RDH BUILDING SCIENCE LABORATORIES

Building Science:
The Foundation of Future Residential Building Design and Practice

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WATERLOO ENGINEERING

Changes and Trends

- Changing projects
  - Retrofit
  - Infill
  - Mid-rise
  - Multi-use
  - Changing / Aging population
  - Regional variations

Changes and Trends

- Changing needs
  - Lower energy
  - More comfort,
  - Better IAQ
  - Faster construction
  - Weather insensitivity
  - Labor efficiency

What is Building Science?

- Still no consensus, but . . .
- *Building science is the **cross-disciplinary** collection of knowledge and experience required to **understand and predict** many aspects of the behaviour (performance) of **buildings** and their systems, specifically including*
  - *durability, comfort, energy, environmental separation, indoor air quality, acoustics, lighting, economics, and constructability.*

The Utility of Building Science

- "Tradition in itself provides no basis for change other than trial and error. Tradition places the emphasis on *how* something should be done; science sets out to explain *why* so that the experience can be carried over to different materials and circumstances."
  - Sir Frederick Lea, BRE 1953?
- Building science allows one to try new things with fewer risk

Building Science

- Is not a list of rules, or strategies
- Requires understanding, calculation, analysis
- Very little building science is applied to residential building design
  - Lots of experience, slow change
- Very little building science is taught

Codes and Standards

- Not a compendium of building science
- May violate laws of physics
- Neither LEED nor PassivHaus are soundly based on science

Prefab and Modular

Penn State RBDCC Brochure

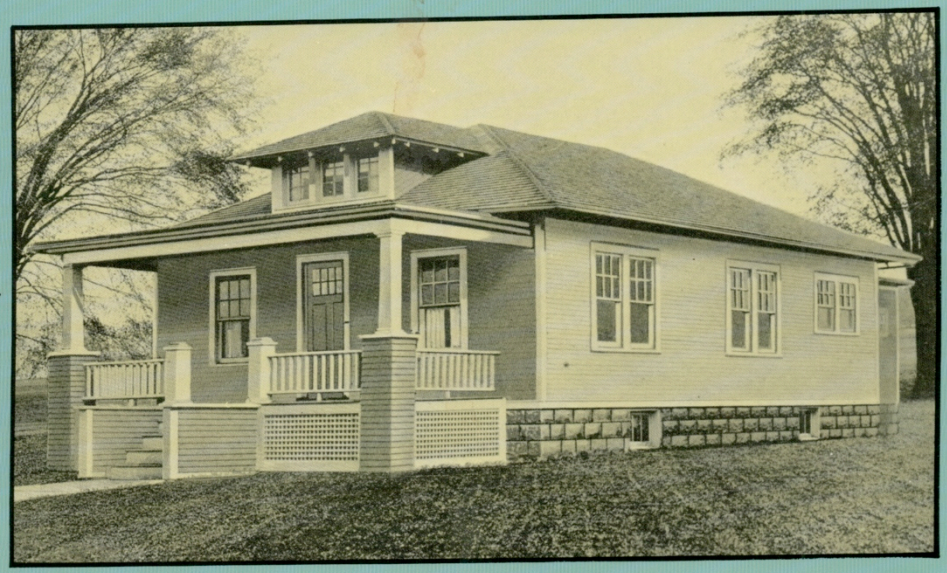
Prefab

- Promises
  - Improve labor efficiency, quality
  - Reduce weather sensitivity
  - Reduce cost
- Challenges
  - Joints
  - Dimensional Control
  - Transport

BENNETT'S SMALL HOUSE CATALOG, 1920

Ray H. Bennett Lumber Co., Inc.

With 217 Illustrations



A Better-Built idea—routing (instead of cleating) stair-stringers for fine workmanship, and accurate fit.

HOW SCIENCE SOLVED THE HIGH COST OF HOME-BUILDING

Up to the present, the great drawback to home-building has been the excessive cost, by the individually-built-house method.

Plans by experienced architects have been costly; the cost of lumber has been high; the amount of labor necessary to cut and trim rough and finished lumber has been a serious item; there have been endless worries—delays—extra costs; plans have looked good on paper, but have not worked out well; contractors have been known to be careless about the quality of the material and of the work on the job.

What will avoid all the usual waste, delays, disappointments, and—what will cut the cost of building a home? Science says—"*simplify*"—*standardize*"—"*eliminate waste.*"

"*This is the day of brains that plans for thousands* at a time, instead of one. Why is it necessary to plan every individual home that is built? There's a wiser, more economical way. Once the plan for a house has been tried and proven true, use it many times over; let hundreds of people divide the cost—let hundreds of people reap the benefit of these plans."

"*This is the day of machinery*, the day for producing in tremendous quantities, thereby accomplishing in minutes that which would consume hours, days and weeks to achieve by usual methods. After having worked out plans to the highest point of economy, why not cut the materials by labor-saving machines *instead of the old hand method*, thereby reducing labor and waste to a minimum."

ALL CHANCES FOR ERRORS AS TO

SCIENCE'S ANSWER IS THE BENNETT-WAY

The best designs and plans have been produced for hundreds to share the benefits—a huge modern mill in the heart of the lumber market has been equipped with labor-and-waste-saving machinery of the latest type—and YOU, who want to build a home, reap the advantages and savings of the Bennett-Way in securing one of finer design, greater convenience, and genuine durability.

Perhaps right here, it is well to establish the difference between a Bennett Ready-Cut Home and a portable house.

The object of the portable system is to produce a building construction which may be put together to form a temporary shelter—taken apart again—moved from place to place as desired. Manufacturers of portable buildings cannot and do not represent their products to be permanent.

But Bennett Homes, Better-Built and Ready-Cut, are built for permanency. Once your Bennett Home is completed, there is absolutely no difference between it and any well constructed home, except, perhaps, that our designs are more attractive and impressive than the average homes one sees.

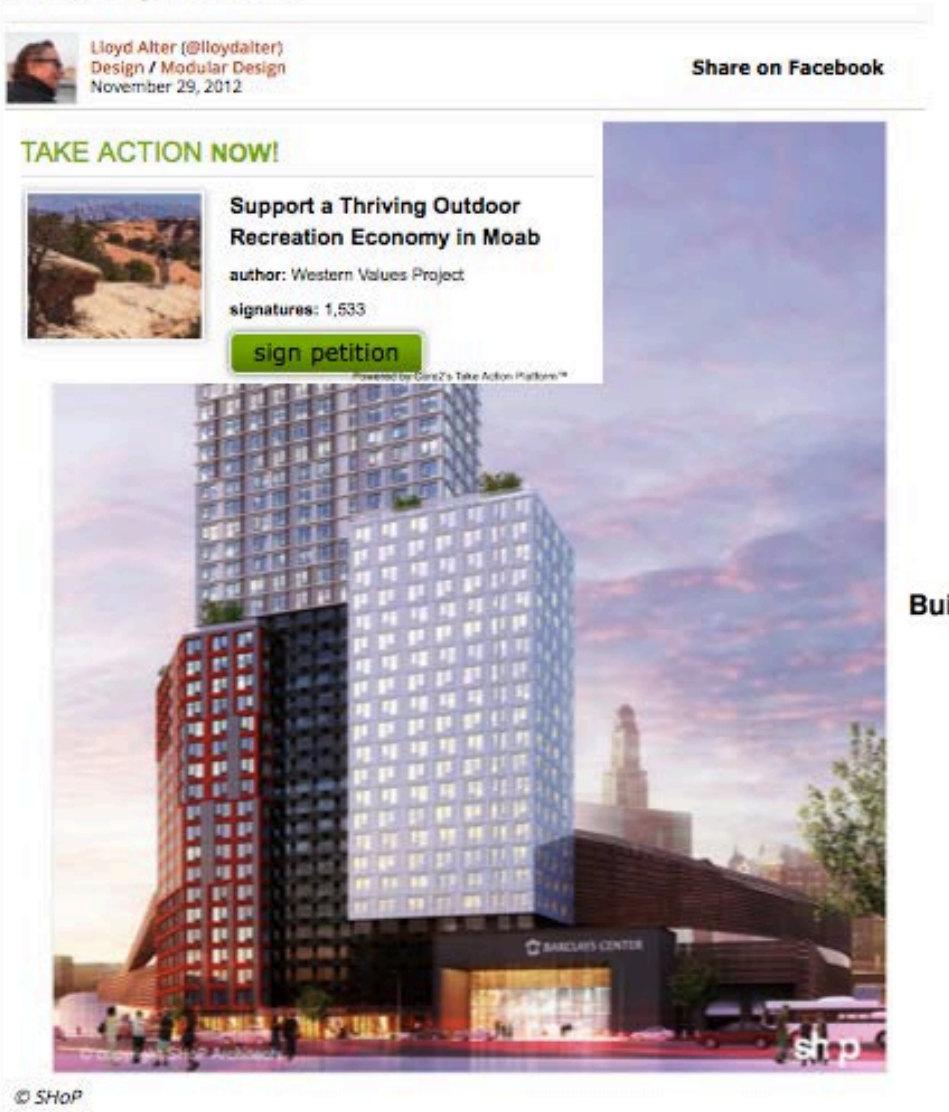
HOW RENT-MONEY COUNTS

This table shows what rent amounts to in ten and twenty years, with six per cent interest compounded annually, and gives an idea of the value of the house one can pay for by applying rent toward paying for a home.

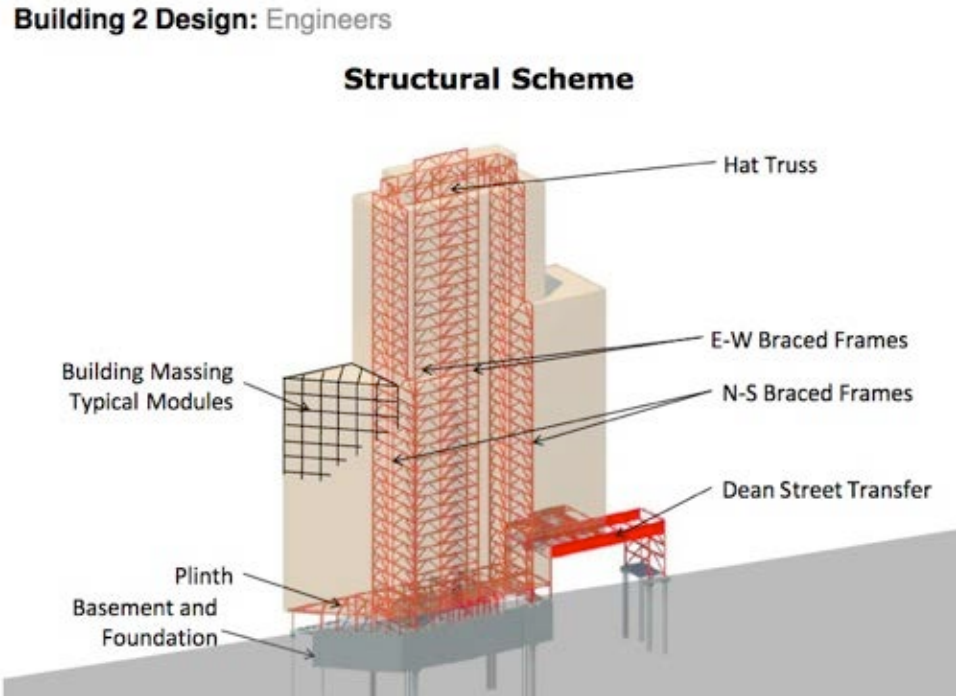
Rent per Month	In 10 Years	In 20 Years
$ 8.00	$1,265.35	$ 3,531.41
12.00	1,898.02	5,279.11
17.00	2,688.86	7,504.24
20.00	3,163.36	8,828.52
25.00	3,954.20	11,035.65
30.00	4,745.04	13,242.78
35.00	5,535.88	15,449.91
50.00	7,908.40	22,071.30

Tonawanda, heart of the Lumber Market. Great lumber-docks on one side, main trunk-line railroads on the other.

