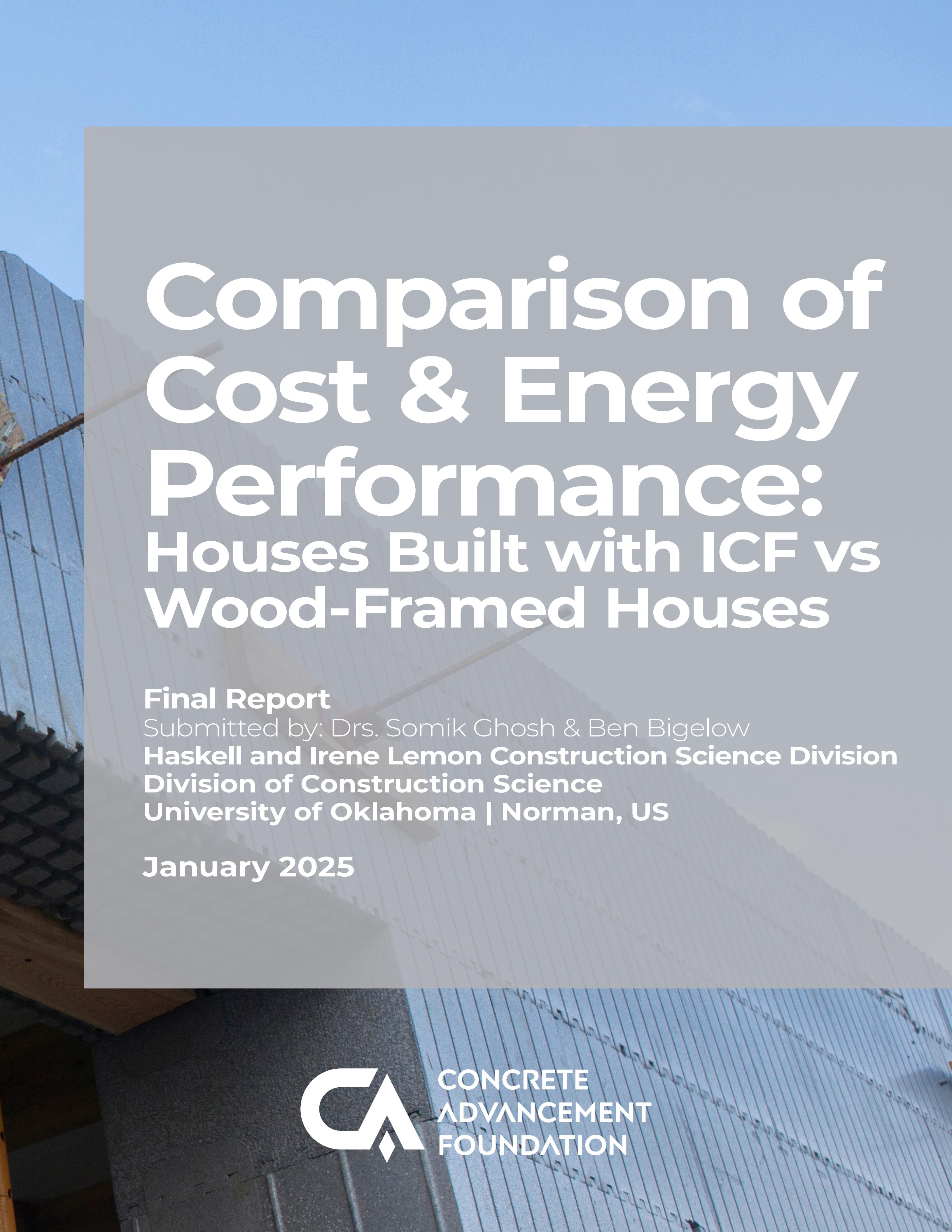

Comparison of Cost & Energy Performance: Houses Built with ICF vs Wood-Framed Houses

Final Report

Submitted by: Drs. Somik Ghosh & Ben Bigelow

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Division of Construction Science
University of Oklahoma | Norman, US

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CONCRETE
ADVANCEMENT
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Abbreviations

BFG – Blown Fiber Glass

C – Centigrade

CCF/ccf – 100 Cubic Feet

DOE – United States Department of Energy

EPS – Expanded Polystyrene

F – Fahrenheit

Ft/ft – Feet

HVAC – Heating Ventilation and Air Conditioning

ICF – Insulated Concrete Form

IRC – International Residential Code

kWh – Kilo Watt-hour

OSB – Oriented Strand Board

S.F. – Square Feet

SF – Spray Foam

U.S. – United States

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Background and Introduction

Wood is widely regarded as the most common building material when it comes to framing walls for houses. Although other options for wall construction like masonry, concrete, or earth offer more comfort, energy efficiency, and sturdiness, the U.S. construction industry has widely adopted wood and wood-framing as the most common option. However, several factors such as the shortage of skilled workers as well as the projected increase in demand for houses in recent times according to the Bureau of Labor Statistics, suggest that there is a need for alternative options that require smaller working crews without increasing construction time. Hence, this study investigates the efficacy of Insulated Concrete Forms (ICF) as an alternative building material. Additionally, examining the energy efficiency of ICF in comparison to wood-framed construction was also a major objective of this study. A typical ICF wall is comprised of two layers of foam (acting as formwork) connected by plastic ties. Traditional wall reinforcements, such as rebars, are positioned between the foam layers, followed by the pouring of mass concrete (Figures 1a-b).

Fig 1a – ICF block used in the houses

Fig 1b – A research team member with ICF corner block

Once the external walls are formed using the ICF blocks, and installed in courses, the reinforcing bars are placed in between the foam layers, and then finally they are filled with concrete (Figures 2a-c). This makes for a firm exterior wall with thermal mass and adequate thermal resistance. Past studies where the performance of ICF envelopes for houses were simulated, show a nonsignificant increase in the construction cost, but substantial savings in energy use. Specifically, Ochsendorf et al. (2011) simulated the performances of ICF envelopes for single-family houses, multifamily units, as well as commercial structures and found that over the total life cycle, ICF construction adds to the cost of traditional wood-framed construction by less than 5%, but the benefit in energy savings is considerable. Mallay and Wiehagen (2014) compared ICF walls with standard wood-framed walls and found a lower whole-house infiltration rate in the house with ICF exterior walls, thus making it a more energy-efficient option for above-grade applications. Similar findings based on simulations were reported by a few other studies (Petrie et al. 2002, Kosny et al. 2001) where energy savings in houses with ICF exterior walls ranged from 4% to 10% over conventional wood-framed houses depending on the climatic region. Gajda and his colleague tested several thermally massive materials such as autoclaved concrete block walls, concrete masonry units, and cast-in-place concrete panels along with ICF in different locations across the U.S. They concluded that ICF walls saved the most energy across all locations (Gajda 2001, Gajda and Van Geem 2000).

Fig 2a – ICF installed courses to form the wall

Fig 2b – Concrete poured using pump truck

Fig 2c – Concrete filled ICF wall

Problem Statement

A study by Ochsendorf et al. (2011) stated that the lower cost of opting for conventional wood-framed houses over other options might be negated due to the higher life-cycle cost to the owner. It is deemed that other options would provide better long-term energy cost savings when compared to wood-framed houses; however, the wood-framed option is still widely accepted and used. Perhaps, this is due to a lack of awareness and the nonavailability of empirical data supporting the comparison. While previous studies have been able to reveal the benefits of ICF based on simulated data, there are little to no studies that have collected and analyzed empirical data to make more accurate and informed assertions; this study presents a comparative analysis of energy usage data collected from multiple houses with wood-framed exterior walls and ICF walls in the Oklahoma City metro area.

Objectives and Research Approach

Given the focus on generating empirical evidence, this study adopted a quantitative research approach in collecting data and analyzing the data to draw comparisons and inferences between wood-framed houses and houses with ICF exterior walls. Data was collected from five houses, referred to as house #1, house #2, and similar with two different floor plans (two houses were 1,950 S.F. each, and three houses were 2,070 S.F. each). The floor plans and elevations of the houses are provided in Appendixes II-IV. All the houses were constructed in 2022 per the 2015 International Residential Code (IRC), as the municipality had adopted the 2015 IRC at the time of construction. Something to note, according to the IRC 2015, the minimum R-value requirement for exterior walls across all climatic zones is R13. ICF walls, with an R-value of R33, exceed this by more than twice. Two houses were wood-framed with blown fiberglass (BFG) walls and attics to represent the control group. One house was wood-framed with BFG walls, but a spray foam (SF) attic, and two houses were built with ICF exterior walls, one with an SF attic, and the other with a BFG attic. The houses were in the same neighborhood and were less than ½ of a mile from one another. The orientations of the houses are shown in Figure 3.

