İZMİR KATİP ÇELEBİ UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE AND ENGINEERING

THE EVALUATION OF INNOVATIVE INSULATION MATERIALS FOR ENERGY EFFICIENCY IN CIVIL ENGINEERING

M.Sc. THESIS

Nezih Serdar YASDIMAN

Department of Civil Engineering

Construction Materials Programme

Thesis Advisor: Prof. Dr. Lütfullah GÜNDÜZ

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İZMİR KATİP ÇELEBİ ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

İNŞAAT MÜHENDİSLİĞİNDE İNOVATİF YALITIM MALZEMELERİNİN ENERJİ VERİMLİLİĞİNİN İNCELENMESİ

YÜKSEK LİSANS TEZİ

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İnşaat Mühendisliği Anabilim Dalı

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Tez Danışmanı: Prof. Dr. Lütfullah GÜNDÜZ

23.06.2017

Nezih Serdar YASDIMAN, a **M.Sc.** student of İzmir Katip Çelebi University **Graduate School of Science and Engineering** student ID **Y140104003**, successfully defended the **thesis/dissertation** entitled "**THE EVALUATION OF INNOVATIVE INSULATION MATERIALS FOR ENERGY EFFICIENCY IN CIVIL ENGINEERING**", which he prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my wife and parents,

FOREWORD

"Thermal Insulation" is a term which is used to provide thermal comfort in spaces occupated by people for different reasons. More simply, it is to keep the heat inside in cold external temperature and prevent it to enter inside in hot external temperature.

"Thermal Comfort" is a basic term which people do extremely need to provide where they spend time where in a world people are created in such a way who needs to be in between certain temperatures to feel comfortable.

"Energy Rating" shows itself in this point which is established to prevent houses to lose heat and become cost-effective to provide thermal comfort temperatures in occupations.

"Thermal Insulation Materials" are used to set a barrier between the external and internal airs. These vary type to type and being used as to pass the regulations in each region where from cold to hot regions.

"Material Categorisation" is to classify materials according to their raw materials and tidy these where lots of inventions are made and needs to be packed up in certain topics.

In this unique research, these materials have been classified and categorised in a new way by researching most of the articles, journals, books...etc. among the academic and market field.

A large background of references have been used and according to these, "Innovative Insulation Materials" have been outlined as will likely to be used commonly in the future.

Also Turkey's position has been involved into evaluation and possible opportunities have been shared as opinion.

I would like to thank my Thesis Advisor who has motivated me to choose this subject and helped me out where I was confused each time.

14 May 2017

Nezih Serdar YASDIMAN
(Structural Engineer)

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ABBREVIATIONS

$	: Dollars
%	: Percentage
T	: Temperature difference
C	: Centigrade degrees
a	: absorptance
A	: Area
ANSI	: American National Standards Institute
APD	: Ambient Pressure Drying
ASHRAE	: American Society of Heating, Refrigerating, and Air-Conditioning Engineers
atm	: atmosphere
bar	: Pressure unit
BER	: Building Energy Rating
Btu	: British thermal unit
c	: Specific heat
C	: Specific heat capacity
C6H12	: Form of sugar
CAD	: Canadian Dollar
Cal	: Calories
CBE	: Center for the Built Environment
CD	: Compact Disc
CH3	: Methylene
CH3O	: Methoxide
CH3OH	: Methanol
cm	: Centimetres
CM	: Square Edge
CO	: Carbon monoxide
CO2	: Carbon Dioxyde
conv.	: Convection
Cp	: Heat capacity at constant pressure
CSD	: Convection suppression device
CWP	: Coring wool paper
d	: Thickness
dB	: decibel
DE	: Diatomaceous Earth
DIN	: German Institute for Standardization
DIY	: Do it yourself
DVD	: Digital Versatile Disk
DWP	: Dorper wool paper
e.g.	: exempli gratia (for example)
EN	: European Standards
EPBD	: Energy Performance of Buildings Directive

EPC : Energy Performance Certificate
EPS : Expanded Polystyrene
et. al. : et alia (and others)
etc. : et cetera
EU : European Union
FEP : Fluorinated Ethylene-Propylene
FETP : fluorinated ethylene teraphithlate
FIG : Figure
ft : Feets
G$: Thousand dollars
GE : General Electric
GFP : Gas-filled panel
Gt : Gigatonnes
h : Hours
H2O : Hydrogen peroxide (water)
H2SO4 : Sulfuric acid
HCl : Hydrogen Chloride
HCN : Hydrogen cyanide
HFC : HydroFluoroCarbon
HMDS : Hexamethyldisilazan
HTSCD : High Temperature Super Critical Drying
HVAC : Heating, Ventilation and Air Conditioning
Hz : Hertz
i.e. : id est (that is)
IARC : International Agency for Research on Cancer
in : Inches
Inc. : Incorporated
IR : Akaike Information Criteria
IR : Radiation losses
ISO : International Organization for Standardisation
J : Joule
K : Kelvin
kcal : Kilocalories
kg : Kilograms
L : Length
LBNL : Lawrence Berkeley National Laboratory
Ltd. : Limited
LTSCD : Low Temperature Super Critical Drying
m : Metres
MA : Massachusetts
mbar : milibar
mm : milimetres
MMA : Methyl methacrylate
Mton : Million tonnes
N : Nitrogene
Na2SiO3 : Sodium Silicate
NFP : Natural Family Planning
NH4OH : Ammonium Hydroxide
OH : Hydroxide
PAS2050 : Publicly Available Specification

Pcr : Critical pressure
PET : Polyethylene terephthalate
PF : Phenol formaldehyde
pH : potential of Hydrogen
PMMA : Poly methyl methacrylate
PMV : Akaike Information Criteria
PS : Polystyrene
PUR : Polyurethane
q : Heat flux
R : Thermal resistance
rad : Radiation
RTE : Radiative transfer equation
s : solar transmittance
SAP : Standard Assessment Procedure
SCD : Super Critical Drying
SI : The International System of Units
Si(OCH3)4 : Tetramethoxysilane
SiO : Silicon Oxide
SiO2 : Silicon Di-Oxide
SL : Shiplap Edge
Ʈ : Transmittance
Tc : Constant(required) temperature
Tcr : Critical temperature
Th : Heating temperature
TIM : Tranparent Insulation Material
TIR : Radiative Infrared Transmission
TSOL : Solar transmittance
TU : The Vienna University of Technology
TVIS : Visual directional-hemispherical transmittance
U : Thermal transmittance
UK : United Kingdom
US OSHA : United States Occupational Safety and Health Administration
US : United States
USA : United States of America
USB : United Soybean Board
UV : Ultra Violet
VIP : Vacuum Insulation Panel
VOC : Volatile organic compounds
vol : Volume
VUT : Vysoke Uceni Technicke (Czech: *Brno* University of Technology; *Brno*, Czech Republic)
W : Watt
XPS : Extruded Polystyrene
ZIP : Zone Improvement Plan
α : Absorptance
ε : Emissivity
λ : Thermal conductivity
µ : Water vapour diffusion resistance
µm : Micrometres
ρ : Density

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THE EVALUTAION OF INNOVATIVE INSULATION MATERIALS FOR ENERGY EFFICIENCY IN CIVIL ENGINEERING

SUMMARY

Thermal insulation term is the most important measure that provides the thermal comfort which human being has been looking for as a natural habit from the first residential lifestyle begins.

The inventions in this topic, especially has been arisen in last centuries and specifically in the last century it has been carried forward and both aesthetic and performance based products have been researched to be discovered.

In the light of researches each in academic and practical fields, the hope of this demand to be provided is increased via innovative insulation materials.

Accordingly, to compare traditional and other insulation materials to innovative insulation materials, figure out the pros and cons and to contribute the literature is the aim of this thesis.

By starting with a wide chamber to a narrowing view and outlining the innovative insulation materials, the method used to explain in this thesis is; to create a knowledge group over lots of books, internet sites, journals, publications etc., to classify the materials per this knowledge, to outline, represent the innovative insulation materials class and to gain the reader knowledge in this subject via results, recommendations and to point out possible researches and spots which needs to be lightened in the future.

To understand the thermal insulation term, the heat term is first need to be understood, it's behavior and to identify how heat loss occurs, how much of it and how should it be prevented are important topics. Air is continuously in a tend to travel from a hot region to a cold region. This ends up with a need of preventing the air escape in winter and preventing the air coming from outside in summer. Thermal insulation materials are used to minimise the passage of the air through a wall section, and these vary due to their basic properties. Each material also has a specific heat capacity. Materials with high heat capacity will store the energy and delay the warming of a room. It is also important to look from this point when selecting the material. Also, to prevent thermal bridges (cold bridge) is a key factor to avoid heat loss. These capillary gaps cause heat flow continuously and lets heat pass.

Subsequently, thermal comfort term and requirements of thermal insulations values in different countries should be known and designs should be carried in accordance with these. Thermal comfort is a temperature zone where a person feels comfortable to spend time in an area. This value is higher where people spend more time whilst it is 1-2 C less in rooms like bathroom and toilet. A person should be living in between certain degrees because of human nature or will feel uncomfortable and will look for alternative solutions. Parallel to this, each country has requirements for thermal

transmittance values (U-value). These values are lower in cold climates and higher in hot climates.

Another topic which concerns individuals is the term also known as "energy efficiency" which states the fuel consumption needed to provide demanded temperature in a space. Again in this field, popularity of green buildings is increasing to minimise the fuel consumption and inevitably the importance of thermal insulation materials have been realised related to this. Expenses to heat the house is climbing to a disturbing rate because of heat loss and low energy efficiency even though it is a basic need. The possibility of saving 40-50% of these expenses with simple tackles shows us the importance of this sector. Known as green buildings, graded as an A class in Building Energy Ratings are expensive during construction but the expenses due to energy saving redeem itself in short periods which has been proved by lots of researches. Energy Performance Certificate; states the stamina of the house against heat by a specialist and gradation of the house's thermal condition between A-G where A is the highest and G is the lowest. A lot of country requires this certificate before selling or renting properties. Individuals can easily have a clue how much the costs might be by looking at these certificates.

Further to that, after understanding these terms it will be much easier to see which of the properties are key for thermal materials and which of them are widely used. The layers in the wall section like paint, plaster, thermal insulation material, brick or block layer are directly involved in thermal transmittance according to their thickness and thermal properties. For example, brick stores heat because of being thick and it's specific heat capacity being high. Another important definition is thermal conductivity value. Each material has a unique thermal conductivity value and thermal transmittance changes due to section thickness and thermal conductivity. It is possible to see the material thermal conductivity value on the label of products. The primary materials widely used around the world are EPS, XPS, rock wool, fiberglass, polyurethane, panel and foam types of these. They are also called as traditional insulation materials. They are satisfying both as costly and thermally at the present, but required thermal transmittance values are likely to decrease against the global warming and cooling, and this will end up with thicker usage of present materials or usage of alternative materials.

In this study, traditional, organic, innovative and textile thermal insulation materials are classified and innovative insulation materials are outlined. Nevertheless, innovative insulation materials have been discovered to tackle the problem mentioned above as result of researches. For example, transparent insulation materials are widely used in glass facade buildings. Again being in this class Vacuum insulation panels have up to 10 times better thermal properties than traditional materials. Numeric examples are also given in this study. Also gas filled panels, naturally aggregated materials and materials made of textile wastes are being subject to competitive researches.

It is possible to make some conclusions in the light of all above. In consequence of these conclusions, there are areas where researches should be carried out and points to focus on to show progress. Particularly, two materials could be called as unique. Yet they are too expensive and they also have some lacks. For example, the service life of vacuum panels are not as long as demanded. They are likely to keep same thermal properties for 30-50 years and subsequently unpredictible values are likely to occur. It is also a necessaty to teach working force how to apply such materials.

Hence, generally daily payed workforce would cost more than normal to apply these already expensive materials which obstructs these materials being widely used.

Turkey's position in energy efficiency has also been evaluated in this research and been shared as a summary. Opinions has been outlined about what point it could be if being used innovative insulation materials by comparing to other countries.

This research also referes to how Turkey can jump ahead in energy efficiency (which is way behind other European Countries) by applying correct policies, but that users should be encouraged to use certain materials or they will continue using materials they think are the most economic ones.

İNŞAAT MÜHENDİSLİĞİNDE İNOVATİF YALITIM MALZEMELERİNİN ENERJİ VERİMLİLİĞİNİN İNCELENMESİ

ÖZET

Isı (termal) izolasyonu terimi insanlığın yerleşik hayata geçmesinden itibaren ideal oda sıcaklığını bulma arzusundan doğan ve asli bir ihtiyaç sayılabilecek konfora ulaşmasını sağlayan en önemli önlemdir.

Bu konuda yapılan yenilikler, özellikle son yüzyıllarda artmış olup bilhassa son yüzyılda daha da ileri götürülerek estetik ve performansı bir arada sağlayabilecek ürünler arayışına girilmiştir.

Gerek akademik, gerekse de uygulama alanında yapılan araştırmalar neticesinde inovatif (yenilikçi) yalıtım malzemelerinin bu arzuyu karşılayabilceği umudu artmıştır.

Bu doğrultuda geleneksel ve diğer yalıtım malzemelerini inovatif malzemeler ile kıyaslayarak eksik ve artı yönlerini ortaya çıkarmak ve literatüre bu yönde bir kazanım sağlamak tezin temelini oluşturmaktadır.

Genel bilgiler vererek başlamak suretiyle, giderek daralan ve inovatif yalıtım malzemelerini ön plana çıkaran bu araştırmanın ele alınış metodu; yine bir çok kitap, internet sitesi, makale, yayın vb. kaynaklardan yararlanarak bir bilgi kümesi oluşturmak, bu oluşturulan bilgi kümesi ışığında bir malzeme kategorizasyonu yapmak, bu kategorizasyonda da yenilikçi malzemelerin nasıl bir sınıf oluşturduğunu öne çıkarmak, tanıtmak ve sonuçlar, öneriler ile okuyucuya bu konuda bilgi kazandırıp gelecekte araştırılabilecek ve genişletilebilecek noktaları işaret etmek şeklindedir.

Isı yalıtımı terimini anlamak için ilk başta ısı terimini, davranışlarını anlamak ve ısı kaybının ne şekilde oluştuğunu, oluşan ısı kaybının ne derece önlenmesi gerektiği ve nasıl önleneceği konuları önem arz etmektedir. Hava daima sıcak ortamdan soğuk ortama doğru hareket etme eğilimindedir. Bu da yaz aylarında dışarıdaki havayı içeriye almama ve kış aylarında içerideki havayı muhafaza etme gereksinimini oluşturmaktadır. Havanın duvar kesitinden geçememesi için ısı yalıtım malzemeleri kullanılmakta olup, bunlar termal özelliklerine göre çeşitlilik göstermektedir. Ayrıca her malzemenin özgün bir ısı depolama kapasitesi bulunmaktadır. Isı depolama kapasitesi fazla olan malzeme, öncelikle ısıyı depolayacak ve odanın ısınmasını geciktirecektir. Bu açıdan da seçilen malzemelerin düşünülmesi gerekmektedir. Yine hava geçişini oluşturacak termal köprülerin de oluşmaması önem arz etmektedir. Bu kılcal boşluklar sürekli olarak havanın akmasına sebebiyet vermekte olup, yine ısıyı muhafaza etmekte sıkıntıya yol açmaktadırlar.

Daha sonraki süreçte termal konfor kavramı ve ülkeler bazında şart koşulan duvar yalıtım değerleri anlaşılmalı ve buna göre tasarımlar yapılmalıdır. Termal konfor bir bireyin bir alanda rahatça zaman geçirebileceği sıcaklık aralığını temsil etmektedir.

Bu değer örnek olarak bir evde en çok zaman geçirilen odalarda daha fazla olup, banyo, tuvalet gibi alanlarda 1-2 C daha azdr. Fakat insanın yaratılışı gereği belli bir sıcaklık aralığında yaşaması gerekmektedir. Aksi takdirde rahatsız olacak ve alternatif çözümler üretme gereksinimi duyacaktır. Bu enlemde ülkelerin duvarlarda aradıkları ve yönetmelik olarak uyguladığı duvar ısı geçirgenliği (U değeri) değerleri vardır. Bu değerler soğuk iklimli ülkelerde daha düşükken, ılık ülkelerde daha yüksek olarak göze çarpmaktadır.

Bireyleri ilgilendiren bir başka başlık ise "enerji verimliliği" olarak bilinen, istenilen oda sıcaklığını sağlamak amacıyla gerekli yakıt tüketimini temsil eden terimdir. Yine bu alanda yakıt tüketimini minimuma indirmek amacıyla yeşil binaların gümüzde popülerliği giderek artmakta olup, ısı izolasyonun da buna paralel olarak önem kazanması kaçınılmaz olmuştur. Bu doğrultuda enerji verimliliği karnelerinin ne olduğu, hangi parametleri gösterdiği ve ileriye dönük nasıl bir önem taşıdığını anlamak gerekmektedir. Yakıt için harcanan paralar her ne kadar asli ihtiyaç için harcanıyor olsa da, bazen ısı kaybı ve enerji verimliliği düşüklüğü sebebiyle zorlayıcı boyutlara ulaşmaktadır. Basit hamlelerle %40-50 oranında tasarruf etmenin mümkün olması, bu sektörün ne kadar önemli olduğunu gözler önüne sermektedir. Yeşil binalar olarak bilinen ve enerji verimliliği karnesinde A sınıfı olarak değerlendirilen binaların üretim esnasında harcanan ücretleri yakıt tasarrufu olarak ne kadar kısa sürelerde amorti ettiği bir çok araştırmaca kanıtlanmıştır. Enerji verimliliği karnesi; uzmanı tarafından evin ısıya karşı dayanıklılığının tespit edilmesi ve A-G arasında, A en yüksek ve G en düşük değer olmak üzere evin termal durumunun belgeye dökülmüş halidir. Bir çok ülkede kiralanacak veya satışı yapılacak evin enerji verimliliği karnesinin gösterilmesi şart koşulmuştur. Kişi buradan yola çıkarak yakıt giderlerini kolaylıkla tahmin edebilektedir.

Bunun ötesinde tüm bu kavramları anladıktan sonra yalıtım malzemelerinin hangi özelliklerini belirleyici olduğu, hangilerinin yaygın olarak kullanıldığını idrak etmek çok daha kolay olacaktır. Duvar kesiti içerisinde yer alan boya,sıva,yalıtım malzemesi, tuğla veya blok örgü katmanlarından her biri kalınlığına ve termal özelliklerine göre ısı geçirgenliğine doğrudan katılım sağlamaktadır. Örneğin tuğla örgüler ısı depolarlar ve bunun sebebi geniş bir yer kaplamaları ve özgün ısı depolama değerlerinin yüksek olmasıdır. Bir diğer önemli tanım ısı iletkenlik değeridir. Her malzemenin yine özgül ısı iletkenlik değeri vardır ve kesit kalınlığına göre ısı dayanıklılığı artış göstermektedir. Isı iletkenlik değerini yalıtım malzemelerinin etiketlerinde görmek mümkündür. Ülkemizde ve dünyada yaygın olarak kullanılan başlıca yalıtım malzemeleri EPS, XPS, taş yünü, cam yünü, poiüretan, bunların panel ve köpük halleridir. Bunlara geleneksel yalıtım malzemeleri de denilmektedir. Mevcut durumda hem ücret olarak hem de performans olarak yeterli ve tatmin edici düzeyde olan bu malzemeler, küresel ısınma ve soğuma karşısında gerekli ısı geçirgenlik değerlerinin aşağı çekilmesi sonucu ya daha kalın olarak kullanılmak durumunda kalacak veya alternatif malzemelere ihtiyaç doğacaktır.

Bu çalışmada geleneksel, organik, inovatif ve textil yalıtım malzemeleri sınıflandırılmış olup inovatif yalıtım malzemeleri ön plana çıkarılmıştır. Nitekim inovatif yalıtım malzemeleri yukarıda bahsedilen probleme karşı önlemler ve yeni malzeme arayışının sonucu yapılan araştırmaların ulaştığı malzemelerdir. Mesela transparan yalıtım malzemeleri camekan olarak inşa edilen binalarda oldukça yaygın olarak kullanılmaktadır. Yine bu sınıf içerisinde olup karşımıza çıkan vakum yalıtım panelleri, geleneksel malzemelerden 10 kata kadar daha iyi termal sonuçlar vermektedir. Bununla ilgili sayısal örnekler de çalışmanın içerisinde mevcuttur. Yine gaz sıkıştırılmış paneller, doğal agrega ile yapılmış paneller ve tekstil atıklarından yapılan yalıtım malzemeleri iddialı araştırmalara konu olmaktadır.

Tüm bunların ışığında bir takım sonuçlara varmak mümkün olmaktadır. Bu sonuçlara binaen araştırma yapılabilecek alanlar ve geliştirilmesi faydalı olduğu görülen noktalar bulunmaktadır. Özellikle iki malzeme biricik olarak nitelendirilebilir. Bunlardan birinci aerojel bir diğeri ise vakum panelleridir. Her ikisi de alanında oldukça fazla araştırma yapılan ve pazarda yerlerini almaya hazırlanan malzemelerdir. Henüz çok pahalı olan bu malzemelerin bir takım eksiklikleri de söz konusudur. Örneğin, vakum panellerini servis ömürleri henüz istenilen kadar uzun değildir. Aynı termal özellikleri 30-50 yıl arasında muhafaza etmekte olup daha sonraki süreçte belirsiz değerler meydana çıkmaktadır. İşgücü ekiplerinin uyglama yönünden eğitilmeleri ayrı bir gerekliliktir. Nitekim geneli yevmiye usülü çalışan işçilerin bu pahalı malzemeleri uygulama için ayrıca fazla ücret talep edecek olmaları bu malzemelerin yaygın kullanımını engellemektedir.

Ayrıca Türkiye'nin enerji verimliliği açısından durumu yine bu araştırmada ele alınmış ve özet olarak irdelenmiştir. Varılan noktada Türkiye'nin yenilikçi yalıtım malzemelerini kullanması durumunda diğer ülkeler ile karşılaştırmalı olarak nasıl bir noktaya gelebileceği konusundaki düşünceler paylaşılmıştır.

Doğru politikalar kullanılarak Türkiye'nin enerji verimliliği açısından bulunduğu noktadan (ki diğer avrupa ülkelerine göre oldukça geridedir) nasıl bir sıçrama yapabileceği ancak bu durumda da malzeme tercihi noktasında yine kullanıcıya yardım etmesi gerektiği veyahutta kullanıcının yine en ekonomik olduğunu düşündüğü malzemeyi seçeceğini kısaca bu araştırmada bulmak mümkündür.

1. THERMAL INSULATION IN CIVIL ENGINEERING

The responsabilities of thermal insulation details are currently left to Mechanical Engineers and Architects in projects, because there exists a subdivision of mechanical engineering as Thermodynamics. Thermodynamics is a science which is related to heat and heat transfer. Since heat motions are mechanic actions, the equations which will be discussed in this thesis are based on mechanic motions.

There is another fact that, these calculations come down to two important points, which are;

1. All equations are corrected by safe insulation materials which construction materials field captures.
2. The materials are applied on the construction phase where a civil engineer is responsible.

These points prove that a civil engineer is and must be involved in thermal insulation as much as mechanical engineers.

There are lots of ongoing projects in the construction materials field working on thermal insulation materials.

Nowadays, it has been well understood that, by insulating buildings with proper calculations and materials, it is possible to save lots of energy and money which also states less polluting the air. On this case there are lots of approvements in manufacturing new insulation materials each day.

While there are lots of inventions of new materials, this brings an untidy materials ruin in the literature. This makes user harder to choose or understand the materials to apply. There to tackle this problem, this research's aim is to provide a new classification among insulation materials.

Before presenting the classifications, there are some knowledge that must be a foundation in thermal insulation.

The main definitions that must be known are thermal insulation, thermal comfort, heat, heat transfer, thermal conduvticity, convection, conduction, radiation, thermal trasmittance, thermal resistance and basic calculations of these members. It is likely to understand insulation materials when these properties are known.

According to these knowledge, to understand the relation between building and environment is likely by knowing building energy rating, energy performance certificates and thermal bridge terms.

What is Thermal Insulation ?

Thermal insulation is a material or combination of materials, that, when properly applied, retard the rate of heat flow by conduction, convection, and radiation. It retards heat flow into or out of a building due to its high thermal resistance [1].

1.1. Thermal Comfort

Thermal comfort is of a great value for HVAC design engineers (HVAC stands for heating, ventilation and air conditioning). This is a state of mind in which it displays satisfaction in a thermal surrounding and it can be observed through subjective evaluation (ANSI/ASHRAE Standard 55) [2].

When heat is produced in a human body due to its metabolism, the thermal neutrality is balanced by this human body through heat dissipation which results in thermal equilibrium with its environment. The basic characteristics that have an effect on thermal comfort are the ones that are responsible for heat loss or gain i.e. metabolic rate, clothing insulation, air temperature, mean radiant temperature, air speed and relative humidity. Thermal comfort may also be influenced through psychological factors like individual expectations [3].

The most accepted thermal comfort model is the Predicted Mean Vote (PMV) model. The model was built on the heat balance principles and all the experiments were carried out in a controlled climate chamber under moderate conditions [4]. The other most used model, the adaptive model, was built on numerous field theories on the concept that occupants dynamically interact with their surroundings. The inhabitants can take control of their thermal surroundings through simple things like clothing, personal heaters, fans, sun shades, and operable windows [3,5].

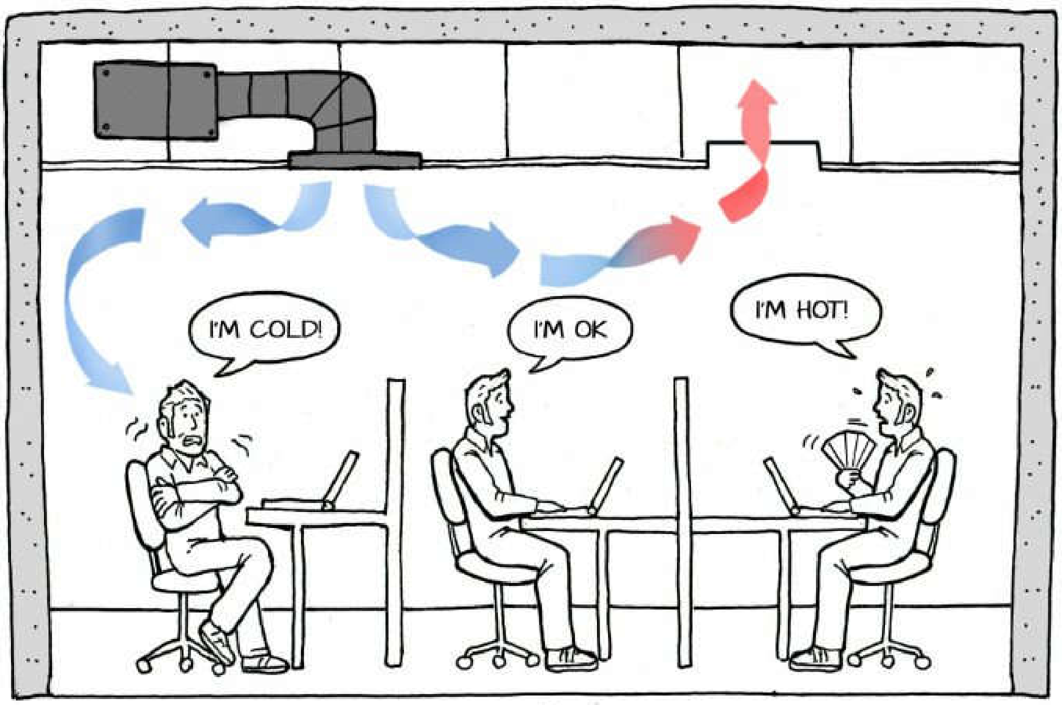


Figure 1.1 : Thermal comfort change individually.

(https://sourceable.net/improving-thermal-comfort-a-boon-to-business/)

The difference between the two models is that the adaptive model can set up in buildings that have no mechanical systems installed whereas the PMV model can be applied to building that have complete mechanical systems like air conditioning installed in them [2]. However, there is no proper model for buildings having partial or temporary mechanical systems.

The calculations for thermal comfort can be done easily with the CBE Thermal Comfort Tool for ASHRAE 55 according to ANSI/ASHRAE Standard 55.

There are many other comfort standards that are just like ASHRAE Standard 55 for example EN 15251 and the ISO 7730 standard [5-7].

1.2. Heat and Heat Transfer

Heat is a kind of energy that is transferred through a system and its surroundings in any other way than through transfer of matter or work. Heat flows from a body of high temperature to a body of low temperature when an acceptable pathway is present [9].

The exchange of thermal energy from one physical body to another is called heat transfer. The rate heat transfer is directly related to the temperatures of the systems and the characteristics of the medium present in between the two systems which are exchanging thermal energy. The three basic modes of heat transfer are: conduction, convection and radiation. Heat transfer is a phenomenon through which a system changes its internal energy. It is also a flow of energy in heat form. It is of great use in applications of First Law of Thermodynamics. Conduction of heat is also called diffusion but it is not the kind of diffusion that occurs when two or more fluids are mixed.

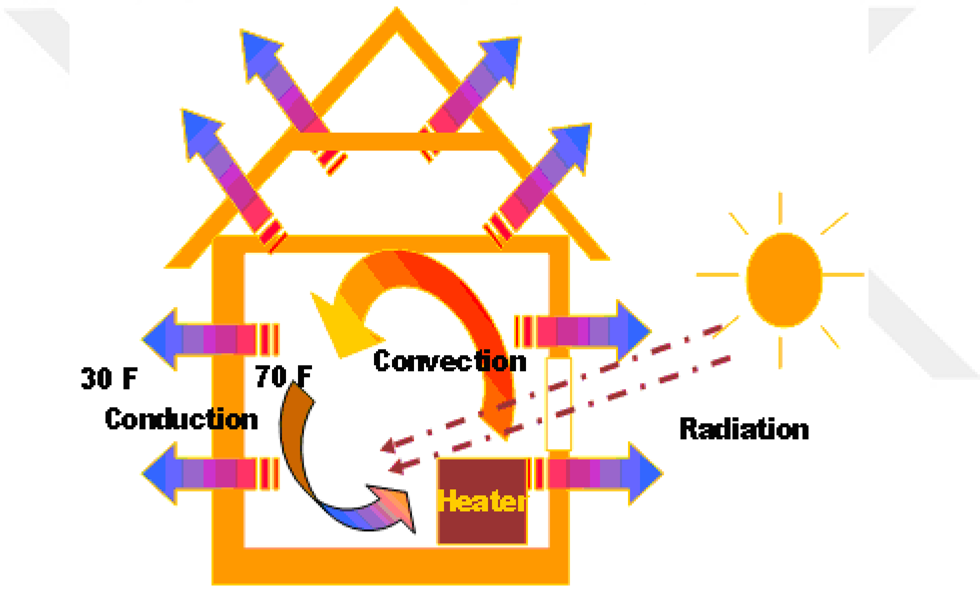


Figure 1.2 : Heat transfer in three basic mechanisms.

(https://www.e-education.psu.edu/egee102/node/2053)

The heat transfer travels from a place of high temperature to a place of lower temperature and is directed by the Second Law of Thermodynamics. The internal energy of the source and where the heat is transferred changes after the heat is transferred from one body to another. The direction of heat transfer follows the increase of entropy of a collective system.

When all the bodies in a given environment and its neighbouring regions acquire the same temperature is called thermal equilibrium. The ability of a body to change its volume when its temperature is being changed is called thermal expansion [10].

1.2.1 Thermal mass

Thermal mass when used in building designs is also known as thermal flywheel effect. It is a characteristic of the mass of a building that lets it contain heat by providing 'inertia' against fluctuations in temperature [11].

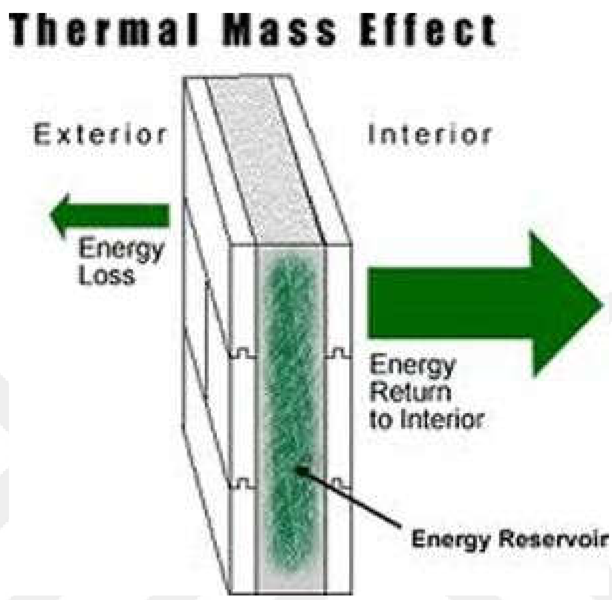


Figure 1.3 : Thermal mass energy reserving logic.

(https://uk.pinterest.com/pin/361202832589366871/)

To illustrate this point of view we can refer the example that, during the time when there are variations in the temperature at day time, a huge amount of thermal mass located at the insulated portion inside a home can help to "flatten out" every day variations in temperature. This happens because the thermal energy will be absorbed in the time when the temperature of the environment is greater than the mass; moreover, it will return the thermal energy at the time when the environment is cool and not going in the state of equilibrium. This is different than the insulative value of the substance, that lowers the thermal conductivity of the building, and permits it to remain hot or cold from the outer surface, or only maintain the thermal energy of the occupant for a larger time (Prof. Dr. Lütfullah GÜNDÜZ, Lecture Notes).

1.2.2. Heat flow

In the condition, where two substances are brought close to each other which have dissimilar temperatures, energy transfer will every time take place from a hot to cold substance. Thereby, it is deduced that when heat always transfers from a hot to cold substance. Heat energy is always under movement.

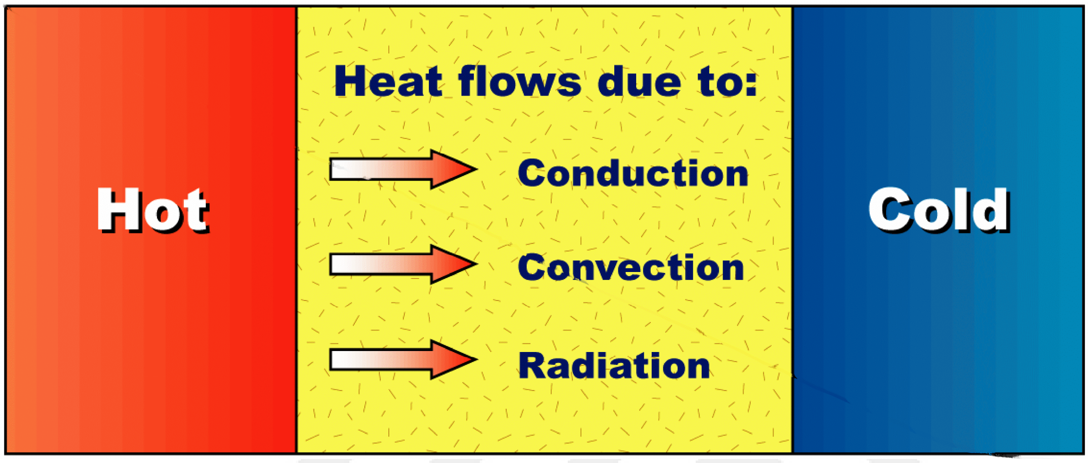


Figure 1.4 : Heat flow directions.

(http://insulplus.com/products/)

The units of heat are same as energy. Joule is the SI unit of energy. Various other conversions of units are the following 1 Cal = 1 kcal = 4186 J, 1 cal = 4.186 J, 1 Btu = 1054 J.

Heat energy in all situations is transferred from a hot substance to cold substance, regardless of any exterior force interfering in the transfer taking place. Two things having temperature difference have an interaction going all the time. There exist three distinct methods in which heat can be transferred from object to object namely: radiation, conduction, convection. [12]

1.2.3. Mechanisms of Heat Transfer

Physical Mechanism;

Heat flow from object to object occurs by help of three following ways [13]:

- Conduction
- Convection and
- Radiation

1.2.3.1. Conduction

A medium in which energy transmission takes place inside both solids and liquids from high to low temperature area because of existence of temperature gradient inside the body is known as conduction [14].

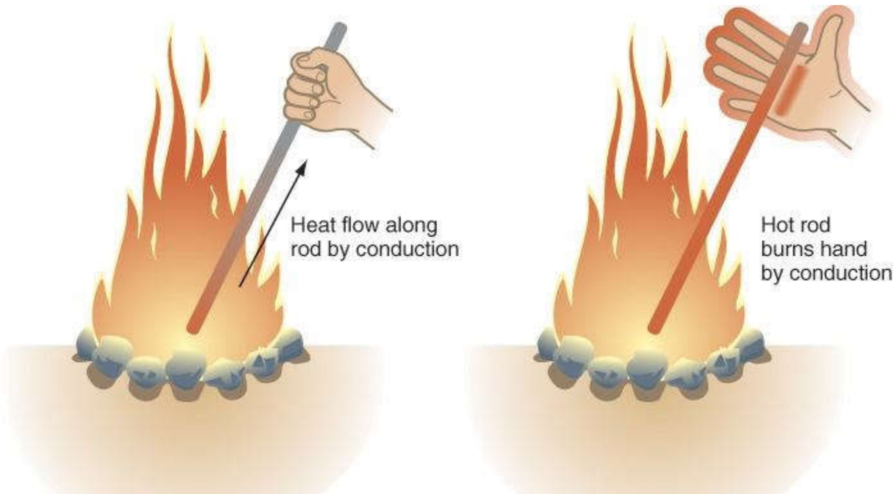


Figure 1.5 : Heat transfer by conduction.

