Revision of the Inertia Concept in the Use of Free Heat Gains. Solar Radiation.

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ABSTRACT

The utilization factor is a relative well-known concept used in some simplified calculation methods such as the procedure described in the CEN EN-13790 where the FU depends on the inertia of the zone. In this paper we will analyse the inertia influence of each component of the zone in the inertia of the zone itself. With the results of this study, we will be able to know where to act if we desire to arise or diminish the whole thermal inertia of a room. The present paper starts analysing the energy stored and released in building components as walls. In this step we will establish a charge period and a discharge period. In the load period the component will storage heat while in the discharge period the component will release heat. The duration of each couple of charge/discharge periods is 24 hours. If we repeat this period a sufficient number of times we will obtain a cuasi-steady-state. In this way we will be able to assess the restored energy in the component.

The energy restored has been studied in three scenarios that successively lead to the actual, more realistic, situation. Establishing a comparison between the results for the different scenarios we could know the influence of the conductivity and the influence of the energy losses. Up to this point we have quantified how much heat is restored to the indoor space adjacent to the component as a consequence of the existence of solar radiation. Further from here we will explain how the heat restored is used to diminish the heating requirements revising the concept of utilization factor. In this step we will analyse all the concerning parameter making special attention to the inertia of the component. Finally we will determine the influence of the inertia of each component in the total inertia of the room.

KEYWORDS

Solar Radiation, Utilisation Factor

INTRODUCTION.

In the present paper, the equations of storage of energy in an element with inertia are developed, and later in a space formed by several elements. In both situations the stored energy is the solar radiation absorbed by these elements.

The main result obtained thanks to this development, it is the constant of time of the energy storage, which can be used for the later development of the utilization factor of the solar radiation for the diminution of the demand of heating of a space.

ENERGY STORAGE OF SOLAR RADIATION IN AN ELEMENT.

If we have only an element with thermal inertia only had, and it is posible to assume a capacity system, the equations are as follows:

For the element with thermal inertia $$MCp\frac{dT}{dt}=hA(T_a-T)+q_{rad} \quad (1)$$

For the air $$hA(T_a-T)=q_a \quad (2)$$

where T is the temperature of the element with thermal inertia

q_{rad} is a heat flux imposed at this element (e.g. solar radiation)

T_a is the air temperature, that it is supposed to be constant

q_a is the convective heat flux

The solution of the equation (Eqn. 1) is:

$$T(t)=C1+C2\,e^{-\frac{hA}{MCp}t} \quad (3)$$

where *C1* y *C2* are constants that are determined from the initial and final conditions (steady state). Thus,

In steady state the ec. 1 becomes: $hA(T_a-T(\infty))+q_{rad}=0$, and then

$$q_a(t)=(hA(T_a-T(0))+q_{rad})e^{-t/\tau}-q_{rad} \quad (4)$$

where $\tau=\frac{MCp}{hA}$ is the constant of time of the element with thermal inertia.

SPACE CHARACTERIZATION.

Let us see an example with two elements with thermal inertia. Supposing capacity system, the equations are:

For the element 1 with thermal inertia $$M_1Cp_1\frac{dT_1}{dt}=h_1A_1(T_a-T_1)+q_{rad1} \quad (5)$$

For the element 2 with thermal inertia $$M_2Cp_2\frac{dT_2}{dt}=h_2A_2(T_a-T_2)+q_{rad2} \quad (6)$$

For the air $$h_1A_1(T_a-T_1)+h_2A_2(T_a-T_2)=q_a \quad (7)$$

The hypotheses considered throughout the development have been:

- Supposition that the elements behave like a capacity system.
- The air temperature remains constant.
- The constants of time of each element are much greater than the considered period of time.

