ESTIMATING THE LATENT HEATING LOAD RESULTING FROM THE CURING AND DRYING OF CONSTRUCTION MATERIALS

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ABSTRACT

The latent heating load imposed by the curing and drying of construction materials is caused by the evaporation of water from concrete, wood, plaster, and drywall. For each pound of water (about one pint) that evaporates, 970 Btu's (0.284 kWh) are added to the sensible space heating load.

This latent heating load has become a significant factor in the estimation of the first-winter space heating bills as dwellings have become more energy efficient. This phenomenon probably accounted for from 5% to 10% of the total heating load for houses in northern climates built to pre-1974 energy standards. For a well insulated, tight house built today, it could double the first year space heating bill. Home owners and designers are often surprised and angered to find the fuel usage much higher than estimated--or guaranteed--during the first winter of occupancy.

The curing load for northern climates can be estimated with the use of the three equations explained. The equations estimate the moisture from the curing of 1) poured concrete foundations with concrete slab floors, 2) slabs on grade, and 3) wood framing and interior finish materials. The seasonal storage and release of moisture is not included in the equations, but a rule-of-thumb for this latent load is mentioned.

Tables and graphs are included which show that as houses become more energy efficient, the curing load becomes a larger percentage of the total heating load. A glossary of terms is also included.

These equations and charts will assist the analyst when predicting the first year heating-fuel use, when analyzing moisture problems, or when responding to high-bill complaints.

Key Words: *Load Calculation, Space Heating, Moisture, Evaporation, Residential.*

INTRODUCTION

The latent heating load imposed by the curing and drying of construction materials--Latent Curing Load (LCL)--is a result of the evaporation of water from concrete, wood, plaster, and drywall. For each pound of water (about one pint) that evaporates, 970 Btu's (0.284 kWh) are added to the overall heating load. This *latent* heating load is only related to the evaporation of water; it is not related to the energy-efficiency characteristics of the building. It is the *sensible* heating load, in this paper referred to as the Annual Sensible Load (ASL), that is affected by the amount of insulation and tightness of a house, the solar gain, and the internal gain attributed to occupants and appliances.

The curing/drying process can take from nine months to two years, depending on the materials used, the indoor environmental conditions, the climatic conditions and when the house is completed, closed up and occupied.

Under ideal conditions for northern climates, new houses should be completed during the spring of the year so that moisture generated by the curing/drying process may be vented through open windows during the warm months, thereby imposing the smallest possible latent load during the first heating season and reducing the risk of moisture problems. In cold climates the construction process, more often than not, begins in the spring and ends in the late summer or fall. This construction completion/occupancy sequence maximizes the curing load and increases the likelihood of resulting moisture problems.

The curing load for northern climates can be estimated with the use of the three equations explained below. These equations yield figures in units of Btu/cure. Please note that these are *estimates* only. The latent heating loads as a result of moisture generated by people and the seasonal storage and release of moisture are not included in the equations.

THE EQUATIONS

1. Poured concrete foundation walls and slab.

$$\text{Btu/cure} = 5460 [0.66 (F \times H) + 0.33 (A)] \qquad \text{Equation 1}$$

2. Concrete slab on grade.

$$\text{Btu/cure} = 1800 (A) \qquad \text{Equation 2}$$

3. Wood framing and interior finish materials.

$$\text{Btu/cure} = 680 (W) \qquad \text{Equation 3}$$

where: F = the foundation perimeter in units of feet.

H = the height of the foundation wall in units of feet.

A = the area of the basement slab or slab on grade in units of square feet.

W = the area of the living space, excluding any living area within the foundation, in square feet. Commonly referred to as the square footage of living area.

Equation 1 is formulated for poured concrete foundations with a full concrete floor slab. Block or wood foundation walls release much less moisture while curing.

For equations 1 and 2, it is assumed that the thickness of the concrete foundation wall is eight inches (0.66 feet) and the thickness of the basement floor slab or slab on grade is four (0.33 feet) inches. For most houses, the products of two of these three equations must be added together to get the total latent heating load for the entire building. The latent heating load for the whole building shall be called the Latent Curing Load (LCL).

The number of pounds of water that evaporate can be estimated by dividing the equation answers by 970 Btu/lb.

Equations 1 and 2 are based upon the assumption that about 18 gallons of water evaporate to the interior of a house per cubic yard of concrete. The remaining water is used in the chemical process that takes place in concrete called hydration.

For equation 3, it is assumed that 0.7 pounds of water evaporate per square foot of above grade living area from materials such as framing lumber, drywall, and finish wood.

