Variation Influence of Buildings interior Mass Distribution in Energy Consumption by Heating

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Resumén

Se estudia el consumo energético por calefacción de tres módulos habitacionales cuando se varían los siguientes factores: naturaleza y resistencia térmica de los materiales de cerramiento, distribución de la masa térmica del interior y tiempo diario de calentamiento. Los materiales de cerramiento y de acumulación de calor son ladrillos cerámicos.

Summary

Energy consumption by heating is studied in three room modules when the following factors are varied: nature and thermic resistence of the closing materials, interior thermic distribution and daily heating time. The closing and heat accumulation materials are ceramic bricks.

1. INTRODUCTION

As is well known, the degree of energy consumption obtained by the heating of living quarters depends on the following factors: climate, use, of enclosure, type of heating system and heating time. Taking this as the point of departure, a long series of mathematical modules, both empirical and analogical, has been constructed, which determine the amount of energy needed to supply to a given building. Each of them has a very specific and limited applicability and it is therefore inadvisable to generalise any of them, above all when the experimental proofs they have been subjected to are still very few.

In Spain's real climatic and constructive conditions (high rate of winter sunshine and wide variation in the daily thermic wave), it is essential to bear in mind both the influence of the thermic inertia of the enclosing elements (roofs floors and walls) and of the horizontal and vertical partitions of the interior space.

The internal inert mass of traditional and massive brick building performs a moderating function on the thermic variations of the surrounding air of direct repercussion on the energy consumption of the place.

However, currently available systems for calculating a building's thermic response do not allow such factors to be considered with a satisfactory enough approximation. This means that experimental modules must be made.

In this work an approximate parameter is determined analytically, including, in a simplified form, the total thermic characteristic of an inhabitable area. This is what we here call the THERMALINDEX OF THE BUILDING which is based -

in the thermic time constant defined by Bruckmayer (1) as equivalent wall. Besides this, experimental determinations have been made, in real climatic conditions, of the energy consumption of three room modules $27 m^3$ each in volume with different closure thermic characteristics, in which heating times and the form of distribution of an interior inert mass consisting in, approximately, $1 m^3$ of perforated ceramic bricks, were varied.

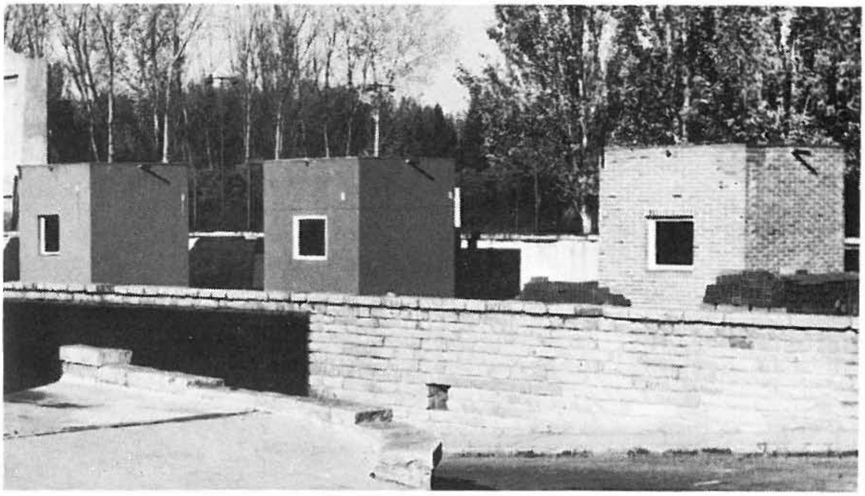

Fig. 1 - Experimental room modules

2. THERMAL INDEX OF THE BUILDING

The calculation of the amount of heat produced through a heterogeneous medium formed by plano-parallel layers of different thermic nature, which is subjected to a variable temperature request, may be determined by the equivalent definition of a hypothetical homogeneous medium whose thermophysical properties - produce an identical effect to the former under the same request. This is the - way taken by McKey and Wright with resistence and equivalent thermal layer - (2), the U.K. Building Research Station's thermal admittance (3), Raychaudhury (4) Warsi and Chaudhury's equivalent thermal diffusivity in India (5), or the - american society ASHRAE's transfer functions (6).

