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Spray Polyurethane Foam Alliance (SPFA)

SPRAY POLYURETHANE FOAM ALLIANCE
SPFA

SPF Residential Energy Modeling Analysis

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Certified WBENC Women's Business Enterprise

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1.0 Introduction and Background

The Spray Polyurethane Foam Alliance (SPFA) has updated the industry-wide LCA (Life Cycle Assessment) of spray polyurethane foam (SPF) products. An LCA is a technique used to assess environmental impacts associated with all stages of a product's life, from cradle-to-grave. As part of the LCA, SPFA is evaluating the impact on energy performance in residential applications using spray foam compared to two baselines: conventional insulation and zero insulation. Sustainable Solutions Corporation (SSC) was retained by SPFA to conduct energy modeling of residential buildings in order to understand the use phase impacts of using SPF.

The intent of this residential building energy analysis is to quantify the energy use impacts of two spray foam insulation implementations in new homes compared to a baseline case and provide credible data to document the expected savings. The baseline case utilizes air permeable insulation. All other attributes for the baseline case are based on International Energy Conservation Code (IECC) 2018, including an infiltration rate that is typical of new homes insulated with air permeable materials (fiberglass, cellulose, etc.).

2.0 Residential Modeling Criteria

The building energy simulations for the homes were completed using Residential Energy Services Network (RESNET)-approved Rem/Rate software by a qualified Professional Engineer. Because the United States is so large and diverse geographically, the country is broken up into eight climate zones, as illustrated in Figure 1. Energy consumption in each climate zone will vary since there are variations in humidity, heating degree days, and cooling degree days. In order to conduct a comprehensive and accurate study, the team conducted energy modeling in multiple climate zones. SSC conducted energy modeling for Climate Zone 2 (Houston), Zone 4 (Richmond), and Zone 6 (Minneapolis) for typical new construction single family homes.

The model home for each climate zone was standardized to a typical single-family detached home above grade, two-stories, four bedrooms over an unconditioned, vented crawl space with an insulated floor. This design was selected to better understand the effects of insulation and eliminate variations in typical home size and types by climate zone. A summary of the modeling parameters for each home and climate zone are listed below in Table 1. Appendix A contains a comprehensive table of all modeling parameters. SSC coordinated with SPFA on the recommended home type for each region and obtained approval from SPFA on home types prior to completing the energy modeling.

