Heat Transfer Fundamentals & SuperTherm

Presented

New Developments in Heat Transfer & Insulation

Prepared by PhD Inn Choi* on behalf of

Superior Products International II, Inc.

* PhD Inn Choi has a PhD in Fluid Mechanics and was one of the PhD's at Owens Corning who designed the R Value formula. PhD Inn Choi also worked with Dr. Raymond Viskanta W.F.M. Goss Distinguished Professor of Engineering, School of Mechanical Engineering, Heat Transfer Laboratory Purdue University where SuperTherm was first tested.

TABLE OF CONTENTS

PART III.
Evaluation of Hot Box Test & TPRL's Thermal Conductivity Test

TEST #1
For BTU and K value of heat flow through a wall unit:

TEST #2
BTU conduction test to determine the BTU conduction block performance for SUPER THERM

COMPARISON #3
Best fiberglass K value compared to SUPER THERM Summary

PART I.

FUNDAMENTAL HEAT TRANSFER COURSE

Why Do We Need to Understand Heat Transfer?

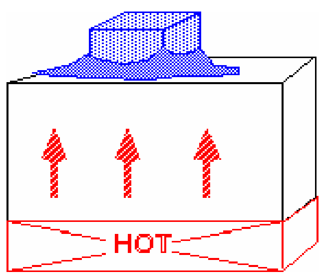
- Changes in temperature require heat transfer from a hot object to a cold object. The objects can be anything: a house, building, pipelines, storage tank or any other devices that are desired to minimize temperature changes within the object. To control and monitor the temperature of the object, we need to understand the mechanisms by which heat is transferred.

- The temperature of air (or gas) stream will be affected by its surroundings such as heated wall and this temperature is in turn changes the nature of the air flow. We need to understand how heat is transferred from/to the air surrounding an object so that we can control and monitor the temperature of the object of our interest.

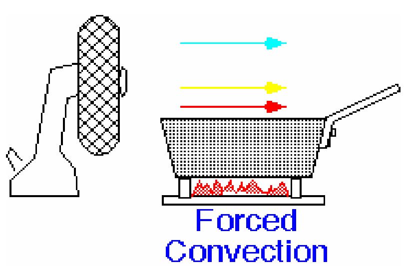
1. Mechanisms of Heat Transfer

Heat transfer occurs by three primary routes:

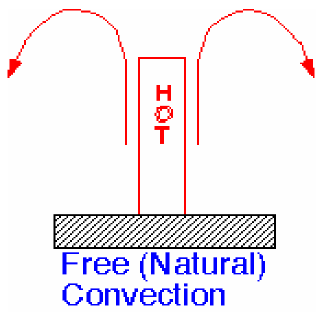
Conduction
Conduction is the motion of heat through a stationary solid, liquid or gas.



Convection
Convection is the physical transfer of gases (air) or liquids containing heat energy.

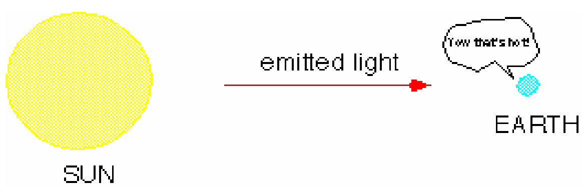


Convective heat transport couples the fluid motion to the energy transfer. Hot air is lighter than cool air, and tends to rise in the presence of gravity. If temperature gradients are large enough and externally imposed fluid velocities small enough, the convective transport is called 'Natural Convection'.



Radiation

Radiation occurs when heat is transferred between two objects even when there is nothing in between by the motion of photons. Radiative heat transfer often dominates all other heat transfer mechanisms in a vacuum.



2. Heat Conduction

The flux of heat is proportional to the gradient in temperature in simple conduction

$$J_{heat} = -K_{th} \frac{\partial T}{\partial x}$$

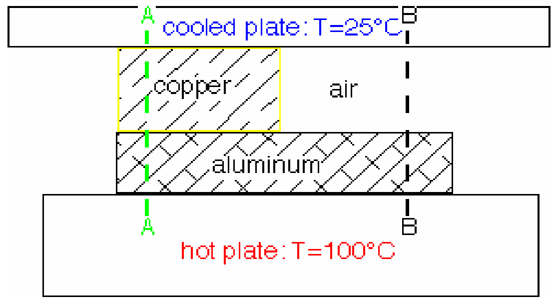
The '-' sign in the equation simply indicates the direction of heat transfer. To put this equation in simpler terms,

Heat Flux = Conductivity x Temperature Difference / distance between hot & cold objects.

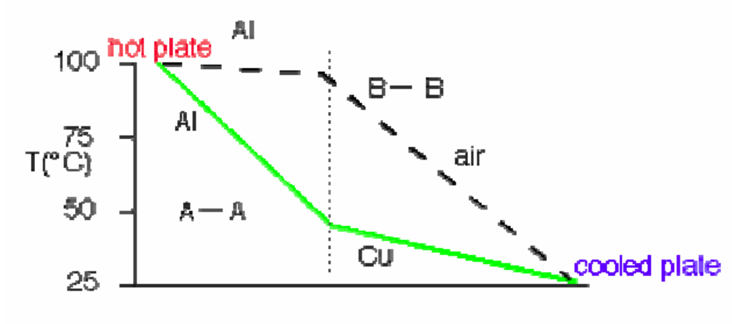
The thermal conductivity varies tremendously between different materials. The heat capacity expressed in molar terms is roughly constant but in volumetric terms it differs tremendously due to the variation in density between e.g. gases and solids. Some useful values are summarized below:

material	c_p (J/gm)	ρ (gm/cm^3)	c_{vol}(J/cm^3)	K_{th} (W/cm°C)
air	1.0	0.0012	.0012	0.0002
wood	2.7	0.6	1.6	0.001
glass	0.75	2.2	1.6	0.01
st. steel	0.4	8.0	3.2	0.15
iron	0.4	7.8	3.1	0.8
silicon	0.75	2.3	1.7	1.2
aluminum	0.9	2.7	2.4	2.4
copper	0.4	8.9	3.6	4
diamond	0.5	3.2	1.6	14
Fiberglass				**0.0004**
SuperTherm				**0.0054-0.0065**

In a steady-state, the temperature drops linearly. But for a composite material the thermal conductivity (K_{th}) varies so much. As a result, big differences in temperature drop slope occur as heat travels through different materials.