There are many variables involved with the heating load caused by the curing and drying of construction materials that are not included in the equations. The equation results should be intuitively adjusted upward and downward according to factors such as the character of the construction materials, the drying time available before the house is closed up and occupied, and the character of the weather during the available drying period.

The equations were assembled with the assumption that very little curing and drying time transpires before a house is completed, closed up for the heating season, and occupied. Therefore, in most cases, the estimates derived from the equations will err on the high side. On the other hand, some analysts estimate that the moisture resulting from curing and drying is much greater than the equations predict.

Examples

A. A 1796 square foot colonial on two floors built over a crawl space. The house dimensions are 28 feet by 32 feet.

$$\text{Btu/cure} = 680 (W) \qquad \text{Equation 3}$$

$$= 680 (1796 \text{ ft}^2)$$

$$= 1,221,280$$

This 1,221,280 Btu/cure equates to 358 kWh/cure ($32.22 at $.09 per kWh).

B. A 1796 square foot colonial on two floors with a slab on grade foundation. The house dimensions are 28 feet by 32 feet.

Btu/cure = 1800 (A) Equation 2

$= 1800 (898\ ft^2)$

= 1,616,400

Btu/cure = 680 (W) Equation 3

$= 680 (1796\ ft^2)$

= 1,221,280

Therefore, for the whole house the Latent Curing Load (LCL) is: 1,616,400 Btu + 1,221,280 Btu = 2,837,680 Btu/cure or 831 kWh/cure ($74.85 at $.09 per kWh).

C. A 1796 square foot colonial on two floors with a full concrete foundation and basement floor. The house dimensions are 28 feet by 32 feet.

Btu/cure = 5460 [0.66 (F x H) + 0.33 (A)] Equation 1

$= 5460 [0.66 (120\ ft \times 8\ ft) + 0.33 (898\ ft^2)]$

= 5,077,472

Btu/cure = 680 (W) Equation 3

$= 680 (1796\ ft^2)$

= 1,221,280

Therefore, for the whole house the Latent Curing Load (LCL) is: 5,077,472 Btu + 1,221,280 Btu = 6,298,752 Btu/cure or 1846 kWh/cure ($166.15 at $.09 per kWh).

D. A 960 square foot ranch on one floor built over a crawl space. The house dimensions are 24 feet by 40 feet.

Btu/cure = 680 (W) Equation 3

$= 680 (960\ ft^2)$

= 652,800

This 652,800 Btu/cure equates to 191 kWh/cure ($17.19 at $.09 per kWh).

E. A 960 square foot ranch on one floor with a slab on grade foundation. The house dimensions are 24 feet by 40 feet.

Btu/cure = 1800 (A) Equation 2

$= 1800 (960\ ft^2)$

= 1,728,000

Btu/cure = 680 (W) Equation 3

$= 680 (960\ ft^2)$

= 652,800

Therefore, for the whole house the Latent Curing Load (LCL) is: 1,728,000 Btu + 652,800 Btu = 2,380,800 Btu/cure or 698 kWh/cure ($62.82 at $.09 per kWh).

F. A 960 square foot ranch on one floor with a full concrete foundation and basement floor. The house dimensions are 24 feet by 40 feet.

$$\text{Btu/cure} = 5460 [0.66 (F \times H) + 0.33 (A)] \qquad \text{Equation 1}$$

$$= 5460 [0.66 (128 \text{ ft} \times 8 \text{ ft}) + 0.33 (960 \text{ ft}^2)]$$

$$= 5,419,814$$

$$\text{Btu/cure} = 680 (W) \qquad \text{Equation 3}$$

$$= 680 (960 \text{ ft}^2)$$

$$= 652,800$$

Therefore, for the whole house the Latent Curing Load (LCL) is: 5,419,814 Btu + 652,800 Btu = 6,072,614 Btu/cure or 1780 kWh/cure ($160.20 at $.09 per kWh).

The resulting latent curing loads (LCL) values for these two houses, three foundation types each and four levels of energy efficiency, are also listed in Table 1, page 7, along with corresponding hourly design heating loads and Annual Sensible Loads (ASL) at three different interior temperatures. Table 2 on page 7 lists the energy-efficiency characteristics of the colonial and the ranch house types. These two houses were chosen for this analysis because 1) they are common residential designs and 2) they demonstrate the vagaries of the effects of latent curing loads.

DISCUSSION

The six examples show that the curing/drying load can be a significantly large load on the heating system in some cases and small in others. If the Latent Curing Load (LCL) is a large percentage of the Annual Sensible Load (ASL), the home owner will notice a larger-than-expected fuel bill the first heating season.

