smart homes alliance

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AZ CORP COMMISSION
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Arizona Corporation Commission
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June 3, 2009

Docket Control
Arizona Corporation Commission
1200 West Washington
Phoenix, AZ 85007

RE: Energy Efficiency Technical Working Groups
Docket Nos. E-00000J-08-0314 and G-00000C-08-0314

Smart Homes Alliance (SHA) is a 501c6 Non-Profit industry organization focused on advancing the use of concrete exterior wall systems and improving energy efficiencies of residential buildings through super-insulated properties and durability. SHA serves its members and production homebuilders with education, training, promotion and implementation of thermal barrier wall systems that optimize and conserve more energy than traditional wood frame techniques.

Through the existing DSM (Demand Side Management) framework, SHA proposes an enhancement to the current builder incentive program currently offered by public utility companies to include additional incentives for homebuilders who incorporate mass wall systems that optimize energy conservation. Exchanging exterior wood-frame and typical insulation products with mass wall systems provide an air-barrier and insulation in one step, delays heat transfer and evens out temperature swings, resulting in a dramatic reduction in energy requirements.

Concrete wall systems provide:

- Tighter construction when compared to traditional wood-frame techniques.
- Provides an air barrier and insulation in one-step.
- Qualifies as OVE 'Optimum Value Engineering' in the Energy Star Thermal Bypass Checklist eliminating the need for pre-drywall inspections.
- ICFs (Insulated Concrete Forms) are listed by Energy Star for Homes as a best practice solution for reduced thermal bridging.
- Durability features less maintenance and builder warranty callbacks.
- Sustainable 100 year designs result in resource conservation.
- Comfort - The thermal mass of concrete evens out interior temperatures keeping homes cooler in the summer and warmer in the winter.
- Thermal lag characteristics of concrete delays heat transfer to the inside of the building resulting in delayed peak loading and reduced HVAC requirements.
- Continuous R-Value guarantees intended product performance.
- Reduced HVAC loads.
- Concrete is a local and regional economy.

Sustainably Yours,

Cindy Langdell, Executive Director

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RESEARCH & DEVELOPMENT INFORMATION

Concrete Foundations Association

PCA CD026

Energy Use of Single-Family Houses With Various Exterior Walls

by John Gajda

KEYWORDS

Concrete, composite wall, energy, housing, ICF, masonry, mass, modeling, steel, thermal mass, wood

ABSTRACT

A typical 2,450 square-foot single-family house design was modeled for energy consumption in twenty-five cities (25 ASHRAE zones) across the US and Canada using DOE 2.1E software. In each location, the house was modeled with eleven different exterior wall systems; conventional wood frame walls, steel frame walls, autoclaved aerated concrete walls, concrete masonry unit walls, insulating concrete form walls, and insulated concrete hybrid walls with exterior insulation, interior insulation, or internal insulation. Walls were designed with typical materials to meet or exceed the minimum energy code requirements of the 2000 International Energy Conservation Code for U.S. locations, or the 1997 Model National Energy Code of Canada for Houses for Canadian locations. Annual energy use was based on heat flow through exterior walls (R-Value and U-value) and thermal mass effects.

Analyses showed that energy for heating and cooling accounted for 20 to 72 percent of the total annual energy cost, depending on the location. Due to the thermal mass of the concrete walls, houses with concrete walls had lower heating and cooling costs than houses with frame walls, except for locations where the concrete walls were extremely under-insulated.

REFERENCE

Gajda, John, *Energy Use of Single-Family Houses With Various Exterior Walls*, CD026, Portland Cement Association, 2001, 49 pages.

ENERGY USE OF SINGLE-FAMILY HOUSES WITH VARIOUS EXTERIOR WALLS

by John Gajda *

INTRODUCTION

Energy consumption of a 2,450-square-foot single-family house with a design typical of new construction in 2000 was modeled in 25 locations across the United States and Canada to compare differences in annual energy use resulting from the use of different types of exterior walls.

Eleven types of exterior walls were modeled. Walls were classified as either "frame" or "mass." Frame walls consisted of conventional wood frame walls and steel frame walls. Mass walls consisted of autoclaved aerated concrete (AAC) block walls, concrete masonry unit (CMU) walls, insulating concrete form (ICF) walls, concrete sandwich panel walls with integral insulation, and cast in place concrete walls with exterior or interior insulation. Frame and CMU walls were constructed with typical residential-grade construction materials and practices.

To ensure a fair and equal comparison of energy use as it relates to the exterior wall systems, occupant habits such as thermostat settings and appliance use were identical for each house. Additionally, air infiltration (leakage), all non-exterior wall building components such as the roofs, floors, windows, interior walls, and the type of heating, ventilation, and cooling (HVAC) systems were also identical. As a result, energy use is dependent solely on the properties and components of the exterior walls.

Properties of the exterior walls that affect the energy use of the house include the type and thickness of insulation, thermal mass, and air infiltration. Heat loss through a frame wall is dependent on the amount of insulation. More insulation typically means less heat loss and less energy for heating and cooling. This is well publicized by insulation manufacturers and is understood by consumers. Thermal mass also has a significant effect on the heating and cooling energy. The concept of thermal mass is less publicized and is poorly understood by consumers. Walls with high thermal mass, namely concrete walls, have the ability to store and later release heat energy. This ability tends to moderate indoor air temperatures, and reduces energy associated with heating and cooling.

Thermal mass is not a new concept; it has been utilized for centuries to build comfortable living environments. Adobe has historically been utilized to construct houses throughout the southwestern United States and Mexico. These houses have high thermal mass walls typically

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constructed of very thick sun-dried clay, sand, and straw bricks. Adobe houses moderate indoor air temperatures by capturing and slowing the transfer of heat and cold from the outside.

The effects of thermal mass are illustrated in Fig. 1. The heating and cooling energy to maintain an indoor air temperature of 70°F is shown over a 48-hour period for a frame wall and a mass wall with interior mass in Boulder, Colorado, over two April days. Assuming year 2000 average U.S. energy costs of $0.786 per therm for natural gas[1] and $0.082 per kilowatt-hour for electricity[2], heating and cooling costs for the two-day period are $7.54 for the frame wall, and $5.96 for the mass wall. The frame wall has a U-factor of 0.078 Btu/hr·Ft.^{2}·°F and a heat capacity (measure of thermal mass) of less than 1 Btu/Ft.^{2}·°F, while the mass wall has a U-factor of 0.090 Btu/hr·Ft.^{2}·°F (less insulation) and a heat capacity of 29 Btu/Ft.^{2}·°F. Although the mass wall has less insulation, the total heating and cooling energy and costs for the house with the mass walls are significantly less. This is because the thermal mass of the mass wall moderates in the indoor temperature, reducing the load on the heating and cooling equipment.

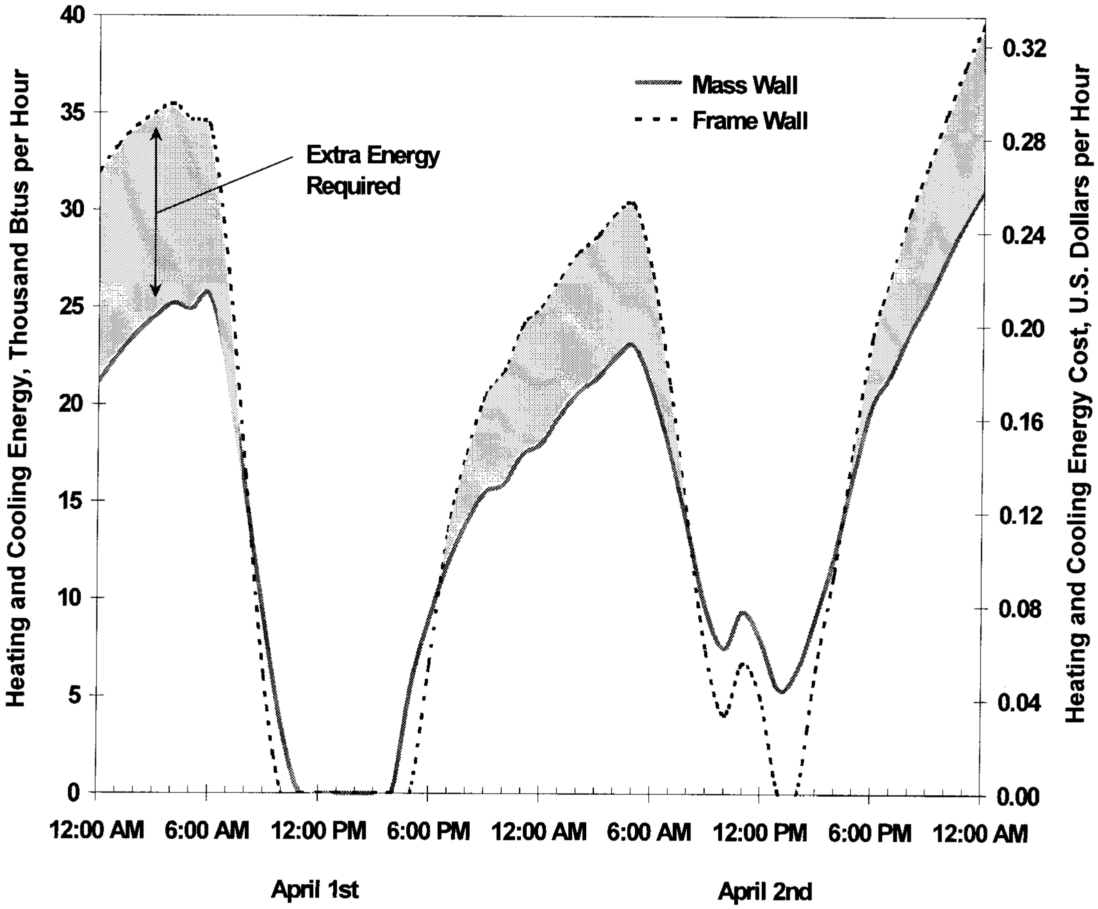


Figure 1. Comparison of heating and cooling energy and costs for identical houses with mass and frame walls in Boulder, Colorado.

LOCATIONS

Twenty locations across the United States and five locations across Canada were selected for energy-use modeling. Locations were selected based on ASHRAE-defined climate zones with available hourly weather data[3]. Results, presented in a later section of this report for a location in a particular climate zone, should be applicable to all other locations in that same climate zone. A complete listing of cities and climate zones is provided in Appendix A. Select climate data from the 25 locations are summarized in Table 1.

Table 1. Select Climate Data

Location	Degree days[3]		ASHRAE climate zone[3]	Average annual temperature,[4] °F	Average daily temperature swing,[4] °F
	Heating, base 65°F	Cooling, base 50°F			
Albuquerque, NM	4425	3908	13	56	26
Astoria, OR	5158	1437	15	51	13
Atlanta, GA	2991	5038	11	61	19
Baltimore, MD	4707	3709	13	55	19
Boston, MA	5641	2897	17	51	14
Boulder, CO	5554	2820	17	50	26
Charlotte, NC	3341	4704	11	60	19
Chicago, IL	6536	2941	17	50	18
Dallas/Ft.. Worth, TX	2259	6587	8	65	20
Fargo, ND	9254	2289	21	42	20
Fresno, CA	2556	5350	9	63	25
Halifax, NS	8133	1464	20	44	13
Houston, TX	1599	6876	6	68	20
Los Angeles, CA	1458	4777	7	62	13
Memphis, TN	3082	5467	10	62	19
Miami, FL	200	9474	2	76	12
Phoenix, AZ	1350	8425	5	73	26
Quebec City, PQ	9449	1571	22	39	16
San Francisco, CA	3016	2883	12	64	12
Seattle/Tacoma, WA	4908	2021	14	52	14
Springfield, IL	5688	3635	16	52	18
Tampa, FL	725	8239	3	71	18
Toronto, ON	7306	2370	19	45	18
Vancouver, BC	5682	1536	18	49	12
Winnipeg, MT	10858	1784	23	35	19

As a comparison, average annual temperatures in the U.S. and Canada range from approximately 27°F in Fairbanks, AK to 78°F in Key West, FL, and average daily temperature swings range from approximately 8°F in Key West, FL to 32°F in Reno, NV. The 25 locations cover all of the populated ASHRAE climate zones in the U.S. and Canada, except very cold climates with heating degree-days in excess of 12,600 HDD65. Locations with heating degree-days outside the limits of this report include Barrow, AK, Fairbanks, AK, and Nome, AK, and several locations across Canada including Churchill, MB, Inuvik, NW, and Whitehorse, YT.

ENERGY CODES

For all U.S. locations, the wood frame, steel frame, and CMU exterior walls were insulated to meet the minimum levels required by the component performance approach in the 2000 International Energy Conservation Code (IECC)[5] using standard construction materials. Similarly, for the Canadian locations, these same wall types were insulated to meet the prescriptive compliance approach of the 1997 Model National Energy Code of Canada for Houses (MNECH).[6]

These energy codes were selected for the modeling because each is the most widely used and current energy code in their respective countries. Both codes use heating degree-days as the basis for determining the minimum insulation requirements.

Table 2 presents the minimum energy code requirements (maximum U-factors*) for exterior walls and roofs. In the IECC, the maximum U-factor of the entire wall exterior, including windows, is specified. Therefore, the U-factor of the non-window portion of the wall is dependent on the U-factor and relative size of the windows. Rather than utilizing the IECC maximum window U-factors to determine the required U-factor of the non-window portion of the exterior walls, the required U-factor was based on assumed windows. For U.S. locations with heating degree-days in excess of 3,500 HDD65, the assumed window had a U-factor of 0.319 Btu/hr·Ft.^{2}·°F. For U.S. locations with heating degree-days of less than 3,500 HDD65, the IECC requires that windows have a solar heat gain coefficient (SHGC) of less than 0.4. Windows in these locations had a U-factor of 0.428 Btu/hr·Ft.^{2}·°F. Windows and the window-to-wall ratio are fully described below. Exterior wall U-factors were calculated from these assumed windows and wall areas.

For warmer locations with less than 3,500 HDD65, the IECC allows exterior walls with a heat capacity of greater than or equal to 6 Btu/Ft.^{2}·°F to contain less insulation than frame walls because the IECC recognizes the benefits of thermal mass. Insulation requirements are based on the location of the insulation in the wall (either interior, exterior, or integral). In general, a wood frame wall with a brick veneer does not qualify for this credit. Most concrete walls described in this report have a heat capacity well in excess of 6 Btu/Ft.^{2}·°F. Because the IECC does not

* The U-factor is the inverse of the R-value. The U-factor is used to describe heat flow though various building components such as walls, doors, and windows, because consumers generally associate R-value with insulation. As an example, many consumers would believe that a wood-frame wall insulated with R-11 insulation has an R-value of 11 hr·Ft.^{2}·°F/Btu. In reality, the R-value of the wall is reduced due to thermal bridging of the wood studs, and may be increased by sheathing materials.

consider the benefits of additional heat capacity, most concrete walls do not receive enough credit in the IECC for their thermal mass. Mass benefits are not described in the MNECH.

Table 2. Maximum Assembly U-factors* Allowed by the IECC and MNECH, Btu/hr·Ft.^{2}·°F

Location	Opaque walls**		Roof
	Frame	Mass	
Albuquerque, NM	0.115	0.132	0.034
Astoria, OR	0.101	0.111	0.030
Atlanta, GA	0.121	0.141	0.036
Baltimore, MD	0.109	0.124	0.032
Boston, MA	0.092	0.102	0.028
Boulder, CO	0.093	0.103	0.028
Charlotte, NC	0.114	0.134	0.036
Chicago, IL	0.075	0.075	0.026
Dallas/Ft. Worth, TX	0.140	0.160	0.037
Fargo, ND	0.066	0.066	0.026
Fresno, CA	0.129	0.149	0.036
Halifax, NS	0.045	0.045	0.022
Houston, TX	0.176	0.216	0.042
Los Angeles, CA	0.173	0.213	0.042
Memphis, TN	0.119	0.139	0.036
Miami, FL	0.224	0.274	0.049
Phoenix, AZ	0.177	0.217	0.042
Quebec City, PQ	0.043	0.043	0.025
San Francisco, CA	0.120	0.140	0.036
Seattle/Tacoma, WA	0.106	0.118	0.031
Springfield, IL	0.091	0.101	0.027
Tampa, FL	0.203	0.253	0.046
Toronto, ON	0.061	0.066	0.031
Vancouver, BC	0.088	0.101	0.033
Winnipeg, MT	0.059	0.059	0.025

* The maximum U-factor is the inverse of the minimum R-value.
** Calculated for the U.S. locations based on the house design and the U-factors of the assumed windows.

