A TECHNICAL REVIEW OF THE "M" FACTOR CONCEPT

RICHARD D. GODFREY
Member ASHRAE

KENNETH E. WILKES
Member ASHRAE

ADRIENNE G. LAVINE

ABSTRACT

There is no question that massiveness of building envelopes affects instantaneous heat transmission through them under transient conditions. In an attempt to include these affects in ASHRAE Standard 90-75 calculations, masonry interests have developed a concept known as the "M" Factor. It has been proposed that the steady state conduction equation specified in 90-75 be modified by a multiplying factor ("M" Factor) to account for massiveness of the envelope.

These factors were calculated by forming the ratio of dynamic heat flux to that predicted by steady state methodology. Ratios were calculated for eight (8) orientations at 8 a.m. for a typical day in January and then averaged. Ten (10) wall types were considered in ten (10) cities in various climatic regions. These ratios are presented graphically as "M" Factor versus degree days for various wall masses.

Although the simplicity of this approach is attractive, consideration of the definition raises serious questions about the technical validity. Most troublesome is implying seasonal energy performance based on a ratio calculated for one hour out of an entire year. Averaging the effect of exposures is also questionable. This paper will address the question of the significance of using one hour per year to characterize seasonal energy performance. Daily and seasonal heat fluxes are calculated using both dynamic and steady state procedures. Typical weather data are utilized. A broad range of wall characteristics are investigated including thermal resistance, massiveness, and placement of mass within the wall. These results are compared to those calculated for an average day in January at 8 A.M. In addition, the effects of interaction of internal partitions with exterior walls are discussed.

INTRODUCTION

ASHRAE Standard 90-75 "Energy Conservation in New Building Design"[1] notes the effect of thermal massiveness on heating thermal performance but makes no specific recommendation on assessing its effect quantitatively. In response to this provision, the Masonry Industry Committee commissioned the consulting firm of Hankins and Anderson to develop a procedure which was compatible with the overall U value approach[2,3,4].

The methodology that evolved from this study is known as the "M" Factor method. Although this method has not received prior technical review or endorsement, the "M" factor method has been promoted widely and in fact has been referenced in

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R. D. Godfrey, Supervisor, Owens-Corning Fiberglas, Granville, Ohio
K. E. Wilkes, Senior Engineer, Owens-Corning Fiberglas, Granville, Ohio
A. G. Lavine, Associate Engineer, Owens-Corning Fiberglas, Granville, Ohio

some codes. Since the definition of these "M" Factors raises questions about the technical validity of the concept, a study was initiated to examine the assumptions underlying the definition. The response factor method was used to study a series of simplified wall constructions and configurations. The calculated "M" factors were contrasted with average energy usage predicted for various constructions.

"M" FACTOR DEFINITION

Yu,[2] of Hankins and Anderson, defined the "M" Factor, M, to be the dimensionless ratio of dynamically calculated heat flux at a specific hour to that calculated by steady state design methodology[5].

$$M = \frac{Q_{AVE,\ 8AM\ JAN}}{UA\ (T_I - T_{DESIGN})} \tag{1}$$

The dynamic heat flux, Q, was calculated using the response factor method[6]. Results were averaged from eight exposures (N, NE, E, etc.) at 8 AM for a statistically determined, typical January day. Both the steady state and dynamic procedures assumed that the indoor temperature, T_I, was a constant 23.9°C (75°F). These ratios were calculated for ten wall types ranging in mass from 20 to 566 kg/m^2 in ten geographical locations. These data were analyzed and presented in graphical form. "M" Factors are plotted versus degree days for various levels of wall weight as shown in Figure 1.

Two major questions arise when the definition of "M" Factor is examined. First, can heat flux for a single hour be representative of seasonal energy consumption? And second, is averaging of heat fluxes from multiple exposures valid without consideration of interactions with other building elements? To address these questions, the basic "M" factor methodology, as described in the open literature, was used to study a series of simplified constructions and configurations. Emphasis was placed on the significance of massiveness, the "M" factor as defined by Yu, and average heat flux.

SIGNIFICANCE OF 8 AM HEAT FLUXES

In order to investigate the significance of 8 AM heat fluxes, an isolated two layer wall was studied, see Figure 2. The outer layer was concrete. Fiberglass insulation constituted the inner layer. The inside surface communicated with room air held constant at 23.9°C (75°F). The outdoor air temperature was assumed to follow a clear sky sol-air profile representative of 40°N latitude[7], see Table 1. Ambient temperature was assumed to be -17.8°C (0°F). Both north and south exposures were analyzed for wall weights ranging from 2 to 684 kg/m^2. The wall thermal resistance of the sandwich was held constant at R=2.03 K-m^2/W (11.5 ft^2-h-°F/Btu).

The resultant inside wall heat flux, Q, for the south wall is plotted versus time of day for each wall type, see Figure 3. Twelve AM in this plot is solar noon. The smoothing effect of wall massiveness is evident. For the light weight wall, the solar effect is very dramatic. In fact, near solar noon the heat loss is negative. For the medium and heavy weight walls, the heat flux is much more constant over the day. It is interesting to note that at 8 AM, the time designated by Yu for calculation of "M" factors, the heat fluxes for the light and heavy walls are lower than that for the medium weight wall. That is to say, the "M" factors are reversing as a function of weight, contrary to the trend shown in Figure 1.

The "M" factors for the south exposure and north exposure were averaged and these values are listed in Table 2. It is not clear from this analysis what significance 8 AM has. However, what is most important when doing an energy calculation is the net heat flux over the period of interest. This is the area under the various curves shown in Figure 3. These values were calculated and found to be identical for each wall type, see Table 2. From this analysis, it can be concluded that a single hour is not representative of daily heat flux. And, mass does not effect net heat flux for a typical day.

It should be pointed out that the typical day used in this study was not the same one used by Yu. To assess this effect, Fourier analysis of the south sol-air temperature profile was made. In general, any periodic function can be represented as a sum of sines and cosines with various periods. Since the sol-air profile used in this study is symmetric about noon, the sine terms are all zero. In Table 3, the south sol-air profile and its first nine harmonics are shown. By summing the contributions of each harmonic, the original profile can be reconstructed. Now the question is, will the sum of the heat fluxes from each harmonic be the same as that from the composite profile? The answer is yes, as shown in Tables 4 and 5. The sum of the components is equal to the actual heat flux for the heavy wall, Table 4. The effects of the sixth and higher harmonics are negligible. For the light wall, Table 5, truncating the series after the ninth harmonic results in a small error. It would be necessary to include more terms to accurately reproduce the actual heat flux. It is always possible, by taking enough terms, to reconstruct the original heat flux profile since the response factor method is based on the principle of superposition for linear systems.

