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THE EFFECT OF DESIGN PARAMETER CHANGES ON THE PERFORMANCE OF THERMAL STORAGE WALL PASSIVE SYSTEMS*

by

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ABSTRACT

Hour-by-hour computer simulations based on one year of solar radiation and temperature data are used to analyze annual energy savings in thermal storage wall passive designs - both Trombe wall and water wall cases. The calculations are rerun many times changing various parameters one at a time to assess the effect on performance. Parameters analyzed are: night insulation R-value, number of glazings, wall absorptance and emittance, thermal storage capacity, Trombe wall properties and vent area size, additional building mass, and temperature control set points. Calculations are done for eight cities.

INTRODUCTION

In the course of building design, many important decisions must be made regarding selection of design parameters. Often the most important considerations are cost and energy savings although availability of materials, thermal comfort, aesthetics, and expected lifetime are also determinants. The purpose of this paper is to present the results of a large number of simulation analyses which show the effect on annual energy savings resulting from changes in design parameters. The buildings analyzed are all of the thermal storage wall type of passive solar heated structures, that is, Trombe walls and water walls.

A reasonable design procedure is the following. The annual thermal performance is estimated for the particular location based on monthly solar and temperature data using a reference design. The Monthly Solar Load Ratio method has been developed for this purpose and correlation curves, based on a large variety of solar/weather data sets, have been published.(1) Then curves showing the effect of variations in design parameters, compared to the reference design, are used to estimate the performance of the actual building. To do this it is desirable to use curves for a climate similar to the one where the building is to be located.

One must be careful in using annual energy savings as the sole performance determinant. For example, the cost-optimum thickness of a concrete Trombe wall, considering only the tradeoff between initial cost and performance, is usually in the range between 6 and 8 in. Increases in thickness beyond this result in only a small increase in annual energy saved but greatly increase the cost of the wall. However the inside surface temperature of a 6 in. wall will swing 40 to 50°F during the course of a clear winter day. Such a swing may be acceptable in some situations but generally would be unacceptable. Therefore one must consider thermal comfort and its value in making this design selection and would probably opt for a thicker wall.

Both analysts and designers should be skeptical of simplified design correlations which presume to incorporate a variety of design variables into one equation. Effects which are thought to be second order and are ignored often turn out to be major when analyzed with a simulation of the actual physical situation on an hour-by-hour basis.

ANALYSIS PROCEDURE

Thermal network models of thermal storage wall passive solar heated buildings are used to mathematically simulate solar heating performance for several U.S. solar/weather data sets. An hour-by-hour calculation is made over a one year period and total auxiliary heating needed to maintain a 65°F room temperature is calculated. The annual solar heating fraction, F, based on energy saved by solar, is then calculated as follows:

$$F = 1 - \frac{\text{auxiliary heating required}}{\text{heating which would be required without solar}}$$

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The heating which would be required without solar is simply the product of the annual degree-hours below 65°F times the building loss coefficient, exclusive of the solar wall.

In the analysis, the building room temperature is allowed to float between 65°F and 75°F. If it tends above 75°F, energy is removed to maintain 75°F.

The thermal network model used has been validated by comparison of predictions against measured data for unheated test rooms in Los Alamos. The test rooms are quite predictable. This does not prove, of course, that all sensitivities are accurately represented in the model, but most of the mathematical representations used are based on well-proved principles and thus should accurately represent the actual situation.

Reference Case

Reference building design parameters used are the following:

- No shading
- Ground reflectance = 0.3, isotropic
- Vertical, south-facing glass
- Glass spacing = 1/4"
- Double glazing, normal transmittance = 0.747
- Wall absorptance = 1.0
- Thermal storage = 45 Btu/°F-ft^2 of glazing
- Building mass is negligible
- Room temperature range: 65°F to 75°F
- Wall-to-room heat transfer coefficient = 1.0 Btu/ft hr °F
- Trombe wall properties:
  - k = 1.0 Btu/ft hr °F
  - c = 30 Btu/ft^3°F
- Night insulation (when used) is R9; 5:00 p.m. to 8:00 a.m.

The variations in each parameter are made assuming that the other parameters remain constant. The solid point plotted on each curve represents the reference value.