ENERGY MODELING SOFTWARE

Modeling was performed using Visual DOE 2.6 energy simulation software[4]. This software uses the United States Department of Energy DOE 2.1-E hourly simulation tool as the calculation engine so that energy usage and peak demand are accurately simulated and evaluated on an hourly basis over a typical one-year period.

Several other hourly energy use modeling software packages were considered for use, including Energy-10[7] and BLAST[8]. All three models compute energy use on an hourly basis, and. Although easier to use than Visual DOE, Energy-10 was not used because Visual DOE is more versatile, and the DOE 2.1-E calculation engine is more widely used. BLAST was not used because it is not user-friendly.

HOUSE DESCRIPTION

The single-family house used in the modeling was designed by CTL and is based on typical designs currently being constructed in the United States. The house was a two-story single-family building with four bedrooms, 9-Ft. ceilings, a two-story foyer and family room, and an attached two-car garage. The house has 2,450 square feet of living space, which was somewhat larger than the 1999 U.S. average of 2,225 square feet.[9] Figures 2 and 3 present the floor plans. Figures 4 through 7 present the front, rear, and side elevations.

Roofs, Interior Walls, Floors, and Windows

In an effort to simplify the analyses and to compare energy use across all locations, typical regional construction material variations were not considered. Building components and insulation were selected to meet the minimum requirements of the IECC and MNECH using standard construction materials. Minimum energy code requirements (maximum U-factors) are presented above in Table 2. Actual U-factors of the roofs, and windows are presented in Table 3.

Roofs were assumed to be of frame construction with oriented strand board (OSB) or plywood decking and medium colored asphalt shingles. Attic insulation was R-19, R-25, R-30, R-38, or R-49 fiberglass batt insulation, as appropriate for each location. Interior walls were assumed to be of frame construction and were not insulated. Interior floors were assumed to be carpeted frame assemblies without insulation.

All houses were assumed to be of slab-on-grade construction. The IECC and MNECH require perimeter insulation for slabs-on-grade in most locations. Energy modeling software cannot model perimeter insulation; therefore, perimeter or under-slab insulation was not utilized. The slab-on-grade floor was assumed to consist of carpeted 6-in. thick normal-weight concrete cast on soil. The U-factor of the floor was 0.27 Btu/hr·Ft.^{2}·°F.

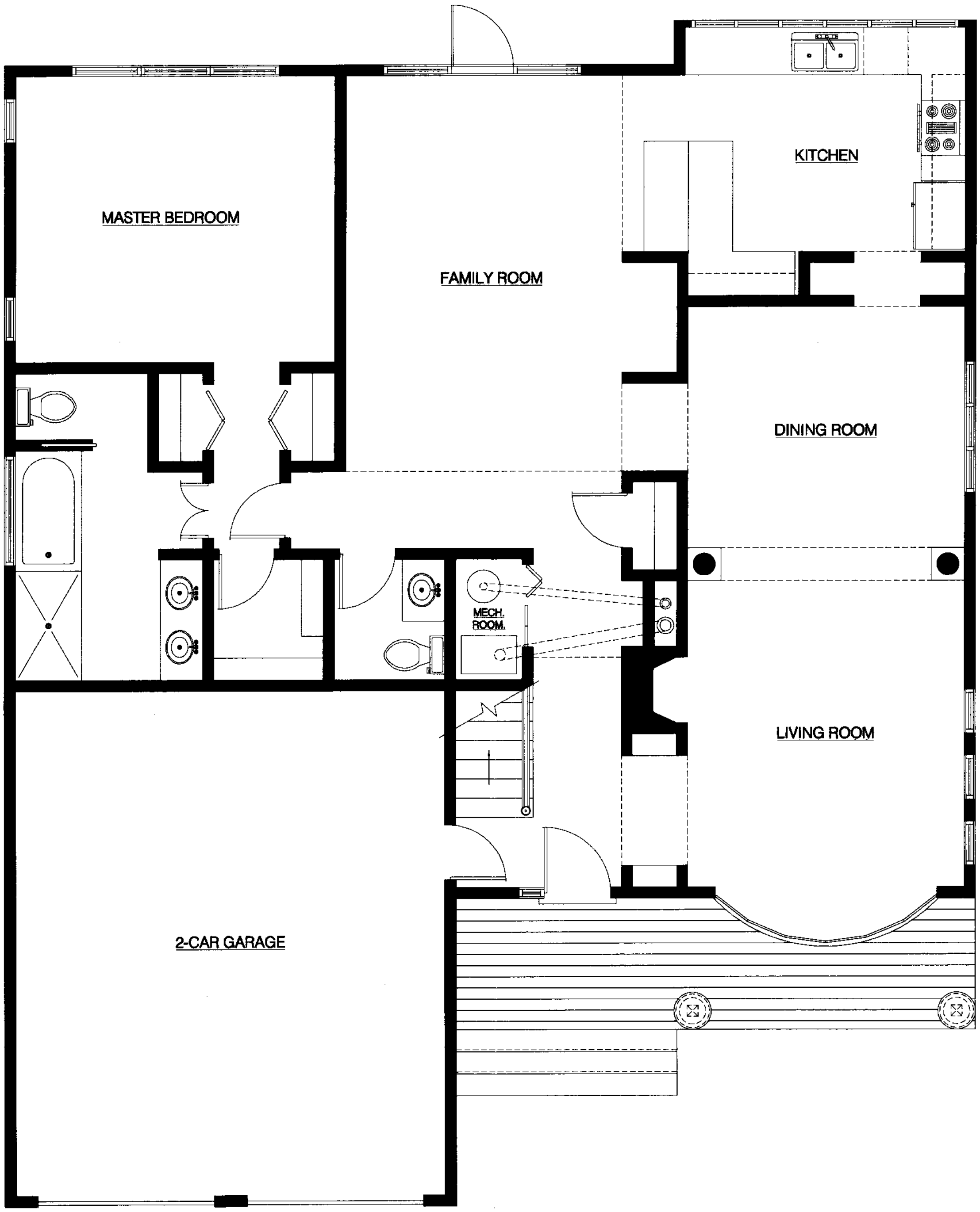


Figure 2. Floor plan of the lower level.

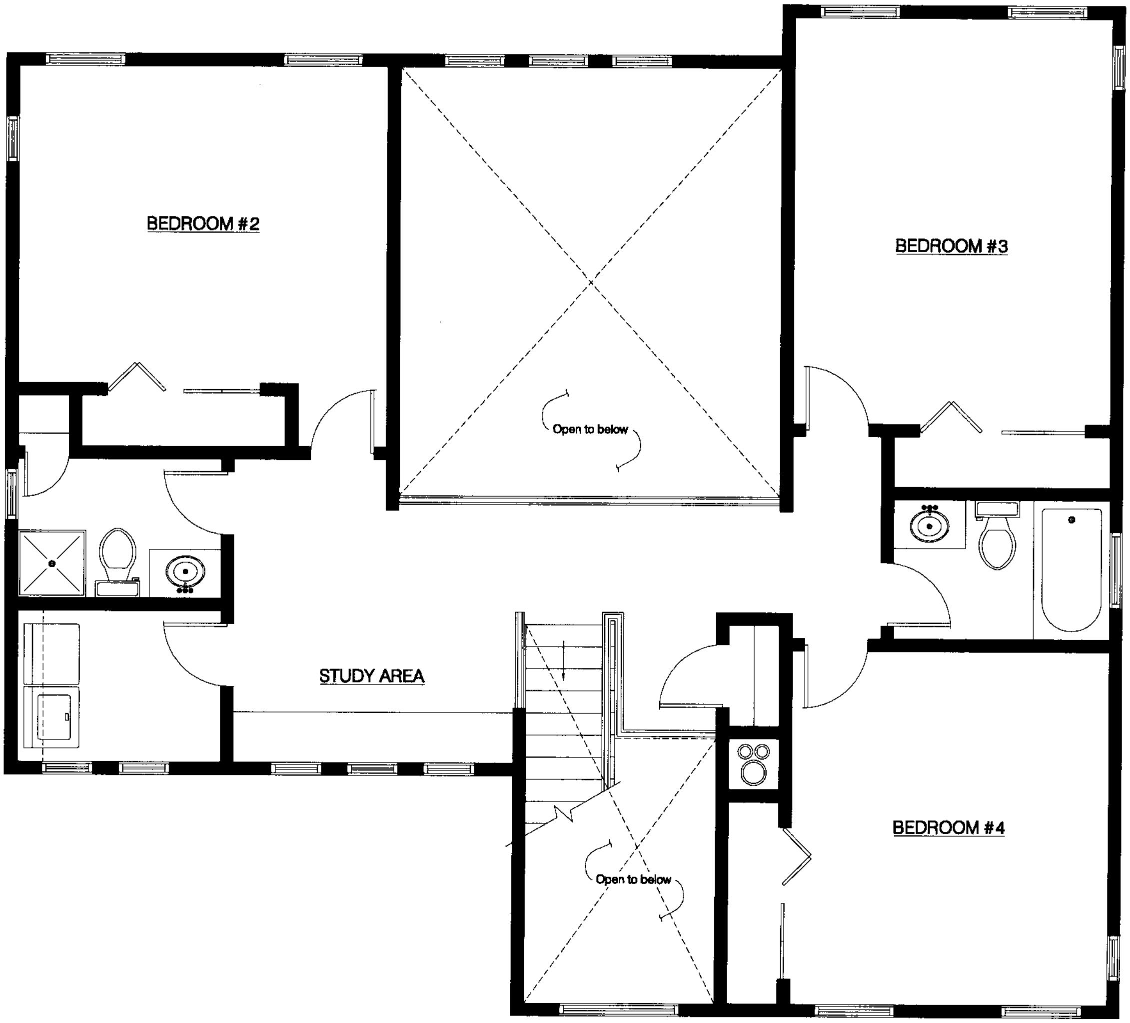


Figure 3. Floor plan of the upper level.

Figure 4. Front elevation.

Figure 5. Rear elevation.

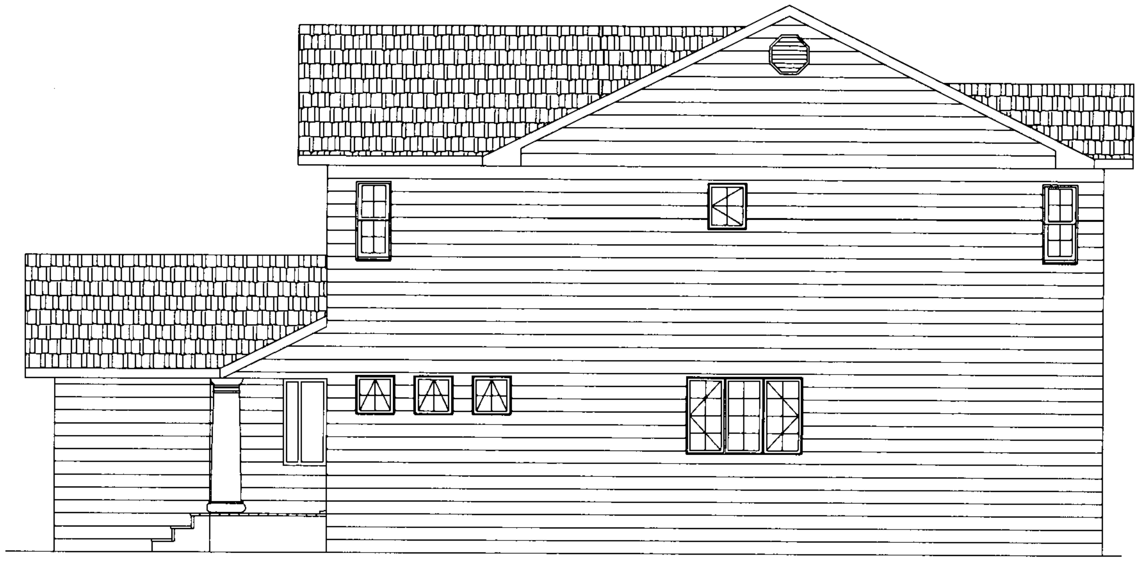


Figure 6. Right elevation.

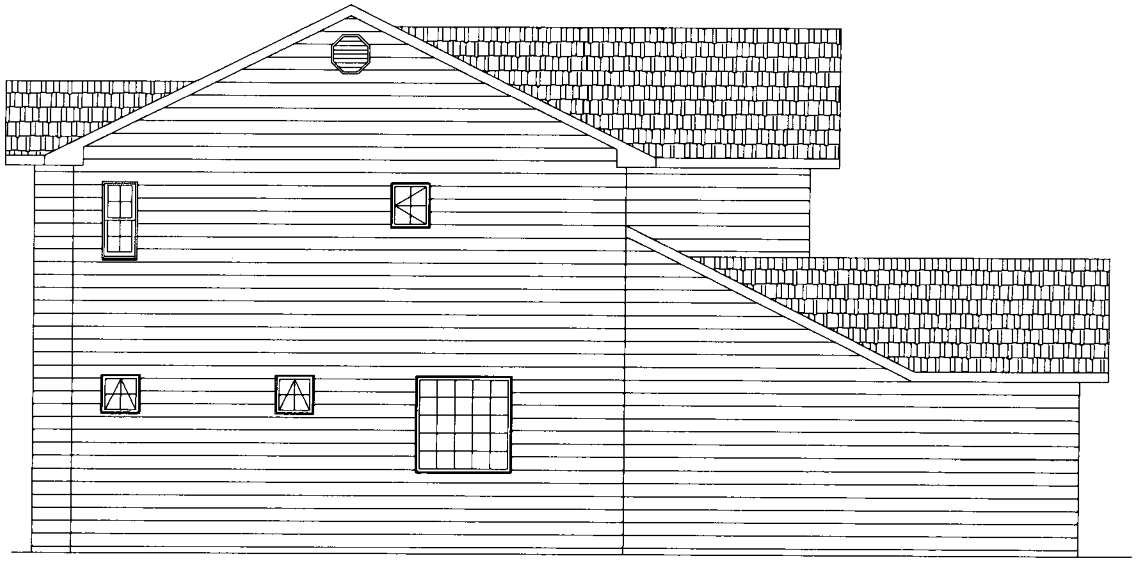


Figure 7 Left elevation.

Table 3. Actual Assembly U-factors of the Windows and Roofs Used in the Modeling

Location	Roof		Window U-Factor, Btu/hr·Ft.^{2}·°F
	Assembly U-factor, Btu/hr·Ft.^{2}·°F	Insulation R-value, hr·Ft.^{2}·°F/Btu	
Albuquerque, NM	0.031	R-30	0.319
Astoria, OR	0.025	R-38	0.319
Atlanta, GA	0.031	R-30	0.428
Baltimore, MD	0.031	R-30	0.319
Boston, MA	0.025	R-38	0.319
Boulder, CO	0.025	R-38	0.319
Charlotte, NC	0.031	R-30	0.428
Chicago, IL	0.025	R-38	0.319
Dallas/Ft. Worth, TX	0.037	R-25	0.428
Fargo, ND	0.025	R-38	0.319
Fresno, CA	0.031	R-30	0.428
Halifax, NS	0.020	R-49	0.319
Houston, TX	0.037	R-25	0.428
Los Angeles, CA	0.037	R-25	0.428
Memphis, TN	0.031	R-30	0.428
Miami, FL	0.048	R-19	0.428
Phoenix, AZ	0.037	R-25	0.428
Quebec City, PQ	0.025	R-38	0.319
San Francisco, CA	0.031	R-30	0.428
Seattle/Tacoma, WA	0.025	R-38	0.319
Springfield, IL	0.025	R-38	0.319
Tampa, FL	0.037	R-25	0.428
Toronto, ON	0.031	R-30	0.319
Vancouver, BC	0.031	R-30	0.319
Winnipeg, MT	0.025	R-38	0.299

Windows were primarily located on the front and back facades. The overall window-to-exterior wall ratio was 16%. Three window types were utilized to meet the IECC and MNECH requirements. Again, for a given location, each exterior wall system had identical windows. All windows consisted of double pane glass with a low-E coating. To meet the SHGC requirement of the IECC, windows in locations with less than 3,500 heating degree-days (HDD65) were assumed to be tinted and had air as the gap gas. As previously stated, these windows had a U-factor of 0.428 Btu/hr·Ft.^{2}·°F. Windows in all other locations except Winnipeg were clear, had air as the gap gas, and had a U-factor of 0.319 Btu/hr·Ft.^{2}·°F. To meet the U-factor requirement of the

MNECH, windows in Winnipeg were clear, had argon as the gap gas, and had a U-factor of 0.299 Btu/hr·Ft.^{2}·°F. Interior shades or drapes were assumed to be closed during periods of high solar heat gains. Houses were assumed to be located in new developments without trees or any other means of exterior shading.