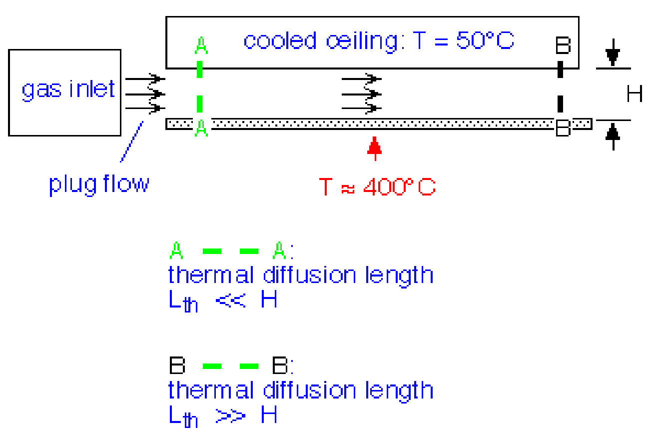


For example, as aluminum is a good conductor, the temperature drop across aluminum is very small. On the other hand, the air is such a poor thermal conductor (if it isn't moving) that the biggest temperature drop occurs across the air space. The cross-section B-B above/below shows this effect.

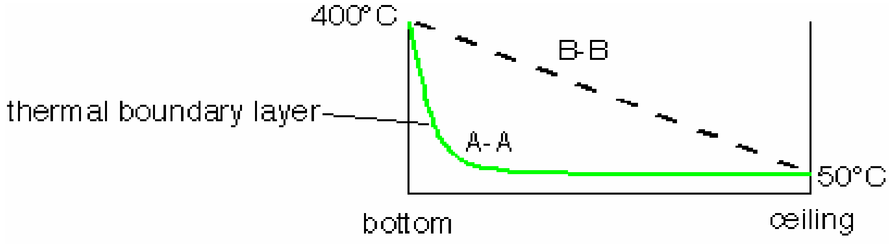


3. Convection

Let's consider a simple example. We approximate the flow velocity as constant everywhere and assume that heat is carried by convection in the direction of gas flow and by conduction from the heated wall (400 C) to the gas stream and then toward the cooled ceiling (50 C) in the perpendicular direction.

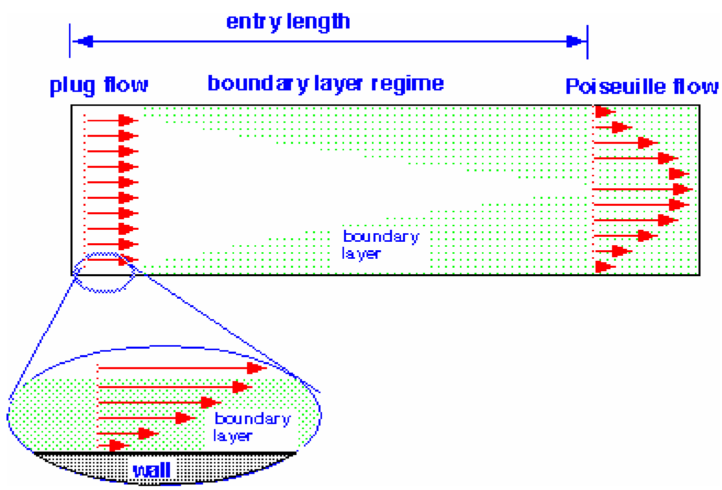


Near the entry region a narrow boundary layer exists near the hot wall, with the remainder of the gas at the initial temperature. In the downstream region the temperature profile is essentially linear for a stationary conductive medium.



Since the heat loss is close to the surface, cooling is much larger in regions like A-A above where large temperature slope exists in the boundary layer. As the gas heats up, thermal expansion occurs. Thus the velocity actually should increase as we go downstream. However, thermal diffusivity also increases. The two effects tend to compensate (for small amounts of heating, anyway), so we often ignore them to first order.

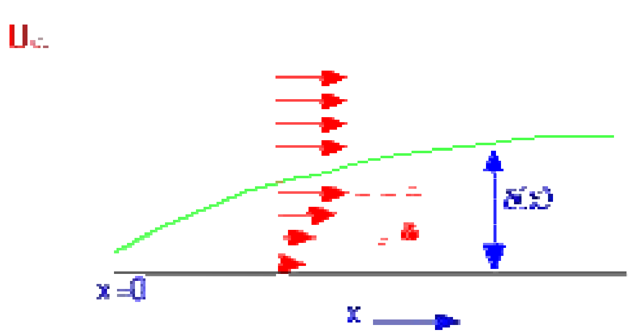
Boundary Layers Flows



In the "plug flow" regime, the real flow configuration has nearly constant velocity in most of the chamber, with a relatively thin "boundary layer" in which the gas or fluid is strongly affected by viscous drag from the walls. In plug flow the boundary layer is so small that we can ignore it to first order.

In the Poiseuille regime, the two boundary layers have grown so much that they no longer exist as distinct regions but have merged to give a smooth continuous variation in velocity.

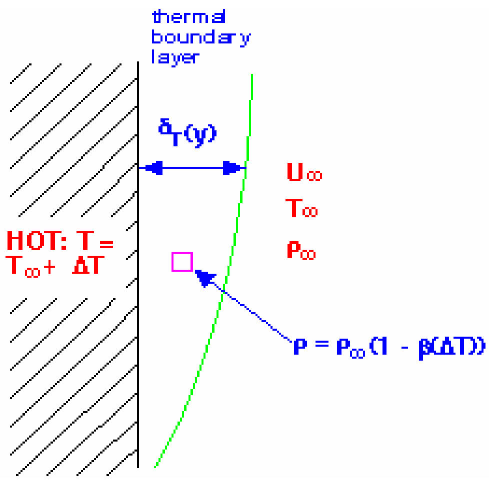
In the intermediate region, we can treat the flow as taking place in two distinct regions: a boundary layer with low velocity, whose thickness we need to determine and a "free stream" region outside the boundary where velocity is relatively fixed.



Natural Convection

When heat is added to a gas it expands and thus changes density. If gravity is present, this change in density induces a change in the body forces and the forces may cause the fluid to move "by itself" without any externally imposed flow velocity. This is the phenomenon of natural convection, ubiquitous in our daily experience: rising clouds of cigarette or campfire smoke, ripples of heat from a car's hood, thunderheads reaching into the stratosphere.

Natural convection is usually very undesirable since it represents an uncontrolled gas flow. We may consider a flow composed of a "free stream" region, in this case with a constant temperature and density as well as velocity and a relatively narrow thermal boundary layer over which temperature, velocity and density change.