Effect of Night Insulation R-value

The effect of using R9 night insulation shows up in the tables and solar load ratio curves in Reference 1. The effect is pronounced, especially in cold climates. For other than R9 night insulation, the results from several cities can be well correlated by a single curve (Fig. 1).

In the analysis, the night insulation was controlled strictly by time of day, being put in place at 5 p.m. each day and removed at 7 a.m. each morning. A number of calculations done with a "smart" controller showed that improvements possible by control strategy are very small.

Effect of Number of Glazings

Effects of different number of glazings for water walls is shown in Figs. 2-7 for several values of load collector ratio (LCR), defined as follows:

$$LCR = \frac{\text{building load} \left(\begin{array}{l}\text{exclusive of}\\ \text{solar wall}\end{array}\right)\text{, Btu/DD}}{\text{collector wall area, sq. ft.}}$$

The curves for a selective surface on the wall assume solar absorptance = 0.35 and infrared emittance = 0.08. The effect of glass absorptance and spacing is given in the following table:

Number of Glazings	DD	LCR	Increase in F: Clear Glass 2	Increase in F: Clear Glass 4	Increase in F: 3/4" spacing 2	Increase in F: 3/4" spacing 4
Albuquerque	4253	48.0	.03	.06	.03	.04
Los Alamos	7350	16.8	.06	.09	.06	.07
Madison	7840	8.0	.07	.07	.10	.09
Medford	5275	19.0	.04	.06	.05	.06
Boston	5535	18.2	.05	.08	.06	.07
Santa Maria	3065	72.0	.04	.07	.03	.03
Nashville	3805	25.4	.04	.07	.05	.05

These effects are all much reduced if night insulation is used, and performance decreases with added glazings in most cases.

Either multiple glazings, up to four, or a selective surface on the wall, but not both combined, are seen to be attractive alternatives to the use of night insulation. Performance may not be quite as good but cost, and especially complexity, are reduced.

The situation for Trombe walls is similar, but differs some in detail. The improvement due to added glazings is slightly less in Madison, Medford and Boston, but about equal in Albuquerque, Nashville, and Santa Maria.

Effect of Wall Absorptance and Emittance

Fig. 8 is a composite plot showing these effects for Los Alamos for various numbers of glazings and for LCR = 16.8.

Effect of Thermal Storage Heat Capacity

For water walls, performance generally increases with increasing thermal storage heat capacity, whereas with Trombe walls there is generally an optimum thickness. These effects are shown in Figs. 9-11 for Boston, Albuquerque, and Madison. If the Trombe wall is unvented, the optimum is at a lower value, for example at M=30 Btu/°F ft^2 (12" thickness) rather than at M=45 Btu/°F ft^2 (18" thickness) with vents. By far, the most important function of storage is to carry over the day's heat into the night rather than multi-day heat storage. Note, however, that the effect of variations in thermal storage is more important for higher values of F (corresponding to smaller values of LCR) for which multi-day storage becomes more important, and is relatively insensitive at low values of F.

Effect of Trombe Wall Properties

Because of the structure of the diffusion equation, the effect of changes in heat capacity, density, thermal conductivity, and wall thickness can be combined into just two groupings of these properties, as follows:

M = ρcL and ρck

where

M = the thermal heat storage capacity, per unit area

L = wall thickness, ft. and

ρ = density, lb/ft^3

c = heat capacity, $Btu/lb^{o}F$

k = thermal conductivity, Btu/ft hr ^{o}F

The reference value of M is 45 and ρck is 30. The effect of changing M has been given in the preceding section. The effect of changing ρck is shown on Figs. 12-14, for the same cities for different values of M and LCR.

Effect of Vent Area

Thermocirculation enhances the performance of a Trombe wall somewhat, especially if daytime temperatures are low requiring daytime heating. (The same effect could be obtained, however, by direct gain). The optimum vent size depends on the solar heating fraction, as follows:

SHF	Vent Area	Comment
25%	3%	Performance levels off above 3%
50%	1%	Performance levels off above 1/%
75%	1/2%	Performance decreases above 1%

The "vent area" is the area of the lower vents (which is the same as the upper vents) measured as a percentage of the total Trombe wall area.