SHoP Architects, Skanska Construction, Forest City Radner



Claims abound..
“World tallest modular”
“we cracked the code”
“up to 25% cheaper” “half the time”



BUILDING SCIENCE LABORATORIES

Documents Reveal Woes at Pioneering Atlantic Yards Building

By **Norman Oder** | August 31, 2015

“ Half of the first 39 apartments suffered significant water damage. The first four floors were largely gutted”

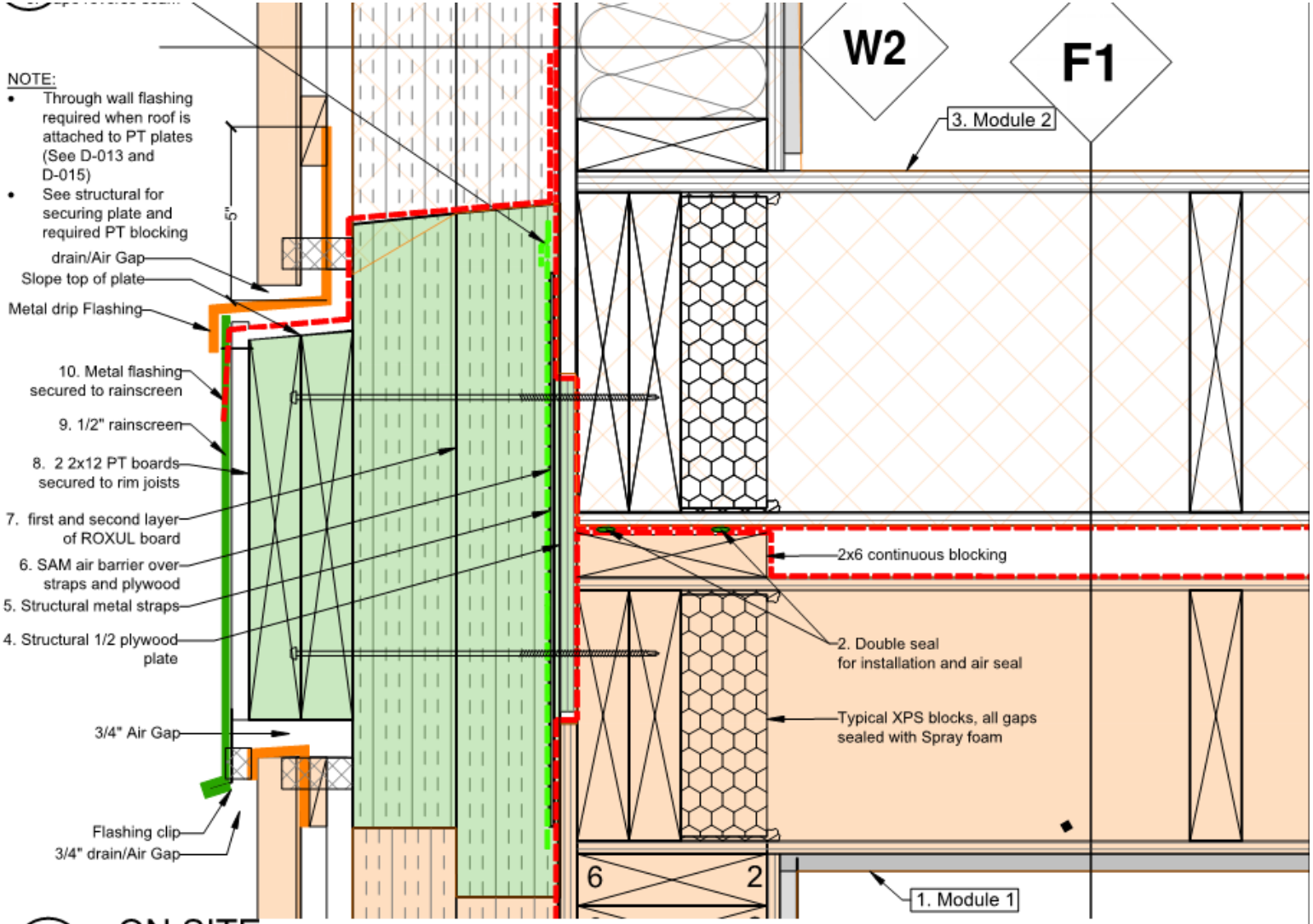
Norman Oder

The modular building known as B2, at 461 Dean Street, was supposed to cost less and be done much faster than a conventional high-rise. But problems in stacking the modules and keeping water out made for a slower, more expensive build-out.

The Atlantic Yards apartment tower known as B2 officially launched (http://atlanticyardsreport.blogspot.com/2012/12/the-atlantic-yards-b2-modular.html) in December 2012 with great fanfare and high hopes, and not just because of what developer Forest City Ratner


JCB


TYPAR
Wharf Road Sechelt
604-885-5818
XRS



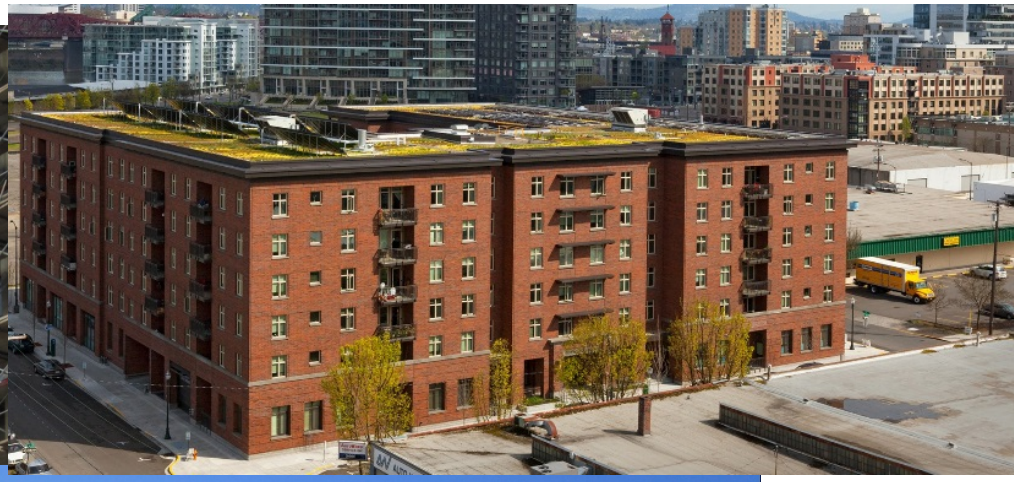
2 ON SITE

Scale: 6"=1'

Multi-unit residential

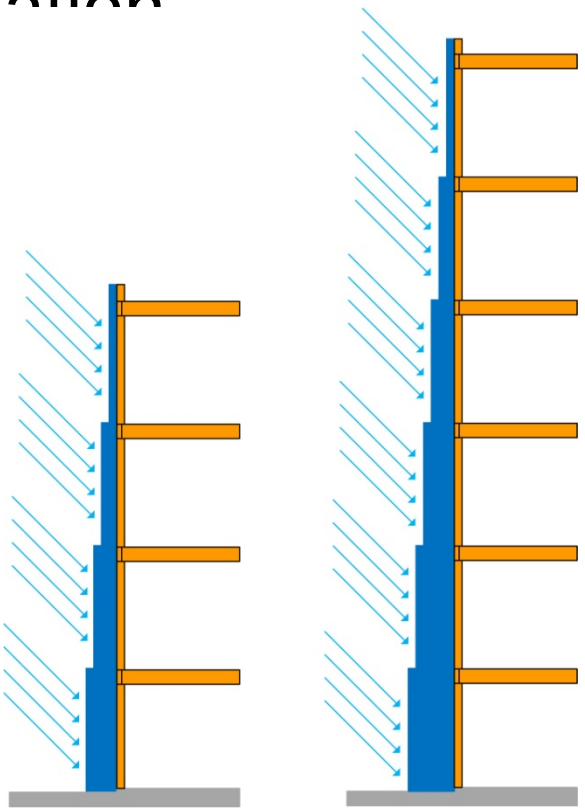
- Land use, walkable cities, aging population etc demand more multi-unit (not multi-family)

Mid-Rise Wood Buildings (framed)



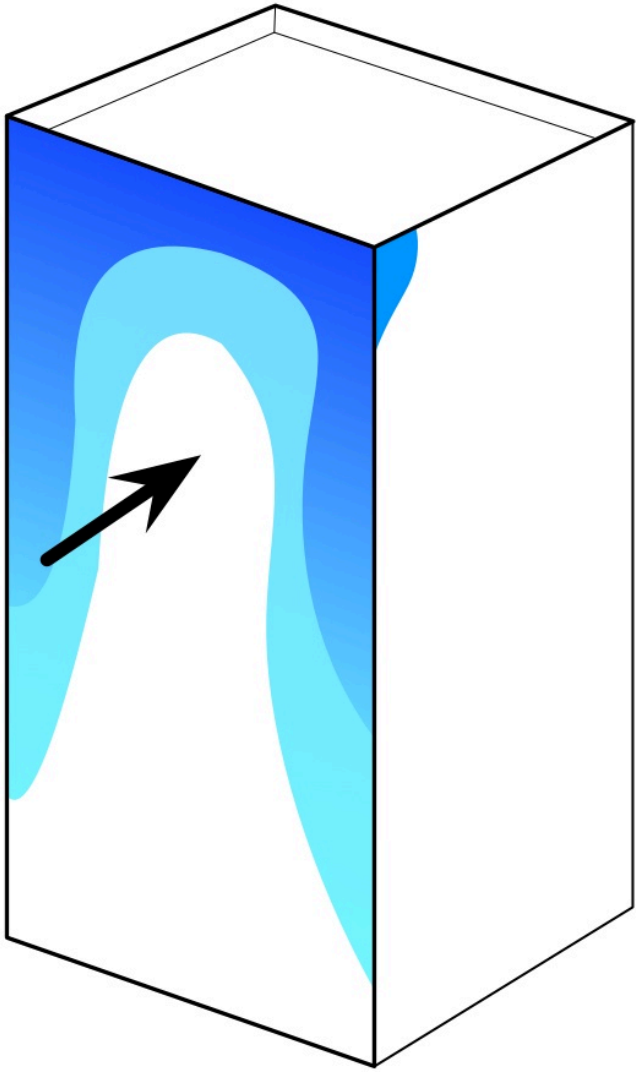
Increase in Wind and Rain Loads

- Specified structural and water penetration performance criteria for windows
  - Some low-rise windows may not work as well in mid-rise buildings
- Cumulative runoff
  - Water shedding features become more important
    - continuity, drip edges
  - Water penetration control strategy