(http://slides.com/arnav/conduction--2/fullscreen#/)

It was seen that the rate at which heat is conducted, is known to be directly proportional to the difference in the temperature in a substance and a region of heat exchange, though it is inversely proportional to the thickness of the substance [15].

$Q = kA\ T/\ x$ (W) **(1.1)**

where ;

Q : conduction

k : thermal conductivity

A : surface area

T : temperature difference

x : thickness

1.2.3.2. Convection

Convection is known as transmission of heat and it is one of the main kinds of transmission, mostly in liquids. Heat exchange in convection occurs through process of diffusion and random Brownian motion happening in the elements of liquid and through advection where heat is transmitted through movements of currents on a bigger level. According to heat as well as mass exchange, the word "convection" is utilized to denote the summation of advective and diffusive transfer [16,17].

$$Q = hAx \ T \quad (W) \qquad \textbf{(1.2)}$$

q= Heat transferred per unit time

T= difference in temperature

h= coefficient of convection

A= cross-sectional area

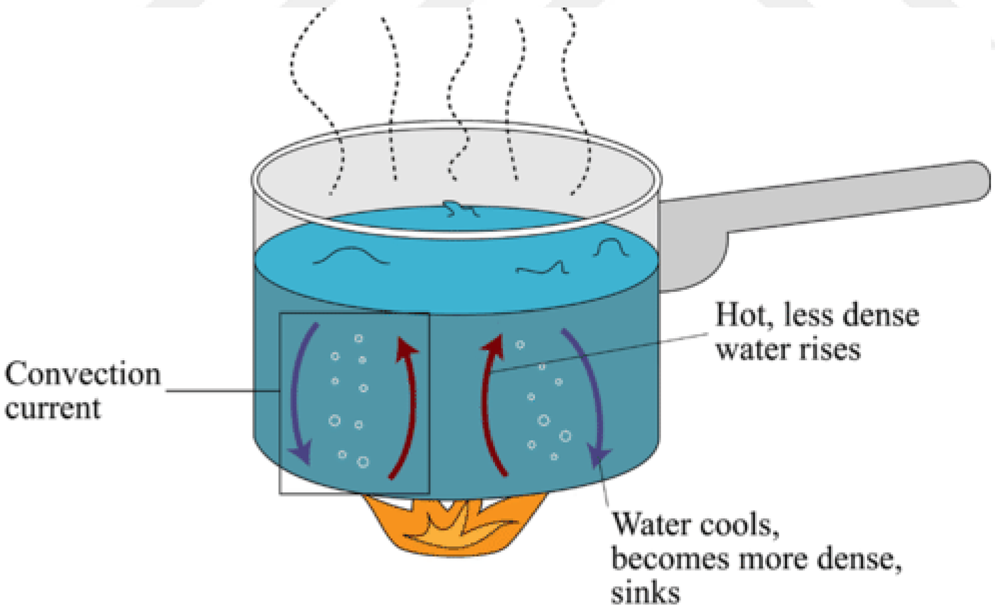


Figure 1.6 : Heat transfer by convection.

(http://www.ck12.org/book/CK-12-Physical-Science-Concepts-For-Middle-School/section/5.15/)

Forced or Assisted Convection;

Forced convection takes place at the time where induction of fluid flow takes place through an outer source, like a pump, fan or a mixer [18].

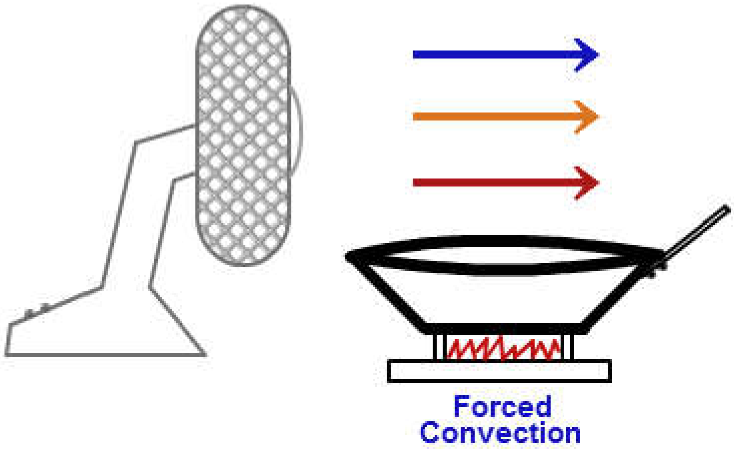


Figure 1.7 : Forced convection.

(http://www.tutorvista.com/physics/example-of-convection-heat-transfer)

Natural or Free Convection;

Natural convection occurs due to variations in density that occurs due to differences in the temperature in liquids which give rise to buoyancy forces. Because of heating modification in density inside the boundary layer the liquids tend to rise and its place can be taken by cold liquids which will increase. This process is known as free or natural convection [18].

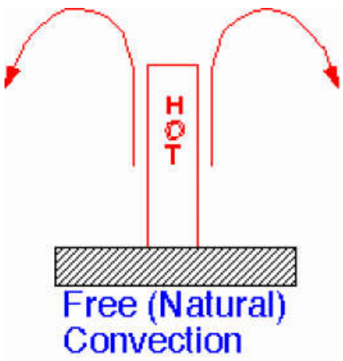


Figure 1.8 : Free convection.

(http://www.enigmaticconsulting.com/ semiconductor_processing/CVD_Fundamentals/xprt/heat_xfr_mech.html)

Natural Convection examples:

- Particles movement which are heated because of fire
- Rise of hot air (have low density)
- Transmission of heat to nearby air particles
- Hot air cools down and its density increases and therefore it sinks
- The procedure continues

1.2.3.3. Radiation

Heat exchange through thermal radiation is different in several forms as compared to conduction and convection. Radiation occurs through electromagnetic waves, and it does not need any media for transmission. Therefore, as compared to various mediums of heat transmissions, energy in radiations can be transmitted by a vacuum, for instance permitting people to obtain solar energy with help of the vacuum of space [19].

The terminology radiative heat transfer as well as thermal radiation is generally utilized to explain the phenomena of transmission of heat which occurs due to electromagnetic waves. General daily examples of thermal radiation consist of impact caused by heating due to sunlight on a clear day, once a person is surrounded by fire, in addition to this, the part which is exposed to fire is found to be hotter as compared to other parts. Moreover, blue colour of the sky is due to thermal radiation, in nights of close weather, it sounds more pleasant if the curtains are closed instead of being opened, furthermore, the red colour of sunsets [20].

$$q = eQA(T_s^4 \quad T_\infty^4) \qquad [19] \qquad \textbf{(1.3)}$$

q= heat transferred per unit time
e= constant of emissivity
A= surface area
T_s = surface temperature (absolute)
T_∞ = sorrounding temperature (absolute)
Ơ= Stefan-Boltzmann's constant

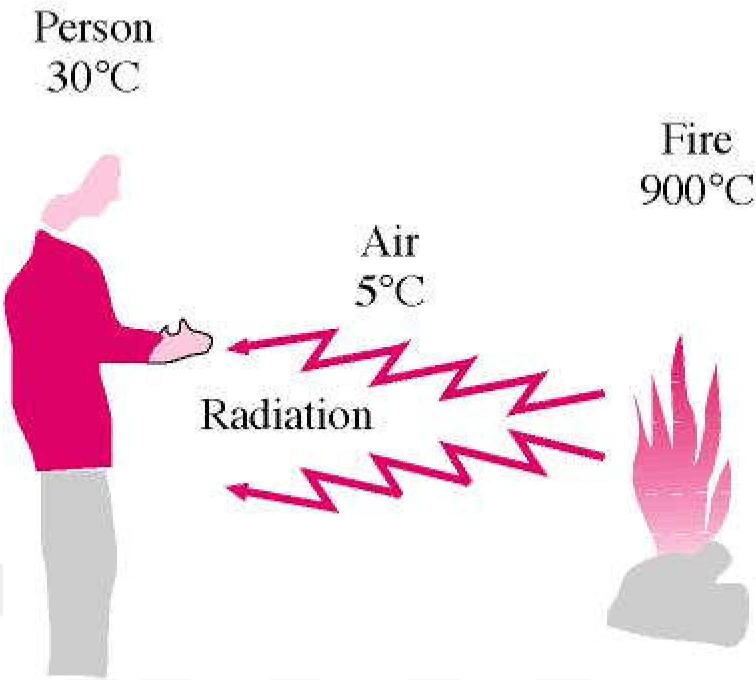


Figure 1.9 : Heat transfer by radiation.

(http://www.mhhe.com/engcs/mech/cengel/notes/ RadiativeHeatTransfer.html)

Queries Regarding Radiation

For what purpose, white colour is chosen for painting the homes in warm regions?

White colour reflects heat radiation and maintains a cold effect

For what purpose players at a marathon race are covered with shiny foil blankets when race is finished?

The heat radiation is reflected by the help of shiny metal, which produces a warming effect in the body of the runner. (Prof.Dr.Lütfullah GÜNDÜZ, Lecture Notes)

1.2.4. Factors that cause an impact on heat loss

The planning and layout of a building have an impact on the weather. It is done by altering four kinds of contact among the building and the atmosphere:

A. Inert cooling and cross ventilation

B. Efficient solar heat gain of the building.

C. Solar contact of the glazed and opaque components of the building such as its top and walls.

D. The pace of convection and conduction of heat transfer in the surrounding air.

The primary layout aspects that cause an impact on above mentioned factors are:

- The design of the building
- Colour of paint that is done on the walls and its direction.
- The position and dimensions of the windows from ventilator point of view
- The impact of airing setup of the building on its inside temperature
- Direction and the shading settings of the windows

While considering the matter of direction of the building, there exist two impacts of it (i): on building's contact with sunlight (ii): and on airing perspective.

For a known volume or floor area of the building, the design of the building is more solid and the uncovered surface area of the walls on the roof is lesser. Therefore, the transmission of heat which takes place through method of conduction across the building and the surrounding air is reduced. At times in which the home is having cold or hot temperature, there is a decrease in energy requirement due to small surface area, comparatively, when a home is designed in a widespread way, it consist of bigger surface area of the walls and leads to a larger heat gain or loss and big expenses of air conditioners. [21]

1.3. Material Properties for Thermal Insulation

The fundamental attributes that show the thermal behaviour of objects are:
ρ stands for Density
λ stands for Thermal conductivity
c stands for Specific heat

Presently as per the realistic view point, analysis about insulation examination is done depending on merely the value of thermal conductivity that is (λ) of the object, and if it's low than the object is regarded as extremely insulative. However, according to this point of view an accurate result is not guaranteed.

Since, in the coefficient of thermal conductivity the application thickness is neglected. λ is taken as constant in regular circumstances.

Thermal conductivity is decreased when the building has low density. Though, the compressive strength is usually because of their less values of density. As a result, usage of objects that have quite low compressive strength is not recommended for the purpose of decreasing the conductivity values of the objects.

Lower coefficient values for water vapour diffusion are possessed by the objects that have low density as well as high porosity, when the value of μ is less inhalation is smooth. (Prof. Dr. Lütfullah GÜNDÜZ, Lecture Notes)

1.3.1. Definition of thermal conductivity:

It is defined as the time rate of steady state heat flow (W) by a unit area of 1 m thick homogeneous substance in a direction perpendicular to isothermal planes, induced by a unit (1 K) temperature difference across the sample [22].

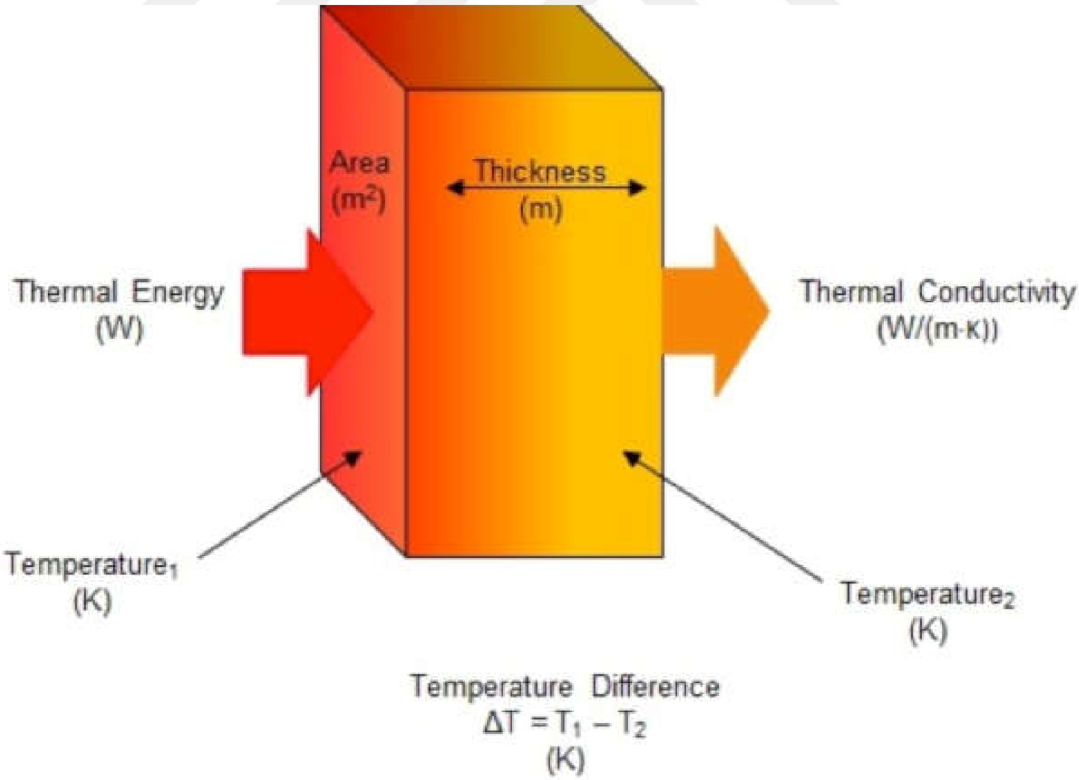


Figure 1.10 : Thermal conductivity working principle

(http://www.puretemp.com/stories/why-thermal-conductivity-matters)

The k-value of Thermal conductivity is denoted by W/m-K (Btu/h-ft-F or Btu-in/hrft2-F). It is known as a function of object's average temperature and humidity amount. Moreover, Thermal conductivity is defined as a means of efficiency of an object to conduct heat. Therefore, having information regarding thermal conductivity values is important to compare the usefulness of various thermal insulation objects. [23]

1.3.2. Definition of thermal resistance:

It is defined as a means of (opposition) heat flow due to suppressing conduction, convection along with radiation. Moreover, it is a function of material thermal conductivity, thickness as well as density. Thermal resistance the R-value, is denoted by m2-K/W (h-ft2-F/Btu). [23]

1.3.3. Definition of Thermal Conductance:

It is defined as the rate of heat flow (W) along a unit surface area of an object having unit (1 K) temperature difference among the surfaces of the two sides of the object. It is known as the reciprocal of the total of the resistances of every layer which make up the object excluding both the interior and exterior air films resistances. It is considered same as thermal conductivity apart from a specific thickness of an object. Thermal conductance, C-value, is denoted by W/m2-K (Btu/h-ft2-F). [23]

1.3.4. Definition of Thermal Transmittance:

It is defined as the rate of heat flow across a unit surface area of the object having unit (1 K) temperature difference among the surfaces of the two sides of the object. It is known as the reciprocal of the total of the resistances of every layer which make up the object excluding both the interior and exterior air films resistances. It is also known as an Overall Heat Transfer Coefficient, U-value, which is denoted by W/m2-K (Btu/h-ft2-F). [23]

1.3.5. Working of thermal insulation:

Due to presence of numerous microscopic dead air-cells which restrain the convective heat transmission the heat flow is resisted by Thermal insulating objects. Moreover, it is known as the air which is trapped by the insulation that gives thermal resistance regardless of insulation object.

The impacts of radiation are reduced by forming small cells (closed cell structure) across the thermal insulation where the temperature difference is less. It results in breaking of radiation 'paths' in smaller paths which absorb as well as scatter the long-wave infrared radiation through the insulation object. Though, when the size of the cell is reduced the process of conduction is speed up.

Normally the R-value of the standing air is not increased by the air-based insulation objects. Though, plastic based insulations make use of gas which is heavy than air in place of air inside the insulation cells that provides greater R-value. As a result, these three mediums of heat transmission explain the efficiency of the insulation on the whole, and are defined by apparent thermal conductivity which tells the deficiency of good conduction particularly at high temperatures. When comparison of open and close cell structure insulation is made with regard to vapour passage as well as moisture absorption, open cell structure is found to be more crucial.

Use of Vapour retarders is made to keep away from humidity getting into low-temperature insulation; they are used in insulation in winters and out of it in warm and moist temperatures (removing the humidity from another side). Fixing of Vapour retarders is difficult in varied weathers. [23]

1.3.6. Advantages of usage of thermal insulation:

The several advantages for utilizing thermal insulation in buildings are mentioned below:

1. A subject of principle: By making use of insulation in building thereby decreasing the dependence on electric and other form of machines to allow functioning in the building smoothly. As a result, energy is saved in related natural resources. This subject of saving natural resources is considered as usual in every individual and religious aspect.

2. Economic advantages: By making use of thermal insulation less money will be spent on the working as energy will be saved that is 5% of making the building. Moreover, the HVAC equipment initial price is also decrease as small sized equipment is needed.

3. Environmental advantages: As energy is conserved by reducing the working cost, thus less pollution is made because of less usage of electrical machinery.

4. Contentment of people and goodwill of nation: As energy will be saved, this means that it will be easily available to other people, less disturbance from the energy providers. Decrease in price of setting new power generating plants needed to fulfil requirement of electrical power. In addition to this, life of energy resource will be increased for life ahead.

5. Thermally secure buildings: Thermal relaxation in all weathers can be ensured.

6. Decreased noise intensity: Discomfort created from loud noises from the surroundings can be eliminated therefore, increase the ease level in the insulated buildings.

7. Constructing structural reliability: Modifications caused due to high temperatures results in unwanted thermal effects that can cause harm to the building and its arrangement. Minimal variations in the temperature can help in maintaining the structure of the building and its components. This can happen by making use of adequate thermal insulation; moreover, it helps in increasing the life of the building.

8. Vapour condensation prevention: Adequate layout and fitting of thermal insulation assist in keeping away the vapour condensation on the building surface. Though, measures should be taken to keep away from dangerous impacts of damaged structure of the building, that can occur from inadequate insulation substances being fixed or bad design. In order to stop entry of humidity in low-temperature insulation use of Vapour barriers is made.

9. Fire safeguard: When a proper insulation substance is used and accurately fixed, heat effects can be prevented and safety from fire can be provided in case of any emergency or accident. [23]

1.4. Basic Thermal Calculations

While carrying out insulation calculations, the values of thermal resistance and thermal transmittance of the walls are very fundamental.
R: Thermal resistance
U: Thermal transmittance

1.4.1. "R" thermal resistance of wall

The calculation of value of thermal resistance of a slab of homogeneous substances is done by dividing its thickness by its thermal conductivity (m^2K/W).
Basically, Thermal resistance,

$$R = d/\lambda \qquad \textbf{(1.4)}$$

d : the thickness of the slab (m)
λ : the thermal conductivity (W/mK)

What ever "R" is higher, it is isolative as much.

Heat flow that is resisted by substances that relies on the following factors: thickness, density, water, content and temperature.

The other two values are obtained from the position of the substances in the structure. The insulating substances are normally safe from humidity and chance of any physical harm because of less value density and strength.

The value of thermal conductivity of masonry can be calculated by dry density as well as the humidity level, which relies on the condition that it is in contact with weather or is in a safe state.

1.4.2. "U" Thermal transmittance of wall

By integrating the boundary layers of air and air cavities besides the thermal resistances of adjacent material layers, we can determine the thermal resistance and after it reciprocal (W/m^2K) is obtained.
Basically, Thermal Transmittance of a material is;

$$U = 1/R \quad \textbf{(1.5)}$$

R : Thermal resistance

What ever "U" is lower, it is isolative as much.

The near-stationary air layer surrounding each part of a building is likely to trigger the boundary layer or surface film thermal resistances. In addition, this phenomenon enables the radiant heat transfer at the surface.

The width, surface emissitives and ventilation are the required parameters for heat transmission across cavities.

The exposure of building is most likely to drive the external surface resistance.
As far as the estimation of thermal transmittance for a wall condition is concerned, the total thermal resistance of wall sections observe the addition of these surface resistance values.

Therefore, Thermal Transmittance of a wall section;

$$R = \alpha_{out} + \frac{d}{\lambda} + \alpha_{in} \quad \textbf{(1.6)}$$

$$U = 1/R$$

More insulation is gained by the wall sections because of thicker plaster, while the group observed the higher rate of plaster thermal conductivity. The application thickness holds greater significance in this regard. [24]

By using the proportional area method, the U values of the two constructions are combined to handle the elements of buildings that are bridged by a material of noticeably different thermal conductivity, such as a dense concrete or steel lintel in a lightweight concrete wall.

If U1 and P1 are the thermal transmittance and the unbridged proportion respectively of the gross wall area, and U2 and P2 are the same parameters for the bridging material, the overall U value is given by;

$$U = P_1 U_1 + P_2 U_2 \qquad \textbf{(1.7)}$$

1.4.3. "C" heat capacity

The heat capacity measures the combined effect of mass and composition.
Heat capacity, C, as distinct from specific heat capacity, is the measure of the energy required to increase the temperature of an object by given temperature interval.
Heat capacity is an extensive property dependent on an amount of material.

1.4.4. "c" specific heat

The specific heat, c, or specific heat capacity, is a property of the compsition only.
It measures the energy required to increase the temperature of a unit quantity of a specific substance by a specific temperature interval.
Heat capacity is the ability of a material to absorb heat.
Quantititvely: The energy required to produce a unit rise in temperature for one mole of a material.

$C = dQ/dT$ **(1.8)**

C: heat capacity (J/mole-K)
dQ: energy input (J/mole)
dT temperature change (K)

*Two ways to measure heat capacity:
- Cp : Heat capacity at constant pressure
- Cv : Heat capacity at constant volume
Cp usually > Cv

1.4.5. Specific heat comparison

- To increase the temperature of a substance with high specific heat capacity than one with low specific heat capacity, more heat energy is required.
- For example, the specific heat energy for enhancing the temperature of glass (cp = 840 J/kg-K) may be compared with the one required for gold of the same mass (cp = 128 J/kg-K)
- Subject to how we measure the quantity of a substance, the symbols used for specific heat capacity are either c or C. (Prof. Dr. Lütfullah GÜNDÜZ, Lecture Notes)

2. ENERGY EFFICIENCY

2.1. Building Energy Rating

The energy label for a household electrical appliance and the BER (building energy rating) are almost identical. The label has a scale of A-G, whereas the G falls in the category of the least energy efficient and the A-rated buildings are the most energy efficient. Consistent with the dwellings, the Sustainable Energy Authority of Ireland "an indication of the energy efficiency of a home is referred to as a BER. Based on the basis of standard occupancy, it includes energy usage for water heating, space heating, lighting and ventilation."[24] For selling a newly constructed building, most important requirements are certificate and a BER assessment. Each country has different methods of calculations and legislations related to BER. The energy efficiency of buildings can be effectively monitored and enhanced with the help of a great tool that is BER.

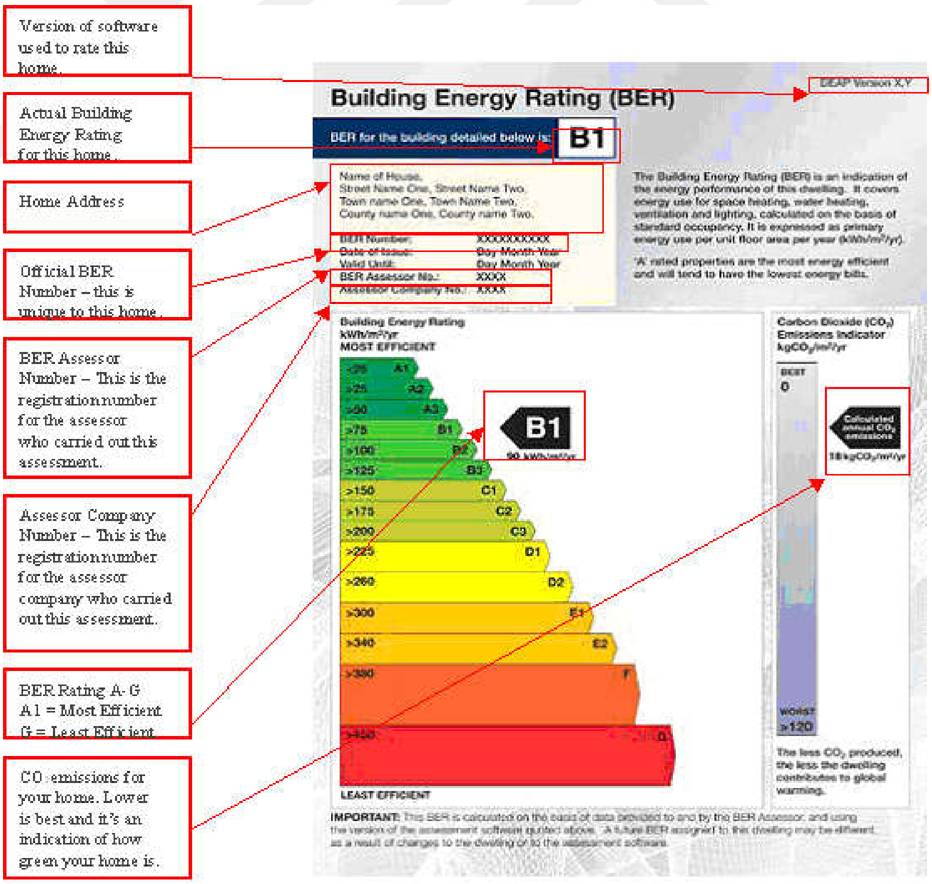


Figure 2.1 : Explanation to parts of Building Energy Rating.

(http://www.berratings.com/ber-rating-explained/)

Indicative ratings for typical homes:

House Built in:	Rating	2 Bed Apartment (75m²)			3 Bed Semi-D (110m²)		
		kWh	CO_2	Cost	kWh	CO_2	Cost
2008+	B1	7,200	1.7	€ 500	10,600	2.5	€ 725
2000s	C1	11,625	2.8	€ 800	17,100	4.1	€ 1,175
1990s	C2	14,250	3.4	€ 1,000	20,900	5.0	€ 1,445
1980s	D1	17,250	4.1	€ 1,200	25,300	6.0	€ 1,745
Pre 1980s	D2/E1*	22,500	5.4	€ 1,600	33,000	7.9	€ 2,280

These ratings are indicative of the levels one might expect for homes built to the prevailing Building Regulations of the period and where no additional remedial measures have been installed..

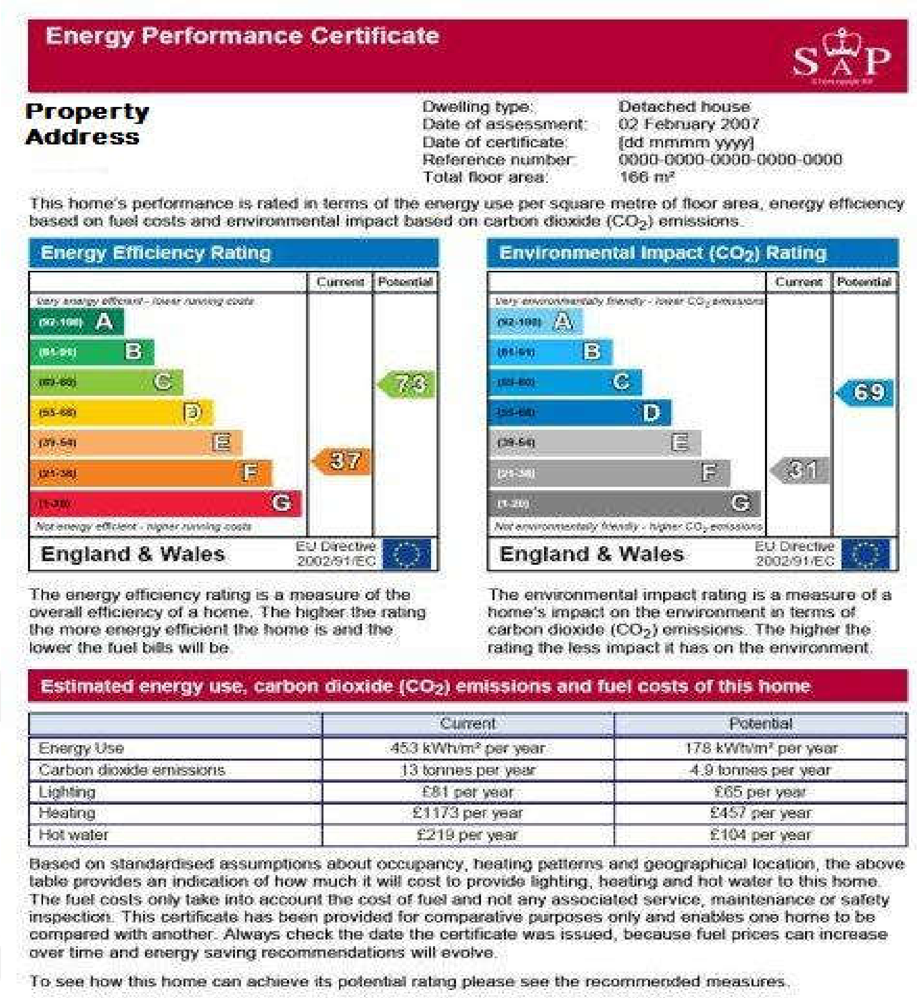
Figure 2.2 : Building energy rate requirements.

(http://adprojectmanagement.ie/ber.html)

2.2. Energy Performance Certificates

A report on the calculated energy performance of a specific building is basically represented by an EPC (Energy Performance Certificate). From 2007 to 2009, the UK (United Kingdom) launched the EPCs in a number of stages so that the requirements of the EU Directive 2002/91/EC on the energy performance of buildings could be fulfilled (EPBD). [25]

Prior to selling / renting out of the property, approval and commissioning of an EPC comes under the responsibility of the seller / landlord. Before signing a contract, the expected buyers or tenants must have an access to the EPC and it is valid for 10 years. [26]


Energy Performance Certificate

Property Address

Dwelling type: Detached house
Date of assessment: 02 February 2007
Date of certificate: [dd mmmm yyyy]
Reference number: 0000-0000-0000-0000-0000
Total floor area: 166 m²

This home's performance is rated in terms of the energy use per square metre of floor area, energy efficiency based on fuel costs and environmental impact based on carbon dioxide (CO_2) emissions.

The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating the more energy efficient the home is and the lower the fuel bills will be.

The environmental impact rating is a measure of a home's impact on the environment in terms of carbon dioxide (CO_2) emissions. The higher the rating the less impact it has on the environment.

Estimated energy use, carbon dioxide (CO_2) emissions and fuel costs of this home

	Current	Potential
Energy Use	453 kWh/m² per year	178 kWh/m² per year
Carbon dioxide emissions	13 tonnes per year	4.9 tonnes per year
Lighting	£81 per year	£65 per year
Heating	£1173 per year	£457 per year
Hot water	£219 per year	£104 per year

Based on standardised assumptions about occupancy, heating patterns and geographical location, the above table provides an indication of how much it will cost to provide lighting, heating and hot water to this home. The fuel costs only take into account the cost of fuel and not any associated service, maintenance or safety inspection. This certificate has been provided for comparative purposes only and enables one home to be compared with another. Always check the date the certificate was issued, because fuel prices can increase over time and energy saving recommendations will evolve.

To see how this home can achieve its potential rating please see the recommended measures.

Figure 2.3 : An example of Energy Peformance Certificate.

(http://www.fsgpropertyservices.co.uk/default.asp?contentID=696)

There are two ratings of an EPC, which are: an environmental impact (CO2 emissions) and energy efficiency. Moreover, the housing can be rated on a sliding scale between A and G, where A is the environment friendly / most energy efficient and G is the least environmentally friendly/ energy efficient. To evaluate the energy performance of dwellings, these ratings are associated with the SAP (Standard Assessment Procedure) of the government. [27]

For the EPCs generation, the defined SAP rating ranges from the bands A–G. Normally, the Reduced Data Standard Assessment Procedure (RdSAP) [27] is used to assess the dwellings being sold or rented till the time a more precise rating would be delivered by a comprehensive SAP assessment because of the unusual conditions of the given building [28].

An energy assessor having the requisite qualification and having an approved accreditation scheme can only produce a genuine EPC [28]. The property would be visited by the energy assessor to gather the required information for producing an EPC. Besides having the information about installed building services and their controls (hot water, heating and lighting), the information must be pertinent to the site/property and contains the construction of the thermal elements, the dimensions and fittings (roof, walls, windows and floor). With the help of the RdSAP calculation routines, this information is entered into a certified software application [27], from which the user can generate the current and prospective ratings in addition to the expected energy price, energy use and suggestions for improvements. Afterwards, a national register is taken into account to log on the certificate through the accreditation scheme of the assessor and a copy is provided to the landlord or seller [28].

2.3. Thermal Bridging

There is a building component known as a thermal bridge where a considerable change is observed in the thermal resistance as compared to that of the envelope, which is on account of the materials with a higher thermal conductivity, and it is also because of the variation in the geometry of the fabric, as in the case of the junction between floors, roofs, walls and ceilings. [29]

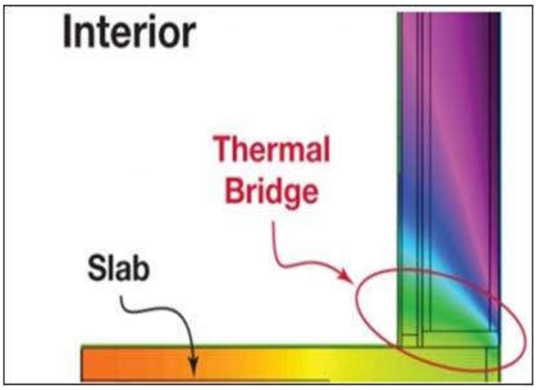


Figure 2.4 : Thermal bridging example.

(https://www.homepower.com/articles/home-efficiency/design-construction/passive-house)

The experts have defined the linear and point thermal bridges in the literature. The junction of two or more elements of the building envelope is most likely to witness a linear thermal bridge. In this scenario, identifying an axis along which the thermal bridge and its orthogonal section does not vary is a doable task. A position where the continuity of the insulation is interrupted is known as a location point of thermal bridge, for example, at three-dimensional corners. During the examination, the researchers often overlook the effect of the point thermal bridges, whose purpose is to specify the building energy performance. On the other hand, a linear thermal transmittance (value) can be represented through the linear thermal bridges, which is defined as the steady heat transfer per unit of length and per unit of temperature difference between the two environments [29].

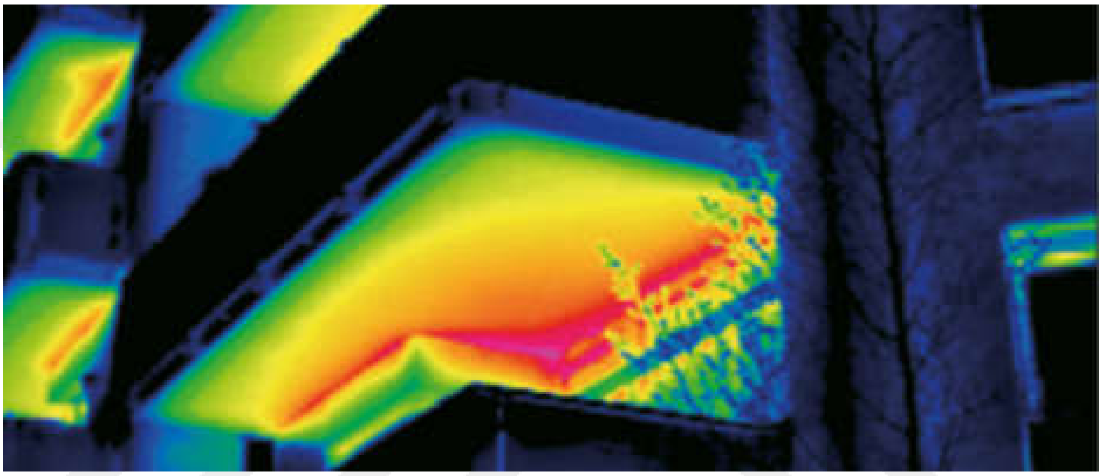


Figure 2.5 : Thermal bridging from a thermal camera view.