In order to get an idea of the magnitude of LCL compared to ASL, the Latent Curing Load Ratio (LCLR) can be calculated. In Figures 1 through 6 on page 8, the Latent Curing Load Ratios (LCLR) are graphed for each of the six example houses (A. through F.). All of the values used for the formulation of these graphs are listed in Table 1 on page 7. The LCLR is calculated by using this equation:

$$\text{LCLR} = \frac{\text{Latent Curing Load (LCL)}}{\text{Annual Sensible Load (ASL)}} \qquad \text{Equation 4}$$

<u>where</u>: LCL is estimated by using one or two of Equations 1, 2, and 3.

ASL is the estimated heating-season Btu heat requirement for the building, taking into account solar gain and internal gain (occupants and appliances).

If the LCLR is multiplied by 100, the resulting value is the LCL as a percentage of the Annual Sensible Load. This has been done in Figures 1 through 8. For example, in Figure 1, the LCLR is 0.12. In other words, LCL is 12% (LCLR x 100) of the annual sensible load for the colonial house built on a crawl space and with an energy-efficiency level defined as 4-SI. Please refer to Table 2 for an explanation of the four energy-efficiency levels used in this analysis.

If the LCLR for a house were 1.0 (100%), the Actual Heating System Load (AHSL) of the building would be twice the Annual Sensible Load (ASL) the first heating season if all of the curing and drying were to take place during the first winter of occupancy. If LCLR were .5 (50%), the AHSL would be 50% greater than the ASL. The Actual Heating System Load (AHSL) is simply:

$$\text{AHSL} = \text{Latent Curing Load (LCL)} + \text{Annual Sensible Load (ASL)} \qquad \text{Equation 5}$$

Designers stating a first-year heating bill may encounter difficulty if the house in question has a high LCLR because the AHSL, and the fuel used, would be underestimated. Estimated-fuel-use per-year calculation procedures do not include estimates for LCL, but only address ASL. It would be in the designers and home buyers best interest to state the estimated AHSL fuel use for the first heating season and perhaps the second, and the ASL fuel use for all following winters.

A hypothetical example of this is shown in Figure 9 on page 8. In this graph, the first heating season after completion and occupancy, the LCL and ASL are both 5,000 kBtu, making the LCLR 1.0 (100%) and the AHSL 10,000 kBtu. The second year, after most of the curing of construction materials has taken place, the LCL is 2,000 kBtu and ASL is 5,000 kBtu, making the LCLR 0.4 (40%) and the AHSL 7,000 kBtu. The third year, all the curing has taken place, as a result, ASL = AHSL.

The values calculated in examples A. through F. above (also listed in Table 1) show that the Latent Curing Load (LCL) for a house is affected by the size of the structure and the foundation type. Of course, the larger the house, the greater the LCL. This is exemplified by comparing example calculations A., the 1796 ft^2 colonial built over a crawl space (LCL = 1,221,280 Btu/cure) and D., the 960 ft^2 ranch built over a crawl space (LCL = 652,800 Btu/cure).

A full concrete foundation with a concrete basement floor yields the highest LCL, next the concrete slab on grade, and the smallest LCL results from a house built on a crawl space (it is assumed that the crawl space area is sealed from the living space above). This is evident from the example calculations. For the 1796 ft^2 colonial, C. with the full concrete foundation has a LCL of 6,298,752 Btu/cure, B. with a concrete slab on grade has a LCL of 2,837,680 Btu/cure, and A. with a crawl space has a LCL of 1,221,280 Btu/cure. The 960 ft^2 ranch types, F., E., and D., show the same corresponding relationships. This is the case because concrete releases more moisture while curing than any other building material.

The Latent Curing Load Ratio (LCLR) will increase 1) if the LCL increases, 2) if the Annual Sensible Load (ASL) decreases. The effect of these variables on the LCLR is clear in Figures 1 through 8. In Figures 1 through 3 the LCLR are graphed for the 1796 ft^2 colonial, example cases A., B., and C. Notice in any of these three figures that as the energy-efficiency level increases, thereby lowering the ASL, the LCLR increases. Also notice that as the interior temperature is decreased, also lowering the ASL, the LCLR increases.

To understand the effect of differing Latent Curing Loads for the colonial house, compare Figures 2 (slab on grade) and 3 (full foundation) at a 65 F. interior temperature, both built to a superinsulated level of energy efficiency (4-SI). In Figure 2 this LCLR is .12 (12%) and in Figure 3 it is .43 (43%). (Please notice that the scale of the vertical axis varies between figures). Of course, a different Annual Sensible Load (ASL) results from a different foundation type because the surface and volume characteristics of the building change, but in this case, comparing Figure 2 with Figure 3, both as defined above, the LCL increased from 2,837,680 Btu/cure to 6,298,752 Btu/cure, an increase of 122%, while ASL decreased from 23,460,000 to 18,260,000, a decrease of 22%. Obviously the major factor effecting the LCLR here is the increase in the LCL rather than the decrease in the ASL.