We are now in the position to ask the more general question. Does the mass of the wall, or its distribution, effect the net heat flux for an isolated wall exposed to a sinusoidally varying temperature on the outside while the indoor temperature is held constant?

Insights into the effects of wall massiveness under steady-periodic conditions can be obtained using the matrix multiplication technique described by Carslaw and Jaeger[8]. Considering a single frequency component, the sinusoidal components of the temperature T and heat flux q at one side (e.g. the inside) of a wall are related to corresponding quantities T' and q' at the other side by the matrix equation

$$\begin{bmatrix} T' \\ q' \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} T \\ q \end{bmatrix} \qquad (2)$$

where A, B, C, and D are complex quantities that depend upon the frequency, wall thickness, and thermal properties of the wall. For a single-layer homogeneous wall, it may be shown that A is equal to D. When a wall is composed of two layers, the matrix equation is simply:

$$\begin{bmatrix} T' \\ q' \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \begin{bmatrix} T \\ q \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & A_1 \end{bmatrix} \begin{bmatrix} A_2 & B_2 \\ C_2 & A_2 \end{bmatrix} \begin{bmatrix} T \\ q \end{bmatrix} \qquad (3)$$

where use has been made of the equality of A and D for any single layer. The two matrices may be multiplied together to give

$$\begin{bmatrix} T' \\ q' \end{bmatrix} = \begin{bmatrix} A_1 A_2 + B_1 C_2 & A_1 B_2 + B_1 A_2 \\ C_1 A_2 + A_1 C_2 & C_1 B_2 + A_1 A_2 \end{bmatrix} \begin{bmatrix} T \\ q \end{bmatrix} \qquad (4)$$

Now suppose the temperature of the inside surface is held constant. In this case, the magnitude of the periodic component of temperature, T, is zero. This allows the inside heat flux, q, to be related to the outside temperature, T', as

$$q = T'/(A_1 B_2 + B_1 A_2) \qquad (5)$$

An interesting consequence of this equation is that for a given outside temperature, T', the two layers may be reversed without changing the inside heat flux. If the two layers were reversed, the denominator would be $(A_2B_1 + B_2A_1)$, which is identical to that of Eq. 5.

Thus for this special case, if one layer were very massive and the other very light, the same result would be obtained for either position of the massive wall. This same conclusion was reached, using a somewhat different approach, by R. C. Sonderegger[9].

As a final check of the general nature of these conclusions, this set of three wall types was analyzed for an entire year using sol-air temperature data for Minneapolis in 1956[10]. Calculations were made for both north and south exposures. The total yearly heat flux was calculated using the response factor methodology. As shown in Table 6, the net heat flux was identical for all wall masses. As a point of interest, "M" factors were calculated for every morning in January at 8 AM, and their average value is also listed. Although these factors decrease with increasing mass, they have no significance, since the net heat fluxes were identical for all three walls. The yearly heat flux was found to be equal to the conductance times the yearly average temperature difference times the number of hours in a year.

These results tend to suggest that ASHRAE Standard 90-75 calculations should not be corrected for massiveness effects. The conclusion is that "M" factors are without a technical basis.

PARTITION EFFECTS

In Yu's analysis, each wall was analyzed as an isolated element. "M" factors were calculated for each exposure (N, NE, E, etc.) and then averaged to give the "M" factor for that geographic location. It is well known that cold exterior walls interact with internal partitions which in turn communicate with the room air. To investigate the effect of neglecting this communication, a simplified "room" was studied which consisted of two external walls and an interior partition, see Figure 4. As in the isolated wall case, the exterior boundary conditions were assumed to be north and south sol-air temperature profiles, see Table 1. The room air temperature was held constant at $23.9^{\circ}C$ ($75^{\circ}F$).

In this study, the heat flux out of the simplified room was compared with the sum of the heat fluxes through the north and south exposures of isolated walls. In addition to varying wall massiveness, wall thermal resistance was varied as shown in Table 7. The partition construction was the same in all cases--an uninsulated frame wall with drywall on both sides. Table 8 lists ratios of daily total heat flux out of the partitioned room to that through the isolated walls. For low R-values there is a strong interaction between the room walls and the partition. As R-value increases, this effect diminishes rapidly but may be significant when comparing differences in loads. As a point of interest, a case was also run where the mass was placed on the interior of the wall. No effect of order was observed.

Since the dominant variable appears to be wall thermal resistance, a steady state analysis was made of a partition communicating with room air and an outside wall as shown in Figure 5. By this circuit analysis, it can be shown that the ratio of heat flux with a partition to that for an isolated wall is:

$$\frac{Q_P}{Q_{IW}} = \frac{R_F + R + R_C}{R_F + R + R_C(R_R + R_C)/(2R_C + R_R)} \qquad (6)$$

The results from Table 8 are plotted along with Eq. 6 in Figure 6. The steady state analysis gives an excellent estimate of the effects of a partition for this simplified geometry. Since this configuration (parallel plates), gives the extreme amount of interaction between an exterior wall and a partition, these results are an estimate of the upper boundary of this type of interaction. However, it is clear that neglecting partition interaction may result in large error in heat flux, especially for low R-value walls. These types of interactions also raise questions about comparisons of walls with different R-values.

Next, let us examine the effect of mass on the partition configuration using dynamic analysis. In Table 9 the ratio of heat flux with partitions to that with partition but low mass wall are tabulated. For both massive wall cases no effect was observed.

From these cases, it can be concluded that: 1) when making comparisons between walls of different R-value effects of internal partitions must be considered, 2) effects of partitions are independent of the amount or placement of mass in the walls, 3) the ratio of heat flux with a partition to that for an isolated wall can be calculated using steady-state methods, and 4) there is no effect of mass on net heat flux.

CONCLUDING REMARKS

Although the "M" Factor as defined by Yu has been shown to be without technical justification, it is not the conclusion of this study that there are no massiveness effects in buildings. Rather, it appears to be unjustified to assign these effects solely to walls. In a real building, temperatures float up and down between thermostat set points, solar radiation is transmitted through windows and is distributed randomly within the structure. In addition, internal loads enter the heat balance and affect the transient response. The system therefore responds to the sum of these loads which manifests itself as energy requirement to heat and cool the structure. Until the complex interplay of these various effects are analyzed using experimentally validated transient analysis programs, assignment of specific effects to one element is unjustified.

