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Measured and Simulated Cooling Performance Comparison; Insulated Concrete Form Versus Frame Construction

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Measured and Simulated Cooling Performance Comparison; Insulated Concrete Form Versus Frame Construction

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ABSTRACT

Four occupied homes near Dallas, Texas were monitored to compare cooling energy use. Two homes were built with typical wood frame construction, the other two with insulated concrete form (ICF) construction. Remote data loggers collected hourly readings of indoor and outdoor temperature, relative humidity, furnace runtime fraction, total building electrical energy and HVAC energy use. Data was recorded from January through August 2000.

Analysis of the measured data shows that insulated concrete form (ICF) construction can reduce seasonal cooling energy use 17 - 19% over frame construction in two-story homes in the North Texas climate. This result includes adjustments to compensate for differences in miscellaneous energy use, (e.g. lights & appliances), and duct leakage. While each home pair had the same floor plan, elevations and orientation there were some differences that were not accounted for in the measured results. These included occupant impacts, exterior wall color (absorptance) and the absence of an attic radiant barrier in one ICF home.

In addition to analyzing the measured data, two sets of DOE2 simulations were performed. An initial comparison of ICF and frame homes modeled in their as-built condition was followed by a comparison of homes modeled with identical features except for wall construction. Both analyses showed a 13% annual cooling energy savings for ICF over frame construction. This result is comparable to a similar simulation study (Gajda 2001) of a two-story home in the Dallas climate, which saved 15% annually on both heating and cooling.

Introduction

Four Centex homes near Dallas, Texas were monitored by the Florida Solar Energy Center as part of the Building America Industrialized Housing Partnership (BAIHP). Centex Homes and the Portland Cement Association are two BAIHP partners that were involved with the study. Two home models (Figure 1) were constructed twice; one with typical wood frame construction and the other using insulated concrete forms (ICF).

Each home was tested to determine building airtightness and the amount of duct leakage. Table 1 shows test results and other relevant building details. Figure 2 illustrates wall construction for each home type.

Figure 1. Home Models

Model E2051   Model E50

According to conventional wisdom and manufacturer's claims, the ICF homes should benefit from a higher and more consistent level of thermal insulation as well as greater airtightness wherever insulated concrete forms replace wood framing. The envelope airtightness measurements in Table 1 (CFM50 and ACH50) however, show that in one case the ICF home was tighter than the frame home while in the other the trend was reversed. This may be attributed to the fact that only the walls of the ICF homes were constructed differently from the frame structures, while the slab-on-grade foundation and wood-framed roof designs were similar. Construction details at the attic and at the junction of the first and second floors are critical to the airtightness of these homes, as is the amount of duct leakage.

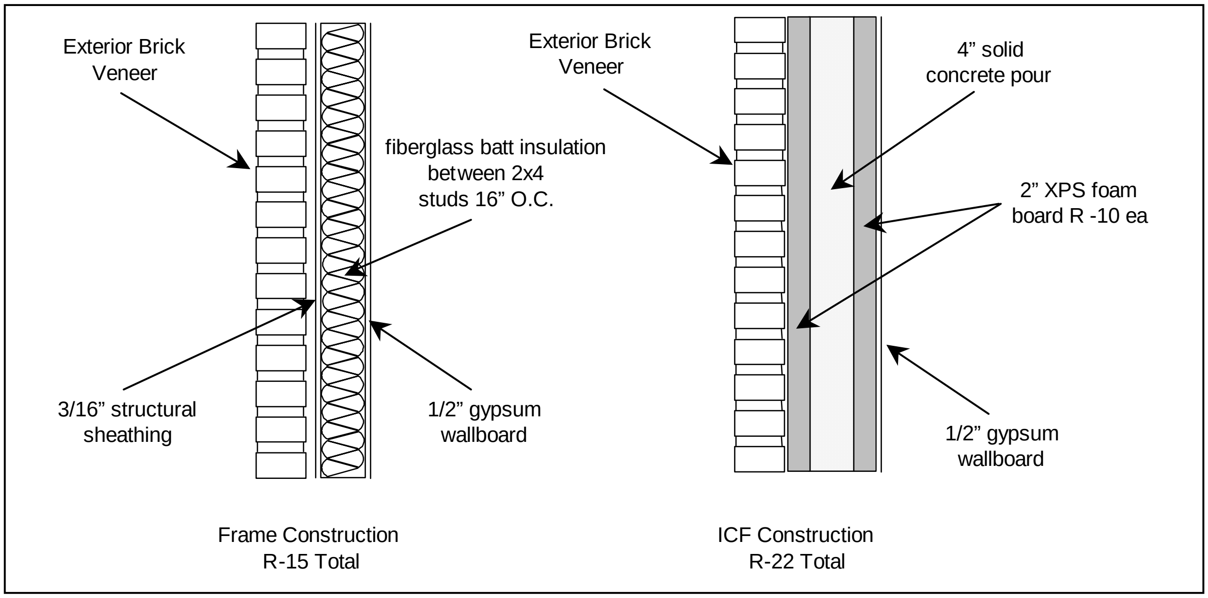
Table 1. Building Construction & Airtightness Details

