



RESILIENT HOUSE

**Appalachian State University
Suburban Single-Family Residence**

Team (re)Connect

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**Sustainable Technology
& the Built Environment**

APPALACHIAN STATE UNIVERSITY



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Industry Partner

Pre-fabricated home builder
based out of Asheville, NC



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Deltec Homes – Renew Collection

Renew Collection // line of high performance and net-zero homes





Renew Collection – Solar Homestead

- Department of Energy's 2011 U.S. Solar Decathlon
- Solar Homestead was ASU's entry into the competition
- The Solar Homestead is now included in Deltec's Renew Collection





Team (re)Connect

Our Question: How do you design a truly responsible building when limited to only one specific site?

Our Solution: Design for the worst case scenario.





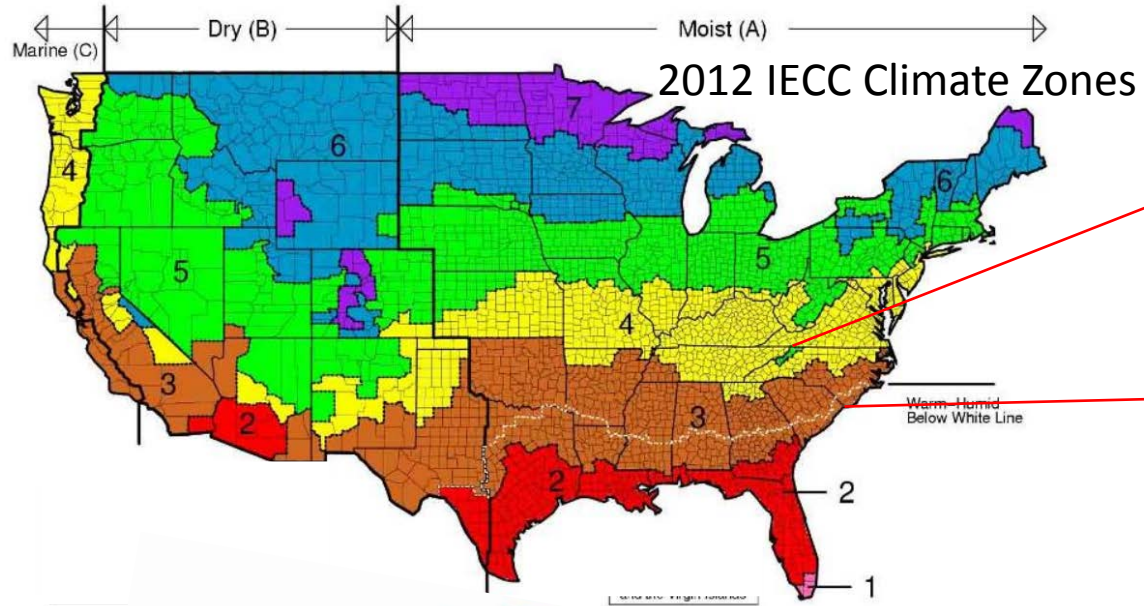
Design Goals



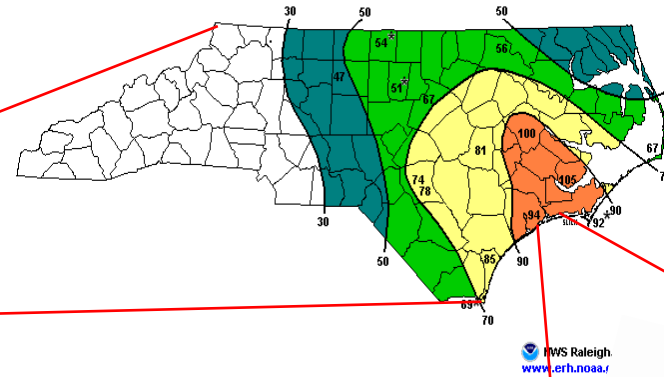
With the prospect of rising sea levels due to environmental degradation and climate change, the future may suggest a new concept for living: ***Every home is a coastal home.***



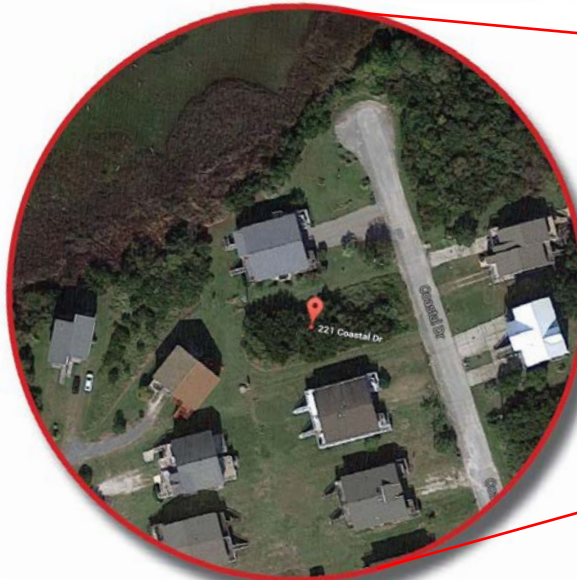
Design Goals – Site Selection



Hurricane Fran Wind Speeds



“Every home is a coastal home”



Resilient House lot
221 Coastal Drive



Topsail Beach



Design Goals – Topsail Island



In an area often referred to as “**Hurricane Alley**,” Topsail Island provides one of the harshest climates for building construction in the United States.



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Design Goals - Resilience





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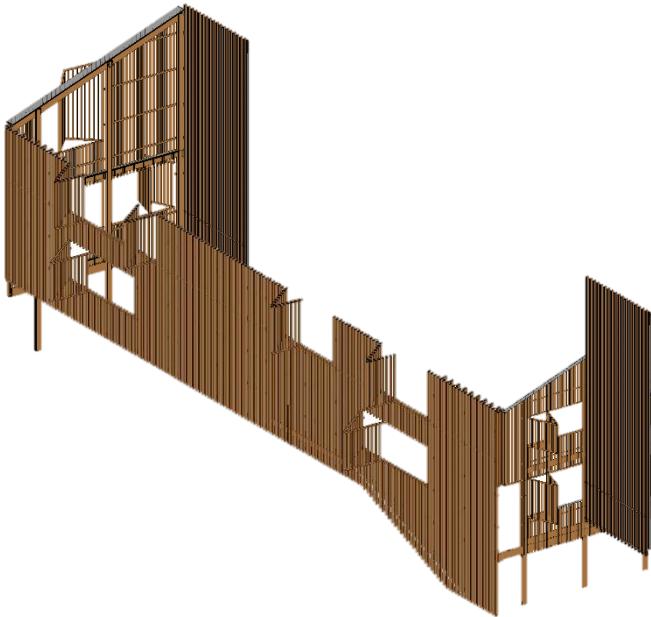
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Design Concept

RESILIENT - An ability to recover from, or adjust easily to misfortune or change.

HOW?





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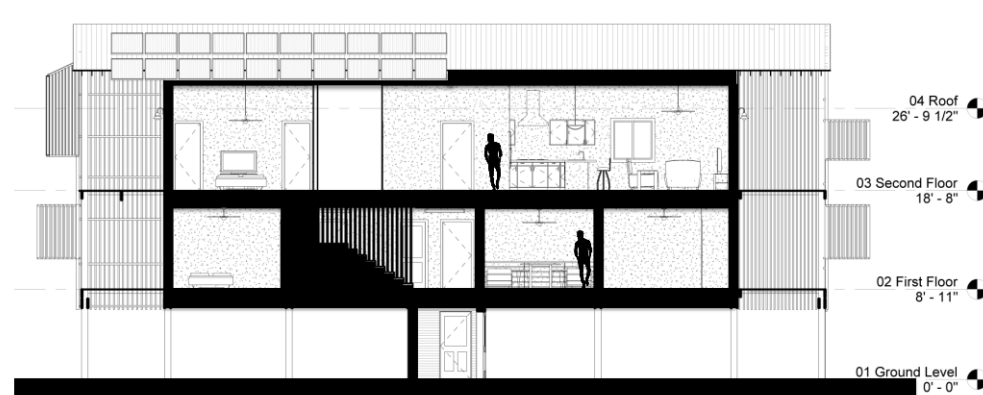
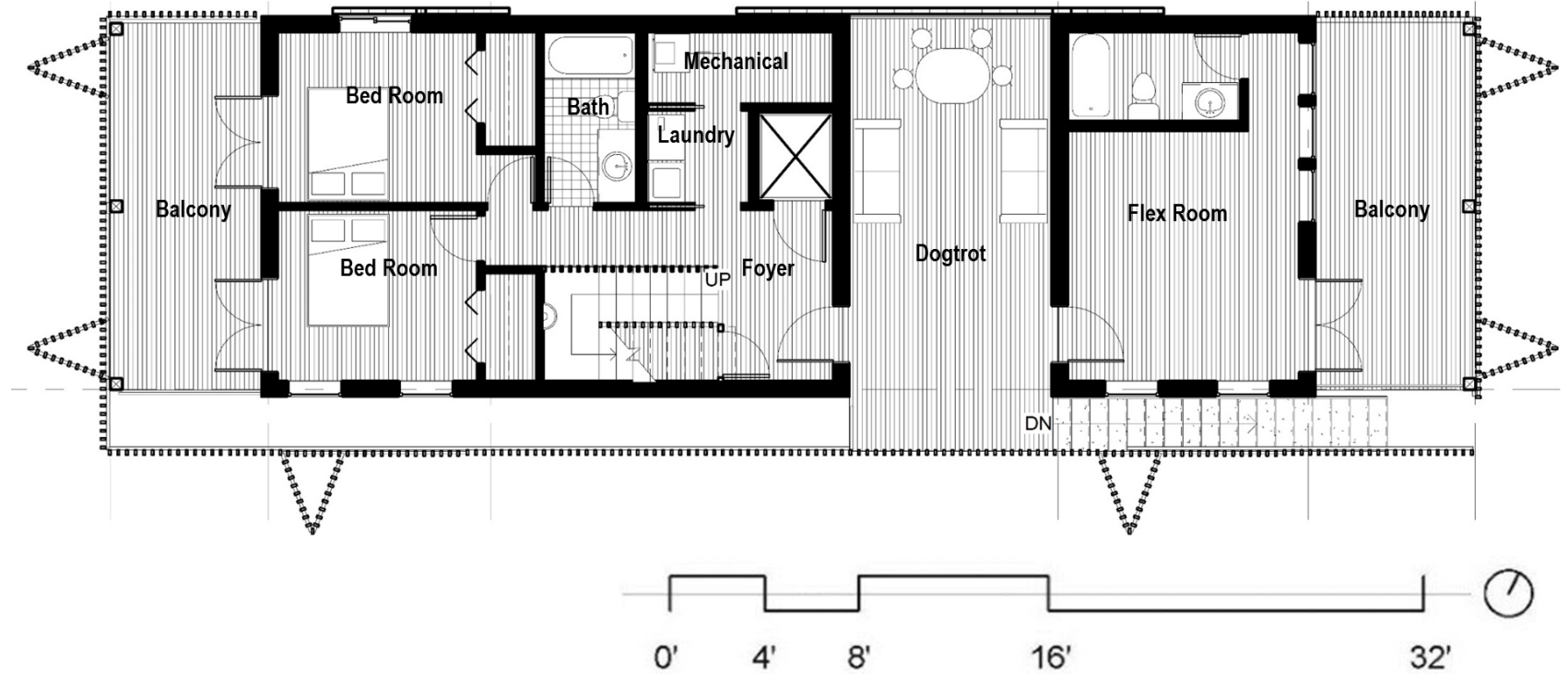
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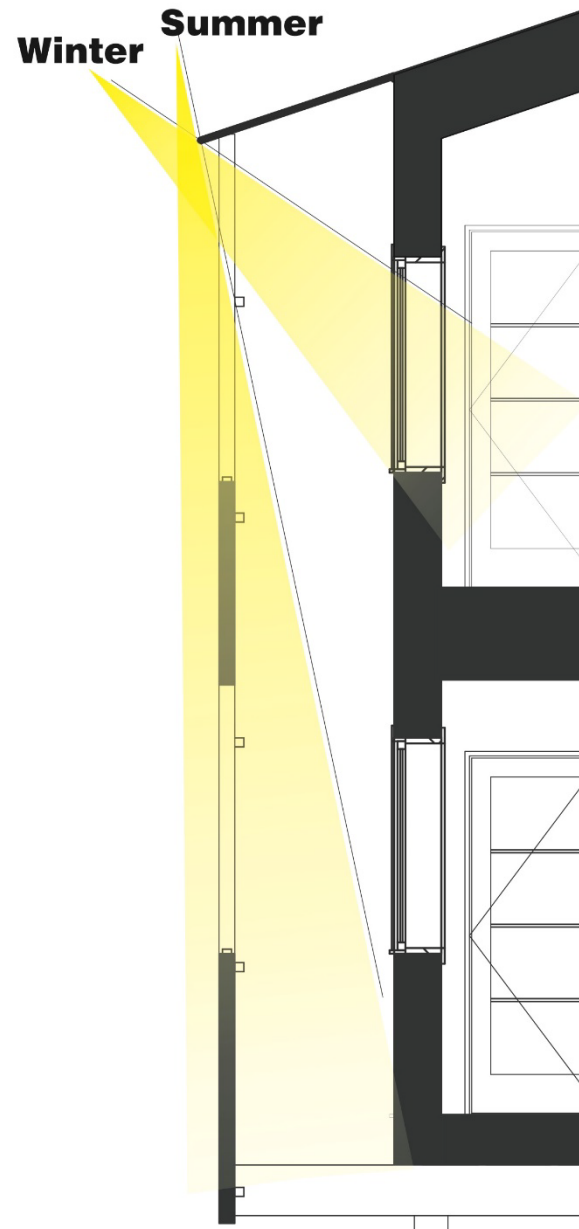
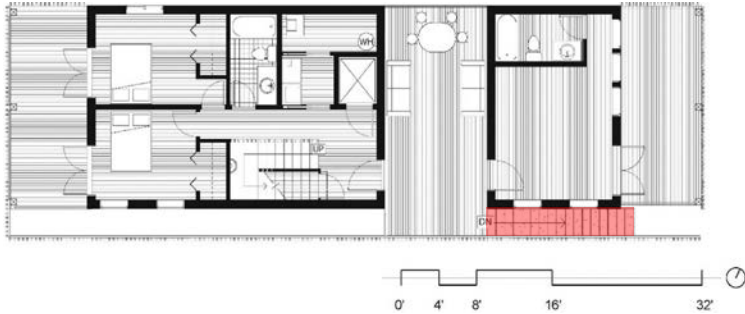
First Floor Plan

