0.7839	
15-Dec-11	20:00	36.0976	34.9870	13.0219	11.8764	21.9651	24.0044	23.0118	22.8967	22.9542	0.9569	1.0450	0.8055	0.7812	
15-Dec-11	21:00	36.0955	34.9914	13.0225	11.8790	21.9689	24.0069	22.9009	22.8607	22.8808	0.9602	1.0415	0.8017	0.7799	
15-Dec-11	22:00	36.0928	34.9917	13.0214	11.8787	21.9703	24.0065	22.8680	22.8530	22.8605	0.9611	1.0405	0.8005	0.7797	
15-Dec-11	23:00	36.0916	34.9881	13.0170	11.8737	21.9710	24.0026	22.8860	22.8160	22.8510	0.9615	1.0400	0.8011	0.7784	
16-Dec-11	00:00	36.0911	34.9889	13.0170	11.8737	21.9719	24.0029	22.8400	22.8377	22.8389	0.9621	1.0394	0.7995	0.7792	
16-Dec-11	01:00	36.0870	34.9847	13.0145	11.8737	21.9702	23.9996	22.8644	22.8214	22.8429	0.9619	1.0397	0.8004	0.7786	
16-Dec-11	02:00	36.0877	34.9841	13.0131	11.8722	21.9710	23.9986	22.8850	22.7994	22.8422	0.9619	1.0396	0.8011	0.7779	
16-Dec-11	03:00	36.0897	34.9846	13.0144	11.8731	21.9702	23.9995	22.9201	22.8072	22.8636	0.9610	1.0406	0.8023	0.7781	
16-Dec-11	04:00	36.0897	34.9848	13.0119	11.8709	21.9730	23.9983	22.9077	22.8120	22.8598	0.9612	1.0403	0.8019	0.7783	
16-Dec-11	05:00	36.0943	34.9866	13.0117	11.8704	21.9750	23.9992	22.9548	22.8048	22.8798	0.9605	1.0411	0.8035	0.7780	
16-Dec-11	06:00	36.0939	34.9874	13.0127	11.8727	21.9748	24.0000	22.9458	22.7998	22.8728	0.9608	1.0408	0.8032	0.7779	

All input in S.I.						EPS_INS_PUR_150x150mm							
Th		Tc		q		Thickness							
(C)		(C)		(W/M2)		(Meter)							
35.0		13.0		22.88		0.0255							
Dt		Tm		R		R/L		C		k			
22.0		24.0		0.96		37.7		1.042		0.02654			

BTU Calculation													
Th		Tc		q		Thickness							
(F)		(F)		(BTU*h/FT2)		(Inches)							
95.0		55.4		7.25		1.00							
Dt		Tm		R		R/L		C		k			
39.5		75.2		5.5		5.4		0.183		0.1840			

Project : Thermal Conductivity of small specimens														
Material : Polyurethane														
Specimen : EPS_INS_PUR_100x100mm														
Thickness = 0.02540 m														
12" HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
5-Jan-12	20:58	36.1305	34.8960	13.1174	11.8326	21.7786	24.0067	25.8073	25.9754	25.8913	0.8412	1.1888	0.9031	0.8859
5-Jan-12	21:58	36.1343	34.8973	13.1170	11.8321	21.7803	24.0072	25.8566	25.9278	25.8922	0.8412	1.1887	0.9048	0.8843
5-Jan-12	22:58	36.1347	34.9001	13.1199	11.8351	21.7802	24.0100	25.8016	25.9575	25.8795	0.8416	1.1882	0.9029	0.8853
5-Jan-12	23:58	36.1352	34.8967	13.1187	11.8335	21.7780	24.0077	25.8798	25.9607	25.9203	0.8402	1.1901	0.9056	0.8854
6-Jan-12	00:58	36.1424	34.9044	13.1238	11.8364	21.7806	24.0141	25.8383	25.9775	25.9079	0.8407	1.1894	0.9041	0.8860
6-Jan-12	01:58	36.1385	34.9025	13.1236	11.8375	21.7789	24.0130	25.8455	25.9576	25.9015	0.8409	1.1893	0.9044	0.8853
6-Jan-12	02:58	36.1464	34.9094	13.1250	11.8392	21.7844	24.0172	25.8353	25.9780	25.9066	0.8409	1.1892	0.9040	0.8860
6-Jan-12	03:58	36.1348	34.9008	13.1213	11.8379	21.7795	24.0110	25.7966	25.9485	25.8725	0.8418	1.1879	0.9027	0.8850
6-Jan-12	04:58	36.1381	34.9038	13.1235	11.8372	21.7803	24.0136	25.7891	25.9812	25.8852	0.8414	1.1884	0.9024	0.8861
6-Jan-12	05:58	36.1329	34.8975	13.1233	11.8392	21.7742	24.0104	25.8153	25.9247	25.8700	0.8417	1.1881	0.9033	0.8842
6-Jan-12	06:58	36.1474	34.9080	13.1269	11.8421	21.7811	24.0175	25.8816	25.9587	25.9202	0.8404	1.1900	0.9057	0.8854
6-Jan-12	07:58	36.1428	34.9068	13.1282	11.8425	21.7786	24.0175	25.8417	25.9744	25.9081	0.8407	1.1896	0.9043	0.8859

All input in S.I.				EPS_INS_PUR_100x100mm			
Th		Tc		q		Thickness	
(C)		(C)		(W/M2)		(Meter)	
34.9		13.1		25.90		0.0254	
Dt		Tm		R		R/L	
21.8		24.0		0.84		33.1	

BTU Calculation							
Th		Tc		q		Thickness	
(F)		(F)		(BTU*h/FT2)		(Inches)	
94.8		55.6		8.21		1.00	
Dt		Tm		R		R/L	
39.2		75.2		4.8		4.8	
						C	
						0.209	
						k	
						0.2094	

Project: Thermal Conductivity of small specimens

Material: Polyurethane

Specimen: EPS_INS_PUR_50x50mm

12" HFM station in Room 121

Thickness = 0.02548 m

Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
12-Jan-12	20:58	36.3670	34.9805	13.0448	11.5995	21.9358	24.0127	28.6796	28.8570	28.7683	0.7625	1.3114	1.0033	0.9837
12-Jan-12	21:58	36.3736	34.9808	13.0448	11.5984	21.9361	24.0128	28.8035	28.8582	28.8308	0.7609	1.3143	1.0076	0.9838
12-Jan-12	22:58	36.3610	34.9735	13.0426	11.5992	21.9308	24.0081	28.6711	28.8607	28.7659	0.7624	1.3116	1.0030	0.9839
12-Jan-12	23:58	36.3711	34.9783	13.0445	11.6014	21.9337	24.0114	28.7887	28.8055	28.7971	0.7617	1.3129	1.0071	0.9820
13-Jan-12	00:58	36.3766	34.9800	13.0438	11.5989	21.9363	24.0119	28.8884	28.8377	28.8631	0.7600	1.3157	1.0106	0.9831
13-Jan-12	01:58	36.3696	34.9785	13.0448	11.6005	21.9337	24.0116	28.7641	28.8426	28.8034	0.7616	1.3131	1.0063	0.9832
13-Jan-12	02:58	36.3637	34.9747	13.0440	11.6002	21.9307	24.0094	28.7053	28.8466	28.7760	0.7621	1.3121	1.0042	0.9834
13-Jan-12	03:58	36.3702	34.9798	13.0443	11.5974	21.9354	24.0120	28.7289	28.8903	28.8096	0.7614	1.3133	1.0050	0.9848
13-Jan-12	04:58	36.3692	34.9762	13.0449	11.5998	21.9313	24.0106	28.7679	28.8141	28.7910	0.7618	1.3127	1.0064	0.9823
13-Jan-12	05:58	36.3684	34.9749	13.0445	11.5983	21.9304	24.0097	28.8092	28.8501	28.8297	0.7607	1.3146	1.0078	0.9835
13-Jan-12	06:58	36.3687	34.9796	13.0462	11.6030	21.9334	24.0129	28.7150	28.8009	28.7579	0.7627	1.3111	1.0045	0.9818
13-Jan-12	07:58	36.3776	34.9860	13.0500	11.6074	21.9359	24.0180	28.7574	28.8475	28.8024	0.7616	1.3130	1.0060	0.9834

All input in S.I.

EPS_INS_PUR_50x50mm

T _h (C)	T _c (C)	q (W/M2)	Thickness (Meter)	D _t	T _m	R	R/L	C	k
35.0	13.0	28.80	0.0255	21.9	24.0	0.76	29.9	1.313	0.03346

BTU Calculation

T _h (F)	T _c (F)	q (BTU*in/FT2)	Thickness (Inches)	D _t	T _m	R	R/L	C	k
95.0	55.5	9.13	1.00	39.5	75.2	4.3	4.3	0.231	0.2320

Project :		Thermal Conductivity of small specimens													
Material :		Polyisocyanurate													
Specimen :		EPS_INS_ISO_200x200mm													
Thickness =		0.02552 m													
12"HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	dt	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
8-Jan-12	21:00	36.0682	35.0080	12.9917	11.8962	22.0163	23.9998	21.8777	21.8720	21.8748	1.0066	0.9935	0.7659	0.7463	
8-Jan-12	22:00	36.0579	35.0030	12.9893	11.8939	22.0137	23.9962	21.7770	21.8718	21.8244	1.0087	0.9913	0.7624	0.7463	
8-Jan-12	23:00	36.0645	35.0093	12.9867	11.8909	22.0226	23.9980	21.7683	21.8692	21.8187	1.0094	0.9907	0.7621	0.7462	
9-Jan-12	00:00	36.0592	35.0070	12.9873	11.8912	22.0197	23.9971	21.7336	21.8783	21.8060	1.0099	0.9902	0.7609	0.7465	
9-Jan-12	01:00	36.0552	35.0001	12.9806	11.8868	22.0194	23.9903	21.7801	21.8398	21.8099	1.0097	0.9904	0.7625	0.7452	
9-Jan-12	02:00	36.0632	35.0108	12.9803	11.8867	22.0306	23.9956	21.7253	21.8420	21.7837	1.0114	0.9887	0.7606	0.7453	
9-Jan-12	03:00	36.0631	35.0070	12.9842	11.8914	22.0228	23.9956	21.8105	21.8235	21.8170	1.0095	0.9906	0.7636	0.7446	
9-Jan-12	04:00	36.0569	35.0043	12.9807	11.8848	22.0236	23.9925	21.7334	21.8492	21.7913	1.0107	0.9894	0.7609	0.7455	
9-Jan-12	05:00	36.0600	35.0076	12.9796	11.8845	22.0279	23.9936	21.7334	21.8445	21.7889	1.0110	0.9891	0.7609	0.7454	
9-Jan-12	06:00	36.0582	35.0039	12.9775	11.8829	22.0264	23.9907	21.7480	21.8444	21.7962	1.0106	0.9895	0.7614	0.7453	
9-Jan-12	07:00	36.0601	35.0089	12.9798	11.8855	22.0291	23.9944	21.7046	21.8374	21.7710	1.0120	0.9882	0.7599	0.7451	
9-Jan-12	08:00	36.0562	35.0065	12.9818	11.8877	22.0247	23.9942	21.6768	21.8255	21.7511	1.0126	0.9875	0.7589	0.7447	

All input in S.I.						EPS_INS_ISO_200x200mm							
Th (C)		Tc (C)		q (W/M2)		Thickness (Meter)							
35.0		13.0		21.80		0.0255							
Dt		Tm		R		R/L		C		k			
22.0		24.0		1.01		39.6		0.990		0.02526			

BTU Calculation													
Th (F)		Tc (F)		q BTU*H/FT2		Thickness (Inches)							
95.0		55.4		6.91		1.00							
Dt		Tm		R		R/L		C		k			
39.6		75.2		5.7		5.7		0.174		0.1752			

Project :		Thermal Conductivity of small specimens													
Material :		Polyiso													
Specimen :		EPS_INS_ISO_150x150mm													
Thickness =		0.02545 m													
12"HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
7-Jan-12	21:00	36.1696	35.0748	12.9764	11.8389	22.0983	24.0236	22.8638	22.8498	22.8568	0.9669	1.0343	0.8004	0.7796	
7-Jan-12	22:00	36.1642	35.0723	12.9782	11.8388	22.0941	24.0253	22.7735	22.8918	22.8327	0.9677	1.0334	0.7973	0.7810	
7-Jan-12	23:00	36.1623	35.0694	12.9785	11.8387	22.0908	24.0240	22.8120	22.8909	22.8515	0.9668	1.0344	0.7986	0.7810	
8-Jan-12	00:00	36.1591	35.0638	12.9735	11.8347	22.0903	24.0187	22.8562	22.8733	22.8647	0.9662	1.0350	0.8002	0.7804	
8-Jan-12	01:00	36.1603	35.0649	12.9730	11.8349	22.0920	24.0190	22.8524	22.8742	22.8633	0.9663	1.0348	0.8000	0.7804	
8-Jan-12	02:00	36.1556	35.0603	12.9728	11.8356	22.0875	24.0165	22.8516	22.8577	22.8546	0.9665	1.0347	0.8000	0.7798	
8-Jan-12	03:00	36.1572	35.0629	12.9704	11.8328	22.0925	24.0166	22.8262	22.8791	22.8527	0.9668	1.0344	0.7991	0.7806	
8-Jan-12	04:00	36.1612	35.0691	12.9743	11.8356	22.0949	24.0217	22.7926	22.8684	22.8305	0.9678	1.0332	0.7979	0.7802	
8-Jan-12	05:00	36.1560	35.0630	12.9727	11.8346	22.0903	24.0179	22.7941	22.8687	22.8314	0.9676	1.0335	0.7980	0.7802	
8-Jan-12	06:00	36.1590	35.0620	12.9733	11.8343	22.0887	24.0176	22.8885	22.8863	22.8874	0.9652	1.0361	0.8013	0.7808	
8-Jan-12	07:00	36.1572	35.0652	12.9721	11.8334	22.0931	24.0186	22.8170	22.8539	22.8354	0.9675	1.0335	0.7988	0.7797	
8-Jan-12	08:00	36.1586	35.0667	12.9736	11.8353	22.0930	24.0201	22.7853	22.8748	22.8301	0.9678	1.0333	0.7977	0.7804	

All input in S.I.						EPS_INS_ISO_150x150mm							
Th (C)		Tc (C)		q (W/M2)		Thickness (Meter)							
35.1		13.0		22.85		0.0254							
Dt		Tm		R		R/L		C		k			
22.1		24.0		0.97		38.0		1.034		0.02632			

BTU Calculation													
Th (F)		Tc (F)		q BTU*H/FT2		Thickness (Inches)							
95.1		55.4		7.24		1.00							
Dt		Tm		R		R/L		C		k			
39.8		75.2		5.5		5.5		0.182		0.1825			

