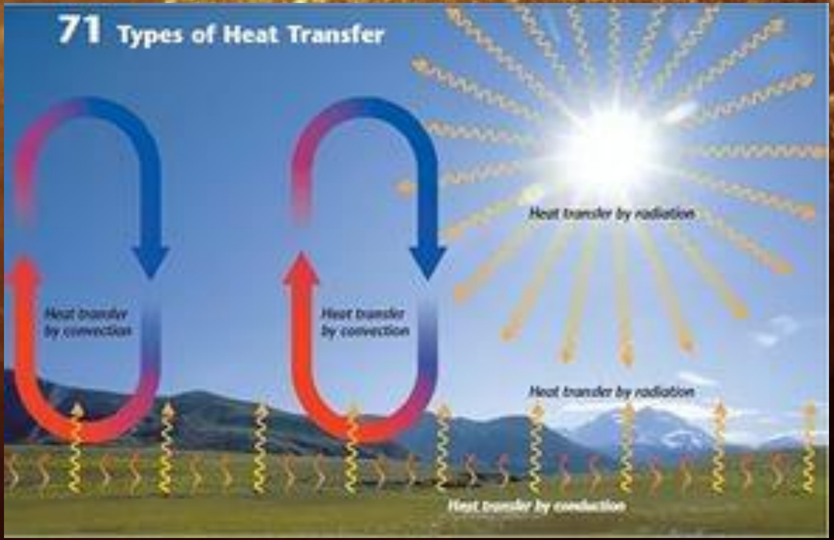
# *HEAT TRANSFER*



**Heat transfer** is the exchange of thermal energy between physical systems, depending on the temperature and pressure, by dissipating heat. The fundamental modes of heat transfer are *conduction* or *diffusion*, *convection* and *radiation*.
Heat transfer always occurs from a region of high temperature to another region of lower temperature. Heat transfer changes the internal energy of both systems involved according to the First Law of Thermodynamics.

The Second Law of Thermodynamics defines the concept of thermodynamic entropy, by measurable heat transfer.

Thermal equilibrium is reached when all involved bodies and the surroundings reach the same temperature. Thermal expansion is the tendency of matter to change in volume in response to a change in temperature.

The fundamental modes of heat transfer are:

Advection

Advection is a transport mechanism of a fluid substance or conserved property from one location to another, depending on motion and momentum.

Conduction or diffusion

The transfer of energy between objects that are in physical contact. Thermal conductivity is the property of a material to conduct heat and evaluated primarily in terms of Fourier's Law for heat conduction.

Convection

The transfer of energy between an object and its environment, due to fluid motion. The average temperature, is a reference for evaluating properties related to convective heat transfer.

Radiation

The transfer of energy from the movement of charged particles within atoms is converted to electromagnetic radiation.

## Conduction

### Thermal conduction

On a microscopic scale, heat conduction occurs as hot, rapidly moving or vibrating atoms and molecules interact with neighboring atoms and molecules, transferring some of their energy (heat) to these neighboring particles. In other words, heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Conduction is the most significant means of heat transfer within a solid or between solid objects in thermal contact. Fluids—especially gases—are less conductive. Thermal contact conductance is the study of heat conduction between solid bodies in contact.

*Steady state conduction* (see Fourier's law) is a form of conduction that happens when the temperature difference driving the conduction is constant, so that after an equilibration time, the spatial distribution of temperatures in the conducting object does not change any further.[10] In steady state conduction, the amount of heat entering a section is equal to amount of heat coming out.

*Transient conduction* (see Heat equation) occurs when the temperature within an object changes as a function of time. Analysis of transient systems is more complex and often calls for the application of approximation theories or numerical analysis by computer.

## Convection

The flow of fluid may be forced by external processes, or sometimes (in gravitational fields) by buoyancy forces caused when thermal energy expands the fluid (for example in a fire plume), thus influencing its own transfer. The latter process is often called "natural convection".

All convective processes also move heat partly by diffusion, as well. Another form of convection is forced convection. In this case the fluid is forced to flow by use of a pump, fan or other mechanical means.

Convective heat transfer, or convection, is the transfer of heat from one place to another by the movement of fluids, a process that is essentially the transfer of heat via mass transfer. Bulk motion of fluid enhances heat transfer in many physical situations, such as (for example) between a solid surface and the fluid. Convection is usually the dominant form of heat transfer in liquids and gases. Although sometimes discussed as a third method of heat transfer, convection is usually used to describe the combined effects of heat conduction within the fluid (diffusion) and heat transference by

The process of transport by fluid streaming is known as advection, but pure advection is a term that is generally associated only with mass transport in fluids, such as advection of pebbles in a river. In the case of heat transfer in fluids, where transport by advection in a fluid is always also accompanied by transport via heat diffusion (also known as heat conduction) the process of heat convection is understood to refer to the sum of heat transport by advection and diffusion/conduction.

Free, or natural, convection occurs when bulk fluid motions (streams and currents) are caused by buoyancy forces that result from density variations due to variations of temperature in the fluid. *Forced* convection is a term used when the streams and currents in the fluid are induced by external means—such as fans, stirrers, and pumps—creating an artificially induced convection current.

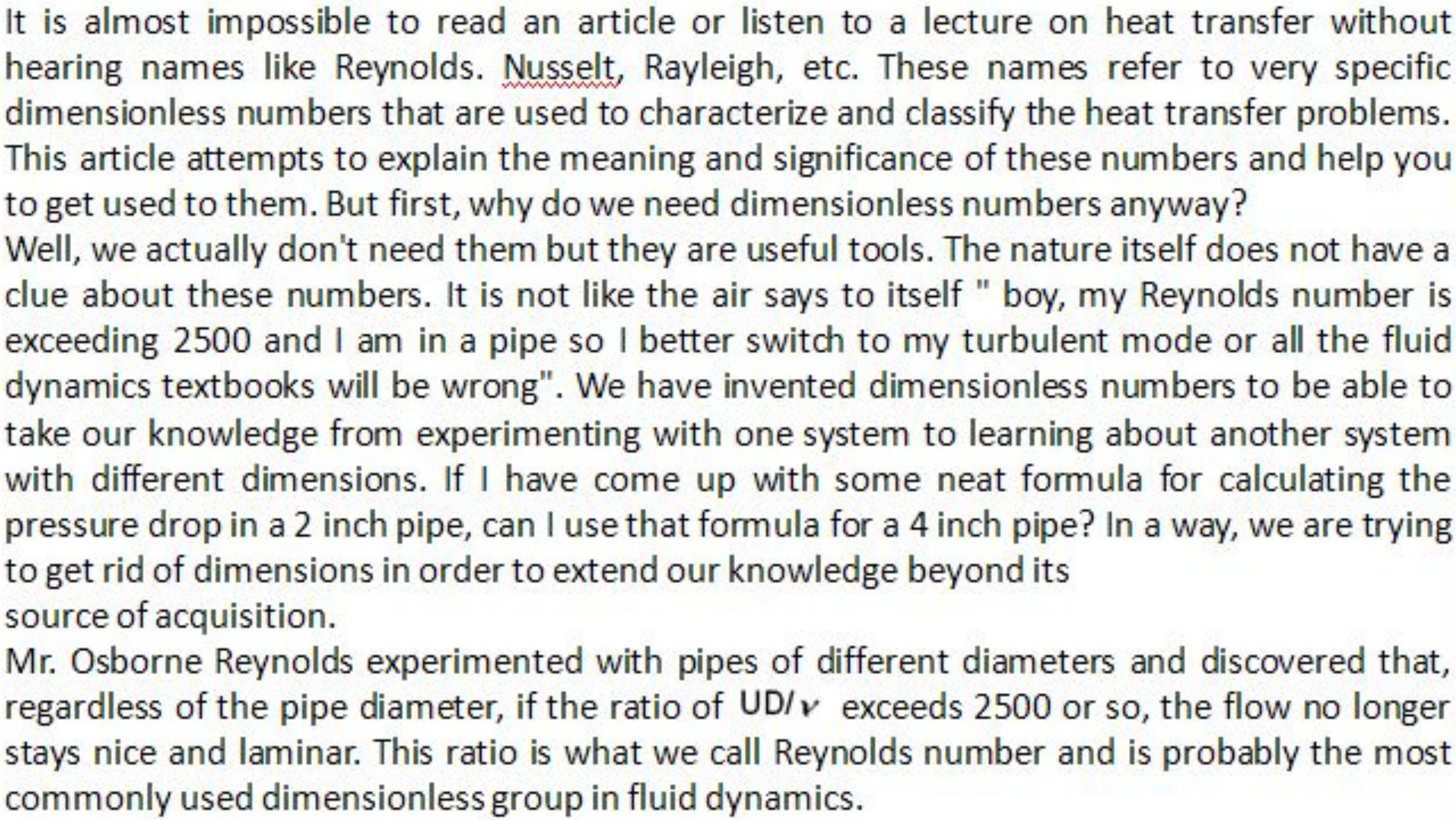
# Radiation

Thermal radiation occurs through a vacuum or any transparent medium (solid or fluid). It is the transfer of energy by means of photons in electromagnetic waves governed by the same laws.

Earth's radiation balance depends on the incoming and the outgoing thermal radiation, Earth's energy budget. Anthropogenic perturbations in the climate system are responsible for a positive radiative forcing which reduces the net longwave radiation loss to space.

Thermal radiation is energy emitted by matter as electromagnetic waves, due to the pool of thermal energy in all matter with a temperature above absolute zero. Thermal radiation propagates without the presence of matter through the vacuum of space. Thermal radiation is a direct result of the random movements of atoms and molecules in matter. Since these atoms and molecules are composed of charged particles (protons and electrons), their movement results in the emission of electromagnetic radiation, which carries energy away from the surface.