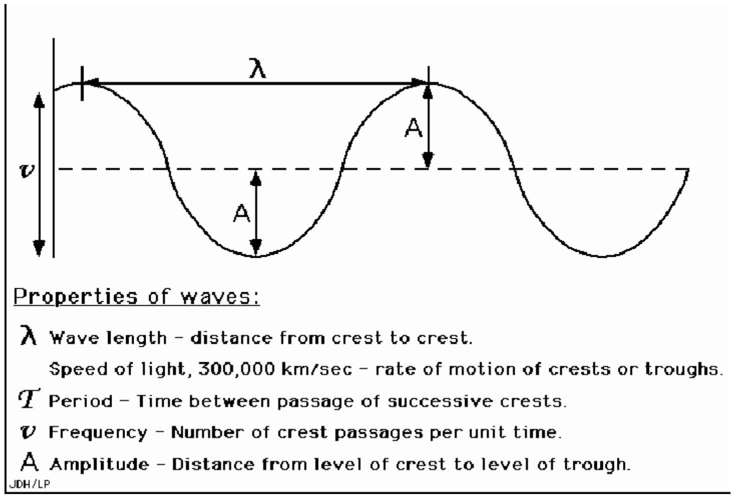
If the natural convection velocity is much smaller than the "forced convection" fluid velocity then natural convection can be safely ignored. In the other extreme, fluid flow in a reactor is dominated by natural convection, leading to many undesirable results. To avoid natural convection in practical situations, make reactors short! The situation is different in the "boiling water" geometry: a large flat cylinder with a hot bottom and cool top. In this case there is no convection at all.

4. Radiative Heat Transfer

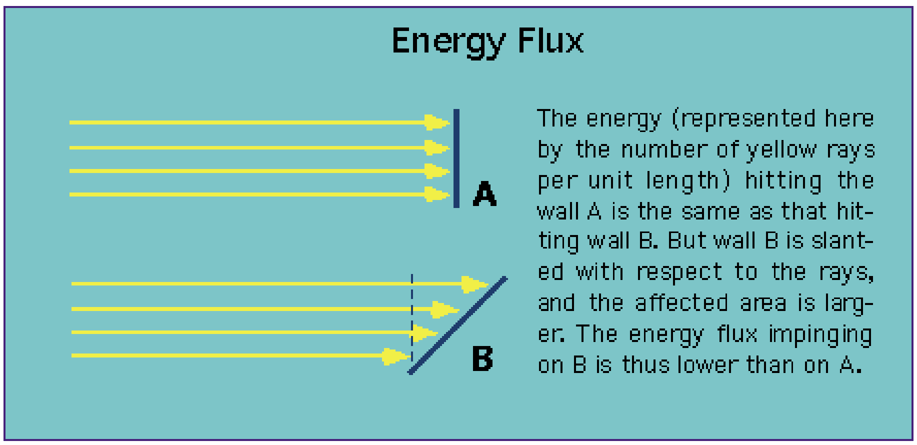
What is Radiation?

All forms of heat transfer move heat from one body to another or from one part of a system (such as the climate system) to another. Heat always moves from where the temperature is relatively high to where it is relatively low. This is true for any form of heat transfer.

Radiation is the transfer of energy through electromagnetic waves. This form of energy transfer does not require the presence of matter to occur. In this form energy can travel through empty space from the Sun to the Earth and other planets in the solar system.

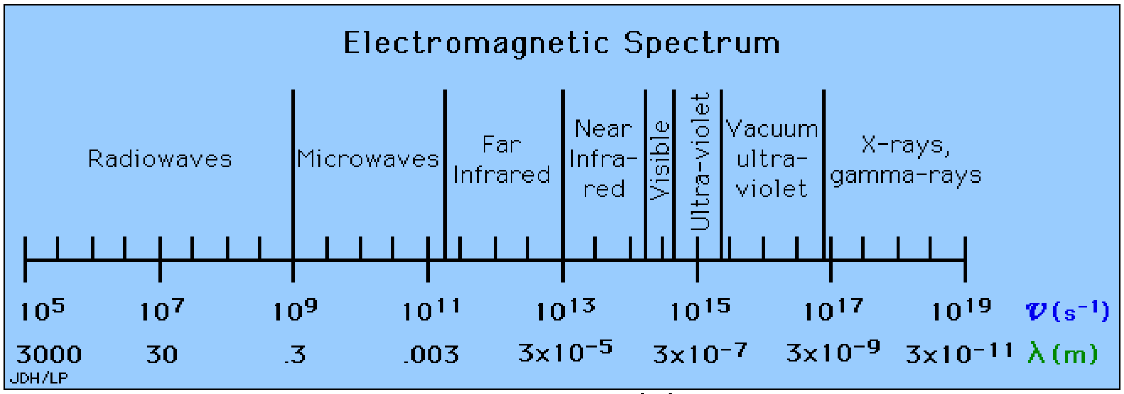


When energy is carried by **photons**, we have a Radiative heat transport which has no analog in heat or mass transport.



Electromagnetic wave spectrum

The range of the entire known spectrum of electromagnetic radiation is shown in the figure below.

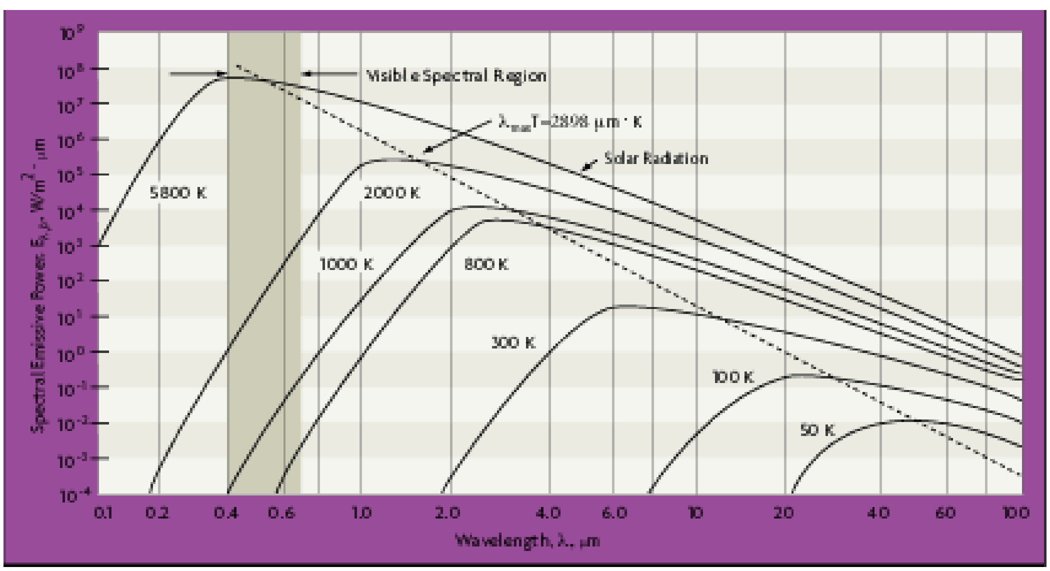


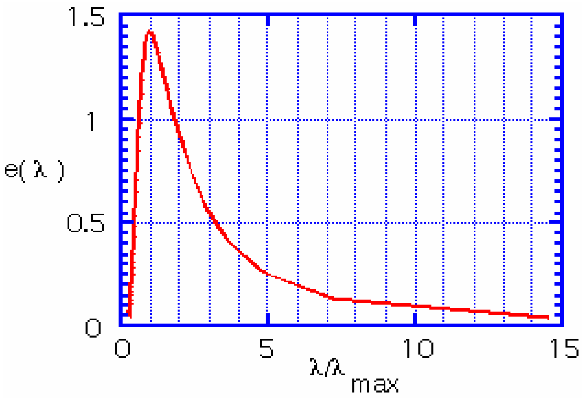
|--|

Visible Region (0.4-0.7 micron)