(http://www.schock-us.com/en_us/solutions/thermal-bridging-186)

3. THERMAL INSULATION MATERIALS

The part of the complex structural elements from which a building's shell is formed is referred to as the insulation materials and they are not the self-reliant energy conservation or production systems. Moreover, their assessment is carried out as an integral part of a building's design and construction and they cannot be evaluated like the energy producing systems, like photovoltaic or solar thermal systems. In addition, an insulating material and its quality are conditional on its flexibility with general, regional or even local building standards. The materials, which are common in specific regions, are exceptional in other areas. While, any material could be used in place of the other if we are talking about the scientist c point of view. Obviously, there would be superb views for the other materials, like foam glass, perlite and wood wool, which are focused on specific applications, where the high conditions are set on certain mechanical attributes, on humidity resistance and on sound insulation, or where the preliminary cost factor is not significant than average commercial and residential buildings. The development of the 'alternative' materials is another point of interest, such as cotton and sheep wool, and the 'intelligent' materials, like dynamic and transparent insulation materials having temperature depending thermal conductivity attributes. Their resilient dissemination into the market is still generally a monetary matter, where researchers take into account the further development subject to both the achieving economies of scale and improvements in the production processes.

For the purpose of installing retro insulation in housing societies, prefabricated panels are used. Moreover, these panels are also installed in office areas and used in the construction of commercial buildings. On the other hand, a myriad of high standard elements was introduced in the market and these elements were meant for particular construction projects and building purposes. Used in constructing roofs with an insulating facility, per insulation thickness is the major factor that determines the energy behaviour of every product. This thickness is present in both inorganic fibrous and organic foam. Nonetheless, factors that determine if the product has proved advantageous or not, includes its price, how it is managed and organized, diversity in its use and compatibility with the environment. [30]

The requirement of enhancing the energy efficiency in buildings has increased owing to the fact that energy consumption in these areas is responsible for greenhouse radiations. Moreover, it also contributes to the global energy consumption quota. Thus, ideas are being introduced to better this situation like zero emission buildings and passive houses. The thermal insulation of these buildings contributes to fulfilling the requirement of the enhanced energy efficiency.

For the purpose of enhancing the thickness of the building's envelopes, latest conventional insulation elements are being used. Moreover, latest alternatives with low thermal conductivity values are still being provided in the market along with latest insulation components. These products are being developed so that maximum value of thermal insulation resistance can be acquired. Nonetheless, owing to the fact that there are dilemmas regarding floor space, portability volumes, architectural shortcomings and cost issues, these really dense building envelopes are not the best option. Other issues regarding this material are the present construction methods and the type of material that is being used. [31]

In a situation, where we want to set the lowest value of thermal conductivity, a plan is devised that includes the use of thermal building insulation component. It is used because its main advantage is its thermal conductivity. The use of comparatively thin building envelopes is made possible when there is low thermal conductivity (W/(mK)). These envelopes have low thermal transmittance U-value (W/(m2K)) and a high thermal resistance (m2K/W).

The aforementioned thermal contributions have to be reduced so that the value of thermal conductivity is reduced to a bare minimum. Usually, there are no holes in the solutions because it would cause thermal leakage transport. Moreover, caused by a variation in pressure, an air and moisture leakage that comes with the leakage thermal conductivity leak is not generally regarded as an insulation component.

Caused by lattice movements in the chemical bonds between atoms, the thermal transport related to these atoms is connected to the solid state thermal conductivity. In case of gases, the thermal conductivity is enhanced when collision takes place between gas molecules. This causes emission of thermal energy from one molecule and the other one receives it. There is a relation between the electromagnetic radiation that is released in the infrared (IR) wavelength area present on a material plane and the radiation thermal conductivity (rad). Thermal mass transfer or the motion of air and motion causes the convection thermal conductivity.

The temperature or the temperature difference determines and creates all of these thermal conductivity contributions. There are many techniques that are used by this myriad of thermal insulation alternatives and materials in order to reduce the particular thermal conductivities. Moreover, there is a list of criteria that must be fulfilled by these thermal building materials and alternatives with regards to other factors. [31]

3.1. Classification of Thermal Insulation Materials

Insulating materials can be classified according to their chemical or their physical structure. The most widely used insulating materials can accordingly be classified as shown in figure 3.1 [30].

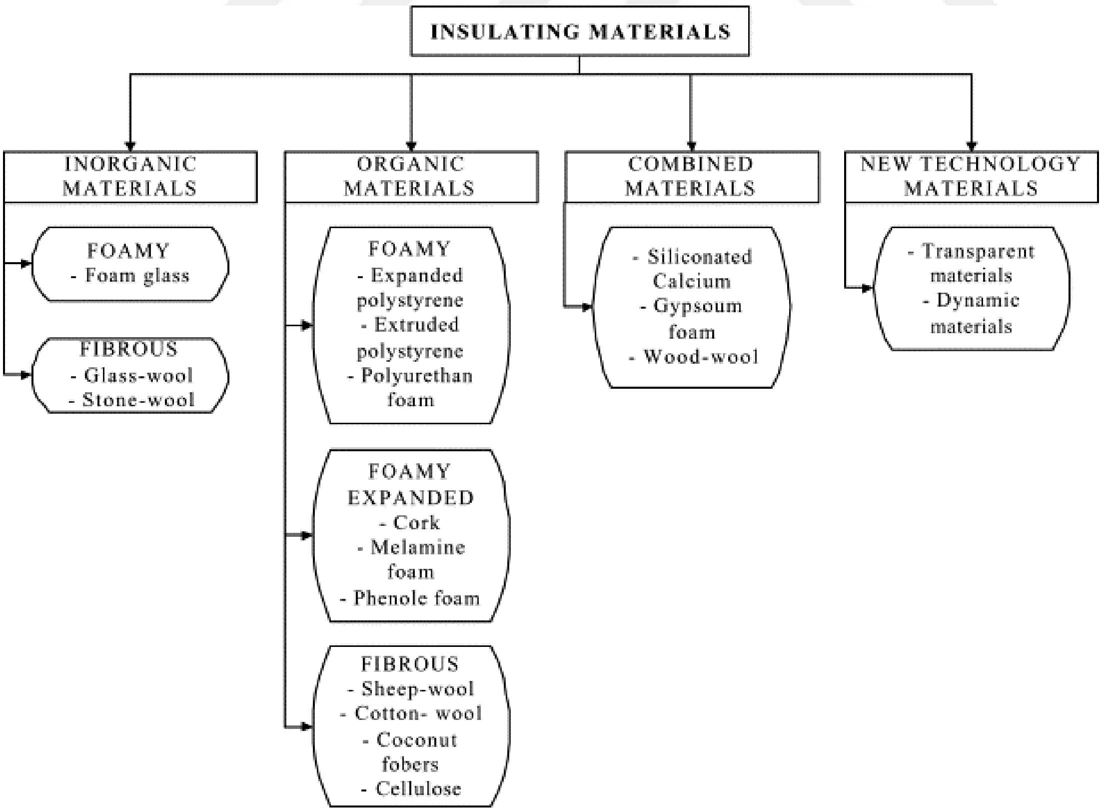


Figure 3.1 : Thermal Insulation Materials' classification in literature.

(**A.M. Papadopoulos** (2004). *" State of art in thermal insulation materials and aims for future developments "*. Energy and Buildings 37 (2005) 77-86.)

The properties of thermal insulation materials are generally subdivided into three principle gatherings. There are the customary physical properties, which portray the material's conduct as far as thickness, mechanical quality, thermal protection capacity, sound retention, imperviousness to dampness and and so on. These conventional physical properties are genuinely simple to decide and affirm, as particular models existed on national level for over 30 years. Meanwhile, there are globally pertinent models and mandates like, among other, the EN ISO 6946, EN 13162, EN 13163, EN13164, BS 476, 89/106/EC [32–38].
At that point there is a moment gathering of less unmistakably expressed, and even less regularly acknowledged, criteria, managing the natural effect of thermal insulation materials. This gathering incorporates properties like the essential exemplified vitality, the gas discharges for the creation of the material, the utilization of added substances against natural effects, the classification of their treatment as waste, and so on. Their ease of use and recyclability and the ecological effect of the material, in view of the Life Cycle Analysis approach as indicated by ISO 14025-00. The last one structures a globally worthy system for the ecological naming [39]. Still, the properties observed are more compex to contrast and with survey, as they can shift for a similar kind of material, as indicated by the area of the creation, the essential vitality assets utilized, national ecological enactment, and so on [40].
At last, there is the gathering of properties managing general wellbeing, amid the creation, the utilization and at the last phase of transfer of the materials. This gathering incorporates properties like clean and bres emanations, biopersistence, danger in the event of flame, and so forth [41,42]. The extensive variety of guidelines and greatest winning focus esteems as of now permitted in Europe can be found in [43]. Notwithstanding, as the wellbeing properties turn out to be more vital, the foundation of generally acknowledged appraisal strategies and benchmarking esteems is unavoidably the subsequent stage during the time spent on European harmonization.
Regardless, when coming to assess the execution of thermal insulation materials and to set goes for their future improvement, one can't neglect to watch that even the physical properties of a solitary kind of material change altogether, as indicated by the specific auxiliary application, which decides the kind of the material that must be utilized. Taking a commonplace inorganic fibrous material, similar to stone fleece, it can highlight a thickness of anything in the vicinity of 25 and 200 kg/m3, with

individually changing thermal conductivity esteems, additionally solid protection properties. It can be in the state of free material, rollbatts, flexible or unbending sections, with individually fluctuating mechanical and physical properties. The scope of properties that happens for each sort of material ends up plainly apparent, while considering the physical properties for the fundamental sorts of materials specified before, which are exhibited in [44].

The protecting execution of thermal insulation materials, to be specific, the thermal conductivity esteem [λ in W/m K] or individually the thermal transmittance coefficient [U in W/m2 K] for composite materials, has remained genuinely steady in the course of the most recent decade and can, from the part of heat exchange be judged as extremely tasteful. This ought not deceive to the conclusion that contemporary materials are at a similar level with those utilized as a part of 1990. There was huge advance amid this period, subsequently of the joint exertion of scholastic and modern research, concentrated on the natural and wellbeing angles, which frame the primary test for the continuous decade 2000–2010. This turns out to be more evident when looking at the information which presents what was resolved, by a review completed in 1996–1997 for the European Commission, as best in class in the mid-1990s [43], to the present best in class and the cutting edge includes as far as ecological and wellbeing parts of thermal insulation materials exhibited.

We are keen to contribute the literature by presenting a new classification suggestion among thermal insulation materials which is shown in the figure3.2 ;

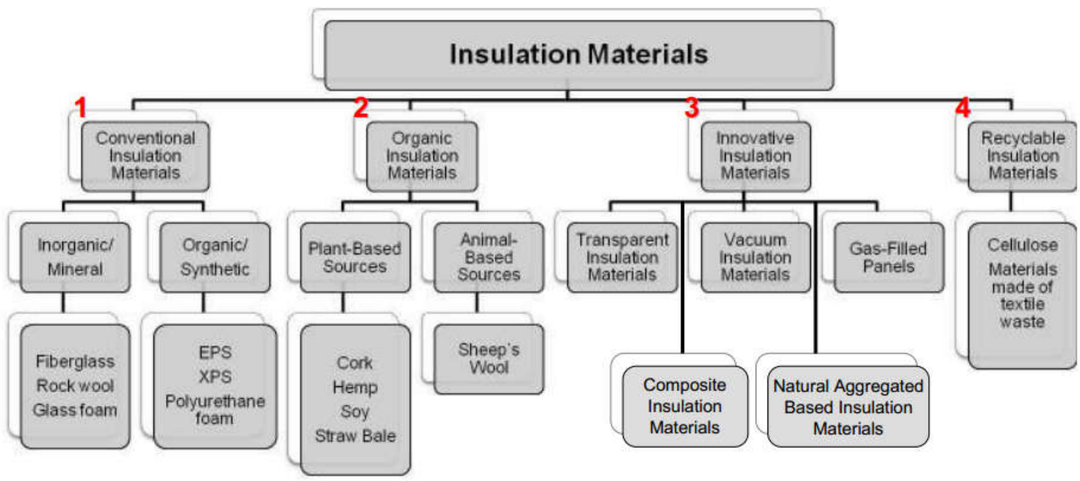


Figure 3.2 : Thermal Insulation Material's classification.

(Prof.Dr.Lütfullah GÜNDÜZ, Lecture Notes)

3.1.1. Conventional insulation materials

3.1.1.1. Inorganic/mineral

a. Fiberglass

Created for the purpose of restricting the thermal variations, fibreglass insulation is developed with a synthetic construction material. This is also used for reducing the sound transmission within buildings. This type of insulation has many advantages including low prices, light in weight, and suitability for commercial and residential use. It is built with a bunch of very thin strips of glass that has the property of high surface area-to-weight ratio. They are installed within the walls and roofs of a building during the construction process in a rolled form. [45]

Figure 3.3 : Fiberglass batt.

(http://onthehouse.com/insulation-2/)

Constructed with interconnected and glass fibres, glass wool is a thermal insulation material. The glass fibres used for its development are very pliable and allows it to 'package' the air. The packaging of air causes low density and this density can be changed via binder content and compression. It is mentioned earlier that air cells play a major role in insulation. Used in various ways like filling up penthouses or connected with an active binder that is used on the inner lining of the structures, panels and sheets. These sheets or panels can then be utilized for insulating flat surfaces like cavity wall insulation, curtain walls and ceiling tiles. Moreover, this glass fibre is also available in loosely structured fill material and can also be used for the process of ducting. Other uses include, soundproofing and insulation process of piping.

Figure 3.4 : Roof loft insulated with fiberglass.

(http://www.diynetwork.com/how-to/rooms-and-spaces/walls-and-ceilings/how-to-install-fiberglass-insulation)

Available as faced batts and unfaced batts, fibre glass batt insulation also comes with kraft paper or foil facing. To explain further, placed in front of the studs if possible or even stapled or adhered to the facing of the sides, faced batts are installed within walls. Whereas, unfaced batts are designed to be placed in wall cavities by the use of friction. Varying in widths, faced batts are made to be compatible with the friction fir that is present between the ideally used wall stud dimensions. In order to fix the batts, floor installations require the use of tiger teeth or metal clips. Moreover, there are two ways batts are fixed that includes, loosely placing them between joists after the drywall or stapling them in their required position prior to that.

In order to acquire the accurate R-value, ceiling insulation is sprayed in a careless manner to the required depth. Installed on the top of ceilings, blown-in fibre glass can also be used in walls. The R-values changes in wall insulation due to the use of acrylic binder for application. This process does not necessarily require the binder and the densities can also change. For perfect placement, insulation is sprayed with a binder and after the installation, it is scraped with studs. In the process that does not require the use of binder, the insulation sprayed into the cavity by using the openings of the mesh after the fabric mesh is installed on the walls.

An example of fiberglass material to be used in a cavity wall is given below [46].

- Width: 455 mm
- Pack Quantity: 6
- Type: BBA
- Material: Glass Mineral Wool
- Length: 1200 mm
- Coverage: 3.28m2
- Usage: Masonry Cavity Wall
- Thickness: 100 mm
- Thermal Conductivity: 0.032 (W/mK)
- Fire Retardant: Y
- Certifications Met: Y
- Thermal Resistance R Value: 3.1(m2K/W)

Even though many options are available where acrylic or bio-based binders are given without any phenol formaldehyde (PF), traditionally the fibreglass batt insulation is developed with PF. This element acts as a glue to hold the fibres together. Dangerous for people who are sensitive to chemicals, PF is emitted continuously into the wall cavity even after most of it wastes away during the process of construction. The process that involves emittance of molecules in a gaseous state into the air or through volatizating process of chemicals is called off-gassing. Specific product series are introduced that do not include PF binders and they are created by various companies.

Although, there are many disadvantages of using loose-fill fibreglass insulation, the use of binders is not done while construction. Formed with toxic chemicals, this fibreglass fibres can release into the air while installation. If it enters human body, it can cause major damage to the victim’s lungs. Even though, it is believed that recycled material is used for the construction of fibreglass insulation most of the time, installations waste material or disposed insulation are usually discarded. This insulation also involves use of a low 20% material for its construction. [31]

b. Rock wool

Rock wall insulation is available in two options including mineral wool or slag wool. Natural basalt rock is used for making rock wool, whereas, Iron or blast furnace waste product is used for the construction of slag wool. Equal amounts of these wools are mixed together for usage by one of the biggest companies in the industry. Slag products that is made with 90% post-industrial recycled material makes up the major part of the entire mineral wool materials.

The fibres of mineral wool insulation have the same property as fibreglass as it is toxic if inhaled as it can emit into the air. This type of insulation is offered in two forms including the batts and loose-fill products. The batts are developed with the help of starch binder. Also, offered in stiff boards, this type of insulation is made in foil faced and unfaced form. Same as Fiberglas, this insulation is made with flame retardants and is not combustible. Moreover, they are offered in variety of densities and many types are perfect for usage under concrete slabs.

Figure 3.5 : Rockwool batt.

(http://www.encon.co.uk/products/view/577/rockwool-rockroll-rollbatt-18af)

Rarely incorporated in the construction process as a filling material, mineral wool is also available in the form of boards and mats and incorporates rock wall and glass wool (fibre glass). When there is a need for thermal insulation in order to handle heavy stuff like one the floors or roofs, massive and rigid mineral wool boards are used that have enhanced value of mass densities. In order to block many cavities and fillings, mineral wool also plays the role of filler mineral.

An environment where the mass with high temperature is released through moving openings that allows the creation of fibres, is used for developing glass fibres by using borosilicate glass at almost 1400 C. The temperature is set at approximately 1500 C for creating rock wool and melting stone like dolerite and diabese is used. In this situation, the heated material is launched from a wheel or a disk that makes fibres. Phenolic resin and duct abatement oil is used as an adhesive to hold the fibres together for both rock wool and glass wool. This helps in enhancing the product's characteristics and normally, the thermal conductivity value is between 30 and 40 mW/(mK) for mineral wool.

An example of rock wool is given below [46]

- Width: 1200 mm
- Length: 2750mm
- Coverage: 6.60 m_
- Pack Quantity: 1
- Thermal Conductivity: 0.044 W/mK
- Fire Retardant: Euroclass A1
- Thickness: 200 mm
- Material: Stone Wool
- Usage: Multipurpose
- Certifications Met: BS EN 13162
- Type: Insulation Rolls
- Thermal Resistance R Value: 4.50 m_K/W
- Manufacturer Model No: 180900
- Country Origin: UK
- Brand Name: Rockwool

Depending on moisture content, mass density and temperature, the thermal conductivity of mineral wool fluctuates. For instance, it is plausible that the thermal conductivity of mineral wool would rise from 37 mW/(mK) to 55 mW/(mK). This would happen if the moisture content increases from 0 vol% to 10 vol%. Moreover, there is a possibility that the mineral wool products are punctured. Without any damage to thermal might also be pierced or displaced from their position in the building. [31]

Figure 3.6 : Wall insulated with rockwool.

(http://www.rockwool.com/business-portfolio/)

Easy to cut in required shape with precision, rockwool thermal insulation products also reduces the time required for installation, perfect for fitting and enhances its performance. [46]

c. Glass Foam

Designed to be utilized in bulk for general building construction process, glass wool is a type of commercial inorganic thermal insulating material. Its properties include maximum thermal insulating abilities when dried, thin in size, enhanced air permeability. The last one is due to the fact that it is a bunch of little laments and its insulating ability is reduced when it is humid.

Nonetheless, openings are formed when they are used for a long time because it cannot lose its shape unless force is applied. Moreover, in order to avoid this situation, specific construction techniques are used. [48]

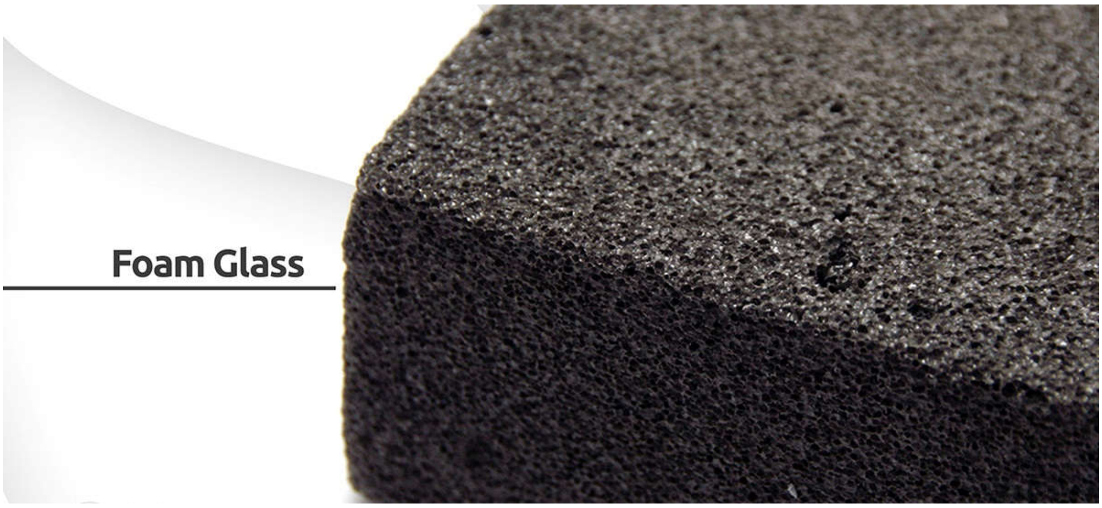


Figure 3.7 : Foam glass panel.

(https://www.styrouae.com/insulation-and-construction/foam-glass/)

Referred here as foaming agent, glass foams are acquired via gas generating agent process. Moreover, this agent is delivered by using a starting mass of powdered and in some situations a perfectly divided glass is used. A temperature is set that reduces the viscosity of the glass and the concoction of gas-generating or foaming agent and glass powder is heated at this temperature. This reduction in the viscosity of glass causes the foaming agent to create a series of little bubbles within the melted glass. The gas is evolved by the foaming agent. The bubbles are changed to solid and form the openings in the foam. [49]

Figure 3.8 : Basement floor walls insulated with foam glass.

(http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/jobsite-foamglas)

Various foam compositions and techniques are used for developing foams, along with both organic and inorganic forms that are available in nature and also known in art. Nonetheless, glass foams are being developed on a large scale and they have comparatively huge or diverse cells. Moreover, the non-uniformity generally forms other irregular properties and fragile areas. These cells diminish in exterior form. There are many properties of this foam with larger cells including reduced insulating effectiveness and increased chalkiness as compared to the foam that has small cells, when it is in inorganic form. [50]

3.1.1.2. Organic/synthetic

a. EPS

Developed with the monomer styrene, Polystyrene (PS) is defined as an artificial aromatic polymer. This type of polystyrene that is generally used is available in foamed or solid form. Moreover, other properties include frigid, easily breakable and clear. It also cannot block oxygen, water vapour and has comparatively low melting point. [4] Used on a wide scale, polystyrene is produced annually in several million tonnes. [5] Often available in different colours with the help of colorants, this material is clear naturally. There are many uses of this material including development of containers like “clamshells”, lids, bottles, tumblers, disposable cutlery and shielding packaging like CD, DVD cases and packing peanuts. [4]

It is a subject of disagreement in the environmentalist community because polystyrene takes a lot of time to decompose. It is present in our surroundings as large amounts of waste product usually along the waterways and sea shores. Generally, in the form of a foam, polystyrene is present in bulk within the Pacific Ocean. [6]

Figure 3.9 : EPS panel.

(http://www.finehomebuilding.com/2009/05/01/which-rigid-insulation-should-i-choose)

Designed by using little balls of polystyrene that contains crude oil and an expansion agent like pentane C6H12, expanded polystyrene (EPS) is used as boards or generally present on a production line. The expanding agent increases in mass when heated with water vapour and the balls are connected together at their point of contact. Moreover, the thermal conductivity value lies between 30 and 40 mW/(mK) and it has partially open pore-like structure.

Below is an example of EPS material properties.

- Width: 600 mm
- Length: 2400 mm
- Coverage: 1.44 m_
- Pack Quantity: 1
- Thermal Conductivity: 0.038 W/mK
- Thickness: 50 mm
- Material: Polystyrene
- Usage: Masonary Wall
- Type: Polystyrene Board
- Thermal Resistance R Value: 1.32 m_K/W
- Brand Name: Wickes

Depending on moisture content, mass density and temperature, the thermal conductivity of EPS changes and for instance, it might increase to 54 mW/(mK) from a low value of 36 mW/(mK). Moreover, it happens when moisture content would increase from 0 vol% to 10 vol%. It is plausible that the EPS products are punctured, or pierced and fixed for any building. It is done while taking care that thermal resistance is not reduced. [31]

Figure 3.10 : Wall being insulated with EPS panels.

(http://www.rowebb.com/product/jubizol-eps-1000x500mm/)

Brand new masonry floors incorporate polystyrene boards. It is also used for roofs and walls while constructing a building or renovating. This would allow the site to be more thermal resistant.

b. XPS

Having the characteristics of being increasingly rigid and low thermal conductivity, extruded polystyrene foam (XPS) has blocked cells. Its density range is approximately 28–45 kg/m3 and also provides better irregular surface.

Figure 3.11 : XPS panels.

(http://doctorpapadopoulos.com/xps-extruded-polystyrene-versus-fiberglass-insulation-is-it-better/)

There is no need for facers in order to enhance the thermal or physical characteristics performance, while XPS are used. Many of its uses include model buildings, crafts and it is specifically used for architectural structures. Extruded polystyrene material is, nonetheless, offered as an alternative for ridged cardboard. Normally the thermal conductivity of XPS is ~0.035 W/(m·K), it can fluctuate between 0.029 and 0.039 W/(m·K) that relies on its power or density.

Below is an example of XPS material used for roofs.

- Length: 610 mm
- Width: 402 mm
- Thickness: 60 mm
- Material: Polystyrene
- Usage: Roofs
- Pack Quantity: 1
- Coverage: 0.74 m2
- Thermal Conductivity: 0.038 W/mK
- Type: Polystyrene Board
- Thermal Resistance R Value: 1.57 m2K/W
- Brand Name: Wickes

The use of XPS is convenient for damp places as compared to EPS due to the fact that the Water vapour diffusion resistance (μ) of XPS is approximately between 80 and 250.

Mould cannot be formed when extruded polystyrene (XPS) is used for construction. It is resistant against water and cannot decompose because of moisture. It exceeds in its performance as a thermal insulator due to its R-Value of 5.0 per inch of thickness. This enhancement boosts the energy efficiency of all buildings and it maintains its insulating characteristics as the time passes. Through openings and holes, energy releasing air leakage can be blocked by using an interconnected shiplap edge (SL) and square edge (CM). There are many situations where XPS Insulation Board can be used like basement walls, outer insulation, over wood sheathing, residing, and slab and beneath grade along the foundation. This board is perfect as an additional resisting agent against moisture penetration.

Formed with a blocked cell foam material, extruded polystyrene does not soak a large amount of moisture and does not decompose easily. Moreover, this foam is not strong against UV light and has little flexibility.

Figure 3.12 : Wall being isulated with XPS panels.
(http://www.archiproducts.com/en/products/brianza-plastica/xps-thermal-insulation-panel-elyfoam_6196/)

Developed by using polystyrene (made from crude oil) in liquid form and adding expansion gas like HFC, C6H12 or CO2, Extruded polystyrene (XPS) is divided in lengths after cooling. The polystyrene mass is ejected through an opening and it is expanded with pressure release. Moreover, it has a blocked pore arrangement and the conductivity values for XPS is usually somewhere between 30 and 40 mW/(mK). This insulation material is kept in long lengths before cutting.

There are instances that prove how thermal conductivity of XPS changes depending on the mass density, moisture content and temperature. Take the example of the boost of thermal conductivity from 34 mW/(mK) to 44 mW/(mK) when the moisture content spikes from 0 vol% to 10 vol%. Without losing any thermal resistance, these products can be easily cut, pierced and placed according to the building. [31]

c. Polyurethane foam

This type of form is developed when polyols and isocyanates react with each other. The former includes alcohols with multiple hydroxyl groups. The blocked pores of Polyurethane (PUR) are filled with an expansion gas like CO2, C6H12 OR HFC during the expansion procedure. It is possible that PUR is utilized in its expanding foam during construction like in order to block many openings, or close areas windows or doors. This material is developed in the form of boards or used in long shapes on a production line. Usually not more than 30 mW/(mK) or less than 20 mW/(mK), normally the thermal conductivity value of PUR is less than mineral wool, cellulose materials and polystyrene.

Figure 3.13 : Polyurethane foam.

(https://www.indiamart.com/proddetail/polyurethane-foam-puf-4528706012.html)

Depending on mass density, moisture content and temperature, the thermal conductivity of PUR changes and for instance, it might reach the high value of 46 mW/(mK) from a low value of 25 mW/(mK). This would happen because of the increase in the value of moisture content from 0 vol% to 10 vol%. When there is a fire, there might be a potential danger to the people's health even if the PUR is deemed safe for use. To explain further, PUR would emit isocyanates and hydrogen cyanide (HCN) if the building is on fire or close to spreading fire. Moreover, without any change in thermal resistance, these products can be pierced, divided or changed according to requirement. [31]

3.1.2.Organic insulation materials

3.1.2.1 Plant-based sources

a. Cork

Normally the thermal conductivity of cork relies between 40 and 50 mW/(mK), while the cork thermal insulation is formed with cork oak. It is developed in two forms including boards or as a filler material.

While keeping thermal resistance intact, it is possible that cork insulation materials are pierced, cut or fixed according to the site's requirement. [31]

Figure 3.14 : Cork insulating panels.

(http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/expanded-cork-greenest-insulation-material)

The Quercus suber (the Cork Oak) is an endemic to northwest Africa and southwest Europe. It is used for the extraction of the cork to be used in a commercial manner. The cork is an impermeable buoyant material which is harvested from the bark tissue's phellem layer. Suberin is a hydrophobic substance which is present within the cork. This cork is not only elastic and buoyant, but also has impermeable and fire redundant properties which is why it is used in various products. Wine stoppers are one of these products where the cork is commonly used. Over the world, annually, harvesting of half of the cork is done on the Portugal montado landscape. Within this industry, the leading organization is called Corticeira Amorim. [52]

Figure 3.15 : Flat roof being insulated with cork insulation panels.

(http://www.conker.cc/project-category/commercial/)

The density of an expanded cork is 7.0–7.5 pounds per cubic foot with an insulation of R-3.6 per inch and a 15 psi (with 10% compression) compressive strength. Additionally, it attains a moisture permeability over an intermediate stage using a 40-mm layer of 2.2 perms permeance. A smoky smell is attained when the insulation of the expanded cork is done. Analysis of a test report was carried out which clearly indicated that the material was in accordance with the strict standards of France applied for twelve volatile organic compounds (VOCs). The sound control characteristics of the Cork are also splendid.

Maintaining the context of being fire-resistant, it measures up to the standards of other valuable and rigid insulation materials and the European Class E title. It does not require flame retardants which are usually needed for the usual boardstock insulation products.

Between sixty to ninety minutes, the burn through would be resisted when a 40 mm-thick boardstock piece is kept upon a torch. This can be compared to the polystyrene which is extruded or expanded for lower than 10 seconds and is part of the Class E title as well.

In Europe, the cork insulation is a well-known rigid insulation material. In the roofs of the houses the 10- to 12-inch layer and the 8- to 10-inch layer is installed in the exterior walls is usually installed. In 1995, in Austria, the first Passive House built was approximately 14 inches with 350 mm layer of this material. Usually, it used like polyisocyanurate, an exterior insulation layer [53].

b. Hemp

Part of the Cannabis sativa plant species is the Hemp or industrial hemp (from Old English hænep),[54] usually present in the northern hemisphere. It is specially grown due to the possibility of using the derived products for industrial use.[55] 10,000 years back, this plant was one of the first to be spun into fibre that could be used. It is considered as the fastest growing plant [57] and can be refined into various materials. These materials include animal feed, food, biofuel, insulation, paint, clothing, textile, paper and biodegradable plastics.[58]

Figure 3.16 : Hemp insulating panel.

(http://www.truthonpot.com/2013/07/16/hemp-insulation-a-carbon-negative-alternative-to-rock-wool/)

Figure 3.17 : Roof being insulated with hemp panels.

(http://www.truthonpot.com/2013/07/16/hemp-insulation-a-carbon-negative-alternative-to-rock-wool/)

Hemp is considered an efficient insulator due to its low conductivity level. 0.039 W/m°K is the hemp insulation thermal conductivity. High thermal mass is present within natural insulations making sure they are able to retain the heat and regulate the performance of the thermal allowing a comfortable indoor atmosphere. With the help of the insulation, winters are warm and overheating does not occur in summer season. This characteristic is quite beneficial for buildings that attain warm attics [60].

c. Soy

The soy based insulation has the below mentioned benefits.

- Urea and formaldehyde is not present which is why it is considered safer than the traditional insulations. The chemical by-products are not off-gassed by the soy-based insulation. Harmful chemicals or hydrofluorocarbons are not present in the water spray it is applied with.
- Soybeans, a renewable resource, is used to make soy-based insulations. Within the United States, nearly 600,000 soybean farmers are supported when soy is bought. Foreign oil dependency also declines when it is used as a petroleum product substitute.
- The issue of fungus growth or mould is not present as it resists moisture.

- Class 1 or high fire rating is present and is an efficient sound barrier.
- Settlement or degradation does not occur.
- The R-value for soy-based insulation is high. As compared to the traditional batting insulation, the soy-based insulation maintains energy-saving features which are much more efficient or same as stated by the United Soybean Board (USB). Additionally, the closed-cell spray foam air-sealing ability is also better.

Figure 3.18 : Soy based insulation foam.

(http://www.moderndallas.net/whysoybean.html)

Trained technicians bring tanks to apply the soy-based insulation. It is possible for the homeowners to purchase the product at a nearby hardware store and then apply it on their own. For its application, a water spray is used and it expands to nearly hundred times of the original volume. It eventually hardens but before reaching this state it sneaks into cervices and small spaces.

The mentioned two kinds are present for the Soy-based insulation.

- First is the closed-cell kind which has a texture like a bubble and is rigid and dense. During high winds, the strength of the structure enhances and it is possible to walk on it as well. It is an efficient insulator with a 5.5 R-value. As compared to the open-cell, it costs much more. A vapour limitation is present for the closed-cell insulation. This means that moisture is unable to pass through, for instance, rainwater may not be able to enter from the rook into the attic.

- The Open-cell is the second kind with a broken bubble kind texture. It is not only lightweight but also pliable. As compared to the closed cell- it has a lower insulation since the R-value is 3.6. At the same time, its price is also lower. There is no vapour barrier but an air barrier is present. It will not be applied for exteriors where it could get wet. The effectiveness of the open-cell insulation would decline if moisture is present and mould is expected to grow.

As compared to the traditional insulation kinds and fiberglass, the soy insulation is much more expensive. The niche market makes use of this premium soy-based insulation. The fiberglass price has not subdued even after the mass production. The environmentalists are interested in this kind of renewable and sustainable insulation.

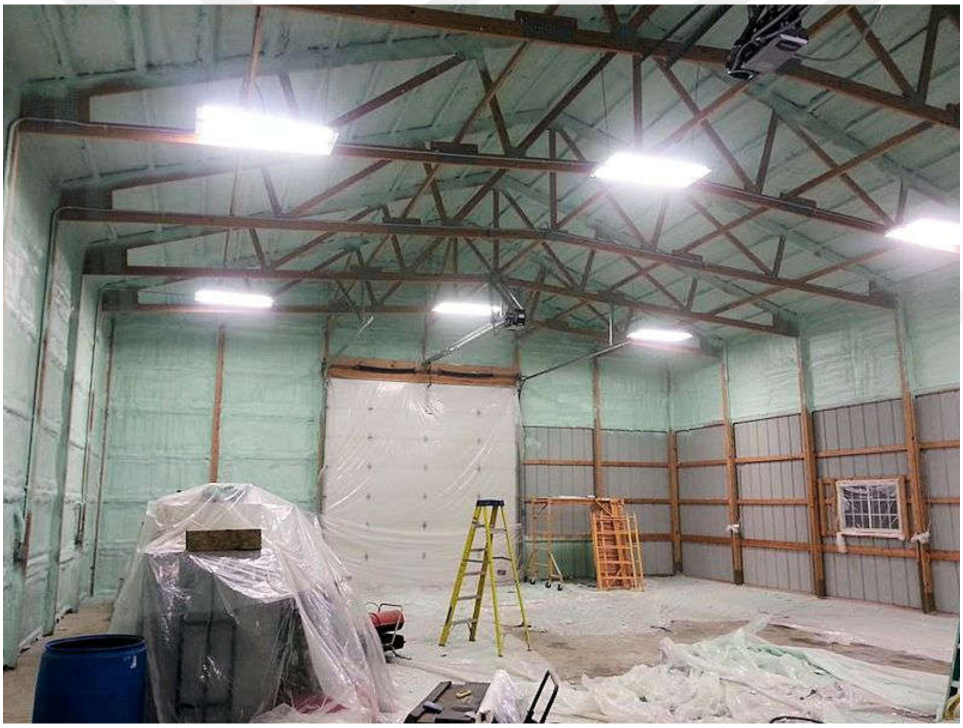


Figure 3.19 : Industrial construction being insulated with soy based insulation.