In conclusion, it is strongly recommended that reference to the "M" Factor method in codes and standards be deleted.

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TABLE 1

NORTH AND SOUTH EXPOSURES OF THE SOL-AIR TEMPERATURE PROFILE

(All Temps. In °C)

HR	NORTH	SOUTH
0	-17.8	-17.8
1	-17.8	-17.8
2	-17.8	-17.8
3	-17.8	-17.8
4	-17.8	-17.8
5	-17.8	-17.8
6	-17.8	-17.8
7	-17.8	-17.8
8	-17.1	- 8.3
9	-15.7	10.4
10	-14.7	20.8
11	-14.2	26.5
12	-14.1	28.4
13	-14.2	26.5
14	-14.7	20.8
15	-15.7	10.4
16	-17.1	- 8.3
17	-17.8	-17.8
18	-17.8	-17.8
19	-17.8	-17.8
20	-17.8	-17.8
21	-17.8	-17.8
22	-17.8	-17.8
23	-17.8	-17.8

where HR = 0 is 12:00 midnight, HR = 8 is 8:00 a.m., etc.

The sol-air temperatures are calculated for a clear sky, 40°N, with an ambient temperature of -17.8°C (0°F).[7]

TABLE 2

EFFECT OF MASS ON "M" FACTOR AND DAILY ENERGY - R = 2.03 K-m^2/W

CONSTRUCTION	"M" FACTOR	DAILY ENERGY, kJ/m^2 (Btu/ft^2)
LIGHT	0.89	1260 (111)
MEDIUM	0.96	1260 (111)
HEAVY	0.88	1260 (111)

TABLE 3 HARMONIC ANALYSIS OF THE SOUTH SOL-AIR TEMPERATURE PROFILE. (All Temps. in °C.)

		HARMONICS										
HR	CONST.	H1	H2	H3	H4	H5	H6	H7	H8	H9	SUM	SOL-AIR
0	-5.8	-20.6	12.7	-4.1	-1.1	2.4	-1.0	-0.5	0.9	-0.4	-17.8	-17.8
1	-5.8	-19.9	11.0	-2.9	-0.6	0.6	0.0	0.1	-0.4	0.3	-17.8	-17.8
2	-5.8	-17.9	6.4	0.0	0.6	-2.0	1.0	0.5	-0.4	0.0	-17.8	-17.8
3	-5.8	-14.6	0.0	3.0	1.2	-1.6	0.0	-0.3	0.9	-0.3	-17.7	-17.8
4	-5.8	-10.3	-6.3	4.2	0.6	1.2	-1.0	-0.2	-0.4	0.4	-17.8	-17.8
5	-5.8	-5.3	-10.9	3.0	-0.6	2.3	0.0	0.5	-0.4	-0.3	-17.7	-17.8
6	-5.8	0.0	-12.6	0.0	-1.1	0.0	1.0	0.0	0.9	0.0	-17.8	-17.8
7	-5.8	5.4	-10.9	-2.9	-0.6	-2.3	0.0	-0.5	-0.4	0.3	-17.8	-17.8
8	-5.8	10.4	-6.3	-4.1	0.6	-1.1	-1.0	0.2	-0.4	-0.4	-8.1	-8.3
9	-5.8	14.6	0.0	-2.9	1.2	1.7	0.0	0.4	0.9	0.3	10.2	10.4
10	-5.8	17.9	6.4	0.0	0.6	2.1	1.0	-0.4	-0.4	0.0	21.2	20.8
11	-5.8	20.0	11.0	3.0	-0.6	-0.6	0.0	-0.1	-0.4	-0.3	26.1	26.5
12	-5.8	20.7	12.7	4.2	-1.1	-2.3	-1.0	0.5	0.9	0.4	28.9	28.4
13	-5.8	20.0	11.0	3.0	-0.6	-0.6	0.0	-0.1	-0.4	-0.3	26.1	26.5
14	-5.8	17.9	6.4	0.0	0.6	2.1	1.0	-0.4	-0.4	0.0	21.2	20.8
15	-5.8	14.6	0.0	-2.9	1.2	1.7	0.0	0.4	0.9	0.3	10.2	10.4
16	-5.8	10.4	-6.3	-4.1	0.6	-1.1	-1.0	0.2	-0.4	-0.4	-8.1	-8.3
17	-5.8	5.4	-10.9	-2.9	-0.6	-2.3	0.0	-0.5	-0.4	0.3	-17.8	-17.8
18	-5.8	0.0	-12.6	0.0	-1.1	0.0	1.0	0.0	0.9	0.0	-17.8	-17.8
19	-5.8	-5.3	-10.9	3.0	-0.6	2.3	0.0	0.5	-0.4	-0.3	-17.7	-17.8
20	-5.8	-10.3	-6.3	4.2	0.6	1.2	-1.0	-0.2	-0.4	0.4	-17.8	-17.8
21	-5.8	-14.6	0.0	3.0	1.2	-1.6	0.0	-0.3	0.9	-0.3	-17.7	-17.8
22	-5.8	-17.9	6.4	0.0	0.6	-2.0	1.0	0.5	-0.4	0.0	-17.8	-17.8
23	-5.8	-19.9	11.0	-2.9	-0.6	0.6	0.0	0.1	-0.4	0.3	-17.8	-17.8

where

HR = 0 is 12:00 midnight, HR = 8 is 8:00 A.M., etc.,

CONST. is the constant term of the Fourier series,

H1 through H9 are the contributions from the first nine harmonics, i.e., H3 = $A_3\cos(3\pi t/12)$,

SUM is the sum of the series, SUM = CONST. + H1 + ... + H9, and SOL-AIR is the actual south sol-air temperature profile.

TABLE 4 HARMONIC ANALYSIS OF THE HEAT FLUX FOR THE HEAVY WALL. (All heat fluxes in W/m^2.)

