THERMAL EXCHANGES THROUGH VENTILATED ATTICS

V. Abrantes, Ph.D.

ABSTRACT

The thermal exchanges within a ventilated attic can be characterized in terms of thermal behavior of its three main components: the roof coatings, the air space, and the attic floor.

To study this situation, a computer simulation algorithm has been developed (BETEH) and validated by comparison with attic temperatures measured in situ for one year. One of the main variables influencing the thermal behavior of attic spaces is the air exchange rate that takes place through the roof. Leakage data for tiled roofs, which were not available in the literature, were measured and are also reported.

With these data, the thermal behavior of ventilated attics was calculated and is presented in terms of the following parameters: solar absorption of the roof coating; U-value and specific mass of the roof coating; U-value and specific mass of the attic floor; attic floor emittance. As a conclusion, a correlation for the total heat-transfer coefficient for ventilated roofs is presented.

INTRODUCTION

Roofs play an important part in the global energy balance of a building. The importance of the thermal exchange in the roof increases as the tightness and overall U-value of the walls and glazings increases and as the number of stories decreases. In addition, certain types of roofs also influence the air exchange rate in a building; whenever there is a communication between the roof and stairwells or elevator shafts, the infiltration is increased.

In Portugal during the 1970s, about 50% of the new construction had a single story and 95% had no more than two storys. The vast majority of these buildings has a sloped tiled roof with an attic space that can be accessed from within. Usually, no insulation is used in the roofs and attics, resulting in a roof U-value of 0.5 Btu/h.ft^2.F (2.8W/m^2.K). Under these circunstances, it is clear that the thermal exchange through the roof in Portuguese buildings is responsible for a significant portion of their energy consumption for heating and cooling.

It is therefore important to be able to quantify the thermal performance of a roof-attic system, namely as a function of the air exchange rate in the attic.

AIR INFILTRATION THROUGH VENTILATED ATTICS

The element pressurization method was chosen in this case (Abrantes and Fernandes 1983). It consists of sealing off a portion of the roof with a plastic sheet and pulling a vacuum between this sheet and the roof. The pressure difference and airflow are then measured and the flow coefficient deduced from the measurement of leakage rates at various pressure differences.

Due to the difficulty in completely sealing off a section of an actual roof in a building and to the little mobility possible in most attics, a model was built in a laboratory and meas-

VITOR ABRANTES, Professor of Civil Engineering, The University of Porto, Portugal.

urement taken under completely controlled conditions. Pressure measurements were taken with an electronic micromanometer having a resolution of 4.10^{-7}in.H_2O(10^{-4}Pa), and airflow was measured with two rotameters with a 2% precision, one for flow rates up to 15.9 cfm (7.5 L/s) and the other for flows to 103 cfm (48.6 L/s). The airflow is driven by an air pump with 2383 Btu/h (700 W), capable of drawing a flow of 40 cfm (19 L/s), which is much larger than the leakage possible trough the element under study. The flow rate is then regulated with two valves. The results are summarized in Table 1 and shown in Figure 1.

THE BETEH SIMULATION PROGRAM

Although numerous calculation procedures and computer programs have been developed to evaluate the energy conservation in building design, very few of them have been subjected to detailed thermal exchanges through ventilatd attics.

The BETEH program (Abrantes and Galanis 1981; Abrantes and Galanis 1982; Abrantes 1985), based upon hour-by-hour heat transfer simulation, uses the so-called ASHRAE weithing factors to incorporate the heat gain effects into the cooling load.

Measured hourly values of the dry-bulb ambient temperature, the global radiation incident on a horizontal surface, as well as the wind speed and direction constitute the necessary meteorological inputs. A detailed description of the building's position, size, construction characteristics, and environment are also needed for the simulation.

The program calculates the amount of energy necessary to maintain thermal comfort at a desired level or, if the heating system's capacity is insufficient, it evaluates the new temperature prevailing in each zone.

The validation of the BETEH program is done by comparison between the computer-simulated values with attic temperatures measured in a test house in Porto, during four months covering March, May and September 1979 and January 1980. Figures 2 and 3 shows that a good agreement is obtained between the computed and observed attic temperature.

SUMMARY CONDITIONS OF SIMULATION

For computer simulation analyses, five different roof coatings and five different attic floors were used. Table 2 provides the thermophysical data of each of the different roofs. Most of these data are taken from the ASHRAE Handbook - (1977 Fundamentals). The roofs that can be considered as the most typical Portuguese roofs are presented in Figures 5 to 12 by x/y where x refers to the roof coating and y refers to the attic floor.

The Porto design climatic conditions presented in Table 3 were used for the simulations. Recommended design dry-bulb temperatures present an average value that has been equalled or exceeded by 5% and 2,5% of the total hours respectively in winter and in summer. The solar radiation intensities on a horizontal surface were the average hourly diffuse solar radiations for the calculation in winter and the hourly solar radiations on average cloudless days to 40 degree north on June 21 from the ASHRAE Handbook - (1981 Fundamentals).