- Compact private spaces
- Flex room
- Dogtrot





Front Stairs

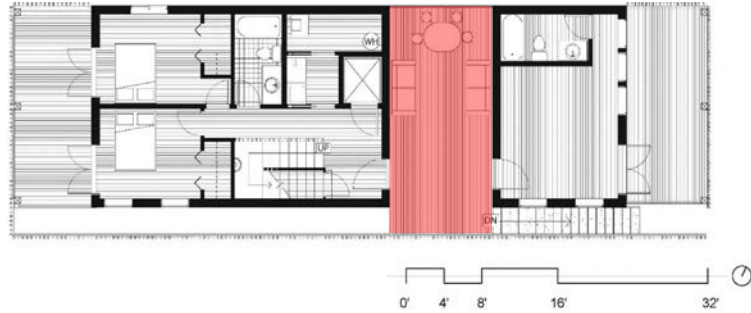


- Focal point
- Front door
- Protected
- Natural lighting diffusion





Dogtrot

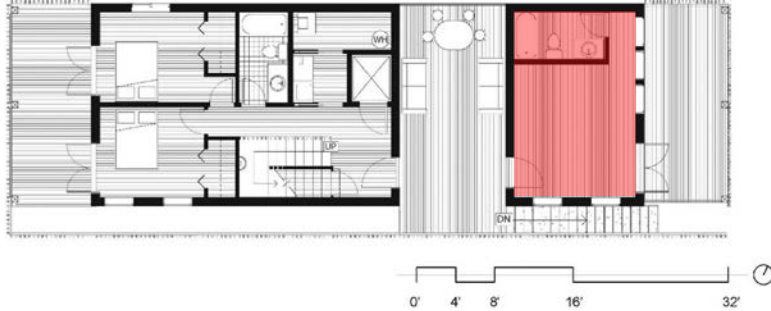


- Protected outdoor space
- Transition space
- Natural ventilation





Flex Room

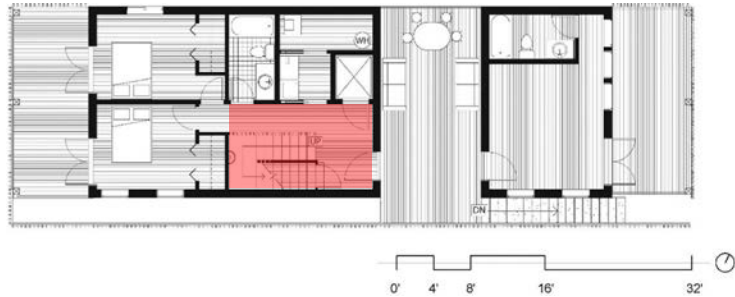


- Creates larger market
- Rentable space
- Multi-use
 - Public/Private
 - (e.g.) Office space, Mother-in-law Suite





Foyer



- Transition space
- Interior architecture





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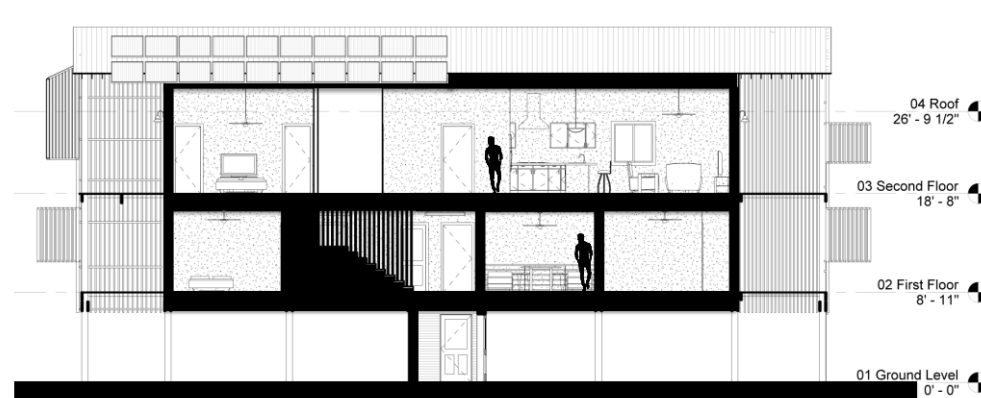
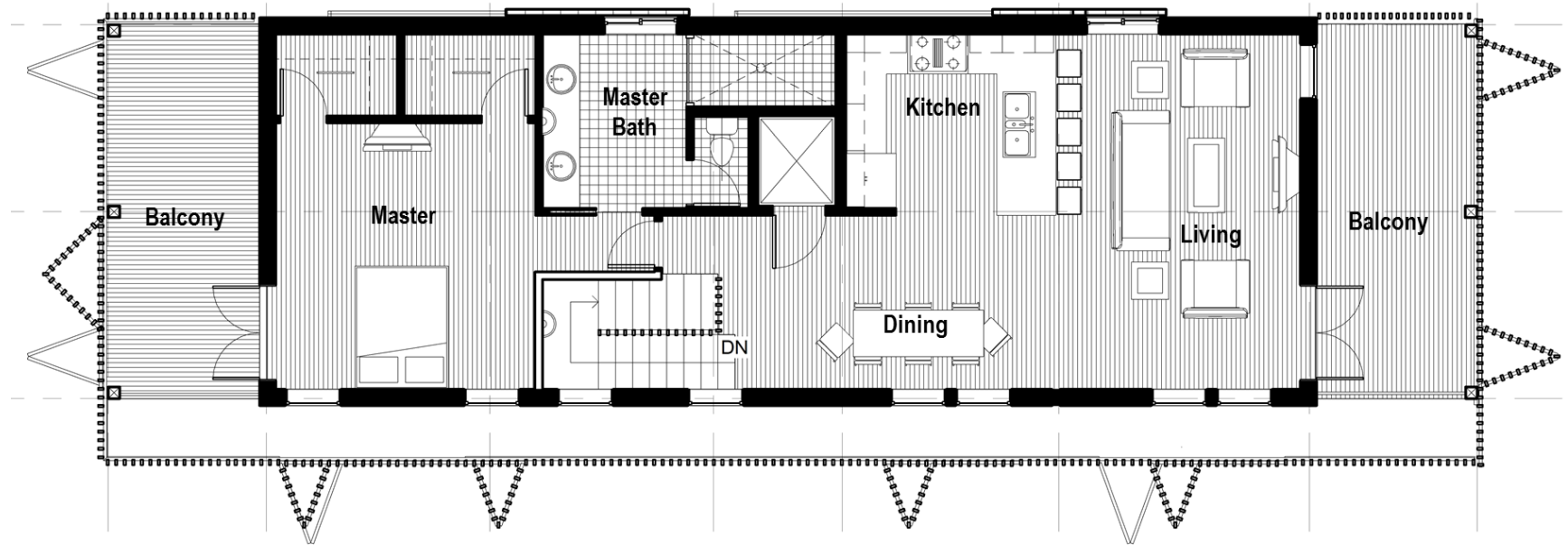
Energy

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Second Floor Plan

- Reversed living
- Open floor plan
- Master bedroom





Kitchen/ Living/ Dining

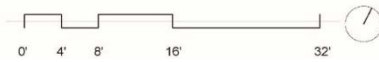


- Flooring-Hardwood
- Wall Color-White
- Open Layout



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Master

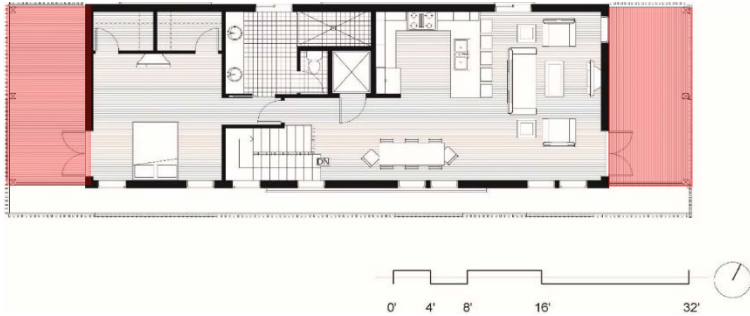


- Flooring-Hardwood
- Wall Color-Light Hue
- Two W.I.C.
- Master Bath





Balcony



- On East and West ends
- Both Levels
- Outdoor Living Space





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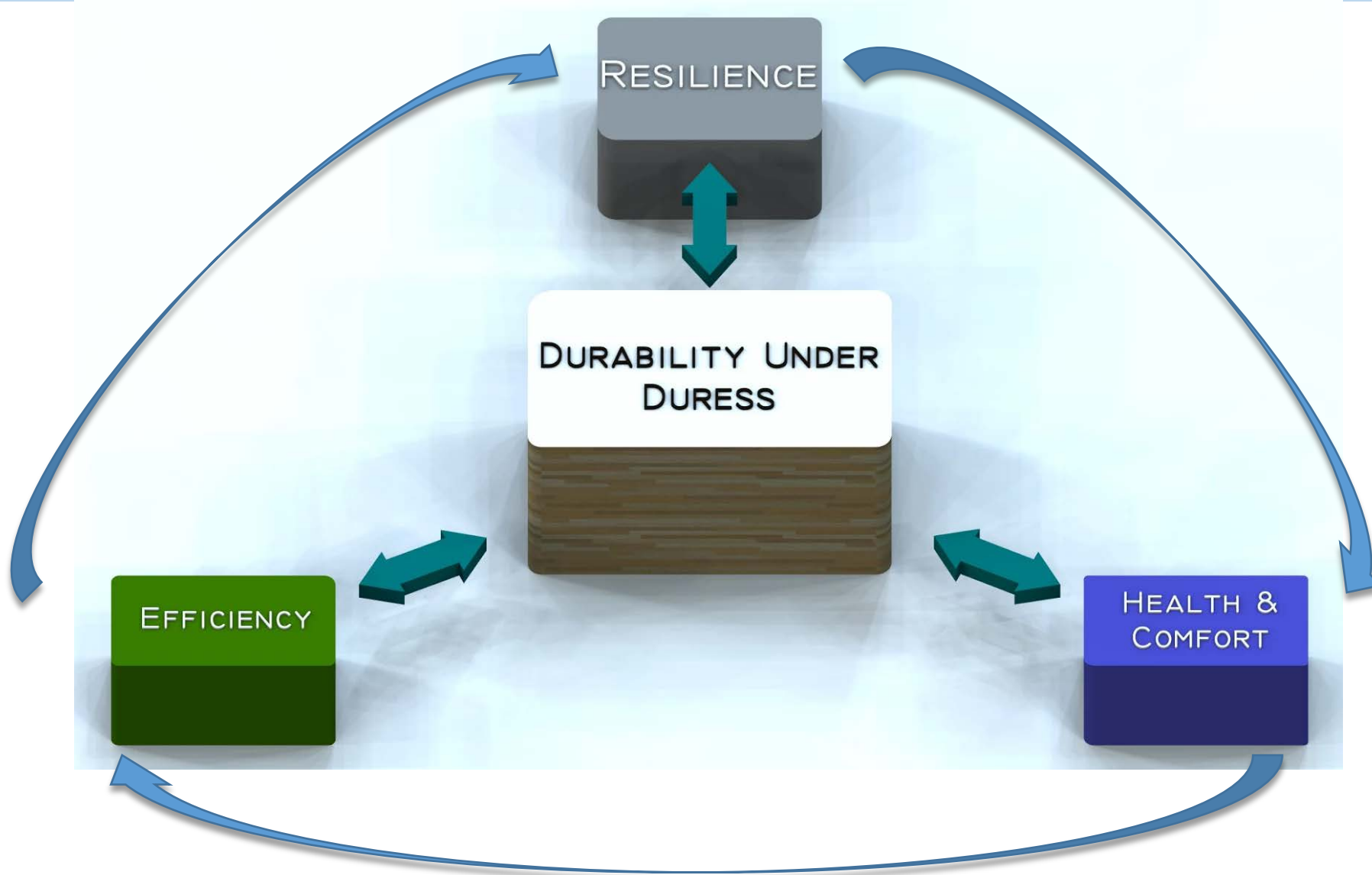
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Envelope Goals





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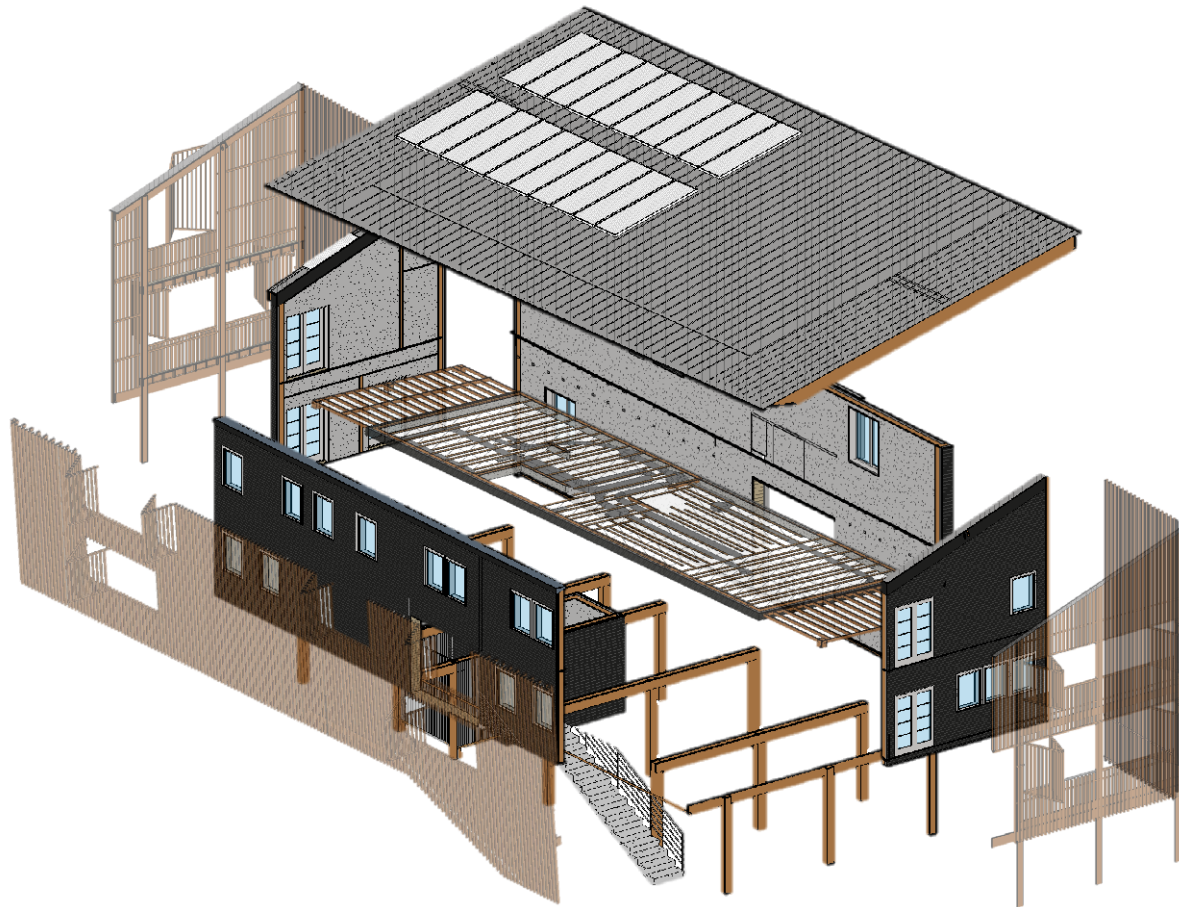
Space Cond

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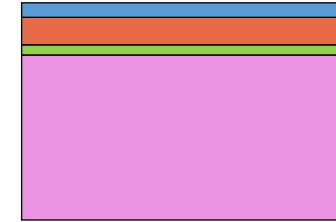
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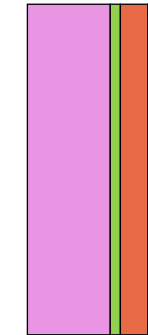
Envelope Design



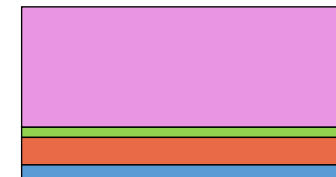
Roof



Wall



Floor



Drained air space
Continuous Insulation
Airtight Sheathing
Cavity Insulation

Exploded Axonometric



Structural Components

- Salt-Treated Timber Pier Foundation
- Pressure-Treated 2x12 Girders
- 9 ½" I-Joist Base floor
- 2X6 24"O.C. Framing
- 18" 2x4 Floor Truss second floor
- 14" I-Joist Rafters (TJI 560)
- ZIP Sheathing (walls and Roof)
- Continuous Header and Top Plates





Structural Connections

FORTIFIED Home Hurricane – Gold Level

- 150 mph Design wind speed
- Huber ZIP wall and roof sheathing – Wind Zone panels
- Simpson Strong-Tie holddowns, saddle clips, strapping





