Field	***Central Heating***
Chapter	***Heating Theory & Heating Techniques***
Subtitle	***Thermal Losses***

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Thermal losses

Heat Loss – Definition

Heat losses from hotter objects occur by three mechanisms. There is no material which can completely prevent heat losses, heat losses can be only minimized. Thermal losses are included on Thermal Engineering , and it is one of the most important phenomenon.

Heat Losses

While thermal energy refers to the total energy of all the molecules within the object, heat is the amount of energy flowing from one body to another spontaneously due to their temperature difference. Heat is a form of energy, but it is energy in transit. Heat is not a property of a system. However, the transfer of energy as heat occurs at the molecular level as a result of a temperature difference. When a temperature difference does exist heat flows spontaneously from the warmer system to the colder system, never the reverse. This direction of thermodynamic processes is given by the second law of thermodynamics.

As a result, any object hotter than the surroundings must continuously lose a part of its thermal energy. This is a natural behavior of all objects. When the flow of heat stops, they are said to be at the same temperature. They are then said to be in thermal equilibrium. Heat losses from hotter objects occur by three mechanisms (either individually or in combination):

- **Heat Conduction**. Heat conduction, also called diffusion, occurs within a body or between two bodies in contact. It is the direct microscopic exchange of kinetic energy of particles through the boundary between two systems. When an object is at a different temperature from another body or its surroundings
- Heat Convection. Heat convection depends on motion of mass from one region of space to another. Heat convection occurs when bulk flow of a fluid (gas or liquid) carries heat along with the flow of matter in the fluid.

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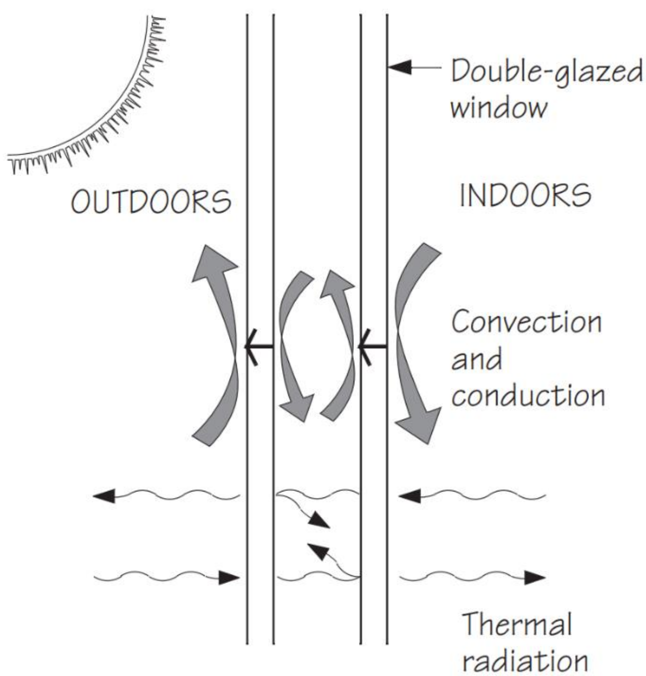
- **Thermal Radiation**. Radiation is heat transfer by electromagnetic radiation, such as sunshine, with no need for matter to be present in the space between bodies.

The 4 types of Heat Loss in Buildings

There are four types of heat loss within any building. These include thermal radiation, conduction, convection, and air infiltration.

To understand these heat loss mechanisms or heat transfer, let’s start at **the surface of a door inside a warm building with a cold outside temperature.** The door itself is conducting heat out of the building because heat always flows from warm to cold. So the inside surface of the door is slightly cool because it is sending all of its heat outside. By contrast, the outside surface of the door is very warm relative to the air’s outside temperature. This is where radiation and convection come in.



Radiation under normal circumstances is driven by a surface’s emissivity, the area of a surface, and the temperature of that surface relative to the surrounding fluid. So with a big door and low outside temperatures, if the door is an excellent thermal conductor (meaning it is letting a lot of heat through it), then the radiation heat transfer will be sending all the heat away from the surface of the door quickly.

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Convection will also be aiding in this transfer of thermal energy away from the door**. If the air outside the door is moving quickly, if it is windy outside, then the heat will be whisked away from the surface of the door.** By continually replacing the air at the door's surface, the temperature difference between the door's surface and the thin layer of air right next to it is never able to change, and the radiation heat transfer never slows down.

By contrast, if the air outside was not moving and convection was low, then the radiation heat transfer would slow down because the thin layer of air right next to the surface of the door would have a chance to warm slightly, thereby lowering the relative temperature difference between the surface of the door and the surrounding fluid.