INFLUENCE OF SOLAR ABSORPTION OF THE ROOF COATING - α

The BETEH load calculations use the concept of sol-air temperature, which involves the combination of incident solar radiation, radiant energy exchange with the sky and other outdoor surroundings, and convective heat exchange with the outdoor air. Consequently, the load calculation depends on the absorptance of the outdoor roof coating for solar radiation.

Figure 4 shows the hourly heat losses through the roof 3.75/A for nonventilated and highly ventilated attics (air changes per hour = 40), with different solar absorption of the roof coating. The effect of the coefficient α is predominantly for the smallest heat losses. Another observation made is that the attic ventilation minimizes the influence of the solar absorption of the roof coating.

Figure 5 and 6 show respectively the variation of the average daily heat losses and heat gains related with the variation $\Delta\alpha = 0.3$, for the different roofs simulated, as a function of the attic ventilation. For the same air changes per hour in attic ventilation, the variation of the heat gains is approximately 8 times superior to the variation of the heat losses. These comparisons show the importance of the solar absorption of the roof coating in the summer.

INFLUENCE OF THERMAL CHARACTERISTICS OF THE ROOF COATING

The computer simulation analyses used, as mentioned above, three different roof coatings in which specific mass is negligible and U-values are 0.66, 0.44, 0.22 Btu/h.ft^2.F (3.75, 2.50, 1.25 W/m^2), respectively, and two other roof coatings, R4, with specific mass of 17.8 lb/ft^2 (87 Kg/m^2) and U-value of 0.21 Btu/h.ft^2.F (1.17W/m^2.K).

Figure 7 shows the average daily heat losses for the different roof coatings simulated as a function of the attic ventilation. The increase of the insulation and the specific mass minimizes significantly the heat losses when the attic ventilation is small, but this influence is reduced when the attic ventilation increases.

Figure 8 shows the average daily heat gains for the different roof coating simulated as a function of the attic ventilation. In this case it is important to note that the attic ventilation increases the heat gains for the roof coatings when specific mass is considered.

INFLUENCE OF THERMAL CHARACTERISTICS OF THE ATTIC FLOOR

The comparison between the attic floors A and E, with specific mass approximately the same and U-values of 0.49 Btu/h.ft^2.F (2.78 W/m^2.K) and 0.31 Btu/h.ft^2.F (1.74 W/m^2.K), respectively, makes it possible to observe the influence of the insulation.

The comparison between the attic floors A and D, with U-values approximately the same and specific mass of 93.2 lb/ft^2(455 Kg/m^2) and 58.8 lb/ft^2(287 Kg/m^2), respectively, makes it possible to observe the influence of the specific mass.

Figure 9 shows the average daily heat losses for the different attic floors simulated as a function of the attic ventilation. This ventilation increases the influence of the insulation, and in the case of attic floors A and E it is possible to observe a decrease of between 30% to 34% of the heat losses. The influence of the specific mass is negligible.

Figure 10 shows the average daily heat gains for the different attic floors simulated as a function of the attic ventilation. As in the winter, the attic ventilation also increases the influence of the insulation and in the case of the attic floors A and E, it is possible to observe a decrease of between 30% to 33% of the heat gains. The influence of the specific mass is small but can be significative in the case of the maximum daily heat gains.

INFLUENCE OF ATTIC FLOOR EMITTANCE - ε

Figure 11 shows the hourly heat losses for roof 3.75/A nonventilated and highly ventilated as a function of the attic floor emittance where $\varepsilon = 0.9$ for the usual surfaces and $\varepsilon = 0.3$ when an aluminum coated paper is used on the attic floor. The influence of the emittance is unchanging during the day, with the greatest values in the case of the nonventilated attic roof. A $\Delta\varepsilon = 0.6$ causes a 15% to 27% change in the heat losses in the nonventilated attic and a 6% to 8% change in the ventilated attics.

Figure 12 shows the hourly heat gains for roof 3.75/A nonventilated and highly ventilated as a function of the attic floor emittance. The degree of the heat gains is more notorious for the maximum hourly values and nonventilated attics. A $\Delta\varepsilon = 0.6$ causes a 35% to 50% change in the heat gains in nonventilated attics and a 20% to 30% change in ventilated attics.

CONCLUSION

Results of BETEH simulations of different pitched roofs indicate the following conclusions:

1. The influence of the solar absorption of the roof coating is negligible in the winter but important in the summer, where a variation $\Delta\alpha = 0.3$ can cause a 30% change in the heat gains.

2. The influence of the insulation of the roof coating, which is significant for nonventilated

attics, is reduced when the attic ventilation increases.

3. The influence of the specific mass of the roof coatings, which is significant for nonventilated attics, is reduced when the attic ventilation increases, but in the case of the roof coating with specific mass, the attic ventilation increases the heat gains.

4. The influence of the insulation of the attic floor is very significant and increases with the attic ventilation.

5. The influence of the specific mass of the attic floor is negligible. However, this influence can be significant in the case of the maximum daily heat gains.

6. The influence of attic floor emittance decreases with the attic ventilation. This influence is more significant for the heat gains and a $\Delta\varepsilon = 0.6$ causes a 35% to 50% change in nonventilated attics and a 20% to 30% change in ventilated attics.