More wind and rain

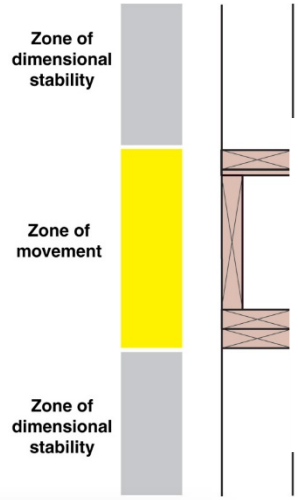
- Required:
  - Better materials
  - Better details
  - Better quality

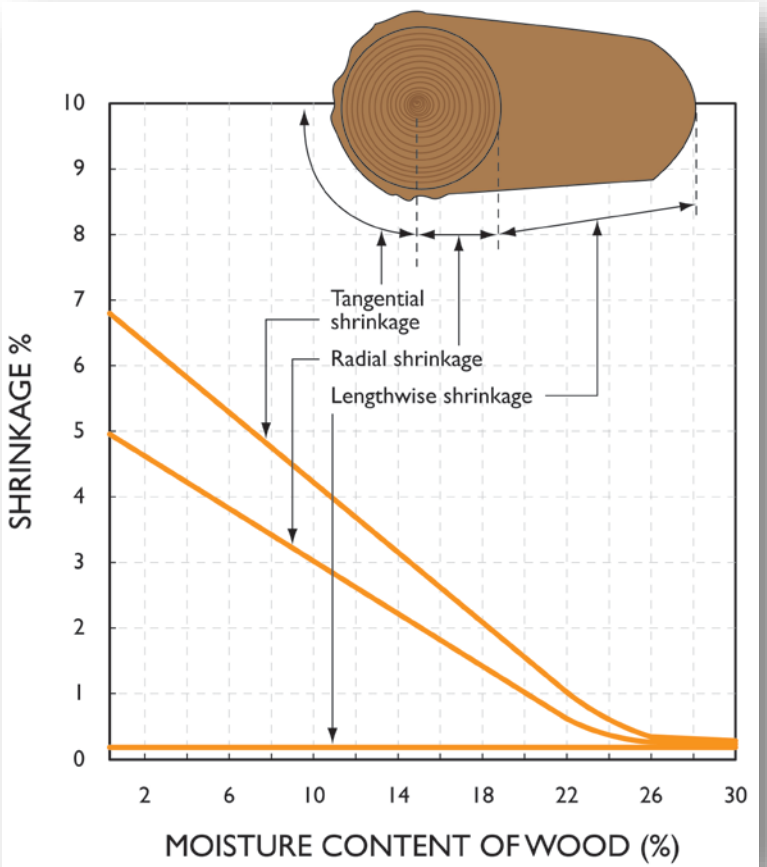


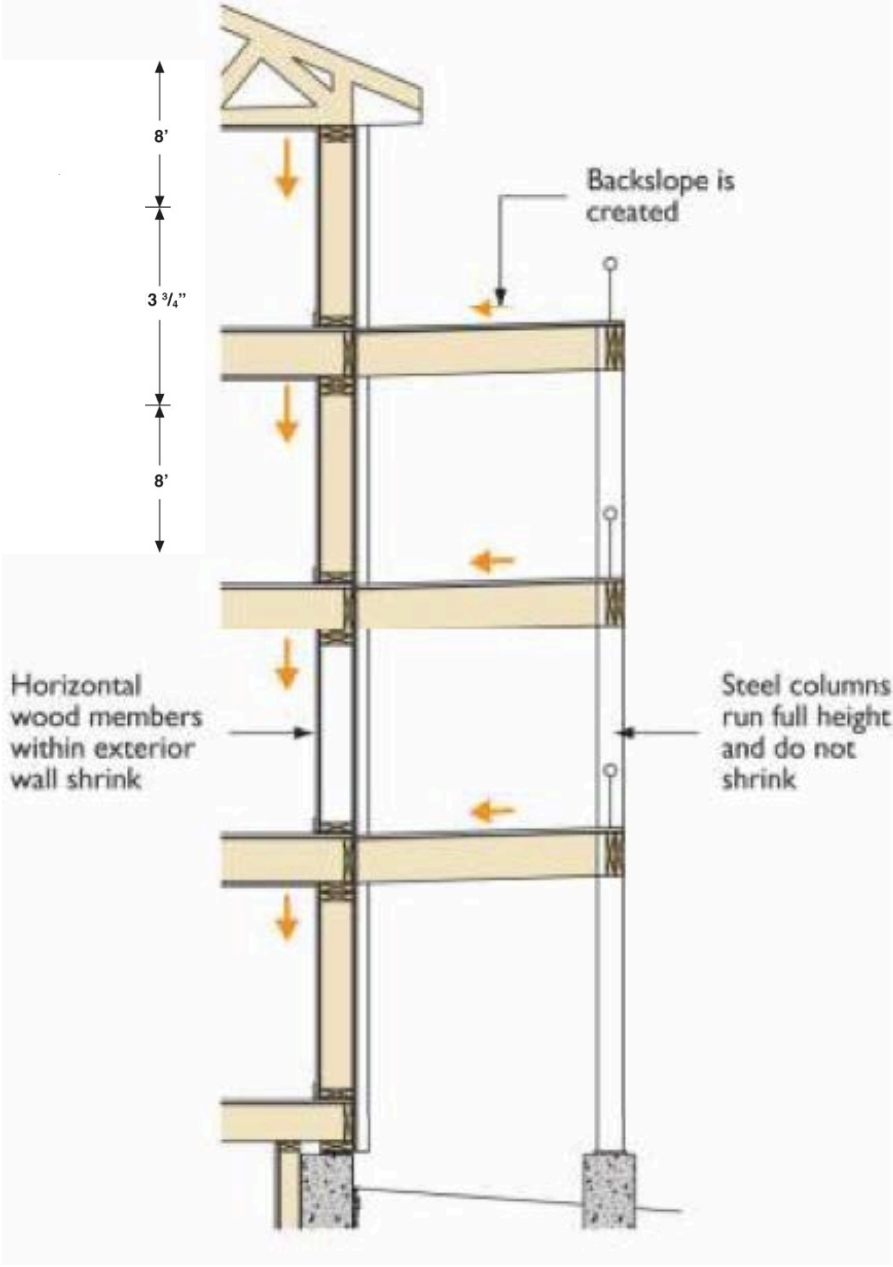
Challenges with Mechanically Attached Air-Water Barriers & Wind During Construction

Shrinkage

- Cross-grain wood shrinks







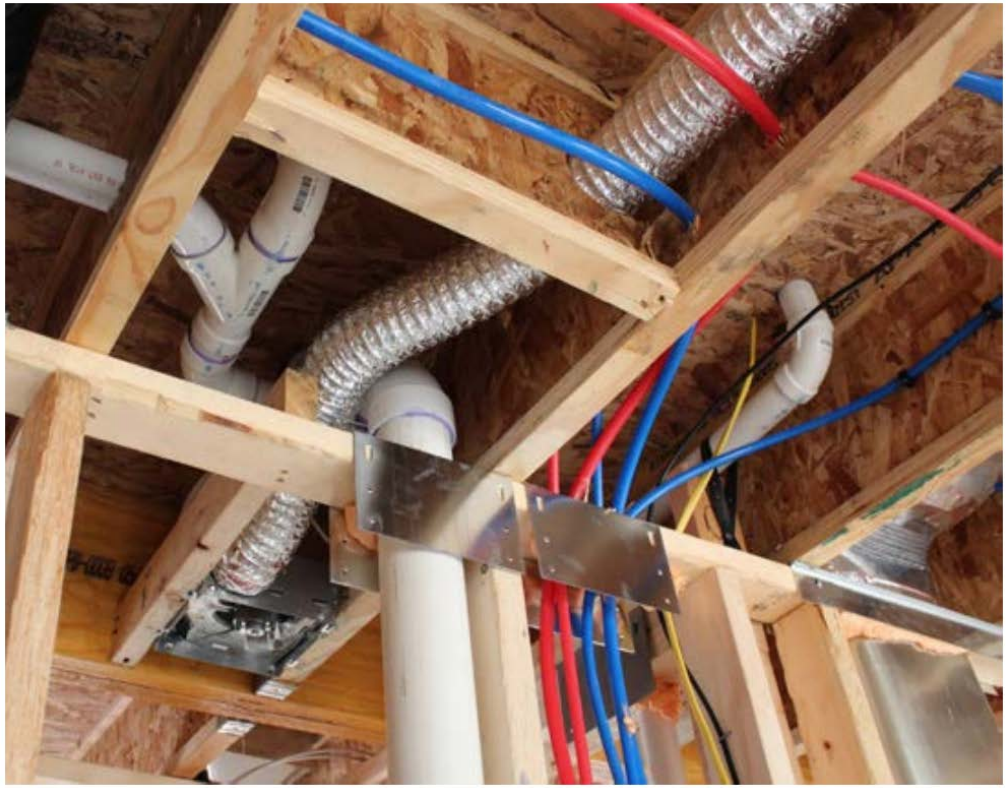
Fire and sound separation

- High Density / Mixed-use means …
- Better separation

- New techniques
- Construction sequencing
- Quality control

Mechanical Systems

- Smaller systems
- Simpler systems
- Efficient
- Quiet
- Maintainable
- Repairable



Smaller furnaces

- Smaller, more efficient and multi-family buildings need **smaller** furnances!
  - Long run times
  - Steady heat
  - Smaller ducts
- Poor industry engagement

Dettson Chinook furnace

Smaller cooling

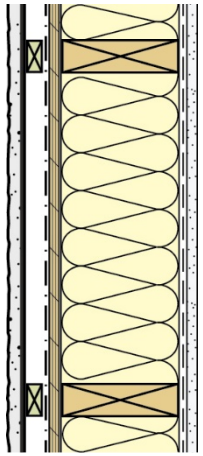
- Runtime = humidity control
- Better glazing & airtightness equals dropping loads
- Short runtime means poor mixing and higher humidities
- Industry MIA
- Japanese mini-splits?

