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Building Science

There's No Such Thing As A Free Thermodynamic Lunch

www.buildingscience.com

Some Physics….

Arrhenius Equation

For Every 10 Degree K Rise
Reaction Rate Doubles

$$k = Ae^{-E_a/(RT)}$$

Damage Functions

Water

Heat

Ultra-violet Radiation

Damage Functions

Water

Heat

Ultra Violet Radiation

Oxidization (Ozone)

Fatigue (Creep)

The Three Biggest Problems In Buildings Are Water, Water and Water…

Laws of Thermodynamics

Zeroth Law – Equal Systems

First Law - Conservation of Energy

Second Law - Entropy

Third Law – Absolute Zero

2nd Law of Thermodynamics

In an isolated system, a process can occur only if it increases the total entropy of the system

Rudolf Clausius

Heat Flow Is From Warm To Cold

Moisture Flow Is From Warm To Cold

Moisture Flow Is From More To Less

Air Flow Is From A Higher Pressure to a Lower Pressure

Gravity Acts Down

Moisture Flow Is From Warm To Cold

Moisture Flow Is From More To Less

Moisture Flow Is From Warm To Cold

Moisture Flow Is From More To Less

Thermal Gradient – Thermal Diffusion

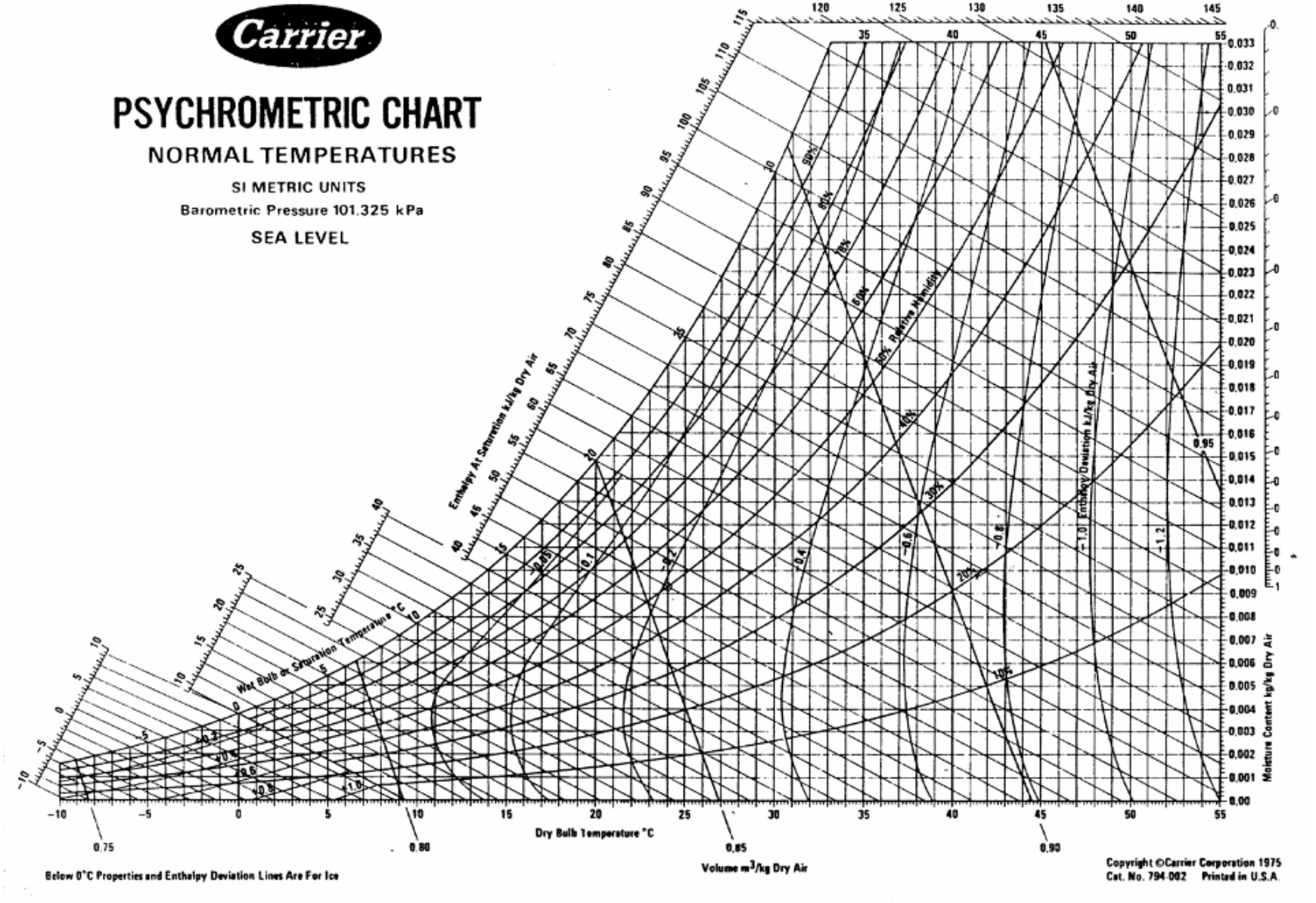
Concentration Gradient – Molecular Diffusion

Moisture Flow Is From Warm To Cold
Moisture Flow Is From More To Less

Thermal Gradient – Thermal Diffusion
Concentration Gradient – Molecular Diffusion