(http://greenglobeinsulation.com/demilec-heatlok-soy-install.html)

The homeowners are able to reduce their energy bills by installing the green form insulation which includes the soy-based and other spray-foam based insulations. As compared to other insulation material, soy-based insulation is greener since the soy is a renewable resource. However, it is quite possible that 85% of soy-based insulation is petroleum based which is why the homeowner must conduct an energy audit.

Overall, it is possible for homeowners to reap the advantages of the soy-based insulation if they are willing to pay a high price. [61]

d. Straw bale

The straw bale is usually used as a building material. [62]
0.0414 to 0.0486 and 0.0353 to 0.0539 W/mK is the thermal conductivity for the wheat and barley straw bales. This is for the bale densities at various temperatures for the wheat and barley straw bales. 20.7 and 34.2 ºC are the average values of thermal conductivity and thermal resistance which are much higher than 10.3 ºC. There is a higher difference in the thermal conductivity and thermal resistance values as temperature changed from 10.3 to 20.7 ºC as compared to the 20.7 to 34.2 ºC. The wheat straw bales thermal conductivity is 0.046 W/mK. The k-value of lightweight straw loam is 0.20 W/mK having a 750 kg/m3 density. On the other hand, 0.18 W/mK is the value of lightweight expanded day loam with 740 kg/m3 density. For the same material, the specific heat is 1.0 kJ/kg K. [63,64,65]
An experiment can be conducted by T. Ashour and his friends where the thermal conductivity of plaster reinforced straw bale was stated. The outcomes were quite satisfactory. [66]

Figure 3.20 : Straw bale insulation pack for construction.

(http://www.motherearthnews.com/diy/insulated-cat-house-zmaz09djzraw)

The insulation characteristics of straw bales is quite efficient and amongst the thermal insulations present, it is most cost effective.

- The R-value for a usual straw bale is higher than 10.
- The straw and fibreglass batts have similar insulation value when considering Centimetre for centimetre.
- The straw bale insulation value would be greater than traditional construction when considering Dollar for dollar.

For a given structure, the objective for design should be that the insulation performance works hand in hand with the building performance at large. Hence, to attain optimum performance from a straw bale building, it is essential to insulate the windows and roofs.

Figure 3.21 : Straw bale house.

(http://buildingwithawareness.com/the-pros-and-cons-of-straw-bale-wall-construction-in-green-building/)

d.1. Durability and moisture resistance

It is possible for a straw bale building to last for a hundred years if there is protection to the straw and waterlogging would not occur.

The durability of the straw bale is highly influenced by the long term or constant subjection to water. Fungus starts to produce inside the bales and within two to three weeks, enzymes are formed which would break the straw cellulose if moisture content is higher in weight by 20%. If a wall is created which is breathable as well as waterproof, it would be possible to avoid any rotting within the complete structure. Nebraska and Alabama have variable climates in terms of temperature and moisture by the historic straw bale structures have shown durability and constant survival.

As compared to the wheat straw bales, the rice straw bales are much more durable since the rot resistance is better due to high silica content. Apart from the characteristics of rice straw bales having high density and being heavy, they are similar to the straw bales.

d.2. Toxicity and breathability

The straw bale construction uses natural material that is not only safe but also biodegradable. However, individuals may be allergic to the dust which generates during construction. The straw bale construction cycle does not have a toxic conclusion and when the straw burns there are no toxic fumes. The breathability of the straw bale walls is efficient which lets the air enter through the structure slowly but the moisture is not allowed to penetrate. The walls may be allowed to breathe better when compared to cement render through the earthen and other earth-lime renders. This is specifically for renders which attain a ratio of high cement to sand.
Within the bush, the straw bale walls are able present efficient insulation during hot days and cold nights.

d.3. Environmental impacts

Usually, by the end of the season, straw is burnt since it is a waste product and cannot be used like hay for feeding. Carbon is stored and air pollution declines when straw is applied for building. It is possible to make use of this straw efficiently so that there is minimum waste at hand.

Large amounts of renewable material are present within straw bales along with being biodegradable. The growing cycle lasts for six months. The straw needs to be grown in a manner that the ecological integrity and soil quality is maintained as it would ensure long term sustainability.

Straw bales influence the environment which can be managed through use of pesticides and fertilisers during industrial farming activities. A similar effect is observed by bailing twine created using petroleum commodities.

The integrated energy within the straw bales is usually low but not for the ones produced using fossil-fuelled machinery. A plastic twine is used to tie them together and they travel a long distance which enhances their inherent energy, tied together by plastic twine and transported long distances. The construction cost rises since the straw bales are in need for concrete footing.
The irrigation agriculture by-product is rice straw which alters the water balance and flow within the valuable rive system catchments in Australia. The water intensity of wheat straw is less.

The straw bales have low greenhouse gas emissions. Nearly fifty times extra energy is needed to produce one concrete ton as compared to straw manufacturing. When straw is used for building, the carbon amount becomes appropriated and low for each dwelling.

The objective of the straw is to behave as an insulation material which helps homes use low levels of energy as well as reduce the emission of carbon dioxide during the life of the building. [67]

3.1.2.2. Animal-based sources

a. Sheep's wool

Materials designed form natural resources or sustainable biological raw materials can be referred as bio products. Referred as a substitute insulating material, the sheep's wool is an example of bio-product that has shown some positive characteristics [68, 69]. Moreover, wool is another product with many physical properties suitable for any raw material like its durability, thermal performance, hydrophobic and hydrophilic properties and how it naturally changes temperature and it also has fire resistance [68,70,71].

As fiberglass does not have an adverse effect on eyes, respiratory tract or skin, wool insulation can be used without protective shield as it does not have the same qualities as fiberglass [68]. With a production between 2.3 and 3.6 kg of raw wool on an annual basis by a sheep regardless of hair sheep breeds, wool is also a renewable material and it can also be sheared if the animal's health requires it. Used for insulation purposes, wool will be used for developing more diverse markets in North America. It is believed that income opportunities would be available to sheep producers and it will be used as a sustainable and green building material.

Figure 3.22 : Sheep wool batts.

(http://www.ecomerchant.co.uk/roofing/insulation.html)

At the moment, in areas of North America, many sheep developers and producers are not provided with a good cost in exchange for their wool. Now, the yearly shearing price has heightened as the cost is less and is not enough for distribution to market and price of shearing [72]. In an evaluation of conventional and natural acoustic materials, Asdrubali et al. (2012) [90] mentioned that sheep's wool has a very low effect on the environment but the value of sustainability of the development procedure for the conversion of raw wool into insulation is ambiguous. Still the wool plays the role of renewable source.

The subject of this study is the sustainability of wool insulation development under the light of researches. They have studied the development procedure utilized by the raw material insulation on an artisan level.

Stiles and Corscadden, (2012) [73] along with a group of experts have mentioned that the marketing of almost 45% of the region's annual wool production is being done and the rest is given to farms or disposed of.

The main purpose of this study is to define the steps that are necessary for development, managing the methods used and overlooking the affect of sheep breed or mixture over the whole process. Moreover, the material characteristics and the costs were also discussed along with the calculation of thermal insulating characteristics, yield and energy demand. In order to calculate the economic achievability of the artisan level based on the wool batt production facility pilot project at Harmeny Woolen Mill in Central North River, Nova Scotia, Canada, the time and motion research was conducted.

Researches like Clarke and Yaneske (2009), Fournier and Klarsfeld (1974) and, Graves and Yarbrough (1992) [74,75,76], have highlighted the insulation material's characteristics. However, its subject was not the application of sheep's wool for insulation. Zhou et al., (2010) [77] has mentioned many substitute materials like stalk fibreboard and cotton along with the study done by Benkreira et al., (2011) [78], discussed the change of waste drains for insulation that involves the renovation of elastomeric waste products.

Papadopoulos (2005) [79] has mentioned in a study about the thermal characteristics of various popular insulating materials like perlite, wool, fiberglass, stretched polystyrene and rocks, among many others done in Europe building industry. It concluded that they were similar in nature but at some places, the disparities could be seen that includes fire resistance, price and its absorbent ability.

The toxicity of the materials was mentioned by Liang and Ho (2007)[80] and concluded that it was higher when combusted same as the case of organic items. The effect of heat and moisture was studied by Jerman and Cerny (2013)[81] on insulating materials. It concluded that the thermal conductivity of mineral wool is positively related to the moisture content. Moreover, this causes a decrease in thermal characteristics at the rate of small increase of 5–20% presence of moisture content.

A hot topic of research is sheep's wool and the use of alternative materials. Many researches highlight the thermal values of wool insulation as compared to other traditional insulation material. A study was conducted by Symons et al. (1995)[82] in Australia that also provided a comparison of cellulose fibres, polyester, wool and fiberglass on the basis of thermal conductivity in relation to thickness and density. It was done for materials that were in batts and loose fill forms.

Results have been produced that say that fiberglass batts do not need more thickness as compared to sheep's wool for any density so that thermal resistance values can be achieved. (Symons et al., 1995)[82] says that sheep's wool is different material and its insulation density is less for deciding thermal performance.

Another research done by (Ballagh, 1996)[83] says that wool has same properties as fiberglass and lessens the sound index till six decibels as mentioned in a study done in New Zealand based materials. As described by Desarnaulds et al. (2005)[84], sheep's wool has improved sound absorption as compared to mineral wool. Sheep's wool is also described as a technical fibber because of its diverse characteristics, as mentioned by Johnson et al. (2003)[70].

The substitute forms of insulating materials were discussed in the studies conducted at Northern Ireland and New Zealand. They concluded that sheep's wool and hemp can produce similar rates of thermal conductivity as mentioned by (Ye et al., 2006)[71].

The environment friendly insulation materials were investigated by Zach et al. (2012) [85] and concluded that there are many pros like fire resistance and hygroscopicity.

The results of the study done by Symons et al. (1995) were compared to the ones developed here [82]. The bulk density of wool being inversely connected with air flow was justified in the Zach et al. (2012)[85] in the pore structure of the insulator and it boosts the thermal insulating characteristics. Ye et al. (2006)[71] also proved that and said that wool thickness is positively connected to the thermal resistance if the density is more than 11 kg/m3. Among them, other researchers like Symons et al. (1995)[82] and Trethowen (1995)[86] proved the same. Moreover, the point made by Ballagh (1996)[83] regarding the acoustic material qualities of sheep's wool was supported by Zach et al. (2012) [85]. Nonetheless, it can be said that more advantages are not availed if the thickness exceeds the value of 170 mm of the material.

The present articles present the point of view that the wool could be utilized as an insulation material even though studies done by K.W. Corscadden et al. / Resources, Conservation and Recycling 86 (2014) 9–15 11 have raised the points of parameters of safe production of sheep wool insulation and its economic reliability. There are few suppliers internationally that offer different variety of sheep's wool insulation but it is costly than other materials.

$19.59/m2 CAD [87], for 10 cm thick insulation is the price in Ireland by a huge supplier. Meanwhile, insulation in Canada is sold by The Good Shepherd, a North American distributor of Black Mountain U.K. sheep's wool insulation at the rate of $20.99/m2 CAD [88] but the cost of fiberglass is only $4.63/m2 CAD [89]. This proves that the price of sheep's wool insulation is four times higher than fiberglass.

Regardless of that, high retail prices are demanded in the markets of United Kingdom, Ireland, Canada, Australia, New Zealand and Europe. It must be mentioned here that suppliers are a part of the sustainability along with value chain and international provision that is provided by the use of recyclable material and provision of safer options provided to the wealthy clients at high prices. Moreover, the supply chain has another member, the sheep producers as they use wool as an internationally traded product in this matter.[91]

Below is an example of sheep's wool insulation material;

Fire	BS 5803-4:1985 Euro Class E
Condensation	BS 5250: 1989
Thermal Conductivity	0.039 W/m°K
Density	19 kg m³

Sheep wool has proved as an efficient insulation material, owing to its natural characteristics and its thermal efficiency. Under the reign of Institute of Technology of Construction Materials and Components to the Construction Faculty, VUT Brno, the research for eco-friendly thermal insulation items is being done that would use natural raw materials. Moreover, the research was boosted by the TU Vienna coalition and it has allowed other possible natural resources to be researched for the purpose of use as insulation materials.
The reason behind this research is to acquire budget friendly, eco-friendly and efficient insulation material that would be used for construction. It was done in order to decide the main characteristic values for thermal and acoustic insulation products acquired for sheep wool along with their nature under different humidity environment. Different calculations were made so that application limits could be decided of the sheep wool insulations and for comparison. The results were used for deciding the fundamental of suitability while these materials are utilized that are eco-friendly and natural.[92]

Being a source of raw material, sheep wool can be easily renewed, recycled and eco-friendly. It comprises of 15% moisture, 10% fat, 60% animal protein fibres, 10% sheep sweat and 5% impurities. The advantages of sheep wool are mentioned below:
-It is recyclable and environment friendly,
-Renewable and clean source of natural material,
-Have no potential health hazard like irritation of skin or mucous membranes and many others.
-Highly hygroscopic that is up to 35% [93].
-No modification is done in matters of loss of elasticity or volume.

-It has self-extinguishing capability but fibres cannot be ignited but char is produced at high temperature.

Used as a source of developing the thermal insulation, sheep wool is intriguing as they have health and environmental characteristics. Additionally, there is a need to discuss the "indoor climate healthiness" for each material and the "thermal and acoustic properties". More studies topics are shortlisted [94] and harmony along with interdisciplinary groups in synergetic studies and health building research must be discussed.

Figure 3.23 : A wall being insulated with sheep's wool insulation.

(http://www.tectonica-online.com/products/1920/insulation_wool_sheep_aislanat/)

Available in the form of rolls of batts or ropes, wool insulation is generally made with different thickness and widths as the developer demands. Normally, lengths of 4000 mm (13 ft 4 in), 5000 mm (16 ft 8 in), 6000 mm (20 ft) and 7200 mm (24 ft), the thickness of 50 mm (2 in) to 100mm (4 in), with widths of 400 mm (16 in) and 600 mm (24 in) are the dimensions of the wool batts. The most commonly used ones are the widths of 16 in and 24 in that is placed between the studs in a stud frame wall. On site, ropes and batts are divided easily and majority of the developers demand their construction to be done in custom sizes.

As compared to the traditional fiberglass insulation, the cost of wool insulation is high; however, it does not need to use protective gloves. Moreover, they reduce health hazards for the installation team and the workers. Its uses are done on roofs, floors, walls of any building with spacious are. It is the same as installing conventional insulation batts and fixed by using staples or friction-fit. In the latter technique, the insulation is cut into bigger sizes in comparison to the space and uses friction to fix it.

Even though, sheep are cleaned on annual basis for good health, they are not used for wool and it is used for designing insulation is the one that is considered waste product by other industries because of their quality. Moreover, it is disposed of after cleaning in the form of controlled of waste product.

Nonetheless, under the act of PAS2050, the energy footprint of washing the wool is caused by the livestock industry and there are some basic characteristics taken under consideration while the source of wool was being tracked down. These sources include the treatment of flock for pesticides, the path between source and destination, and the chemicals for treating wools after shearing. Dipping is defined as the process in which the sheep are mostly treated with fungicide and insecticides that leaves its remnant on the fleece. It can cause contamination after improper use [96]. Even though, they are cleaned when fleece is sheared, by-products like sludge, liquor or grease.

Sheepswool insulation sometimes mixed with borax to ignite the fire retardant and its pest repellent characteristics. Moreover, the first two can be extracted but the last one still has some pesticides that might be a problem for disposal. Even though the scouring baths have a higher load of 8–9% but the level of borax is very low at only 4% dry weight [97]. Borax is being widely considered as a reproductive chemical after it was deemed safe even though its mines use the most efficient techniques [98]. There is research proof that borates have adverse reproductive and developmental effect when used in high amounts for animal’s ingestion.

There is a possibility that wool insulation can cause harm to exposed humans with their dust even though it would not harm anyone other than the workers. There is only one way humans could be exposed and that is inhalation and many companies use pesticides in the form of DE (Diatomaceous Earth). It is a common belief that DE does not harm if digested and animals are fed in case of peristalsis [99].

3.1.3. Innovative insulation materials

The purpose of this research is to provide a comparison of the mentioned material with the ones that are most successful globally. This will be done after this section will be summarized. It is understood that innovative materials are costly as compared to others, they require the same investigation prior to the development and their involvement in the competition of the market is studied. It is our belief that they will rule the consumer's choice even though they might not be as popular at the present moment.

3.1.3.1. Transparent insulation materials

Part of the latest group of materials, transparent or translucent insulation materials or TIMs are highly useful for boosting the effectiveness of the solar thermal conversion mechanisms. It is used for high temperature collectors, as windows, industrial glazings, integrated storage collectors, transparently insulated structures and seasonal heat storage mechanisms. Many materials have been researched on experimental and theoretical grounds.

After examination, it can be concluded that almost 40% of the main energy quota is spent on the production of low temperature thermal energy that is used in heating for commercial areas and dwellings. Other areas include, domestic hot water and low temperature industrial process heat. Moreover, this implies that in Central European Climate, there will be a high success rate for thermal solar energy consumption and production that will prove fruitful for everyone.

Figure 3.24 : Some examples of transparent insulation materials.

(https://www.designingbuildings.co.uk/wiki/Transparent_insulation)

Passive mechanism like windows and greenhouse is used in thermal solar energy and in active fields, suitable collector mechanisms have been developed for domestic hot water and swimming pools. Recently, latest systems such as transparently insulated walls and high efficiency collector mechanisms for process heat have been introduced in the aforementioned fields and areas.

The wavelength difference between the solar radiation and the thermal radiation is the main physical element implemented in all places. Here, the former is absorbed from dark planes and the latter is released by heated absorber. This enables the use of selective cover layers. They are made up of TIM or transparent insulation material that is opaque for thermal radiation and transparent for solar radiation. Consequently, the mechanism works well without a cover and the IR-radiation losses of the heated system are lowered significantly. Others are not that necessary even through other heat loss systems are also available.

Glass pane is the most preferred option for selective cover as it is in accordance with the needs of the system and it is the most uncomplicated type of transparent insulation item. With different physical properties, many TIM materials can be made that will fulfil the different requirements of systems. Even though other features are also important, the amalgamation of low thermal conductivity and solar radiation is most preferred in terms of physical standards. Here, high transmittance can initiate overheating issues in greenhouse and direct light might not be suitable for day lighting uses as compared to scattered light. Another reason why they are used is their affordability no matter how they are used.

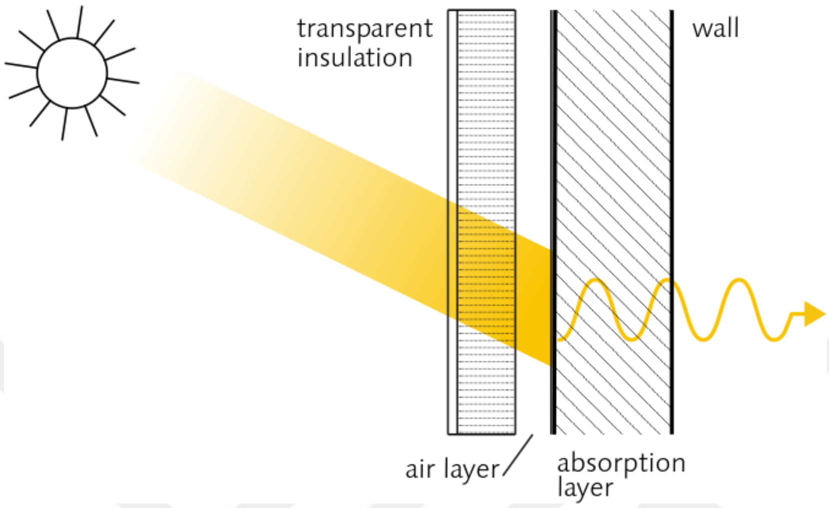


Figure 3.25 : TIM working principle.

(http://www.ecobine.de/print.php?SESSID=5d7092d85d384778d6c3226dcb5d3204&id=2.5.7.1.4&kurs=11&l=en)

The two main features of energy efficiency in a thermal mechanism are the storage of heat for later use and the role of the solar input. The former relies on the thermal insulation of the system i.e. U-value and the latter relies on the transmittance of the cover and the absorptance of the absorber. A high $\tau\alpha$ – product and high irradiation level is necessary for more energy gains and here, α is the absorptance of the absorber plate and τ is the transmittance of the collector cover. On the other hand, the U-value and its effect relies more on the temperature level of the mechanism as compared to its storage times and environment. There are various situations where the TIM has to enhance for systems.

With the air gap of 10 cm in front of the absorber, a glass of 5mm thick pane is installed in the black absorber insulated on the back by the expert. In the next example, the basic properties of this latest TIM will be mentioned. Next, the expert tries to optimize the collector for various purposes by changing the distribution of the glass and he would most likely initiate the process with one glazed collector whose amount will increase. After that, it will be halted when the thermal insulation is improved but the transmittance lowers. Moreover, there is limit to the process of

adding more layers for this mechanism even if the researcher had utilized latest antireflection materials or low-reflective index technology.
The experts have altered the structure in order to solve the reflection issues and the reflection loss is zero when the glass is rotated at 90°C. For non-absorbing and non-scattering materials, the transmittance will be almost 1.0. Nonetheless, it was to be done meticulously and if the structure was loose, the losses would occur because of the convection. To worsen the situation, the thermal radiation would be very low, too. As compared to that, the use of honeycomb structures or capillaries that have large aspect ratio would give low thermal conductance and high transmittance. Consequently, the thermal conductivity of the glass and air would be calculated but the thermal radiation losses would remain the same.

Whenever a question is raised regarding the improvement of the properties and functions of materials, a homogenous distribution of the 5 mm glass is suggested over the total volume of the 10 cm. Aerogel is a material that is close to having perfect properties and it has an open porous nature with a 5% volume of the glass in normal cases. The size of the pore diameter is less than the wavelength of the visible light. Hence, the amount of Rayleigh scattering is very low, the thermal conductivity of the size and the solid state conductivity is negligible owing to the structure of the material as compared to the glass.

The price, long term stability, easy process of manufacturing and efficiency are all very imperative in the matters of implementation. Other than glass, there are many other plastic items that are utilized for the same purposes. Moreover, various gas fillings including vacuum, air holes and a grouping of spectrally selective surfaces is utilized in the majority of real mechanisms. [100]

Table 3.1: Ideal values of transmittance and thermal insulation for an arrangement involving pure glass.

Configuration	1 pane	2 panes	3 panes	honeycomb	aerogel
Diffuse transmittance	0.85	0.77	0.71	0.95	0.77
U-value (W/m^2K)	8	4	2.7	0.8	0.2

a. Generic kinds of transparent materials

Groups should be made even though, there is a variety of different sorts of material and every one of them should be explained using a theoretical mechanism at least once. Factors like environmental risks regarding material construction, fire resistance, mechanical reliance, base items, and the process can be considered for grouping. They are not that rudimentary for fundamental physics and thermal remittance can be used as a physical standard. This implies a distinction between low-emitting and high-emitting materials and it will prove useful while combining materials.

When the materials are combined with spectrally selective absorbers, its importance will be explained. Classification can be done on the basis of optical characteristics. It will be done according to the optical path of an entering beam. For example, diffusing structures are not transparent, that is why it can only save the incidence angle and not show it. Even though the standards might be acceptable in terms of physical properties, on the basis of emittance, a range of materials still exist in extreme situation.

Nonetheless, on the basis of optical behaviour, many mixed types can be seen. The incidence angle for the transmitted beam cannot be preserved by the honeycomb mechanism that is built with plastic material that is not scattered properly. However, they also have a small diffusing feature. It is efficient to group according to geometric style and four types have been presented that have displayed various physical behaviours and mainly mentions real items.

Absorber-parallel (Multiple glazing, plastic films, IR-reflective glass)
Cavity structure (duct plates, foams)
(quasi-) homogeneous (glass fibres, aerogel)
Absorber-vertical (parallel slats, honeycombs, capillaries)

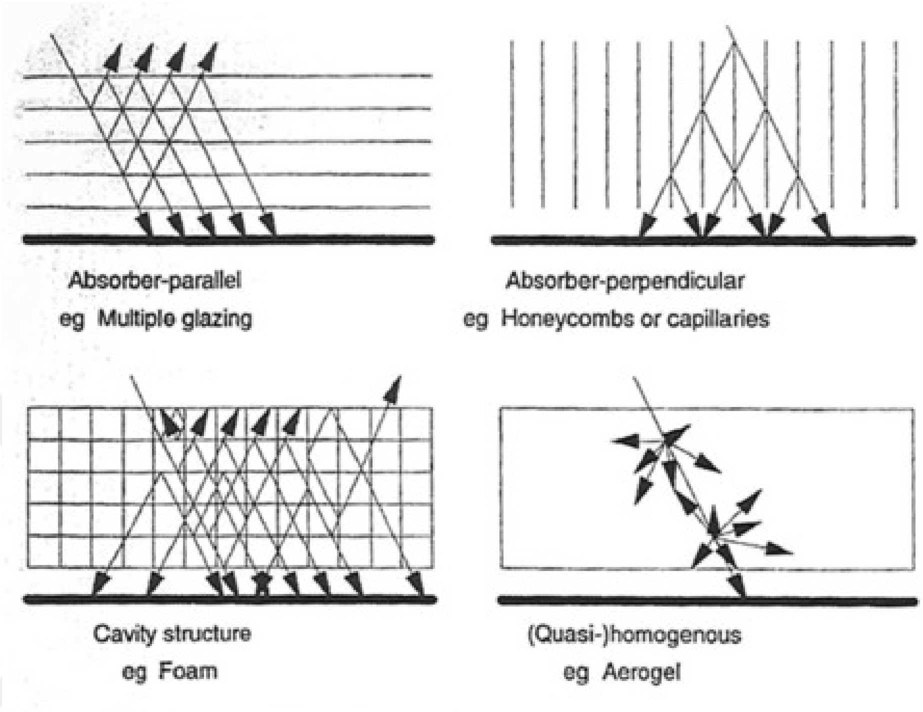


Figure 3.26 : Types of transparent insulation materials.

(http://bigladdersoftware.com/epx/docs/8-0/engineering-reference/page-024.html)

Described as a popular absorber-parallel, the first type has many plastic sheets or glazing that might diffuse. Moreover, many layers cannot be used if there are high optical reflection reductions. Temperatures are decided by the glass panes or plastic sheets, however, one dimensional temperature distribution is not provided because of the convection in the intersectional spaces.

Capillary materials and honeycomb are part of the absorber-vertical structures. They have a variety of slit structures like plastic layers spread inside the collector and cross-sectional geometries. The transmission does not depend on the thickness in the clear sheets that have low extinction. It is plausible that the optical losses would be negligible if the incoming beam is transmitted by the structure walls towards the absorber. After that, little amount of absorption and scattering takes place in the sheets that decreases the transmittance.

Hence, dense items are utilized. Opposite to the first type, the convection for absorber-parallel structures could be repressed when the aspect ratio is selected efficiently and it is generally used. In reality, transparent duct plates or transparent foam with bubble sizes of some millimetres is developed when both of these types are mixed together. Moreover, the multiple sheet cover has the same transmittance as these materials, in terms of optical perspective. In this case, their positive characteristics include their ability to sufficiently repress the convection even though the reflection is a very heavy loss.

Grouped according to the Quasi-homogeneous layers as it is explained before, they are actually inspired by other physical properties like absorption and scattering. In this category, aerogel that is a micro porous “silicate foam" is included and light is scattered inside the material owing to the 100 ‘A’ size of the holes. This phenomenon is called the famous Rayleigh scattering the blue sky. Although, glass fibre materials can be studied using same techniques, homogeneity is not a part of it unlike single fibres.

Theoretical methods sufficiently offer an explanation for rudimentary elements of the items in every four generic type, even though, transition items cannot be grouped like Folded or V-corrugated foils. The cover acts like an absorber-parallel material, if the corrugation angle is not large enough and if that is the case, it plays the role of the absorber-parallel item. Moreover, absorbers are considered while honeycomb structures with cells are produced vertically. It offers a shift between the cavity structure type and absorber-parallel.

Nonetheless, basic types offer an efficient estimation of real items and also an insight into these categories. It is important prior to the construction of more intricate materials. [100]

Made by transparent cellular array that are pressed in an air layer that is also called honeycomb, transparent insulation materials (TIM) belongs to an innovative group of thermal insulation. In this group, the air spaces and empty gaps would lessen the excessive heat losses. Moreover, in the matters of situating the air spaces in the transparent solid media, the layers are same as the traditional insulation items. TIM maximize the solar gain of outdoor thermal energy mechanisms and offer thermal insulation even though, they are solar transparent. They are separated on the basis of heat loss coefficient and solar transmittance. The wavelength difference between IR radiation released by the absorber and the solar radiation received by it is a crucial physical property of TIM. The explanation at [101] offers a status summary on TIM technology and applications.

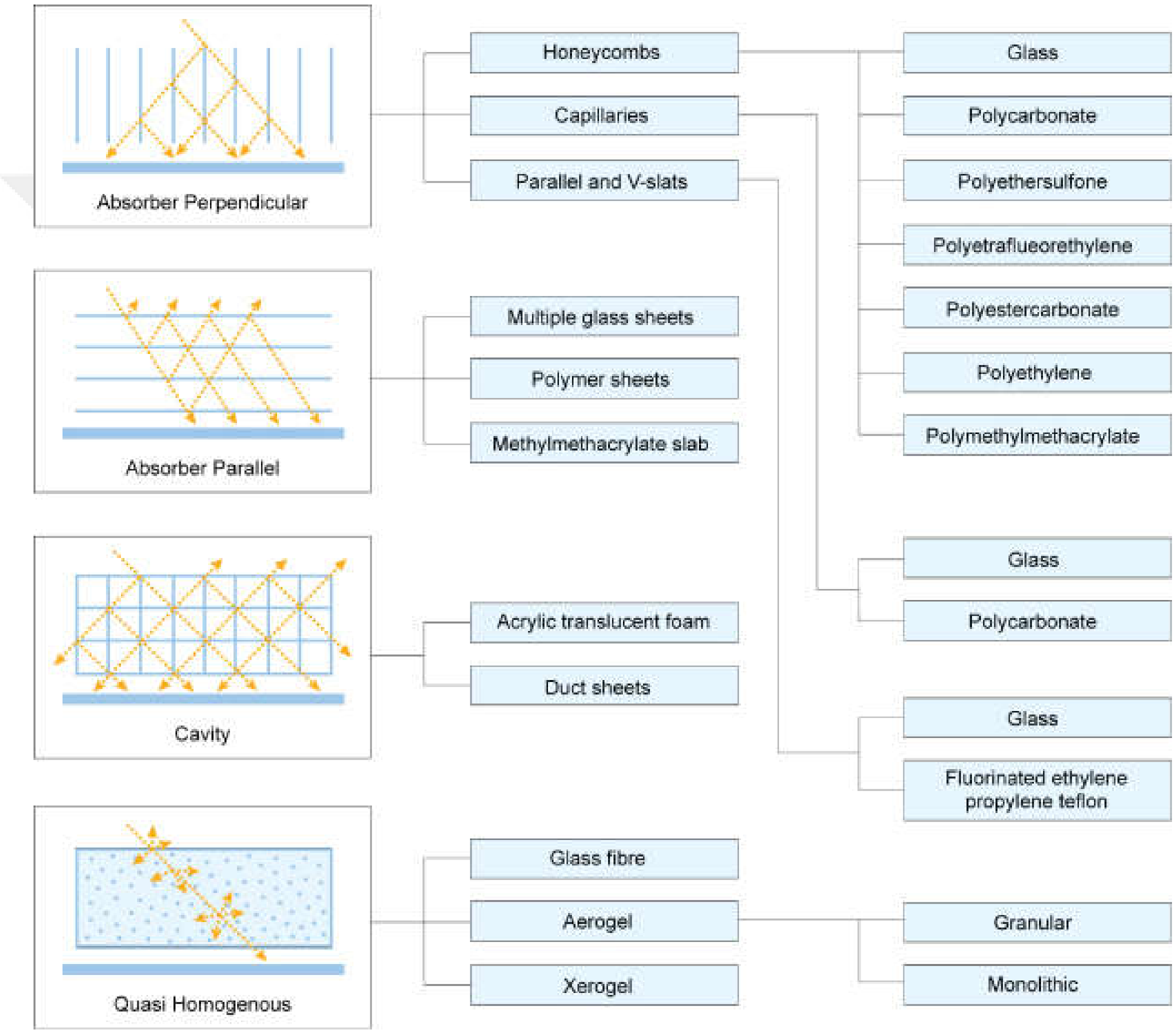


Figure 3.27 : Examples to types of transparent insulation materials.

(https://www.designingbuildings.co.uk/wiki/Transparent_insulation)

b. Background research of history

The efficiency of these anti-radiating cells in medium to high temperature solar energy absorbers was observed by Francia [102]. After that, in matters of solar energy, the role of "deep narrow meshes" in solar absorber as a solar transparent honeycomb insulation was also studied by Veinberg [103]. Extensive explanation of cellular honeycomb arrays was provided by Tabor [104]. This explained how the efficient application of honeycomb insulation can be done in designing methods and, the theoretical properties of a cellular honeycomb as a convection suppression device (CSD) was studied by Hollands [105]. The CSD is situated in between the exterior glass cover of the flat plate collector and the absorber. Later, for the purpose of decreasing the natural convection, extensive theoretical and experimental study has been conducted on honeycomb items. Please refer to the review [106].

Owing to the challenging properties of items and techniques for construction, the use of honeycomb as a convection suppression device in a solar flat plate collector was unsuccessful. Moreover, the present plastic items were insufficient for stringent needs required for working at temperature more than 80 °C and glass honeycomb were not strong enough to be used in solar collectors. For a non-convective solar pond, the concept of using the honeycomb was introduced as a much preferred transparent insulation as opposed to the salt gradient solar pond [107,108,109].

As foretold by the simulation results of the honeycomb solar pond, the solar collection efficiency would be 40–50% at 70–80 °C [110,111]. Additionally, the use of ground like sand or concrete, collector or storage media and water have been studied in the honeycomb solar collector and the transparent honeycomb insulated passive water heating mechanism [112–115]. Moreover, TIM and its uses have also been theoretically and experimentally researched. Among other uses, TIM can be used as a transparently insulated façade element for day lighting in workplace, solar storage, solar hot air sterilizers and cookers, bifacial irradiated solar flat plate collector [116] and solar passive heating of construction sites [117,118–120].

c. Categorization

Categorized according to factors like material, cellular geometry and construction procedure, many categories of TIM have been manufactured. Following is the grouping on the basis of cellular geometry [121]:

1. Absorber-parallel
2. Mixed configuration
3. Absorber-perpendicular
4. Homogeneous
5. Cavity structures

One of the main issues of the absorber-parallel structure is the increased amount of parallel covers in order to minimize the heat loss as it is manufactured with multiple layers of glass or plastic sheets placed parallel to the absorber. This restricts solar gain and solar transmittance. There are many pros of placing the cell walls perpendicular to the absorber plane in an absorber perpendicular structures, including, the forward reflection of solar radiation through vertical walls. This provides the absorber with a large amount of incident radiation. Duct plates and many wall plastic sheets are made by mixed and cavity structures that are a mixture of absorber-parallel and absorbervertical items.

Even though heat losses have lessened considerably, lowered solar transmittance still poses a threat to this mechanism. Suitable for high temperature, TIM of glass fibres and aero gels are some of the homogenous items used [122]. Pore gas conduction, irradiative heat transfers and solid conduction are the three elements of heat transfer in aero gels. TIM has less radiation exposure and absorption as compared to aforementioned items. At high temperature, the thermal conductivity of transparent silica aerogel rises swiftly but it is slow in carbon opacified products [123].

d. Fabrication of Devices

For the purpose of solar heat trap, a transparent slab of methyl methacrylate (MMA) was recommended by Cobble [124] and Cobble et al. [125]. It would play the role of transparent insulation item and for multiple layers of glazing, glass and polymer materials are used. Moreover, Polycarbonate is used for designing sheets with spectral selectivity by Polygal Plastic Industries, Ltd [126]. Also used as absorber parallel TIM, multi-walled plastic sheets have been developed by the General Electric Plastic Industries, Ltd.

Among manufactured items, non transparent reflecting material [127], thin walled plastic-like polyester, for example; polyethylene, FEP Teflon, acrylic etc. and honeycombs of thick-walled glass material of 1–3 mm [102,128] are also constructed. According to many experts, hexagonal; shape of bee honeycomb is the most reasonably priced item made of two-dimensional space and hence, hexagonal cross section was the first preference, after many shapes were researched. Designs like rectangular [129,130], capillaries [131,132], parallel slats [131,133], the hexagonal [134], and square [135,136] were shortlisted. Normally called Perspex, poly methyl methacrylate (PMMA) was used for the manufacture of thick-walled device. It was not difficult and their thickness was 1 mm or less than that at the temperature of approximately 70 °C.

Figure 3.28 : Honeycomb TIM.