Changing Energy Codes

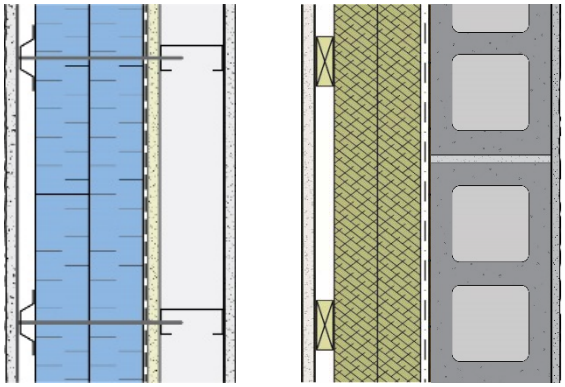
- More airtightness
  - Blower door testing
- More insulation
  - Quality inspection
  - Less thermal bridging
- Changing techniques

Getting to Higher Insulation Levels

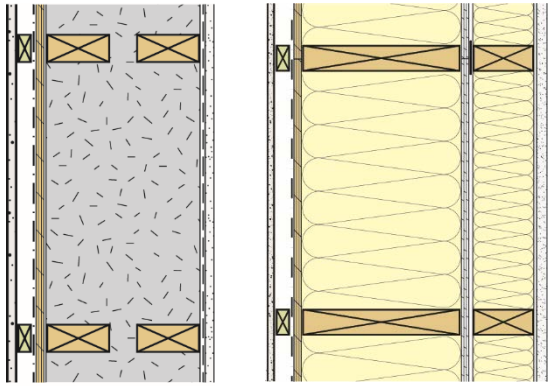
Base 2x6 Framed Wall *<R-16 (wood)*



Exterior Insulation
R-15 to R-60+



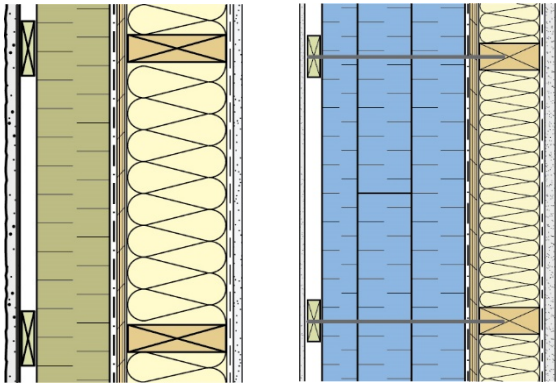
Issues: cladding attachment, thickness



Deep Stud, Double Stud, SIPS
R-20 – R-80+

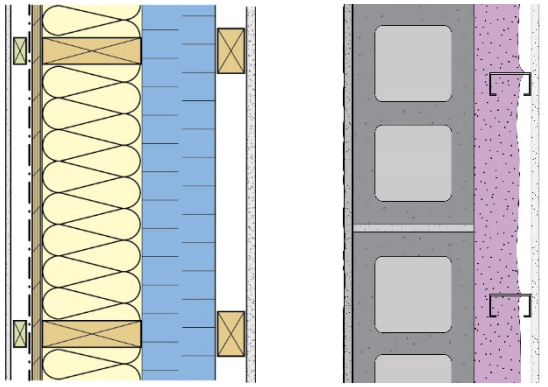
Issues: thermal bridging, thickness, durability

Split Insulation R-20 to R-60+

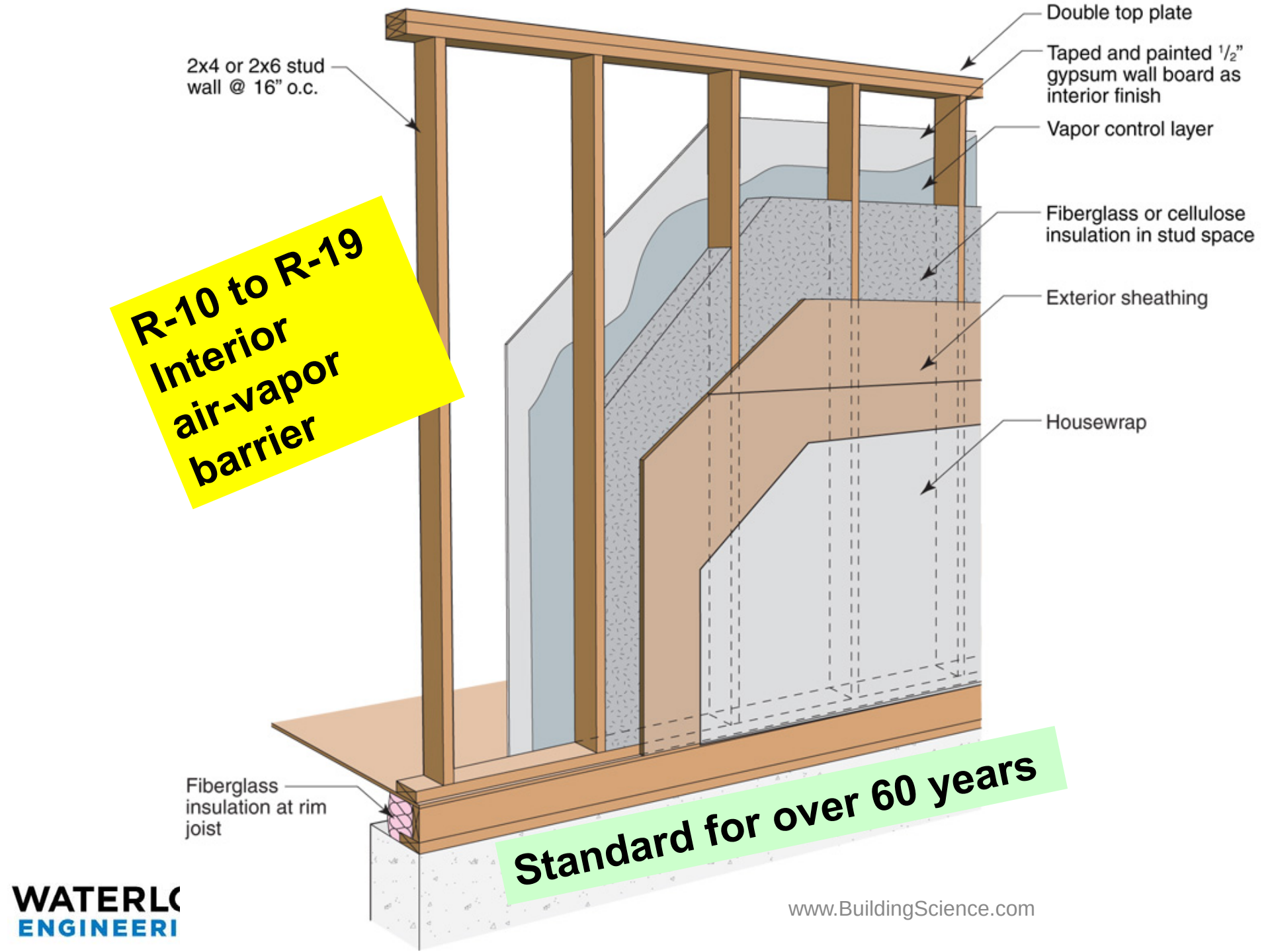


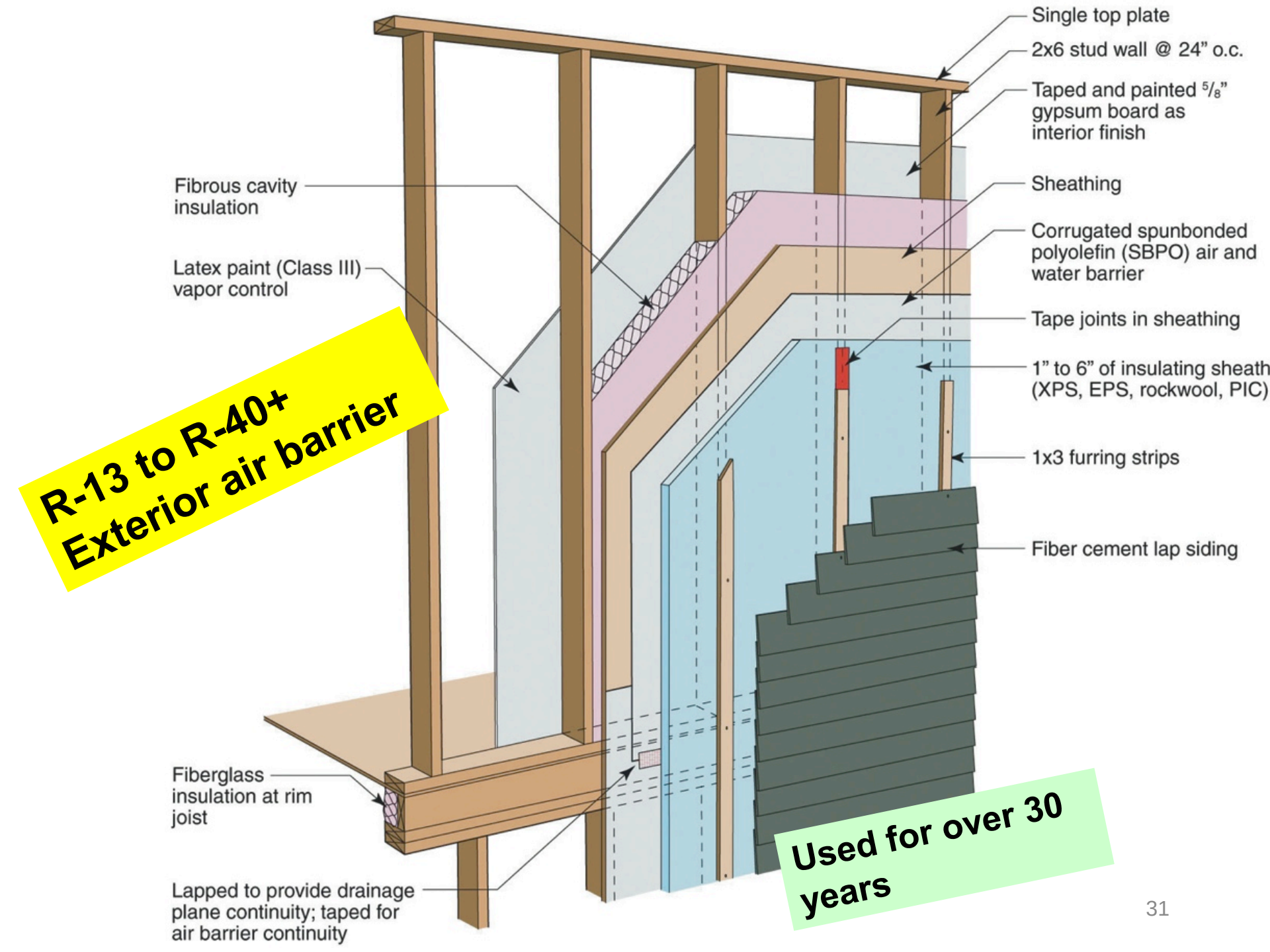
Issues: cladding attachment, material selection

