Residential Energy Efficiency Design Guide for Small Multifamily Homes

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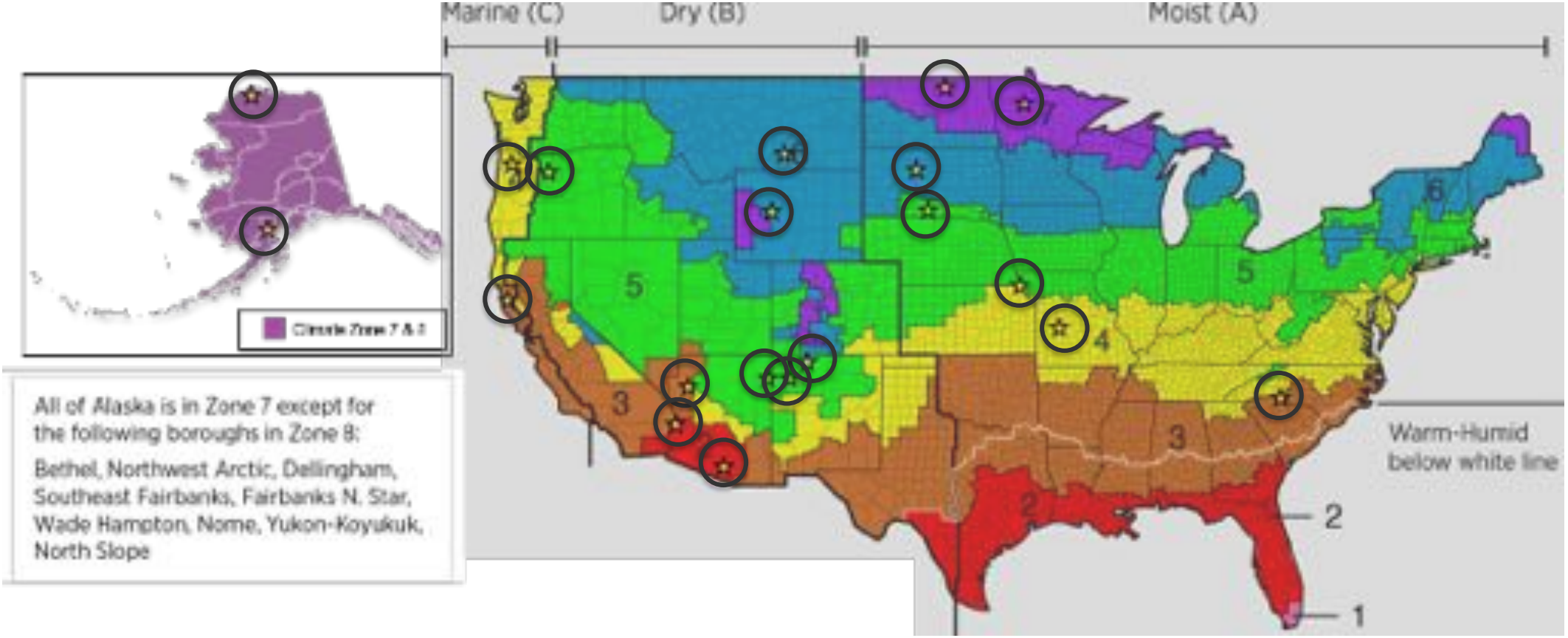
Energy Efficiency Design Guide



Goal: Indian Health Services (IHS) reduce residential energy consumption by 30% compared to IECC 2021 baseline in locations across the U.S.

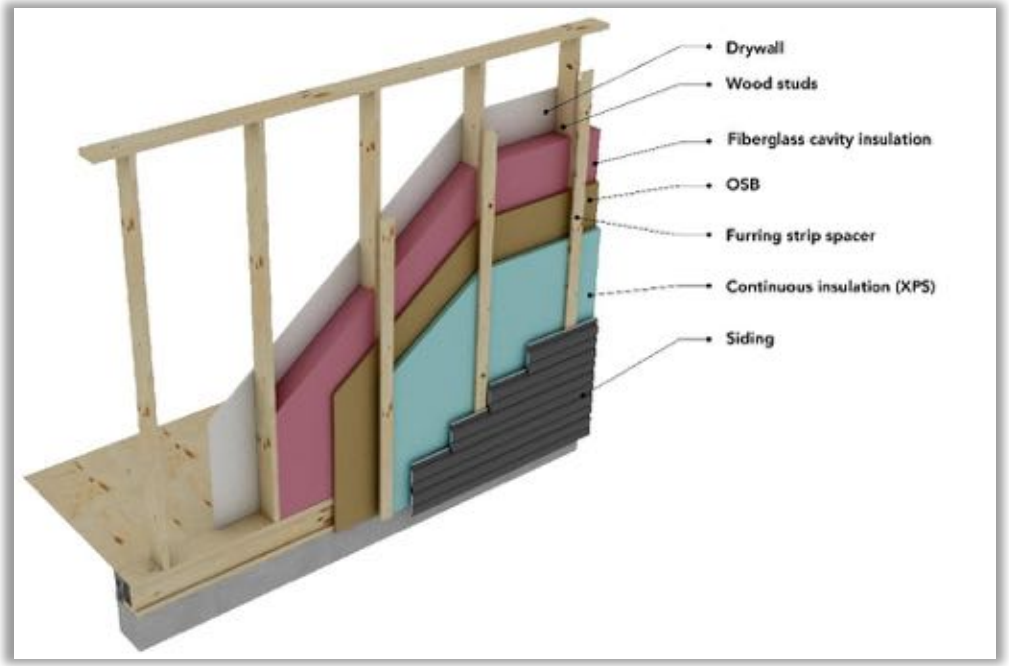
Housing provided for doctors and nurses.

Motivation

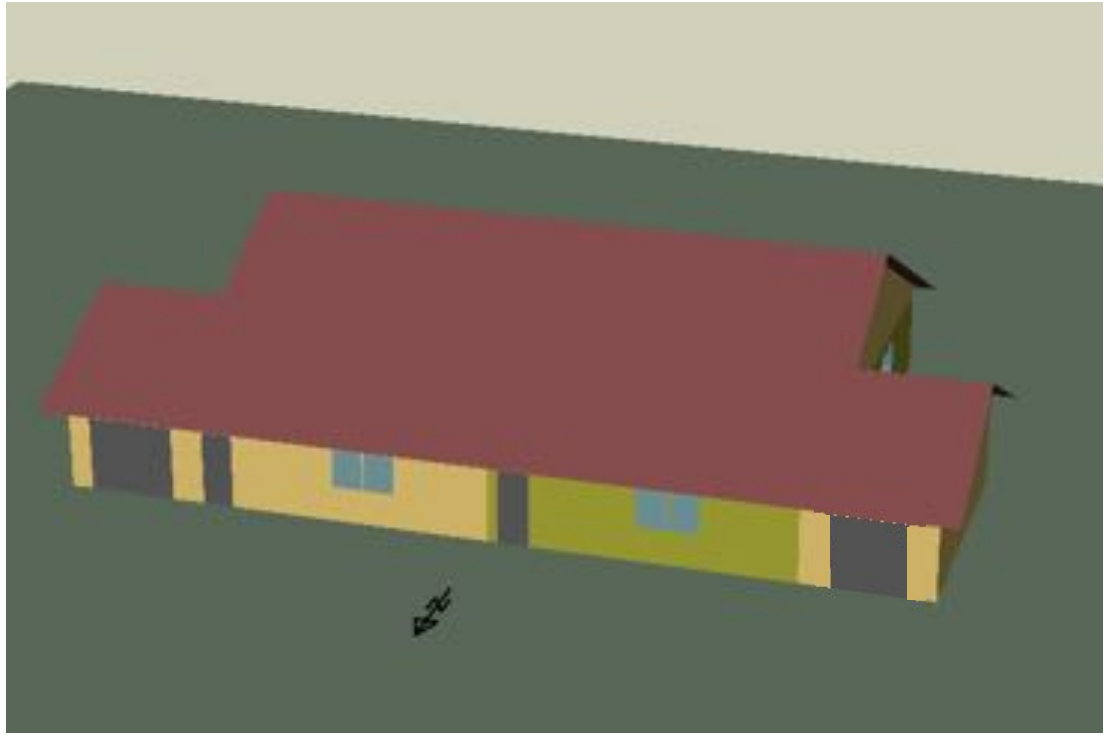
- Complex and costly to determine life-cycle cost effective whole-home designs
  - HVAC vs envelope
  - Windows or slab insulation
- Lack of resources for builders/designers looking at whole-home efficiency designs for smaller residential projects
- Rural areas may lack equipment, materials, local knowledge so providing tradeoffs allows for what is available locally