Back on the inside surface of the door, similar principals are at work. Radiation and convection are functioning to send more heat to the surface of the door. Remember, the inside surface is cool because it is conducting heat from inside to the cold outside. The principle of thermal equilibrium demands that all objects and fluids in contact with one another come to the same temperature. This radiation can occur within the glazing of the windows, causing the heat to radiate outwards, escaping.

Conduction can move through all of the solid parts of the door. (Jambs, panels, sill, etc.). The heat that is lost from air movement near to and in the space between the glass or the door and frame is caused by convection.

With **air infiltration**, cracks within the joins or underneath the door can cause heat to move out of the building.

<u>How to reduce heat loss in a building</u>

The less thermal insulation the building fabric has, the greater the heat loss will be. Designers use many different techniques to reduce the heat loss of a building and increase their ability to capture or generate their energy.

<u>How to calculate heat loss in a building</u>

When we have the R, K, and/or U-values of all the external building fabric elements, volume, and average ventilation rate, you can calculate its overall heat loss coefficient. This is done through a formula that considers many variables such as heat transmission, the element's conductance, ventilation, thermal resistance, etc.

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The “R” value of a material refers to its resistance to heat flow through the material. “K” measures the heat flow through an individual substance. “U” measures the overall building heat loss and is, therefore a more complex (but complete) value.

When calculating heat loss, it isn’t surprising doors receive a lot of attention. Without a solid door that keeps the air circulation to an absolute minimum, an extreme amount of heat can be lost.

$$U = \frac{1}{{}^{1}/_{h_1} + {}^{L_1}/_{k_1} + {}^{1}/_{h_2}}$$

<u>Example – Heat Loss through a Wall</u>

A major source of heat loss from a house is through walls. Calculate the rate of heat flux through a wall 3 m x 10 m in area (A = 30 m2). The wall is 15 cm thick (L1) and it is made of bricks with the thermal conductivity of k1 = 1.0 W/m.K (poor thermal insulator). Assume that, the indoor and the outdoor temperatures are 22°C and -8°C, and the convection heat transfer coefficients on the inner and the outer sides are h1 = 10 W/m2K and h2 = 30 W/m2K, respectively. Note that, these convection coefficients strongly depend especially on ambient and interior conditions (wind, humidity, etc.).

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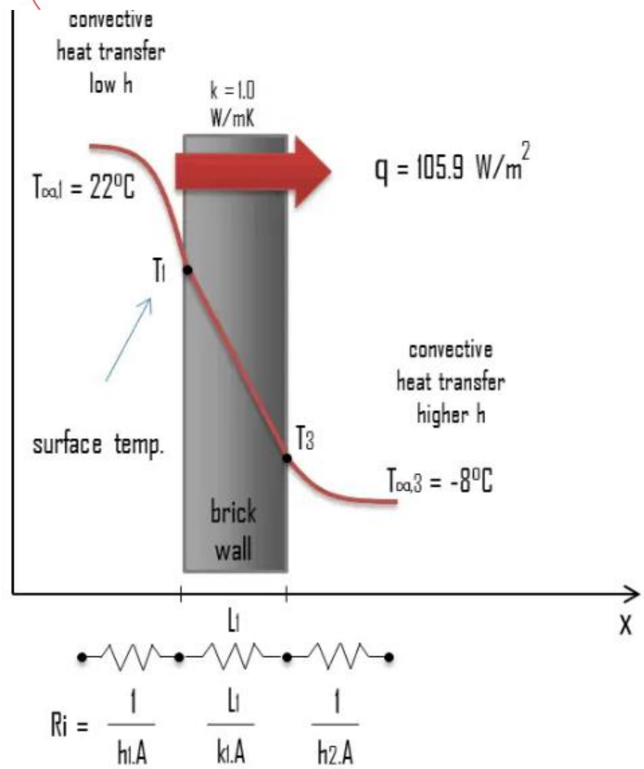

$$q = U\Delta T = \frac{(T_{\infty,1} - T_{\infty,3})}{{}^{1}/_{h_1} + {}^{L_1}/_{k_1} + {}^{1}/_{h_2}}$$

where
q is the local heat flux [W.m^{-2}]
U is the overall heat transfer coefficient [W.m^{-2}K]
k is the materials conductivity [W.m^{-1}.K^{-1}]
h is the convection heat transfer coefficient [W.m^{-2}K]

- Calculate the heat flux (heat loss) through this non-insulated wall.
- Now assume thermal insulation on the outer side of this wall. Use expanded polystyrene insulation 10 cm hick (L2) with the thermal conductivity of k2 = 0.03 W/m.K and calculate the heat flux (heat loss) through this composite

Solution:
As was written, many of the heat transfer processes involve composite systems and even involve a combination of both conduction and convection. With these composite systems, it is often convenient to work with an overall heat transfer coefficient**,** known as a **U-factor**. The U-factor is defined by an expression analogous to **Newton's law of cooling**:

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$$q = U\Delta T$$

where

q is the local heat flux density [W.m^{-2}]

U is the overall heat transfer coefficient [W.m^{-2}.K]

ΔT is the temperature difference [K]

The overall heat transfer coefficient is related to the total thermal resistance and depends on the geometry of the problem.