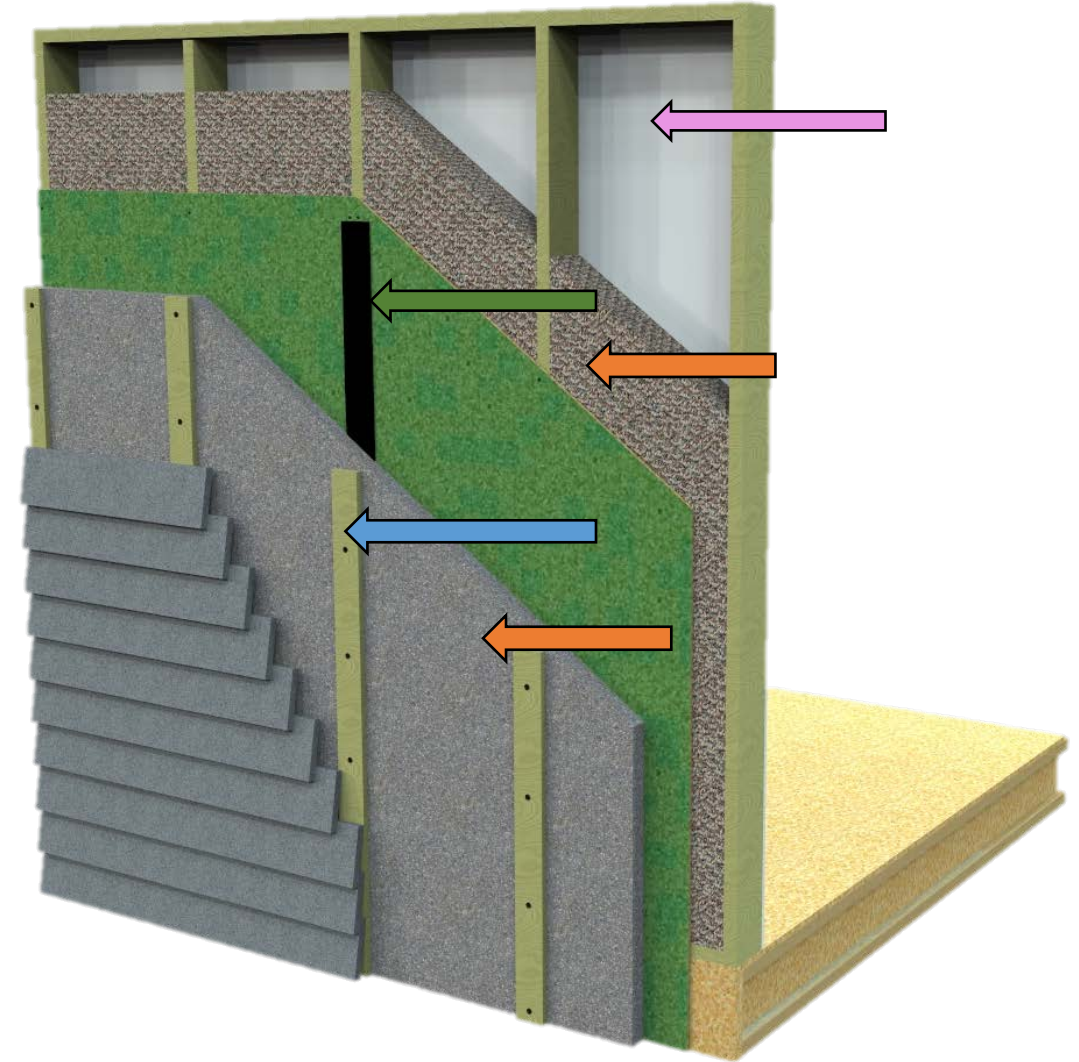
Envelope Decision Summary

Resilient House Wall System Selection Summary								
Wall System Considered	Nominal R-Value	Cost/SqFt/ R-value	Construct-ability (1-10)	Sheathing Condensation Safety (°F)	Energy Savings (MMBtu/yr)	Payback vs. Standard Wall (years)	Wall System Score	Rank 1-12
Weight (%)	10	10	25	25	15	15		
2X4 R-13 Batt	13	\$0.16	10	-3.8	0		21.7	12
2X4 R-15 Batt, 2" Continuous XPS.	25	\$0.12	8	3.9	4.5	30	52.1	7
2X4 R-15 Batt, 4" Continuous XPS	35	\$0.12	6	8.7	5.5	48	57.1	4
2X6 R-21 Batt, 24" O.C.	21	\$0.14	9	4.2	2.2	5	56.0	6
2X6 R-21 Batt, 1" Continuous XPS	26	\$0.14	Resilient House Wall		4.4	21	45.0	10
2X6 R-21 Batt, 2" Continuous XPS	31	\$0.13	7	3.2	5.1	27	51.2	8
2X6, Cellulose, 2 1/4" Continuous EPS	31	\$0.11	7	2.7	5.2	18	62.0	1
2x6, Cellulose, 4" Continuous XPS	41	\$0.11	5	7.4	5.9	46	56.1	5
2x8, Cellulose	26	\$0.15	Mountain Laurel Wall		4.4	8	48.4	9
2x8 Cellulose, 2" Continuous XPS	36	\$0.16	7	2.1	5.6	51	39.0	11
2x8 Staggered, Cellulose	26	\$0.13	7	-4.0	4.9	7	57.5	3
2X8 Staggered, Cellulose 2 1/4" Continuous EPS	36	\$0.11	6	2.1	5.7	19	61.0	2



Envelope Control Layers

- Bulk Water Drainage (Durability)
- Air Barrier (Durability, Health/Comfort, Efficiency)
- Thermal Insulation (Efficiency, Comfort)
- Moisture Management (Durability, Health/Comfort)





Ease of Construction, Pre-Fab Potential

ASU Building Science program promotes hands-on learning



- If we can build this wall, any framing crew can build it



Cavity Insulation

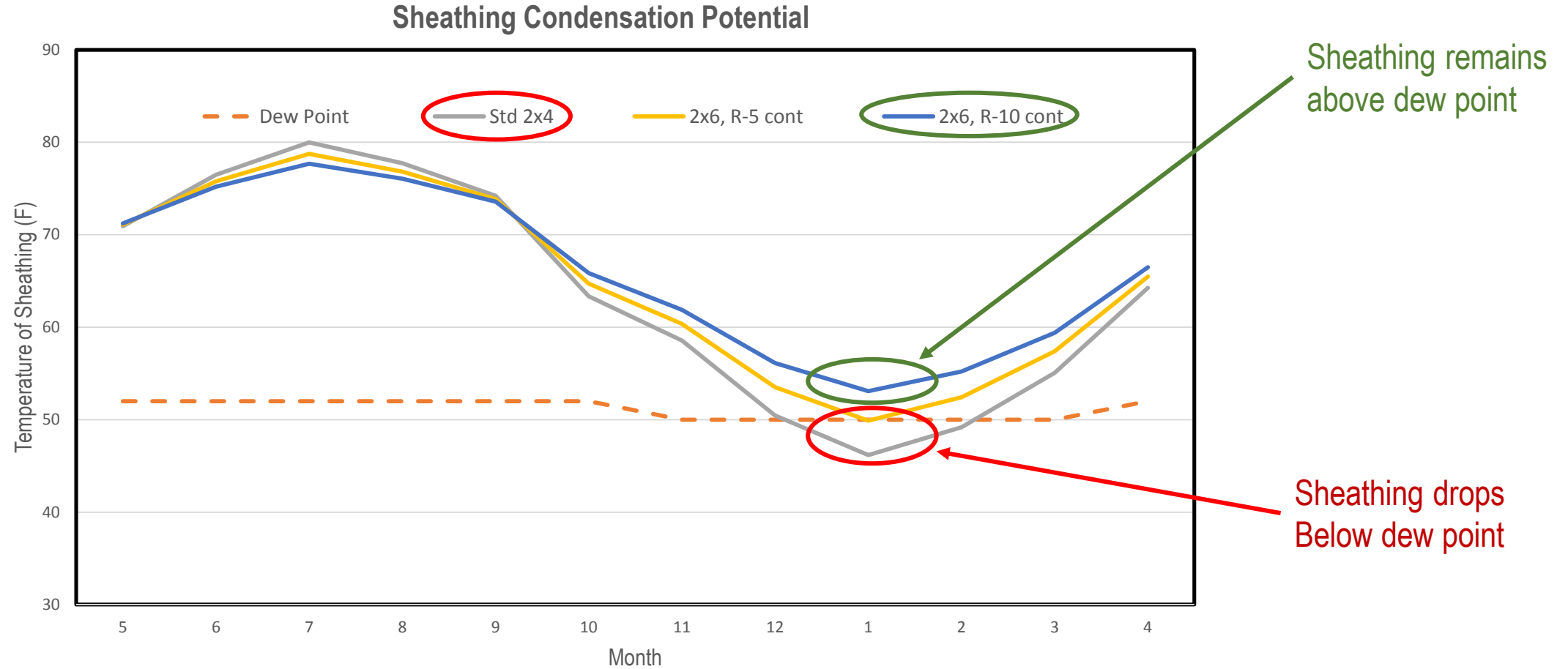
- Blown-In Cellulose supplied by GreenFiber