Project : Thermal Conductivity of small specimens															
Material : Polyiso															
Specimen : EPS_INS_ISO_100x100mm															
Thickness = 0.02567 m															
12"HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
9-Jan-12	20:00	36.2120	34.9686	13.0148	11.7274	21.9538	23.9917	25.9567	25.9502	25.9534	0.8460	1.1821	0.9083	0.8850	
9-Jan-12	21:00	36.2114	34.9685	13.0139	11.7281	21.9546	23.9912	25.9460	25.9315	25.9387	0.8465	1.1814	0.9080	0.8844	
9-Jan-12	22:00	36.2067	34.9682	13.0126	11.7270	21.9556	23.9904	25.8919	25.9574	25.9246	0.8470	1.1807	0.9061	0.8852	
9-Jan-12	23:00	36.1966	34.9589	13.0106	11.7252	21.9483	23.9848	25.8612	25.9257	25.8935	0.8477	1.1797	0.9050	0.8842	
10-Jan-12	00:00	36.1976	34.9611	13.0096	11.7238	21.9515	23.9853	25.8552	25.9400	25.8976	0.8476	1.1797	0.9048	0.8846	
10-Jan-12	01:00	36.2006	34.9638	13.0105	11.7253	21.9533	23.9871	25.8451	25.9332	25.8891	0.8480	1.1792	0.9044	0.8844	
10-Jan-12	02:00	36.2037	34.9641	13.0102	11.7244	21.9540	23.9871	25.8925	25.9497	25.9211	0.8470	1.1807	0.9061	0.8850	
10-Jan-12	03:00	36.1967	34.9574	13.0086	11.7240	21.9488	23.9830	25.8728	25.9370	25.9049	0.8473	1.1802	0.9054	0.8845	
10-Jan-12	04:00	36.2034	34.9654	13.0083	11.7222	21.9571	23.9868	25.8610	25.9673	25.9141	0.8473	1.1802	0.9050	0.8856	
10-Jan-12	05:00	36.1968	34.9610	13.0063	11.7199	21.9547	23.9836	25.8058	25.9391	25.8725	0.8486	1.1784	0.9031	0.8846	
10-Jan-12	06:00	36.1994	34.9669	13.0099	11.7260	21.9570	23.9884	25.7635	25.9189	25.8412	0.8497	1.1768	0.9016	0.8839	
10-Jan-12	07:00	36.2038	34.9638	13.0119	11.7274	21.9519	23.9879	25.9197	25.9069	25.9133	0.8472	1.1804	0.9070	0.8835	

All input in S.I.				EPS_INS_ISO_100x100mm			
Th		Tc		q		Thickness	
(C)		(C)		(W/M2)		(Meter)	
35.0		13.0		25.91		0.0257	
Dt		Tm		R		R/L	
22.0		24.0		0.85		33.0	

Project : Thermal Conductivity of small specimens														
Material : Polyiso														
Specimen : EPS_INS_ISO_50x50mm														
Thickness = 0.02548 m														
12"HFM station in Room 121														
Date	Time	T hp	T h	T c	T cp	d t	T m	Q h	Q c	Q avg	R	C	E h	E c
10-Jan-12	21:01	36.3545	34.9665	13.0405	11.5961	21.9260	24.0035	28.6704	28.8473	28.7589	0.7625	1.3116	1.0030	0.9834
10-Jan-12	22:01	36.3570	34.9667	13.0371	11.5930	21.9295	24.0019	28.7356	28.8391	28.7874	0.7618	1.3127	1.0052	0.9831
10-Jan-12	23:01	36.3640	34.9700	13.0344	11.5911	21.9357	24.0022	28.8017	28.8443	28.8230	0.7611	1.3139	1.0076	0.9833
11-Jan-12	00:01	36.3564	34.9638	13.0340	11.5878	21.9298	23.9989	28.7796	28.8991	28.8393	0.7604	1.3150	1.0068	0.9851
11-Jan-12	01:01	36.3534	34.9644	13.0305	11.5832	21.9339	23.9974	28.7473	28.8870	28.8172	0.7612	1.3138	1.0057	0.9847
11-Jan-12	02:01	36.3624	34.9644	13.0313	11.5834	21.9331	23.9978	28.9016	28.9010	28.9013	0.7589	1.3177	1.0110	0.9852
11-Jan-12	03:01	36.3527	34.9612	13.0291	11.5822	21.9321	23.9951	28.7758	28.9057	28.8408	0.7605	1.3149	1.0066	0.9854
11-Jan-12	04:01	36.3553	34.9602	13.0294	11.5820	21.9308	23.9948	28.8204	28.8874	28.8539	0.7601	1.3156	1.0082	0.9847
11-Jan-12	05:05	36.3434	34.9617	13.0288	11.5809	21.9330	23.9952	28.5789	28.8657	28.7223	0.7636	1.3095	0.9998	0.9840
11-Jan-12	06:05	36.3530	34.9615	13.0290	11.5831	21.9325	23.9952	28.7792	28.8490	28.8141	0.7612	1.3137	1.0068	0.9834
11-Jan-12	07:05	36.3519	34.9990	13.0297	11.5832	21.9293	23.9943	28.8076	28.8952	28.8514	0.7601	1.3156	1.0078	0.9850
11-Jan-12	08:05	36.3606	34.9658	13.0312	11.5853	21.9346	23.9985	28.8102	28.8950	28.8526	0.7603	1.3153	1.0078	0.9850

All input in S.I.				EPS_INS_ISO_50x50mm			
Th	Tc	q	Thickness				
(C)	(C)	(W/M2)	(Meter)				
35.0	13.0	28.82	0.0255				
Dt	Tm	R	R/L	C	k		
21.9	24.0	0.76	29.9	1.314	0.03349		

BTU Calculation					
Th	Tc	q	Thickness		
(F)	(F)	BTU*H/FT2	(Inches)		
94.9	55.5	9.14	1.00		
Dt	Tm	R	R/L	C	k
39.5	75.2	4.3	4.3	0.231	0.2322

Project :		Thermal Conductivity of small specimens													
Material :		High density glass fiber													
Specimen :		EPS_INS_HDGF_200x200mm													
Thickness =		0.02582 m													
12" HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
14-Jan-12	21:00	36.4404	35.0402	13.0023	11.5560	22.0379	24.0212	29.0266	29.0699	29.0482	0.7587	1.3181	1.0155	0.9909	
14-Jan-12	22:00	36.4531	35.0431	12.9995	11.5521	22.0436	24.0213	29.1912	29.0986	29.1449	0.7564	1.3221	1.0212	0.9919	
14-Jan-12	23:00	36.4417	35.0334	13.0003	11.5538	22.0331	24.0168	29.2131	29.1013	29.1572	0.7557	1.3233	1.0220	0.9920	
15-Jan-12	00:00	36.4246	35.0277	12.9979	11.5505	22.0299	24.0128	28.9540	29.1188	29.0364	0.7587	1.3180	1.0129	0.9926	
15-Jan-12	01:00	36.4278	35.0310	12.9944	11.5477	22.0367	24.0127	28.9657	29.1003	29.0330	0.7590	1.3175	1.0133	0.9920	
15-Jan-12	02:00	36.4337	35.0329	12.9984	11.5525	22.0345	24.0157	29.0368	29.0690	29.0529	0.7584	1.3185	1.0158	0.9909	
15-Jan-12	03:00	36.4238	35.0302	12.9958	11.5491	22.0344	24.0130	28.9300	29.0849	29.0074	0.7596	1.3164	1.0121	0.9914	
15-Jan-12	04:00	36.4404	35.0356	12.9974	11.5505	22.0382	24.0165	29.1251	29.1155	29.1203	0.7568	1.3213	1.0189	0.9925	
15-Jan-12	05:00	36.4410	35.0317	12.9954	11.5465	22.0363	24.0136	29.2089	29.1023	29.1556	0.7559	1.3230	1.0218	0.9920	
15-Jan-12	06:00	36.4330	35.0331	12.9939	11.5447	22.0392	24.0135	29.0273	29.1099	29.0686	0.7582	1.3189	1.0155	0.9923	
15-Jan-12	07:00	36.4351	35.0363	12.9929	11.5438	22.0434	24.0146	29.0109	29.1226	29.0667	0.7584	1.3186	1.0149	0.9927	
15-Jan-12	08:00	36.4392	35.0355	12.9964	11.5508	22.0391	24.0159	29.1202	29.0822	29.1012	0.7574	1.3204	1.0187	0.9914	

All input in S.I.						EPS_INS_HDGF_200x200mm							
T _h		T _c		q		Thickness							
(C)		(C)		(W/M2)		(Meter)							
35.0		13.0		29.08		0.0258							
D _t		T _m		R		R/L		C		k			
22.0		24.0		0.76		29.4		1.320		0.03407			

BTU Calculation													
T _h		T _c		q		Thickness							
(F)		(F)		BTU*H/FT2		(Inches)							
95.1		55.4		9.22		1.02							
D _t		T _m		R		R/L		C		k			
39.7		75.2		4.3		4.2		0.232		0.2362			

Project : Thermal Conductivity of small specimens														
Material : High density glass fiber														
Specimen : EPS_INS_HDGF_150x150mm														
Thickness = 0.02555 m														
12"HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
14-Jan-12	21:00	36.4404	35.0402	13.0023	11.5560	22.0379	24.0212	29.0266	29.0699	29.0482	0.7587	1.3181	1.0155	0.9909
14-Jan-12	22:00	36.4531	35.0431	12.9995	11.5521	22.0436	24.0213	29.1912	29.0986	29.1449	0.7564	1.3221	1.0212	0.9919
14-Jan-12	23:00	36.4417	35.0334	13.0003	11.5538	22.0331	24.0168	29.2131	29.1013	29.1572	0.7557	1.3233	1.0220	0.9920
15-Jan-12	00:00	36.4246	35.0277	12.9979	11.5505	22.0299	24.0128	28.9540	29.1188	29.0364	0.7587	1.3180	1.0129	0.9926
15-Jan-12	01:00	36.4278	35.0310	12.9944	11.5477	22.0367	24.0127	28.9657	29.1003	29.0330	0.7590	1.3175	1.0133	0.9920
15-Jan-12	02:00	36.4337	35.0329	12.9984	11.5525	22.0345	24.0157	29.0368	29.0690	29.0529	0.7584	1.3185	1.0158	0.9909
15-Jan-12	03:00	36.4238	35.0302	12.9958	11.5491	22.0344	24.0130	28.9300	29.0849	29.0074	0.7596	1.3164	1.0121	0.9914
15-Jan-12	04:00	36.4404	35.0356	12.9974	11.5505	22.0382	24.0165	29.1251	29.1155	29.1203	0.7568	1.3213	1.0189	0.9925
15-Jan-12	05:00	36.4410	35.0317	12.9954	11.5465	22.0363	24.0136	29.2089	29.1023	29.1556	0.7559	1.3230	1.0218	0.9920
15-Jan-12	06:00	36.4330	35.0331	12.9939	11.5447	22.0392	24.0135	29.0273	29.1099	29.0686	0.7582	1.3189	1.0155	0.9923
15-Jan-12	07:00	36.4351	35.0363	12.9929	11.5438	22.0434	24.0146	29.0109	29.1226	29.0667	0.7584	1.3186	1.0149	0.9927
15-Jan-12	08:00	36.4392	35.0355	12.9964	11.5508	22.0391	24.0159	29.1202	29.0822	29.1012	0.7574	1.3204	1.0187	0.9914

All input in S.I.

EPS_INS_HDGF_150x150mm

Th		Tc		q		Thickness	
(C)		(C)		(W/M2)		(Meter)	
35.0		13.0		29.08		0.0255	
Dt		Tm		R		R/L	
22.0		24.0		0.76		29.7	

BTU Calculation

Th		Tc		q		Thickness	
(F)		(F)		BTU*H/FT2		(Inches)	
95.1		55.4		9.22		1.01	
Dt		Tm		R		R/L	
39.7		75.2		4.3		4.3	

C		k	
1.320		0.03371	
0.232		0.2337	

Project : Thermal Conductivity of small specimens Material : High density glass fiber Specimen : EPS_INS_HDGF_100x100mm Thickness = 0.02562 m														
12" HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	dt	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
16-Jan-12	21:00	36.4223	35.0066	13.0047	11.5363	22.0018	24.0057	29.3686	29.3619	29.3652	0.7493	1.3346	1.0274	1.0008
16-Jan-12	22:00	36.4252	35.0076	13.0063	11.5383	22.0012	24.0069	29.3939	29.3968	29.3953	0.7485	1.3360	1.0282	1.0020
16-Jan-12	23:00	36.4178	35.0024	13.0066	11.5371	21.9959	24.0045	29.3806	29.3745	29.3776	0.7488	1.3356	1.0278	1.0013
17-Jan-12	00:00	36.4110	35.0051	13.0024	11.5370	22.0027	24.0038	29.2079	29.3585	29.2832	0.7514	1.3309	1.0218	1.0007
17-Jan-12	01:00	36.4231	35.0049	13.0058	11.5379	21.9991	24.0054	29.4497	29.4133	29.4315	0.7475	1.3378	1.0302	1.0026
17-Jan-12	02:00	36.4221	35.0086	13.0050	11.5372	22.0036	24.0068	29.3069	29.4047	29.3558	0.7496	1.3341	1.0252	1.0023
17-Jan-12	03:00	36.4111	35.0054	13.0058	11.5346	21.9996	24.0056	29.1546	29.4226	29.2886	0.7512	1.3313	1.0199	1.0029
17-Jan-12	04:00	36.4155	35.0070	13.0081	11.5381	21.9989	24.0075	29.2194	29.4239	29.3217	0.7503	1.3328	1.0222	1.0029
17-Jan-12	05:00	36.4202	35.0111	13.0076	11.5376	22.0035	24.0093	29.2355	29.4481	29.3418	0.7499	1.3335	1.0227	1.0038
17-Jan-12	06:00	36.4245	35.0126	13.0118	11.5397	22.0007	24.0122	29.3367	29.4362	29.3865	0.7487	1.3357	1.0263	1.0034
17-Jan-12	07:00	36.4205	35.0129	13.0109	11.5432	22.0020	24.0119	29.2009	29.3582	29.2795	0.7515	1.3307	1.0215	1.0007
17-Jan-12	08:00	36.4241	35.0117	13.0092	11.5399	22.0025	24.0104	29.2862	29.3893	29.3378	0.7500	1.3333	1.0245	1.0018
All input in S.I.														
EPS_INS_HDGF_100x100mm														
Th (C)		Tc (C)		q (W/M2)		Thickness (Meter)								
35.0		13.0		29.35		0.0256								
dt		Tm		R		R/L		C		k				
22.0		24.0		0.75		29.3		1.334		0.03417				
BTU Calculation														
Th (F)		Tc (F)		q (BTU*H/FT2)		Thickness (Inches)								
95.0		55.4		9.30		1.01								
dt		Tm		R		R/L		C		k				
39.6		75.2		4.3		4.2		0.235		0.2369				