The solutions of the equations (Eqn. 5 y Eqn.6) are:

$$\frac{T_1(t)-T_a}{T_1(0)-T_a}=e^{-t/\tau_1}+\frac{q_{rad1}}{h_1A_1(T_1(0)-T_a)}\left(1-e^{-t/\tau_1}\right) \quad (8)$$

$$\frac{T_2(t)-T_a}{T_2(0)-T_a} = e^{-t/\tau_2} + \frac{q_{rad2}}{h_2 A_2 (T_2(0)-T_a)}\left(1-e^{-t/\tau_2}\right) \tag{9}$$

where $\tau_1 = \frac{M_1 Cp_1}{h_1 A_1}$, $\tau_2 = \frac{M_2 Cp_2}{h_2 A_2}$ are the constants of time of the elements with thermal inertia.

Replacing in Eqn. 7, it is had:

$$q_a(t) = (h_1 A_1 (T_a - T_1(0)) + q_{rad1})e^{-t/\tau_1} - q_{rad1} + (h_2 A_2 (T_a - T_2(0)) + q_{rad2})e^{-t/\tau_2} - q_{rad2} \tag{10}$$

We want to express this equation based on an only constant of time, being of the form of the Eqn. 4, for this purpose we have used the development of the exponential.

$$q_a(t) = (h_1 A_1 (T_a - T_1(0)) + q_{rad1}) \cdot \left(1 - t/\tau_1\right) - q_{rad1} + (h_2 A_2 (T_a - T_2(0)) + q_{rad2}) \cdot \left(1 - t/\tau_2\right) - q_{rad2} \tag{11}$$

we want that it stays as the Eqn. 4., this is:

$$q_a(t) = (hA(T_a - T(0)) + q_{rad}) \cdot \left(1 - t/\tau\right) - q_{rad} \tag{12}$$

where $q_{rad} = q_{rad1} + q_{rad2}$ as it is deduced from the steady state condition, $t \to \infty$

Therefore it will have to be fulfilled that:

$$\begin{cases} (hA(T_a - T(0)) + q_{rad})\, t/\tau = (h_1 A_1 (T_a - T_1(0)) + q_{rad1})\, t/\tau_1 + (h_2 A_2 (T_a - T_2(0)) + q_{rad2})\, t/\tau_2 \\ hA(T_a - T(0)) = h_1 A_1 (T_a - T_1(0)) + h_2 A_2 (T_a - T_2(0)) \end{cases}$$

from the first equation the constant of time of the system is deduced, τ , whereas the second it can be used to determine $T(0)$ based on the rest of variables.

$$\tau = \frac{1}{\dfrac{(h_1 A_1 (T_a - T_1(0)) + q_{rad1})\,(hA(T_a - T(0)) + q_{rad})}{\tau_1} + \dfrac{(h_2 A_2 (T_a - T_2(0)) + q_{rad2})\,(hA(T_a - T(0)) + q_{rad})}{\tau_2}} \tag{13}$$

where

$\tau_1 = \frac{M_1 Cp_1}{h_1 A_1}$, $\tau_2 = \frac{M_2 Cp_2}{h_2 A_2}$ are the constants of time of elements 1 and 2 separately.

For the particular case of a system in which a different heat flux arrives to each element, as it could be a radiant flux, we can use an additional hypothesis, that it would be to consider that the initial solutions agree with the temperature of the air, $T_1(0) = T_2(0) = T_a \;\Rightarrow\; T(0) = T_a$, then the Eqn. 13 it would be:

$$\tau = \frac{1}{\frac{q_{rad1}/q_{rad}}{\tau_1} + \frac{q_{rad2}/q_{rad}}{\tau_2}} \qquad (14)$$

where q_{rad1}/q_{rad} is the fraction of the total radiant flux arriving to the element 1

q_{rad2}/q_{rad} is the fraction of the total radiant flux arriving to the element 2

GENERAL EXPRESSION OF THE UTILIZATION FACTOR OF A SYSTEM.

The utilization factor for radiation is defined as the fraction of the radiation gain of a space that is used to diminish the demand of heating.