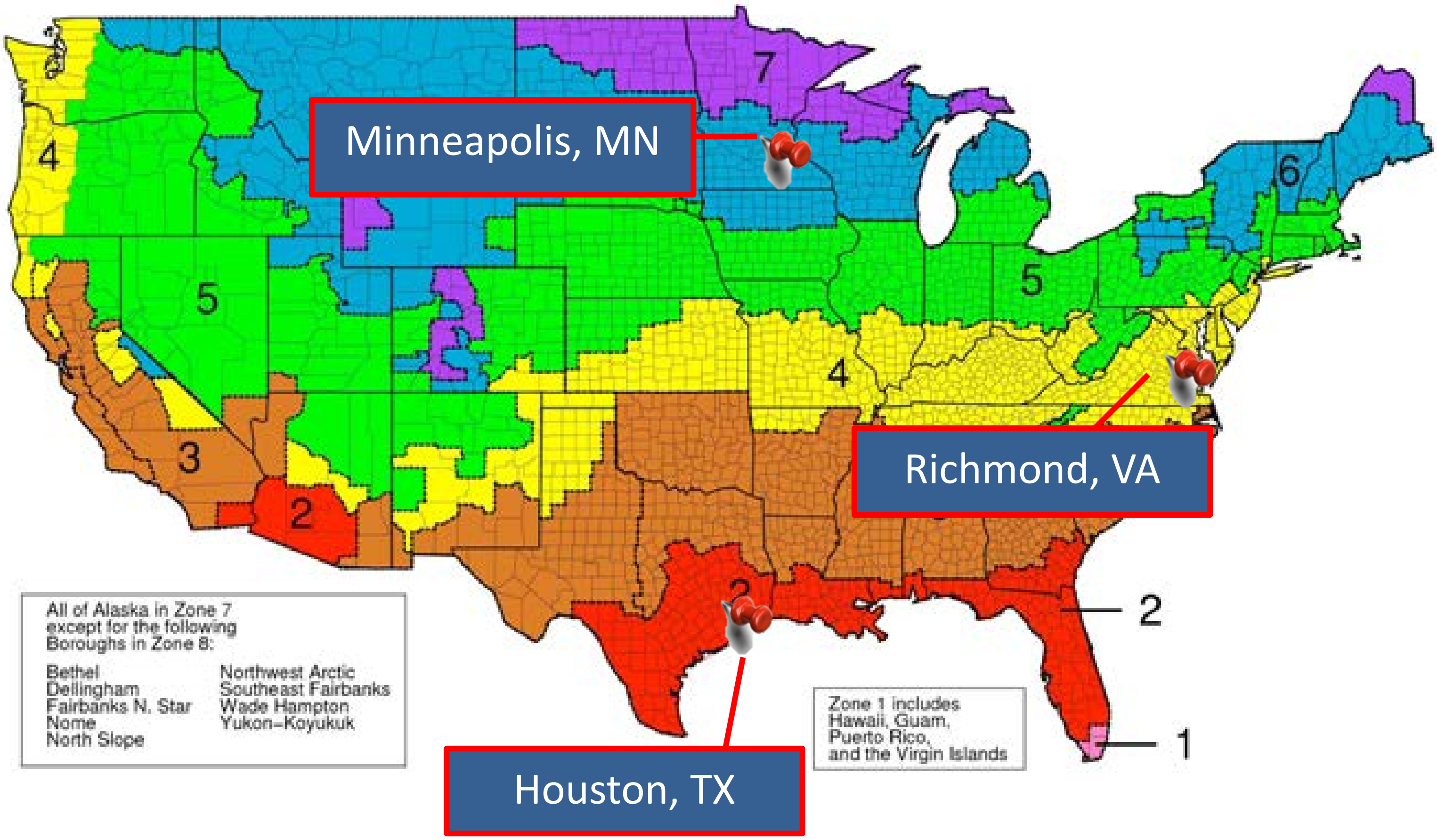

Figure 1: United States Climate Zone Map

Table 1: Typical New Home (Circa 2011) Building Construction (See Appendix A for more details)

Building Type	Climate Zone 2 (Houston)	Climate Zone 4 (Richmond)	Climate Zone 6 (Minneapolis)
Above Grade (sq ft)	2,434	2,434	2,434
Conditioned Area (sq ft)	2,434	2,434	2,434
Conditioned Volume (cu ft)	20,689	20,689	20,689
Housing Type	Single Family	Single Family	Single Family
# Stories (floors on or above grade)	2	2	2
Number of Bedrooms	4	4	4
Conditioned Floors (including basement where applicable)	2	2	2
Slab on Grade (Yes=1, No=0)	0	0	0
Crawl (Yes=1, No=0)	1	1	1
Basement (Yes=1, No=0)	0	0	0
Cavity Insulation R-Value (Assume Grade I)	Case 1: R-13 Case 2A: R-13 Case 2B: R-13	Case 1: R-20 Case 2A: R-20 Case 2B: R-20	Case 1: R-20 + 5 Case 2A: R-34.1 Case 2B: R-34.1
Ceiling Insulation R-Value	Case 1: R-38 Case 2A: R-38 Case 2B: R-38	Case 1: R-49 Case 2A: R-49 Case 2B: R-49	Case 1: R-49 Case 2A: R-49 Case 2B: R-49
Window Area (sq ft)	376.8	376.8	376.8
Total Area for All Doors (sq ft)	40	40	40
Construction Type	Comp shingle on wood sheathing	Comp shingle on wood sheathing	Comp shingle on wood sheathing
Mechanical Equipment			
Gas-fired forced air furnace + AC (AFUE/SEER)? (N/A=0)	80/14	80/14	80/13
Gas-fired water heater, 40 gallons (EF)	0.62	0.62	0.62
Whole-House Mechanical Ventilation	ERV	ERV	ERV
Airflow (cfm)	75	75	75
Daily Run Time	Continuous	Continuous	Continuous

3.0 Infiltration Rate Research

SSC conducted detailed research on infiltration rates for the various insulation materials in order to develop an accurate energy model for each climate zone. Since modeling parameters are based on the requirements of 2018 IECC energy code, the R-values for cases 2A and 2B are dictated by the code. Therefore, there is no variation of total R-value between the conventional and spray foam cases. The most significant difference between SPF and conventional air permeable insulation is the effect on air sealing and infiltration rates. SSC evaluated multiple studies and data sources to identify an average infiltration rate for homes using a variety of construction methods. Much of the data was based on blower door testing of existing and new homes which provides "real world data" based on actual homes. A summary of the research is described below.