If vents are to be used, they should have some means to prevent backflow at night, such as passive backdraft dampers or performance will be severely impaired at values of LCR less than 24 unless night insulation is used.

Effect of Additional Building Mass

Additional building mass enhances performance by adding heat storage. The following values of F (in percent) are for a water wall.

The added mass is in square feet of mass surface area, internal to the building thermal insulation, per unit of heating load ($ft^2/[Btu/hr\ ^{o}F]$). The wall is one foot thick.

		Added Building Mass		
City	LCR	0	1.0	2.5
Albuquerque	24	76	83	87
	48	50	56	58
	108	26	31	33
Madison	4.8	61	66	71
	8	53	57	60
	32	23	25	27
Los Alamos	7.2	78	84	90
	16.8	56	60	63
	43.2	28	34	35

Effect of Temperature Control Set Points

Raising the upper temperature limit above 75^{o}F has less than a 2% effect on annual solar heating fraction. Reducing the limit has a larger effect, especially at higher values of F, reducing the value by as much as 5% (from 85% to 80% for LCR = 0.73 in Albuquerque) if the allowable swing is reduced to zero.

Lowering the minimum temperature limit below 65^{o}F, of course, has a much larger effect as shown on Figs. 15 and 16.

REFERENCE

1. J. D. Balcomb, and R. D. McFarland, "A Simple Empirical Method for Estimating the Performance of Passive Solar Heating Systems," Proceedings of the 2nd National Passive Solar Conference, Philadelphia, March 1978.