Vapor Diffusion

Thermodynamic Potential


Carrier
PSYCHROMETRIC CHART
NORMAL TEMPERATURES
SI METRIC UNITS
Barometric Pressure 101.325 kPa
SEA LEVEL
Enthalpy At Saturation kJ/kg Dry Air
Wet Bulb or Saturation Temperature °C
Dry Bulb Temperature °C
Moisture Content kg/kg Dry Air
50% Relative Humidity
Below 0°C Properties and Enthalpy Deviation Lines Are For Ice
Volume m³/kg Dry Air
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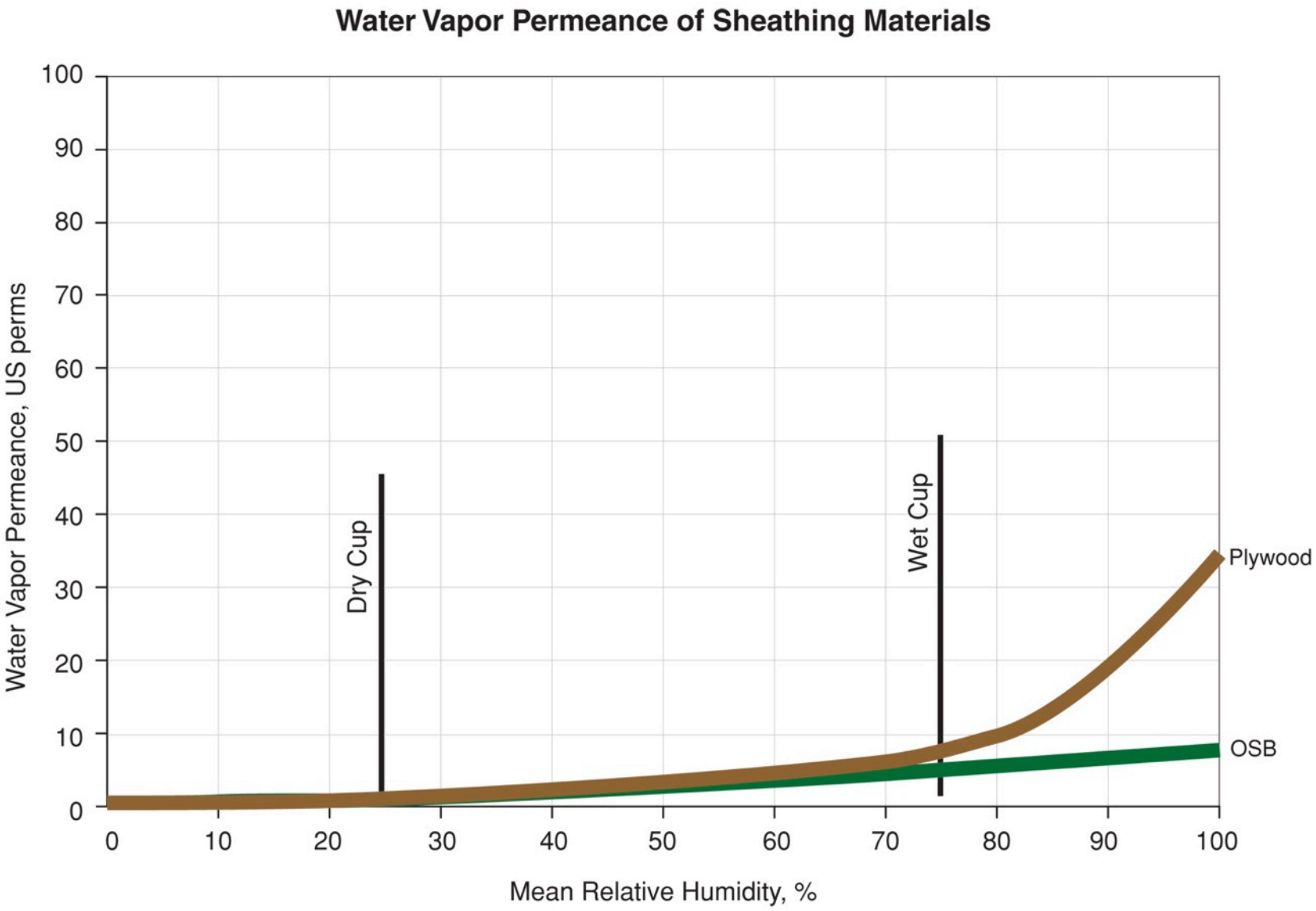
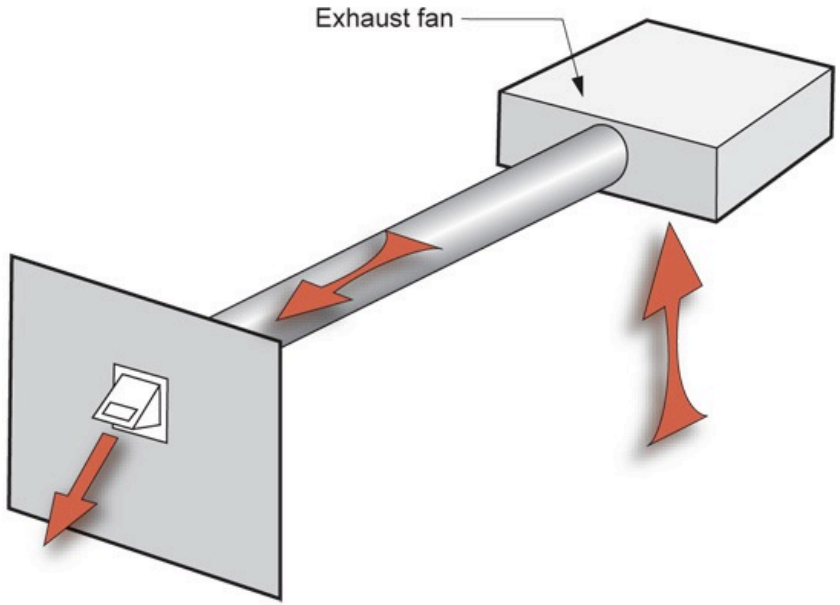
Energy Flow

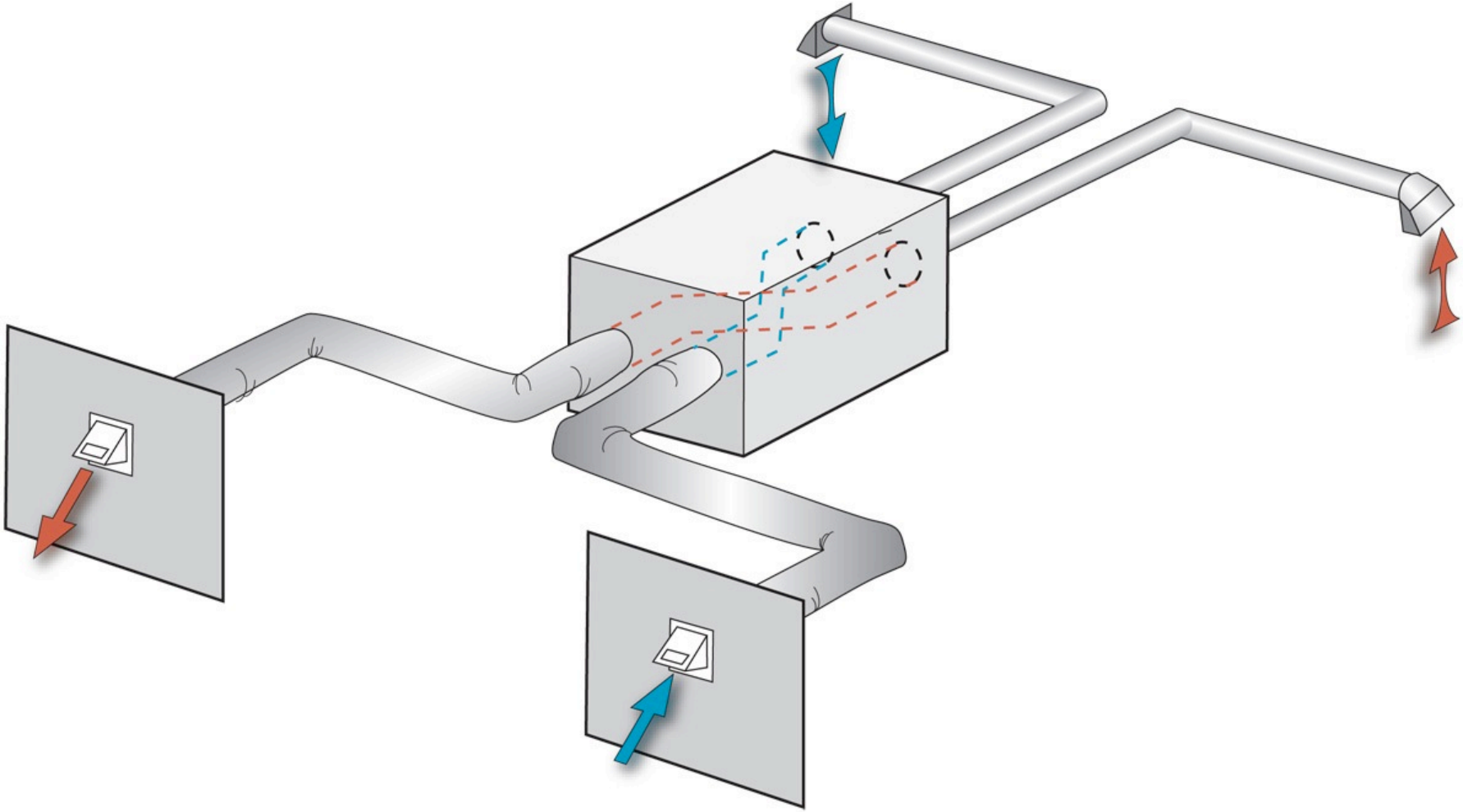
Materials


Water Vapor Permeance of Sheathing Materials
Water Vapor Permeance, US perms
100
90
80
70
60
50
40
30
20
10
0
Dry Cup
Wet Cup
Plywood
OSB
0
10
20
30
40
50
60
70
80
90
100
Mean Relative Humidity, %