1. **Bare wall**

Assuming one-dimensional heat transfer through the plane wall and disregarding radiation, the overall heat transfer coefficient can be calculated as:

$$U = \frac{1}{{}^{1}/_{h_1} + {}^{L_1}/_{k_1} + {}^{1}/_{h_2}}$$

where

U is the overall heat transfer coefficient [W.m^{-2}K]

k is the materials conductivity [W.m^{-1}.K^{-1}]

h is the convection heat transfer coefficient [W.m^{-2}K]

The overall heat transfer coefficient is then:

U = 1 / (1/10 + 0.15/1 + 1/30) = 3.53 W/m2K

The heat flux can be then calculated simply as:

q = 3.53 [W/m2K] x 30 [K] = 105.9 W/m2

The total heat loss through this wall will be:

qloss = q . A = 105.9 [W/m2] x 30 [m2] = 3177W

2. **Composite wall with thermal insulation**

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Assuming one-dimensional heat transfer through the plane composite wall, no thermal contact resistance and disregarding radiation, the overall heat transfer coefficient can be calculated as:

$$U = \frac{1}{1/h_1 + L_1/k_1 + L_2/k_2 + 1/h_2}$$

where
U is the overall heat transfer coefficient [$W.m^{-2}K$]
k is the materials conductivity [$W.m^{-1}.K^{-1}$]
h is the convection heat transfer coefficient [$W.m^{-2}K$]

The **overall heat transfer coefficient** is then:

U = 1 / (1/10 + 0.15/1 + 0.1/0.03 + 1/30) = 0.276 W/m2K

The heat flux can be then calculated simply as:

q = 0.276 [W/m2K] x 30 [K] = 8.28 W/m2

The total heat loss through this wall will be:

qloss = q . A = 8.28 [W/m2] x 30 [m2] = 248 W

As can be seen, an addition of thermal insulator causes significant decrease in heat losses. It must be added, an addition of next layer of thermal insulator does not cause such high savings. This can be better seen from the thermal resistance method, which can be used to calculate the heat transfer through **composite walls**. The rate of steady heat transfer between two surfaces is equal to the temperature difference divided by the total thermal resistance between those two surfaces.

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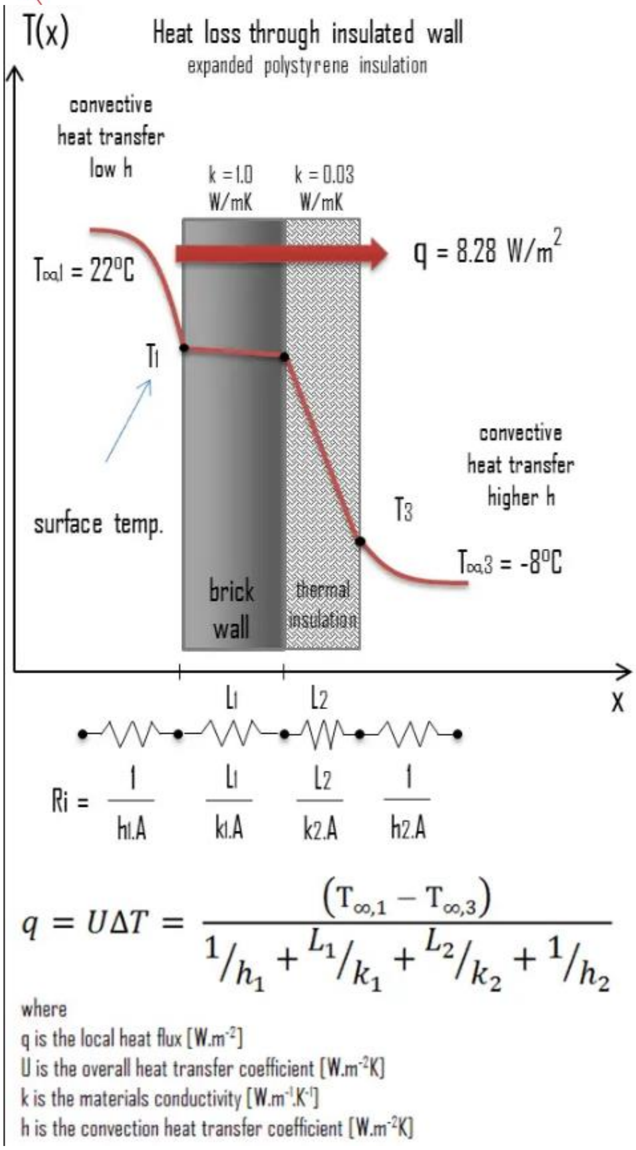

$$\dot{Q}_{wall} = -\frac{T_{\infty,1} - T_{\infty,3}}{R_{total}} = -\frac{T_{\infty,1} - T_{\infty,3}}{R_{\infty,1} + R_1 + R_2 + R_1 + R_{1,\infty}}$$

