Sudan University of Science and Technology

College of Graduate Studies

Measuring the Thermal Conductivity Coefficient and the Specific Heat Capacity for Some Building Materials

قياس معامل التوصيل الحراري و الحرارة النوعية لبعض مواد البناء

A Thesis submitted in partial fulfillment of the requirement for the degree of M.sc. in Solid state physics

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بسم الله الرحمن الرحيم

الاية

﴿ هُوَ الَّذِي بَعَثَ فِي الْأُمِّيِّينَ رَسُولًا مِنْهُمْ
يَتْلُو عَلَيْهِمْ آيَاتِهِ وَيُزَكِّيهِمْ وَيُعَلِّمُهُمُ الْكِتَابَ
وَالْحِكْمَةَ وَإِنْ كَانُوا مِنْ قَبْلُ لَفِي ضَلَالٍ مُبِينٍ ﴾

صدق الله العظيم

سورة الجمعة(2)

Dedication

To my father the sun that is glowing from our lives one day

To my mother who cannot explain the amount of sacrifices

To my brothers Abozer and Khalid

To my sisters

Acknowledgment

Thanks to my teachers and colleagues during all my educational and thanksgiving stages and to those who stood with me during my studies and supplementary research

And to my colleagues in Batch 17 Master of Solid State Physics.

Special thanks to **Dr. Ali Sulaiman**, who knows about us

Abstract

Specific heat and thermal conductivity are important property of building materials which are used for thermal evaluation of building constructions. Implication of these variations in thermal conductivity is significant in terms of commercial profile of the insulations and also in terms of calculating energy saving in large scale use of that specific insulation. Thus it is important to know which of the measuring instrument for thermal conductivity can produce relatively accurate and representative result.

In this thesis thermal conductivity and specific heat capacity for three types of building material (cement, Gypsum and wood) were investigated. It was found the thermal conductivity of those material was varied, (0.062 $w/m.c$) for wood, (0. 236$w/m.c$) for gypsum and (0.158 $w/m.c$) for cement which reveals that wood has small thermal conductive compared to that of the other two samples. While the specific heat capacity calculated for wood is $(2611.34\ j/Kg.k)$ gypsums was equal to$(2201.82\ j/Kg.k)$ and for cement is equal$(1147.1\, j/Kg.k)$.

المستخلص

تعتبر قياس الحرارة النووعية والموصلية الحرارية من الخصا ئص المهمة في اختبار وتقييم مواد البناء المستخدمة في الانشاءات. لاتمام التعرف على هذا التباين في الموصلية الحرارية والاستفادة من خاصية العزل الحراري من الناحية التجارية وادخار للطاقة يجب معرفة الاجهزة المستخدمة في الموصلية الحرارية والحرارة النوعية وحدود دقتها للحصول على نتائج دقيقة نسبيا تمكن من اختيار مواد البناء الانسب من حيث العزل الحراري

في هذا البحث تمت دراسة الحرارة النوعية ومعامل التوصيل الحراري لثلاثة مواد من مواد البناء (الجبص والخشب والاسمنت) ووجدت ان الموصلية الحرارية لهذه المواد متباينة. حيث كانت للخشب وللاسمنت $\left(0.158\,\frac{\mathrm{w}}{\mathrm{m.c}}\right)$ $\left(0.062\,\frac{\mathrm{w}}{\mathrm{m.c}}\right)$ والجبص $\left(0.236\,\frac{\mathrm{w}}{\mathrm{m.c}}\right)$

و الاسمنت و بمقارنة النتائج المتحصل عليها بالقيم النظرية لمعامل التوصيل الحرارى يتضح ان الخشب هي اقل المواد توصيلا للحرارة مقارنة بالمادتين الاخريين بينما الحرارة النوعية لهذه المواد للجبص $\left(2201.82\,\frac{j}{kg.k}\right)$ للاسمنت و $\left(1147.1\,\frac{j}{kg.k}\right)$ للخشب و هي $\left(2611.34\,\frac{j}{kg.k}\right)$

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Chapter One

Introduction

1.1Introduction

Heat can be transferred to or from a material in three fundamental ways; conduction, convection, and/or radiation. Any and all of the three types of heat transfer can occur for a system, so one must be careful not to neglect any heat transferred during the process. In conduction, heat is transferred from one part of a body to another part of that same body, or between bodies that are in contact with each other without any appreciable displacement of the particles within the body. The discussion on conduction will begin with Fourier's Law, which allows for equations to be derived for steady state uniaxial heat transfer. A simplified equation that can be used in the event that heat is not generated (via chemical or nuclear reactions or electrical current) will also be presented. Finally, equations for heat transfer through bodies in series and bodies in parallel will be given. Due to the level of complexity, unsteady state conduction is outside of the scope of this site, and generally involves advanced algorithms and assistance from computer software. These systems are indicative of materials whose temperatures change with respect to both time and position. Some references will be given for those readers interested can pursue at their leisure. In convection, heat is transferred from one point to another through a moving fluid, most likely a gas or liquid, as a result of the mixing of different portions of the fluid. There are two sub-segments of convection, natural and forced. In natural convection, the motion of the fluid is the inherent result of the density gradient that results from the temperature differential. In forced convection, the motion of the fluid is the result of some mechanical work, such as a blow or pump moving the fluid across the material. Heat is transferred through radiation from one body to another by means of wave motions through space [1].

1.2 Research Problem

In transient condition, thermal conductivity data of a material is still needed since diffusivity is a function of conductivity and volume heat capacity. Good heat insulating lowers the building temperature and thus reduces the voltage consumption in their condition. Therefore, in this research, the measurement of the thermal conductivity coefficient in building materials will be discussed

1.3 Aim of the work

The main objective of this thesis it was concluded on Measure of the specific heat capacity and thermal conductivity for building materials.

1.4 Methodology

Three blocks of building material were used to find the specific heat capacity and thermal conductivity by means of lees disc. To do so sample of cement, wood and gypsum were prepared in the form of disks with known thickness and a given area. Then samples were putted between lees disc.

1.5 Presentation of Thesis

This Thesis contains four chapters, chapter One Introduction chapter two heat Transfer Chapter three Heat Insulation, chapter four materials and methods

1.6 literature review

1.6.1 Anastasios Karamanos, Agis Papadopoulos1, Dimitrios Anastasellos. Heat Transfer Phenomena in Fibrous Insulating Materials

Concluded that the Insulation has been and still remains one of the fundamental tools for achieving energy conservation both in the buildings’ and in the industrial sector. Whilst specific insulating materials are used for

Each application, according to the physical and operational requirements, there is a group of materials that is used in both cases, namely in organic fibrous materials. The study of industrial insulating materials is a rather hard task, duet the complex phenomena which take place in the materials’ structure, because of the extreme conditions, in which the materials applied. In this paper are discussed some of these changes. The study presented focuses on stone wool, which is the most widely used, and in that sense the most representative inorganic fibrous material. Its performance is based on their embodied between its fibers, which produce a low thermal conductivity factor. Under some operational conditions, however, like the increased presence of moisture, the thermal conductivity factor may change. The objective of this paper is to describe the theoretical approach and the resulting data on the assessment of the change sins tone wool’s thermal conductivity, under various operational conditions. In order to achieve that, adscription of stone wool’s chemical composition and structure is given, followed by the physical and mathematical background necessary for determining the thermal conductivity factor. The results yielded in this way are compared to experimental and theoretical references available, in order to verify the validity of the adopted approach.

1.6.2 E Latif*, M Pruteanu***and G Rhydwen*, D C Wijeyesekera *, S Tucker **, M A Ciupala *, D Newport Thermal Conductivity of Building Materials: An Overview of Its Determination,

A range of instruments are available to measure thermal conductivity of building materials. Some of these tools are heat-flow meter, hot plate, hot box and heat transfer analyzer. Thermal conductivity data derived by using different instruments can be different from each other. Implication of these variations in thermal conductivity is significant in terms of commercial profile of the insulations and also in terms of calculating energy saving in

Large scale use of that specific insulation. Thus it is important to know which of the measuring instrument for thermal conductivity can produce relatively accurate and representative result. This paper firstly looks at the methods and instrument for measuring thermal conductivity of building materials and secondly compares and analyses the results of testing thermal conductivity of fibrous insulations using a heat analyzer and a hot plate.

1.6.3 JITKA MOHELNIKOVA Determination of Specific Heat of a Building Material

Specific heat is important property of building materials which is used for thermal evaluation of building constructions. The paper presents method for determination of this property for samples of chip-wood boards. The determination of physical properties of the boards was a task of a research project focused on the energy evaluation of low-energy housing. The specific heat capacity was determined on the basis of experimental measurements of selected samples of chip-wood boards.

Chapter Two

Heat Transfer

2.1 Definition

Heat transfer consists in the flow of heat from a region of higher temperature to a region f lower temperature next to it. This heat transfer can occur through three different media: convection, radiation and conduction. In many cases, these three modes of heat transfer happen in the same time but it is important to differentiate them . Measuring the thermal conductivity imply being able to measure the heat transport by conduction only. This is possible only if a certain control can be done on radiation and convection [2].

2.1.1 Convection

The convection is the heat transfer due to the bulk movement of a fluid, usually between a solid and a fluid. This heat transfer uses the heat conduction of the fluid particles by the fluid motion itself. The fluid can be a liquid or a gas and must be able to withstand the heat involved. If the fluid is forced to move by a pump or a blower, the convection is known as forced convection. The simplest illustration of this case is the use of the fan: the movement of air generated by the fan motion increases the heat conduction of the air itself. If the fluid move is due to difference in density, the convection is known as natural or free convection. An example of free convection could be the use of a heater in a room, as presented in Figure (2.1).

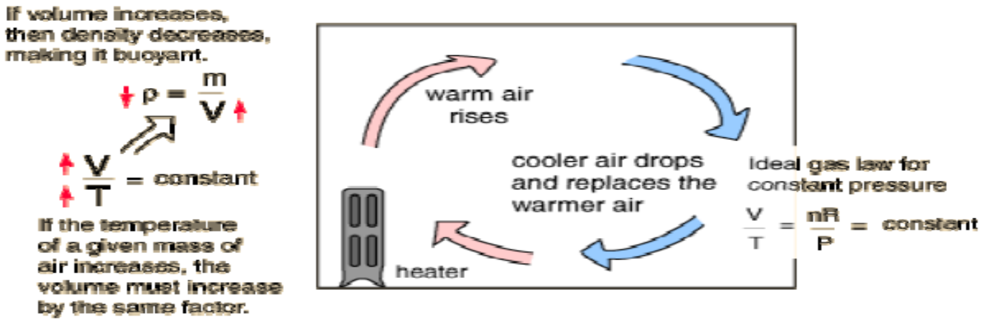

Figure (2.1) Scheme of free convection due by a heater

The same quantity of warm air, n, takes a bigger volume V than cold air, according to the ideal gas low (PV = nRT) with P constant. The density of the warmer air is less than cold air. The warmer air rises, which gives the fluid motion. For the measurement of thermal conductivity, this very phenomenon can occur as a heat flow is commonly created in every method. The common control of the convection is realized by setting the fixture in a high vacuum. If no gas is in the environment of the sample, no free convection is possible.

2.1.2 Radiation.

The radiation is a transfer of energy by electromagnetic wave motion with a defined range of wavelengths, typically infrared. All surfaces emit radiant heat. The dominant wavelength of the emitted radiation decreases with increasing temperature of the body .The higher the temperature is, the greater the rate of emission of radiant energy per unit area of the surface. The relationship governing radiation from hot objects is called the Stefan-Boltzmann law.

$$P = e\,\sigma\,A\,(T^4 - Tc^4) \qquad (2.1)$$

Where P is the radiated power, A is the radiating area, σ (5.6703 10-8 W/m2K4) is Stefan’s constant, e is the emissivity of the material, T is the temperature of the radiator and T_C the temperature of the surroundings. To account for a body's outgoing radiation or its emissive power, which is defined as the heat flux per unit time, one makes a comparison to a perfect

Body that emits as much thermal radiation as possible. Such an object is known as a blackbody, and the ratio of the actual emissive power E to the emissive power of a blackbody is defined as the surface emissivity e = E $/E_{\text{blackbody}}$. A blackbody is then a material with an emissivity e equal to 1. The following table presents some values of emissivity for different material.