Airtightness

Typical	5 ach@50
Getting rid of big holes	3 ach@50
Getting rid of smaller holes	1.5 ach@50
Getting Passive	1.0 ach@50


Exhaust fan

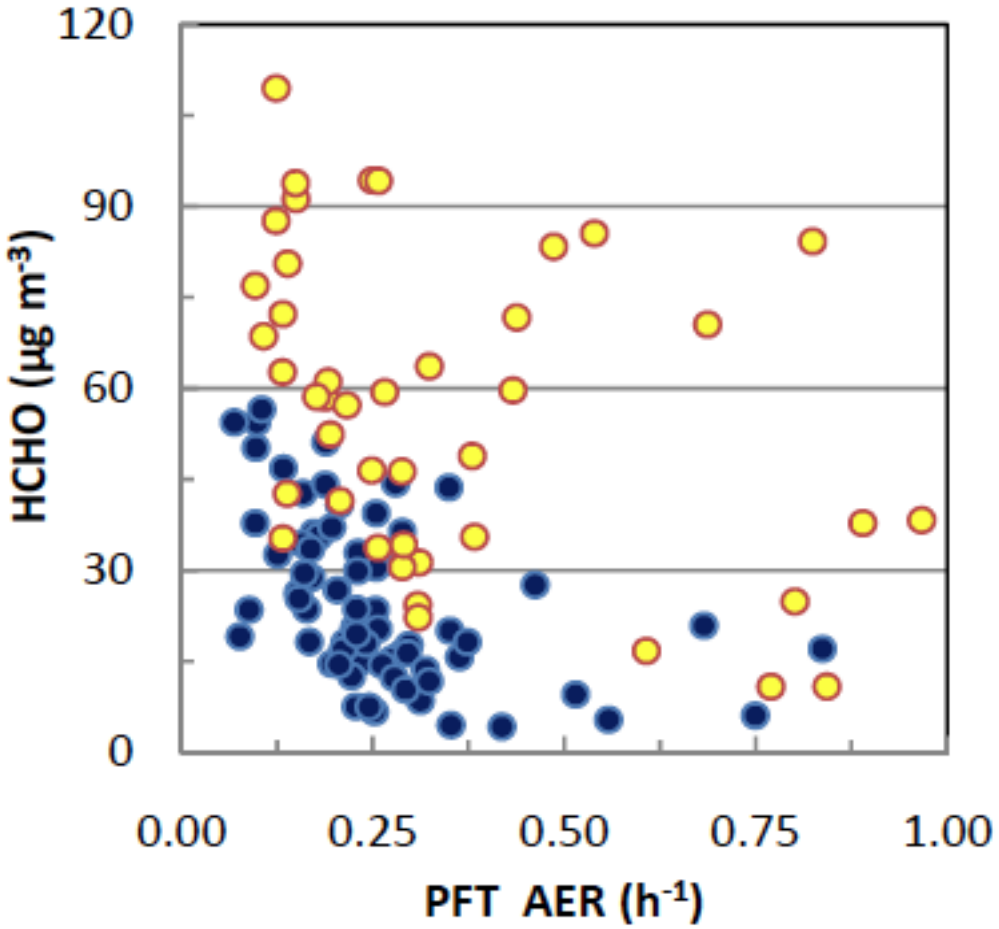


Ventilation Rates

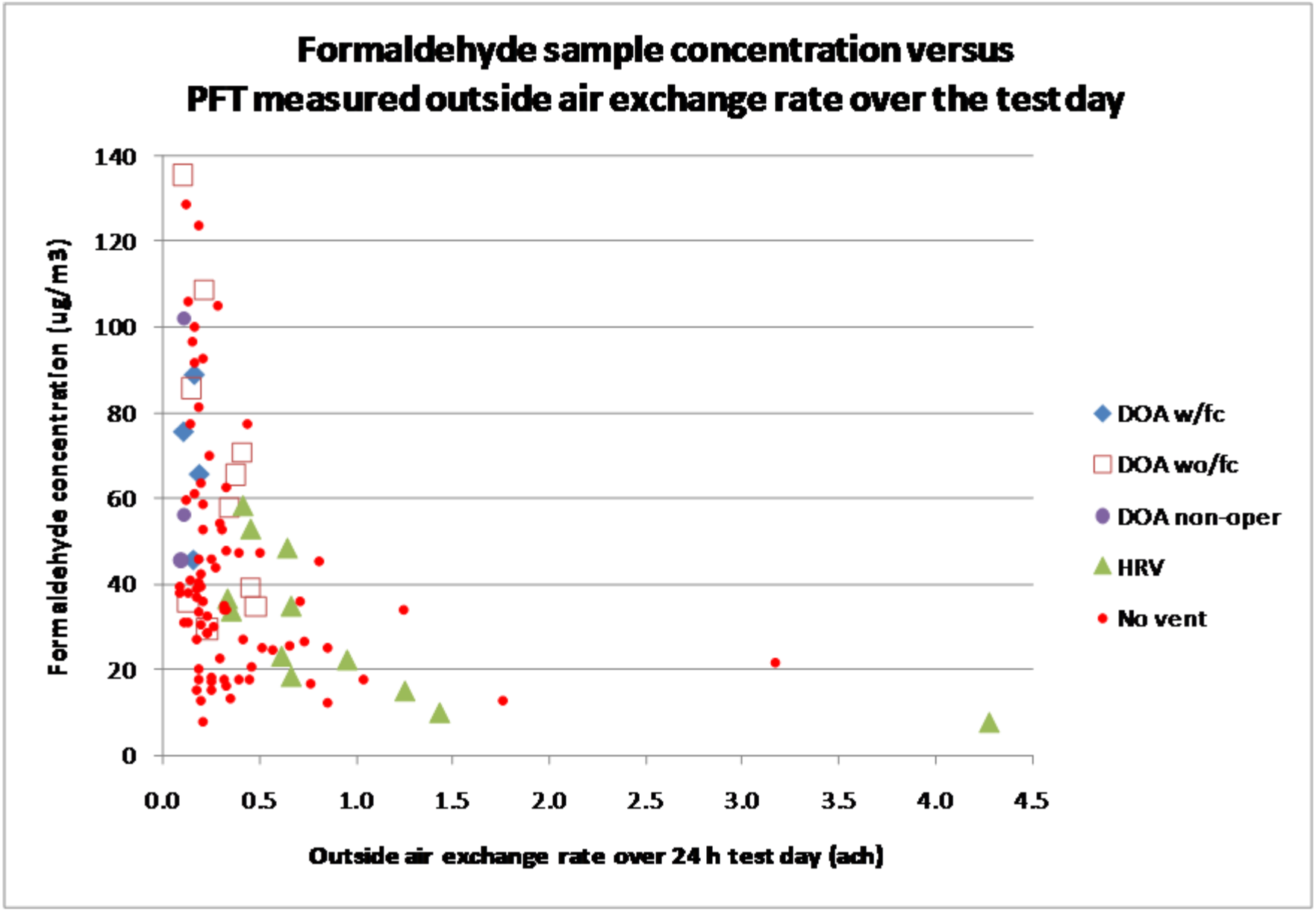
- Dilution Is Not The Solution To Indoor Pollution
- Source Control