2.1. Thermal index of walls

In the closure diagram in Fig. 2, the exterior surface temperature is given by the formula:

$$T_{si} = T_e \pm \frac{T_e - T_i}{h_e R}$$

and the average temperature of each layer of material equals the exterior temperature plus:

$$\frac{\left(\frac{1}{h_e} + {}^{e}1/2\lambda 1\right)(T_i - T_e)}{R}$$

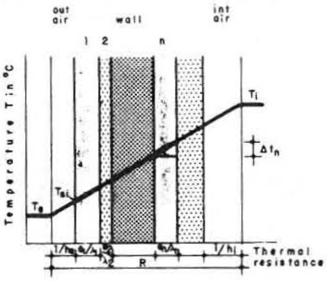

Fig. 2 - Layers resistances

On the other hand the amount of heat accumulated in the interior of this material, for this temperature difference, equals:

$$\frac{\left(\frac{1}{h_e} + {}^{e}1/2\lambda\ 1\right)}{R}\ (l_1 \cdot \rho_1 \cdot C_1)$$

where $(l_1 . \rho_1 . C_1)$ is the volumetric heat capacity of each layer.

Thus the amount of heat which is transmitted through the whole en closing wall (K) respecting that which is accumulated in the first layer (Q_1) is the relation which defines the so-called thermal index of this layer (Q_1/K). Analytically:

$$\left(\frac{Q1}{K}\right) = (Q_1 . R) = \left(\frac{1}{h_e} - \frac{l_1}{2\lambda_1}\right)\ (l_1 \cdot \rho_1 \cdot C_1)$$

Operating in the same way on the successive layers, the equivalent thermic diffusivity of the whole wall is determined. Thus, the thermal index of the wall (ITM) is obtained from the following equation:

$$(ITM) = \left(R_e + \frac{1}{2} R_1\right)(Q_1) + \left(R_e + R_1 + \frac{1}{2} R_2\right) Q_2 + \left(R_e + \sum_{1}^{n-1} R_n + 1/2\, R_n\right)(Q_n)$$

where:

$$R_e = \frac{1}{h_e} \backsim 0.06\ m^2K/W$$

$$R_1 = l_n/\lambda n,\ m^2K/W$$

$$Q_n = (l_n \cdot \rho_n \cdot C_n),\ kJ/m^2.K$$

2. 2. Thermal index of a room

When considering the real phenomenon of thermic exchange in a living space it is necessary to bear in mind not only the phenomenon of heat transmission through the closing walls, but those produced by air renewal (ventilation) and

the thermic accumulator effect carried out by the furniture and interior partitions (partition walls and floors in the case of a house).

Taking these three factors into account, although in a general, approximate way, the thermal index of a whole site or room could be defined by the approximate equation proposed by Hoffman (7) as follows:

$$(ITE) = \sum_{1}^{n} (ITM) + (ITA) + (ITV)$$

The coefficient (ITM) is calculated for each facing delimiting the site as was stated earlier, while the following statements are taken for the index of accumulation and ventilation:

$$(ITA) = \left[\sum_{1}^{n} R_n + \frac{1}{2} R_{MASS} + 2R_i\right] . Q_{MASS}$$

MASS = Total of interior accumulator elements

$$R_i = \frac{1}{h_i} \sim 0.11 \ m^2K/W$$

$$Q_{MASS} = 1/2 \ m. \ C_e, \ kJ/K$$

C_e = specific heat, kJ/Kg.K

$$(ITV) = N\,(\rho . C)_{AIR} . V$$

N = number of air renewals per hour.

$(\rho . C)_{AIR}$ = Volumetric heat capacity of air, $kJ/m^3.K$

V = Volume of site, m^3

An analogy for the room be established similar to the electric on made by Bruckmayer for a facing, extending it to a possible interior accumulator mass which would act as a moderator of the thermic variations of the Surrounding air.

Weighing up thermal indices defined earlier respecting the heat-transmitting facing surfaces, the general formula proposed by Hoffman and adopted in this work, is:

$$(ITE) = \frac{\sum_{1}^{n}\left[A._n (ITM)_n\right]}{\sum_{1}^{n} An} + Q_{MASS} \left[\frac{\sum_{1}^{n}\left(A_n . R_n\right)}{\sum_{1}^{n} An} + 1/2 \ R_{MASS} + 2R_i\right] +$$

$$+ \frac{N(\rho \cdot C)_{AIR} \cdot V}{\sum_{1}^{n} An}$$

3. EXPERIMENTATION

Three room modules were constructed with equal openings, interior partitions and volume, varying the vertical perimetral closures. The interior air temperature may be regulated around $20^{\circ}C$ by means of the thermostatic control of three thermoconvectors.

Between November and April, inclusive, in 1979 and 1980 - not very cold in - Madrid - the energy consumed by the thermoconvectors in each room was measured. The calculations were made in a continuous heating system and with nightly stops of 6, 8 and 12 hours respectively.