7. A correlation was obtained from the results of the computer simulations of the different roofs which thermophysical data are given in Table 2. This correlation for the total heat-transfer coefficient for ventilated roofs, U_V, is presented as a function of the total heat-transfer coefficient for nonventilated roofs, U, and air changes per hour of the attic space, N (N = 13 and N = 9 for asbestos cement shingles and N = 41 and N = 28 for ceramic tiles, respectively, in winter and in summer).

$$U_V = U + \alpha_{w(s)}\, N^{0.70} \qquad (1)$$

Where $\alpha_{w(s)}$ = Ventilation factor, values of which are given in Table 4.

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ACKNOWLEDGMENT

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TABLE 1

Experimental Values of Flow Coefficients of Roof Coatings

TYPE OF ROOF	FLOW COEFFICIENTS C Cfm/ft².in.water	C (ℓ/s.m².Pa)	n	STATISTICS* N	STATISTICS* r^2
CERAMIC TILES					
- Type I	33.17	4.59	0.537	11	0.999
- Type II	28.67	3.97	0.595	12	0.997
CEMENT TILES	33.51	4.64	0.385	12	0.976
ASBESTOS CEMENT SHINGLES					
- Type I	7.80	1.08	0.936	12	0.933
- Type I**	4.84	0.67	0.688	14	0.972
- Type II	4.62	0.64	0.668	14	0.997

* Number of experimental points and correlation coefficient

** Weatherstripped

TABLE 2

Characteristics of Roof Elements

DESIGNATION	DESCRIPTION	SPECIFIC MASS ℓb/ft²	SPECIFIC MASS (Kg/m²)	U-VALUE Btu/h.ft²	U-VALUE (W/m².K)	NUMBER FOR TRANSFER FUNCTION COEFFICIENTS
3.75	Ceramic tiles or asbestos cement shingles			0.66	3.75	
2.50	Arbitrary			0.44	2.50	
1.25	Arbitrary			0.22	1.25	
R4	4-in. ℓ. w. concrete	17.8	87	0.21	1.21	28*
R5	2-in. h. w. concrete with 1-in. insulation	28.7	140	0.21	1.17	34*
A	8-in. h. w. concrete	93.2	455	0.49	2.78	21**
B	8-in. common brick	79.9	390	0.34	1.92	20**
C	12-in h. w. concrete	139.9	683	0.42	2.41	22**
D	4-in. h. w. concrete with 0.75-in. plaster	58.8	287	0.50	2.83	5**
E	8-in. common brick plastered both sides	92.4	451	0.31	1.74	9**

* ASHRAE Handbook 1977 Fundamentals, Chapter 25, Table 26

** ASHRAE Handbook 1977 Fundamentals, Chapter 25, Table 29

TABLE 3

PORTO Design Climatic Conditions Used for the Simulations

HOUR	WINTER				SUMMER			
	OUTDOOR TEMP.		SOLAR RADIATION		OUTDOOR TEMP.		SOLAR RADIATION	
	F	(°C)	Btu/h.ft²	(W/m²)	F	(°C)	Btu/h.ft²	(W/m²)
1	29.3	- 1.5			73.6	23.1		
2	28.6	- 1.9			72.7	22.6		
3	28.4	- 2.0			72.5	22.5		
4	28.6	- 1.9			72.6	22.6		
5	29.3	- 1.5			73.6	23.1	3.5	11
6	30.6	- 0.8			74.8	23.8	46.0	145
7	32.0	0.0			76.6	24.8	111.6	352
8	33.8	1.0	9.5	30	78.4	25.8	175.6	554
9	35.6	2.0	30.4	96	80.6	27.0	230.8	728
10	37.4	3.0	35.5	112	82.8	28.2	273.2	862
11	39.2	4.0	45.6	144	84.7	29.3	298.6	942
12	40.6	4.8	46.3	146	86.4	30.2	306.9	968
13	41.9	5.5	45.6	144	87.6	30.9	298.6	942
14	42.6	5.9	36.1	114	88.3	31.3	273.2	862
15	42.8	6.0	30.4	96	88.7	31.5	230.8	728
16	42.6	5.9	13.3	42	88.3	31.3	175.6	554
17	41.9	5.5			87.6	30.9	11.6	352
18	40.6	4.8			86.4	30.2	46.0	115
19	39.2	4.0			84.7	29.3	3.5	11
20	37.4	3.0			82.8	28.2		
21	35.6	2.0			80.6	27.0		
22	33.8	1.0			78.4	25.8		
23	32.0	0.0			76.6	24.8		
24	30.6	- 0.8			74.8	23.8		

TABLE 4

Values of the Ventilation Factor $\alpha_{w(s)}$

TYPE OF ROOF	α_{winter}		α_{summer}	
	Btu/h.ft².F	(W/m².K)	Btu/h.ft².F	(W/m².K)
Usual	0.004	0.024	- 0.005	- 0.031
Roof coating insulated	0.013	0.074	- 0.001	- 0.003
Roof coating with specific mass	0.019	0.106	0.004	0.021
Attic floor insulated	0.002	0.010	- 0.005	- 0.027