In Figures 4 through 6 the LCLR are graphed for the 960 ft^2 ranch, example cases D., E., and F., for different energy-efficiency levels and interior temperatures.

Figures 7 and 8 on page 8 show the effect of different LCL and energy-efficiency levels for the colonial and the ranch, all at 65 F. interior temperature.

This methodology addresses a one-time latent heating load; once the construction materials have dried, there is no remaining latent load due to curing. However, if water is in contact with the construction materials, e.g., water in contact with the foundation footing, a latent heating load will result and continue as long as the water source remains. This is a very difficult load to estimate, but awareness of its occasional existence is important.

CONCLUSIONS AND RECOMMENDATIONS

General conclusions regarding the affects of the Latent Curing Load (LCL) can be formulated from the simulations discussed above:

- The more concrete there is exposed to the living space of the house, the greater will be the Latent Curing Load. This is demonstrated by the full-foundation examples C. and F. having higher LCL than the slab on grade or crawl space examples.
- For a given LCL, the lower the Annual Sensible Load (ASL), the higher the Latent Curing Load Ratio (LCLR). Many factors can account for a low ASL including 1) a high degree of energy efficiency, 2) a low permanent thermostat setting, 3) a low and/or lengthy thermostat setback, 4) a large amount of solar gain, and 5) a large amount of internal gain. Most of these influential affects are demonstrated by the examples.
- If the house is built with a slab on grade or a full foundation, the greater the "footprint" to volume ratio, the higher will be the LCLR for a given level of energy efficiency, thermostat setting, number of occupants, and solar gain.
- For northern climates, the later in the building season the house is completed and occupied, the greater the LCLR.

• If a house were equipped with a heat recovery ventilation system which recovered latent thermal energy, a portion the the LCL would be recovered as sensible thermal energy. The percentage recovered would depend upon the characteristics of the heat recovery ventilator, the LCL, the climatic conditions, the thermostat setting, the habits of the occupants, and other factors. Because of all the variables, this percentage is very difficult to estimate. However, because of the fact that some of the LCL would be recovered makes this type of heat recovery ventilator attractive.

• The LCL, a heating load which may be imposed over a total period of from nine months to two years, most likely, does not affect the heating load enough during any *hour* to warrant an increase in the size of the heating system output. In other words, it is not recommended that the Design Heat Load (in units of Btu/hr) or the heating system output size be increased on account of the LCL. Conventional methods of calculating the Design Heat Load and the subsequent sizing of heating systems need not be adjusted. LCL affects the fuel *use* requirements only.

• Finally, it is recommended that designers begin to estimate the Latent Curing Load (LCL) in addition to the often calculated Annual Sensible Load (ASL). If this is done, the Actual Heating System Load (AHSL) for the first and second heating seasons can be *estimated* in a fashion similar to that shown in Figure 9.

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ACKNOWLEDGMENTS

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TABLE 1

HEATING LOAD VALUES[1]
(kBtu)

	HOUSE TYPES[2]					
	A.	B.	C.	D.	E.	F.
Design Heat Load (kBtu)						
1-BASE	69.8	101.5	64.5	46.3	79.8	40.0
2-MES	44.7	54.8	47.8	24.2	34.8	26.6
3-GC	28.5	38.5	30.7	21.8	32.4	23.5
4-SI	22.2	27.6	24.4	13.4	19.1	15.2
Latent Curing Load (LCL)[3]	1221.3	2837.7	6298.8	652.8	2380.8	6072.6
Annual Sensible Load (ASL), 70 F. Interior Temp, 3 Occupants						
1-BASE	128690	211550	115150	76170	162810	60830
2-MES	66790	91410	74300	24410	47880	28890
3-GC	29950	48630	33890	18810	40000	23330
4-SI	17580	28350	21000	5250	14590	7500
Annual Sensible Load (ASL), 65 F. Interior Temp, 3 Occupants						
1-BASE	109570	178510	97950	64210	137550	48750
2-MES	53840	76060	59340	20270	39410	25560
3-GC	24680	43300	28140	16790	35370	19330
4-SI	14400	23460	18260	3670	12560	6740
Annual Sensible Load (ASL), 65/55 F.[4] Interior Temp, 3 Occupants						
1-BASE	86190	144540	76910	50700	111530	38570
2-MES	42520	57850	46970	15890	30890	19870
3-GC	19360	33970	22340	12820	27640	15030
4-SI	10090	18260	13620	2710	9250	4700