Project : Thermal Conductivity of small specimens Material : High density glass fiber Specimen : EPS_INS_HDGF_50x50mm Thickness = 0.02355 m														
12" HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	dt	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
17-Jan-12	20:58	36.4439	35.0081	13.0439	11.5576	21.9641	24.0260	29.8151	29.7766	29.7958	0.7372	1.3565	1.0429	1.0150
17-Jan-12	21:58	36.4312	35.0025	13.0405	11.5544	21.9619	24.0215	29.6802	29.7809	29.7305	0.7387	1.3537	1.0382	1.0151
17-Jan-12	22:58	36.4376	35.0051	13.0439	11.5552	21.9613	24.0245	29.7256	29.8056	29.7656	0.7378	1.3553	1.0398	1.0159
17-Jan-12	23:58	36.4438	35.0159	13.0449	11.5569	21.9710	24.0304	29.6640	29.7981	29.7310	0.7390	1.3531	1.0377	1.0157
18-Jan-12	00:58	36.4381	35.0087	13.0447	11.5546	21.9640	24.0267	29.6592	29.8575	29.7584	0.7381	1.3548	1.0375	1.0177
18-Jan-12	01:58	36.4339	35.0043	13.0428	11.5546	21.9615	24.0235	29.6654	29.7922	29.7288	0.7388	1.3536	1.0377	1.0155
18-Jan-12	02:58	36.4309	35.0003	13.0439	11.5573	21.9564	24.0221	29.6986	29.8219	29.7602	0.7378	1.3554	1.0389	1.0165
18-Jan-12	03:58	36.4404	35.0083	13.0444	11.5575	21.9639	24.0264	29.7232	29.8234	29.7733	0.7378	1.3555	1.0397	1.0165
18-Jan-12	04:58	36.4266	35.0032	13.0458	11.5558	21.9575	24.0245	29.5682	29.8502	29.7092	0.7391	1.3530	1.0343	1.0175
18-Jan-12	05:58	36.4385	35.0054	13.0420	11.5577	21.9634	24.0237	29.7558	29.7544	29.7551	0.7382	1.3547	1.0409	1.0142
18-Jan-12	06:58	36.4376	35.0040	13.0463	11.5564	21.9577	24.0251	29.7438	29.8608	29.8023	0.7368	1.3572	1.0404	1.0178
18-Jan-12	07:58	36.4385	35.0048	13.0468	11.5603	21.9580	24.0258	29.7482	29.7794	29.7638	0.7378	1.3555	1.0406	1.0151
All input in S.I.														
EPS_INS_HDGF_50x50mm														
Th (C)		Tc (C)		q (W/M2)		Thickness (Meter)								
35.0		13.0		29.76		0.0235								
dt		Tm		R		R/L		C		k				
22.0		24.0		0.74		28.9		1.355		0.03461				
BTU Calculation														
Th (F)		Tc (F)		q (BTU*H/FT2)		Thickness (Inches)								
95.0		55.5		9.43		1.01								
dt		Tm		R		R/L		C		k				
39.5		75.2		4.2		4.2		0.239		0.2400				

Project: Thermal Conductivity of small specimens														
Material: Low density glass fiber														
Specimen: EPS_INS_LDGF_200x200mm														
Thickness = 0.02541 m														
12" HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	dt	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
3-Nov-11	20:59	36.2448	35.0288	13.0060	11.7430	22.0227	24.0174	33.371643	33.308779	33.420981	0.6601	1.5148	1.1805	1.1601
3-Nov-11	21:59	36.2520	35.0342	13.0054	11.7417	22.0288	24.0198	33.387288	33.387874	33.499329	0.6600	1.5150	1.1812	1.1605
3-Nov-11	22:59	36.2413	35.0270	13.0046	11.7393	22.0223	24.0158	33.307183	33.755739	33.402274	0.6606	1.5137	1.1827	1.1603
3-Nov-11	23:59	36.2436	35.0280	13.0048	11.7412	22.0232	24.0164	33.354941	33.385051	33.401836	0.6603	1.5144	1.1817	1.1593
4-Nov-11	00:59	36.2484	35.0302	13.0026	11.7399	22.0275	24.0164	33.388544	33.824116	33.453549	0.6602	1.5147	1.1822	1.1590
4-Nov-11	01:59	36.2443	35.0295	13.0042	11.7401	22.0253	24.0169	33.378718	33.30307	33.491846	0.6601	1.5149	1.1818	1.1597
4-Nov-11	02:59	36.2429	35.0279	13.0053	11.7412	22.0226	24.0166	33.308779	33.371843	33.408779	0.6610	1.5129	1.1819	1.1603
4-Nov-11	03:59	36.2492	35.0323	13.0037	11.7398	22.0286	24.0180	33.387874	33.387288	33.487874	0.6610	1.5130	1.1819	1.1603
4-Nov-11	04:59	36.2513	35.0342	13.0064	11.7423	22.0278	24.0203	33.755739	33.307183	33.455739	0.6603	1.5144	1.1802	1.1605
4-Nov-11	05:59	36.2411	35.0250	13.0027	11.7396	22.0223	24.0138	33.385051	33.354941	33.465051	0.6602	1.5146	1.1815	1.1595
4-Nov-11	06:59	36.2446	35.0267	13.0037	11.7402	22.0229	24.0152	33.824116	33.388544	33.424116	0.6608	1.5134	1.1820	1.1604
4-Nov-11	07:59	36.2500	35.0344	13.0035	11.7387	22.0309	24.0189	33.30307	33.378718	33.40307	0.6602	1.5147	1.1814	1.1597

All input in S.I.

EPS_INS_LDGF_200x200mm

Th	Tc	q	Thickness
(C)	(C)	(W/M2)	(Meter)
35.0	13.0	33.42	0.0254

Dt	Tm	R	R/L	C	k
22.0	24.0	0.66	25.9	1.517	0.03853

BTU Calculation

Th	Tc	q	Thickness
(F)	(F)	BTU*H/FT2	(Inches)
95.1	55.4	10.59	1.00

Dt	Tm	R	R/L	C	k
39.6	75.2	3.7	3.7	0.267	0.2673

Project: Thermal Conductivity of small specimens														
Material: Low density glass fiber														
Specimen: EPS_INS_LDGF_150x150mm														
Thickness = 0.02560 m														
12" HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
5-Nov-11	20:59	36.5649	35.0105	12.9824	11.3689	22.0281	23.9965	32.0220	32.1471	32.0845	0.6866	1.4565	1.1198	1.0953
5-Nov-11	21:59	36.5673	35.0115	12.9830	11.3706	22.0284	23.9972	32.0451	32.1487	32.0969	0.6863	1.4570	1.1206	1.0954
5-Nov-11	22:59	36.5696	35.0130	12.9843	11.3714	22.0286	23.9987	32.0331	32.1461	32.0896	0.6865	1.4567	1.1202	1.0953
5-Nov-11	23:59	36.5665	35.0127	12.9833	11.3719	22.0293	23.9980	31.9927	32.1434	32.0681	0.6870	1.4557	1.1188	1.0952
6-Nov-11	00:59	36.5727	35.0163	12.9846	11.3728	22.0317	24.0005	32.0482	32.1536	32.1009	0.6863	1.4570	1.1208	1.0955
6-Nov-11	01:59	36.5740	35.0139	12.9868	11.3730	22.0271	24.0003	32.0932	32.1524	32.1228	0.6857	1.4583	1.1223	1.0955
6-Nov-11	02:59	36.5700	35.0114	12.9849	11.3729	22.0265	23.9981	32.0743	32.1418	32.1081	0.6860	1.4577	1.1217	1.0951
6-Nov-11	03:59	36.5671	35.0094	12.9837	11.3717	22.0257	23.9965	32.0521	32.1384	32.0952	0.6863	1.4571	1.1209	1.0950
6-Nov-11	04:59	36.5665	35.0093	12.9822	11.3700	22.0271	23.9957	32.0418	32.1522	32.0970	0.6863	1.4571	1.1205	1.0955
6-Nov-11	05:59	36.5710	35.0117	12.9842	11.3707	22.0276	23.9980	32.0888	32.1514	32.1201	0.6858	1.4582	1.1222	1.0955
6-Nov-11	06:59	36.5684	35.0118	12.9844	11.3712	22.0274	23.9981	32.0495	32.1519	32.1007	0.6862	1.4573	1.1208	1.0955
6-Nov-11	07:59	36.5673	35.0117	12.9860	11.3746	22.0257	23.9989	32.0443	32.1374	32.0909	0.6864	1.4569	1.1206	1.0950

All input in S.I.				EPS_INS_LDGF_150x150mm			
Th		Tc		q		Thickness	
(C)		(C)		(W/M2)		(Meter)	
35.0		13.0		32.10		0.0256	
Dt		Tm		R		R/L	
22.0		24.0		0.69		26.8	
						C	
						1.457	
						k	
						0.03731	

BTU Calculation							
Th		Tc		q		Thickness	
(F)		(F)		BTU*H/FT2		(Inches)	
95.0		55.4		10.17		1.01	
Dt		Tm		R		R/L	
39.6		75.2		3.9		3.9	
						C	
						0.257	
						k	
						0.2587	

Project : Thermal Conductivity of small specimens															
Material : Low density glass fiber															
Specimen : EPS_INS_LDGF_100x100mm															
Thickness = 0.02575 m															
12" HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
7-Nov-11	21:01	36.5254	35.0168	12.9741	11.4087	22.0427	23.9955	30.9180	31.1572	31.0376	0.7102	1.4080	1.0814	1.0617	
7-Nov-11	22:01	36.5284	35.0198	12.9768	11.4117	22.0430	23.9983	30.9325	31.1387	31.0356	0.7103	1.4079	1.0819	1.0611	
7-Nov-11	23:01	36.5295	35.0244	12.9780	11.4115	22.0463	24.0012	30.8602	31.1569	31.0085	0.7110	1.4065	1.0793	1.0617	
8-Nov-11	00:01	36.5331	35.0253	12.9802	11.4157	22.0451	24.0027	30.9340	31.1350	31.0345	0.7104	1.4077	1.0819	1.0610	
8-Nov-11	01:01	36.5295	35.0237	12.9791	11.4136	22.0446	24.0014	30.8981	31.1335	31.0158	0.7108	1.4069	1.0807	1.0609	
8-Nov-11	02:01	36.5366	35.0258	12.9819	11.4164	22.0439	24.0039	30.9658	31.1296	31.0477	0.7100	1.4084	1.0830	1.0608	
8-Nov-11	03:01	36.5330	35.0246	12.9814	11.4156	22.0432	24.0030	30.9274	31.1403	31.0339	0.7103	1.4078	1.0817	1.0611	
8-Nov-11	04:01	36.5299	35.0254	12.9818	11.4154	22.0436	24.0036	30.8811	31.1414	31.0113	0.7108	1.4068	1.0801	1.0612	
8-Nov-11	05:01	36.5347	35.0275	12.9815	11.4158	22.0460	24.0045	30.8946	31.1354	31.0150	0.7108	1.4068	1.0805	1.0610	
8-Nov-11	06:01	36.5300	35.0226	12.9786	11.4134	22.0440	24.0006	30.9009	31.1347	31.0178	0.7107	1.4071	1.0808	1.0610	
8-Nov-11	07:01	36.5300	35.0237	12.9798	11.4143	22.0439	24.0018	30.8758	31.1351	31.0055	0.7110	1.4065	1.0799	1.0610	
8-Nov-11	08:01	36.5367	35.0237	12.9806	11.4160	22.0430	24.0021	30.9965	31.1291	31.0628	0.7096	1.4092	1.0841	1.0608	

All input in S.I.				EPS_INS_LDGF_100x100mm			
Th		Tc		q		Thickness	
(C)		(C)		(W/M2)		(Meter)	
35.0		13.0		31.03		0.0257	
Dt		Tm		R		R/L	
22.0		24.0		0.71		27.6	

Project: Thermal Conductivity of small specimens															
Material: Low density glass fiber															
Specimen: EPS_INS_LDGF_50x50mm															
Thickness = 0.02557 m															
12" HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
8-Nov-11	20:59	36.4464	34.9942	12.9330	11.4197	22.0612	23.9636	30.0316	30.2378	30.1347	0.7321	1.3659	1.0505	1.0305	
8-Nov-11	21:59	36.4437	34.9922	12.9336	11.4212	22.0586	23.9629	30.0108	30.2135	30.1121	0.7326	1.3651	1.0497	1.0297	
8-Nov-11	22:59	36.4432	34.9907	12.9310	11.4197	22.0597	23.9608	30.0743	30.1986	30.1365	0.7320	1.3661	1.0520	1.0292	
8-Nov-11	23:59	36.4442	34.9930	12.9333	11.4206	22.0597	23.9632	30.0134	30.2098	30.1116	0.7326	1.3650	1.0498	1.0295	
9-Nov-11	00:59	36.4426	34.9903	12.9296	11.4190	22.0607	23.9599	30.0379	30.2125	30.1252	0.7323	1.3655	1.0507	1.0296	
9-Nov-11	01:59	36.4422	34.9867	12.9271	11.4136	22.0596	23.9569	30.0860	30.2244	30.1552	0.7315	1.3670	1.0524	1.0300	
9-Nov-11	02:59	36.4409	34.9878	12.9268	11.4146	22.0610	23.9573	30.0427	30.2265	30.1346	0.7321	1.3659	1.0508	1.0301	
9-Nov-11	03:59	36.4377	34.9843	12.9281	11.4165	22.0562	23.9562	30.0578	30.1972	30.1275	0.7321	1.3659	1.0514	1.0291	
9-Nov-11	04:59	36.4414	34.9857	12.9264	11.4127	22.0593	23.9560	30.0936	30.2230	30.1583	0.7315	1.3671	1.0526	1.0300	
9-Nov-11	05:59	36.4370	34.9856	12.9248	11.4117	22.0608	23.9552	30.0307	30.2231	30.1269	0.7323	1.3656	1.0504	1.0300	
9-Nov-11	06:59	36.4366	34.9850	12.9250	11.4114	22.0600	23.9550	30.0251	30.2271	30.1261	0.7323	1.3656	1.0502	1.0301	
9-Nov-11	07:59	36.4410	34.9871	12.9284	11.4146	22.0587	23.9577	30.0682	30.2109	30.1396	0.7319	1.3663	1.0517	1.0296	

