# TEMPERATURE AND HUMIDITY BALANCE OF PREMISES

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## Contents



## Summary

This article describes the mechanisms affecting the thermal behavior of buildings. This behavior depends upon the temperature and humidity balance in premises. First the physical mechanisms of heat transfer are explained, followed by a description of the heat and humidity sources and sinks in premises. The next three sections deal with the physics of psychrometry, necessary for understanding the humidity balance. Finally, the last section describes the principles of humidification and dehumidification systems.

## 1. Principles of Heat Transfer in Buildings

Heat transfer occurs when two thermodynamic systems have different temperatures. According to the Second Law of Thermodynamics, the heat flows from the system of higher temperature to that of lower temperature. There are three modes of heat transfer:

- Conduction
- Convection
- Radiation

The differences between these modes will be analyzed later on but at this point a major difference can be already pointed out. If the heat is transferred via conduction or convection, the heat flow stops as soon as the temperatures of the two thermodynamic systems become equal. Then the systems arrive to a “static” equilibrium. Things are different when heat is transferred via radiation. In this case the heat flow between the two systems does not stop even when their temperatures become equal (unless this is the absolute zero). Each system continues to radiate energy, but the flow radiated from the first system, equals the flow radiated from the second system. Since each system radiates the same amount of radiation as the one it receives, the total effect is zero.

Conduction is the basic heat transfer mode through solids and, in some cases, through fluids (if these are still or through a part of their boundary layer). Conduction takes place only if the two systems are in physical contact. The process is described mathematically by the so-called Fourier law. Let us suppose that we want to describe the heat flow across a homogeneous wall, whose two surfaces have different temperatures $T_1$ and $T_2$ respectively. The Fourier law in this case takes its most simple form (assuming that $T_1 > T_2$):

$$q = kA\frac{T_1 - T_2}{e} \tag{1}$$

where $k$ ($W \cdot m^{-2} K^{-1}$) is a coefficient called thermal conductivity, $A$ ($m^2$) is the surface of the wall, normal to the heat flow, and $e$ (m) is the thickness of the wall. Thermal conductivity characterizes the material of the wall. The well known insulating materials used in buildings and in other engineering applications have low thermal conductivity. This is also a function of temperature, although dependence on this is not great for the materials and temperature ranges encountered in the thermal behavior of buildings are therefore usually neglected. Thermal conductivity values for various materials can be found in tables.

The physical mechanism is the following: the molecules at the warmer surface oscillate more and therefore these collide more frequently with the molecules in the layers below them. Therefore there is a transfer of energy. This process between layers continues until the surface of the lower temperature starts to rise (unless heat is removed by other means).

Convection is the mechanism by which heat is transferred inside fluids and at the interface between fluids and solids. When a fluid is heated by some means, its temperature locally changes and therefore its density drops, making this fluid element less heavy than its surroundings. Due to the buoyancy forces developing in this fluid element, this will then start moving. Automatically, due to the continuity of fluids, this is replaced by another cooler element; this element is warmed up, and so on. From this description it is clear that convection also requires physical contact.

In the mechanism just described, it can be seen that motion is induced by the heat transfer process itself. This is natural convection. Heat can be also transferred, even if the motion of the fluid is triggered by another fluid exogenous to the heat transfer process, like a ventilator or a pump. This process is called forced convection. In both cases however, the amount of heat transferred is given by the so-called Newton law:

$$q = h \cdot A(T_1 - T_2) \tag{2}$$

where $h$ ($W \cdot m^{-2} K^{-1}$) is the convective heat transfer coefficient. The determination of the appropriate heat transfer coefficient is an important issue when studying convective heat transfer phenomena. This is because this coefficient depends on a series of parameters, including temperature, fluid velocity, type of convection (natural or forced), etc. The description of the methodology for determining this is however beyond the scope of this article.

Comparing conduction and convection we can see that for both to develop, physical contact between the systems of different temperatures is necessary. The basic difference is that while during convective heat transfer there is macroscopic motion of the matter, in conductive heat transfer the matter remains macroscopically still but the change in motion occurs at microscopic level.

The third heat transfer mechanism is radiation. There are two main differences between this mechanism and the two previous ones. The first is that heat can be transferred via radiation between two systems even if these are not in contact directly or indirectly, i.e., when there is not any matter between them. This is due to the fact that in this case heat is transferred in the form of electromagnetic waves, which can propagate in the void. The second difference is that systems exchanging heat by radiation arrive at a dynamic equilibrium, as explained at the start of this section.

The notion of radiation is directly linked to that of wavelength. One therefore might ask what the spectrum of the radiated heat energy is. Theoretically, every body at a temperature higher than absolute zero emits radiation of wavelengths from zero to infinity. The maximum energy however is not equally distributed within this range; its distribution is given by the so-called Planck's law. The position of the maximum of this distribution on the electromagnetic spectrum depends on temperature. The lower the temperature, the higher the wavelength. For the range of temperatures encountered in building physics, the corresponding wavelengths are within the infrared part of the electromagnetic spectrum (0.8 to 100 μm).

The amount of heat emitted by radiation from a body of surface *A* at temperature *T* is given by the Stefan–Boltzmann law:

$$q = A \cdot \varepsilon \cdot \sigma \cdot T^4 \tag{3}$$

where σ is the Stefan–Boltzmann constant ($5.67 \cdot 10^{-8}$ W m$^{-2}$ K$^{-4}$). The dimensionless coefficient ε is called emissivity and is a characteristic of the radiating surface. Based on this law, the heat transferred between two bodies can be derived as:

$$q_{1\to 2} = \sigma \cdot F_{1\to 2}(\varepsilon_1 \cdot A_1 \cdot T_1^4 - \varepsilon_2 \cdot A_2 \cdot T_2^4) \tag{4}$$

where $F_{1\to 2}$ is a coefficient without dimensions, called the view factor. This is a purely geometrical factor, depending only on the geometry and the relative position of the two bodies.

All three mechanisms are encountered inside a building and influence its thermal behavior. This influence is not only between the building and the ambience but also between the building and the HVAC (Heating, Ventilation and Air Conditioning) components in it. Some basic examples are described below.

Conduction basically occurs across all parts of the building shell, opaque or transparent. Usually the internal and external surfaces of the building are at different temperatures and therefore heat is transferred via them. In order to reduce losses of building heat due to conduction, the building envelope is insulated. Insulating materials like polystyrene are placed inside the opaque parts; double–glazing is now a common practice for this. Both measures decrease the thermal conductivity of the envelope and therefore, according to Fourrier's law, the amount of heat transferred decreases. Since both sides are usually in contact with air, the heat losses or gains across the building envelope are due not only to conduction but also to convection. This convection is natural on both sides if the wind speed outdoors is zero and if there are no fans or ventilation devices indoors. Otherwise there is forced convection. The most common case for buildings without ventilation devices is to have forced convection outdoors (since the occurrence of zero wind speed is rare) and natural convection indoors.

Heat from a simple radiator in the building space is transferred by natural convection mainly but also by radiation. If instead of the simple radiator there is a fan coil, then heat is transferred by forced convection. A fireplace heats the space mainly via radiation. Radiation is the mechanism by which parts of the building envelope exchange heat with the sky. This heat transfer mechanism is particularly important during clear winter nights. Since normal glazing is opaque to infrared radiation, the heat radiated by the indoor surfaces of a building can not be transferred outdoors. This parameter is important for the use of solar radiation.

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**Biographical Sketch**

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