Table (2.1) Emissivity data for material in different state

Material	$*C$	Emissivity
G-10EPoxy Resin	----	0.95
Glass	20-100	0.94 - 0.91
Carbon		
Filament	1000-1400	0.53
Graphite	0-3600	0.7 - 0.8
Lamp Black	20-400	0.96
Soot Applied to solid	50-1000	0.96
Soot With Water Glass	200-200	0.96
Aluminum		
Polished	50-500	0.04 - 0.06
Rough Surfaces	20-50	0.06 - 0.07
Strongly Oxidized	55-500	0.2 - 0.3
Oxidized	200	0.11

The control of radiation is more difficult than the control of convection. Indeed, the radiation occurs even without any gas. The radiation cannot be eliminated but different Possible. For that, the sample size is as small as possible. More important in the relation is the difference of temperature between the sample and its surroundings. This parameter is to the power 4 and can vary along the measure. The best protection against radiation is then to set a radiation shield around the sample. A radiation shield is a material of high thermal conductivity in thermal contact with the fixture. Its high thermal conductivity allows it to follow the difference of temperature during the measurements in order to create a surrounding of the sample with a temperature close to the sample itself. This shield cannot however be perfect and the heat loss by radiation must be taken into account.

2.1.3 Conduction

The conduction can be defined as the transmission of heat within a material motion of the substance. The heat transfer goes from higher to lower temperature regions in a material. The ability of a substance to conduct heat is characterized by its thermal conductivity κ or λ, which in turn is defined by the atomic structure of the substance. Conduction is more tied to material development than convection or radiation. Gases transfer heat by direct collisions between molecules. Their thermal conductivity is low compared to most solids since they are dilute media. Thermal conduction can involve electrons, ions, and/or phonons. Electrons and ions move from a point of higher temperature to a point of lower temperature, thereby transporting heat. Due to the high mass of ions compared to electrons, electrons move much more easily. In a crystal, the thermal agitation of atoms creates spontaneously vibration waves. Their amplitude increases as the temperature rises. These elastic waves are called phonons in the Einstein model. Einstein postulated the existence of phonons as lattice vibration quanta, which are thought to be created in large numbers in the hot part of a solid and partially eliminated in the cold part. Heals postulated their particle-wave duality. For a lattice such as one defined by a metal or a crystal [3].

2.1.3.1 Fourier’s Law

The fundamental differential equation for conduction heat transfer is Fourier’s Law, which states:

$$\frac{dQ}{dt} = -kA\left(\frac{dT}{dx}\right)$$

$$= m.C.\frac{dT}{dt} \qquad (2.2)$$

Where Q is heat, t is time, k is the thermal conductivity, A is the area normal to the direction of heat flow, T is temperature, and x is distance in the direction of heat flow. At this point, it is worth noting that the thermal conductivity typically varies with temperature, but not necessarily in the same direction. A common simplification in heat transfer calculations is to assume this term is constant within the conditions of the system under study. It is strongly suggested investigate literature, obtain values from material vendors, or carefully conduct calorimetric testing within one's lab to determine the proper values for k for the given material as a function of temperature, especially if a phase transition occurs within the range of temperatures under study.

Using Fourier's Law, we can write an expression for a three dimensional unsteady-state energy equation for a solid.

$$c_\rho \frac{\delta T}{\delta t} = \frac{\delta}{\delta x}\left(k\frac{\delta T}{\delta x}\right) + \frac{\delta}{\delta y}\left(k\frac{\delta T}{\delta y}\right) + \frac{\delta}{\delta z}\left(k\frac{\delta T}{\delta z}\right) + q_{gen} \qquad (2.3)$$

Where c is the specific heat of the material, is the density of the material, T is temperature, t is time, x, y, and z are distances in Cartesian coordinates, and q_{gen} is the rate of heat generated per unit volume, typically by chemical or nuclear reactions or electrical current. This equation will serve as the basis for solving steady state heat transfer problems [4].

2.2.1 Steady State Conduction

In steady state conduction, the rate of heat transferred relative to time (dQ/dt) is constant and the rate of change in temperature relative to time (dT/dt) is equal to zero. For heat transfer in one dimension (x-direction), the previously mentioned equations can be simplified by the conditions set forth by steady-state to yield:

$$\frac{\delta^2 T}{\delta x^2} = -\frac{1}{k}\left[\frac{\frac{\delta Q}{\delta t}}{\delta x}\right] \qquad (2.4)$$

Similar relationships can be derived for other coordinate systems including:

Cylindrical

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{dt}{dr}\right) = -\frac{1}{k}\left(\frac{\frac{\delta Q}{\delta t}}{\delta r}\right) \qquad (2.5)$$

Spherical

$$\frac{1}{r^2}\frac{d}{dr}\left(r^2\frac{dt}{dr}\right) = -\frac{1}{k}\left(\frac{\frac{\delta Q}{\delta t}}{\delta r}\right) \qquad (2.6)$$

Upon integration of these second order differential equations, the following are obtained:

In Cartesian coordinates:

$$T=-\frac{\left(\frac{\frac{\delta Q}{\delta t}}{\delta x}\right)x^2}{2k}+c_1 x + c_2 \qquad (2.7)$$

While in Cylindrical coordinates as

$$T=-\frac{\left(\frac{\frac{\delta Q}{\delta t}}{\delta r}\right)r^2}{4k}+c_1 ln r + c_2 \qquad (2.8)$$

And in Spherical coordinate as

$$T=-\frac{\left(\frac{\frac{\delta Q}{\delta t}}{\delta r}\right)xr^2}{6k}+\frac{c_1}{r} + c_2 \qquad (2.9)$$

In the event that heat is not generated in the system of interest, (dQ/dt)/dx is equal to zero. For a steady state, one dimensional system, Fourier's law can be integrated to give:

$$q\int_{x_1}^{x_2 2}\frac{dx}{A} = -\int_{T_1}^{T_2} KdT \qquad (2.10)$$

Where q is the rate of heat transfer, to solve this equation, the area (A) through which the heat is being transferred must be known as a function of position (x). In the event that k is a constant, the integration of the above equation results in:

$$Q = -k.A.\frac{dT}{dt} \qquad (2.11)$$

Where A_{avg} is calculated by:

$$A_{avg} = \frac{1}{dx}\int_{x_1}^{x_2}\frac{dx}{A} \qquad (2.12)$$

Table (2.2) gives some equations to calculate A_{avg} based on the relationship between A and x

Area (A) is proportional to:	A_{avg} is equal to:
Constant	$A_1=A_2$
X	$\dfrac{A_2 - A_1}{\ln\left(\dfrac{A_x}{A_1}\right)}$
x^2	$\sqrt{\dfrac{A_2}{A_1}}$

2.3 Thermal Conductivity.

The coefficient of thermal conductivity κ of a material can be determined using Fourier's Law of conduction:

$$Q = -K.A.\frac{\Delta T}{L} \tag{2.13}$$

Where Q is heat flow in watt per surface area generated by the temperature gradient ΔT over the thickness L with cross-section area A

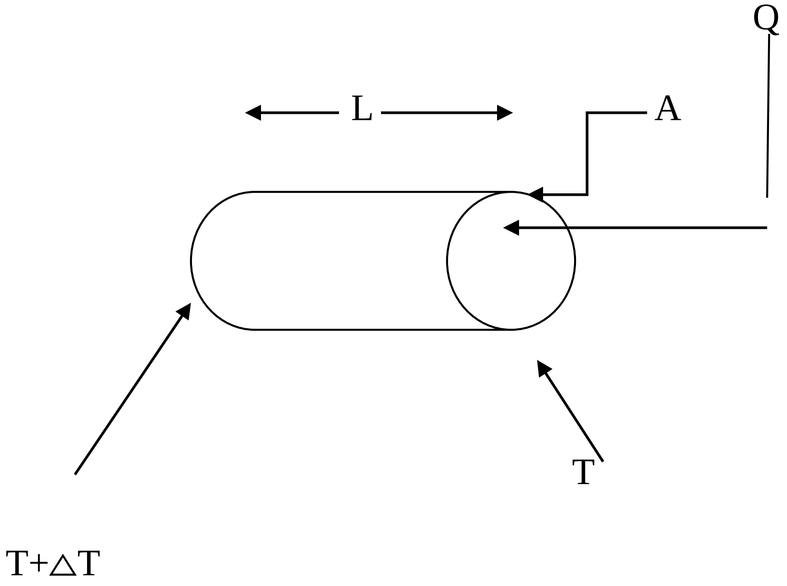

Figure (2.2) Illustration of the parameters in the Fourier's law of conduction

Thermal conductivity can also be obtained by other properties of the material:

$$\kappa = \rho \cdot C_P . h \tag{2.14}$$

Where Cp is the heat capacity at constant pressure, ρ is the density of the material and h is the thermal diffusivity [cm2/s]. This relation is used to calculate the thermal conductivity with the laser flash technique. The difficulty of the calculation of the thermal conductivity is also associated with the heat flux measurement. Where the measurement of the heat flux is done directly (for example, by measuring the electrical power going into the heater), the measurement is called absolute. Where the flux measurement is done indirectly (by comparison), the method is called comparative [5].

2.4 Thermal Expansion

Description most solids increase their dimensions when heated at constant pressure. This phenomenon is called the thermal expansion. However, some substances contract when heated and thus present a negative coefficient of thermal expansion (CTE). Moreover, the thermal expansion of a solid can be anisotropic if the solid presents different properties according to direction. This situation occurs in composites materials with a directional reinforcement. Thermal expansion is commonly explained as a change of dimension according to temperature due to atoms interactions. When heated, the energy brought to the atoms increases their vibrations, causing the mean distance between the atoms to increase. However, this model only takes into account the longitudinal component of vibration motion along the line joining two atoms. In solids, there are also components of relative motion transverse to this line that can pull the atoms toward each other, decreasing the distance between atoms. When this pulling force is stronger than the longitudinal component, it produces a material with negative CTE. These two mechanisms have opposite effects and the expansion will be positive or negative depending upon which is larger. The coefficient of thermal expansion quantified the thermal expansion of the solid. This coefficient can be volumetric or linear according to the fact that the measurement is done on the change of volume or length of the sample. The equations to calculate the volumetric (β) and linear (α) coefficient of thermal expansion are the following.

$$\beta = (\frac{\partial V}{\partial T})_P.\frac{1}{V} \tag{2.15}$$

$$\alpha =(\frac{\partial yL}{\partial T})_P.\frac{1}{L} \tag{2.16}$$

Where V is the volume, L is the length, T is the temperature and the derivative is at constant pressure. However, the usual technical values, such as the values presented in Tables (2.3) and (2.4) use the volume (VRT) or length (LRT) at room temperature as reference, instead of using the volume or length at temperature measured [12].

$$\beta = (\frac{\partial V}{\partial T})_P \frac{1}{V_{RT}} \tag{2.17}$$

$$\alpha = (\frac{\partial V}{\partial T})_P \tag{2.18}$$

Table (2.3) Coefficient of thermal linear expansion for reference materials

Material	Thermal expansion in $10^{-6}c^{-1}$
Glass. ordinary	9
Glass, Pyrex	4
Quartz, fused	0.59
Aluminum	24
Brass	19
Copper	17
Iron	12
Steel	13
Platinum	9
Gold	14
Silver	18

For polymer, such as epoxy, the coefficients of thermal expansion are divided in two parts: before and after the temperature of glass transition $\mathrm{T_g}$. The most useful coefficient concerns the temperature before $\mathrm{T_g}$as the polymer or composite lost most of its mechanical properties after $\mathrm{T_g}$. By comparing table2:3 and 2:4, we can notice that polymer and polymer composite have a higher CTE than metals. However by reinforcement with a material of lower CTE (such as glass fiber), the CTE of the composites are reduced, as shown in Table (2.4) [6].