Dilution For People

Source Control For The Building

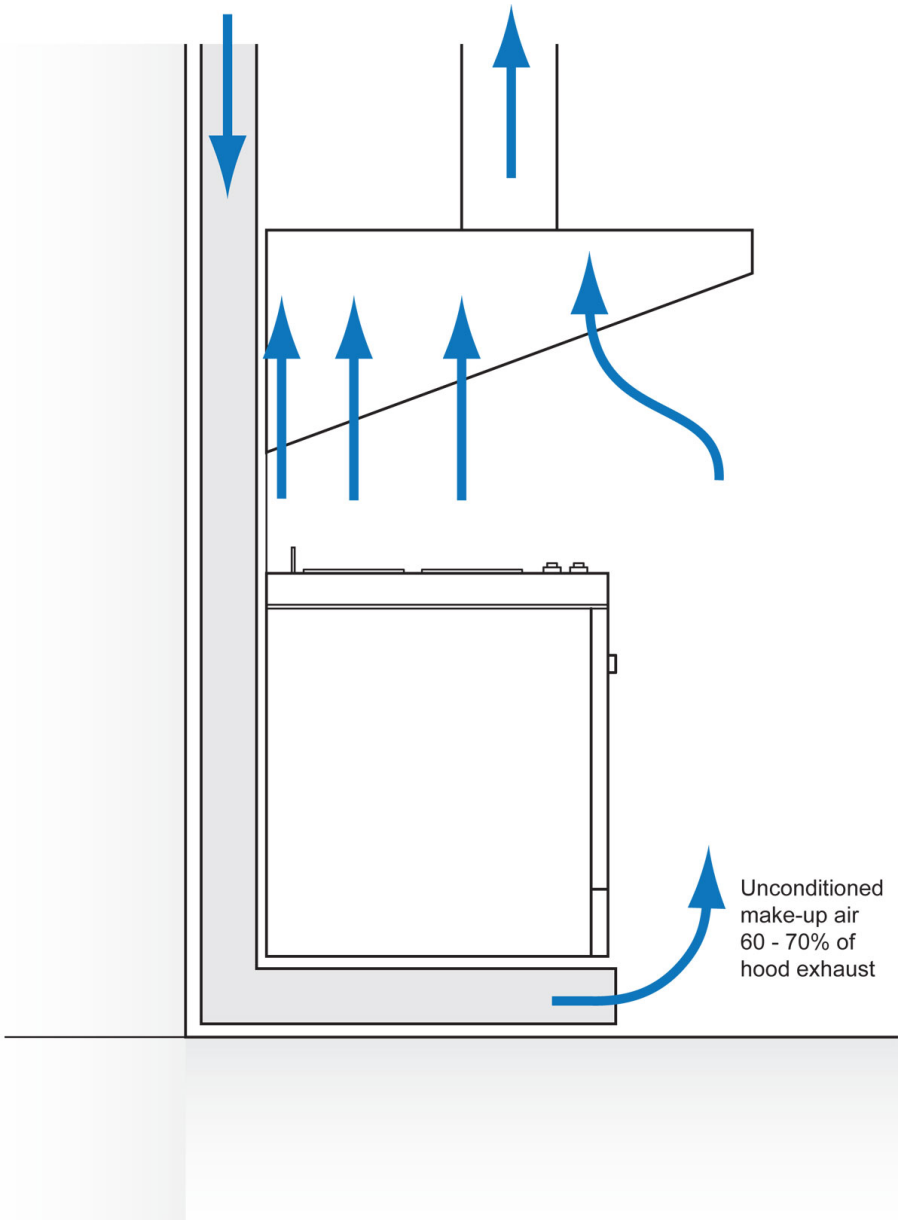


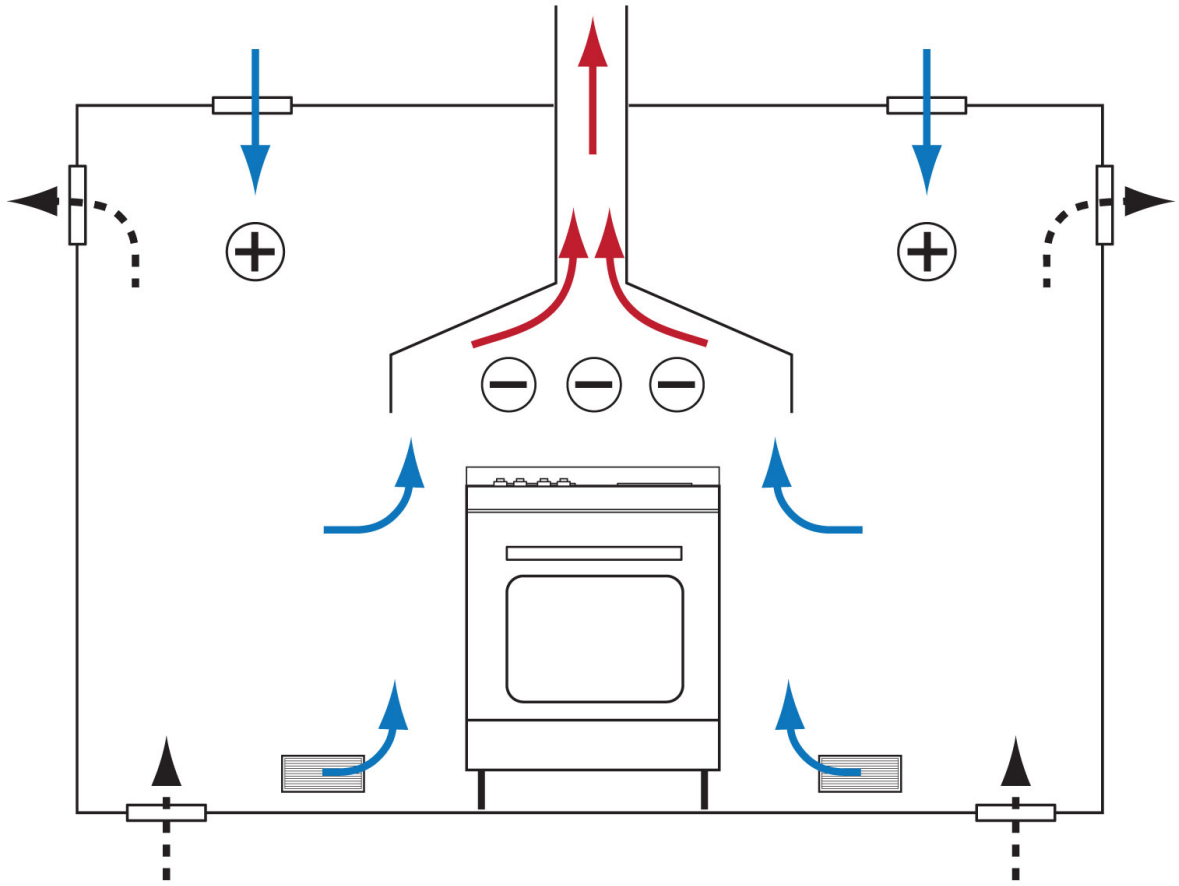
Aubin, D., Won, D.Y., Schleibinger, H., 2010