All input in S.I.						EPS_INS_LDGF_50x50mm								
Th		Tc		q		Thickness								
(C)		(C)		(W/M2)		(Meter)								
35.0		12.9		30.13		0.0256								
Dt		Tm		R		R/L		C		k				
22.1		24.0		0.73		28.6		1.366		0.03492				

BTU Calculation														
Th		Tc		q		Thickness								
(F)		(F)		BTU*H/FT2		(Inches)								
95.0		55.3		9.55		1.01								
Dt		Tm		R		R/L		C		k				
39.7		75.1		4.2		4.1		0.241		0.2421				

Project :		Thermal Conductivity small specimen of insulation													
Material :		Expanded Polystyrene													
Specimens :		EPS_INS_EPS_200x200 mm													
Thickness =		0.01277 m													
12" HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
19-Jun-11	22:00	37.7554	35.0063	13.0262	10.1337	21.9802	24.0163	57.3868	58.2778	57.8323	0.3801	2.6311	2.0016	1.9787	
19-Jun-11	23:00	37.7561	35.0044	13.0239	10.1375	21.9805	24.0142	57.3711	58.2379	57.8045	0.3803	2.6298	2.0010	1.9773	
20-Jun-11	00:00	37.7547	34.9995	13.0256	10.1350	21.9739	24.0126	57.3753	58.2635	57.8194	0.3800	2.6313	2.0012	1.9782	
20-Jun-11	01:00	37.7519	35.0042	13.0251	10.1335	21.9791	24.0147	57.3474	58.2619	57.8046	0.3802	2.6300	2.0002	1.9781	
20-Jun-11	02:00	37.7541	35.0028	13.0238	10.1373	21.9790	24.0133	57.3857	58.2510	57.8184	0.3801	2.6306	2.0015	1.9778	
20-Jun-11	03:00	37.7547	35.0031	13.0254	10.1319	21.9777	24.0142	57.3833	58.2806	57.8319	0.3800	2.6314	2.0015	1.9788	
20-Jun-11	04:00	37.7520	35.0013	13.0239	10.1355	21.9774	24.0126	57.3343	58.2486	57.7914	0.3803	2.6296	1.9997	1.9777	
20-Jun-11	05:00	37.7528	35.0003	13.0212	10.1321	21.9792	24.0108	57.3820	58.2669	57.8244	0.3801	2.6309	2.0014	1.9783	
20-Jun-11	06:00	37.7516	34.9988	13.0236	10.1337	21.9751	24.0112	57.4040	58.2720	57.8380	0.3799	2.6320	2.0022	1.9785	
20-Jun-11	07:00	37.7523	35.0029	13.0264	10.1354	21.9766	24.0146	57.3288	58.2588	57.7938	0.3803	2.6298	1.9996	1.9780	
20-Jun-11	08:00	37.7517	35.0000	13.0257	10.1358	21.9742	24.0129	57.3739	58.2593	57.8166	0.3801	2.6311	2.0011	1.9781	
20-Jun-11	09:00	37.7575	35.0024	13.0248	10.1358	21.9777	24.0136	57.4265	58.2881	57.8573	0.3799	2.6325	2.0029	1.9790	

All input in S.I.				EPS_INS_EPS_200x200 mm			
Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)				
35.0	13.0	57.82	0.0128				
Dt	Tm	R	R/L	C	K		
22.0	24.0	0.38	29.8	2.631	0.03361		

BTU Calculation							
Th (F)	Tc (F)	Q BTU*H/FT2	Thickness (Inches)				
95.0	55.4	18.33	0.50				
Dt	Tm	R	R/L	C	K		
39.6	75.2	2.2	4.3	0.463	0.2330		

Project :

Thermal Conductivity small specimen of insulation

Material :

Expanded Polystyrene

Specimen :

EPS_INS_EPS_150x150 mm

Thickness =

0.01275 m

12"HFM station in Room 121

Date	Time	T _{hp}	T _h	T _c	T _{cp}	dt	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
21-Jun-11	04:04	37.7576	34.9903	13.0358	10.1332	21.9545	24.0131	57.4922	58.3478	57.9200	0.3791	2.6382	2.0052	1.9810
21-Jun-11	05:04	37.7568	34.9903	13.0380	10.1343	21.9523	24.0142	57.5216	58.3728	57.9472	0.3788	2.6397	2.0062	1.9819
21-Jun-11	06:04	37.7513	34.9874	13.0406	10.1378	21.9468	24.0140	57.4681	58.3882	57.9282	0.3789	2.6395	2.0043	1.9824
21-Jun-11	07:04	37.7549	34.9904	13.0416	10.1386	21.9488	24.0160	57.4809	58.3767	57.9288	0.3789	2.6393	2.0048	1.9820
21-Jun-11	08:04	37.7560	34.9891	13.0414	10.1400	21.9477	24.0152	57.5101	58.3563	57.9332	0.3788	2.6396	2.0058	1.9813
21-Jun-11	09:04	37.7599	34.9941	13.0392	10.1351	21.9548	24.0167	57.5079	58.3716	57.9398	0.3789	2.6390	2.0057	1.9818
21-Jun-11	10:04	37.7584	34.9943	13.0455	10.1416	21.9488	24.0199	57.4457	58.3517	57.8987	0.3791	2.6379	2.0036	1.9811
21-Jun-11	11:04	37.7540	34.9908	13.0430	10.1423	21.9478	24.0169	57.4831	58.3477	57.9154	0.3790	2.6388	2.0049	1.9810
21-Jun-11	12:04	37.7605	34.9951	13.0444	10.1421	21.9507	24.0198	57.5008	58.3693	57.9351	0.3789	2.6393	2.0055	1.9818
21-Jun-11	13:04	37.7580	34.9918	13.0437	10.1410	21.9481	24.0178	57.4894	58.3692	57.9293	0.3789	2.6394	2.0051	1.9817
21-Jun-11	14:04	37.7594	34.9977	13.0445	10.1436	21.9531	24.0211	57.4687	58.3755	57.9221	0.3790	2.6384	2.0044	1.9820
21-Jun-11	15:04	37.7652	34.9966	13.0442	10.1427	21.9524	24.0204	57.5105	58.3607	57.9356	0.3789	2.6391	2.0058	1.9815

All input in S.I.

EPS_INS_EPS_150x150 mm

Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)
35.0	13.0	57.93	0.0127

Dt 22.0	Tm 24.0	R 0.38	R/L 29.7	C 2.639	K 0.03364
------------	------------	-----------	-------------	------------	--------------

BTU Calculation

Th (F)	Tc (F)	Q BTU*h/FT2	Thickness (Inches)
95.0	55.5	18.36	0.50

Dt 39.5	Tm 75.2	R 2.2	R/L 4.3	C 0.465	K 0.2332
------------	------------	----------	------------	------------	-------------

Project : Thermal Conductivity smal specimen of insulation

Material : Expanded Polystyrene

Specimen : EPS_INS_EPS_100x100 mm

Thickness = 0.01275 m

12" HFM station in Room 121

Date	Time	T _{hp}	T _h	T _c	T _{cp}	dt	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
21-Jun-11	21:00	37.8076	35.0095	13.0220	10.0805	21.9875	24.0157	58.4036	59.2560	58.8298	0.3738	2.6756	2.0368	2.0116
21-Jun-11	22:00	37.8171	35.0111	13.0242	10.0903	21.9869	24.0177	58.5058	59.2700	58.8879	0.3734	2.6783	2.0404	2.0121
21-Jun-11	23:00	37.8111	35.0102	13.0276	10.0892	21.9826	24.0189	58.4145	59.2429	58.8287	0.3737	2.6761	2.0372	2.0112
22-Jun-11	00:00	37.8103	35.0101	13.0268	10.0882	21.9833	24.0185	58.3582	59.2739	58.8160	0.3738	2.6755	2.0353	2.0122
22-Jun-11	01:00	37.8108	35.0091	13.0239	10.0838	21.9852	24.0165	58.3993	59.2832	58.8413	0.3736	2.6764	2.0367	2.0125
22-Jun-11	02:00	37.8102	35.0060	13.0247	10.0854	21.9813	24.0154	58.4436	59.2884	58.8660	0.3734	2.6780	2.0382	2.0127
22-Jun-11	03:02	37.8087	35.0069	13.0204	10.0843	21.9866	24.0136	58.4101	59.2764	58.8432	0.3736	2.6763	2.0370	2.0123
22-Jun-11	04:02	37.8076	35.0037	13.0205	10.0834	21.9833	24.0121	58.4449	59.2354	58.8401	0.3736	2.6766	2.0382	2.0109
22-Jun-11	05:02	37.8053	35.0018	13.0197	10.0819	21.9821	24.0107	58.4856	59.2567	58.8711	0.3734	2.6781	2.0397	2.0116
22-Jun-11	06:02	37.8029	35.0034	13.0162	10.0815	21.9871	24.0098	58.3861	59.2554	58.8207	0.3738	2.6752	2.0362	2.0116
22-Jun-11	07:02	37.8001	34.9973	13.0161	10.0787	21.9813	24.0067	58.4230	59.2536	58.8383	0.3736	2.6767	2.0375	2.0115
22-Jun-11	08:02	37.8034	35.0010	13.0178	10.0817	21.9832	24.0094	58.4001	59.2797	58.8399	0.3736	2.6766	2.0367	2.0124

All input in S.I.

EPS_INS_EPS_100x100 mm

Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)		
35.0	13.0	58.84	0.0128		
Dt	Tm	R	R/L	C	K
22.0	24.0	0.37	29.3	2.677	0.03413

BTU Calculation

Th (F)	Tc (F)	Q BTU*H/FT2	Thickness (Inches)		
95.0	55.4	18.65	0.50		
Dt	Tm	R	R/L	C	K
39.6	75.2	2.1	4.2	0.471	0.2366

Project : Thermal Conductivity small specimen of insulation
 Material : Expanded Polystyrene
 Specimen : EPS_INS_EPS_50x50 mm
 Thickness = 0.01277 m

12"HFM station in Room 121

Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
22-Jun-11	21:00	37.8073	35.0491	12.9845	10.0862	22.0646	24.0168	57.5034	58.3670	57.9352	0.3809	2.6257	2.0057	1.9816
22-Jun-11	22:00	37.8093	35.0509	12.9819	10.0870	22.0691	24.0164	57.5317	58.3867	57.9592	0.3808	2.6263	2.0067	1.9823
22-Jun-11	23:02	37.8109	35.0518	12.9836	10.0887	22.0682	24.0177	57.4793	58.3762	57.9278	0.3810	2.6249	2.0049	1.9819
23-Jun-11	00:02	37.8089	35.0467	12.9825	10.0872	22.0642	24.0146	57.5244	58.3949	57.9596	0.3807	2.6269	2.0064	1.9826
23-Jun-11	01:02	37.8089	35.0485	12.9787	10.0845	22.0697	24.0136	57.5285	58.3844	57.9565	0.3808	2.6260	2.0066	1.9822
23-Jun-11	02:02	37.8092	35.0490	12.9824	10.0858	22.0666	24.0157	57.5393	58.3688	57.9540	0.3808	2.6263	2.0069	1.9817
23-Jun-11	03:02	37.8111	35.0503	12.9810	10.0872	22.0693	24.0156	57.5397	58.3678	57.9538	0.3808	2.6260	2.0069	1.9816
23-Jun-11	04:02	37.8105	35.0515	12.9817	10.0879	22.0697	24.0166	57.5237	58.3816	57.9526	0.3808	2.6259	2.0064	1.9821
23-Jun-11	05:02	37.8107	35.0507	12.9808	10.0860	22.0699	24.0158	57.5079	58.4011	57.9545	0.3808	2.6259	2.0058	1.9828
23-Jun-11	06:04	37.8070	35.0499	12.9790	10.0818	22.0710	24.0144	57.4695	58.3991	57.9343	0.3810	2.6249	2.0045	1.9827
23-Jun-11	07:04	37.8117	35.0524	12.9826	10.0890	22.0698	24.0175	57.5052	58.3725	57.9389	0.3809	2.6252	2.0058	1.9818
23-Jun-11	08:04	37.8063	35.0502	12.9815	10.0870	22.0687	24.0158	57.4806	58.3617	57.9211	0.3810	2.6246	2.0049	1.9814

All input in S.I.

EPS_INS_EPS_50x50 mm

Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)
35.1	13.0	57.95	0.0128
Dt	Tm	R	R/L
22.1	24.0	0.38	29.8

C	K
2.626	0.03354

BTU Calculation

Th (F)	Tc (F)	Q BTU*H/FT2	Thickness (Inches)		
95.1	55.4	18.37	0.50		
Dt	Tm	R	R/L	C	K
39.7	75.2	2.2	4.3	0.462	0.2325

Project : Thermal Conductivity of small specimens
 Material : Low density glass fiber
 Specimen : EPS_INS_LDGF_200x200mm
 Thickness = 0.01277 m

12"HFM station in Room 121

Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
16-Oct-11	20:59	38.2018	34.9775	13.0068	9.6574	21.9707	23.9922	67.2156	67.3943	67.3050	0.3264	3.0634	2.3419	2.2853
16-Oct-11	21:59	38.2065	34.9828	13.0123	9.6622	21.9705	23.9975	67.1880	67.4092	67.2986	0.3265	3.0631	2.3410	2.2858
16-Oct-11	22:59	38.2079	34.9841	13.0168	9.6675	21.9673	24.0004	67.1910	67.3867	67.2889	0.3265	3.0631	2.3411	2.2850
16-Oct-11	23:59	38.2071	34.9834	13.0180	9.6706	21.9654	24.0007	67.1967	67.3795	67.2881	0.3264	3.0634	2.3413	2.2848
17-Oct-11	00:59	38.2086	34.9859	13.0182	9.6698	21.9676	24.0020	67.1839	67.3854	67.2847	0.3265	3.0629	2.3408	2.2850
17-Oct-11	01:59	38.2094	34.9864	13.0199	9.6716	21.9665	24.0032	67.2106	67.3793	67.2950	0.3264	3.0635	2.3418	2.2848
17-Oct-11	02:59	38.2103	34.9861	13.0187	9.6711	21.9674	24.0024	67.2062	67.3816	67.2939	0.3264	3.0633	2.3416	2.2849
17-Oct-11	03:59	38.2121	34.9894	13.0208	9.6717	21.9685	24.0051	67.2005	67.4097	67.3051	0.3264	3.0637	2.3414	2.2858
17-Oct-11	04:59	38.2124	34.9880	13.0216	9.6709	21.9664	24.0048	67.1943	67.4230	67.3087	0.3264	3.0642	2.3412	2.2863
17-Oct-11	05:59	38.2126	34.9889	13.0212	9.6706	21.9677	24.0051	67.1981	67.4074	67.3027	0.3264	3.0637	2.3413	2.2857
17-Oct-11	06:59	38.2106	34.9857	13.0232	9.6730	21.9624	24.0045	67.2151	67.4046	67.3098	0.3263	3.0648	2.3419	2.2856
17-Oct-11	07:59	38.2142	34.9922	13.0270	9.6764	21.9652	24.0096	67.1750	67.4114	67.2932	0.3264	3.0636	2.3405	2.2859

All input in S.I.