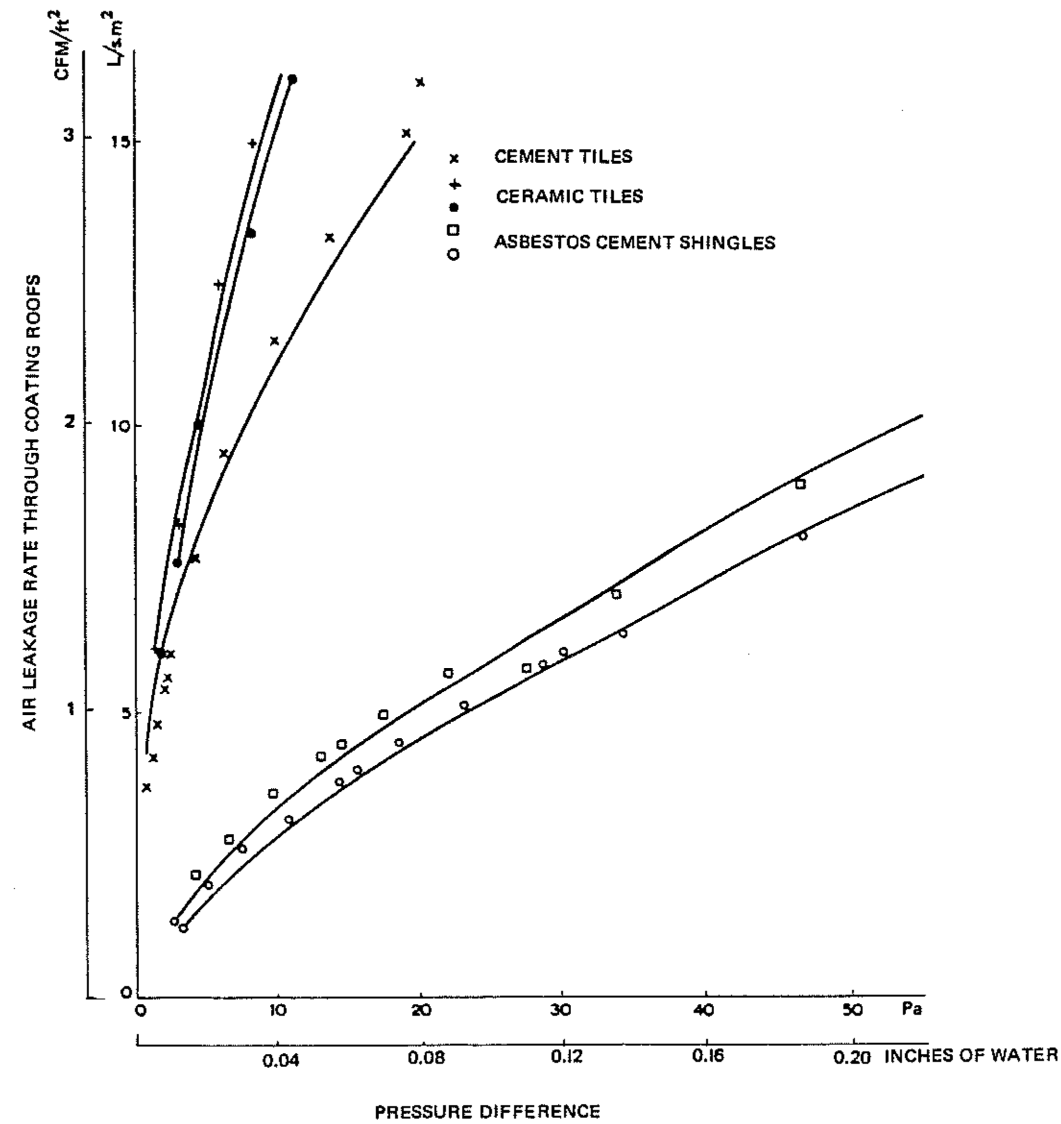

Figure 1. Leakage characteristics of coating roofs

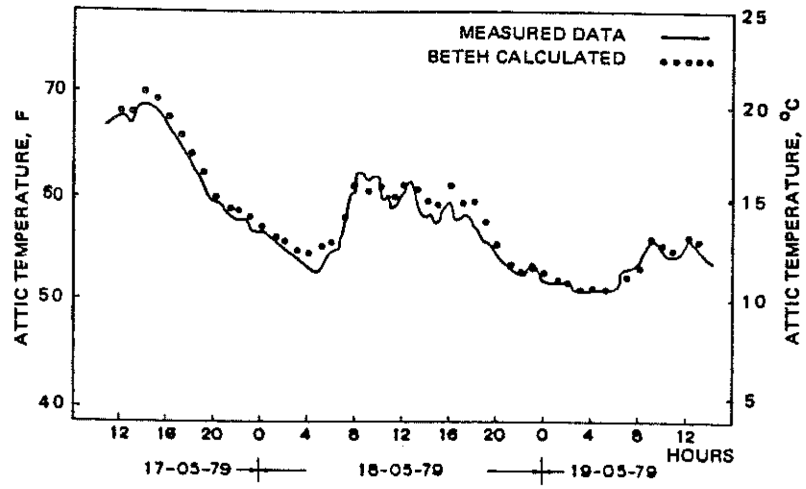

Figure 2. Comparison between the BETEH--calculated and observed attic temperatures

