Towards Zero Energy Homes

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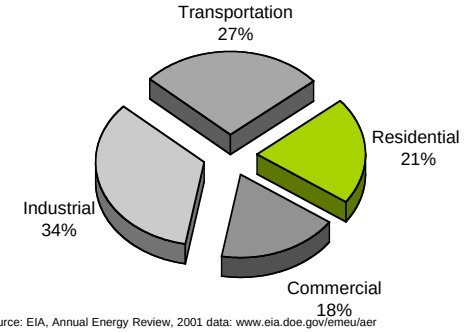
www.buildingscience.com

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

Assessing the Impact of US Housing

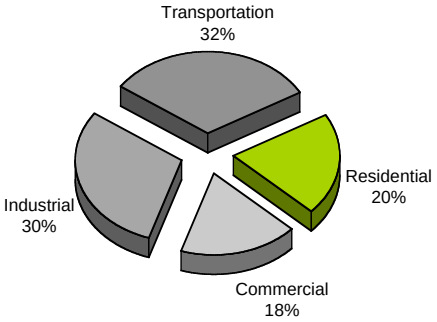
Primary Energy Consumption by Sector, 2001



Source: EIA, Annual Energy Review, 2001 data: www.eia.doe.gov/emeu/aer

Contribution to Climate Change

Carbon Dioxide Emissions from Energy Consumption by Sector, 2001



Source: EIA, Annual Energy Review, 2001 data: www.eia.doe.gov/emeu/aer

Sustainability
=
Energy Efficiency
+ Durability

Your Environmental Separator

- At the most basic level a building provides shelter - shelter from the elements as well as from other dangers.
- Its' function is to separate the inside from the outside as required by the local environment and the wishes of its occupants.
- A building creates an interior environment that is different from the exterior environment – it is an environmental separator.
- This interior environment should be controllable by the occupants in a manner that meets their needs.

Principles of Building Science

- Energy moves from higher state to lower state
  - (the second law of thermodynamics)
- Heat moves from warm to cold (thermal gradient)
- Moisture moves from more to less (concentration gradient)
- This is the thermodynamic potential
  - The psychrometric chart is a visual representation of the thermodynamic potential of water vapor
- It takes even more energy to counteract this phenomena

The Rules

1. **Heat Flow is From Warm to Cold**
2. **Air Flow is From a Higher Pressure to a Lower Pressure**
3. **Moisture Flow is From Warm to Cold**
4. **Moisture Flow is From More to Less**
5. **Water Flows Down (Gravity)**

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 heating, cooling, and DHW units
8. Use efficient lighting, appliances, match to occupant needs
9. Reduce energy use 40-70% before adding onsite energy
10. Commission mechanical and onsite energy production systems

1: SINGLE-FAMILY HOUSE
Westford, MA

Lowell Habitat for Humanity Westford, MA
2,200 sq. ft. @ $85/sq. ft. HERS 49

Gas = $50/month @ $1.50 /therm
Electric = $50/month @ $.15/kWh Average = $3.30 per day

With 4 kW PV and 94 sq. ft. solar hot water
Electric = $0 Gas = $37.50/month Average = $1.25/day

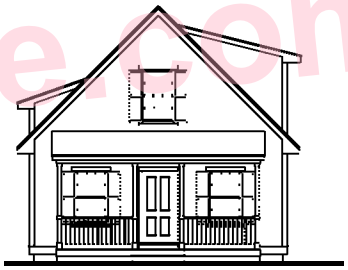
Lowell Habitat for Humanity in Westford

18 Williams Avenue Westford, MA

1.5 Story Single Family Home with Conditioned Basement (2200 ft² total)

Sunrise Company
C. Nelson Homes
Habitat for Humanity
Integrated Green Building Solutions
GreenCraft Builders
David Weekley Homes
Catholic Charities
ICI Homes
Landmark Fine Homes
Project Home Again