This can be expressed as follows:

$$Heating\ Demand = \underset{without\ solar\ radiation}{Heating\ Demand} - UF * Radiation\ Gains \qquad (15)$$

and then:

$$UF = \frac{\left(\underset{without\ solar\ radiation}{Heating\ Demand} - Heating\ Demand\right)}{Radiation\ Gains} \qquad (16)$$

On the other hand, it is deduced that the amount of radiation gains that it is not used to diminish the demand of heating is responsible for the space overheating during a certain period of time. The overheating can be obtained from:

$$Overheating = Radiation\ Gains - UF * Radiation\ Gains \qquad (17)$$

and then:

$$UF = 1 - \frac{Overheating}{Radiation\ Gains} \qquad (18)$$

A development from the method of transference functions can be followed for the calculation of the overheating. This method is based on well-known the Room Air Weighting Factors, that allow to calculate the increase of the heat flow and the increase of temperature of a space from its values at previous moments.

$$\Delta Q(t) = \sum_{i=0}^{na} a(i)\Delta T(t-i) - \sum_{i=1}^{nd} d(i)\Delta Q(t-i)$$
$$\Delta T(t) = \frac{1}{a(0)}\left[\sum_{i=0}^{nd} d(i)\Delta Q(t-i) - \sum_{i=1}^{na} a(i)\Delta T(t-i)\right] \qquad (19)$$

where a(i) are the RAWF numerators and d(i) the denominators.

Using this method, it is possible to calculate the overheating, for each differenct case, by using the following equation:

$$Overheating = UA \cdot \sum_{t=1}^{nh1} \Delta T(t) + UA \cdot \sum_{t=nh1}^{24} \Delta T(t)$$

where nh1 is the number of hours in which $\Delta Q(0) \neq 0$, and (24-nh1) is the number of hours in which $\Delta Q(0) = 0$.

In order to simplify the development, we have supposed that there are only two numerators and two denominators. This hypothesis allows to reach a general solution that it is also the real thing for a capacity system.

In this way, and following a complex development, we can finalise with the expression for the utilization factor:

$$FU = 1 - \frac{1}{RadiationGains}\left\{ \begin{array}{l} UA \cdot \frac{\Delta Q}{a(0)} \cdot \left[\frac{1-e^{\frac{-1}{\tau}}}{1-\frac{X}{a(0)}} \cdot \left(nh1 - 1 - \frac{X}{a(0)} \cdot \frac{1-\left(\frac{X}{a(0)}\right)^{nh1-1}}{1-\frac{X}{a(0)}} \right) + \frac{1-\left(\frac{X}{a(0)}\right)^{nh1}}{1-\frac{X}{a(0)}} \right] \\ + UA \cdot \frac{\left[X \cdot \Delta T(nh1) - \Delta Q \cdot e^{\frac{-1}{\tau}} \right]}{a(0)} \cdot \left(\frac{1-\left(\frac{X}{a(0)}\right)^{24-nh1}}{1-\frac{X}{a(0)}} \right) \end{array} \right\}$$

where $\Delta T(nh1) = \frac{\Delta Q}{a(0)}\left[\left(1-e^{\frac{-1}{\tau}}\right)\left(\frac{1-\left(\frac{X}{a(0)}\right)^{nh1-1}}{1-\frac{X}{a(0)}} \right) + \left(\frac{X}{a(0)}\right)^{nh1-1} \right]$

CONCLUSIONS.

The previous equation has been applied for numerous examples of different types of loads, and for several inertias of spaces. The following figure is one of thoses cases.