Construction	ICF	Frame	ICF	Frame
Model	E2051	E2051	E50	E50
Floor Area (ft^2)	3,767	3,767	2,861	2,861
Heat Pumps $1^{st}/2^{nd}$ fl.	5 ton /4 ton	5 ton / 4 ton	4 ton / 2.5 ton	4 ton / 2.5 ton
Glass/Floor Area	18%	18%	13.5%	13.5%
Attic Radiant Barrier	No	Yes	Yes	Yes
Exterior Brick Color	Red w/Black Tint	Red	Red w/Pink Tint	Red
CFM50	2,701	3,105	2,632	2,426
ACH50	4.3	5.0	5.6	5.1
$CFM25_{total}$	620	742	602	674
$CFM25_{out}$	268	407	296	385
Occupancy	6	4?	4	4

Notes:

- All homes are 2-story with the front facing north
- All windows are double pane, clear glass, aluminum frame, U=0.81.
- All attics have R-30 blown insulation.
- SEER 12 Heat pumps were designed to run until the outside temperature dropped below 47ºF after which natural gas backup heat came on. (no electric strip heat)

Figure 2. Frame and ICF Wall Construction Details



Data Collection And Analysis

Remote data loggers collected hourly readings of indoor and outdoor temperature, relative humidity, furnace runtime fraction, total building electrical energy and HVAC energy use. Data were recorded from January through August 2000.

Isolating cooling energy use from the measured HVAC energy data provided the most useful and straightforward comparison. Analysis of heating energy use was complicated by the use of electric heat pump units backed up by a gas furnace. Consequently, heating control strategies were not consistent between homes.

To assess the cooling energy difference between the frame and ICF homes the average daily indoor to outdoor temperature difference (delta T) was plotted against the total daily cooling energy use. All hours between Jan 1 and Aug 23 (the last full day of data) were used in this analysis but only the hours where the ambient temperature was above 65ºF are included. This allowed the isolation of those hours in which cooling is taking place regardless of the time of year. In some cases only a few cooling hours from a given day were included, while in others all 24 hours were used. The average daily indoor temperatures (IDT) were derived from the same hours when ambient temperature was above 65ºF. Indoor temperatures were recorded hourly at the return plenum on each floor and averaged together.

