Portland Cement Association

Energy Comparisons of Concrete Homes Versus Wood Frame Homes

By Dr. Pieter VanderWerf

RP119

TABLE OF CONTENTS

EXECUTIVE SUMMARY ii

METHODS 1
- Identifying ICF Houses 1
- Interviewing ICF Homeowners 1
- Identifying Frame Houses 2
- Interviewing Frame Homeowners 2
- Acquiring Energy Data 3
- Dividing Total Energy Consumption 4
- Normalizing Energy Consumption 4
- Calculating Summary Statistics 5
- Tallying Open-ended Responses 6

RESULTS 6
- Sample Comparability 6
- Conditioning Energy Savings 6
- Savings Rates and Climate 8
- Total Savings and Climate 9
- Reasons for Liking/Disliking One's Home 10

INTERPRETATION 10
- Average Energy Savings 10
- Reliability of Savings 12
- HVAC Sizing 12
- Potential Data Biases 12
- Owners' Preferences 13
- Need for Basement Heating 14

APPENDIX A: Normalization Calculations 15

APPENDIX B: Energy Conversion Factors 18

EXECUTIVE SUMMARY

Statistical comparison indicates that constructing the exterior walls of a house with insulating concrete forms (ICFs) instead of conventional wood frame will reduce the amount of energy consumed for space heating by approximately 44%, and for space cooling (where applicable) by approximately 32%. All figures are averages for houses constructed across the U.S. and Canada. All ICF homes were constructed with a system made of pure foam (no foam-cement composites).

The statistics derive from analysis of 58 homes, 29 ICF and 29 frame. The investigators undertook several steps to get an "apples-to-apples" comparison. They solicited participation so each ICF house would be paired and compared with one frame house that was (1) nearby, (2) of similar square footage, and (3) of new construction (less than 6 years old). They then adjusted the energy consumption of each house to control for differences in size, design, foundation, number of occupants, thermostat settings, and HVAC equipment.

The corresponding estimated dollar savings averaged approximately $221 per year for heating energy and (where applicable) $89 for cooling energy.

The energy savings rates (44% for heating, 32% for cooling) showed no discernible relationship to local climate. That is, it was impossible to detect that savings rates for either heating or cooling went up or down appreciably in warmer (or cooler) climates. The appropriate tentative conclusion therefore is that these rates of savings should be fairly constant regardless of location.

An important implication of this result is that <u>absolute</u> savings will be higher in extreme climates, where total bills are higher. Projected savings on heating are several times greater in cold climates (Minneapolis: $342 per year for a 2000 sf home) than in warm ones (Dallas: $100). Projected cooling savings are higher in warmer climates ($108 in Dallas, versus $34 in Minneapolis).

Responses to open-ended questions showed that the vast majority of owners of new homes had positive feelings toward their homes regardless of the composition of their exterior walls. However, the reasons that ICF owners liked their homes contrasted sharply with the reasons cited by frame owners. The ICF owners most often cited functional advantages resulting from ICF walls: comfort (including evenness of temperature and low air infiltration), sound reduction, energy efficiency, and solidity/strength. Frame owners most often cited advantages that accrue to new homes regardless of their construction: location, floor plan, and inclusion of the owner's preferred features.

These differences in qualitative responses suggest that frame homeowners saw little advantage to their new houses beyond the features one might expect in any new house. Mention of benefits attributable to superior construction of their new houses was conspicuously infrequent. In contrast, ICF owners were impressed by advantages of their new houses attributable to the superior construction of the walls.

Interviews uncovered some possible impacts of ICF construction that have important energy implications not picked up by the energy analysis. Several ICF owners with unheated basements commented that their basements were about as warm in winter as their conditioned living space upstairs. They therefore felt that when they finished their basements they could avoid enlarging their heating systems or consuming more fuel to condition them.

The data sizes and statistical tests indicate that the numerical estimates of this study are reliable. However, there are limitations to the research methods of surveys of actual houses such as this. Refinement of the estimates and additional information on the sources of the savings could come from detailed energy modeling or careful metering of specially constructed test modules.

Energy Consumption of Concrete Homes Versus Wood Frame Homes

Dr. Pieter VanderWerf

METHODS

Research consisted of:

1) Identifying ICF houses across the U.S. and Canada;
2) Interviewing the owners for information on characteristics of each house and its use, and to get permission to receive energy consumption data from the applicable utilities and fuel vendors;
3) Identifying, for each ICF house, comparable frame houses;
4) Interviewing the owners of the frame houses for the same information requested of ICF owners;
5) Acquiring the energy data from the utilities and fuel vendors;
6) Dividing total energy consumption among the relevant uses (heating, cooling, and nonconditioning consumption);
7) Normalizing the energy consumptions of each house to a common basis to control for differences in house characteristics and use;
8) Calculating useful summary statistics; and
9) Classifying responses to key open-ended questions.

Building Products Group engaged contractors with specialized skills to perform portions of the research. Bernett Market Research conducted most of the interviews. Conservation Services Group solicited energy release permission from homeowners and the actual data from their utilities and fuel vendors. Xenergy Inc. provided the procedures and formulas for data analysis.

Identifying ICF Houses

Initial work focused on locating a large pool of all-ICF houses from which to draw a sample. The houses were to have a distribution of locations approximately representative of the geographic distribution of new construction in the U.S. and Canada. From ICF manufacturers we requested contacts with ICF builders, and from these, contacts with homeowners. Through this procedure we obtained names and telephone numbers of approximately 125 alleged ICF homeowners.

Interviewing ICF Homeowners

The Principal Investigator and professional interviewers from Bernett Market Research attempted telephone interviews of the ICF homeowners. They failed to reach several within the available time, and stopped pursuing or set aside the interview results from others because of one or more of the following:

- the house failed to meet requirements (was not all-ICF, used an ICF made of a foam-cement composite, had been occupied too briefly for generation of sufficient energy data); or
- the house or its use had characteristics that made accurate measure of energy consumption impossible (occupants spent long periods away from home, a large share of conditioning derived from an unmeasurable source such as solar gain, metered energy included supplies to the heating or cooling systems of other structures).

In all, acceptable interviews concerning 79 different houses were completed. Each interview provided the following data:

Data items from telephone interview
square footage of conditioned space
number of stories above grade
type of foundation
number of regular occupants
thermostat settings
fenestration opening practices
comfort of indoor climate
overall reaction to house
reasons for overall reaction
primary heating fuel
secondary heating fuel (if any)
tertiary heating fuel (if any)
cooling fuel (if any)

Although not directly asked, many respondents also volunteered the following:

type of equipment for primary heating fuel;
type of equipment for secondary heating fuel (if any);
type of equipment for tertiary heating fuel (if any); and
type of cooling equipment (if any).