HR	CONST.	HARMONICS H1	H2	H3	H4	H5	H6	H7	H8	H9	SUM	ACT.
0	12.34	-1.01	0.30	-0.03	-0.00	-0.00	0.00	0.0	-0.00	0.0	11.59	11.60
1	12.34	-0.74	0.29	-0.05	-0.01	0.00	-0.00	0.0	0.0	0.0	11.84	11.84
2	12.34	-0.41	0.20	-0.04	-0.00	0.01	-0.00	0.0	0.0	0.0	12.09	12.09
3	12.34	-0.06	0.05	-0.00	0.00	-0.00	0.00	0.0	-0.00	0.0	12.33	12.33
4	12.34	0.30	-0.10	0.03	0.01	-0.01	0.00	0.0	0.0	0.0	12.57	12.57
5	12.34	0.64	-0.23	0.05	0.00	-0.00	-0.00	0.0	0.0	0.0	12.79	12.79
6	12.34	0.93	-0.30	0.04	-0.00	0.01	-0.00	0.0	-0.00	0.0	13.01	13.01
7	12.34	1.16	-0.29	0.00	-0.01	0.00	0.00	0.0	0.0	0.0	13.22	13.22
8	12.34	1.31	-0.20	-0.03	-0.00	-0.00	0.00	0.0	0.0	0.0	13.42	13.42
9	12.34	1.37	-0.05	-0.05	0.00	-0.01	-0.00	0.0	-0.00	0.0	13.61	13.61
10	12.34	1.34	0.10	-0.04	0.01	0.00	-0.00	0.0	0.0	0.0	13.76	13.75
11	12.34	1.22	0.23	-0.00	0.00	0.01	0.00	0.0	0.0	0.0	13.80	13.80
12	12.34	1.01	0.30	0.03	-0.00	0.00	0.00	0.0	-0.00	0.0	13.68	13.68
13	12.34	0.74	0.29	0.05	-0.01	-0.00	-0.00	0.0	0.0	0.0	13.39	13.39
14	12.34	0.41	0.20	0.04	-0.00	-0.01	-0.00	0.0	0.0	0.0	12.97	12.97
15	12.34	0.06	0.05	0.00	0.00	0.00	0.00	0.0	-0.00	0.0	12.46	12.46
16	12.34	-0.30	-0.10	-0.03	0.01	0.01	0.00	0.0	0.0	0.0	11.92	11.92
17	12.34	-0.64	-0.23	-0.05	0.00	0.00	-0.00	0.0	0.0	0.0	11.43	11.44
18	12.34	-0.93	-0.30	-0.04	-0.00	-0.01	-0.00	0.0	-0.00	0.0	11.07	11.07
19	12.34	-1.16	-0.29	-0.00	-0.01	-0.00	0.00	0.0	0.0	0.0	10.88	10.88
20	12.34	-1.31	-0.20	0.03	-0.00	0.00	0.00	0.0	0.0	0.0	10.86	10.86
21	12.34	-1.37	-0.05	0.05	0.00	0.01	-0.00	0.0	-0.00	0.0	10.96	10.96
22	12.34	-1.34	0.10	0.04	0.01	-0.00	-0.00	0.0	0.0	0.0	11.14	11.14
23	12.34	-1.22	0.23	0.00	0.00	-0.01	0.00	0.0	0.0	0.0	11.36	11.36
TOT	296.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	296.17	296.18

where

HR = 0 is 12:00 midnight, HR = 8 is 8:00 A.M., etc.,

CONST. is the constant term of the Fourier series,

H1 through H9 are the contributions from the first nine harmonics, i.e. H3 = $A_3\cos(3\pi t/12)$,

SUM is the sum of the series, SUM = CONST. + H1 + ... + H9,

ACT. is the actual heat flux throughout the day,

and TOT shows the total daily heat flux from each column.

TABLE 5 HARMONIC ANALYSIS OF THE HEAT FLUX FOR THE LIGHT WALL. (All heat fluxes in W/m^2.)

		HARMONICS										
HR	CONST.	H1	H2	H3	H4	H5	H6	H7	H8	H9	SUM	ACT.
0	12.34	8.55	-5.19	1.67	0.46	-0.90	0.37	0.18	-0.30	0.13	17.32	17.32
1	12.34	8.32	-4.63	1.27	0.27	-0.32	0.04	-0.03	0.13	-0.08	17.31	17.32
2	12.34	7.52	-2.83	0.13	-0.19	0.73	-0.37	-0.16	0.18	-0.01	17.33	17.32
3	12.34	6.21	-0.27	-1.09	-0.46	0.70	-0.04	0.11	-0.30	0.10	17.29	17.32
4	12.34	4.48	2.36	-1.67	-0.27	-0.37	0.37	0.11	0.13	-0.13	17.34	17.32
5	12.34	2.44	4.35	-1.27	0.19	-0.89	0.04	-0.17	0.18	0.08	17.30	17.32
6	12.34	0.23	5.18	-0.13	0.46	-0.09	-0.37	-0.02	-0.30	0.01	17.31	17.32
7	12.34	-1.99	4.63	1.09	0.27	0.84	-0.04	0.18	0.13	-0.10	17.34	17.32
8	12.34	-4.08	2.83	1.67	-0.19	0.53	0.37	-0.07	0.18	0.13	13.70	13.77
9	12.34	-5.89	0.27	1.27	-0.46	-0.57	0.04	-0.14	-0.30	-0.08	6.48	6.39
10	12.34	-7.29	-2.36	0.13	-0.27	-0.82	-0.37	0.14	0.13	-0.01	1.61	1.75
11	12.34	-8.20	-4.35	-1.09	0.19	0.14	-0.04	0.06	0.18	0.10	-0.68	-0.83
12	12.34	-8.55	-5.19	-1.67	0.46	0.90	0.37	-0.18	-0.30	-0.13	-1.95	-1.79
13	12.34	-8.32	-4.63	-1.27	0.27	0.32	0.04	0.03	0.13	0.08	-1.01	-1.16
14	12.34	-7.52	-2.83	-0.13	-0.19	-0.73	-0.37	0.16	0.18	0.01	0.92	1.05
15	12.34	-6.21	-0.27	1.09	-0.46	-0.70	-0.04	-0.11	-0.30	-0.10	5.24	5.14
16	12.34	-4.48	2.36	1.67	-0.27	0.37	0.37	-0.11	0.13	0.13	12.51	12.56
17	12.34	-2.44	4.35	1.27	0.19	0.89	0.04	0.17	0.18	-0.08	16.91	16.90
18	12.34	-0.23	5.18	0.13	0.46	0.09	-0.37	0.02	-0.30	-0.01	17.31	17.31
19	12.34	1.99	4.63	-1.09	0.27	-0.84	-0.04	-0.18	0.13	0.10	17.29	17.32
20	12.34	4.08	2.83	-1.67	-0.19	-0.53	0.37	0.07	0.18	-0.13	17.34	17.32
21	12.34	5.89	0.27	-1.27	-0.46	0.57	0.04	0.14	-0.30	0.08	17.29	17.32
22	12.34	7.29	-2.36	-0.13	-0.27	0.82	-0.37	-0.14	0.13	0.01	17.33	17.32
23	12.34	8.20	-4.35	1.09	0.19	-0.14	-0.04	-0.06	0.18	-0.10	17.31	17.32
TOT	296.16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	296.16	296.16

where

HR = 0 is 12:00 midnight, HR = 8 is 8:00 A.M., etc.,

CONST. is the constant term of the Fourier series,

H1 through H9 are the contributions from the first nine harmonics, i.e., H3 = $A_3 \cos(3\pi t/12)$,

SUM is the sum of the series, SUM = CONST. + H1 + ... + H9,

ACT. is the actual heat flux throughout the day,

and TOT shows the total daily heat flux from each column.