In a closed system, the amount of energy absorbed from the photon gas is equal to that emitted by each object according to the **blackbody distribution** discovered by Planck. Since the amount of photons at each energy level is proportional to the fourth power of the temperature, the total heat energy emitted per unit area of surface is proportional to the fourth power of temperature; sigma is the Stefan-Boltzmann constant.

$$J = \sigma T^4$$





Shorter wavelength to longer wavelength region
X-Rays & Gamma Rays -> Ultra Violet -> Violet -> Visible Region (0.4-0.7 micron) -> Infrared region -> Microwave -> Radio Waves

The chart above shows a typical emissive power distribution with normalized wavelength. The peak in the distribution is at the radiated energy in the far infrared at room temperature. What this means is that the radiation energy is not visible. Even at 1000 C, where objects appear to glow brightly, most of the energy is still being emitted in the mid-IR. (3.5 microns is a typical wavelength).

T (°C)	λ(max) [μm]	E(max) [eV]
25	16.5	.075
100	12.9	.096
300	8.4	.148
500	6.2	0.20
700	4.9	0.25
900	4.1	0.30
1100	3.5	0.35

Radiation & Visibility

The dependence of the intensity and wavelength (color!) of radiation on temperature can be demonstrated by a simple experiment: Consider an iron bar placed in a hot fire. At first its color does not change but if taken out from the fire, it will warm its surroundings because it radiates in the infrared range (invisible radiation in the wavelength range of 0.7-100 µm). When we continue to heat the iron bar it will begin glowing red and then as it continues to warm, turn brighter to orange, yellow, white and finally blue-white in color (the wavelength becoming shorter and shorter within the visible light range, 0.4-0.7 µm).

Light Bulb filament runs at about the temperature of 5000 F. This high temperature is necessary in order to bring the peak radiation energy (emissive power) from Infrared to the visible region. If the filament temperature is low, all radiation energy will be lost in the invisible region.

Sun is the ideal Black Body at about 10,000 F. The peak energy is closer to the visible region. Literally God made it that way, i.e. our eyes were made to be most sensitive to the Sun's peak energy. Otherwise, we won't be able to see things the way we do now.

Radiation through Objects

When electromagnetic radiation encounters a body, be it a solid, liquid or gas, it goes through one or all of three processes:

¤ = Transmission
¡ = Reflection
‘ = Absorption

If › = incident radiation energy then

¤ + ¡ + ‘ = ›

This means the incident energy is either transmitted, reflected or absorbed.

To represent the degree to which each process occurs we associate a dimensionless coefficient with each. These are the coefficients of matter.

Ä(tau) = transmissivity (=¤ / ›) Á (roh)= reflectivity
(=¡ / ›)
± (alpha)= absorptivity (=‘ / ›)

All these coefficient determine the fraction of incident radiation that is either transmitted, reflected or absorbed. Therefore:

Ä+ Á + ± = 1

For most opaque bodies there is no transmission of energy. Therefore Ä= 0. The above equation reduces to:

Á + ± = 1

What this means is that part of the incident energy is reflected and the rest Absorbed.

When radiation energy falls on a body, the body will warm up until it emits as much heat as it absorbs and then stop warming, reaching a state of thermal equilibrium. If the heat loss by the body takes place in empty space, the only way in which the body can lose heat is through radiation. In that case the body is said to be in a radiative balance and its radiated energy flux will be equal to the absorbed flux. So:

± = µ
where µ = emissivity.

To put this in engineering terms, Kirchoff's law says that the emissivity must equal the absorptivity at each wavelength; we can often ignore wavelength dependence and set emissivity = absorptivity.

Highly reflective objects have emissivities near 0. The "dull" black objects have emissivities near 1. Some typical emissivities are shown here.

Surface	T(°C)	ε
pure Al	200-600	0.04-0.06
oxidized Al	90-540	0.2-0.33
asbestos	40	0.95
carbon soot	40	0.94
white paint	40	0.9 - 0.97

Note that white paint has a high emissivity: it is reflective in the visible but not in the IR. SuperTherm is reflective in visible as well as in infrared range. That is why SuperTherm is more effective in blocking radiation energy than white paint.

What is emissivity and emittance?

The terms emittance and emissivity are often used interchangeably. There is however a technical distinction. Emissivity refers to the properties of a material; emittance to the properties of a particular object. In this latter sense, emissivity is only one component in determining emittance. Other factors including the shape of the object, oxidation and surface finish must be taken into account.

The values for the emissivity of almost all substances are known and published in reference literature. However the emissivity determined under laboratory conditions seldom agrees with actual emittance of an object under real operating conditions. For this reason, one is likely to use published emissivity data when the values are high.

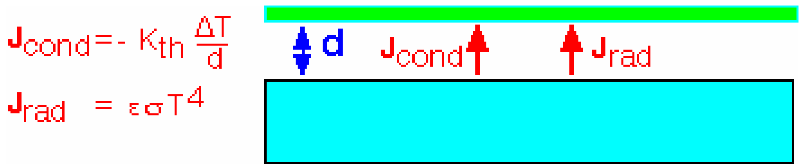
As a rule of thumb, most opaque non-metallic materials have a high and stable emissivity (0.85 to 0.90). Most unoxidized metallic materials have a low to medium emissivity value (0.2 to 0.5). Gold, silver and aluminum are exceptions, with emissivity values in the 0.02 to 0.04 range.

The apparent emittance of a material also depends on the temperature at which it is determined and the wavelength at which the measurement is taken. Surface condition affects the value of an object's emittance, with lower values for polished surfaces and higher values for rough or matte surfaces. In addition, as materials oxidize, emittance tends to increase and the surface condition dependence decreases.

The reflectivity of a surface defines the fraction of incident radiation reflected by a surface.