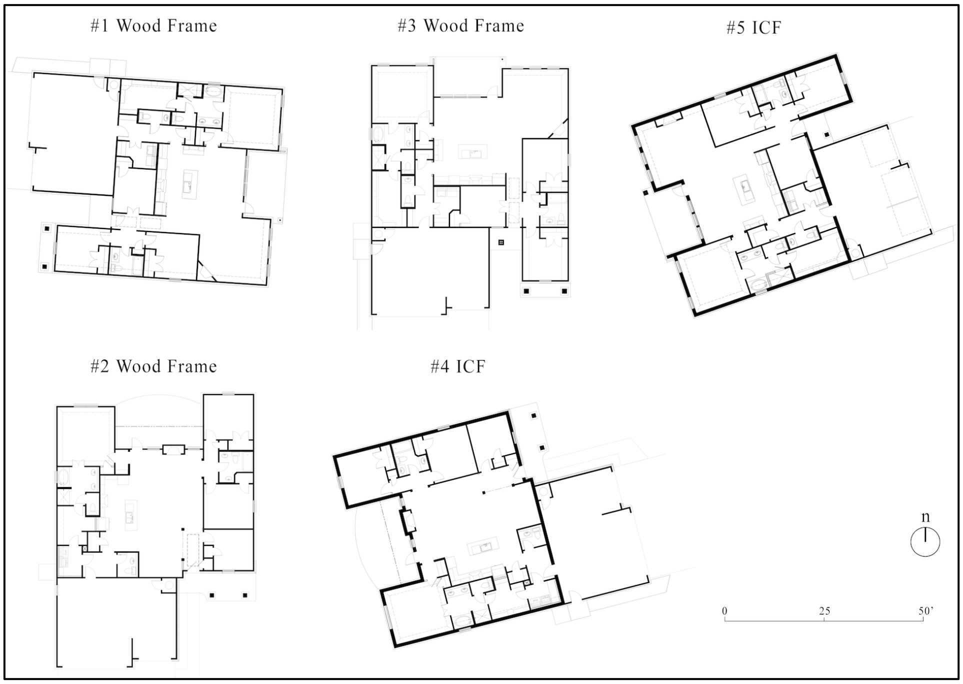

Figure 3. Orientation of the houses

Table 1 below provides the details of the walls and insulation types of each house. In addition, the window-to-wall ratios (shown as %) of the houses are provided in Table 2. The ratios are provided by north, east, west, and south walls, although some houses are not perfectly oriented. Houses #4 and #5, featuring ICF exterior walls, exhibit higher window-to-wall ratios compared to the other houses. The floor plans of the houses with similar square footage have minor variations in the window sizes.

Table 1. Wall and insulation details of the houses

Home	Square Footage	Wall Type	Wall Insulation	Attic Insulation	HVAC System
#1	2,070	Wood Frame	BFG – R15	BFG - R30	Single, SEER 16.0
#2	1,950	Wood Frame	BFG – R15	BFG – R30	Single, SEER 15.0
#3	2,070	Wood Frame	BFG – R15	SF > R30	Single, SEER 16.0
#4	1,950	ICF	EPS Foam > R15	BFG – R30	2 stage, SEER 15.0
#5	2,070	ICF	EPS Foam > R15	SF > R30	2 stage, SEER 16.0

Table 2. Window-to-wall ratios (shown as %) of the houses

Direction of Ext Wall	House #1	House #2	House #3	House #4	House #5
East	33.4%	3.0%	3.2%	9.4%	6.4%

South	3.2%	9.5%	10.8%	1.8%	1.9%
West	10.8%	1.7%	1.8%	31.5%	34.5%
North	1.8%	34.0%	33.4%	2.7%	3.3%

Note: The gross exterior wall is measured horizontally from the exterior surface; it is measured vertically from the top of the floor to the bottom of the roof. The gross exterior wall area includes below-grade as well as above-grade walls. It includes walls, doors, and windows.

The energy performances of the houses were compared using a twofold approach. The research team first assessed the energy performance of the houses based on energy models before occupancy and then analyzed actual usage data after occupancy over a 12-month period. For creating the energy models, the team used eQuest, a DOE-2 based software. The energy models only accounted for the R-value of the ICF insulation. The total thickness of the walls was 9.5” with 4” of concrete and 5.5” of EPS foam. To capture the benefits of the thermal mass of the concrete, which the models did not consider, actual performance data was gathered and compared. Few existing studies have attempted to capture the benefits of thermal mass to reduce the fluctuations in interior conditions with the variations of outside conditions (Kosny 1998, Kosny 2001, Kossecka 1998). This study explored the benefits of thermal mass in ICF on thermal performance and compared that with conventional wood-framing. For that, the team installed thermal sensors inside the houses (at two locations in every house).

Description of Research Project Objectives

The following tasks were completed as part of this study.

Comparison of material cost and installation time of houses with ICF exterior walls and wood-framed houses

The research team gathered first-hand cost information through a combination of direct interaction with and observation of workers on the ICF job sites and invoices provided by the supplier. The houses were in Moore, a city in Cleveland County, and part of the Oklahoma City metropolitan area (Figure 4).

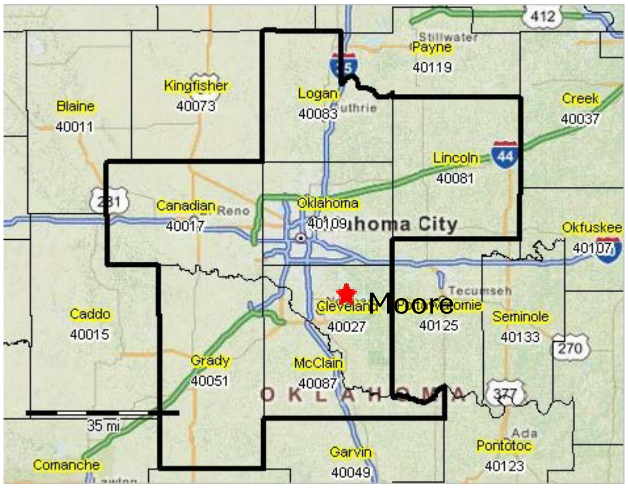

Figure 4. Location of Moore in the Oklahoma City metro area

The installation times and material costs of the two houses using ICF exterior walls are presented in Tables 3-6. Though the square footage of house #4 was less than that of house #5, the installation time for house #4 was 27% longer than that for house #5. This could be attributed to house #4 being constructed during the winter holiday season, leading to a shortage of available workers. The cost of materials to build the exterior walls of houses #4 and #5 are commensurate with their square footage.

Table 3 – Installation time for house #4 (ICF with BFG insulation)

Date	Crew Size	Crew Hours	Total Labor-Hours
12/16/2021	1	9	9
12/17/2021	2	9	18
12/20/2021	1	9	9
12/21/2021	2	9	18
12/22/2021	1	9	8
12/23/2021	1	9	9
12/27/2021	1	9	9
12/28/2021	1	9	9
12/29/2021	1	9	9
12/30/2021	2	9	18
12/31/2021	1	9	9
1/3/2022	2	9	18
1/4/2022	1	9	9
1/5/2022	4	10.5	42
1/6/2022	3	9	27
1/7/2022	2	9	18
	TOTAL		239

Table 4 – Material cost for house #4 (ICF with BFG insulation)

Item	Quantity	Unit Cost ($)	Total Cost ($)
ICF Blocks – 4” standard form	271 ea	$19.16	$5192.36
ICF Blocks – 4” left corner	56 ea	$19.16	$1072.96
ICF Blocks – 4” right corner	56 ea	$19.16	$1072.96
ICF Blocks – 4” gorilla buck	25 ea	$43.34	$1083.50
Zip ties (50/bag)	4 bag	$16.38	$65.52
Vertical ties (150/box)	4 box	$81.28	$325.12
Foam cans	5 ea	$13.86	$69.30
Foam cleaner	1 ea	$14.97	$14.97
Anchor plates	75 ea	$2.46	$184.50
Delivery of Blocks & Miscl. items		lumpsum	$900.00
Concrete, 3500 psi	23.5 CY	$141	$3595.17
Rebar – 20’	135	$8.83	$1192.05
TOTAL			$15,540.32

Table 5 – Installation time for house #5 (ICF with SF insulation)

Date	CrewSize	Crew Hours	Total Labor-Hours
10/4/2021	5	8.5	42.5
10/5/2021	5	8.5	42.5
10/6/2021	5	8.5	42.5
10/7/2021	7	8.5	59.9
TOTAL			187.4

Table 6 – Material cost for house #5 (ICF with SF insulation)