Normalized Cooling Energy

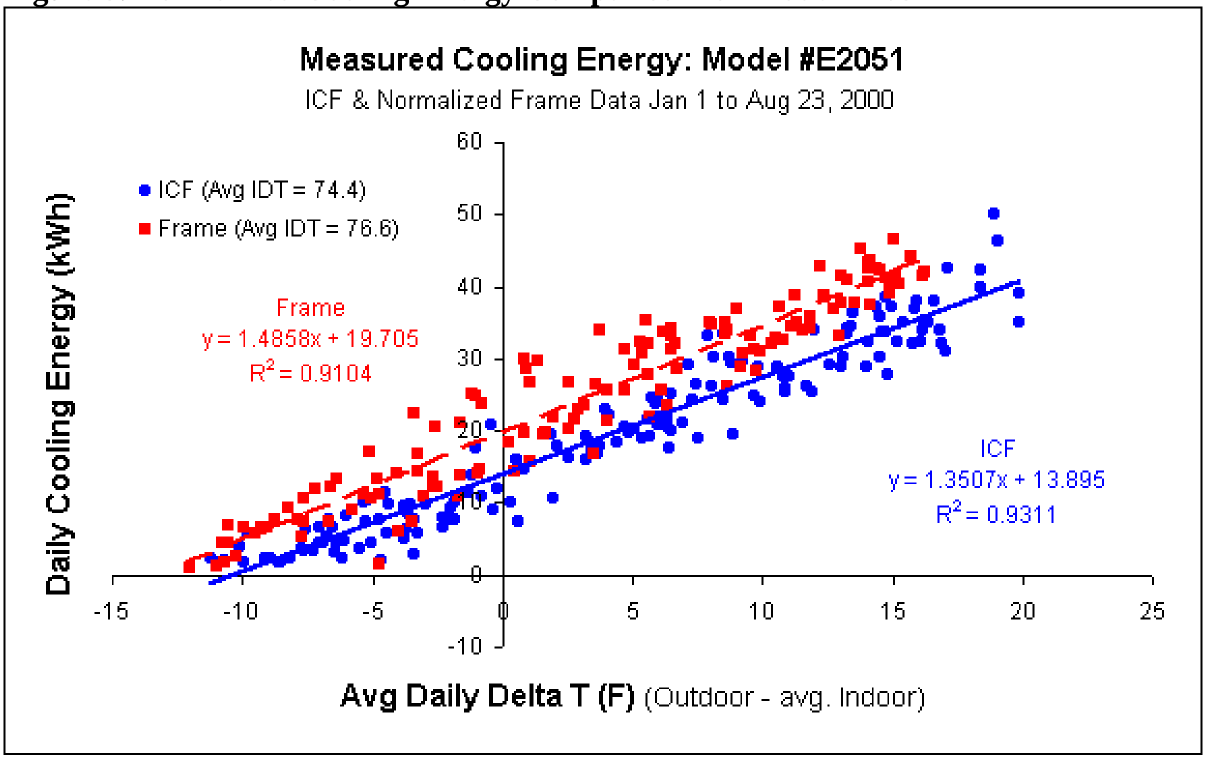
In comparing both pairs of homes it was found that the ICF buildings consistently used less miscellaneous energy (lights, appliances, etc.) than the frame structures. While no attempt was made to monitor or survey these energy end uses, they could be isolated by subtracting HVAC energy from total building energy use. Reducing the energy data of both frame homes provided a more conservative comparison since much of the miscellaneous energy use would be added to the home in the form of heat that the air conditioner must then remove. Water heating energy was not a factor here because it was provided by natural gas, however the units were located in the conditioned space.

To normalize the comparison, the daily cooling energy in each frame home was reduced by subtracting the difference in miscellaneous energy between each ICF and frame home pair while factoring in the COP of the air conditioning equipment (Equation 1). Figures 3 and 4 show the collected data after this adjustment and the resulting trend lines.

Equation 1. Normalized Frame Cooling Energy

$$(\text{Cooling kWh})_{\text{frame}} = (\text{Cooling kWh})_{\text{frame}} - [(\text{Misc.kWh}_{\text{frame}} - \text{Misc.kWh}_{\text{ICF}}) / \text{COP}_{\text{AC}}]$$