Exterior Walls

Eleven exterior wall systems were modeled in each location. Of the 11 wall types, two were frame walls, eight were mass walls, and the remaining wall was a fictitious code-matching wall with no thermal mass and a U-factor selected to match the energy code requirements of the frame wall presented in Table 2. The code-matching wall was used as a basis for comparison because in many locations, the use of standard building materials resulted in some or all of the walls being over-insulated. Comparing wall U-factors in Tables 2 (minimum energy code requirements) to those of Tables 4, 5, and 6 (actual for the assumed wall configuration) shows the degree of over-insulation.

Frame walls. The frame walls consisted of a typical wood framed wall and a typical steel framed wall. Across all 25 locations, these walls contained various thicknesses and types of commonly available standard insulating materials, depending on the required U-factor.

All wood frame walls were assumed to have 2x4 or 2x6 wood studs at 16-in. centers, ½-in. gypsum wallboard in the interior surface, and ½-in. OSB or plywood sheathing with aluminum or vinyl siding on the exterior surface. In some locations insulated sheathing was utilized instead of wood sheathing to meet energy code requirements. Stud cavities were assumed to be insulated with fiberglass insulation batts.

Steel frame walls were assumed to have 2x4 or 2x6 steel studs at 16-in. centers, ½-in. gypsum wallboard in the interior surface, and OSB or plywood sheathing with aluminum or vinyl siding on the exterior surface. Wood sheathing was utilized for racking resistance and a nailing surface for additional board insulation for locations where additional insulation was required to meet energy code requirements. Again, stud cavities were assumed to be insulated with fiberglass insulation batts.

All frame walls had a heat capacity of less than 1 Btu/Ft.^{2}·°F. Table 4 presents the U-factors and materials for the wood framed walls for each location. Table 5 presents the U-factors and materials for the steel framed walls for each location. In most cases, use of typical construction materials resulted in wall assemblies that exceeded the IECC and MNECH requirements. Typical sections for the wood and steel frame walls are shown in Fig. 8.

Table 4. Actual Assembly U-factors of the Wood Frame Walls

Location	U-Factor*, Btu/hr·Ft.^{2}·°F	Components**
Albuquerque, NM	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Astoria, OR	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Atlanta, GA	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Baltimore, MD	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Boston, MA	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Boulder, CO	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Charlotte, NC	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Chicago, IL	0.074	2x4 Studs with R-13 Batts and Wood Sheathing
Dallas/Ft. Worth, TX	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Fargo, ND	0.058	2x6 Studs with R-19 Batts and Wood Sheathing
Fresno, CA	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Halifax, NS	0.041	2x6 Studs with R-19 Batts and Insulated Sheathing
Houston, TX	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Los Angeles, CA	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Memphis, TN	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Miami, FL	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Phoenix, AZ	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Quebec City, PQ	0.041	2x6 Studs with R-19 Batts and Insulated Sheathing
San Francisco, CA	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Seattle/Tacoma, WA	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Springfield, IL	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Tampa, FL	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Toronto, ON	0.058	2x6 Studs with R-19 Batts and Wood Sheathing
Vancouver, BC	0.078	2x4 Studs with R-11 Batts and Wood Sheathing
Winnipeg, MT	0.058	2x6 Studs with R-19 Batts and Wood Sheathing

* The U-factor of the insulation/wood stud layer of the wall was provided in the analysis software.

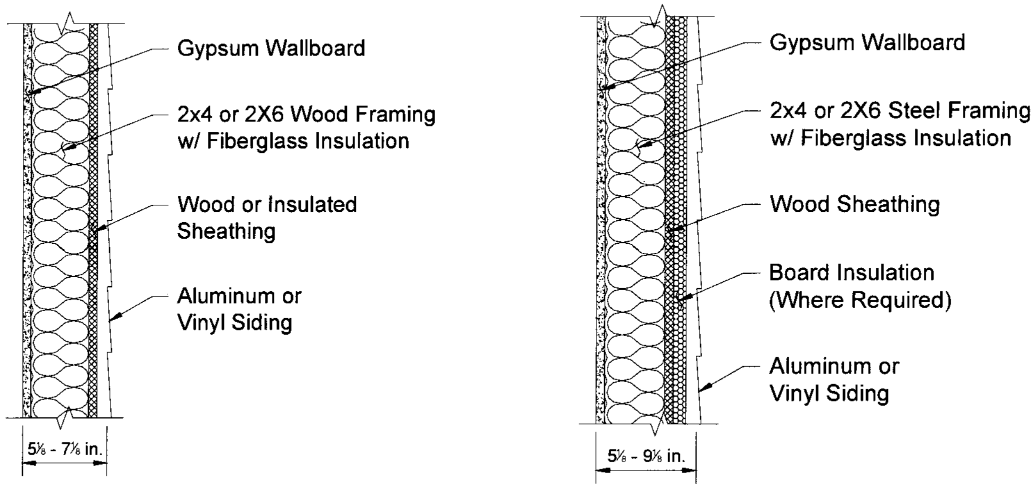
** Batts refer to fiberglass insulation. Wood sheathing is ½ -in. thick OSB or plywood. Insulated sheathing is 1½ in. thick extruded polystyrene board insulation.

Table 5. Actual Assembly U-factors of the Steel Frame Walls

Location	U-Factor*, Btu/hr·Ft.^{2}·°F	Components**
Albuquerque, NM	0.101	2x4 Studs with R-11 Batts
Astoria, OR	0.101	2x4 Studs with R-11 Batts
Atlanta, GA	0.101	2x4 Studs with R-11 Batts
Baltimore, MD	0.101	2x4 Studs with R-11 Batts
Boston, MA	0.087	2x6 Studs with R-19 Batts
Boulder, CO	0.087	2x6 Studs with R-19 Batts
Charlotte, NC	0.101	2x4 Studs with R-11 Batts
Chicago, IL	0.071	2x6 Studs with R-19 Batts and ½-in. XPS Sheathing
Dallas/Ft. Worth, TX	0.101	2x4 Studs with R-11 Batts
Fargo, ND	0.065	2x6 Studs with R-19 Batts and ¾-in. XPS Sheathing
Fresno, CA	0.101	2x4 Studs with R-11 Batts
Halifax, NS	0.042	2x6 Studs with R-19 Batts and 2-in. Urethane Sheathing
Houston, TX	0.101	2x4 Studs with R-11 Batts
Los Angeles, CA	0.101	2x4 Studs with R-11 Batts
Memphis, TN	0.101	2x4 Studs with R-11 Batts
Miami, FL	0.101	2x4 Studs with R-11 Batts
Phoenix, AZ	0.101	2x4 Studs with R-11 Batts
Quebec City, PQ	0.042	2x6 Studs with R-19 Batts and 2-in. Urethane Sheathing
San Francisco, CA	0.101	2x4 Studs with R-11 Batts
Seattle/Tacoma, WA	0.101	2x4 Studs with R-11 Batts
Springfield, IL	0.087	2x6 Studs with R-19 Batts
Tampa, FL	0.101	2x4 Studs with R-11 Batts
Toronto, ON	0.059	2x6 Studs with R-19 Batts and 1.1-in. XPS Sheathing
Vancouver, BC	0.087	2x6 Studs with R-19 Batts
Winnipeg, MT	0.059	2x6 Studs with R-19 Batts and 1.1-in. XPS Sheathing

* The U-factor of the insulation/steel stud layer of the walls was provided in the analysis software.

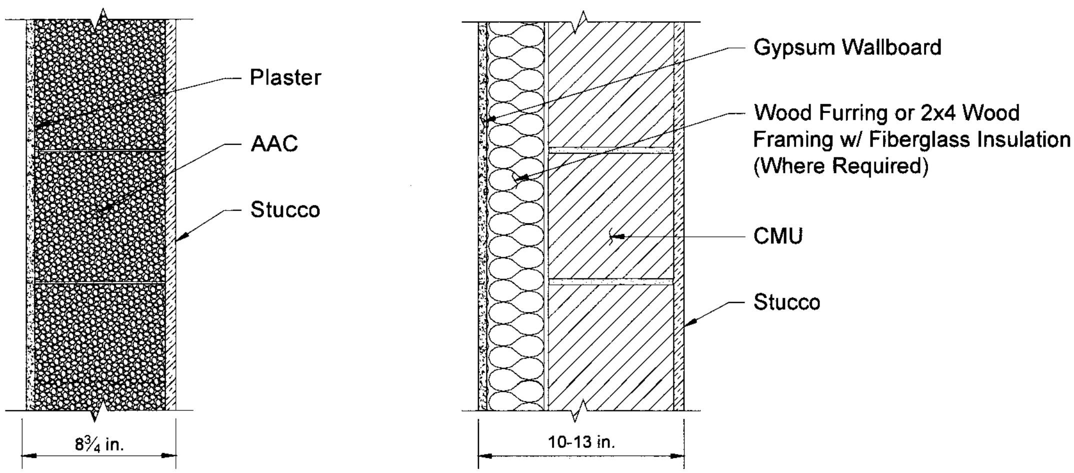
** All walls had OSB or plywood sheathing for racking resistance. Batts refer to fiberglass insulation. XPS sheathing is extruded polystyrene board insulation. Urethane sheathing is expanded polyurethane board insulation.



Wood Frame **Steel Frame**

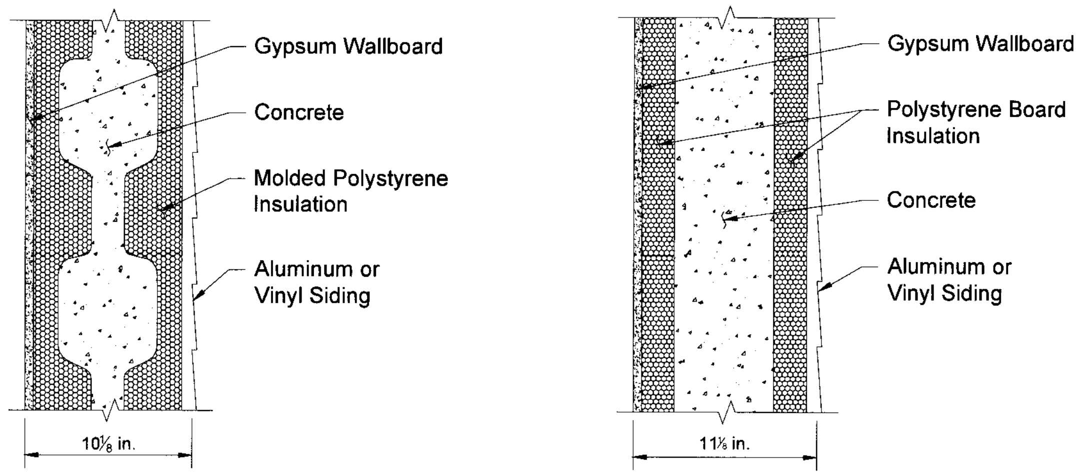
Figure 8. Typical frame wall sections.

Mass walls. The eight mass walls consisted of an autoclaved aerated concrete (AAC) block wall, a concrete masonry unit (CMU) wall, two types of insulating concrete form (ICF) walls, one cast in place concrete wall with exterior insulation, one cast in place concrete wall with interior insulation, and two sandwich panel walls with insulation between an interior and exterior concrete panel. With the exception of the CMU wall, the materials, quantities, and thickness of the mass walls were identical in each of the 25 locations. Figures 9 through 12 present the typical sections of the mass walls.



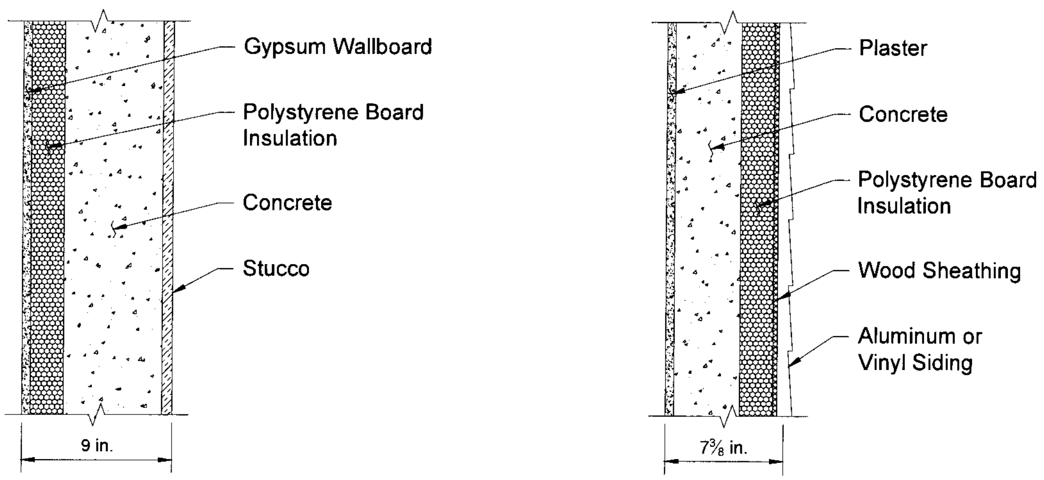
AAC **CMU**

Figure 9. Typical AAC and CMU wall sections.



Waffle Grid ICF **Flat Panel ICF**

Figure 10. Typical ICF wall sections.



Interior Insulation **Exterior Insulation**

Figure 11. Typical cast in place wall sections.

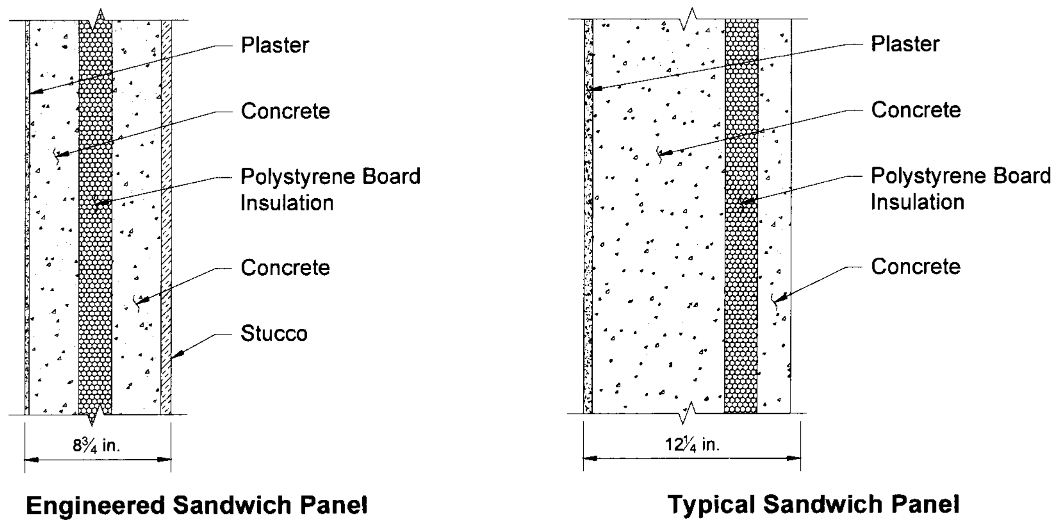


Figure 12. Typical sandwich panel wall sections.