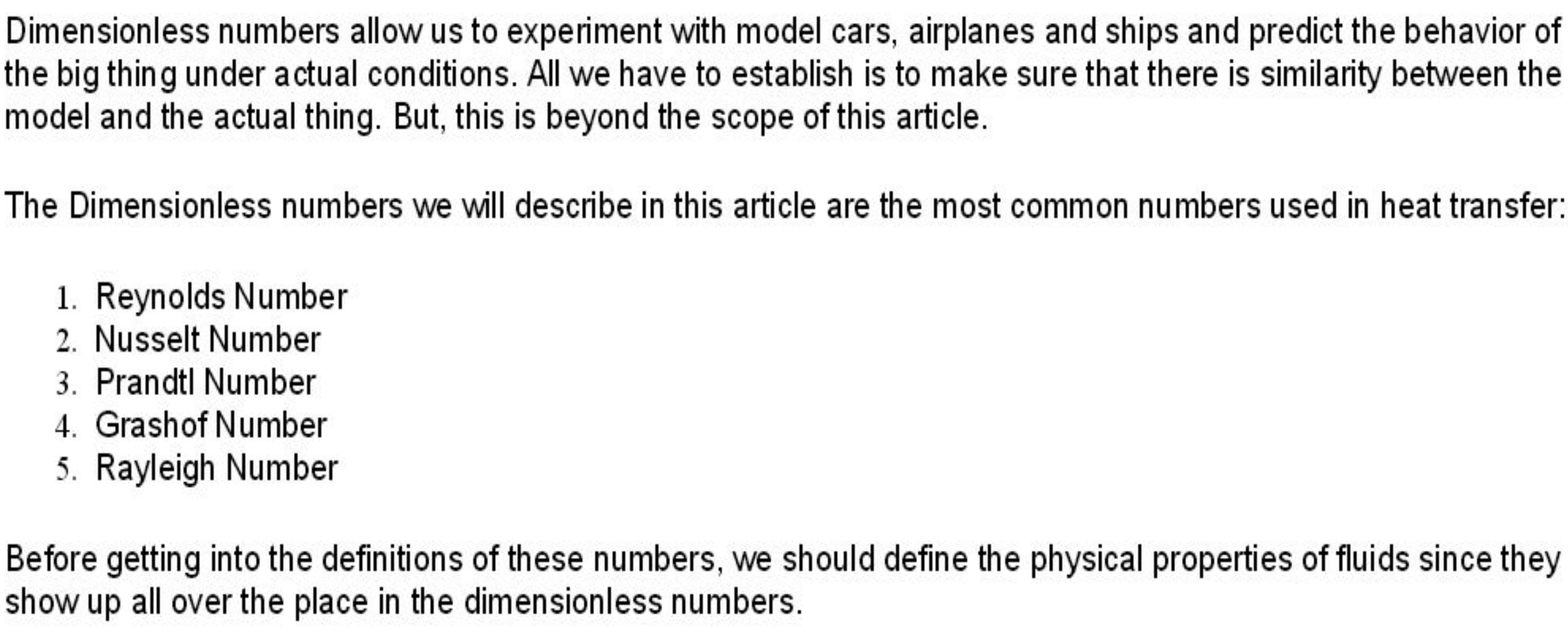
# Dimensionless Numbers in Heat Transfer



It is almost impossible to read an article or listen to a lecture on heat transfer without hearing names like Reynolds. Nusselt, Rayleigh, etc. These names refer to very specific dimensionless numbers that are used to characterize and classify the heat transfer problems. This article attempts to explain the meaning and significance of these numbers and help you to get used to them. But first, why do we need dimensionless numbers anyway?

Well, we actually don't need them but they are useful tools. The nature itself does not have a clue about these numbers. It is not like the air says to itself " boy, my Reynolds number is exceeding 2500 and I am in a pipe so I better switch to my turbulent mode or all the fluid dynamics textbooks will be wrong". We have invented dimensionless numbers to be able to take our knowledge from experimenting with one system to learning about another system with different dimensions. If I have come up with some neat formula for calculating the pressure drop in a 2 inch pipe, can I use that formula for a 4 inch pipe? In a way, we are trying to get rid of dimensions in order to extend our knowledge beyond its
source of acquisition.

Mr. Osborne Reynolds experimented with pipes of different diameters and discovered that, regardless of the pipe diameter, if the ratio of $UD/\nu$ exceeds 2500 or so, the flow no longer stays nice and laminar. This ratio is what we call Reynolds number and is probably the most commonly used dimensionless group in fluid dynamics.



Dimensionless numbers allow us to experiment with model cars, airplanes and ships and predict the behavior of the big thing under actual conditions. All we have to establish is to make sure that there is similarity between the model and the actual thing. But, this is beyond the scope of this article.

The Dimensionless numbers we will describe in this article are the most common numbers used in heat transfer:

1. Reynolds Number
2. Nusselt Number
3. Prandtl Number
4. Grashof Number
5. Rayleigh Number

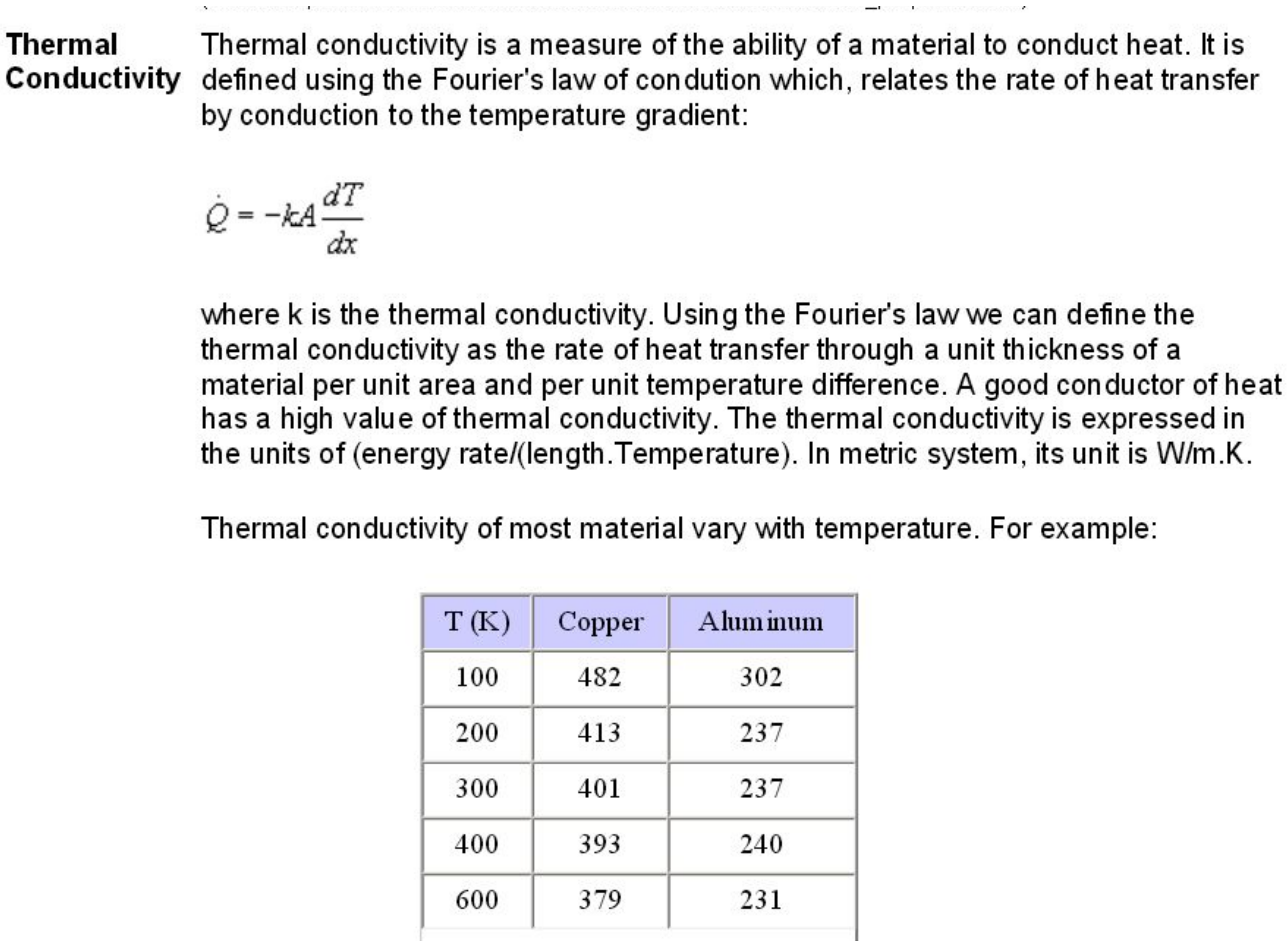
Before getting into the definitions of these numbers, we should define the physical properties of fluids since they show up all over the place in the dimensionless numbers.

**Density** Mass of fluid contained in a unit volume. Its units are Kg/m^3 or slugs/ft^3. Typical values: Water = 1000 kg/m^3, Mercury = 13546 kg/m^3, Air = 1.23 kg/m^3, Paraffin Oil = 800 kg/m^3. (at pressure =1.013e+5 Pascals and Temperature = 288.15 K.)

**Viscosity**

Viscosity, $\mu$, is the property of a fluid, due to cohesion and interaction between molecules, which offers resistance to sheer deformation of the fluid. Different fluids deform at different rates under the same shear forces. Fluid with a high viscosity such as syrup, deforms more slowly than fluid with a low viscosity such as water. All fluids are viscous, "Newtonian Fluids" obey the linear relationship given by Newton's law of viscosity. $\tau = \mu \frac{du}{dy}$ , where $\tau$ is the shear stress. $\mu$ is the "coefficient of dynamic viscosity" - The Coefficient of Dynamic Viscosity, , is defined as the shear force, per unit area, (or shear stress ), required to drag one layer of fluid with unit velocity past another layer a unit distance away. Units: Newton seconds per square meter, or Kilograms per meter per second,. (Although note that is often expressed in Poise, P, where 10 P = 1 $kgm^{-1} s^{-1}$ .) Typical values: Water =1.14xe-3 $kgm^{-1} s^{-1}$, Air =1.78e-5 $kgm^{-1} s^{-1}$, Mercury =1.552 $kgm^{-1} s^{-1}$, Paraffin Oil =1.9 $kgm^{-1} s^{-1}$.

Kinematic Viscosity, $\nu$, is defined as the ratio of dynamic viscosity to mass density, $\nu = \frac{\mu}{\rho}$. Units: square meters per second, (Although note that $\nu$ is often expressed in Stokes, St, where St = 1e-4 $m^2 s^{-1}$.) Dimensions: . Typical values: Water =1.14e-6 $m^2 s^{-1}$, Air =1.46e-5 $m^2 s^{-1}$, Mercury =1.145e-4 $m^2 s^{-1}$, Paraffin Oil =2.375e-3 $m^2 s^{-1}$.



**Thermal Conductivity**

Thermal conductivity is a measure of the ability of a material to conduct heat. It is defined using the Fourier's law of condution which, relates the rate of heat transfer by conduction to the temperature gradient:

$$\dot{Q} = -kA\frac{dT}{dx}$$

where k is the thermal conductivity. Using the Fourier's law we can define the thermal conductivity as the rate of heat transfer through a unit thickness of a material per unit area and per unit temperature difference. A good conductor of heat has a high value of thermal conductivity. The thermal conductivity is expressed in the units of (energy rate/(length.Temperature). In metric system, its unit is W/m.K.