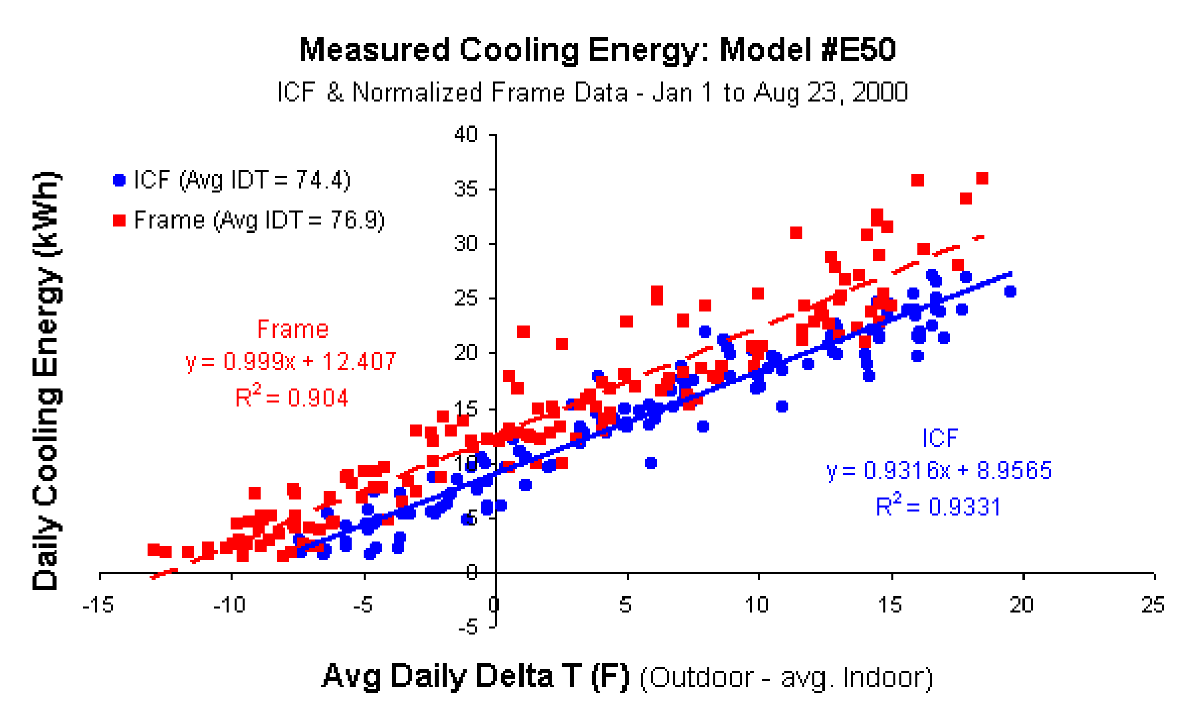
Figure 3. Normalized Cooling Energy Comparison for Model E2051



Duct Leakage Impact

Analysis of the measured data was also complicated by the fact that, while the duct systems in each model were the same, both ICF homes had tighter ducts than their frame counterparts (see CFM25 in Table 1). Since this random variation would favor the ICF homes, DOE2 simulations were performed to estimate the impact. Using the E50 model home and TMY2 weather data for Fort Worth, Texas; DOE2 simulations were performed with a 76ºF setpoint. Results showed that increasing the duct leakage in proportion to that found in Table 1 (CFM25out) increased cooling energy use by about 4%. This then was added to the ICF energy use in the final comparison below.

Figure 4. Normalized Cooling Energy Comparison for Model E50



Measured Seasonal Cooling Savings

Including adjustments for differences in miscellaneous energy use and duct leakage, the measured data shows that, in both models, the ICF home used less cooling energy than the home built with conventional frame construction. Measured savings of ICF construction over frame during the Dallas cooling season are shown in Table 2. These values were derived from the linear fit equations of Figures 3 and 4 as detailed in the Table 2 notes. Note that the final savings values in Table 2 were decreased 4% to account for duct leakage differences as described above.

Table 2. Measured Seasonal Cooling Savings – ICF over Frame Construction

Model	Type	Slope	Intercept	Energy(kWh)	Cost	Savings	Adj. Savings
E2051 ($3,767\ ft^2$)	Frame	1.486	19.71	4,448	$356	22.9%	18.9%
	ICF	1.351	13.90	3,429	$274		
E50 ($2,861\ ft^2$)	Frame	0.999	12.41	2,862	$229	20.8%	16.8%
	ICF	0.932	8.95	2,268	$181		

Notes:
Energy = [slope x (82.3 – 76) + intercept] x 153
Where: 82.3 = average summer ambient temperature (ºF)
76 = average cooling setpoint (ºF)
and 153 = Dallas cooling season (May 1 through September 30)
Frame home energy was reduced in Figures 3 & 4 to account for differences in miscellaneous energy use
Final savings values were reduced 4% to account for duct leakage differences
Utility rate of $0.08/kWh used to obtain cost savings

Occupant Impacts

Occupant activity and homeowner habits can have a major impact on residential energy use. Each of the four homes had at least 4 occupants (E2051 ICF home had 6 occupants). No other measure of occupancy or occupant activity was recorded during the study period.