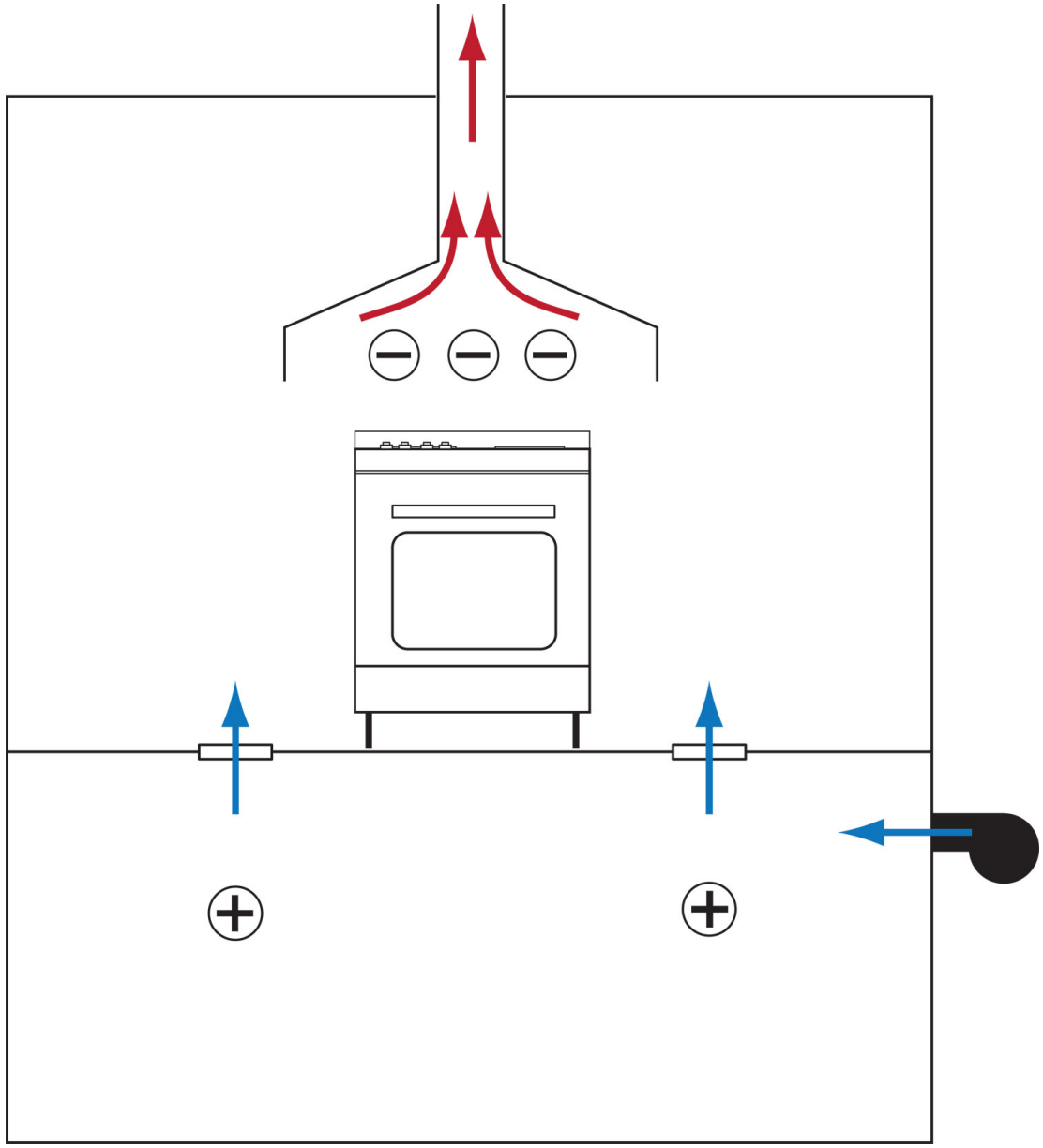

Formaldehyde sample concentration versus
PFT measured outside air exchange rate over the test day
Formaldehyde concentration (ug/m3)
140
120
100
80
60
40
20
0
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Outside air exchange rate over 24 h test day (ach)
DOA w/fc
DOA wo/fc
DOA non-oper
HRV
No vent