Fig. 3 - Thermal mass concentrated

A heat accumulating mass formed by $1 m^3$ of perforated ceramic bricks was placed in the interior of each module. This mass was concentrated in the middle of the space (Fig. 3) on the East - side (Fig. 4) and on the opaque facings (Fig. 5).

The hollows were closed and sealed - to minimise heat losses by ventilation or infiltrations of air.

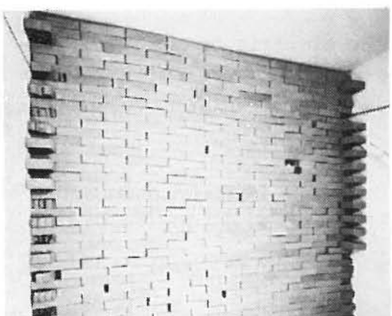

Fig. 4 - Thermal mass on the east side

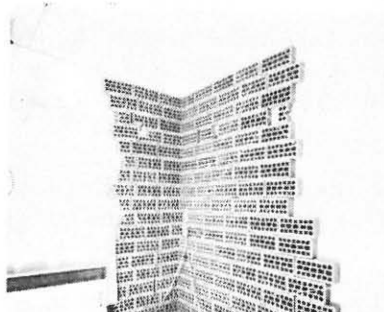

Fig. 5 - Thermal mass distributed

3.1. Thermophysical parameters and thermal indices. Both the thermophysical properties of the materials making up the enclosures, and the dimensions and thermal indices obtained by the application of the equations described earlier - are set out in the following tables.

Element	Material	l (m)	λ (W/m K)	ρ (Kg/m^3)	C (kJ/Kg K)	A (m^2)	ITM (hr)
Wall (1)	Facing brick	0, 09	0, 87	1800	0, 9	25, 5	26
	Polystyrene	0, 025	0, 034	20	1, 6		
	Plaster board	0, 013	0, 18	900	0, 9		
Wall(2)	Com. brick	0, 05	0, 76	1600	0, 9	7, 3	91
Wall(3)	Com. brick	0, 12	0, 76	1600	0, 9	6, 4	190

(1) Mass at the center of the room
(2) mass distributed on all sides
(3) mass on the east wall

TABLE 1.a - Wall thermal index of Model I.

Element	Material	l (m)	λ (W/m K)	ρ (Kg/m^3)	C (kJ/Kg K)	A (m^2)	ITM (hr)
Wall (1)	Cmt. plaster	0, 02	1, 4	2000	1	25, 5	40
	Hollow brick	0, 12	0, 49	1200	0, 9		
	P. styrene	0, 025	0, 034	20	1, 6		
	Plast. board	0, 013	0, 18	900	0, 9		
Wall(2)	Com. brick	0, 05	0, 76	1600	0, 9	7, 3	122
Wall(3)	Com. brick	0, 12	0, 76	1600	0, 9	6, 4	245

TABLE 1.b - Wall thermal index of Model II.

Element	Material	l (m)	λ (W/m K)	ρ (Kg/m^3)	C (kJ/Kg K)	A (m^2)	ITM (hr)
Wall (1)	Facing brick	0, 24	0, 87	1800	0, 9	25, 5	89
	Polystyrene	0, 025	0, 034	20	1, 6		
	Plast. board	0, 013	0, 18	900	0, 9		
Wall(2)	Com. brick	0, 05	0, 76	1600	0, 9	7, 3	173
Wall(3)	Com. brick	0, 12	0, 76	1600	0, 9	6, 4	298

TABLE 1. c - Wall thermal index of Model III.

Element	Material	l (m)	λ (W/m K)	ρ (Kg/m^3)	C (kJ/Kg K)	A (m^2)	ITM (hr)
Window	Glass	0,.004	0, 95	2500	0, 8	0, 6	0, 5
Door	Wood	0, 01	0, 08	650	3	1, 1	1, 1
Roof	Gravel	0, 03	0, 81	1700	1	5, 2	38
	Concrete	0, 04	1, 16	2000	1		
	H. Tile	0, 12	-	660	1		
	P. styrene	0, 025	0, 034	20	1, 6		
	Plast. board	0, 013	0, 18	900	0, 9		
Floor	Concrete	0, 2	1, 6	2000	1	5, 2	243
	Cmt. mortar	0, 03	1, 4	2000	1		
	Tile	0, 03	0, 9	1800	1		
	Cmt. mortar	0, 05	1, 4	2000	1		
	Concrete	0, 10	1, 6	2000	1		
	Corck	0, 04	0, 04	110	1, 7		
	Mortar	0, 03	1, 4	2000	1		

TABLE 1. d - Thermal index of all the common elements

Thermal Mass Position \ Room Model	I	II	III
Concentrated	70	90	131
Distributed	80	122	149
On East Wall	104	146	173

TABLE 2. - Model's thermal index (ITE)

3. 2. Results

The value of the energy consumed daily by each room module, when length of - heating time was varied, has been written in Table 3. This shows also the de-greesday throughout 24 hours.