EPS_INS_LDGF_200x200mm

Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)		
35.0	13.0	67.30	0.0128		
Dt	Tm	R	R/L	C	K
22.0	24.0	0.33	25.6	3.064	0.0381

BTU Calculation

Th (F)	Tc (F)	Q BTU*H/FT2	Thickness (Inches)		
95.0	55.4	21.33	0.50		
<hr/>					
Dt	Tm	R	R/L	C	K
39.5	75.2	1.9	3.7	0.540	0.271

Project :		Thermal Conductivity of small specimens													
Material :		Low density glass fiber													
Specimens :		EPS_INS_LDGF_150x150mm							12"HFM station in Room 121						
Thickness =		0.01276 m													
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
15-Oct-11	21:01	38.0095	34.9058	13.0947	9.8644	21.8112	24.0003	63.8723	64.3589	64.1156	0.3402	2.9396	2.2259	2.1832	
15-Oct-11	22:01	38.0077	34.9096	13.0979	9.8670	21.8117	24.0038	63.7725	64.3517	64.0621	0.3405	2.9370	2.2224	2.1830	
15-Oct-11	23:01	38.0116	34.9105	13.0976	9.8663	21.8129	24.0041	63.8179	64.3731	64.0955	0.3403	2.9384	2.2240	2.1837	
16-Oct-11	00:01	38.0091	34.9103	13.1001	9.8684	21.8102	24.0052	63.7892	64.3536	64.0714	0.3404	2.9377	2.2230	2.1830	
16-Oct-11	01:01	38.0084	34.9103	13.1004	9.8701	21.8100	24.0053	63.7661	64.3400	64.0531	0.3405	2.9369	2.2222	2.1826	
16-Oct-11	02:01	38.0137	34.9126	13.1029	9.8723	21.8097	24.0078	63.8313	64.3469	64.0891	0.3403	2.9385	2.2245	2.1828	
16-Oct-11	03:01	38.0160	34.9141	13.1017	9.8713	21.8123	24.0079	63.8465	64.3490	64.0978	0.3403	2.9386	2.2250	2.1829	
16-Oct-11	04:01	38.0091	34.9111	13.1015	9.8698	21.8096	24.0063	63.7685	64.3723	64.0704	0.3404	2.9377	2.2223	2.1837	
16-Oct-11	05:01	38.0114	34.9103	13.1010	9.8689	21.8093	24.0056	63.8183	64.3638	64.0911	0.3403	2.9387	2.2240	2.1834	
16-Oct-11	06:01	38.0130	34.9132	13.1006	9.8700	21.8126	24.0069	63.7945	64.3387	64.0666	0.3405	2.9371	2.2232	2.1825	
16-Oct-11	07:01	38.0170	34.9163	13.1042	9.8735	21.8121	24.0103	63.8374	64.3345	64.0859	0.3404	2.9381	2.2247	2.1824	
16-Oct-11	08:01	38.0095	34.9109	13.1039	9.8730	21.8070	24.0074	63.7768	64.3445	64.0607	0.3404	2.9376	2.2226	2.1827	

All input in S.I.				EPS_INS_LDGF_150x150mm			
T _h	T _c	Q	Thickness				
(C)	(C)	(W/M2)	(Meter)				
34.9	13.1	64.08	0.0128				
D _t	T _m	R	R/L	C	K		
21.8	24.0	0.34	26.7	2.938	0.03750		

BTU Calculation							
T _h	T _c	Q	Thickness				
(F)	(F)	BTU*H/FT2	(Inches)				
94.8	55.6	20.31	0.50				
D _t	T _m	R	R/L	C	K		
39.3	75.2	1.9	3.8	0.517	0.2600		

Project: Thermal Conductivity of small specimens														
Material: Low density glass fiber														
Specimens: EPS_INS_LDGF_100x100mm														
12" HFM station in Room 121														
Thickness = 0.01279 m														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
17-Oct-11	20:59	37.9858	35.0583	12.9351	9.8932	22.1232	23.9967	60.7176	61.0526	60.8851	0.3634	2.7521	2.1170	2.0719
17-Oct-11	21:59	37.9831	35.0594	12.9339	9.8927	22.1255	23.9967	60.6757	61.0652	60.8704	0.3635	2.7511	2.1156	2.0723
17-Oct-11	22:59	37.9801	35.0572	12.9331	9.8930	22.1241	23.9952	60.6370	61.0519	60.8444	0.3636	2.7501	2.1142	2.0718
17-Oct-11	23:59	37.9842	35.0576	12.9339	9.8927	22.1237	23.9957	60.6945	61.0562	60.8754	0.3634	2.7516	2.1162	2.0720
18-Oct-11	00:59	37.9795	35.0580	12.9326	9.8918	22.1254	23.9953	60.6265	61.0566	60.8415	0.3637	2.7498	2.1139	2.0720
18-Oct-11	01:59	37.9795	35.0570	12.9319	9.8921	22.1250	23.9944	60.6414	61.0778	60.8596	0.3635	2.7507	2.1144	2.0727
18-Oct-11	02:59	37.9793	35.0552	12.9320	9.8916	22.1232	23.9936	60.6773	61.0404	60.8588	0.3635	2.7509	2.1156	2.0715
18-Oct-11	03:59	37.9805	35.0563	12.9314	9.8907	22.1249	23.9938	60.6720	61.0451	60.8585	0.3635	2.7507	2.1154	2.0716
18-Oct-11	04:59	37.9744	35.0524	12.9302	9.8897	22.1222	23.9913	60.6361	61.0731	60.8546	0.3635	2.7508	2.1142	2.0726
18-Oct-11	05:59	37.9792	35.0563	12.9319	9.8920	22.1244	23.9941	60.6464	61.0489	60.8476	0.3636	2.7502	2.1146	2.0717
18-Oct-11	06:59	37.9803	35.0576	12.9358	9.8951	22.1218	23.9967	60.6498	61.0582	60.8540	0.3635	2.7509	2.1147	2.0721
18-Oct-11	07:59	37.9826	35.0586	12.9375	9.8975	22.1212	23.9981	60.6742	61.0662	60.8702	0.3634	2.7517	2.1155	2.0723

All input in S.I.						EPS_INS_LDGF_100x100mm							
Th		Tc		Q		Thickness							
(C)		(C)		(W/M2)		(Meter)							
35.1		12.9		60.86		0.0128							
Dt		Tm		R		R/L		C		K			
22.1		24.0		0.36		28.4		2.751		0.03520			

BTU Calculation													
Th		Tc		Q		Thickness							
(F)		(F)		BTU*H/FT2		(Inches)							
95.1		55.3		19.29		0.50							
Dt		Tm		R		R/L		C		K			
39.8		75.2		2.1		4.1		0.484		0.2440			

Project : Thermal Conductivity of small specimens														
Material : Low density glass fiber														
Specimens : EPS_INS_LDGF_50x50mm														
12"HFM station in Room 121														
Thickness = 0.01279 m														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
18-Oct-11	06:59	37.9803	35.0576	12.9358	9.8951	22.1218	23.9967	60.6498	61.0582	60.8540	0.3635	2.7509	2.1147	2.0721
18-Oct-11	07:59	37.9826	35.0586	12.9375	9.8975	22.1212	23.9981	60.6742	61.0662	60.8702	0.3634	2.7517	2.1155	2.0723
18-Oct-11	08:59	37.9791	35.0575	12.9360	9.8948	22.1216	23.9968	60.6302	61.0747	60.8525	0.3635	2.7508	2.1140	2.0726
18-Oct-11	09:59	37.9833	35.0587	12.9370	9.8962	22.1218	23.9978	60.6695	61.0521	60.8608	0.3635	2.7512	2.1154	2.0719
18-Oct-11	10:59	37.9836	35.0601	12.9384	9.8991	22.1217	23.9992	60.6590	61.0227	60.8408	0.3636	2.7503	2.1150	2.0709
18-Oct-11	11:59	37.9845	35.0616	12.9397	9.8991	22.1219	24.0006	60.6567	61.0642	60.8605	0.3635	2.7511	2.1149	2.0723
18-Oct-11	12:59	37.9879	35.0613	12.9386	9.8957	22.1226	24.0000	60.7273	61.0910	60.9091	0.3632	2.7532	2.1174	2.0732
18-Oct-11	13:59	37.9813	35.0573	12.9339	9.8924	22.1234	23.9956	60.6742	61.0643	60.8692	0.3635	2.7513	2.1155	2.0723
18-Oct-11	14:59	37.9805	35.0547	12.9294	9.8885	22.1254	23.9920	60.7003	61.0832	60.8917	0.3634	2.7521	2.1164	2.0729
18-Oct-11	15:59	37.9763	35.0536	12.9296	9.8903	22.1240	23.9916	60.6369	61.0658	60.8514	0.3636	2.7504	2.1142	2.0723
18-Oct-11	16:59	37.9788	35.0533	12.9302	9.8891	22.1231	23.9918	60.6920	61.0900	60.8910	0.3633	2.7524	2.1161	2.0731
18-Oct-11	17:27	37.9744	35.0499	12.9256	9.8852	22.1243	23.9877	60.6846	61.0754	60.8800	0.3634	2.7517	2.1159	2.0726

All input in S.I.						EPS_INS_LDGF_50x50mm							
Th		Tc		Q		Thickness							
(C)		(C)		(W/M2)		(Meter)							
35.1		12.9		60.87		0.0128							
Dt		Tm		R		R/L		C		K			
22.1		24.0		0.36		28.4		2.751		0.03520			

BTU Calculation													
Th		Tc		Q		Thickness							
(F)		(F)		BTU*H/FT2		(Inches)							
95.1		55.3		19.30		0.50							
Dt		Tm		R		R/L		C		K			
39.8		75.2		2.1		4.1		0.485		0.2441			

Project :	Thermal Conductivity of small specimens													
Material :	Extruded polystyrene													
Specimen :	EPS_INS_XPS_200x200mm													
Thickness =	0.01272 m													
12" HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
12-Jul-11	14:00	37.4605	34.9867	13.0002	10.4160	21.9863	23.9935	51.4568	52.1352	51.7960	0.4245	2.3558	1.7958	1.7716
12-Jul-11	15:00	37.4603	34.9931	12.9985	10.4126	21.9946	23.9958	51.4302	52.1612	51.7957	0.4246	2.3549	1.7949	1.7725
12-Jul-11	16:00	37.4663	34.9954	12.9994	10.4124	21.9960	23.9974	51.4274	52.1522	51.7898	0.4247	2.3545	1.7948	1.7721
12-Jul-11	17:00	37.4612	34.9926	12.9978	10.4116	21.9948	23.9952	51.4441	52.1405	51.7923	0.4247	2.3547	1.7954	1.7718
12-Jul-11	18:00	37.4667	34.9938	12.9924	10.4100	22.0014	23.9931	51.4887	52.1538	51.8213	0.4246	2.3554	1.7969	1.7722
12-Jul-11	19:00	37.4599	34.9898	12.9940	10.4101	21.9958	23.9919	51.4536	52.1628	51.8082	0.4246	2.3554	1.7957	1.7725
12-Jul-11	20:00	37.4569	34.9878	12.9872	10.4013	22.0007	23.9875	51.4526	52.1689	51.8108	0.4246	2.3549	1.7957	1.7727
12-Jul-11	21:00	37.4522	34.9828	12.9859	10.3986	21.9968	23.9844	51.4447	52.1918	51.8182	0.4245	2.3557	1.7954	1.7735
12-Jul-11	22:00	37.4542	34.9849	12.9870	10.3993	21.9979	23.9859	51.4400	52.1823	51.8111	0.4246	2.3553	1.7953	1.7731
12-Jul-11	23:00	37.4546	34.9846	12.9865	10.4014	21.9980	23.9855	51.4535	52.1703	51.8119	0.4246	2.3553	1.7957	1.7728
13-Jul-11	00:00	37.4546	34.9853	12.9867	10.3970	21.9986	23.9860	51.4640	52.2104	51.8372	0.4244	2.3564	1.7961	1.7741
13-Jul-11	01:00	37.4512	34.9798	12.9838	10.3984	21.9961	23.9818	51.4371	52.1806	51.8088	0.4246	2.3554	1.7951	1.7731

All input in S.I.						EPS_INS_XPS_200x200mm							
Th (C)		Tc (C)		Q (W/M2)		Thickness (Meter)							
35.0		13.0		51.81		0.0127							
Dt 22.0		Tm 24.0		R 0.42		R/L 33.4		C 2.355		K 0.02896			

BTU Calculation													
Th (F)		Tc (F)		Q BTU* ^h /FT ²		Thickness (Inches)							
95.0		55.4		16.42		0.50							
Dt 39.6		Tm 75.2		R 2.4		R/L 4.8		C 0.415		K 0.2078			

Project :	Thermal Conductivity of small specimens													
Material :	Extruded polystyrene													
Specimen :	EPS_INS_XPS_150x150mm													
Thickness =	0.01271 m													
12"HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
16-Jul-11	20:15	37.3968	34.9718	13.0192	10.4746	21.9527	23.9955	50.4844	51.0700	50.7772	0.4323	2.3130	1.7621	1.7356
16-Jul-11	21:15	37.4013	34.9756	13.0044	10.4598	21.9711	23.9900	50.5270	51.0657	50.7964	0.4325	2.3120	1.7635	1.7354
16-Jul-11	22:15	37.4015	34.9753	13.0028	10.4572	21.9725	23.9891	50.5200	51.0783	50.7991	0.4325	2.3119	1.7633	1.7359
16-Jul-11	23:15	37.4032	34.9776	13.0053	10.4603	21.9723	23.9915	50.5325	51.0907	50.8116	0.4324	2.3125	1.7637	1.7363
17-Jul-11	00:15	37.4057	34.9790	13.0066	10.4609	21.9724	23.9928	50.5471	51.0974	50.8223	0.4323	2.3130	1.7642	1.7365
17-Jul-11	01:15	37.4001	34.9759	13.0063	10.4611	21.9696	23.9911	50.4737	51.1181	50.7959	0.4325	2.3121	1.7617	1.7372
17-Jul-11	02:15	37.3988	34.9731	13.0049	10.4616	21.9682	23.9890	50.5050	51.1061	50.8056	0.4324	2.3127	1.7628	1.7368
17-Jul-11	03:15	37.4016	34.9756	13.0065	10.4617	21.9690	23.9911	50.5359	51.0878	50.8119	0.4324	2.3129	1.7639	1.7362
17-Jul-11	04:15	37.4015	34.9754	13.0058	10.4639	21.9696	23.9906	50.5241	51.0849	50.8045	0.4324	2.3125	1.7634	1.7361
17-Jul-11	05:15	37.4040	34.9782	13.0104	10.4650	21.9677	23.9943	50.5289	51.0978	50.8133	0.4323	2.3131	1.7636	1.7365
17-Jul-11	06:15	37.4040	34.9774	13.0112	10.4663	21.9662	23.9943	50.5252	51.0865	50.8059	0.4324	2.3129	1.7635	1.7362
17-Jul-11	07:15	37.4044	34.9783	13.0123	10.4666	21.9661	23.9953	50.5135	51.1201	50.8168	0.4323	2.3134	1.7631	1.7373
All input in S.I.														
EPS_INS_XPS_150x150mm														
Th (C)		Tc (C)		Q (W/M2)		Thickness (Meter)								
35.0		13.0		50.81		0.0127								
Dt 22.0		Tm 24.0		R 0.43		R/L 34.0		C 2.313		K 0.02939				
BTU Calculation														
Th (F)		Tc (F)		Q BTU*h/FT2		Thickness (Inches)								
95.0		55.4		16.11		0.50								
Dt 39.5		Tm 75.2		R 2.5		R/L 4.9		C 0.407		K 0.2038				