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1. Hourly Design Heat Load figures were estimated with "Residential Loads Calculation" software by Cornerstones-Wright, Inc., Portland, Maine, 1987. This software is based upon *Manual J: Load Calculation for Residential Winter and Summer Air Conditioning*, seventh edition, by the Air Conditioning Contractors of America (ACCA), Washington, D.C., 1986. Annual load figures were estimated with "Residential Operating Cost Analysis" software by Cornerstones-Wright, Inc., Portland, Maine, 1987. This is a bin analysis procedure. All weather and solar data are for Portland, Maine.
2. House type definitions are listed on page 7. Latent Curing Loads (LCL) for each of the listed house types are listed on pages 2 through 4 in the text. The letters in the text correspond with the letters in this table.
3. The three formulas for estimating the latent curing load ratios (LCL) are included in the text of this paper. The LCL is not dependent upon the energy-efficiency level of the structure.
4. The interior temperature is assumed to be 65 F. for 16 hours and 55 F. for 8 hours of each 24 hour period.

TABLE 2

HOUSE-TYPE DEFINITIONS
(for calculation of heating loads)

ENERGY CHARACTERISTICS	FOUNDATION TYPES		
	1796 ft^2 Colonial, 150 ft^2 of Glass		
	A.	B.	C.
	960 ft^2 Ranch, 120 ft^2 of Glass		
	D.	E.	F.
1-BASE[1] Wall, R-11 Win., R-1.8 Door, R-1.5 Ceil., R-19 Infil., Loose	Wood floor w/ closed crawl space, no floor insulation	Concrete slab floor, no perimeter insulation,	Full concrete foundation w/ concrete floor, no insulation
2-MES[2] Wall, R-19 Win., R-1.8 Door, R-5.2 Ceil., R-38 Infil., Medium	Wood floor w/ closed crawl space, R-19 floor insul.	Concrete slab floor, R-10 perimeter insulation	Full concrete foundation w/ R-10 insulation, concrete floor
3-GC[3] Wall, R-19 Win., R-3.1 Door, R-5.2 Ceil., R-49 Infil., Tight	Wood floor w/ closed crawl space, R-19 floor insul.	Concrete slab floor, R-10 perimeter insulation	Full concrete foundation w/ R-10 insulation, concrete floor
4-SI[4] Wall, R-40 Win., R-3.1 Door, R-5.2 Ceil., R-60 Infil., Tight	Wood floor w/ closed crawl space, R-30 floor insul.	Concrete slab floor, R-20 perimeter insulation	Full concrete foundation w/ R-20 insulation, concrete floor

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1. Base case, pre-1974 energy 'standard' (BASE).
2. Maine Energy Standard (MES).
3. Energy standard used for the Central Maine Power Company's Good Cents(tm) residential new home construction program (GC).
4. Superinsulated 'standard' as it is often practiced in the southern Maine area (SI).