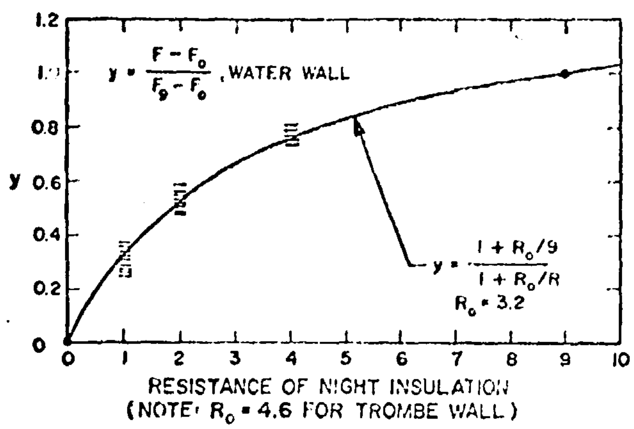

Fig. 1. Effect of Night Insulation Resistance

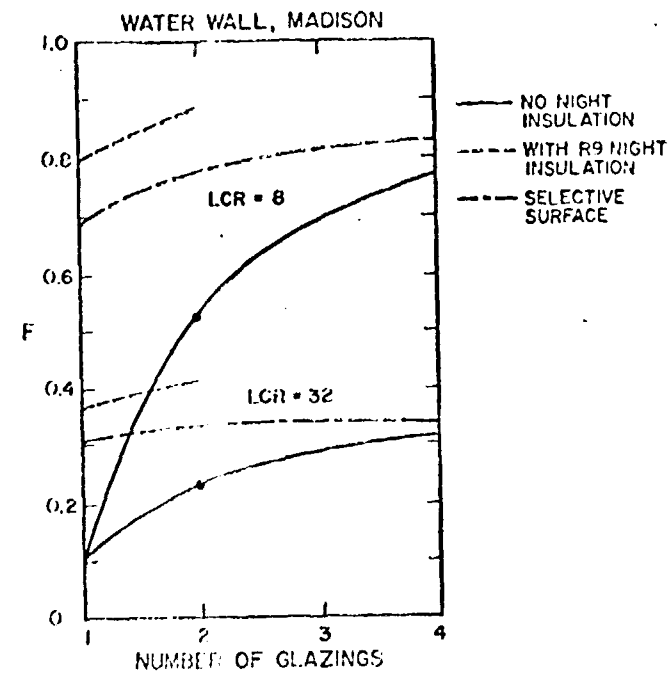

Fig. 3. Effect of Glazings Madison

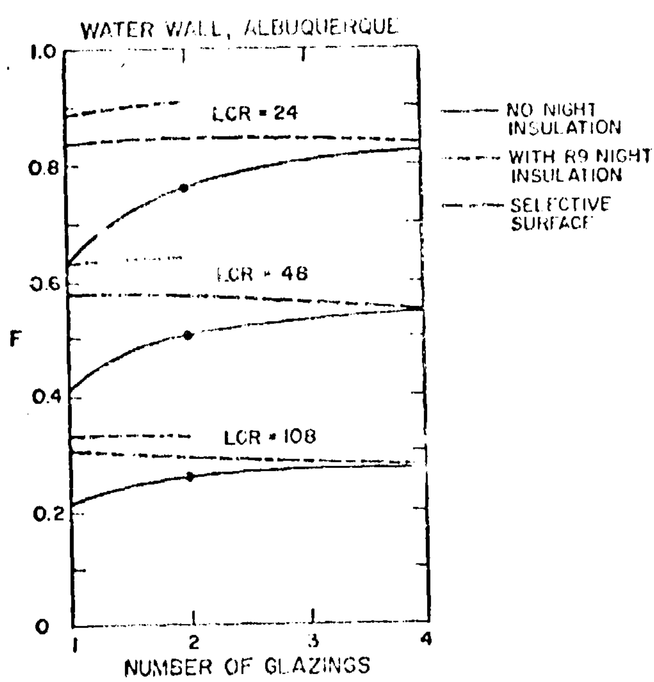

Fig. 2. Effect of Glazings Albuquerque

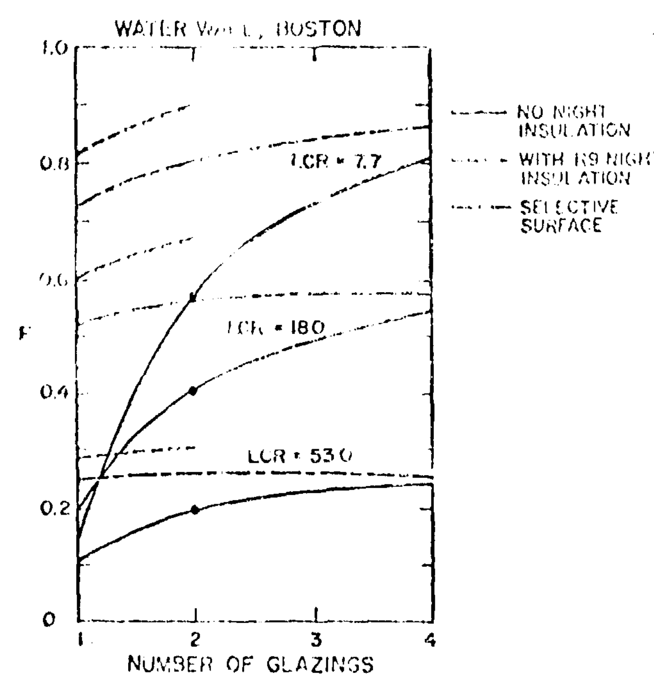