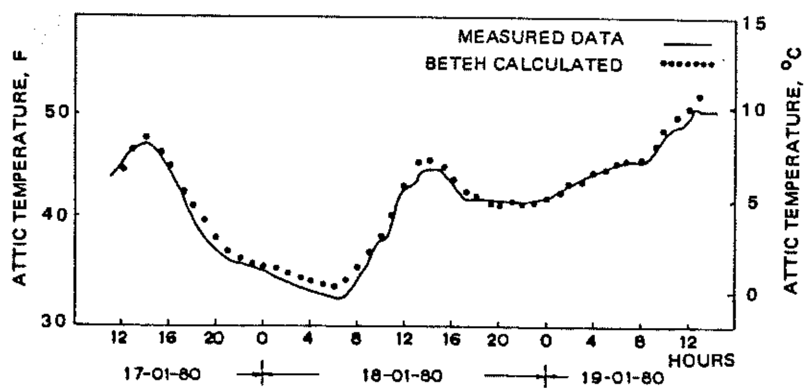

Figure 3. Comparison between the BETEH--calculated and observed attic temperatures

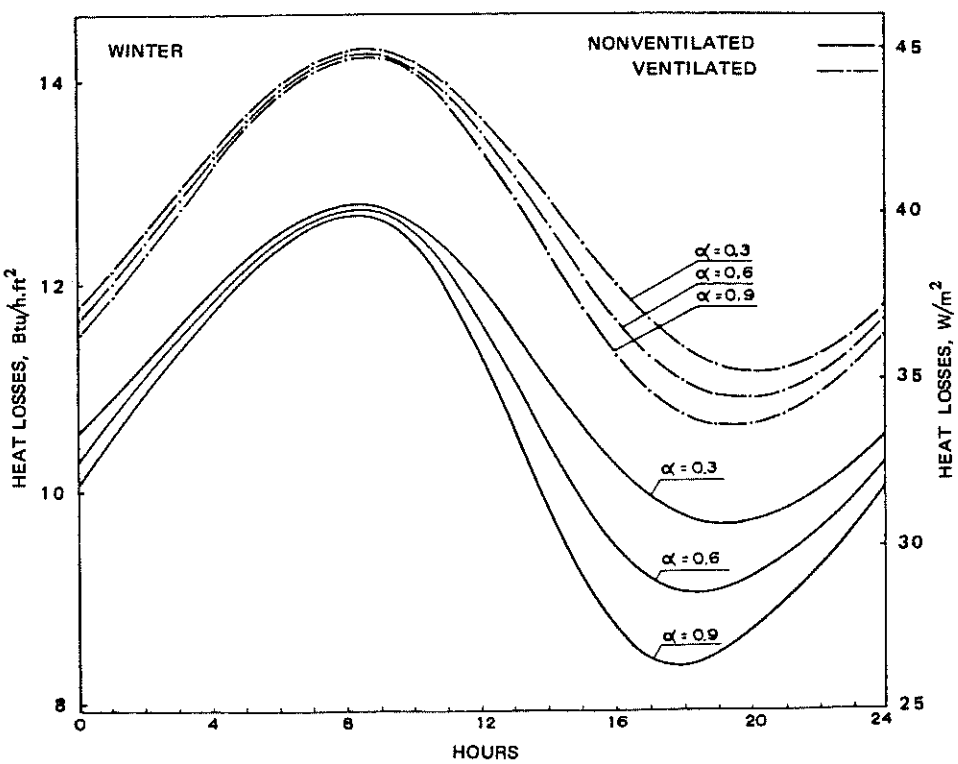

Figure 4. Comparison between different solar absorption of the coating roofs for nonventilated and ventilated attics