(https://www.toppolycarbonatesheet.com/industry-insulation-honeycomb-transparent-panel.html)

The material is divided into slats of size 50 × 10 cm, for the purpose of fabricating the honeycomb modules in the size of 50 × 50 × 10 cm. After that, the slats are made into a square cell of (1 × 1 cm). Materials like FEP Teflon or fluorinated ethylene teraphithlate (FETP), polyester and polycarbonate are utilized to manufacture films for the purpose of fabricating of thin-walled items. Many cross sections like square, circle and hexagonal are used for designing the capillaries and items for product extrusion, in order to construct cellular honeycomb arrays. Nonetheless, there are issues faced regarding glue dispersion when film is used for making these devices.

e. Price Trends

In the matters of inexpensive development of the TIM device, a lot of growth has been seen in the last two decades and it is a noteworthy feature of practical realization of the TIM insulated. A lot of research has been done regarding the thermal and optical characteristics of many plastic items and GE Plastics has started the development of structures items made of lexan material like polycarbonate nature, in the recent years.

The price of these items in India is approximately US$360–400/m2 that acts as a cavity type TIM because of its transparent nature. When in 1990, US$100/m2 is the price of the TIM developed by the ArEl Energy Ltd., Israel. Similarly, the cost of the Tedlar device whose dimensions were 0.03 mm (d) thick, (at) eff of 0.72 and aspect ratio of 5 ($A = L/d$), was US$19/m2. The price of optimized honeycomb covers were presented by Schaefer and Lowrey [111] as $9/m2 and $7/m2 that were made of Mylar and Lexan, respectively.

Moreover, an industrial manufacturing method was provided by the Hollands et al. [138] for the honeycomb device and the prices mentioned above are mere estimations as the quotation presented by the designers are not steady that is in the experimental stage.

f. Categorization of Devices

Increasing the solar heat collection within the device is the main purpose of the TIM device. In this process, heat transfer techniques and solar radiation transmittance systems are used. Selected experimental, computational mechanisms and text calculations provide with the solar transmittance, and heat loss coefficient information. For engineering design, trade-off techniques, these models are made to assist and handle various compelling elements regarding the price of the TIM device.

By using one of the below mentioned modes, cellular device i.e. honeycomb is utilized to transfer heat:

– Conduction and radiation through the solid cellular walls

– Conduction, convection and radiation across the air cell.

The primary phenomena responsible for total heat transport across the honeycomb device are radiation and conduction, since the phenomenon of convection is generally limited. Hot plate apparatus is utilized to measure the total heat transfer across TIM devices [138]. This involves electrically heating the hot plate till 200 °C (Th) while a thermostat is utilized to keep the cold plate at the required temperature (Tc). The sample is kept between the two aforementioned plates. Some authors have also measured the stagnation temperature to analyse the high temperature (80 °C) performance of the honeycomb solar collector [139]. The experiments shed light on the fact that the small-celled polycarbonate honeycomb started melting at 120 °C. However, the highest temperature achieved after the introduction of an air gap between honeycomb device and the observer was 140 °C. Furthermore, the stagnation temperature of a TIM solar collector is estimated to be 250 °C taking into consideration U values of the small-celled TIM device and the solar transmittance.

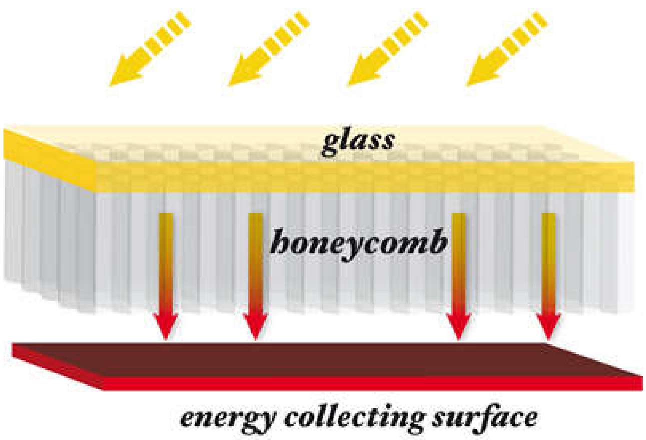


Figure 3.29 : Working principle of honeycomb TIM.

(http://www.tigisolar.com/how-it-works.html)

In opaque walls, employing standard insulation materials minimize the reduction of heat through conduction, convection and radiation [140]. The thickness of insulation materials generally used is found to be 25–30 cm, taking into consideration the regulations and the building codes utilized in various countries [141]. Consequently, the wall achieves thickness of about 50 cm, leading to minimization of letable or occupied space of buildings for a given building foot print [142]. To get around this issue, TIM has been employed which also adds value with thermal conductivity of less than 0.2 W/m2 K and solar energy transmittance of more than 50% [141].

g. Physical Properties of TIMs

The primary applications of thermal solar energy include the conversion of solar radiation ino heat at the absorber. When an energy equilibrium is achieved between the incoming solar energy and the outgoing thermal energy, the temperature of the heated surface reaches a steady state. To suppress the heat losses through convection, a transparent cover, for instance glass pane, can be utilized in the solar collector and the steady state temperature is increased. The fraction of the solar energy absorbed and the portion of the thermal energy given out determines the performance of a TIM-system. The variables influencing this include the intrinsic thermal insulation (U-value), solar transmittance (s) at the cover and the absorptance (a) at the absorber [143].

h. Aerogels

Accounting for more than 30% of the greenhouse gas emissions across various developed nations, edifices emanated 8.3 Gt carbon dioxide in 2005. For the abatement of the greenhouse gas emissions, one of the most cost effective solutions include residential and commercial retrofit insulation [144]. In contrast to that, many buildings were, and still are, being built using traditional insulation materials [145]. However, since these traditional materials are used in multiple and thicker layers, it leads to likely heavier load supporting constructions, complex edifice intricacies and adverse net-to-gross floor area. As it became evident that the utilization of air as an insulator has reached its maximum potential [146], it requires that research must be undertaken to develop more effective solutions regarding thermal insulation materials.

Although their practical applications are only limited to commercial products [147,148–150], vacuum insulation together with aerogels, which was not discovered until early 1930s [151], are one of the novice highly efficient materials available for thermal insulation of buildings [152,153]. For the 29 G$ insulation market around the globe, however, aerogel technologies are of immense importance. This is due to the fact that the market for aerogels around the globe has tripled to 83 M$ in 2008 and is projected to reach about 646 M$ by 2013 [154].

Figure 3.30 : Thin aerogel layers.

(http://www.innovationintextiles.com/aerotherm-aerogel-insulation-brings-space-technology-to-everyday-life/)

Cost reductions have been the primary objective for aerogel manufacturers, through development of novice aerogels and attempting to enter huge commercial markets where the overall growth for aerogels is primarily driven by applications including acoustic and thermal insulation [154].

h.1. Synthesis

Discovered in the early 1930s by Kistler [151], the characteristic feature of aerogels is their dry form along with high porosity [152]. In comparison to xerogels where evaporation is used to dry the wet gels, supercritical drying is utilized to dry aerogels after being synthesized by conventional low-temperature sol–gel chemistry [155,156]. Consequently, the porous structure of the wet stage persists in the dried samples. Typically, aerogels are characterized by low refraction index, high specific surface area and extremely low apparent density [157,158,159]. Moreover, if aerogels are treated with heat and/or aged in a liquid medium, their thermal characteristics undergo structural changes during the synthesis stage. Three typical steps can be delineated when taking into consideration the synthesis of silica (aerogels). These include: sol-gel processes which prepare the gel followed by ageing of the gel in the mother solution to prevent shrinking of the gel during drying and finally, drying the gel under specific circumstances to prevent the collapse of the gel structure. The following equation symbolizes a simplified mechanism for silica aerogel synthesis, i.e. the general kind of aerogels utilized for insulation [160]:

$Si(OCH3)4 + 2H2O \leftrightarrow SiO2 + 4CH3OH$

Dorcheh and Abbasi [161] recently wrote a comprehensive review regarding the synthesis of silica aerogels which should be taken into account for an extensive analysis of aerogel synthesis and the novice developments.

h.2. Gel Preparation

Brinker and Scherer [162] provide an extensive account of the sol-gel process involving the agglomeration of solid nanoparticles suspended in liquid eventually forming a continuous three-dimensional network extending throughout the liquid.

Utilizing a catalyst, generally an acid or base catalysis or even a two-step [163] catalysis, silicon alkoxides are hydrolyzed. The sol-gel transformation occurs when the solid nanoparticles in the liquid bond together forming a network of particles continuing throughout the liquid. The collision of nanoparticles is necessary for the synthesis of the gel since this allows them to stick together. While this is easier for those nanoparticles which are comprised of reactive surface groups that use bonding or electrostatic forces to stick together, other nanoparticles might require an additive for the bonding to happen. Typically, gelation duration is comparatively longer when acid hydrolysis is used since condensation forms linear or weekly branched chains and microporous structures in silica sols [164]. However, base catalysis (i.e. mostly NH4OHbased) usually forms uniform particles easily and results in broader distribution of larger pores, which is less favourable for thermal insulation materials [165]. Although literature lists alkoxides as expensive products resulting in reduced production, sodium silicate (water glass) Na2SiO3 is a cheaper substitute for silica [166]. It is now being utilized as a typical raw material in technical applications for commercial aerogel synthesis which involves acidification of the aqueous sodium silicate solution with, e.g. HCl or H2SO4 to produce silica hydrogel [167,168].

h.3. Ageing

At the end of the last stage, gel point is reached which is signified by the polymer of silica formed inside the container. A considerable amount of unreacted alkoxide groups, however, still remain inside the silica spine of the gel. For the straightening of the silica network, it is crucial that ample time is provided for hydrolysis and condensation to continue occurring which can be further reinforced by maintaining the pH, concentration and water content of the covering solution [169,170,171]. During this process, the characteristic structure of the gel might be influenced by dissolution of smaller particles into larger ones and transference of material to the neck region. Generally, the polymerization of the gel structure is enhanced during ageing since it utilizes ethanol–siloxane mixtures [170], thus adding new monomers to the solid SiO network. Consequently, the gel generated is strengthened and more stiff.

Diffusion also influences the process of ageing since transference of materials is not affected by convection or mixing due to the solid silica network while thickness of the gel itself affects the diffusion process. Consequently, as the thickness of the gel is enhanced, the time span for each processing step also increases and decreases the feasibility of the production of aerogels in turn. Following ageing, the extra water within pores must be removed before drying which is easily undertaken through washing of the gel using ethanol and heptanes [170]. If any liquid is left in the gel, supercritical drying will not be able to remove it, leading to the formation of an aerogel which is characteristically very dense and opaque.

h.4. Drying

For the generation of aerogels, drying is the last and the most significant step. Capillary pressure is the primary phenomenon in drying (except for supercritical drying and freeze-drying), which can result in shrinking and fracturing owing to the small pore sizes and the capillary tention due to that. Consequently, two different methods have been devised to achieve this purpose: 1) supercritical drying (SCD), which involves removal of pore liquid above critical temperature Tcr and pressure Pcr to avoid capillary tension, and 2) ambient pressure drying (APD) which is affected by capillary tention [172].

Supercritical Drying;
For silica aerogels, Supercritical drying (SCD) is the typical method which is most widely used:
"Replacement of the liquid with air is an obvious step for the generation of an aerogel. This involves using any method in which the surface of the liquid is not allowed to recede within the gel. If the temperature of the liquid is raised while simultaneously keeping the pressure greater than the vapour pressure, the transformation of the liquid into the gas phase will occur without the co-existence of the two phases at the same time." [173]

The SCD can be further ramified into high temperature supercritical drying (HTSCD) [224] and low temperature supercritical drying from carbon dioxide (LTSCD) or the Hunt Process [174]. Though it will be delineated to allow for the whole image and to encourage comparison, the method of HTSCD is irrelevant to aerogels for applications in buildings.

The following three steps are important for the successful undertaking of HTSCD: placing the aged gel in an autoclave filled half-way with the same solvent held in the gel's pores. Sealing and heating of the vessel is carried out beyond the solvent's critical temperature and pressure (i.e. most-used organic solvents have a relatively high Tcr or 300–600 K with a Pcr of 30–80 atm [175]). This is followed by isothermal depressurization of the fluid.

The pressure surrounding the autoclave is maintained such that the temperature is lowered to room temperature. Methanol is mostly employed as solvent for HTSCD when silica aerogels are under consideration. At a certain temperature and pressure, combination of which is known as critical point (i.e. Tcr = 512.6 K, Pcr = 79.783 atm [175]), methanol forms CH3O groups over the surface of the gel by reacting with the available OH. The presence of these CH3O groups enhances the hydrophobicity of silica aerogels partially and consequently improves the quality of the HTSCD silica aerogels. Furthermore, shrinkage of the gel has also been made minimal with the HTSCD technique.

Every solvent that can be used in the drying process has a specific pressure at which shrinkage of the aerogels becomes no more than 5% during drying [176]. Both LTSCD [174] and HTSCD are similar processes and consist of three steps. The three steps for LTSCD are given below: the aged gel is placed in an autoclave, and the autoclave is filled with the safer option of non-flammable liquid carbon dioxide (i.e. Tcr = 304.2 K, Pcr = 72.786 atm [175]) at 4–10 C until 100 bar replaces the solvent in the pores of the gel. After all solvents have been replaced, the temperature of autoclave is brought to 313 K while the pressure is maintained at 100 bar. The fluid is then isothermally depressurized. In the final step the autoclave is cooled to room temperature by the help of ambient pressure. The shrinkage in aerogels dried by LTSCD is higher than HTSCD but the reason behind it is the replacement of the original solvent with liquid carbon dioxide and SCD.

Ambient Pressure Drying;

Ambient pressure drying (APD) is a preferable drying technique particularly when costs are a concern. Two steps are involved in the APD procedure: all OH groups are silylated to prevent absorption of water which may result as a consequence of formation of a hydrophobic aerogel. The present solvent is replaced with the combination of a non-aqueous solvent and a silylating agent (e.g. hexamethyldisilazane HMDS) [177], which causes the replacement of H from OH groups by an alkyl such as CH_3. Then ambient pressure evaporation is employed for drying [178] and this step consists of three sub-steps: first the aerogel is kept at a warming temperature, the first drying period is said to be complete when the volume loss of the gel is equal to the evaporated liquid as free water moves continuously to the external surface by capillary forces. In the second drying period or falling rate period, the liquid is allowed to escape slowly to the exterior by diffusive vapour transport.[172]

h.5. Solid Properties of Silica Aerogel

The silica aerogels owe their high potential to the solid material properties they possess. Silica aerogels have cross-linked internal structure made up of SiO_2 chains air-filled pores are present in between in abundance.

This pore-size helps us differentiate aerogel from pure aerogel as it is relatively low. The silica aergels have an average pore diameter between 5 and 70 nm [179], and that of pure aerogels varies between 10 and 100 nm. The value within the range depends on the purity and the fabrication method [180]. These pores may make up 85 to 99.8% of the total aerogel volume. Silica aerogels owe their extraordinary physical, thermal, optical and acoustical properties to their small pore sizes and high porosity. However, these small pore sizes and high porosity causes silica aerogels to have a very low mechanical strength. These aerogels are the lightest solid material known yet. The skeleton density of aerogels is around 2200 kg/m3, but their bulk density is as low as 3 kg/m3 due to the high porosity. The bulk density of aersogels is comparable to the density of air (~1.2 kg/m3) [181]. The overall density of aerogels currently used for building applications ranges between 70–150 kg/m3. Silica aerogels have a high compression strength of up to 3 bar, which gives them remarkable load bearing strength however, they have a very low tensile strength which makes the material rather fragile. Proper hydrophobization is important otherwise contact with water could result in dismantling of an aerogel structure because of the surface tension in the pores [182]. Therefore, generally aerogel is used in combination with a vacuum, so that the envelope prevents the inclusion of water and the vacuum reduces the thermal conductivity furthermore. However, a fibre matrix is incorporated with the commercially available aerogel insulation materials to resolve issues relating to weak tensile properties.

h.6. Thermal Conductivity

The low solid skeleton conductivity, a low gaseous conductivity and a low radiative infrared transmission TIR of aerogels render it to have a very low thermal conductivity total (W/(m K)) [54,183]. The thermal conductivity of aerogels cannot be increased by modifying one or the other factors mentioned above as they are correlated for instance if the infrared absorbance is modified it will in-turn change the solid skeleton conductivity.

Dense silica is known to have high intrinsic solid thermal conductivity of however, in silica aerogels there is only a small fraction of solid silica present. Deadends are present within the inner skeleton structure, which may cause ineffective and long tortuous path of thermal transmittance within a silica aerogel in the ultraviolet, visible and near transport.

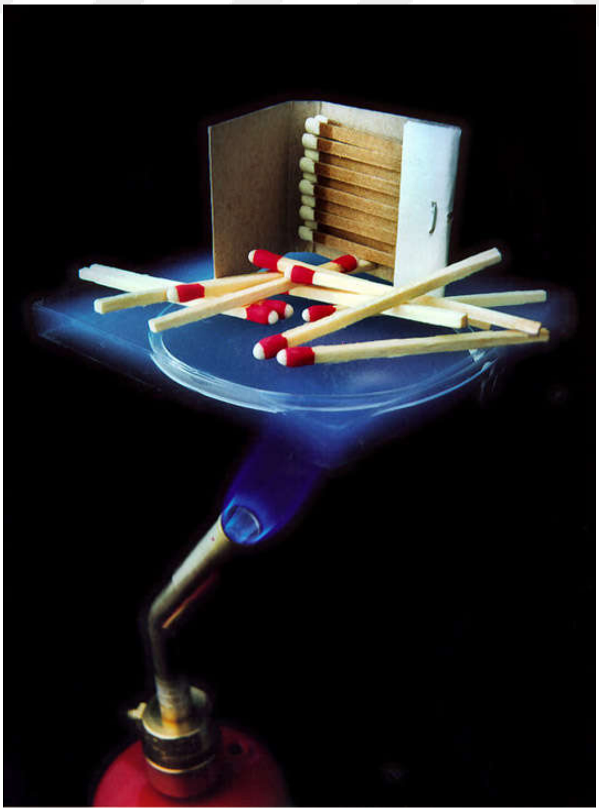


Figure 3.31 : An experiement to find out thermal conductivity of aerogel.

(http://inhabitat.com/exciting-advances-in-insulation-with-aerogel/)

Silica aerogels are known to have an intrinsic low characteristic pore size and a very high porosity, which means the gaseous thermal conductivity will greatly effect the overall thermal conductivity of aerogels, but because of the Knudsen effect it will also be strongly reduced at ambient pressure. Other ways to reduce the gaseous thermal conductivity can be as under

(i) by filling the aerogel with an inert gas (e.g. noble gases),

(ii) by lowering the maximum pore size

(iii) by application of a vacuum on the aerogel.

Hence, if a pressure of 50 mbar or less is applied an overall thermal conductivity of 8 mW/(m K) can be reached for silica aerogels, given there is no other attempts for decreasing the radiation transfer are being carried out [184,185].

Silica aerogels appear transparent in the infrared spectrum. At higher temperatures the radiative transfer will greatly influence thermal conductivity (>200 C). However, it will have no such effect at lower temperatures. Additionally, for reducing the radiative transfer additional component such as carbon black can be added to the aerogel, i.e. before or after the critical drying, for either absorbing or scattering the infrared radiation. The overall thermal conductivity can be lowered to a value of 13.5 mW/ (m K) at ambient pressure and to 4 mW/ (m K) at a pressure of 50 mbar or less following these guidelines.

The thermal conductivity of the most modern commercially available aerogel insulation for building purposes ranges between 13.1 and 13.6 mW/(m K) at ambient temperature [186] and temperature has no effect on it up till 200 C.

Figure 3.32 : An example of aerogel insulation dividing the cold form hot.

(http://www.innovationintextiles.com/aerotherm-aerogel-insulation-brings-space-technology-to-everyday-life/)

h.7. Optical Properties

The optical properties of silica aerogels are rather fascinating. The high transmittance of radiation within the visible light range, which means radiation have a wavelength between 380 and 780 nm. Monolith translucent silica aerogel has a 10 mm thickness and comes as packed bed with a solar transmittance TSOL of 0.88 [187]. If greater transparency is required in aerogels, they must undergo the heat treatment, which can increase is it up to 6% [182], this is done by water desorption and burning of organic components. The parameters of the sol–gel process can be manipulated to modify the optical properties of aerogels; selection of optimal synthesis parameters is one way to achieve that [188].

The colour of the light reflected by (silica) aerogels appears to be bluish and transmitted light appears to reddish in shade. Rayleigh or bulk scattering and exterior surface scattering can be employed to explain this scattering of the light. Rayleigh scattering can be minimized if the particle size is similar to the wavelength of the incident light; this scattering happens because of the interaction between the contaminations in solids, liquids or gases such as dust particles in the atmosphere. If the number of pores within this range is present in aerogels it can act as a 'scattering centres'. There exists a relation between the size of the scattering centres and the extent of scattering, while the magnitude with which the radiation scatters depends on its wavelength. [172]

The transparency of silica aerogels in the infrared spectrum is rather high, i.e. a TIR of 0.85. This transparency has a direct association with thermal conductivity of silica aerogels, especially at higher temperatures. The direct-hemispherical transmission in the visible range can be strongly reduced down to half by adding only a few vol% isopropanol [189] or other opacifiers to the aerogel, when transparency is not required.

h.8. Acoustic Properties

The speed of sound in monolith silica aerogels is lower than in air. Sound velocities as low as 40m/s have been measured [190], however in (non-monolith) commercially available products sound velocity of 100 m/s through the structure is claimed by manufacturers [191]. Granular aerogels are excellent for sound proofing as they reflect any audible sound [192,193]. Using a combination of multiple layers of varying granular sizes, mitigation up to 60 dB can be achieved in the thickness of only 7cm [194].

h.9. Safety Aspects and Fire Behaviour

Aerogel insulation sheets become a victim of dust production. The majority of the commercially available aerogel insulation products are completely made up of amorphous silica, which reduces the exposure to 5 mg/m3 for respirable dust count in the US OSHA. However, the International Agency for Research on Cancer (IARC) has not listed synthetic amorphous silica carcinogenic for humans (i.e. group 3). Epidemiological studies of workers with long-term exposure to synthetic silica have been conducted and no evidence of silicosis has yet been found. Some studies have been carried out on animals and the results suggest that amorphous silica can be completely cleared from the lungs [195,196].

In monolith silica aerogels the SiO_2 structure is treated with a CH_3 to obtain a hydrophobic surface. These are found to be non-flammable and non-reactive. Most commercially products containing silica aerogels have similar properties [197]. Aerogel insulation can also be employed as fire-protecting material [186,197] in place of the PET fibres [198].

h.10. Building Applications of Aerogels

The high thermal performance of silica aerogels makes them preferable over traditional insulation. However, it is not cost effective for certain industries such as the building industry. The aerogel industry is tirelessly working on improving the insulation performance and lowering the costs of production.

Currently, aerogel insulations have three different types of applications in buildings:

(i) Insulation materials which only use the high thermal performance of silica aerogels

(ii) granular aerogel-based translucent insulation materials

(iii) transparent monolithic aerogel.

h.11. Opaque Aerogel Insulation Materials

Aspen Aerogels, Inc. (Northborough, MA, US) is developing an aerogel based insulation material known as Spaceloft® by [192]. Spaceloft® is a flexible aerogel blanket and the thickness available at the moment measures 10 mm and it has a thermal conductivity of 13.1 mW/ (m K) at 273 K, which is at least two folds lower than the traditional thermal insulation materials [187]. Monolith silica aerogels are very fragile, where as Aspen aerogel insulation products are textile-like blankets. The product has an application in wood-frame or steel-frame building envelopes for reduction of the thermal bridges due to studs [199]. As of November 2008 the product is within the price range of 25 $ /m2 or 4000 $/m3. The traditional material insulation costs at least 10 times less for the same thermal resistance. However, when space is an important factor, aerogel is the most preferable option. The aerogel insulation material consists of amorphous silica instead of crystalline silica, which poses lower health risks at exposure. [172]

h.12. Translucent Aerogel Insulation Materials

Aerogel is a unique insulation material due to its translucent or transparent properties [180,200]. The low thermal conductivity and a high transmittance of daylight and solar energy gives it the translucent or transparent properties. This has led to research for the development of highly insulating windows based on granular aerogel and monolithic aerogel, e.g. [201,202].

There are three different high performance thermal insulation solutions designed on the basis of this principle:

i. A system that employs daylight has been developed by application two low-e coatings with an emissivity ε of 0.08 onto the glass panes. A visual directional-hemispherical transmittance TVIS between 0.24 and 0.54 and a total TSOL between 0.33 and 0.45 were achieved, while the complete system had an U-value between 0.44 and 0.56 W/(m2 K).

ii. A sun protecting system has also been developed by application of two low e coatings with an ε of 0.03 onto the glass panes. Here, a TVIS between 0.19 and 0.38 and a TSOL between 0.17 and 0.23 were obtained, while the complete system had a U-value between 0.37 and 0.47 W/(m2 K).

iii. An evacuated solar collector has been proposed, stacking a heat exchanger between a layer of aerogel and a layer of fumed silica and two glass panes. This window is developed in combination with the technology of vacuum glazing by applying a pressure between 1 and 10 mbar. An overall heat loss coefficient Uwindow of 0.66 W/ (m2 K) and a TSOL of more than 0.85 were calculated for an evacuated glazing having the thickness of 13.5 mm, and reduces the noise upto 33 dB [204]. The U-value can be lowered more (0.5 W/ (m2 K)) by increasing the aerogel thickness to 20.0 mm, while the solar transmittance will not be lower than 0.75 [203]. Danish climate conditions are used as the model for window simulations, and an energy saving of 19% with 13.5 mm and 34% with 20 mm have been used replace triple glazed argonfilled glazing for a house built according to the Danish standard and also for a house insulated to the passive house standard. However, scattering becomes apparent when the sunlight directly hits aerogel window; this limits the use of aerogel for north face windows and for daylight components in general. [182]

The aerogel product has a thermal conductivity of 18 mW/(m K) and the fabricator offers skylights with a heat transmittance coefficient between 0.6 W/(m2 K) for layers of 30mm and 0.3 W/(m2 K)for layers of 60 mm Okagel® .The visible light transmission TVIS is 0.40 while there is 52dB sound reduction. [182]

Aerogel is of great interest among other thermal insulating materials as it offers application in highly energy-efficient windows. Silica aerogels are best known for their low thermal conductivity with high solar energy and daylight transmittance. Silica aerogels can be used for space-heating in cold climates by means of passive solar energy through windows, and consequently will reduce the annual energy consumption particularly in the northern European Countries or in highlands [204].

Aerogel gains its physical properties by being a highly porous light material. It has been the centre of attention of researchers for over a decade now in different fields of science and technology. The first aerogel specimens can be traced back to 1920s [205]. It has been produced in Europe (Sweden, Germany), USA, Japan and Russia. Aerogels are manufactured on the basis of silicon dioxide (SiO2, amorphous quartz): which made up of 96% of air and 4% open-poreid structure of silica; which gives it its characteristic of extreme lightness to the material (density is about 50-200 kg/m3). Aerogel has the capacity to absorb IR radiation and has the lowest thermal conductivity among solid materials known yet (~ 0.021 W/ (m K) at 25°C) making it somewhat lighter than air. The starting silica source and the condition of its preparation process greatly influence the optical and thermal properties of aerogel [206-208].

Aerogels can be used various fields such as [209]:

microelectronics, as the dielectric constant of aerogels is lowest amongst all known materials

And the parasitic capacitances are reduced by their use consequently increasing the response speed;

electrical engineering: carbon silica aerogel can be employed as electrodes having large

area for the creation of super high capacitances;

acoustics: having a low sound propagation velocity, aerogel can be used in acoustic devices;

oil and gas pipelines: the oil and gas transport operators can greatly benefit from insulation with aerogel;

space exploration: aerogel is already part of thermal insulation in USA spacecraft; they can also be used in space investigations done by artificial satellites, systems with aerogel are also being studied as they are thought to be able to capture micro particles (micrometeorites, microscopic fragments of comets and asteroids);

heat insulation of buildings: aerogel is a transparent material having unique optical properties, i.e. high light and solar transmittance but, differently from the normally used transparent materials such as glass, it has also exceptional thermal insulation properties; it is also employed as transparent wall in solar collectors and in buildings of offices.

Panes and granules aerogels are commercially available [210,211]. However, glazing systems with monolithic aerogel are not yet produced on a commercial scale [212,213], but during the year 2005 many types of translucent granular aerogel have made their way in the market for daylighting systems [214,215]. The different systems found in the Literature (polycarbonate panels, structural panels, insulated glasses) not only offer remarkable thermal performance, high quality of the diffused light, but are also a source of good solar heat gain and have good sound insulation characteristics [216].

3.1.3.2 Vacuum insulation materials

Heat can pass from one object to another by three modes i.e. radiation, convection and conduction. Convection is not used up from heat transmittance when a vacuum is formed, as now the heat has to be transferred through gas molecules together in large amount. However, the gas's thermal conductivity is not affected by decreasing the pressure to a small amount. This happens because when gas molecules of a container run over each other, the energized molecules are diminished, but when the pressured is lowered extremely down, and then the molecules are farther apart in the container, resulting into decrease in pressure [217].

As the thermal features of conventional insulation components and the VIP's core material are comparable, quite inferior thermal conductivity value i.e. k-value is given to the VIP material in comparison to conventional insulation component. It can be said that the conventional insulation component holds a greater thermal resistance value in terms of breadth per unit. The thermal conductivity value of VIP materials is 0.006-0.008 W/(m-K), whereas it retains the value of 0.004 per W/(m-K) from its middle part, when there is vacuum's gradual loss in some time and thermal bridging takes place i.e. the panel edges are passed over with head conduction [218].

VIP is an abbreviation of Vacuum Insulation Panel and this can help in saving from heat passing away.

Consider an air tight box, and suppose if the temperature of one side of the air is increased, then the air inside the box will also get warm, passing it to the other side of the box by means of conduction or convection processes.
The box will be an empty space upon removing all the air from the box, resulting in the termination of heat transference processes of conduction and convection. It is called hard vacuum but it is near to impossible to make sure that no air molecules are present inside the box, as the box may disintegrate upon this condition.

Have you ever thought why thermos flasks are made of cylindrical shape and never in any other shape? This is because it helps in creating hard vacuum inside the vessel, keeping the liquid inside warm or cold for a long time.

In comparison of vacuum insulation and thermos flasks, the thermos flasks have a strong vacuum i.e. allowing a little amount of convection or conduction processes' presence.

Figure 3.33 : Thermoflask example for VIP.

(http://ffden-2.phys.uaf.edu/webproj/212_spring_2014/Robert_Colles/Robert_Colles/Thermos%20Materials.html)

However, you may ponder that we have not conferred over the last heat transfer process of radiation as radiation occurs in every object no matter of the VIP holds the most absolute vacuum. The internal part of the VIP's panel comprises of a little emissivity surface that doesn't allow heat radiation and this is the mere way of doing it. [219]

a. Significance of vacuum insulation panels

The energy conservation in buildings in the upcoming time will be significant with the vacuum insulation panels, regardless of its present situation.

In contemporary times, the walls are built with the U-value of 0.3 W/m^{2}k in the 100 mm of EPS insulation (Expanded Polystyrene); whereas, in contrast if the 30 mm boards of a VIP is utilised with its U-value of 0.17 W/m^{2}k then it is equivalent to using wool insulation of 270 mm.

The energy conservation could be made greater with the 100 mm of VIP insulation at homes and there will be no need to pay thousands of pounds annually for insulation in our homes. [219]

Below is an example of a VIP product [220].

Board size (mm)	1000 x 1000 1000 x 500
Weight (Kg/m^3)	13 per 60mm approx
Thickness (mm)	60 mm total High density PIR 17 mm Vacuum core 40 mm Rubber crumb base 3 mm
Surface finish	Top: High density PIR Core: Pyrogenic silica vacuum Underside: Rubber granulate
Thermal conductivity (Lambda Value W/mK)	0.009
Compressive strength (N/mm^2)	Min. 0.12

b. Reasons of not utilising vacuum insulations frequently

Price is one of the major reasons for the negligence of vacuum insulation panels. These are more expensive and resultantly become exorbitant for majority of the population with its complicated production procedure. [219]

VIPs (Vacuum Insulation Panels) are found better and more efficient in comparison with the outmoded insulation materials as they have higher capability of insulation by twenty times and are ultra-thin. They conserve space for majority of the electrical items which demands for lower energy loss while heat transference in different materials like refrigerated transportation mechanisms and temperature-controlled packaging. There is a hard and high-porous core component in the VIP, attached with a substance of air-tight outer envelope, slender, vacated from inside and does not allow external gases to enter into the panel. This enables the formation of an excessively greater thermal resistance, enabling thinner insulation in different materials where space is needed the most.

In 1930, the first VIP came into being from permeable material enclosed in rubber. Moreover, in 1960s, the nanostructured materials started to show up. A glass wool core was welded into a steel panel in the 1950s. And, finally in 1900s, the advancement of VIPs was strengthened and the initial/ first VIPs made of precipitated silica were constructed.

People are aware about the VIPs made of precipitated silica from approx. 100 years. In addition, they are utilized for designing appliances for many decades. Now, with the advancement in the material sciences along with elevated attention on the energy effectiveness of buildings, VIP products are being broadly applied in voluminous industries even in those where they are not utilized formerly.

c. Merits

After production, the thermal conductivity of a well-evacuated dry VIP in addition to fumed silica core is approximately 0.004 W/ (m•K). Moreover, at ambient pressure, it is measures around 0.020 W/ (m•K). Through compare and contrast technique, the thermal conductivities of traditional insulation materials typically lie amid 0.030 and 0.040 W/ (m•K).

The benefits and provisions of Vacuum Insulation Panel technology along are as follows [221]:

- Helps to attain extremely low insulation thicknesses (10 mm to 25 mm) that ultimately elevate the volume tendency of applications; however, deficiency of space for insulation thickness is a complicated problem;
- Offer stable, long-term thermal performance if installed properly and endangered from destruction and penetration;
- Assure high performance thermal insulation panel along with a thermal conductivity of 8 to 10 times lower than other traditional insulation materials (3 mW/(m•K)); and
- Provide latest design as well as building potentials.

d. Core materials

A secure and open-porous model is needed by the core materials for VIPs in order to permit evacuation along with possessing adequate compressive strength so as to resist the mechanical pressure load. Core material classes are classified into three models which include porous powders, fibbers, and foams. Each and every model possesses its inherent solid mechanical properties.

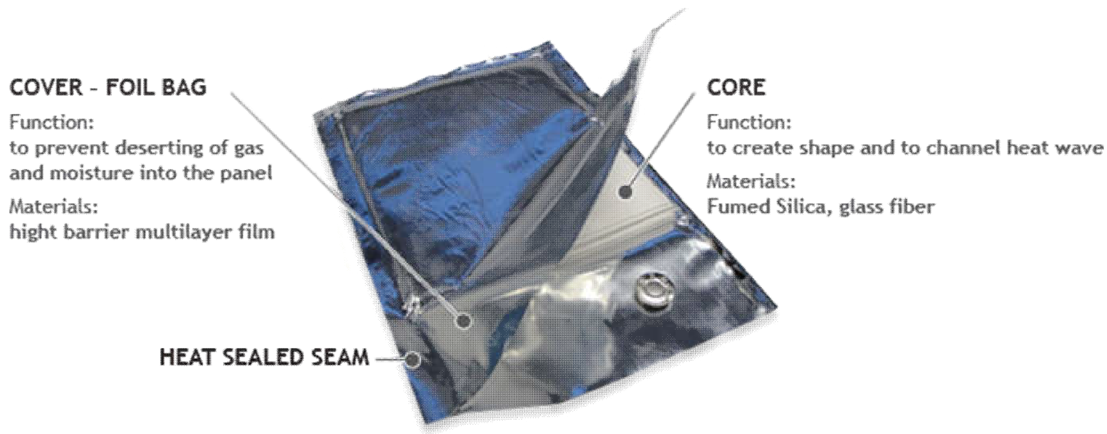


Figure 3.34 : Core material of VIP.

(http://vipa-international.com/vacuum-insulation-panels)

With the motive to resist atmospheric pressure loads, the existing lowest density is unique and the centre of panel (COP) value for the thermal conductivity, relying upon the solid mainstay of the core material. In order to make sure the VIP's finest enactment, the core material should possess minimum possible thermal conductivity. If ideal materials do not have a micro porous structure and capability to absorb humidity, then getters need to be added. Fumed silica and glass fibres are most widespread core materials. And, in very rare situations cell polymer foams; for instance, special polyurethane or polystyre foams, are utilized [221].

e. Envelope materials

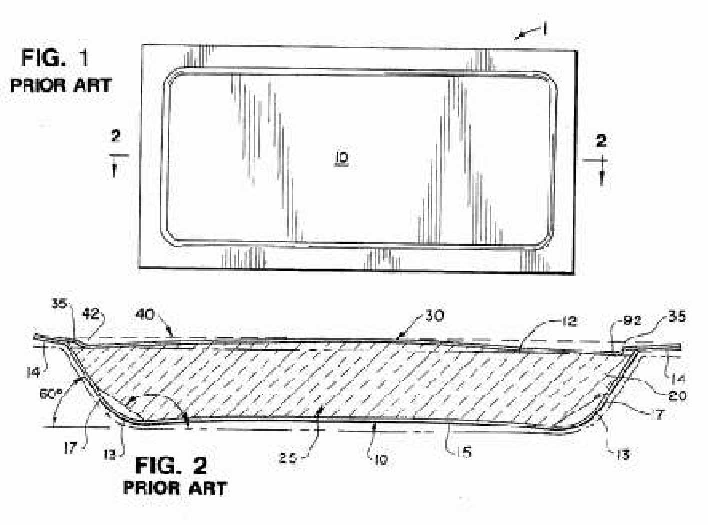
One of the chief factors which affect the assortment of envelope materials for VIPs includes the gas impermeability. The impermeability to water vapour is extremely significant in reference to VIP's life expectancy. Moreover, so as to keep the thermal bridge effect as low as possible as well as the edges of the panels, a low thermal conductivity is needed. The envelope materials should also possess adequate puncture resistance due to the mechanical loads arising during the manufacturing. For flat Vacuum Insulation Panels, the envelope materials utilize for the sake of thermos flasks, termed as stainless steel, aluminium and glass are usually appropriate. In addition to filler materials; for instance, foams and fibres and these are the only materials that help to attain the required maximum gas impermeability, which is needed for reliable merchandises. Aluminium-metallised high barrier plastic laminates, aluminium composite films, stainless steel films or sheets are the utilized by most of the manufacturers so as to provide the VIP envelopes [221].

