Affordable Housing Toward Zero Energy Case Studies in Cold Climates

Betsy Pettit, FAIA
Building Science Corporation
www.buildingscience.com

Better Buildings By Design 2008 Conference
February 14, 2008 Burlington, Vermont

Building America U.S. Department of Energy
Research Toward Zero Energy Homes

Affordable Housing Design Context

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Small and Compact like a Traditional Cape House or 2 Story Gable End House
- 1.5 to 2 Stories 1200 to 1900 sq. ft.
- 3 to 4 BR / 1.5 to 2 bath

Adaptable and/or Able to be Expanded
- Upper level left to be finished
- 3 BR 2 bath when finished
- BR/bath on ground level with minor changes for wheelchair
- Variety of foundation designs

Townhouse Type Construction
- 2 to 3 Stories 1200 to 1600 sq. ft.
- 3 BR 2.5 bath
- Variety of foundation designs

Affordability Guidelines
- Habitat, CDC's, State and Federal

House System Integration-By Design

Specific by Climate Zone

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Advanced Framing/Structural Systems
2 x 6 24" o.c., Advanced Framing with insulating sheathing Or SIPS/ICF's

Air Flow Retarder Systems
Interior/Exterior/Both

Moisture Control Systems
Liquid Water (drainage plane) / Vapor Diffusions Control
Roof/Walls/Foundations

Thermal Envelope System
Exceed Model Energy Code requirements

Air Distribution System
Innovative ductwork and ductwork location

Mechanical Systems
Integration of ventilation and heating/cooling systems

1995 Ostrander, OH Gates Residence

1900 sq.ft. Single Family Home

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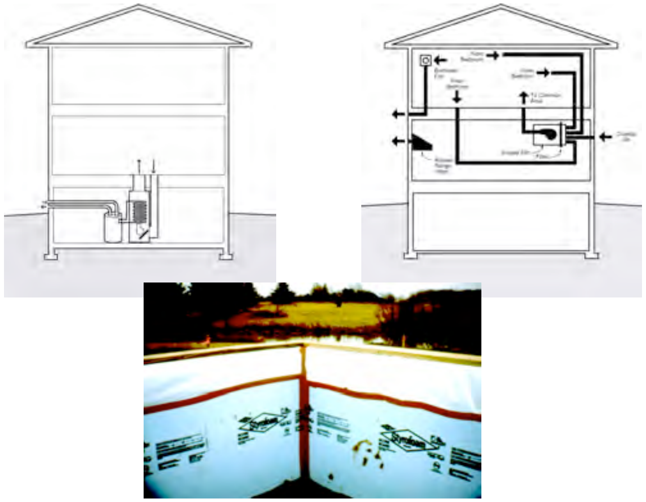
1995 Ostrander, OH Gates Residence
1900 sq.ft. Single Family Home



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1995 Ostrander, OH Gates Residence
1900 sq.ft. Single Family Home

6

1999 Cleveland, OH Infill House
2,200 sq.ft. 4 BR 2.5 bath

7

1999 Cleveland, OH Infill House
2,200 sq.ft. 4 BR 2.5 bath

8

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2000 Denver, CO Habitat Denver
EEBA Denver Conference Demonstration Project

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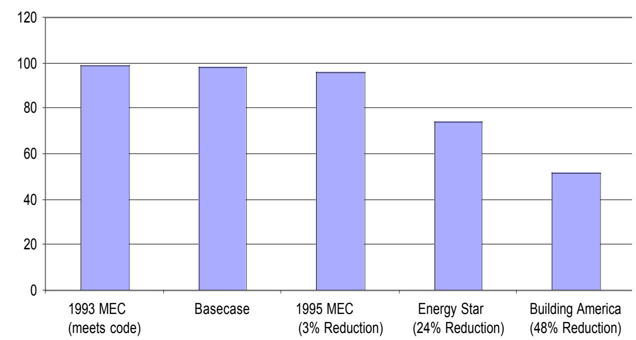
Energy Use Comparison



Predicted Heating and Hot Water Energy Use (MMBtu/yr)

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Cleveland EcoVillage Townhouses

Project Highlights (1666 sf House)

Building Enclosure	R-19 2x6 24 oc + R-5 walls
	R-38 vented attic
	Low E windows (U-0.36, SHGC-0.45)
	R-10: 2" XPS on basement walls
	R-8 2" EPS under entire slab
	BSC BA Airtightness (2.5 ins/100 sf)
Mechanical	90%+ AFUE Sealed-Combustion Furnace
	12 SEER Air Conditioner Split System
	0.59 EF Power-Direct Vent Water Heater
	Fan cycler ventilation system
Solar Site Collection	3.8 kW Peak PV system

Energy Performance

	MMBtu/yr
Heating	38.6
Cooling	5.4
Hot water	21.4
Light/Appl	n/c
Sub-total	65.4
Solar PV Collection	-13.5
Total Predicted Use	51.9
MEC 95 Predicted Use	130.8
% Savings vs MEC 95	60%

Enclosure Details

- R-38 ceiling
- R-19 24" o.c. walls with 1" XPS sheathing
- R-10 basement walls
- R-8 slab insulation
- Double glazed low e windows (U=0.36, SHGC=0.45)
- 2.5 sq in leakage area per 100 sf envelope

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2002 Cleveland, OH Eco-Village Infill Town-Houses

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2002 Cleveland, OH Infill Houses

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2003 Pontiac, MI Venture Inc. Scattered Site Infill

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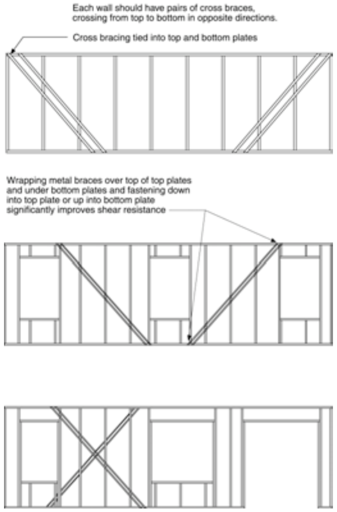
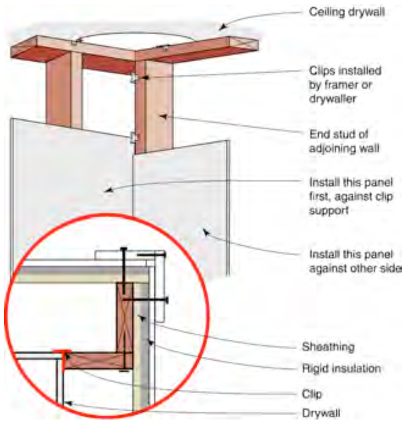
2003 Pontiac, MI Venture Inc.
Scattered Site Infill



2003 Pontiac, MI Venture Inc.
Scattered Site Infill



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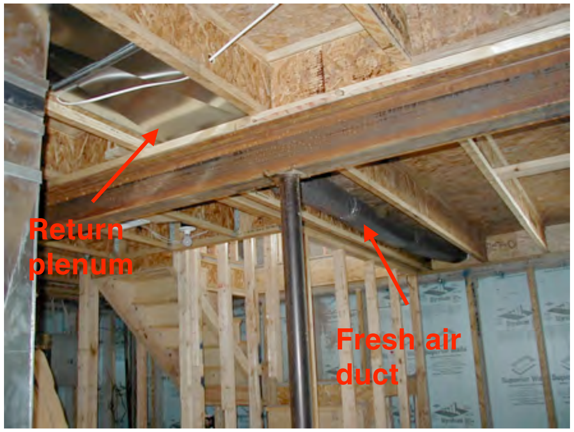
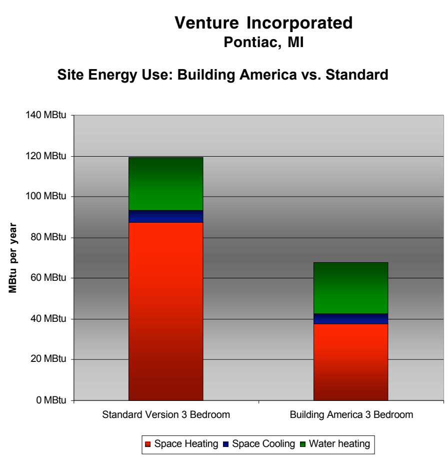