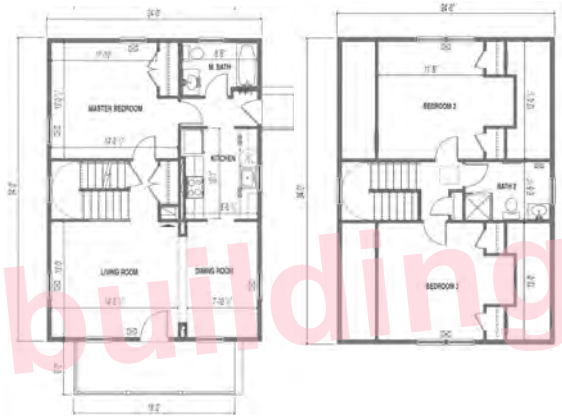
18 Williams Avenue Under Construction



Front Elevation

Tested Air Leakage 2 ach@ 50 Pascals

12



First floor plan

Second floor plan

House characteristics

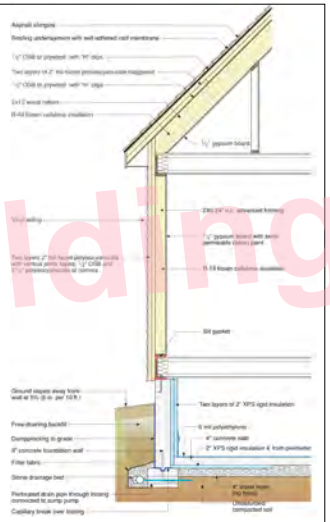
Building envelope

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

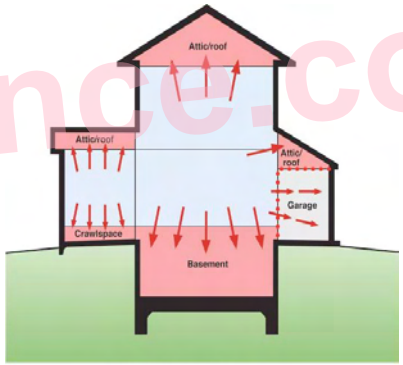
Mechanical systems

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

Building Section

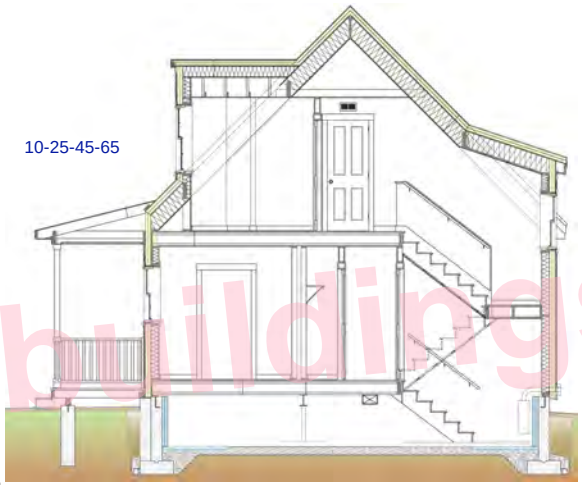


Defining Design Freedom



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



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©2008 Building Science Corporation Bedford cross section

18 Williams Avenue — Westford, MA

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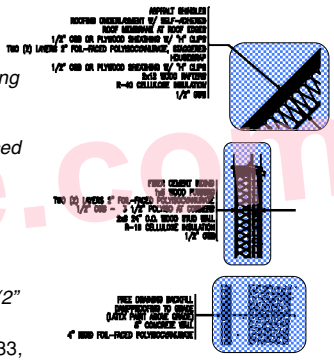
C. Nelson Homes
Habitat for Humanity
Integrated Green Building Solutions
GreenCraft Builders
David Weekley Homes
Catholic Charities
ICI Homes
Landmark Fine Homes
Project Home Again

- Enclosure Details
  - R-66 roof insulation
  - R-45 walls *(2x6 framing @ 24" o.c. blown cellulose cavity insulation + 4" foil-faced polios insulating sheathing)*
  - R-26 basement walls *(4" foil-faced polyiso insulating sheathing)*
  - R-10 basement slab *(2" XPS below slab)*
  - Low E windows U=0.33, SHGC=0.28



Roof, Wall and Basement Wall Enclosure Details

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Benchmark vs. Prototype

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

Table 1. Summary of End-Use Site-Energy

	Annual Site Energy			
	BA Benchmark		Prototype	
End-Use	kWh	therms	kWh	therms
Space Heating	479	599	205	256
Space Cooling	724		203	
DHW	0	223	0	119
Lighting*	1865		870	
Appliances + Plug	4984	0	4650	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

	Estimated Annual Source Energy		Source Energy Savings	
			Percent of End-Use	Percent of Total
	BA Benchmark	Prototype	Prototype savings	Prototype savings
End-Use	10^6 BTU/yr	10^6 BTU/yr		
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 s

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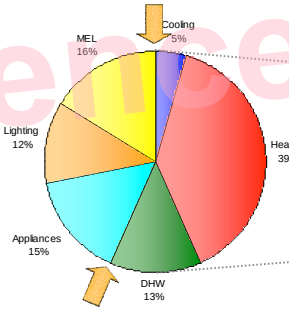
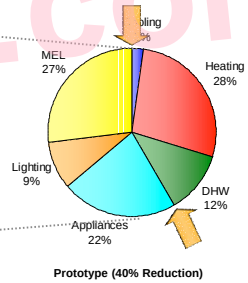
Load Reductions