In the end of the 1990s, with the intention to come up with finest and efficacious insulations, the vacuum insulation panels (VIP) grabbed the attention of construction industry. Their most appealing feature is their relatively low thickness of VIPs (5–50 mm) and their capability to replace traditional insulations of up to 250 mm. The reason behind this is extremely minimum thermal conductivity of the core of VIPs comprising a micro porous material preserved under vacuum through a gas- and moisture-tight barrier envelope. Thin metal or plastic sheets to aluminium-coated multilayered foils and from open-celled PUR (polyurethane) or XPS (extruded polyurethane) to fumed silica that shows the envelope barrier and the core material are utilized in the accomplishment of these two components. Concurrently, for evaluating the thermal conductivity of VIPs, the test methodologies were explained along with exclusive approaches (Smith and Urso, 1999) and round robin tests were also accomplished and stated through guarded hot plate [222].

In a patent research carried out by Bruce E. Lyman and A. Neeser, below explained type of vacuum panel was invented.

In light of FIGS 1 and 2, the known vacuum panels are stereotypically formulated through the welding a pan-shaped base 10 to a flat cover 12 to define an internal space 25. The FIG. 2 demonstrates a cross-section of an acknowledges vacuum panel in which dotted lines denote the panel shape former to the application of a vacuum to the internal space 25 and solid lines represent the panel shape after application of the internal vacuum. In this research, a term "evacuation" 0 denotes the forces because of atmospheric pressure on a panel that possesses evacuated Base 10 is constructed as a generally rectangular bottom surface 15 which encompasses into a smoothly rounded outlying corner within section 13. Wall 17 and an outer flange 14 is an extension of Corner section 13. The shape of Cover 12 is actually a planar sheet and is associated to range 14 possessing base 10 through welding to hermetically seal the panel. Surface 30 is generated from Cover 12 due to which the vacuum panel is merged with a planar target surface (denoted by line 40) that is the surface expected to be attached and cut off by the panel.

Single or multifarious seal off ports (not shown) that are offered on the base or cover helps to attain the application of the internal vacuum. The seal-off port is generally offered in addition to a slot apertures disposed of in a recessed segment of the panel. In order to deal with the molten braze material rows into the slots so as to insulate the panel, Solid braze material is positioned in the recess, contiguous to the apertures. Usually, the whole panel is shifted in a vacuum chamber at that point the panel is isolated after suitable steps have been taken to make sure removal of the internal space. Inside the vacuum chamber, takes place through the utilization of an exclusive radiant heater head developed for limited heating of braze.



Sheet metal builds the base 10 and covers 12 that have a motive to offer a tremendous hurdle to gasses which would migrate into the interior vacuum cavity throughout the life of the panel. 3 mil stainless steel is used in the construction of both the cover and base; nevertheless, carbon steel or other appropriate material can be utilized. For instance, T304L stainless is preferable and specifically designed for the vacuum panel of the invention since it is cost efficient, not gas permeable, readily accessible, formable, possess little out gassing, good corrosion confrontation, low thermal conductivity, and a high melting temperature.

Before base 10 and cover 12 are welded together, a fibreglass mat 20 is archetypal located inside the panel. The motive of glass mat is to provide insulation characteristics along with structural support for the panel walls and it is compressed during the assemblage of the panel. Mat 20 is a combination of a dense glass wool made by Owens Corning Fiberglas, Toledo, Ohio possessing a density in the range of 9.0 to 20.0 pounds per cubic foot. With the intention to offer padding against heat transfer and to keep up the panel walls alongside the forces of atmospheric pressure, the mat 20 is compressed during association of the panel and operations. In general, a lower density glass mat possesses high efficiency as compared to an insulator. In contrast to this, a lower density mat isn't that favourable as it contributes less structural hold to the panel walls. Therefore, so as to attain a given degree of structural support for the panel walls, some insulating efficacy may be sacrificed [223].

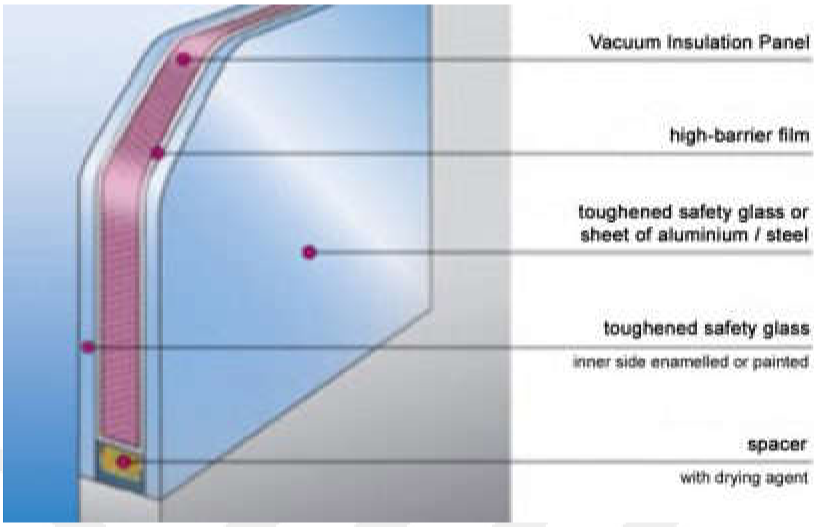


Figure 3.35 : Glazing section with VIP.

(http://www.uniglas.net/technology-fields-of-application-172.html)

Vacuum insulation panels (VIPs) possess a thermal resistance approximately a factor of 10 greater than that of equally thick traditional polystyrene boards [224].

A VIP is an evacuated open permeable material that is located inside a multilayer envelope. The chief elements of a VIP include inner core, barrier envelope and getters, and desiccants. In order to provide security against environmental and handling stresses, the envelope comprises of thick metal sheets or multilayer barrier of metalized polymeric layers. It is mandatory to insert an appropriate getter or a desiccant within the VIP core so as to absorb gasses and water vapours that may penetrate into a VIP via envelope barrier. When it comes to traditional non-vacuum insulation materials, the dominant heat transfer across such materials occurs due to convection in material pores; however, in VIP this mode of heat transfer is suppressed through the construction of a vacuum within the core material. The VIP is divided into two type's i.e. sheet based VIPs and film based VIPs [225]. These are the static VIPs since the vacuum can only be accomplished while construction and can't be recreated with the useful passage of time. Metal sheet envelope is needed by Sheet based VIPs as they possess enhanced load bearing capability and resistant to mechanical damages; however, they tolerate heavier weight and possess thermal bridging effect [226,227].

On the other hand, the cylindrical or spherical thermos flasks tolerate the external atmospheric pressure load of 1 bar. A load-bearing material needs to be put in between the evacuated walls of flat panels with the intention to avoid them from collapsing. There are multifarious diverse types of materials that can be utilized for the purpose of filling material; such as, fibres, powders or foams. Nanostructure porous materials are highly preferable because they are the least sensitive to case pressure is elevated. In light of the eminent thermos flasks, it can be concluded that the stainless steel, aluminium or glass are productive in the form of envelopes of flat components. Nevertheless, special high-barrier covers or polyethylene (PE)-coated Al-foils is extremely beneficial in terms of flexibility in the production process and the manufacturing costs. The durability requirements for building applications can only be fulfilled by the amalgamation of the finest covers with lowest permeation rates and leakage-insensitive nanostructure materials. Envelopes with a factor of 100 more gas-tight are needed by the filling materials with larger pores; for instance, foams or fibres for such applications by using anticipated service life of about 50 years. For the vacuum insulation of white goods or in the production of shipment boxes of pharmaceuticals, less optimal, inexpensive materials may be hired. The gasses penetrating the envelope or degassing from the filling material may be captured by chemisorptions or physisorption. The service life of VIPs is prolonged to some extent. An extra thermal- or pressure sensor is integrated into the VIP to offer the opportunity for quality control of the production process itself and for in-situ tests of the thermal performance of the VIP for the application. [224]

Vacuum insulation panels is an evacuated foil which is compressed and fully permeable material utilized in order to attain efficacious performance thermal insulating material. [228]

f. Vacuum

With the motive to reduce the thermal conductivity of most traditional insulation materials, a vacuum can be utilized; whereas, the gaseous thermal conductivity lag of an evacuated material is the part of the function of the applied pressure as well as the core materials physiognomies. For demonstrating the gaseous thermal conductivity of a porous medium at lower pressure, the number of gas molecules (determined by the particle frequency of the vacuum or the internal pressure) is utilized along with the number of barriers for the gas imminent from the hot to the cold side. The gas conductivity of the non-convective gas remains almost same while reducing the gas pressure in a material until and unless the mean free path of the gas molecules reaches values in the same order of size as the largest pores in the medium. The air molecules will only collide with the pore surfaces without transferring energy by this elastic effect when the pore diameter of the material turns less than the average free length of the path of gas molecules [228].

g. Core

The core material should fulfil different requirements to be suitable for vacuum insulation due to the association amid the gas thermal conductivity of air and the pore diameter, which are as follows:

1- The diameter of the materials should be very small. In order to decline the gas conductivity in insulation materials with large pore sizes, the pressure should be extremely low; however, it is complicated to uphold it through envelopes, which are mainly manufactured of organic materials. Hence, a nanostructure core material in addition with the finest vacuum is preferable in VIPs. The pore size of 10 nm or less is ideal and it will help to decline the gaseous conductivity to zero on at atmospheric conditions as well.

2- It is mandatory for the material to be 100% open cell structure so as to evacuate any gas in the material. There are two other necessities as well because of the particular character of vacuum insulation panels.

3- The material should withstand to compression: The VIPs that are manufactured recently possess an internal pressure in the range of 0.2–3 mbar. In this, the panel bears the pressure load of about 1 bar or 100 kN/m2. In order to make sure that the pores do not fall when the panels are evacuated, the core material should be adequate stable.

4- With the intention to infrared radiation, the material has to be as resistant as probable. For all this, it is mandatory to decrease the radiation transfer within the material in order to attain a very low conductivity value of the panel [228].

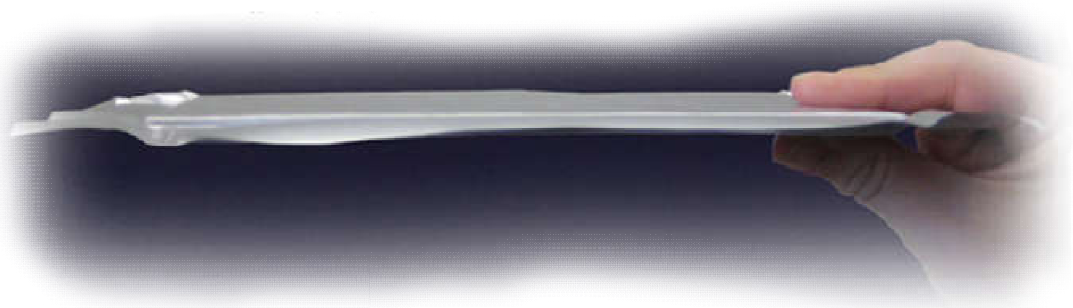


Figure 3.36 : Thinnest known usable insulation material in the market (VIP).
(https://eu.industrial.panasonic.com/products/motors-compressors-pumps/vacuum-insulation/vacuum-insulation-panel-vip)

h. Thermal conductivity of fumed silica

The construction of the material is accountable for the occurrence of the good thermal accomplishments of fumed silica. Due to the Knudsen effect, the free air conduction l g, 0 will be declined in case we consider the narrow maximum pore size in porous silica of 300 nm. The mean free path of air lmean in usual circumstances (23 8C and 1 atm) is 70 nm that shows that the Knudsen effect is applicable and it will decrease the gas conductivity in fumed silica with roughly 40% at ambient pressure. Fumed silica possess an archetypal value P 1/2 of 630 mbar; whereas, a traditional PUR foam has a P1/2 of 2.6 mbar that again demonstrates that fumed silica is extremely appropriate as a core material in VIPs. [228]

i. Fire behaviour

In light of the French Standard NF P 92-510, the powder boards of fumed silica are not at all combustible as matched to ‘non-combustible’ label A1 and it follows the trends of the recent European cataloguing EN 13501-1 and the EN ISO 1182. As stated by DIN 4102, a combustibility label B2 is owned by the VIPs that are commercially obtainable and they are known as the shortest label of non-combustibility, which is commonly approved and implemented under construction applications. [228]

j. Outer envelope

In a VIP, the outer envelope is one of the most significant features and is accountable for sustaining the vacuum in the panel. Multi-layer films that cover the entire element along with the edges are a part of the envelope of VIPs. The aluminium layer is commonly used in these multi-layer films due to extremely minimum gas and water vapour permeation. The heat flux rises at the edges and corners because of the comparatively high thermal conductivity of such sort of envelopes. Keeping all this in mind, the VIP envelope won't be designed from the perspective of gas and water vapour tightness; however, from the perspective to reduce these thermal edge damages. The multilayer films are utilized by the VIP envelopes which comprises of dissimilar layers having an overall thickness of 100–200 mm. now, there are three different kinds of film that are being utilized for VIP envelopes:

* The metal foils are created by covering it with PET layer and inner covering with PE for making it scratch resistant and sealed respectively. Moreover, its central part is covered with the layer of aluminium barrier.
* At minimum, three aluminium coated PET film layers and inner with PE sealing layers are utilised to formulate metallized films.
* However, disparate plastic layers are attached with each other to formulate polymer films and this is the main reason that they endow better permeation rates in comparison to metallized films. Nonetheless, when VIPs are integral part of special getters and its lifetime is not required for many years, then it is only efficient to use. [228]

k. Getters, opacifiers and desiccants

In order to maintain the inner vacuum, getters, desiccants and opacifiers are extremely significant for the service life of the VIPs. And, with the motive to elevate the service life, getters and desiccants are usually mixed up in the VIPs. So, as to prevent the growth of the internal gas and vapour pressure, getters that continuously absorb the gasses and desiccants adsorb water vapour within the VIP core material are utilized. Until and unless the capacity of the getters and desiccants is reached, the inner water vapour pressure and gas pressure remains same as the manufacturing conditions. Therefore, they avert the escalation of the thermal conductivity because of the higher pressure along with incrementing the lifetime of the VIP. There is a probability that the core materials of the VIPs accomplish the purpose of getters and desiccants themselves; however, not each of them. Despite of the fact that they lower the thermal resistance of the VIP and increase the manufacturing costs, it is equally significant to add these chemicals. To make it opaque to infrared as well as to reduce the radiative conductivity to a low level, the opacifiers are added to the fumed silica. Silicon carbide powder is the most widespread opacifier for fumed silica cores. [228]

l. VIP's service life forecast

There are various factors on which the service life of vacuum insulation panels relies upon. According to this description, the first factor revolves around the anticipated description of the service life along with the anticipated needs. In the second factor, as stated by inner gas pressure and water content, the service life that evaluate the increase of the thermal conductivity of the VIP will be affected by the core material. The final and the last vital element is the category and the quality of the VIP envelope revolving around the core as well as the atmospheric circumstances under which the VIP is applied so as to evaluate the increment in the inner gas pressure and water content. [228]

In a VIP, thermal transport arises through solid conduction, gaseous conduction and radiation. The solid conduction is completely reliant on the assembly and material properties of the core. The gas pressure upsurges with time by infusion of atmospheric gases and outgassing of the inner material, controls and manages the gaseous conduction by residual gases. Thermal radiation is reliant upon the construction and optical physiognomies of the core. [229]

m. Solid Conduction

Powder Insulation;

Powders are usually utilized in the form of filling material in vacuum for cryogenic uses. Materials; for instance, perlite or silica are converted into fine granular particles. Because of the randomness of the packed bed structure, it is complicated to define the efficacious solid conductivity. As an alternative, two different models are utilized for determining the two cases. Initially, the archetypal model is referred to a loose simple cubic arrangement of packed spheres. Afterwards, a hexagonal close-packed model is determined. [229]

Foam Insulation;

Due to the low cost and ease of production, foam insulations are most commonly utilized. They are divided into closed-cell and open-cell foams. The former comprises of cell walls so as to trap low thermal conductivity gas inside. Conduction of heat takes place via struts and the cell wall. In order to attain VIP core material for the accomplishment of evacuation, the open-cell foams such as rigid polyurethane are generally utilized. As this researched is only limited to VIP, the open-cell type is reflected. As a consequence, the cell wall effect is not considered. [229]

Fibrous Insulation;

The reason behind the utilization of fibrous materials is its delicate weight along with high temperature sturdiness. According to Fricke et al. [230], the number of parameters; such as, solid conductivity of the fibre material, Young's modulus, porosity, imposed pressure and fibre orientation, control or manage the effective conductivity. The fibres are typically concerned about the main heat flow direction.

Staggered Beam Structure;

The Filling materials of VIPs should possess the capability to resist the compression by means of the external atmospheric pressure and should consume minimum solid conduction. A fundamental model of the fibrous insulation path must be twistingly long. [231]

n. Gaseous Conduction

The motive behind thermal transport in VIPs is residual thin gas in the internal space. Thermal conductivity of gas is not at all reliant on the pressure whenever the gaseous conduction is utilized as continuum. This phenomenon is attained because of inverse relation between pressure and mean free path [231].

o. Radioactive Conductivity

In heat transfer mechanism for VIPs, one of the most significant mechanisms is radiation at low pressure. Through scattering and absorption/emission of the core structure, the radiation from a hot surface is attenuated. In order to explain the radiation heat transfer in thermal insulations structures, two techniques are usually considered as stated by Petrov [232].
The first and the initial technique revolve around the radiative transfer equation (RTE). In case we are aware about the spectral and temperature dependencies of the absorption coefficient and refractive index; so, this can be solved. The second one deals with the usage of diffusion estimation that is considered as the most frequently used methodology. Its merits involve simplicity and ease; however, the application is restricted and is applicable only when it comes to optically thick medium. [233]

3.1.3.3. Gas-filled panels

It is distinguished that gasses like argon and krypton, which have low-conductivity, greatly enhance the energy performance of windows. This is done due to the fact that they have lower gas-phase conductivity as compared to air, thus they slow heat flow through the window.

It has been a lengthy debate for the researchers at Lawrence Berkeley National Laboratory (LBNL) that the same law could be utilized for the development of high-performance building institution, and the technology was developed for the purpose of encapsulating gasses in flexible foil and plastic honeycomb material. Such technology was authorized by LBNL to the radiant barrier maker, Fi-Foil, which presented a gas-filled panel (GFP) insulation material at the International Builders Showin January of this year. [234]

For the purpose of reducing every parameter of heat transfer, Gas-filled panels (GFPs) are utilized which use a gas with low-conductivity as the chief insulator to effect both the gaseous thermal conductivity lg and the thermal conductivity of the solid structure lcd. A core material is no more essential to shift forces as in vacuum insulation due to the reason that the gas is used at ambient pressure. GFPs confine the gas and reduce the shifting of heat caused by radiation with a low emissivity surface baffle structure in a barrier envelope.[228]

The heat transfer having the most significance is the thermal conductivity through the gas. Gases having thermal conductivity less than air are utilized by high performance GFPs. To elaborate this lesser thermal conductivity of a gas, a couple of general rules can be expressed [235]. First of all, a gas having a higher molecular weight will relatively have a lower thermal conductivity. Secondarily, mono-atomic gases for instance, argon, krypton, xenon, will have a lesser thermal conductivity than that of polyatomic gases having identical molecular weight.

This is due to the reason that an excess possible energy shift caused by rotation and resonance of the gas molecules. Superior attention is given to the capacity of GFPs with the inert noble gasses argon, krypton and xenon as a gas-fill since these gasses can be educed from the surroundings and consequently, annihilate the global warming potential.

Figure 3.37 : Gas-filled panel insulation material.

(https://www.buildinggreen.com/news-article/innovative-gas-filled-panel-insulation-fi-foil)

The two kinds of polymer films of which gas-filled panels are comprised of include: A tied assembly known as 'the baffle' utilizes metallized films, resulting in creating a cellular structure in the panel which repress transfer and radiation. A hermetic 'barrier' utilizes low diffusion gas barrier by holding the panels gas-tight. Such panels may be produced as firm or pliant insulation panels subject to the sort of foils utilized for the structure.

The barrier is composed of an air-tightly sealed enclosure for the purpose of conserving the gas-fill and a vital element for the GFPs. The foil will have to serve as being an efficacious bi-directional gas barrier: Humidity and air gases are sent into the panel and the gas-fill is exiled out of the panel. Identical to the envelope foil for vacuum insulation panels will the quality of GFP barriers be measured by the rate of their gas transfer. Nevertheless, due to the definite gas content of the panel, a dissimilarity will be developed for every gas type. GFPs tolerate a gas loss of 0.1 vol%. Amidst this restriction, a number of films and foil configurations are accessible commercially.

Figure 3.38 : General view to GFP.

(https://www.slideshare.net/internationalenergyagency/7-selkowitz)

Every foil of vacuum applications, having really thin aluminium layers like vacuum insulation panels, is in the first group. Polymer barrier resins is the second group which includes ethylene-vinylalcohol, polyvinylidene-chloride and polyvinyl-alcohol [236]. To repress transmission and radiation, the baffles are essential. Creating partitions by developing the baffle from a solid material reduces the convective heat shifting of the gas. Thin sheets are assembled in a three-dimensional form of multiple layers of cavities for the purpose of dividing this gas into partitions. The radiation heat transfer is lessened by utilizing cavity surfaces with low-emissivity, which are low-priced and available in the form of metallized thin polymer films. The layers of the foil and the moulded cavities are chosen to reduce the convection of gas in these cavities, to lessen the conduction of solid and to minimize the expenditure. There is a prime number of layers of baffle [237] to utilize in a GFP with its special thickness, gas-fill and temperature dissimilarity with respect to the expenditure and the thermal performance.

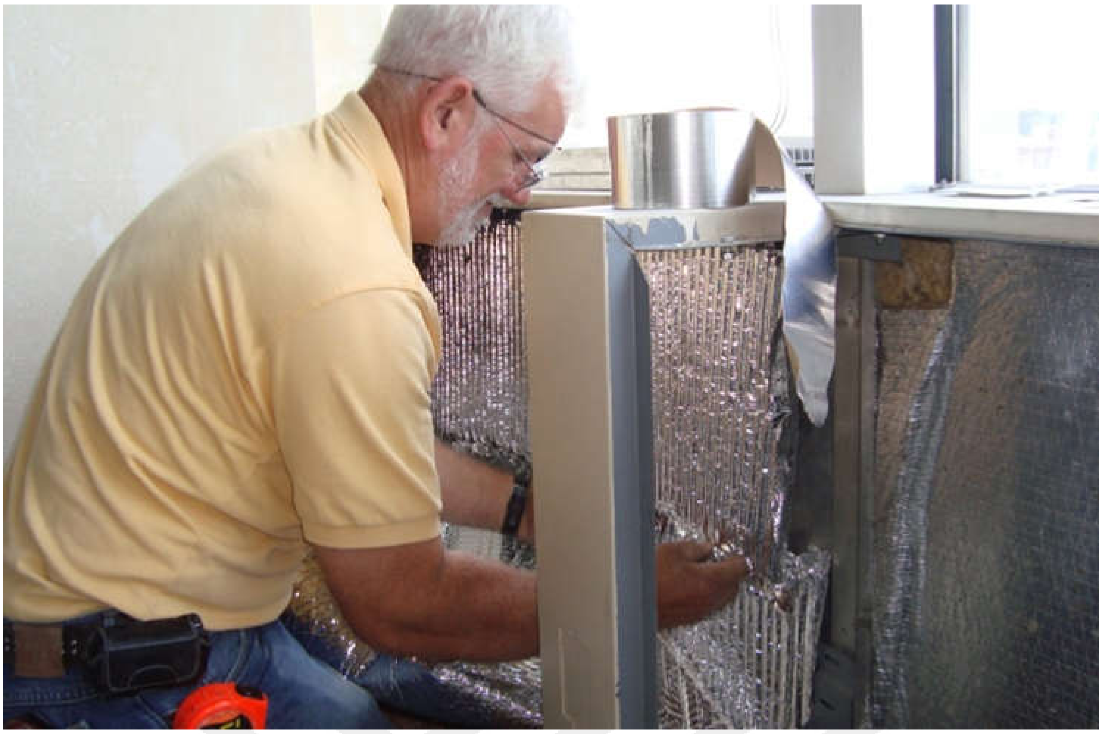


Figure 3.39 : GFP being applied for insulation.

(https://www.buildinggreen.com/news-article/innovative-gas-filled-panel-insulation-fi-foil)

3.1.3.4. Composite insulation materials

For hastening the enhancement of the action of the energy of buildings that are already present, more flexible and versatile ready to use composite materials will be needed. This will result in setting elevated requirements on the mechanical characteristics of materials used for insulation, due to the reason that they will have to participate with different plasters, foils, particle and chip boards, aluminium plates, etc. In that sense, the chief qualities of novelty may be in the creation of incorporated insulation products. This step is also very vital for the feasibility of these types of interventions, remaining forever a sensitive matter, relying on present energy retail prices. [238]

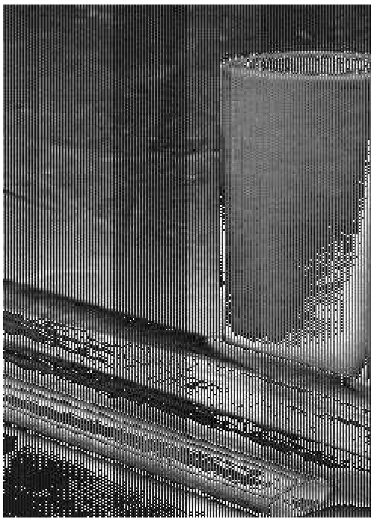


Figure 3.40 : Different combinations of composite materials.

(http://wwyyffan.en.ec21.com/Polyester_Film_Flexible_Composite_Insulation--907103.html)

3.1.3.5. Natural aggregated based insulation materials

These can be defined as small fired clay pellets which enlarge at really high temperatures so they could become light in weight, penetrable and weight-bearing. They can be utilized in fundamentals by turning into both an insulator and aggregate. They possess really good thermal insulation characteristics, yet high embodied energy.[239]

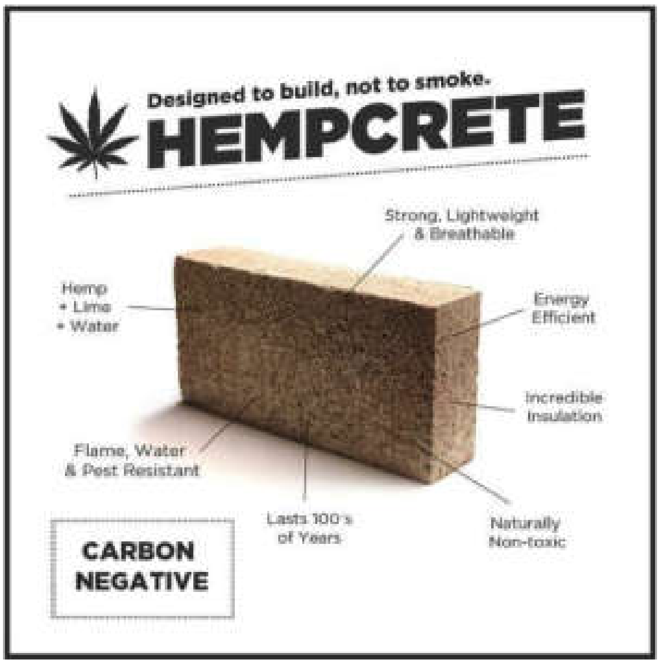


Figure 3.41 : Hempcrete product.

(http://www.ismokemag.co.uk/hempcrete-great-building-material/)

Hempcrete may be elaborated as a mixture of chopped hemp, hydrated lime and a small quantity of either Portland cement or quick-set gypsum, and probably comprises sand or pozzolans. A material really light in weight which still has sensible strength to contract is resulted due to the reaction between lime and hemp. The hempcrete is both structural and insulative, therefore the two ends are attained in the same pour, this is the reason why it is more beneficial than normal cement. It is less in embodied energy too. The drawbacks include a longer set time (2-4 weeks) and the strengths are low. It is simpler to work than traditional lime mixes and serves in regulating the moisture. It deficits the power and brittleness of cement and as a result has no requirement of expansion joints. Its density is lesser as compared to concrete and is vended under names like Hemcrete, Canobiote, Canosmose, and Isochanvre.In circumstances where the high ultimate power of concrete is not required, this option serves well. [240]

Figure 3.42 : An example of hempcrete structure building.

(https://www.420magazine.com/forums/hemp-news/275483-turku-university-study-industrial-hemp-uses-construction.html)

3.1.4. Recyclable insulation materials

3.1.4.1. Cellulose

A superior option for DIYers is cellulose insulation. A higher R-rating and cheapness in price as compared to either blown fiberglass or fiberglass batts are the key benefits to this choice. It's an eco-friendly material made out of recycled newspaper, therefore it's easier on your skin and lungs. And it can be blown, without any problem and with quickness, into odd-shaped spaces in an attic, where access is restricted and dragging up batts is trouble-some.
Almost all home centres vend bagged cellulose insulation, and quite a few give the blower for an only a little amount of fee or without any cost when you purchase a specific number of bags (normally 10 or more). One can also get the blowers on rent from a rental center.

However, rental machines aren't as strong as the truck-mounted units the pros have, they work splendid for a DIYer.

Figure 3.43 : Cellulose insulation material.

(http://www.affordablequalityhomeinsulation.com/cellulose-insulation/)

The values of R amidst blown in insulation of cellulose and fiberglass insulation are identical but the thickness could be different. Typically, blown in cellulose insulation is 2-3 inches thinner as compared to fiberglass insulation when the values of R for both insulations is found out to be identical. Both blown in cellulose insulation and fiberglass insulation give fine performance for the purpose of insulating your home. Nevertheless, without caring of which insulation you prefer, the performance of the insulation is proportional to the quality of workmanship. This happens to be commonly true more so for cellulose insulation than fiberglass insulation. Moreover, cellulose insulation could be the cause of a little corrosion on metal that it gets in contact with yet can also insulate the whole cavity of the wall and flow around wall studs whilst fiberglass insulation may not be the reason of some corrosion but it can not flow around wall stubs because it has to be placed there. Notwithstanding, this is usually not done.

Insulation loses its r value usually when its moist. Only 4% moisture can lessen thermal efficiancy, in that region, even up to 70%. Cellulose insulation fibers are found to be naturally "hygroscopic". This indicates that they are really efficacious when it comes to absorption and reservation of dampness. Moisture difficulties like rot and mildew propagation can result when moisture stays above 20-25% for prolonged time periods. The use of a vapour barrier with both blown in cellulose insulation and fiberglass insulation applications is suggested.

Restraining dampness/water leaks serves as a major element in getting superior outcomes for your home insulation. Allowing inner humidity to escape is also necessary. Dimpled membrane besides blocking water and humidity from entering your home, also let's water and moisture to escape. This twofold action assists in shielding and lengthening the lifespan of both blown in cellulose insulation and fiberglass insulation by allowing your home breathe. Therefore, both of the insulations will keep you free from all dangers. [241]

Figure 3.44 : A wall being insulated with cellulose.

(http://www.platinumsavesenergy.com/services/cellulose-insulation-installation-dayton-ohio)

Essentially, modern cellulose insulation is a chopped newsprint, commonly its treatment is performed with a fire retardant chemical. As it can be observed in the images above, it seems to be a fluffy grey papery material. Wood fragments that have been added to this mix might be the lighter collared chips.

Normally, cellulose insulation is blown-in to building cavities as an insulation retrofit or into attics where it is being added or the places which are physically trouble-some to access. Since or before 1937, cellulose building insulation has been utilized in buildings and remains to be placed in buildings (2008) in the U.S.

Several manufacturers yield cellulose insulation which is a mixture of chopped paper and wood fibbers (sawdust).

As it can be seen above, a magnified look at cellulose insulation will usually display small fragments paper on which one might make out printed characters or partial characters. Or you may observe tiny fragments of paper of various colours. These details can assist in locating cellulose insulation and will differentiate it from almost any other building insulation product.

Figure 3.45 : Cellulose behaviour against fire.

(http://celbar.com/)

a. How to inspect cellulose insulation for defects

One should not cut a large-sized hole to look for blown-in cellulose insulation, it may easily fall out.

It may be easily seen if cellulose insulation has been blown into the walls of the building, if one examines the basement of an older building or crawl space.

Observes at the sills of the buildings above the foundation walls.

Blown-in cellulose is usually allowed to fall onto the top of the sill by the openings in building walls as you can observe in the image located at the right-side.

For the depth of 10-inch,the thermal resistance or heat-loss resistance of cellulose insulation, was found to be 0.635 per square meter. The range of the product heat resistance was from 0.004 to 1.602 $m^2 \cdot K \cdot W^{-1}$ (In terms of thickness). Blown-in cellulose building insulation of the new era has an approximate R-value of 3.70 per inch.

The mighty impact on building heat loss of the degree of care with which any insulating product has been planted is not comprised by such data and most reports of the resistance to heat loss of insulation products.

Drafts which can overwhelm contrarily high “R” values that may be linked with the insulating material might result due to the gaps amid insulating materials and building surfaces. (Think of a well-insulated house in the dead of winter but with a couple of windows open.)

Due to their physical nature, insulating substances lean to fill the cracks and gaps besides a lot of human effort, like blown-in stocks or foamed products, are probable to be a cause of a less number of air leaks and therefore can be anticipated to nurture the economy of heating or cooling a building when equated with construction wherein diligence was not a watchword. [242]

The thermal performance of loose filled cellulose contrasts helpfully to other kinds of inexpensive insulation, but is lower as compared to that of polyurethane and polyisocyanurate foams. Approximately like or a little better than glass wool or rock wool, the thermal conductivity of loose-fill cellulose is about 40 mW/m·K (an R-value of 3.8 per inch). One might not be able to conclude the full picture of thermal performance by this. How finely the building envelope is blocked from air infiltration, convective airflows, and thermal bridging are the other factors one should be considerate about.

Similar to pipes and wirings fitted in a wall, cellulose has expertise in fitting around materials, leaving some air pockets that can lower the entire efficacy of the wall. Walls can be blocked from air infiltration due to dense pack cellulose, whilst delivering the density to restrict convection, albeit planted correctly. The University of Colorado School of Architecture and Planning held a research that contrasted a couple of seemingly alike test structures, the first one insulated with cellulose and the other with fiberglass. The cellulose insulation suffered a loss of 26.4% less heat energy with time compared to the fiberglass insulation. It also was demonstrated that it stiffened the structure more than 30%.[243]

Quite a few grades of paper and/or products based over pulp can be utilized as means for cellulose in the current invention. Illustration of such cellulose sources include newspaper, computer printer paper, writing paper, and chip-board. Of these cellulose means, recovered newsprint and other wood pulp based items that have been retrieved from Waste streams are specifically low in cost, and are therefore preferred. The cellulose is pulverized to decrease its volume to separate fibres or clusters of fibre made from cellulose, rather possessing a normal length of no more than approximately 10 mm. [244]

Specimens of blown cellulose insulation were placed adjacent to water for the purpose of testing to commence an isothermal humidity intake process in which water in liquid form was permitted to go in against gravity into the specimens without any trouble. The apportionment of transient dampness in the specimens was measured with the utilization of the gamma-ray attenuation technique over a time-interval of 10 days. The results produce the signs that, as with most porous systems, firstly the specimens set up a typical water retention curve and then perform a sui generis subordinate procedure of transporting humidity. This letter provides the experimental data from the analysis. The data were utilized for the purpose of obtaining information about the moisture diffusivity of cellulose insulation, linked to the subordinate moisture transport procedure experienced by the trial specimens.[245]

3.1.4.2. Materials Made of Textile Waste

Also an area of great interest is the recycle of items and with potential application is because of the elevated quantity of waste that is generated across the globe in the most different endeavours. Consequently, the assessment of the recycle of items and various kinds of waste in buildings construction is vital [246,247,248].

Figure 3.46 : Textile waste.