The AAC wall consisted of commercially available 8-in. thick AAC blocks with a nominal density of 30 lb/Ft.^{3}. The exterior surface had ½ in. of portland cement stucco. The interior surface was plastered with ¼ in. of cement plaster. The total thickness of the AAC wall was approximately 8¾ in.

The CMU walls were assumed to consist of 8-in. thick normal-weight CMUs with partly grouted uninsulated cells*, interior wood furring, or insulation with wood framing at 16 in. centers, if necessary. The nominal unit weight of the CMU was assumed to be 115 pcf with U-factors as presented in ASHRAE Standard 90.1-1999[3].

The waffle-grid ICF had a thickness of approximately 9 in., and consisted of molded expanded polystyrene with metal through-wall ties. The exterior surface was sided with aluminum or vinyl siding. The interior surface was covered with ½ in. gypsum wallboard. The total thickness of the waffle-grid ICF wall was approximately 10 in.

The flat-panel ICF wall consisted of two layers of 2-in. thick expanded polystyrene insulation separated by approximately 6 in. of normal-weight concrete with plastic through-wall ties. The exterior surface was sided with aluminum or vinyl siding. The interior surface consisted of ½ in. gypsum wallboard. The total thickness of the flat-panel ICF wall was approximately 11 in.

The cast in place concrete wall with interior insulation consisted of a 6-in. thick concrete wall with 2 in. of extruded polystyrene board insulation, fastened by integral plastic ties. The exterior surface had ½ in. of portland cement stucco. The interior surface consisted of ½ in. gypsum wallboard. The total thickness of the wall was approximately 7 in. This wall also represents a typical flat panel ICF wall where the exterior insulation was removed.

* "Partly grouted uninsulated cells" means that some CMU cells were grouted, while others were empty (did not contain insulation or grout). Grouted cells typically contain reinforcing steel. The ratio of grouted to non-grouted cells is defined in ASHRAE Standard 90.1-1999.[1]

The cast in place concrete wall with exterior insulation consisted of a 4-in. thick normal-density concrete wall with 2 in. of expanded polystyrene board insulation. Exterior insulation was held in place by integral plastic ties. Plywood or OSB sheathing was applied to the exterior of the polystyrene to act as a nailing surface for the aluminum or vinyl siding. The interior surface was plastered with ¼ in. of cement plaster. The total wall thickness was approximately 7¼ in.

The engineered sandwich panel wall consisted of 2 layers of 3-in. thick normal weight concrete separated by 2 in. thick extruded polystyrene board insulation. Integral plastic ties were used to connect the concrete layers. The exterior surface had ½ in. of portland cement stucco. The interior surface was plastered with ¼ in. of cement plaster. The total wall thickness was approximately 8¾ in.

The typical sandwich panel wall consisted of 2 in. of normal-density architectural concrete, 2 in. of extruded polystyrene board insulation, and 8 in. of normal-weight prestressed concrete. Concrete layers were connected with ⅛-in. diameter metal ties spaced at 24 in. centers. The 2-in. thick architectural concrete layer was on the exterior side of the wall. The interior surface was plastered with ¼ in. of cement plaster. The total wall thickness was approximately 12¼ in.

U-factors for mass walls were either calculated or measured by CTL or other reputable organizations, or were taken from third-party literature. U-factors and thermal mass of all mass walls, except the CMU walls, are presented in Table 6. Table 7 describes the CMU walls for each of the 25 locations.

Table 6. Description of mass walls

Wall type	U-factor, Btu/hr·Ft.^{2}·°F	Heat capacity, Btu/lb·°F	Description of thermal mass
Flat-panel ICF	0.046	18.5	Isolated
Waffle-grid ICF	0.075	12.8	Isolated
Engineered sandwich panel	0.089	18.1	Interior and exterior
Interior insulation	0.089	18.0	Exterior
Typical sandwich panel	0.090	29.0	Interior (mainly)
Exterior insulation	0.101	12.2	Interior
AAC*	0.120	5.5	Distributed or integral
CMU	See Table 7		Exterior

* Due to the 8 in. thickness and low density of the AAC, the heat capacity of the AAC wall does not meet IECC definition of a mass wall.

The common wall between the house and the garage and all exterior garage walls except the front wall (with the overhead doors) were assumed to be identical to that of the exterior walls of the house. The wall with the overhead doors was assumed to be a low-mass light-colored wall with a U-factor of 0.50 Btu/hr·Ft.^{2}·°F. This is representative of a wall with typical insulated steel overhead garage doors.

Table 7. Actual Assembly U-factors of the CMU Walls

Location	U-Factor, Btu/hr·Ft.^{2}·°F	Components*
Albuquerque, NM	0.078	CMU with 2x4 studs and R-11 batts
Astoria, OR	0.078	CMU with 2x4 studs and R-11 batts
Atlanta, GA	0.078	CMU with 2x4 studs and R-11 batts
Baltimore, MD	0.078	CMU with 2x4 studs and R-11 batts
Boston, MA	0.078	CMU with 2x4 studs and R-11 batts
Boulder, CO	0.078	CMU with 2x4 studs and R-11 batts
Charlotte, NC	0.078	CMU with 2x4 studs and R-11 batts
Chicago, IL	0.073	CMU with 2x4 studs and R-13 batts
Dallas/Ft.. Worth, TX	0.078	CMU with 2x4 studs and R-11 batts
Fargo, ND	0.058	CMU with 2x6 studs and R-19 batts
Fresno, CA	0.078	CMU with 2x4 studs and R-11 batts
Halifax, NS	0.042	CMU with XPS and 2x4 studs with R-13 batts
Houston, TX	0.170	CMU with interior wood furring
Los Angeles, CA	0.170	CMU with interior wood furring
Memphis, TN	0.078	CMU with 2x4 studs and R-11 batts
Miami, FL	0.170	CMU with interior wood furring
Phoenix, AZ	0.170	CMU with interior wood furring
Quebec City, PQ	0.042	CMU with XPS and 2x4 studs with R-13 batts
San Francisco, CA	0.078	CMU with 2x4 studs and R-11 batts
Seattle/Tacoma, WA	0.078	CMU with 2x4 studs and R-11 batts
Springfield, IL	0.078	CMU with 2x4 studs and R-11 batts
Tampa, FL	0.170	CMU with interior wood furring
Toronto, ON	0.058	CMU with 2x6 studs and R-19 batts
Vancouver, BC	0.078	CMU with 2x4 studs and R-11 batts
Winnipeg, MT	0.058	CMU with 2x6 studs and R-19 batts

* Batts refer to fiberglass insulation. XPS is continuous extruded polystyrene board insulation attached to the CMU, between the CMU and the wood framing. The heat capacity of the CMU walls in Halifax and Quebec City is 18.3 Btu/lb·°F, and 18.2 Btu/lb·°F in all other locations.

Occupant Energy Use

Because occupant habits such as thermostat settings, appliance types and usage, hot water usage, and building envelope maintenance greatly affect the total annual energy use, occupant habits were assumed to be identical for all wall types in all locations.

Hot water was assumed to be provided by a typical natural gas fired hot water heater with a peak utilization of 2.5 gallons per minute. The hot water load profile was taken from ASHRAE Standard 90.2.[10] The HVAC system was assumed to consist of a forced air system with a medium-efficiency (90% AFUE) natural gas fired furnace and typical central air conditioner (12 SEER). Efficiencies of the HVAC system components were assumed to be identical for all exterior wall variations, in all locations.

The HVAC system was controlled by a typical residential thermostat located in the family room. The cooling set-point temperature was assumed to be 75°F. The heating set-point temperature was assumed to be 70°F. Daily temperature setbacks were not used.

Occupant energy consumption for uses other than heating and cooling were assumed to be 23.36 kilowatt-hours (kWh) per day. This value was calculated from ASHRAE Standard 90.2[10] and assumed the house had an electric clothes dryer and an electric stove. Energy costs were assumed to utilize 2000 average U.S. costs of $0.082 per kWh of electricity[2] and $0.786 per therm of natural gas[1].

Air infiltration rates of the living areas were based on ASHRAE Standard 62.[11] The air infiltration rates were identical for all variations and were 0.35 air changes per hour (ACH) in the living areas of the house and 2.5 ACH in the unconditioned attached garage. This assumption does not account for the inherent air-tightness of the mass walls, or air-leakage of the frame walls. If a house is tighter than 0.35 ACH, ASHRAE and many building envelope experts recommend that an air-to-air heat exchanger be installed. A family of four was assumed to live in the house.

RESULTS

With the exception of the exterior walls, for each location, all factors affecting the energy use were identical. Because the air infiltration of each wall system was assumed to be identical, the amount of insulation (U-factor), the thermal mass, and location of the mass within the wall were the only influences on the HVAC system and the associated heating and cooling energy use.

Because the design of the house, with windows concentrated on the front and back, is subject to orientation dependent solar effects, modeling was performed with the house rotated in each of the four cardinal (north, south, east, and west) orientations. Results were averaged to produce results free of orientation effects.

Heating and Cooling Energy

Because occupant habits such as hot water and appliance use were identical for houses with different walls and in all locations, the only factor affecting the total energy use was that of heating and cooling systems. It is important to note that few single-family houses have separate metering of the HVAC system. Results presented in this section do not consider energy for appliance use and hot water, and therefore are not compatible with the monthly consumer energy bills. Results also do not consider the inherent differences in air tightness of the mass and frame walls. These differences are considered in the sensitivity analyses.

HVAC energy consumption is presented in Table 8 in terms of annual operating cost for all wall types in all locations. Annual heating and cooling costs are highly climate dependent, ranging from $343 to $2,101 for wood frame walls. In general, locations with high heating and cooling costs are those with high cooling or heating degree-days.

Because all walls have different levels of insulation, both above and below code requirements, Table 9 presents costs savings based on heating and cooling costs associated with the code-matching wall. In this table, negative percentages mean that heating and cooling costs are greater than that of the house with the code-matching walls. Shaded cells represent locations where the walls are less insulated (have a greater U-factor) than the code-matching wall. As can be seen, many of the mass walls that are shaded have significant energy savings over that of the code-matching wall, even though the mass walls contain less insulation. This demonstrates the effects of thermal mass. Several of the mass wall houses cost more to heat and cool in cold climates of the U.S. and Canada. This is because the walls are significantly under-insulated in comparison to the code requirements, as indicated by the shaded cells of Table 9. It is likely that the AAC would have exterior insulation and the non-ICF mass walls would have extra insulation in these climates.

Total Energy Use

Total annual energy use is the heating and cooling energy, energy associated with hot water, and occupant energy. Total energy use is compatible with consumer energy bills; however, therms and kWh presented in this report should be compared rather than costs, due to service charge differences in energy prices. It should be noted that energy use associated with occupant habits such as frequency and length of showering, frequency of dishwasher usage and clothes laundering, and thermostat set-points, as well as the number, age, and efficiency of appliances, is highly variable.

For all houses with different exterior walls, in all locations, occupant energy was 23.36 kWh per day, or approximately 8,526 kWh annually. This represents 34 to 97% of the total electricity usage, depending on the location and exterior wall.

Table 8. Annual HVAC Energy Costs, U.S. Dollars*

Location	Code matching	Wood frame	Steel frame	AAC	CMU	ICF		Sandwich panel		Cast in place	
						Flat-panel	Waffle-grid	Typical	Engineered	Interior insulation	Exterior insulation
Albuquerque, NM	1241	1110	1183	1115	1014	928	991	950	966	1042	1011
Astoria, OR	1183	1103	1177	1118	1008	920	983	950	968	1037	1015
Atlanta, GA	1120	993	1055	1011	922	843	900	875	888	947	924
Baltimore, MD	1368	1253	1330	1296	1180	1078	1153	1131	1152	1211	1196
Boston, MA	1437	1380	1412	1435	1309	1195	1278	1262	1284	1345	1325
Boulder, CO	1378	1309	1343	1314	1188	1088	1163	1121	1139	1221	1193
Charlotte, NC	1128	1014	1078	1021	935	859	919	899	908	960	944
Chicago, IL	1511	1498	1484	1578	1422	1310	1404	1387	1408	1476	1458
Fargo, ND	1904	1854	1886	2050	1790	1714	1835	1827	1847	1922	1909
Dallas/Ft. Worth, TX	1294	1103	1167	1107	1020	941	999	975	989	1046	1024
Fresno, CA	1239	1072	1142	1062	974	893	950	917	932	1000	975
Halifax, NS	1476	1453	1442	1704	1403	1393	1497	1495	1519	1576	1575
Houston, TX	1179	930	985	921	996	786	831	801	817	877	845
Los Angeles, CA	559	406	440	349	367	299	312	271	278	327	301
Memphis, TN	1272	1142	1209	1163	1067	982	1044	1031	1043	1095	1079
Miami, FL	1223	901	949	882	950	779	814	787	799	851	820
Phoenix, AZ	1693	1339	1420	1345	1455	1144	1212	1185	1201	1271	1241
Quebec City, PQ	1784	1770	1756	2074	1723	1718	1847	1874	1891	1927	1952
San Francisco, CA	406	343	372	286	263	249	259	218	225	269	246
Seattle/Tacoma, WA	1260	1164	1241	1195	1079	979	1046	1017	1046	1109	1090
Springfield, IL	1545	1487	1522	1531	1400	1279	1369	1354	1369	1438	1416
Tampa, FL	1109	812	861	788	853	682	717	683	697	755	720
Toronto, ON	1647	1626	1623	1788	1558	1494	1602	1590	1608	1675	1663
Vancouver, BC	1263	1215	1246	1249	1118	1024	1095	1075	1097	1148	1145
Winnipeg, MT	2112	2101	2098	2327	2022	1944	2080	2070	2087	2172	2152

* The wood frame, steel frame, and CMU walls are described in Tables 4, 5, and 7. Mass walls are described in Table 6 and the text.

Table 9. Heating and Cooling Cost Savings Based on the Code-Matching Wall, Percent*

Location	Code matching	Wood frame	Steel frame	AAC	CMU	ICF		Sandwich panel		Cast in place	
						Flat-panel	Waffle-grid	Typical	Engineered	Interior insulation	Exterior insulation
Albuquerque, NM	0%	11%	5%	10%	18%	25%	20%	23%	22%	16%	19%
Astoria, OR	0%	7%	0%	6%	15%	22%	17%	20%	18%	12%	14%
Atlanta, GA	0%	11%	6%	10%	18%	25%	20%	22%	21%	16%	18%
Baltimore, MD	0%	8%	3%	5%	14%	21%	16%	17%	16%	11%	13%
Boston, MA	0%	4%	2%	0%	9%	17%	11%	12%	11%	6%	8%
Boulder, CO	0%	5%	3%	5%	14%	21%	16%	19%	17%	11%	13%
Charlotte, NC	0%	10%	4%	9%	17%	24%	18%	20%	19%	15%	16%
Chicago, IL	0%	1%	2%	-4%	6%	13%	7%	8%	7%	2%	4%
Fargo, ND	0%	3%	1%	-8%	6%	10%	4%	4%	3%	-1%	0%
Dallas/Ft.. Worth, TX	0%	15%	10%	14%	21%	27%	23%	25%	24%	19%	21%
Fresno, CA	0%	13%	8%	14%	21%	28%	23%	26%	25%	19%	21%
Halifax, NS	0%	2%	2%	-15%	5%	6%	-1%	-1%	-3%	-7%	-7%
Houston, TX	0%	21%	16%	22%	15%	33%	29%	32%	31%	26%	28%
Los Angeles, CA	0%	27%	21%	38%	34%	47%	44%	52%	50%	42%	46%
Memphis, TN	0%	10%	5%	9%	16%	23%	18%	19%	18%	14%	15%
Miami, FL	0%	26%	22%	28%	22%	36%	33%	36%	35%	30%	33%
Phoenix, AZ	0%	21%	16%	21%	14%	32%	28%	30%	29%	25%	27%
Quebec City, PQ	0%	1%	2%	-16%	3%	4%	-3%	-5%	-6%	-8%	-9%
San Francisco, CA	0%	16%	8%	30%	35%	39%	36%	46%	45%	34%	39%
Seattle/Tacoma, WA	0%	8%	2%	5%	14%	22%	17%	19%	17%	12%	14%
Springfield, IL	0%	4%	1%	1%	9%	17%	11%	12%	11%	7%	8%
Tampa, FL	0%	27%	22%	29%	23%	38%	35%	38%	37%	32%	35%
Toronto, ON	0%	1%	1%	-9%	5%	9%	3%	3%	2%	-2%	-1%
Vancouver, BC	0%	4%	1%	1%	11%	19%	13%	15%	13%	9%	9%
Winnipeg, MT	0%	1%	1%	-10%	4%	8%	2%	2%	1%	-3%	-2%

* Percent change from the code-matching wall. Negative percentages mean that more energy is needed for heating and cooling. The wood frame, steel frame, and CMU walls are described in Tables 4, 5, and 7. Mass walls are described in Table 6 and the text.