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



Prototype (40% Reduction)
•5968 kWh/year predicted -
(4000 kWh/year budgeted*)
•387 therms/year

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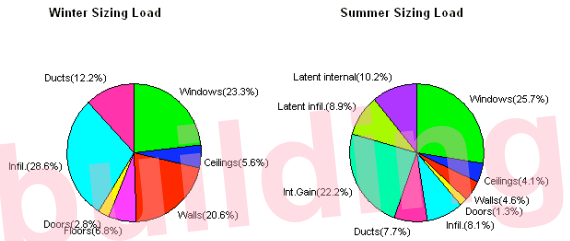
Where are the remaining loads? (Heating/Cooling)



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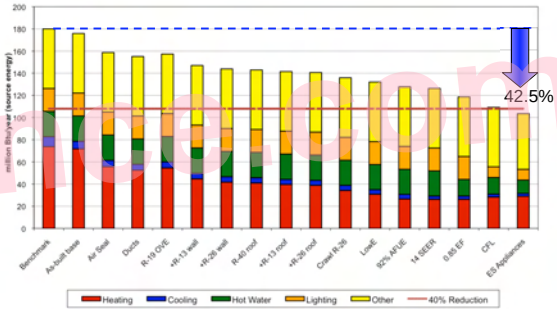
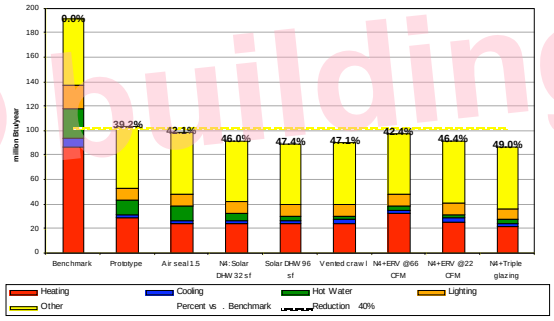
Source Energy Parametric Annual Loads Study



Pushing the house to 50% savings

Parametric Annual Loads Study



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
• Interior finishes, cabinets, appliances, GWB and installation	$30,000
• Septic systems and site work	$13,000
• General labor and overhead	$40,000
TOTAL PRE SITE GENERATED ENERGY	$200,000
Lowell HFH donated labor	-$40,000
Lowell HFH donated materials	-$50,000
Total Cost to HFH	$110,000
• 64 sq. ft. glycol solar hot water installed with storage	$ 6,000
• 4 kW PV system after rebates	$16,000
TOTAL WITH SITE GENERATE ENERGY	$224,000
Energy Balance left:	
+- 150 therms of gas at $1.75/therm	$262 per year

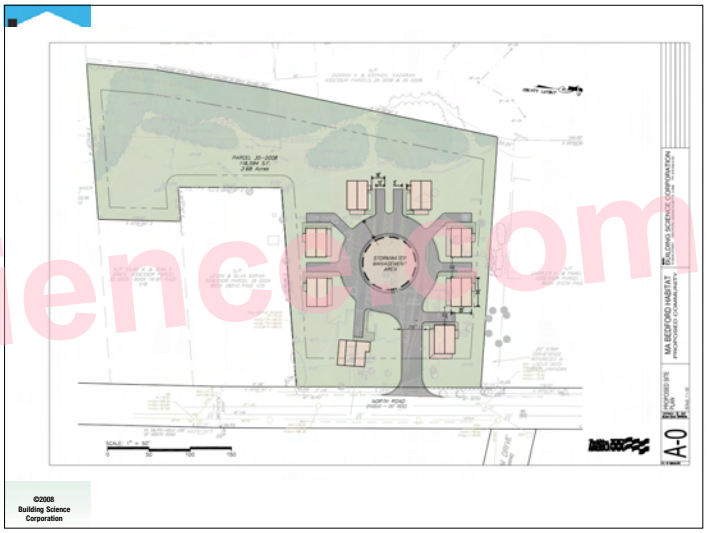
Gas = $50/month @ $1.50 /therm
Electric = $50/month @ $.15/kWh Average = $3.30 per day

With 4kWh PV and 94 sq. ft. solar hot water $105/sq.ft.
Electric = $0 Gas = $37.50/month Average = $1.25/day

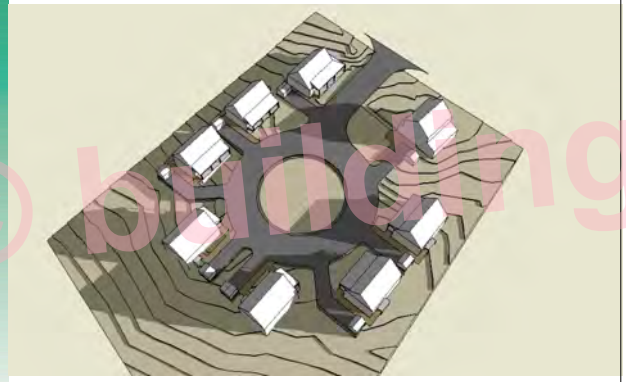
Solar Thermal @$5,000 saves $150/yr
33 year simple payback