Table (2.4) shows the CTE for plastics and glass-reinforced plastics

Material	Thermal expansion in $10^{-6}c^{-1}$
Epoxy	54
Polypropylene	86
TP Polyester	124
polyethylene	130
Polycarbonate (glass reinforced)	22
TP polyester (glass reinforced)	25
Polypropylene (glass reinforced)	32
Epoxy (glass reinforced)	36
Polypropylene sulfide (glass reinforced)	36

2.5 Specific heat capacity

Specific heat capacity of materials and components are of vital importance in their final functionality i.e. thermal storage in building elements or transient heat flux. There are different methods for determination of the specific heat capacity. One method is the adiabatic calorimetric where heat is added to a sample while the temperature increase is measured continuously. The sample is surrounded by a heating guard keeping the initial measuring temperature to minimize the heat losses from the sample to the surrounding. If the losses are negligible, the heat capacity can be calculated from the known energy input and temperature [7].

Chapter Three

Thermal Insulation

3.1 Definition

Thermal insulation is the process of insulating material from transferring heat between the materials that are in thermal contact. Thermal insulation is measured by its thermal conductivity. Low thermal-conductive materials are used for thermal insulation. Besides thermal conductivity, density and heat capacity are also important properties of insulating materials. Corrosion under insulation is prevalent in petrochemicals and other industries where pipes and equipment are insulated from heat. Corrosion normally occurs on the insulation materials underlying piping or equipment. It also affects the insulation of jacket materials [8].

3.2The Advantages of Thermal Insulation

1. Reduce the amount of heat transmitted through the parts of the house.
2. Reduce the energy required for heating or cooling the house.
3. Make the internal temperature of the building stable, non-volatile.
4. Keep the temperature of the building elements stable thus long time life.
5. Reduce energy bills.
6. Reduce the burning of fuel in power plants.
7. Reduce the emission of greenhouse gases.

3.3 Classification of Thermal Insulators

3.3.1 According to the structure

1. Organic materials, such as:

Cotton, Wool, Cork, Rubber and Cellulose.

2. Inorganic materials: such as.

Glass, Asbestos, Rockwool, Prelate, Vermiculite and Calcium Silicate.

3. Metallica's: such as aluminum foils and tin reflectors.

3.3.2According to the Shape

1) Rolls: vary in the degree of flexibility and the ability to bend or pressure. They could be fastened by nails like glass wool, rock wool, polyethylene and foil-ceramic rolls.

2) Sheets: There are specific dimensions and thicknesses such as polyethylene layers, polystyrene, cork and cellulose.

3) Liquid or gaseous fluids: poured or sprayed on to form the desired dielectric layer, such as polyurethane foam and epoxy.

4) Grains: a powder or granules are usually placed in the spaces between the walls and it can also be mixed with some other materials. Examples of such materials granulated cork and polymers.

3.4 Commercial Insulators

the thermal insulation refers to all isolators systems and processes that reduce the heat exchange between inside and outside. Thermal insulation in buildings in hot climates is designed to prevent the entry of heat to the building. Thus, the using of thermal insulation materials reduces the heat transfer. The most important thermal insulators are glass wool, cork, polyurethane and other polymeric materials as well as evacuated panels. It should refer here that air is one of the best thermal insulators due to its low coefficient of thermal conductivity (0.025 W/m.K) and availability everywhere.

3.5The most common insulators

1) Cellulose: which is made from wood or recycled paper and is characterized by its susceptibility to water and dust absorption.

2) Cork: This is taken from cork tree. It could be made industrial from petroleum product which is called the Expanded Polystyrene (EPS). It is found in the form of panels and used as thermal and acoustic insulators.

3) Glass wool: are widely used to insulate buildings, as well as boilers and

reservoirs.

4. Rock wool: This material is used to isolate the buildings and storages.

5) Polyurethane: usually uses as insulated panel or foam to fill the cracks.

6) Polystyrene cork: both types, EPS and XPS

7) Astrofoil (XPE) layers: consist of two aluminum foils and including air bubbles which are made of polyethylene materials. The aluminum layers reflect the solar radiations in the summer while the air bubbles reduce the heat transfer through the walls because of high air isolation. This material is a good insulator against the water and air leaks.

8) Polycarbonate panels: These sheets are lightweight panels, and are composed of several layers to be able to withstand the shocks with the presence of air cavities for the purposes of thermal insulation.

9) Reflective materials: such as aluminum panels, alu-cobond and reflective paints. These materials are used to reflect solar radiation on the exterior walls.

10) Fire retardant sheets: are wooden panels characterized by their ability to delay the fire growth in addition to the thermal insulation ability [9].

3.6 Main properties of thermal insulation materials (Density)

Knowing of the density of the material, gives a lot of information about it’s thermal insulation and strength characteristics. The lower is the density of the material; the lower is the thermal conductivity. But as low density, as low possibility of installing of the material, and usually high water absorption, and as a result life of the material will be decrease. For determining of the properties of the thermal insulation material, uses average density. Porosity. As was said before, the lower density, the lower thermal conductivity. Density depends on porosity. So, low density means high porosity (it’s mean a big amount of air in the material,

which have very low thermal conductivity 0,027 W/(*m k*) at temperature 200C /6, t. D1./) and low thermal conductivity. Thermal insulation properties don’t depend only on porosity, but also on kind of the material, structure of pore, there size and form, uniform of the distribution of pores in the material and also are pores closed or open, can they communicate with surroundings air. So, the best thermal insulation properties have materials with a big amount of little closed pores which are have uniform distribution in the volume of the material .

3.7 Design criteria, function

The purpose of thermal insulation in buildings is to maintain a comfortable and hygienic indoor climate at low ambient temperatures. A minimal amount of thermal insulation is required to protect the constructional elements against thermal impact and moisture related damage. The main aim of thermal insulation in winter is energy conservation leading to a decrease in heating demand and hence the protection of the environment. This aim has to be considered in new buildings as well as in renovating the building stock. Strategies to reach this aim are the use of building materials with low thermal conductivity λ-values and the installation of windows with low U-Values (see Windows) on the one side and the avoidance of thermal bridges and uncontrolled infiltration (see Ventilation) on the other side. Besides the above mentioned purpose, thermal insulation plays a major role in preventing summertime overheating of buildings through reducing the transmission of solar radiation, absorbed on the building’s exterior surfaces, to the interior. The lowest λ-values of non-evacuated elements achievable is the one of motionless air. Hence the basic principle in developing insulation materials is to enclose as much non-moving air into the structure of the material as possible and.

3.8 Parameters related to building physics

The thermal properties of structural elements are characterized by the mass density ρ, the λ-values of the building elements layers and the heat transfer coefficients α at the surfaces. The heat transmission through an element is defined by the air to air heat transmission coefficient U. reducing the λ-value of a material or increasing the thickness of the insulation layer results in a decreasing U-value. The heat transfer coefficients are composed of a convective and a radioactive part.

The heat transfer mechanisms are shown in Figure (3.1).

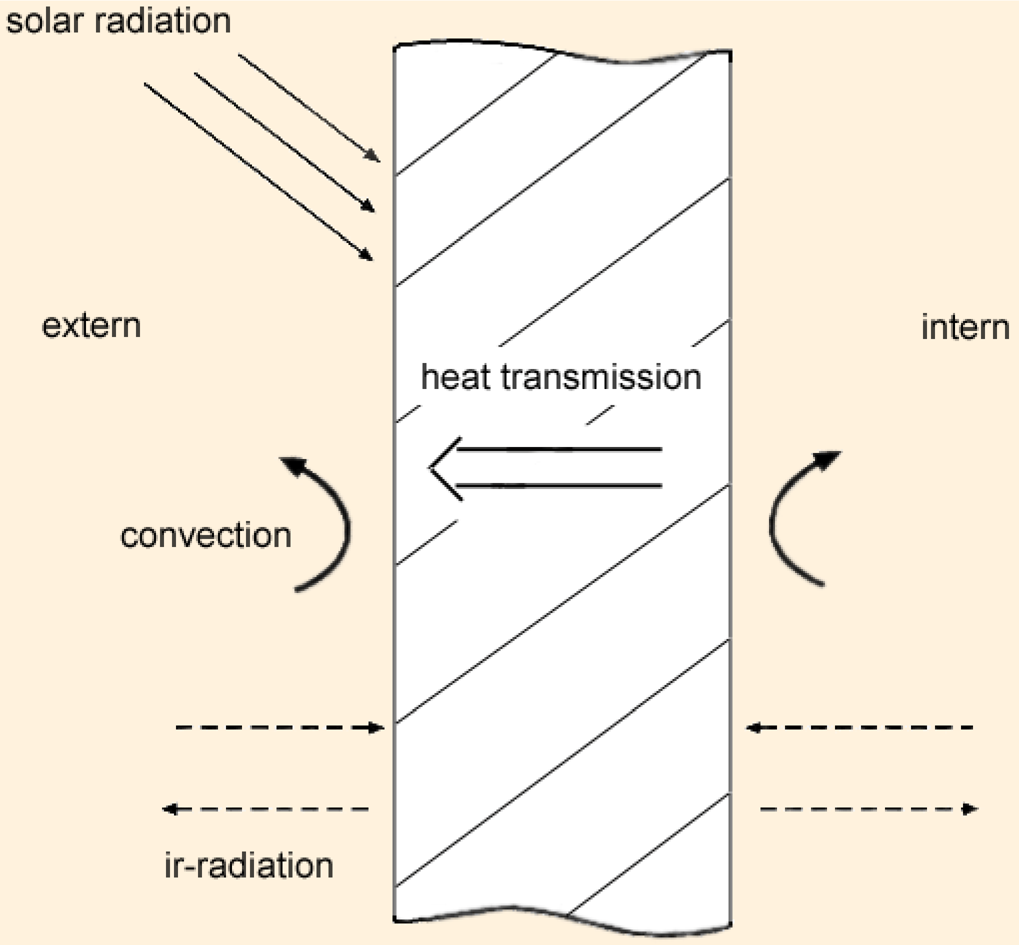

Figure (3.1) Thermal transfer mechanisms of an exterior partition in the heating season.

The hygroscopic properties are defined by the resistance to water vapor migrations number**.** Quantifies the resistance of a material against the migration of water vapor. To guarantee a positive moisture balance, the insulating materials have to be open to diffusion and have to absorb and release moisture quickly.

Table (3.1) Selected material properties of insulating materials

insulating material	**thermal conductivity (W/m K)**	**mass density (kg/m³)**	**resistance to water vapour migrations number (-)**
Organic			
Natural			
Cork	0.045-0.055	80-500	5-10
Wool	0.04	20-25	1-2
Cotton	0.04	20	1-2
Synthetic			
polystyrene, EPS	0.035-0.04	15-30	30-70
polystyrene, XPS	0.035-0.04	25-40	80-300
polyurethane rigid foam	0.025-0.035	30	30-100
Inorganic			
foam glass	0.04-0.055	10-160	praktisch dampfdicht
mineral fibre	0.035-0.05	15-80	1
air, motionless	0.0025	1.2	1
evacuated panel	0.006	-	praktisch dampfdicht

Figure (3.2) shows the decrease in the U-value as the thickness of the insulation layer increases. The U-value of a constructional element decreases rapidly as the first few centimeters of insulation are added. A further increase in insulation thickness does not always lead to an equally fast decrease in the U-value. The thicker the insulation layer already is, the less the decrease in the U-value is by further adding insulation.