Item	Quantity	Unit Cost ($)	Total Cost ($)
ICF Blocks – 4” standard form	261 ea	$19.16	$5000.76
ICF Blocks – 4” left corner	35 ea	$19.16	$670.60
ICF Blocks – 4” right corner	35 ea	$19.16	$670.60
ICF Blocks – 4” taper tops	50 ea	$20.04	$1002.00
ICF Blocks – 4” gorilla buck	60 ea	$43.34	$2600.40
Zip ties (50/bag)	6 bag	$16.38	$98.28
Vertical ties (150/box)	5 box	$81.28	$406.40
Foam cans	8 ea	$13.86	$133.92
Foam cleaner	1 ea	$14.97	$15.50
Anchor plates	180 ea	$2.46	$442.80
Delivery of Blocks & Miscl. items		lumpsum	$900.00
Concrete, 3500 psi	24 CY	$122	$3255.06
Rebar – 20’	135	$8.83	$1192.05
TOTAL			$17,326.91

The cost of materials for the wood-framed houses was collected from the builder. Houses #1 and #2 had the same floor plan as that of house #4, the only difference being the construction method. Similarly, houses #3 and #5 were similar except the construction methods. As the materials of these houses were not procured at the same time, the material prices were affected by price escalations. The research team adjusted for these price escalations. The material and labor costs for the exterior walls, roof framing, and interior framing of house #4 were more than that of house #2 by $8,107, marking a 20% increase.

Similarly, the material and labor costs for the exterior walls, roof framing, and interior framing of house #5 were higher by $9,825 compared to house #1 or #3, which corresponds to a 23% difference. Table 7 below compares the material costs for the four houses. The material cost of wood-framed walls includes both exterior and interior wall framing, so for the houses with ICF exterior walls, the cost of wood-framed walls refers to the material cost of roof framing, roof decking, and interior wall framing.

Table 7 – Material and labor costs comparison (exterior and interior framing) between the houses

House	Framing Lumber	ICF Forms	ICF Concrete	ICF Rebar	ICF Labor	Framing Labor	Wall Insulation	TOTAL
#1	$31,982	0	0	0	0	$9,052	$1,979	$43,010
#2	$28,944	0	0	0	0	$9,267	$2056	$40,267
#3	$31,982	0	0	0	0	$9,052	$1,979	$43,010
#4	$17,484	$10,753	$3,595	$1,192	$8,400	$6,950*	0	$48,374
#5	$19,860	$12,880	$3,750**	$1,192	$8,364	$6,789*	0	$52,835

* Framing labor cost has been reduced by 25%

**Concrete price has been adjusted using $144/CY plus 8.5% tax

The research team has collected the cost of labor for the four study houses. However, the framing crew was paid by the S.F. of the house area; thus, the houses with ICF exterior walls did not have any savings in the framing labor cost. In conversation with the builder, it became clear that in the future the builder would negotiate a lower unit cost for the framing of the houses with ICF exterior walls. The total framing package for the houses was divided equally into 50% wall framing and 50% roof/attic framing. In houses with ICF exterior walls, wall framing requirements were reduced by 45%-50%, potentially lowering the overall framing labor cost by 25%. For these houses, wall framing was only necessary for the garage walls and the interior walls.

Remark:

The cost of materials for houses constructed with ICF exterior walls was approximately 20% higher than that of similarly sized wood-framed houses. However, there is potential for labor cost savings if the framing crew is compensated differently from the prevailing method based on square footage of the houses.

Comparison of the energy performance of houses with ICF exterior walls to wood-framed houses based on computer simulation models

The research team compared the houses' energy performance before occupancy using computer models. Energy models were created using eQuest, a DOE-2 based software application. The modeling software requires specific information, which was incorporated into the models. All houses were successfully modeled, including those with ICF exterior walls and those with wood-framed exterior walls. The location for models was Moore, Oklahoma, where the actual houses are situated. The parameters used to model the houses are detailed below.

- *General information:* this includes building type, (residential), building location (Moore, OK, U.S.), square footage, floor-to-ceiling height (10-ft), number of floors above grade (1), number of floors below grade (0), Cooling Equipment (DX coils), Heating Equipment (furnace).
- *Building footprint:* all four models had their floor plans (.dwg files) imported from AutoCAD. This is done to establish the buildings' footprint and size. Zoning patterns for these models were two, namely perimeter and core zones.
- *Seasons definition:* for this study, just two seasons were defined, summer and winter. This is important so the software can simulate heating and cooling in both seasons.
- *Building schedule information:* buildings are assumed to be operational 24 hours each day, however, with differing energy periods.
- *Electricity utility time-of-use-periods*: it is assumed that from Monday to Friday, each week, utility usage is on-peak between 7 a.m. and 9 a.m., as well as between 2 p.m. and 9 p.m.; while on Saturdays, Sundays, and holidays, the on-peak period if from 11 a.m. and 9 p.m. as well as during summers.
- *Building envelope construction:* the layer-by-layer assembly for the roof as well as the walls were filled out on the software. In this case, the exterior wall assembly for the wood framed option (wood, fiberglass insulation, face bricks, OSB board) differed from the ICF

exterior walls assembly (two layers of pEPS for a total of 5.5", 4" of concrete, face bricks, and OSB board). R-value for the lumber framed option is R-19 whilst the R-value for the ICF exterior wall option is R-33. Other information included the type (wood, solid core flush), thickness, location, and size of doors, type, thickness, location, and size of windows (double low-E, aluminum framed), etc.

- *Weather*: Oklahoma City weather file was used in this modelling, (oklahook.bin). All *.bin weather files are owned by the United States Department of Energy (DOE).
- *HVAC system definition:* system type (split system single DX with Furnace), minimum design flow (0.75 cfm / sq. ft). Cooling equipment; size (3.5 tons), Condenser type (Air-cooled), SEER Efficiency (15.0). Heating equipment; size (60 kBtu), AFUE Efficiency (96%). Supply fans; power & Meter Efficiency (4.5 in WG, High standard), Fan Flow (1400 CFM), Fan Type (Variable speed drive), Heater Specification; Heater type(storage), Heater fuel (Natural Gas), How water use (15 gallons/day/person), Input rating (36 kBtuh), Energy Factor (0.66), Tank capacity (40 gallons), supply water temperature (110^0 F).

The model information for all the houses was similar except for the square footage (2070 and 1950 S.F.) and the exterior wall material (ICF: R33 and conventional wood-framed: R19). Based on the modeled information and simulations, the houses with ICF walls consistently showed less electricity consumption. The anticipated consumption based on eQUEST is presented in Table 8. As might be expected, the wood-framed houses with BFG insulation in both walls and attic (#1 & #2) have the highest modeled consumption, averaging 0.445 kWh/month/S.F. over a 12-month period. This was 5.4% more than the wood-framed houses with BFG in walls and spray foam insulation in the attics, about 9% more than the house with ICF exterior walls and BFG attic, and 5% more than the house with ICF exterior walls and SF attic (the lowest modeled consumption came from the house with ICF exterior walls and BFG attic). This result was surprising to the researchers as it was expected that the home with ICF exterior walls and an SF attic would have the lowest consumption.

Table 8. Monthly electricity consumption (kWh) of houses based on eQUEST

Month	#1	#2	#3	#4	#5
Feb	551.899	467.296	502.989	452.089	480.340
Mar	588.377	493.862	540.894	471.242	530.203
Apr	727.142	543.848	674.532	514.555	662.937
May	1,049.772	807.073	989.236	777.451	974.145
Jun	1,329.963	1,105.127	1,261.098	1,087.980	1,242.669
July	1,600.535	1400.93	1521.61	1,502.171	1,378.93
August	1770.58	1684.95	1567.92	1538.97	1663.75

September	1191.60	1127.50	1149.28	1145.86	1119.03
October	818.80	764.73	772.35	774.92	761.78
November	542.54	501.00	482.56	469.30	488.69
December	610.44	558.92	507.20	479.89	534.50
January	720.39	652.71	572.47	538.82	626.30
Total	11502.05	10107.94	10542.14	9630.01	10586.51
Monthly Average Per S.F.	0.46	0.43	0.42	0.41	0.43
Delta			-5.4%	-8.7%	-5%

When the modeled electricity consumption of the houses was compared for the summer months (June through September) as shown in Table 9 below, two things were evident: first, the average monthly consumption per S.F. for all the houses during these months was almost six times higher than that during the entire year. This is because the cooling equipment for the houses runs on electricity. Secondly, house #4 (ICF exterior walls and BFG attic) showed even lesser electricity consumption compared to the wood-framed houses during the entire year.