Solar Electric @ $20,000 saves $600/yr
33 year simple payback

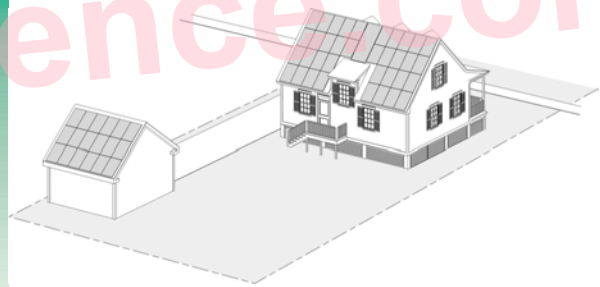
Solar Electric @ $40,000 saves $600/yr
Without subsidy 66 year simple payback



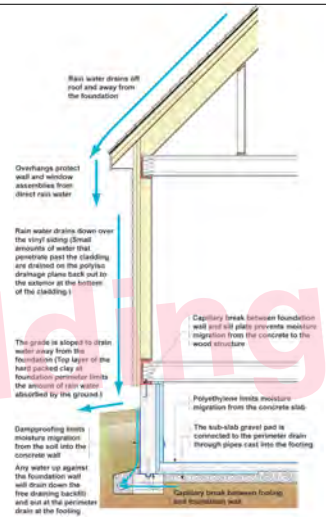
Model of Southern Roof Exposure



PV & SHW Installation



Bedford Water Management System



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Project Home Again

- Design Highlights
  - 4" of foil-faced polyiso insulating sheathing on roof, walls and basement walls
  - Advanced Framing


Basement Insulation


Exterior Insulation


Exterior Insulation

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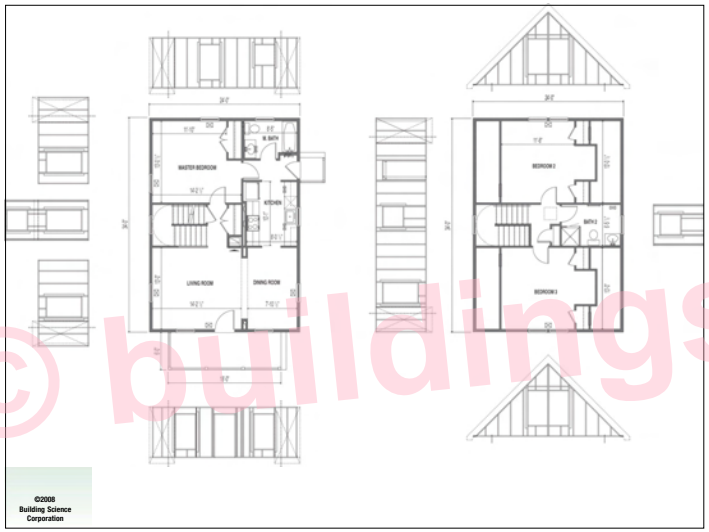
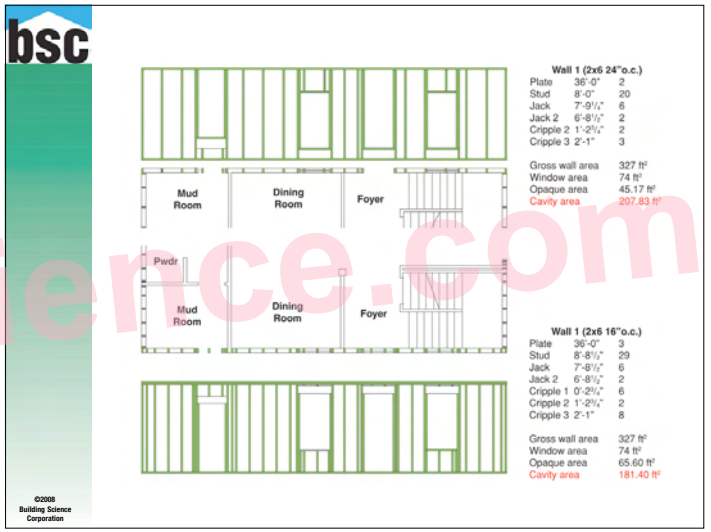




Wall 1 (2x6 24"o.c.)