- Made in Charlotte, NC from recycled newsprint and borate



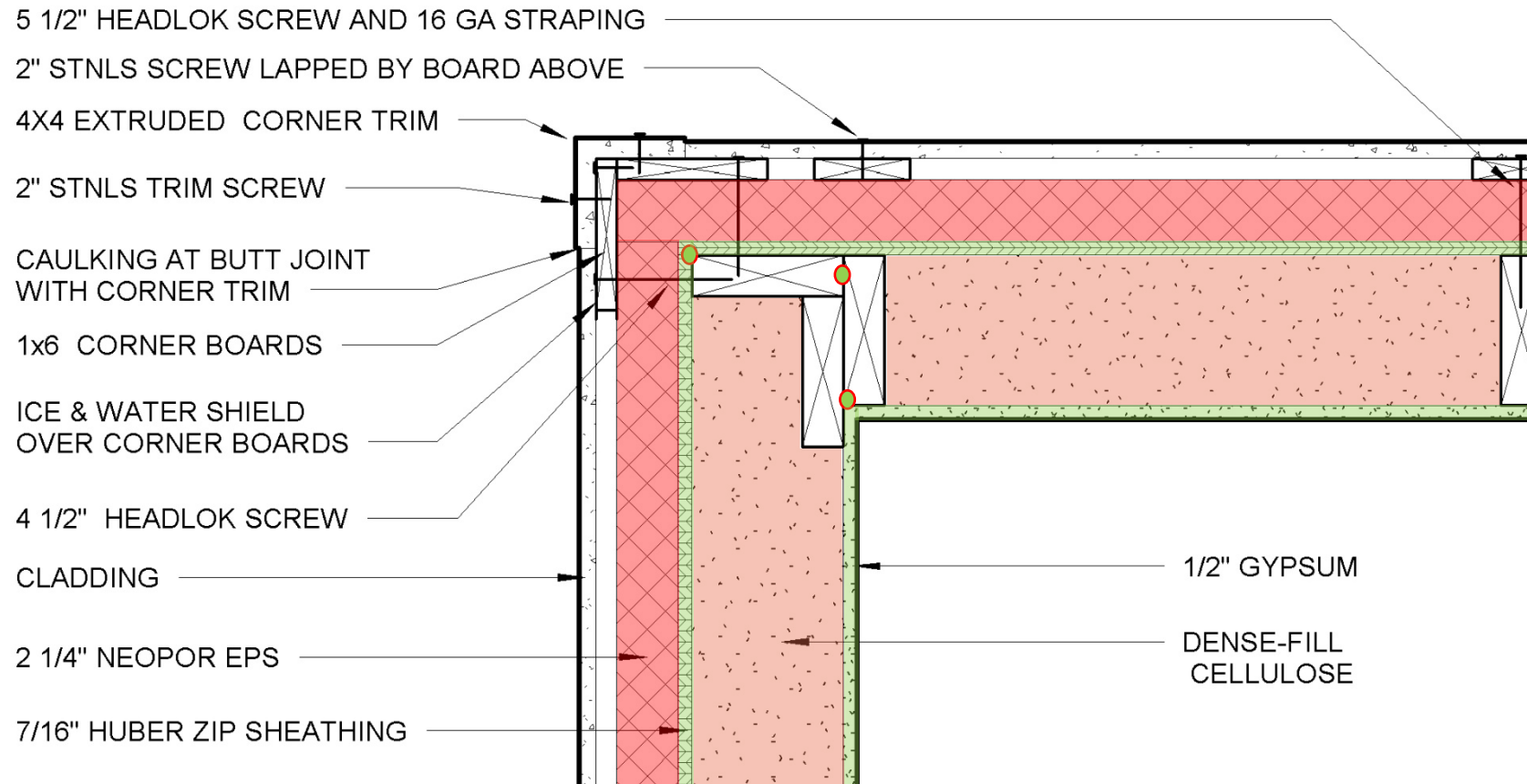
Condensation Potential





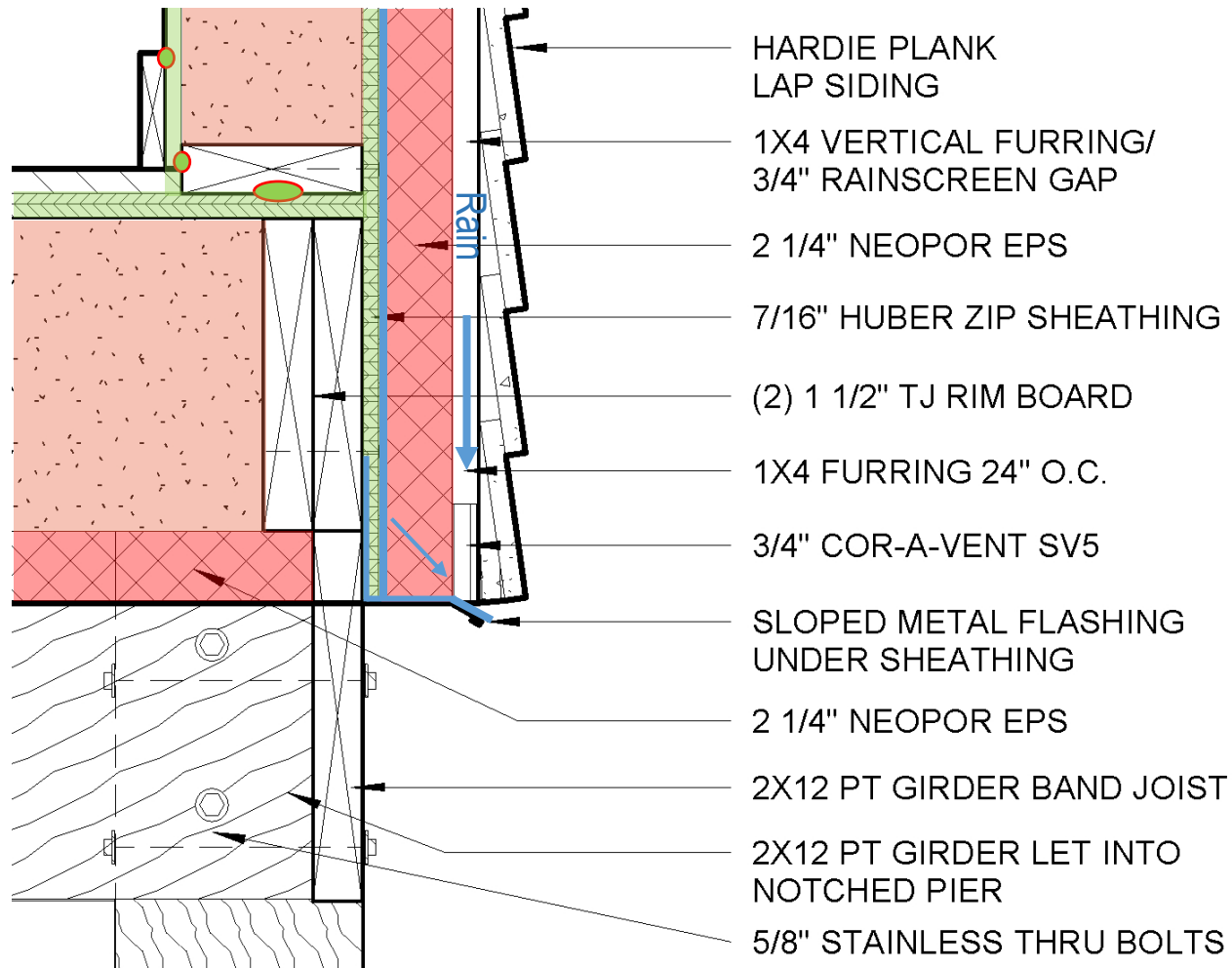
Advanced Wall Framing

Exterior Wall Corner – Plan View



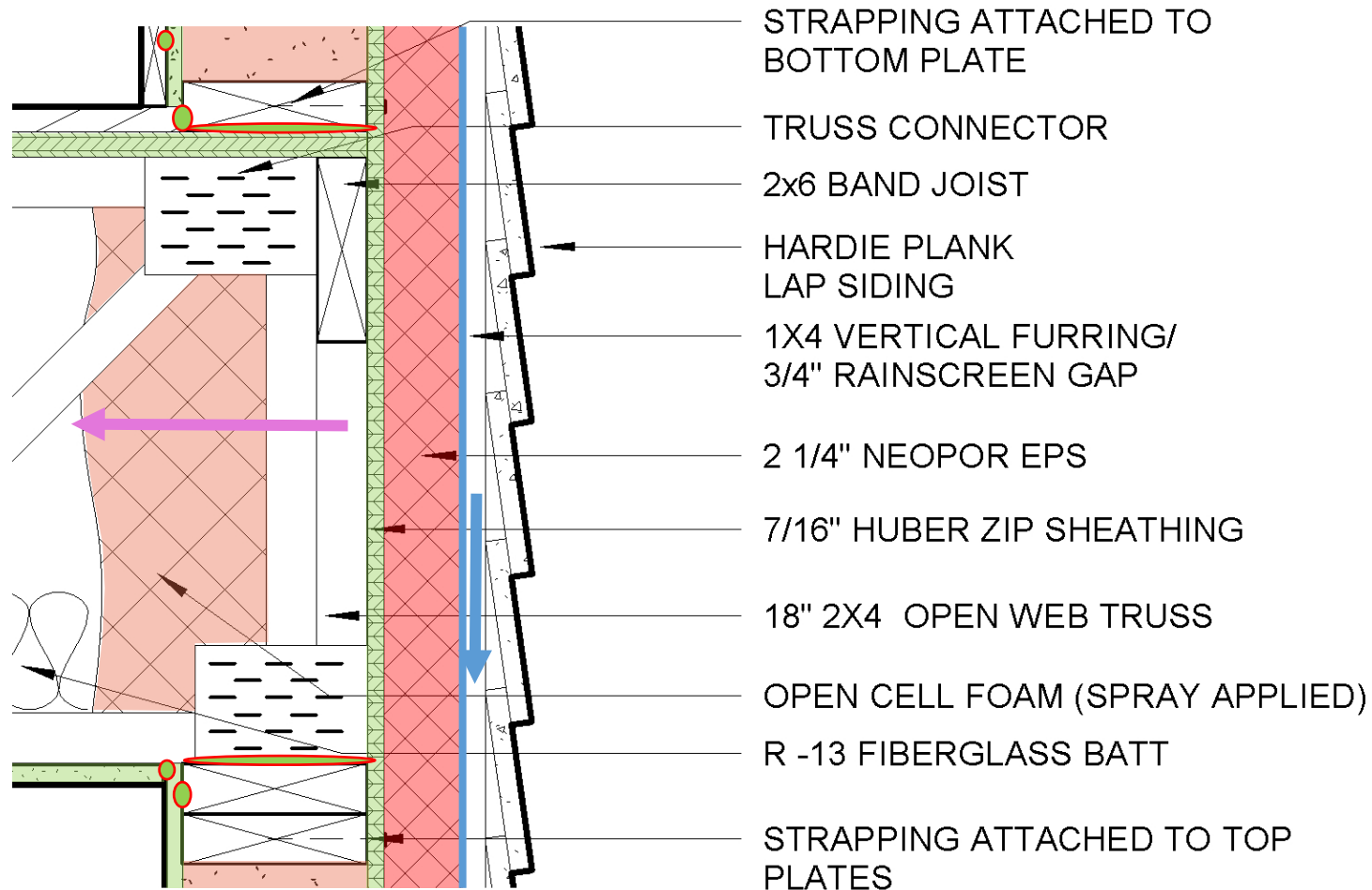


Weather Resilience



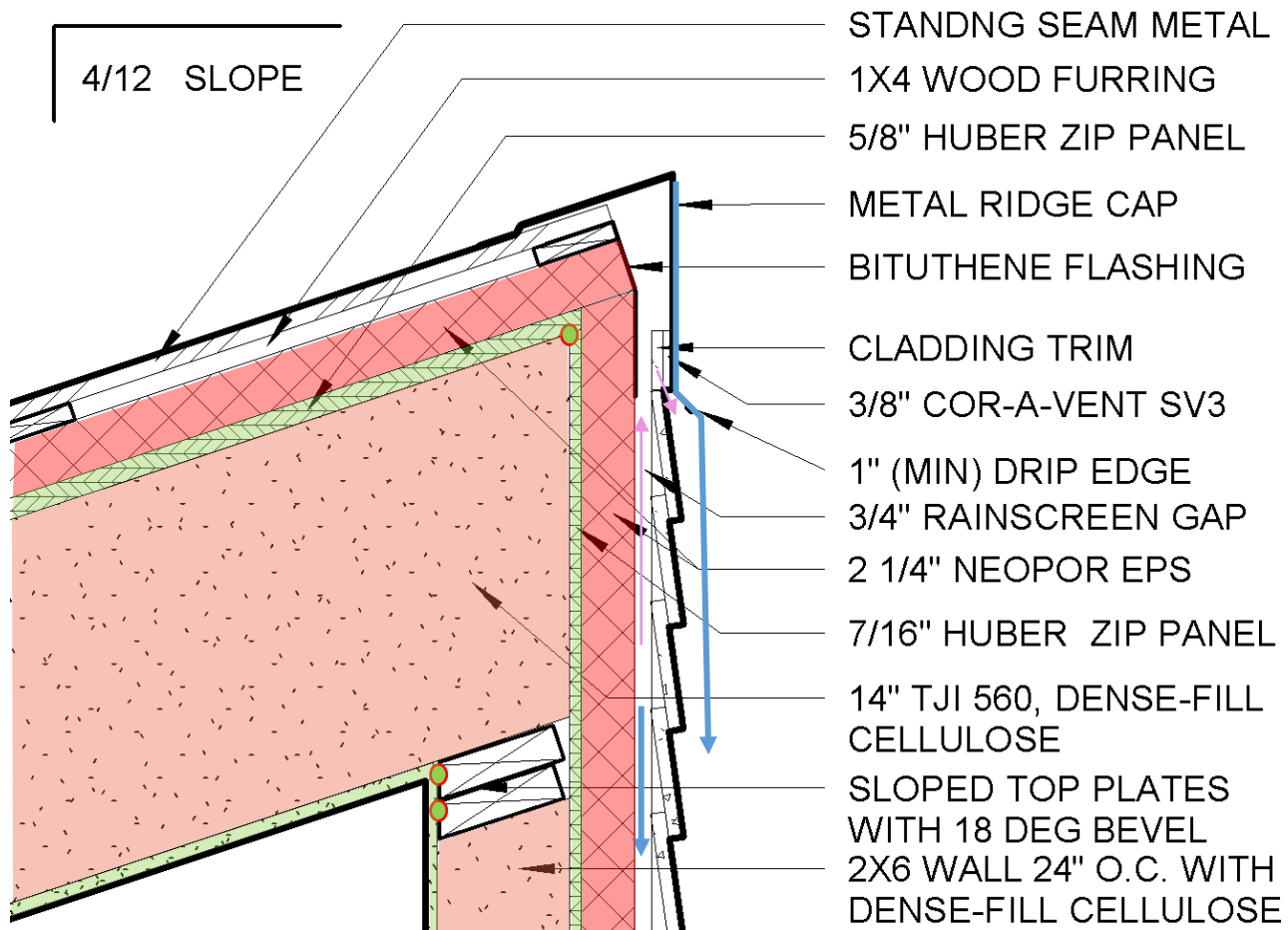


Air Barrier, Thermal Envelope, Moisture Management





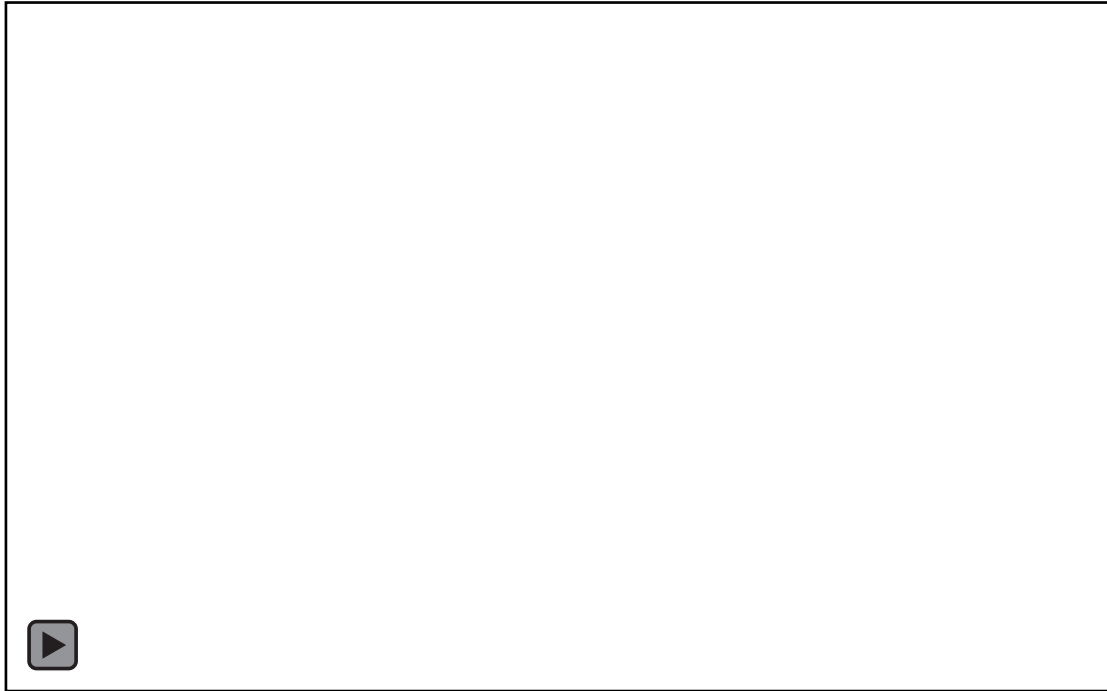
Capping it off



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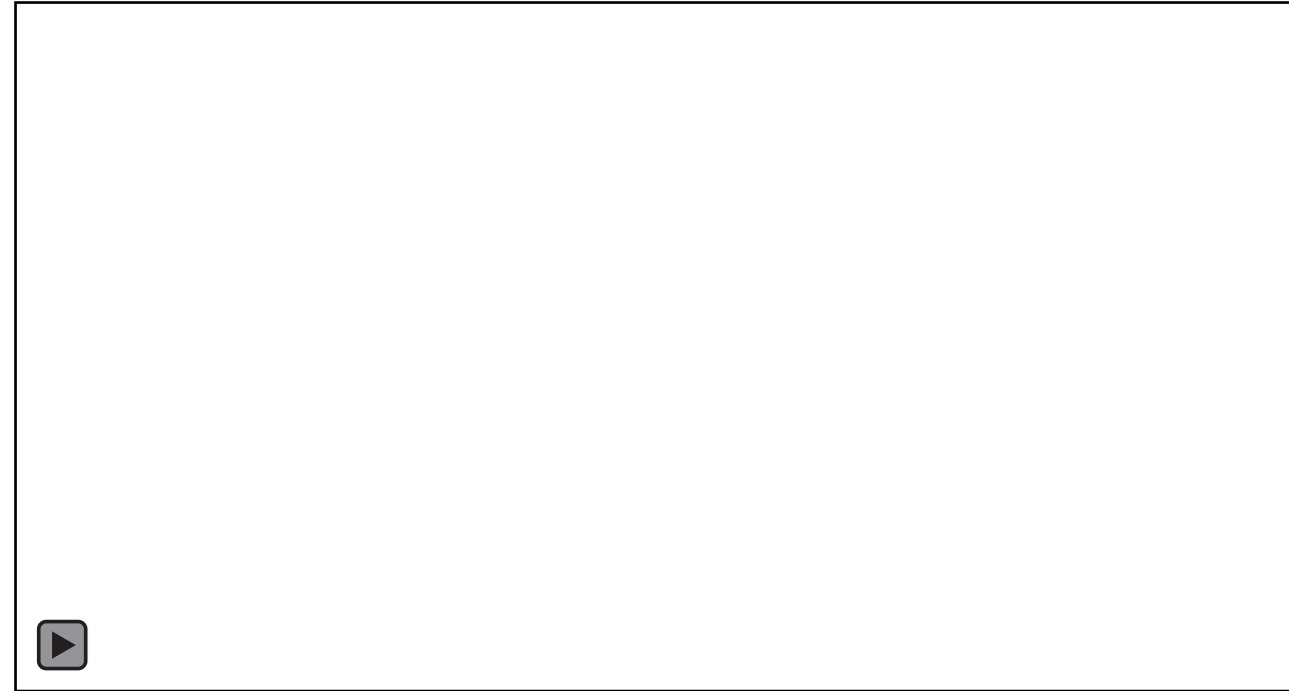
Hygrothermal Modeling – WUFI Pro

2x4 Code Wall



Fiber Cement Siding
Oriented Strand Board
R-13 Batt Insulation
Gypsum Wall Board

2x6 Resilient House Wall



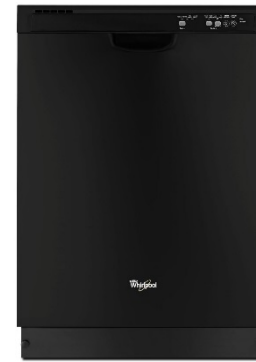
Fiber Cement Siding
Air Space
Expanded Polystyrene
Weather Barrier
Oriented Strand Board
Cellulose
Gypsum Wall Board



Indoor Air Quality & Appliances



- Design Follows EPA Indoor airPLUS
- No Combustion Appliances
- Broan ERV140TE
- Ultra-Aire XT105H Dehumidifier
- No VOC's