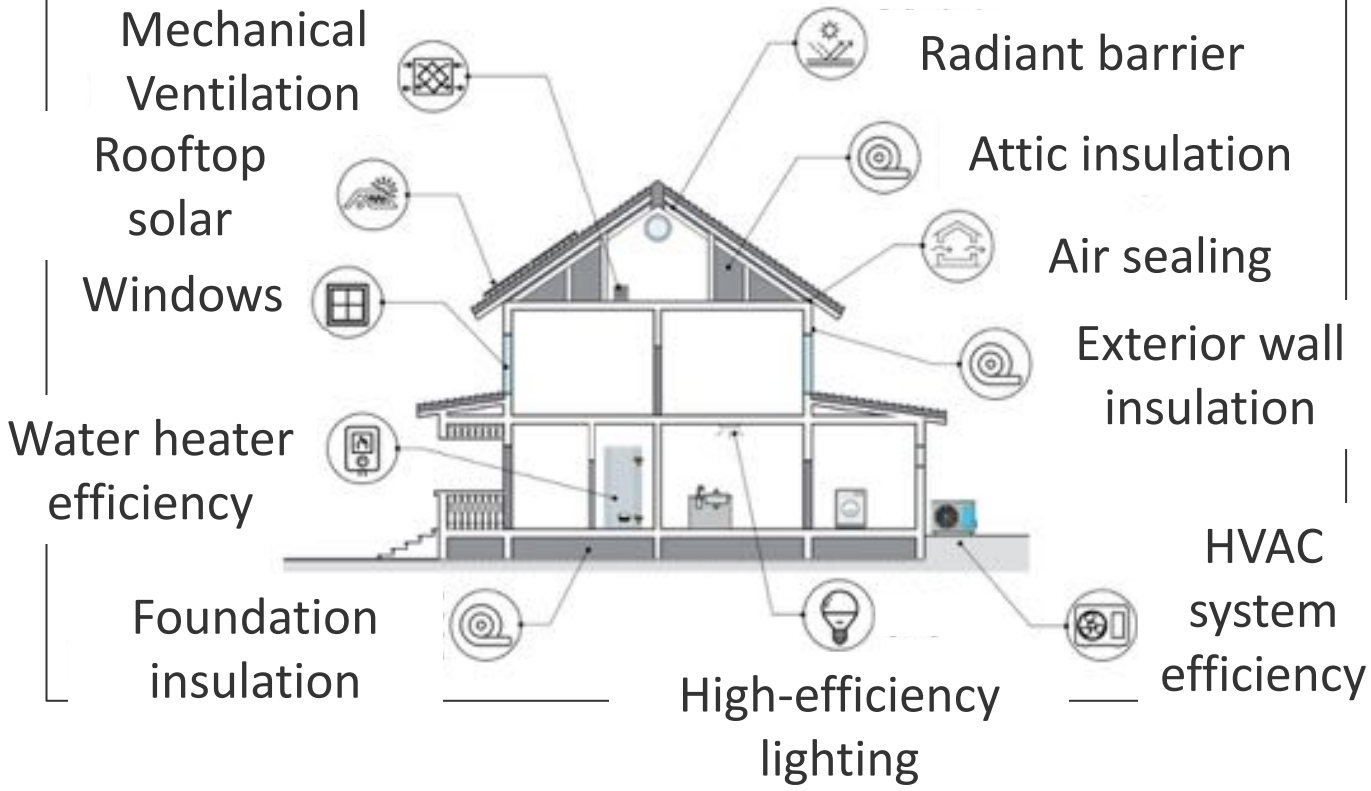
Research Outcomes

- **Methodology to select cost-effective packages that maximize option diversity**
- Context for the IECC 2021 minimum, challenges in meeting 30% savings
- Resilience of whole home design in extreme weather situations