The analysis software indicated that the energy associated with hot water was different in each of the 25 locations, ranging from 346 therms per year in warm climates to 671 therms per year in cold climates. The average energy associated with hot water was 507 therms per year. Given the variability in actual use of hot water by a typical family, the use of the average value is considered to be adequate for purposes of comparison.

The total annual cost of occupant energy and hot water, using the average U.S. energy costs, is approximately $1,098. Comparison of the heating and cooling energy cost to the total energy cost reveals that the heating and cooling costs represent 17 to 65% of the total energy costs, depending on the location and type of exterior wall.

HVAC System Size

HVAC system capacities were automatically sized by the energy analysis software and are presented in Tables 10 and 11. These system capacities represent the minimum (plus 10%) furnace and air conditioner sizes to adequately heat and cool the houses with the different exterior walls. In some cases, particularly that of Phoenix, the HVAC system is size is larger than expected. Phoenix has large daily temperature swings. The HVAC system was sized to keep the indoor temperature within a few degrees of the thermostat set point. This resulted in HVAC systems with large heating and cooling capacities.

It is important to note that natural gas fired forced air furnaces are typically available in 10 to 20 kBtu/hr capacity increments and high-efficiency central air conditioners are typically available in 6 to 12 kBtu/hr (½ to 1 ton) capacities. Because HVAC systems are typically oversized (the installed capacity is the required capacity rounded to the next larger available capacity), actual installed system capacity savings may be reduced.

Table 12 presents the HVAC system capacities as a function of percent reduction from that of the code-matching wall. Again, it is important to note that the only difference between house variations for a given location is the exterior wall assembly. All other influences on heating and cooling energy, including the air leakage, were identical. Properties of the exterior walls greatly influenced the indoor temperatures, and the need for heating and cooling.

Results presented in Table 12 show that in a vast majority of the cases considered, the HVAC system in houses with mass walls could be downsized from that of the code-matching and frame walls, even when the mass walls had a higher U-factor (less insulation). This clearly shows that thermal mass moderates temperatures and peak loads, resulting in reduced heating and cooling energy and reduced HVAC system capacities.

Table 10. Calculated Furnace Size, kBtu/hr*

Location	Code matching	Wood frame	Steel frame	AAC	CMU	ICF		Sandwich panel		Cast in place	
						Flat-panel	Waffle-grid	Typical	Engineered	Interior insulation	Exterior insulation
Albuquerque, NM	105	96	100	91	86	82	84	78	80	88	83
Astoria, OR	76	72	75	62	60	57	57	49	52	61	54
Atlanta, GA	95	86	90	82	77	71	74	70	72	79	75
Baltimore, MD	100	93	98	89	85	79	82	77	79	86	82
Boston, MA	88	85	87	81	77	73	74	70	72	79	74
Boulder, CO	96	92	94	84	80	75	77	70	72	81	76
Charlotte, NC	93	85	89	80	75	70	73	69	71	77	73
Chicago, IL	90	89	88	86	81	76	78	74	76	83	79
Fargo, ND	92	90	91	92	84	80	83	81	83	88	85
Dallas/Ft. Worth, TX	111	95	100	90	84	80	83	78	79	86	82
Fresno, CA	114	100	106	95	89	83	86	82	84	91	87
Halifax, NS	74	73	72	74	68	65	67	62	65	72	67
Houston, TX	108	87	92	81	85	73	75	70	72	79	75
Los Angeles, CA	91	72	76	64	65	56	57	51	53	61	56
Memphis, TN	97	87	92	82	78	73	75	72	73	79	75
Miami, FL	117	86	90	79	83	72	74	69	70	77	73
Phoenix, AZ	147	119	126	118	125	103	107	103	105	112	109
Quebec City, PQ	82	81	80	88	77	75	78	78	80	83	82
San Francisco, CA	84	75	79	67	64	60	61	56	58	65	60
Seattle/Tacoma, WA	95	89	93	80	76	70	71	63	68	77	71
Springfield, IL	97	94	96	89	85	80	82	78	79	87	82
Tampa, FL	113	84	89	78	82	70	72	67	69	76	71
Toronto, ON	82	81	80	79	74	71	73	69	70	77	73
Vancouver, BC	75	72	73	65	62	58	59	53	55	63	57
Winnipeg, MT	99	99	98	92	91	88	90	85	87	94	89

* The wood frame, steel frame, and CMU walls are described in Table No. 4, 5, and 7. Mass walls are described in Table 6 and the text.

Table 11. Calculated Air Conditioner Size, kBtu/hr

Location	Code matching	Wood frame	Steel frame	AAC	CMU	ICF		Sandwich panel		Cast in place	
						Flat-panel	Waffle-grid	Typical	Engineered	Interior insulation	Exterior insulation
Albuquerque, NM	53	49	51	46	44	41	42	39	41	45	42
Astoria, OR	37	34	36	29	29	27	27	24	25	29	26
Atlanta, GA	50	46	48	44	41	38	40	38	39	42	40
Baltimore, MD	52	48	51	47	44	41	42	40	41	45	43
Boston, MA	44	43	44	41	39	37	38	35	37	40	38
Boulder, CO	49	47	48	42	40	38	39	35	37	41	38
Charlotte, NC	48	44	46	41	39	36	38	36	37	40	38
Chicago, IL	46	46	45	45	42	39	41	39	40	43	41
Fargo, ND	48	47	47	48	44	42	43	42	43	46	44
Dallas/Ft. Worth, TX	57	50	52	47	45	42	44	42	43	46	44
Fresno, CA	62	55	58	53	49	45	47	45	46	50	48
Halifax, NS	36	36	35	37	33	32	32	30	32	35	33
Houston, TX	56	45	47	42	44	38	39	37	37	41	39
Los Angeles, CA	45	35	37	30	31	27	28	25	26	30	27
Memphis, TN	50	45	47	43	41	38	39	38	38	41	39
Miami, FL	58	43	45	41	43	37	38	36	36	39	38
Phoenix, AZ	85	71	74	70	74	61	63	61	62	66	64
Quebec City, PQ	39	39	39	43	37	36	38	38	39	40	40
San Francisco, CA	41	36	38	33	31	29	30	27	28	32	29
Seattle/Tacoma, WA	49	46	48	41	39	36	36	33	35	40	36
Springfield, IL	50	49	50	46	44	42	43	41	42	45	42
Tampa, FL	57	43	46	40	42	37	37	35	36	39	37
Toronto, ON	41	40	40	40	37	36	37	35	36	39	37
Vancouver, BC	35	34	35	31	29	28	28	25	26	30	27
Winnipeg, MT	50	50	49	47	46	45	46	43	44	48	45

* The wood frame, steel frame, and CMU walls are described in Table No. 4, 5, and 7. Mass walls are described in Table 6 and the text. Central air conditioners are commonly sold in ½ ton increments of cooling capacity (½ ton = 6 kBtu/hr).

Table 12. Average Furnace and Air Conditioner Size Reduction Based on the Code-Matching Wall, Percent*

Location	Code matching	Wood frame	Steel frame	AAC	CMU	ICF		Sandwich panel		Cast in place	
						Flat-panel	Waffle-grid	Typical	Engineered	Interior insulation	Exterior insulation
Albuquerque, NM	0%	8%	4%	13%	18%	22%	20%	26%	24%	16%	21%
Astoria, OR	0%	6%	1%	19%	21%	25%	26%	36%	32%	20%	29%
Atlanta, GA	0%	9%	5%	13%	18%	24%	21%	25%	23%	17%	20%
Baltimore, MD	0%	7%	3%	11%	15%	21%	19%	24%	21%	14%	18%
Boston, MA	0%	3%	1%	7%	12%	17%	15%	20%	18%	10%	16%
Boulder, CO	0%	5%	3%	13%	18%	22%	20%	28%	25%	16%	22%
Charlotte, NC	0%	9%	4%	14%	19%	24%	21%	25%	23%	17%	21%
Chicago, IL	0%	1%	2%	4%	10%	15%	12%	17%	15%	7%	12%
Fargo, ND	0%	2%	1%	0%	8%	12%	9%	12%	10%	4%	8%
Dallas/Ft. Worth, TX	0%	14%	9%	18%	23%	28%	24%	28%	27%	21%	24%
Fresno, CA	0%	12%	7%	16%	21%	27%	24%	27%	26%	19%	23%
Halifax, NS	0%	2%	3%	-1%	9%	13%	10%	16%	12%	4%	9%
Houston, TX	0%	20%	15%	25%	21%	32%	30%	35%	33%	27%	31%
Los Angeles, CA	0%	22%	17%	32%	30%	39%	38%	45%	43%	34%	39%
Memphis, TN	0%	9%	5%	14%	19%	24%	21%	25%	24%	17%	22%
Miami, FL	0%	26%	22%	31%	28%	37%	36%	40%	39%	33%	36%
Phoenix, AZ	0%	18%	14%	19%	14%	30%	27%	29%	28%	23%	25%
Quebec City, PQ	0%	1%	2%	-7%	6%	8%	4%	4%	2%	-1%	-1%
San Francisco, CA	0%	11%	6%	20%	24%	28%	27%	33%	31%	22%	28%
Seattle/Tacoma, WA	0%	6%	2%	16%	20%	26%	25%	33%	29%	19%	26%
Springfield, IL	0%	3%	1%	8%	12%	18%	15%	20%	18%	11%	16%
Tampa, FL	0%	25%	21%	30%	27%	37%	35%	40%	38%	32%	36%
Toronto, ON	0%	1%	2%	3%	10%	13%	11%	16%	13%	6%	10%
Vancouver, BC	0%	4%	2%	13%	18%	22%	21%	29%	26%	16%	23%
Winnipeg, MT	0%	1%	2%	8%	8%	11%	9%	14%	13%	5%	10%

* The wood frame, steel frame, and CMU walls are described in Table No. 4, 5, and 7. Mass walls are described in Table 6 and the text. Percent change from the code-matching wall. Negative percentages mean the furnace and air conditioner must be of greater capacity.

Sensitivity Analyses

The sensitivity of the heating and cooling energy use to changes in the building orientation and air infiltration was briefly explored.

Building Orientation. As previously stated, because of the concentration of windows on the front and back of the house, the orientation of the house greatly influenced the heating and cooling loads.

Table 13 shows the effects of orientation on the heating and cooling costs, total energy costs, and capacity of the HVAC system. Results are similar regardless of the type of exterior wall and show that the effect of orientation is significant. In some cases, the effect of orientation on heating and cooling costs is more significant that the type of exterior wall. Therefore, if identical houses are not compared, results can be misleading. This is illustrated by comparing the variability of heating and cooling costs for Albuquerque. Tables 8 and 13 indicate that annual heating and cooling costs range from $977 to $1243 for a wood frame house, and range from $817 to $1039 for a flat-panel ICF house. Although Table 8, which presents the heating and cooling energy of the houses without orientation effects, indicates that the wood-frame house costs approximately 20% more to heat and cool, comparing the extremes of the cost ranges shows that the wood frame house costs from 52% more to 6% less to heat and cool. Results do not consider the effect of air infiltration.

Air Infiltration (Leakage). The effect of natural air infiltration on the heating and cooling energy is multifaceted. Air leaks into or out of the building envelope through gaps between building materials. The amount of leakage is dependent on the size of the gaps and pressure differences due to building height, indoor-outdoor temperature differences, and wind pressure. Air leakage increases as pressure differences increase.

Stack pressure or the "chimney effect" causes a slight positive pressure at the ceiling, and a negative pressure at the floor level (for a multi-story house, the ceiling is the ceiling of the top level, and the floor is the floor of the lowest above-grade level). Pressures are increased as the ceiling height increases, and for multistory houses. The net result is that outdoor air is drawn into the conditioned space at the floor, and conditioned air is pushed out of the conditioned space at the ceiling.

Temperature differences between the indoor conditioned air and outdoor air increase pressure because the density of air decreases with increasing temperatures. Air leakage rates increase as temperature differences increase.

Wind pressures can greatly increase the air infiltration and resulting energy heating and cooling use. Information presented in ASHRAE[12] indicates that for a two-story wood-frame house with 8 Ft. ceilings, a 20 mph wind can easily double the air infiltration. Wind-induced air infiltration is dependent on the dimensions of the house, the type and locations of air leakage, the wind speed, local terrain features, and the difference between the indoor and outdoor temperatures.

Air leakage into wall cavities also affects the U-factor of frame walls with batt insulation. Although exterior air barriers are installed to minimize air movement through the insulation, joints and wall penetrations are often not sealed. Air movement can often be felt though wall outlets or below the baseboard on exterior frame walls.

Table 13. Variability* in Results due to Orientation Effects, %

Location	Heating and cooling energy costs	Total energy costs**	HVAC system size
Albuquerque, NM	12%	6%	14%
Astoria, OR	9%	4%	12%
Atlanta, GA	7%	3%	8%
Baltimore, MD	9%	5%	10%
Boston, MA	8%	5%	10%
Boulder, CO	11%	6%	11%
Charlotte, NC	8%	4%	9%
Chicago, IL	5%	3%	9%
Fargo, ND	4%	2%	7%
Dallas/Ft. Worth, TX	7%	3%	8%
Fresno, CA	8%	4%	8%
Halifax, NS	4%	2%	8%
Houston, TX	6%	3%	9%
Los Angeles, CA	14%	3%	7%
Memphis, TN	7%	4%	9%
Miami, FL	5%	2%	6%
Phoenix, AZ	7%	4%	8%
Quebec City, PQ	4%	2%	3%
San Francisco, CA	15%	3%	10%
Seattle/Tacoma, WA	10%	5%	13%
Springfield, IL	7%	4%	6%
Tampa, FL	7%	3%	7%
Toronto, ON	3%	2%	5%
Vancouver, BC	6%	3%	15%
Winnipeg, MT	5%	3%	8%

* Variability in terms of percent above or below the results in Tables 8, 10, and 11.
** Total annual energy use is the heating and cooling energy, energy associated with hot water, and occupant energy.

For the previous analyses presented in this report, an air infiltration of 0.35 ACH was used. This is the minimum air infiltration recommended by ASHRAE[11]. If a house is tighter and has an air infiltration of less than 0.35 ACH, mechanical ventilation with outdoor air is recommended. In reality, mechanical ventilation is rarely installed unless mandated by local building codes.

ASHRAE[12] indicates natural air infiltration rates for typical U.S. housing average approximately 0.5 ACH, with a range of 0.05 to 1.63 ACH. Other sources[13] indicate that a "tight" U.S. house has a natural air infiltration rate of 0.16 ACH, a "typical" house has an air infiltration rate of 0.78 ACH, and a "leaky" U.S. house has a natural air infiltration rate of 1.6 ACH. No data is presented in either reference regarding the type of house or construction materials; however, it is assumed that this is representative of wood-frame houses because a vast majority of the U.S. housing is frame construction.[9]

Owing to their monolithic construction, houses with mass walls should have air leakage rates that are significantly lower than that of houses with frame walls[14]. ASHRAE[12] indicates that walls contribute from 18 to 50% of the air leakage into a typical wood frame house. Air leakage paths do not exist at sill plates, or through the wall cavity via plumbing and electrical penetrations in a house with monolithic mass walls. A 1995 study[15] confirmed that houses with mass walls typically have lower air infiltration rates. Natural air infiltration rates of ICF houses averaged approximately 0.15 ACH, with a range of 0.05 to 0.26 ACH.