2003 Pontiac, MI Venture Inc.
Scattered Site Infill

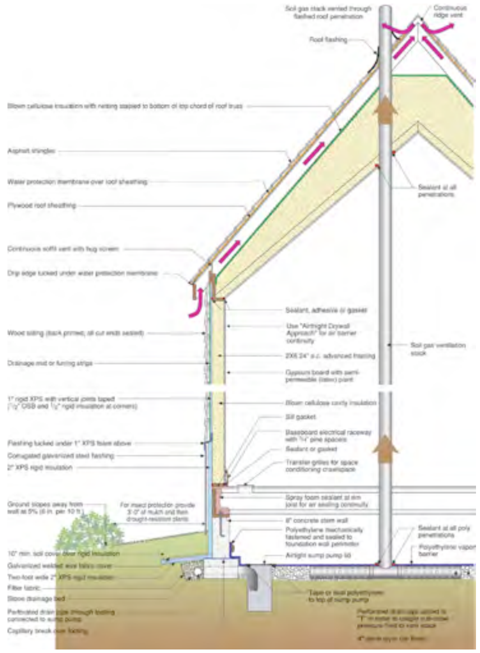
Energy Use Comparison

Predicted Heating and Hot Water Energy Use (MMBtu/yr)



2004 Carbondale, CO CORE
Toward Zero Energy Demonstration Homes

Cross section through house



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Toward Zero Energy Demonstration Homes

Building envelope

Ceiling	R-56 blown cellulose (14" minimum)
Walls	R-19 2x6 24 oc OVE w. damp-spray cellulose R-5 XPS foam sheathing (R-3 + OSB @ corners)
Rim joist	Spray foam & full cavity + R-10 2" XPS on outside
Foundation	Sealed conditioned crawl space R-10 2" XPS walls R-10 2" XPS 2' horizontal wing insulation Lightweight gypcrete slab on framed floor
Windows	Cardinal LoE 178 U=0.31 SHGC=0.63 (IGU) South South overall window U=0.36 SHGC=0.48 Lowen Triple Glazed (N/E/W) overall window U=0.26 SHGC=0.24
Infiltration	2.5 sq in leakage area per 100 sf envelope

Mechanical systems

Heat	Munchkin Boiler or Trinity Boiler (90+ % AFUE) with radiant slab
Cooling	none (alternate cooling strategies): ceiling fans, natural ventilation, night cooling
DHW	Trinity boiler (with solar tank connection) EF estimated at 0.75-0.80
Ventilation	Heat recovery ventilator LifeBreath 95MAX ~65-80 CFM, draw from kitchen, supply at BRs ASHRAE 62.2 Rate 42 CFM
Solar DHW	2x 3'7"x7'4" panels as living room solar shade closed loop system with glycol; 105 gallon tank Stiebel Eltron 2 coil SBB 400 K SOL 400 liter
Photovoltaics	1.68 kW array on roof: 12 panels rectangles Sharp ND-NOECU modules (140 W units)

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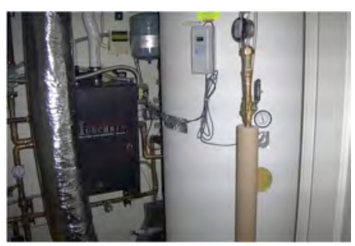
Toward Zero Energy Demonstration Homes



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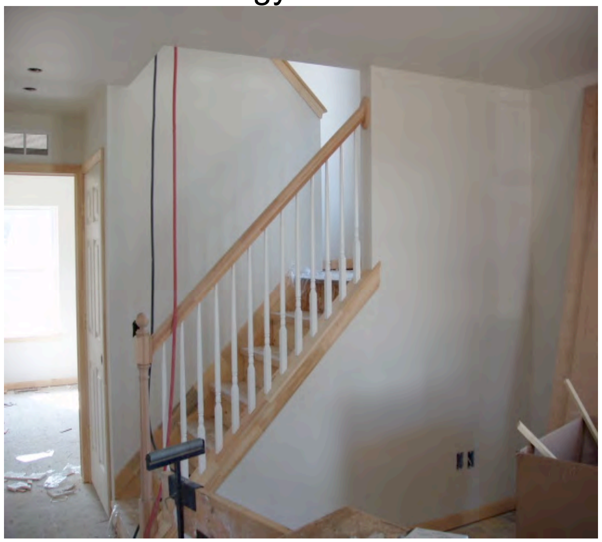
Toward Zero Energy Demonstration Homes



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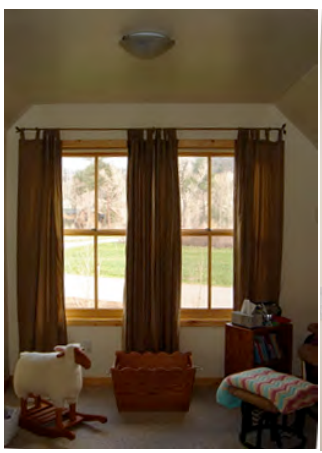

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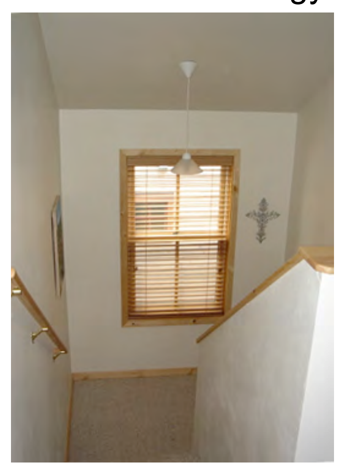

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Scattered Site Infill

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2006 Hydaburg, AK Haida House

Extreme Climate Energy Demonstration Home

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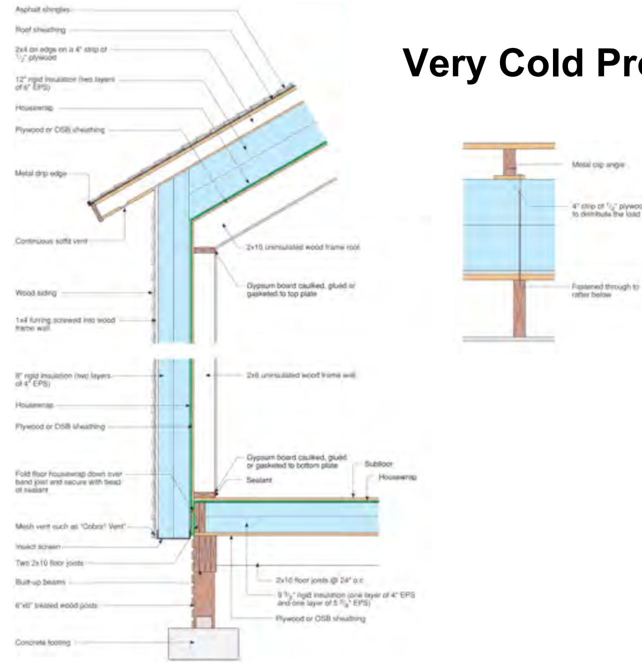
Very Cold Profile