Fig. 4. Effect of Glazings Boston

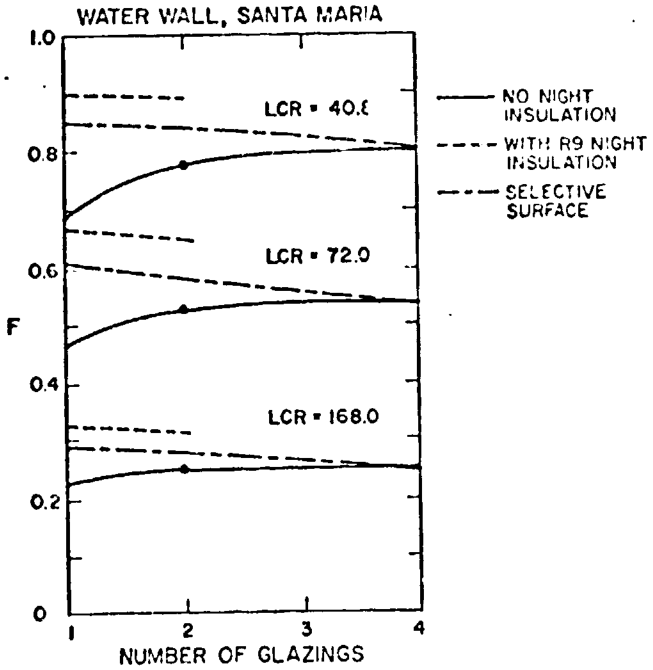

Fig. 5. Effect of Glazings
Santa Maria

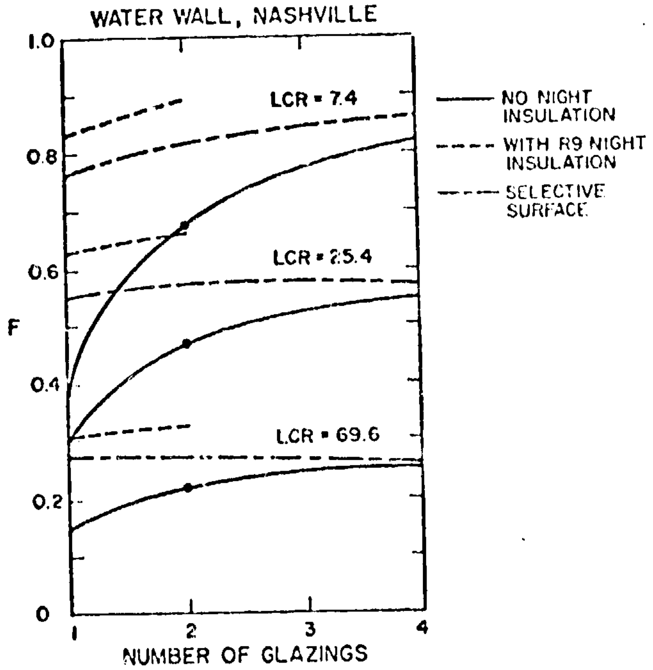

Fig. 6. Effect of Glazings
Nashville

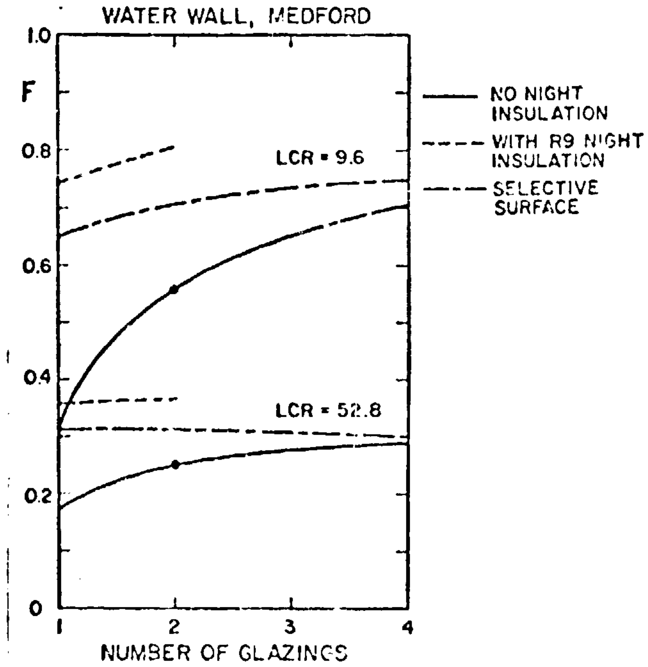

Fig. 7. Effect of Glazings
Medford