Thermal Mass Position	Intermattance Time (hr)	24	18	16	12
	Model	(kw hr/day)	(kw hr/day)	(kw hr/day)	(kw hr/day)
Concen-trated	I	6, 9	7, 9	5, 4	4, 1
	II	3, 7	6, 8	3, 6	2, 9
	III	7, 9	7, 5	5, 5	3, 8
Distri-buted	I	8, 9	6, 6	7, 8	4, 0
	II	7, 8	6, 6	7, 0	3, 0
	III	10, 8	8, 0	8, 3	4, 8
On the East Wall	I	3, 3	8, 2	5, 5	3, 8
	II	1, 8	6, 2	3, 7	2, 1
	III	3, 6	8, 6	5, 8	4, 2

TABLE 3. - Daily energy consumption measured

Fig. 6 shows the relation existing between the amplitudes of the interior air - temperature in the modules and the average daily temperature of the exterior - air, in terms of the thermal inertia index in each room and the heating times.

As may be seen, when the interior accumulator mass is distributed through the whole of the interior perimeter of the enclosure the fall in temperature of the - surrounding air is higher than in the cases where this mass is concentrated both in a wall and in the centre of the room. In all the cases, except in this last one in module III, the intermittance time affects the variation in the amplitude of - the interior temperature regularly and not very significantly.

Fig. 7 shows the hourly energy consumptions produced in each case studied referring to the existing degrees-days in this period of time.

Although experimental work is still going more deeply into the analysis of the - phenomenon of thermal inertia in buildings, it may be concluded for the moment that, contrary to the case of exploitation of direct solar energy entering a room through the windows, the distribution of the thermic mass acts less efficiently - in the regulation of air temperature in a heated space than when this temperature is concentrated on a single facing and consequently greater energy consumption is produced in the heating of the room.

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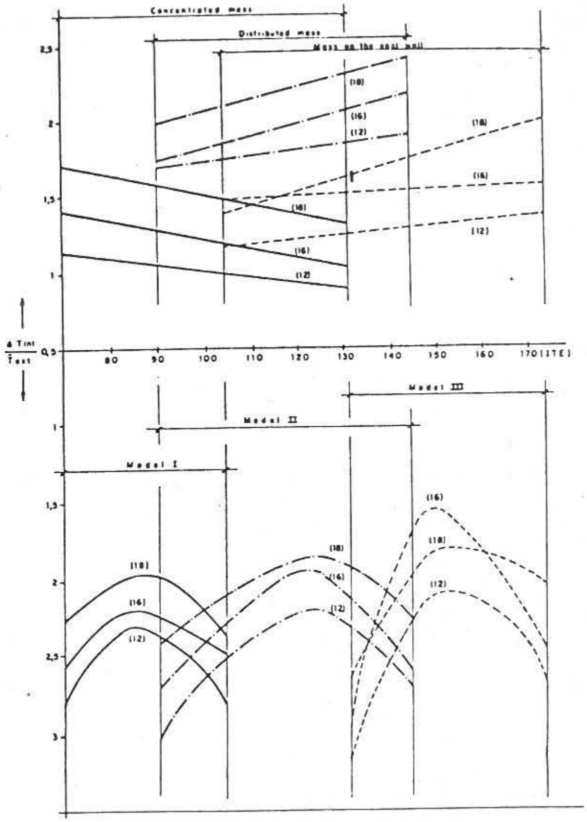

NOTE: FIGURES IN BRACKETS INDICATE THE TIME LAST OF HEATING

FIG. 6 - INDOOR AIR TEMPERATURE VARIATION BETWEEN MEAN OUTSIDE AIR TEMPERATURE RELATION

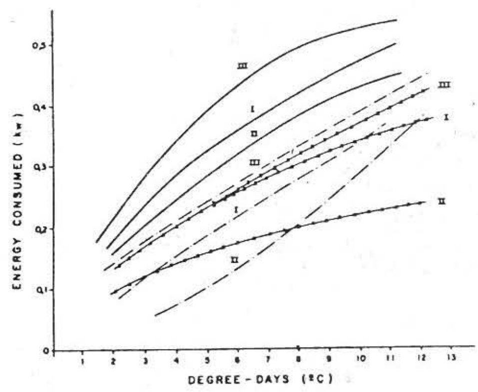

FIG. 7 - ENERGY CONSUMPTION