Table 9. Monthly electricity consumption (kWh) of houses during summer months based on eQUEST

Month	#1	#2	#3	#4	#5
Jun	1,329.963	1,105.127	1,261.098	1,087.980	1,242.669
July	1,600.535	1400.93	1521.61	1,502.171	1,378.93
August	1770.58	1684.95	1567.92	1538.97	1663.75
September	1191.60	1127.50	1149.28	1145.86	1119.03
Total	5892.68	5318.50	5499.91	5151.74	5527.62
Monthly Average Per S.F.	2.85	2.73	2.66	2.49	2.83
Delta			-4.9%	-12.0%	1.7%

The modeled natural gas consumption of the houses with ICF exterior walls and conventional wood-framed houses based on eQUEST are shown in Table 10 below. Based on the modeled information and simulations, the houses with ICF walls consistently showed less gas consumption. As might be expected, the houses that were wood-framed with BFG insulation in both walls and attic (#1 & #2) have the highest consumption, averaging 0.026 CCF/month/S.F. over the 12-month period. This was 21% more than the wood-framed house with BFG walls and an SF attic, about 35% more than the house with ICF exterior walls and BFG attic, and 10% more than the house with ICF exterior walls and SF attic.

Table 10. Monthly natural gas consumption (ccf) of houses based on eQUEST

Month	#1	#2	#3	#4	#5
Feb	109.00	75.00	109.00	80	102.00
Mar	78.00	56.00	78.00	65	74.00
Apr	53.00	37.00	53.00	47	50.00
May	28.00	18.00	27.00	21	26.00
Jun	16.00	10.00	16.00	12.00	15.00
July	9.00	7.00	9.00	8.00	9.00
August	7.00	7.00	6.00	6.00	6.00
September	15.00	14.00	8.00	8.00	14.00
October	31.00	30.00	15.00	13.00	28.00
November	69.00	68.00	41.00	38.00	56.00
December	107.00	107.00	69.00	61.00	95.00
January	148.00	148.00	98.00	86.99	110.00
TOTAL	670.00	577.00	529.00	445.99	585.00
Monthly Average Per S.F.	0.0270	0.0247	0.0213	0.0191	0.0236
Delta			-21.2%	-35.4%	-9.6%

When the modeled gas consumption of the houses was compared for the winter months (November through February) as shown in Table 11 below, two things were evident: first, the average monthly consumption per S.F. for all the houses during these months was almost seven times higher than during the rest of the year. This is because the heating equipment for the houses runs on natural gas. Secondly, house #4 (ICF exterior walls and BFG attic) showed even lesser gas consumption compared to the wood-framed houses during the entire year.

Table 11. Monthly natural gas consumption (ccf) of houses during winter months based on eQUEST

Month	#1	#2	#3	#4	#5
January	148.00	148.00	98.00	86.99	110.00
Feb	109.00	75.00	109.00	80	102.00
November	69.00	68.00	41.00	38.00	56.00
December	107.00	107.00	69.00	61.00	95.00
TOTAL	433.00	398.00	317.00	252.81	368.00
Monthly Average Per S.F.	0.21	0.20	0.15	0.12	0.19
Delta			-34.9%	-69.2%	-9.5%

Remark:

Based on computer simulation models, the houses constructed with ICF exterior walls consumed at least 5% less electricity than the wood-framed houses during a 12-month period. When compared specifically during the summer months (June through September), the houses with ICF exterior walls showed even lower electricity consumption in comparison to the wood-framed houses.

The computer simulation models showed that the houses with ICF exterior walls consumed almost 10% less natural gas than the wood-framed houses during a 12-month period.

Comparison of the energy performance of houses with ICF exterior walls to wood-framed houses based on actual consumption

The average actual consumption for the wood-framed houses with BFG walls and attics (#1 & #2) was 0.425 kWh/month/S.F., 5% less than the model predicted. The other houses consumed 19% less (#3: wood-framed with BFG walls and SF attic), 41% less (#4: ICF exterior walls with BFG attic), and 17% less (#5: ICF exterior walls with SF attic), than the average of houses #1 and #2. Table 12 presents the monthly actual electricity consumption of the houses. Based on the collected data on indoor moisture content, the relative humidity in house #5 was high, likely due to the tightness of the building envelope. This could be due to the ICF exterior walls and spray foam insulation in the attic; however, the research team did not do any further investigation. As a result, the HVAC system ran more frequently, leading to increased electricity consumption. Implementing different ventilation strategies to introduce fresh air could resolve this issue.

Table 12. Monthly actual electricity consumption (kWh) of houses

Month	#1	#2	#3	#4	#5
Feb	518.81	659.75	349.43	271.15	337.25
Mar	566.67	798.39	351.39	362.86	400.42
Apr	627.56	615.81	419.51	393.64	421.17
May	978.19	615.13	646.29	593.11	676.74
Jun	1,289.35	980.73	1,088.70	966.33	1,063.80
July	1,658.71	1,275.33	1,496.04	1,204.16	1,351.40
August	1,651.03	1,409.85	1,391.66	1,147.30	1,338.76
September	1,274.50	946.40	1,064.91	692.11	1,124.71
October	782.72	555.49	689.54	365.74	697.20
November	593.62	398.57	442.16	275.80	517.68
December	637.80	449.53	461.12	308.07	640.51

January	601.12	545.02	413.06	454.17	442.17
TOTAL	11,180.09	9,250.00	8,813.80	7,034.43	9,011.82
Monthly Average Per S.F.	0.45	0.40	0.35	0.30	0.36
Delta			-19.1%	-40.6%	-16.5%

The difference in average actual electricity usage among the houses was reduced during the summer months (June through September). This reduction in difference is attributed to the high cooling loads of the houses during this period, due to being in Oklahoma. Notably, house #5 exhibited better performance than house #3 during the summer months, which is different from the 12-month average consumption. Table 13 provides a breakdown of the monthly actual consumption of the houses during the summer months.

Table 13. Monthly actual electricity consumption (kWh) of houses during summer months

Month	#1	#2	#3	#4	#5
Jun	1,289.35	980.73	1,088.70	966.33	1,063.80
July	1,658.71	1,275.33	1,496.04	1,204.16	1,351.40
August	1,651.03	1,409.85	1,391.66	1,147.30	1,338.76
September	1,274.50	946.40	1,064.91	692.11	1,124.71
TOTAL	5,873.60	4,612.32	5,041.31	4,009.90	4,878.68
Monthly Average Per S.F.	0.71	0.59	0.65	0.51	0.59
Delta			-0.6%	-26.5%	-10.4%

The average actual natural gas consumption for the wood-framed houses with BFG walls and attics (#1 & #2) was 0.02445 CCF/month/S.F., which is about 6% less than the model predicted. In comparison to houses #1 and #2, the other houses consumed 6% less (#3: wood framed with BFG walls and SF attic), 3% less (#4: ICF exterior walls with BFG attic), and 6% less (#5: ICF exterior walls with SF attic), than the baseline houses with wood-framed walls and BFG insulation. Table 14 presents the monthly actual consumption of the five houses. House #2 (wood-framed with BFG walls and attic) had the lowest gas consumption among all five houses.

Table 14. Monthly actual natural gas consumption (ccf) of houses

Month	#1	#2	#3	#4	#5
Jan	147.00	143.00	126.00	132.00	120.00
Feb	102.00	82.00	94.00	91.00	96.00
Mar	78.00	58.00	70.00	68.00	75.00

Apr	64.00	42.00	56.00	55.00	60.00
May	28.00	14.00	24.00	20.00	22.00
Jun	13.00	11.00	12.00	10.00	15.00
July	11.00	11.00	11.00	11.00	12.00
August	10.00	11.00	9.00	10.00	9.00
September	11.00	9.00	10.00	10.00	10.00
October	11.00	11.00	9.00	13.00	13.00
November	29.00	30.00	30.00	26.00	28.00
December	83.00	73.00	73.00	61.00	65.00
TOTAL	587.00	495.00	524.00	507.00	525.00
Monthly Average Per S.F.	0.0258	0.0231	0.0230	0.0236	0.0231
Delta	-	-	-6.2%	-3.4%	-5.9%

A similar trend in the average consumption of natural gas among the houses was observed during the winter months (December through March). However, the difference from the baseline houses was slightly more. It is worth noting that the difference in gas consumption could have been higher if the heating loads were greater, but Oklahoma experienced a mild winter during 2023-2024. Notably, house #5 exhibited better performance than house #3 during the winter months, which is different from the 12-month average consumption. Table 15 provides a breakdown of the monthly actual consumption of the five houses during the winter months.