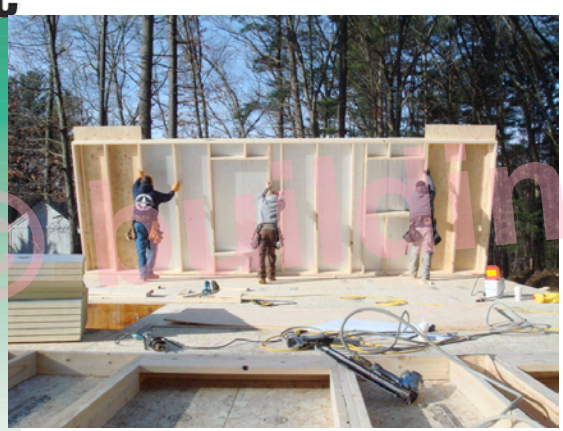
Plate	36'-0"	2
Stud	8'-0"	20
Jack	7'-9 1/4"	6
Jack 2	6'-8 1/2"	2
Cripple 2	1'-2 3/4"	2
Cripple 3	2'-1"	3

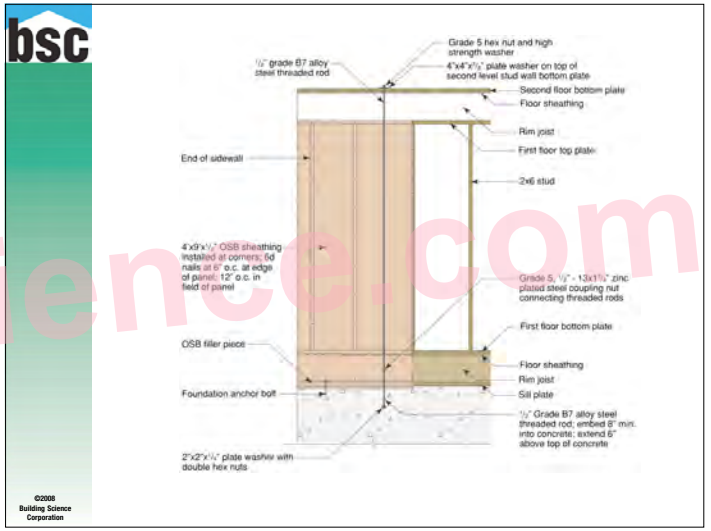
Gross wall area	327 ft²
Window area	74 ft²
Opaque area	45.17 ft²
Cavity area	207.83 ft²

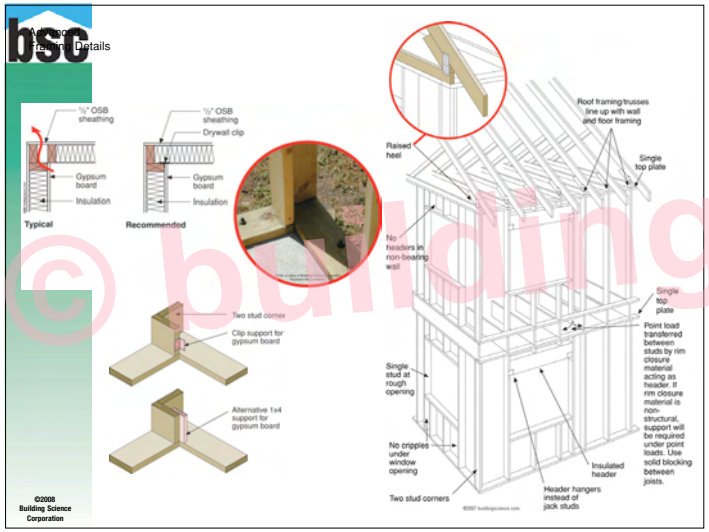
Wall 1 (2x6 16"o.c.)

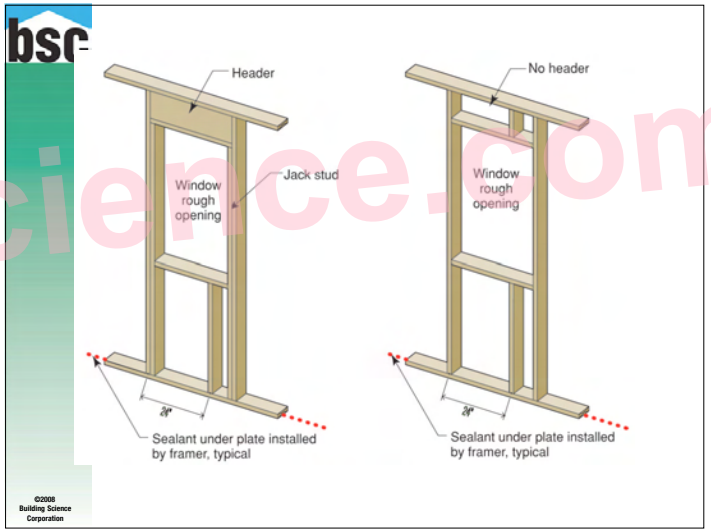
Plate	36'-0"	3
Stud	8'-8 1/2"	29
Jack	7'-8 1/2"	6
Jack 2	6'-8 1/2"	2
Cripple 1	0'-2 3/4"	6
Cripple 2	1'-2 3/4"	2
Cripple 3	2'-1"	8