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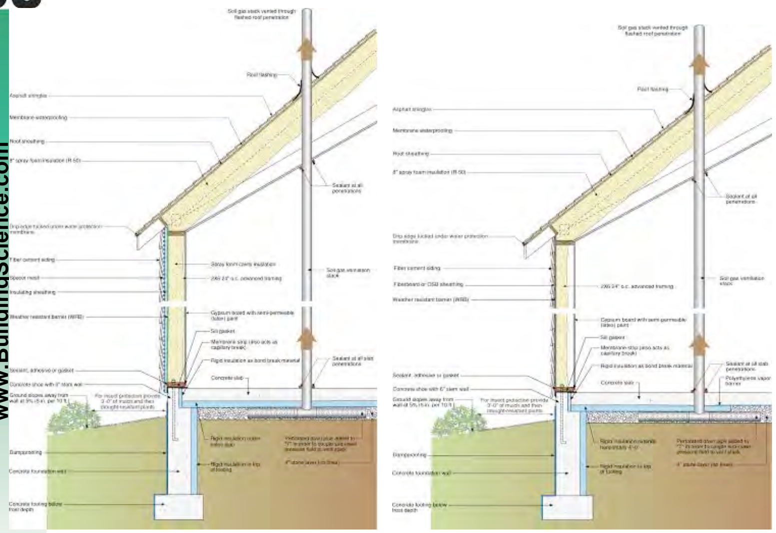
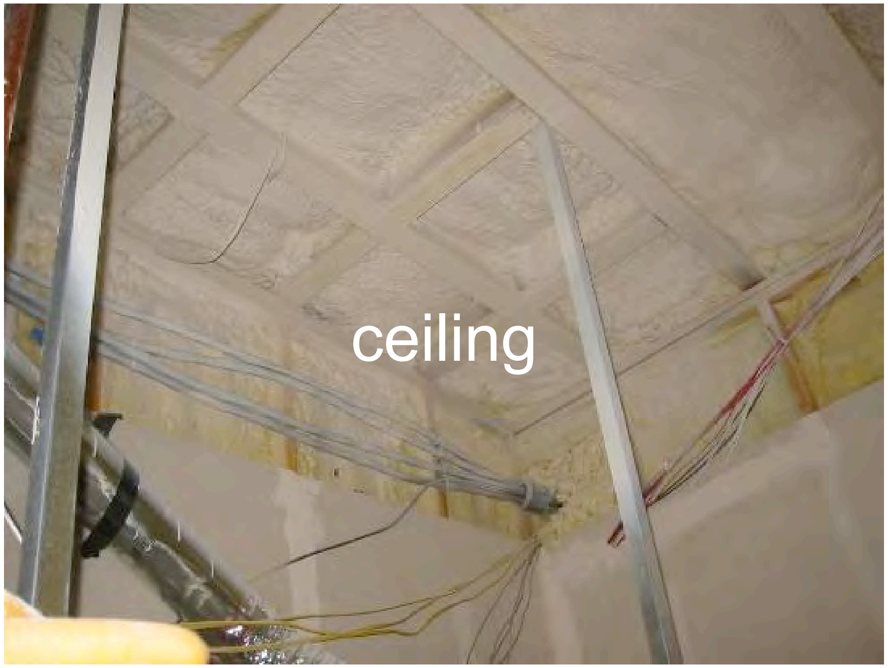
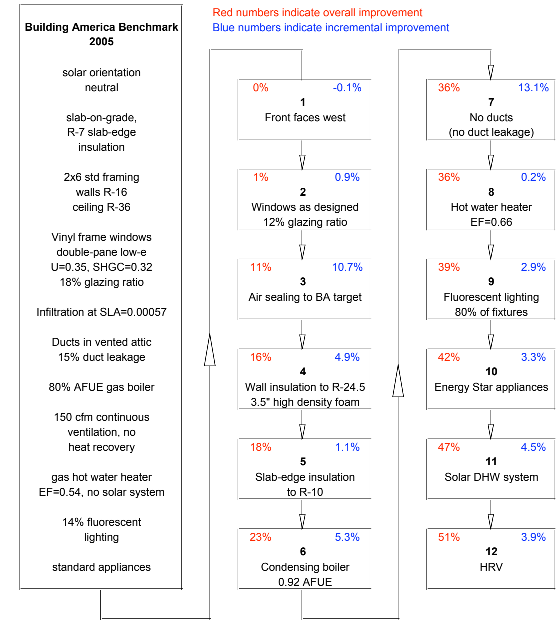
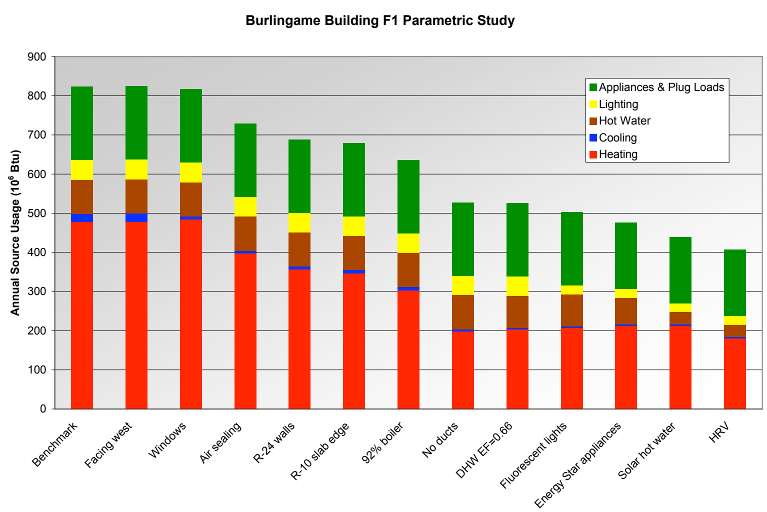




	Building F(1) Benchmark	Building F(1) Prototype
Building envelope		
Ceiling	R-36	R-48
Walls	U=0.076 (approximately R-15), 2x4, 16" o.c.	R-24 2x6, 24" o.c.
Slab Edge	R-7	R-10
Windows	U=0.35, SHGC=0.32 WWR=19%, no exterior shading	Milgard Vinyl Classic Series (Double glazed Low-E) U=0.36, SHGC=0.32 WWR=11%
Infiltration	5.7 sq in leakage area per 100 sf envelope area 0.46 ACH	2.5 sq in leakage area per 100 sf of envelope area 0.20 ACH
Mechanical systems		
Heat	Central boiler system, 80% efficiency	Central boiler system, 90% efficiency
Cooling	Individual 10 SEER AC units	No cooling, modeled as individual 10 SEER AC units
DHW	Individual standard HWHs, EF=0.56 120°F set point, 260 gpd	central system with boiler backup (EF=0.66) 192 sf solar panel w/ 250 gallon tank 120°F set point, 195 gpd
Ducts	ducts in unconditioned attic, 15% duct leakage	no ducts (no duct leakage)
Ventilation	150 cfm continuous, no energy recovery	150 cfm continuous, HRV (60% efficient)
Lights & Appliances		
Lighting	86% incandescent, 14% fluorescent	10% incandescent, 90% fluorescent
Appliances	standard appliances	Energy Star appliances





Overview of the Design approach

Top ten elements in the design of high performance homes:

1. Design for comfort with as little added energy as possible
2. Build tight
3. Ventilate
4. Use more insulation
5. Provide for durability by controlling moisture
6. Design a roof that is sloped to the south
7. Use the most efficient equipment the project can afford
8. Use efficient lighting, appliances and match to occupant needs
9. Reduce energy use 40-70% before adding onsite energy generation
10. Commission mechanical and onsite energy systems

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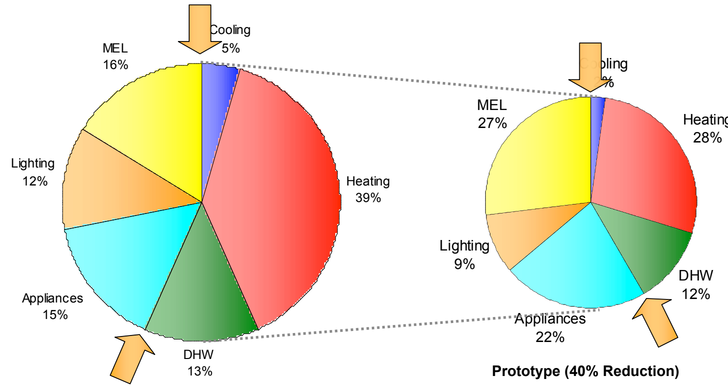
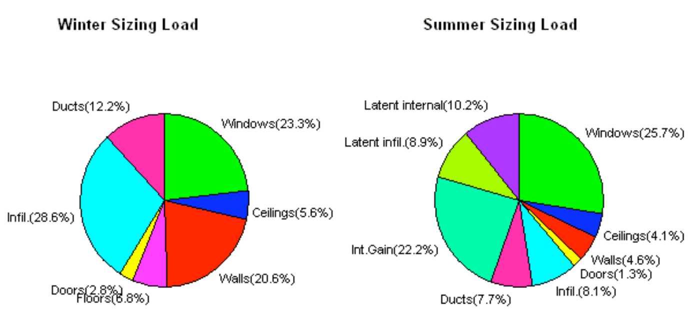
Bedford Load Reductions



Building America Benchmark
- 8052 kWh/year
- 822 therms/year

Prototype (40% Reduction)
- 5968 kWh/year
- 387 therms/year

Where are the remaining loads? (Heating/Cooling)



Cyan Charts Bench vs. Proto

Parametric Run L: 0 Benchmark
Parametric Run R: 16 15 + ES Appliances

Table 1. Summary of End-Use Site-Energy

End-Use	Annual Site Energy			
	BA Benchmark		Prototype	
	kWh	therms	kWh	therms
Space Heating	479	599	206	256
Space Cooling	724		203	
DHW	0	223	0	119
Lighting*	1865		870	
Appliances + Plug	4984	0	4655	0
OA Ventilation**	0		0	
Total Usage	8052	822	5934	375
Site Generation	0	0	0	0
Net Energy Use	8052	822	5934	375