Whole House Dehumidifier Justification



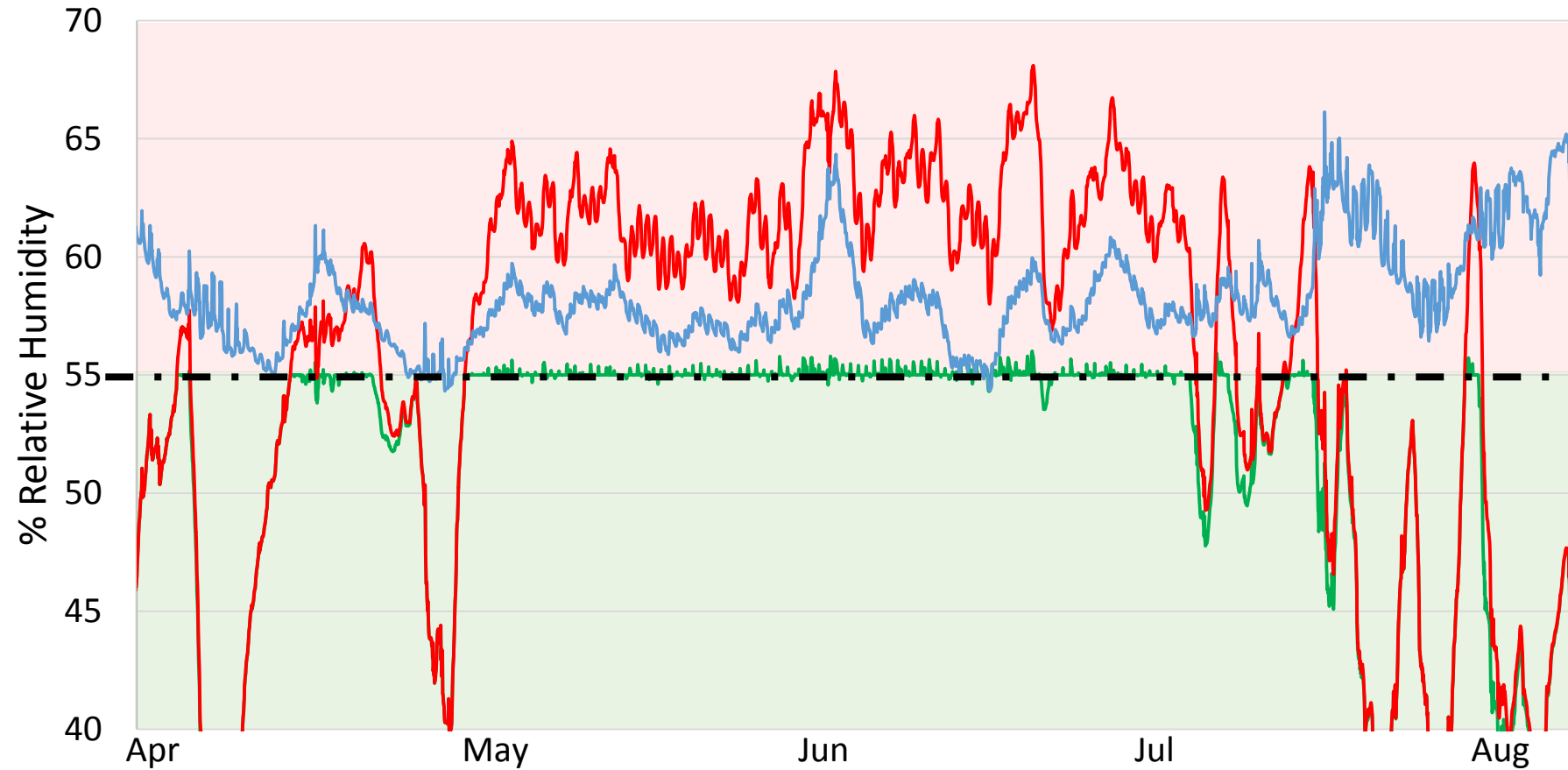
- Latent loads based on D-View
- Based on Past Weather data

● No ERV or Dehumidifier

● Only ERV

● ERV with Dehumidifier

Indoor Relative Humidity





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Appliance Selection

APPLIANCE SELECTION

Appliance	Model	Cost	Energy Usage	Cost	Extra Cost	Energy Savings	Extra Mortgage Payment	Payback Period
Fridge								
Energy Star	WRT541SZDW	\$854	399 kWh	\$40	\$45	\$4	\$3	10.2
Non-Energy Star	WRT511SZDW	\$809	443 kWh	\$44				
Dishwasher								
Energy Star	WDF320PADW	\$270	260 kWh	\$26	\$1	\$3	-\$1	0.3
Non-Energy Star	WRT511SZDW	\$269	290 kWh	\$29				
Washing Machine								
Energy Star	WFW81HED	\$599	109 kWh	\$11	\$160	\$19	\$9	8.4
Non-Energy Star	WTW5000DW	\$439	300 kWh	\$30				
Water Heater								
Heat Pump WH	GEH50DEEJSC	\$1,000	1514 kWh	\$151	\$620	\$311	\$36	2.0
Electric Storage WH	E50R6-45-110	\$380	4622 kWh	\$462				
Stove								
Induction Range	WFI910H0AS	\$1,704	n/a	n/a	\$1,095	n/a	n/a	n/a
Standard Stove	LFEF3048QF	\$609	n/a	n/a				
Dryer								
Energy Star	WED99HEDW	\$1,349	531 kWh	\$53	\$750	\$8	\$43	97.4
Non-Energy Star	WED72HEDW	\$599	608 kWh	\$61				



Plumbing System Design

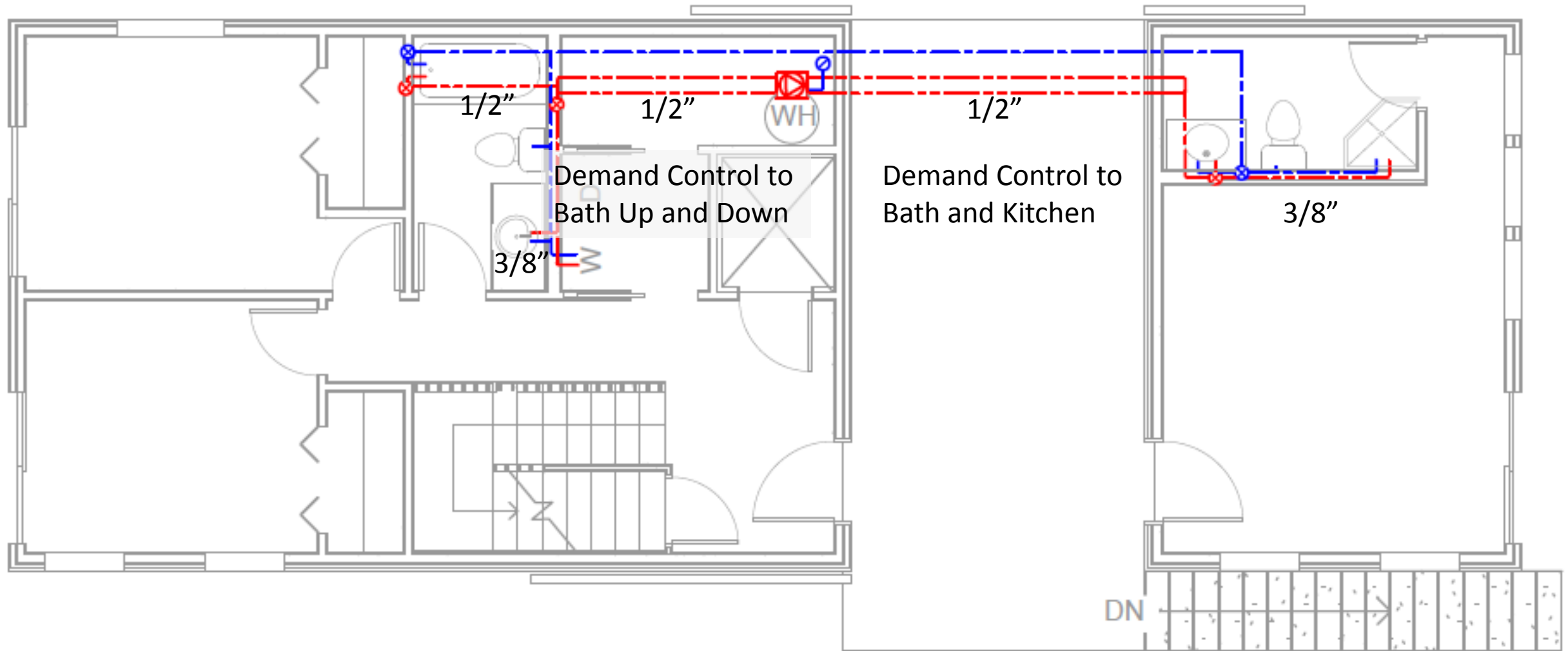
- Exceeds WaterSense requirements
- Compact plumbing layout
- Stacked plumbing and shortest possible runs
- Demand initiated recirculation (Two loops)
- Heat Pump Water Heater intakes from behind refrigerator – Captures waste heat
- Minimal heat loss



Recirculation Loop Energy Loss		
	Left Loop	Right Loop
Length	16 ft	28 ft
Pipe Diameter	0.5 inch	0.5 inch
Volume	0.15 Gal.	0.27 Gal.
Insulation	R-6	R-6
Heat loss/Hour	9.2°F	9.2°F

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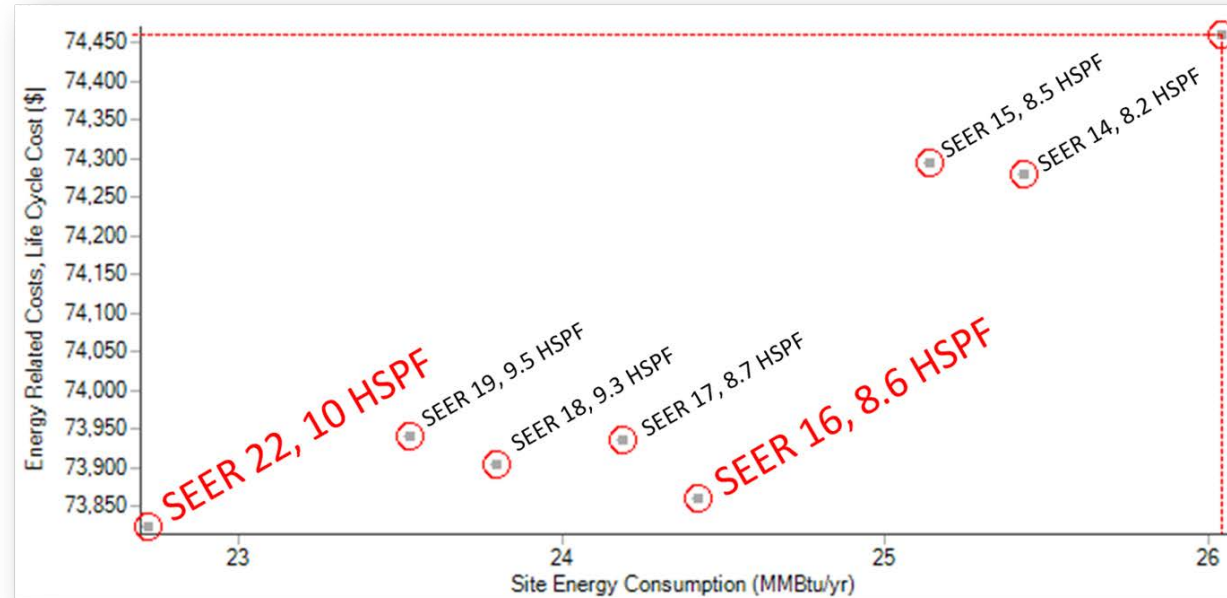
Plumbing System Design





Space Conditioning Equipment Selection

- BEOpt was heavily used
- Pointed to a 16 and 22
- SEER Air Source Heat Pump
- Based on:
 - 4% interest rate
 - 20% down payment
 - 30 yr mortgage period
 - 28% Income Tax Reduction
 - \$0.10/kWh

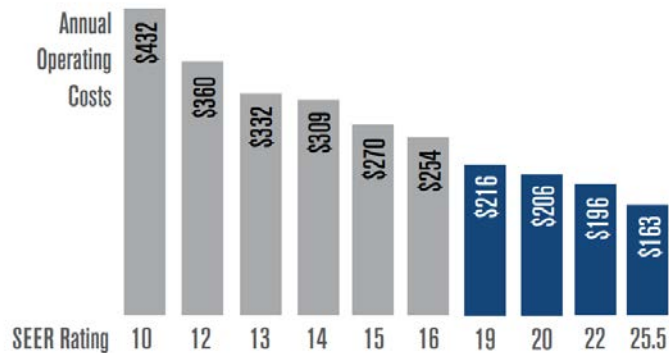


HVAC SYSTEM PAYBACK								
	Annual Energy Use (MMBtu)	Annual Energy Cost	Annual Energy Savings	Cost	Extra Cost	Extra Mortgage	Income Tax Reduction	Net Savings
SEER 14/ HSPF 8.2	25.3	\$ 742		\$ 5,972				
SEER 15/ HSPF 8.5	25	\$ 733	\$ 9	\$ 6,210	\$ 238	\$ 14	\$ 4	\$ (1)
SEER 16/ HSPF 8.6	24.3	\$ 712	\$ 29	\$ 6,448	\$ 476	\$ 28	\$ 8	\$ 9
SEER 17/ HSPF 8.7	24.1	\$ 706	\$ 35	\$ 6,687	\$ 715	\$ 41	\$ 12	\$ 5
SEER 18/ HSPF 9.3	23.7	\$ 695	\$ 47	\$ 6,925	\$ 953	\$ 55	\$ 15	\$ 7
SEER 19/ HSPF 9.5	23.4	\$ 686	\$ 56	\$ 7,164	\$ 1,192	\$ 69	\$ 19	\$ 6
SEER 22/ HSPF 10	22.5	\$ 659	\$ 82	\$ 7,466	\$ 1,494	\$ 86	\$ 24	\$ 20



Space Conditioning

- Maytag iQ Drive Variable Speed Air Source Heat Pump
- 22 SEER
- 10 HSPF
- ECM fan motor
- Resilient Galvanized Steel Finish
- iQ Zone thermostats in 4 comfort zones

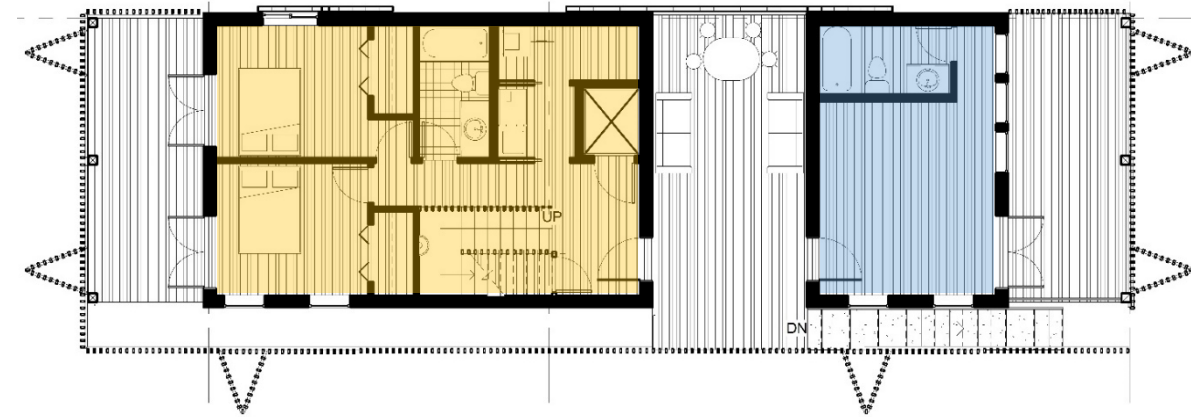




Manual J Summary

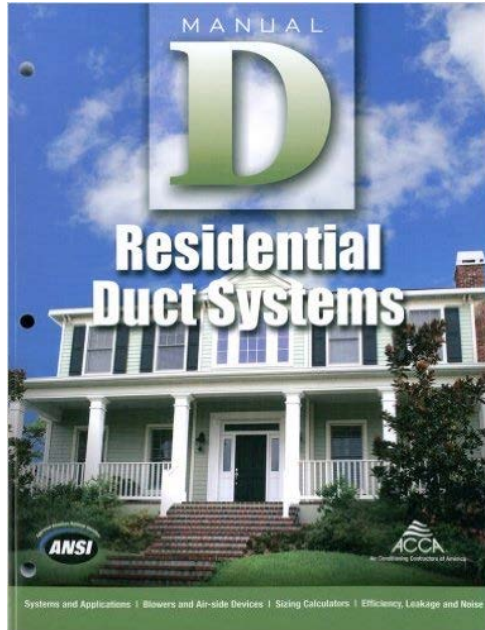
Manual J Summary					
	HEAT LOSS	HTG CFM	HEAT GAIN	CLG CFM	Final CFM
Bedroom 1	500	51	1,036	81	81
Bedroom 2	407	41	1,122	88	88
Hallway	1,274	129	991	78	129
Flex	1,189	121	1,517	119	121
Master	2,022	205	1,885	147	205
Living/Dining	2,482	252	3,673	287	287
Room Envelope Totals	7,874	800	10,223	800	