(http://www.recycleaid.co.uk/cloth-and-fabric-recycling/waste-clothes-and-fabric-recycling/)

The garbage of the textile industry incorporates the set of recyclable items which can be comprised in the construction of the building and that possess various chances of application. These textile litter may have foundations in the textile industry or may simply be an outcome of clothes that are no more in use. The inspection of the delivery of such kinds of wastes in the construction should be somewhat relative to the performance of the tissues when they are in the form of clothes. Providing a shield to the human body against cold and heat is the basic purpose of dresses, so it could keep thermal comfort conditions. This can be gained guaranteeing a proper heat transfer amidst the human body and the external conditions.

Considering this, studies to evaluate the sensations of heat transfer through the textile fabrics have been evolved. These researches display that their thermal insulation characteristics are really linked to the characteristics and configuration of their parts, namely to the structure of capillary, surface characteristics of yarns and air volume apportionment in the fabrics [249,250,251].

Figure 3.47 : Textile waste insulation material.
(https://ec.europa.eu/easme/en/news/giving-textile-waste-second-lease-life-construction-industry)

As a result, the information of thermal, mechanical and physical performance of a number of kinds of textile fabrics and their remainders is fundamental to maximise its utilization as a crude material in the building construction. [252]

More exploration is required regarding the utilization of dissipates of the textile industry. The work formed thus far is founded substantially on the usage of textile waste in the making of bricks and materials which are light in weight [253-256], more notably using cotton mixed with other materials, like limestone powder, fly ash, barite, and paper. Sound insulation, thermal conductivity, bending strength and radioactivity are a few of the characteristics studied.

An eco-friendly thermal insulation material has been pondered over by Hanifi Binici et. al. which is made out of sunflower stalk, textile waste and stubble fibres in Turkey in concern to the subject of burning agricultural wastes which becomes the reason of polluting the air and the waste usage will deal with both problems and provide to the thermal insulation market. [257]

The production of textile products becomes the reason of a great quantity of wastes, normally inclined into landfill or utilized for the recovery of energy. In the European Union fresh schemes for the recovery of textile garbage are required hastily, due to the reason that just 1.5 of 5.8 Mton are presently recycled [258]. Valverde et al. observed an item produced from artificial textile industry scraps, comprised of polyester and polyurethane. The thermal conductivity of the tested specimens was found to be between 0.041 and 0.053 W/mK. The least value was calculated for the specimen distinguished because it has the density of 396 kg/m3 [259]. The thermal insulation characteristics of materials found using two dissimilar types of acrylic textile dissipates were shown in [260]. The material giving the most superior performance was distinguished by a thermal conductivity of 0.044 W/mK and a density of 440 kg/m3. Innovative insulation panels composed by a couple of exterior dimensions (2.5 mm thick) of polyethylene fibres and an internal one of ground dissipates. Thermal and characteristics of absorbing sounds of sample tested in [261] had recycled PET. RPET was the mat which had only recycled mat. CWP and DWP constituted of 50% respectively of Coring and Dorper wool paper bonded with artificial glue were examined in terms of thermal, acoustical and ambient characteristics in [262]. Two specimens were examined, N7 and N15,dissimilar only for the thickness of the layer in the middle (individually of 7 and 15 mm). The thermal conductivity of the examined specimens was found to be 0.034 for N7 and of 0.039 W/mK for N15. Thermal conductivity was calculated with the help of the Hot Box technique. A few producers functioning in the building section have already acquired the knowledge about the capability of recycled textile items and they are utilizing them to manufacture thermal insulation panels and strong mats for floating floors. The thermal insulation product with the best performance gives a thermal conductivity of 0.0358 W/mK, a water vapour resistance of 2.2 and 80 kg/m3 of density. The same item is distinguished by a sound absorption coefficient above 0.85 for frequencies higher than 500 Hz. As far as the damping characteristics, the dynamic rigidity value of 41 MN/m3 was calculated for a 3.5–4.5 mm thick specimen [263].A few commercialized items constituting of recycled textile fibres hit a specific heat value of 1600 J/kgK [264, 265].

Figure 3.48 : Denim insulation

(https://continuingeducation.bnpmedia.com/courses/bonded-logic-inc/recycled-material-innovations/3/)

We are already aware that India possess a number of textile industries. The textile garbage from such kinds of industries are advantageous in a lot of ways viz. For the production of mattress and car industries. There also exists the kind of waste fibres acquired from industries, microstructure of the tissue sub waste. This textile dissipate can be utilized as thermal insulation for double external walls. The structure of this sub waste is dependent upon the constitution of the thread which might be wool, cotton, acrylic amidst various kinds. The sub waste is, in this case, chiefly acrylic and the particles have a diameter ranging between 8 and 15 μm. Researches were performed on double wall and outcomes were acquired for a time-span of two months i.e April-May, May-June and readings of heat flux (q) and temperature gradient (ΔT) was attained. [266,267]

4. TURKEY'S POSITION IN ENERGY EFFICIENCY COMPARED TO EUROPEAN COUNTRIES

We have explained these materials to get the reader to be aware of materials and have basic knowledge of working through thermal properties of materials. Let's see Turkey's and other countries' position in energy efficiency.

Turkey has used a political view of using as much as energy has been spent. In distribution, with runaways 18% and overall sectors time to time over 50% of energy saving possibilities have been ignored. Very expensive investments were spent to be able to afford energy demand and on the other hand while these runaways continue, external dependence in energy for Turkey has arised to a serious extent. For this reason, the politics which should exist from now on should be "to invest fot energy savings first, to consider the savings via these investments, planning new energy producing facilities". To overcome the foreseen energy trouble is to invest to the savings for the upcoming years.

Industrial and building sectors are the most possible areas for energy efficiency; besides even if there are difference of potential energy efficiency gaining between sectors, industrial sector needs more encouragement as most energy consumption is in that field.

Building sector has higher potential of efficiency. The buildings built before 2000 are consuming energy two times more than todays regulations. There has not been done much till today for the old buildings and the requirments of todays regulations are 30% less efficient than a similar degree-day condition European country. Some important revisions have been made in building regulations. Energy Performance Guide in Buildings has been introduced and labelling guide has been brought in force. Even though current low energy efficient buildings are still waiting to provide potential energy efficiency. 6-7 million buildings are awaiting to be rehabilitated to halfen their energy consumption. The business opportunities in this field is also well known from the results of other countries.

Being the last user sectors industry, building (residence and service), transportation, farming overall consumption in 2010 was over 83.3 m tonnes worth petrol, and in this overall industry has being the most consuming field since 15 years. Because of narrow in economy, in 2008 building sector has become the most energy consuming field by consuming 36% of overall troughout the year. In 2010 the increase of producing in the sector has increased the consumption and arrived to a 37%. Building sector has followed the industry sector with 32%.

Energy efficiency for economists means; the energy consumed to be able to create one unit value-added is named as "Energy Density".

In all countries around the world same level of energy recovery at the same time couldn't have been provided. Different developments hav been recorded due to their politics and developments. All other countries except for an important energy producer Saudi Arabia, even if they show increase som times, 1990-2008 they have shown a decreasing trend in primary energy density. Turkey, in this period as an average in primary energy density, even if it is a small decrease, has shown an important success between 2001-2004 with nearly 3% decrease showing one of the best performance after Russia. In this period, wide education and support in industry and the new regulations for insulation in buildings are thought to be effective in this result.

In May 2007, after Energy Efficienct Laws being brought under force, November 2009 dated document with the topic of "Energy Efficiency, Status and future Planning" has been announced by Electric Works Research General Management. In this document, 15% in industry, 35% in building sector and 15% in transportation sector exists potential of energy savings. Mentioned potential means, even if renewable energy sources were used, instead of producing energy, energy enfficiency measures application will save a lot more energy. If successful steps can be taken in energy efficiency, the demand can be reduced approximately 20% by 2020 (45 m TWP). This amount means more than 2,5 times of the energy demand for produced with local and renewable energy sources and 30 million residential units. [268]

a. Energy Performans Guide in Buildings

Being introduced in 2008, new and old buildings' energy consumption and greenhouse gas emmision's classification, to organise protection of environment, being prepared by taing EU's 2002/91/EC numbered "Directive of Building Energy Performance" as basic "The Energy Performance of Buildings Guide" has been brought in force in 2009 and has been seriously revised in April of 2010. The purpose of Building Energy Performance Guide is; to determine the calculation rules to be able to evaluate the whole building's energy use, classification of the primary energy and carbon dioxide (CO2), determine the minimum energy performance requirements for new and existing buildings which will be refurbished, evaluate usage of renewable energy sources, control heating and cooling systems, organise performance criterias and determine application rules by considering condition of outside climate, requirements of interior areas, local conditions and cost-effectiveness.

According to the Guide, the workout of labelling building energy performance certificate and building energy rating as A,B,C,D,E,F and G to certify energy consumption and greenhouse gas emmisions has been started; increase energy performance of existing buildings and generate energy performance certificate has been aimed to be labelled by the end of 2017. New buildings can not be built lower than Grade C.

The process of regaining potential energy efficiency by improving current conditions can be shortened by financial support. In a lot of country, successful results are obtained by supports in effective amounts and extent in this program.

b. Energy Efficiency in Buildings

In construction field is one of the main sectors from sustainable development point of view; but from area use to take the material out of nature, energy consumption brings negative effect in a wide space to environment and natural sources. In 2010 global construction volume's distribution according to sectors; housing construction takes the first place with a 40% percentage; ground work follows this with 32% and other buildings than housing with 28%. With changing according to the countries' development level it takes place in overall energy use of 25-40% Economic Cooperation and Progress Organisation countries, 45% of buildings in the European

Union. In our country, according to 2010 data 32% of final energy consumption (28,3 m TWP) has became in building and service sector. From the year 1980 energy consumption has been doubled and building sector is involved in this final energy consumption. In building sector enregy consumption, renewable energy sourced from sun, geothermal, wood, plant and animal waste has 21% of the share. Traditionally, more often in rural areas, animal and plant waste used for heating purposes, is used from source of buildings which have density in the sector as 16% and gradually is leaving its place to imported natural gas and coal.

Yet there has not been carried out a research which evaluates building and energy statistics together in Turkey. Statistics about building types, being tracked in accordance with construction and residential permition the number and properties of illegal buildings cannot be exactly known. Last investigation related to this is "Building Counting" made in 2000. In the year 2000, Turkey Statistical Institution has carried out a counting of constructions in the areas which was under the responsability of the councils and being not in the areas but under responsability. According to this building counting, 86% of these are used as housing purposes.
Even it can be observed the energy efficiency activities in buildings after the regulations in 2000 which are stricter, especially in buildings built after the year 2007 has a tendancy of the usage in larger areas.

According to this, buildings having energy consumption rate D or under cannot be designed or constructed. With Building Energy Performance, alongside bringing a limit to energy usage compared to European Union countries having similar climate conditions, thermal trasnmittance values (U-values) being used are still reasonably low.

Being announced in 2008 " Building Energy Performance Guide" has been a new step in increasing energy efficiency in buildings with its new regulations. In April 2010, the guide has been reformed, and obligation of taking energy performance certificates for new buildings has been brought into force in 1st of January 2011. Lowest limit has been specified for energy consumption of new built buildings with Building Energy Performance Guide.

In our country, apart from first climate region, for other climate regions while avarage energy demand is 90-100 kWh/m2-year, in a lot of European Union country this value is aimed to be fairly under 100 kWh/m2-year with standards. This limit value is, 40-60 kWh/m2 in Austria, 51-97 kWh/m2 in Czech Republic, according to climate and altitude primary energy demand in new buildings is 40-65 kWh/m2 and rehabilitation of existing buildings is 80 kWh/m2. Foreseen thermal insulation level or in other words Minimum Thermal Transmittance Values in building compositions are inadequate compared to other country standards, for this reason these values should be increased over time to other countries standards.

	Duvar	Çatı	Zemin	Pencere
İsveç	0,18	0,13	0,15	
Norveç	0,22	0,18	0,18	1,6
Finlandiya	0,25	0,16	0,25	1.8
İngiltere	0,35	0,2	0,25	
Danimarka	0,4	0,25	0,3	
İsviçre	0,3	0,3	0,3	
Fransa	0,36-0,4	0,2-0,25	0,27-0,36	2,6
Almanya	0,3	0,2	0,4	
Çek Cumhuriyeti	0,38	0,3	0,45	
Hollanda	0,37	0,37	0,37	
İtalya	0,46-0,64	0,43-0,6	0,43-0,6	
İspanya	0,66-0,82	0,38-0,45	0,66-0,82	
Türkiye, 3 DG Bölgesi*	0,5	0,25	0,4	2,4

Table 4.1: Min. U values around the world.

It could be said by looking at the table that energy need limit stated for new buildings is not enough. Stockholm city of Sweden which is colder than Erzurum has half as thermal transmittance value as it. Considering these values in new standard revisions can positively effect energy consumptions for upcoming 50 or maybe 100 years in Turkey. Building sector in developed countries, is the primary action field in "Passage Strategies to Low Carbon Economy" because it is eaiser and cost efficient compared to industry and transportation.

EU is aiming to decrease the greenhouse gas emmisions to 20%, take renewable energy share in energy demand to 20% and increase energy efficiency to 20% by the year of 2020. In ths extent, it is foreseen in EU that new built public buildings by 2018 and other buildings by 2020 will have "0" emission.In USA about renewable energy produce, overall energy consumption value being zero, in the extent of Zero Energy Buildings (ZEB) program (Building America) it is being aimed to arrive to zero energy buildings by the year of 2020. It is being thought that this goal would be achieved by the year of 2025.

With expensive renewable electricity produce and cheap saving measures buildings not producing carbon dioxide "0 emission building" consept is whilst a little expensive and competitive goal, though it is not perceived as a fantasy anymore around the world. Construction sector has entered a process which we can say green transformation in almost all the countries to struggle with the climate change. Certificate standards have been generated in this extent. There is many green building standards and certificates being used volunteeringly in the world. Main one of these are GBC (Green Building Challange), LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method). Apart from Certificate system, passive buildings having architectural design to use passive solar energy and heating energy ≤ 15 kWh/m2-year or sustainable buildings are started to be considered in new building design around the world.

In these buildings, special measures are taken which do not increase the cost significantly to provide 0.10 – 0.15 W/m² U-value for walls, roofs and ground by insulating properly according to regional climate condition, 3 layered glass coating and gas filled glass, using ground heat ... etc. These applications are started to be used by private establishments for prestige in Turkey. Yet it is not common and there is no public establishment to lead. The standards need to be increased as other countries as soon as possible and a path should be determined to have "0" emission buildings.

For this reason, the is a need of encourage programs to be able to apply energy efficiency measures more effectively. These encouragements could be various like direct subvention, free or subventional technical help and consulting, granting programs, privileged loans, tax exemption and so on.

In other countries there are lots of encouraging programs kicking about regarding improvement of existing buildings. For example, in Germany, building rehabilitation is being supported since 2001 by kfW, to improve energy performances. For new

buildings and rehabilitations, as it has been arranged in energy saving guide, loans are being provided with "0" interest for first year, up to 75000.
Since 2005 in France, new buildings which suits environmental criteria, area and hot water heaitng , use less energy than standards, use renewable material and energy sources, apply energy saving measures are subjected to an exemption of 15-30 from property tax.

If our country is also appealing to improve the existing building stock which has at least 50% energy saving opportunity, an encouragement mechanism is a must, and improvement price should be put into shape which people can afford.
According to a research carried out by IZODER; with running the encouragement mechanisms noted below, it is assumed and aimed to be reached to a 10 million buildings being insulated by 2023.
To reach to this aim;
to decrease the VAT (KDV in Turkish) to 1% in sales and applications of insulation materials, to eliminate the taxes received when loaning money individually from banks, to provide discounts in sale/purchase tax, property tax, environment cleaning tax, deed fees in building and houses wihch are A,B and C status, to apply the "energy performance certificate" which is stated in the Building Energy Performance Guide effectively until 2023.

According to IZODER's evaluation; if measures taken to inspire investers, uninsulated house amount 16 million will decrease to 5-6 million by 2023. Yearly avarage of 10 billion TL economic loss will be prevented and 10000 people will find the opportunity to work.

Service sector and market of insulation materials are well active in our country. While insulation material per person in America is 1 m^3/person, it is 0,60 m^3/person in Europe. As a result of the Guides insulation market has grown 25%, even though insulation material per person amount is 0,15 m^3/person. Low amount of insulation material consumption compared to Europe explains the energy loss from our buildings and meanwhile shows a sign of potential in job opportunities in this field. [268]

c. Effective Policies in Building Sector

With Integrated Building Design approach by taking necessary measures in design phase, there is a possibility to increase the energy efficiency without extra cost. Methodologies should be developed to provide cooperated design between architect and engineers, this subject should be included in to education system, introduced and applied. Being a sunny country in Turkey, solar energy is commonly used in regions; but not used for heating and cooling purposes. Measures should be taken and encouragments should be given to spread this around.

Special design architectures, thermal insulation beyond standards, integrate the solar energy and below ground heating to the system, utilise the trash and provide regional heating systems with electric... etc. Measures could be taken where public investments are being made in urban revolution.

It is an obligation to rehabilitate old building stock causing very high energy consumption. For this reason, condominium law should be revised, innovative assumptions should be found to create circulating capital fund in councils, public and banks should provide finance for approvement investments, VAT exemption should be provided to used materials, should be investigated by related establishments and a law should be prepared for this topic. [268]

d. Support of Effective Energy Efficiency

Energy regaining potential in current system of industry and building sector can be shortened by improving investments and financial supports. With the Energy Efficiency Law there has been started for the first time a "investment support" program for energy efficiency, that makes it very important. But this program only captures 100 TWP and higher energy consuming industry sector and buildings but there is no investement support concerning especially 16-17 million houses. Energy efficiency supports should be variated and it's yearly volume should be increased according to energy saving amount, applying and reply/pay mechanisms should be easier, faster and burocracy should be lessened which even blocks "ready to use" sources. [268]

As a result in other words;

According to the knowledge above, it is crucial to understand that the position of Turkey in the name of thermal insulation will thoroughly be changed in the future and will arrive to a point at least as near as European countries.

It will then be a responsability of the landlords to get their properties to provide the required U-values in the future. Even if it doesn't seem to look like there is a necessity to change the commonly used materials for Turkey, the thickness of these materials will significantly change when the standards are arised.

It will then be a demand to find an alternative material to reduce the thickness because Turkey is not developing houses using cavity external walls where materials layed loose and provide an insulation layer.

Foreseeing the potential threat for this, it is highly recommended that Turkey should start using innovative insulation materials to keep up with other countries in the meaning of energy efficiency, instead of gradually trying to keep up.

This is not a situation that could be left to the building contracters to decide for the insulation. The standards should clearly state what is to be done and should be monitored whether if it is executed in the construction phase.

Then it is down to the builder to decide which material will be used. Just in this specific moment, it is well clear that, the builder will go for the most economic solution.

It is not easy to individually decide to use innovative materials where the market is encouraging to use conventional ones. So, it should well be the governments goal to hit and even go ahead of European standards in the meaning of energy efficiency. To be able to acheive this, there is already a demand to refurbish existing buildings to provide the existing standards which are way behind other developed countries. A good solution would be to advice innovative insulation materials to the users and support them to finance such materials. This is up to country policies to get the users to choose these materials. With helping the users choose innovative materials, the country will end up saving energy sources which we already are using by buying them from other countries.

It will take a long time to reach to a point where Turkey is equally the same with Europe if the standards do not rise and reach to a level with them. Old and existing buildings should not only be refurbished, they should also be insulated with innovative materials so that we can well get ahead of other countries. World is getting in to a shape where sources are likely to run out and natural environment is likely to get dirty. We should be thinking of next generations and try to leave them a usable world in health.

The only way to provide this is to reduce the usage of sources which produce carbon dioxide and use materials made of natural sources.

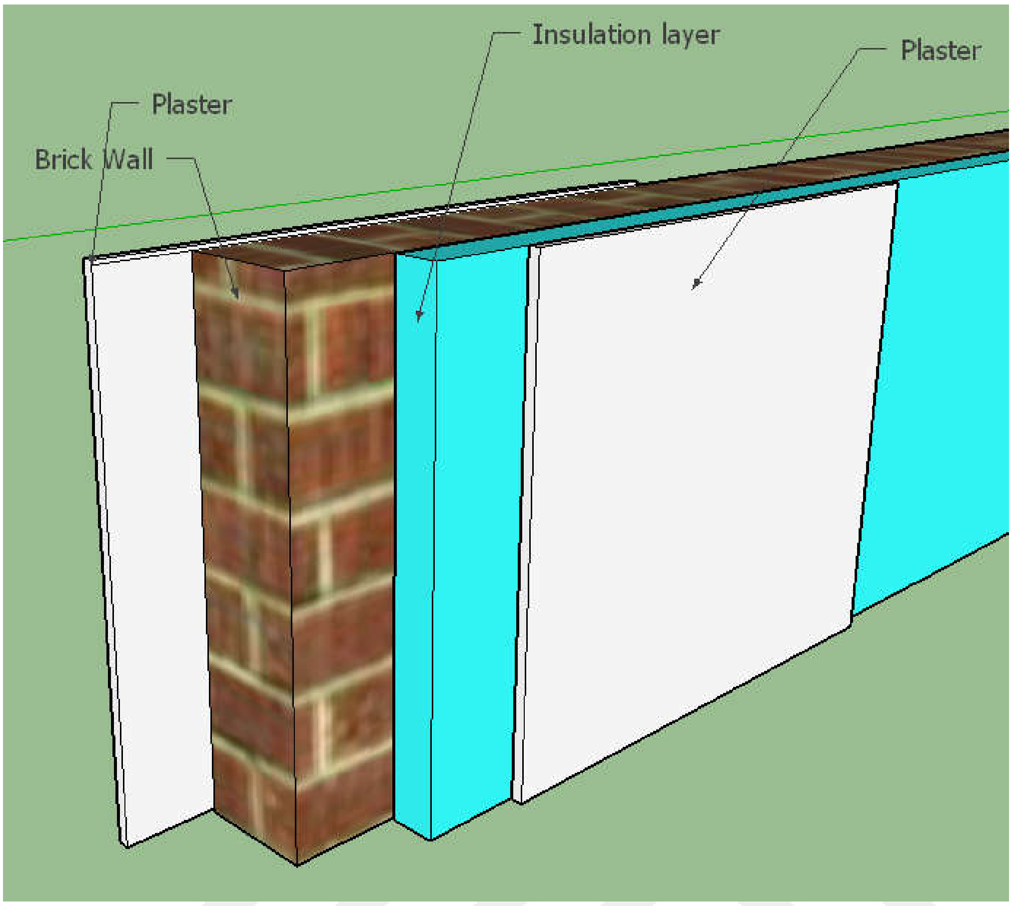
5.SOME NUMERIC EXAMPLES

In this section, few numeric examples will be given to be able to explain how this really works in practice. These examples will contain external wall and window sections. Five different sections have been selected where two of these are windows and three are wall sections. The basic thermal properties are being shared and calculations are carried out to find and compare their U and R values.

Wall sections are thought to be as plaster-wall-insulation-plaster layers which is a common application for Turkey. Other common external walls being used in non-earthquake areas are cavity walls which are basicly plasterboard-block-insulation-brick wall layers being used in order where blockwork support vertical loads and brick wall resists to horizontal (wind) loads, also windposts are being used where necessary.

Glass window sections are thought to be glass-insulation-glass layer which is common application throughout the world. Especially transparent insulation materials are being widely used for this purpose which is aesthetically glomorous and excel at thermal insulation properties.

Three common materials being used in Turkey are XPS, EPS and Rockwool which has been selected to be used in the examples and other two examples are with aerogel (TIM) and vacuum insulation material being used in window sections where glass having almost no thermal insulation ability.
Therefore, TIM and VIP can be compared to Turkey's commonly used materials.



Material	Thickness(d) (cm)	Density(P) (kg/m3)	Thermal Conductivity(k) (W/mK)	Heat Capacity(C) (kcal/kg C)
TraditionalPlaster	3	1750	0.87	0.24
EPS	5	20	0.035	0.36
Brick Wall	25	850	0.22	0.30
TraditionalPlaster	3	1850	1.20	0.25
Gypsum Plaster	0.30	1300	0.35	0.22

Assume external temperature as 0 C and internal temperature as 20 C.
Assume wall area as 50 m². Assume surface convection values do not affect.
Following calculations will be carried out;
- R (thermal resistance of the wall)
- U (thermal transmittance of the wall)
- Q (heat loss from the wall)
- q (heat stored in the wall)

$R = d/\lambda$

$$\sum R = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \frac{d_3}{\lambda_3} + \frac{d_4}{\lambda_4} +$$

$R = 0{,}034 + 1{,}429 + 1{,}136 + 0{,}025 + 0{,}009 = 2{,}633\ m^2K/W$

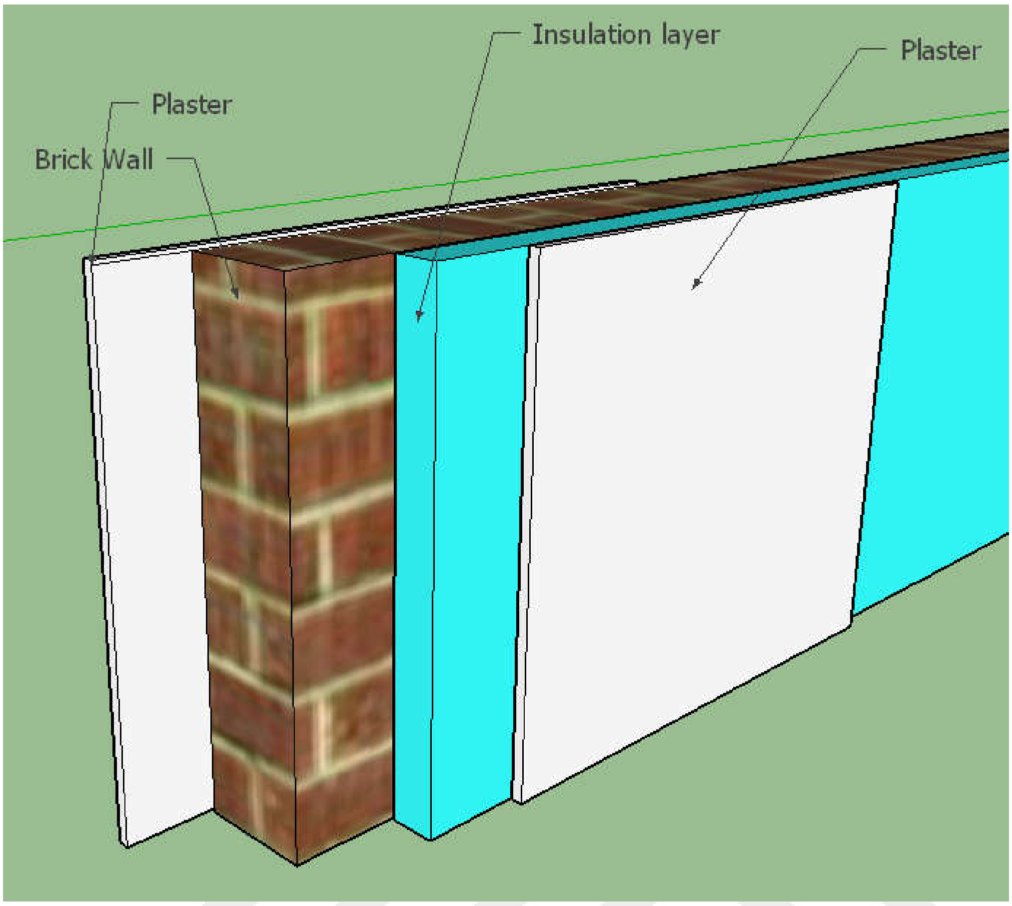
$U = 1/R$

$U = 0{,}380\ W/m^2K$

$$Q = U \times A \times \quad T$$
$$Q = 0{,}380 \times 50 \times 20 = 0{,}380\ kW$$

$$q = m \times C \times \quad T$$
$$q = [50 \times 20(0{,}03 \times 1750 \times 0{,}24 + 0{,}05 \times 20 \times 0{,}36 + 0{,}25 \times 850 \times 0{,}30 + 0{,}03 \times 1850 \times 0{,}25 + 0{,}0030 \times 1300 \times 0{,}22)] \times 1{,}163$$
$$q = [50 \times 20(12{,}6 + 0{,}36 + 63{,}75 + 13{,}875 + 0{,}858)] \times 1{,}163 = 50 \times 20 \times 91{,}443 \times 1{,}163 = 106348{,}21\ W = 106{,}348\ kW$$

$$Total\ Heat\ Loss = Q + q = 0{,}380 + 106{,}348 = 106{,}728\ kW$$



Material	Thickness(d) (cm)	Density(P) (kg/m3)	Thermal Conductivity(k) (W/mK)	Heat Capacity(C) (kcal/kg C)
TraditionalPlaster	3	1750	0.87	0.24
XPS	5	35	0.040	0.36
Brick Wall	25	850	0.22	0.30
TraditionalPlaster	3	1850	1.20	0.25
Gypsum Plaster	0.30	1300	0.35	0.22

Assume external temperature as 0 C and internal temperature as 20 C.
Assume wall area as 50 m². Assume surface convection values do not affect.
Following calculations will be carried out;
- R (thermal resistance of the wall)
- U (thermal transmittance of the wall)
- Q (heat loss from the wall)
- q (heat stored in the wall)

$R = d/\lambda$

$\sum R = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \frac{d_3}{\lambda_3} + \frac{d_4}{\lambda_4} +$

$R = 0{,}034 + 1{,}250 + 1{,}136 + 0{,}025 + 0{,}009 = 2{,}454\ m^2K/W$

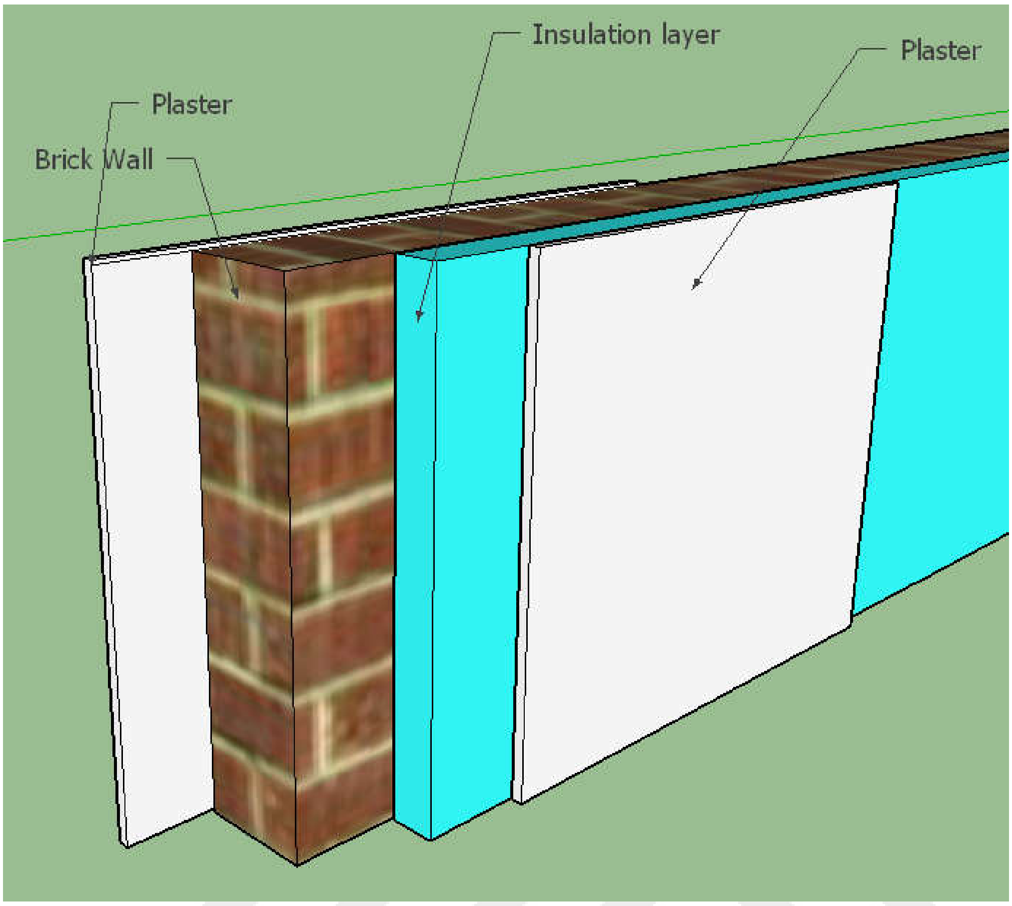
$U = 1/R$

$U = 0{,}407\ W/m^2K$

$$Q = U \times A \times \quad T$$
$$Q = 0{,}407 \times 50 \times 20 = 0{,}407\ kW$$

$$q = m \times C \times \quad T$$
$$q = [50 \times 20(0{,}03 \times 1750 \times 0{,}24 + 0{,}05 \times 35 \times 0{,}036 + 0{,}25 \times 850 \times 0{,}30 + 0{,}03 \times 1850 \times 0{,}25 + 0{,}0030 \times 1300 \times 0{,}22)] \times 1{,}163$$
$$q = [50 \times 20(12{,}6 + 0{,}63 + 63{,}75 + 13{,}875 + 0{,}858)] \times 1{,}163 = 50 \times 20 \times 91{,}713 \times 1{,}163 = 106662{,}219\ W = 106{,}662\ kW$$

$$Total\ Heat\ Loss = Q + q = 0{,}407 + 106{,}662 = 107{,}069\ kW$$



Material	Thickness(d) (cm)	Density(P) (kg/m3)	Thermal Conductivity(k) (W/mK)	Heat Capacity(C) (kcal/kg C)
TraditionalPlaster	3	1750	0.87	0.24
Rock wool	5	90	0.036	0.20
Brick Wall	25	850	0.22	0.30
TraditionalPlaster	3	1850	1.20	0.25
Gypsum Plaster	0.30	1300	0.35	0.22

Assume external temperature as 0 C and internal temperature as 20 C.
Assume wall area as 50 m². Assume surface convection values do not affect.
Following calculations will be carried out;
- R (thermal resistance of the wall)
- U (thermal transmittance of the wall)
- Q (heat loss from the wall)
- q (heat stored in the wall)

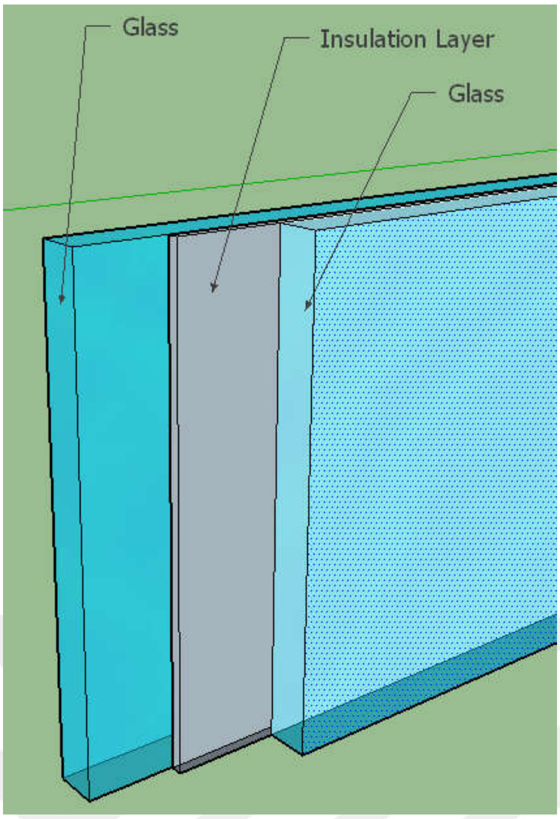
$$R = d/\lambda$$
$$\sum R = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \frac{d_3}{\lambda_3} + \frac{d_4}{\lambda_4} +$$
$$R = 0{,}034 + 1{,}389 + 1{,}136 + 0{,}025 + 0{,}009 = 2{,}593\ m^2K/W$$

$$U = 1/R$$
$$U = 0{,}386\ W/m^2K$$

$$Q = U \times A \times \quad T$$
$$Q = 0{,}386 \times 50 \times 20 = 0{,}386\ kW$$

$$q = m \times C \times \quad T$$
$$q = [50 \times 20(0{,}03 \times 1750 \times 0{,}24 + 0{,}05 \times 90 \times 0{,}20 + 0{,}25 \times 850 \times 0{,}30 + 0{,}03 \times 1850 \times 0{,}25 + 0{,}0030 \times 1300 \times 0{,}22)] \times 1{,}163$$
$$q = [50 \times 20(12{,}6 + 0{,}9 + 63{,}75 + 13{,}875 + 0{,}858)] \times 1{,}163 = 50 \times 20 \times 91{,}983 \times 1{,}163 = 106976{,}229\ W = 106{,}976\ kW$$

$$Total\ Heat\ Loss = Q + q = 0{,}386 + 106{,}976 = 107{,}362\ kW$$



Material	Thickness(d) (cm)	Density(P) (kg/m3)	Thermal Conductivity(k) (W/mK)	Heat Capacity(C) (kcal/kg C)
Glass	1	2500	0.800	0.19
Aerogel	5	150	0.014	0.24
Glass	1	2500	0.800	0.19

Assume external temperature as 0 C and internal temperature as 20 C.
Assume glass wall area as 50 m². Assume surface convection values do not affect.
Following calculations will be carried out;
- R (thermal resistance of the glass wall)
- U (thermal transmittance of the glass wall)
- Q (heat loss from the glass wall)
- q (heat stored in the glass wall)

$R = d/\lambda$

$\sum R = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \frac{d_3}{\lambda_3} + \frac{d_4}{\lambda_4} +$

$R = 0{,}013 + 3{,}571 + 0{,}013 = 3{,}597\ m^2K/W$

$U = 1/R$

$U = 0{,}278\ W/m^2K$

$Q = U \times A \times \ T$

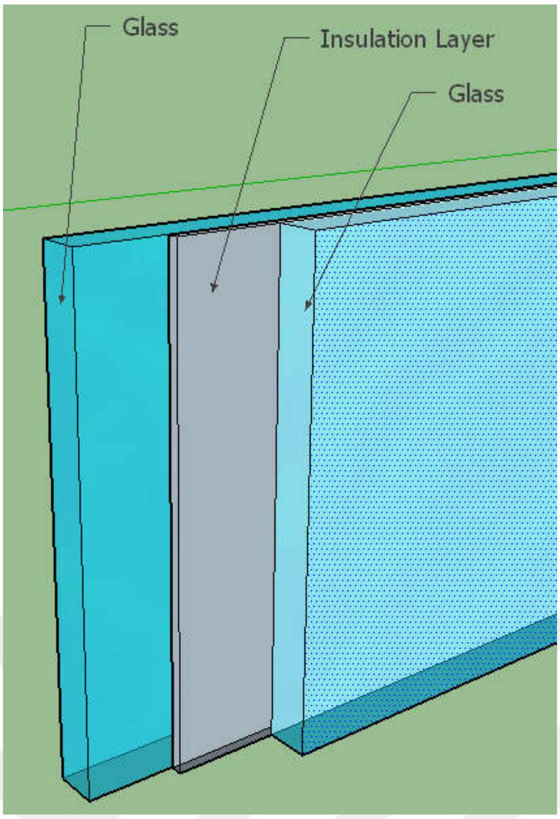
$Q = 0{,}278 \times 50 \times 20 = 0{,}278\ kW$

$q = m \times C \times \quad T$

$q = [50 \times 20(0{,}01 \times 2500 \times 0{,}19 + 0{,}05 \times 150 \times 0{,}24 + 0{,}01 \times 2500 \times 0{,}19)] \times 1{,}163$

$q = [50 \times 20(4{,}75 + 1{,}8 + 4{,}75)] \times 1{,}163 = 50 \times 20 \times 11{,}3 \times 1{,}163 = 13141{,}9\ W = 13{,}141\ kW$

$Total\ Heat\ Loss = Q + q = 0{,}278 + 13{,}141 = 13{,}419\ kW$



Material	Thickness(d) (cm)	Density(P) (kg/m3)	Thermal Conductivity(k) (W/mK)	Heat Capacity(C) (kcal/kg C)
Glass	1	2500	0.800	0.19
Vacuum Panel	5	186	0.004	0.19
Glass	1	2500	0.800	0.19

Assume external temperature as 0 C and internal temperature as 20 C.
Assume glass wall area as 50 m². Assume surface convection values do not affect.
Following calculations will be carried out;
- R (thermal resistance of the glass wall)
- U (thermal transmittance of the glass wall)
- Q (heat loss from the glass wall)
- q (heat stored in the glass wall)

$$R = d/\lambda$$
$$\sum R = \frac{d_1}{\lambda_1} + \frac{d_2}{\lambda_2} + \frac{d_3}{\lambda_3} + \frac{d_4}{\lambda_4} +$$
$$R = 0{,}013 + 12{,}5 + 0{,}013 = 12{,}526\ m^2K/W$$

$$U = 1/R$$
$$U = 0{,}08\ W/m^2K$$

$$Q = U \times A \times \quad T$$
$$Q = 0{,}08 \times 50 \times 20 = 0{,}08\ kW$$

$$q = m \times C \times \quad T$$
$$q = [50 \times 20(0{,}01 \times 2500 \times 0{,}19 + 0{,}05 \times 186 \times 0{,}19 + 0{,}01 \times 2500 \times 0{,}19)] \times 1{,}163$$
$$q = [50 \times 20(4{,}75 + 1{,}767 + 4{,}75)] \times 1{,}163 = 50 \times 20 \times 11{,}267 \times 1{,}163 = 13103{,}5\ W = 13{,}103\ kW$$

$$Total\ Heat\ Loss = Q + q = 0{,}08 + 13{,}103 = 13{,}111\ kW$$

5.1. Results

Same wall sections were used to calculate the thermal properties of a wall and a glass section.

