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Review Article

Housing Heat Transport for Comfort Considerations: A Brief Review

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Abstract - *Housing construction materials cause emissions in their production, and combining them is necessary for air conditioner use in a room. In many cases, environmental impact heat transfer processes are closely related to energy consumption and, therefore, city sustainability. The method of changing the interior temperature in a living space affects the comfort of users. Different criteria must consider for the study, and various equations must recognize for estimating this property. This paper corresponds to a brief review of the temperature changes through a solid corresponding to a wall or vertical or structural element exposed to a higher temperature source. It considers a cubical room and the basic process that must be considered when estimating comfort.*

Keywords - *Housing comfort, Heat transport model, Room temperature.*

1. Introduction

Thermal comfort is defined, according to the ISO-7730 standard, as "That condition of mind in which satisfaction with the thermal environment is expressed"[1], a definition that, in itself, is very complex to express through the measurement of physical parameters [2]. The body's interior temperature has an average value of 37 degrees Celsius and is defined by metabolic activity and by the exchange of heat of the body with the environment. The human body is prepared to react to climate changes, but these reactions cause it to consume metabolic energy. If the room temperature is too high, vasodilation and sweating are generated in humans. At the same time, too low a temperature leads to vasoconstriction and the need to generate heat through muscle movement (shivering). The feeling of comfort arises from the stay in a microclimate that avoids the body's reaction[3,4], which depends, among other factors, on the room's temperature.

The temperature inside the houses depends on the heat exchange established with the outside [5]. From the point of view of energy transport, the entire envelope of the house (furniture, walls, ceiling, floor, windows, curtains etc.) behaves like a barrier that allows thermal energy to pass, contributing to its accumulation [6]. When designing and building a house, it is essential to try to take advantage of the thermal characteristics (conductivity and specific heat) of the materials to act as a filter and energy store so that the temperature inside a building varies within a range of values that guarantee the feeling of comfort [7]. Since it is almost always the external conditions that are considered undesirable, the material of the exterior walls must have a relatively low value of the coefficient of thermal conductivity. That is, they are appropriate as insulating materials, so the heat transfer between the exterior and interior of the house is minimized [8,9].

On the other hand, in houses, there is more than one room, where in addition to an exchange of heat with the outside, there is heat exchange between the adjacent rooms. In turn, the rooms will have different temperatures depending on their position inside the house, and the number of walls exchanged with the outside.

This course presents the fundamental bases that allow us to understand the mechanisms associated with estimating the temporal behavior of temperature in a room, which are closely related to heat transport processes.

2. Definition of Heat and Transport Mechanisms

Heat is the energy flow between two systems that interact with each other, one at higher and another at lower energy, where heat transfers from the higher energy system to the lower energy system. [25]

The energy associated with a material system is associated with the kinetic energy of the molecules that compose it [11], whose magnitude is closely related to the temperature of the system through the Boltzmann constant [12,13]:

$$E_c = \sum^N \frac{1}{2} m_i v_i^2 = kT \qquad (1)$$

where m and v are the mass and velocity of an individual molecule, T is the absolute temperature (K), N is the total number of molecules and is Boltzmann's constant:κ

$$\kappa = 1.380658 \times 10^{-23} \mathrm{JK}^{-1} \qquad (2)$$

In the case of electromagnetic waves, their associated energy depends on the frequency of the wave:ν

$$E = h\nu \qquad (3)$$

where h is Planck's constant:

$$h = 6.6260755 \times 10^{-34} \mathrm{Js} \qquad (4)$$

The process by which energy transmits from one medium or material to another of lower temperature is known as heat transfer, with three fundamental mechanisms:

Conduction [14, 15]: takes place through the temperature difference that establishes in a material body, where the heat flow, defined as the heat transferred per unit area, is determined according to:

$$J = -k\frac{dT}{dy} \qquad (5)$$

where k is the coefficient of thermal conductivity.

Convection [16, 17]: is the heat transfer mechanism that occurs through the movement of a mass of substance within the system, so it is only manifested in the case that the medium is a fluid (gas or liquid), where the flux of heat by conduction is determined as:

$$q = \frac{1}{2}\rho v^2 v \qquad (6)$$

where v is the vector representing the velocity of the fluid.

Thermal radiation [18,19] is the energy emitted by matter at a given temperature and occurs due to changes in the electronic configurations of the constituent atoms or molecules. This type of energy does not require a medium for its transmission but is transported directly through electromagnetic waves and photons, so it is also known as electromagnetic radiation.

3. Heat balance and Temporal Temperature Behavior

Heat balance is based on mathematically describing the processes of energy transport that take place in a system by considering the law of energy conservation, which states that "Energy is neither created nor destroyed, but transformed". In this context, heat constitutes the energy in transition and flows from higher temperature to lower temperature systems.