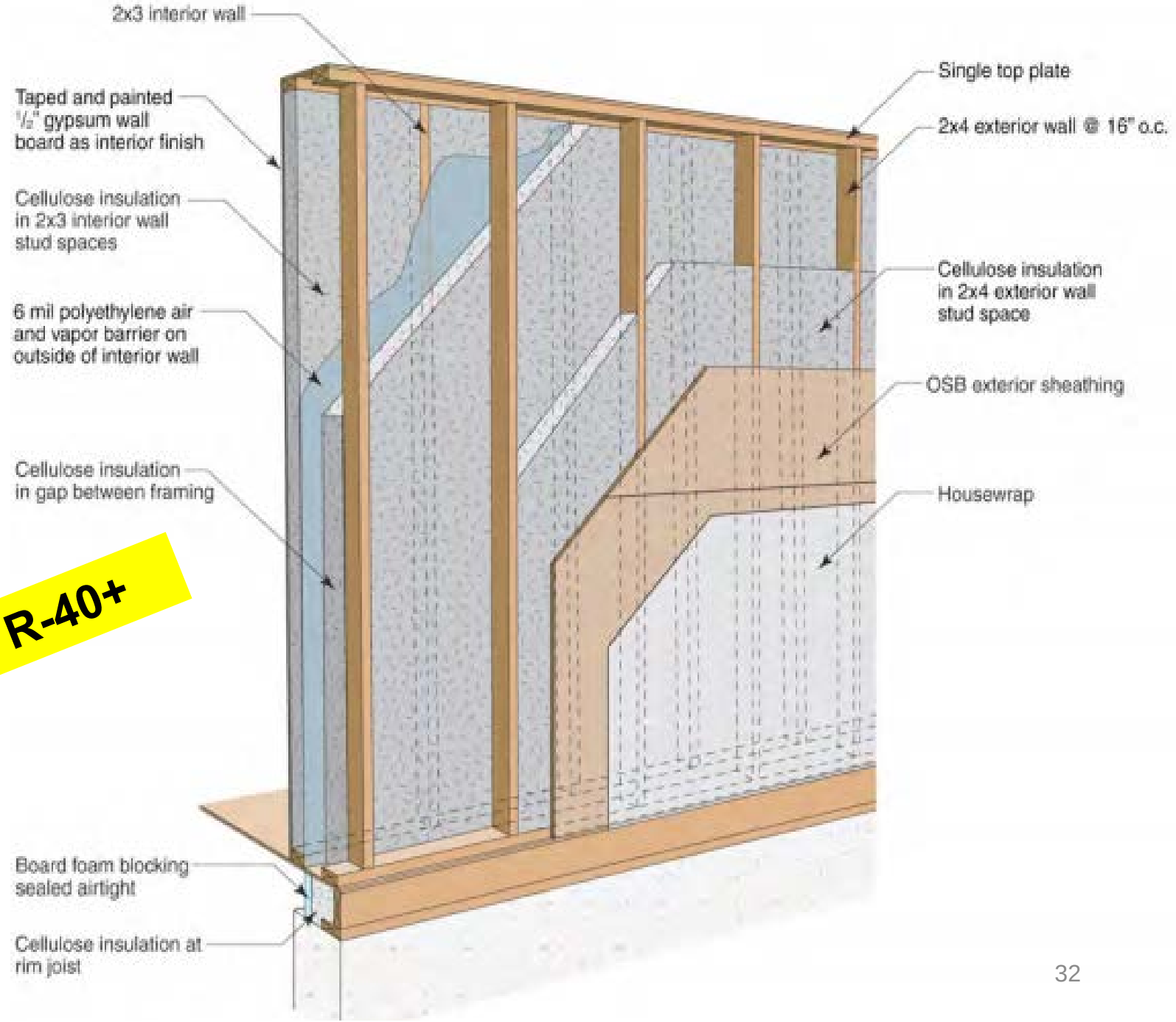
Interior Insulation
R-20 to R-30+



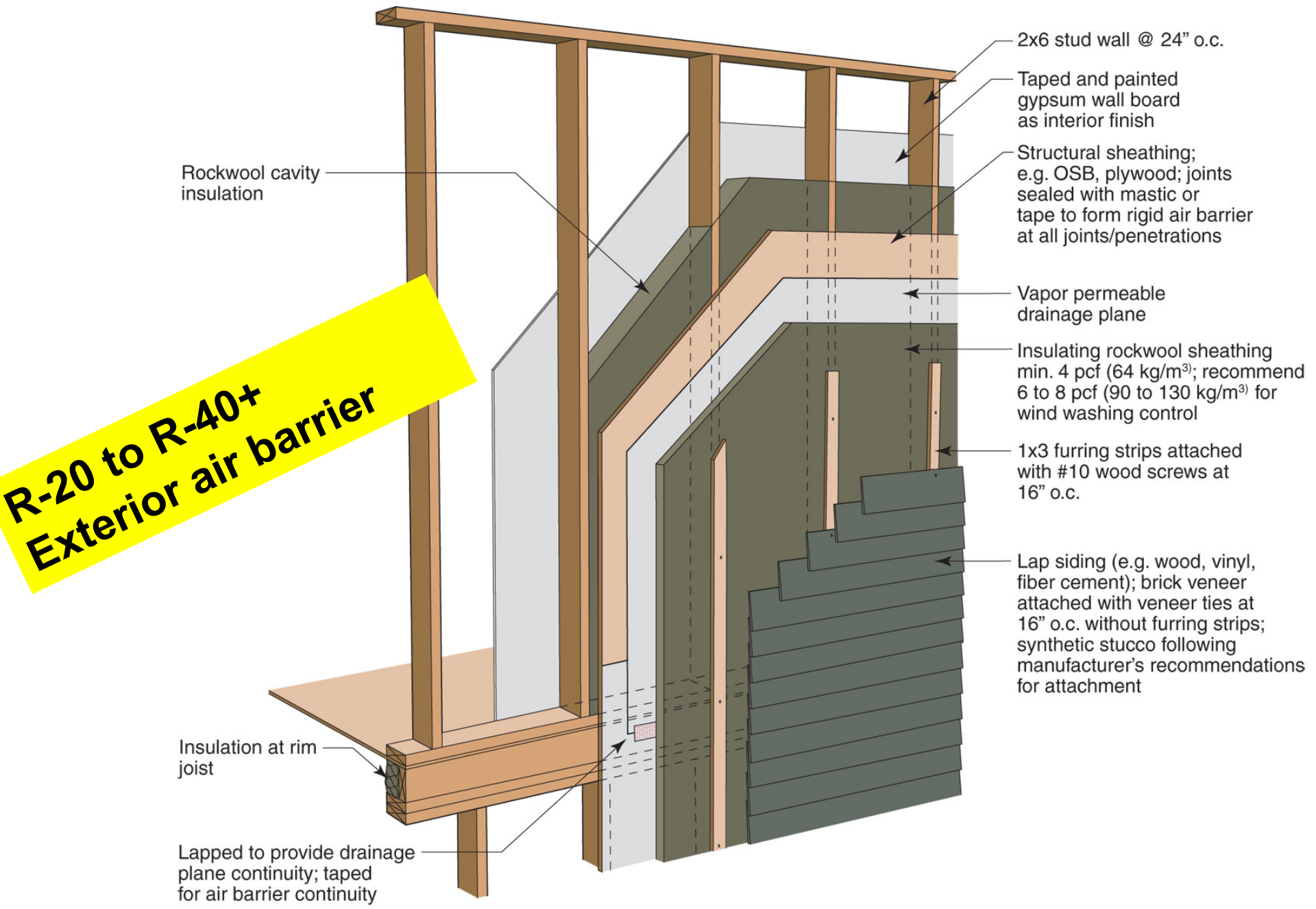
Issues: thickness, durability, interior details


Double top plate
Taped and painted ½" gypsum wall board as interior finish
Vapor control layer
Fiberglass or cellulose insulation in stud space
Exterior sheathing
Housewrap
2x4 or 2x6 stud wall @ 16" o.c.
Fiberglass insulation at rim joist
R-10 to R-19 Interior air-vapor barrier
Standard for over 60 years


Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted 5/8" gypsum board as interior finish
Sheathing
Corrugated spunbonded polyolefin (SBPO) air and water barrier
Tape joints in sheathing
1" to 6" of insulating sheath (XPS, EPS, rockwool, PIC)
1x3 furring strips
Fiber cement lap siding
Fibrous cavity insulation
Latex paint (Class III) vapor control
Fiberglass insulation at rim joist
Lapped to provide drainage plane continuity; taped for air barrier continuity
R-13 to R-40+
Exterior air barrier
Used for over 30 years


2x3 interior wall
Taped and painted ½" gypsum wall board as interior finish
Cellulose insulation in 2x3 interior wall stud spaces
6 mil polyethylene air and vapor barrier on outside of interior wall
Cellulose insulation in gap between framing
Board foam blocking sealed airtight
Cellulose insulation at rim joist
Single top plate
2x4 exterior wall @ 16" o.c.
Cellulose insulation in 2x4 exterior wall stud space
OSB exterior sheathing
Housewrap

R-20 to R-40+


R-20 to R-40+
Exterior air barrier
2x6 stud wall @ 24" o.c.
Taped and painted gypsum wall board as interior finish
Structural sheathing; e.g. OSB, plywood; joints sealed with mastic or tape to form rigid air barrier at all joints/penetrations
Rockwool cavity insulation
Vapor permeable drainage plane
Insulating rockwool sheathing min. 4 pcf (64 kg/m3); recommend 6 to 8 pcf (90 to 130 kg/m3) for wind washing control
1x3 furring strips attached with #10 wood screws at 16" o.c.
Lap siding (e.g. wood, vinyl, fiber cement); brick veneer attached with veneer ties at 16" o.c. without furring strips; synthetic stucco following manufacturer's recommendations for attachment
Insulation at rim joist
Lapped to provide drainage plane continuity; taped for air barrier continuity

Exterior Insulation (“ci”)

- Research and experience have shown it works
- But knowledge not well disseminated
    - Vapor control
    - Wetting and drying
    - Cladding attachment