5. Comparison of Radiation with Conduction

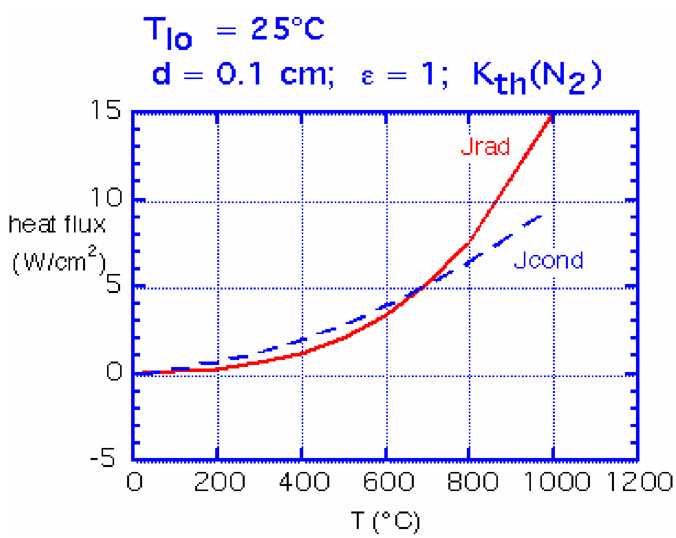
How do conduction and radiation compare in importance? Radiation is essentially independent of spacing, whereas conduction is strongly dependent on spacing.



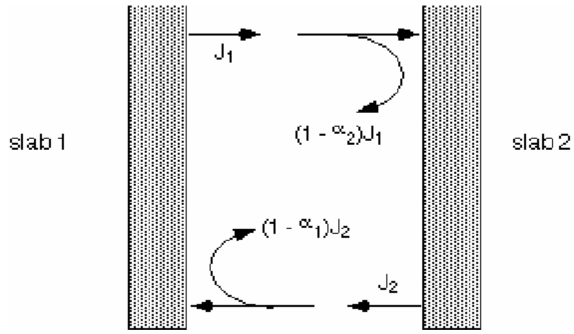
Here we show calculated fluxes in the simple case where the upper (cool) surface is a perfect black absorber, held at room temperature.

For a spacing of about 0.1 mm the two fluxes remain comparable over a wide range of temperatures. Of course, if the plate separation is increased the conducted flux falls rapidly whereas radiated flux is essentially unchanged.

Typical heat flux varies from 1-2 W/cm2 at 200°C, to around 10 W/cm2 at 900°C.



When surfaces are not perfectly absorptive, calculation of the net heat flux from one surface to another is rather subtle. One must account for the energy reflected from each slab.



The final result contains a term of the form $T1^4 - T2^4$, as would be the case with simple black objects. The coefficient dependent on emissivity is rather complex: let's look at a few special cases.

$$J_{(rad,net)} = \left(\frac{1}{\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1 \right)} \right) \sigma \left(T_1^4 - T_2^4 \right)$$

When both objects are perfect absorbers, the net heat is just the difference of two blackbody terms. When one emissivity is small and the other close to 1, the smaller emissivity dominates the net flux. When both are comparable but small, they combine in the same fashion as two resistors in parallel.

Limits:

$\varepsilon_1 = \varepsilon_2 = 1$ $\quad J_{(rad,net)} = \sigma \left(T_1^4 - T_2^4 \right)$

$\varepsilon_1 << \varepsilon_2 \approx 1$ $\quad J_{(rad,net)} = \varepsilon_1 \sigma \left(T_1^4 - T_2^4 \right)$

$\varepsilon_1 , \varepsilon_2 << 1$ $\quad J_{(rad,net)} = \frac{\varepsilon_1 \varepsilon_2}{\varepsilon_1 + \varepsilon_2} \sigma \left(T_1^4 - T_2^4 \right)$

PART II.

HEAT TRANSFER TRAINING FOR SUPERTHERM

In describing insulation effectiveness of building material such as fiberglass, we often encounter words like Conductivity, Conductance and Transmittance. Quite often, these words are mistaken and mixed up with words like R-value, K-value or Lambda value. As a consequence, a correct assessment of insulation effectiveness cannot be made. This often leads to unnecessary confusions among field operators.

1. Heat Transfer mechanism inside Fiberglass

Fiberglass is an 'air trapper'. The air is "trapped" on a great many small chambers called "cells". While each cell sets up its own convection current, heat transfer is reduced in direct proportion to the size of the cell. The smaller the cell is, the greater the reduction in convection. The air inside each cell reacts together when one side of the containment chamber is heated. The air sets up an active circulation. The heated air rises and the cold air falls. This circulation constantly exposes the colder air to the warm wall, thus increasing the temperature gradient (delta-T) across that wall and greatly increases the rate of heat transfer through the chamber. As it is impossible to individually study the heat transfer in a cell, most heat transfer study for fiberglass is conducted experimentally using average quantity of temperature levels and heat transfer rates. The measured values of heat transfer often reflect the properties of air rather than that of fiberglass itself.

2. What is R-Value?

Part of the confusions in dealing with insulation material comes from so-called 'R- Value'. The R-value concept started with this electric wire analogy. The electric resistance (Ohm), voltage drop (Volt) and current (Ampere) corresponds to thermal resistance (R-Value), temperature drop (°F) and heat flux (Btu/hr) respectively. The smaller and the longer an electric wire, the higher its electric resistance. In the same token, the narrower and thicker an insulation material is the higher the R-Value.

This R-Value concept was adopted specifically for the fiberglass material which Owens Corning Fiberglass Corporation developed in the middle of 70's. R-value is simply defined as the ability of a material to resist heat when it is transferred from the hot side to the cold side. Technically, it is defined as the amount of temperature drop (°F) per unit heat transfer rate (Btu/hr). For convenience, however, R-Value is often expressed as the inverse of the rate of heat transfer (Btu/hr) per unit temperature (°F). The R-Value definition can be expressed as follows:

$$R = 1/(kA/d)$$

Since $U=k/d$, the R-Value can also be expressed as $R= 1/(UA)$

If the we consider a unit cross-sectional are, $A=1$ sq.ft, then,

$$R=1/U$$

Where:
- R: R-Value (°F hr/Btu)
- k: Thermal conductivity (Btu inch/hr sq.ft °F)
- A: Cross-sectional area (sq.ft) (perpendicular to the heat transfer direction) d: Insulation thickness (inch)
- U: Thermal Conductance (Btu/hr sq.ft °F)

Please note that the following terms are all identical:

Thermal Conductance = **U-value** = **K-value** = **Transmittance**

The above terms are all associated with heat conduction through a material. If heat convection is included in a calculation in addition to heat conduction, we use the term **Heat Transfer Coefficient (h).** It has the same unit as above. Heat convection is surface phenomena and associated with heating or cooling of the surface of a material by blowing air in general.

Note that, if **Thermal Conductance** (U), or any of the above, is divided by thickness (d), you have **Thermal Conductivity** (k).

Thermal Conductivity, k, is the measurement of the speed at which heat travels through a material by conduction. More specifically, it is the number of BTUs of heat which will travel through one sq. foot of material which is one inch thick when there is one degree of temperature difference across the material (I.e.: Delta T). Thermal Conductivity is a material's inherent property and does not change with material thickness.