TABLE 6

EFFECT OF MASS ON "M" FACTOR AND YEARLY ENERGY - R = 2.03 $K\text{-}m^2/W$

CONSTRUCTION	"M" FACTOR	YEARLY ENERGY, MJ/m^2 (Btu/ft^2)
LIGHT	0.83	186 (16,400)
MEDIUM	0.80	186 (16,400)
HEAVY	0.76	186 (16,400)

TABLE 7

MATRIX OF WALL TYPES STUDIED

INSULATION, R ($K\text{-}m^2/W$)	MASS, kg/m^2 1	340	680
0.2	x	x	x
2	x	x	x
4	x	x	x

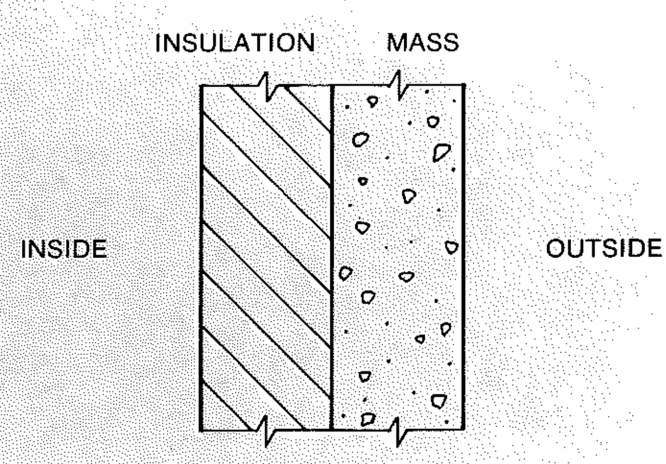


TABLE 8

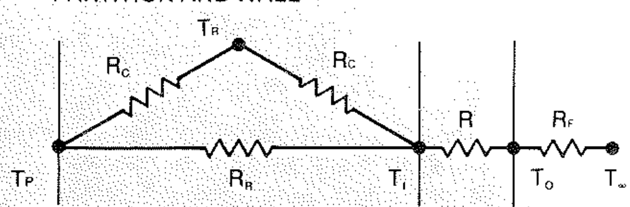
EFFECT OF PARTITION INTERACTION ON HEAT FLUX

($Q_{partition}/Q_{isolated\ wall}$)

INSULATION, R ($K\text{-}m^2/W$)	MASS, kg/m^2 1	340	680
0.2	1.28	1.28	1.28
2	1.05	1.05	1.05
4	1.03	1.03	1.03

1.03 (Mass and Insulation Reversed)

PARTITION AND WALL



ISOLATED WALL

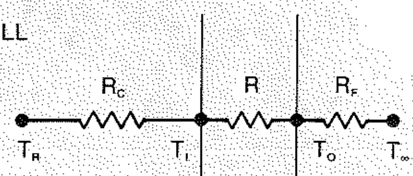


TABLE 9

EFFECT OF MASS ON HEAT FLUX

($Q_{partition}/Q_{partition\ with\ low\ mass\ wall}$)

INSULATION, R ($K\text{-}m^2/W$)	MASS, kg/m^2 1	340	680
0.2	1.0	1.0	1.0
2	1.0	1.0	1.0
4	1.0	1.0	1.0

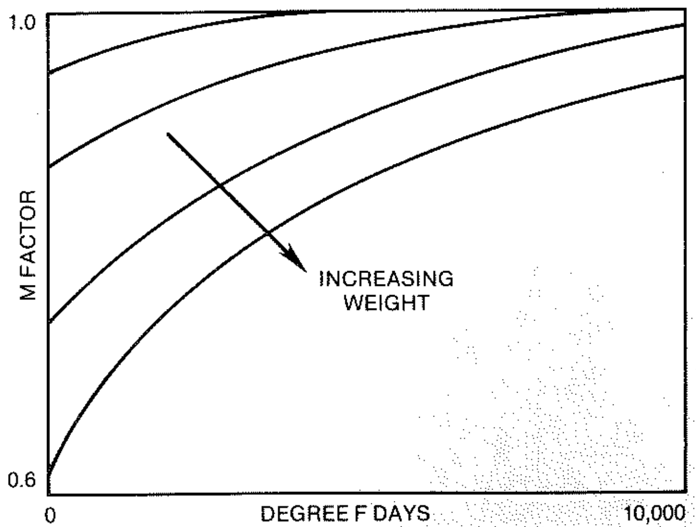


FIG. 1 "M" FACTOR VS. DEGREE DAYS FOR VARIOUS WALL WEIGHTS[2]