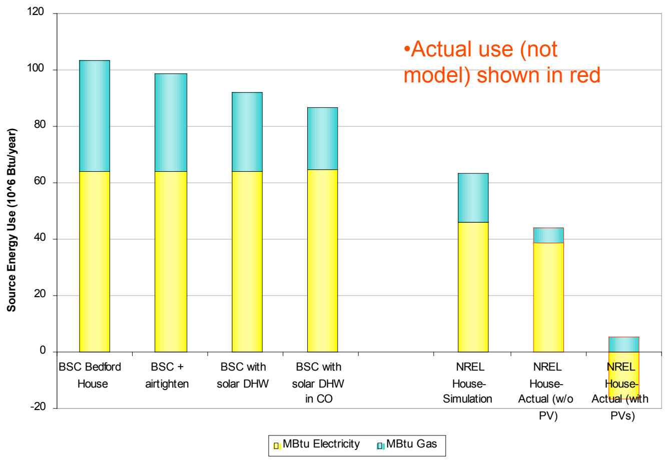
*Lighting end-use includes both interior and exterior lighting
**In EGUSA there are currently no hooks to disaggregate OA Ventilation
it is included in Space Heating and Cooling

Table 2. Summary of End-Use Source-Energy and Savings

End-Use	Estimated Annual Source Energy		Source Energy Savings	
	BA Benchmark	Prototype	Percent of End-Use	Percent of Total
	10^6 BTU/yr	10^6 BTU/yr	Prototype savings	Prototype savings
Space Heating	66	28	**57%**	**22%**
Space Cooling	8	2	**72%**	**3%**
DHW	23	12	**47%**	**6%**
Lighting*	20	9	**53%**	**6%**
Appliances + Plug	54	50	**7%**	**2%**
OA Ventilation**	0	0	**0%**	**0%**
Total Usage	171	102	**40%**	**40%**
Site Generation	0	0		**0%**
Net Energy Use	171	102	**40%**	**40%**

Notes:
The "Percent of End-Use" columns show how effective the prototype building is at reducing energy use in each end-u
The "Percent of Total" columns show how the energy reduction in each end-use category contributes to the overall sa

Bedford & NREL Source Use

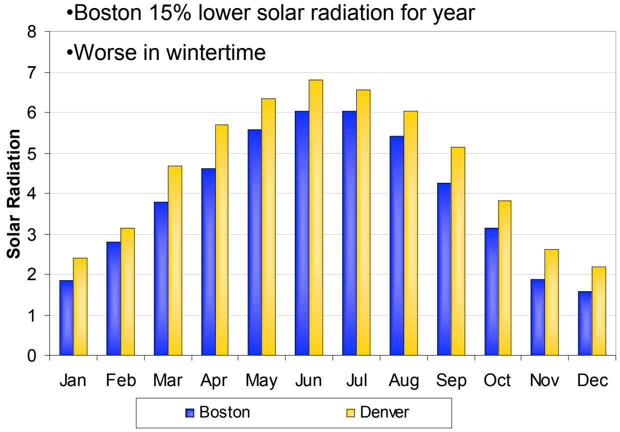


Data for Previous Bar Graph

	kWh	therms	MBtu Electricity	MBtu Gas	MBtu Total
BSC Bedford House	5968	387	64.3	39.5	103.8
BSC + airtighten	5944	341	64.1	34.8	98.9
BSC with solar DHW	5944	276	64.1	28.2	92.2
BSC with solar DHW in CO	6013	217	64.8	22.1	87.0
What PV system needed to zero out	8551		92.2		92.2
8 kW system @ 45 degrees	9909	Placed in Boston, 0.77 derate			
7 kW system @ 45 degrees	**8670**	Placed in Boston, 0.77 derate			
6 kW system @ 45 degrees	7432	Placed in Boston, 0.77 derate			
4 kW system @ 45 degrees	4954	Placed in Boston, 0.77 derate			
NREL House-Simulation	4295	167	46.3	17.0	63.3
NREL House-Actual (w/o PV)	3585	56	38.7	5.7	44.4
NREL House-Actual (with PVs)	-1542	56	-16.6	5.7	-10.9

Boston vs. Denver (Solar)

- Boston 15% lower solar radiation for year
- Worse in wintertime



House characteristics (Bedford)

Building envelope

Ceiling	R-26 4" polyisocyanurate on roof deck (x2 2" layers) with R-40 loose-fill cellulose (2x12 bays; 11.25")
Walls	R-19 2x6 OVE frame w. R-26 4" polyiso (x2 2" layers)
Foundation	Sealed conditioned crawl space R-26 4" polyiso walls (x2 2" layers) / 2" (R-10) XPS on floor 4' from exterior
Windows	Double Pane Vinyl Spectrally Selective LoE_ U=0.33, SHGC=0.40 (minimum requirements)
Infiltration	2.5 sq in leakage area per 100 sf envelope 1016 CFM 50 (3.9 ACH 50) Plan 1

Mechanical systems

Heat	95% AFUE gas furnace
Cooling	14 SEER air conditioner split system
DHW	0.85 EF water heater (e.g., instantaneous)
Ducts	R-4.2 flex runouts in conditioned space
Leakage	none to outside (5% or less)
Ventilation	Aprilaire VCS 8126 or similar supply-only system integrated with AHU; 25 W system power 50 CFM @ 33% Duty Cycle: 10 minutes on; 20 minutes off
Return Pathways	Transfer grilles/jump ducts at bedrooms
PV System	no information
Solar Hot Water	no information

House characteristics (NREL)

Building envelope

Ceiling	R-60 blown-in fiberglass insulation
Walls	R-40 double stud wall with fiberglass batts (3x R-13)
Floor	R-30 fiberglass batt insulation framed floor over vented (uninsulated/unconditioned) crawl space
Windows	Low E U=0.30, SHGC=0.58 (south side, with 3' overhangs) Low E heat mirror U=0.23, SHGC=0.27 (remaining sides)
Infiltration	2.5 sq in leakage area per 100 sf envelope 1016 CFM 50 (3.9 ACH 50) Plan 1

Mechanical systems

Heat	Direct vent ductless gas heater and electric baseboard heaters in bedrooms
Cooling	none
DHW	0.85 EF gas instantaneous water heater backup
Ventilation	Energy recovery ventilation with ECM motor
Lighting	All compact fluorescent lights
Appliances	Energy Star clothes washer and refrigerator
PV System	4 kW nominal photovoltaic system
Solar Hot Water	Drainback system; 96 ft^2 collector with 200 gallon storage

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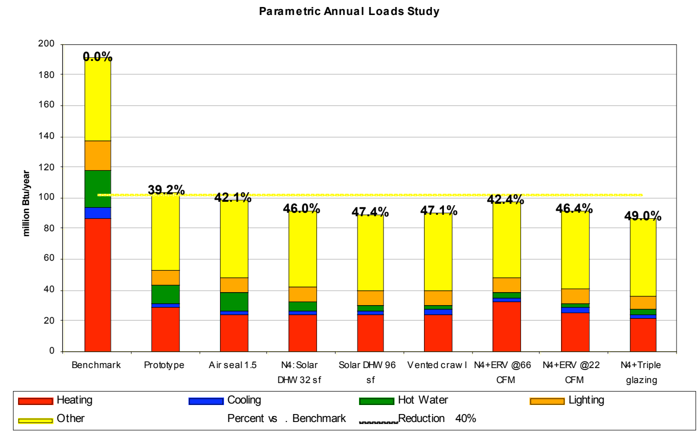
Pushing Bedford House



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How the Costs Breakdown

• Foundations installed including concrete	$ 3,500
• Slab installed including concrete	$ 1,000
• Lumberyard Pricing of entire package including foam sheathing	$70,000
• Framer's cost to enclose building including windows and foam	$12,500
• Electrical, Plumbing, Mechanical equipment and installation	$30,000
TOTAL PRE SITE GENERATED ENERGY	$117,000*

* This price assumes volunteer labor completes the rest

• 94 sq. ft. glycol solar hot water installed with storage	$ 5,000
• 5 kw PV system with MA rebates	$20,000
TOTAL WITH SITE GENERATE ENERGY	$142,000

Energy Balance left:

+- 100 therms of gas at $1.20/therm	$120 per year

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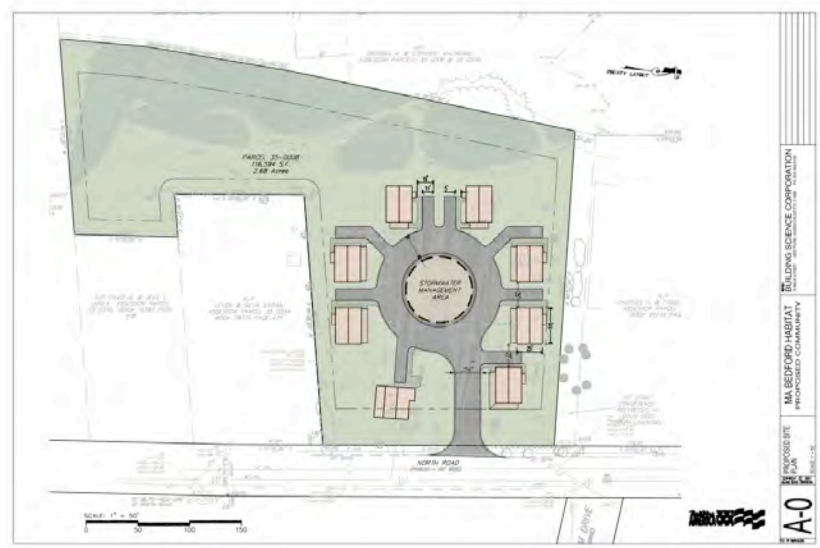
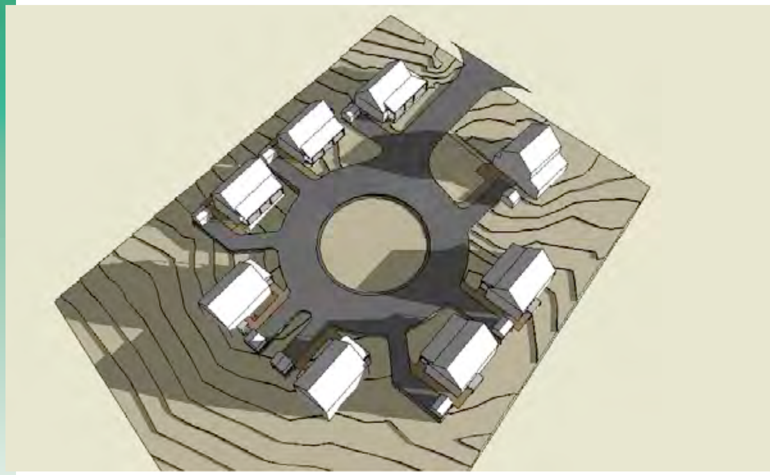
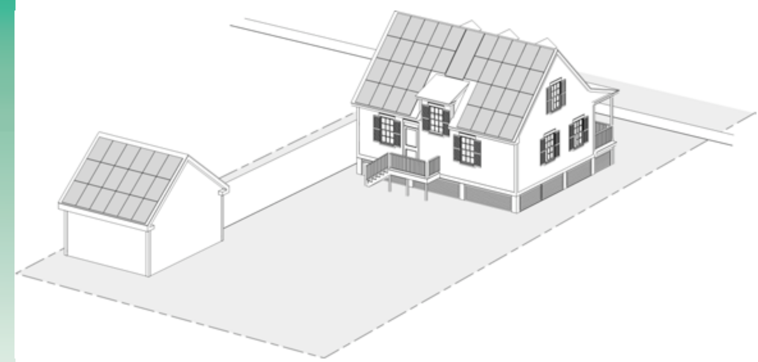


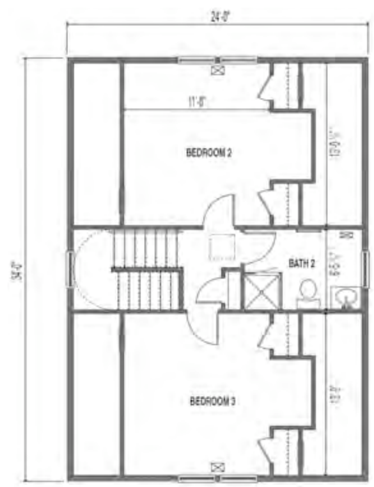
3-D Model of Proposed Development



Plan 1 – PV & SHW Installation



Westford
First floor plan

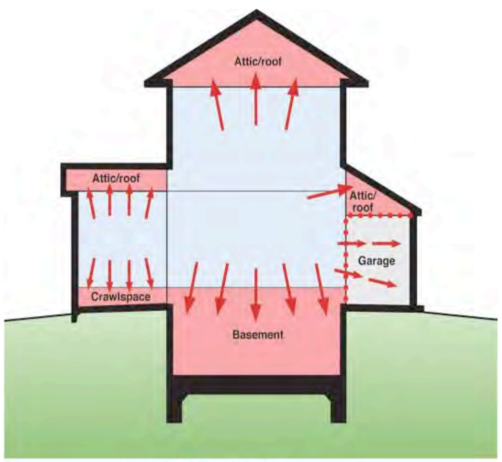


Westford
Second floor plan

Bedford
First floor plan

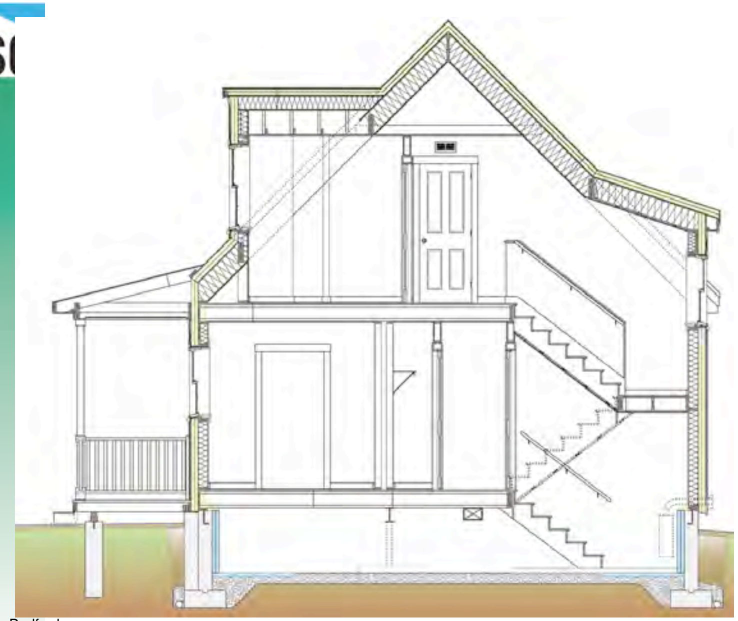
Bedford
Second floor plan

Defining Design Freedom

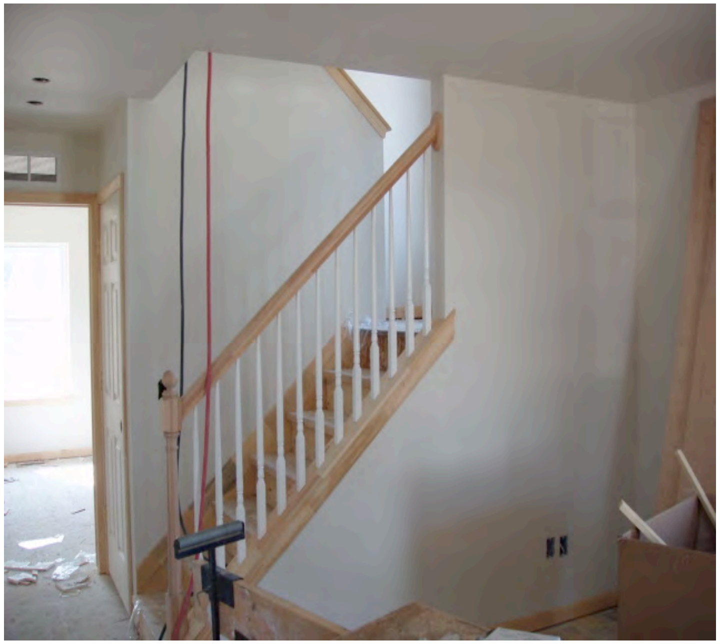


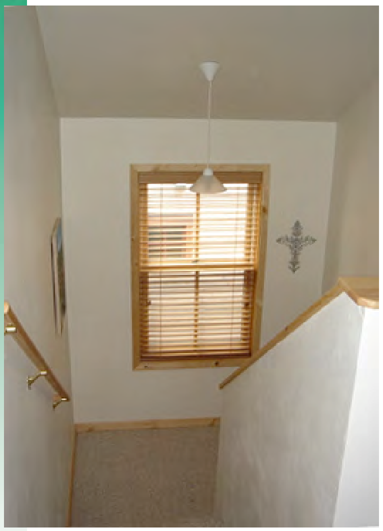
Expansion of Conditioned Space

- Conditioned space boundaries moving towards exterior surfaces of building
- Garage isolated from house by air barrier/pressure boundary
- Garage ventilated and conditioned independently of rest of conditioned spaces