Where not volunteered, the researchers determined this information, re-calling the owners or their builders as necessary.

Many respondents also volunteered various other characteristics of their houses or its use that they considered relevant, such as the level of insulation in other (non-wall) parts of the house, what other appliances or structures were serviced from the same energy source, and family vacation patterns. In some cases the researchers disqualified houses based on this information for one or more of the reasons described above.

Identifying Frame Houses

The interviewers also asked ICF homeowners for contacts owning conventional frame houses that were nearby. The request specified that the frame houses be of similar square footage to the owner's ICF house, and of new construction (under 6 years of age). Forty-two of them provided one or more names. Candidate frame houses for the remaining ICF homes came from separate calls to the builder of the ICF home in question, other known builders in the area, or builders in public listings for the area. These procedures generated a list of approximately 150 frame homeowners.

Interviewing Frame Homeowners

The Principal Investigator and Bernett Market Research undertook interviews of the frame homeowners in closely analogous fashion to the interviews of the ICF Homeowners. Many potential interviewees were dropped or eliminated for the same reasons cited earlier (under "Interviewing ICF Homeowners"). The same questions (with a few rewordings required by the differences in wall composition) were asked, and these returned the same data items (listed under "Interviewing ICF Homeowners"). HVAC equipment was determined by the same methods and procedures.

This process returned complete, usable data for 75 frame houses. Matching these with usable ICF interviews showed 56 usable matched pairs of one ICF house and one comparable frame house. The reduction to 56 pairs from 79 ICF and 75 frame interviews arises from uneven response among the frame owners on the call list. For 23 ICF houses, none of the comparable frame home owners responded, while for others multiple comparable frame owners responded.

Acquiring Energy Data

In each interview the interviewer asked permission to mail the homeowner a release form for each fuel used in heating or cooling. This form, when completed and presented to the supplying utility or fuel vendor, directed the supplier to provide the quantity and cost of fuel delivered to the house, broken down by time periods, for the last 18 months (or less if not available for all of that time).

A few homeowners preferred to relay these data directly from their records over the telephone or through the mail. Reasons included: privacy, convenience (Some had already assembled the data for their own interest), or feasibility. Users of wood heat, in particular, generally had no outside provider that kept records, but could recall their past usage.

Under contract to Building Products Group, Conservation Services Group solicited the release forms from homeowners and, in turn, the energy data from their fuel providers. A total of 67 ICF homeowners and 53 frame homeowners returned forms. Complete energy data arrived for 54 ICF and 48 frame houses. Nine of these houses were subsequently disqualified because problems identified under "Interviewing ICF Homeowners" became apparent after the data arrived. Complete, usable data arrived from fuel utilities and vendors for 29 matched pairs (one ICF house plus its corresponding frame house). These, therefore, comprise the data base for the energy comparisons presented in this report.

Table 1 compares the geographic distribution of the final 29 matched pairs with that of housing starts.

TABLE 1: Distribution of Data Versus Housing Starts

District	Share of '96 house starts*	Data pairs in sample*
1. New England	3%	14% (4)
2. Middle Atlantic	7%	3% (1)
3. East North Central	16%	14% (4)
4. West North Central	6%	10% (3)
5. South Atlantic	23%	14% (4)
6. East South Central	6%	7% (2)
7. West South Central	9%	10% (3)
8. Mountain	11%	7% (2)
9. Pacific	11%	10% (3)
10. Canada	8%	10% (3)
Total	100%	100% (29)

*May not add to exactly 100 because of rounding.

It was not possible to compare both heating and cooling energy consumption in all 29 houses. Some houses had no air conditioning, and in a very few cases it was possible to get complete data for one segment of conditioning (heating or cooling) only. The precise tally of instances is as follows:

House pairs with:		
Heating and cooling in both houses of which:		14
data available on both heating and cooling	12	
data available on heating only	1	
data available on cooling only	1	
Heating in both houses, cooling in only one		5
Heating in both houses, cooling in neither		10
Total		29

Thus data were available to compare heating consumption in 28 houses, and cooling consumption in 13 houses. All energy comparisons in this report are therefore based on samples of these respective sizes.

As one would expect, the air conditioned houses tended to be concentrated in the lower half of the United States.

Dividing Total Energy Consumption

To conduct the statistical tests it is necessary to isolate the portion of a fuel's consumption that goes to each segment (heating or cooling) of space conditioning. In a few cases a fuel was used for one segment of space conditioning and nothing else. For example, usually wood consumption was solely for heating. The total Btus from such a fuel can thus be placed directly into the space conditioning total for the relevant segment. But the majority of fuels are also used for nonconditioning tasks, and sometimes for both heating and cooling.

The consulting engineering firm of Xenergy Inc. provided Building Products Group with customized methods for discriminating the energy consumed for other uses (so-called "base consumption") and for each conditioning segment.

The separation procedure followed is the defacto standard in energy research. It begins with finding the two months of lowest consumption, averaging them, and assuming that the average equals monthly base consumption. All remaining consumption is assumed to be for conditioning. For a fuel used only for one segment of conditioning (such as gas for heating), this results in adding the consumption of two extreme nonconditioning months (as July and August), multiplying by six to get base consumption for the year, and subtracting from the year's total consumption to get conditioning consumption.

For a fuel used for both heating and cooling (almost always electricity powering a heat pump), the lowest months are termed "shoulder months." They are separated in time and, depending on local climate, usually in late spring and early fall. The consumption above base in the warm months between the shoulders is assumed to be cooling consumption, and that falling in the remaining cool months is assumed to be heating consumption.

For some houses, consumption of a fuel in certain months was missing. For some others, consumption was metered only for longer periods (such as oil or propane delivered only every few months). In these cases the distribution of consumption across the missing months or aggregated time period was extrapolated from that of other houses in the area.

Normalizing Energy Consumption

Xenergy Inc. also provided methods for controlling for important energy-related differences across the houses. Conceptually, the methods used "normalize" the energy consumption of a house to that of a "typical" house.

Specifically, the normalization procedure yields the estimated conditioning energy the house would have consumed if the composition of its exterior walls were the same but its design and usage were adjusted so that it:

1) were 2100 square feet of conditioned space;
2) included 2 stories above grade;
3) housed 3 regular occupants;
4) bore an average winter thermostat setting (day and night) of 69°F and an average summer thermostat setting (where applicable) of 74°F;
5) used heating equipment that is 100% efficient;
6) used cooling equipment that is 285% efficient;
7) included a full basement foundation.