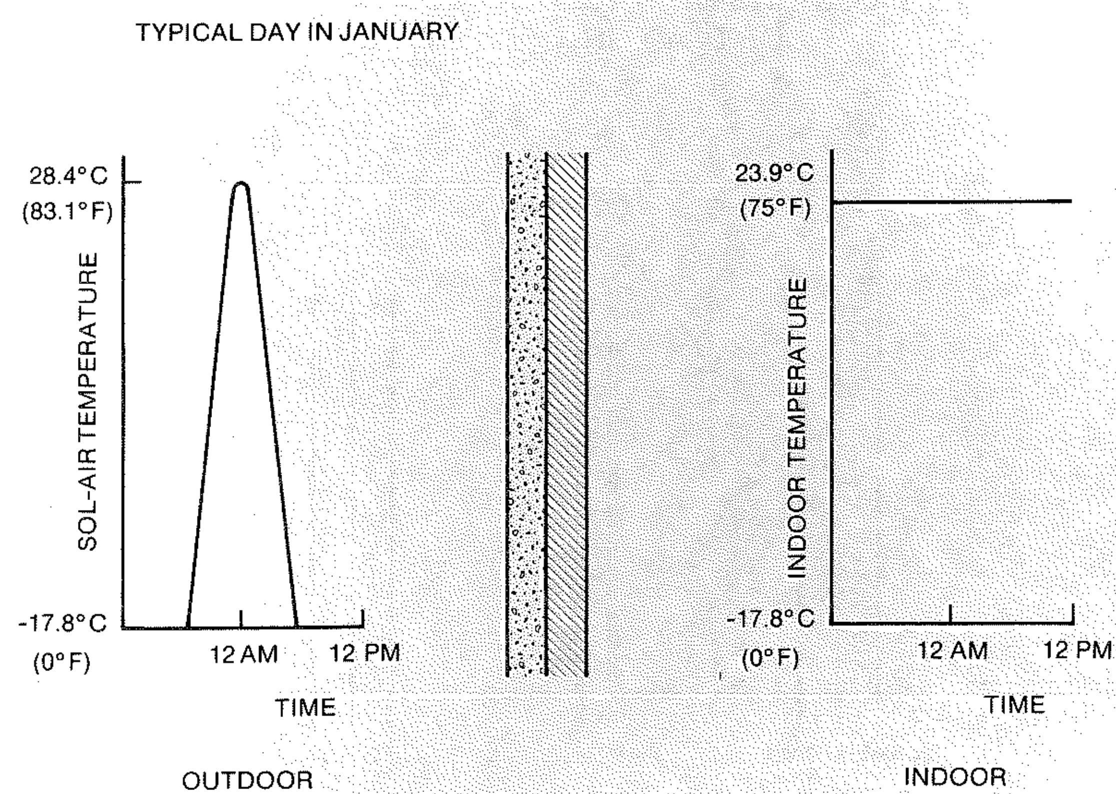


FIG. 2 ISOLATED WALL MODEL

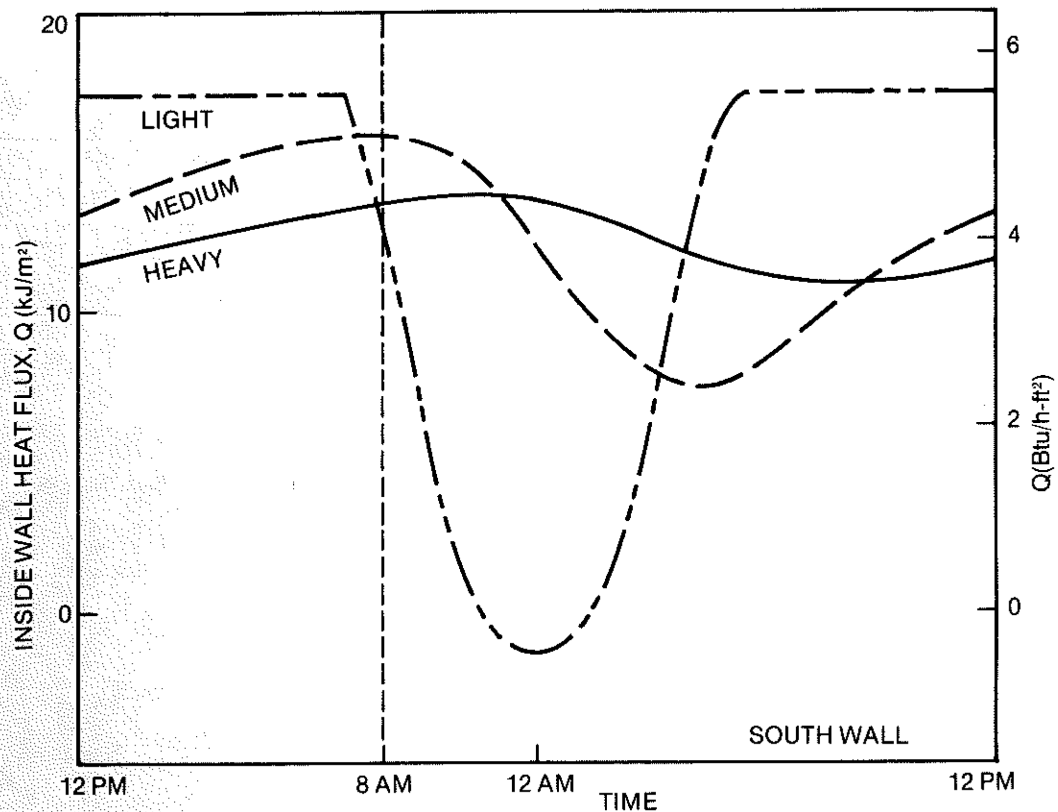


FIG. 3 INSIDE WALL HEAT FLUX VS. TIME OF DAY FOR THREE WALL TYPES.

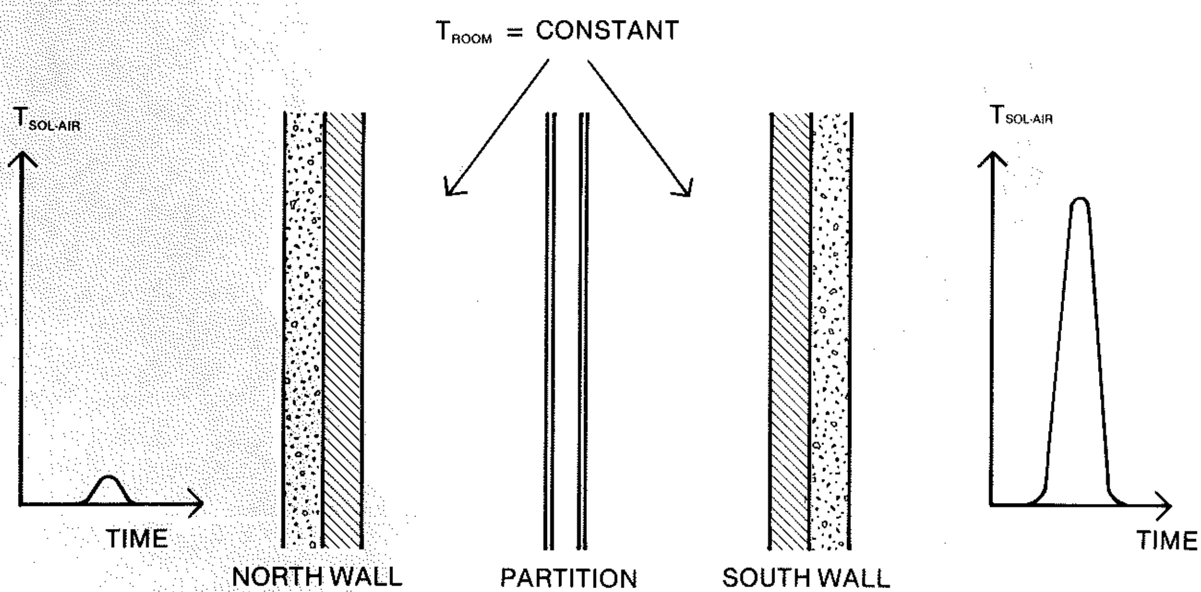
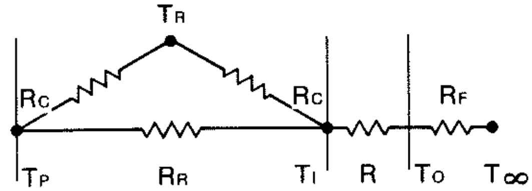