Thermal conductivity of most material vary with temperature. For example:

| T (K) | Copper | Aluminum |
|---|---|---|
| 100 | 482 | 302 |
| 200 | 413 | 237 |
| 300 | 401 | 237 |
| 400 | 393 | 240 |
| 600 | 379 | 231 |

## Specific Heat

Specific heat is the amount of heat that is required to raise the temperature of a unit mass of a substance by one degree. In a constant pressure process

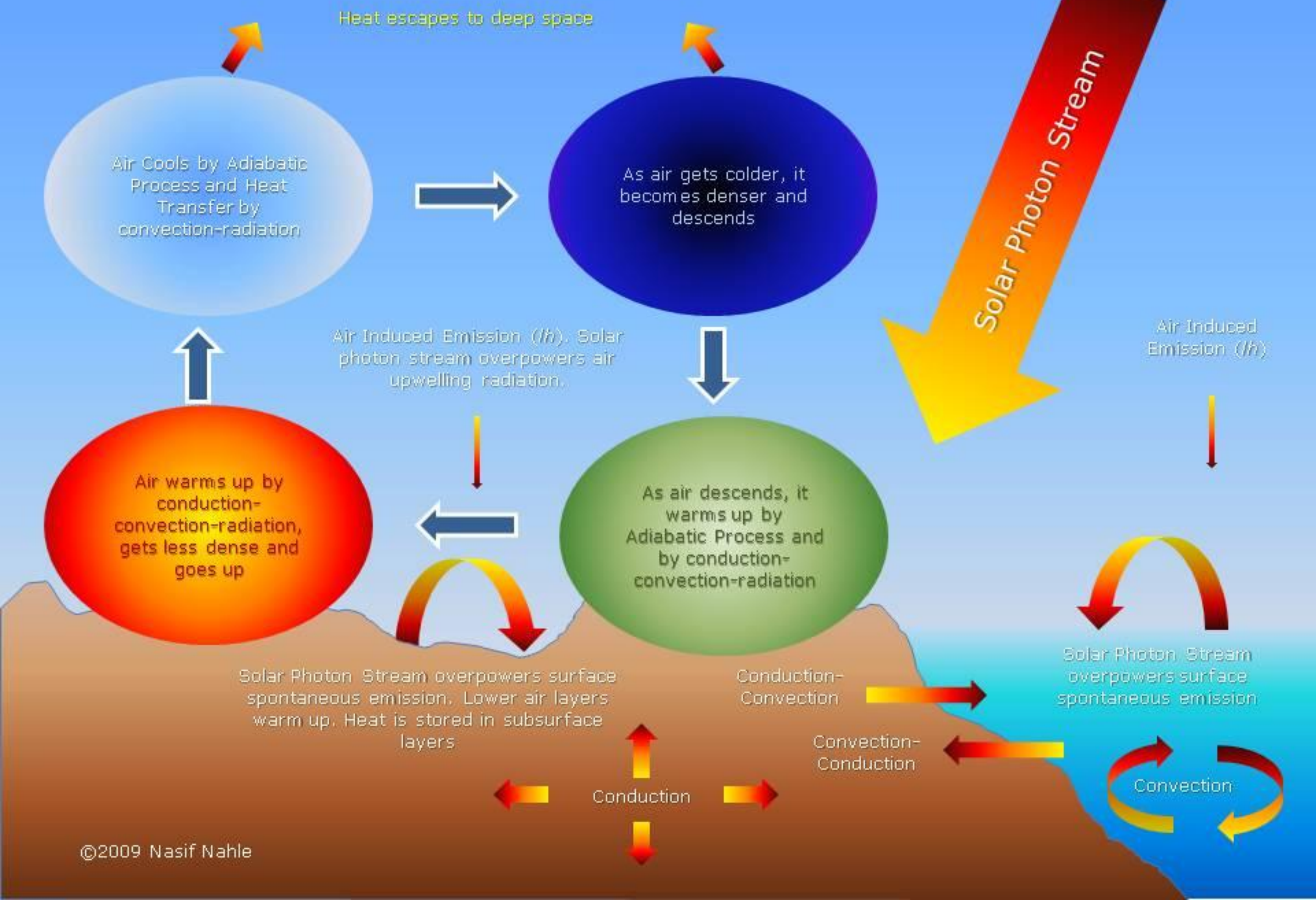
$$\dot{Q} = \dot{m} C_p \Delta T$$

where $C_p$ is the specific heat at constant pressure.

The units for the specific heat are kJ/kg.K (or C). Typical values of Cp for various materials (at 300 K) are shown below:

| Material | Cp (kJ/kg.K) |
|---|---|
| Aluminum (pure) | 903 |
| Copper (pure) | 385 |
| Gold | 129 |
| Silicon | 712 |
| Water | 4180 |
| Air | 1005 |

# HEAT TRANSFER DURING DAYTIME



Heat escapes to deep space

Air Cools by Adiabatic Process and Heat Transfer by convection-radiation

As air gets colder, it becomes denser and descends

Solar Photon Stream

Air Induced Emission (*Ih*). Solar photon stream overpowers air upwelling radiation.

Air Induced Emission (*Ih*)

Air warms up by conduction-convection-radiation, gets less dense and goes up

As air descends, it warms up by Adiabatic Process and by conduction-convection-radiation

Solar Photon Stream overpowers surface spontaneous emission. Lower air layers warm up. Heat is stored in subsurface layers

Conduction-Convection

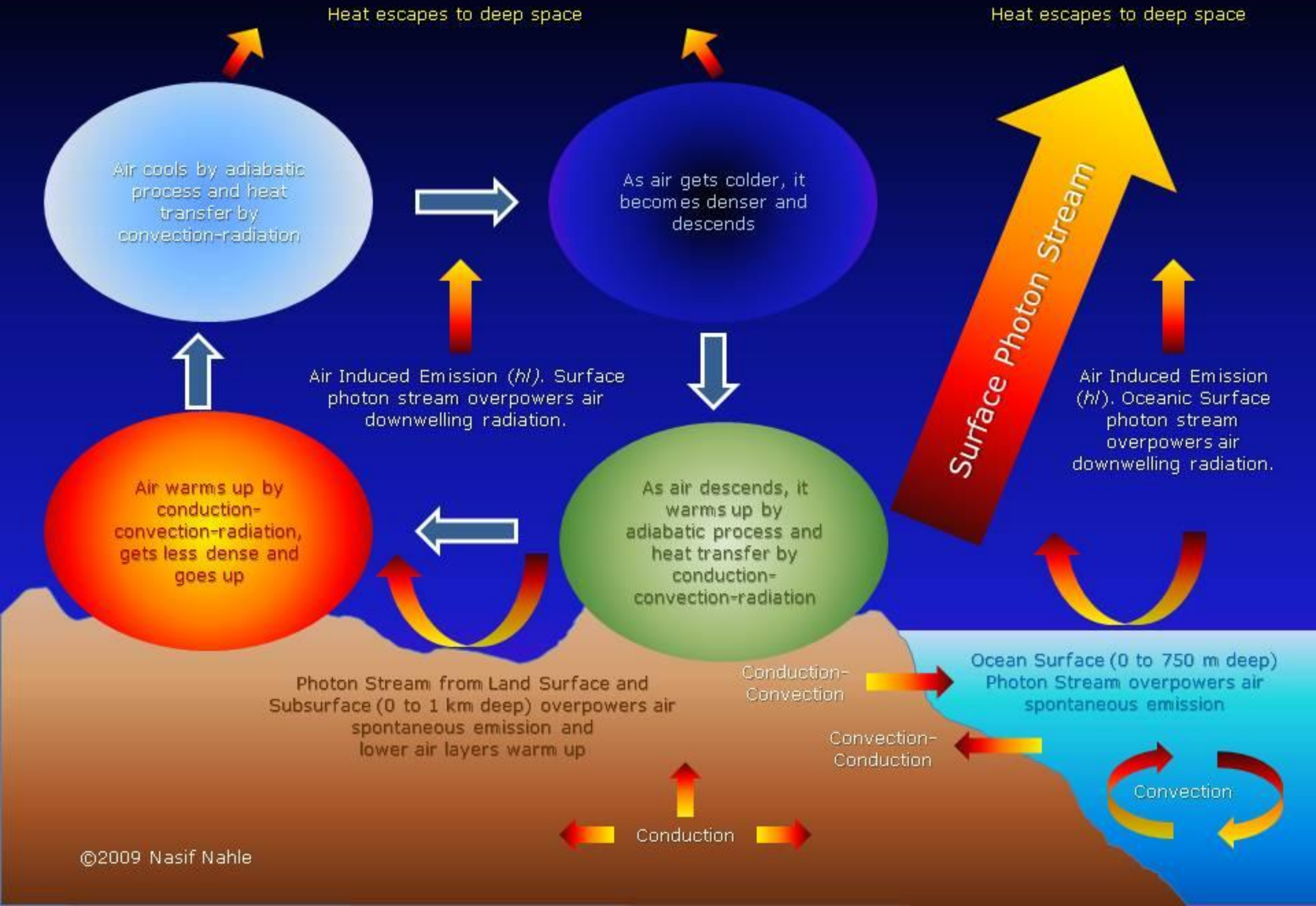
Solar Photon Stream overpowers surface spontaneous emission

Convection-Conduction

Conduction

Convection

# HEAT TRANSFER DURING NIGHTTIME



Heat escapes to deep space

Heat escapes to deep space

Air cools by adiabatic process and heat transfer by convection-radiation

As air gets colder, it becomes denser and descends

Surface Photon Stream

Air Induced Emission (*hl*). Surface photon stream overpowers air downwelling radiation.

Air Induced Emission (*hl*). Oceanic Surface photon stream overpowers air downwelling radiation.

Air warms up by conduction-convection-radiation, gets less dense and goes up

As air descends, it warms up by adiabatic process and heat transfer by conduction-convection-radiation

Photon Stream from Land Surface and Subsurface (0 to 1 km deep) overpowers air spontaneous emission and lower air layers warm up

Conduction-Convection

Convection-Conduction

Ocean Surface (0 to 750 m deep) Photon Stream overpowers air spontaneous emission

Convection

Conduction

**Thermal insulation** is the reduction of heat transfer (the transfer of thermal energy between objects of differing temperature) between objects in thermal contact or in range of radiative influence. Thermal insulation can be achieved with specially engineered methods or processes, as well as with suitable object shapes and materials.

Heat flow is an inevitable consequence of contact between objects of differing temperature. Thermal insulation provides a region of insulation in which thermal conduction is reduced or thermal radiation is reflected rather than absorbed by the lower-temperature body.

The insulating capability of a material is measured with thermal conductivity (k). Low thermal conductivity is equivalent to high insulating capability (R-value). In thermal engineering, other important properties of insulating materials are product density (ρ) and specific heat capacity (c).

The original purpose of a building is to provide shelter and to maintain a comfortable or at least liveable internal temperature. Other purposes include security, privacy and protection from wind and weather. To feel comfortable in a thermal sense, a human has to be able to release a well-defined amount of **Heat**. If this gets difficult, a person will either feel cold or hot. The human body operates as a chemical reactor that converts chemical energy of food and respiratory oxygen into mechanical work and heat. Heat output can vary from about 100 W for a sedentary person to 1000 W for an exercising person.