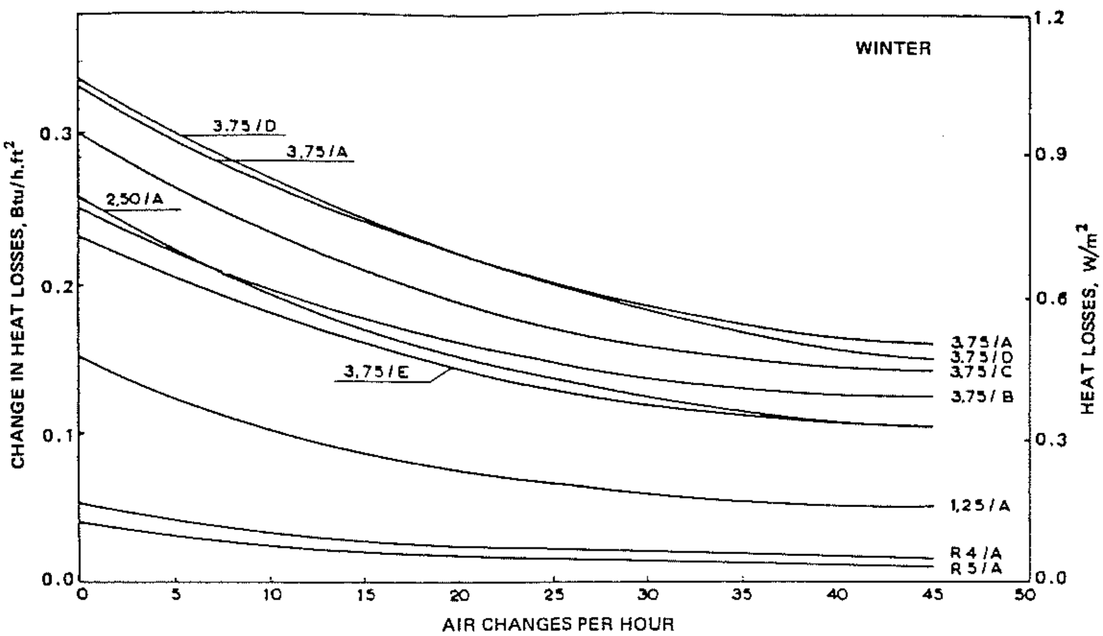

Figure 5. Variation of average daily heat losses for different coating roofs as a function of attic ventilation, when $\Delta\alpha = 0.3$

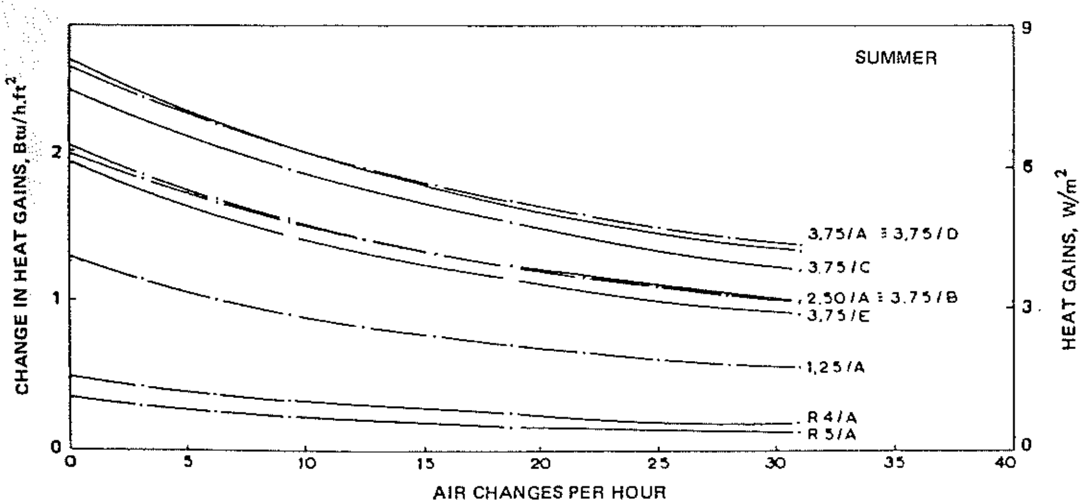

Figure 6. Variation of average daily heat gains for different coating roofs as a function of attic ventilation, when $\Delta\alpha = 0.3$

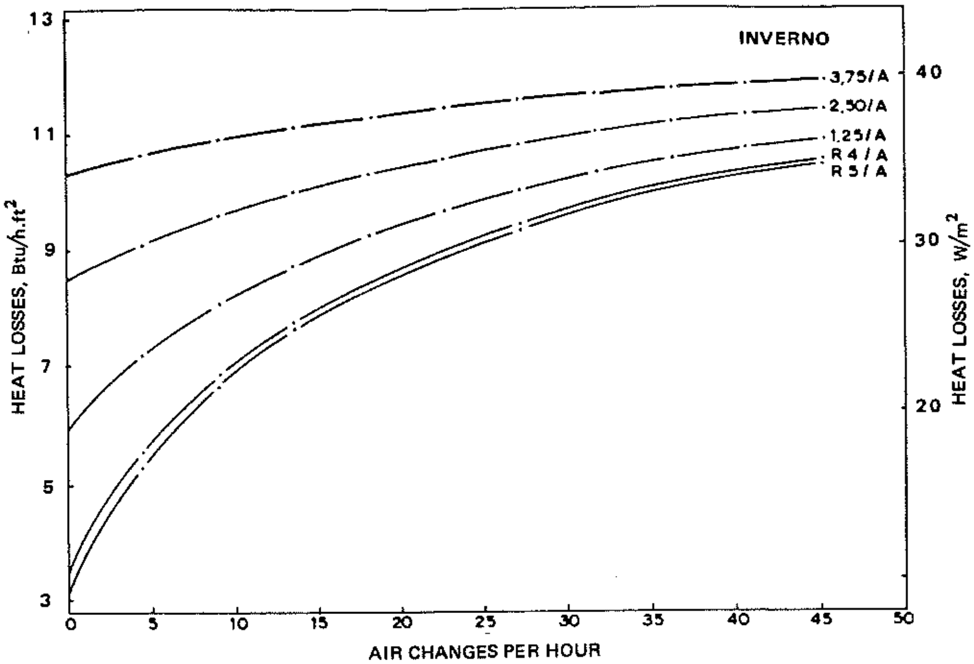

Figure 7. Average daily heat losses for different coating roofs as a function of attic ventilation.