Total Area (sq ft)	Construction Components	Heat Loss (Btu/hr)		Heat Gain (Btu/hr)	
394	Windows & Glass Doors	315	3.13%	4,977	37.88%
	Skylights				
40	Wood & Metal Doors	400	3.97%	350	2.66%
2,309	Above Grade Walls	2,956	29.34%	1,130	8.60%
	Partition Walls				
	Below Grade Walls				
1,065	Ceilings	682	6.77%	24	0.18%
	Partition Ceilings				
	Passive Floors				
1,749	Exposed Floors	1,539	15.28%	847	6.44%
	Slab Floors				
	Basement Floors				
	Partition Floors				
	Infiltration	1,982	19.68%	545	4.15%
	Internal Gains			2,350	17.88%
	Duct Loss & Gain				
	Ventilation	2,200	21.84%	1,210	9.21%
	Blower Heat Gain			1,707	12.99%
	Total Sensible	10,074	100.00%	13,140	100.00%
	Total Latent			4,008	
	Total Cooling Load			17,149	

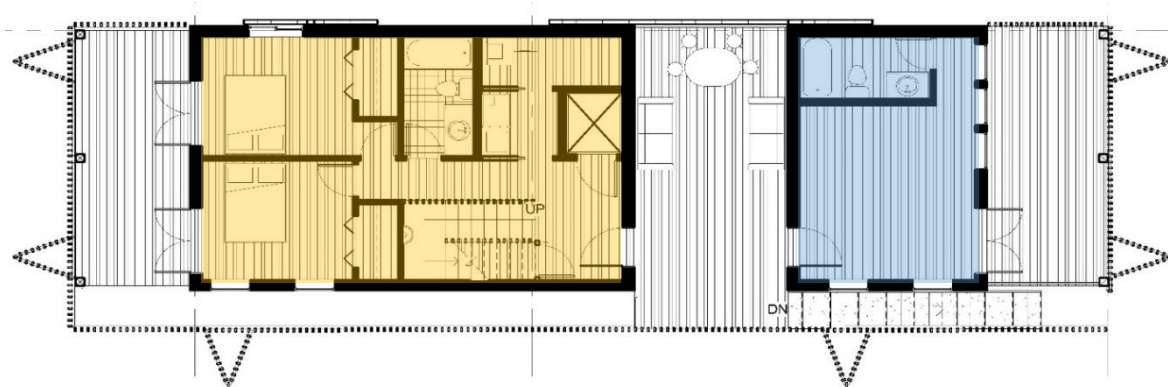




Manual D Summary

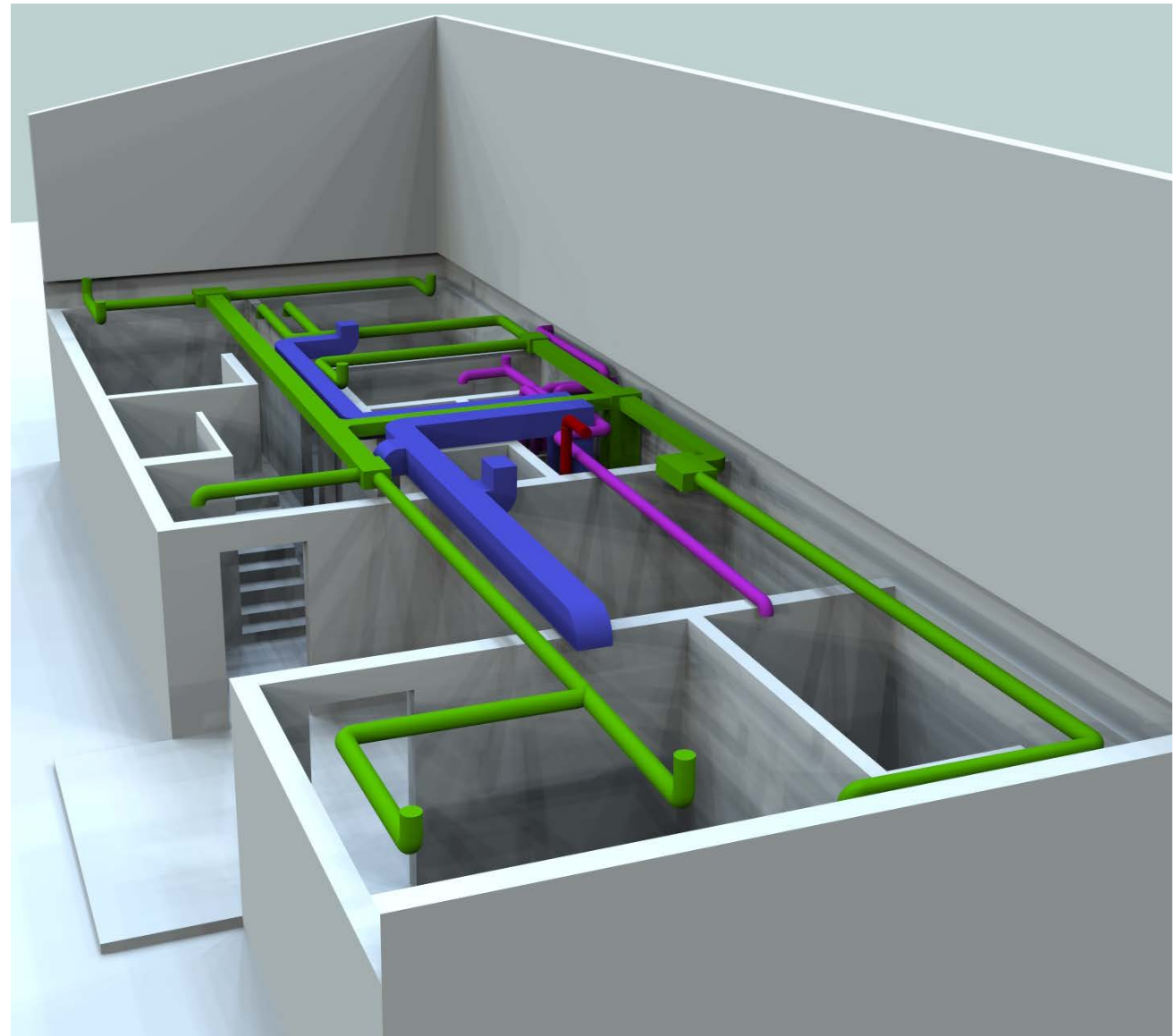
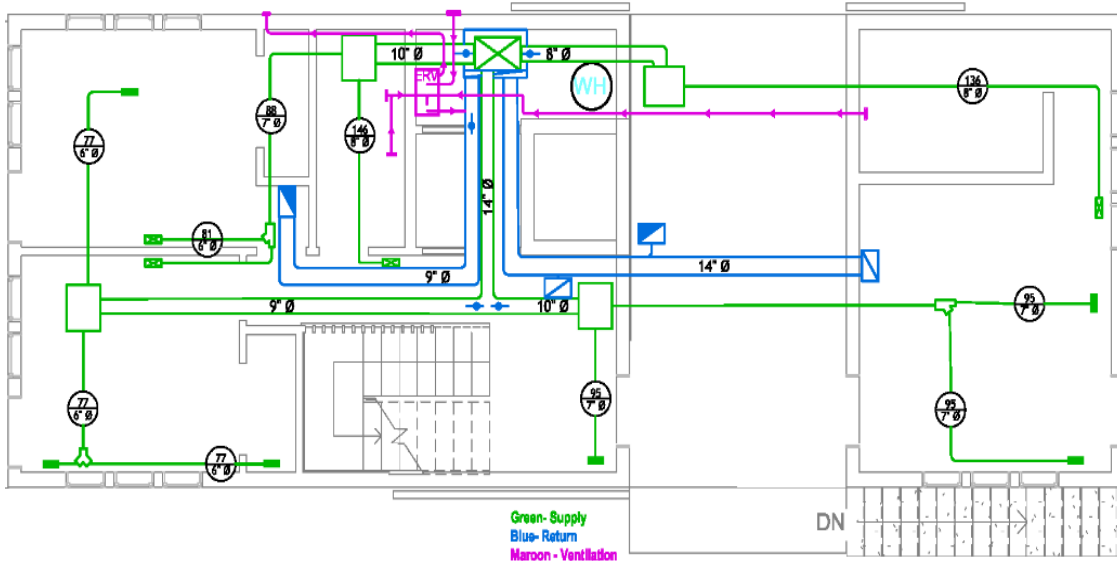
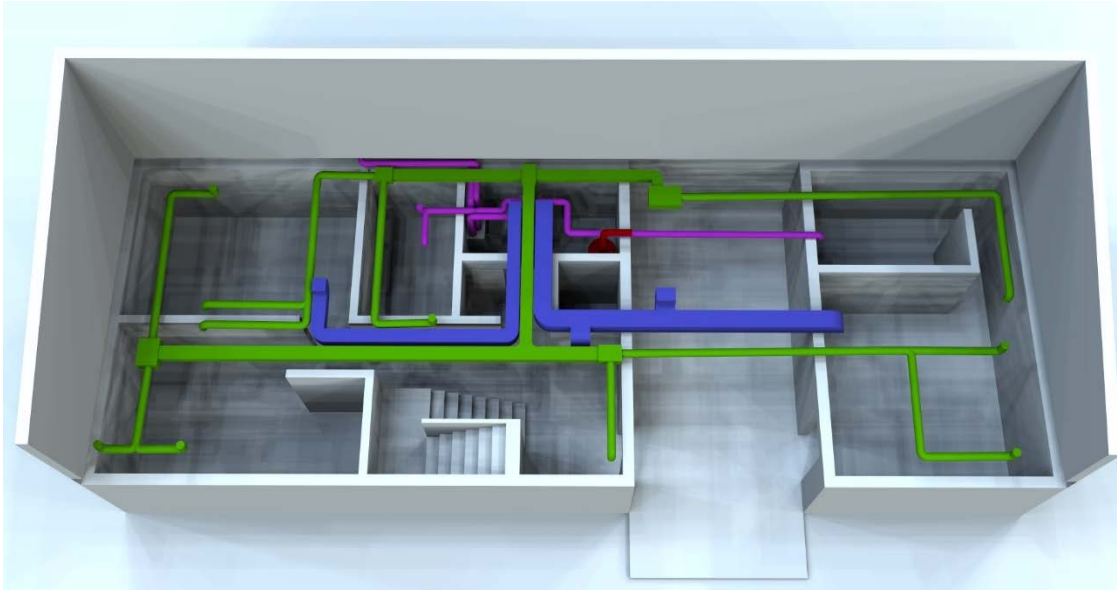


Manual D Summary							
Room Name	HTG CFM	CLG CFM	DSN CFM	Round Size	Velocity	Final Size	Equivalent Flex
Bedroom 1	57	81	81	6	414	6	6
Bedroom 2	47	88	88	6	448	6	7
Hallway	146	78	146	7	545	7	8
Bath 1	Shared	Shared	Shared	Shared	Shared	Shared	Shared
Flex	136	119	136	7	509	7	8
Flex Bath	Shared	Shared	Shared	Shared	Shared	Shared	Shared
Master Bedroom	231	247	231	9	523	9	9
Master Bathroom	Shared	Shared	Shared	Shared	Shared	Shared	Shared
Living / Dining	284	287	287	9	650	9	10





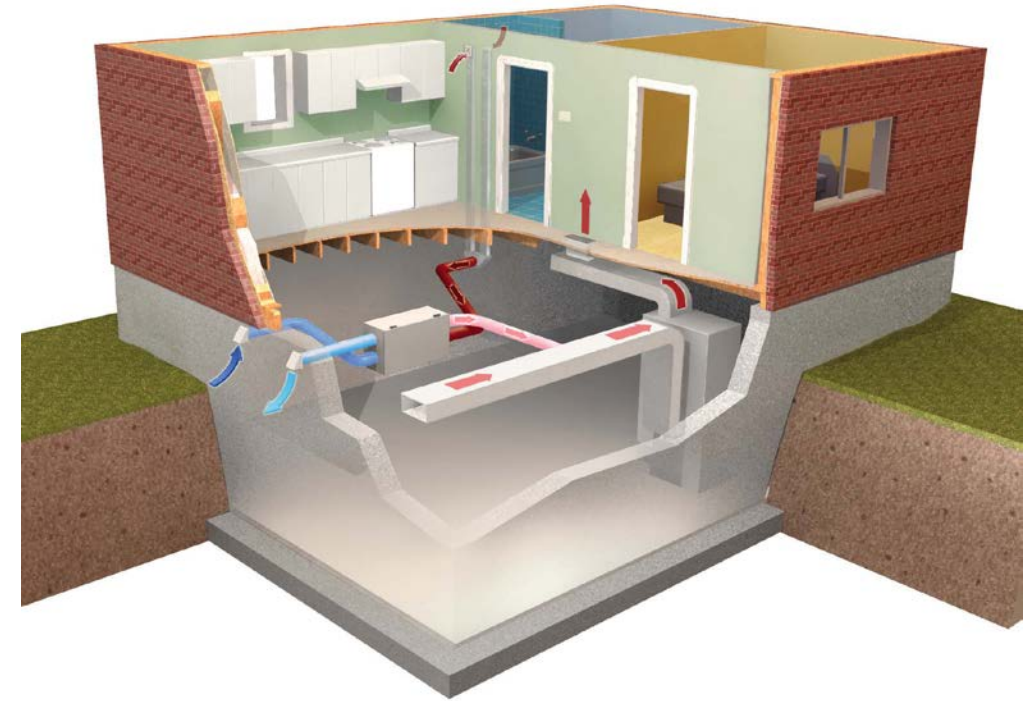
Duct Design





Mechanical Ventilation Strategy

- ASHRAE 62.2
- Point Source ERV
- Continuous Exhaust of Bathrooms
- Fresh Air Ventilation