Project:		Thermal Conductivity of small specimens													
Material:		Extruded polystyrene													
Specimen:		EPS_INS_XPS_100x100mm													
Thickness =		0.01274 m													
12"HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
17-Jul-11	22:01	37.5521	34.9628	13.0413	10.3229	21.9215	24.0020	54.0560	54.7845	54.4203	0.4028	2.4825	1.8860	1.8610	
17-Jul-11	23:01	37.5482	34.9589	13.0402	10.3207	21.9187	23.9996	54.0436	54.8166	54.4301	0.4027	2.4833	1.8856	1.8621	
18-Jul-11	00:01	37.5540	34.9643	13.0413	10.3213	21.9230	24.0028	54.0673	54.8225	54.4449	0.4027	2.4834	1.8864	1.8623	
18-Jul-11	01:01	37.5553	34.9642	13.0414	10.3207	21.9229	24.0028	54.1049	54.8334	54.4692	0.4025	2.4846	1.8877	1.8626	
18-Jul-11	02:01	37.5572	34.9657	13.0422	10.3227	21.9234	24.0039	54.1200	54.8309	54.4755	0.4024	2.4848	1.8882	1.8626	
18-Jul-11	03:01	37.5492	34.9602	13.0420	10.3222	21.9182	24.0011	54.0596	54.8078	54.4337	0.4027	2.4835	1.8861	1.8618	
18-Jul-11	04:01	37.5503	34.9606	13.0403	10.3210	21.9204	24.0005	54.0690	54.8227	54.4459	0.4026	2.4838	1.8865	1.8623	
18-Jul-11	05:01	37.5491	34.9603	13.0413	10.3208	21.9190	24.0008	54.0503	54.8201	54.4352	0.4027	2.4835	1.8858	1.8622	
18-Jul-11	06:01	37.5528	34.9602	13.0394	10.3187	21.9209	23.9998	54.1083	54.8469	54.4776	0.4024	2.4852	1.8878	1.8631	
18-Jul-11	07:01	37.5509	34.9610	13.0438	10.3240	21.9172	24.0024	54.0620	54.8152	54.4386	0.4026	2.4838	1.8862	1.8620	
18-Jul-11	08:01	37.5523	34.9616	13.0458	10.3273	21.9158	24.0037	54.0898	54.8080	54.4489	0.4025	2.4844	1.8872	1.8618	
18-Jul-11	09:01	37.5475	34.9545	13.0376	10.3176	21.9169	23.9960	54.1071	54.8419	54.4745	0.4023	2.4855	1.8878	1.8629	

All input in S.I.						EPS_INS_XPS_100x100mm							
T _h		T _c		Q		Thickness							
(C)		(C)		(W/M2)		(Meter)							
35.0		13.0		54.45		0.0127							
D _t		T _m		R		R/L		C		K			
21.9		24.0		0.40		31.6		2.484		0.03218			

BTU Calculation													
T _h		T _c		Q		Thickness							
(F)		(F)		BTU* ^h /FT2		(Inches)							
94.9		55.5		17.26		0.50							
D _t		T _m		R		R/L		C		K			
39.5		75.2		2.3		4.6		0.437		0.2194			

Project :		Thermal Conductivity of small specimens													
Material :		Extruded polystyrene													
Specimen :		EPS_INS_XPS_50x50mm													
Thickness =		0.01264 m													
12"HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
13-Jul-11	16:54	37.6666	34.9772	13.1720	10.3216	21.8053	24.0746	56.1335	57.5310	56.8322	0.3837	2.6063	1.9581	1.9538	
13-Jul-11	17:54	37.5737	34.8665	12.9925	10.1579	21.8740	23.9295	56.4277	57.2397	56.8337	0.3849	2.5982	1.9681	1.9437	
13-Jul-11	18:54	37.5767	34.8659	12.9850	10.1508	21.8809	23.9255	56.5098	57.2723	56.8911	0.3846	2.6000	1.9710	1.9448	
13-Jul-11	19:54	37.5738	34.8645	12.9827	10.1481	21.8818	23.9236	56.4882	57.2603	56.8742	0.3847	2.5991	1.9702	1.9444	
13-Jul-11	20:54	37.5771	34.8644	12.9817	10.1481	21.8828	23.9231	56.5301	57.2654	56.8977	0.3846	2.6001	1.9716	1.9445	
13-Jul-11	21:54	37.5694	34.8578	12.9836	10.1483	21.8742	23.9207	56.4770	57.2535	56.8653	0.3847	2.5996	1.9698	1.9441	
13-Jul-11	22:54	37.5703	34.8604	12.9824	10.1441	21.8780	23.9214	56.4651	57.2800	56.8726	0.3847	2.5995	1.9694	1.9450	
13-Jul-11	23:54	37.5652	34.8553	12.9737	10.1375	21.8816	23.9145	56.5147	57.2726	56.8937	0.3846	2.6001	1.9711	1.9448	
14-Jul-11	00:54	37.5664	34.8570	12.9759	10.1375	21.8811	23.9164	56.4588	57.2819	56.8703	0.3848	2.5990	1.9692	1.9451	
14-Jul-11	01:54	37.5645	34.8536	12.9751	10.1409	21.8785	23.9144	56.4846	57.2596	56.8721	0.3847	2.5994	1.9701	1.9443	
14-Jul-11	02:54	37.5650	34.8553	12.9729	10.1370	21.8824	23.9141	56.4835	57.2492	56.8663	0.3848	2.5987	1.9700	1.9440	
14-Jul-11	03:54	37.5641	34.8548	12.9729	10.1346	21.8819	23.9138	56.4905	57.2962	56.8933	0.3846	2.6000	1.9703	1.9455	
All input in S.I.															
EPS_INS_XPS_50x50mm															
T _h		T _c		Q		Thickness									
(C)		(C)		(W/M2)		(Meter)									
34.9		13.0		56.87		0.0126									
D _t		T _m		R		R/L		C		K					
21.9		23.9		0.38		30.4		2.600		0.033					
BTU Calculation															
T _h		T _c		Q		Thickness									
(F)		(F)		BTU* _h /FT ²		(Inches)									
94.8		55.4		18.03		0.50									
D _t		T _m		R		R/L		C		K					
39.4		75.1		2.2		4.4		0.458		0.2279					

Project : Thermal Conductivity of small specimens														
Material : Polyurethane														
Specimen : EPS_INS_PUR_200x200mm														
Thickness = 0.01274 m														
12" HFM station in Room 121														
Date	Time	T hp	T h	T c	T ep	dt	T m	Q h	Q c	Q avg	R	C	E h	E c
28-Sep-11	20:59	37.1592	35.0315	12.9822	10.7608	22.0492	24.0069	44.0470	44.5098	44.2784	0.4980	2.0081	1.5385	1.5140
28-Sep-11	21:59	37.1579	35.0318	12.9829	10.7609	22.0489	24.0074	44.0252	44.4792	44.2522	0.4983	2.0070	1.5377	1.5129
28-Sep-11	22:59	37.1555	35.0320	12.9830	10.7631	22.0490	24.0075	44.0037	44.4790	44.2413	0.4984	2.0065	1.5370	1.5129
28-Sep-11	23:59	37.1607	35.0354	12.9814	10.7622	22.0540	24.0084	44.0327	44.4701	44.2514	0.4984	2.0065	1.5380	1.5126
29-Sep-11	00:59	37.1523	35.0276	12.9793	10.7585	22.0483	24.0034	43.9784	44.4791	44.2287	0.4985	2.0060	1.5361	1.5129
29-Sep-11	01:59	37.1578	35.0312	12.9811	10.7607	22.0501	24.0062	44.0383	44.4684	44.2534	0.4983	2.0069	1.5382	1.5126
29-Sep-11	02:59	37.1566	35.0313	12.9808	10.7598	22.0505	24.0061	44.0098	44.4740	44.2419	0.4984	2.0064	1.5372	1.5128
29-Sep-11	03:59	37.1597	35.0311	12.9822	10.7629	22.0489	24.0067	44.0498	44.4582	44.2540	0.4982	2.0071	1.5385	1.5122
29-Sep-11	04:59	37.1527	35.0263	12.9712	10.7526	22.0551	23.9988	43.9992	44.4582	44.2287	0.4987	2.0054	1.5368	1.5122
29-Sep-11	05:59	37.1471	35.0179	12.9600	10.7406	22.0580	23.9890	44.0567	44.4823	44.2695	0.4983	2.0070	1.5388	1.5130
29-Sep-11	06:59	37.1448	35.0184	12.9672	10.7479	22.0512	23.9928	44.0068	44.4530	44.2299	0.4986	2.0058	1.5370	1.5120
29-Sep-11	07:59	37.1510	35.0236	12.9729	10.7545	22.0507	23.9983	44.0286	44.4451	44.2369	0.4985	2.0061	1.5378	1.5118

All input in S.I.

EPS_INS_PUR_200x200mm

Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)
35.0	13.0	44.25	0.0127
Dt	Tm	R	R/L
22.1	24.0	0.50	39.1
C	K		
2.007	0.02697		

BTU Calculation

Th (F) 95.1	Tc (F) 55.4	Q BTU*H/FT2 14.03	Thickness (Inches) 0.50		
Dt 39.7	Tm 75.2	R 2.8	R/L 5.6	C 0.353	K 0.1773

Project : Thermal Conductivity of small specimens															
Material : Polyurethane															
Specimen : EPS_INS_PUR_150x150mm															
Thickness = 0.01274 m															
12"HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{ep}	dt	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
29-Sep-11	21:01	37.1818	34.9961	12.9980	10.7202	21.9981	23.9970	45.6956	45.9244	45.8100	0.4802	2.0824	1.5958	1.5619	
29-Sep-11	22:01	37.1826	34.9980	12.9961	10.7186	22.0019	23.9970	45.6729	45.9265	45.7997	0.4804	2.0816	1.5950	1.5619	
29-Sep-11	23:01	37.1706	34.9860	12.9904	10.7129	21.9956	23.9882	45.6664	45.9076	45.7870	0.4804	2.0816	1.5948	1.5613	
30-Sep-11	00:01	37.1783	34.9906	12.9928	10.7141	21.9978	23.9917	45.7205	45.9057	45.8131	0.4802	2.0826	1.5966	1.5612	
30-Sep-11	01:01	37.1701	34.9879	12.9912	10.7150	21.9966	23.9896	45.6412	45.8715	45.7563	0.4807	2.0801	1.5939	1.5601	
30-Sep-11	02:01	37.1781	34.9914	12.9900	10.7146	22.0014	23.9907	45.7081	45.8874	45.7977	0.4804	2.0816	1.5962	1.5606	
30-Sep-11	03:01	37.1732	34.9889	12.9914	10.7151	21.9976	23.9902	45.6689	45.8818	45.7753	0.4806	2.0809	1.5948	1.5604	
30-Sep-11	04:01	37.1785	34.9934	12.9952	10.7171	21.9982	23.9943	45.6729	45.8962	45.7845	0.4805	2.0813	1.5950	1.5609	
30-Sep-11	05:01	37.1760	34.9903	12.9905	10.7130	21.9998	23.9904	45.6940	45.8996	45.7968	0.4804	2.0817	1.5957	1.5610	
30-Sep-11	06:01	37.1737	34.9910	12.9899	10.7135	22.0011	23.9905	45.6391	45.8905	45.7648	0.4807	2.0801	1.5938	1.5607	
30-Sep-11	07:01	37.1733	34.9869	12.9914	10.7135	21.9955	23.9891	45.7018	45.8815	45.7917	0.4803	2.0819	1.5960	1.5604	
30-Sep-11	08:01	37.1777	34.9920	12.9941	10.7157	21.9980	23.9930	45.6895	45.8932	45.7913	0.4804	2.0816	1.5956	1.5608	

All input in S.I.