Table 15. Monthly actual natural gas consumption (ccf) of the houses during winter months

Month	**#1**	**#2**	**#3**	**#4**	**#5**
Jan	147.00	143.00	126.00	132.00	120.00
Feb	102.00	82.00	94.00	91.00	96.00
Mar	78.00	58.00	70.00	68.00	75.00
December	83.00	73.00	73.00	61.00	65.00
TOTAL	410.00	356.00	363.00	352.00	356.00
Monthly Average Per S.F.	0.0660	0.0609	0.0585	0.0602	0.0573
Delta	-	-	-8.5%	-5.4%	-10.7%

Remark:

Over a period of 12 months, houses with ICF exterior walls demonstrated a reduction in both electricity and natural gas consumption compared to wood-framed houses.

During the summer months (June through September), houses with ICF exterior walls used at least 10% less electricity than their wood-framed counterparts.

During the winter months (December through March), houses with ICF exterior walls consumed at least 5% less natural gas compared to wood-framed houses.

Comparison of indoor temperature fluctuations with variations of outdoor temperatures for houses with ICF exterior walls to wood-framed houses

The team worked with the homebuilder to include a clause in the sale contract that allowed them to install sensors on the inside and outside of the houses for a period of 12 months. Two indoor sensors were installed in each of the houses to collect temperature data. Outdoor sensors were installed in the neighborhood where the houses were to collect localized outdoor temperature data. By computing the differences between the indoor temperatures with the outdoor temperatures, considering the unique set-point temperatures of each home, the variation in these differences was assessed using the coefficient of variation. The team decided to compare the coefficient of variations, as the variability of the temperature differences would otherwise be difficult to compare. A larger coefficient of variation means that there is more variability in the data set, while a smaller coefficient of variation means there is less variability in the data set. Table 16 provides the coefficients of variations in all five houses post occupancy for a period of 12 months.

Houses #4 and #5 (ICF exterior walls with BFG insulation and ICF exterior walls with SF insulation respectively) showed a smaller coefficient of variations in comparison to houses #1 and #2 (wood-framed houses with BFG walls and attics). The range of coefficient of variations for houses #4 and #5 ranged from 0.17 – 0.26 and 0.17 – 0.28 respectively, whereas that of houses #1 and #2 are 0.47-0.67 and 0.30-0.49. This showed that there were more fluctuations in the indoor temperatures in houses #1 and #2 with the change in outdoor temperatures. House #3 showed less variation with the change in outdoor temperature (range of coefficient of variations 0.20-0.40). The lower coefficients of variation observed in houses #4 and #5 (ICF exterior walls with BFG and SF insulation) suggest that the thermal mass of the concrete in ICF walls could have played a role in moderating heat flow into the interior spaces. This reduced temperature fluctuations and helped regulate indoor conditions, leading to decreased peak heating and cooling demands. By comparison, houses #1 and #2 (wood-framed homes) exhibited greater temperature fluctuations due to the lack of thermal mass in the exterior walls, resulting in a less stable indoor thermal environment. The more stable indoor temperatures in ICF homes could contribute to increased occupant comfort and improved energy efficiency. These lower coefficients of variation suggest that the ICF homes will be more comfortable to occupants than wood-framed homes.

Table 16. Variations (coefficient of variation) in the differences between indoor/outdoor temperatures of houses

Month	**#1**	**#2**	**#3**	**#4**	**#5**
January	0.49	0.38	0.27	0.19	0.28
Feb	0.47	0.30	0.20	0.17	0.21
Mar	0.58	0.42	0.21	0.2	0.17
Apr	0.56	0.42	0.25	0.2	0.27
May	0.48	0.38	0.34	0.21	0.22
Jun	0.59	0.43	0.25	0.26	0.28
July	0.67	0.49	0.30	0.19	0.21
August	0.63	0.42	0.33	0.20	0.22
September	0.55	0.38	0.38	0.25	0.27
October	0.58	0.41	0.39	0.25	0.28
November	0.67	0.39	0.40	0.25	0.26
December	0.59	0.44	0.40	0.22	0.27
Mean (Std. Dev.)	0.57 (0.067)	0.41 (0.046)	0.31 (0.074)	0.22 (0.030)	0.25 (0.037)

Remark:

Indoor temperatures of houses with ICF exterior walls fluctuated less with variations in outdoor temperatures than that of the wood-framed houses.

Energy usage behaviors of occupants of the houses

The team surveyed homeowners to gather data on the energy usage behaviors of the occupants in the houses. The number of occupants, including adults and children, in each house ranged from two to four individuals. Occupants in houses #1 through #4 occupied their houses for 11-15 hours per day. In contrast, house #5 had an occupancy duration of 6-10 hours per day. The duration for which lights were left on was consistent across all houses. Occupants of houses #3 and #4 demonstrated a higher level of energy consumption monitoring compared to those in the other houses. Higher energy consumption monitoring and relatively lower set point temperatures could be some of the reasons why the actual consumption of electricity and natural gas was low for house #4. However, because the actual consumption was consistent with the modeled consumption, with house #4 performing the best, the difference is likely not entirely driven by occupant behavior. Table 17 below summarizes the number of occupants in each house and their corresponding energy usage behaviors.

Table 17. Energy usage behaviors of occupants of the houses

Criteria		**#1**	**#2**	**#3**	**#4**	**#5**
Number of occupants	**Adults**	2	2	2	2	3
	Children	1	0	1	1	1
Number of hours each person occupies the home	**Adults**	11-15	11-15	11-15	11-15	6-10
	Children	11-15		11-15	11-15	6-10
Number of hours, lights are on in the main living area		<12	13-16	< 12	< 12	< 12
How often do you rely on natural ventilation		Never	Half the time	Never	Sometimes	Never
Set point temperature		70-72	78	69-70	68-73	70-71
Do you utilize ceiling fan		Yes	Yes	Yes	Yes	No
Do you take advantage of Smart hour Program		Yes	No	No	No	No
How closely do you monitor your energy consumption (1=never; 5 =always)		1	2	4	4	1

Cost-benefit analysis of houses with ICF exterior walls

The team conducted a cost-benefit analysis comparing houses with ICF exterior walls to those with wood-framed walls. The potential savings for houses with ICF exterior walls come from reduced framing labor costs (when framing crews agree to an alternative payment method other than the prevailing one based on the square footage of the houses) and lower utility bills due to reduced consumption of natural gas and electricity. Utility expenses for each house were calculated based on their actual consumption of natural gas and electricity, as detailed in Table 18. The analysis considered potential savings in framing labor costs*, estimating that 25% of the framing labor costs, approximately $2,200, could be saved for houses #4 and #5 with ICF exterior walls. Considering the savings on labor costs and utility bills it would take over 20 years to recoup the additional cost of constructing houses with ICF exterior walls. However, the break-even period could be shortened if utility prices increase in the coming years.

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[*] The total framing package of the houses was divided into 50% wall framing and 50% roof/attic framing. In houses with ICF exterior walls, the wall framing requirements were reduced by 45%-50%. Wall framing was only necessary for the garage walls and the interior walls in the houses with ICF exterior walls.

- The monthly rates of natural gas per ccf were gathered from the utility provider. $39 per month is set as a monthly fee by the utility provider and cost based on usage varied from excess of $100 during the winter months to less than $10 during the summer months.
- The monthly rates of electricity included a fixed charge of $13 for residential consumers and surcharges for fuel cost, and past winter events in the region. The rate per kWh varied after the first 600 kWh.
- On average, the occupants of the houses with ICF exterior walls paid ~$270/year less in energy bills compared to the base houses.
- The range of savings in utility bills for an ICF to a wood-framed house was $141 to $396/year.

Table 18. Utility expenses of the houses

	#1	#2	#3	#4	#5
Feb	$ 210.25	$ 206.43	$ 182.11	$ 169.75	$ 182.47
Mar	$ 193.13	$ 194.76	$ 159.45	$ 159.02	$ 170.04
Apr	$ 190.36	$ 167.84	$ 158.30	$ 154.17	$ 162.43
May	$ 170.51	$ 134.08	$ 141.91	$ 135.24	$ 143.27
Jun	$ 227.82	$ 185.25	$ 200.29	$ 182.83	$ 198.37
July	$ 276.55	$ 224.86	$ 254.62	$ 215.26	$ 235.59
August	$ 275.96	$ 244.00	$ 240.43	$ 208.04	$ 233.29
September	$ 225.82	$ 180.44	$ 196.99	$ 146.72	$ 205.05
October	$ 159.38	$ 129.12	$ 145.70	$ 106.13	$ 149.00
November	$ 131.33	$ 111.93	$ 116.41	$ 96.82	$ 122.91
December	$ 157.69	$ 134.95	$ 136.14	$ 114.41	$ 148.84
January	$ 191.55	$ 183.72	$ 161.19	$ 168.58	$ 161.01
Total	$ 2,410.35	$ 2,097.38	$ 2,093.53	$ 1,856.98	$ 2,112.28
Summer Total	$ 1,006.15	$ 834.55	$ 892.32	$ 752.85	$ 872.30
Winter Total	$ 752.62	$ 719.86	$ 638.89	$ 611.76	$ 662.36

Table 19. Summary of material cost, labor cost, and utility cost for the wood-framed houses and houses with ICF exterior walls

Cost/S.F.	**Wood-framed houses**	**Houses with ICF walls**
Materials Costs	$16.16	$17.60
Labor Costs	$4.56	$7.60
Utility Costs	$1.12	$0.99

Per square foot (S.F.) costs were calculated by dividing the total costs for each category of the houses with two different floor plans by 4020 S.F. (the combined square footage of the two floor plans).