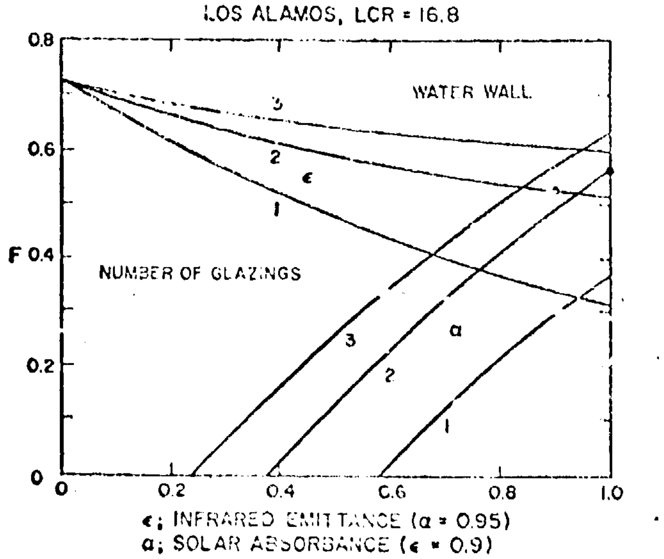

Fig. 8. Wall Infrared Emittance and Solar Absorptance

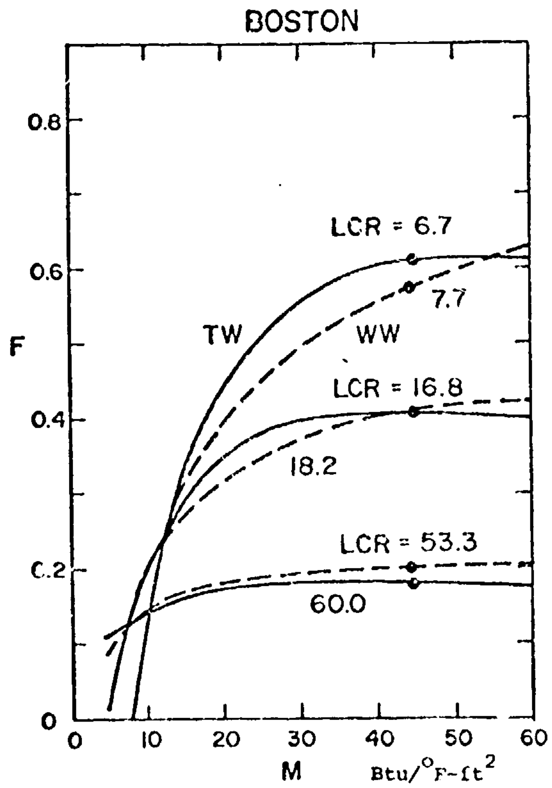

Fig. 9. Effect of Wall Thermal Mass Boston

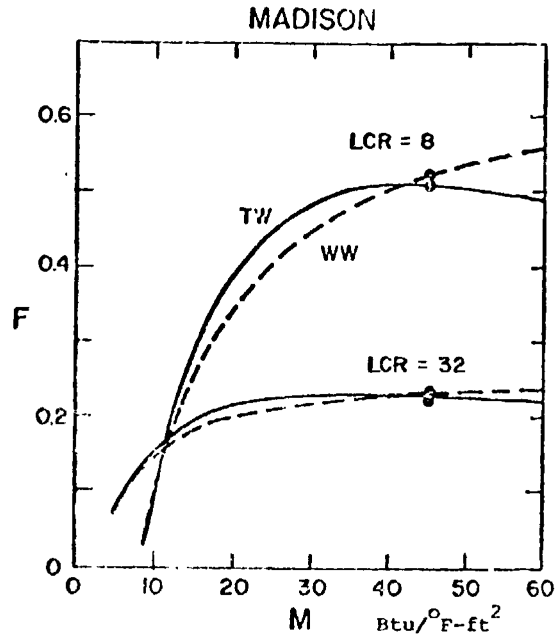

Fig. 11. Effect of Wall Thermal Mass Madison