Energy Analysis

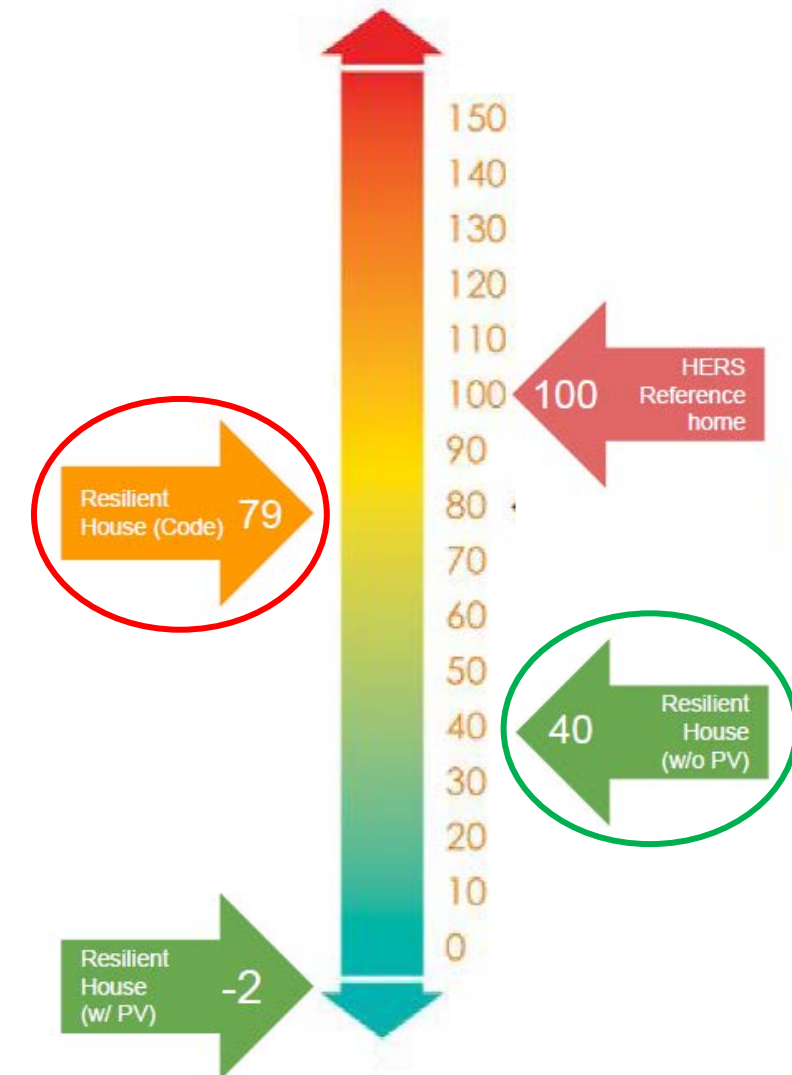
REM/Rate™

- Energy analysis guided our design
- Both REM/Rate and BEopt heavily used
- Some home upgrades based on certification requirements

INITIAL & FINAL REM/Rate INPUTS

Building Component	Base Home Input	Resilient House Input
Wall System	R-13 Batt w/ OSB Sheathing	R-21 Cellulose w/ R-10 c.
Floor Insulation	R-30 BATT	R-45 Cellulose w/ R-10 c.
Windows	U-0.35/SHGC 0.30	U-0.23/SHGC 0.18
Ceiling/Attic	R-30 attic	R-50 Cellulose w/ R-10 c.
Infiltration	5.0 ACH50	0.5 ACH50
Duct Leakage	6% of conditioned floor area	In conditioned Space
HVAC	SEER 14 / HSPF 8.2 Heat Pump	SEER 22 / HSPF 10 Heat Pump
HVAC Location	Attic	Conditioned space
Water Heater	50 gal. 93% EF	50 gal. 3.39 EF HP
Lighting	75% Fluorescent	100% Fluorescent
Appliances	RESNET Defaults	See appliances

HERS Index



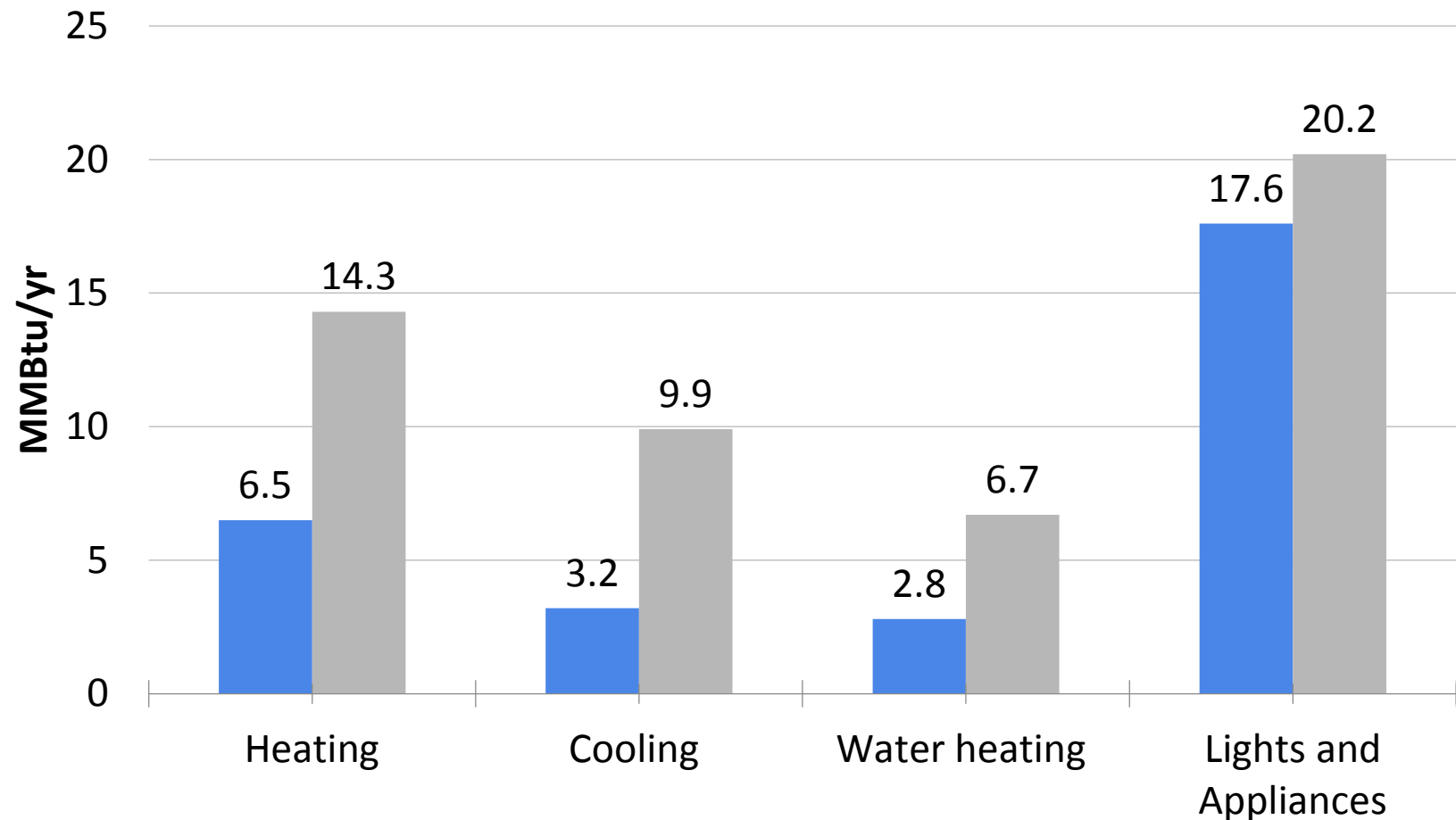


Energy Consumption Improvement Summary

REM/Rate™

ENERGY CONSUMPTION COMPARISON

■ Resilient House ■ Code House



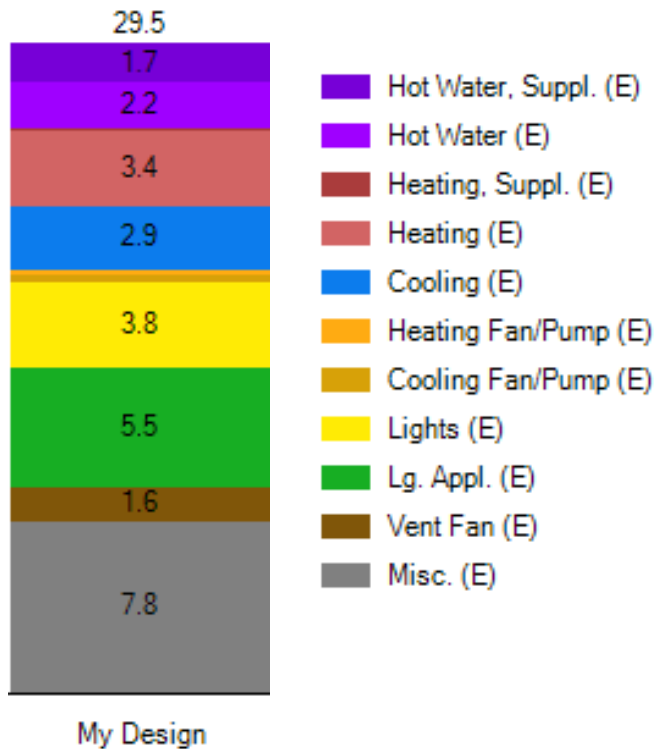
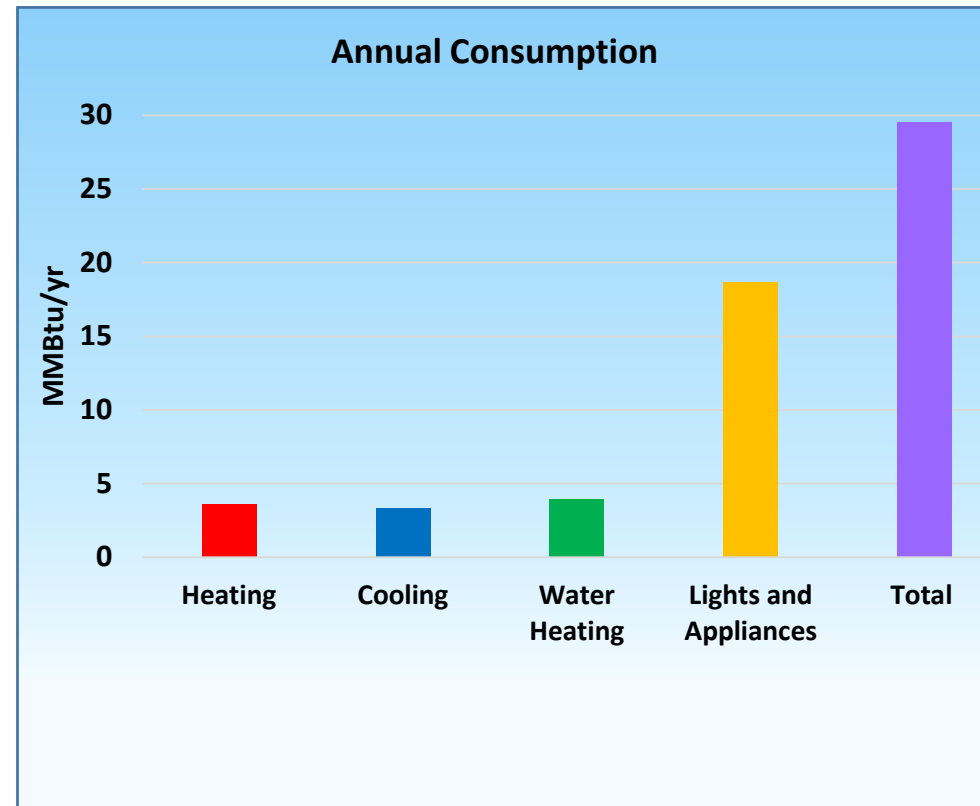
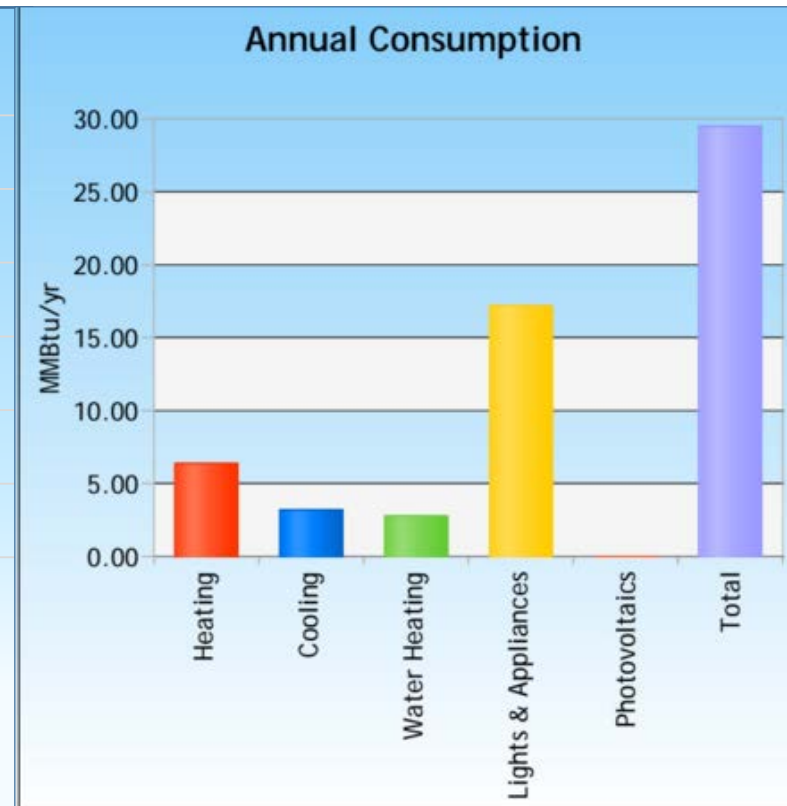
- Annual Energy Reductions Based on REM/Rate
- Biggest Reductions in Space Conditioning
- Less Reductions in Lighting & Appliances
- LED Lights not accounted for



Total Loads

**BEopt****REM/Rate™**

- 51.1 MMBtu/yr (NC Code Home)
- 29.5 MMBtu/yr (Resilient House) - BEopt and REM/Rate agree on total Consumption
- Total reduction of 21.6 MMBtu/yr or 6331 kWh/yr`

**BEopt****REM/Rate**

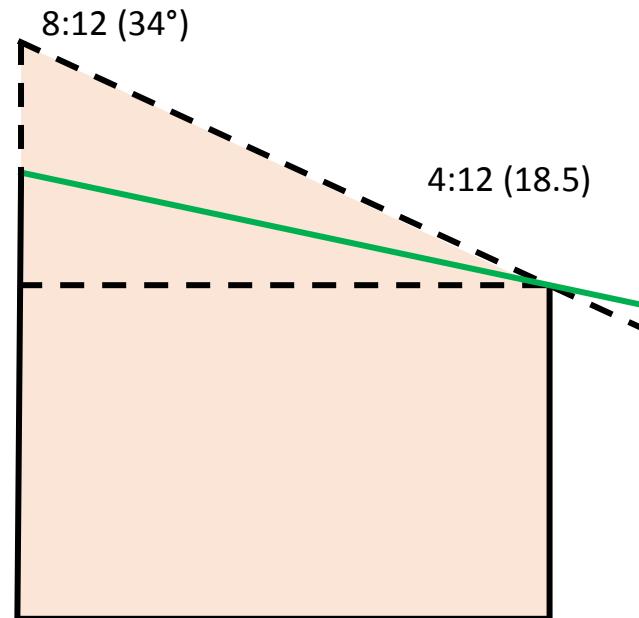


Adjusted PV Energy Production

PVWatts® Calculator

Resilient House

- Roof Pitch: 4/12 (18.5 Degrees)
- Roof Orientation ~160 Degrees
- PVWatts used to calculate to losses
- Based on this information we needed a 6.1 kW PV System to satisfy the annual load



RESILIENT HOUSE Monthly PV OUTPUT				
Month	AC System Output kWh/Month		Solar Radiation kWh/m2/day	
	Resilient House	Optimum	Resilient House	Optimum
Jan	536	629	3.4	4.0
Feb	561	617	4.0	4.4
Mar	779	810	5.2	5.5
Apr	862	848	6.1	6.0
May	855	804	5.9	5.6
Jun	852	783	6.3	5.8
Jul	807	750	5.8	5.4
Aug	783	759	5.6	5.4
Sep	706	717	5.1	5.2
Oct	642	695	4.4	4.8
Nov	545	628	3.8	4.4
Dec	488	577	3.2	3.8
Average	701	718	4.90	5.02
Total	8416	8616	59	60
% Decrease	2.32%		2.25%	



PV System and Storage

- Storage for added resilience
- PV self consumption – Use what you produce (batteries required to be Net Zero)
- Battery Technology
 - Sealed Lead Acid
- PV System Components
- Hybrid Inverter improves energy security