Infiltration rate for the baseline (Case 1A)

Establishing accurate infiltration rates was critical to ensure the legitimacy of the energy modeling results. The infiltration rates together with ventilation were the primary variances between the baseline and spray foam cases. SSC performed an extensive review of all data pertaining to typical infiltration rates for new construction. The Lawrence Berkeley National Laboratory Blower Door Test database was a primary source for many of the studies reviewed [3, 4]. In addition, SSC reviewed data from several of the LEED Certified residential projects conducted by SSC, as well as data from Home Energy Rating System (HERS) raters and research conducted by Villanova University. There was substantial variation in the infiltration rates for these studies with infiltration rates ranging from 0.18 ACH50 to 9.1 ACH50. To maintain consistency, baseline infiltration rates were based on IECC 2018 Section 405. This section describes assumptions to be used when pursuing the performance path through energy modeling and references an infiltration rate in Climate Zones 1 and 2 to be 5 ACH50 (air changes per hour at 50 Pa) and in Climate Zones 3 through 8 to be 3 ACH50.

Infiltration rate for spray foam case (Cases 2A and 2B)

The infiltration rate for the spray foam case was determined as a result of various blower door test databases, including SSC's private database. There are limited studies that correlate infiltration rate with insulation type. Based on blower door tests and the previous modeling efforts in 2012, the infiltration rate utilized for the spray foam energy model (Case 2) was 1.5 ACH50.

4.0 Residential Modeling Assumptions

IECC 2018 was the guiding criterion for all residential modeling assumptions. Wherever possible, prescriptive requirements of IECC 2018 were adhered to for each residential model. This approach maintains an unbiased approach for the modeling assumptions and simplifies comparison between SPF and the baseline cases.

The residential energy modeling parameters for each climate zone in Appendix A were reviewed by SSC and the SPFA project team. Descriptions of all energy modeling assumptions are provided below:

- 80% AFUE furnaces – While this efficiency is not typical for new furnaces, the IECC 2018 minimum efficiency was used to maintain consistency.
- Duct leakage rate – The duct leakage rate (cfm/100 sq ft) of 4.0 is based on 2018 IECC Section 403.3.1.

- All homes are built on an unconditioned, vented crawl space with an insulated floor to eliminate regional differences in typical house designs and to isolate the effects of spray foam in Cases 2A and 2B.
- Mechanical ventilation rate was calculated in accordance with IRC 2018, table M1505.4.3. Mechanical rates for all homes in Houston, Richmond, and Minneapolis were calculated to 75 cfm based on the dwelling unit floor area and the number of bedrooms of the baseline and design homes.
- Ventilation rates for all cases remained constant to maintain consistency of results and to isolate energy savings from the spray foam cases. All cases are designed with whole house mechanical ventilation (WHMV) and an energy recovery ventilator (ERV) using the IRC 2018 ventilation rates. Typically, WHMV is accompanied by the use of an ERV, which is now the trend on new building codes as standard construction building envelope becomes more sealed. ERV efficiencies were calculated based on 2018 IEC table R403.6.1 requirements.

5.0 Residential Energy Modeling Results

The intent of this residential building energy analysis is to quantify the energy use impacts of spray foam insulation in new homes compared to the two baseline case homes and provide credible data to document the differences. SSC completed several energy models based on the parameters and assumptions listed above using REM/Rate software. A summary of each model case is listed below.

Table 2: Descriptions of Construction Cases used in Model

Case	Description
1A	Typical new home construction, using air permeable insulation, using infiltration rate from IRC 2018 Section 405
2A	Typical new home construction using spray from insulation with closed cell; SPF at ceiling
2B	Typical new home construction using spray foam insulation with closed cell; conditioned attic with SPF at roof deck

The results of the energy modeling are listed below in Tables 3 and 4. The HERS index for each case is provided. The HERS index is a metric that compares energy performance of residential buildings. The index typically ranges from 0 to 100, where a 0 represents a net zero energy home and a 100 represents a home that is built to IECC 2004 standards. A home could also receive a score outside of this range depending on its characteristics. Future energy efficiency tax credits and rebates are expected to be based on improvement to the HERS index. Whole house energy consumption is listed in therms/yr and kWh/yr. The whole house energy savings represents a reduction of energy use (percentage) compared to the baseline case.

Energy savings showed that Case 2B had the greatest savings across all climate zones with an average of 17% savings in heating therms and 7% savings in total kWh compared with the baseline Case 1A. Case 2A showed much more favorable heating savings in Houston and Minneapolis averaging 11% savings versus only 3% savings in Richmond along with showing mostly negligible electricity savings. These results indicate that homes that are air sealed using spray foam have significantly decreased energy consumption, compared to a home that is conventionally insulated and is even more efficient to design a conditioned attic with spray foam at the roof deck.