Appendix A contains details of the calculations to normalize energy consumptions. An intuitive summary of them follows. Items (1) and (2) above (square footage and number of stories) are included in a single factor that adjusts consumption to that of a house with the exterior envelope (walls and roof) equivalent to a 2-story, 2100-sf home. In this way it compensates for differences in the envelope area of houses of different sizes and geometries. It also compensates for the differing ratios of wall to roof area, and for the differential heat losses between walls and roof.

The adjustment for number of occupants recognizes that people reduce heating loads somewhat and increase cooling loads. The correction factor is therefore different for heating and cooling equations.

Adjustments for thermostat settings recognize that heating load increases with higher settings, and cooling with lower settings. The applicable factor again differs depending on whether the adjustment is to heating or cooling.

Adjusting for HVAC equipment efficiency recognizes that homes using inefficient equipment (such as a wood stove) consume more energy than those with efficient equipment (gas furnace, heat pump), independent of the energy efficiency of the exterior walls. The control heating efficiency of 100% (applied to heating consumption only) lies amidst the ratings of the various equipments; is a convenient, round figure to which to normalize; and happens to be the efficiency of baseboard electric resistance heating. The control cooling efficiency of 285% corresponds to an air-to-air heat pump in cooling mode, far and away the most common cooling equipment. Appendix B lists the energy efficiencies assumed for different actual types of heating and cooling equipment.

Normalization to a full basement foundation recognizes that heating (but not cooling) losses are greater with stem wall or slab foundations.

Note that we made no correction for whether the house's windows and doors were "frequently left open" or not. A sizeable fraction of the respondents indeed claimed that they left fenestration open. However, recorded comments of approximately a third of those making this claim show that they did so only in temperate weather when the HVAC load was zero and was therefore probably unaffected by this action. We therefore felt, a priori, that no correction was necessary. Simply put, the interviews indicate that virtually no one leaves windows and doors open much during heating or cooling season.

Calculating Summary Statistics

The most important summary statistics are the average savings of the conditioning energy consumptions. For each matched pair of houses, the fractional difference between ICF and frame house consumption was calculated for each of heating energy, cooling energy, and the total of the two. (In houses with no air conditioning, total conditioning energy simply equals heating energy. Thus total savings equals heating savings.) The average of the conditioning energy differences across all houses yields average heating savings, average cooling savings, and average total savings.

Dollar savings expended on fuel were also calculated for heating, cooling, and total energy. Dollars saved was an average of the dollar savings realized by each house. The dollar savings for heating (or cooling) each house was a product of (1) the fractional energy savings for heating (cooling), (2) the total amount of energy expended on heating (cooling) in Btus, and (3) the average cost of heating (cooling) energy per Btu.

Total dollars saved was an average of the total of heating and cooling savings for each house. Again, total dollars saved average the dollar savings of some houses with both heating and air conditioning, and some houses with only heating (and thus no cooling savings).

Comparing Btus and dollars saved to total energy consumption and bills provides estimates of savings as a fraction of total household fuel consumption and cost. Note that dollar savings as a fraction of total utility charges are much less than energy savings as a fraction of total conditioning energy. This is because total charges include items that are "fixed". That is, they are not affected by the conditioning energy efficiency of a home. These include flat monthly service charges and the energy consumed for non-conditioning uses, such as lights and cooking equipment.

Averages of all interview variables also allow us to examine differences between the characteristics and use of ICF and frame houses. These are useful in evaluating the comparability of the two groups of houses.

Tallying Open-ended Responses

In addition to the closed-end questions asked for data analysis purposes, all interviewees were asked why they liked (or disliked) living in their homes. As one would expect, the responses to this open-ended question varied widely.

The researchers aggregated responses into categories for reporting purposes. The categorization method was consistent for all interviewees. In particular, the same response would be classified in the same way regardless of whether it came from the owner of an ICF or frame house.

RESULTS

Complete, usable energy consumption information is available for 29 matched pairs of ICF and frame houses, as noted previously. These 29 pairs include 28 matched heating comparisons and 13 matched cooling comparisons. These comprise the data base on which the energy-related statistics are based.

Analysis of responses to the one open-ended question are not dependent on access to energy data. Therefore all completed interviews involving qualified houses (all-ICF houses or new frame houses) can be, and were, included in this portion of the analysis. The major result of this practice is that responses from ICF houses for which usable energy data were not later obtained were nonetheless included.

Sample Comparability

Table 2 lists average values for data items related to the characteristics and use of the 29 ICF and 29 frame houses in the energy analysis sample. The two subsamples are close on key items. This provides confidence that the two groups of houses were similar in important respects other than the composition of their exterior walls. Note that the normalization procedures corrected for the differences between an ICF house and its matched frame house, anyway.

Conditioning Energy Savings

Table 3 contains key statistics comparing energy savings of ICF and frame houses.

Relative heating energy savings in Btus is estimated at 44.25%, and that for cooling and total conditioning energy at 32.03% and 41.93%. The finding of ICF savings was consistent across pairs of houses. In only 1 of the 29 pairs did

Table 2: Comparison of ICF and Frame Characteristics and Usage

Question 1: Size of House	<1000	1000-2000	2000-3000	3000-4000	>4000	
ICF	0.00%	34.48%	41.38%	10.34%	13.79%	100.00%
Frame	0.00%	41.38%	31.03%	13.79%	13.79%	100.00%
Question 2: How many stories in House	Single Story	Two Story	Three Story +	Split Level		
ICF	62.07%	37.93%	0.00%	0.00%		100.00%
Frame	37.93%	51.72%	10.34%	0.00%		100.00%
Question 3: Type of Foundation	Full Basement	Crawl Space	Slab			
ICF	41.38%	13.79%	44.83%			100.00%
Frame	44.83%	31.03%	24.14%			100.00%
Question 4: # of People in House	One or Two	Three or Four	Five +			
ICF	48.28%	48.28%	3.45%			100.00%
Frame	41.38%	37.93%	20.69%			100.00%
Question 5: Thermostat Setting	Avg. Win/Day	Avg. Win/Night	Avg. Sum/Day	Avg. Sum/Night		
ICF	69.33	67.83	73.23	72.98		
Frame	68.31	67.76	73.24	72.65		
Question 6: Window/Door Left Open?	Yes	No				
ICF	41.38%	58.62%				100.00%
Frame	41.38%	58.62%				100.00%
Question 10A: Primary Heating Fuel	Electricity	Gas	Oil	Propane	Wood	
ICF	41.38%	37.93%	13.79%	6.90%	0.00%	100.00%
Frame	34.48%	44.83%	13.79%	0.00%	6.90%	100.00%
Question 10B: Secondary Heating Fuel	Electricity	Gas	Oil	Propane	Wood	
ICF	50.00%	50.00%	0.00%	0.00%	0.00%	100.00%
Frame	33.33%	33.33%	0.00%	0.00%	33.33%	100.00%
Question 11: Is Home Air Conditioned?	Yes	No				
ICF	58.62%	41.38%				100.00%
Frame	58.62%	41.38%				100.00%
Question 12: Fuel Used for Cooling	Electricity	Gas	Oil	Other		
ICF	100.00%	0.00%	0.00%	0.00%		100.00%
Frame	100.00%	0.00%	0.00%	0.00%		100.00%