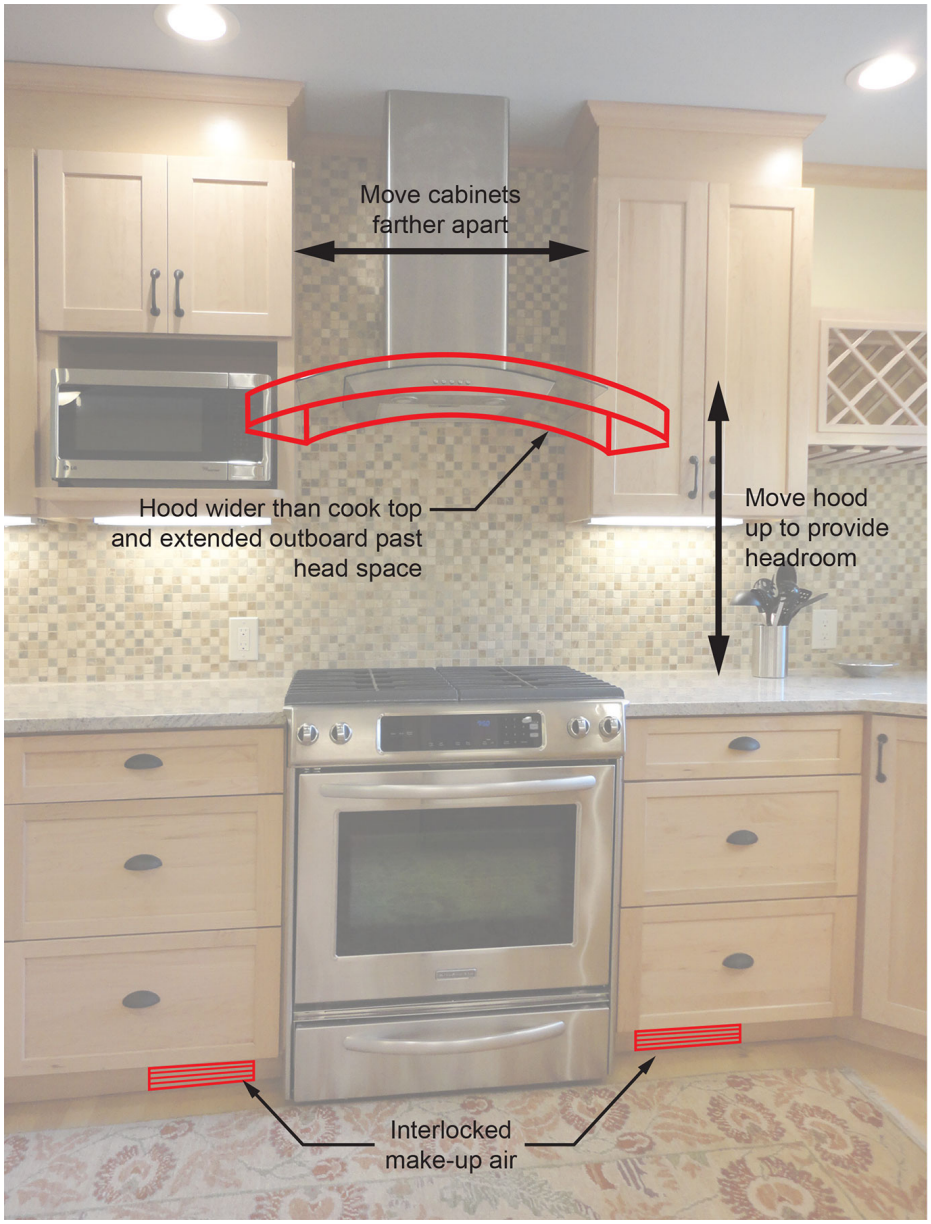
Pressures

Kitchen Exhaust Hoods


Unconditioned
make-up air
60 - 70% of
hood exhaust






Move cabinets
farther apart
Hood wider than cook top
and extended outboard past
head space
Move hood
up to provide
headroom
Interlocked
make-up air