Table 3: Building Energy Simulation Results – Spray Foam Compared to Conventional Insulation

	Houston, TX			Richmond, VA			Minneapolis, MN		
	Air Permeable Insulation	Spray Foam Case 2A	Spray Foam Case 2B	Air Permeable Insulation	Spray Foam Case 2A	Spray Foam Case 2B	Air Permeable Insulation	Spray Foam Case 2A	Spray Foam Case 2B
Modeling Case	1A	2A	2B	1A	2A	2B	1A	2A	2B
Heating (therms)	194	154	136	356	344	295	706	618	536
Heating (kWh)	200	188	112	428	424	250	742	700	416
Cooling (kWh)	3,920	3,793	3,150	2,986	2,993	2,467	2,304	2,343	1,973
Total Gas, Electric Use, and HERS Index									
Total Gas (therms)	302	263	244	499	486	437	890	801	720
Total Electric (kWh)	10,919	10,780	10,062	10,214	10,216	9,516	9,846	9,843	9,189
HERS Index	66	63	58	66	66	60	64	61	56
Gas (therms) and Electricity (kWh) Percent Savings Compared to Case 1A									
Savings, (therms)		13%	19%		3%	12%		10%	19%
Savings, (kWh)		1%	8%		0%	7%		0%	7%
HERS Index Improvement Compared to Case 1A									
HERS Index Change		3	8		0	6		3	8

For Houston, Richmond, and Minneapolis, Case 2B resulted in the lowest combined electricity and gas energy usage. The increased electricity demand resulting in net negative savings (-0.02%) for Richmond and only slight electricity savings in Minneapolis (0.03%) for the spray foam case 2A is due in part to having a tighter envelope but a constant ventilation rate in the ERV.

6.0 Life Cycle Impacts and Payback Periods of Various Spray Foams

To better understand the environmental impacts of utilizing spray foam insulation in residential walls and ceilings, the global warming potential (GWP) and cumulative energy demand (CED) of hydrofluorocarbon (HFC) blowing agent and hydrofluoroolefin (HFO) blowing agent variations of 2K-LP closed cell spray foams were calculated, as well as open cell spray foam, along with payback periods. CED, also called primary energy consumption, is a measure of the total primary energy input for the generation of the product. Utilizing the reductions in energy use from Table 3 along with the environmental impacts from Environmental Product Declarations for spray foam and batt insulation, payback periods were calculated for HFO and HFC spray foams. Tables 4 and 5, below, show the GWP and CED savings resulting from the energy savings of using the spray foams from Case 2A; Tables 6 and 7, below, show the GWP and CED savings from Case 2B.

Table 4: Residential Building Global Warming Potential Impacts and Payback Periods (Case 2A)

Case 2A - Ceiling Insulation	Houston	Richmond	Minneapolis	Unit
Energy Modeling Results				
Natural Gas Savings	1,143	381	2,608	kWh
Electricity Savings	139	(2)	3	kWh
Global Warming Potential Annual Savings	349	84	589	kg CO_2/yr
Total Ceiling Insulation FU in Energy Model	819	1,057	1,057	Functional Units
Total Wall Insulation FU in Energy Model	534	822	1,401	Functional Units
Global Warming Potential of Insulation Materials				
2K-LP HFC	48,403	67,169	87,884	kg CO_2
2K-LP HFO	5,160	7,160	9,369	kg CO_2
Closed Cell HFC	27,321	37,914	49,607	kg CO_2
Closed Cell HFO	5,633	7,818	10,229	kg CO_2
Open Cell	2,242	3,111	4,070	kg CO_2
Baseline Fiberglass Insulation*	1,633	2,266	2,266†	kg CO_2
GWP Payback Period of SPF				
2K-LP HFC	134	769	145	years
2K-LP HFO	10	58	12	years
Closed Cell HFC	74	422	80	years
Closed Cell HFO	11	66	14	years
Open Cell	2	10	3	years

**Assumption based on multiple fiberglass insulation EPDs. Results may vary.*
† The wall volume limits the amount of Open Cell SPF applied for the Minneapolis Climate Zone. Other exterior-applied continuous insulation will be needed to achieve R-value. This analysis does not account for the difference in environmental impacts between material types.

Table 5: Residential Building Cumulative Energy Demand Impacts and Payback Periods (Case 2A)

Case 2A - Ceiling Insulation	Houston	Richmond	Minneapolis	Unit
Energy Modeling Results				
Natural Gas Savings	1,143	381	2,608	kWh
Electricity Savings	139	-2	3	kWh
Cumulative Energy Demand Annual Savings	4,433	938	6,609	MJ/yr
Total Ceiling Insulation FU in Energy Model	819	1,057	1,057	Functional Units
Total Wall Insulation FU in Energy Model	534	822	1,401	Functional Units
Cumulative Energy Demand of Insulation Materials				
2K-LP HFC	124,871	173,286	226,727	MJ
2K-LP HFO	123,409	171,258	224,073	MJ
Closed Cell HFC	144,133	200,016	261,701	MJ
Closed Cell HFO	149,154	206,985	270,819	MJ
Open Cell	58,927	81,774	106,992	MJ
Baseline Fiberglass Insulation*	20,634	28,635	28,635†	MJ
CED Payback Period of SPF				
2K-LP HFC	24	154	30	years
2K-LP HFO	23	152	30	years
Closed Cell HFC	28	183	35	years
Closed Cell HFO	29	190	37	years
Open Cell	9	57	12	years