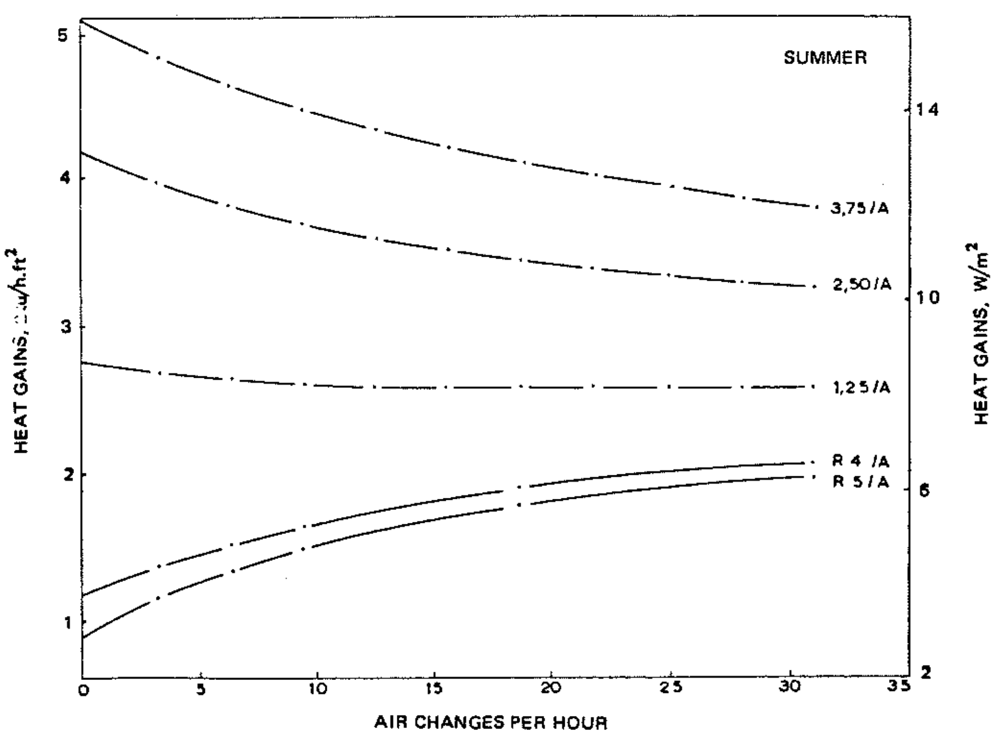

Figure 8. Average daily heat gains for different coating roofs as a function of attic ventilation

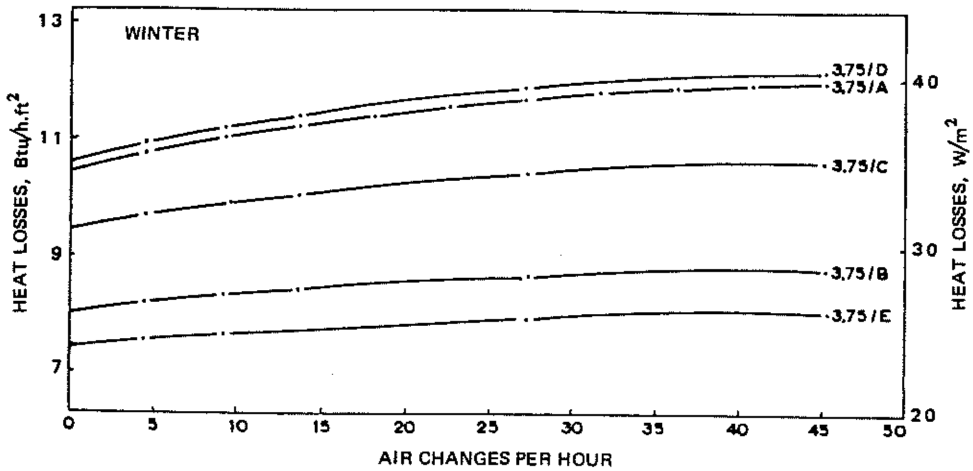

Figure 9. Average daily heat losses for different attic floors as a function of attic ventilation