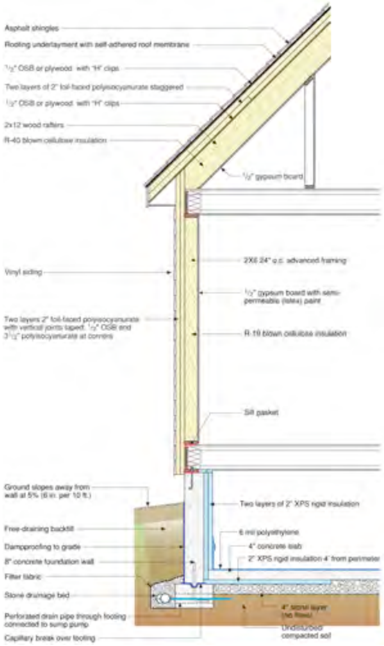


Bedford
Cross section

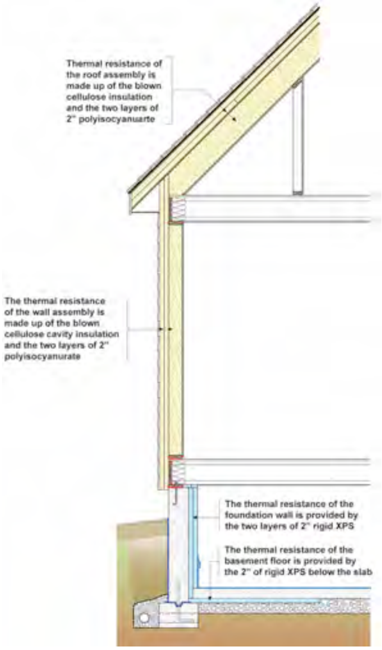




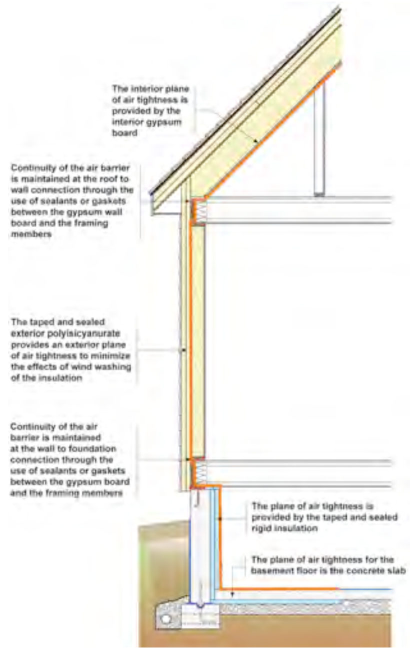
Bedford Profile with crawlspace



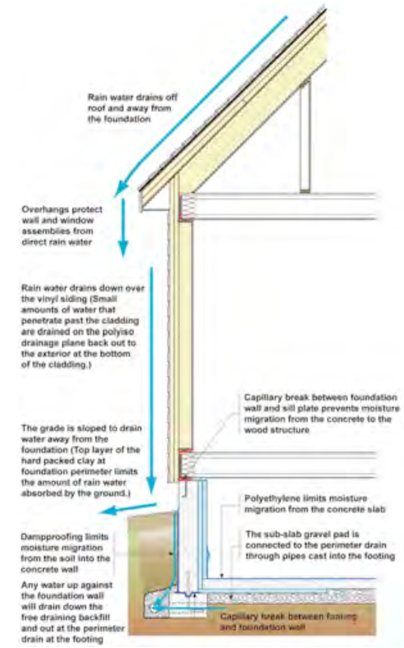
Bedford Thermal Insulation System



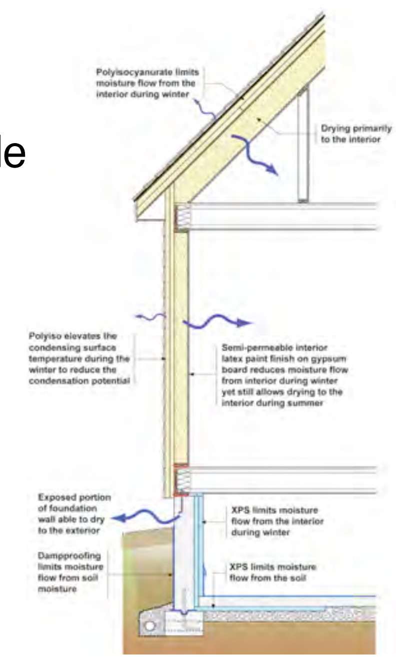
Bedford Air Flow Retarder System

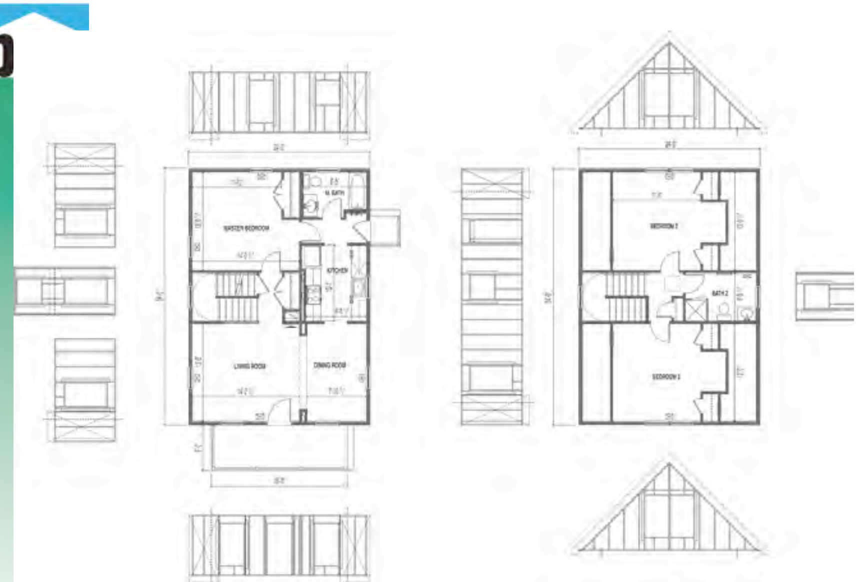


Bedford Water Management System

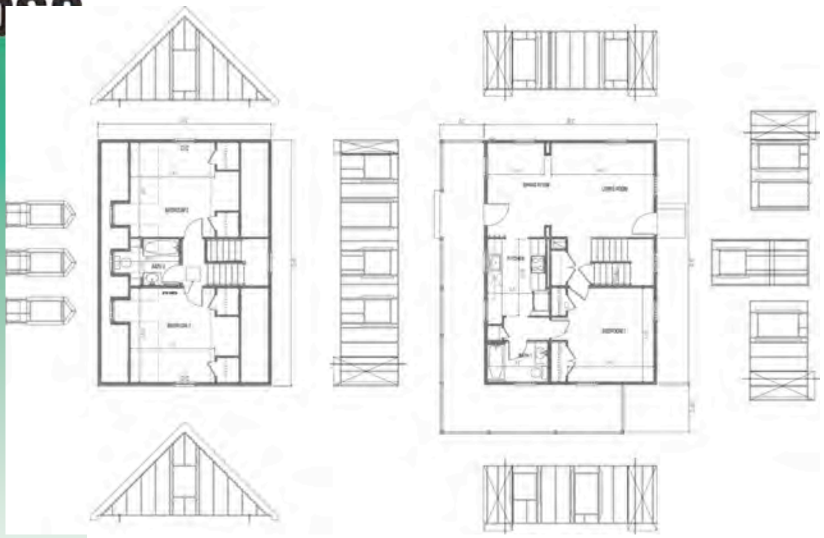


Bedford Vapor Retarde System

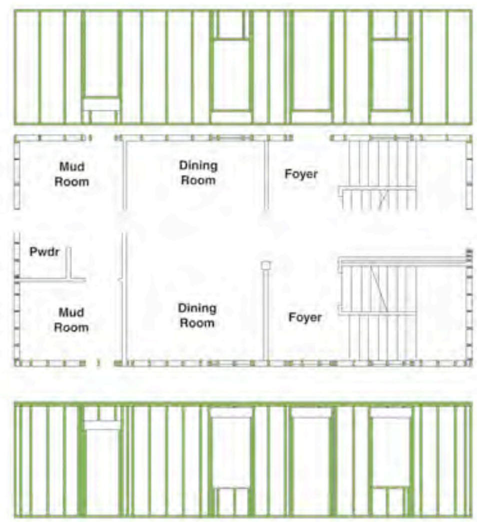




Westford
Wall framing



Bedford
Wall framing



Wall 1 (2x6 24"o.c.)