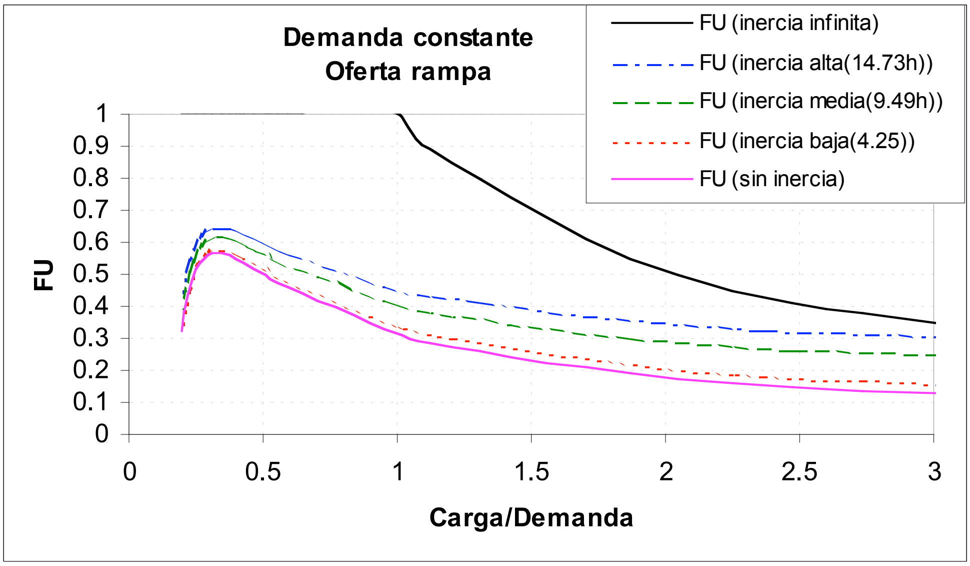

Fig 1. Utilization factor for a case with constant demand and ramp load.

It can be seen:

- The form of the curve is the same one in the cases with and without inertia.
- The existence of a maximum UF and their location depends on the relative form between the load and the demand.
- The cases with inertia present a maximum UF for the same relation of load/demand that the same case without inertia.
- As it increases inertia, it increases the UF.

- The increase of the UF with inertia is greater as it increases the relation of load/demand, coming near more and more to the maximum (infinite inertia).

As a validation, in the following graphs two particular cases of typical curves of UF are represented versus the relation load/demand. Both have been obtained with simulations of the thermal simulation program for the calculations of heating and cooling demands of a space of aspect ratio equal to unity, with a facade facing to the east and located in Seville.

The first graph corresponds to the UF of solar radiation and the second one corresponds to the UF of ventilation.

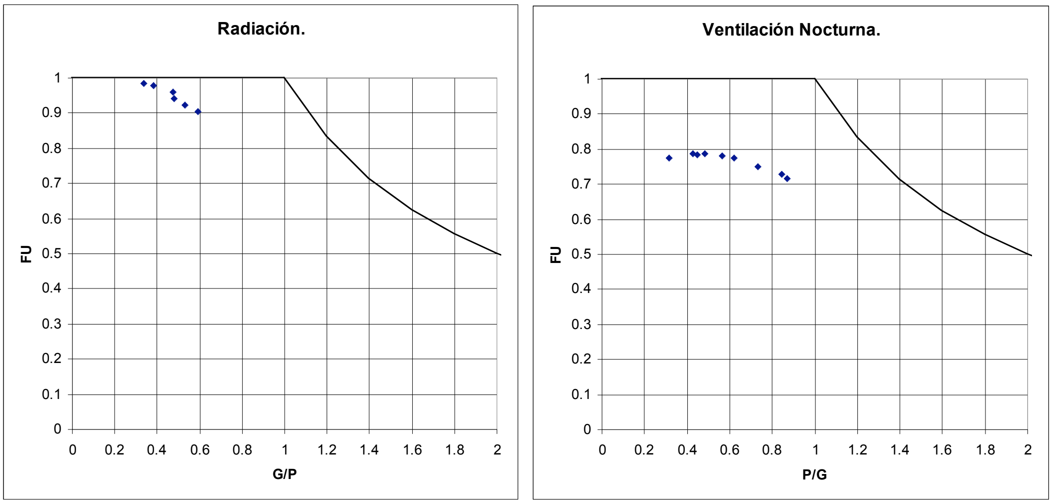

Fig 2. Utilization Factors calculated using a thermal simulation program.

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