Remark:

On average, the occupants of houses with ICF exterior walls paid approximately $270 less per year in energy bills compared to the wood-framed houses.

The savings in utility bills ranged from $141 to $396 per year.

Conclusions

This study investigated the energy consumption patterns of five houses in two different floor plans (two of which were 1,950 S.F., and three were 2,070 S.F.). All the houses were built in 2022 and the municipality they are located had adopted the 2015 IRC at the time of construction. Two houses were wood-framed with BFG walls and attics to represent the baseline for comparison in this study (houses #1 and #2). One house was wood-framed with BFG walls but an SF attic; two houses were built with ICF exterior walls, one with an SF attic, and the other with a BFG attic. The houses with wood-framed construction and BFG insulation in both walls and attic (#1 & #2) exhibited the highest modeled electricity consumption, averaging 0.445 kWh/month/S.F. over the 12-month period. This was 5.4% more than the wood-framed house with BFG walls and an SF attic, approximately 9% more than the house with ICF exterior walls and BFG attic, and 5% more than the house with ICF exterior walls and SF attic (with the lowest modeled consumption observed in the house with ICF exterior walls and BFG attic).

The actual consumption data revealed that the wood-framed houses with BFG walls and attics (#1 & #2) consumed 5% less than the model predicted. The other houses demonstrated even greater reductions:

- House #3 (wood-framed with BFG walls and SF attic) consumed 19% less than the baseline wood-framed houses based on actual consumption data.
- House #4 (ICF exterior walls with BFG attic) consumed 41% less than the baseline wood-framed houses based on actual consumption data.
- House #5 (ICF exterior walls with SF attic) consumed 17% less than the baseline wood-framed houses based on actual consumption data.

Notably, during the summer months (from early June through September), the difference in average actual electricity usage among houses decreased. This reduction can be attributed to the high cooling loads in the houses due to their geographical location.

Furthermore, the houses with ICF exterior walls consistently exhibited lower gas consumption. As expected, the wood-framed houses with BFG insulation in both walls and attic (#1 & #2) had the highest modeled gas consumption, averaging 0.026 CF/month/S.F. over the 12-month period.

This was 21% more than the wood-framed house with BFG walls and an SF attic, approximately 35% more than the house with ICF exterior walls and BFG attic, and 10% more than the house with ICF exterior walls and SF attic (with the lowest modeled consumption observed in the house with ICF walls and BFG attic).

Additionally, houses #4 and #5 (ICF exterior walls with BFG insulation and ICF exterior walls with SF insulation, respectively) demonstrated smaller coefficients of variation compared to houses #1 and #2 (wood-framed houses with BFG walls and attics). Specifically, the coefficient of variation ranged for houses #4 and #5 was 0.17–0.26 and 0.17–0.28, respectively. In contrast, houses #1 and #2 had wider ranges: 0.47–0.67 and 0.30–0.49. A higher coefficient of variations suggests that houses #1 and #2 experienced more fluctuations in indoor temperatures due to changes in outdoor temperatures.

Following are the major findings of this study:

- The cost of materials for houses constructed with ICF exterior walls was approximately 20% higher than that of similarly sized wood-framed houses. However, there is potential for labor cost savings if the framing crew is compensated differently from the prevailing method based on the square footage of the houses.
    - Approximately 25% of the framing labor costs could be saved for houses with ICF exterior walls if the framing crew is not compensated based on the square footage of the houses.
- Based on computer simulation models, houses constructed with ICF exterior walls consumed at least 5% less electricity than wood-framed houses over a 12-month period. Additionally, these models indicated that houses with ICF exterior walls used almost 10% less natural gas than wood-framed houses during the same period.
- Actual consumption data over a 12-month period showed that houses with ICF exterior walls demonstrated reduced electricity and natural gas usage compared to wood-framed houses.
    - During the summer months (June through September), houses with ICF exterior walls used at least 10% less electricity than their wood-framed counterparts.
    - During the winter months (December through March), houses with ICF exterior walls consumed at least 5% less natural gas compared to wood-framed houses.

- Indoor temperatures in houses with ICF exterior walls fluctuated less with variations in outdoor temperatures compared to wood-framed houses.
- On average, the occupants of houses with ICF exterior walls paid approximately $270 less per year in energy bills compared to those in wood-framed houses.

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Appendix – I

Image 1: Research team member holding an ICF block

Image 2: Jobsite foreman places concrete inside ICF walls

Image 3: Pump truck operator and foreman working in tandem to place concrete inside ICF walls

Image 4: Workers install courses of ICF blocks

Image 5: View of inside of ICF house prior to concrete placement

Image 6: Workers vibrate the concrete inside the ICF walls

Image 7: Pump truck at ICF house site

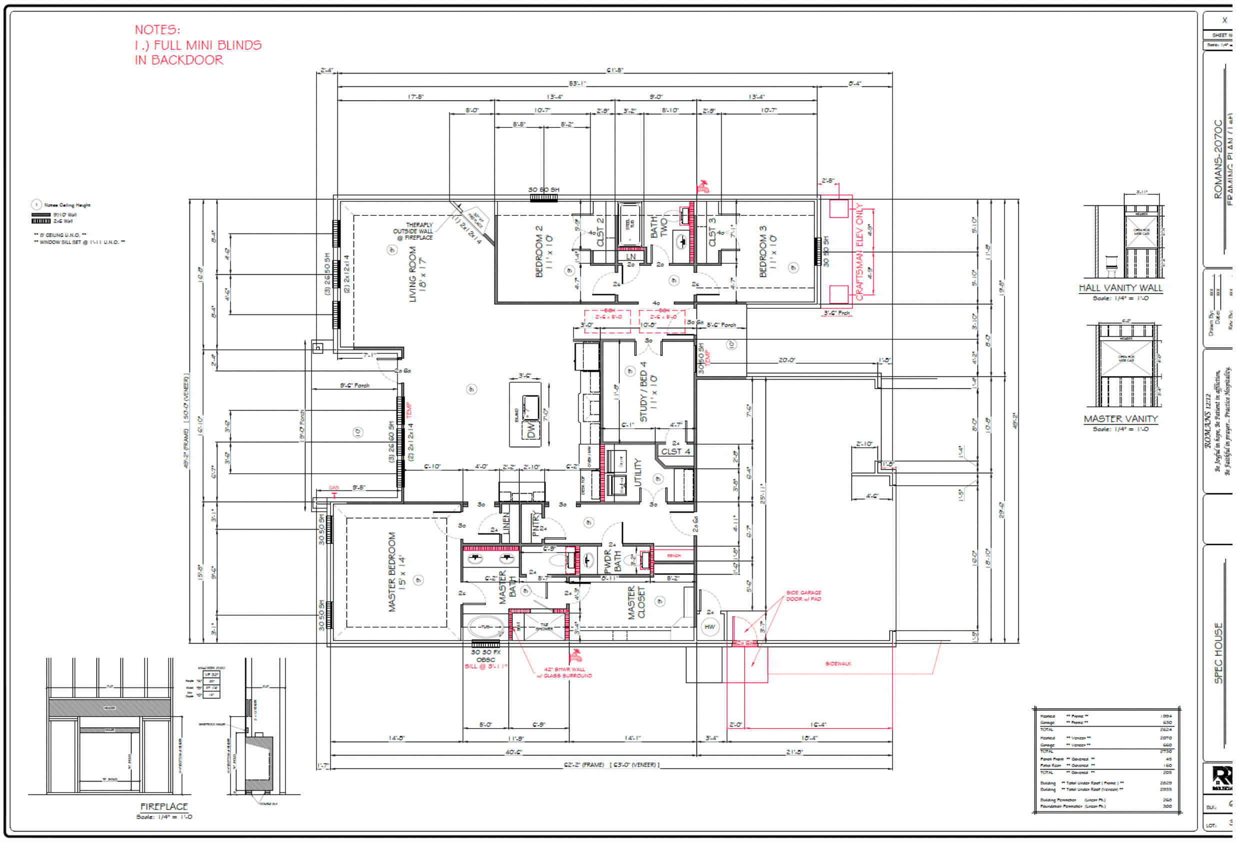
Image 8: A view of ICF blocks before final exterior cladding is installed