The results are shown below:

EPS

R (Thermal Resistance) = 2,633 m^2K/W

U (Thermal Transmittance) = 0,380 W/m^2K

Q (Total Heat Loss) = 106,348 kW

XPS

R (Thermal Resistance) = 2,454 m^2K/W

U (Thermal Transmittance) = 0,407 W/m^2K

Q (Total Heat Loss) = 107,069 kW

Rock Wool

R (Thermal Resistance) = 2,593 m^2K/W

U (Thermal Transmittance) = 0,386 W/m^2K

Q (Total Heat Loss) = 106,976 kW

Aerogel

R (Thermal Resistance) = 3,597 m^2K/W

U (Thermal Transmittance) = 0,278 W/m^2K

Q (Total Heat Loss) = 13,141 kW

Vacuum Panel

R (Thermal Resistance) = 12526 m^2K/W

U (Thermal Transmittance) = 0,08 W/m^2K

Q (Total Heat Loss) = 13,111 kW

Summary

-As it could be seen from the calculations brick wall provides benefit almost as much as insulation layers. But they store energy and cause energy loss which effects the fuel costs.

- On the other hand XPS, EPS and rockwool are pretty much the same as in values but they are used in different thicknesses practically. For example; EPS and XPS is commonly used in 3-4 cm thick panels where rockwool is 5-6 cm thick. So rockwool would be a better insulator when used in that thickness.

- Therefore, even if there are no bricks to additionally insulate the air, aerogels were 1,5 times better insulation wise than traditional materials at the same thickness.
- Vacuum panels are still very expensive and their life span keeping the same thermal properties is shorter than demanded (30-50 years).

Although they are a unique material with up to 10 times better thermal insulation than traditional materials, they are not commonly used practically.
But it is not hard to see that innovative insulation materials, especially vacuum panels and transparent insulation materials will be the future materials used worldwide where U values requirements are getting less.
Below are some U values required for some countries.

Recommended U-values for building elements in some European countries at April 2007. (Windows 2005)
Units = W / m^2 K Source: www.eurima.org/u-values-in-europe/

	Wall	Roof	Floor	Window
Denmark	0.20	0.15	0.12	1.8
France	0.36	0.20	0.27	2.2
Germany	0.30	0.20	0.40	- - -
Ireland	0.27	0.16	0.25	2.2
Poland	0.30	0.30	0.60	2.6
Spain	0.82	0.45	0.82	- - -
United Kingdom	0.25	0.13	0.20	2.2

6. CONCLUSION AND FUTURE RESEARCH

The literature have been researched for this thesis and lots of knowledge have been involved to define each material and a classification has been derived according to their properties. It is a well known fact that costings are what concerns individuals at each stage. The contracter worries about the construction cost from the beginning, after on the house buyer cares about the costs of fuel, which states they will be happy with an energy efficient building. It is just the balance needed to be minded in this unique criteria where contracter should be aware of importance of thermal comfort and energy savings both for the environment and the people. House buyers should be aware of paying a little more will save energy on total and contribute the environment by helping it to be kept safe from fuel gas and toxic.

This is our planet and it is very important to deliver a healthy environment to next generations. Sustainability is the term which should enter each of the construction whether it is a simple house or a complex skyscrapper. Even if it seems to be money which is the most important thing, environment should be the key point to be minded.

Blasting from this point, thermal insulation materials are being subject to new researches and new developments each day, and traditional and non recyclable materials are being tryed to be replaced with innovative and other insulation materials.

Yet there is still lots to improve as it has been clearly mentioned throuhgout this study, two materials are likely to dominate the market within upcoming years in accordance with researches on their field. First are transparent insulation materials and the other are vacuum insulation panels.

These two material types are being mentioned under innovative insulation materials and they are way effective than traditional insulation materials widely being used at the present.

a. Aerogel

In past several years, aerogel has taken the place of the most durable and supple thermal insulation component and it also acts as a good substitute of present contemporary building insulation components and endows with several advantages of thermal conductivity lesser than that of conventional wool component (a vigorous large quantity material) with around 2-2.5 times lower conductivity. The production of aerogel can provide with a better substitute when produced for a small fraction of economy and atmospheric cost. Aerogels are more considerable components with its certain characteristics like energy saving greater ratio in skylights and upcoming windows, as these are a bit crystalline material or may be some sort of transparent.

b. Vacuum Panel

Yet having uncertanties in some properties, vacuum insulation panels with 10 times lower thermal conductivities are surely the next generation of thermal insulation materials. Like any other technological unit, it is a demand to invent smaller and thinner but more effective solutions. Just as in vacuum panels, this problem is likely to be tackled where it is still very expensive even if it saves room or expenses. Service life of vacuum insulation panels are the other concern within vacuum panels. Core material is likely to lose its properties after 30-50 years which will surely be sorted in the upcoming couple years thanks to the researchers.

Future researches should be carried out in gas-filled panels and composite materials which are also promising inventions. Gas-filled panels are started to be used and ongoing researches are hopeful of positive results. They are also light and thin solutions.

Composite materials are being researched and yet needs a lot of research, though with developing technology and chemistry, different materials are being combined and being tryed in various fields just as in this field as well.

Not being popular at the present, with discovering more and more, these are the state of art materials which are likely to dominate the market with abnormal low thermal conductivies.

Denim insulation and textile waste insulation are being choosed in decoration purposes from inside in some examples. They will be more used with educated people selecting recyclable units in each field. These materials are environment friendly and are giving enough results. These sort of materials should be cheaper to contribute the environment. Government might help providers to supply such products to provide a healthy environment in the future. With a knowledge of healthier world, these products are also likely to be commonly used in the field alongside with plant and animal-based materials.

All in all, this study was to outline the innovative insulation materials and to represent their useful ways to create an awareness where traditional materials are likely not to be used in the future with being non-recyclable. Global warming and cooling is another reason to change our view of using traditional materials. Another aim of this research was to introduce Turkey's position in energy efficiency and to advice solutions and recommend the usage of innovative insulation materials.

Future research could be carried out in this field by comparing the costings to region to region and figure out the redeem times of each material to prove such materials could be used even if it doesn't seem to be cost effective at the moment.
Further research could be carried out to figure how often these materials are being selected and the increase in years could be observed and could be compared to the traditional materials in the base of costings, applications and technology.

Another research area could be carried out for a whole building as like an EPC being prepared and evaluated on the basis of costs being compared to different countries as to improve the aspect of energy efficiency especially in our country.

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APPENDICES

APPENDIX A: Complete Table of Insulation and Other Building Materials

APPENDIX A

Complete Table of Insulation & Other Building Material Properties - Alphabetical Order								
Insulation or other Building Material [9]	**R-Value**[1]	**Density**[2]	**Perm**[3]	**Absorption**[4]	**Flame Spread** [5]	**Smoke**[6]	**Toxicity**[7]	**Aging Effects & Comments**
Air gap or air film, 3/4" air space insulating properties	0.87							The R=0.87 value Does not consider internal convection effects. Does not consider presence / absence of reflective barriers. Does not consider directions of heat flow uip or down nor winter/summer conditions. Also note that there are differences for inside vs outside air films. For all of these air space R-values also see Masonry citations below. For a 3/4" air gap or air space

Air film, inside surface, still air, no reflective surface, directions vary: horizontal, vertical, up, or down	0.61 - 0.92							Heat flow direction: up, no reflective surfaces, R=0.75 (Summer) or R=0.87 (Winter) Heat flow direction: up, one reflective surface, R=2.22 (Summer) or R=2.21 (Winter) Heat flow direction: down, no reflective surfaces, R=0.85 (Summer) or R=1.02 (Winter) Heat flow direction: down, one reflective surface, R=3.29 (Summer) or R=3.59 (Winter) Heat flow direction: horizontal, no reflective surfce, R= 0.84 (Summer) or R=1.01 (Winter) Heat flow direction: horizontal, one reflective surfce, R= 3.24 (Summer) or R=3.46 (Winter)
Air film, inside surface, still air, + reflective surface or barrier, directions vary: horizontal, vertical, up, or down	1.32 - 4.55							
Air film, outside surface, any direction, any position, 15 mph wind in winter	0.17							
Air film, outside surface, any direction, any position, 7.5 mph wind in summer	0.25							
Air, exterior film on walls	0.17							Presumes no wind or air movement
Air, interior film on walls	0.68							Presumes no air movement
Dead air space in wall	0.97							Presumes no convection air movement

cavity, 3/4" to 4" (winter)								Convection movements reducing R-values are more likely in wider dead air spaces and are virtually certain if there are leaks or penetrations at wall top and bottom.
Air Krete®[26] also see Concrete, Insulating, below	3.9	2.07 lbs/cuFt	0.1457 in/sec coefficient, or 0.3407 in/sec flow rate at 68 degF H2O		0	0	no	Cementious foam insulation, fireproof, non-toxic, non-shrinking, also used for acoustical sound proofing; MgO cement (Magnesium Oxide); 6 mil poly vapor barrier required
Asbestos, corrugated paper pipe insulation	1.4							Estimated R-value of asbestos insulation per inch for pipe insulation corrugated paper. Asbestos lagging and paste will have a lower value
Asbestos cement board R-value	0.25							www.msu.edu
Asbestos loose packed fibers / powder								Thermal conductivity k = 0.15
Asbestos cement shingle siding	0.03							

Notes on the R-value & K-values of different forms of asbestos:

Rosato (ASBESTOS INSULATION) is the most authoritative source on asbestos properties and gives data for the thermal conductivity of asbestos in different forms and with varying temperatures. For magnesia-asbestos insulation at mean temperatures ranging from 100°F to 400°F the K-value (thermal conductivity, BTU in. per hr per sq.ft. per °F) ranged from 0.35 to 0.46.

Details about the insulating, heat, and other properties of asbestos are at ASBESTOS PROPERTIES

Current sources of asbestos R-values such as engineeringtoolbox provide very inconsistent data: Thermal conductivity k = 0.744 for "cement board", k=0.14 for asbestos millboard, and k= 1.66 for asbestos cement sheets; but the same source puts asbestos cement k = 2.07 and for loosely-packed asbestos k=0.15 - this is very inconsistent data -

source: engineeringtoolbox.com retrieved 3/23/2014.								
Balsam Wool insulation	2 - 3.5							Spills out of wall or roof insulation if facing is cut
Brick, common	0.2							BRICK LINED WALLS BRICK VENEER WALL AIR LEAKS BRICK WALL INSULATION RETROFIT
Brick facing, 1"	0.11							
Building Paper, asphalt impregnated felt, 15# permeable	0.06							
Building paper, red rosin paper	0.06							
Cardboard as insulation	3 - 4							
Ceiling Panels, suspended or drop ceilings	0.4 - 6							varies widely by material CEILINGS, DROP or SUSPENDED PANEL

Cellulose Insulation R-Values by type								
Cellulose insulation loose fill	3.1 - 3.8	2.2-3.0	High	5-20%	15-40	0-45	CO	0-20% settlement, corrodes metal, mold resistant Or R 3.13 - 3.70
Cellulose insulation, spray-on (wet spray)	2.8 - 3.5							
Cementious Foam	0.35 - 0.69							
Cement asbestos wall shingles	0.03							
Concrete Insulating R-values by type (Also see "Masonry Materials R-Values" below)								
Concrete, air entrained	3.90							
Air Krete®[26] also ThermalKrete and similar air-entraned MgO Products	3.90	2.07 lbs/cuFt	0.1457 in/sec coefficient, or 0.3407 in/sec flow rate at 68 degF H2O		0	0	no	Cementious foam insulation, fireproof, non-toxic, non-shrinking, also used for acoustical sound proofing; MgO cement (Magnesium Oxide); 6 mil poly vapor barrier required See CONCRETE INSULATION, light-weight
Concrete, uninsulated	0.08 - 0.3125							Typical residential weight concrete 8" wall = R 2.5
Concrete, sand &	0.13 - 0.64							8" thick concrete slab or foundation wall has an

gravel aggregate								R-value of about 1.04 while lightweight aggregate filled 8" thick concrete has an R-value of about 2.18
Concrete-insulated	0.85 - 1.2	12-88	Varies	Varies	0	0	0	Insulated forms available
Concrete block, 4-inch hollow core	1.11							
Concrete block, 8-inch hollow core	1.04 - 2.18, commonly 1.04							
Concrete block, 12-inch hollow core	1.90							
Concrete block, lightweight 8-inch	2.2							
Carpeting with fiber padding	2.08							
Carpeting with foam padding	1.23							Typical low-pile carpeting with foam or rubber carpet padding
Cotton Insulation R-Values by type								
Insulation or other Building Material [9]	**R-Value**[1]	**Density**[2]	**Perm**[3]	**Absorption**[4]	**Flame Spread** [5]	**Smoke**[6]	**Toxicity**[7]	**Aging Effects & Comments**
Cotton insulation	0.5	.25-10						

Cotton Batts	3.7							"blue jean" insulation batts fireproofed with boric acid
Dirt or Soil	0.25 - 1 0.80 typical at 20% moisture							Depends on soil properties: density, moisture content, moisture movement
Drywall, 1/2-inch	0.45							
Drywall, 3/4-inch	0.56							
Fiberboard insulating boards - per inch	2.8							Questionable data, Some sources claim 2.64
Fiberboard 1/2" intermediate density, per inch	2.44							Questionable; Divide this per inch numberby 2 to obtain the R-value for 1/2" medium density fiberboard = R 1.22
Fiberboard insulating sheathing, regular density, per inch	2.64							Questionable; Divide this per inch number by 2 to obtain the R-value for 1/2" regular density fiberboard = R 1.32
Fiberboard insulating sheathing, 25/32" thick, regular density, per inch	2.64							Questionable; 25/32" Board = R 2.06
Fiberboard nail base insulating board, 1/2-inch	1.14							Highly questionable HARDBOARD

Fiberglass Insulation R-Values by type								
Insulation or other Building Material [9]	**R-Value**[1]	**Density**[2]	**Perm**[3]	**Absorption**[4]	**Flame Spread** [5]	**Smoke**[6]	**Toxicity**[7]	**Aging Effects & Comments**
Fiberglass chopped, loose fill	2.5 - 3.7							
Fiberglass chopped/blown insulation	3.6 - 4.4		100					6" = about R-22. Installers say expanding fiberglass assists in sealing air leaks
Fiberglass batt insulation	3.1 - 4.3	.6 - 1.2	100	1%	15-20	0-20	Fumes from paper, binders	May collect debris/allergens/mold 3-3 1/2" thick fiberglass insulation = R 11 5 1/4" - 6 1/2" thick fiberglass = R 19 6-7" thick fiberglass = R22 8 1/2 - 9" thick fiberglass = R30 12" thick fiberglass = R38
Fiberglass, batts, high density	3.6 - 5							
Fiberglass panel, rigid (fiberglass "boards")	2.5							e.g. used in HVAC ductwork or air handlers.
Fiberglass, spray-on	3.7 - 2.9							
Flooring, hardwood, 3/4" thick, per inch:	1.10							3/4" hardwood flooring = R 0.68 presuming no air leakage
Flooring,	0.05							Applies to Asphalt/asbestos floor tiles, linoleum,

sheet resilient floors, linoleum, or tiles								vinyl, rubber floor tiles, per inch.
Glass, insulating properties & R or U Values								
Insulation or other Building Material [9]	**R-Value**[1]	**Density**[2]	**Perm**[3]	**Absorption**[4]	**Flame Spread**[5]	**Smoke**[6]	**Toxicity**[7]	**Aging Effects & Comments**
Glass single glazing Note double glazed glass U-values in Comments at right	0.14							**U-Values for Glass & Glazing** Single pane glass, Winter U = 1.10 Single pane glass, Summer U = 1.04 **Insulated Glass, double pane U=Values** 3/16" Air Space, Winter U = 0.62 [30] 3/16" Air Space, Summer U = 0.65 1/4" Air Space, Winter U = 0.58 1/4" Air Space, Summer U = 0.61 1/2" Air Space, Winter U = 0.49 1/2" Air Space, Summer U = 0.56 Note that the larger air space has a reduced U-value, probably because of convection currents within the sealed thermopane or insulated glass panel.
Glass, triple-glazed	2.27 - 3.22							U Value, Winter 0.31-0.39

								U Value, Summer 0.39 - 0.44 R = 1 / U U 1 = R 1 U 0.5 = R 2 U 0.333 = R 3 U 0.20 = R 5 U 0.15667 = R 6 the R-values given at left are questionable.
Glass Storm Windows, 1 - 4" space between storm interior surface & interior window exterior surface	0.50							Highly questionable without assessment of the leakiness of the storm window and also of the leakiness of the principal window sash.
Gypsum board	0.6							Drywall 1/2" Gypsumboard = R 0.45 5/8" Gypsum board = R 0.56 DRYWALL
Home®Foam Spray or pour	3.9	0.51 lbs/ft^3						Insulthane 100, See Plastic, foamed insulation below Home Foam? should not be installed within 2" / 50mm of heat emitting devices producing temperatures in excess of 200deg.

Hardboard, high density, standard tempered 1/4" thick, Per Inch	1							1/4" thick hardboard, high-density = R 0.25 Note that many builders refer to this wood product hardboard by a specific trade name "Masonite™" or "Masonite hardboard"
Hardboard underlayment, 1/4", per inch:	1.24							1/4" thick hardboard underlayment = R 0.31
Insulating Board R-Values								
Insulating board, glass fiber organic bonded	4.00							
Insulating board, expanded ploystyrene, extruded, cut cell	4.00							
Insulating board, expanded polystyrene extruded smooth	5.00							
Insulating board, expanded polystyrene molded bead panel	3.57							POLYSTYRENE
Insulating board, expanded polyurethane	6.25							POLYURETHANE
Insulating board, polyisocyanurate	7.20							POLYISOCYANURATE

foam								
Insulating board, mineral fiber, resin binder	3.45							
Icynene Foam Insulation R-Values								
Insulation or other Building Material [9]	**R-Value[1]**	**Density[2]**	**Perm[3]**	**Absorption[4]**	**Flame Spread [5]**	**Smoke[6]**	**Toxicity[7]**	**Aging Effects & Comments**
Icynene® Foam-poured insulation or pour fill insulation	4[23]	.5-2	low	low	low			Fire safety: may not be left exposed in living area; very good air bypass leak sealing properties
Icynene® Foam-sprayed insulation	3.6 - 3.7	.5-2	low	low	low			Fire safety: may not be left exposed in living area; very good air bypass leak sealing properties
Mineral Wool insulation (Rock Wool)	3.2 - 3.7	1.5-2.5	100	2%	0	0	0	May collect debris/allergens/mold, also referred-to as rock wool, slag wool, glass wool (but not fiberglass) 3 3/4" - 5" Mineral Wool = R 11 6 1/2" - 8 3/4" Mineral Wool = R19 7 1/2" - 10" Mineral Wool = R22 10 1/4" - 13 3/4" Mineral Wool = R30

								13" - 17 1/4" Mineral Wool = R38
Masonry Materials R-Values: concrete block, "cinder block", brick, concrete masonry units, perlite filled concrete block								
Insulation or other Building Material [9]	**R-Value[1]**	**Density[2]**	**Perm[3]**	**Absorption[4]**	**Flame Spread [5]**	**Smoke[6]**	**Toxicity[7]**	**Aging Effects & Comments**
Brick, common	0.20							
Brick, 4"	0.44							This is for clay brick.
Brick, 4" + 1" reflective air space								
Brick, facing or veneer	0.11							
Concrete Block, two rectangular core, 8"	1.04							Filled with sand and gravel aggregate. We consider this questionable and note that moisture
Concrete Block, two rectangular core, 8"	0.44 + 2.89 = 3.33							Filled with lightweight aggregate, same warning as above.
Concrete Block, 4" 72% solid (115#/ft^3)	1.19							(Also see "Concrete" above)

Concrete Block, 6" 59% solid	1.25							
Concrete Block, 6" 59% solid perlite-filled	3.95							
Concrete Block, 8" 54% solid	1.45							
Concrete Block, 8" 54% solid perlite-filled	4.65							
Concrete Block 10" 52% solid	1.55							
Concrete Block, 10" 52% solid perlite filled	5.65							
Concrete Block 12" 48% solid	1.65							
Concrete Block, 12" 48% solid perlite-filled	7.05							

Masonry R-values Source: adapted from "Sample R-Value Calculations" found at www.maconline.org

Notes:

1. Effects of water intrusion on insulating value and R-values are not included in the above nor was there discussion of variation in thermal conductivity at block segments that are solid rather than perlite filled.

2. Additional R-value for a masonry wall constructed using these materials needs to add the insulating value of additional wall components typically included, such as 1" solid foam (polyisocyanurate R 8, extruded polystyrene R 5, expanded polystyrene R 4, or 1" of perlite R 2.7) and for an exterior air film (winter, no wind, R 0.17), an interior air film (again no air movement, R 0.68), 3/4" of reflective air space (no convective air movement, R 2.89), 1/2" drywall (R 0.45), interior wall cavity insulation (see various fiberglass or other insulating values in this table), to achieve a greater overall R-value than that afforded by the masonry block or brick wall alone.

3. Presumably the R-values given are then calcuated for the overall wall structure, averaging the effects of thermal breaks etc. - Ed.

Particleboard 5/8" underlayment, per inch	1.31							5/8" particleboard underlayment has an R-value of 0.82
Perlite insulation	2.5 - 3.7	2-11	High	0	0	0	0	
Plywood, A/C	1.4							
Plywood, 1/4"								R 0.31
Plywood 3/8"								R 0.47
Plywood 1/2"								R 0.62
Plywood 5/8"								R 0.77

Phenolic Foam Insulation R-Values								
Phenolic foam spray insulation	4.8 - 7							
Phenolic foam insulation Phenolic rigid panel	8.3 4.4 - 8.2 4 - 5							Corrosion problems when in contact with steel roofing & moisture; very good air bypass leak sealing properties
Plaster, 1/2" lightweight	0.32							
Plastic, foamed: Home Foam[25] low-density	3.9	0.51 lbs/ft^3						Water-blown Unidentified ingredients Spray or pour application see HomeFoam® above.
Polyethylene foam	3							

Polyisocyanurate Foam Insulation R-Values								
Insulation or other Building Material [9]	**R-Value**[1]	**Density**[2]	**Perm**[3]	**Absorption**[4]	**Flame Spread** [5]	**Smoke**[6]	**Toxicity**[7]	**Aging Effects & Comments**
Polyisocyanurate / Polyurethane panel	5.6 - 7.0							
Polyisocyanurate foam panel or board, foil faced	6.8 - initial, pentane expanded 5.5 - aged 5 to 10 years							Rigid panel insulation board with foil facing both sides, edges exposed Aged R-values for foam panels assume aging in-situ for 5-10 years.
Polyisocyanurate spray, poured, or board insulation	4.3 - 8.3 5.5 - 6.2 to 7.04 - 8.0	2	2-3	0	25	55-200	CO	Closed cell, HCFC or CFC gases; 0-12% shrinkage, Fire safety: may not be left exposed in living area; thermal drift with aging; foil faced improves performance to R7-8.; very good air bypass leak sealing properties
Polyisocyanurate composite insulation	2.8 (5.8-6.2)	2.0	2-3					Closed cell Foil faced See POLYISOCYANURATE FOAM and IAQ

Polystyrene Foam Insulation R-Values									
Polystyrene peanuts for building insulation	not recom-mended				5-25+	10-400		Not recommended for building insulation, may be serious fires hazard.
Polystyrene loose fill beads for building or window-wall insulation	2.3				5-25+	10-400		Static charge makes particles hard to control
Polystyrene board or beadboard [8] MEPS insulation molded EPS low density	3.6 - 5.0 3.85	0.8-2.0	1.2-3.0	0.7-4%	5-25	10-400	CO	Degrades in sunlight (UV); R-value varies by board density
Polystyrene Expanded (EPS) insulation low-density	3.85 3.9 - 4.4 3.6 - 4.7							See POLYSTYRENE FOAM INSULATION
Polystyrene board, extruded expanded high-density (XPS) Molded	5 - 5.4 4.2							
Polystyrene board	5	1.5	1.2-3.0					Closed cell See POLYSTYRENE FOAM INSULATION

Polyisocyanurate / Polyurethane *Foam* Insulation R-Values

Insulation or other Building Material [9]	R-Value[1]	Density[2]	Perm[3]	Absorption[4]	Flame Spread [5]	Smoke[6]	Toxicity[7]	Aging Effects & Comments
Polyurethane spray - closed cell foam insulation. .	5.0 - 6.8 5.5 - 6.5 Initial 7.14 Aged 6.8	2.0	2-3	0	30-50	155-200	CO	Closed cell foam spray insulation; 0-12% shrinkage, Fire safety: may not be left exposed in living area. Initial R of 7.14 declines to 6.8 after several months of curing; very good air bypass leak sealing properties
Polyurethane foam insulation rigid panels	7-8 - Initial 6.25 - aged 5 to 10 years							CHC/HCFC expanded foam
Polyurethane foam insulation rigid panels	6.8[21] - Initial 5.5 - aged 5 to 10 years							Pentane expanded foam
Polyurethane spray foam insulation rigid panels, foil-faced	7.9 - 8.4							Pentane expanded foam, presence of an air-gap may increase panel performance. RSI = 45-48
Polyurethane spray foam insulation - open cell insulation	3.6 - 7 (est)							Expands & seals more than closed-cell; lower cost; pourable-version available for building retrofit; See URETHANE FOAM Deterioration, Outgassing

Insulation or other Building Material [9]	R-Value[1]	Density[2]	Perm[3]	Absorption[4]	Flame Spread [5]	Smoke[6]	Toxicity[7]	Aging Effects & Comments
Reflective insulation	2 - 17							Need details of products in this range
Rock Wool Batts Slag wool Batts	3 - 3.85							See MINERAL WOOL
Rock Wool, Slag wool Loose Fill insulation R-value	2.5 - 3.7							
Roofing: Asphalt shingles	0.44							
Roofing: built-up 3/8" thick plies	0.33							
Roofing: wood shingles	0.94							Also see below at "wood". The use of this R-valuye is highly questionable since wood shingle roofs do not block air flow whatsoever.
Silica Aerogel	10							
Snow	1							
Soil or "dirt"	0.25 - 1 0.80 typical at 20% moisture							Depends on soil properties: density, moisture content, moisture movement See SOIL R-VALUES
Straw Bale	1.45							STRAW BALE CONSTRUCTION
Stucco, conventional	0.20							

plaster/cement								
Tectum™ insulated roof panels	2.0							Tectum: a patented cementitious wood fiber EPS-core insulating roof deck tile, plank, or panel of several thicknesses.
Thinsulate	5.75							Clothing insulation, not used in buildings
Urea Formaldehyde UFFI Foam Insulation R-Values & Properties								
Insulation or other Building Material [9]	**R-Value[1]**	**Density[2]**	**Perm[3]**	**Absorption[4]**	**Flame Spread [5]**	**Smoke[6]**	**Toxicity[7]**	**Aging Effects & Comments**
Urea Formaldehyde Foam Panels or in-wall spray	4 - 4.6							Formaldehyde outgassing concerns, especially new, possibly
UFFI insulation (Urea Formaldehyde Foam)	4.2 5.25	0.6-0.9	4.5-100	18%	0-25	0-30	0 (may outgas formal-dehyde)	1-4% shrinkage, Fire safety: may not be left exposed in living area; on aging, leaves significant air bypass leaks at shrinkage points
Vacuum Insulated Panels								
Vacuum "insulated" panel	30-50		Low					Vacuum insulated panels (VIPs) are rigid, air-tight hollow-core panels from which air has been evacuated. An internal support is needed to keep the panel walls from collapsing when evacuated.

								The effectiveness as a vacuum insulating panel will also vary by panel thickness (e.g.l 25mm), as panel walls close together may transer heat by radiation and by the temperatures on the two sides of the panel as radiation transfer of heat increases with the temperture difference.
Vacuum Powder Insulation	25 - 30							
Vacum powder insulated panels	20 - 100							U.S. DOE. Others cite R-30 - R-50.
Vermiculite insulation	2.13 - 3.0 2.10 - 3.7	4-10	High	0	0	0	0 (may contain asbestos)	May contain asbestos, virtually always installed as loose-fill. Some sources cite R = 2.08 Some sources cite R = 2.13 - 2.27
Vinyl Siding	0.61		Low	0				1/16" (0.175")to 3/32" (0.093") thick vinyl siding, hollow-backed
Vinyl Thin Film Window Covering			Low	0				U-value and emissivity values vary depending on the type of film, with emissivity values from 0.07 to 0.81
Wood, Hardwood, Softwood Insulation R-Values								
Insulation or other Building Material [9]	**R-Value**[1]	**Density**[2]	**Perm**[3]	**Absorption**[4]	**Flame Spread** [5]	**Smoke**[6]	**Toxicity**[7]	**Aging Effects & Comments**
Wood R-Values Log wall R-Values	1.01 - 1.41 (softwoods)							The R-value of wood varies by wood density,

vary[16]	0.71 (hardwoods)							species, moisture content. R-value of typical 3/4" thick pine softwood = about R 1.25
Wood door, solid, per inch	1.56							Varies by species, no authoritative source.
Wood, soft	1.25							
Wood Flooring, assume 3/4" hardwood	0.68							
Wood sheathing panels (Plywood,OSB)	2.5[21]							
Wood shingle siding, single course	0.87							
Wood siding, 1/2-inch clapboard or shiplap	0.81							

Where

- **R-Value** is expressed as rate of heat loss per hour per square foot per inch of thickness of material per deg. F - For some building materials (such as sheet flooring) we give an R-value for a specfic thickness other than the standard 1".

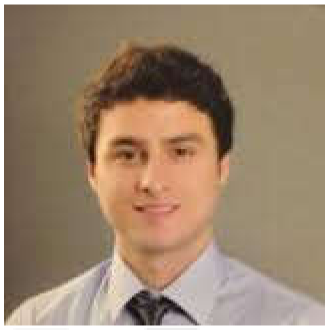
RSI-Values: convert U.S. R-values to SI units or RSI as follows: R-Value / 5.685 = RSI-Value

R-1 = 5.678263337 RSI
or
RSI-1 = 0.1761101838 R

- **Insulation density** is expressed in pounds per cubic foot of material
- **Permeability** is expressed as the water vapor permeability of the material per inch of thickness. These numbers are most useful to compare one insulating material to another.
- **Absorption** is the tendency of the insulation to absorb water in percent by weight. This is important for assessing the risk of mold in some materials
- **Flame Spread** is a measure of fire resistance of the material. Use these numbers to compare one insulating material to another.
- **Smoke** is a measure of fire safety - that is, the relative amount of smoke produced if the insulation is exposed to flame or combustion
- **Toxicity** is a measure of fire safety - that is, toxins given off if the insulation is exposed to flame or combustion.

Reference: http://inspectapedia.com/insulation/Insulation_Values_Table.php (Retreived 14.01.2017)

CURRICULUM VITAE



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B.Sc.: Civil Engineering

M.Sc: Construction Materials

Professional Experience and Rewards:

Structural Engineer / BSP Consulting Dec 2014 – Current

Is responsible for designing structures by choosing frames and calculating them to necessary codes. Also reporting to the senior engineer about the progress being involved in a team.

Duties:

- Designing buildings to British and Euro codes using the software programs.
- Calculating or drawing by hand when necessary.
- Drawing and detailing the projects using the software program "Auto CAD".
- Site visiting and technical support during construction.
- Liaising with engineers, architects and clients.

Structural Engineer / M.M.B. Engineering and Design Aug 2014 – Nov 2016

Was responsible for designing buildings and prepare drawings in the first year. After being involved and successful, managed a little team to develop the models and reported to senior engineer. Took full responsibility for estimations and calculations in projects. Also, have done site visits and provided technical support during construction.

Senior Site Engineer / Seba Steel Construction (Limited Time Transfer from M.M.B. Engineering) Feb 2015 – Jul 2015

Being a subcontractor of a pretty known company in Turkey, I was responsible for organising and finishing out two different high-risk sites at the same time managing a mediocre scale team. Executing safety limits, working schedule, handling problems, weekly progress presentations and meeting other business opportunities were some key duties of mine.

Site Engineer / Gözde Construction Team Mar 2014 – Aug 2014

Was responsible for managing the trim works and delivering the houses to the clients in a large-scale residential project. Orchestrating among 15 subcontractors to be organised to finish individual works within the time limitations.

Structural Engineer / Air Force Command (Military) Mar 2013 – Mar 2014

Was responsible for every sort of site or structural engineering inside the military bounds being the only engineer. Designing, drawing, estimating, reporting, inspecting, critical decisions, progress payment were some of my key duties.

Project Engineer / Tepekule Construction Inspection Mar 2012 – Mar 2013

Was responsible for monitoring whether the construction is matching the project. Giving technical advice, arranging necessary documents for the Council, and reporting to the Manager, for buildings in progress in a large district in Izmir.