Two sources of occupant impacts were factored out of the measured data. One by describing HVAC energy use in terms of the difference in temperature across the building envelope, which helps account for thermostat settings, and the other by accounting for the difference in miscellaneous energy use between each home pair. Some examples of occupant activity that could not be accounted for include:

- The level of interior shade usage
- The amount of outdoor air allowed to enter the home
- Moisture released inside the home by cooking and cleaning activities
- Long-term interior door closure in rooms where insufficient return air pathways exist

Wall Solar Absorptance and Radiant Barriers

Despite efforts to build each pair of homes with identical construction except for the wall assemblies, two oversights existed – exterior brick color differed between each home pair and an attic radiant barrier was absent in one of the ICF homes.

The solar absorptance level of exterior walls can have a measurable effect on the space cooling load. This effect is even more pronounced in two-story homes where the wall surface area is much greater than with single story construction and where roof overhangs are less beneficial. Brick colors for the four homes are described in Table 1 and the two pictures visually show the difference. In the Model E2051 comparison, the frame home had the lighter (more favorable) brick color, whereas the ICF home had the lighter color in the E50 model comparison.

Three of the homes had roof decking with radiant barrier laminated to the underside to reduce radiant heat transmission to the second floor space. The model E2051 ICF home however did not have this benefit and received a greater cooling load as a result.

DOE2 Simulation Analysis

One set of matched-pair homes (Model E50, Frame & ICF) was analyzed using DOE2 simulation software to corroborate the measured data results. The software called EnergyGauge USA® (Parker et al. 1999), provides an input interface for performing hourly computations with the DOE2.1E simulation engine. Annual simulations were performed using the TMY2 weather data for Fort Worth, Texas.

A rough comparison of the measured data with the TMY2 data set (Table 3) shows that the weather was slightly warmer in 2000 than the typical meteorological year. Cooling degree-days, which may approximate energy use, were 13% higher during the data collection period from January through August. The average ambient temperature from May through August was also higher in the collected data (82.3 ºF) versus the TMY2 data for the same period (79.8 ºF).

Table 3. Comparison of Measured vs. TMY2 Weather Data

	Measured Data (2000)	**Ft. Worth TMY2 Data**
Cooling Degree-Days (Jan – Aug)	2,225	1,939
Average Seasonal Summer Temperature (May – Aug)	82.3 ºF	79.8 ºF

The computer simulations were used for two purposes: (1) Authenticate the measured savings by comparing it with DOE2 models of frame and ICF homes in their as-built condition, and (2) Provide estimated savings of ICF over frame with identical construction except for the makeup of exterior walls. The variation in brick cladding color on each home pair was expected to have a significant impact on the cooling energy use (Parker et al. 2000). Ideally, solar absorptance would have been measured for the actual bricks used in each home, instead estimates taken from Table 4 were used in the simulations (BIA 1988).

Table 4. Absorptivity of Brick

Brick Color	**Absorptance**
Flashed (Blue)	0.86 – 0.92
Red	0.65 – 0.80
Yellow or Buff	0.50 – 0.70
White or Light Cream	0.30 – 0.50

Source: Brick Industry Association. Technical Notes 43D

Authentication of Measured Savings

DOE2 simulations of the model E50 frame and ICF homes were performed with identical inputs except for brick color, thermostat setting, building leakage and duct leakage. Input values and final results are shown in Table 5. The simulations showed a savings of only 13% as compared with the 17 to 19% found in the measured data after adjusting for duct leakage differences in both data sets. Note that the 17 to 19% savings determined from the measured data was a seasonal cooling estimate for the period from May through September, while the 13% savings found in the simulation results is taken from cooling energy use for the entire year. Although confidence in the measured results is reduced due to the small sample size, the DOE2 simulations support the measured analysis.