Image 9: A view from the top of ICF filled with concrete

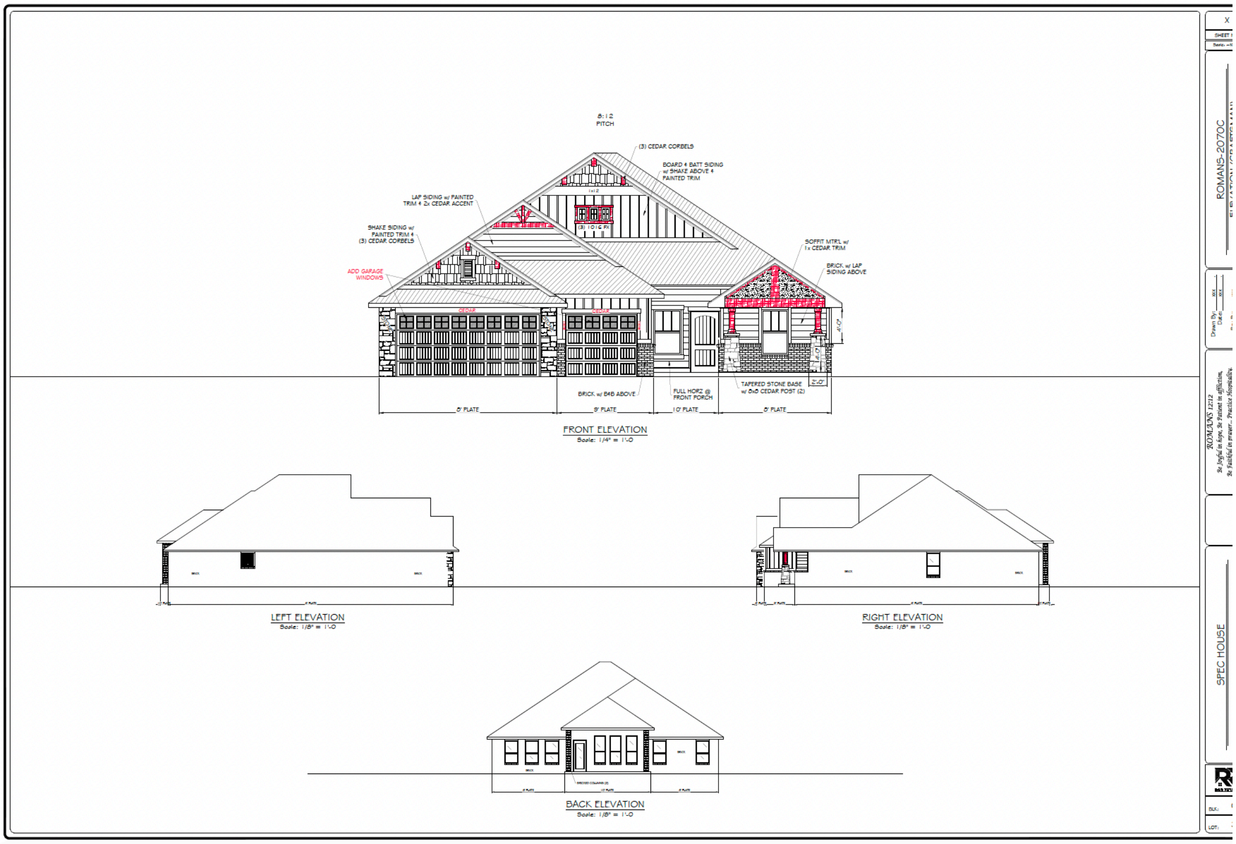
Image 10: Example of a typical ICF block