**Assumption based on multiple fiberglass insulation EPDs. Results may vary.*

† The wall volume limits the amount of Open Cell SPF applied for the Minneapolis Climate Zone. Other exterior-applied continuous insulation will be needed to achieve R-value. This analysis does not account for the difference in environmental impacts between material types.

Table 6: Residential Building Global Warming Potential Impacts and Payback Periods (Case 2B)

	Houston	Richmond	Minneapolis†	Unit
Energy Modeling Results				
Natural Gas Energy Savings	1,699	1,817	4,981	kWh
Electricity Energy Savings	857	698	657	kWh
Global Warming Potential from Annual Energy Savings	950	871	1,556	kg CO_2/yr
Total Roofing Insulation FU in Energy Model	1,513	1,951	1,951	Functional Units
Total Wall Insulation FU in Energy Model	534	822	1,401	Functional Units
Global Warming Potential of Insulation Materials*				
2K-LP HFC	73,198	99,143	119,858	kg CO_2
2K-LP HFO	7,803	10,569	12,777	kg CO_2
Closed Cell HFC	41,317	55,962	67,655	kg CO_2
Closed Cell HFO	8,519	11,539	13,950	kg CO_2
Open Cell	3,390	4,592	5,551	kg CO_2
Baseline Fiberglass Insulation*	1,633	2,266	2,266†	kg CO_2
Global Warming Potential Payback Period				
2K-LP HFC	75	111	76	years
2K-LP HFO	6	10	7	years
Closed Cell HFC	42	62	42	years
Closed Cell HFO	7	11	8	years
Open Cell	2	3	2	years

**Assumption based on multiple fiberglass insulation EPDs. Results may vary.*

† The wall volume limits the amount of Open Cell SPF applied for the Minneapolis Climate Zone. Other exterior-applied continuous insulation will be needed to achieve R-value. This analysis does not account for the difference in environmental impacts between material types.

Table 7: Residential Building Cumulative Energy Demand Impacts and Payback Periods (Case 2B)

	Houston	Richmond	Minneapolis†	Unit
Energy Modeling Results				
Natural Gas Energy Savings	1,699	1,817	4,981	kWh
Electricity Energy Savings	857	698	657	kWh
Cumulative Energy Demand from Annual Energy Savings	13,855	12,375	19,896	MJ/yr
Total Roofing Insulation FU in Energy Model	1,513	1,951	1,951	Functional Units
Total Wall Insulation FU in Energy Model	534	822	1,401	Functional Units
Cumulative Energy Demand of Insulation Materials*				
2K-LP HFC	188,839	255,772	309,213	MJ
2K-LP HFO	186,629	252,778	305,593	MJ
Closed Cell HFC	217,969	295,225	356,910	MJ
Closed Cell HFO	225,563	305,511	369,345	MJ
Open Cell	89,113	120,698	145,917	MJ
Baseline Fiberglass Insulation*	20,634	28,635	28,635†	MJ
Cumulative Energy Demand Payback Period				
2K-LP HFC	12	18	14	years
2K-LP HFO	12	18	14	years
Closed Cell HFC	14	22	16	years
Closed Cell HFO	15	22	17	years
Open Cell	5	7	6	years

**Assumption based on multiple fiberglass insulation EPDs. Results may vary.*

† The wall volume limits the amount of Open Cell SPF applied for the Minneapolis Climate Zone. Other exterior-applied continuous insulation will be needed to achieve R-value. This analysis does not account for the difference in environmental impacts between material types.

Spray foam in Case 2A showed that the most favorable GWP payback was Open Cell followed by 2K-LP HFO and Closed Cell HFO across all climate zones. Open Cell also had the most favorable CED and was followed by 2K-LP HFO but 2K-LP HFC had a better payback compared to Closed Cell HFO across all climate zones. Case 2B showed that Open Cell still had the best paybacks across all climate zones for GWP and CED. There are also similar trends of GWP in case 2B that were observed in 2A but CED showed very similar paybacks for all spray foam types following Open Cell being the only outlier.