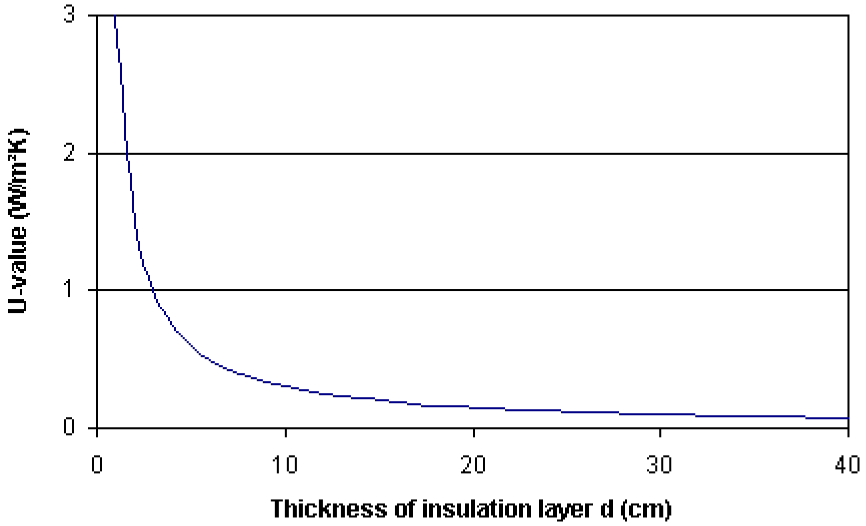

Figure (3.2) Decrease in the U-value with increasing thickness of the insulation layer.

Constructural requirements of insulation materials concerning the structural stability and the constancy of shape are characterized by the dynamic stiffness s` (MN/m²) and the thermal coefficient of longitudinal deformation αL [10].

Chapter Four

Material and Method

4.1 Introductions

Knowing the thermal conductivity of building materials is important in order to choose the least contact. In the lees method of finding thermal conductivity, one has to know the specific heat capacity of the material. The values of the specific heat capacity and thermal conductivity for three building materials were found. The values were determined and compared to the theoretical results as shown in Table (4.6).

4.2 Materials

A thermometer and calorimeter were used in this study to measure the specific heat capacity, a Lee’s disk sample and as of cement, wood and gypsum in form of disks was constructed to measure thermal conductivity.

4.3 Methods

Three blocks of different building materials were used to find the specific heat capacity and thermal conductivity by means of lees disk. The samples (cement, wood and gypsum) were prepared in the form of disks with a known thickness and cross section area. The samples putted between the tablets of the device. When the vapor passed through the upper disc, the raise of temperature was observed at the thermometer putted in the top disc T_1 and the temperature at the lower disc T_2 recorded. The rate of increase in temperature will not exceed half a degree within 10 minutes then difference between T_1 and T_2 recorded.

Separated the steam room and removed the top disk. We covered the upper surface of the lower disc with a buffer material and recorded the temperature every 10 seconds. The slope of the cooling curve, which represents the cooling rate ($\frac{dT}{dt}$) was recorded.

Figure (4.1) sample of wood

Figure (4.2) sample of gypsum

Figure (4.3) sample of cement

Figure (4.4) lees disk device

4.4 Results

The experimental results which have been carried out during the experiment was explained in section (4.4.1 and 4.4.2)

4.4.1 Specific Heat

$m_{0=}$ Mass of the calorie = 0.0495kg

c_0 =Specific heat of calorie = 389

c_2= Specific heat of water = 4186

T=temperature of sample=100c

m_1 = mas of sample

m_2=Mass of water

T_1 = Temperature of water and calorie

T_2 =The temperature of the mixture

dT =$T_1 - T_2$

$c_{1=}$ Specific heat of sample

$$c_1 = \frac{(m_2.c_2+m_0.c_0)(T_1\_T_2)}{m_1(T_1\_T)} \qquad (4.1)$$

Table (4.1) Specific heat of sample

matter	m_1 (kg)	m_2 (kg)	T_1 ℃	T_2 ℃	Specific heat of sample(c_1)
wood	0.004	0.1066	34	36.5	2611.34 j/Kg.k°
cement	0.0174	0.0609	34	38	1147.1 j/Kg.k°
gypsum	0.0106	0.0596	31.5	37	2201.82 j/Kg.k°

4.4.2 Thermal Conductivity Coefficient

K≡Thermal conductive cofficent

A≡ Surface area of sample

m≡mas of sample

C≡specefic heat for sample

dx≡ sampling thickness

$dT=T_1 - T_2$

$\frac{dT}{dt}$ ≡Cooling rate

Q≡ Thermal power

$$Q=A.k.\frac{dT}{dx}=m.c.\frac{dT}{dt} \qquad (4.2)$$

Then $$k = \left(m.c.\frac{dT}{dt}\right) \Big/ \left(A.\frac{dT}{dx}\right) \qquad (4.3)$$

Table (4.2): Cooling rate for Wood

time	temp	Time	temp	time	temp	time	temp
0	68	70	63	140	58	210	54
10	67	80	62	150	57.5	220	53.5
20	66	90	61	160	56.5	230	53
30	65	100	60.5	170	56	240	52.5
40	64.5	110	60	180	55.5	250	52
50	64	120	59	190	55	260	51.5
60	63.5	130	58.5	200	54.5	270	51

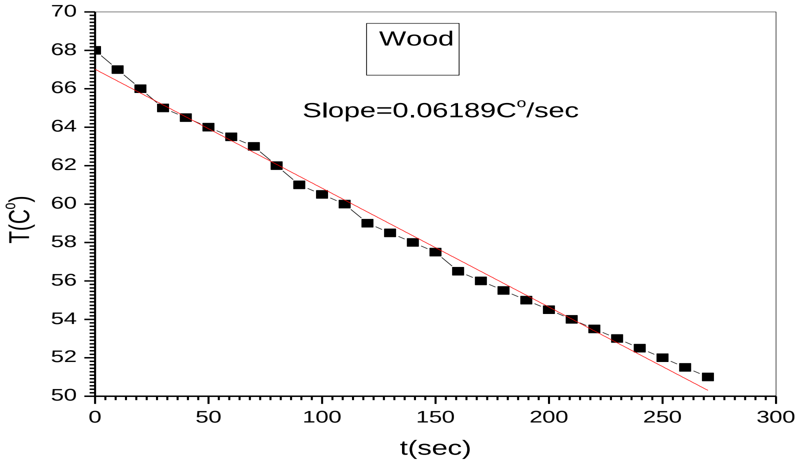

Figure (4.5) cooling rate curve for wood

Table (4.3): cooling rate for cement

Time (t)	Temp (T)	Time (t)	Temp (T)	Time (t)	Temp (T)	Time (t)	Temp (T)
0	86.5	70	82.5	140	76	210	71
10	86	80	82	150	75.5		
20	85.5	90	81	160	75		
30	84.5	100	80.5	170	74		
40	84	110	78.5	180	73.5		
50	83.5	120	78	190	73		
60	83	130	77.5	200	72		

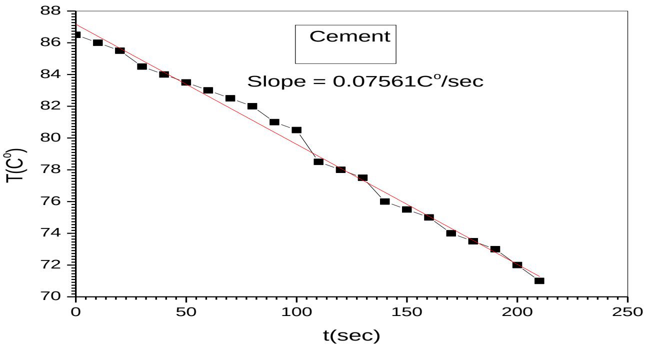

Figure (4.6) cooling rate curve for cement

Table (4.4): cooling rate for gypsum

Time (t)	Temp (T)	Time (t)	Temp (T)	Time (t)	Temp (T)	Time (t)	Temp (T)
0	70	70	66	140	62.5	210	58.5
10	69.5	80	65.5	150	62	220	58
20	69	90	65	160	61.5	230	57.5
30	68	100	64.5	170	61	240	57
40	67.5	110	64	180	60	250	56
50	67	120	63.5	190	59.5	260	55.5
60	66.5	130	63	200	59	270	55

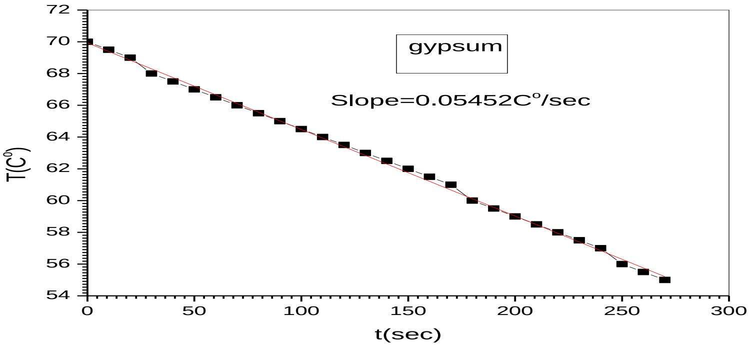

Figure (4.7) curve of cooling rate for gypsum

Table (4.5) Thermal conductivity coefficient

Matter	m (kg)	C (j/Kg.k°)	T_1(°C)	T_2(°C)	dT	$\frac{dT}{dt}$	dx (cm)	K ($W/$m.c)
Wood	0.04	2611.32	92	52	40	0.061	0.38	0.062
Cement	0.1	11470.1	99	71	28	0.065	0.576	0.158
Gypsum	0.085	2201.82	91	55	36	0.054	0.7	0.236

4.4.3 Comparison between the theoretical values and experimental values

Table (4.6): Comparison between the theoretical values and experimental values

no	material	Thermal conductivity (experimental)	Thermal conductivity (Theoretical values)	References
1	wood	$0.062\left(\frac{W}{m.c}\right)$	0.4---0.04 $\left(\frac{W}{m.c}\right)$	[11]
2	cement	$0.158\left(\frac{W}{m.c}\right)$	$0.29\ \left(\frac{W}{m.c}\right)$	[11]
3	gypsum	$0.236\left(\frac{W}{m.c}\right)$	$0.17\ \left(\frac{W}{m.c}\right)$	[12]

4.5 Discussion

In this work three types of building material blocks of made cement, wood and gypsum were used to calculate the thermal conductivity coefficient and specific heat capacity. Equation (4.3) was used to calculate the thermal conductivity factor for those samples. Table (4.6) show that wood has less thermal conductivity then cement and gypsum. It was found that the thermal conductivity of cement it was slightly different from considered theoretical value due to manufactory different in additive materials. Table (4.1) shows the specific heat for the samples which reveals different value $2611.34\frac{j}{k_g k^0}$ for wood, $1147.1\ \frac{j}{k_g k^0}$ for cement and for gypsum $2201.82\frac{j}{k_g k^0}$.

4.6 Conclusion

- Wood is the least heat conduction
- Cement has higher thermal conductivity than wood but less than gypsum
- Gypsum is the highest thermal conductivity

4.7 Recommendation

1) Conduct studies on a larger number of building materials

2) Mixing between these materials and studying the effect of change on thermal conductivity

3) Measurements by other devices to ensure a high degree of accuracy

4) Conducting a comparative study between the methods of measuring thermal conductivity

5) The accuracy of the results in this method to measure the thermal conductivity coefficient depends on the accuracy of the observation

References

[1]Hollingsworth, M., Jr., “Experimental Determination of the Thickness Effect in Glass Fiber Building Insulation” Thermal Insulation Performance, ASTM STP 718, D.L.McElroy and R.P.Tye, Eds., American Society for Testing and Materials, 1980, pp.255-271.

[2] Thermal Conductivity and Coefficients of Thermal Expansion of SWNTs/Epoxy Nan composites 2004 Philippe Gonnet

[3] Pelanne, C.M., “Discussion on Experiments to Separate the “Effect of Thickness” from Systematic Equipment Errors in Thermal Transmission Measurements,” Thermal Insulation Performance, ASTM STP 718, D.L.McElroy and R.P.Tye, Eds., American Society for Testing and Materials, 1980, pp.322-334. [3 Holman, J.P., “Heat Transfer” 8th ed., McGraw-Hill, Inc., New York etc., 1997, p.430.