Table 3: Estimates of Annual Energy-Related Savings

	Percentage Savings			Dollar Savings		
	95% Confidence Interval			95% Confidence Interval		
	Average	Lower Bound	Upper Bound	Average	Lower Bound	Upper Bound
Heating Energy Savings	44.25%	36.05%	52.46%			
Heating Fuel Cost Savings	26.28%	21.41%	31.16%	$220.51	$179.61	$261.41
Cooling Energy Savings	32.03%	15.64%	48.42%			
Cooling Fuel Cost Savings	10.01%	4.89%	15.13%	$88.73	$43.32	$134.14
Heating & Cooling Energy Savings	41.93%	33.85%	50.01%			
Heating & Cooling Fuel Cost Savings	21.28%	17.18%	25.38%	$249.60	$201.49	$297.72

normalized total conditioning consumption for the ICF house exceed that of its frame counterpart. Standard tests place the 95% confidence interval on total conditioning savings at 20.56-49.37%.

Results are lower for dollar savings as a fraction of total utility bills, as evident in the Table. As noted previously, utility bills (referred to as "Fuel Cost" in the Table) include flat service charges and the cost of non-conditioning energy as well. The average total savings are slightly less than the sum of the average heating and average cooling savings because not all houses had cooling.

By applying the fractional savings of dollars to the average conditioning bills of frame homes, we can estimate absolute dollar savings. From Table 3 we see that the average frame house in our sample would save an estimated $220.51 on heating energy and $88.73 on cooling energy (where applicable) if its exterior walls were constructed instead of ICFs. Averaging the total savings of all houses, including those that do not include cooling equipment, shows estimated total conditioning savings for the "average" of all houses in the sample was $249.60.

Savings Rates and Climate

There are theoretical reasons to expect that the fractional savings in energy might be different in different climates. For example, the thermal mass effect should be more pronounced in moderate or warm climates because the outdoor temperature there more often fluctuates about the thermostat set point. Thus fractional heating savings might be greater.

Figure 1. Heating Savings by Climate

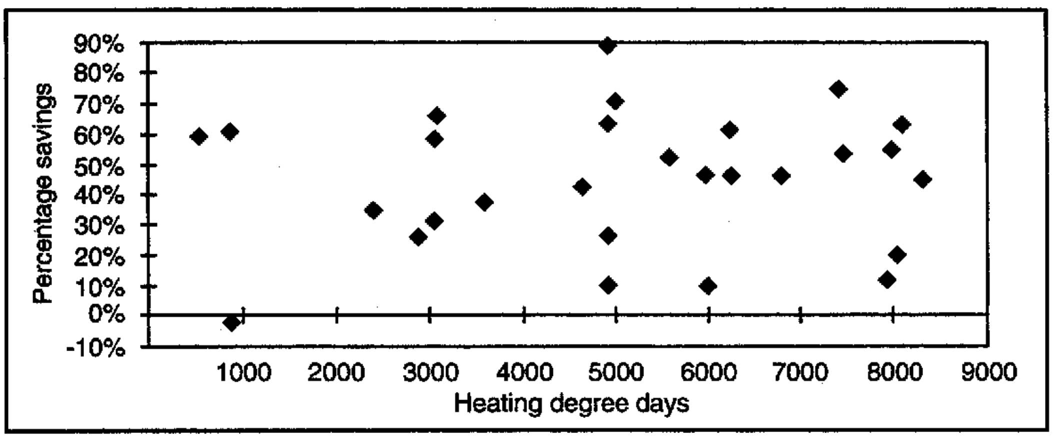

Figure 2. Cooling Savings by Climate

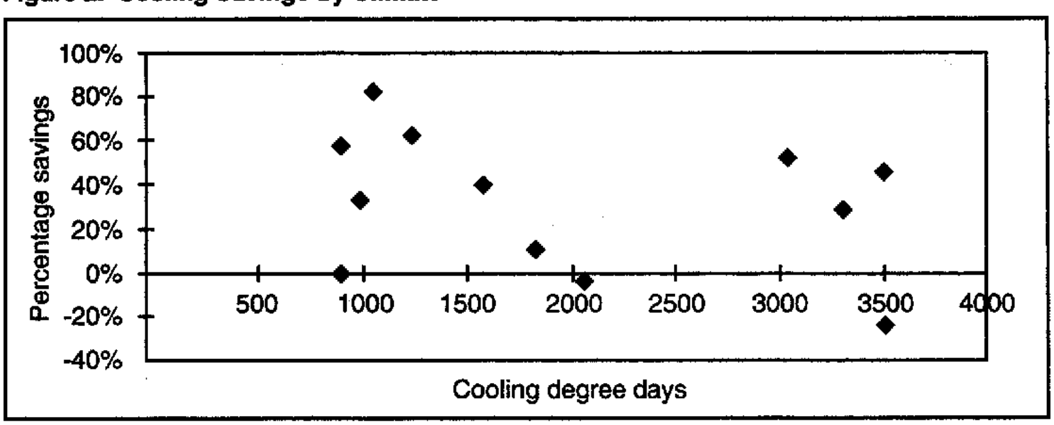

Table 4: Estimates of Annual Dollar Energy Savings by House Size and Location

HEATING SAVINGS

Location	House size (sf) 1,000	2,000	3,000
Minneapolis	$233.67	$342.17	$430.08
St. Louis	$141.07	$206.58	$259.65
Dallas	$68.33	$100.06	$125.76

COOLING SAVINGS

Location	House size (sf) 1,000	2,000	3,000
Minneapolis	$23.35	$34.20	$42.98
St. Louis	$44.32	$64.90	$81.57
Dallas	$73.96	$108.30	$136.12

TOTAL

Location	House size (sf) 1,000	2,000	3,000
Minneapolis	$257.03	$376.37	$473.06
St. Louis	$185.39	$271.48	$341.22
Dallas	$142.29	$208.36	$261.89

However, the data do not support any such hypothesis. Figures 1 and 2 contain scatter plots of heating and cooling savings as a function of heating and cooling degree days, respectively. There appears to be virtually no relationship between the local climate and the fraction of energy saved. Correlation statistics bear this out. They are small (Pearson's product moment for heating is .11; for cooling .034) and not statistically significant.

Therefore, based on these data, the practical conclusion is that heating and cooling savings will tend to be about as estimated in the "average" numbers, regardless of location.