An isolated system, which does not exchange heat or mass with the outside, and which in its beginnings has a temperature difference, evolves until it reaches a state of equilibrium where the temperature remains unchanged over time. In systems that are in thermodynamic equilibrium, a flow of heat is not manifest.

On the other hand, in an open system, which exchanges mass and energy with its surroundings, it is possible to establish a steady state in which the temperature is constant, which finds when the amount of heat entering the system is equal to the amount of heat that comes out. The heat balance in an open system expresses precisely how temperature changes as a function of the inlet and outlet heat flow.

The general heat balance equation [20], expressed as the equation of temperature change, is represented as:

$$\rho C_p V \frac{dT}{dt} = Q_{ent} - Q_{sal} \qquad (7)$$

where it represents the heat flow, the density of the substance in the system and its volume, the heat capacity at constant pressure, and the temperature and time. $Q\left(\frac{J}{s}\right) \rho \left(\frac{\mathrm{kg}}{m^3}\right) V\ (m^3)\, C_p \left(\frac{J}{\mathrm{kgK}}\right) T\ (K)\, t\ (s)$

3.1. Temperature Change in a House Room

For a dwelling, the heat that enters and leaves is related to two processes: one, related to the mechanism of heat transport by convection, is associated with the temperature of the air that enters and leaves it, and the other, related to the transport of heat by conduction, is associated with the flow of heat that enters or goes through the walls of the house [21].

Assuming the air is mixed in the room in such a way that the outlet temperature of this is equal to the inlet temperature, it has to be that the heat exchange by convection is given by:

$$Q_{conv} = \rho v C_p (T_{ent} - T) \qquad (8)$$

where is the air velocity. Note that if there is a heat input, that causes an increasing temperature of the room, while if a heat outlet occurs, that causes the temperature of the room decreases. $v\left(\frac{m}{s}\right) T_{ent} > T\ T_{ent} < T$

The heat transferred by conduction is given by:

$$Q_{cond} = \frac{kA}{\delta}(T_{ext} - T) \qquad (9)$$

where is the thermal conductivity coefficient, the wall's area and thickness, respectively, and the outside temperature:

$k\left(\frac{J}{\mathrm{sm°C}}\right) A\ (m^2) \delta\ (\mathrm{m}) T_{ext}$

Substituting in the heat balance equation yields the differential equation:

$$\rho C_p V \frac{dT}{dt} = \rho v C_p (T_{ent} - T) + \frac{kA}{\delta}(T_{ext} - T)$$
$$T(0) = T_0 \qquad (10)$$

The above differential equation can be written as follows:

$$\tau \frac{dT}{dt} = -T + (g_1 T_{ent} + g_2 T_{ext})$$
$$T(0) = T_0 \qquad (11)$$

where:

$$\tau = \frac{\rho C_p V}{\left(v \rho C_p + A \frac{k}{\delta}\right)}$$

$$g_1 = \frac{v \rho C_p}{\left(v \rho C_p + A \frac{k}{\delta}\right)}$$

$$g_2 = \frac{A \frac{k}{\delta}}{\left(v \rho C_p + A \frac{k}{\delta}\right)}$$

(12)

$\tau\ (s)$ is the time constant of the system, a magnitude related to the time it takes for temperature T to reach a steady state, and express in what proportion the temperature of room T changes when there is a change in the inlet temperature of the air and the outside temperature of the wall, respectively. $g_1\, g_2$

The solution of the above differential equation is given by:

$$T(t) = g_1 T_a + g_2 T_p - exp\left(-\frac{t}{\tau}\right)\left(g_1 T_a - T_0 + g_2 T_p\right) \qquad (13)$$

in steady-state time tends to infinity, so that the value of the temperature that reaches is given by:

$$T_{ss} = g_1 T_a + g_2 T_p \qquad (14)$$

The model previously obtained has the following limitations: 1) considers that the entire exterior of the house is subjected to the same temperature, when it is known that, according to the arrangement of the walls of the house concerning sunrise and sunset, the temperature in each of the walls may be different; 2) does not take into account that within the house there are interior walls that delimit the different individual rooms, through which heat exchange establishes as a result of the different temperatures that may exist between the rooms.