[4] Flynn, D.R. and Gorthala, R., “Radiation Scattering versus Radiation Absorption – Effects on Performance of Thermal Insulation under Non-Steady-State Conditions,” Insulation Materials: Testing and Applications: Third volume, ASTM STP 1320,R.S.Graves and R.R.Zarr, Eds., American Society for Testing and Materials, 1997, pp.366-380

[5] Klemens, P.G. and Kim, N., “Radiative Heat Transfer in Inhomogeneous Media and Insulations,” Thermal Conductivity 19, Plenum Press, New York – London, 1985, pp.453-458.

[6] Rish III, J.W., Roux, J.A. and Fairey III, P.W., “The Resistance of Fibrous Insulations Undergoing Coupled Transient Conduction and Radiation Heat Transfer,” Thermal Conductivity 19, Plenum Press, New York –London, 1985, pp.497-510.

[7] Kamran Daryabeigi, AIAA 2002-3332 / Heat Transfer in High – Temperature Fibrous Insulation, 8th AIAA/ASME Joint Thermo physics and Heat Transfer Conferencet, St. Louis, MO, June 24-26, 2002

[8] Insulation Materials By: Dr. Tawfeeq Wasmi M. Salih
Academic year 2015-2016

[9] Comparison of Thermal Insulation Materials for Building Envelopes of Multi-storey Buildings in Saint-Petersburg (by Martti Veuro)

[10] http://nesa1.uni-siegen.de/wwwextern/idea/keytopic/6.htm 11 MAY, 2018\ 5:30pm

[11] https://ar.wikipedia.org/wiki/ 11 MAY, 2018\ 5:30pm

[12] https://civteam.files.wordpress.com/2012/02/d8a7d984d985d984d8add9824-d8a7d984d8b9d8b2d984-d8a7d984d8add8b1d8a7d8b1d98a.pdf \14 MAY, 2018\ 5:30pm

Chapter One

Introduction

1.1Introduction

Heat can be transferred to or from a material in three fundamental ways; conduction, convection, and/or radiation. Any and all of the three types of heat transfer can occur for a system, so one must be careful not to neglect any heat transferred during the process. In conduction, heat is transferred from one part of a body to another part of that same body, or between bodies that are in contact with each other without any appreciable displacement of the particles within the body. The discussion on conduction will begin with Fourier’s Law, which allows for equations to be derived for steady state uniaxial heat transfer. A simplified equation that can be used in the event that heat is not generated (via chemical or nuclear reactions or electrical current) will also be presented. Finally, equations for heat transfer through bodies in series and bodies in parallel will be given. Due to the level of complexity, unsteady state conduction is outside of the scope of this site, and generally involves advanced algorithms and assistance from computer software. These systems are indicative of materials whose temperatures change with respect to both time and position. Some references will be given for those readers interested can pursue at their leisure. In convection, heat is transferred from one point to another through a moving fluid, most likely a gas or liquid, as a result of the mixing of different portions of the fluid. There are two sub-segments of convection, natural and forced. In natural convection, the motion of the fluid is the inherent result of the density gradient that results from the temperature differential. In forced convection, the motion of the fluid is the result of some mechanical work, such as a blow or pump moving the fluid across the material. Heat is transferred through radiation from one body to another by means of wave motions through space [1].

1.2 Research Problem

In transient condition, thermal conductivity data of a material is still needed since diffusivity is a function of conductivity and volume heat capacity. Good heat insulating lowers the building temperature and thus reduces the voltage consumption in their condition. Therefore, in this research, the measurement of the thermal conductivity coefficient in building materials will be discussed

1.3 Aim of the work

The main objective of this thesis it was concluded on Measure of the specific heat capacity and thermal conductivity for building materials.

1.4 Methodology

Three blocks of building material were used to find the specific heat capacity and thermal conductivity by means of lees disc. To do so sample of cement, wood and gypsum were prepared in the form of disks with known thickness and a given area. Then samples were putted between lees disc.

1.5 Presentation of Thesis

This Thesis contains four chapters, chapter One Introduction chapter two heat Transfer Chapter three Heat Insulation, chapter four materials and methods

1.6 literature review

1.6.1 Anastasios Karamanos, Agis Papadopoulos1, Dimitrios Anastasellos. Heat Transfer Phenomena in Fibrous Insulating Materials

Concluded that the Insulation has been and still remains one of the fundamental tools for achieving energy conservation both in the buildings' and in the industrial sector. Whilst specific insulating materials are used for

Each application, according to the physical and operational requirements, there is a group of materials that is used in both cases, namely in organic fibrous materials. The study of industrial insulating materials is a rather hard task, duet the complex phenomena which take place in the materials' structure, because of the extreme conditions, in which the materials applied. In this paper are discussed some of these changes. The study presented focuses on stone wool, which is the most widely used, and in that sense the most representative inorganic fibrous material. Its performance is based on their embodied between its fibers, which produce a low thermal conductivity factor. Under some operational conditions, however, like the increased presence of moisture, the thermal conductivity factor may change. The objective of this paper is to describe the theoretical approach and the resulting data on the assessment of the change sins tone wool's thermal conductivity, under various operational conditions. In order to achieve that, adscription of stone wool's chemical composition and structure is given, followed by the physical and mathematical background necessary for determining the thermal conductivity factor. The results yielded in this way are compared to experimental and theoretical references available, in order to verify the validity of the adopted approach.

1.6.2 E Latif*, M Pruteanu***and G Rhydwen*, D C Wijeyesekera *, S Tucker **, M A Ciupala *, D Newport Thermal Conductivity of Building Materials: An Overview of Its Determination,

A range of instruments are available to measure thermal conductivity of building materials. Some of these tools are heat-flow meter, hot plate, hot box and heat transfer analyzer. Thermal conductivity data derived by using different instruments can be different from each other. Implication of these variations in thermal conductivity is significant in terms of commercial profile of the insulations and also in terms of calculating energy saving in

Large scale use of that specific insulation. Thus it is important to know which of the measuring instrument for thermal conductivity can produce relatively accurate and representative result. This paper firstly looks at the methods and instrument for measuring thermal conductivity of building materials and secondly compares and analyses the results of testing thermal conductivity of fibrous insulations using a heat analyzer and a hot plate.

1.6.3 JITKA MOHELNIKOVA Determination of Specific Heat of a Building Material

Specific heat is important property of building materials which is used for thermal evaluation of building constructions. The paper presents method for determination of this property for samples of chip-wood boards. The determination of physical properties of the boards was a task of a research project focused on the energy evaluation of low-energy housing. The specific heat capacity was determined on the basis of experimental measurements of selected samples of chip-wood boards.

Chapter Two

Heat Transfer

2.1 Definition

Heat transfer consists in the flow of heat from a region of higher temperature to a region f lower temperature next to it. This heat transfer can occur through three different media: convection, radiation and conduction. In many cases, these three modes of heat transfer happen in the same time but it is important to differentiate them . Measuring the thermal conductivity imply being able to measure the heat transport by conduction only. This is possible only if a certain control can be done on radiation and convection [2].

2.1.1 Convection

The convection is the heat transfer due to the bulk movement of a fluid, usually between a solid and a fluid. This heat transfer uses the heat conduction of the fluid particles by the fluid motion itself. The fluid can be a liquid or a gas and must be able to withstand the heat involved. If the fluid is forced to move by a pump or a blower, the convection is known as forced convection. The simplest illustration of this case is the use of the fan: the movement of air generated by the fan motion increases the heat conduction of the air itself. If the fluid move is due to difference in density, the convection is known as natural or free convection. An example of free convection could be the use of a heater in a room, as presented in Figure (2.1).

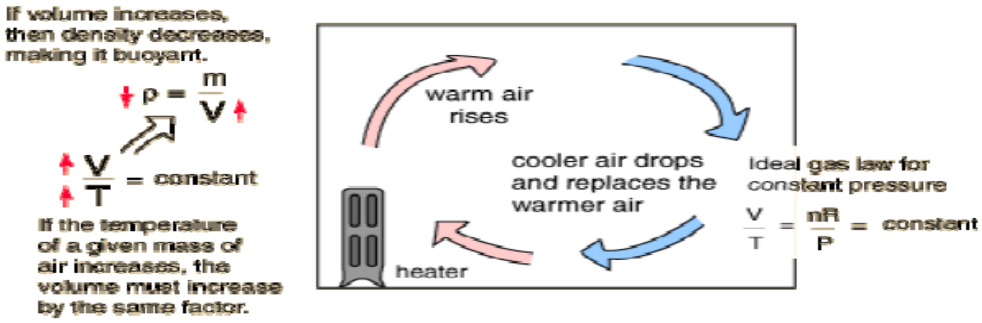

Figure (2.1) Scheme of free convection due by a heater

The same quantity of warm air, n, takes a bigger volume V than cold air, according to the ideal gas low (PV = nRT) with P constant. The density of the warmer air is less than cold air. The warmer air rises, which gives the fluid motion. For the measurement of thermal conductivity, this very phenomenon can occur as a heat flow is commonly created in every method. The common control of the convection is realized by setting the fixture in a high vacuum. If no gas is in the environment of the sample, no free convection is possible.

2.1.2 Radiation.

The radiation is a transfer of energy by electromagnetic wave motion with a defined range of wavelengths, typically infrared. All surfaces emit radiant heat. The dominant wavelength of the emitted radiation decreases with increasing temperature of the body .The higher the temperature is, the greater the rate of emission of radiant energy per unit area of the surface. The relationship governing radiation from hot objects is called the Stefan-Boltzmann law.

$$P = e\,\sigma\,A\,(T^4 - Tc^4) \qquad (2.1)$$

Where P is the radiated power, A is the radiating area, σ (5.6703 10-8 W/m2K4) is Stefan’s constant, e is the emissivity of the material, T is the temperature of the radiator and T_C the temperature of the surroundings. To account for a body's outgoing radiation or its emissive power, which is defined as the heat flux per unit time, one makes a comparison to a perfect

Body that emits as much thermal radiation as possible. Such an object is known as a blackbody, and the ratio of the actual emissive power E to the emissive power of a blackbody is defined as the surface emissivity e = E /$E_{\text{blackbody}}$. A blackbody is then a material with an emissivity e equal to 1. The following table presents some values of emissivity for different material.

Table (2.1) Emissivity data for material in different state

Material	$*_C$	Emissivity
G-10EPoxy Resin	----	0.95
Glass	20-100	0.94 - 0.91
Carbon		
Filament	1000-1400	0.53
Graphite	0-3600	0.7 - 0.8
Lamp Black	20-400	0.96
Soot Applied to solid	50-1000	0.96
Soot With Water Glass	200-200	0.96
Aluminum		
Polished	50-500	0.04 - 0.06
Rough Surfaces	20-50	0.06 - 0.07
Strongly Oxidized	55-500	0.2 - 0.3
Oxidized	200	0.11

The control of radiation is more difficult than the control of convection. Indeed, the radiation occurs even without any gas. The radiation cannot be eliminated but different Possible. For that, the sample size is as small as possible. More important in the relation is the difference of temperature between the sample and its surroundings. This parameter is to the power 4 and can vary along the measure. The best protection against radiation is then to set a radiation shield around the sample. A radiation shield is a material of high thermal conductivity in thermal contact with the fixture. Its high thermal conductivity allows it to follow the difference of temperature during the measurements in order to create a surrounding of the sample with a temperature close to the sample itself. This shield cannot however be perfect and the heat loss by radiation must be taken into account.