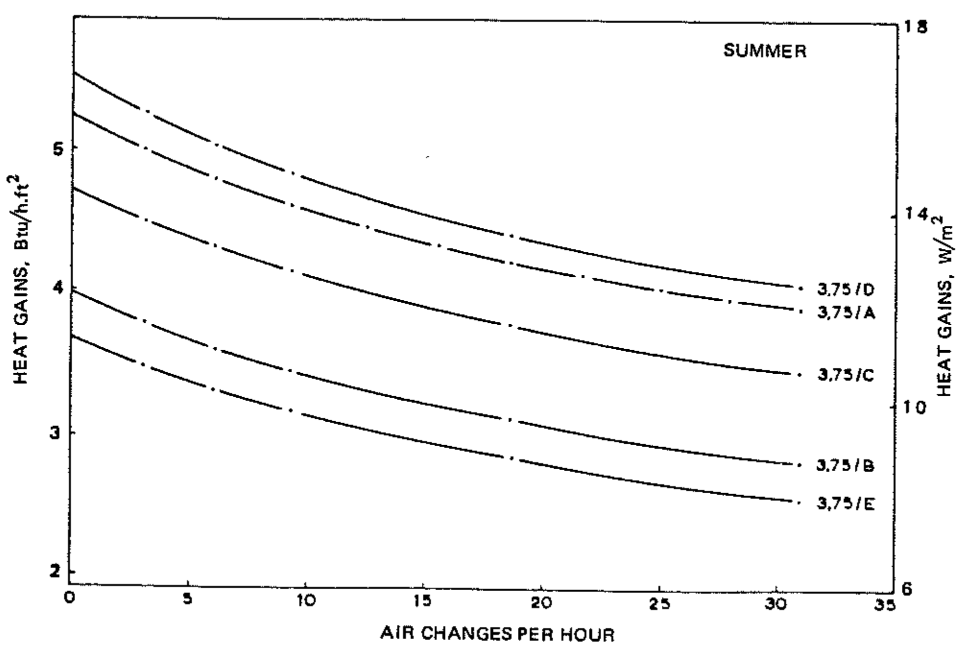

Figure 10. Average daily heat gains for different attic floors as a function of attic ventilation

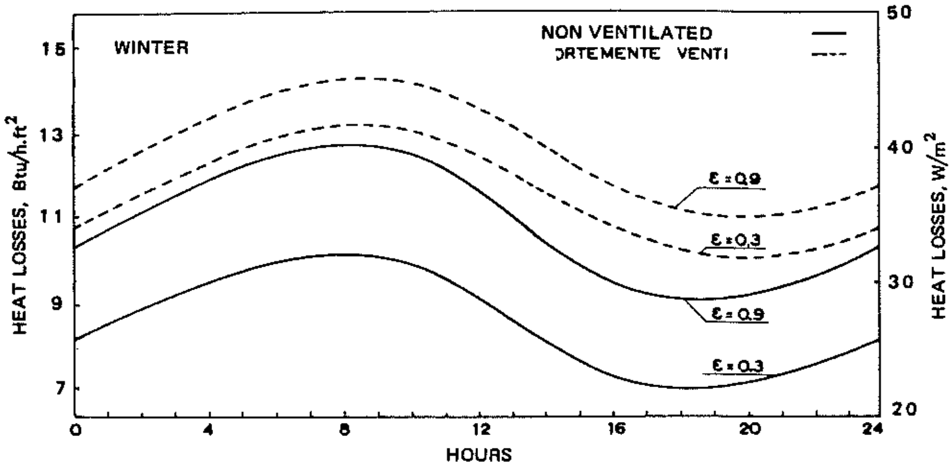

Figure 11. Comparison of hourly heat losses between different attic-floor emissivity

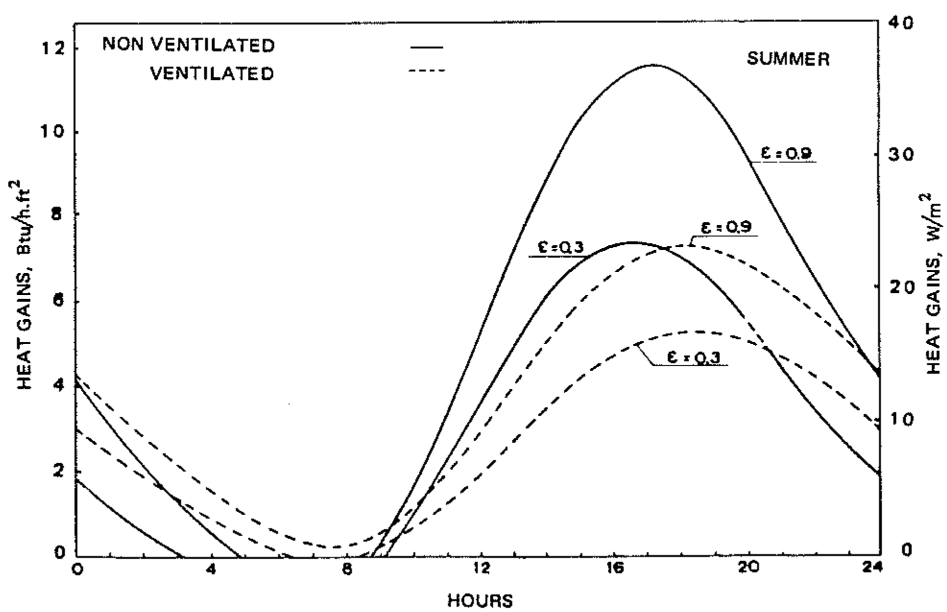

Figure 12. Comparison of hourly heat gains between different attic-floor emissivity