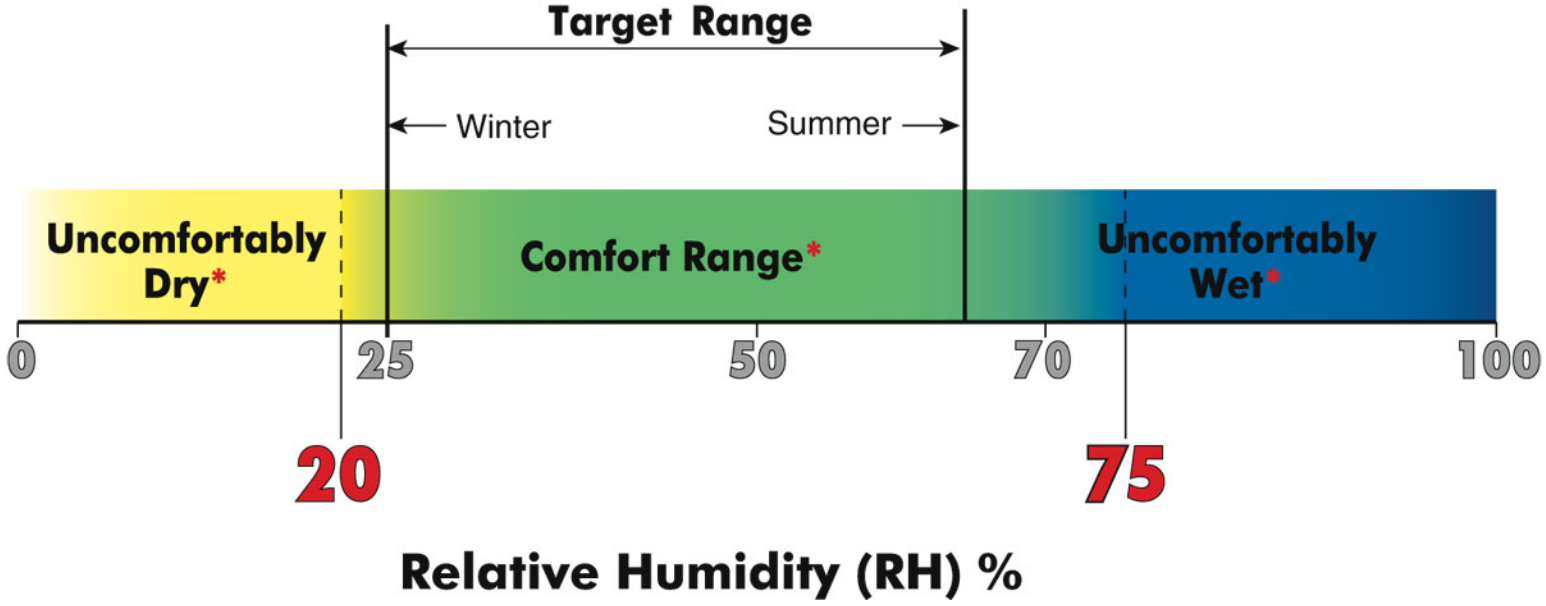
Clothes Dryers


ENERGYGUIDE


ASKO
ASKO
ENERGUIDE
209

Fireplaces

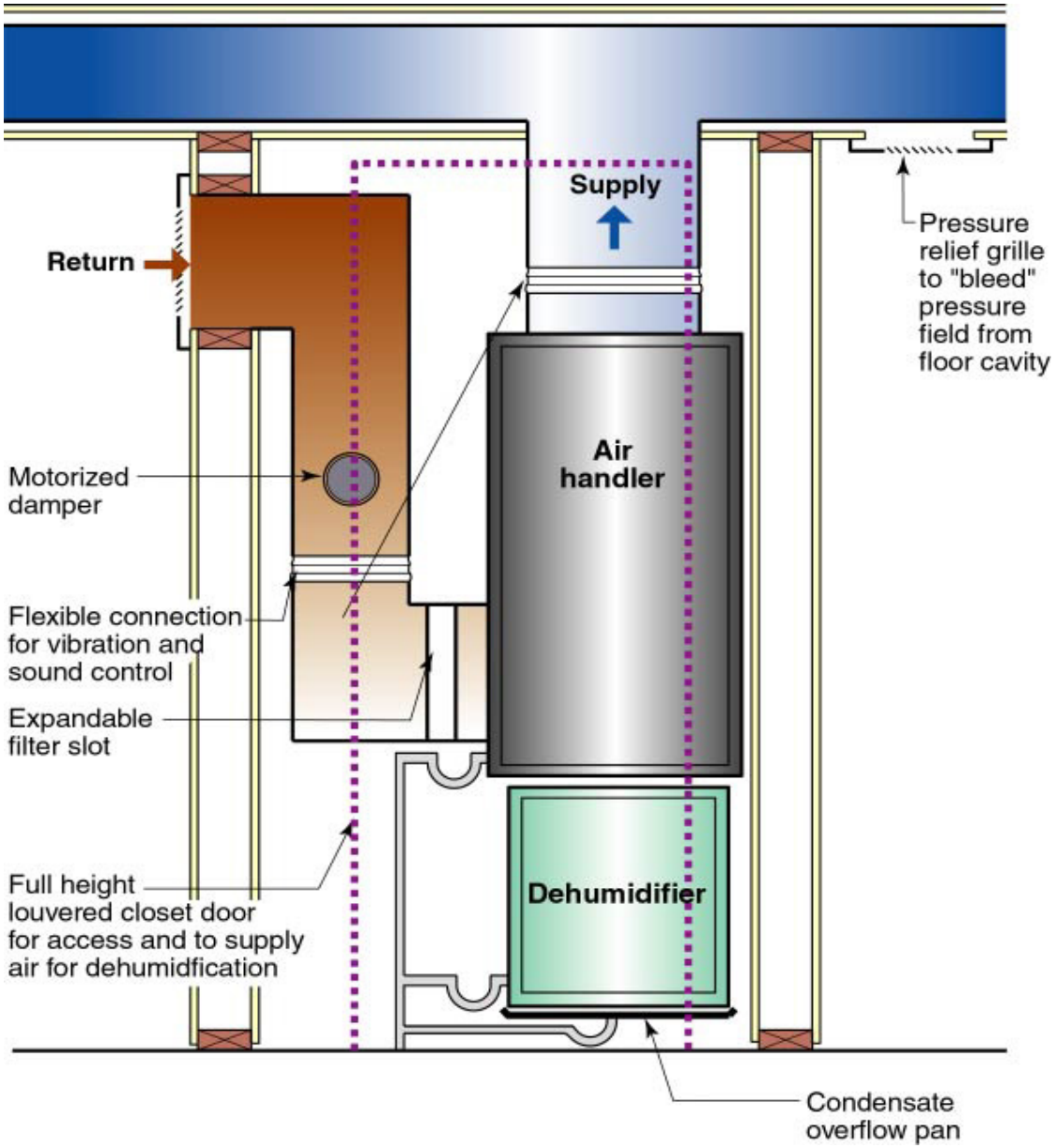
Relative Humidty


Target Range
Winter
Summer
Uncomfortably Dry*
Comfort Range*
Uncomfortably Wet*
0
25
50
70
100
20
75
Relative Humidity (RH) %

Recommended Range of Relative Humidity

Above 40 percent during winter

Below 60 percent during summer


Supply
Return
Pressure relief grille to "bleed" pressure field from floor cavity
Air handler
Motorized damper
Flexible connection for vibration and sound control
Expandable filter slot
Full height louvered closet door for access and to supply air for dehumidfication
Dehumidifier
Condensate overflow pan

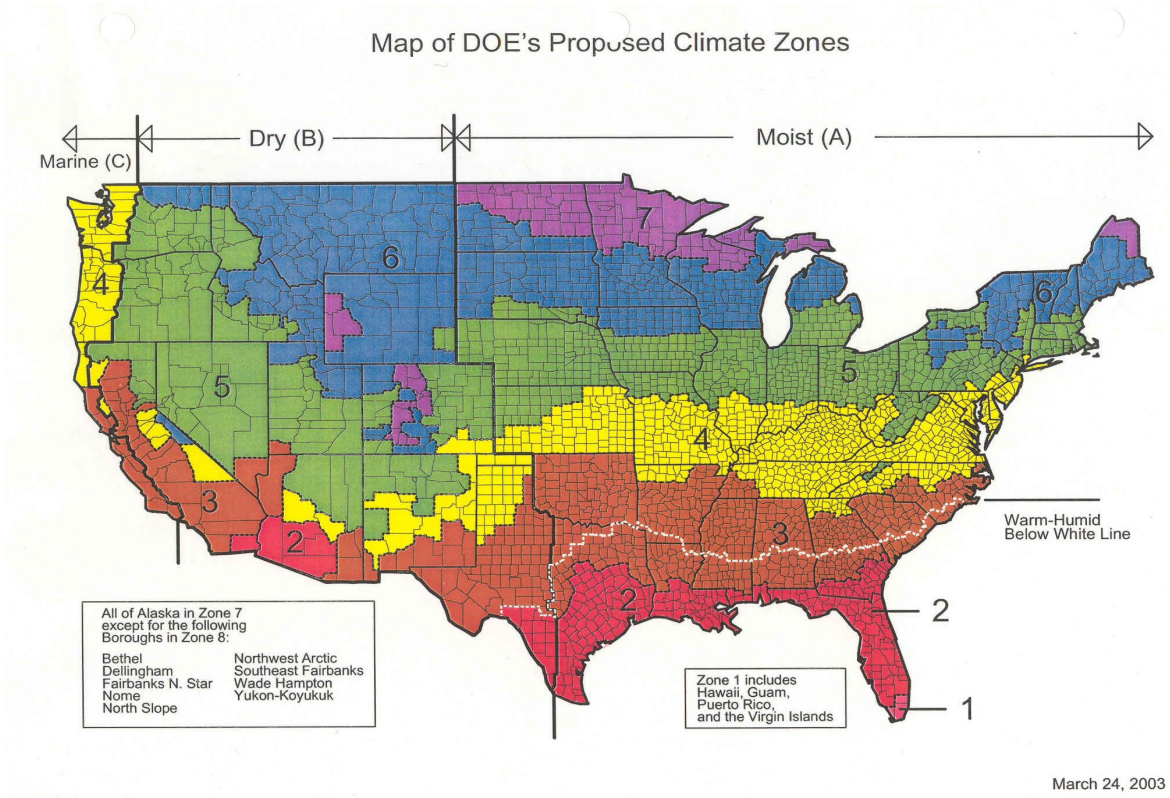

WARNING
TRANE
MAXIMUM
Hoodx
25

Net Zero Buildings…..

Net Zero Buildings…..

75 percent conservation

25 percent renewables


Map of DOE's Proposed Climate Zones
Marine (C)
Dry (B)
Moist (A)
Warm-Humid
Below White Line
All of Alaska in Zone 7
except for the following
Boroughs in Zone 8:
Bethel
Dellingham
Fairbanks N. Star
Nome
North Slope
Northwest Arctic
Southeast Fairbanks
Wade Hampton
Yukon-Koyukuk
Zone 1 includes
Hawaii, Guam,
Puerto Rico,
and the Virgin Islands
March 24, 2003