2.1.3 Conduction

The conduction can be defined as the transmission of heat within a material motion of the substance. The heat transfer goes from higher to lower temperature regions in a material. The ability of a substance to conduct heat is characterized by its thermal conductivity κ or λ, which in turn is defined by the atomic structure of the substance. Conduction is more tied to material development than convection or radiation. Gases transfer heat by direct collisions between molecules. Their thermal conductivity is low compared to most solids since they are dilute media. Thermal conduction can involve electrons, ions, and/or phonons. Electrons and ions move from a point of higher temperature to a point of lower temperature, thereby transporting heat. Due to the high mass of ions compared to electrons, electrons move much more easily. In a crystal, the thermal agitation of atoms creates spontaneously vibration waves. Their amplitude increases as the temperature rises. These elastic waves are called phonons in the Einstein model. Einstein postulated the existence of phonons as lattice vibration quanta, which are thought to be created in large numbers in the hot part of a solid and partially eliminated in the cold part. Heals postulated their particle-wave duality. For a lattice such as one defined by a metal or a crystal [3].

2.1.3.1 Fourier's Law

The fundamental differential equation for conduction heat transfer is Fourier's Law, which states:

$$\frac{dQ}{dt} = -kA\left(\frac{dT}{dx}\right)$$

$$= m.C.\frac{dT}{dt} \qquad (2.2)$$

Where Q is heat, t is time, k is the thermal conductivity, A is the area normal to the direction of heat flow, T is temperature, and x is distance in the direction of heat flow. At this point, it is worth noting that the thermal conductivity typically varies with temperature, but not necessarily in the same direction. A common simplification in heat transfer calculations is to assume this term is constant within the conditions of the system under study. It is strongly suggested investigate literature, obtain values from material vendors, or carefully conduct calorimetric testing within one's lab to determine the proper values for k for the given material as a function of temperature, especially if a phase transition occurs within the range of temperatures under study.

Using Fourier's Law, we can write an expression for a three dimensional unsteady-state energy equation for a solid.

$$c_{\rho}\frac{\delta T}{\delta t} = \frac{\delta}{\delta x}\left(k\frac{\delta T}{\delta x}\right) + \frac{\delta}{\delta y}\left(k\frac{\delta T}{\delta y}\right) + \frac{\delta}{\delta z}\left(k\frac{\delta T}{\delta z}\right) + q_{gen} \qquad (2.3)$$

Where c is the specific heat of the material, is the density of the material, T is temperature, t is time, x, y, and z are distances in Cartesian coordinates, and q_{gen} is the rate of heat generated per unit volume, typically by chemical or nuclear reactions or electrical current. This equation will serve as the basis for solving steady state heat transfer problems [4].

2.2.1 Steady State Conduction

In steady state conduction, the rate of heat transferred relative to time (dQ/dt) is constant and the rate of change in temperature relative to time (dT/dt) is equal to zero. For heat transfer in one dimension (x-direction), the previously mentioned equations can be simplified by the conditions set forth by steady-state to yield:

$$\frac{\delta^2 T}{\delta x^2} = -\frac{1}{k}\left[\frac{\frac{\delta Q}{\delta t}}{\delta x}\right] \tag{2.4}$$

Similar relationships can be derived for other coordinate systems including:

Cylindrical

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{dt}{dr}\right) = -\frac{1}{k}\left(\frac{\frac{\delta Q}{\delta t}}{\delta r}\right) \tag{2.5}$$

Spherical

$$\frac{1}{r^2}\frac{d}{dr}(r^2\frac{dt}{dr}) = -\frac{1}{k}\left(\frac{\frac{\delta Q}{\delta t}}{\delta r}\right) \tag{2.6}$$

Upon integration of these second order differential equations, the following are obtained:

In Cartesian coordinates:

$$T = -\frac{\left(\frac{\frac{\delta Q}{\delta t}}{\delta x}\right)x^2}{2k} + c_1 x + c_2 \tag{2.7}$$

While in Cylindrical coordinates as

$$T = -\frac{\left(\frac{\frac{\delta Q}{\delta t}}{\delta r}\right)r^2}{4k} + c_1 lnr + c_2 \tag{2.8}$$

And in Spherical coordinate as

$$T = -\frac{\left(\frac{\frac{\delta Q}{\delta t}}{\delta r}\right)xr^2}{6k} + \frac{C_1}{r} + c_2 \tag{2.9}$$

In the event that heat is not generated in the system of interest, (dQ/dt)/dx is equal to zero. For a steady state, one dimensional system, Fourier’s law can be integrated to give:

$$q\int_{x_1}^{x_2 2} \frac{dx}{A} = - \int_{T_1}^{T_2} KdT \qquad (2.10)$$

Where q is the rate of heat transfer, *to* solve this equation, the area (A) through which the heat is being transferred must be known as a function of position (x). In the event that k is a constant, the integration of the above equation results in:

$$Q = -k.A.\frac{dT}{dt} \qquad (2.11)$$

Where A_{avg} is calculated by:

$$A_{avg} = \frac{1}{dx}\int_{x_1}^{x_2} \frac{dx}{A} \qquad (2.12)$$

Table (2.2) gives some equations to calculate A_{avg} based on the relationship between A and x

Area (A) is proportional to:	A_{avg} is equal to:
Constant	$A_1=A_2$
X	$\dfrac{A_2 - A_1}{\ln\left(\dfrac{A_x}{A_1}\right)}$
x^2	$\sqrt{\dfrac{A_2}{A_1}}$

2.3 Thermal Conductivity.

The coefficient of thermal conductivity κ of a material can be determined using Fourier’s Law of conduction:

$$Q = -K.A.\frac{\Delta T}{L} \quad (2.13)$$

Where Q is heat flow in watt per surface area generated by the temperature gradient ΔT over the thickness L with cross-section area A

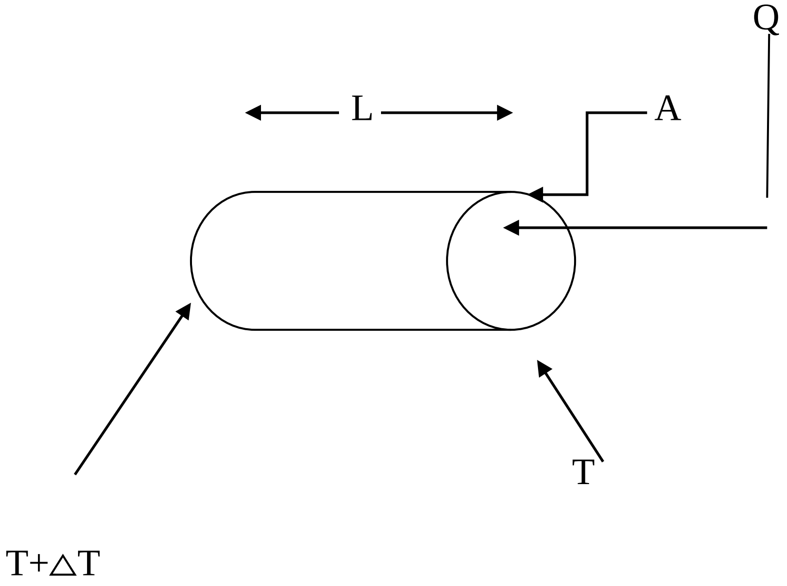

Figure (2.2) Illustration of the parameters in the Fourier's law of conduction

Thermal conductivity can also be obtained by other properties of the material:

$$\kappa = \rho \cdot C_P . h \quad (2.14)$$

Where Cp is the heat capacity at constant pressure, ρ is the density of the material and h is the thermal diffusivity [cm2/s]. This relation is used to calculate the thermal conductivity with the laser flash technique. The difficulty of the calculation of the thermal conductivity is also associated with the heat flux measurement. Where the measurement of the heat flux is done directly (for example, by measuring the electrical power going into the heater), the measurement is called absolute. Where the flux measurement is done indirectly (by comparison), the method is called comparative [5].

2.4 Thermal Expansion

Description most solids increase their dimensions when heated at constant pressure. This phenomenon is called the thermal expansion. However, some substances contract when heated and thus present a negative coefficient of thermal expansion (CTE). Moreover, the thermal expansion of a solid can be anisotropic if the solid presents different properties according to direction. This situation occurs in composites materials with a directional reinforcement. Thermal expansion is commonly explained as a change of dimension according to temperature due to atoms interactions. When heated, the energy brought to the atoms increases their vibrations, causing the mean distance between the atoms to increase. However, this model only takes into account the longitudinal component of vibration motion along the line joining two atoms. In solids, there are also components of relative motion transverse to this line that can pull the atoms toward each other, decreasing the distance between atoms. When this pulling force is stronger than the longitudinal component, it produces a material with negative CTE. These two mechanisms have opposite effects and the expansion will be positive or negative depending upon which is larger. The coefficient of thermal expansion quantified the thermal expansion of the solid. This coefficient can be volumetric or linear according to the fact that the measurement is done on the change of volume or length of the sample. The equations to calculate the volumetric (β) and linear (α) coefficient of thermal expansion are the following.

$$\beta = (\frac{\partial V}{\partial T})_P . \frac{1}{V} \tag{2.15}$$

$$\alpha = (\frac{\partial yL}{\partial T})_P . \frac{1}{L} \tag{2.16}$$

Where V is the volume, L is the length, T is the temperature and the derivative is at constant pressure. However, the usual technical values, such as the values presented in Tables (2.3) and (2.4) use the volume (VRT) or length (LRT) at room temperature as reference, instead of using the volume or length at temperature measured [12].

$$\beta = (\frac{\partial V}{\partial T})_P \frac{1}{V_{RT}} \tag{2.17}$$

$$\alpha = (\frac{\partial V}{\partial T})_P \tag{2.18}$$

Table (2.3) Coefficient of thermal linear expansion for reference materials

Material	Thermal expansion in $10^{-6} c^{-1}$
Glass. ordinary	9
Glass, Pyrex	4
Quartz, fused	0.59
Aluminum	24
Brass	19
Copper	17
Iron	12
Steel	13
Platinum	9
Gold	14
Silver	18

For polymer, such as epoxy, the coefficients of thermal expansion are divided in two parts: before and after the temperature of glass transition $\mathrm{T_g}$. The most useful coefficient concerns the temperature before $\mathrm{T_g}$as the polymer or composite lost most of its mechanical properties after $\mathrm{T_g}$. By comparing table2:3 and 2:4, we can notice that polymer and polymer composite have a higher CTE than metals. However by reinforcement with a material of lower CTE (such as glass fiber), the CTE of the composites are reduced, as shown in Table (2.4) [6].

Table (2.4) shows the CTE for plastics and glass-reinforced plastics

Material	Thermal expansion in $10^{-6}c^{-1}$
Epoxy	54
Polypropylene	86
TP Polyester	124
polyethylene	130
Polycarbonate (glass reinforced)	22
TP polyester (glass reinforced)	25
Polypropylene (glass reinforced)	32
Epoxy (glass reinforced)	36
Polypropylene sulfide (glass reinforced)	36

2.5 Specific heat capacity

Specific heat capacity of materials and components are of vital importance in their final functionality i.e. thermal storage in building elements or transient heat flux. There are different methods for determination of the specific heat capacity. One method is the adiabatic calorimetric where heat is added to a sample while the temperature increase is measured continuously. The sample is surrounded by a heating guard keeping the initial measuring temperature to minimize the heat losses from the sample to the surrounding. If the losses are negligible, the heat capacity can be calculated from the known energy input and temperature [7].

Chapter Three

Thermal Insulation

3.1 Definition

Thermal insulation is the process of insulating material from transferring heat between the materials that are in thermal contact. Thermal insulation is measured by its thermal conductivity. Low thermal-conductive materials are used for thermal insulation. Besides thermal conductivity, density and heat capacity are also important properties of insulating materials. Corrosion under insulation is prevalent in petrochemicals and other industries where pipes and equipment are insulated from heat. Corrosion normally occurs on the insulation materials underlying piping or equipment. It also affects the insulation of jacket materials [8].

3.2The Advantages of Thermal Insulation

1. Reduce the amount of heat transmitted through the parts of the house.
2. Reduce the energy required for heating or cooling the house.
3. Make the internal temperature of the building stable, non-volatile.
4. Keep the temperature of the building elements stable thus long time life.
5. Reduce energy bills.
6. Reduce the burning of fuel in power plants.
7. Reduce the emission of greenhouse gases.