EPS_INS_PUR_150x150mm

Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)
35.0	13.0	45.79	0.0127
Dt	Tm	R	R/L
22.0	24.0	0.48	37.7
C	K		
2.081	0.02652		

BTU Calculation

Th (F)	Tc (F)	Q BTU*H/FT2	Thickness (Inches)		
95.0	55.4	14.52	0.50		
Dt	Tm	R	R/L	C	K
39.6	75.2	2.7	5.4	0.367	0.1839

Project: Thermal Conductivity of small specimens															
Material: Polyurethane															
Specimen: EPS_INS_PUR_100x100mm															
12" HFM station in Room 121															
Thickness = 0.01277 m															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
30-Sep-11	21:01	37.4226	34.9457	13.0573	10.4745	21.8884	24.0015	51.8452	52.2209	52.0330	0.4207	2.3771	1.8093	1.7746	
30-Sep-11	22:01	37.4253	34.9518	13.0557	10.4764	21.8961	24.0038	51.7849	52.1544	51.9697	0.4213	2.3734	1.8072	1.7723	
30-Sep-11	23:01	37.4280	34.9544	13.0596	10.4802	21.8949	24.0070	51.7721	52.1587	51.9654	0.4213	2.3734	1.8068	1.7725	
1-Oct-11	00:01	37.4260	34.9548	13.0602	10.4804	21.8945	24.0075	51.7584	52.1610	51.9597	0.4214	2.3732	1.8063	1.7726	
1-Oct-11	01:01	37.4270	34.9542	13.0615	10.4805	21.8928	24.0078	51.7632	52.1592	51.9612	0.4213	2.3734	1.8065	1.7725	
1-Oct-11	02:01	37.4254	34.9537	13.0588	10.4794	21.8949	24.0062	51.7438	52.1407	51.9422	0.4215	2.3723	1.8058	1.7719	
1-Oct-11	03:01	37.4281	34.9536	13.0596	10.4801	21.8940	24.0066	51.8015	52.1732	51.9874	0.4211	2.3745	1.8078	1.7730	
1-Oct-11	04:01	37.4234	34.9532	13.0596	10.4781	21.8936	24.0064	51.7316	52.1810	51.9563	0.4214	2.3731	1.8054	1.7732	
1-Oct-11	05:01	37.4266	34.9531	13.0603	10.4805	21.8929	24.0067	51.7899	52.1667	51.9783	0.4212	2.3742	1.8074	1.7728	
1-Oct-11	06:01	37.4235	34.9519	13.0572	10.4763	21.8946	24.0046	51.7549	52.1891	51.9720	0.4213	2.3737	1.8062	1.7735	
1-Oct-11	07:01	37.4099	34.9416	13.0582	10.4792	21.8834	23.9999	51.6778	52.1399	51.9089	0.4216	2.3720	1.8035	1.7719	
1-Oct-11	08:01	37.3647	34.8962	13.0495	10.4754	21.8467	23.9729	51.6697	52.0585	51.8641	0.4212	2.3740	1.8031	1.7691	

All input in S.I.								EPS_INS_PUR_100x100mm							
Th (C)		Tc (C)		Q (W/M2)		Thickness (Meter)									
34.9		13.1		51.96		0.0128									
Dt 21.9		Tm 24.0		R 0.42		R/L 33.0		C 2.374		K 0.03163					

BTU Calculation															
Th (F)		Tc (F)		Q BTU*H/FT2		Thickness (Inches)									
94.9		55.5		16.47		0.50									
Dt 39.4		Tm 75.2		R 2.4		R/L 4.8		C 0.418		K 0.2102					

Project: Thermal Conductivity of small specimens															
Material: Polyurethane															
Specimen: EPS_INS_PU_50x50mm															
12" HFM station in Room 121															
Thickness = 0.01268 m															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
2-Oct-11	21:01	37.6217	34.9516	13.0614	10.2805	21.8902	24.0065	55.3925	55.8055	55.5990	0.3937	2.5399	1.9323	1.8954	
2-Oct-11	22:01	37.6181	34.9508	13.0636	10.2801	21.8872	24.0072	55.3504	55.8123	55.5813	0.3938	2.5394	1.9308	1.8956	
2-Oct-11	23:01	37.6212	34.9510	13.0611	10.2798	21.8899	24.0061	55.3912	55.7880	55.5896	0.3938	2.5395	1.9322	1.8948	
3-Oct-11	00:01	37.6178	34.9489	13.0616	10.2794	21.8873	24.0053	55.3572	55.7806	55.5689	0.3939	2.5389	1.9311	1.8945	
3-Oct-11	01:01	37.6165	34.9486	13.0614	10.2788	21.8872	24.0050	55.3500	55.8171	55.5835	0.3938	2.5395	1.9308	1.8958	
3-Oct-11	02:01	37.6190	34.9477	13.0601	10.2773	21.8876	24.0039	55.4067	55.8116	55.6092	0.3936	2.5407	1.9328	1.8956	
3-Oct-11	03:01	37.6147	34.9457	13.0582	10.2766	21.8875	24.0019	55.3652	55.7998	55.5825	0.3938	2.5395	1.9313	1.8952	
3-Oct-11	04:01	37.6162	34.9477	13.0602	10.2798	21.8874	24.0039	55.3713	55.7934	55.5824	0.3938	2.5395	1.9315	1.8950	
3-Oct-11	05:01	37.6171	34.9478	13.0611	10.2796	21.8867	24.0044	55.3750	55.8088	55.5919	0.3937	2.5400	1.9317	1.8955	
3-Oct-11	06:01	37.6199	34.9495	13.0621	10.2798	21.8874	24.0058	55.3887	55.8044	55.5965	0.3937	2.5401	1.9322	1.8953	
3-Oct-11	07:01	37.6144	34.9462	13.0648	10.2847	21.8814	24.0055	55.3376	55.7681	55.5528	0.3939	2.5388	1.9304	1.8941	
3-Oct-11	08:01	37.6178	34.9481	13.0665	10.2849	21.8815	24.0073	55.3687	55.8192	55.5940	0.3936	2.5407	1.9315	1.8958	

All input in S.I.								EPS_INS_PU_50x50mm							
Th (C)		Tc (C)		Q (W/M2)		Thickness (Meter)									
34.9		13.1		55.59		0.0127									
Dt 21.9		Tm 24.0		R 0.39		R/L 31.1		C 2.540		K 0.03220					

BTU Calculation															
Th (F)		Tc (F)		Q BTU*H/FT2		Thickness (Inches)									
94.9		55.5		17.62		0.50									
Dt 39.4		Tm 75.2		R 2.2		R/L 4.5		C 0.447		K 0.2233					

Project : Thermal Conductivity of small specimens															
Material : Polyisocyanurate															
Specimen : EPS_INS_ISO_200x200mm															
Thickness = 0.01269 m															
12"HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
29-Jul-11	10:01	37.2843	35.1283	12.8835	10.6255	22.2447	24.0059	45.0268	45.5414	45.2841	0.4912	2.0357	1.5727	1.5488	
29-Jul-11	11:01	37.2827	35.1291	12.8850	10.6267	22.2441	24.0071	44.9903	45.5179	45.2541	0.4915	2.0344	1.5714	1.5480	
29-Jul-11	12:01	37.2770	35.1242	12.8777	10.6197	22.2465	24.0010	44.9533	45.5411	45.2472	0.4917	2.0339	1.5701	1.5488	
29-Jul-11	13:01	37.2826	35.1287	12.8848	10.6269	22.2440	24.0067	44.9823	45.5168	45.2496	0.4916	2.0342	1.5711	1.5479	
29-Jul-11	14:01	37.2831	35.1315	12.8900	10.6322	22.2415	24.0107	44.9268	45.5181	45.2225	0.4918	2.0332	1.5692	1.5480	
29-Jul-11	15:01	37.2847	35.1318	12.8906	10.6337	22.2412	24.0112	44.9856	45.5029	45.2443	0.4916	2.0342	1.5713	1.5475	
29-Jul-11	16:01	37.2891	35.1349	12.8928	10.6341	22.2421	24.0138	44.9859	45.5273	45.2566	0.4915	2.0347	1.5713	1.5483	
29-Jul-11	17:01	37.2847	35.1322	12.8901	10.6329	22.2421	24.0111	44.9600	45.5314	45.2457	0.4916	2.0342	1.5704	1.5484	
29-Jul-11	18:01	37.2879	35.1336	12.8925	10.6348	22.2411	24.0131	45.0065	45.5256	45.2661	0.4913	2.0352	1.5720	1.5483	
29-Jul-11	19:01	37.2822	35.1306	12.8838	10.6262	22.2468	24.0072	44.9584	45.5020	45.2302	0.4919	2.0331	1.5703	1.5474	
29-Jul-11	20:01	37.2841	35.1288	12.8831	10.6256	22.2457	24.0059	45.0056	45.5372	45.2714	0.4914	2.0350	1.5720	1.5486	
29-Jul-11	21:01	37.2784	35.1267	12.8830	10.6256	22.2437	24.0048	44.9494	45.5395	45.2444	0.4916	2.0340	1.5700	1.5487	

All input in S.I.

EPS_INS_ISO_200x200mm

Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)
35.1	12.9	45.25	0.0127

Dt	Tm	R	R/L	C	K
22.2	24.0	0.49	38.7	2.034	0.02591

BTU Calculation

Th	Tc	Q	Thickness		
(F)	(F)	BTU* h/FT2	(Inches)		
95.2	55.2	14.34	0.50		
Dt	Tm	R	R/L	C	K
40.0	75.2	2.8	5.6	0.358	0.1790

Project :		Thermal Conductivity of small specimens												
Material :		Polyisocyanurate												
Specimen :		EPS_INS_ISO_150x150mm												
Thickness =		0.01265 m												
12"HFM station in Room 121														
Date	Time	T hp	T h	T c	T cp	d t	T m	Q h	Q c	Q avg	R	C	E h	E c
7-Feb-12	21:01	37.3857	35.0995	13.1131	10.7350	21.9863	24.1063	48.1252	48.0988	48.1120	0.4570	2.1883	1.6804	1.6355
7-Feb-12	22:01	37.3843	35.1013	13.1118	10.7321	21.9895	24.1066	48.0580	48.1077	48.0828	0.4573	2.1866	1.6781	1.6358
7-Feb-12	23:01	37.3812	35.0995	13.1121	10.7319	21.9874	24.1058	48.0270	48.1011	48.0640	0.4575	2.1859	1.6770	1.6356
8-Feb-12	00:01	37.3792	35.0976	13.1101	10.7288	21.9875	24.1038	47.9962	48.1098	48.0530	0.4576	2.1854	1.6759	1.6359
8-Feb-12	01:01	37.3797	35.0994	13.1077	10.7273	21.9916	24.1036	47.9905	48.1409	48.0657	0.4575	2.1856	1.6757	1.6369
8-Feb-12	02:01	37.3820	35.1005	13.1097	10.7323	21.9908	24.1051	48.0163	48.0488	48.0326	0.4578	2.1842	1.6766	1.6338
8-Feb-12	03:01	37.3801	35.0989	13.1096	10.7297	21.9893	24.1043	47.9967	48.1198	48.0582	0.4576	2.1855	1.6759	1.6362
8-Feb-12	04:01	37.3763	35.0981	13.1046	10.7233	21.9934	24.1014	47.9371	48.1128	48.0250	0.4580	2.1836	1.6739	1.6360
8-Feb-12	05:01	37.3763	35.0971	13.1112	10.7300	21.9859	24.1041	47.9520	48.1028	48.0274	0.4578	2.1845	1.6744	1.6356
8-Feb-12	06:01	37.3788	35.0975	13.1102	10.7273	21.9873	24.1038	47.9826	48.1196	48.0511	0.4576	2.1854	1.6754	1.6362
8-Feb-12	07:01	37.3797	35.1000	13.1090	10.7287	21.9910	24.1045	47.9540	48.1220	48.0380	0.4578	2.1844	1.6744	1.6363
8-Feb-12	08:01	37.3825	35.0984	13.1100	10.7309	21.9884	24.1042	48.0314	48.0921	48.0617	0.4575	2.1858	1.6771	1.6353

All input in S.I.

EPS_INS_ISO_150x150mm

Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)		
35.1	13.1	48.06	0.0126		
Dt	Tm	R	R/L	C	K
22.0	24.1	0.46	36.2	2.185	0.02694

BTU Calculation

Th	Tc	Q	Thickness		
(F)	(F)	BTU ^o h/FT ²	(Inches)		
95.2	55.6	15.23	0.50		
Dt	Tm	R	R/L	C	K
39.6	75.4	2.6	5.2	0.385	0.1916

Project :		Thermal Conductivity of small specimens													
Material :		Polyisocyanurate													
Specimen :		EPS_INS_ISO_100x100mm													
Thickness =		0.01272 m													
12"HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	dt	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
8-Feb-12	21:01	37.4261	34.9667	13.0289	10.4595	21.9379	23.9978	51.6636	52.0175	51.8405	0.4232	2.3630	1.8031	1.7677	
8-Feb-12	22:01	37.4247	34.9652	13.0272	10.4581	21.9380	23.9962	51.6916	51.9831	51.8374	0.4232	2.3629	1.8040	1.7665	
8-Feb-12	23:01	37.4296	34.9693	13.0304	10.4585	21.9388	23.9999	51.6873	52.0356	51.8614	0.4230	2.3639	1.8039	1.7683	
9-Feb-12	00:01	37.4252	34.9647	13.0317	10.4584	21.9330	23.9982	51.6927	52.0431	51.8679	0.4229	2.3648	1.8041	1.7686	
9-Feb-12	01:01	37.4352	34.9720	13.0310	10.4597	21.9410	24.0015	51.7566	52.0344	51.8955	0.4228	2.3652	1.8063	1.7683	
9-Feb-12	02:01	37.4384	34.9710	13.0325	10.4629	21.9385	24.0017	51.8569	52.0059	51.9314	0.4225	2.3671	1.8098	1.7673	
9-Feb-12	03:01	37.4337	34.9699	13.0343	10.4664	21.9356	24.0021	51.7723	51.9972	51.8848	0.4228	2.3653	1.8069	1.7670	
9-Feb-12	04:05	37.4363	34.9695	13.0330	10.4626	21.9366	24.0012	51.8188	52.0354	51.9271	0.4225	2.3671	1.8085	1.7683	
9-Feb-12	05:05	37.4344	34.9666	13.0313	10.4589	21.9353	23.9989	51.8240	52.0505	51.9373	0.4223	2.3677	1.8086	1.7688	
9-Feb-12	06:05	37.4268	34.9641	13.0284	10.4573	21.9357	23.9963	51.7334	52.0336	51.8835	0.4228	2.3652	1.8055	1.7682	
9-Feb-12	07:05	37.4294	34.9690	13.0326	10.4630	21.9364	24.0008	51.6837	52.0181	51.8509	0.4231	2.3637	1.8038	1.7677	
9-Feb-12	08:05	37.4378	34.9749	13.0343	10.4620	21.9406	24.0046	51.7251	52.0530	51.8890	0.4228	2.3650	1.8052	1.7689	

All input in S.I.						EPS_INS_ISO_100x100mm									
Th (C)		Tc (C)		Q (W/M2)		Thickness (Meter)									
35.0		13.0		51.88		0.0127									
Dt 21.9		Tm 24.0		R 0.42		R/L 33.2		C 2.365		K 0.03008					

BTU Calculation															
Th (F)		Tc (F)		Q BTU* ^h /FT2		Thickness (Inches)									
94.9		55.5		16.45		0.50									
Dt 39.5		Tm 75.2		R 2.4		R/L 4.8		C 0.417		K 0.2085					