To maintain body temperature within a narrow band, the heat produced by an occupant must be released to the indoor environment. If too much heat is lost, room temperature should be increased or warmer clothes be worn. The heat transfer on the human skin, the indoor temperature and the heat transfer through the building envelope are factors that influence thermal comfort.

Maintaining acceptable temperatures in buildings (by heating and cooling) uses a large proportion of global energy consumption. Building insulations also commonly use the principle of small trapped air-cells as explained above, e.g. fiberglass (specifically glass wool), cellulose, rock wool, polystyrene foam, urethane foam, vermiculite, perlite, cork, etc.

When well insulated, a building:

is energy-efficient, thus saving the owner money.

provides more uniform temperatures throughout the space. There is less temperature gradient both vertically (between ankle height and head height) and horizontally from exterior walls, ceilings and windows to the interior walls, thus producing a more comfortable occupant environment when outside temperatures are extremely cold or hot.

has minimal recurring expense. Unlike heating and cooling equipment, insulation is permanent and does not require maintenance, upkeep, or adjustment.

lowers the carbon footprint of a building.

Many forms of thermal insulation also reduce noise and vibration, both coming from the outside and from other rooms inside a building, thus producing a more comfortable environment.

Window insulation film can be applied in weatherization applications to reduce incoming thermal radiation in summer and loss in winter.

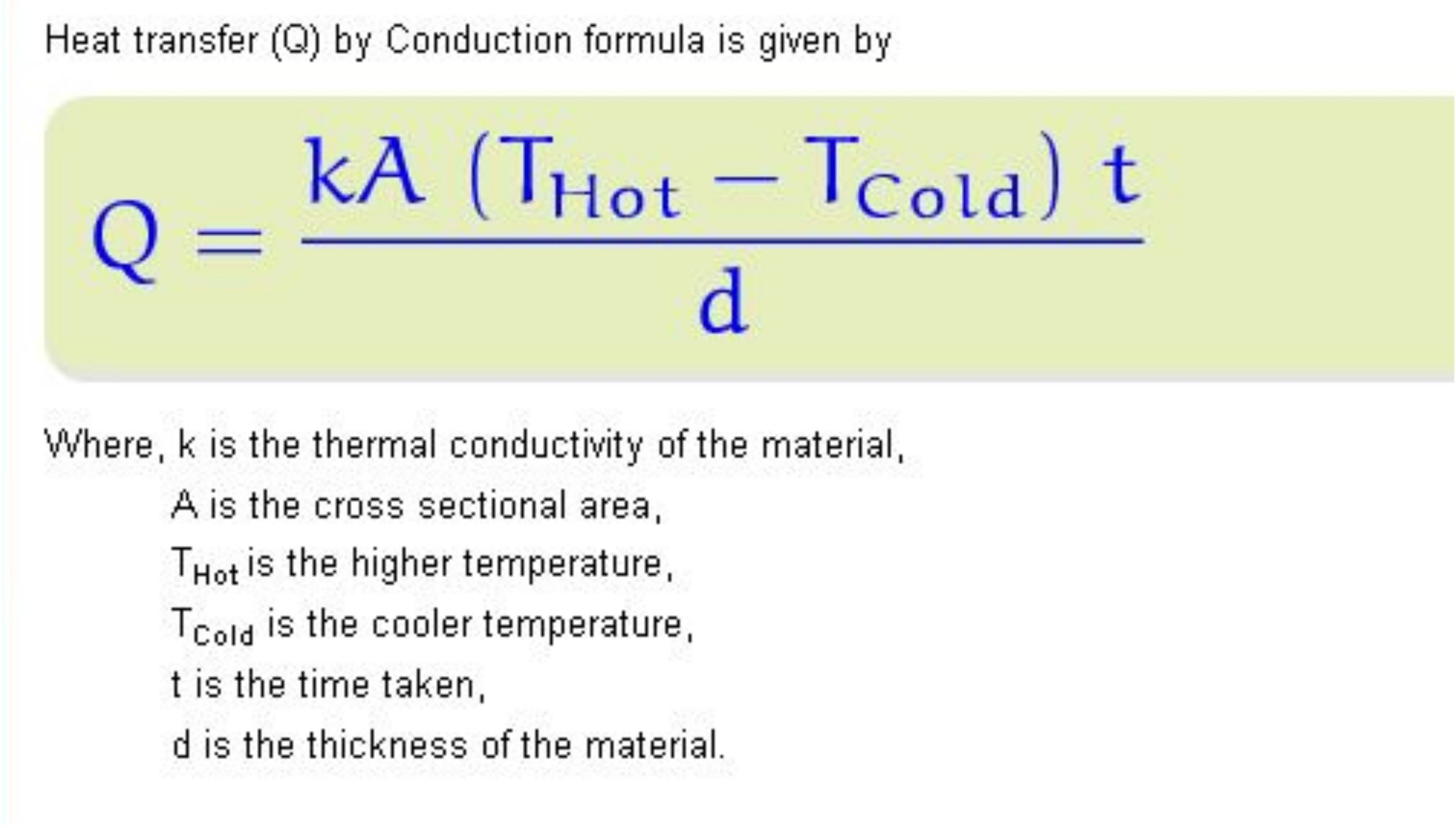
*Insulation materials are not all equal at preventing heat loss and unwanted heat gains. Their thermal performance varies and is identified by R-value (thermal resistance) or by their U-value (the reciprocal of the R-value).*

"R" stands for thermal performance. The **thermal performance of specific materials** per inch of thickness (or, say, per 50 mm of thickness) is measured by its R-value: standard fiberglass batts may have an Imperial R-value of 3.4, while blown cellulose has R-3.2 to R-3.6.

The **thermal performance or the recommended insulation for a specific building assembly (a wall, a ceiling, a floor...)** is also expressed in terms of R-value or U-value.
For instance: in cold climates, wall insulation should be R-30 to R-40 (U-value, Metric system: U-0.19 and U-0.14), which requires about 9.5 inches (24 cm) of fiberglass, 7.5 inches (19 cm) of expanded polystyrene, 8 inches (20 cm) of low-density polyurethane or 4.5 inches (12 cm) of polyso.

## R-Value, U-Value, Imperial US System and Metric System

R-value is the reciprocal of U-value or *U-factor* (the Heat Transfer coefficient). A high U-value means a high overall heat transfer. Hence: **the lower the U-value of the material the better** (similarly, **the higher the R-value the better**)



Heat transfer (Q) by Conduction formula is given by

$$Q = \frac{kA\,(T_{Hot} - T_{Cold})\,t}{d}$$

Where, k is the thermal conductivity of the material,

A is the cross sectional area,

$T_{Hot}$ is the higher temperature,

$T_{Cold}$ is the cooler temperature,

t is the time taken,

d is the thickness of the material.

# Heat insulation

## How does heat escape from your home?

Why does heat escape from your home in the first place? To understand that, it helps to know a little bit about the science of heat. As you probably know, heat travels in three different ways by processes called conduction, convection, and radiation. (If you're not sure of the difference, take a look at our main article on heat for a quick recap.)

Knowing about these three types of heat flow, it's easy to see lots of ways in which your cozy warm home is leaking heat to the freezing cold world all around it:

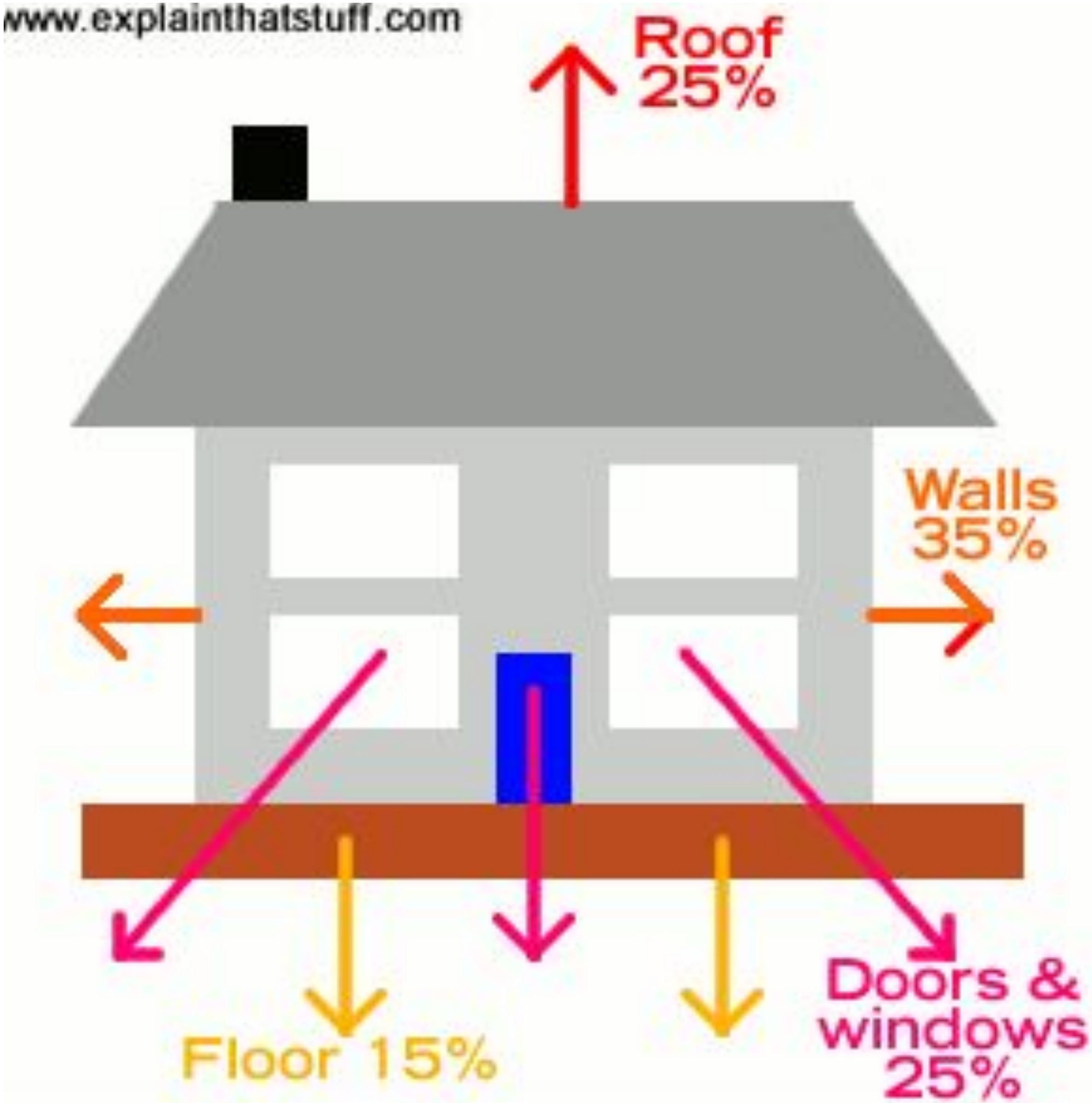
Your house is standing on cold soil or rock, so heat flows down directly into the Earth by conduction.