Appendix A: Typical New Home (Circa 2019) Expanded Table

New Homes - Circa 2019			
City	Houston	Richmond	Minneapolis
State	TX	VA	MN
Reference Code	2018 IECC	2018 IECC	2018 IECC
Climate Zone, IECC	2	4	6
Cooling Employed (Yes=1, No=0)	1	1	1
House orientation for front of home	South	South	South
Above grade sqft & for calculating mechanical ventilation rates	2434	2434	2434
Aspect ratio	1	1	1
First Floor Ceiling Height (ft)	8.5	8.5	8.5
Second Floor Ceiling Height (ft)	8.5	8.5	8.5
Conditioned area (sqft)	2434	2434	2434
Conditioned volume (cuft)	20689	20689	20689
Housing Type	SFD	SFD	SFD
# Stories (floors on or above grade)	2	2	2
Bedrooms	4	4	4
Conditioned floors (including basement where applicable)	2	2	2
Foundation			
Slab on grade (Yes=1, No=0)	0	0	0
Crawl (Yes=1, No=0)	1	1	1
Basement (Yes=1, No=0)	0	0	0
Conditioned basement (Yes=1, No=0)	0	0	0
Floor U-factor	0.064	0.047	0.033
Foundation Full Perimeter (ft)	139.5	139.5	139.5
Crawlspace height	3	3	3
Band Joist			
Band joist area (sqft)	139.5	139.5	139.5
Above Grade Wall			
Gross area (sqft)	2512	2512	2512
Length (ft)	34.9	34.9	34.9
Width (ft)	34.9	34.9	34.9
Solar absorptance	0.75	0.75	0.75
Solar emittance	0.9	0.9	0.9
Windows			
Window U-value	0.40	0.32	0.30
Window SHGC	0.25	0.40	0.40
Window area (sqft)	376.8	376.8	376.8
NW	94.2	94.2	94.2
SE	94.2	94.2	94.2
NE	94.2	94.2	94.2
SW	94.2	94.2	94.2
Interior shading, winter	0.87	0.84	0.84
Interior shading, summer	0.87	0.84	0.84

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New Homes - Circa 2019			
City	Houston	Richmond	Minneapolis
Overhang depth (ft)	0.0	0.0	0.0
Overhang to top of window (ft)	0.0	0.0	0.0
Overhang to bottom of window (ft)	0.0	0.0	0.0
Doors			
Orientation (one front, one back)			
Total area for all doors (sqft)	40	40	40
U-factor	0.40	0.32	0.30
Attic/Ceiling			
Gross area (sqft)	1217	1217	1217
Roof			
Construction type	Comp shingle on wood sheathing	Comp shingle on wood sheathing	Comp shingle on wood sheathing
Venting ratio	1:300	1:300	1:300
Solar Absorptance	0.75	0.75	0.75
Emittance	0.9	0.9	0.9
Radiant barrier? (Yes=1, No=0)	0	0	0
Mechanical Equipment			
Gas-fired forced air furnace + AC (AFUE/SEER)? (N/A=0)	80/14	80/14	80/13
Gas-fired water heater, 40 gallons (EF)	0.62	0.62	0.62
Location of space heating and cooling equipment (CA=ConditionedArea)	Attic	Attic	Attic
Location of water heater (F=first floor, G=garage, B=Basement)	G	G	G
Heating set point (deg F)	72	72	72
Cooling set point (deg F)	75	75	75
Programmable T-stat (Yes=1, No=0)	1	1	1
Duct System - set areas by EnergyGauge default			
Sq Ft served	2434	2434	2434
Conditioned areas			
Supply duct	REM default	REM default	REM default
Return duct	REM default	REM default	REM default
Attic			
Supply duct	REM default	REM default	REM default
Return duct	REM default	REM default	REM default
Cooling season ventilation (Natural Ventilation)	0	0	0
Lighting, % high efficacy	90%	90%	90%
Refrigerator (kWh/yr)	403	403	403
Dishwasher (EF)	0.46	0.46	0.46
Ceiling Fan (cfm/Watt)	0	0	0
Whole-House Mechanical Ventilation	ERV	ERV	ERV
Airflow (cfm)	75	75	75
Daily run time (hours)	continuous	continuous	continuous
Fan power draw (watts)	63	63	63

New Homes - Circa 2019			
City	Houston	Richmond	Minneapolis
Effectiveness: SRE	70%	70%	70%
Effectiveness: TRE	50%	50%	50%