Project :	Thermal Conductivity of small specimens													
Material :	Polyisocyanurate													
Specimen :	EPS_INS_ISO_50x50mm													
Thickness =	0.01260 m													
12"HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
14-Feb-12	21:01	37.5414	34.8393	13.1842	10.4226	21.6551	24.0117	56.2208	57.2112	56.7160	0.3818	2.6190	1.9609	1.9434
14-Feb-12	22:01	37.5426	34.8427	13.1869	10.4262	21.6558	24.0148	56.1568	57.2008	56.6788	0.3821	2.6172	1.9587	1.9431
14-Feb-12	23:01	37.5289	34.8384	13.1836	10.4234	21.6548	24.0110	56.0013	57.1884	56.5949	0.3826	2.6135	1.9533	1.9426
15-Feb-12	00:01	37.5385	34.8379	13.1841	10.4217	21.6538	24.0110	56.1863	57.2524	56.7193	0.3818	2.6194	1.9597	1.9448
15-Feb-12	01:01	37.5390	34.8391	13.1823	10.4204	21.6569	24.0107	56.1696	57.2145	56.6921	0.3820	2.6177	1.9591	1.9435
15-Feb-12	02:01	37.5368	34.8382	13.1844	10.4236	21.6538	24.0113	56.2000	57.1864	56.6932	0.3819	2.6181	1.9602	1.9426
15-Feb-12	03:01	37.5449	34.8400	13.1870	10.4279	21.6530	24.0135	56.2460	57.2149	56.7305	0.3817	2.6200	1.9617	1.9436
15-Feb-12	04:01	37.5477	34.8394	13.1843	10.4257	21.6551	24.0119	56.3266	57.1889	56.7577	0.3815	2.6210	1.9645	1.9427
15-Feb-12	05:01	37.5344	34.8337	13.1813	10.4210	21.6523	24.0075	56.1924	57.2099	56.7011	0.3819	2.6187	1.9599	1.9434
15-Feb-12	06:01	37.5353	34.8367	13.1800	10.4197	21.6567	24.0083	56.1719	57.2436	56.7078	0.3819	2.6185	1.9592	1.9445
15-Feb-12	07:01	37.5345	34.8344	13.1809	10.4192	21.6535	24.0077	56.1400	57.2138	56.6769	0.3821	2.6174	1.9581	1.9435
15-Feb-12	08:01	37.5442	34.8351	13.1845	10.4241	21.6506	24.0098	56.3186	57.1542	56.7364	0.3816	2.6205	1.9642	1.9415

All input in S.I.						EPS_INS_ISO_50x50mm					
Th (C)		Tc (C)		Q (W/M2)		Thickness (Meter)					
34.8		13.2		56.70		0.0126					
Dt 21.7		Tm 24.0		R 0.38		R/L 30.3		C 2.618		K 0.03300	

BTU Calculation											
Th (F)		Tc (F)		Q BTU*h/FT2		Thickness (Inches)					
94.7		55.7		17.97		0.50					
Dt 39.0		Tm 75.2		R 2.2		R/L 4.4		C 0.461		K 0.2288	

Project: Thermal Conductivity of small specimens														
Material: High density glass fiber														
Specimen: EPS_INS_HDGF_200x200mm														
Thickness = 0.01277 m														
12" HFM station in Room 121														
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c
18-Sep-11	20:59	37.8242	35.0142	12.9908	10.0457	22.0233	24.0025	58.6463	59.3440	58.9952	0.3733	2.6788	2.0453	2.0145
18-Sep-11	21:59	37.8252	35.0135	12.9909	10.0437	22.0227	24.0022	58.6940	59.3535	59.0237	0.3731	2.6801	2.0469	2.0148
18-Sep-11	22:59	37.8255	35.0144	12.9884	10.0422	22.0260	24.0014	58.6954	59.3548	59.0251	0.3732	2.6798	2.0470	2.0149
18-Sep-11	23:59	37.8236	35.0135	12.9885	10.0434	22.0249	24.0010	58.6474	59.3347	58.9911	0.3734	2.6784	2.0453	2.0142
19-Sep-11	00:59	37.8221	35.0111	12.9876	10.0416	22.0235	23.9993	58.6651	59.3404	59.0028	0.3733	2.6791	2.0459	2.0144
19-Sep-11	01:59	37.8215	35.0127	12.9871	10.0398	22.0256	23.9999	58.6168	59.3591	58.9880	0.3734	2.6782	2.0442	2.0150
19-Sep-11	02:59	37.8158	35.0102	12.9837	10.0365	22.0265	23.9969	58.5921	59.3617	58.9769	0.3735	2.6775	2.0434	2.0151
19-Sep-11	03:59	37.8154	35.0033	12.9805	10.0348	22.0228	23.9919	58.6918	59.3579	59.0248	0.3731	2.6802	2.0468	2.0150
19-Sep-11	04:59	37.8119	35.0038	12.9818	10.0364	22.0220	23.9928	58.6232	59.3405	58.9819	0.3734	2.6783	2.0444	2.0144
19-Sep-11	05:59	37.8124	35.0007	12.9804	10.0343	22.0203	23.9905	58.6611	59.3381	58.9996	0.3732	2.6793	2.0457	2.0143
19-Sep-11	06:59	37.8217	35.0102	12.9862	10.0391	22.0240	23.9982	58.6714	59.3557	59.0136	0.3732	2.6795	2.0461	2.0149
19-Sep-11	07:59	37.8240	35.0114	12.9874	10.0417	22.0241	23.9994	58.6880	59.3672	59.0276	0.3731	2.6801	2.0467	2.0153

All input in S.I.				EPS_INS_HDGF_200x200mm			
T _h		T _c		Q		Thickness	
(C)		(C)		(W/M2)		(Meter)	
35.0		13.0		59.00		0.0128	
D _t		T _m		R		R/L	
22.0		24.0		0.37		29.2	
						C	
						2.679	
						K	
						0.03420	

BTU Calculation							
T _h		T _c		Q		Thickness	
(F)		(F)		BTU*H/FT2		(Inches)	
95.0		55.4		18.70		0.50	
D _t		T _m		R		R/L	
39.6		75.2		2.1		4.2	
						C	
						0.472	
						K	
						0.2371	

Project : Thermal Conductivity of small specimens															
Material : High density glass fiber															
Specimen : EPS_INS_HDGF_150x150mm															
Thickness = 0.01275 m															
12" HFM station in Room 121															
Date	Time	T _{hp}	T _h	T _c	T _{cp}	d _t	T _m	Q _h	Q _c	Q _{avg}	R	C	E _h	E _c	
13-Sep-11	20:59	37.8430	35.0114	13.0372	10.0791	21.9742	24.0243	58.9547	59.4969	59.2258	0.3710	2.6952	2.0559	2.0197	
13-Sep-11	21:59	37.8473	35.0165	13.0379	10.0814	21.9786	24.0272	58.9462	59.4995	59.2229	0.3711	2.6946	2.0556	2.0198	
13-Sep-11	22:59	37.8341	35.0052	13.0234	10.0672	21.9818	24.0143	58.9371	59.5041	59.2206	0.3712	2.6941	2.0553	2.0199	
13-Sep-11	23:59	37.8268	34.9973	13.0199	10.0632	21.9774	24.0086	58.9278	59.4910	59.2094	0.3712	2.6941	2.0550	2.0195	
14-Sep-11	00:59	37.8303	35.0010	13.0216	10.0652	21.9793	24.0113	58.9273	59.5023	59.2148	0.3712	2.6941	2.0550	2.0199	
14-Sep-11	01:59	37.8286	35.0000	13.0192	10.0623	21.9808	24.0096	58.9033	59.5198	59.2116	0.3712	2.6938	2.0541	2.0205	
14-Sep-11	02:59	37.8285	34.9973	13.0140	10.0567	21.9833	24.0056	58.9588	59.5277	59.2433	0.3711	2.6949	2.0560	2.0207	
14-Sep-11	03:59	37.8242	34.9952	13.0150	10.0583	21.9802	24.0051	58.9162	59.4900	59.2031	0.3713	2.6935	2.0546	2.0194	
14-Sep-11	04:59	37.8288	34.9982	13.0155	10.0591	21.9826	24.0069	58.9357	59.5195	59.2276	0.3712	2.6943	2.0552	2.0205	
14-Sep-11	05:59	37.8288	34.9965	13.0140	10.0554	21.9825	24.0052	58.9633	59.5167	59.2400	0.3711	2.6949	2.0562	2.0203	
14-Sep-11	06:59	37.8257	34.9971	13.0157	10.0586	21.9813	24.0064	58.8980	59.5200	59.2090	0.3713	2.6936	2.0539	2.0205	
14-Sep-11	07:59	37.8295	34.9989	13.0177	10.0607	21.9812	24.0083	58.9435	59.5208	59.2322	0.3711	2.6947	2.0555	2.0205	

All input in S.I.															
EPS_INS_HDGF_150x150mm															
T _h		T _c		Q		Thickness									
(C)		(C)		(W/M2)		(Meter)									
35.0		13.0		59.22		0.0127									
D _t		T _m		R		R/L		C		K					
22.0		24.0		0.37		29.1		2.694		0.03434					

BTU Calculation															
T _h		T _c		Q		Thickness									
(F)		(F)		BTU*H/FT2		(Inches)									
95.0		55.4		18.77		0.50									
D _t		T _m		R		R/L		C		K					
39.6		75.2		2.1		4.2		0.474		0.2381					

Project : Thermal Conductivity of small specimens															
Material : High density glass fiber															
Specimens : EPS_INS_HDGF_100x100mm															
12"HFM station in Room 121															
Thickness = 0.01276 m															
Date	Time	T h p	T h	T c	T c p	dt	T m	Q h	Q c	Q avg	R	C	E h	E c	
14-Sep-11	21:01	37.8232	34.9996	12.9988	10.0490	22.0008	23.9992	58.6344	59.2527	58.9436	0.3733	2.6791	2.0448	2.0114	
14-Sep-11	22:01	37.8248	35.0007	13.0022	10.0536	21.9985	24.0015	58.6330	59.2331	58.9330	0.3733	2.6789	2.0447	2.0107	
14-Sep-11	23:03	37.8317	35.0053	13.0062	10.0548	21.9991	24.0008	58.6621	59.2468	58.9544	0.3732	2.6798	2.0457	2.0112	
15-Sep-11	00:03	37.8247	35.0030	13.0036	10.0543	21.9994	24.0033	58.6066	59.2356	58.9211	0.3734	2.6783	2.0438	2.0108	
15-Sep-11	01:03	37.8291	35.0043	13.0048	10.0550	21.9995	24.0046	58.6582	59.2291	58.9436	0.3732	2.6793	2.0456	2.0106	
15-Sep-11	02:05	37.8244	35.0005	13.0027	10.0535	21.9978	24.0016	58.6099	59.2350	58.9225	0.3733	2.6786	2.0439	2.0108	
15-Sep-11	03:05	37.8273	35.0016	13.0016	10.0534	22.0000	24.0016	58.6477	59.2416	58.9446	0.3732	2.6793	2.0452	2.0110	
15-Sep-11	04:07	37.8248	35.0010	12.9996	10.0510	22.0014	24.0003	58.6145	59.2416	58.9280	0.3734	2.6784	2.0441	2.0110	
15-Sep-11	05:07	37.8242	34.9981	12.9989	10.0500	21.9992	23.9985	58.6647	59.2352	58.9499	0.3732	2.6796	2.0458	2.0108	
15-Sep-11	06:07	37.8230	34.9995	12.9991	10.0491	22.0004	23.9993	58.6258	59.2443	58.9350	0.3733	2.6788	2.0445	2.0111	
15-Sep-11	07:07	37.8301	35.0045	13.0062	10.0563	21.9983	24.0053	58.6613	59.2579	58.9596	0.3731	2.6802	2.0457	2.0116	
15-Sep-11	08:07	37.8286	35.0068	13.0058	10.0556	22.0011	24.0063	58.5778	59.2623	58.9201	0.3734	2.6780	2.0428	2.0117	

All input in S.I.

EPS_INS_HDGF_100x100mm

Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)
35.0	13.0	58.94	0.0128
Dt	Tm	R	R/L
22.0	24.0	0.37	29.3
C	K		
2.679	0.03418		

BTU Calculation

Th (F) 95.0	Tc (F) 55.4	Q BTU* ^h /FT ² 18.68	Thickness (Inches) 0.50		
Dt 39.6	Tm 75.2	R 2.1	R/L 4.2	C 0.472	K 0.2370

Project : Thermal Conductivity of small specimens														
Material : High density glass fiber														
Specimen : EPS_INS_HDGF_50x50mm														
12"HFM station in Room 121														
Thickness = 0.01266 m														
Date	Time	T h p	T h	T c	T c p	d t	T m	Q h	Q c	Q avg	R	C	E h	E c
20-Sep-11	21:01	37.7657	35.0100	12.9694	10.0927	22.0407	23.9897	57.3738	57.9006	57.6372	0.3824	2.6150	2.0011	1.9659
20-Sep-11	22:01	37.7561	35.0052	12.9666	10.0897	22.0385	23.9859	57.3020	57.8753	57.5887	0.3827	2.6131	1.9986	1.9650
20-Sep-11	23:01	37.7574	35.0033	12.9636	10.0872	22.0396	23.9834	57.3519	57.9005	57.6262	0.3825	2.6146	2.0003	1.9658
21-Sep-11	00:01	37.7596	35.0047	12.9636	10.0871	22.0411	23.9842	57.3539	57.9082	57.6311	0.3825	2.6147	2.0004	1.9661
21-Sep-11	01:01	37.7560	35.0007	12.9592	10.0812	22.0415	23.9799	57.3728	57.9177	57.6452	0.3824	2.6153	2.0011	1.9664
21-Sep-11	02:01	37.7552	34.9990	12.9586	10.0807	22.0404	23.9788	57.3652	57.9232	57.6442	0.3824	2.6154	2.0008	1.9666
21-Sep-11	03:01	37.7544	34.9982	12.9597	10.0816	22.0386	23.9789	57.3740	57.8950	57.6345	0.3824	2.6152	2.0011	1.9656
21-Sep-11	04:01	37.7477	34.9949	12.9594	10.0814	22.0354	23.9771	57.3190	57.9109	57.6149	0.3825	2.6146	1.9992	1.9662
21-Sep-11	05:01	37.7548	34.9969	12.9574	10.0810	22.0395	23.9772	57.4150	57.9074	57.6612	0.3822	2.6163	2.0025	1.9661
21-Sep-11	06:01	37.7522	34.9970	12.9559	10.0806	22.0410	23.9765	57.3699	57.8898	57.6298	0.3825	2.6146	2.0010	1.9655
21-Sep-11	07:01	37.7569	35.0024	12.9624	10.0856	22.0400	23.9824	57.3762	57.8925	57.6343	0.3824	2.6150	2.0012	1.9656
21-Sep-11	08:01	37.7607	35.0034	12.9650	10.0865	22.0384	23.9842	57.4046	57.9119	57.6583	0.3822	2.6163	2.0022	1.9662

All input in S.I.

EPS_INS_HDGF_50x50mm

Th (C)	Tc (C)	Q (W/M2)	Thickness (Meter)
35.0	13.0	57.63	0.0127
Dt	Tm	R	R/L
22.0	24.0	0.38	30.2
C	K		
2.615	0.03311		

BTU Calculation

Th	Tc	Q	Thickness		
(F)	(F)	BTU* h/FT2	(Inches)		
95.0	55.3	18.27	0.50		
-----	-----	-----	-----		
Dt	Tm	R	R/L	C	K
39.7	75.2	2.2	4.4	0.461	0.2295