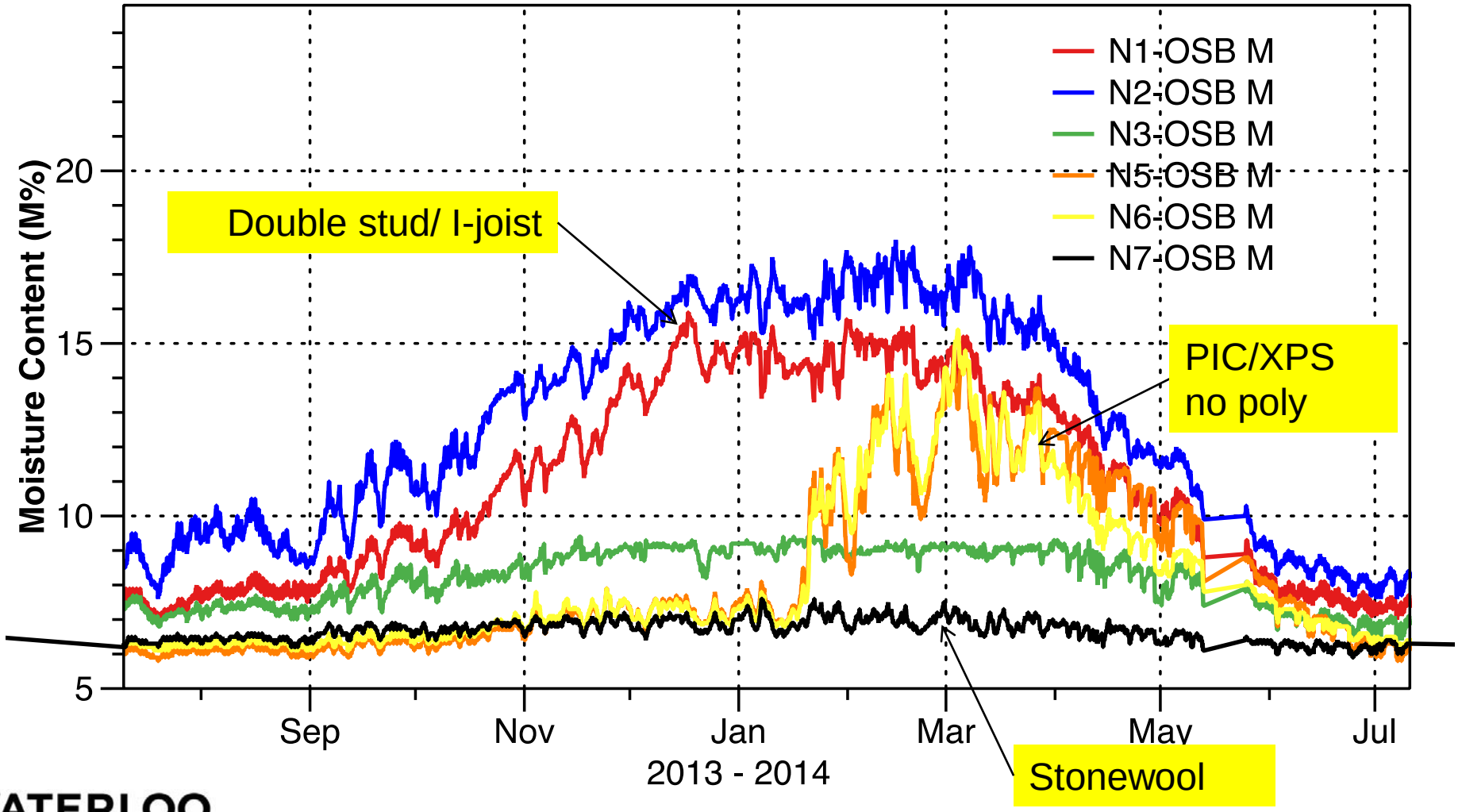
Test Wall R-values

- 2x8 with ccSPF only R24
- Others reduce heat flow by nearly half

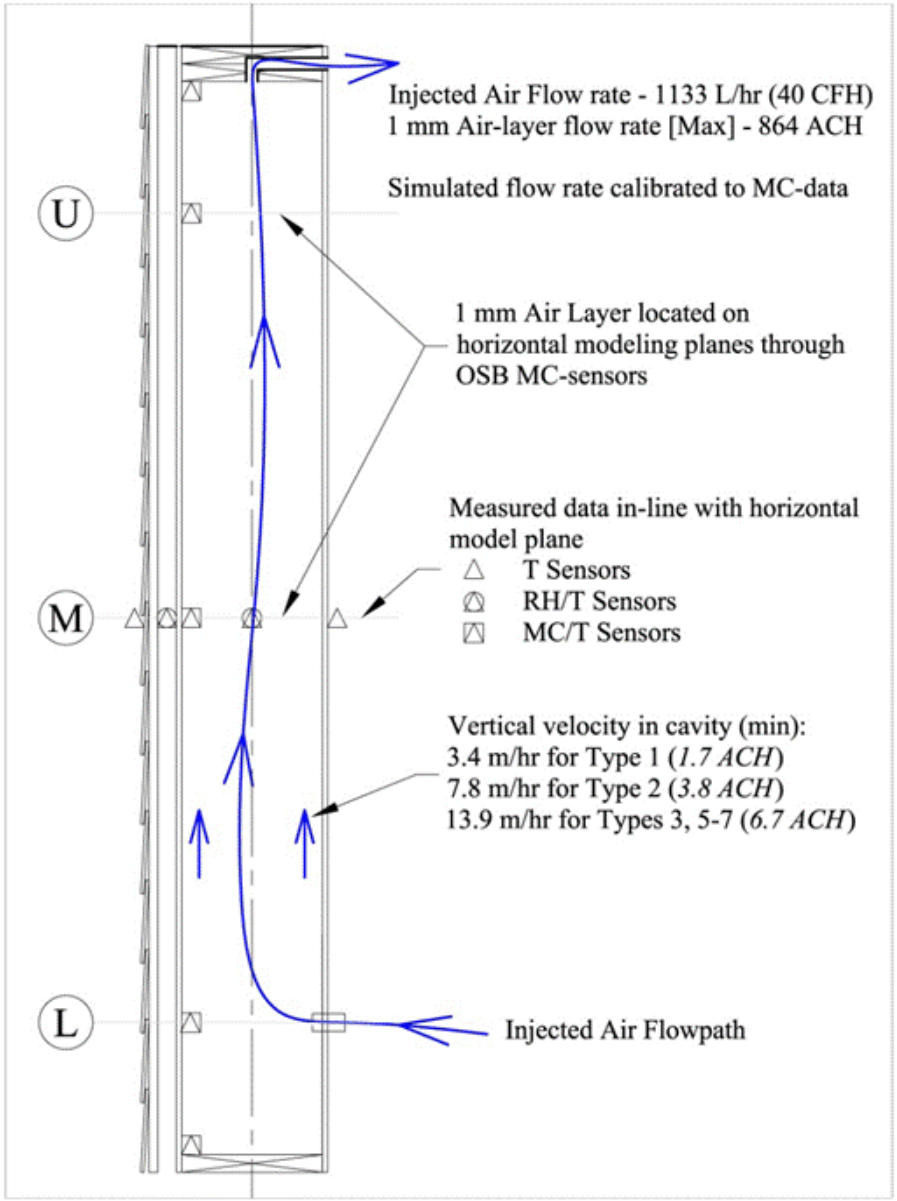
Wall	Cavity W/m2K	Stud W/m2K	Effective U W/m2K	R-imp
1. Double Stud R44	0.124	0.256	0.150	37.7
2. I-Joist R44	0.156	0.213	0.167	33.9
3. 2x6 Datum	0.228	0.602	0.303	18.7
4. 2x8 ccSPF R40	0.148	0.492	0.217	26.2
5. 2x6 PIC R22 batt	0.154	0.264	0.176	32.2
6. 2x6 2.5" XPS	0.153	0.261	0.175	32.5
7. 2x6 3" MFI	0.152	0.257	0.173	32.8

Field “research” / demo

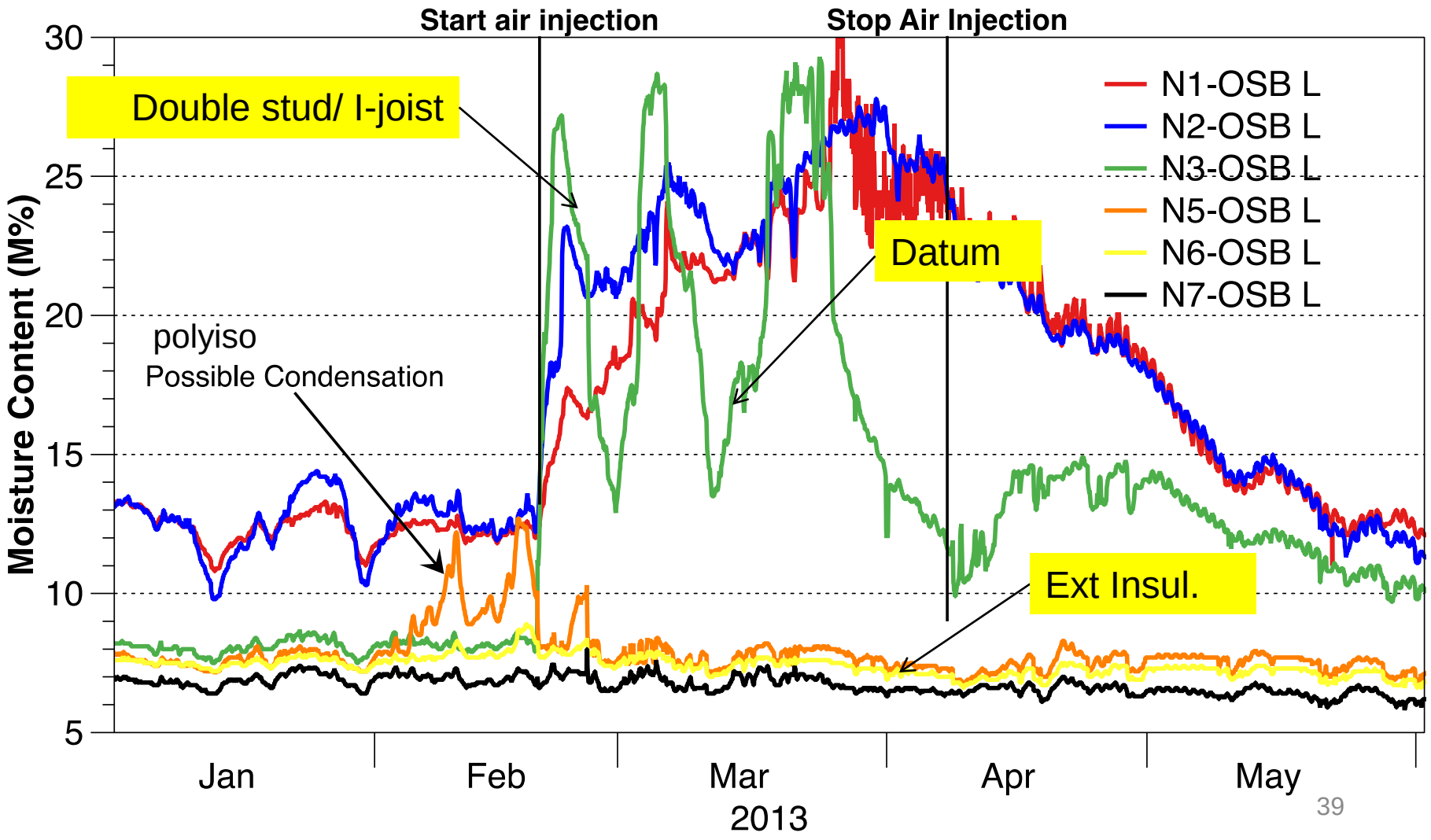
North OSB MC


N1-OSB M
N2-OSB M
N3-OSB M
N5-OSB M
N6-OSB M
N7-OSB M
Double stud/ I-joist
PIC/XPS
no poly
Stonewool
Moisture Content (M%)
20
15
10
5
Sep
Nov
Jan
Mar
May
Jul
2013 - 2014