Case 1, System "A" Air Permeable Insulation, additional parameters

New Homes - Circa 2019			
City	Houston	Richmond	Minneapolis
Conditioned floor area for REM/Rate (ft2)	2434	2434	2434
Conditioned volume for REM/Rate (ft3)	20689	20689	20689
Whole Dwelling Infiltration (ACH)	5.0	3.0	3.0
Duct location (unconditioned attic/ conditioned space)	75/25	75/25	75/25
Duct insulation R-value	8	8	8
Duct leakage rate, total (cfm25/ 100 sq ft)	4	4	4
Duct leakage rate, to exterior (cfm25)	73	73	73
Ceiling insulation R-value	38	49	49
Ceiling insulation R-value per inch	3.5	3.5	3.5
Ceiling cavity R-value	12.3	12.3	12.3
Ceiling cavity insulation thickness (in)	3.5	3.5	3.5
Ceiling continuous insulation R-value	25.8	36.8	36.8
Ceiling continuous insulation thickness (in)	7.4	10.5	10.5
Wall insulation R-value	13 + 0	20 + 0	20 + 5
Wall cavity R-value	13	20	20
Wall cavity insulation thickness (in)	3.5	5.5	5.5
Wall continuous insulation R-value	0	0	5
Wall continuous insulation thickness (in)	0	0	1

Case 2, System "A" Spray Foam Insulation with Closed Cell; SPF at Ceiling

New Homes - Circa 2019			
City	Houston	Richmond	Minneapolis
Conditioned sq ft for REM rate	2434	2434	2434
Conditioned volume for REM rate	20689	20689	20689
Ceiling Insulation R-Value	38	49	49
Ceiling insulation R-value per inch	6.2	6.2	6.2
Ceiling cavity R-value	21.7	21.7	21.7
Ceiling cavity insulation thickness (in)	3.5	3.5	3.5
Ceiling continuous insulation R-value	16.3	27.3	27.3
Ceiling continuous insulation thickness (in)	2.6	4.4	4.4
Wall Insulation R-Value	13 + 0	20 + 0	34.1 + 0
Wall insulation R-value per inch	6.2	6.2	6.2
Wall cavity R-value	13.0	20.0	34.1
Wall cavity insulation thickness (in)	2.1	3.2	5.5

New Homes - Circa 2019			
City	Houston	Richmond	Minneapolis
Wall continuous insulation R-value	0	0	0
Wall continuous insulation thickness (in)	0	0	0
Whole Dwelling Infiltration (ACH)	1.5	1.5	1.5
Duct location (unconditioned attic/ conditioned space)	75/25	75/25	75/25
Duct insulation R-value	8	8	8
Duct leakage rate, total (cfm25/ 100 sq ft)	4	4	4
Duct leakage rate, to exterior (cfm25)	73	73	73

Case 2, System "B" Spray Foam Insulation with Closed Cell; Conditioned Attic with SPF at Roof Deck.

New Homes - Circa 2019			
City	Houston	Richmond	Minneapolis
Conditioned floor area for REM/Rate (ft2)	2434	2434	2434
Conditioned attic volume (ft3)	4422	4422	4422
Combined volume for REM/Rate (ft3), including conditioned attic	25111	25111	25111
Roof deck interior insulation R-Value	38	49	49
Roof deck interior insulation R-value per inch	6.2	6.2	6.2
Roof deck interior cavity R-value	21.7	21.7	21.7
Roof deck interior cavity insulation thickness (in)	3.5	3.5	3.5
Roof deck interior continuous insulation R-value over top chord of truss	16.3	27.3	27.3
Roof deck interior continuous insulation thickness over top chord of truss (in)	2.6	4.4	4.4
Wall Insulation R-Value	13 + 0	20 + 0	34.1 + 0
Wall insulation R-value per inch	6.2	6.2	6.2
Wall cavity R-value	13	20	34.1
Wall cavity insulation thickness (in)	2.1	3.2	5.5
Wall continuous insulation R-value	0	0	0
Wall continuous insulation thickness (in)	0	0	0
Whole Dwelling Infiltration (ACH)	1.5	1.5	1.5
Duct location (unconditioned attic/ conditioned space)	0/100	0/100	0/100
Duct insulation R-value	0	0	0
Duct leakage rate, total (cfm25/ 100 sq ft)	4	4	4
Duct leakage rate, to exterior (cfm25)	0	0	0

Appendix B: Infiltration Data

Infiltration data is sourced from "Air Infiltration Data Analysis for Newly Constructed Homes Insulated with Icynene Spray Foam." [1]