Heat travels by conduction through the solid walls and roof of your home. On the outside, the outer walls and the roof tiles are hotter than the atmosphere around them, so the cold air near to them heats up and flows away by convection.

Your house may seem like a big complex space with lots going on inside in but, from the point of view of physics, it's exactly the same as a camp fire in the middle of vast, cold surroundings: it constantly radiates heat into the atmosphere.

Artwork: Where does the heat escape in a typical home? It varies from building to building, but these are some rough, typical estimates. The walls give the biggest heat loss, followed by the doors and windows, the

The more heat escapes from your home, the colder it gets inside, so the more you have to use your heating and the more it costs you. The more you use your heating, the more fuel has to be burned somewhere (either in your own home or in a power plant up-state), the more carbon dioxide gas is produced, and the worse global warming becomes. It's far better to insulate your home and reduce the heat losses. That way, you'll need to use your heating much less. The great thing about home insulation is that it usually pays for itself quite quickly in lower fuel bills. Before long, it's even making you money! And it's helping the planet too.


www.explainthatstuff.com
Roof 25%
Walls 35%
Floor 15%
Doors & windows 25%

## The best way to insulate your home

Now, unfortunately, we can't build our houses exactly like a vacuum flask. We have to have air to breathe, so a vacuum's out of the question. Most people like windows too, so living in a sealed box lined with metallic foil isn't that practical either. But the basic principle of cutting down heat losses from conduction, convection, and radiation still applies nevertheless.

### Walls

Many homes, for example, have what are called cavity walls with two layers of brick or blocks between the inner rooms and the world outside and an air gap between the walls. The air gap reduces heat losses from the walls by both conduction and convection: conduction, because heat can't conduct through gases; convection, because there's relatively little air between the walls and it's sealed in, so convection currents can't really circulate.

By itself, air isn't the best insulating material to have between your walls. It's actually far more effective to have the cavities in your walls filled with expanding foam or another really good insulating material that stops heat escaping. Cavity-wall insulation, as this is known, takes only hours to install and costs relatively little. Cavity walls are often filled with loosely packed, air-filled materials such as vermiculite, shredded recycled paper, or glass fibers (specially treated to make them fireproof). These materials work in exactly the same way that your clothes work: extra layers of clothing make you warmer

## Which are the best home insulation materials?

Some forms of insulation are better than others, but how can you compare them?
The best way is to look out for a measurement called R-value.
The R-value of a material is its thermal resistance: how effectively it resists heat flowing through it. The bigger the value, the greater the resistance,
and the more effective the material is as a heat insulator.

- Single glass: 0.9.
- Air: 1 (0.5-4 inch air gap).
- Double-glazing: 2.0 (with 0.5 inch air gap).
- Vermiculite: 2.5 per inch.
- Fiberglass: 3 per inch.
- Triple-glazing: 3.2 (with 0.5 inch air gap).
- Expanded polystyrene: 4 per inch.
- Polyurethane: 6-7 per inch
- Polyisocyanurate (foil-faced): 7 per inch.
- Aerogel: Space-age insulating material: 10

## Roof

Since warm air rises, plenty of heat escapes through the roof of your home (just as lots of heat escapes from your body through your head, if you don't wear a hat). Most people also have insulation inside the roof (loft area) of their homes, but there's really no such thing as too much insulation. Loft insulation is generally made from the same materials as cavity-wall fillings—such things as rock wool and fiberglass.

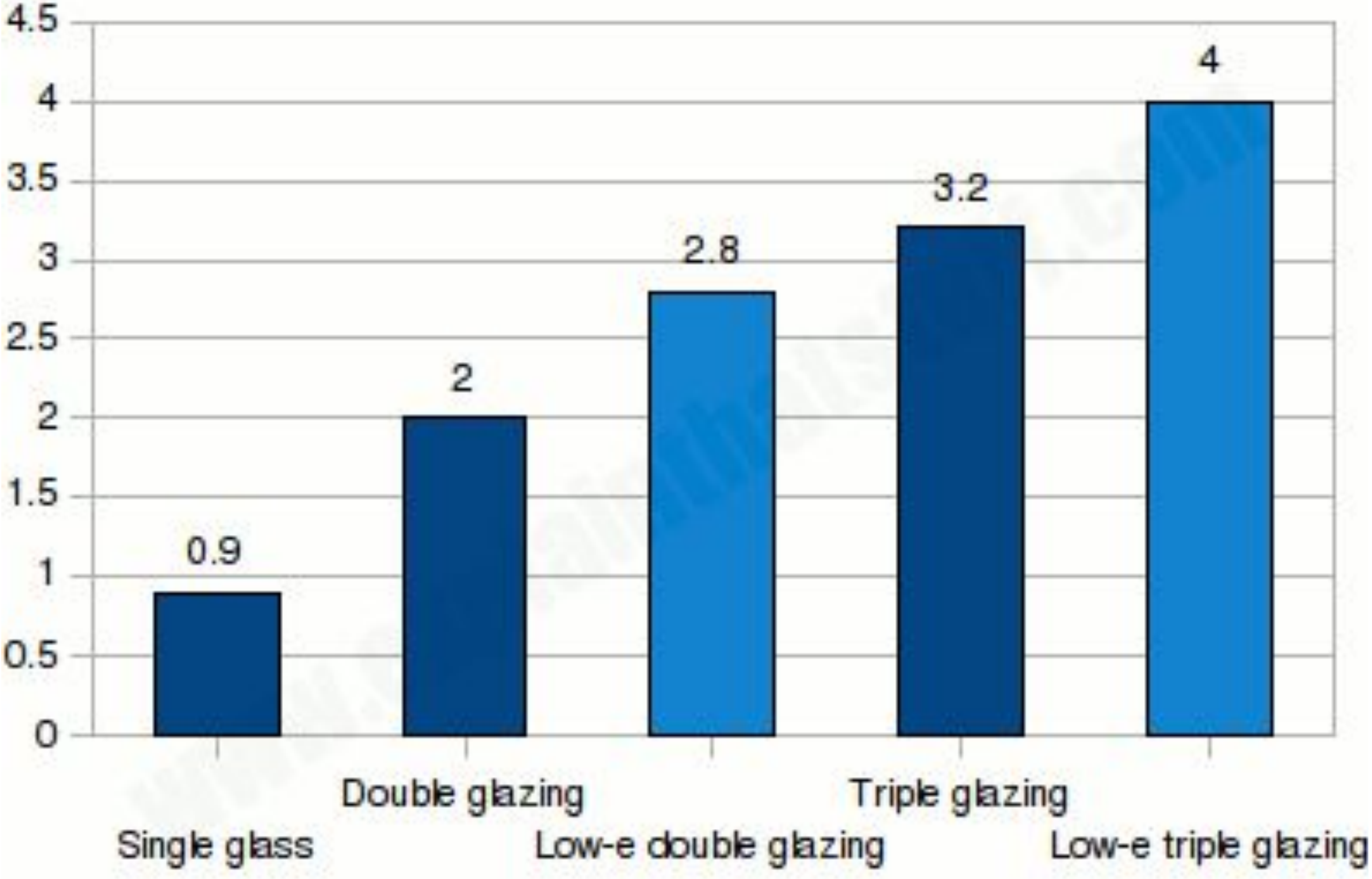
## Radiation losses

Wall and roof insulation cuts down on heat losses by convection and conduction, but what about radiation? In a vacuum flask, that problem's solved by having a reflective metallic lining—and the same idea can be used in homes too. Some homeowners install thin sheets of reflective metallic aluminum in the walls, floors, or ceilings to cut down on radiation losses. Good products of this kind can reduce radiation losses by as much as 97 percent.

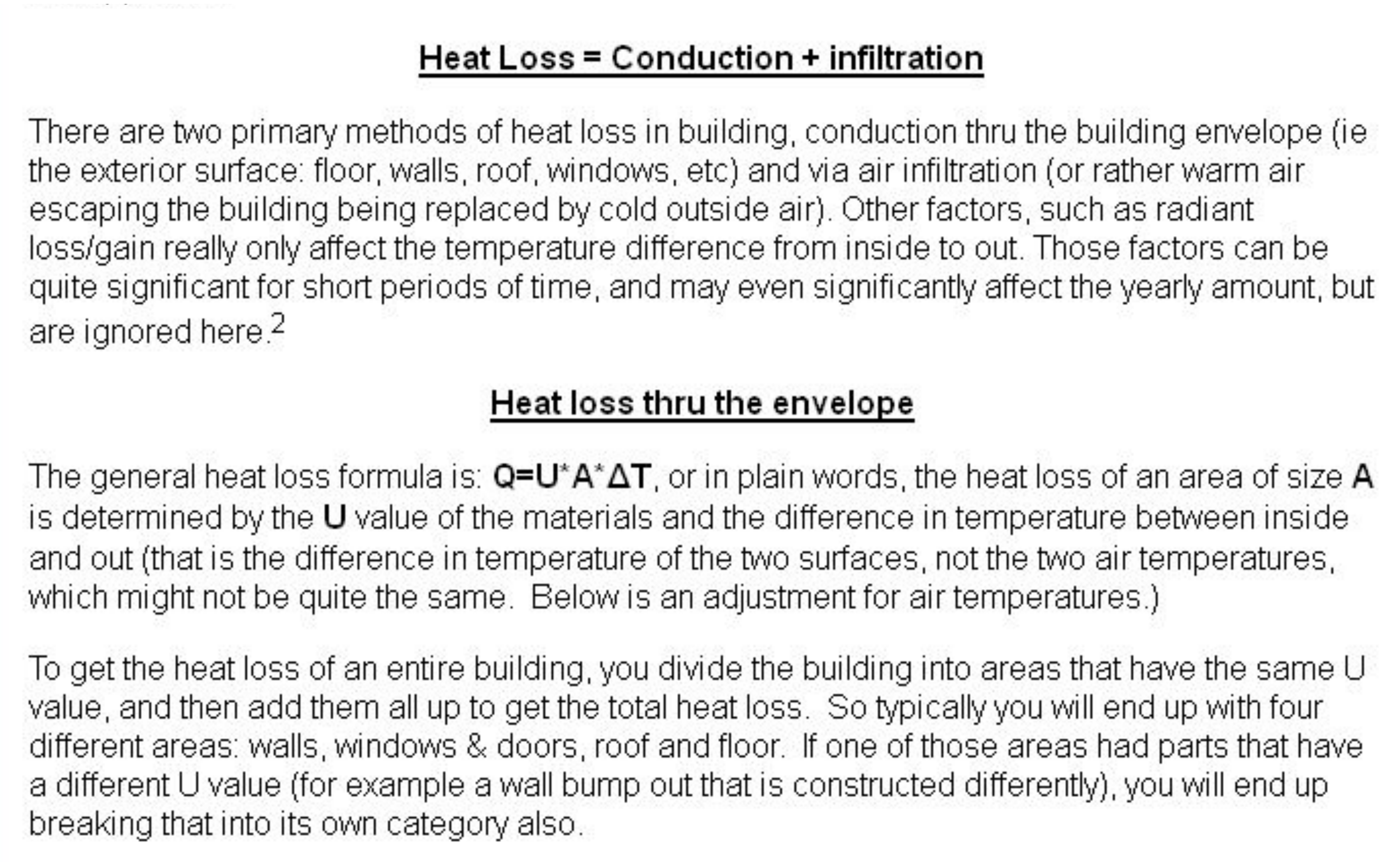
That still leaves the windows as a major source of heat loss, but there are ways to tackle that problem too. Double-glazed windows have two panes of glass separated by a sealed air gap. The air stops heat losses by conduction and convection, while the extra pane of glass reflects more light and heat radiation back into your home and reduces heat losses that way too. You can have your windows treated with a very thin reflective metallic coating or made from special thermal glazing (such as Pilkington-K, which traps heat a bit like a greenhouse) that reduces heat losses even further. (Read more in our main article on heat-reflective windows.)