Total Savings and Climate

If fractional savings are the same regardless of location, absolute savings must vary. In cold climates total heating consumption is greater, so the same percentage saved will result in greater total savings. In warm climates, total cooling savings will be greater.

As an example, Table 4 presents projections of total annual dollar savings for three separate locations representative of a range of climates. They are extrapolated from the estimated "average" savings appearing in Table 3. The averages of Table 3 are based on an assumption of a 2100 square foot, 2-story house on a full basement foundation. The average climate of houses in the data sample consisted of 5076 heating degree days and 2035 cooling degree days. The figures in Table 4 adjust the average figures by using the formulas used elsewhere in the study to:

1) shift to the degree days of either Minneapolis, St. Louis, or Dallas;
1) shift to a 2-story house of either 1000, 2000, or 3000 square feet;
2) retain a basement foundation for purposes of the Minneapolis calculation; shift to a stem wall for St. Louis; and shift to a slab for Dallas.

The builder of a medium-sized house in Minneapolis, for example, might guess that building with ICFs instead of typical frame construction would save about $342 in heating, plus another $34 (for a total of $376) if the house is also air conditioned.

Reasons for Liking/Disliking One's Home

Table 5 tallies the reasons given by the homeowners for liking or disliking their houses. Note that virtually every owner in both the ICF and frame category answered the closed-ended part of the like/dislike question with an affirmative. That is, the owners (with negligible exceptions) said they liked their houses. What distinguishes the ICF and frame owners more is their responses to the open-ended part of the question: their reasons for liking their houses.

Note that each respondent was allowed to cite any number of reasons. Therefore the number of responses exceeds the number of respondents, and percentages total well over 100%. Note also that the respondents tallied here include not only those returning complete information and energy data. They include some for whom energy data were not available or that were disqualified from statistical tests for various other reasons. In short, any considered to have had a valid experience with an ICF or frame house was included in analysis of this question regardless of whether it was possible to include the house in the energy statistics. This explains the larger *n* of the sample.

Most ICF homeowners cited the quiet of their houses, which was the most often-mentioned single item by far in either group. This was followed in order by energy efficiency, comfort, evenness of temperature, lack of drafts, overall "solidness," and resistance to wind. However, some further aggregation may be useful. We might consider:

- "even temperature" and "no drafts" to be a variant on "comfort;"
- "well insulated" to be a variant on "energy efficiency;" and
- "withstands wind" to be a variant on "solidness/strength."

The retabulated results would be as follows:

1) comfort and related	62 mentions	80.52%
2) quiet	50	64.94%
3) energy efficiency and related	33	42.86%
4) solidness/strength and related	24	31.17%

In contrast, frame homeowners most often cited location-related features, their involvement in design or ability to specify house features, floor plan, comfort, newness, and size, in that order. This is a noteworthy list since most of these items are equally available in any new house regardless of its construction materials. Thus, with the possible exception of comfort, they generally do not attest to advantages of the materials or workmanship.

Respondents occasionally cited dislikes for their houses, even when they had stated they liked their houses overall. There were few such statements. We can note that ICF houses received fewer such negative comments, and the complaints about frame houses more often had to do with space conditioning-related problems. The differences are not significant, however.

INTERPRETATION

Average Energy Savings

The data offer strong statistical evidence that houses constructed with ICF exterior walls consume less space conditioning energy than otherwise comparable wood frame houses. The estimated Btu savings for heating, cooling, and the total of these are over 40, 30, and 40 percent for the "average" U.S. or Canadian home.

The ever-present possibility of sampling error makes it probable that the actual average savings is either higher or lower. However, the statistical confidence interval indicates that there is only a five percent chance that the true value for total savings is outside the range of 34-50%.

Table 5: Owners' Reasons for Liking/Disliking Homes

ICF

# of Respondents	77	
Like ICF Homes	76	98.70%
Dislike ICF Homes	1	1.30%

Reasons for Liking ICF Houses

Quiet/Reduced Noise	50	64.94%
Energy Efficiency	29	37.66%
Comfort	25	32.47%
Even Temperature	19	24.68%
Tight/No Drafts	18	23.38%
Solidness/Strength	15	19.48%
Withstands Wind	9	11.69%
Thicker Walls	7	9.09%
Sense of Security	5	6.49%
No Movement	5	6.49%
Well Insulated	4	5.19%
Construction Advantages	4	5.19%
Walls More Stable	3	3.90%
Low Maint.	3	3.90%
Doesn't Creak	3	3.90%
Wouldn't Know/It's Concrete	2	2.60%
Less $$ Than Frame	2	2.60%
Less Cracks Walls/Ceiling	2	2.60%
Insect Resistance	2	2.60%
Not Damp	2	2.60%
No Cold Spots	1	1.30%
No Vibration	1	1.30%
Looks Great	1	1.30%
Ecology Benefits	1	1.30%
Design Advantages	1	1.30%
Less Dust	1	1.30%
No Echo	1	1.30%

Reasons for Disliking ICF Houses

Dif Hang On Walls	3	3.90%
Construction Problems	1	1.30%
Moisture Condensation	1	1.30%
Lose Space Thick Walls	1	1.30%
Expensive to Heat	1	1.30%
No Different Than Frame	1	1.30%

Frame

# of Respondents	77	
Like ICF Homes	72	98.63%
Dislike ICF Homes	1	1.37%

Reasons for Liking Frame Houses

Location/View	24	32.88%
Involvement in Design/Constr.	22	30.14%
Layout/Floor Plan	15	20.55%
Comfort	13	17.81%
Because It's New	10	13.70%
Size/It's Spacious	9	12.33%
Energy Efficiency	6	8.22%
Design Advantages	6	8.22%
Well-Insulated	4	5.48%
Looks Great	4	5.48%
Lots of Windows	3	4.11%
Interior Temperature	2	2.74%
Air/Easier to Breathe	2	2.74%
Well-construction	2	2.74%
Construction Advantages	1	1.37%
Air-Conditioning	1	1.37%
Tight/No Drafts	1	1.37%
Quiet	1	1.37%

Reasons for Disliking ICF Houses

Too Large/Too Small	3	4.11%
Construction Problems	3	4.11%
Layout	3	4.11%
Humid	1	1.37%
Drafty	1	1.37%
Heating Problems	1	1.37%

Reliability of Savings

In fact, the most extreme observed levels of ICF energy savings (both high and low) are probably irrelevant for the planning purposes of a builder or homeowner. This is because it is unlikely that much of the variation in savings observed from house to house is the result of ICF walls being more effective in some applications than in others.