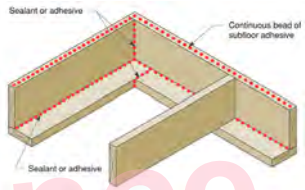
Gross wall area	327 ft²
Window area	74 ft²
Opaque area	65.60 ft²
Cavity area	181.40 ft²

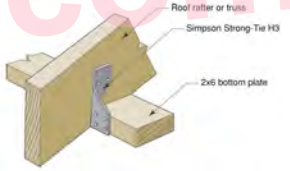


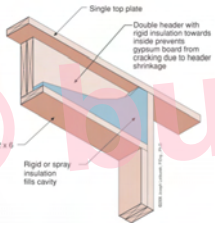


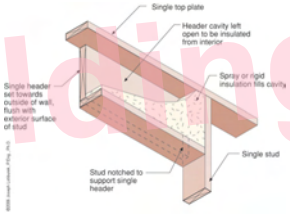






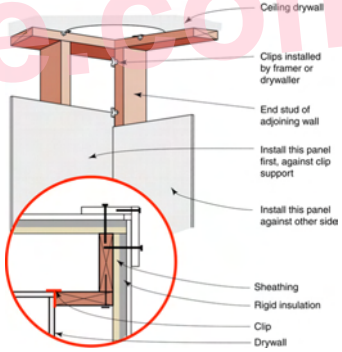


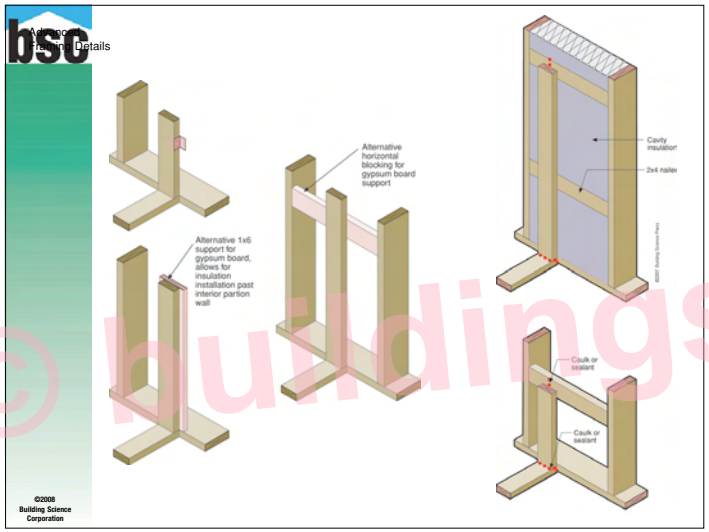


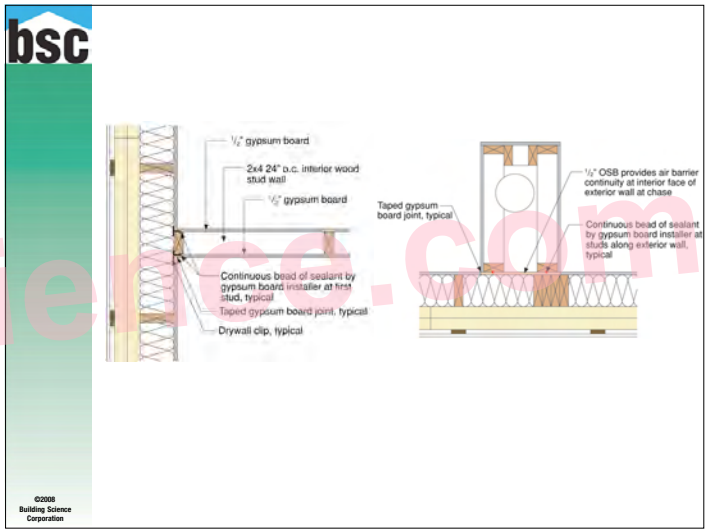


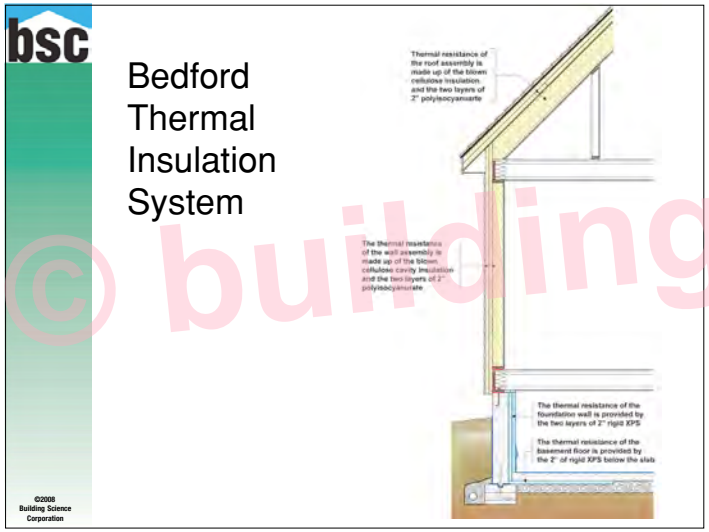
Advanced Framing System

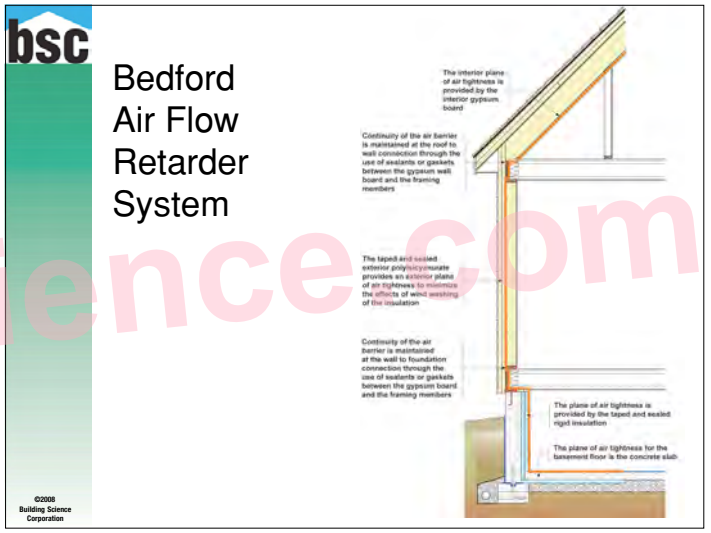
- Drywall clips allow for better installation with less drywall cracking