Data Set for Icynene Insulated Homes

City	State	CFM @ 50 Pa	CFM @ 50 / s.f.	ACH @ 50 Pa	Natural ACH	House Volume (ft^3)	Floor Area (ft^2)
Spencer	WI	109	0.05	0.18	0.02	36,000	2,050
Hermantown	MN	482	0.12	0.77	0.04	37,558	4,017
Stratford	WI	416	0.21	0.80	0.05	31,000	1,950
Bovey	MN	537	0.15	0.85	0.05	38,016	3,472
Sioux Falls	SD	380	0.11	0.75	0.05	30,500	3,358
Sioux Falls	SD	380	0.11	0.75	0.05	30,500	3,358
Janesville	WI	876	0.20	1.36	0.06	38,737	4,420
Janesville	WI	574	0.15	0.94	0.06	36,684	3,852
Boyd	WI	444	0.18	0.65	0.06	41,000	2,500
Duluth	MN	311	0.16	1.08	0.06	17,278	1,944
Bartonville	IL	720	0.15	1.10	0.06	39,273	4,800
Bartonville	IL	720	0.15	1.10	0.06	39,273	4,800
Duluth	MN	407	0.19	1.23	0.07	19,792	2,184
Metamora	IL	815	0.23	3.32	0.07	14,729	3,543
Metamora	IL	815	0.23	3.32	0.07	14,729	3,543
Stratford	WI	369	0.21	0.56	0.08	39,600	1,800
Jersey Village	TX	1,055	0.28	2.11	0.08	30,040	3,755
Pekin	IL	1,158	0.20	1.41	0.08	49,277	5,790
Morton	IL	1,175	0.26	1.75	0.08	40,286	4,519
Westville	IN				0.08	53,561	5,290
Pekin	IL	1,158	0.20	1.41	0.08	49,277	5,790
Peoria	IL	1,175	0.26	1.75	0.08	40,286	4,519
Amhearst Junction	WI	489	0.28	1.86	0.09	15,750	1,750
Wausau	WI	963	0.25	1.70	0.09	34,000	3,824
Rexburg	ID	1,188	0.27	1.79	0.09	39,788	4,332
Montgomery	TX	1,096	0.36	2.67	0.09	24,632	3,079
Arbor Vitae	WI	316	0.22	0.79	0.10	24,000	1,450
Mosinee	WI	450	0.26	0.83	0.10	32,500	1,710
Iron River	WI	794	0.20	1.00	0.10	47,600	3,900
Colby	WI	494	0.32	1.11	0.10	26,656	1,568
New Hope	PA				0.10		
Colby	WI	494	0.32	1.11	0.10	26,656	1,568
Lac DU Flambeau	WI	735	0.27	0.64	0.11	69,100	2,764
Mosinee	WI	748	0.30	1.04	0.11	43,000	2,500
Littleton	CO				0.12		
Stratford	WI	537	0.31	1.01	0.13	32,000	1,750
Deer River	MN	766	0.25	1.19	0.13	38,611	3,118
Janesville	WI	736	0.23	1.54	0.14	28,687	3,148
Tomahawk	WI	449	0.36	0.80	0.14	33,800	1,250
Duluth	MN	463	0.31	2.05	0.14	13,527	1,503
Farmington	IL	1,253	0.49	3.37	0.14	22,309	2,557
Peoria	IL	1,253	0.49	3.37	0.14	22,309	2,557
Junction City	WI	1,024	0.43	1.92	0.15	32,000	2,400
Duluth	MN	630	0.29	2.14	0.15	17,672	2,146
Cambridge Falls		1,347	0.53	3.98	0.16	20,320	2,540
Iron River	WI	744	0.39	0.93	0.19	48,000	1,900
Union Springs	NY				0.27	12,720	1,590
Mooresville	NC	1,458	0.42	2.10		41,694	3,464
Ankeny	IA	937	0.23	1.47		38,185	4,040
Huxley	IA	682	0.18	1.19		34,416	3,824
Louisville	KY	900					
Louisville	KY	1,750					
Fisherville	KY	1,100					
Webb Lake	WI	957	0.25	1.03		55,800	3,836
Westville	IN					53,561	5,290

Appendix C: References for Air Infiltration Research

1. "Air Infiltration Data Analysis for Newly Constructed Homes Insulated with Icynene Spray Foam." Upper Marlboro, MD 20774: NAHB Research Center, November 2007.
2. "Field Demonstration of Alternative Wall Insulation Products." Project Number 3037. Upper Marlboro, MD 20774: NAHB Research Center, May 4, 1998.
3. Chan, Wanyu R., et al. "Analysis of U.S. Residential Air Leakage Database." Rep. no. LBNL-53367. Berkeley, CA: Lawrence Berkeley National Library, July 2003.
4. Sherman, Max H., and Nance E. Matson. "Air Tightness of New U.S. Houses: A Preliminary Report." Rep. no. LBNL-48671. Berkeley, CA: Lawrence Berkeley National Library, March 20. 2002.
5. U.S. Climate Zones Map, LEEDuser, http://www.leeduser.com/sites/default/files/credit_docs/US%20climate%20zone.pdf