Gene ave, the warmer you'll be. But the a ng on where you live and how cold i

Photo: Double glazing: the air gap between the two panes of glass provides heat insulation.



Switching from single- to double- or even triple glazing can make a big difference (darker blue), especially if you use low-e, heat-reflective glass (lighter blue). The numbers shown are R-values, with a 0.5 inch air gap.



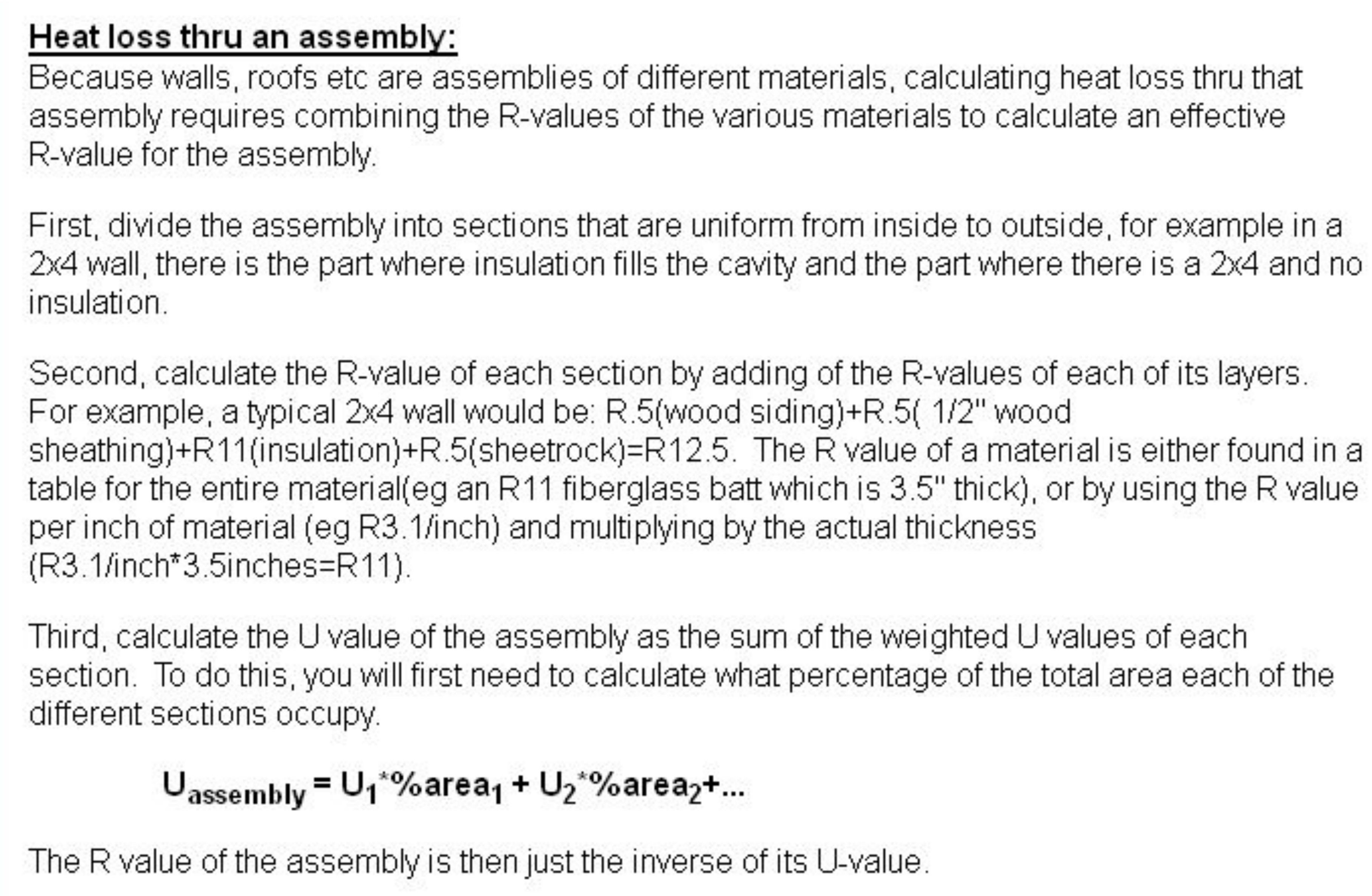
## Heat Loss = Conduction + infiltration

There are two primary methods of heat loss in building, conduction thru the building envelope (ie the exterior surface: floor, walls, roof, windows, etc) and via air infiltration (or rather warm air escaping the building being replaced by cold outside air). Other factors, such as radiant loss/gain really only affect the temperature difference from inside to out. Those factors can be quite significant for short periods of time, and may even significantly affect the yearly amount, but are ignored here.[2]

## Heat loss thru the envelope

The general heat loss formula is: **$Q=U*A*\Delta T$**, or in plain words, the heat loss of an area of size **A** is determined by the **U** value of the materials and the difference in temperature between inside and out (that is the difference in temperature of the two surfaces, not the two air temperatures, which might not be quite the same. Below is an adjustment for air temperatures.)

To get the heat loss of an entire building, you divide the building into areas that have the same U value, and then add them all up to get the total heat loss. So typically you will end up with four different areas: walls, windows & doors, roof and floor. If one of those areas had parts that have a different U value (for example a wall bump out that is constructed differently), you will end up breaking that into its own category also.



## Heat loss thru an assembly:

Because walls, roofs etc are assemblies of different materials, calculating heat loss thru that assembly requires combining the R-values of the various materials to calculate an effective R-value for the assembly.

First, divide the assembly into sections that are uniform from inside to outside, for example in a 2x4 wall, there is the part where insulation fills the cavity and the part where there is a 2x4 and no insulation.

Second, calculate the R-value of each section by adding of the R-values of each of its layers. For example, a typical 2x4 wall would be: R.5(wood siding)+R.5( 1/2" wood sheathing)+R11(insulation)+R.5(sheetrock)=R12.5. The R value of a material is either found in a table for the entire material(eg an R11 fiberglass batt which is 3.5" thick), or by using the R value per inch of material (eg R3.1/inch) and multiplying by the actual thickness (R3.1/inch*3.5inches=R11).

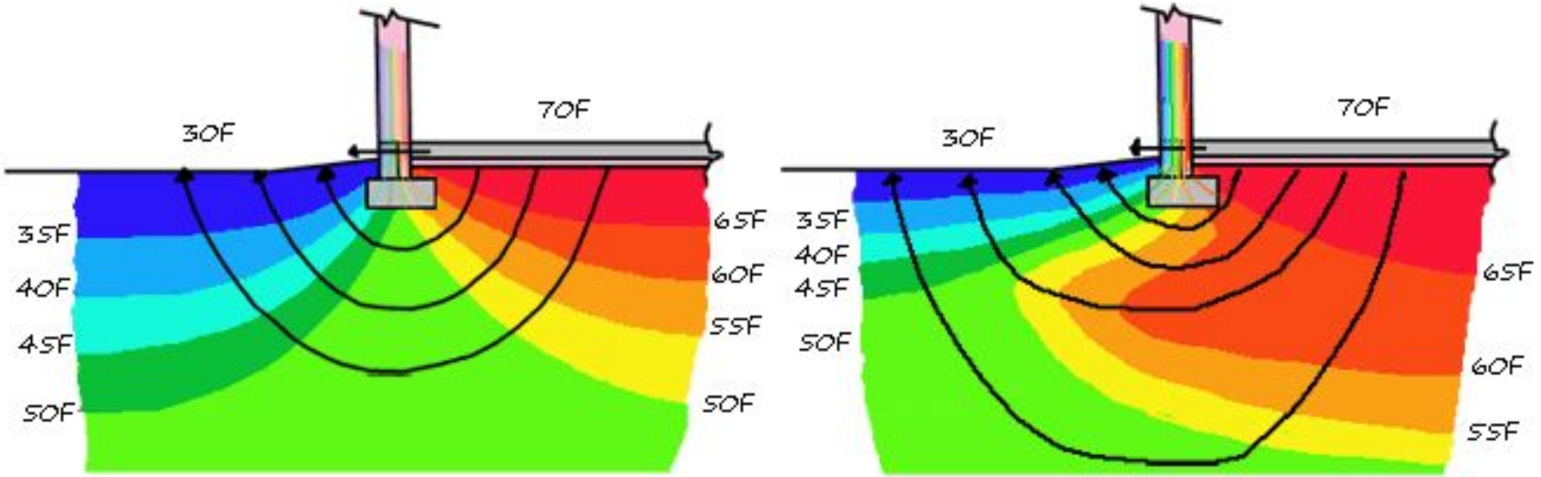
Third, calculate the U value of the assembly as the sum of the weighted U values of each section. To do this, you will first need to calculate what percentage of the total area each of the different sections occupy.

$$\mathbf{U_{assembly} = U_1{}^{*}\%area_1 + U_2{}^{*}\%area_2 + \ldots}$$

The R value of the assembly is then just the inverse of its U-value.

## Modeling slab heat loss

Unlike heat loss above ground, there appears to be no simple way to model heat loss thru the ground, and many fairly complex models have been proposed and incorporated into energy modeling software. The diagrams below illustrate the issue, by showing two possible arrangements of heat distribution in the vicinity of a slab.