FIG. 4 THE SIMPLIFIED ROOM MODEL -- WALLS COMMUNICATING THROUGH AN INTERMEDIATE PARTITION



$$\frac{Q_P}{Q_{IW}} = \frac{R_F + R + R_C}{R_F + R + R_C \quad (R_R + R_C) \;/\; (2R_C + R_R)}$$

FIG. 5 CIRCUIT DIAGRAM FOR PARTITION AND OUTSIDE WALL. ALSO, RATIO OF HEAT FLUXES WITH A PARTITION TO THAT FOR AN ISOLATED WALL

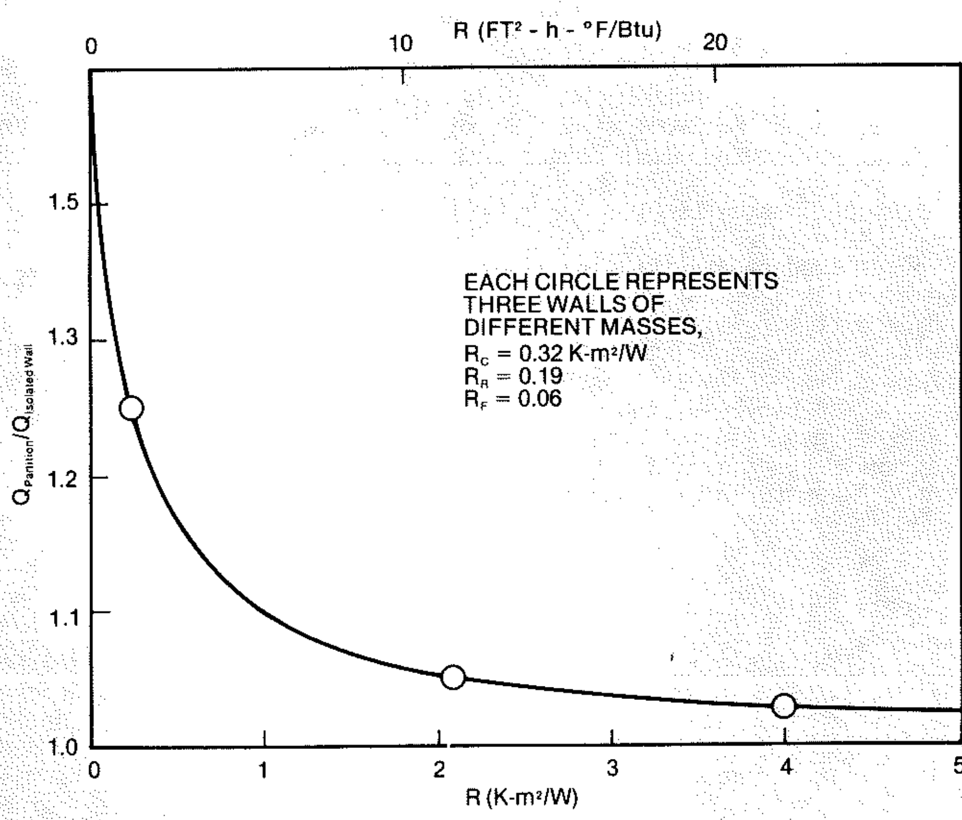


FIG. 6 EFFECT OF PARTITION ON HEAT FLUX

SESSION V QUESTION AND/OR COMMENT

Howanski & Fiorato

a. Jack A. Giglio

Q. Effects of a UI Foam are probably skewed by type block and lack of full fill. Determine performance with either full fill of test block (i.e., pressure fill techniques) or further test of more commonly use block config., i.e., nominal 3/4" depth ear on one side only. Performance should reflect closed to an incremental R-5 to 5.3

A. The block wall was filled by a local licensed UF foam applicator to best represent field application techniques. The blocks chosen also represent a typical block configuration. We would be glad to review any test data that you may have in the future.

b. Bud Coutu, Atlas Industries

Q. Please send copy of your paper given December 4, at 3:40 PM. Has there been any testing on Ground Polyurethane (Rigid) for masonry block fill? Also your comment on enclosed literature would be appreciated.

A. We do not know of any test performed on block walls filled with ground polyurethane foam. Thermal conductivity of a core insulation material is not the sole factor in the overall thermal performance of a masonry wall. The ability of the core insulation to fill all voids in the wall is also important. Based on the bulk density of the ground polyurethane foam, it may be difficult to fill all voids in block cores, as in the case of EPS beads.

Kenneth L. Wilkes

a. Paul Lewis, Florida Power Corporation

Q. Has any research been done on Power Vent vs. STD Ridge, etc. been done for Southeast United States. If so, what results were shown - cost effective - temperature reduction at insulation point - etc?

A. The experimental program described in the paper consists of laboratory measurements rather than field measurements. Thus, natural ventilation forces produced by the wind are not present. To obtain controlled and measurable ventilation rates, the attic is ventilated by a blower connected by a duct to a slot in the ridge of the roof. Experiments are being run with various ventilation rates to see the effect on temperatures and heat flow rates. Data on these effects will be published at a later time. Since the blower system is not typical of commercial power ventilators, we are not measuring its energy consumption and hence will not have direct data on cost effectiveness. However, it is expected that some estimates of cost effectiveness may be made by appropriate analyses.