LATENT CURING LOAD RATIOS FOR
1796 SQUARE FOOT COLONIAL AT VARIOUS
INTERIOR TEMPERATURES, CRAWL SPACE

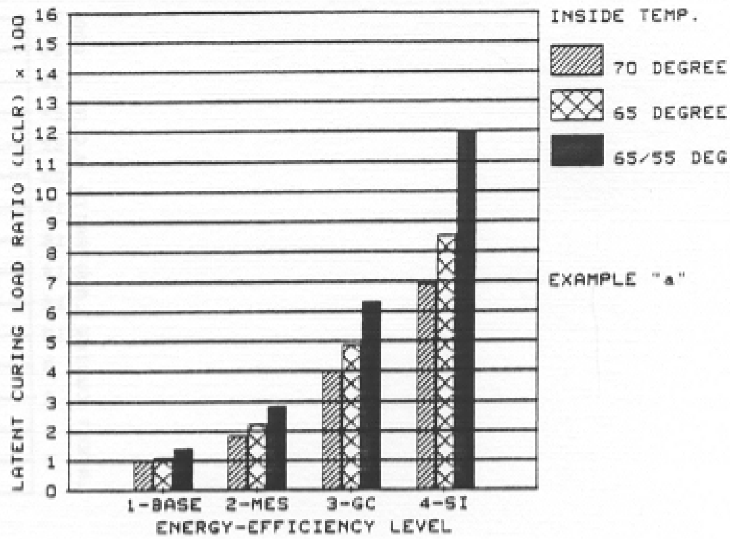

FIGURE 1

LATENT CURING LOAD RATIOS FOR
1796 SQUARE FOOT COLONIAL AT VARIOUS
INTERIOR TEMPERATURES, SLAB ON GRADE

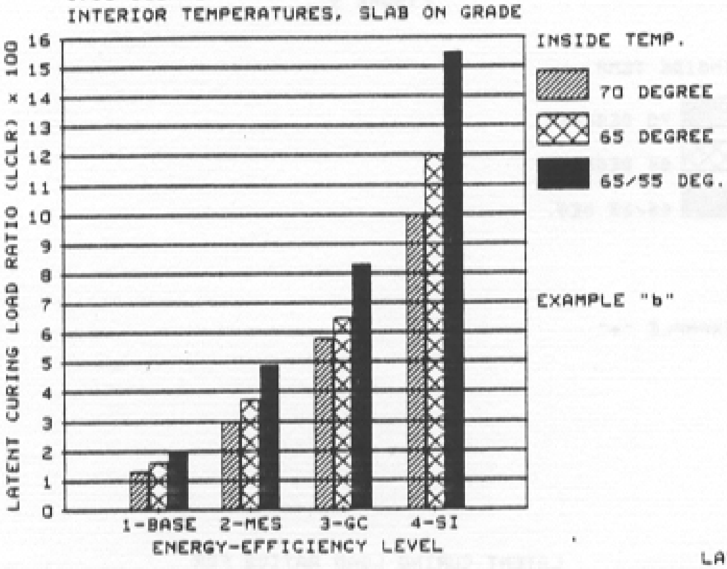

FIGURE 2

LATENT CURING LOAD RATIOS FOR
1796 SQUARE FOOT COLONIAL AT VARIOUS
INTERIOR TEMPERATURES, FULL FOUNDATION

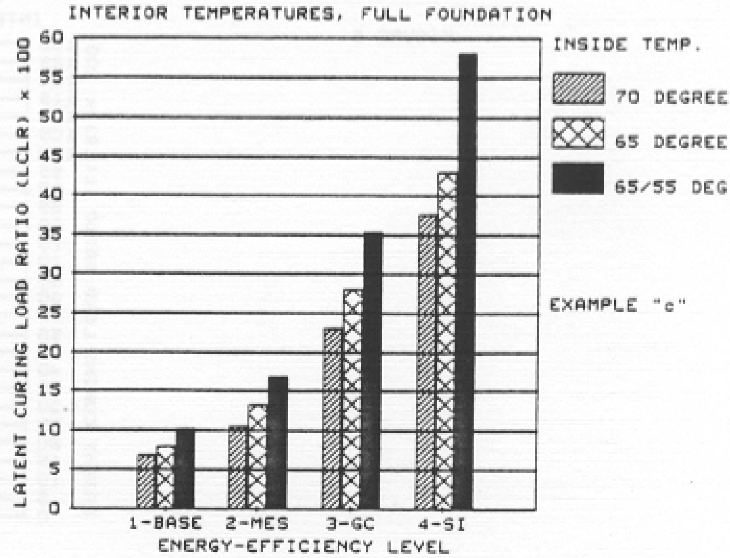

FIGURE 3

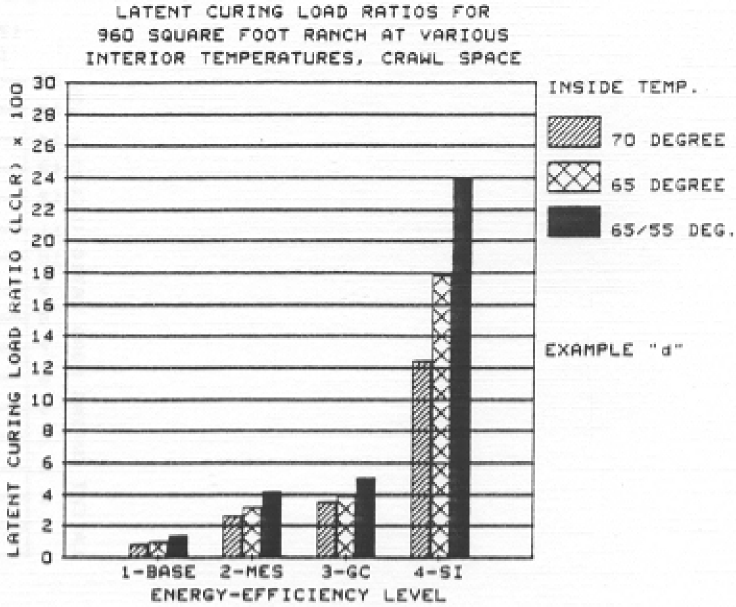

FIGURE 4

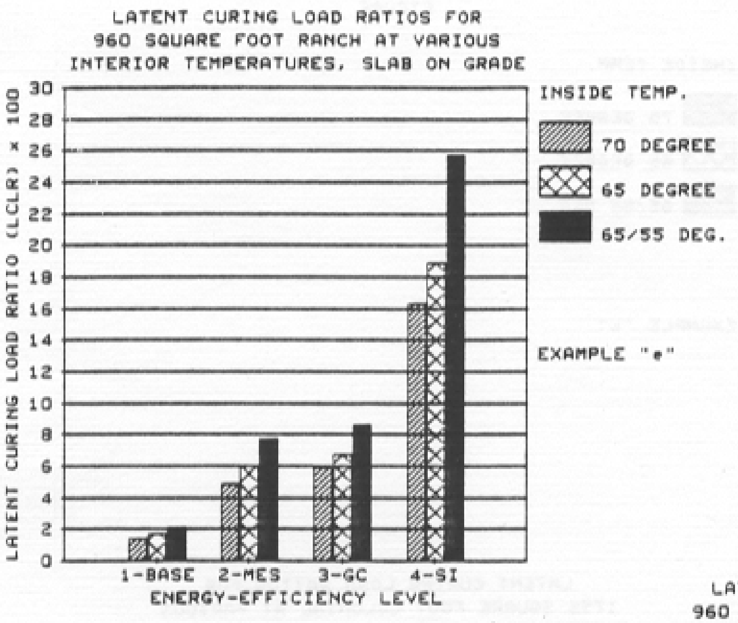

FIGURE 5

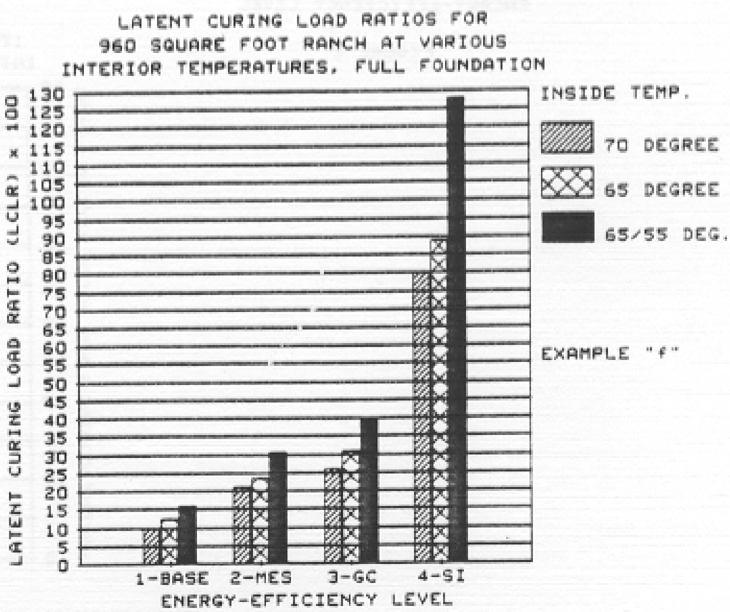

FIGURE 6

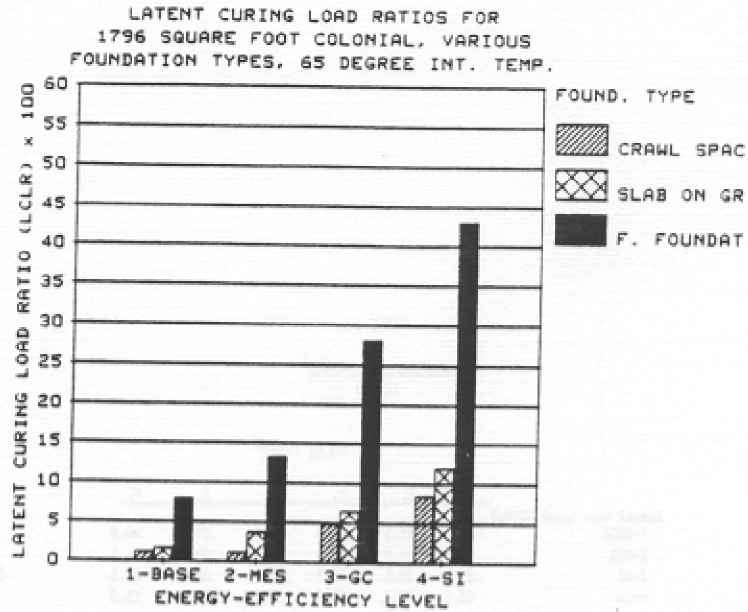

FIGURE 7

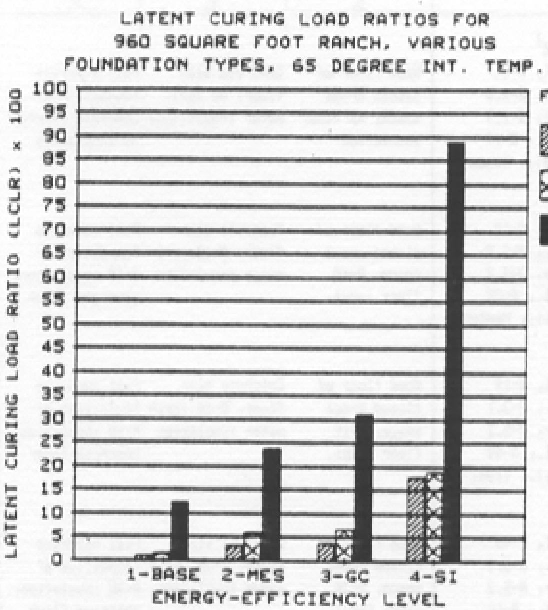

FIGURE 8