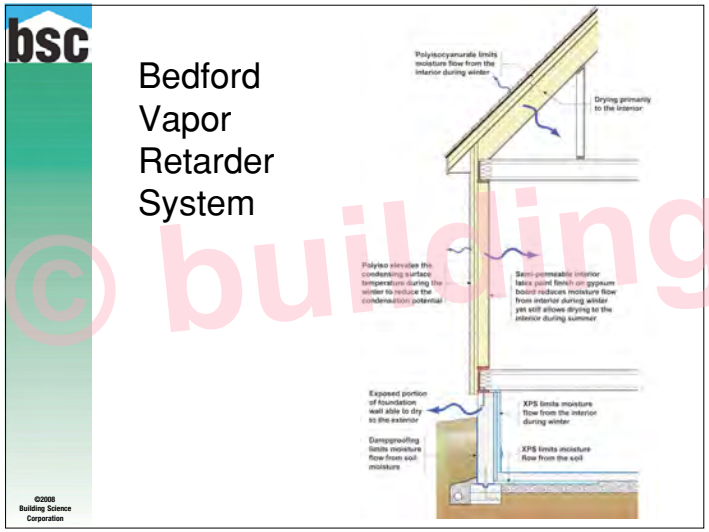


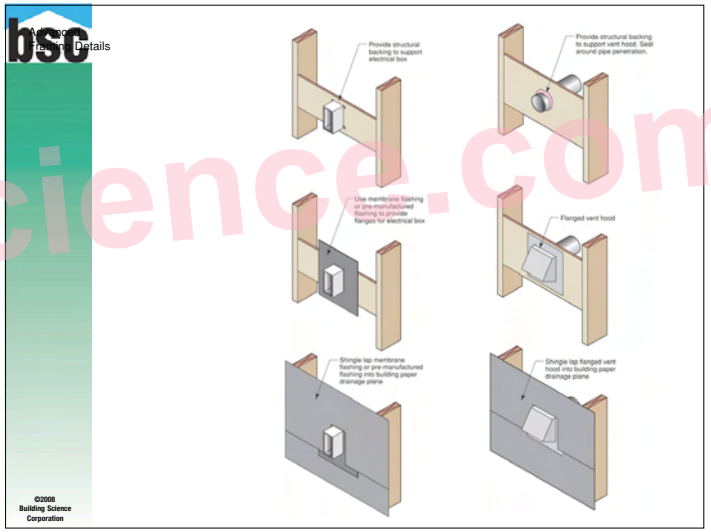


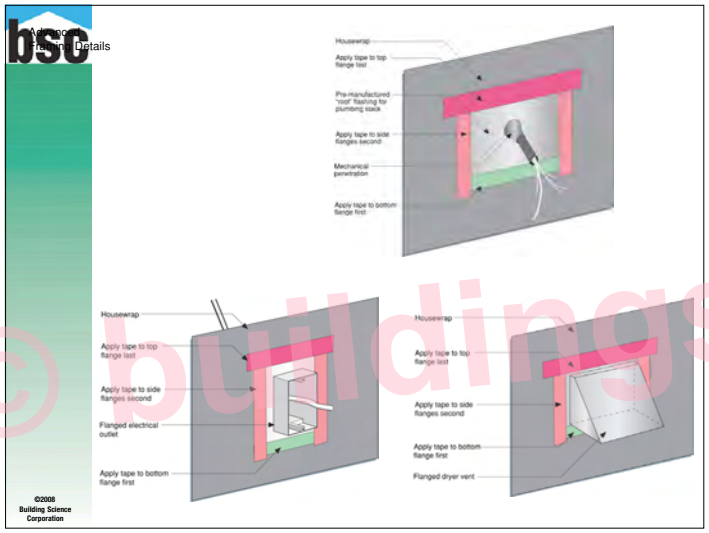


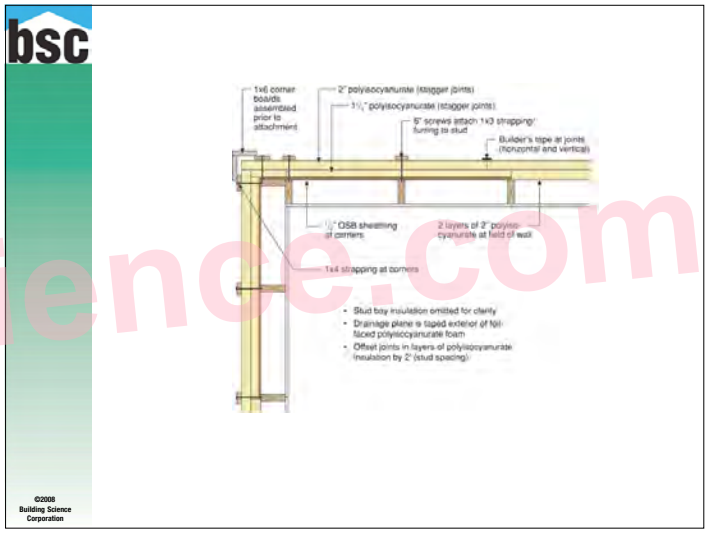


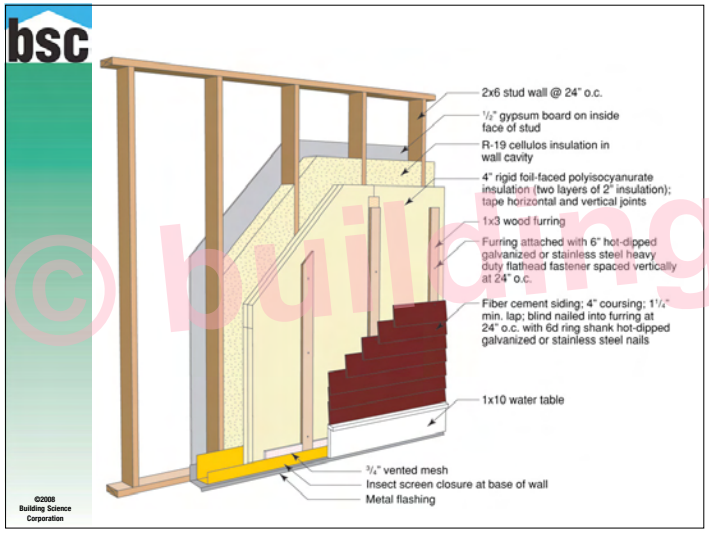


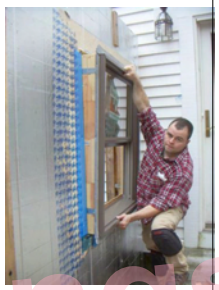










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- Mechanical Details
  - 92% AFUE Gas Furnace
  - 14 SEER Air Conditioner Split System
  - 0.85 EF Instantaneous Water Heater
  - Fantech Energy Recovery Ventilator (ERV)


Fantech ERV


Furnace and Return Ductwork Installed in Basement