Model Overview





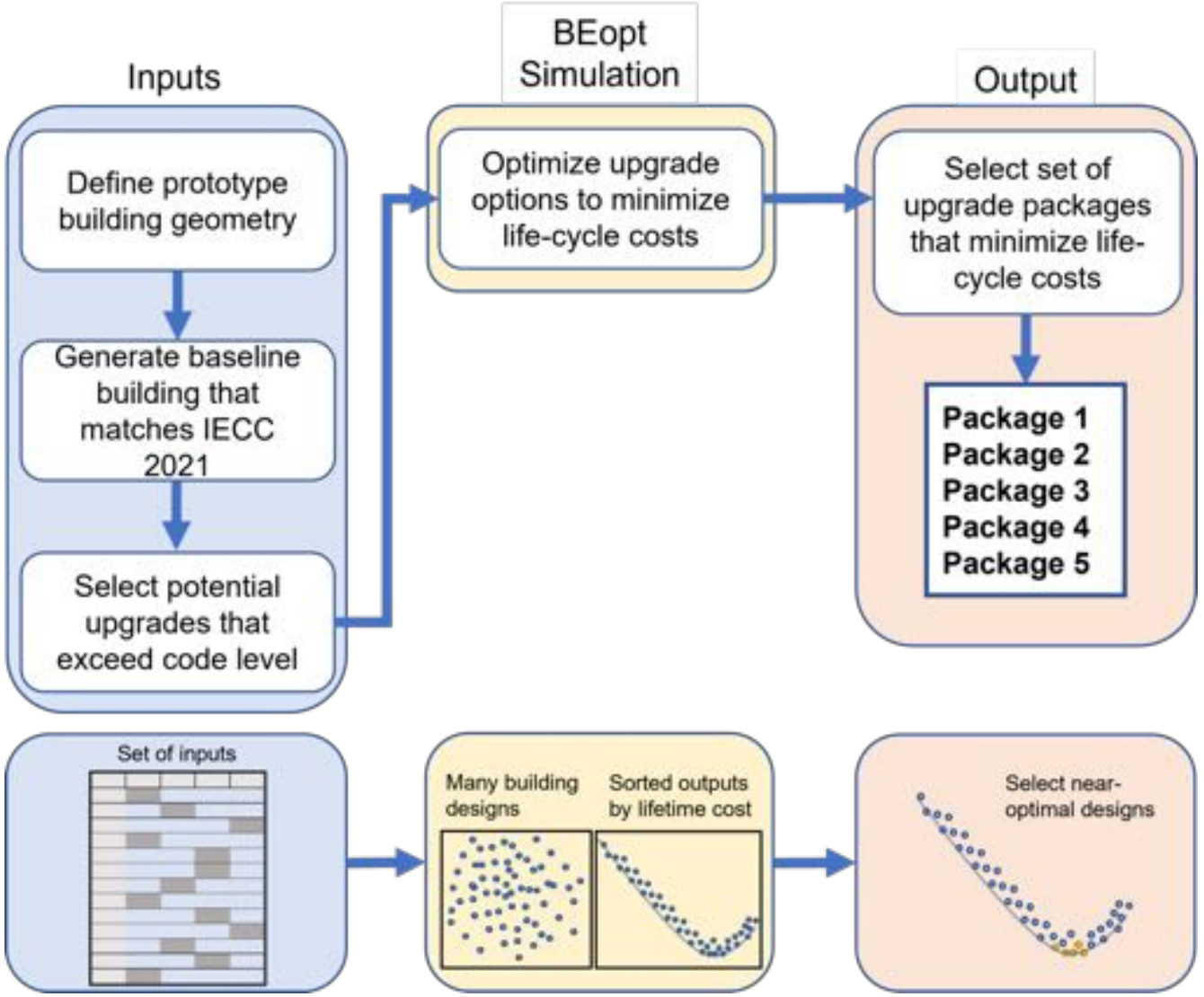
Housing specifications from IHS

- 1,400 sqft single story duplex facing North
- 2 bedrooms, 1 bathroom, and 1 car garage per unit
- Other building assumptions based on ResStock, IECC, and other home survey metrics
- Upgrade potentials are shown on the right

Approach

1) **Energy efficiency design recommendations**
   - **Goal: inform decisions to better meet the guiding principles for federal low-rise residential**
   - **Driven by building energy optimization software (BEopt)**
2) Rooftop PV and solar hot water
   - Goal: preliminary analysis for the technical potential of site-specific PV and solar hot water
   - Using NREL's SAM (PVWatts module) and BEopt
3) Building energy resiliency
   - Goal: provide context into the potential for resiliency as it relates to the EE recommendations
   - Using NREL's ResStock Analysis Tool (OpenStudio)

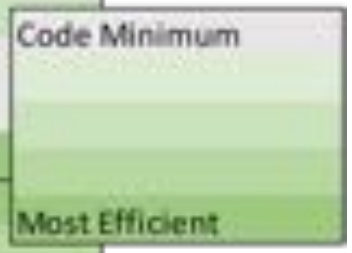
Energy Efficiency Package Selection Workflow



EE Package Outputs

- Recommend five unique designs that are life-cycle cost effective and reduce site energy demand
- Packages chosen by:
  1. Meet or come close to the lifetime costs + energy savings of the minimum point
  2. Maximize the number of differences between the other packages

Category	Option	Code Minimum (IECC 2021)	Package 1	Package 2	Package 3	Package 4	Package 5
Envelope	Envelope Options	Code minimum options selected					
Eqpt. & Lighting	Equipment & Lighting Options	Code minimum options selected					
Energy & Cost Metrics	Site Energy Savings (%)	% Energy savings compared to the IECC 2021 case					
	Annualized Energy Costs ($/yr)	Total cost of energy-related expenses during the lifetime of the home					
	Annualized Energy Costs Savings (%)	% Annualized energy costs savings compared to the IECC 2021 case					
	Source Energy Use (MMBtu/yr)	Primary energy required by a central power plant to produce fuel or electricity					



Energy Efficiency Packages – Sells, AZ 2B

5.1 Climate Zone 2B – Sells, AZ (Electric Heating)

Energy Efficiency Packages

Model Details:

Heating Fuel: Electric
Representative City: Sells, AZ
Heating Setpoint: 72°F
Cooling Setpoint: 75°F
Foundation Type: Slab
Electricity Rate:

kWh Range	Rate ($/kWh)
0–50	$ 0.235
51–200	$ 0.145
201+	$ 0.1085

- Package 1 is the package with the lowest annual energy costs
- Energy efficiency options not highlighted means they did not change from baseline
- Difference between code minimum and package 5 is simply HVAC system and lighting, produces a 20.5% site energy savings and 10.6% annual energy costs savings

Category	Option	Code Min. (IECC 2021)	Package 1	Package 2	Package 3	Package 4	Package 5
Envelope	Wood Stud	R-13 Fiberglass, 2x4, 16"	R-21 Fiberglass, 2x6, 16"	R-21 Fiberglass, 2x6, 16"	R-21 Fiberglass, 2x6, 16"	R-15 Fiberglass, 2x4, 16"	R-13 Fiberglass, 2x4, 16"
	Wall Sheathing	None	None	R-5 XPS	R-5 XPS	None	None
	Unfinished Attic	Ceiling R-49 Fiberglass	Ceiling R-49 Fiberglass	Ceiling R-60 Fiberglass	Ceiling R-49 Fiberglass	Ceiling R-49 Fiberglass	Ceiling R-49 Fiberglass
	Radiant Barrier	None	None	None	Double-Sided, Foil	None	None
	Slab	Uninsulated	2ft R10 Exterior XPS	2ft R10 Exterior XPS	2ft R10 Exterior XPS	2ft R5 Exterior XPS	Uninsulated
	Windows	U = 0.37, SHGC = 0.25	U = 0.37, SHGC = 0.25	U = 0.37, SHGC = 0.25	U = 0.37, SHGC = 0.25	U = 0.37, SHGC = 0.25	U = 0.37, SHGC = 0.25
	Air Leakage	5 ACH50	3 ACH50	2 ACH50	2 ACH50	4 ACH50	5 ACH50
Eqpt. & Lighting	Ducts	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space
	Mechanical Ventilation	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard
	Water Heater	Electric Tank, UEF=0.92	Electric Tank, UEF=0.92	Electric Tank, UEF=0.92	Electric Tank, UEF=0.92	Electric Tank, UEF=0.92	Electric Tank, UEF=0.92
	Air Source Heat Pump	None	SEER 16, 8.6 HSPF	SEER 16, 8.6 HSPF	SEER 16, 8.6 HSPF	SEER 15, 9.3 HSPF	SEER 22, 10 HSPF
	Central Air Conditioner	SEER 14	None	None	None	None	None
	Furnace	Electric, 100% AFUE	None	None	None	None	None
	Lighting	100% CFL	100% LED	100% LED	100% LED	100% LED	100% LED
Energy & Cost Metrics	Site Energy Savings (%)	0.0%	19.4%	20.5%	20.5%	19.4%	20.5%
	Ann. Energy Costs ($/yr)	2,488	2,149	2,167	2,175	2,178	2,223
	Ann. Energy Costs Savings (%)	0.0%	13.6%	12.9%	12.6%	12.5%	10.6%
	Source Energy Use (MMBtu/yr)	180.3	143.8	141.7	141.6	143.8	141.6

Energy Efficiency Packages – Sells, AZ 2B

5.2 Climate Zone 2B – Sells, AZ (Propane Heating)

Energy Efficiency Packages

Model Details:

Heating Fuel: Propane
Representative City: Sells, AZ
Heating Setpoint: 72°F
Cooling Setpoint: 75°F
Foundation Type: Slab
Propane Rate: $3.00/gal
Electricity Rate:

kWh Range	Rate ($/kWh)
0–50	$ 0.235
51–200	$ 0.145
201+	$ 0.1085

- Package 1 is the package with the lowest annual energy costs
- Variety of energy efficiency packages shown
- More site savings for propane heating than electric heating

Category	Option	Code Min. (IECC 2021)	Package 1	Package 2	Package 3	Package 4	Package 5
Envelope	Wood Stud	R-13 Fiberglass, 2x4, 16"	R-21 Fiberglass, 2x6, 16"	R-15 Fiberglass, 2x4, 16"	R-21 Fiberglass, 2x6, 16"	R-21 Fiberglass, 2x6, 16"	R-21 Fiberglass, 2x6, 16"
	Wall Sheathing	None	R-10 XPS	R-15 XPS	R-5 XPS	R-15 XPS	R-10 XPS
	Unfinished Attic	Ceiling R-49 Fiberglass	Ceiling R-49 Fiberglass	Ceiling R-60 Fiberglass	Ceiling R-49 Fiberglass	Ceiling R-60 Fiberglass	Ceiling R-49 Fiberglass
	Radiant Barrier	None	None	None	None	None	None
	Slab	Uninsulated	2ft R10 Exterior XPS	2ft R10 Exterior XPS	2ft R10 Exterior XPS	2ft R10 Exterior XPS	2ft R10 Exterior XPS
	Windows	U = 0.37, SHGC = 0.25	U = 0.37, SHGC = 0.25	U = 0.37, SHGC = 0.25	U = 0.37, SHGC = 0.25	U = 0.37, SHGC = 0.25	U = 0.19, SHGC = 0.25
	Air Leakage	5 ACH50	1 ACH50	1 ACH50	2 ACH50	1 ACH50	1 ACH50
Eqpt. & Lighting	Ducts	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space
	Mechanical Ventilation	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard	HRV, 70% SRE	ASHRAE 62.2 Standard
	Water Heater	Propane Tank, UEF=0.62	Propane Tankless, UEF=0.82	Propane Tankless, UEF=0.82	Propane Tankless, UEF=0.82	Propane Tankless, UEF=0.82	Propane Tankless, UEF=0.82
	Central Air Conditioner	SEER 14	SEER 16 (2 Stage)	SEER 18	SEER 21	SEER 16	SEER 14
	Furnace	Propane, 80% AFUE	Propane, 80% AFUE	Propane, 80% AFUE	Propane, 80% AFUE	Propane, 80% AFUE	Propane, 80% AFUE
	Lighting	100% CFL	100% LED	100% LED	100% LED	100% LED	100% LED
Energy & Cost Metrics	Site Energy Savings (%)	0.0%	31.8%	23.4%	22.6%	24.3%	21.3%
	Ann. Energy Costs ($/yr)	2,892	2,437	2,456	2,462	2,506	2,509
	Ann. Energy Costs Savings (%)	0.0%	15.7%	15.1%	14.2%	13.3%	13.3%
	Source Energy Use (MMBtu/yr)	149.1	123.3	120.5	120.2	123.7	128.5

Energy Efficiency Packages – Rosebud, SD 5A

5.17 Climate Zone 5A – Rosebud, SD (Electric Heating)

Energy Efficiency Packages

Model Details:

Heating Fuel: Electric
Heating Setpoint: 70°F
Cooling Setpoint: 71°F
Foundation Type: Slab
Electricity Rate: $0.10/kWh

- Package 1 is the package with the lowest annual energy costs, but package 2 has the most site energy savings
- Difference between code minimum and package 3 is simply HVAC system, lighting, air tightness, and insulation levels, and produces a 27.5% site energy savings and 27.7% annual energy costs savings

Category	Option	Code Min. (IECC 2021)	Package 1	Package 2	Package 3	Package 4	Package 5
Envelope	Wood Stud	R-13 Fiberglass, 2x4, 16"	R-21 Fiberglass, 2x6, 16"	R-19 Fiberglass, 2x6, 16"	R-21 Fiberglass, 2x6, 16"	R-21 Fiberglass, 2x6, 16"	R-21 Fiberglass, 2x6, 16"
	Wall Sheathing	R-10 XPS	R-15 XPS	R-15 XPS	R-10 XPS	R-15 XPS	R-10 XPS
	Unfinished Attic	Ceiling R-60 Fiberglass	Ceiling R-60 Fiberglass	Ceiling R-60 Fiberglass	Ceiling R-60 Fiberglass	Ceiling R-60 Fiberglass	Ceiling R-60 Fiberglass
	Radiant Barrier	None	None	None	None	None	None
	Slab	4ft R10 Exterior XPS	4ft R15 Exterior XPS	4ft R15 Exterior XPS	4ft R10 Exterior XPS	4ft R15 Exterior XPS	4ft R10 Exterior XPS
	Windows	U = 0.30, SHGC = 0.38	U = 0.30, SHGC = 0.38	U = 0.30, SHGC = 0.38	U = 0.30, SHGC = 0.38	U = 0.30, SHGC = 0.38	U = 0.21, SHGC = 0.40
	Air Leakage	3 ACH50	1 ACH50	1 ACH50	1 ACH50	2 ACH50	1 ACH50
Eqpt. & Lighting	Ducts	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space
	Mechanical Ventilation	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard	ASHRAE 62.2 Standard
	Water Heater	Electric Tank, UEF=0.92	Electric Tank, UEF=0.92	Electric Tank, UEF=0.92	Electric Tank, UEF=0.92	Electric Tank, UEF=0.92	Electric Tank, UEF=0.92
	Air Source Heat Pump	None	SEER 14, 8.2 HSPF	SEER 15, 8.5 HSPF	SEER 15, 8.5 HSPF	SEER 15, 8.5 HSPF	SEER 14, 8.2 HSPF
	Central Air Conditioner	SEER 13	None	None	None	None	None
	Furnace	Electric, 100% AFUE	None	None	None	None	None
	Lighting	100% CFL	100% LED	100% LED	100% LED	100% LED	100% LED
Energy & Cost Metrics	Site Energy Savings (%)	0.0%	27.7%	28.2%	27.5%	27.6%	27.6%
	Ann. Energy Costs ($/yr)	2,705	1,955	1,954	1,955	1,959	1,960
	Ann. Energy Costs Savings (%)	0.0%	27.8%	27.8%	27.7%	27.6%	26.8%
	Source Energy Use (MMBtu/yr)	255.8	182.7	181.3	183.1	182.3	183