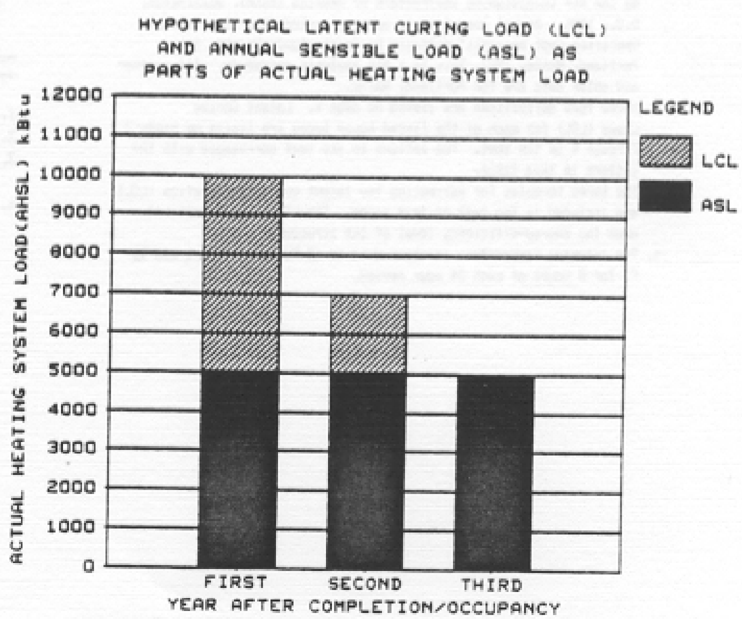

FIGURE 9

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ENERGY CHARACTERISTICS	FOUNDATION TYPES		
	1796 ft² Colonial, 150 ft² of Glass		
	A.	B.	C.
	960 ft² Ranch, 120 ft² of Glass		
	D.	E.	F.
1-BASE[1] Wall, R-11; Win., R-1.8; Door, R-1.5; Ceil., R-19; Infil., Loose	Wood floor w/ closed crawl space, no floor insulation	Concrete slab floor, no perimeter insulation,	Full concrete foundation w/ concrete floor, no insulation
2-MES[2] Wall, R-19; Win., R-1.8; Door, R-5.2; Ceil., R-38; Infil., Medium	Wood floor w/ closed crawl space, R-19 floor insul.	Concrete slab floor, R-10 perimeter insulation	Full concrete foundation w/ R-10 insulation, concrete floor
3-GC[3] Wall, R-19; Win., R-3.1; Door, R-5.2; Ceil., R-49; Infil., Tight	Wood floor w/ closed crawl space, R-19 floor insul.	Concrete slab floor, R-10 perimeter insulation	Full concrete foundation w/ R-10 insulation, concrete floor
4-SI[4] Wall, R-40; Win., R-3.1; Door, R-5.2; Ceil., R-60; Infil., Tight	Wood floor w/ closed crawl space, R-30 floor insul.	Concrete slab floor, R-20 perimeter insulation	Full concrete foundation w/ R-20 insulation, concrete floor

1. Base case, pre-1974 energy "standard" (BASE).
2. Maine Energy Standard (MES).
3. Energy standard used for the Central Maine Power Company's Good Cents(tm) residential new home construction program (GC).
4. Superinsulated "standard" as it is often practiced in the southern Maine area (SI).