Wang

a. Sherwood R. Peters, LBL

Q. The usefulness of two dimensional heat transfer analytical model for basements appears very useful. To make the techniques useful it appears necessary to have detailed information on the computer coding used included with the paper. To make the techniques useable it also appears necessary to have references for materials properties such as overall thermal conductivity of various block materials in various directions and ways of accessing various soil properties dependent on frost conditions and moisture conditions as well as the soil itself.

A. This is true for any mathe-modeling. The accuracy of the simulated results cannot be more than the accuracy of the input information. Thermal properties, boundary conditions and so on are very important to thermal simulations. The conductivity of construction material is, in general, isotropic - i.e., very little difference in different direction, with the exception of air porous insulation material, such as mineral wool or glass fibers. It is conceivable to have different conductivities for such material depending on whether the heat transfer direction is from top to bottom, or bottom to top, or side to side. It is also true with soil of high water content. Professor Mile S. Kerstern of the University of Minnesota has completed such studies on the thermal conductivities of different soils, (i.e., clay, silt, sandy soil, etc) as a function of water contents. More recently, Mr. Bernard Nidowitz has converted such relationships into programs, that can be executed through pocket calculators.

This shows that the thermal conductivities of soil, frozen or thawed, lend themselves to computer programing. (Northern Engineers, vg) 10, No1, pg9-14)

The accessibility of this program is only slightly more involved than the most common alternative, namely the finite difference computer program. Unless one decided not to simulate this 2-D problem with a computer, otherwise, this finite element approach is in many ways superior to the other approaches.

b. M. McCabe, National Bureau of Standards

Q. To what extent does vertical conduction in the foundation wall affect the heat loss calculation, i.e., ratio of heat loss with and without conduction in concrete or masonry wall?

A. We believe that the vertical conduction is quite significant in the overall heat loss through a basement wall. First, we tried the two-path hand calculations, and the results showed that the total heat loss was about 50 and 50% distributed between the A and B path for each concrete block. This was the case when the exposed part was eight (8) inches. Second, by comparing case F & G of the first set of simulations, this difference is about 47% Which is primarily because of the vertical conduction. On cases B and E of the same set of simulations, the difference of (0.28-0.19) or 47% should not be existing if the vertical conduction along the block wall were not there. How much effect of this vertical conduction would be on the total heat loss depending on whether there exists a heat loss window (or short) in the system. Such as the exposed block wall, the un-insulated box sill and so on would stimulate more heat loss by vertical conductions.

Godfrey, Wilkes, Lavine

a. Mario J. Catani, Portland Cement Association

Q: The authors are commended for their continuation of work related to the evaluation of the benefits of mass in building envelopes. It is important that this kind of work be continued to improve our ability to evaluate the behavior of different building materials in walls.

The authors raise two questions regarding the development of the M Factor, namely "Can heat flux for a single hour be representative of seasonal energy consumption?" and "Is averaging of heat fluxes from multiple exposures valid without consideration of interaction with other building elements?"

These questions would be valid under most circumstances but do not apply in the case of the M Factor and its application within the context of the ASHRAE Standard 90-75 or model codes based on this standard.

Heat flux through a wall for a single hour is not representative of seasonal energy consumption or load but the ASHRAE Standard does not address energy consumption or even annual or seasonal load. The requirements for energy conservation in the standard are for peak load, whether for heating or cooling. It should also be pointed out here that 8:00 A.M. in January was selected for convenience and that it was assumed to be the most critical peak load time. However, as pointed out in other articles on the subject, values obtained using this assumption were checked against values which were obtained using similar data for 6:00, 7:00 and 9:00 A.M. for October, November, December, February and March. Figure 1 shows the results obtained for Atlanta and indicates that they are rather insensitive to hour or month.

The second question raised challenged the use of values which are averaged over the eight exposures studied. It is true that there are errors involved when building walls are analyzed alone without considering their interaction with interior partitions, internal heat gains, orientation, and many other variables. But again it must be pointed out that the ASHRAE Standard handles heat transmission through walls and windows based on an average exposure without considering interaction with partitions or internal loads. Why should the modifier be more sophisticated than the factor being modified?

The ultimate question should be "Does the use of the M Factor produce results which are inconsistent with the intent of the ASHRAE Standard or which are not conservative when compared with sophisticated analysis of buildings taking into account all of the variables which are proper?" In answer to this, many studies have been made to compare the effect of wall mass in reducing peak and annual energy loads (PCA, NRC, University of Pittsburgh, NBS, FmHA). These studies show that except for very cold climates such as occur in Canada the M Factor benefit is so small that this inconsistency is negligible. It should also be pointed out that in the cold climates, the error is reduced considerably when the mass is placed inside the insulation as is the case with some of the walls studied. In southern climates, the use of the M Factor is extremely conservative and can be used very effectively until a more sophisticated approach can be developed.

<u>SUMMARY</u>: It should be noted that the M Factor is at least as sophisticated as the ASHRAE 90-75 method and that the assumptions used in determining the M Factor are consistent with the 90-75 method, i.e., peak load, no partitions, no internal heat gain.

It should also be noted that the use of the M Factor yields conservative results especially in temperate climates where most of the masonry construction is used.

It is essential that engineers be able to apply the intent of the ASHRAE Standard by using the M Factor until either the standard is changed to be more sophisticated or until a more sophisticated method can be developed to reflect the benefits of wall mass. It should be noted that this latter task is being approached now.

A: The requirements for energy conservation in the Standard (ASHRAE 90-75) are peak load. However, no mention of peak load is made in Section 4 of that standard, Exterior Envelope Requirements. Instead, this section sets minimum U-values for building envelope components, based on annual heating degree days. Clearly, the intent is to regulate the annual building load, with the aim of conserving energy. This objective would not be accomplished simply by reducing the peak load.

Our paper clearly demonstrates that, given the assumptions used in Mr. Catani's study (specifically, constant indoor temperature and no internal partitions), massiveness has no effect on the daily or annual heat flow through a wall. The "M" factor may well be a measure of reduction in peak load, but in no way is it indicative of energy savings due to wall massiveness. Therefore, it would be inappropriate to use the "M" factor in connection with ASHRAE Standard 90-75 or similar building codes, which have the intent of promoting energy conservation.

We do recognize that wall massiveness can have an effect on buildings loads under more realistic conditions. We fully agree with Mr. Catani that there is a need for a relatively simple means to account for the benefits of wall massiveness, when appropriate. The "M" factor, however, is not a valid tool for this purpose.