Energy Efficiency Packages – Rosebud, SD 5A

5.18 Climate Zone 5A – Rosebud, SD (Propane Heating)

Energy Efficiency Packages

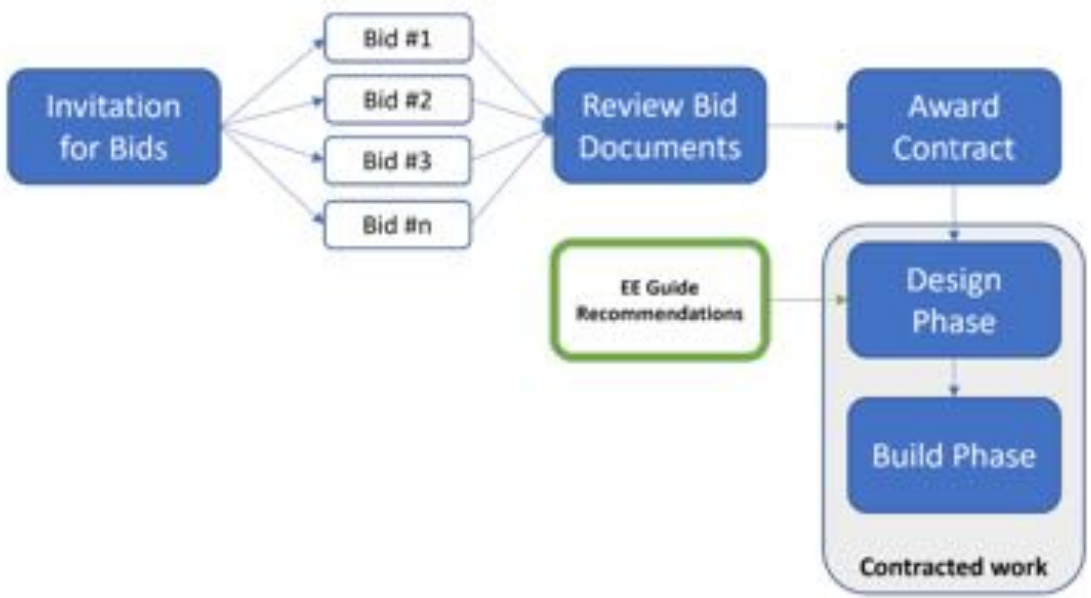
Model Details:

Heating Fuel: Propane
Heating Setpoint: 70°F
Cooling Setpoint: 71°F
Foundation Type: Slab
Propane Rate: $2.20/gal
Electricity Rate: $0.10/kWh

- Package 1 is the package with the lowest annual energy costs, but package 5 has the biggest site energy savings
- Overall, less site energy savings and annual energy cost savings than electric heating

Category	Option	Code Min. (IECC 2021)	Package 1	Package 2	Package 3	Package 4	Package 5
Envelope	Wood Stud	R-13 Fiberglass, 2x4, 16"	R-21 Fiberglass, 2x6, 16"	R-21 Fiberglass, 2x6, 16"	R-21 Fiberglass, 2x6, 16"	R-21 Fiberglass, 2x6, 16"	R-19 Fiberglass, 2x6, 16"
	Wall Sheathing	R-10 XPS	R-15 XPS	R-15 XPS	R-15 XPS	R-10 XPS	R-15 XPS
	Unfinished Attic	Ceiling R-60 Fiberglass	Ceiling R-60 Fiberglass	Ceiling R-60 Fiberglass	Ceiling R-60 Fiberglass	Ceiling R-60 Fiberglass	Ceiling R-60 Fiberglass
	Radiant Barrier	None	None	None	None	None	None
	Slab	4ft R10 Exterior XPS	4ft R20 Exterior XPS	4ft R15 Exterior XPS	4ft R20 Exterior XPS	4ft R20 Exterior XPS	4ft R20 Exterior XPS
	Windows	U = 0.30, SHGC = 0.38	U = 0.18, SHGC = 0.40	U = 0.18, SHGC = 0.40	U = 0.21, SHGC = 0.40	U = 0.18, SHGC = 0.40	U = 0.18, SHGC = 0.40
	Air Leakage	3 ACH50	1 ACH50	1 ACH50	1 ACH50	1 ACH50	1 ACH50
Eqpt. & Lighting	Ducts	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space	In Conditioned Space
	Mechanical Ventilation	ASHRAE 62.2 Standard	ERV, 70% SRE	ERV, 70% SRE	ERV, 70% SRE	ERV, 70% SRE	ERV, 70% SRE
	Water Heater	Propane Tank, UEF=0.62	Propane Tankless, UEF=0.82	Propane Tankless, UEF=0.82	Propane Tankless, UEF=0.82	Propane Tankless, UEF=0.82	Propane Tankless, UEF=0.82
	Central Air Conditioner	SEER 13	SEER 13	SEER 13	SEER 13	SEER 13	SEER 13
	Furnace	Propane, 80% AFUE	Propane, 80% AFUE	Propane, 80% AFUE	Propane, 90% AFUE	Propane, 90% AFUE	Propane, 94% AFUE
	Lighting	100% CFL	100% LED	100% LED	100% LED	100% LED	100% LED
Energy & Cost Metrics	Site Energy Savings (%)	0.0%	21.8%	21.1%	25.2%	24.9%	26.4%
	Ann. Energy Costs ($/yr)	2,887	2,490	2,501	2,534	2,540	2,560
	Ann. Energy Costs Savings (%)	0.0%	13.7%	13.4%	12.2%	12.0%	10.6%
	Source Energy Use (MMBtu/yr)	173.4	147.4	148.3	143.5	143.9	142.1

Conclusions



- Guide can be used in locations across the U.S.
- Whole home energy modeling displays tradeoffs between different components of a home
- Now part of architect and engineer design guide that all builders and designers must follow

Q&A and Thank You

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PV, Baseline, Resilience Assumptions

Table 3. High-Level Inputs for Rooftop PV Analysis[a,b]

Input	Value
Available roof area	1,227 ft²
System size[c]	6.5 kWdc
Inverter efficiency	96%
Total system losses[d,e]	14.1%
Snow cover losses	Table A-3
Annual degradation rate	0.5%/yr
Azimuth	180° (South)
Tilt	26.6° (roof pitch)
Billing mechanism	With and without net metering (2 runs)

[a] Default inputs from PVWatts were used if not specified in this table (Dobos 2014).
[b] These are assumptions used in modeling software, actual system inputs will likely differ
[c] Based on 80% of the south facing roof
[d] Does no
[e] Further t

Table 1. High-Level Baseline Inputs

Input	Value
Above-Grade Square Footage	1,400 ft²/unit
Units	2
Above-Grade Stories[a]	1
Bedrooms	2/unit
Bathrooms	1/unit
Garage	1-car/unit
Wall Type	Wood frame[b]
Attic Type	Vented attic[c]
Foundation Type	Specified in Table A-1
Window To Wall Ratios	9% at each facade
Building Orientation	North
HVAC	Heating and cooling present[d]
Analysis Lifetime	40 years
Inflation Rate	2.4%

[a] Some locations include below-grade finished basements, which match footprint of above-grade space (Table A-1).
[b] Utqiagvik, AK cases have structural insulated panels (SIP).
[c] Utqiagvik, AK cases have finished roofs.
[d] Cooling is not present in Utqiagvik, AK.