To be sure, certain factors can influence the extent of savings from ICFs. Local climate patterns should influence the savings realized from thermal mass. Likewise, the lower the percentage of the exterior walls comprised of fenestration, the higher the savings from ICF walls, since the influence of the opaque walls on total load rises (as that of the windows and doors falls). But engineers' measures of the thermal mass effect show it to vary total loads across cold and warm climates by only a few percent. Fenestration percentages, in practice, are tightly concentrated about the 12-16% range throughout North America. Other factors moderating the effectiveness of ICF construction are also likely to be of small impact for similar reasons.

So in practice, the house-to-house variation in savings observed is likely to come more from unmeasured differences between the ICF and frame houses this study compared. Non-wall design and construction details such as the tightness of the roof, the extent of roof insulation, solar incidence, the routing of HVAC ductwork, and the energy efficiency of the windows and doors are known to have large impacts on conditioning energy consumption. When one of the two houses in one of our matched pairs contains significantly better construction in these details, the research methods will not correct for them, and the observed savings from ICF walls will be higher or lower accordingly.

The implication for the homebuilder or homebuyer is that savings from the incorporation of ICF exterior walls instead of frame walls is likely to be near the estimated average, rather than at one of the extremes of the confidence interval. For planning purposes the figure of interest is the likely reduction in energy from (conceptually) swapping in ICF for frame walls, without varying other factors. This is what the average savings figure derived through this research is designed to estimate.

HVAC Sizing

The results also support the notion that HVAC equipment can be downsized for ICF homes. Exactly how much is not determinable from the figures in this report, however. HVAC sizing depends on peak load and load uncertainty (which includes engineering safety factors) rather than total load. The thermal mass effect is supposed to reduce peak load even more than it reduces total load. Moreover, ICF houses may or may not exhibit less uncertainty in energy efficiency than frame houses. Therefore contractor claims that HVAC equipment can safely be reduced in size by as much as one-half may be valid.

Potential Data Biases

There are two ways in which biases may have entered into the statistical estimations, making them over- or underestimates. The first is that ICF homes might tend to contain more energy efficiency features unaccounted for in the research. The average ICF homebuyer might be more energy-conscious than the average frame buyer. Thus the ICF buyer might not have included simply ICF walls, but also other energy-conserving items as well. The estimated savings might therefore result, as least in part, from these other items. The calculated savings for the ICFs would therefore be overestimates.

However, based on the available data such a bias appears unlikely. Several interviewees volunteered extra information about their houses in the course of questioning. Usually the information offered was that the house had one or more premium energy-efficiciency features not directly asked about in the interview. These included:

- low-e argon-filled windows;
- above-average roof insulation;

- high solar gain in a heating climate;
- zone heating; and
- special high-efficiency HVAC systems.

Of the 29 ICF houses included in the energy analysis data sample, the owners of 3 of them (10%) mentioned one of these features. Of the 29 frame houses, the owners of 4 (14%) mentioned one. Based on these numbers, the tendency of the ICF owners to include extra energy features (other than the ICF walls) appears not to have been any greater than the tendency of the frame owners to which they were compared.

The second potential bias arises from the need to calculate the base energy consumption in houses conditioned with heat pumps from "shoulder" months. This procedure may lead to underestimates in both the total and the fractional conditioning savings in ICF houses.

In reality the "shoulder" months are probably periods of modest amounts of both heating and cooling. Therefore by using their energy consumptions as an estimate of base consumption one is actually overestimating base consumption and, hence, underestimating heating and cooling consumption. Therefore estimated total savings from use of ICFs will be calculated on a smaller base (of total heating and cooling) and thus be underestimated.

But in addition, the percentage of energy savings might be underestimated. The shoulder months are periods of moderate temperature. Thus they are periods when the thermal mass effect should be greatest and ICF savings should be at their peak. Therefore energy consumption in ICF houses should be especially low, leading to a relatively low estimate of base consumption (compared with the estimate that would occur in frame houses) and a higher estimate of heating and cooling consumption. So the shoulders method of estimation might lead to an understatement of the fractional energy savings from ICF construction, as well as an understatement of the total savings.

Whether either of these factors in fact introduces a bias to the estimates, and how large it might be, is difficult to determine by surveys such as this. Surveys compare populations based on large samples and limited data from each member of the sample. To determine the impact of such second-order effects it would be necessary to collect fine data on very small samples.

Logical methods of assessing these potential data biases include (1) detailed energy modeling of hypothetical, prototypical houses; or (2) construction and measurement of standardized ICF and frame test "houses". Either would involve significant cost and lack the field verification of a survey. However, the potential refinement in precision and in understanding of the mechanisms of ICF savings might justify such an effort.

Owners' Preferences

The respondents' reasons for liking their homes suggest important patterns in perceptions of the benefits of ICF and frame construction.

The reasons raised by frame owners were almost all characteristics one would generally expect of a new house that one had selected (location, design that conforms to buyer preferences), independent of the method of construction. In contrast, ICF owners most often named characteristics on which ICF homes are believed to surpass frame (quietness, comfort, energy efficiency).

Unsolicited comments from interviewees suggest that this difference stems from their frame of reference. Several frame owners made it clear that they were comparing their new houses to their previous, older one. Comments of ICF owners reveal that they focused on the differences between their new houses and frame houses, not new versus old. They used their own previous frame house, or the house of a friend or neighbor, as the basis of comparison.

A logical conclusion is that frame owners focus on the location and design attributes of new construction because the construction of their new houses offered little functional advantage over their old homes. Location and design were the distinctive attributes. Conversely, ICF owners may have focused on functional benefits because the location and design advantages are, to them, unremarkable. These advantages would have been available regardless, while the levels of comfort, quiet, and energy efficiency stood out.

These conclusions have important practical implications. The first is that occupants of ICF houses indeed perceive that they have multiple, significant advantages over frame. The short list of "dislikes" also suggests that these people perceive few if any significant disadvantages.

A second implication is that the buyers' perceived advantages closely match the alleged advantages long touted by ICF sellers. Comfort, quiet, energy efficiency, and strength are both widely advertised by sellers and widely appreciated by buyers.

A final implication is that new ICF construction is perceived as having more advantages over new frame construction than new frame construction is perceived as having over old frame construction. In short, new frame walls are not perceived as having much functional advantage. In contrast, ICF walls are.

Need for Basement Heating

In unsolicited side comments, several ICF owners suggested that they did not feel a need to expand their heating systems should they ever decide to finish their unfinished basements. Their opinion was that their basements currently maintained a sufficiently warm ambient temperature without any dedicated heating. Note that if they were in fact to finish their basements without increasing their conditioning energy consumption, their living space would increase sharply without any increase in energy consumption. Thus their normalized energy consumption, as measured by our methods, would drop sharply and probably widen the gap between ICF and frame construction.