Thermal Conductance, U, on the other hand, is same as Thermal Conductivity, k, except that it is thickness-dependent. What it mean is that, for a given material, Thermal Conductance is different for different thicknesses for the same material, As an example, let's say, a 6-inch fiberglass material has R-value of 19 (°F hr/Btu). Then,

R-Value (R)	**Therm. Conductance (U)**	**Therm. Conductivity (k) 6" Fiberglass**
19 (°F hr/Btu)	0.053 (Btu/hr sq.ft °F)	0.316 (Btu inch/hr sq.ft °F)

Where:

R=19 (°F hr/Btu)
UA=1/R=1/19 (°F hr/Btu)=0.0526 (Btu/hr°F)
For A=1 sq.ft (cross area), U=0.0526(Btu/hr°F)/1(sq.ft)=0.053(Btu/hr sq.ft °F) For d=6 inches (thickness), k= Ud=0.0526 (Btu/hr sq.ft °F) x 6 (inches) = 0.316 (Btu inch/hr sq.ft °F)

For this given Thermal Conductivity, k, we can back-calculate Thermal Conductance, U, and R-Value, R, for any thickness. As an example, for 12" fiberglass, we get the following:

Therm.Conductivity (k)	**Therm.Conductance (U)**	**R-Value (R) 12" Fiberglass**
0.316 (Btu inch/hr sq.ft °F)	0.026 (Btu/hr sq.ft °F)	38 (°F hr/Btu)

Where:

k= Ud=0.0526 (Btu/hr sq.ft °F) x 6 (inches) = 0.316 (Btu inch/hr sq.ft °F) U=k/d=0.316 (Btu inch/hr sq.ft °F) / 12 (inches) = 0.026 (Btu/hr sq.ft °F)

For A=1 sq.ft (cross area), UA=0.026 (Btu/hr sq.ft °F)x 1(sq.ft)=0.026(Btu/hr °F) R = 1/(UA) = 1 / 0.026(Btu/hr °F) = 38 (°F hr/Btu)

This illustration clearly shows that while Thermal Conductivity does not change with thickness, R-Value is directly proportional to insulation thickness and Thermal Conductance is inversely proportional to insulation thickness. If insulation thickness increases two fold from its original value, its R-Value increases two fold and Thermal Conductance decreases to one half from its original value.

3. Why Fiberglass cannot have a Fixed Material Property?

When we say property, we usually have a fixed property in mind. By definition, the property may change slightly with temperature or pressure but not with the size. As they say, size shouldn't matter for property.

Then why don't we use Thermal Conductivity instead of R-value for fiberglass? Unfortunately, fiberglass cannot have a fixed property such as Thermal Conductivity. This is because fiberglass is nothing but a flexible 'air trapper'.

Essentially its property is air property. Air is a very good insulator. The more air volume a fiberglass retains within, the higher its R-Value.

During fiberglass installation, however, fiberglass wrapper is torn and allows the outside air and moisture migrates into the fiberglass wool pack. A small amount of moisture or externally induced air pocket can cut down fiberglass' R-value by more than 50% easily. When the fiberglass is squashed and loses its air, its R- Value diminishes significantly. When it is exposed to wind, its value also changes drastically.

The fiberglass wrapper itself also affects R-value. Its function is to protect fiberglass and maintain it at a certain thickness. Not only its thickness varies depending on how it is squashed or pulled, the wrapper material itself affects the R-value significantly.

Foils cannot be used as a wrapper material. If it is used to reflect radiation, all heat reaching the foil barrier is conductive and passes straight through making the barrier useless. If R-value measurement is made including the fiberglass wrapper, the wrapper thermal properties, thickness, and how it bonds with fiberglass all affect the results.

4. Comparison of SuperTherm and Fiberglass

Fiberglass and SuperTherm should not be compared for R-Value for any practical purposes especially because of R-Value's thickness dependence. As an example, one spray of SuperTherm insulation is 0.01 inch (10 mils) thick.

Compare this with one layer of fiberglass of 6 inches (6,000 mils). Fiberglass's R- value is 600 times more than SuperTherm independent of insulation properties simply because of the way R-value was defined. This is like comparing apples with oranges.

Fiberglass was developed for Conduction only. In real life, all heat transfer phenomena take place by Conduction, Convection and Radiation. Without taking all these three heat transfer modes into account, a realistic comparison of insulation effectiveness cannot be made for any material.

Radiation is a surface heat transfer mechanism like convection. But radiation works in a very different way because the heat transfer is made as the fourth power of temperature. What this means is that the magnitude of heat transferred by radiation is much higher than that transferred by convection or conduction especially when the temperature level of the heat source is high. However, most insulation materials such as fiberglass are designed primarily for conduction.

The real issue in dealing with building insulation is to prevent ambient heat entering into a building. Once the heat enters, various building materials like fiberglass reduces the rate of heat transfer. This heat is not prevented from entering into a building – it is simply 'slowed down' so to speak. Thermal Conductivity is simply a measure of a material's ability that determines the rate of heat being transferred across the material. A high or low thermal conductivity of a material simply makes the heat transferred faster or slower. But, in a steady state in the real world, the total amount of heat transferred is eventually the same no matter what the conductivity value is. It is literally a matter of 'time' when this steady state is reached.

Preventing heat from entering into a building is clearly a much more effective solution than allowing the heat to enter into a building and then trying to slow the heat transfer rate down. SuperTherm was designed to 'prevent' heat entering into a building. This is accomplished by SuperTherm reflecting more than 95% of incident radiation heat. When 95% of heat input into a building is blocked and only less than 5% of heat is allowed to enter into a building, the overall benefits from different material insulation properties for this 5% are trivial.

SuperTherm works as the most effective radiation reflector to prevent heat entering into a building. Fiberglass works as an insulator to slow down the heat transfer rate 'after' the radiation heat enters into a building. If radiation is included in R-Value calculation (although doing so may not serve the purpose correctly), **its R-value equivalence would go up 'significantly' because radiation heat transfer increases by 4-th power of temperature difference. Then we will be able to say that one spray of SuperTherm can be equivalent or even exceed 6-8 inches of fiberglass batt insulation.**

5. Conversion between British and Metric Units

There has been confusion between British units and Metric units in dealing with insulation properties. The following table shows conversion factor when British units are converted into Metric units.