Table 4. Details of the two energy resilience analyses

Location	Sells, AZ	Bemidji, MN
Analysis dates	6/18/17 – 6/25/17	1/24/19 – 1/31/19
Simulated outages	None, 12-hour, 24-hour, and 5-day	None, 12-hour, 24-hour, and 5-day
Fuel type	Electric	Natural Gas
Description	Extreme heat exceeding 110°F for several days	Extreme cold ranging from -1°F to -38°F

Locations, Heating Fuel, and Foundation Type Combinations

Table 5. List of Locations, Heating Fuels, and Foundation Types Considered

IECC Climate Zone	City	IHS Area	Heating Fuel	Foundation Type
2B	Sells, AZ	Tucson	Electricity	Slab
2B	Sells, AZ	Tucson	Propane	Slab
2B	Parker, AZ	Phoenix	Electricity	Slab
2B	Parker, AZ	Phoenix	Propane	Slab
3A	Rock Hill, SC	Nashville	Electricity	Slab
3A	Rock Hill, SC	Nashville	Natural Gas	Slab
3B	Peach Springs, AZ	Phoenix	Electricity	Slab
3B	Peach Springs, AZ	Phoenix	Natural Gas	Slab
3C	Ukiah, CA	California	Natural Gas	Slab
3C	Ukiah, CA	California	Propane	Slab
4A	White Cloud, KS	Oklahoma	Natural Gas	Slab
4A	White Cloud, KS	Oklahoma	Propane	Slab
4B	San Fidel, NM	Albuquerque	Natural Gas	Slab
4B	San Fidel, NM	Albuquerque	Electricity	Slab
4C	Salem, OR	Portland	Electricity	Vented Crawlspace
4C	Salem, OR	Portland	Natural Gas	Vented Crawlspace
5A	Rosebud, SD	Great Plains	Electricity	Slab
5A	Rosebud, SD	Great Plains	Propane	Slab
5B	Dulce, NM	Albuquerque	Natural Gas	Slab
5B	Dulce, NM	Albuquerque	Electricity	Slab
5B	Warm Springs, OR	Portland	Electricity	Slab
5B	Warm Springs, OR	Portland	Natural Gas	Slab
5B	Window Rock, AZ	Navajo	Electricity	Slab
5B	Window Rock, AZ	Navajo	Propane	Slab
6A	Eagle Butte, SD	Great Plains	Electricity	Heated Basement
6A	Eagle Butte, SD	Great Plains	Propane	Heated Basement
6B	Crow Agency, MT	Billings	Natural Gas	Heated Basement
6B	Crow Agency, MT	Billings	Propane	Heated Basement
6B	Ft Washakie, WY	Billings	Natural Gas	Heated Basement
6B	Ft Washakie, WY	Billings	Propane	Heated Basement
7A	Bemidji, MN	Bemidji	Natural Gas	Heated Basement
7A	Bemidji, MN	Bemidji	Electricity	Heated Basement
7A	Belcourt, ND	Great Plains	Electricity	Heated Basement
7A	Belcourt, ND	Great Plains	Fuel Oil	Heated Basement
7	Anchorage, AK	Alaska	Natural Gas	Slab
7	Anchorage, AK	Alaska	Electricity	Slab
8	Utqiagvik, AK	Alaska	Natural Gas	Raised Foundation
8	Utqiagvik, AK	Alaska	Fuel Oil	Raised Foundation

Annual Snow Cover Loss Factors

Table A-3. Annual Snow Cover Loss Factors Used in Rooftop PV Modeling

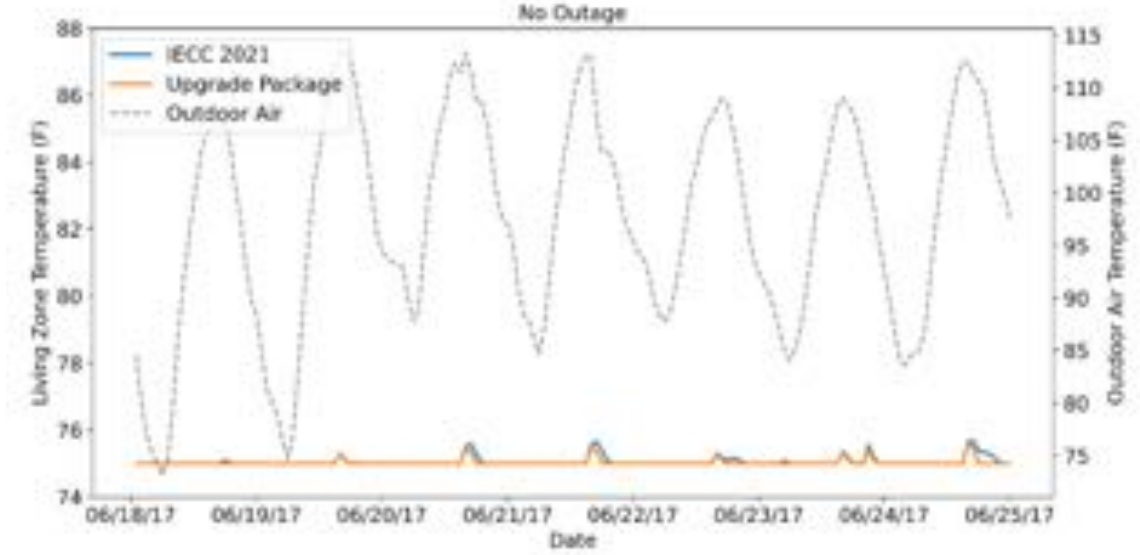
Location	State	Climate Zone	Representative City*	Annual Snow Loss Factor*
Sells	AZ	2B	-	-
Parker	AZ	2B	-	-
Rock Hill	SC	3A	-	-
Peach Springs	AZ	3B	-	-
Ukiah	CA	3C	-	-
White Cloud	KS	4A	Kansas City, MO	3.7%
San Fidel	NM	4B	-	-
Salem	OR	4C	-	-
Rosebud	SD	5A	Pierre, SD	6.7%
Window Rock	AZ	5B	Grand Junction, CO	2.6%
Warm Springs	OR	5B	Redmond, OR	1.7%
Dulce	NM	5B	Boulder, CO	5.5%
Eagle Butte	SD	6A	Pierre, SD	6.7%
Ft Washakie	WY	6B	Lander, WY	9.0%
Crow Agency	MT	6B	Billings, MT	7.7%
Bemidji	MN	7A	Rochester, MN	11.0%
Belcourt	ND	7A	Bismarck, ND	9.5%
Anchorage	AK	7	Anchorage, AK	7.1%
Utqiagvik	AK	8	Barrow, AK	33.0%

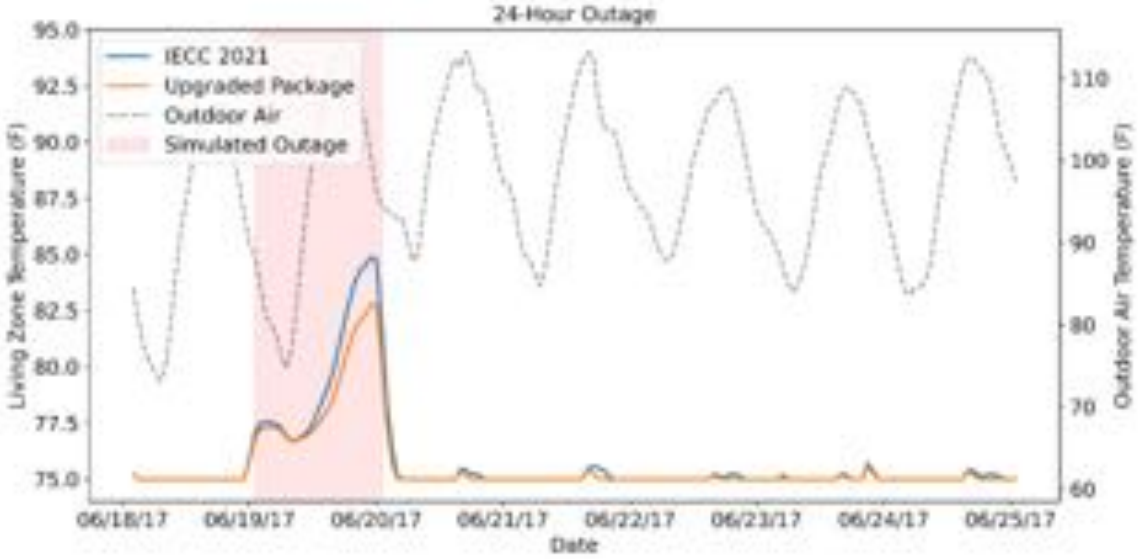
*From Appendix A of Ryberg and Freeman 2017