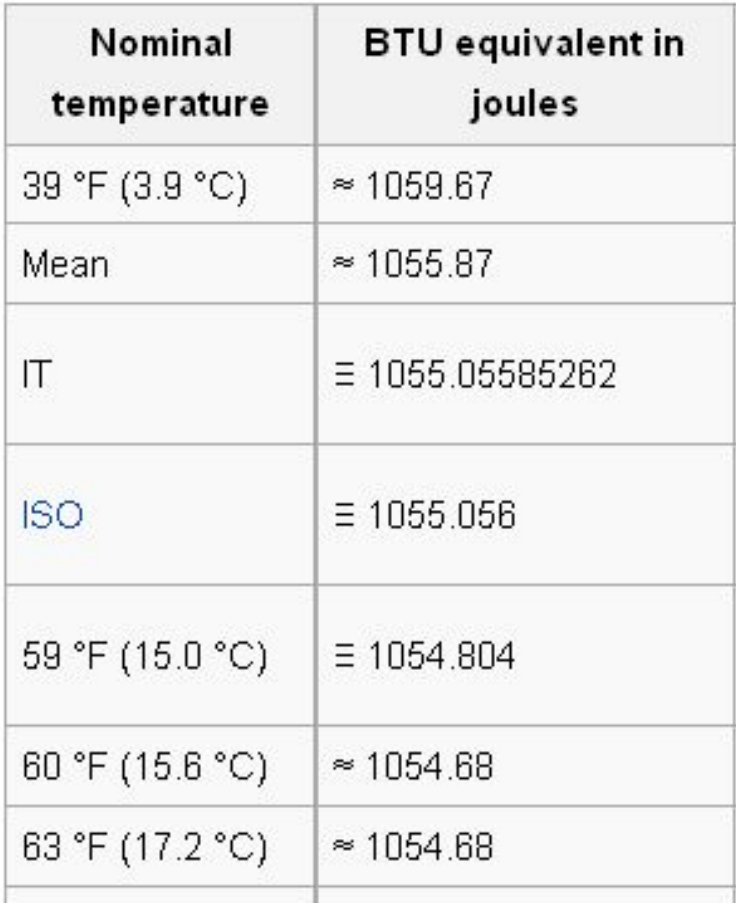
The left diagram represents an idealized steady state heat distribution during winter, assuming a uniform R value over all the soil (note that in reality the temperature gradient is continuously variable--it's just easier to draw as incremental steps). In this case, the mid point in the soil becomes the mid point in temperature between inside and out. The black arrows indicate the direction of heat flow which is the shortest path from warm to cold. The right diagram shows a different, but still possible heat distribution. This distribution could be because the R value of the soil isn't uniform, or because the weather is making a long term change from warm to cold. Since the heat distribution is different, the heat flow is also different: longer paths means slower heat loss since the R value of the longer path is greater. Note that in these simplified diagrams the deep ground temperature is assumed to be 50°F[6] .

# British thermal unit

The **British thermal unit** (**BTU** or **Btu**) is a traditional unit of work equal to about 1055 joules. It is the amount of work needed to raise the temperature of one pound of water by one degree Fahrenheit (Physical analogue: one four-inch wooden kitchen match consumed completely generates approximately 1 BTU). In science, the joule, the SI unit of energy, has largely replaced the BTU.

The BTU/h is most often used as a measure of power in the power, steam generation, heating, and air conditioning industries, and also as a measure of agricultural energy production (BTU/kg).[*verification needed*] It is still used in metric English-speaking countries (such as Canada). In North America, the heat value (energy content) of fuels is expressed in BTUs.

A BTU is the amount of heat required to raise the temperature of 1 avoirdupois pound of liquid water by 1 degree Fahrenheit at a constant pressure of one atmosphere. As with the calorie, several definitions of the BTU exist, because the temperature response of water to heat energy is non-linear. This means that the change in temperature of a water mass caused by adding a certain amount of heat to it will be a function of the water's initial temperature. Definitions of the BTU based on different water temperatures can therefore vary by up to 0.5%. A BTU can be approximated as the heat produced by burning a single wooden kitchen match or as the amount of energy it takes to lift a one-pound weight 778 feet (237 m)

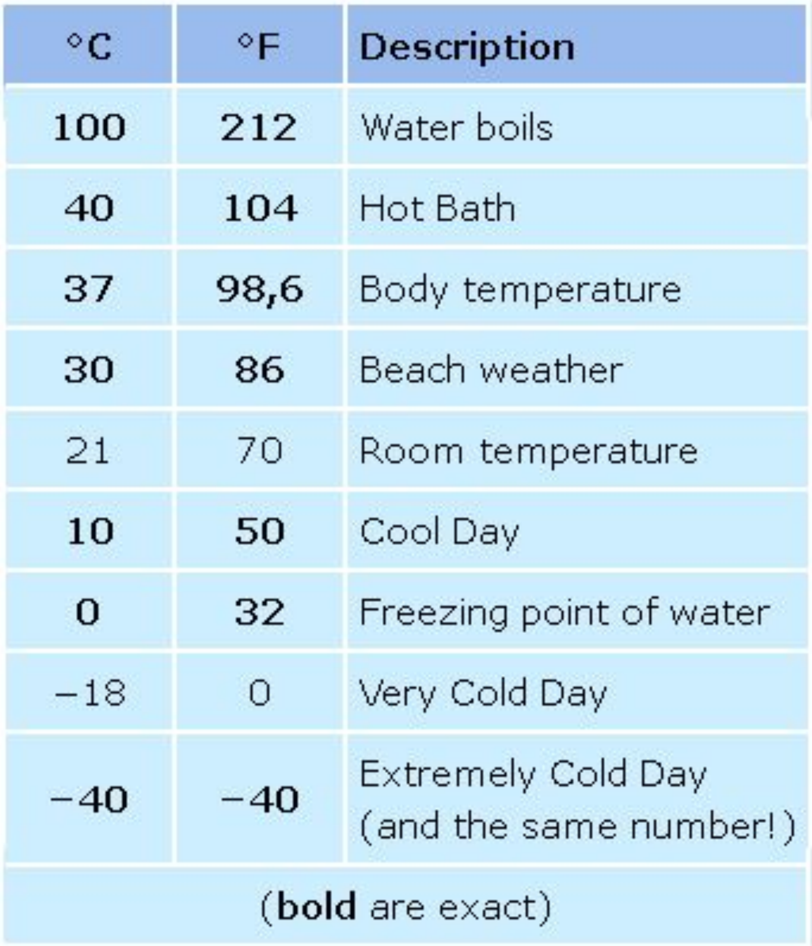


| Nominal temperature | BTU equivalent in joules |
|---|---|
| 39 °F (3.9 °C) | ≈ 1059.67 |
| Mean | ≈ 1055.87 |
| IT | ≡ 1055.05585262 |
| ISO | ≡ 1055.056 |
| 59 °F (15.0 °C) | ≡ 1054.804 |
| 60 °F (15.6 °C) | ≈ 1054.68 |
| 63 °F (17.2 °C) | ≈ 1054.68 |

## One BTU is approximately:

1.054 to 1.060 kJ (kilojoules)
0.293071 W·h (watt hours)
252 to 253 cal (calories, or "little calories")
0.25 kcal (kilocalories, "large Calories," or "food Calories")
25,031 to 25,160 ft·pdl (foot-poundal)
778 to 782 ft·lbf (foot-pounds-force)
5.40395 (lbf/in$^2$)·ft$^3$

# Typical Temperatures



| °C | °F | Description |
|---|---|---|
| **100** | **212** | Water boils |
| **40** | **104** | Hot Bath |
| **37** | **98,6** | Body temperature |
| **30** | **86** | Beach weather |
| 21 | 70 | Room temperature |
| **10** | **50** | Cool Day |
| **0** | **32** | Freezing point of water |
| −18 | 0 | Very Cold Day |
| **−40** | **−40** | Extremely Cold Day<br>(and the same number!) |
| (**bold** are exact) | | |

*16 is about 61*

*28 is about 82*

Celsius to Fahrenheit: $(°\mathrm{C} \times {}^{9}/_{5}) + 32 = °\mathrm{F}$
Fahrenheit to Celsius: $(°\mathrm{F} - 32) \times {}^{5}/_{9} = °\mathrm{C}$

**Example:** Convert 26° Celsius *(a nice warm day)* to Fahrenheit

*First:* 26° × 9/5 = 234/5 = 46,8
*Then:* 46,8 + 32 = **78,8°** F

**Example:** Convert 98,6° Fahrenheit *(normal body temperature)* to Celsius

*First:* 98,6° – 32 = 66,6
*Then:* 66,6 × 5/9 = 333/9 = **37°** C

| Mode | Transfer Mechanism | Rate of heat transfer (*W*) | Thermal Resistance (*K/W*) |
|---|---|---|---|
| Conduction | Diffusion of energy due to random molecular motion | $q = -kA\frac{dT}{dx}$ | $R_k = \frac{L}{kA}$ |
| Convection | Diffusion of energy due to random molecular motion plus bulk motion | $q = h\,A(T_s - T_\infty)$ | $R_c = \frac{1}{\bar{h}A}$ |
| Radiation | Energy transfer by electromagnetic waves | $q = \sigma\,\varepsilon\,A(T_s^4 - T_{sur}^4)$ | $R_r = \frac{T_s - T_{sur}}{\sigma\varepsilon\,A(T_s^4 - T_{sur}^4)}$ |

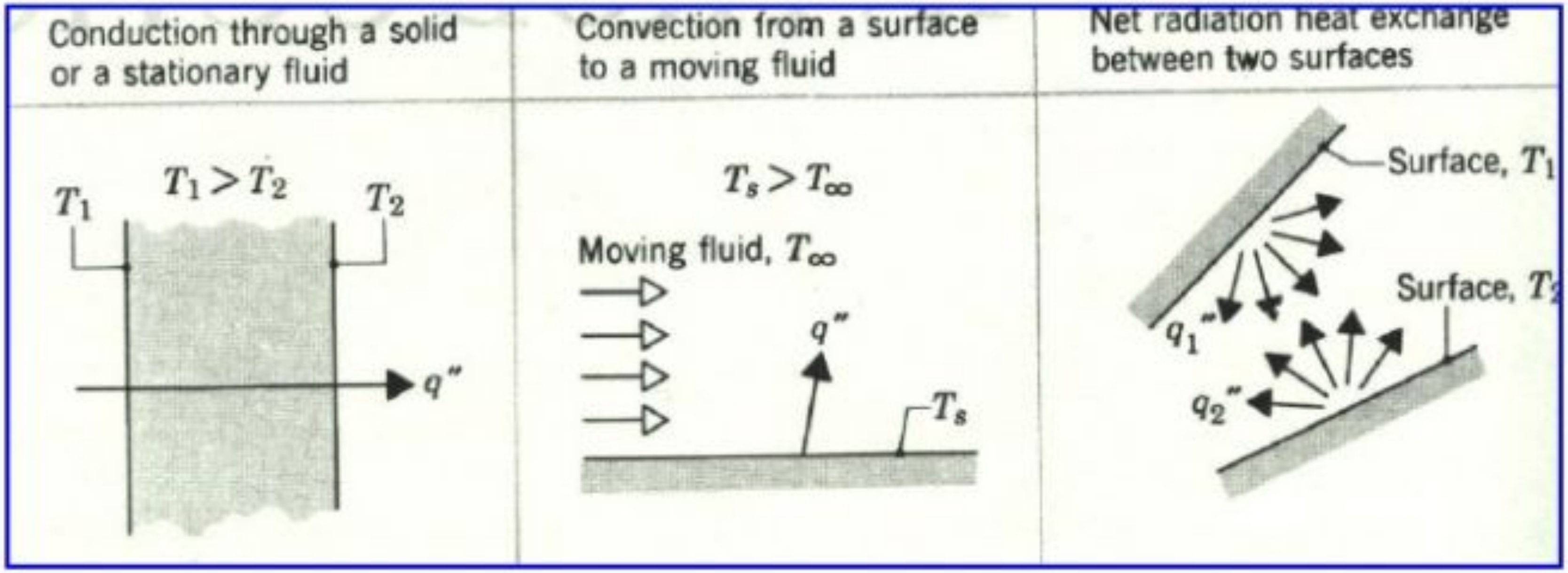


***Figure (1.5) Conduction, Convection and Radiation Heat transfer Modes***

***Example 1.1***

Calculate the rate of heat transfer by natural convection between a shed roof of area 20 m x 20 m and ambient air, if the roof surface temperature is *27°C*, the air temperature *3°C*, and the average convection heat transfer coefficient *$10\ W/m^2\ K$*.