Heat loss through windows

A major source of heat loss from a house is through the windows. Calculate the rate of heat flux through a glass window 1.5 m x 1.0 m in area and 3.0 mm thick, if the temperatures at the inner and outer surfaces are 14.0°C and 13.0°C, respectively. Calculate the heat flux through this window.

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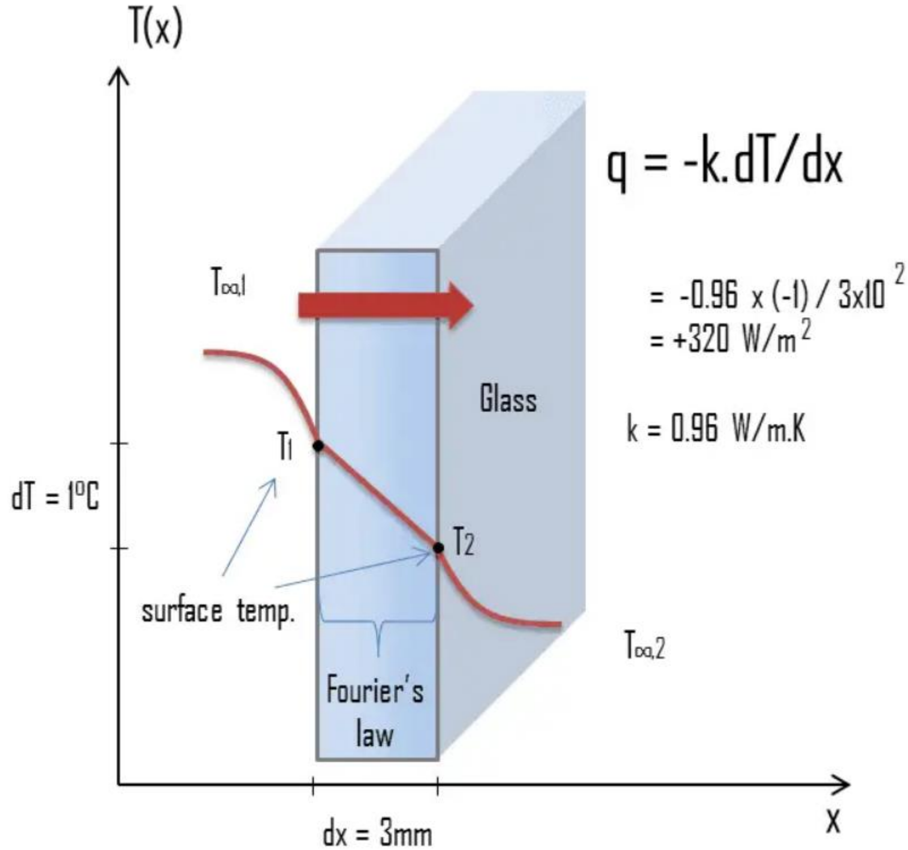

Solution:
At this point, we know the temperatures at the surfaces of material. These temperatures are given also by conditions inside the house and outside the house. In this case, heat flows by conduction through the glass from the higher inside temperature to the lower outside temperature. We use the heat conduction equation:

$$q = -k\nabla T$$

where
q is the local heat flux density [W.m^{-2}]
k is the materials conductivity [W.m^{-1}.K^{-1}]
∇T is the temperature gradient [K.m^{-1}]

We assume that the thermal conductivity of a common glass is k = 0.96 W/m.K.

The heat flux will then be:

q = 0.96 [W/m.K] x 1 [K] / 3.0 x 10-3 [m] = 320 W/m2

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The total heat loss through this window will be:

qloss = q x A = 320 x 1.5 x 1.0 = 480W

It must be added, 15°C is not very warm for the living room of a house. But this temperature does not correspond to the interior temperature but correspond to the surface temperature. Due to the finite convective heat transfer coefficient, there is always a considerable temperature drop between the interior temperature and the window surface temperature. Note that, both convection coefficients strongly depend especially on ambient and interior conditions (wind, humidity, etc.).

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