BATTERY TYPE CONSIDERATIONS

Battery Type	kWh	Cost	DoD	Actual kWh	\$/kWh
Juicebox	8.6	\$9,900	95%	8.17	\$1,211.75
Enphase	1.2	\$980.00	96%	1.152	\$850.69
Powerwall	6.4	\$3,000	95%	6.08	\$493.42
Trojan 31-AGM	1.33	\$300	80%	1.064	\$281.95

PV SYSTEM COMPONENT SELECTION

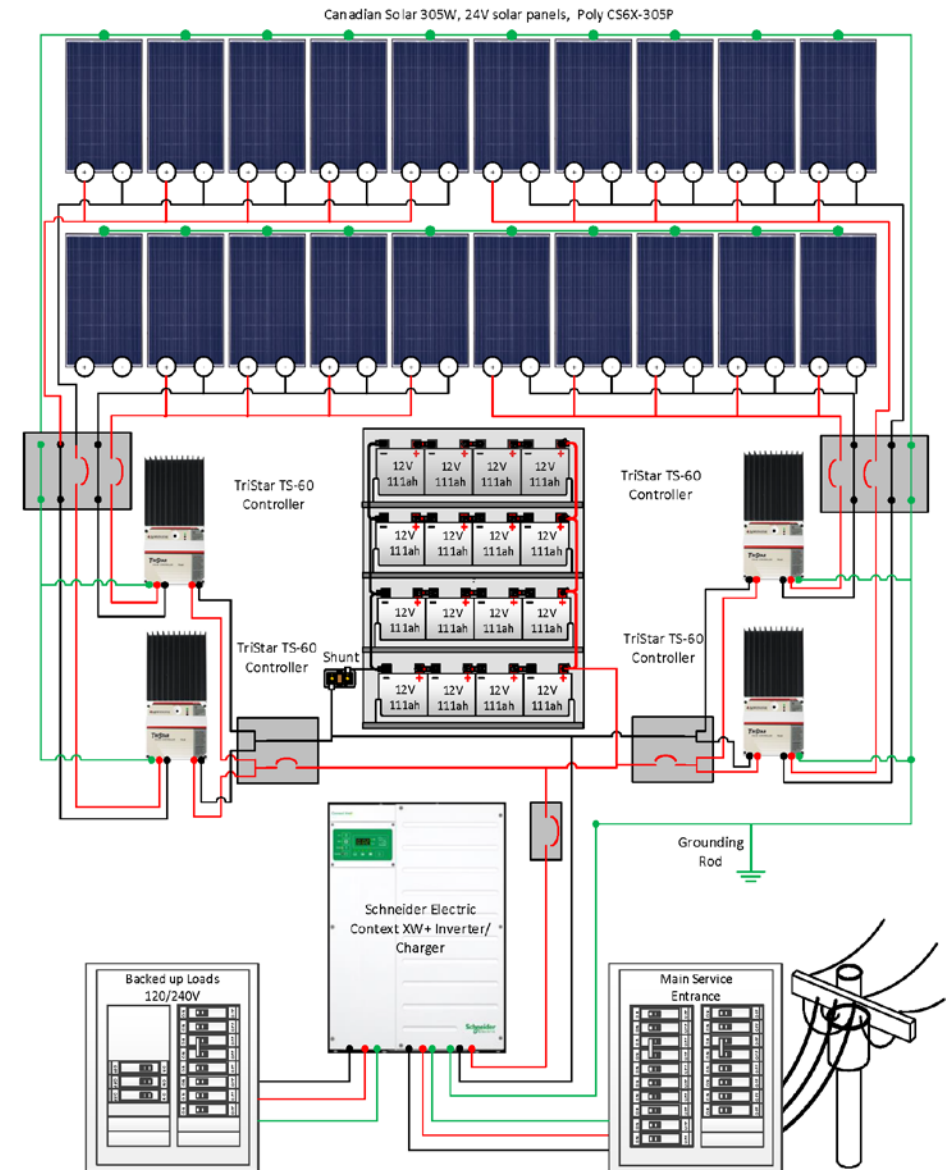
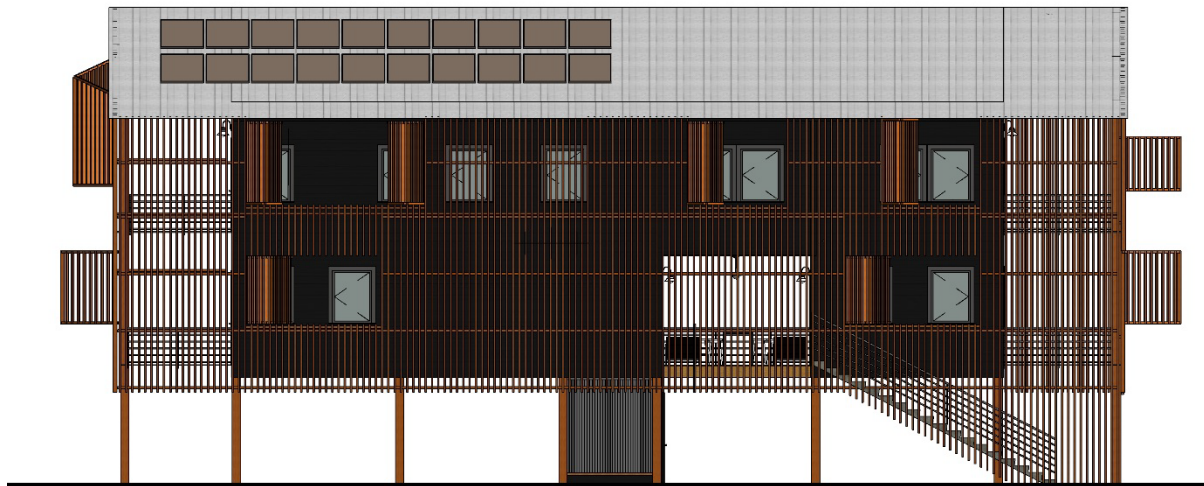
Component	Manufacturer	Number	Watts	Volts	Amps	Quantity	Cost/unit
Module	Canadian Solar	CS6X-305P	305	24	8.97	20	\$273
Charge Controller	Xantrex	C60	n/a	24	60	4	\$199
Hybrid Inverter	Schneider Electric	XW+ 6848	6800	48	180	1	\$4,564
Batteries	Trojan	31-AGM	n/a	21	n/a	16	\$300



PV System Layout



- 6.1 kW PV System
- 16, 111 Ah batteries provides ~ 16 hours of storage
- Many days when used only for critical loads





PV Financial Analysis

- Financial Analysis of \$21,000 6.1kW PV system w/ 1,611 Ah battery bank
- Tax credit is substantially greater than downpayment
- Net costs in future years are near zero
- Over a 45% return on investment per year

Annual Costs/ Savings and Internal Rate of Return of Residential Photovoltaic System

Downpayment	\$4,200
Tax Credit	\$6,300
Annual Loan Payments*	\$975
Interest Deduction on Taxes**	\$8 - \$200
Electrical Revenues	\$841-972
Insurance Costs	\$30
O&M Costs	\$30
Internal Rate of Return	46%



Construction Cost

- Construction cost comparison between Race to Zero “Default Home”, Resilient House w/o PV, and Resilient house w/ PV
- Resilient house construction cost exceed “Default” by \$9,506
- Utility incentive reduce difference to \$1,670
- Resilient house w/ PV exceeds “Default Home” by 22,629

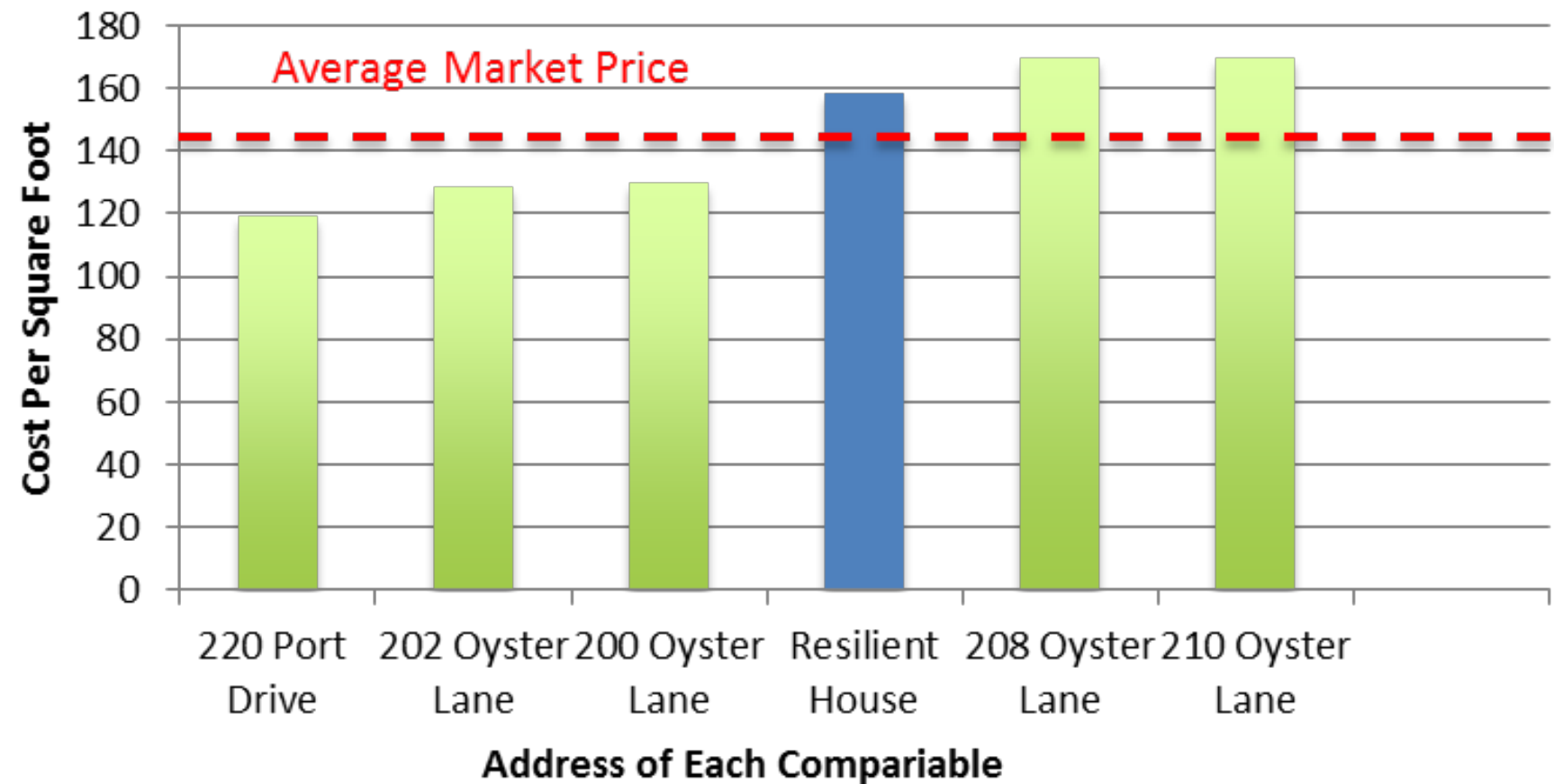
Cost Estimate Comparison			
Category	Standard Home	Resilient Home	Comparison
Pre Construction and Site Work	\$ 12,456	\$ 15,922	-\$ 3,466
Foundations	\$ 17,324	\$ 7,441	\$ 9,883
Framing	\$ 34,821	\$ 32,065	\$ 2,756
Exterior Shade Wall	\$ -	\$ 6,338	-\$ 6,338
Exterior Wall Finish	\$ 26,261	\$ 36,876	-\$ 10,615
Plumbing	\$ 8,753	\$ 7,115	\$ 1,638
Electrical	\$ 7,379	\$ 4,826	\$ 2,553
HVAC	\$ 8,269	\$ 12,539	-\$ 4,270
Insulation	\$ 3,543	\$ 10,714	-\$ 7,171
Appliances	\$ 3,101	\$ 6,930	-\$ 3,829
Interior Finishes	\$ 46,837	\$ 39,655	\$ 7,182
Other	\$ 1,676	\$ -	\$ 1,676
Driveway, Decks, Landscaping and Clean up	\$ 12,033	\$ 11,538	\$ 495
Utility Incentives from Duke Power	\$ -	-\$ 7,836	\$ 7,836
Cost Without PV	\$ 182,453	\$ 184,123	-\$ 1,670
Solar PV System with 30% Tax Credit	\$ -	\$ 20,960	\$ -
Cost With PV	\$ 182,453	\$ 205,082	\$ 22,629



Target Market

- Gathered sales prices of houses in the area from Onslow County Register of Deeds Office
- Resilient House's sales price is only \$15 more per sq.ft. than the target market average.

Target Market Analysis





Mortgage Comparison

- Compared mortgages of the Resilient House with and without PV compared to the Race-to Zero “Default House.”
- Mortgage of Resilient House exceeds Default Home by only \$69
- Mortgage of Resilient House w/ PV exceeds Default Home by \$156

Standard Construction Mortgage		Resilient Home Without PV Mortgage		Resilient Home With PV Mortgage	
Construction Cost (provided by R2Z)	\$ 182,453	Construction Cost + 20% O and P	\$ 191,959	Construction Cost + 20% O and P	\$ 191,959
Sales Price	\$ 295,780	Sales Price	\$ 305,248	Sales Price	\$ 326,208
Downpayment	\$ 59,156	Downpayment	\$ 61,050	Downpayment	\$ 65,242
Net Price After Downpayment	\$ 236,624	Net Price After Downpayment	\$ 244,198	Net Price After Downpayment	\$ 260,966
Points	2.5	Points	2.5	Points	2.5
Principal	\$ 242,540	Principal	\$ 250,303	Principal	\$ 267,491
Interest Rate	4.50%	Interest Rate	4.50%	Interest Rate	4.50%
Years	30	Years	30	Years	30
Monthly Mortgage Payment	\$ 1,228.91	Monthly Mortgage Payment	\$ 1,268.25	Monthly Mortgage Payment	\$ 1,355.34



Summary of Monthly Bills

- Resilient House saves the homeowner \$97 on monthly bills
- Over the 30 year mortgage, savings equate to \$34,920
- Resilient House w/ PV saves the homeowner \$67 on monthly bills

Summary of Race to Zero Construction Cost and Financial Analysis				
Category	Baseline House	Resilient House with all features	Resilient House w/out Upscale Features	Resilient House With PV
Sales Price	\$295,780	\$305,248	\$287,334	\$308,294
Monthly Costs:				
Mortgage	\$1,199	\$1,237	\$1,165	\$1,322
Monthly Household Debt (0.5% MFI)	\$321	\$321	\$321	\$321
Operations and Maintenance Costs	\$196	\$110	\$110	\$110
Monthly Utility Costs	\$160	\$78	\$78	\$4
Property Tax	\$283	\$272	\$272	\$290
Insurance	\$79	\$64	\$64	\$64
Total	\$2,238	\$2,082	\$2,010	\$2,111
Annual Median Family Income (MFI)	\$64,167	\$64,167	\$64,167	\$64,167
Debt to Income Ratio	41.86%	38.94%	37.58%	39.48%



Innovation

Innovations:

- Flexible design to fit to any site
- Screen wall to provide shade and protection
- Reversed living layout
- Outdoor living during dynamic weather
- Potential pre-fabricated envelope
- Elevated construction to improve air quality and reduce moisture problems
- Heat pump water heater captures waste heat from refrigerator
- Occupancy sensors to control hot water recirculation loops and lighting
- Envelope is suitable for any climate zone
- Minimal thermal bridging
- Minimize condensation potential in the building envelope

“Every home is a coastal home”



“Durability under Duress”



Thank you.

Special thanks to Jeff Tiller and Chad Everhart