In practical terms this means that the heat savings of an ICF homeowner with a finished basement (compared with a similar frame house with a finished basement should be higher than estimated in this study, both in relative (percentage) and absolute (Btus or dollars) terms.

Appendix A: Normalization Calculations

I. GIVEN

All interview questionnaire data

For primary heating fuel

A1	heat consumption	millions of btu
B1	heat consumption cost	U.S. dollars
C1	heat source consumption	millions of btu
D1	heat source consumption cost	U.S. dollars
E1	heating equipment efficiency	energy out/energy in

For secondary and tertiary heating fuels
Analogous, A2-E2 and A3-E3

For cooling fuel

F	cooling energy	millions of btu
G	cooling cost	U.S. dollars
H	cooling fuel energy	millions of btu
I	cooling fuel cost	U.S. dollars
J	cooling equipment efficiency	energy out/energy in

II. CALCULATE INTERMEDIATE VARIABLES

E4	average heating equipment efficiency (A1xE1 + A2xE2 + A3xE3)/(A1 + A2 + A3)	
N1	primary heating fuel unit cost	B1/A1
N2	secondary heat unit cost	B2/A2
N3	tertiary heat unit cost	B3/A3
N4	average heat unit cost	(B1+B2+B3)/(A1+A2+A3)
O	cooling fuel unit cost	G/F
P	total heating energy	A1+A2+A3
Q	total heating cost	B1+B2+B3
R	total heating fuel energy	C1+C2+C3
S	total heating fuel cost	D1+D2+D3
T	total heating + cooling energy	F+P
U	total heating + cooling cost	G+Q
V	total heating + cooling fuel energy	H+R
W	total heating + cooling fuel cost	I+S
X	ave. winter thermostat setting	2/3(winter day setting) +1/3(winter night setting)
Y	ave. summer thermostat setting	2/3(summer day setting) +1/3(summer night setting)
Z	foundation loss factor Where type = 1 for a basement 2 crawl space 3 slab	.125(foundation type - 1)

III. CALCULATE NORMALIZED CONSUMPTIONS

1. Normalized to 2100 sf
   2 above-grade stories

NC1A heating energy
P x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]

NC1B heating cost
Q x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]

NC1C cooling energy
F x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]

NC1D cooling cost
G x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]

NC1E total heating + cooling energy
NC1A + NC1C

NC1F total heating + cooling cost
NC1B + NC1D

2. Normalized to 2100 sf
   2 above-grade stories
   3 occupants

NC2A heat consumption
[P + (.86 x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
- (.86 x 3)

NC2B heat consumption cost
[Q + (.86 x N4 x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
- (.86 x N4 x 3)

NC2C cooling consumption
[F - (.73 x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
+ (.73 x 3)

NC2D cooling consumption cost
[F - (.73 x O x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
+ (.73 x O x 3)

NC2E total conditioning consumption
NC2A + NC2C

NC2F total conditioning consumption cost
NC2B + NC2D

3. Normalized to 2100 sf
   2 above-grade stories
   3 occupants
   average winter thermostat setting = 69F
   average summer thermostat setting = 74F

NC3A heat consumption
[P + (.86 x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
x [1+.03(69-X)]
- (.86 x 3)

NC3B heat consumption cost

[Q + (.86 x N4 x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
x [1+.03(69-X)]
- (.86 x N4 x 3)

NC3C cooling consumption

[F - (.73 x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
x [1+.05(Y-74)]
+ (.73 x 3)

NC3D cooling consumption cost

[F - (.73 x O x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
x [1+.05(Y-74)]
+ (.73 x O x 3)

NC3E total conditioning consumption

NC3A + NC3C

NC3F total conditioning consumption cost

NC3B + NC3D

4. Normalized to

2100 sf
2 above-grade stories
3 occupants
average winter thermostat setting = 69F
average summer thermostat setting = 74F
1.0 efficiency heating equipment
2.15 efficiency of cooling equipment

NC4A heat consumption

[P + (.86 x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
x [1+.03(69-X)]
x (E4/1)
- (.86 x 3)

NC4B heat consumption cost

[Q + (.86 x N4 x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
x [1+.03(69-X)]
x (E4/1)
- (.86 x N4 x 3)

NC4C cooling consumption

[F - (.73 x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
x [1+.05(Y-74)]
x (J/2.15)
+ (.73 x 3)

NC4D cooling consumption cost

[F - (.73 x O x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
x [1+.05(Y-74)]
x (J/2.15)
+ (.73 x O x 3)

NC4E total conditioning consumption

NC4A + NC4C

NC4F total conditioning consumption cost

NC4B + NC4D

5. Normalized to
   2100 sf
   2 above-grade stories
   3 occupants
   average winter thermostat setting = 69F
   average summer thermostat setting = 74F
   1.0 efficiency heating equipment
   2.15 efficiency of cooling equipment
   full basement foundation

NC5A heat consumption
[P + (.86 x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
x [1+.03(69-X)]
x (E4/1)
x (1 - Z)
- (.86 x 3)

NC5B heat consumption cost
[Q + (.86 x N4 x no. of occ.)]
x [28.5153xSQRT(no. of stories/sf)+126x(no. of stories/sf)]
x [1+.03(69-X)]
x (E4/1)
x (1 - Z)
- (.86 x N4 x 3)

NC5E total conditioning consumption
NC5A + NC4C

NC5F total conditioning consumption cost
NC5B + NC4D

IV. CALCULATE ENERGY SAVINGS

(Calculated for each matched pair)

SA savings on heat consumption
[NC5A(frame house) - NC5A(ICF house)]/NC5A(frame house)

SB savings on heat consumption cost
[NC5B(frame house) - NC5B(ICF house)]/NC5B(frame house)

SC savings on cooling consumption
[NC4C(frame house) - NC4C(ICF house)]/NC4C(frame house)

SD savings on cooling consumption cost
[NC4D(frame house) - NC4D(ICF house)]/NC4D(frame house)

SE savings on total conditioning
[NC5E(frame house) - NC5E(ICF house)]/NC5E(frame house)

SF savings on total conditioning cost
[NC5F(frame house) - NC5F(ICF house)]/NC5F(frame house)

Appendix B: Energy Conversion Factors

ENERGY UNITS

One	equals so many btus
kwh of electricity	3,413
cubic foot of gas	1,020
therm of gas	100,000
gallons of oil	141,000
gallons of propane	91,600
cords of wood	22,000,000

EQUIPMENT EFFICIENCIES

Equipment	assumed efficiency
air-to-air heat pump (heating mode)	2.15
air-to-air heat pump (cooling mode)	2.85
electric resistance baseboards	1.0
ground source heat pump (heating mode)	3.0
ground source heat pump (cooling mode)	3.6
electric furnace	0.95
gas furnace	0.9
gas boiler	0.845
gas stove	0.5
oil furnace	0.845
oil boiler	0.82
propane furnace	0.9
propane boiler	0.9
wood stove	0.35
wood fireplace	0.05
wood furnace	0.6

METRIC CONVERSION FACTORS

The following list provides the conversion relationship between U.S. customary units and SI (International System) units. The proper conversion procedure is to multiply the specified value on the left (primarily U.S. customary values) by the conversion factor exactly as given below and then round to the appropriate number of significant digits desired. For example, to convert 11.4 ft to meters: 11.4 x 0.3048 = 3.47472, which rounds to 3.47 meters. Do not round either value before performing the multiplication, as accuracy would be reduced. A complete guide to the SI system and its use can be found in ASTM E 380, Metric Practice.