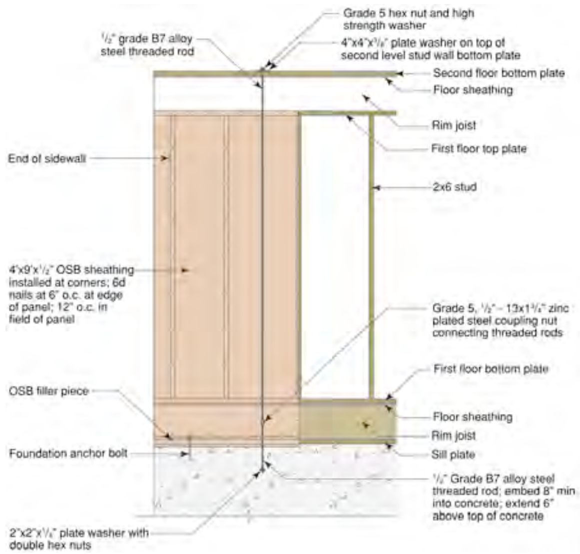
Plate	36'-0"	2
Stud	8'-0"	20
Jack	7'-9¼"	6
Jack 2	6'-8½"	2
Cripple 2	1'-2¾"	2
Cripple 3	2'-1"	3

Gross wall area	327 ft²
Window area	74 ft²
Opaque area	45.17 ft²
Cavity area	207.83 ft²

Wall 1 (2x6 16"o.c.)

Plate	36'-0"	3
Stud	8'-8½"	29
Jack	7'-8½"	6
Jack 2	6'-8½"	2
Cripple 1	0'-2¾"	6
Cripple 2	1'-2¾"	2
Cripple 3	2'-1"	8

Gross wall area	327 ft²
Window area	74 ft²
Opaque area	65.60 ft²
Cavity area	181.40 ft²



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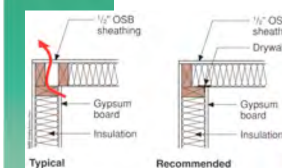
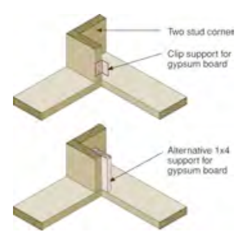
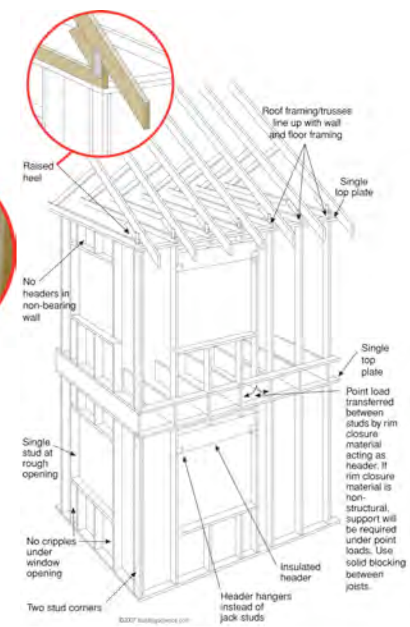
Advanced Framing Details







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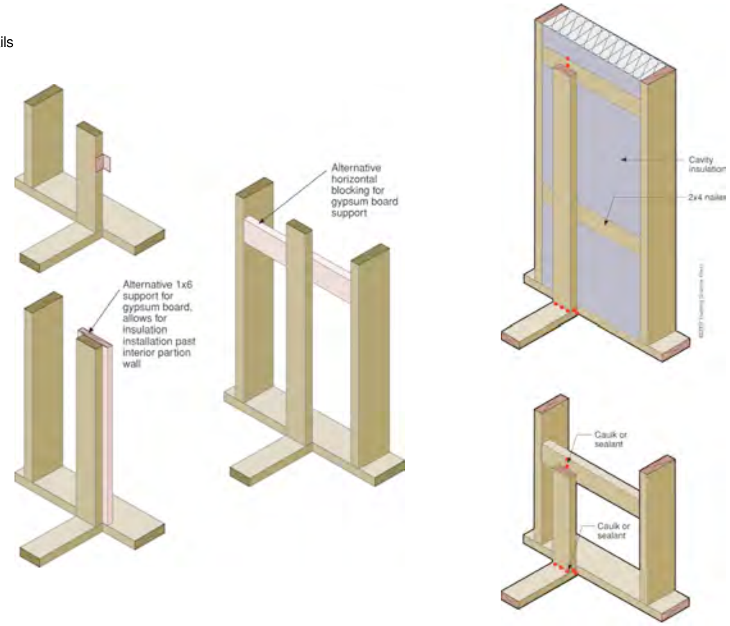
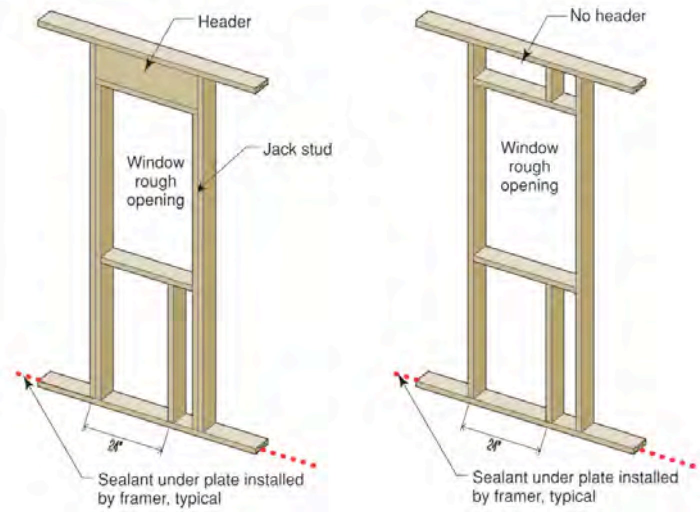
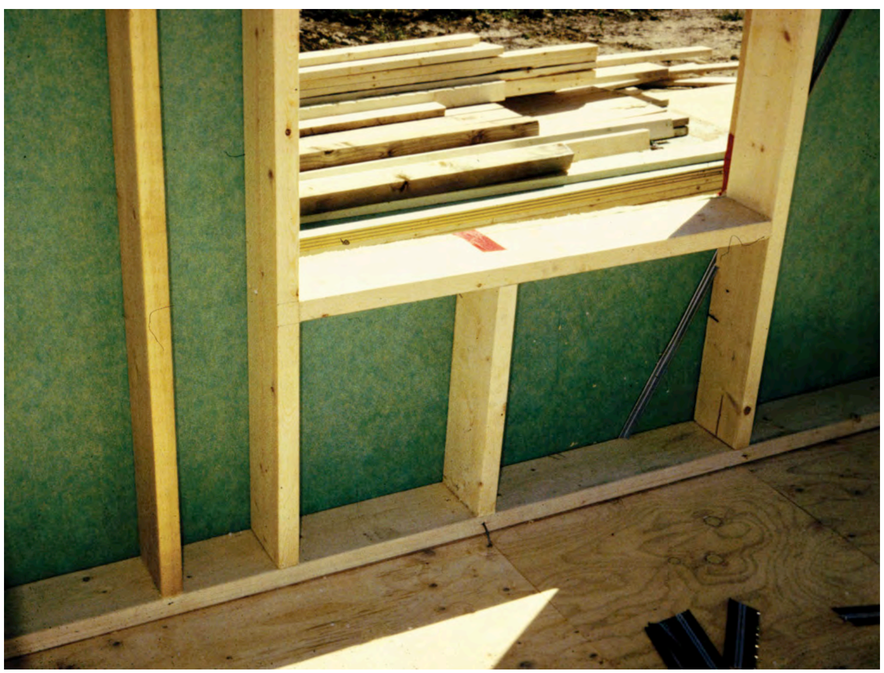
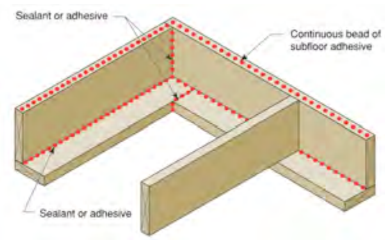
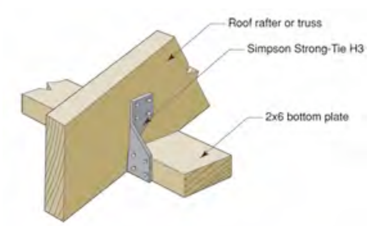
Advanced Framing Details











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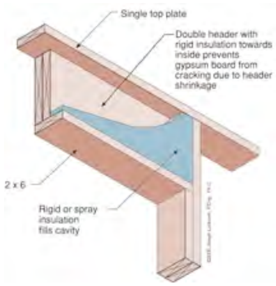

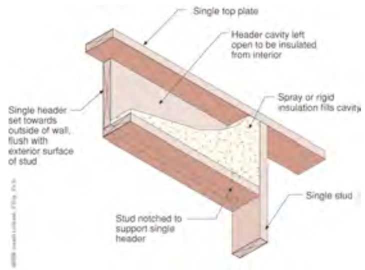

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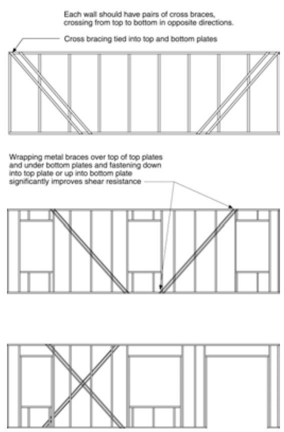
Advanced Framing System