Technically there are different ways to produce forced effects of clear transfer or changes in indoor temperatures. [22, 23]

3.2. *Temperature variation in each room of a dwelling for a house in which it is considered that there is no exchange of air with the outside*

The temperature of a room depends on the exchange of heat by conduction that establishes through the walls, which can be interior (separate the rooms from each other [24]) or exterior (they are in contact with the environment). In the case of an interior wall, the heat transferred through a wall separating rooms i and j are estimated as: $q_{ij}\left(\frac{J}{s}\right)$

$$q_{ij} = \frac{\kappa_{ij} A_{ij}}{\delta_{ij}}\left(T_i - T_j\right) \qquad (15)$$

where and are the area and thickness of the wall, respectively, and is the material's thermal conductivity coefficient. In the case of an outer wall, the heat transferred by conduction determines as: $A_{ij}\ (m^2)\ \delta_{ij}\ (m)\ \kappa_{ij}\left(\frac{J}{\mathrm{sm°C}}\right)$

$$q_{kj} = \frac{\kappa_{kj} A_{kj}}{\delta_{kj}}\left(T_k - T_j\right) \qquad (16)$$

where is the temperature on the outer side of the wall and the room's temperature. Suppose the room is considered to be closed. In that case, the heat transferred by convection due to airflow can be considered negligible in such a way that the temperature variation of room j with respect to time determines through the relationship: $T_k\, T_j$

$$\rho C_p V_j \frac{dT_j}{dt} = \sum_{i=1}^{n} \frac{\kappa_{ij} A_{ij}}{\delta_{ij}}\left(T_i - T_j\right)$$
$$+ \sum_{k=1}^{m} \frac{\kappa_{kj} A_{kj}}{\delta_{kj}}\left(T_k - T_j\right) \qquad (17)$$

where represents the number of interior and exterior walls corresponding to the room, is the air's density, the air's heat capacity, and the room's volume. It is evident that the equation (ecu 3) cannot be solved independently since it is required to include the temperature behavior of each adjacent room. Leading propose a differential equations system regarding the simultaneous behavior of the temperature of each room, expressed through the vector differential equation: $nmj\ \ \rho \left(\frac{\mathrm{kg}}{m^3}\right) C_p \left(\frac{J}{\mathrm{kg°C}}\right) V_j\ (m^3)$

$$\frac{d}{dt} Tg = V^{-1}(\alpha T - T\alpha) g + V^{-1}(\beta \Theta - T\beta) u \qquad (18)$$

where is a diagonal matrix where each element represents the temperature of the room, being the total number of rooms: $T\ \ n \times n\ T_{jj} j = 1, \ldots, nn$

$$T = \begin{bmatrix} T_1 & 0 & 0 \\ 0 & \cdot & 0 \\ 0 & 0 & T_n \end{bmatrix}_{n \times n}$$

(19)

$V$is a diagonal matrix where each element represents the volume of the room : $n\times n\, V_{jj}j$

$$V = \begin{bmatrix} V_1 & 0 & 0 \\ 0 & \cdot & 0 \\ 0 & 0 & V_n \end{bmatrix}_{n\times n} \qquad (20)$$

α is a symmetric matrix whose diagonal is equal to zero, representing the coefficient of heat transport by conduction between rooms:$n \times n$

$$\alpha = \begin{bmatrix} 0 & \cdot & \alpha_{1n} \\ \cdot & 0 & \alpha_{2n} \\ \alpha_{n1} & \alpha_{n2} & 0 \end{bmatrix}_{n\times n}$$

$$\alpha_{ij} = \alpha_{ji} = \frac{\kappa_{ij}A_{ij}}{\delta_{ij}\rho C_p}$$

$$\alpha_{ii} = 0 \qquad (21)$$

β is a matrix representing the coefficient of heat transport through the outer walls:$n \times mm$

$$\beta = \begin{bmatrix} \beta_{11} & \beta_{1m} \\ \cdot & \cdot \\ \beta_{n1} & \beta_{nm} \end{bmatrix}_{n\times m}$$

$$\beta_{kj} = \frac{\kappa_{kj}A_{kj}}{\delta_{kj}} \qquad (22)$$

Θ is a diagonal matrix whose elements represent the ambient temperature corresponding to each outer wall $m\times m\,\Theta_k k$

$$\Theta = \begin{bmatrix} \Theta_1 & 0 \\ 0 & \Theta_m \end{bmatrix}_{m\times m} \qquad (23)$$

Values of the matrix must be specified to solve the differential equations, where each temperature may be expressed as a constant value or as a time-dependent function.

y y are vectors of dimension n and m, respectively, with components equal to 1:gu

$$g = \begin{bmatrix} 1 \\ \cdot \\ 1 \end{bmatrix}_n \qquad (24)$$

$$u = \begin{bmatrix} 1 \\ \cdot \\ 1 \end{bmatrix}_m \qquad (25)$$

The vector differential equation is subject to the initial conditions:

$$T(0) = T_0 \qquad (26)$$

It is necessary to specify the ambient temperature value corresponding to each outer wall, which can be described as a time-dependent or independent function.

4. Conclusion

In this paper, we described information about the general heat transport in walls applied to a room, useful for comfort calculation in houses. This information is necessary for an architect, showing a formalism to understand the initial process in a room. We also show a general matrix form to compile a representation in process for every variable possible.

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