To convert from	to	multiply by	
Length			
inch (in.)	micron (μ)	25,400	E*
inch (in.)	centimeter (cm)	2.54	E
inch (in.)	meter (m)	0.0254	E
foot (ft)	meter (m)	0.3048	E
yard (yd)	meter (m)	0.9144	
Area			
square foot (sq ft)	square meter (sq m)	0.09290304	E
square inch (sq in.)	square centimeter (sq cm)	6.452	E
square inch (sq in.)	square meter (sq m)	0.00064516	E
square yard (sq yd)	square meter (sq m)	0.8361274	
Volume			
cubic inch (cu in.)	cubic centimeter (cu cm)	16.387064	
cubic inch (cu in.)	cubic meter (cu m)	0.00001639	
cubic ft (cu ft)	cubic meter (cu m)	0.02831685	
cubic yard (cu yd)	cubic meter (cu m)	0.7645549	
gallon (gal) Can. liquid	liter	4.546	
gallon (gal) Can. liquid	cubic meter (cu m)	0.004546	
gallon (gal) U.S. liquid**	liter	3.7854118	
gallon (gal) U.S. liquid	cubic meter (cu m)	0.00378541	
fluid ounce (fl oz)	milliliters (ml)	29.57353	
fluid ounce (fl oz)	cubic meter (cu m)	0.00002957	
Force			
kip (1000 lb)	kilogram (kg)	453.6	
kip (1000 lb)	newton (N)	4,448.222	
pound (lb) avoirdupois	kilogram (kg)	0.4535924	
pound (lb)	newton (N)	4.448222	
Pressure or stress			
kip per square inch (ksi)	megapascal (MPa)	6.894757	
kip per square inch (ksi)	kilogram per square centimeter (kg/sq cm)	70.31	
pound per square foot (psf)	kilogram per square meter (kg/sq m)	4.8824	
pound per square foot (psf)	pascal (Pa)†	47.88	
pound per square inch (psi)	kilogram per square centimeter (kg/sq cm)	0.07031	
pound per square inch (psi)	pascal (Pa)†	6,894.757	
pound per square inch (psi)	megapascal (MPa)	0.00689476	
Mass (weight)			
pound (lb) avoirdupois	kilogram (kg)	0.4535924	
ton, 2000 lb	kilogram (kg)	907.1848	
grain	kilogram (kg)	0.0000648	

To convert from	to	multiply by	
Mass (weight) per length			
kip per linear foot (klf)	kilogram per meter (kg/m)	0.001488	
pound per linear foot (plf)	kilogram per meter (kg/m)	1.488	
Mass per volume (density)			
pound per cubic foot (pcf)	kilogram per cubic meter (kg/cu m)	16.01846	
pound per cubic yard (lb/cu yd)	kilogram per cubic meter (kg/cu m)	0.5933	
Temperature			
degree Fahrenheit (°F)	degree Celsius (°C)	$t_c = (t_F - 32)/1.8$	
degree Fahrenheit (°F)	degree Kelvin (°K)	$t_K = (t_F + 459.7)/1.8$	
degree Kelvin (°K)	degree Celsius (°C)	$t_c = t_K - 273.15$	
Energy and heat			
British thermal unit (Btu)	joule (J)	1055.056	
calorie (cal)	joule (J)	4.1868	E
Btu/°F • hr • ft²	W/m² • °K	5.678263	
kilowatt-hour (kwh)	joule (J)	3,600,000.	E
British thermal unit per pound (Btu/lb)	calories per gram (cal/g)	0.55556	
British thermal unit per hour (Btu/hr)	watt (W)	0.2930711	
Power			
horsepower (hp) (550 ft-lb/sec)	watt (W)	745.6999	E
Velocity			
mile per hour (mph)	kilometer per hour (km/hr)	1.60934	
miler per hour (mph)	meter per second (m/s)	0.44704	
Permeability			
darcy	centimeter per second (cm/sec)	0.000968	
feet per day (ft/day)	centimeter per second (cm/sec)	0.000352	

*E indicates that the factor given is exact.
**One U.S. gallon equals 0.8327 Canadian gallon.
†A pascal equals 1.000 newton per square meter.

Note:
One U.S. gallon of water weights 8.34 pounds (U.S.) at 60°F.
One cubic foot of water weights 62.4 pounds (U.S.).
One milliliter of water has a mass of 1 gram and has a volume of one cubic centimeter.
One U.S. bag of cement weights 94 lb.

The prefixes and symbols listed below are commonly used to form names and symbols of the decimal multiples and submultiples of the SI units.

Multiplication Factor	Prefix	Symbol
1,000,000,000 = 10^9	giga	G
1,000,000 = 10^6	mega	M
1,000 = 10^3	kilo	k
1 = 1	—	—
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000001 = 10^{-6}	micro	μ
0.000000001 = 10^{-9}	nano	n

Caution: Contact with wet (unhardened) concrete, mortar, cement, or cement mixtures can cause SKIN IRRITATION, SEVERE CHEMICAL BURNS, or SERIOUS EYE DAMAGE. Wear waterproof gloves, a long-sleeved shirt, full-length trousers, and proper eye protection when working with these materials. If you have to stand in wet concrete, use waterproof boots that are high enough to keep concrete from flowing into them. Wash wet concrete, mortar, cement, or cement mixtures from your skin immediately. Flush eyes with clean water immediately after contact. Indirect contact through clothing can be as serious as direct contact, so promptly rinse out wet concrete, mortar, cement, or cement mixtures from clothing. Seek immediate medical attention if you have persistent or severe discomfort.

Portland Cement Association *5420 Old Orchard Road, Skokie, Illinois 60077-1083 847/966-6200, Web site: www.portcement.org*

An organization of cement manufacturers to improve and extend the uses of portland cement and concrete through market development, engineering, research, education, and public affairs work.

Printed in U.S.A.

RP119.01T