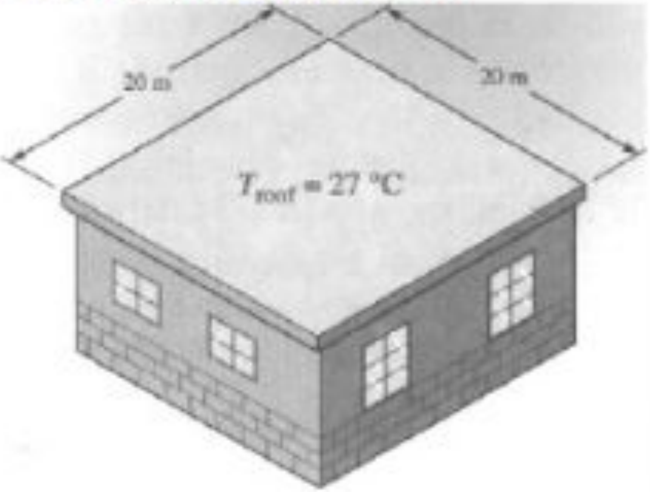


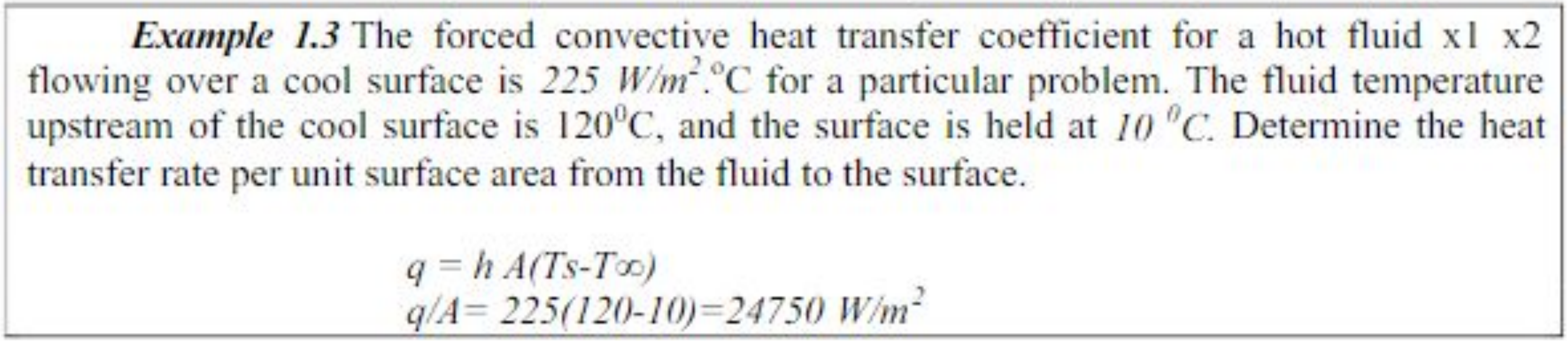
***Figure 1.7*** *Schematic Sketch of Shed for Analysis of Roof Temperature.*

***Solution***

Assume that steady state exists and the direction of heat flow is from the air to the roof. The rate of heat transfer by convection from the air to the roof is then given by Eq:

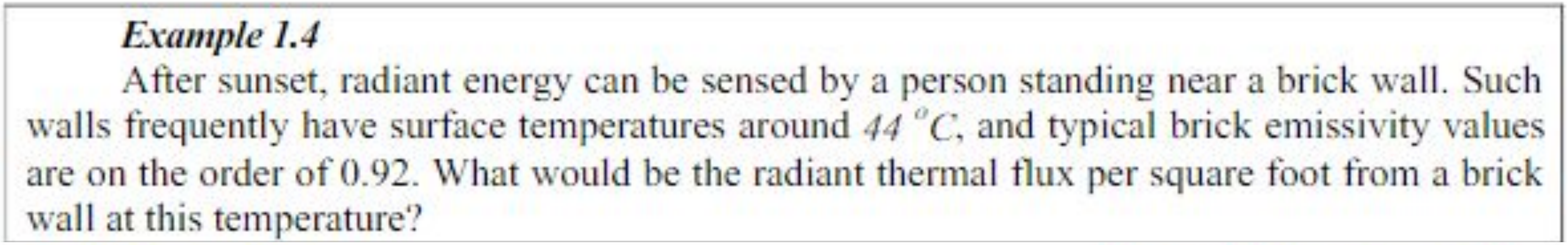
$$\begin{aligned} q_c &= \bar{h}_c A_{roof}(T_{air} - T_{roof}) \\ &= 10\,(\mathrm{W/m^2\,K}) \times 400\,\mathrm{m^2}\,(-3 - 27)\mathrm{^\circ C} \\ &= -120{,}000\ \mathrm{W} \end{aligned}$$

*Note* we initially assumed that the heat transfer would be from the air to the roof. But since the heat flow under this assumption turns out to be a negative quantity the *direction of heat flow is actually from the roof to the air.*



***Example 1.3*** The forced convective heat transfer coefficient for a hot fluid x1 x2 flowing over a cool surface is *225 $W/m^2.^{\circ}C$* for a particular problem. The fluid temperature upstream of the cool surface is $120^0$C, and the surface is held at *$10\ ^0C$*. Determine the heat transfer rate per unit surface area from the fluid to the surface.

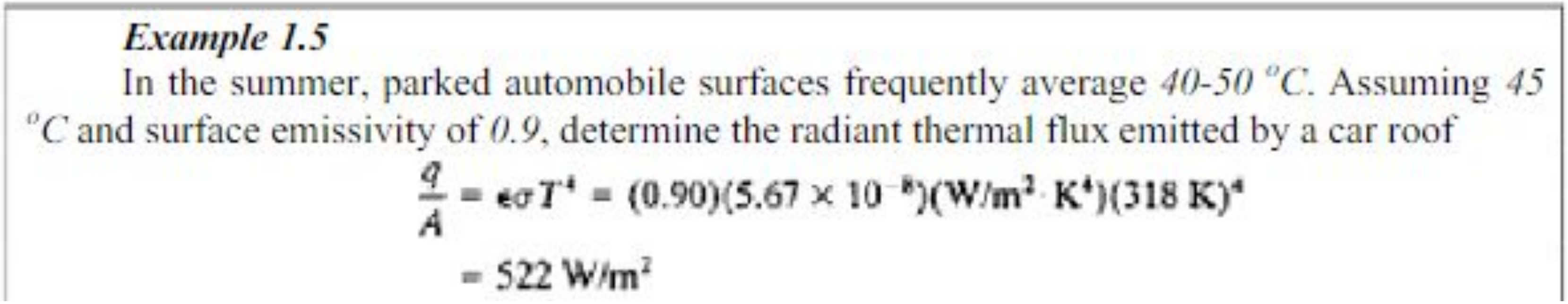
$$q = h\,A(Ts-T\infty)$$
$$q/A= 225(120-10)=24750\ W/m^2$$



***Example 1.4***

After sunset, radiant energy can be sensed by a person standing near a brick wall. Such walls frequently have surface temperatures around *$44\ ^oC$*, and typical brick emissivity values are on the order of 0.92. What would be the radiant thermal flux per square foot from a brick wall at this temperature?

$$\frac{q}{A} = \epsilon\sigma T^4 = (0.92)(5.6697\times 10^{-8})(\mathrm{W/m^2\cdot K^4})(44+273)^4\ \mathrm{K^4}$$
$$= (0.92)(5.6697\times 10^{-8})(317)^4 = 527\ \mathrm{W/m^2}$$



***Example 1.5***

In the summer, parked automobile surfaces frequently average *$40\text{-}50\ ^oC$*. Assuming *$45\ ^oC$* and surface emissivity of *0.9*, determine the radiant thermal flux emitted by a car roof

$$\frac{q}{A} = \epsilon\sigma T^4 = (0.90)(5.67\times 10^{-8})(\mathrm{W/m^2\cdot K^4})(318\ \mathrm{K})^4$$
$$= 522\ \mathrm{W/m^2}$$

***Example 1.7***

Calculate the thermal resistance and the rate of heat transfer through a pane of window glass *(k = 0.78 W/m K)* 1 m high, *0.5 m* wide, and *0.5 cm* thick, if the outer-surface temperature is *24°C* and the inner-surface temperature is *24.5°C*

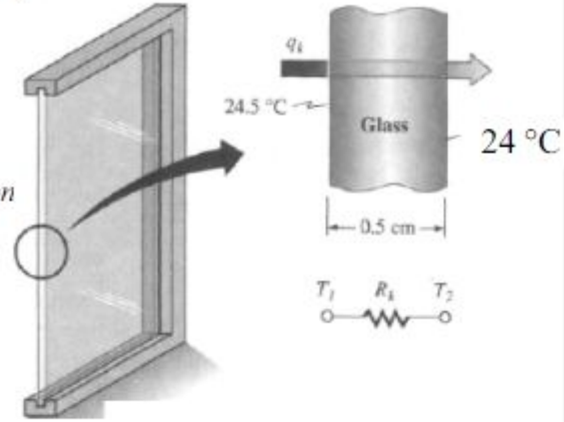


***Figure 1.5*** *heat transfer by con*

**Solution**

Assume that steady state exists and that the temperature is uniform over the inner and outer surfaces. The thermal resistance to conduction $R_k$ is from Eq

$$R_k = \frac{L}{kA} = \frac{0.005m}{0.78w/mk \times 1m \times 0.5m} = 0.0128\frac{K}{W}$$

The rate of heat loss from the interior to the exterior surface is

$$q = \frac{\Delta T}{R_k} = \frac{24.5 - 24}{0.0128} = 39.1 \text{ W}$$