Research Outcomes

- Methodology to select cost-effective packages that maximize option diversity
- Snow cover in our PV models
- Context for the IECC 2021 minimum, challenges in meeting 30% savings
- Resilience of whole home design in extreme weather situations

Resilience Results – Hot Climate 24 Hour Outage



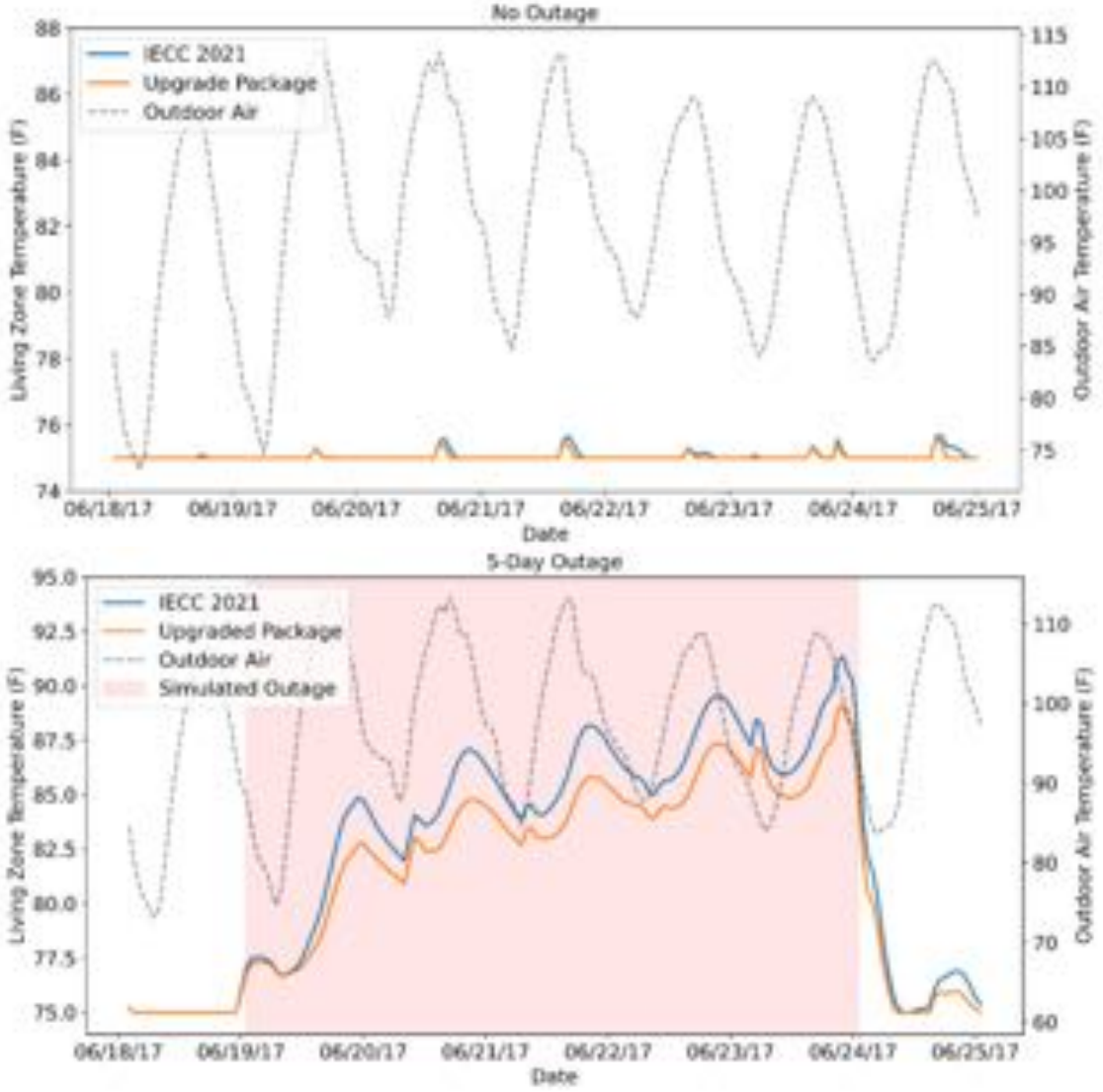


Location: Sells, AZ
Climate Zone: 2B

Conclusion

- House simulated with upgraded package stayed roughly 2.5°F cooler
- Similar time to get back to acceptable indoor air temperature

Resilience Results – Hot Climate 5 Day Outage

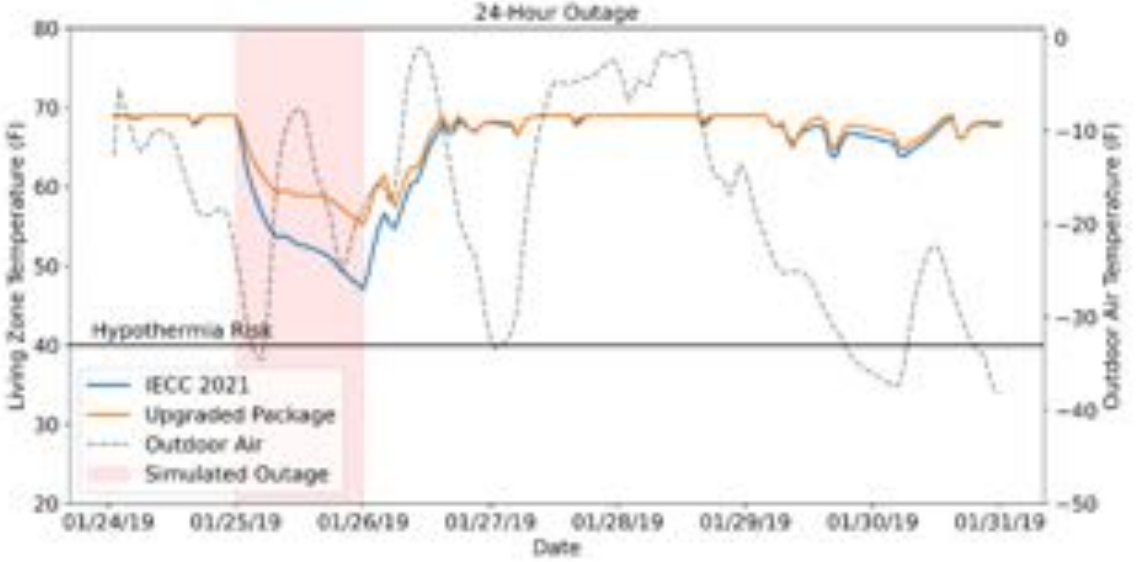


Location: Sells, AZ
Climate Zone: 2B

Conclusion

- House simulated with upgraded package stayed cooler over all 5 days
- House was cooler even through the next day