The effect of air leakage into the conditioned living space was explored by varying the natural air infiltration of the houses from 0.1 to 1.0 air changes per hour (ACH) using the energy analysis software. The effect of air infiltration on heating and cooling costs was found to be a linear relationship, as shown in Fig. 13 for houses with all 11 exterior wall types in Chicago. Assuming average natural air infiltration rates of 0.15 and 0.78 ACH for mass and frame walls, respectively, annual heating and cooling energy costs for houses with mass walls decrease by 4%, while costs for houses with frame walls increase by 9%. Table 14 presents the equations that relate air infiltration rates to heating and cooling costs for houses in Boulder, Chicago, and Houston.

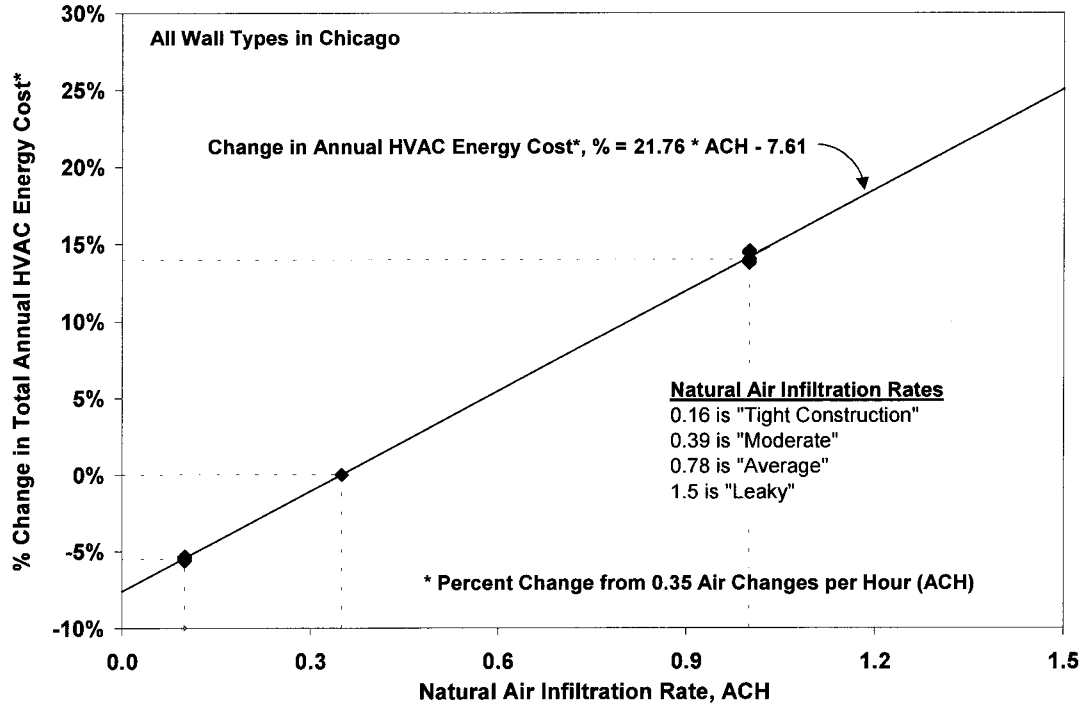


Figure 13. Effect of natural air infiltration rate on HVAC energy costs in Chicago.

Table 14. Effect of Natural Air Infiltration (ACH) on Heating and Cooling Costs

Location	Annual energy cost versus air infiltration equation coefficients*		Annual heating and cooling (HVAC) energy costs,** percent increase or decrease				
	Slope	Intercept	0.16 ACH	0.35 ACH	0.39 ACH	0.78 ACH	1.5 ACH
Boulder	16.30	-5.63	-3%	0%	1%	7%	19%
Chicago	21.76	-7.61	-4%	0%	1%	9%	25%
Houston	19.32	-6.76	-4%	0%	1%	8%	22%

* Change in Annual HVAC Energy Cost (%) = **Slope** * ACH + **Intercept**
** Change in annual heating and cooling costs from those presented in Table 8 for 0.35 ACH.

Comparisons with Highly Insulated Wood Frame Walls. To further illustrate the savings in heating and cooling energy of houses with mass walls over that of houses with wood frame walls, additional modeling was performed. Houses with mass walls were compared to houses with one of five additional frame walls with increased insulation. Mass walls were identical to those previously described. Again, all air infiltration rates and occupant habits were identical.

The additional frame walls were constructed with wood studs at 16 in. centers, ½ in. OSB or plywood sheathing and aluminum or vinyl siding on the exterior, and ½ in. gypsum wallboard on the interior. Frame walls consisted of 2x4 studs with R-11 fiberglass batt insulation, 2x6 studs with R-19 fiberglass batt insulation, 2x8 studs with R-25 fiberglass batt insulation, 2x10 studs with R-30 fiberglass batt insulation, and 2x12 studs with R-38 fiberglass batt insulation. Obviously, construction of walls with 2x8, 2x10, or 2x12 lumber are not economically justifiable; however, these comparisons are made to illustrate the relative energy efficiencies of the mass walls.

Tables 15, 16, and 17 present the comparisons for Chicago, Boulder, and Houston. Chicago represents a typical cool climate, Boulder represents a cool climate with large daily temperature swings where thermal mass works well, and Houston represents a typical hot climate. Data in the tables are sorted for walls with lowest to highest annual heating and cooling costs. As can be seen, the flat-panel ICF wall has a performance essentially equal to or better than the 2x12 wood frame wall with R-38 insulation in all three locations. In Boulder, exterior insulated and sandwich panel walls performed better (had a lower annual heating and cooling energy cost) than the 2x6 walls with R-19 insulation. In Houston, all non-block walls (CMU and AAC) outperformed the 2x6 walls. In Chicago, only the ICF and sandwich panel walls outperformed the 2x6 walls.

Table 15. Comparison of Annual Heating and Cooling Energy in Chicago

Wall type	Therms	kWh	Cost*, U.S. dollars	
			Equal ACH**	Typical ACH***
2x12 (R-38) Wood frame	1368	2770	1302	1419
Flat-Panel ICF	1388	2675	1310	1258
2x10 (R-30) Wood frame	1400	2828	1332	1452
2x8 (R-25) Wood frame	1432	2886	1362	1485
Typical sandwich panel	1494	2592	1387	1332
Waffle-grid ICF	1493	2805	1404	1348
Engineered sandwich panel	1513	2671	1408	1352
2x6 (R-19) Wood frame	1486	2983	1413	1540
CMU	1508	2887	1422	1365
Exterior insulation	1568	2751	1458	1400
Interior insulation	1567	2984	1476	1417
Steel frame	1564	3107	1484	1647
Code-matching	1588	3209	1511	1618
2x4 (R-11) Wood frame	1623	3232	1541	1680
AAC	1688	3068	1578	1515

* Based on average U.S. energy rates described above.
** Air infiltration rate of 0.35 ACH. Ranking is performed on this column.
*** Air infiltration rate of 0.15 ACH for the mass walls, and 0.78 for the frame walls. Cost adjustment based on Table 14.

Table 16. Comparison of Annual HVAC Energy Use in Boulder

Wall type	Therms	kWh	Cost*, U.S. dollars	
			Equal ACH**	Typical ACH***
Flat-panel ICF	1138	2366	1088	1055
2x12 (R-38) Wood frame	1141	2531	1104	1181
Typical sandwich panel	1199	2171	1120	1086
2x10 (R-30) Wood frame	1170	2594	1132	1211
Engineered sandwich panel	1217	2229	1139	1105
2x8 (R-25) Wood frame	1200	2658	1161	1242
Waffle-grid ICF	1223	2470	1164	1129
CMU	1245	2553	1188	1152
Exterior Insulation	1274	2341	1193	1157
2x6 (R-19) Wood frame	1250	2768	1209	1294
Interior insulation	1281	2621	1222	1185
AAC	1392	2681	1314	1275
2x4 (R-11) Wood frame	1376	3046	1331	1424
Steel frame	1388	3075	1343	1437
Code-matching	1419	3203	1378	1474

* Based on average U.S. energy rates described above.
** Air infiltration rate of 0.35 ACH. Ranking is performed on this column.
*** Air infiltration rate of 0.15 ACH for the mass walls, and 0.78 for the frame walls. Cost adjustment based on Table 14.

Table 17. Comparison of Annual HVAC Energy Use in Houston

Wall type	Therms	kWh	Cost*, U.S. dollars	
			Equal ACH**	Typical ACH***
Flat-panel ICF	366	6076	786	755
Typical sandwich panel	378	6154	802	770
2x12 (R-38) Wood frame	377	6175	803	867
Engineered sandwich panel	387	6251	817	784
2x10 (R-30) Wood frame	386	6292	819	885
Waffle-grid ICF	392	6383	832	799
2x8 (R-25) Wood frame	396	6418	838	905
Exterior insulation	407	6409	845	811
Interior insulation	412	6739	876	841
2x6 (R-19) Wood frame	421	6758	885	956
AAC	446	6963	922	885
2x4 (R-11) Wood frame	453	7165	944	1020
Steel frame	475	7459	985	1064
CMU	477	7579	996	956
Code-matching	573	8878	1178	1272

* Based on average U.S. energy rates described above.
** Air infiltration rate of 0.35 ACH. Ranking is performed on this column.
*** Air infiltration rate of 0.15 ACH for the mass walls, and 0.78 for the frame walls. Cost adjustment based on Table 14.

SUMMARY AND CONCLUSIONS

Energy consumption was modeled for a typical 2,450-square-foot single-family house in 25 locations across the United States and Canada to compare the heating and cooling energy use due to the use of 11 different types of exterior walls. Modeling was performed using energy simulation software that uses the DOE 2.1-E calculation engine so that hourly energy usage and peak demand are accurately simulated and evaluated over a one year period using average annual weather data.

In all locations, building components such as roofs, walls, and windows were selected or insulated to meet or exceed the minimum levels required in the 2000 International Energy Conservation Code (IECC) or the 1997 Model National Energy Code of Canada for Houses (MNECH) using standard construction materials.

Exterior walls included a conventional wood frame wall, a steel frame wall, an autoclaved aerated concrete (AAC) block wall, a concrete masonry unit (CMU) wall, two types of insulating concrete form (ICF) walls, and two cast in place concrete walls with interior or exterior insulation, and two sandwich panel walls with internal insulation.

In some locations due to the use of standard construction-grade materials, some frame and CMU walls were over-insulated. For example, frame walls were assumed to be insulated with fiberglass batt insulation. If the energy codes required the wall to be insulated with the equivalent of R-7 fiberglass batts, R-11 fiberglass batts were used because R-7 batts are not commonly available. The resulting wall was over-insulated in comparison to the energy codes. Because mass wall variations were identical in all locations, some mass walls were over-insulated in some locations, while in other locations some mass walls were under-insulated. For example, the same ICF wall was used in both Miami and Halifax. In Miami, the ICF greatly exceeds the required minimum U-factor, while in Halifax, the ICF does not quite meet the energy code requirements. For purposes of comparison, a fictitious non-mass exterior wall that exactly met prescribed minimum energy code requirements was also included.

Modeling was performed so that the only differences for a given location were the exterior wall type and the capacity of the HVAC system. The HVAC system capacity was automatically sized to maintain the thermostat settings by the analysis software.

Analyses showed that energy for occupant uses and hot water was essentially identical for all locations, and that heating and cooling energy accounted for 17 to 65% of the total annual energy cost, depending on the location.

Due to the thermal mass of the concrete walls, houses with concrete walls had lower heating and cooling costs than houses with frame and code-matching walls, except for locations where the concrete walls were extremely under-insulated.

Houses with mass walls also showed additional savings resulting from a reduction in the required heating and cooling system capacity. Houses with mass walls required a smaller heating and cooling system than code-matching or frame walls, except for locations were the concrete walls were extremely under-insulated.

Sensitivity analyses were performed to determine the effect of building orientation and air leakage into the conditioned space. The effects of orientation were found to be significant. An example comparing houses with wood frame and flat-panel ICF walls in Albuquerque showed that if orientations are not identical, heating and cooling costs ranged from 52% more for the wood frame house to 6% more for the ICF house. A comparison of the same houses with orientation effects averaged showed a 20% cost savings for the ICF house.

Effects of air leakage into frame walls and conditioned spaces were discussed. Correction factors for air leakage into conditioned spaces were developed for houses in three of the 25 locations. A comparison using average air leakage rates into two identical houses in Chicago, one with mass walls with an air leakage rate of 0.15 ACH and one with frame walls and an air leakage rate of 0.78 ACH, showed a 4% additional saving for heating and cooling energy for the ICF house, and a 9% increase in heating and cooling energy costs for the wood-frame house. These energy savings do not account for wind pressures or airflow through insulation of frame walls and the resulting decrease in the U-factor of the wall.

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APPENDIX A – ASHRAE CLIMATE ZONES FOR U.S. AND CANADIAN LOCATIONS[3]

This appendix is used in conjunction with Table 1 to extrapolate results presented in the test for locations throughout the U.S. and Canada. For example, to compare the relative performance of various exterior walls in Auburn, AL, utilize this appendix to determine the *ASHRAE Climate Zone*. From the information below, Auburn, AL is in ASHRAE Climate Zone No. 8. Table 1 indicates that Dallas and Fort Worth, TX are also in ASHRAE Climate Zone No. 8. Therefore, the relative performance of walls in Auburn, AL, should be similar to that of identical walls in Dallas, TX.

Alabama (AL)

Alexander City	11	Huntsville	11
Anniston	11	Mobile	6
Auburn	8	Montgomery	8
Birmingham	11	Selma	8
Dothan	6	Talladega	11
Gadsden	11	Tuscaloosa	8

Alaska (AK)

Anchorage	22	Juneau	20
Barrow	26	Kodiak	20
Barrow	26	Nome	24
Fairbanks	24		

Arizona (AZ)

Douglas	11	Prescott	14
Flagstaff	18	Tucson	6
Kingman	11	Winslow	13
Nogales	11	Yuma	5
Phoenix	5		

Arkansas (AR)

Blytheville	13	Jonesboro	11
Camden	11	Little Rock	11
Fayetteville	13	Pine Bluff	10
Ft. Smith	11	Texarkana	8
Hot Springs	11		

California (CA)

Bakersfield	8	Petaluma	12
Blythe	5	Pomona	7
Burbank	6	Redding	11
Chico	11	Redlands	8
Crescent City	15	Richmond	9
El Centro	5	Riverside	9

California (CA) Continued

Eureka City	15	Sacramento	11
Fairfield	9	Salinas	12
Fresno	9	San Bernardino	8
Laguna Beach	9	San Diego	7
Livermore	11	San Francisco	12
Lompoc	9	San Jose	9
Long Beach	7	San Luis	9
Los Angeles	7	Santa Ana	6
Merced	9	Santa Barbara	9
Monterey	12	Santa Cruz	12
Napa	12	Santa Maria	12
Needles	5	Santa Monica	9
Oakland	9	Santa Paula	9
Oceanside	9	Santa Rosa	12
Ontario	6	Stockton	11
Oxnard	9	Ukiah	11
Palm Springs	5	Visalia	9
Palmdale	11	Yreka	14
Pasadena	6		

Colorado (CO)

Alamosa	20	Grand Junction	16
Boulder	17	Greeley	17
Colorado Sprgs	17	La Junta	13
Denver	17	Pueblo	17
Durango	17	Sterling	17
Ft. Collins	17	Trinidad	17

Connecticut (CT)

Bridgeport	17	Norwalk	17
Hartford	17	Norwich	17

Delaware (DE)

Dover	13	Wilmington	14

Florida (FL)

Belle Glade	3	Ocala	5
Daytona Beach	5	Orlando	3
Ft. Lauderdale	2	Panama City	6
Ft. Myers	3	Pensacola	6
Ft. Pierce	3	St Augustine	5
Gainesville Mun	6	St Petersburg	3
Jacksonville	6	Tallahassee	6
Key West	2	Tampa	3
Lakeland	3	West Palm Beach	2
Miami	2		