Image 11: Example of a shipment of ICF blocks on the jobsite

Appendix – II

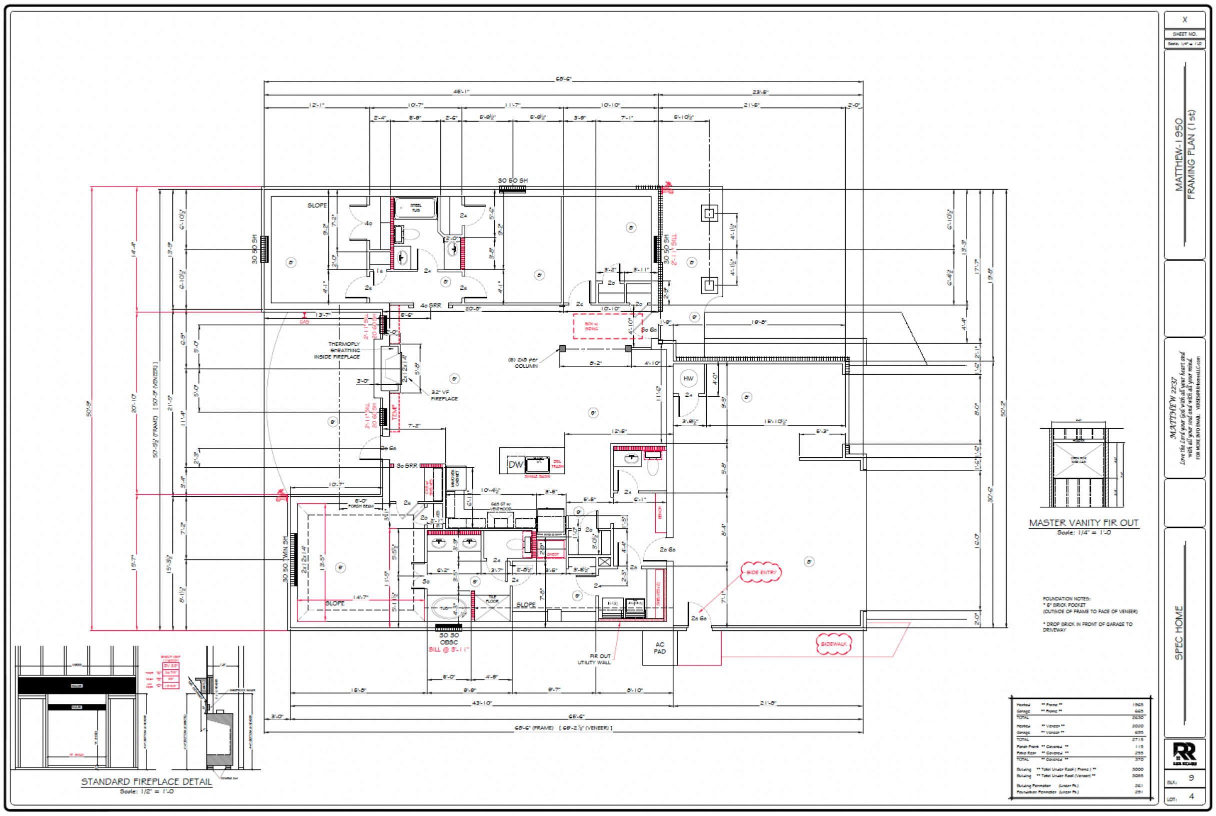


Floor plan of House #1 and #3

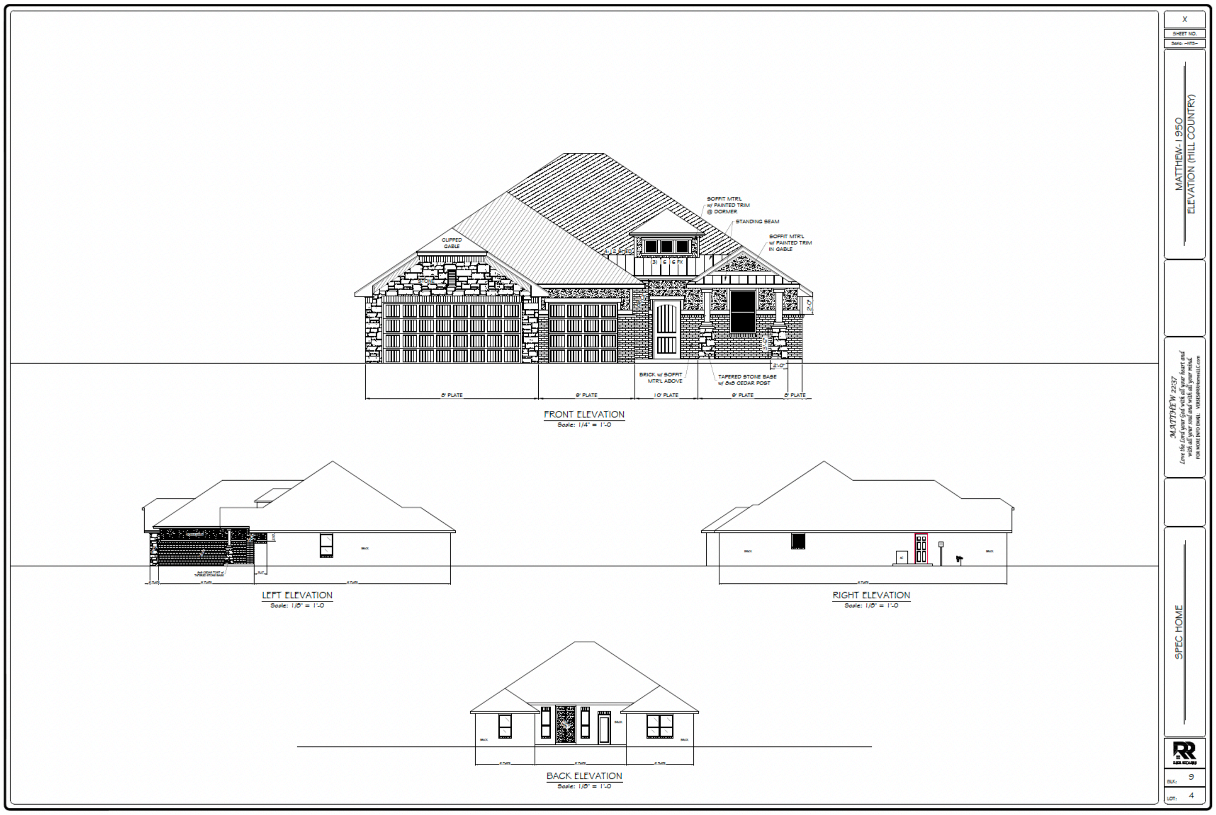


Elevations of House #1 and #3

Appendix – III

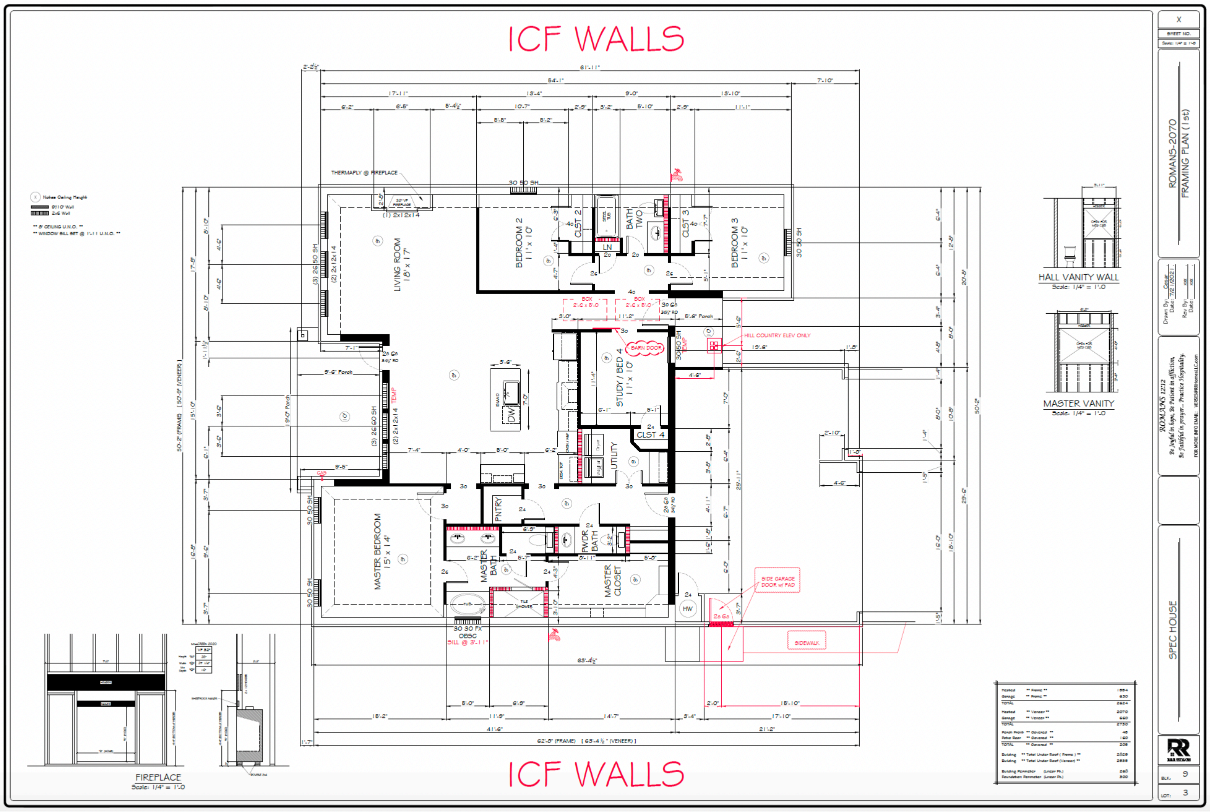


Floor plan of House #4

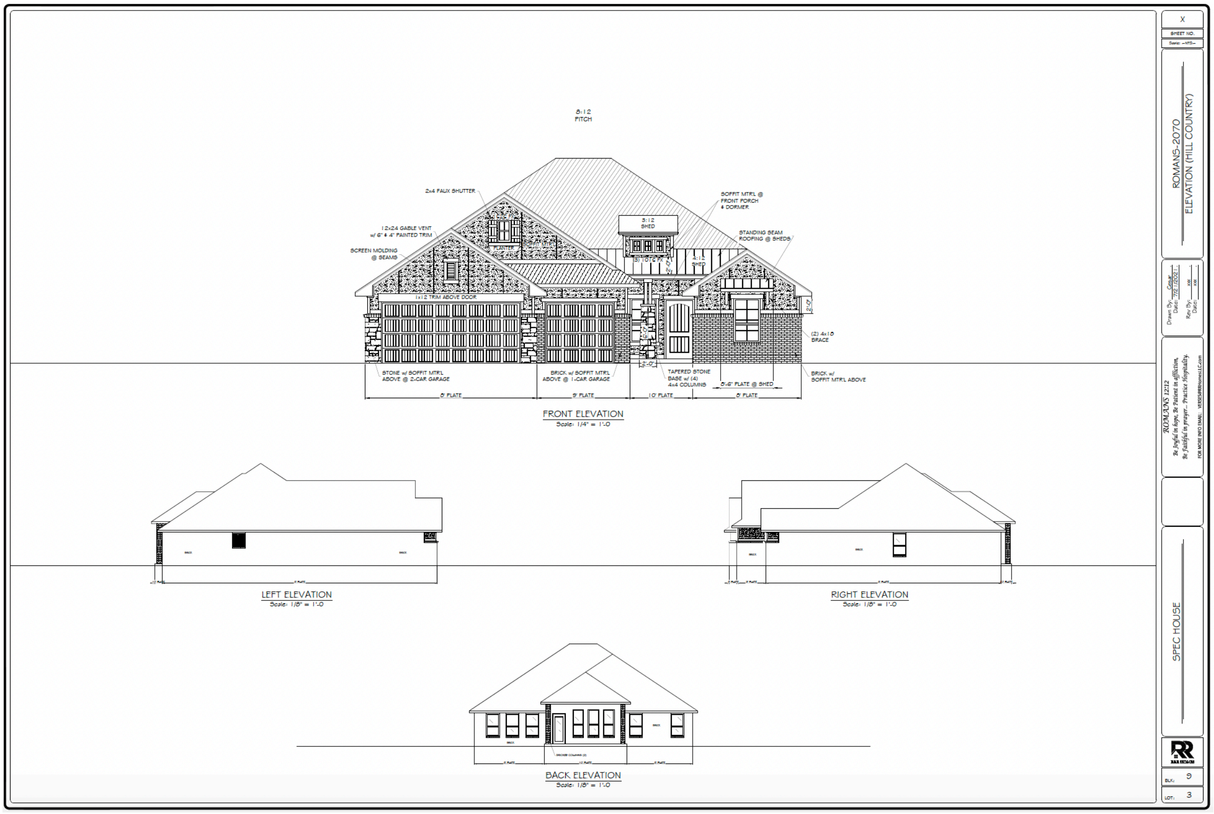


Elevations of House #4

Appendix – IV



Floor plan of House #5



Elevations of House #5

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