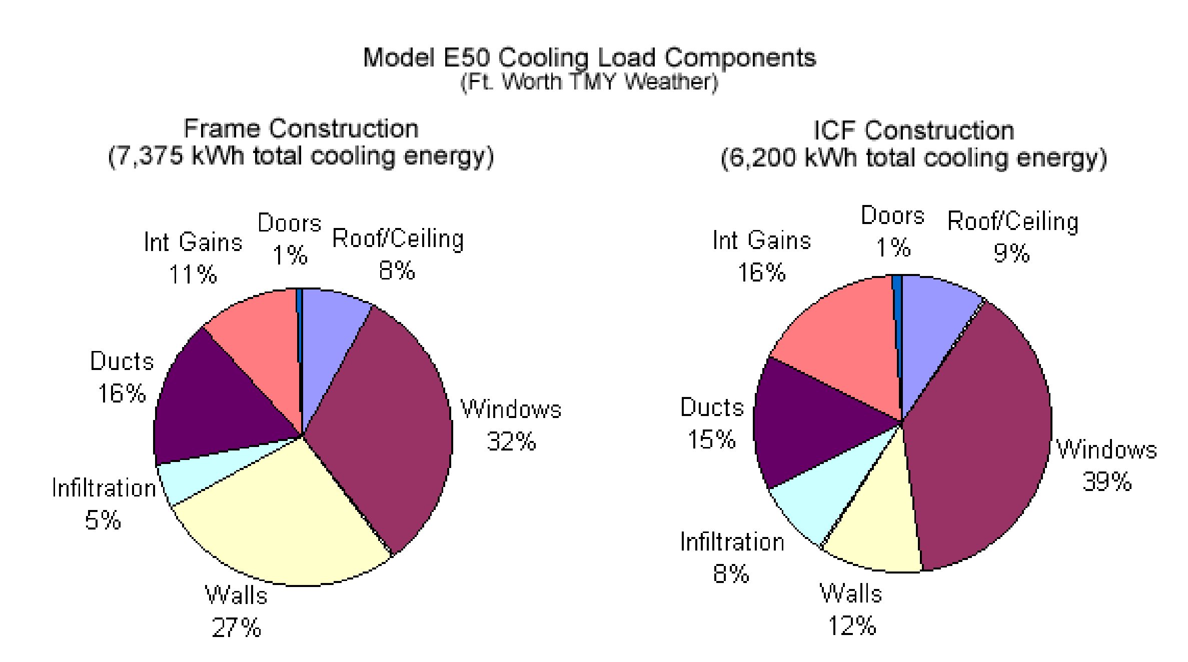
Table 5. DOE2 Inputs and Results – As-Built Simulations

Construction	**Absorptance**	**Cooling Setpt**	**ACH50**	**Qn**	**Cooling Energy**	**Savings**	**Adj.Savings**
ICF	0.55	75ºF	5.6	0.105	6,200 kWh	15.9%	12.9%
Frame	0.88	76ºF (prog)	5.1	0.135	7,375 kWh		

Notes:
Final savings values were reduced 3% to account for duct leakage differences
Qn represents duct leakage as a percent of floor area ($Qn=CFM25_{out}$/floor area)
Frame home thermostat was programmed with a 3ºF temperature rise 9am to 3pm daily

Annual cooling load distributions were also derived from the as-built simulation set (AEC 1992). The pie charts in Figure 5 represent the cooling load components in each home as constructed and tested including the differences found (brick color, thermostat setting, building and duct leakage). Although internal gains differed in the monitored homes, they are held constant here. The charts show the strong impact of changing the wall construction and absorptance of the brick cladding (solar absorptance of 0.55 for ICF home and 0.88 for frame home).

Figure 5. E50 Cooling Loads – As-Built Comparison



Ideal Comparison of ICF and Frame Construction

Another set of DOE2 simulations were performed with the Model E50 home to determine the value of ICF over frame when the only difference between the homes existed in the wall construction. In this case all other parameters were held constant including: wall absorptance, thermostat setting, building airtightness and duct leakage. As shown in Table 6, the 2-story ICF home saves about 13% in annual cooling energy over a similar frame home. In another 2-story home simulation study (Gajda, 2001) with many similar characteristics to the E50, ICF construction saved 15% over frame in the Dallas climate. Gajda's value included both heating and cooling energy use however and brick cladding was not present in either wall design.