3.3 Classification of Thermal Insulators

3.3.1 According to the structure

1. Organic materials, such as:

Cotton, Wool, Cork, Rubber and Cellulose.

2. Inorganic materials: such as.

Glass, Asbestos, Rockwool, Prelate, Vermiculite and Calcium Silicate.

3. Metallica's: such as aluminum foils and tin reflectors.

3.3.2According to the Shape

1) Rolls: vary in the degree of flexibility and the ability to bend or pressure. They could be fastened by nails like glass wool, rock wool, polyethylene and foil-ceramic rolls.

2) Sheets: There are specific dimensions and thicknesses such as polyethylene layers, polystyrene, cork and cellulose.

3) Liquid or gaseous fluids: poured or sprayed on to form the desired dielectric layer, such as polyurethane foam and epoxy.

4) Grains: a powder or granules are usually placed in the spaces between the walls and it can also be mixed with some other materials. Examples of such materials granulated cork and polymers.

3.4 Commercial Insulators

the thermal insulation refers to all isolators systems and processes that reduce the heat exchange between inside and outside. Thermal insulation in buildings in hot climates is designed to prevent the entry of heat to the building. Thus, the using of thermal insulation materials reduces the heat transfer. The most important thermal insulators are glass wool, cork, polyurethane and other polymeric materials as well as evacuated panels. It should refer here that air is one of the best thermal insulators due to its low coefficient of thermal conductivity (0.025 W/m.K) and availability everywhere.

3.5The most common insulators

1) Cellulose: which is made from wood or recycled paper and is characterized by its susceptibility to water and dust absorption.

2) Cork: This is taken from cork tree. It could be made industrial from petroleum product which is called the Expanded Polystyrene (EPS). It is found in the form of panels and used as thermal and acoustic insulators.

3) Glass wool: are widely used to insulate buildings, as well as boilers and

reservoirs.

4. Rock wool: This material is used to isolate the buildings and storages.

5) Polyurethane: usually uses as insulated panel or foam to fill the cracks.

6) Polystyrene cork: both types, EPS and XPS

7) Astrofoil (XPE) layers: consist of two aluminum foils and including air bubbles which are made of polyethylene materials. The aluminum layers reflect the solar radiations in the summer while the air bubbles reduce the heat transfer through the walls because of high air isolation. This material is a good insulator against the water and air leaks.

8) Polycarbonate panels: These sheets are lightweight panels, and are composed of several layers to be able to withstand the shocks with the presence of air cavities for the purposes of thermal insulation.

9) Reflective materials: such as aluminum panels, alu-cobond and reflective paints. These materials are used to reflect solar radiation on the exterior walls.

10) Fire retardant sheets: are wooden panels characterized by their ability to delay the fire growth in addition to the thermal insulation ability [9].

3.6 Main properties of thermal insulation materials (Density)

Knowing of the density of the material, gives a lot of information about it's thermal insulation and strength characteristics. The lower is the density of the material; the lower is the thermal conductivity. But as low density, as low possibility of installing of the material, and usually high water absorption, and as a result life of the material will be decrease. For determining of the properties of the thermal insulation material, uses average density. Porosity. As was said before, the lower density, the lower thermal conductivity. Density depends on porosity. So, low density means high porosity (it's mean a big amount of air in the material,

which have very low thermal conductivity 0,027 W/(*m k*) at temperature 200C /6, t. D1./) and low thermal conductivity. Thermal insulation properties don’t depend only on porosity, but also on kind of the material, structure of pore, there size and form, uniform of the distribution of pores in the material and also are pores closed or open, can they communicate with surroundings air. So, the best thermal insulation properties have materials with a big amount of little closed pores which are have uniform distribution in the volume of the material .

3.7 Design criteria, function

The purpose of thermal insulation in buildings is to maintain a comfortable and hygienic indoor climate at low ambient temperatures. A minimal amount of thermal insulation is required to protect the constructional elements against thermal impact and moisture related damage. The main aim of thermal insulation in winter is energy conservation leading to a decrease in heating demand and hence the protection of the environment. This aim has to be considered in new buildings as well as in renovating the building stock. Strategies to reach this aim are the use of building materials with low thermal conductivity λ-values and the installation of windows with low U-Values (see Windows) on the one side and the avoidance of thermal bridges and uncontrolled infiltration (see Ventilation) on the other side. Besides the above mentioned purpose, thermal insulation plays a major role in preventing summertime overheating of buildings through reducing the transmission of solar radiation, absorbed on the building’s exterior surfaces, to the interior. The lowest λ-values of non-evacuated elements achievable is the one of motionless air. Hence the basic principle in developing insulation materials is to enclose as much non-moving air into the structure of the material as possible and.

3.8 Parameters related to building physics

The thermal properties of structural elements are characterized by the mass density ρ, the λ-values of the building elements layers and the heat transfer coefficients α at the surfaces. The heat transmission through an element is defined by the air to air heat transmission coefficient U. reducing the λ-value of a material or increasing the thickness of the insulation layer results in a decreasing U-value. The heat transfer coefficients are composed of a convective and a radioactive part.

The heat transfer mechanisms are shown in Figure (3.1).

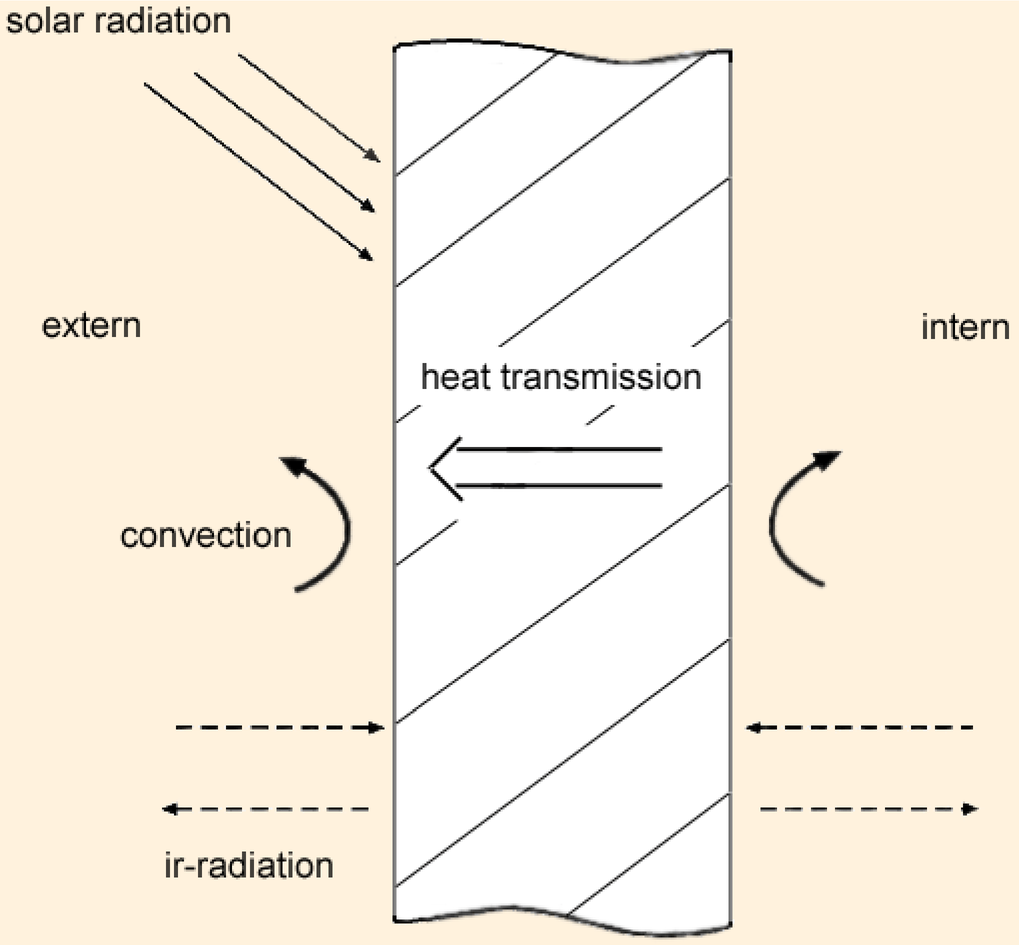

Figure (3.1) Thermal transfer mechanisms of an exterior partition in the heating season.

The hygroscopic properties are defined by the resistance to water vapor migrations number**.** Quantifies the resistance of a material against the migration of water vapor. To guarantee a positive moisture balance, the insulating materials have to be open to diffusion and have to absorb and release moisture quickly.

Table (3.1) Selected material properties of insulating materials

insulating material	**thermal conductivity (W/m K)**	**mass density (kg/m³)**	**resistance to water vapour migrations number (-)**
Organic			
Natural			
Cork	0.045-0.055	80-500	5-10
Wool	0.04	20-25	1-2
Cotton	0.04	20	1-2
Synthetic			
polystyrene, EPS	0.035-0.04	15-30	30-70
polystyrene, XPS	0.035-0.04	25-40	80-300
polyurethane rigid foam	0.025-0.035	30	30-100
Inorganic			
foam glass	0.04-0.055	10-160	praktisch dampfdicht
mineral fibre	0.035-0.05	15-80	1
air, motionless	0.0025	1.2	1
evacuated panel	0.006	-	praktisch dampfdicht

Figure (3.2) shows the decrease in the U-value as the thickness of the insulation layer increases. The U-value of a constructional element decreases rapidly as the first few centimeters of insulation are added. A further increase in insulation thickness does not always lead to an equally fast decrease in the U-value. The thicker the insulation layer already is, the less the decrease in the U-value is by further adding insulation.

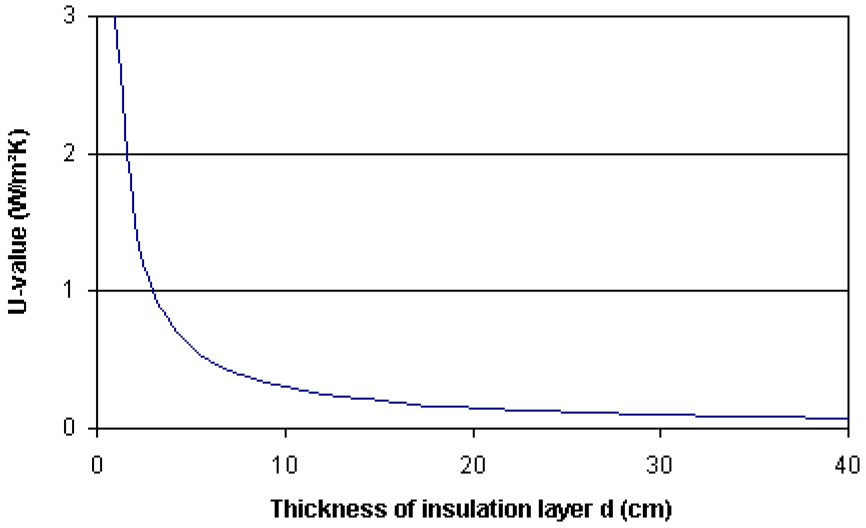

Figure (3.2) Decrease in the U-value with increasing thickness of the insulation layer.

Constructural requirements of insulation materials concerning the structural stability and the constancy of shape are characterized by the dynamic stiffness s` (MN/m^2) and the thermal coefficient of longitudinal deformation αL [10].

Chapter Four

Material and Method

4.1 Introductions

Knowing the thermal conductivity of building materials is important in order to choose the least contact. In the lees method of finding thermal conductivity, one has to know the specific heat capacity of the material. The values of the specific heat capacity and thermal conductivity for three building materials were found. The values were determined and compared to the theoretical results as shown in Table (4.6).

4.2 Materials

A thermometer and calorimeter were used in this study to measure the specific heat capacity, a Lee's disk sample and as of cement, wood and gypsum in form of disks was constructed to measure thermal conductivity.