Georgia (GA)

Albany	8	Dublin	8
Americus	8	Gainesville	11
Athens	11	La Grange	9
Atlanta	11	Macon	8
Augusta	8	Savannah	8
Brunswick	6	Valdosta	5
Columbus	8	Waycross	8
Dalton	11		

Hawaii (HI)

Hilo (Hawaii)	3	Kaneohe Mauka (Oahu)	3
Honolulu (Oahu)	2		

Idaho (ID)

Boise	17	Moscow	18
Burley	17	Mountain Home	17
Coeur D'Alene	17	Pocatello	17
Idaho Falls	19	Twin Falls	17
Lewiston	14		

Illinois (IL)

Aurora	17	Galesburg	17
Belleville	13	Moline	17
Carbondale	13	Mt. Vernon	13
Champaign	16	Peoria	17
Chicago	17	Quincy	17
Danville	17	Rantoul	17
Decatur	16	Rockford	17
Dixon	17	Springfield	16
Freeport	17		

Indiana (IN)

Anderson	17	Lafayette	17
Bloomington	14	Marion	17
Columbus	17	Muncie	17
Evansville	13	Peru	17
Ft. Wayne	17	Richmond	17
Goshen	17	Shelbyville	17
Hobart	17	South Bend	17
Indianapolis	17	Terre Haute	17
Kokomo	17	Valparaiso	17

Iowa (IA)

Ames	17	Iowa City	17
Burlington	17	Keokuk	17
Cedar Rapids	17	Mason City	19
Clinton	17	Newton	17

Iowa (IA) Continued

Des Moines	17	Ottumwa	17
Dubuque	19	Sioux City	17
Ft. Dodge	19	Waterloo	19

Kansas (KS)

Atchison	13	Liberal	13
Chanute	13	Manhattan	13
Dodge City	13	Parsons	13
El Dorado	13	Russell	13
Garden City	13	Salina	13
Goodland	17	Topeka	13
Great Bend	13	Wichita	13
Hutchinson	13		

Kentucky (KY)

Ashland	14	Louisville	13
Bowling Green	13	Madisonville	13
Covington	14	Owensboro	13
Hopkinsville	13	Paducah	13
Lexington	13		

Louisiana (LA)

Alexandria	8	Minden	8
Baton Rouge	6	Monroe	8
Bogalusa	8	Natchitoches	8
Houma	6	New Orleans	6
Lafayette	6	Shreveport	8
Lake Charles	6		

Maine (ME)

Augusta	19	Millinocket	20
Bangor	19	Portland	19
Caribou	22	Waterville	19
Lewiston	19		

Maryland (MD)

Baltimore	13	Hagerstown	14
Cumberland	14	Salisbury	13

Massachusetts (MA)

All Locations	17

Michigan (MI)

Adrian	17	Lansing	17
Alpena	20	Marquette	20

Michigan (MI) Continued

Battle Creek	17	Mt. Pleasant	19
Benton Harbor	17	Muskegon	17
Detroit	17	Pontiac	17
Escanaba	20	Port Huron	17
Flint	17	Saginaw	17
Grand Rapids	17	Sault Ste. Marie	22
Holland	17	Traverse City	19
Jackson	17	Ypsilanti	17
Kalamazoo	17		

Minnesota (MN)

Albert Lea	19	Mankato	19
Alexandria	19	Minneapolis-St Paul	19
Bemidji	22	Rochester	19
Brainerd	21	St. Cloud	19
Duluth	22	Virginia	22
Faribault	19	Willmar	19
International Falls	22	Winona	19

Mississippi (MS)

Biloxi	6	Laurel	8
Clarksdale	11	McComb	8
Columbus	10	Meridian	8
Greenville	10	Natchez	8
Greenwood	8	Tupelo	11
Hattiesburg	8	Vicksburg	8
Jackson	8		

Missouri (MO)

Cape Girardeau	13	Kirksville	17
Columbia	13	Mexico	16
Farmington	13	Moberly	13
Hannibal	16	Poplar Bluff	13
Jefferson City	13	Rolla	13
Joplin	13	St. Joseph	16
Kansas City	13	St. Louis	13

Montana (MT)

Billings	17	Havre	19
Bozeman	22	Helena	19
Butte	22	Kalispell	20
Cut Bank	20	Lewistown	20
Glasgow	19	Livingston	19
Glendive	19	Miles City	19
Great Falls	19	Missoula	20

Nebraska (NE)

All Locations	17

Nevada (NV)

Carson City	17	Lovelock	17
Elko	17	Reno	17
Ely	20	Tonopah	17
Las Vegas	8	Winnemucca	17

New Hampshire (NH)

Berlin	20	Keene	17
Concord	19	Portsmouth	17

New Jersey (NJ)

Atlantic City	14	Newark	13
Long Branch	14		

New Mexico (NM)

Alamogordo	11	Grants	17
Albuquerque	13	Hobbs	11
Artesia	11	Raton	17
Carlsbad	10	Roswell	11
Clovis	13	Socorro	13
Farmington	17	Tucumcari	13
Gallup	17		

New York (NY)

Albany	17	Massena	19
Auburn	17	NYC	14
Batavia	17	Oswego	17
Binghamton	19	Plattsburgh	19
Buffalo	17	Poughkeepsie	17
Cortland	17	Rochester	17
Elmira	17	Rome	19
Geneva	17	Schenectady	17
Glens Falls	19	Syracuse	17
Gloversville	19	Utica	17
Ithaca	19	Watertown	19
Lockport	17		

North Carolina (NC)

Asheville	14	Henderson	13
Charlotte	11	Hickory	13
Durham	13	Jacksonville	8
Elizabeth City	11	Lumberton	11
Fayetteville	11	New Bern	11
Goldsboro	11	Raleigh-Durham	11
Greensboro	13	Rocky Mount	11
Greenville	11	Wilmington	8

North Dakota (ND)

Bismarck	19	Grand Forks	21
Devils Lake	21	Jamestown	21
Dickinson	19	Minot	21
Fargo	21		

Ohio (OH)

Cincinnati	13	All Other Locations	17
Portsmouth	14		

Oklahoma (OK)

Ada	11	Muskogee	11
Altus	10	Norman	11
Ardmore	10	Oklahoma City	13
Bartlesville	13	Ponca City	13
Chickasha	11	Seminole	10
Enid	13	Stillwater	13
Lawton	11	Tulsa	13
McAlester	11	Woodward	13

Oregon (OR)

Astoria	15	Klamath Falls	17
Baker	18	Medford	14
Baker	18	Pendleton	14
Bend	18	Portland	14
Corvallis	14	Roseburg	14
Eugene	14	Salem	14
Grants Pass	14		

Pennsylvania (PA)

Philadelphia	13	York	14
Harrisburg	14	All Other Locations	17
West Chester	14		

Rhode Island (RI)

All Locations	17

South Carolina (SC)

Anderson	11	Greenville	11
Charleston	8	Greenwood	11
Charleston City	8	Orangeburg	8
Columbia	8	Spartanburg	11
Florence	8	Sumter	8
Georgetown	8		

South Dakota (SD)

All Locations	19

Tennessee (TN)

Athens	13	Jackson	11
Bristol	13	Knoxville	13
Chattanooga	11	Memphis	10
Clarksville	13	Murfreesboro	13
Columbia	13	Nashville	13
Dyersburg	11	Tullahoma	13
Greeneville	13		

Texas (TX)

Abilene	8	Lamesa	11
Alice	5	Laredo	5
Amarillo	13	Longview	8
Austin	6	Lubbock	11
Bay City	5	Lufkin	8
Beaumont	6	McAllen	3
Beeville	5	Midland	10
Big Spring	10	Mineral Wells	8
Brownsville	3	Palestine	8
Brownwood	8	Pampa	13
Corpus Christi	5	Pecos	8
Corsicana	8	Plainview	13
Corsicana	8	Port Arthur	6
Dallas	8	San Angelo	8
Del Rio	5	San Antonio	6
Denton	8	Sherman	10
Eagle Pass	5	Sherman	10
El Paso	10	Snyder	11
Ft. Worth	8	Temple	8
Galveston City	5	Tyler	8
Greenville	10	Vernon	10
Harlingen	3	Victoria	5
Houston	5	Waco	8
Huntsville	8	Wichita Falls	10
Killeen	8		

Utah (UT)

Cedar City	17	Richfield	17
Logan	17	Saint George	10
Moab	13	Salt Lake City	17
Ogden	17	Vernal	19

Vermont (VT)

Burlington	19	Rutland	17

Virginia (VA)

Charlottesville	13	Richmond	13
Danville	13	Richmond	13

Virginia (VA) Continued

Fredericksburg	13	Roanoke	13
Lynchburg	13	Staunton	14
Norfolk	11	Winchester	14

Washington (WA)

Aberdeen	15	Port Angeles	18
Bellingham	18	Seattle	14
Bremerton	14	Spokane	17
Ellensburg	17	Tacoma	14
Everett	15	Walla Walla	14
Kennewick	14	Wenatchee	17
Longview	14	Yakima	17
Olympia	18		

West Virginia (WV)

Beckley	17	Huntington	13
Bluefield	14	Martinsburg	14
Charleston	13	Morgantown	14
Clarksburg	17	Parkersburg	14
Elkins	17		

Wisconsin (WI)

Appleton	19	Manitowoc	19
Ashland	19	Marinette	19
Beloit	17	Milwaukee	19
Eau Claire	19	Racine	17
Fond du Lac	19	Sheboygan	17
Green Bay	19	Stevens Point	19
La Crosse	19	Waukesha	17
Madison	19	Wausau	19

Wyoming (WY)

Casper	19	Newcastle	19
Cheyenne	19	Rawlins	20
Cody	19	Rock Springs	20
Evanston	20	Sheridan	19
Lander	19	Torrington	17
Laramie	22		

Alberta (AB)

Calgary	22	Lethbridge	20
Edmonton	23	Medicine Hat	19
Grande Prairie	23	Red Deer	22
Jasper	22		

British Columbia (BC)

Dawson Creek	23	Penticton	17
Ft. Nelson	24	Prince George	22
Kamloops	17	Prince Rupert	20
Nanaimo	18	Vancouver	18
New Westminster	18	Victoria	18

Manitoba (MB)

Brandon	23	Portage La Prairie	21
Churchill	25	The Pas	23
Dauphin	23	Winnipeg	23
Flin Flon	23		

New Brunswick (NB)

Chatham	22	Moncton	20
Fredericton	20	Saint John	20

Newfoundland (NF)

Corner Brook	20	St. John's	20
Gander	22	Stephenville	20
Goose	23		

Northwest Territories (NW)

Ft. Smith	24	Resolute	26
Inuvik	25	Yellowknife	24

Nova Scotia (NS)

All Locations	20

Ontario (ON)

Belleville	19	Ottawa	19
Cornwall	19	Owen Sound	19
Hamilton	17	Peterborough	19
Kapuskasing	23	St. Catharines	17
Kenora	23	Sudbury	22
Kingston	19	Thunder Bay	22
London	19	Timmins	23
North Bay	22	Toronto	19
Oshawa	19	Windsor	17

Prince Edward Island (PE)

All Locations	20

Quebec (PQ)

Bagotville	22	Sherbrooke	22
Drummondville	19	St. Jean de Cherbourg	23
Granby	19	St. Jerome	22
Montreal	19	Thetford	22

Quebec (PQ) Continued

Quebec	22	Trois Rivieres	22
Rimouski	22	Val d'Or	23
Sept-Iles	23	Valleyfield	19
Shawinigan	22		

Saskatchewan (SK)

Estevan	22	Regina	22
Moose Jaw	21	Saskatoon	23
North Battleford	23	Swift Current	22
Princelbert	23	Yorkton	23

Yukon Territory (YT)

Whitehorse	24

concrete homes *Technology Brief*

No. 1

Beautiful Homes Built To Last

Concrete Homes Save Energy

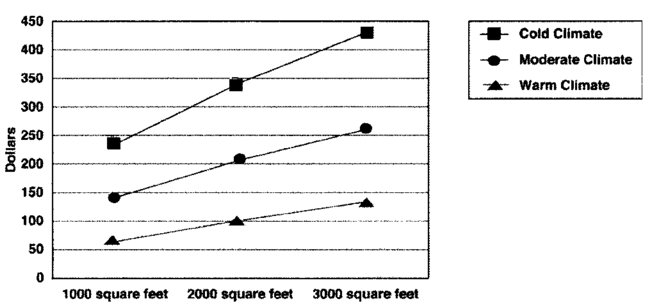
Building a concrete home with insulating concrete forms (ICFs) saves energy and money. The greater insulation, tighter construction, and temperature-moderating mass of the walls conserve heating and cooling energy much better than conventional wood-frame walls. This reduces monthly fuel bills. It also allows use of smaller heating and cooling equipment, saving money in construction.

How much will I save?

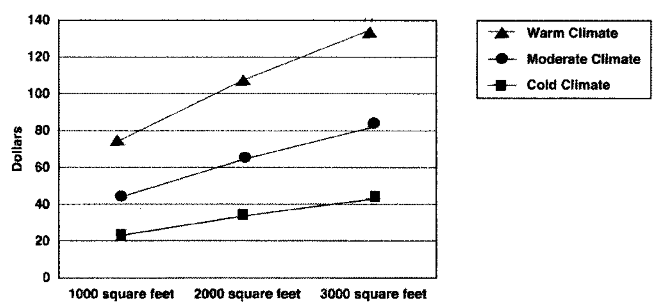
Houses built with ICF exterior walls require 44% less energy to heat and 32% less energy to cool than comparable frame houses. A typical 2000 square foot ICF home in the central US will save $200 in heating costs, and $65 in cooling costs each year.

The bigger the house the bigger the savings. In colder areas of the US and Canada, heating savings will be more and cooling savings less. In hotter areas, heating savings will be less and cooling savings more.

Estimated Annual Heating Savings



Estimated Annual Cooling Savings



The smaller heating and cooling equipment needed for such an energy-efficient house can cut construction costs by an estimated $500 to $2000. The biggest equipment savings come with the houses that have the most energy savings.

How do we know all this?

The energy savings estimates are from a study of 58 single-family houses across the US and Canada. Half had exterior walls constructed with concrete using ICFs made of expanded polystyrene (EPS) or extruded polystyrene (XPS) foam.

The other half were neighboring houses with wood-frame walls. All houses were less than 6 years old.

The researchers compared the energy bill of each concrete house to its frame counterpart, carefully correcting for important differences to get an "apples-to-apples" comparison.

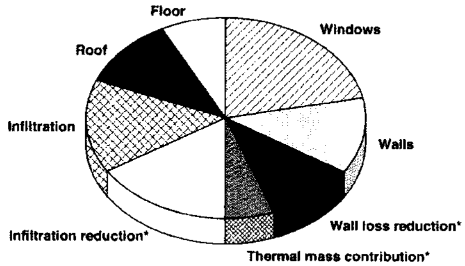
Estimates of equipment savings are actual numbers reported by contractors who build ICF houses.

Where do the savings come from?

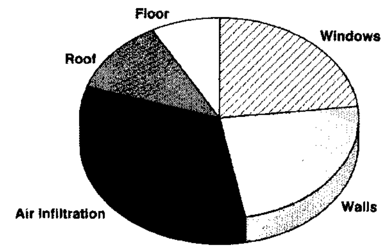
Insulating values for ICF walls using polystyrene foam are R-17 to R-26, compared to wood frame's R-9 to R-15. So ICF walls are expected to cut conduction losses through foundation and above-grade walls in half. And ICF walls are tighter. In tests, they averaged about half as much infiltration (air leakage) as wood-frame homes.

Concrete Homes Save Energy

Energy Loss Reduction



Sources of Energy Loss



The energy efficiency of ICF houses has been independently verified by other agencies. They compared the energy use of single family houses with various exterior walls including ICF, concrete masonry and wood framing. The results show that in almost all climates across the US and Canada, concrete homes use less energy for heating and cooling.