- Insulating sheathing with **diagonal metal bracing** for racking strength



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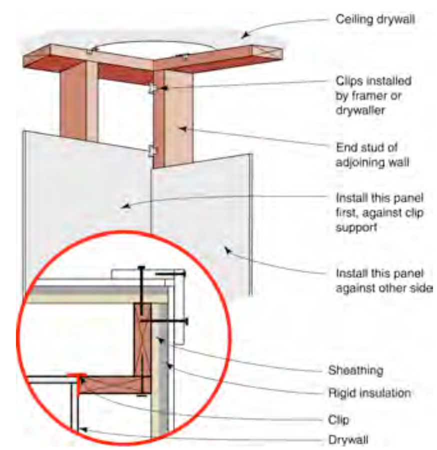
Advanced Framing System

- Drywall clips allow for better installation with less drywall cracking



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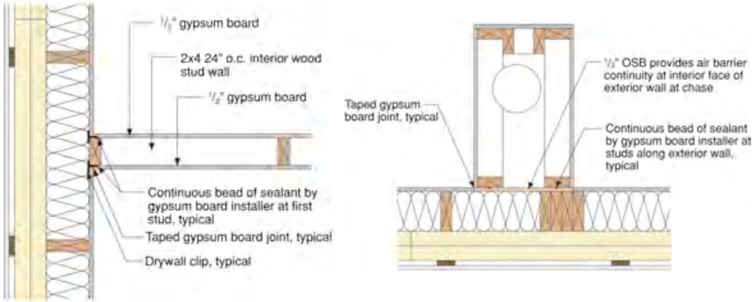

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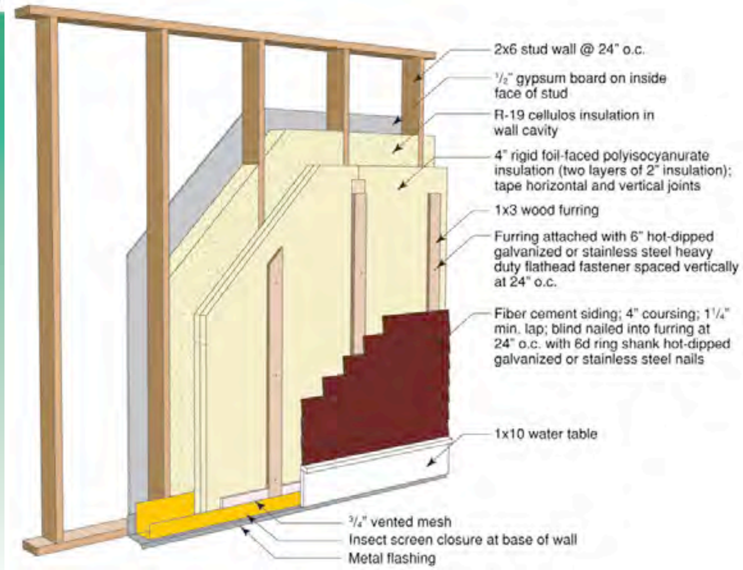

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Water Managed Systems

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Engineered wood siding being installed over 3/8” furring strips

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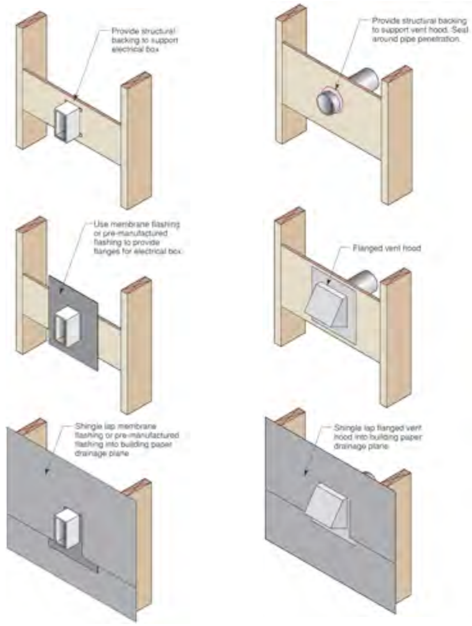
Advanced Framing Details



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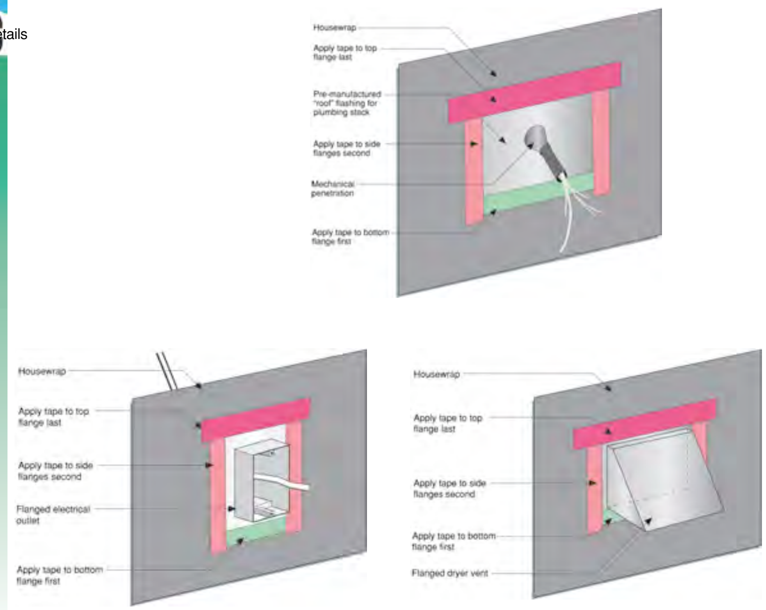

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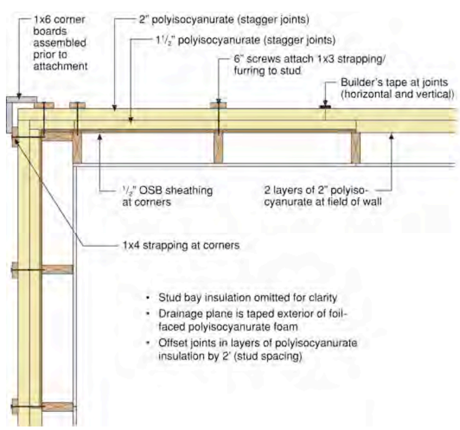

- Stud bay insulation omitted for clarity
- Drainage plane is taped exterior of foil-faced polyisocyanurate foam
- Offset joints in layers of polyisocyanurate insulation by 2' (stud spacing)

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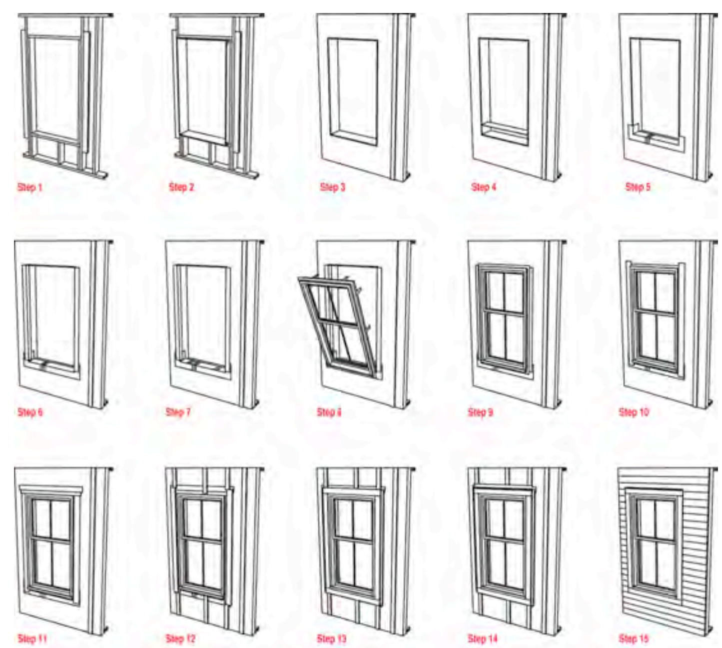

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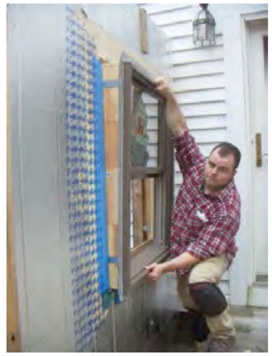

Interior Air Leakage Control and Water Management