	British Unit(US)	**Metric Unit(Europe)**	**Conversion Factor**
k: Thermal conductivity	Btu inch/hr sq.ft °F	W/cm °K	British / 694
d: Insulation thickness	inch	cm	British / 0.394
U: Conductance	Btu/hr sq.ft °F	W/ sq.cm °K	British / 1767
A; Cross sectional area	sq.ft	sq.cm	British / 0.0011
R: Thermal resistance	hr °F/Btu	°K/W	British / 0.526 (5.66)
Q: Heat Flux	Btu/hr sq.ft	W/sq.cm	British / 3171

Note (1): 1 (kilo-calorie/hr) is 3.9657 Btu/hr, or 0.0011622 KW.

Note (2) : The R-Value conversion unit 0.526 is based 1 sq.ft area. Use the conversion unit 5.66 to get the Metric R-Value based on 1 sq.m unit area directly from the British R-Value. (1 sq.m = 10.76 sq.ft)

(Example) 6" Fiberglass Properties in British & Metric Units

	Thermal Conductivity (k)	**Thermal Conductance (U)**	**R-Value (R)**
British Units	0.316 (Btu inch/hr sq.ft °F)	0.053 (Btu/hr sq.ft °F)	19 (°F hr/Btu)
Metric Units	0.0004553(W/cm °K)	0.00003 (W/ sq.cm °K)	36 (°K/W) / 3.36 (°K/W)

Note: The R-Value 36 (°K/W) is based in a 1 sq.ft area. The R-Value 3.36 (°K/W) is based in a 1 sq.meter area.

Thermal Conductivity in Metric Units is Lambda Value.

Please note that the actual number for R value is totally different depending on which units are used. It must be defined with units. As far as the units are consistent, it really doesn't matter which definition we use. If one wants to see whether people who use these words actually mean the same thing, you can check the units and see whether they are consistent. The same goes for K-value or » (Lambda) value. If units are converted from British to metric units, we can easily see that it is the same thing.

	Conversion from British to Centi-Metric	
	British Unit	**Centi-Metric Unit**
Total heat flux	Btu/hr	W
	1	0.293
	Btu/hr	K-Cal/hr
	1	0.252
Heat Flux	(Btu/hr)/ (sq.ft)	W/(sq.cm)
	1	0.0003154
	(Btu/hr)/ (sq.ft)	W/(sq.m)
	1	3.154
	(Btu/hr)/ (sq.ft)	(K-Cal/hr) / (sq.m)
	1	2.714
	1	30.48
Area	sq.ft	sq.cm
	1	929
	sq.ft	sq.m
	1	0.0929
Thermal	(Btu/hr) in/ (sq.ft F)	W cm /(sq.cm K)
Conductivity	1	0.00144
	693.5153584	1.00000
U-Value	(Btu/hr)/ (sq.ft F)	W/(sq.cm K)
	1	0.00057
	1761.52901	1.0000
R-Value	F/(Btu/hr)	K/W
	1	1.896
	0.5274	1

6. Defeating R-Value based Building Insulation Assessment

For heat transfer in buildings, there are basically three heat transfer mechanisms involved.

Radiation (Reflectivity)
This is the most dominant heat transfer mechanism as the heat comes from the sun. In this case, reflecting heat is the most effective way to prevent the heat coming into a building. If 100% of heat were reflected, there is no heat transfer taking place, which means a perfect insulation. SuperTherm reflects more than 95% of heat.

Conduction (Thermal Conductivity)
This is the main heat transfer mechanism after part of heat is absorbed by a building. The heat transfer takes place through the enclosing walls. In this case, a good insulation material is one with the lowest Thermal Conductivity. Fiberglass is an air trapper and air has a low Thermal Conductivity. R-Value applies only to Thermal Conduction.

Convection (Heat Transfer Coefficient)
This is the main heat transfer mechanism after part of the heat penetrates through the building walls. The heat is now transferred into the interior of a building by indoor air current movement. This has little to do with any insulation material properties.

It is obvious that it is most effective to ‘prevent’ incident heat entering into a building to begin with than allowing the heat to enter into a building and then use a super insulation material to ‘slow down’ the heat entering inside a building. What I mean by ‘slowing-down’ is the time rate, i.e. the entire heat enters into a building no matter what but at a different rate depending on the insulation material. Fiberglass never prevents heat entering into a building, SuperTherm does. Therefore SuperTherm is a true and much more effective insulator than Fiberglass.

7. Defeating Fiberglass Claims

Then why do we see so many people who are tangled up with the idea of R- Value of Fiberglass? This perception is based in a deep-seated blind acceptance of the 1970's fiberglass general concept of how insulation works. These rules of insulation principles developed by Owens Corning are seriously limited as it does not take into account the contribution of radiation which is the most significant component of heat transfer for insulation for buildings.

Most all insulation guidelines are currently built on fiberglass claims and calculations. These claims are short sighted, disputed and can easily be shown to be invalid. This, of course, leaves the engineering and architectural groups with a responsibility for determining true and accurate numbers to be used for quotations on insulation requirements for buildings and facilities nationwide and worldwide under their review.

As an example, ASTM R-test was designed by a committee to give us measurement values that hopefully would be meaningful. However, the test does not account for air movement (wind) or any amount of moisture (water vapor). In other words, the test used to create the R-value is a test in non-real-world conditions. If a fiberglass is assigned an R-value of 3.5, it can achieve this R- value if tested in an absolute zero wind and zero moisture environment. And zero wind and zero moisture are not the real-world.

8. Why SuperTherm?

Totally reflect radiation
SuperTherm is most effective when coated on roofs. It reflects more than 95% of solar radiation to begin with. This ability alone is sufficient to beat fiberglass as the most effective heat barrier. Therefore debating the effectiveness of conduction heat transfer with R-value for the remaining 5% of energy input into a building is not practical. Besides, R-value comparison without taking real-world conditions into account is totally meaningless.

Prevent air penetration, free water, and moisture
In a nut shell, it is very likely that insulating the roof can handle more than half of the insulation needs for the entire building. This is because the primary heat transfer in nature always takes place vertically, i.e. hot air goes up and cold air comes down. Therefore roofing insulation is much more effective than sidewall insulation. By applying SuperTherm on top of roofs and if necessary, in the attic, air penetration can be stopped, free water can be blocked and moisture migration can be prevented.

Corrosion Protection
SuperTherm will not allow corrosion to develop under it. The ceramics bond tight to the substrate surface preventing the passage of moisture, air and atmospheric conditions to affect the surface. In all fiberglass wrapped pipes found in industrial or petrochemical plants, the pipes are all corroded when the fiberglass is removed. Fiberglass breaths the air, moisture and conditions into the air pockets and holds this mixture causing the surface of the pipes walls, etc. to be corroded in a short amount of time. From industry testing, 1.5% of moisture in fiberglass will kill 35% of its effectiveness. A 1.5% is breathing on it. Most climates range from 40% to 80% humidity and given the ability to absorb this moisture, the fiberglass is worthless in a matter of days.

PART III.