4.3 Methods

Three blocks of different building materials were used to find the specific heat capacity and thermal conductivity by means of lees disk. The samples (cement, wood and gypsum) were prepared in the form of disks with a known thickness and cross section area. The samples putted between the tablets of the device. When the vapor passed through the upper disc, the raise of temperature was observed at the thermometer putted in the top disc T_1 and the temperature at the lower disc T_2 recorded. The rate of increase in temperature will not exceed half a degree within 10 minutes then difference between T_1 and T_2 recorded.

Separated the steam room and removed the top disk. We covered the upper surface of the lower disc with a buffer material and recorded the temperature every 10 seconds. The slope of the cooling curve, which represents the cooling rate ($\frac{dT}{dt}$) was recorded.

Figure (4.1) sample of wood

Figure (4.2) sample of gypsum

Figure (4.3) sample of cement

Figure (4.4) lees disk device

4.4 Results

The experimental results which have been carried out during the experiment was explained in section (4.4.1 and 4.4.2)

4.4.1 Specific Heat

$m_{0=}$ Mass of the calorie = 0.0495kg

c_0 =Specific heat of calorie = 389

c_2= Specific heat of water = 4186

T=temperature of sample=100c

m_1 = mas of sample

m_2=Mass of water

T_1 = Temperature of water and calorie

T_2 =The temperature of the mixture

$dT = T_1 - T_2$

$c_{1=}$ Specific heat of sample

$$c_1 = \frac{(m_2.c_2+m_0.c_0)(T_1{}_-T_2)}{m_1(T_1{}_-T)} \qquad (4.1)$$

Table (4.1) Specific heat of sample

matter	m_1 (kg)	m_2 (kg)	T_1 ℃	T_2 ℃	Specific heat of sample(c_1)
wood	0.004	0.1066	34	36.5	$2611.34\, j/Kg.k^o$
cement	0.0174	0.0609	34	38	$1147.1\, j/Kg.k^o$
gypsum	0.0106	0.0596	31.5	37	$2201.82\, j/Kg.k^o$

4.4.2 Thermal Conductivity Coefficient

K≡Thermal conductive cofficent

A≡ Surface area of sample

m≡mas of sample

C≡specefic heat for sample

dx≡ sampling thickness

$dT = T_1 - T_2$

$\frac{dT}{dt}$ ≡Cooling rate

Q≡ Thermal power

$$Q = A.k.\frac{dT}{dx} = m.c.\frac{dT}{dt} \qquad (4.2)$$

$$\text{Then } k = \left(m.c.\frac{dT}{dt}\right) \Big/ \left(A.\frac{dT}{dx}\right) \qquad (4.3)$$

Table (4.2): Cooling rate for Wood

time	temp	Time	temp	time	temp	time	temp
0	68	70	63	140	58	210	54
10	67	80	62	150	57.5	220	53.5
20	66	90	61	160	56.5	230	53
30	65	100	60.5	170	56	240	52.5
40	64.5	110	60	180	55.5	250	52
50	64	120	59	190	55	260	51.5
60	63.5	130	58.5	200	54.5	270	51

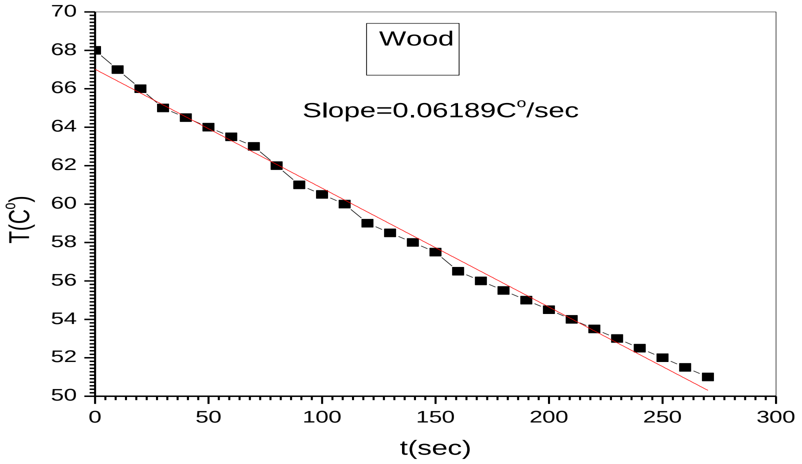

Figure (4.5) cooling rate curve for wood

Table (4.3): cooling rate for cement

Time (t)	Temp (T)	Time (t)	Temp (T)	Time (t)	Temp (T)	Time (t)	Temp (T)
0	86.5	70	82.5	140	76	210	71
10	86	80	82	150	75.5		
20	85.5	90	81	160	75		
30	84.5	100	80.5	170	74		
40	84	110	78.5	180	73.5		
50	83.5	120	78	190	73		
60	83	130	77.5	200	72		

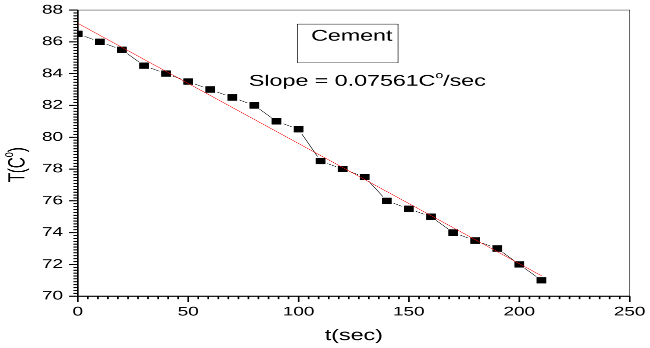

Figure (4.6) cooling rate curve for cement

Table (4.4): cooling rate for gypsum

Time (t)	Temp (T)	Time (t)	Temp (T)	Time (t)	Temp (T)	Time (t)	Temp (T)
0	70	70	66	140	62.5	210	58.5
10	69.5	80	65.5	150	62	220	58
20	69	90	65	160	61.5	230	57.5
30	68	100	64.5	170	61	240	57
40	67.5	110	64	180	60	250	56
50	67	120	63.5	190	59.5	260	55.5
60	66.5	130	63	200	59	270	55

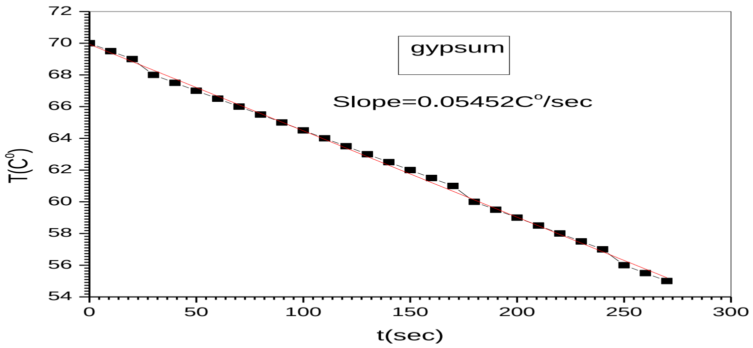

Figure (4.7) curve of cooling rate for gypsum

Table (4.5) Thermal conductivity coefficient

Matter	m (kg)	C $(\mathrm{j/Kg.k^o})$	$T_1(^\circ\mathrm{C})$	$T_2(^\circ\mathrm{C})$	dT	$\frac{dT}{dt}$	dx (cm)	K $(^{W}/_{\mathrm{m.c}})$
Wood	0.04	2611.32	92	52	40	0.061	0.38	0.062
Cement	0.1	11470.1	99	71	28	0.065	0.576	0.158
Gypsum	0.085	2201.82	91	55	36	0.054	0.7	0.236

4.4.3 Comparison between the theoretical values and experimental values

Table (4.6): Comparison between the theoretical values and experimental values

no	material	Thermal conductivity (experimental)	Thermal conductivity (Theoretical values)	References
1	wood	$0.062\left(\frac{W}{m.c}\right)$	0.4---0.04 $\left(\frac{W}{m.c}\right)$	[11]
2	cement	$0.158\left(\frac{W}{m.c}\right)$	$0.29\left(\frac{W}{m.c}\right)$	[11]
3	gypsum	$0.236\left(\frac{W}{m.c}\right)$	$0.17\left(\frac{W}{m.c}\right)$	[12]

4.5 Discussion

In this work three types of building material blocks of made cement, wood and gypsum were used to calculate the thermal conductivity coefficient and specific heat capacity. Equation (4.3) was used to calculate the thermal conductivity factor for those samples. Table (4.6) show that wood has less thermal conductivity then cement and gypsum. It was found that the thermal conductivity of cement it was slightly different from considered theoretical value due to manufactory different in additive materials. Table (4.1) shows the specific heat for the samples which reveals different value $2611.34\frac{j}{k_g k^0}$ for wood, $1147.1\frac{j}{k_g k^0}$ for cement and for gypsum $2201.82\frac{j}{k_g k^0}$.

4.6 Conclusion

- Wood is the least heat conduction
- Cement has higher thermal conductivity than wood but less than gypsum
- Gypsum is the highest thermal conductivity

4.7 Recommendation

1) Conduct studies on a larger number of building materials

2) Mixing between these materials and studying the effect of change on thermal conductivity

3) Measurements by other devices to ensure a high degree of accuracy

4) Conducting a comparative study between the methods of measuring thermal conductivity

5) The accuracy of the results in this method to measure the thermal conductivity coefficient depends on the accuracy of the observation

References

[1]Hollingsworth, M., Jr., “Experimental Determination of the Thickness Effect in Glass Fiber Building Insulation” Thermal Insulation Performance, ASTM STP 718, D.L.McElroy and R.P.Tye, Eds., American Society for Testing and Materials, 1980, pp.255-271.

[2] Thermal Conductivity and Coefficients of Thermal Expansion of SWNTs/Epoxy Nan composites 2004 Philippe Gonnet

[3] Pelanne, C.M., “Discussion on Experiments to Separate the “Effect of Thickness” from Systematic Equipment Errors in Thermal Transmission Measurements,” Thermal Insulation Performance, ASTM STP 718, D.L.McElroy and R.P.Tye, Eds., American Society for Testing and Materials, 1980, pp.322-334. [3 Holman, J.P., “Heat Transfer” 8th ed., McGraw-Hill, Inc., New York etc., 1997, p.430.

[4] Flynn, D.R. and Gorthala, R., “Radiation Scattering versus Radiation Absorption – Effects on Performance of Thermal Insulation under Non-Steady-State Conditions,” Insulation Materials: Testing and Applications: Third volume, ASTM STP 1320,R.S.Graves and R.R.Zarr, Eds., American Society for Testing and Materials, 1997, pp.366-380

[5] Klemens, P.G. and Kim, N., “Radiative Heat Transfer in Inhomogeneous Media and Insulations,” Thermal Conductivity 19, Plenum Press, New York – London, 1985, pp.453-458.

[6] Rish III, J.W., Roux, J.A. and Fairey III, P.W., “The Resistance of Fibrous Insulations Undergoing Coupled Transient Conduction and Radiation Heat Transfer,” Thermal Conductivity 19, Plenum Press, New York –London, 1985, pp.497-510.

[7] Kamran Daryabeigi, AIAA 2002-3332 / Heat Transfer in High – Temperature Fibrous Insulation, 8th AIAA/ASME Joint Thermo physics and Heat Transfer Conferencet, St. Louis, MO, June 24-26, 2002

[8] Insulation Materials By: Dr. Tawfeeq Wasmi M. Salih
Academic year 2015-2016

[9] Comparison of Thermal Insulation Materials for Building Envelopes of Multi-storey Buildings in Saint-Petersburg (by Martti Veuro)

[10] http://nesa1.uni-siegen.de/wwwextern/idea/keytopic/6.htm 11 MAY, 2018\ 5:30pm

[11] https://ar.wikipedia.org/wiki/ 11 MAY, 2018\ 5:30pm

[12] https://civteam.files.wordpress.com/2012/02/d8a7d984d985d984d8add9824-d8a7d984d8b9d8b2d984-d8a7d984d8add8b1d8a7d8b1d98a.pdf \14 MAY, 2018\ 5:30pm