But ICF walls do more than cut down on energy loss. Concrete gives them the heat-absorbing property, "thermal mass," the ability to smooth out large temperature swings. It keeps the walls warmer when the outdoor temperature hits its coldest extreme and cooler when the outdoor temperature is hottest. The walls "add back" heat or cooling, which contributes about 6% of the needed energy to the house for free.

Since the energy needed is less, furnaces and compressors that heat and cool can be smaller. And the more the energy savings, the greater the possible reduction in equipment size—and cost.

Estimating the size of heating and cooling equipment for concrete homes is complicated because the effect of thermal mass must be simulated in a computer program. But the software tool "HVAC Sizing for Concrete Homes" takes care of the difficult calculations. All you have to do is enter information about the house, like location, house size, and wall construction.

What's the bottom line?

In planning a new house you can estimate that building with ICFs will save hundreds of dollars per year in energy costs. You may also save hundreds or thousands of dollars in construction costs for heating and cooling equipment. Talk with an ICF homebuilder for estimates.

The following resources are available to learn more about saving energy with concrete homes:

RP119 **VanderWerf "Energy Comparisons of Concrete Homes Versus Wood Frame Homes" $10.00**

CD026 **"Energy Use of Single-Family Houses with Various Exterior Walls" $20.00**

CD044 **"HVAC Sizing Software for Concrete Homes" $59.95**

PCA Portland Cement Association Concrete Homes

5420 Old Orchard Road, Skokie, Illinois 60077-1083
Phone: 847.966.6200 Fax: 847.966.9281 Web: www.cement.org
More information? Helpline 1.888.333.4840 www.concretehomes.com

concrete homes Technology Brief

No. 21

Beautiful Homes Built To Last

Easier Energy Star® Compliance with Concrete Homes

A Thermal By-Pass Checklist must be completed for all homes earning the Energy Star® Label. The Checklist identifies required exterior wall details homebuilders must incorporate into the homes, and that third party energy inspectors must review, to make sure the exterior envelope performs efficiently. Properly installed continuous concrete and foam wall systems, such as Insulating Concrete Forms (ICFs) inherently provide alignment of insulation and air barriers with no gaps, voids or compression. This can provide the homebuilder with a greatly simplified thermal assembly. Concrete wall systems reduce the more expensive and time consuming challenges and coordination of attempting to obtain compliance with conventionally insulated frame construction.

How do homes qualify for the Energy Star® Label?

The program for Energy Star® qualified homes was developed by the US Environmental Protection Agency (EPA), to ensure that new houses are built to higher performance standards. Homes built to meet Energy Star are at least 15% more energy efficient than the requirements of the International Residential Code and include additional energy-saving features often making them even more efficient than conventional residential construction. Each Energy Star® qualified home can keep an EPA estimated 4,500 lbs of greenhouse gases out of our air each year.[1]

What is Thermal By-Pass?

Thermal By-Pass refers to the movement of heat around and through insulation. For insulation to be an effective thermal barrier it must be combined with an air barrier, material that restricts the flow of air through the wall assembly. Both must be installed without any holes, gaps, voids, compression, or wind intrusion. Creating just a 5 percent gap in insulation coverage reduces the effective R-value by 50 percent,[2] leaving little room for substandard work.

Conventional insulation products work only by trapping air. Allowing air flow through insulation greatly reduces its effectiveness. This frequently occurs when conventional frame construction is insulated with conventional thermal blankets, called batts, installed in the open spaces between framing members. If the insulation is not carefully installed tightly on all sides up against surrounding air barriers, framing, and finishes, if it is compressed around electrical wiring, pipes, or other obstructions within the wall, the actual thermal performance of the wall can easily be reduced. Even small gaps between the air barrier and insulation can cause air to begin to circulate as it heats.

Why is the Thermal By-Pass Checklist Required?

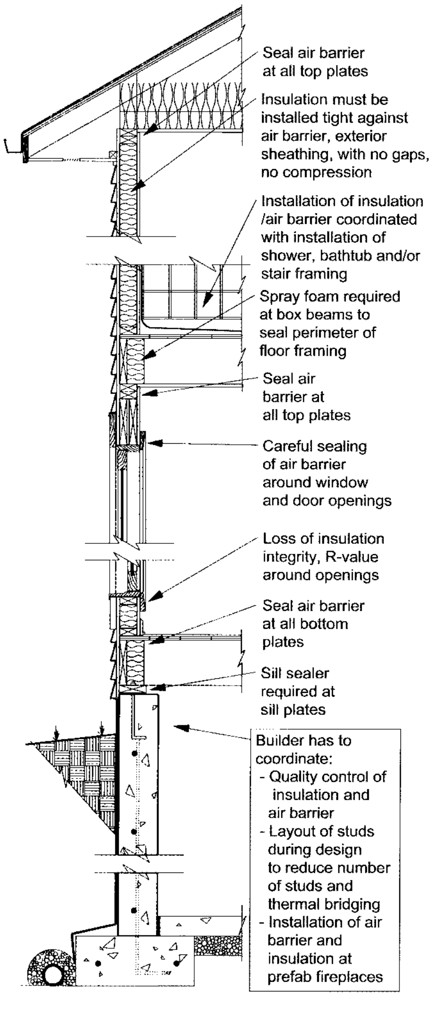
EPA recognizes how much the careful construction of the exterior envelope can impact the overall energy efficiency of a home. The Thermal By-Pass Checklist was developed to provide builders and inspectors with a comprehensive list of critical frame construction details that must be carefully addressed to make sure improper workmanship has not compromised the thermal performance of the exterior wall assembly.

How Do Concrete Walls Make the Builder's Job Faster and Less Complicated?

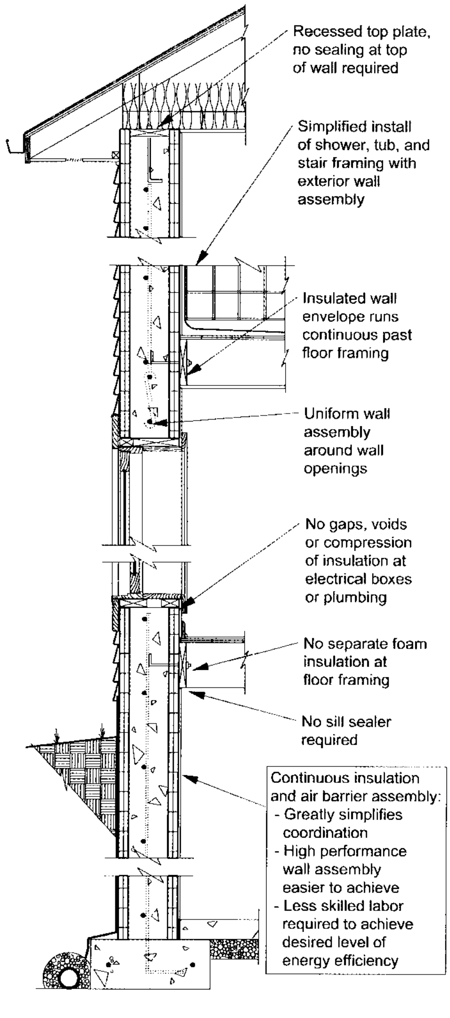
Complying with the meticulous requirements of the Checklist is time consuming and difficult. EPA's Thermal ByPass Checklist Guide indicates air barriers "must be perfectly aligned with the insulation" in order for conventionally built wall assemblies to insulate properly. Wall Section 1 shows a cross section of a typical 2-story wood frame exterior wall insulated with batt insulation. It identifies the many potential trouble spots identified in the Checklist that have to be carefully handled by the builder, and reviewed by the energy raters.

Wall Section 2, shows a 2-story ICF exterior wall section, showing the far less complicated wall assembly, with fewer areas requiring special consideration and inspection. Building with ICFs, removable forms, precast concrete, or similar concrete and foam systems eliminates critical coordination issues and construction details that would have to be addressed and verified when building typical Energy Star®

compliant exterior walls. This saves valuable time and allows high performance concrete homes to be completed faster. One construction cycle study estimates each day of delay costs homebuilders $140 in combined capital cost, management cost, and sales opportunities.[3]



1 Wood Frame Wall Section



2 Insulated Concrete Wall Section

What's the Bottom Line?

Advances in building science now demonstrate the shortcomings of traditional batt insulated frame construction. To make it work properly, extra steps, care, and time are required, adding significantly to the cost of a home. Concrete wall systems offer homebuilders a faster, simpler approach to building high performance exterior wall construction that meets Energy Star® insulation and air barrier installation requirements.

1. "Energy Star® Qualified Homes Thermal Bypass Checklist Guide," US Environmental Protection Agency, Version 2.1, June 2008

2. Cutchin, Kelly, & Rashkin, Sam (May 2008) So You Think You Know Building? Sustainable Home Magazine, pages 48–49

3. Caldeira, E. (1998) Cycle time reduction – what is a day worth? (online) www.toolbase.org/Best-Practices/Business-Management/Cycle-Time-Reduction

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IS320

The ICF Effect

Energy efficient construction is booming, driven by higher fuel prices, record-setting temperatures and more stringent energy codes. Contractors are pushed to find better solutions for the building envelope. While R-values have been the traditional measure of energy effectiveness, evidence now points to other factors which contribute equally to energy efficiency. This is the rest of the story - the story of the ICF Effect.

The R-value measurement came about in response to the oil crisis in the 1970's. Up until then, fuel was cheap and minimal attention was placed on energy use, as evidenced by the lack of insulation in mid-century homes. The skyrocketing fuel prices triggered a need for immediate improvements in residential energy efficiency. Minimum insulation values were prescribed as a quick and immediate remedy. The values were based on the insulation materials typically used at the time. The existing hot box testing method, measured resistance of heat flow, or R-value.[1]

The R-value testing measures the resistance to heat flow of a given material, in a steady state. While not an ideal representation of real world conditions, the R-value provides a straightforward system for comparing insulation materials.

" The synergy of higher R-value, virtually no air infiltration and the added thermal mass in ICF assemblies result in performance that simply can't be duplicated with traditional framed assemblies."

David Shepherd, AIA
Director of Sustainability
Portland Cement Association

As builders adapted new insulation materials and the HVAC industry developed more accurate equipment sizing software, one thing became quite apparent: R-value alone does not reflect the true effectiveness of a material when installed. If it did, then a wood frame house with an R-19 fiberglass batt would have the same energy performance as an Insulated Concrete Form (ICF) house with R-19 polystyrene foam, all other parts being equal.

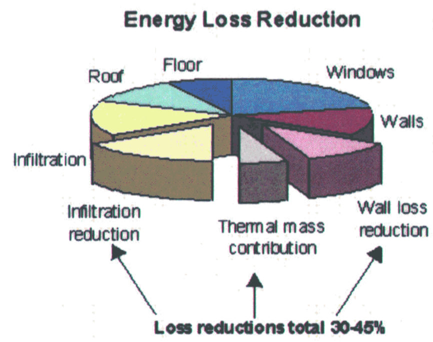
However, houses built with ICF exterior walls typically require 44% less energy to heat and 32% less energy to cool than comparable frame houses. [2]

What's the difference?

We call this the ICF Effect.

The energy effectiveness of an ICF wall is due to three important factors:

- ***Continuous R-value,***
- ***Reduced air infiltration, and***
- ***Thermal mass moderation.***



Energy Savings from the ICF Effect

Continuous R-Value

The R-value of a material is based on laboratory testing of a sample piece. It does not take into account gaps or variations in thickness. In real life, the R-value of an installed wall assembly should be a weighted average of all the wall components. For example: fiberglass batt (R-13), wood studs (R-4.38 for a 2x4), and air gaps (R-0 zero). In this case, the combined R-value is less than the tested value of the insulation component.

By comparison, the R-value of ICFs is constant. The foam form and its associated R-value, is continuous by necessity as a forming system. For example, an R-22 ICF system performs at a true R-22 level.

Reduced Air Infiltration

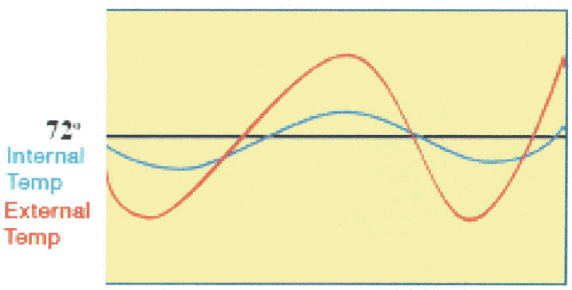
Over half the energy loss of a frame home is due to unwanted air infiltration and heat loss through the wall assembly. Air can penetrate into a building through many channels – sheathing gaps, penetrations at balconies or cantilevered floors, and insulation gaps in the wall cavity. Also, humidity and drying of the wood frame causes movement in the wood framing and contributes to post-construction leakage. Air infiltration coming from these gaps is typically around .5 ACH (air changes per hour), which means that each hour, half the air volume of a house is exchanged for outside air that needs to be heated/ cooled.

There are several ways to combat air infiltration. Choosing blown-in or spray-on insulation can help reduce the air gaps around the wood studs. However, no amount of blown in insulation will address the thermal bridging caused by the lower R-value wood framing.

Insulating Concrete Forms (ICFs) provide a ready solution to these issues. The monolithic concrete core forms a tight air barrier, with penetrations (e.g. windows and doors) which are easy to identify and seal. And, time has no impact on these materials. The foam has a consistent R-value for the full service life of the wall.

Thermal Mass

The benefits of thermal mass have been enjoyed in practice for centuries. Recently, the scientific community has also quantified and validated this effect. Studies conducted by the U.S. Department of Energy (USDOE) confirmed that concrete mass in exterior walls reduces annual energy costs in buildings. In 1987, this was written into the energy code in the form of reduced R-value requirements for a thermal mass wall assembly. [3]



Thermal mass delays the transfer of heat and evens out temperature swings.

The ICF concrete core offers the characteristic thermal mass qualities of heat absorption and thermal lag. The additional insulation of an ICF wall further delays the transfer of heat to the inside of the building. This combination serves to reduce and delay peak loads, which may result in lower off-peak energy pricing and reduced HVAC equipment size. In climates with large diurnal temperatures swings, the mass wall can release absorbed heat energy to the cooler night air, a process called heat flow reversal.

This insulated thermal mass application provides an excellent pairing with passive solar design. The ICF wall moderates indoor temperature swings and reduces the amount of heating/ cooling needed. This in turn reduces the amount of exposed thermal mass needed for passive solar heating. Mass floors, interior walls and other surfaces can meet this exposed mass requirement.

"The new ENERGY STAR Qualified Homes specification effectively levels the playing field between framed construction and advanced wall systems like insulated concrete forms. This is because complete air barrier assemblies that have been often missing in framed construction, but standard with advanced wall systems, are now required in every labeled home."

Sam Rashkin
National Director ENERGY STAR for Homes
United States Environmental Protection Agency

Energy efficient construction is a top priority for the construction industry. The Energy Star for Homes program has experienced a sizeable increase in builder participation. The guidelines call for a continuous thermal envelope and a tighter air barrier requirements, which are the very strengths of ICFs. The Thermal Bypass Checklist even lists ICFs as a best practices solution for reduced thermal bridging.

The USDOE has set its goal even higher, aiming for a Net-Zero Energy Home. Such a house will remain comfortable even when utilities are disrupted, providing passive resistance to disasters. The only way to make this economically feasible is to improve the thermal envelope for a lower overall HVAC load and thus yield a more affordable renewable energy package. ICFs can help provide this solution.

It's time to look beyond the R-value and learn the rest of the story. Insulating Concrete Form construction offers a complete energy solution that makes economic sense today, while helping to meet the energy needs for future generations.

[1] American Society for Testing and Materials (ASTM) Designation: C976

[2] RP119 VanderWerf, *Energy Comparisons of Concrete Homes vs Wood Frame Homes.*

[3] Currently Section 402.1.1, IECC 2006

REV. 1/31/08

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The Insulating Concrete Form Association (ICFA) is a business association, representing over 500 international firms through ICF promotion, codes and standards, research, partnering and education. Founded in 1994, the ICFA is located in Chicago, IL.