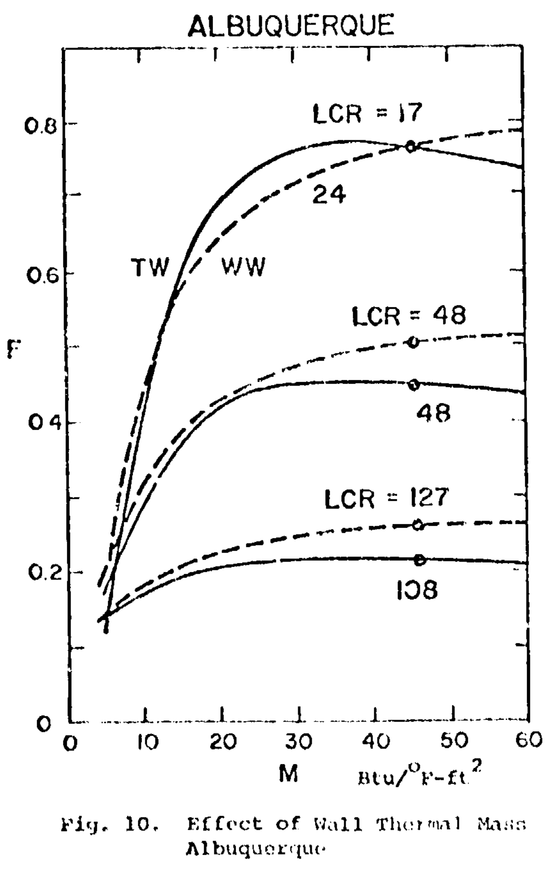

Fig. 10. Effect of Wall Thermal Mass Albuquerque

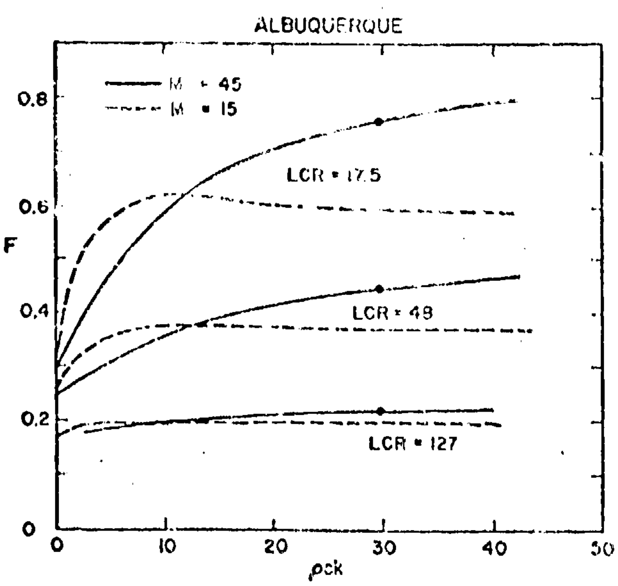

Fig. 12. Effect of Wall Properties Albuquerque

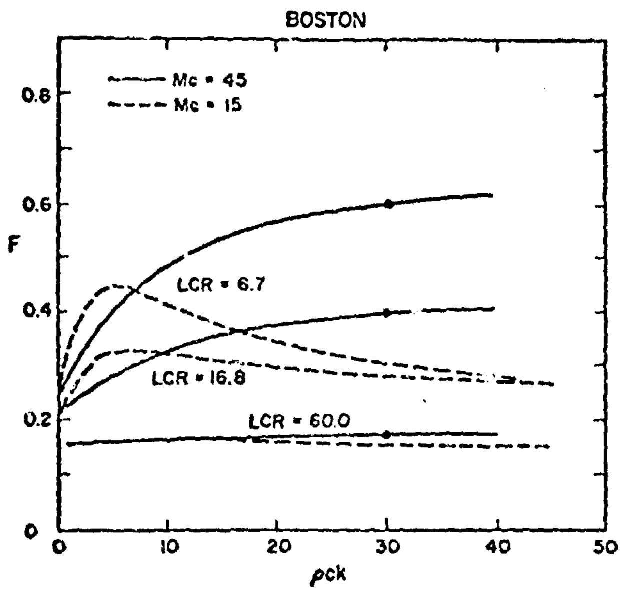

Fig. 13. Effect of Wall Properties Boston

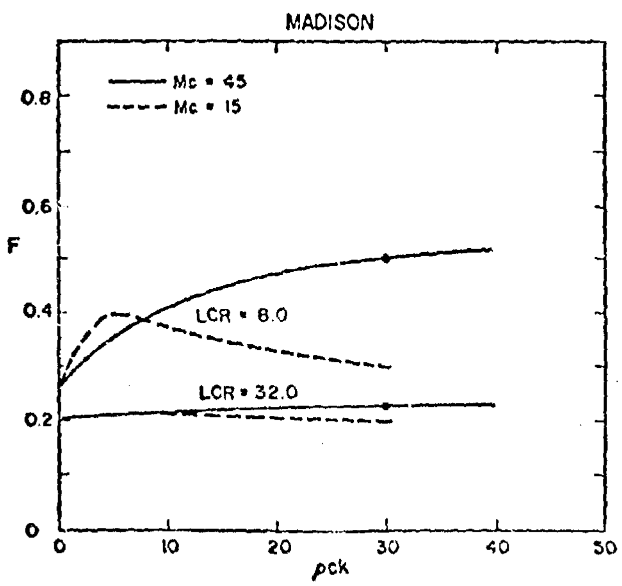