Calibrated Air leak



Air Leakage

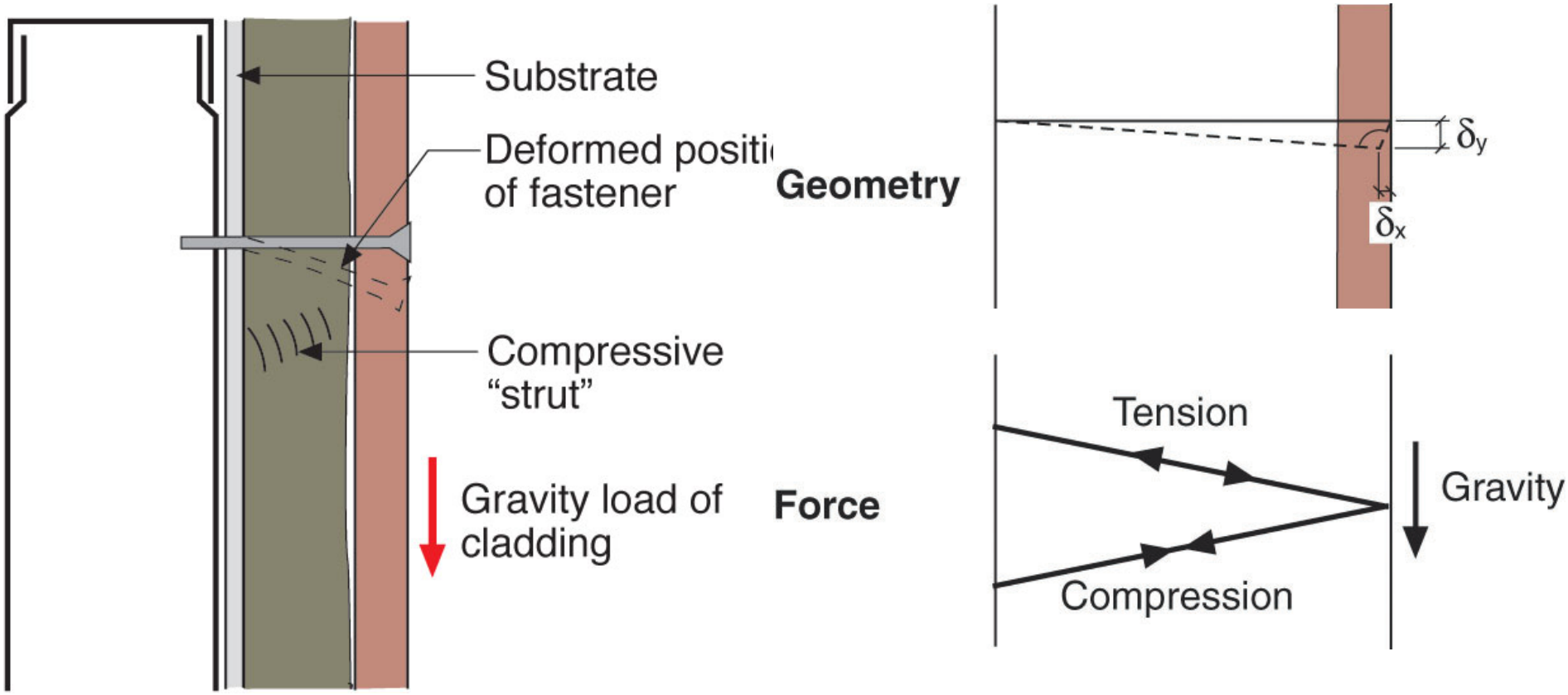

Start air injection
Stop Air Injection
Double stud/ I-joist
Datum
polyiso
Possible Condensation
Ext Insul.
N1-OSB L
N2-OSB L
N3-OSB L
N5-OSB L
N6-OSB L
N7-OSB L
Moisture Content (M%)
30
25
20
15
10
5
Jan
Feb
Mar
Apr
May
2013