Evaluation of Hot Box Test & TPRL's Thermal Conductivity Test

TEST #1
For BTU and K value of heat flow through a wall unit: "ASTM C-236 Guarded Hot Box Test"

Test requested by Bombardier Transportation and Engineering Group. Testing performed by VTEC Laboratory, Inc. and National Certified Testing Laboratories. This test is used to establish R value for fiberglass and other batt materials as determined from these results. Control is the fiberglass test density board of 3 inch thickness. Result of applying SuperTherm over the standard fiberglass test density board. Thermal Conductivity, ke, was reduced.

3 inch high-density **fiberglass board tested**: **k = 0.52** (Btu inch/hr sq.ft °F); **R=5.77** (hr/Btu inch)

- 10 mils of **SuperTherm** tested: **ke = 0.31**(Btu inch/hr sq.ft °F) **; RE=9.7** (hr/BTU inch)
  One coat on heat source side of board. This implies that SuperTherm helps prevent radiation from the heat side (heat source), thus making 40% improvement.

- 20 mils **SuperTherm** tested: **ke = 0.21**(Btu inch/hr sq.ft °F) **; RE= 14.3** (hr/BTU inch)

One coat on each side of board (heat source and cold side) total of 2 coats or 20 mils. This implies that SuperTherm helps prevent radiation heat from hot side (heat source) and from convection from cold side, thus making a 60% improvement.

Note: k: Thermal Conductivity; ke: Equivalent Thermal Conductivity

Note: R-value is defined as R=d/kA. For 3" thickness (d) and 1 sq.ft cross- sectional area (A), the fiberglass board has R=5.77 (hr/Btu inch) as shown above. Now as SuperTherm coating adds almost no thickness (0.01 & 0.02 inches) and SuperTherm conductivity is more than 10 times of Fiberglass, the only major contribution of SuperTherm to cutting down the heat flow in above test is by blocking radiation and convection. Therefore we can safely conclude that the conductivity of SuperTherm - coated fiberglass board above is actually an Equivalent Conductivity (radiation effect included in the conductivity). The Equivalent R-Value (RE) above was obtained by the same definition: RE=d/keA where d is thickness (inches), ke is Equivalent Thermal conductivity (Btu inch/hr sq. ft. °F), and A is cross-sectional are (ft^2).

TEST #2
BTU conduction test to determine the BTU conduction block performance for SUPER THERM.

ASTM E-1461-92 Thermal Diffusivity ASTM E-1269 Specific Heat

BTU value measurement testing of SUPERTHERM alone as a single coating film at 100 C or 212 F. Metal Plate was tested without the coating to allow 367.20 BTU/sq.ft./hour/F to Pass through. SUPER THERM was tested in one coat at 14.9 mils over the metal plate and allowed 3.99 BTU/sq.ft./hour/F (this is U- Value) to pass through. ASTM E 1269 Specific Heat and ASTM E-1461-92 Thermal Diffusivity used to find these results.

This test was done to calculate Thermal Conductivity from:
Thermal Conductivity = Thermal Diffusivity x Density x Specific Heat.
The heat input and output values have nothing to do with the standard steady state 1-D conduction test as this test was conducted to get property values when temperature rises with time (unsteady state). SuperTherm Conductivity calculated in this test is in the range 3.77-4.51 (Btu inch/hr sq.ft °F) for various thicknesses. Please note that Thermal Conductivity is independent of thickness but slightly dependent on temperature and mass. The deviation of conductivity values are associated with these dependencies.

Comparison #3

Best fiberglass K value compared to SUPER THERM Lambda Value:

Thermal Conductivity is independent of thickness. Whether it is 3”, 6”, or 12” insulation, Thermal Conductivity is same. But R-value increase proportionally with these thicknesses.

If we assume 6” Fiberglass has R-Value of 19 (°F hr/Btu), and back-calculate Thermal Conductivity, we get k=0.316 (Btu inch/hr sq.ft °F). If we convert this value into Metric Unit, the result is Lambda Value. Lambda Value in this case will be 0.0004553(W/cm °K) or 0.04553(W/m °K). SuperTherm Thermal Conductivity, k, (K-Value) is again in the range 3.77-4.51 (Btu inch/hr sq.ft °F), not 0.101 (Btu inch/hr sq.ft °F).

Summary

The 1997 TPRL Report that shows ASTM E-146 & 1269 Test was conducted to get SuperTherm’s Thermal Conductivity by using Flash Method. This method is totally different from Steady-State Method we are familiar with.

In Steady-State Method, we used a device such as a guarded hot box. In this case, the temperature does not change with time so we call it a steady-state method. Thermal Conductivity or R-Value may be calculated from this kind of tests.

In Flash Method, an instant laser energy input is given and the consequent temperature rise in time is measured to determine Thermal Diffusivity and Thermal Conductivity. The heat flux value used in Flash Method can NOT be used to calculate Thermal Conductivity or R-Value using the traditional energy balance method.

The following summarizes two cases where SuperTherm's Thermal Conductivity can be looked at from two different aspects. The 3 columns represent Thermal Conductivity in 3 different units.

Test 1 ASTM C-236 Guarded Hot Box Test (Steady State)

	k (Btu in / hr sqft F)	k (W/m K)	k (kcal/m hr C)
3" fiberglass	0.52	0.0749	0.0645
10 mil SuperTherm (hot side)	0.31 (ke)	0.0447 (ke)	0.0384 (ke)
20 mil SuperTherm (hot & cold side)	0.21 (ke)	0.0303 (ke)	0.0260 (ke)

Test 2 ASTM E-1461 & ASTM E-1269 (Laser Flash Method: Unsteady State)

SuperTherm	k (Btu in / hr sqft F)	k (W/m K)	k (kcal/m hr C)
Minimum	3.77	0.5432	0.4674
Average	3.99	0.5749	0.4947
Maximum	4.51	0.6499	0.5592

Test 3 K-Value comparison between Fiberglass & SuperTherm

k (Btu in / hr sqft F)	k (W/m K)	k (kcal/m hr C) 6" Fiberglass
0.32	0.0455	0.0392

Note: k: Thermal Conductivity; ke: Equivalent Thermal Conductivity
The values in these tables indicate that:

1. Test 1 may be showing SuperTherm's 'Effective" Thermal Conductivity (I still need to confirm this but do not have the test report). These thermal conductivity values were obtained in engineering-controlled test environment.

2. Test 2 gives SuperTherm's "Actual" Thermal Conductivity. These thermal conductivities values were obtained in a scientifically-controlled test environment.

3. Test 3 is part of the result obtained from you. I don't have the actual report so can't confirm the validity of the values.

4. **At any rate, given these values, please note that a 10-mil thickness of SuperTherm is the same as 6" of fiberglass in Thermal Conductivity.** 20-mil thickness of SuperTherm cuts down about an additional 30%.