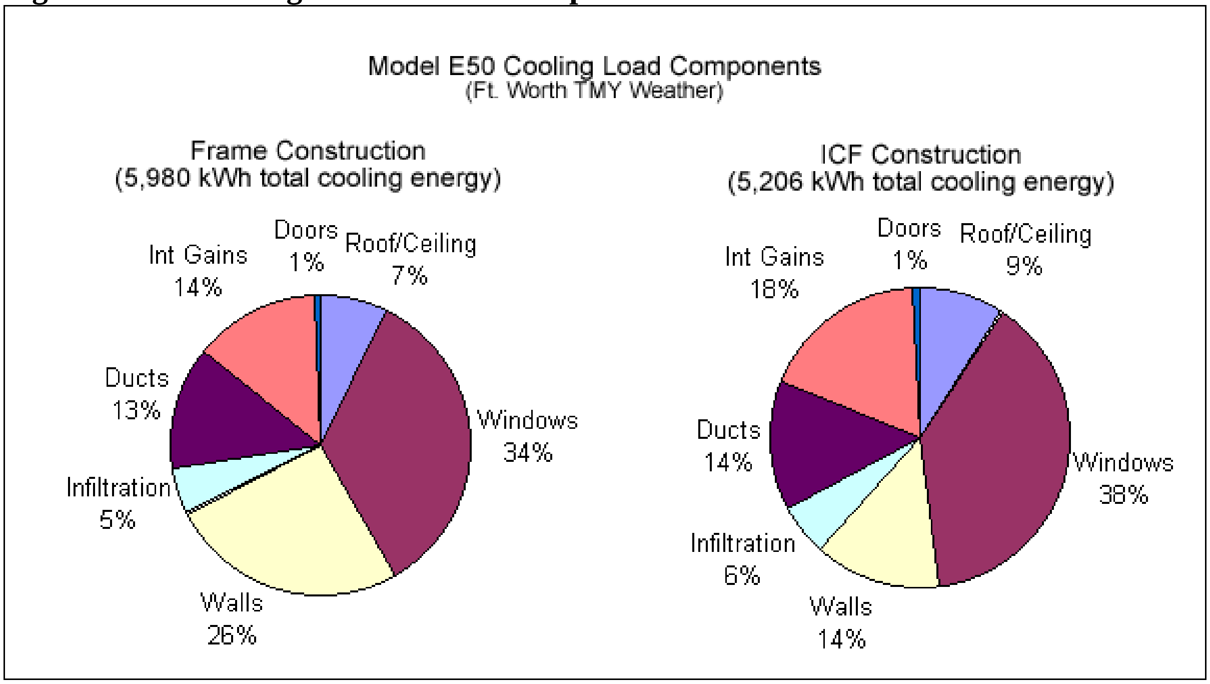
Table 6. DOE2 Inputs and Results – Ideal Comparison

Construction	Absorptance	Cooling Setpt	ACH50	Qn	Cooling Energy	Savings
ICF (R-20)	0.70	78ºF	5.0	0.105	5,206 kWh	12.9%
Frame (R-13)	0.70	78ºF	5.0	0.105	5,980 kWh	

Notes:
Differences in DOE2 input deck were limited to wall construction properties as detailed in Figure 2
Qn represents duct leakage as a percent of floor area (Qn=$CFM25_{out}$/floor area)

Figure 6 illustrates the annual cooling load distributions (AEC 1992) when comparing frame and ICF homes that are identical except for their wall construction. These results give an estimate of the true impact of only changing the wall construction while holding all other parameters constant.

Figure 6. E50 Cooling Loads – Ideal Comparison



Conclusions

Measured data collected in two nearly matched-pair homes shows that insulated concrete form (ICF) construction can save 17 to 19% over the cooling season with two-story homes in the North Texas climate. Adjustments to the measured data were made to compensate for differences in miscellaneous energy use (e.g. lights & appliances), and duct leakage. Differences not quantified here included occupant impacts, exterior wall color (or absorptance) and the absence of an attic radiant barrier in one of the four homes.

In addition to analyzing the measured data, two sets of DOE2 simulations were performed. An initial comparison of ICF and frame homes modeled in their as-built condition was followed by a comparison of homes modeled with identical features except for wall construction. Both analyses showed a 13% annual cooling energy savings for ICF over frame construction. This result is comparable to a similar simulation study (Gajda 2001) of a two-story home in the Dallas climate, which saved 15% annually on both heating and cooling.

Relative cooling savings of ICF versus frame construction would be smaller in single story homes due to smaller wall areas. Two-story construction makes up 33% of US housing (DOE/EIA 1995), with single story being much more common. Cooling energy savings on single story construction could amount to only half of that found in this study.

Further research is needed to more precisely quantify the energy benefits of insulated concrete form homes. Such research should compare homes that are identical in every aspect except wall construction and ideally should be monitored without occupancy or with simulated occupancy. Results of such carefully controlled experiments and subsequent analysis by validated hourly simulation software can provide a more accurate estimate of the benefits of ICF construction. Any analysis of occupied homes would require monitoring of a statistically valid (large) sample of ICF and conventional residences.

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