Fig. 14. Effect of Wall Properties Madison

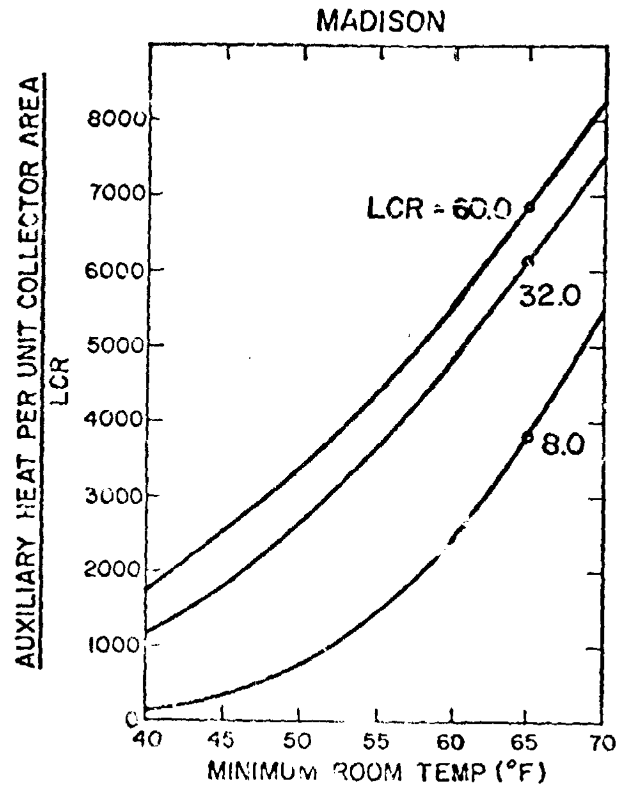

Fig. 15. Auxiliary Heat as a Function of Minimum Room Temperature - Madison

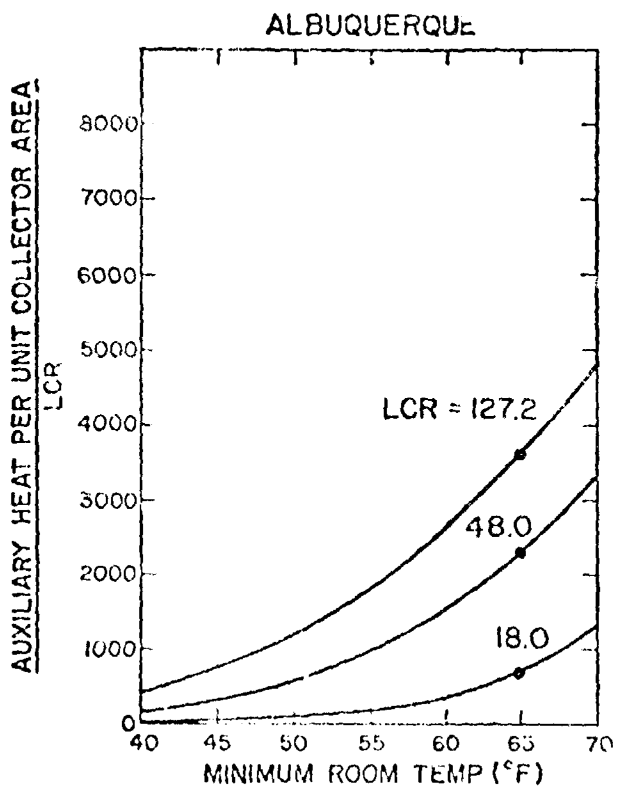

Fig. 16. Auxiliary Heat as a Function of Minimum Room Temperature - Albuquerque