DOW
DOW

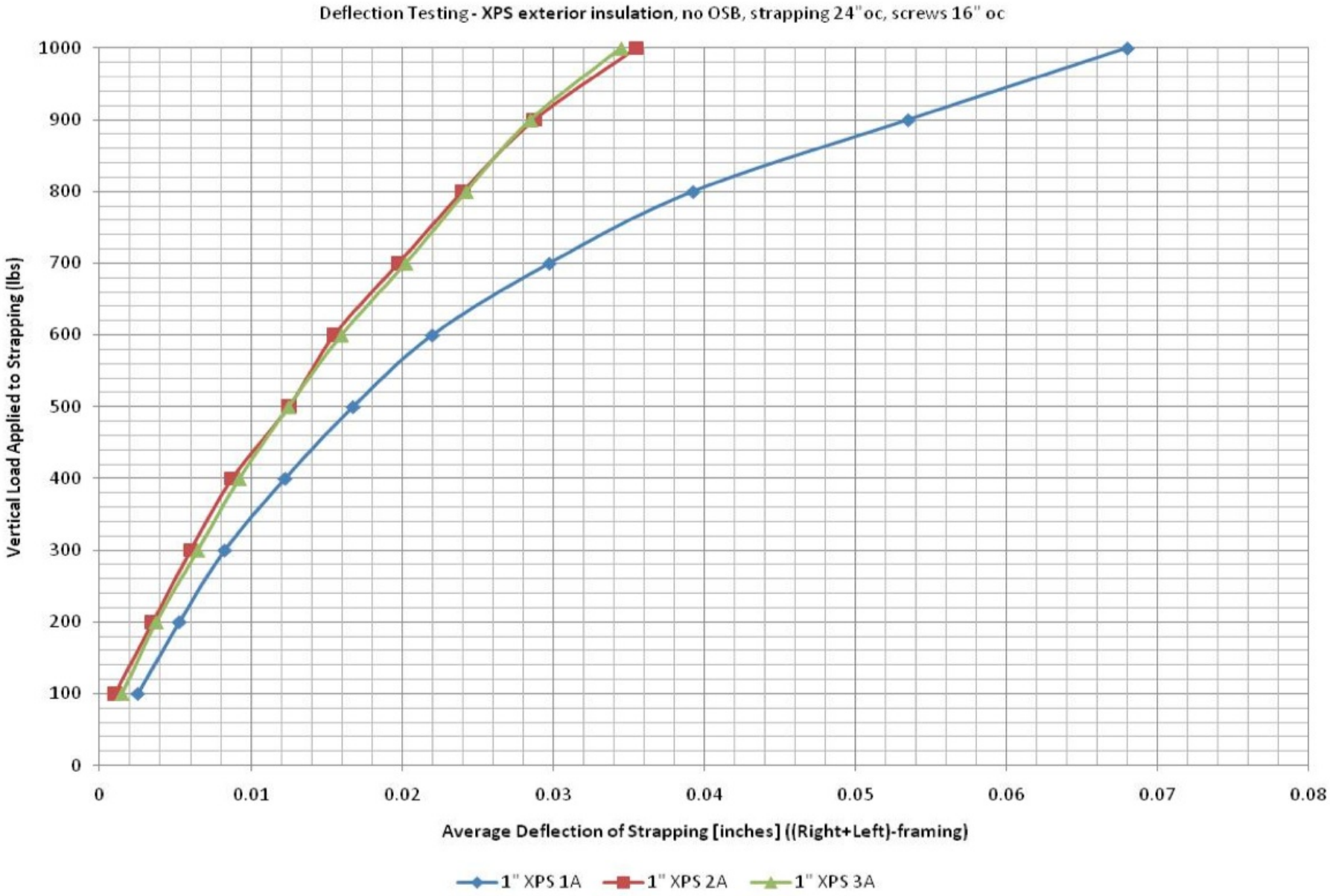
State College

- Vinyl over stonewool
- Around 1997

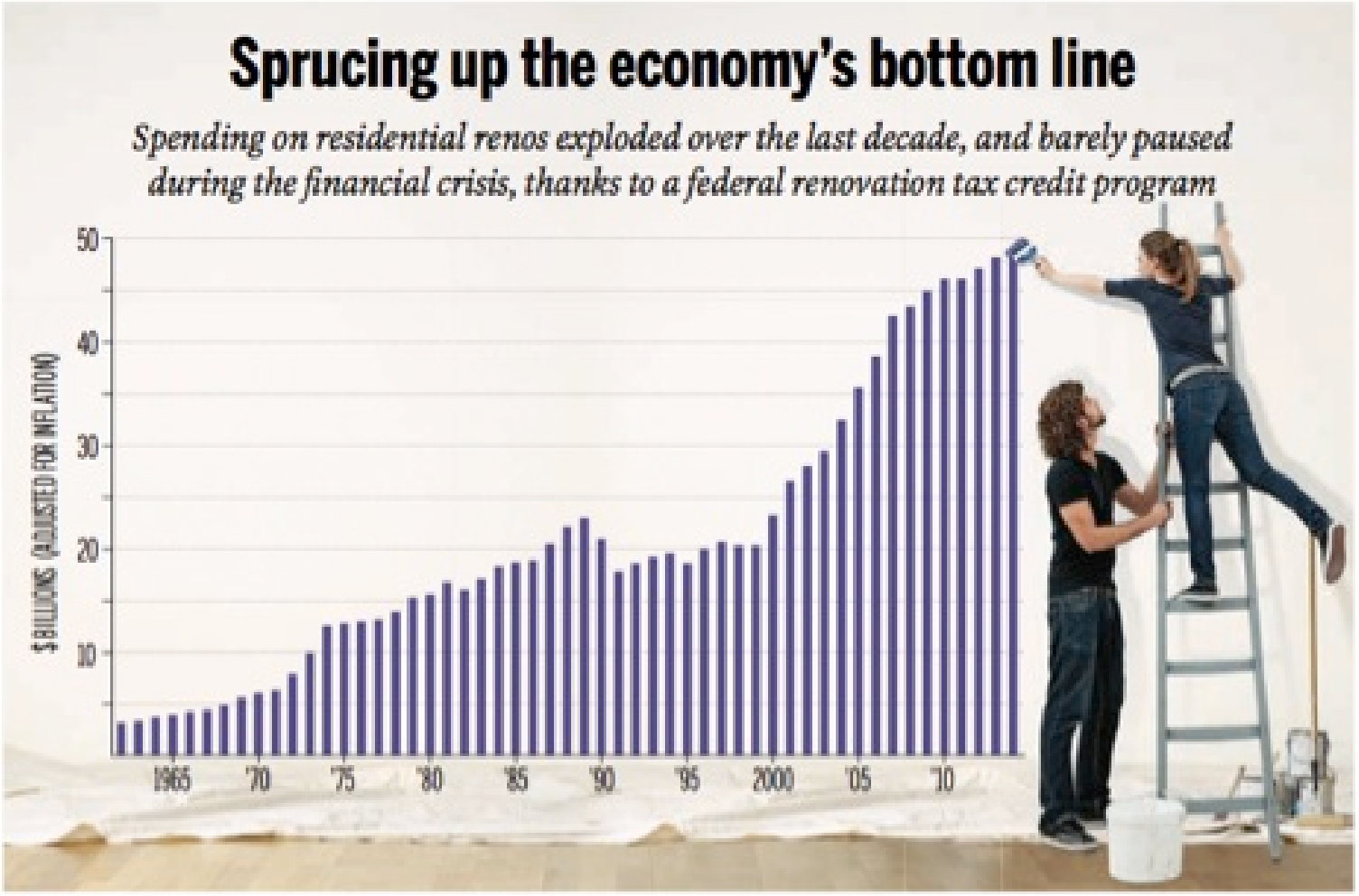
Load Carrying



Lab testing


Deflection Testing - XPS exterior insulation, no OSB, strapping 24" oc, screws 16" oc
Vertical Load Applied to Strapping (lbs)
1000
900
800
700
600
500
400
300
200
100
0
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
Average Deflection of Strapping [inches] ((Right+Left)-framing)
1" XPS 1A
1" XPS 2A
1" XPS 3A

Renovation & Retrfoit



Retrofits

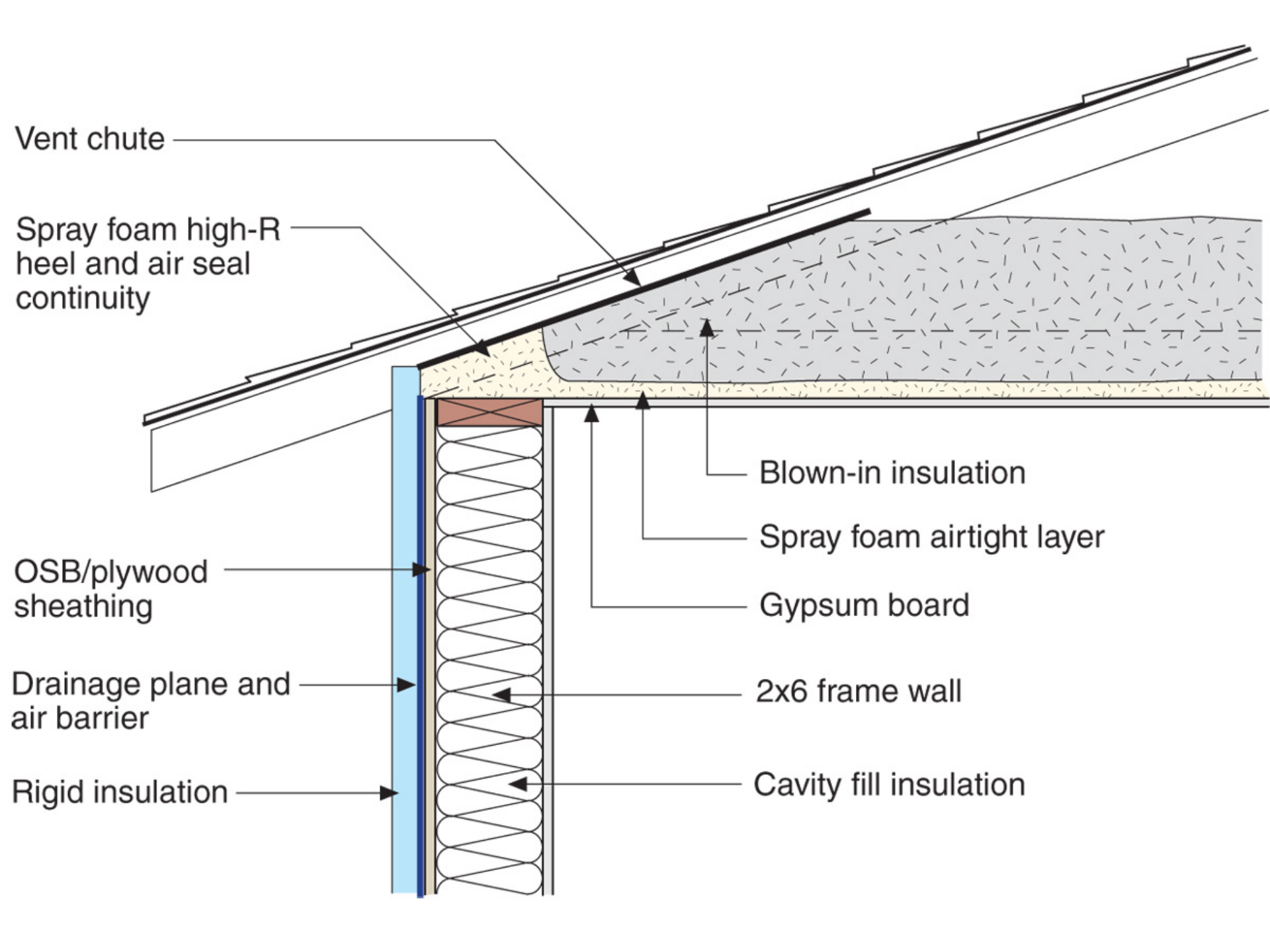
- Huge existing stock of buildings, means:
  - **Energy-efficient retrofits** must be part of any solution
- Approach varies, but generally similar strategy to new construction

Changing things …

- Changes things
- New windows, new furnace, added insulation
  - Increased airtightness
  - Different temperatures
- Approach
  - Add airtightness (add mechanical ventilation)
  - Add exterior insulation (improve rain control)

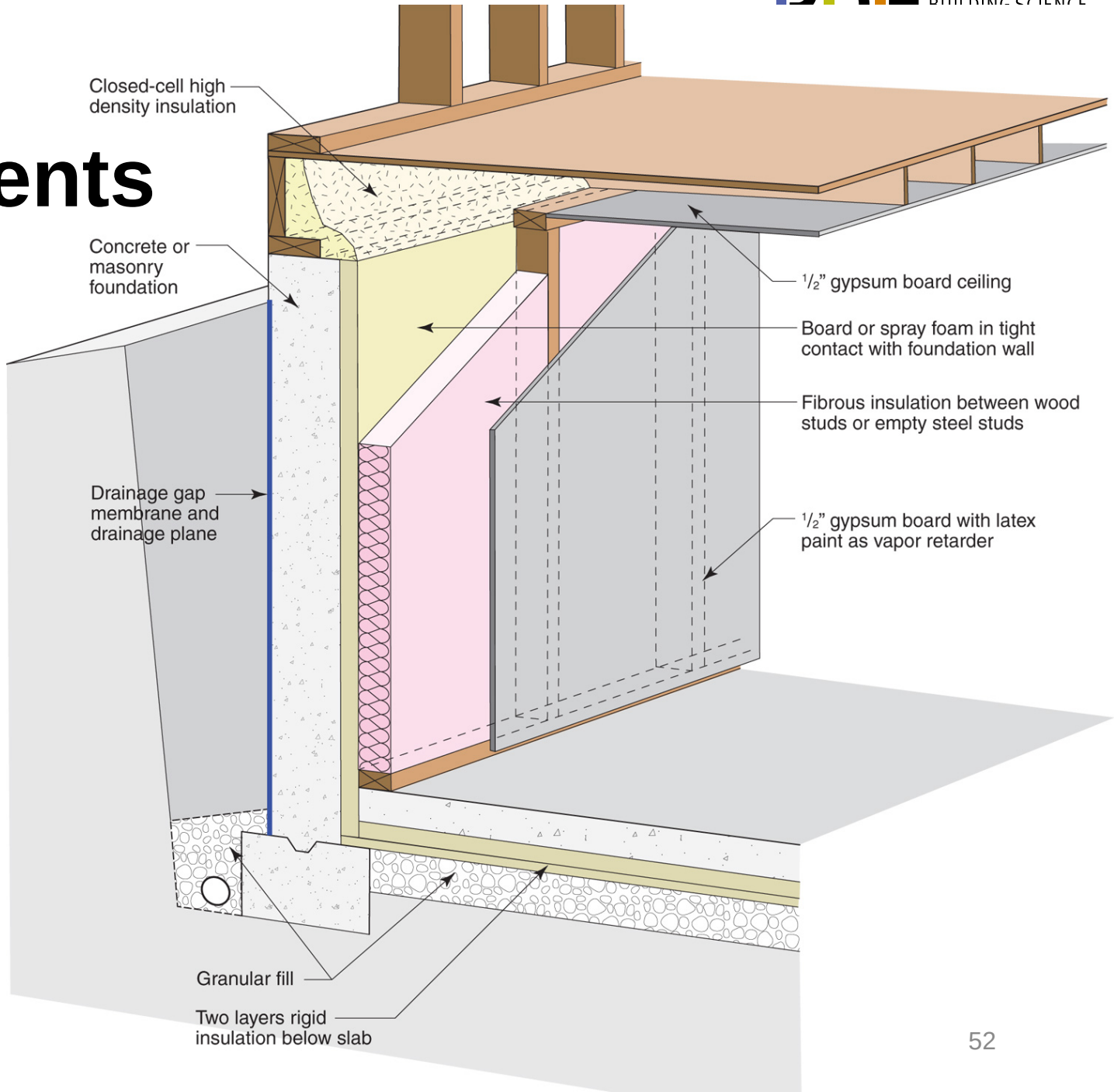

DOW
STYROSPAN


Energy Shield
Atlas Roofing Corporation


Vent chute
Spray foam high-R heel and air seal continuity
Blown-in insulation
Spray foam airtight layer
OSB/plywood sheathing
Gypsum board
Drainage plane and air barrier
2x6 frame wall
Rigid insulation
Cavity fill insulation

Basements

-


Closed-cell high density insulation
Concrete or masonry foundation
½" gypsum board ceiling
Board or spray foam in tight contact with foundation wall
Fibrous insulation between wood studs or empty steel studs
Drainage gap membrane and drainage plane
½" gypsum board with latex paint as vapor retarder
Granular fill
Two layers rigid insulation below slab

Conclusions

- Many new changes and demands
- Building Science Knowledge can help…
- *Education* needed of
  - Trades, professions, codes, etc.
- Building Science Research can
  - Answer new questions