Resilience Results – Cold Climate 24 Hour Outage

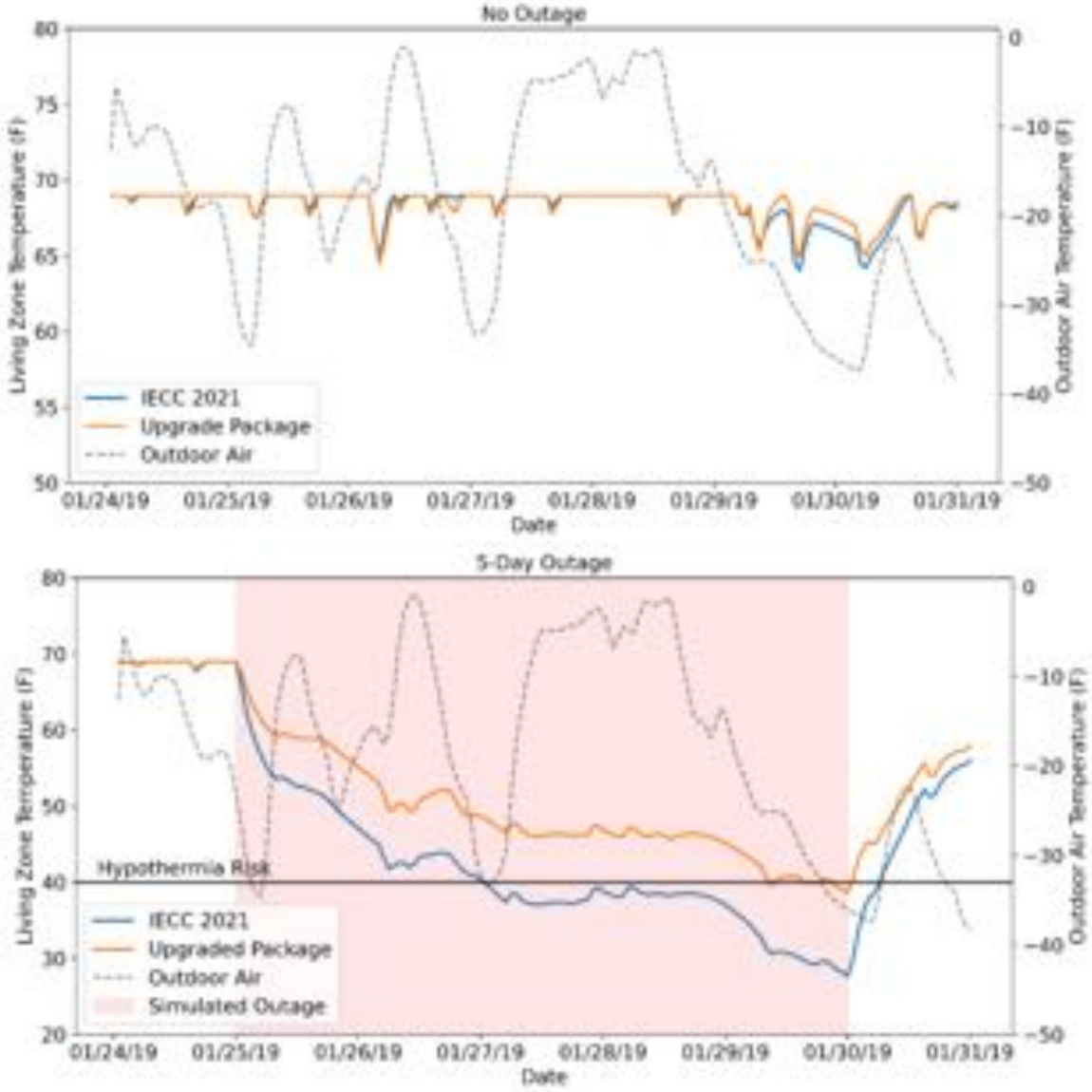


Location: Bemidji, MN
Climate Zone: 7A

Conclusion

- House simulated with upgraded package stayed warmer over whole day
  - Largest temperature difference of 6°F
- House warmed up faster than baseline house

Resilience Results – Cold Climate 5 Day Outage



Location: Bemidji, MN
Climate Zone: 7A

Conclusion

- House simulated with upgraded package stayed warmer over the 5 day period, an average of 8°F warmer
- Suggests smaller risk of hypothermia

Overview of nearby package selection process

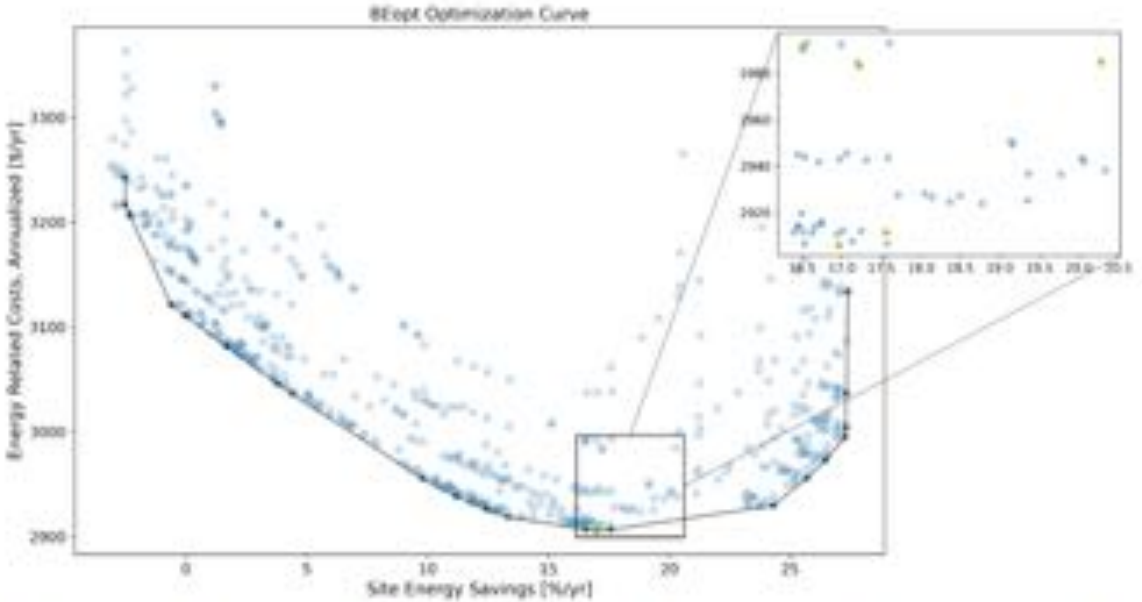


Figure 22. Example BEopt optimization with a zoomed in selection of near-optimal points

Each point represents a separate building design with unique inputs. The highlighted points are the selected energy efficiency packages

A post-processing routine filtered the BEopt results to identify the near-optimal cluster of designs and the five EE packages (steps 4 and 5 of the methodology above). The set of potential designs from which the five designs were chosen were bound within 4% of the cost of the minimum point (y-axis of Figure 18) and from -3.5% to +25% of the energy savings relative to the cost minimum point (y-axis of Figure 18). From the cluster of near-optimal designs, packages were selected based on the relative diversity of the options. Starting from the cost-minimum point and ascending toward the highest cost package, points were selected based on the maximum number of different options from the already selected packages. This approach produces recommendations that span several of the option categories in Figure 7, and therefore provides more flexibility for building designers to customize their designs.