Conservation

5 – 10 – 20 – 40 – 60 – 1.5

Windows, Slab, Crawl/Basement, Wall, Roof

1.5 ach@50 with ERV

Renewables – IECC 2 and 3

2,500 ft2 home - 7.5 kw PV

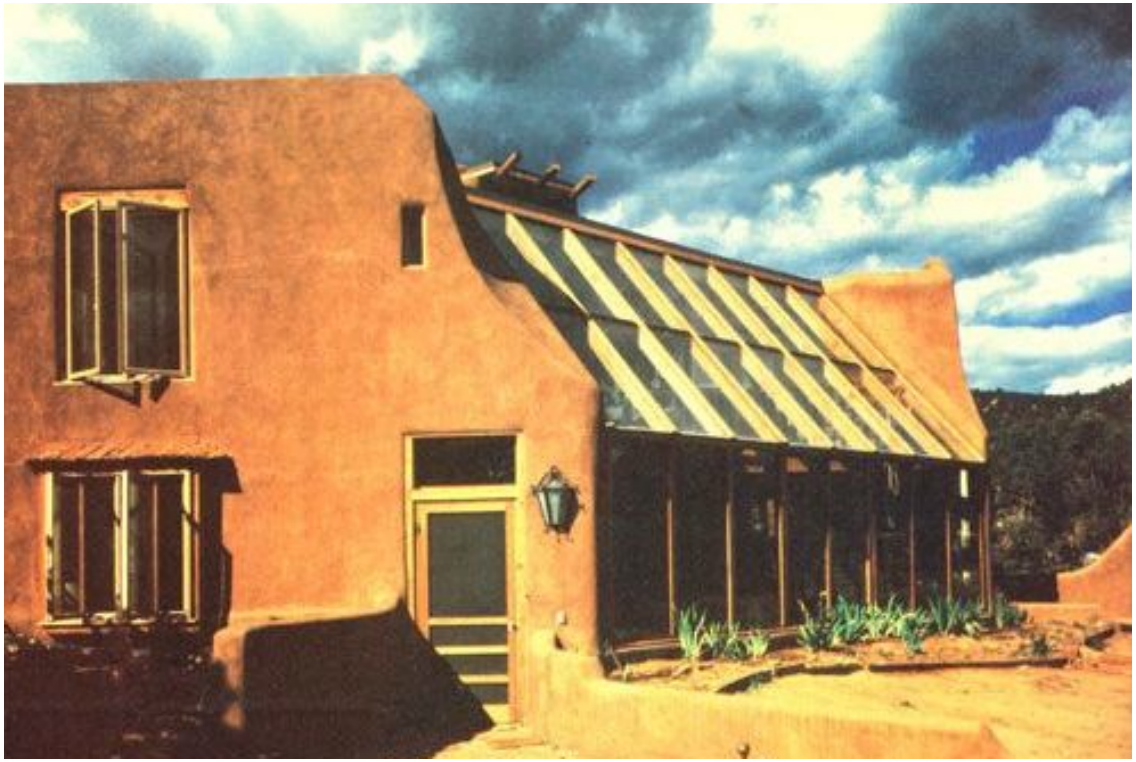
Conservation – IECC 2 and 3

5 – 10 – 20 – 40 – 60 – 1.5

Windows, Slab, Crawl/Basement, Wall, Roof

1.5 ach@50 with ERV

….Distributed Thermal Mass….



Light and Tight…..

beat

Mass and Glass….

But….

the time constant now matters

Conservation – IECC 2 and 3

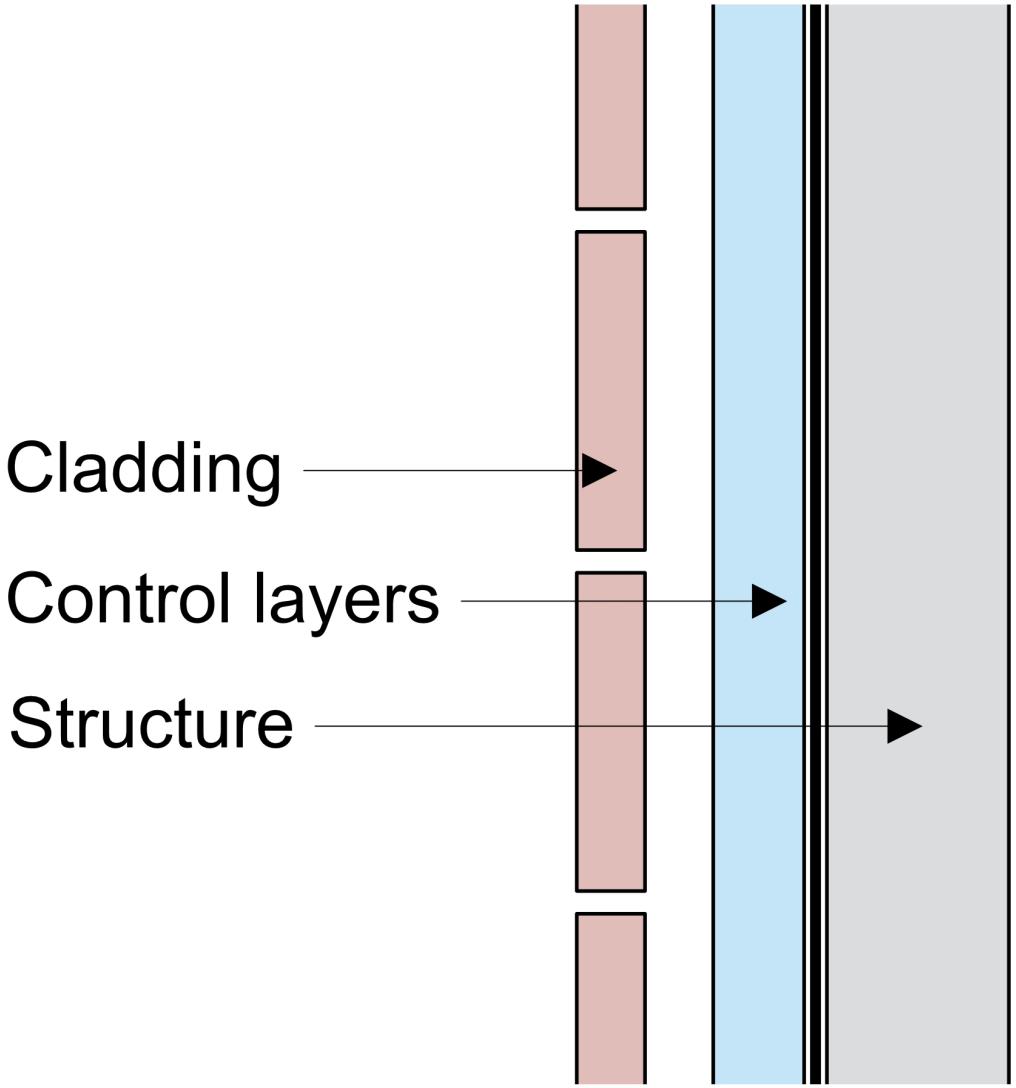
5 – 10 – 20 – 40 – 60 – 1.5

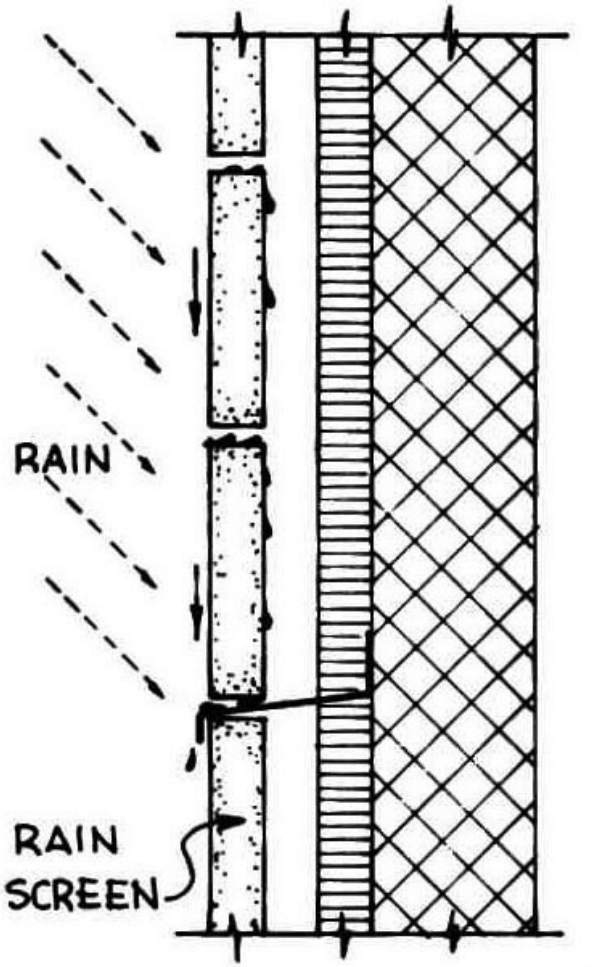
Windows, Slab, Crawl/Basement, Wall, Roof

1.5 ach@50 with ERV

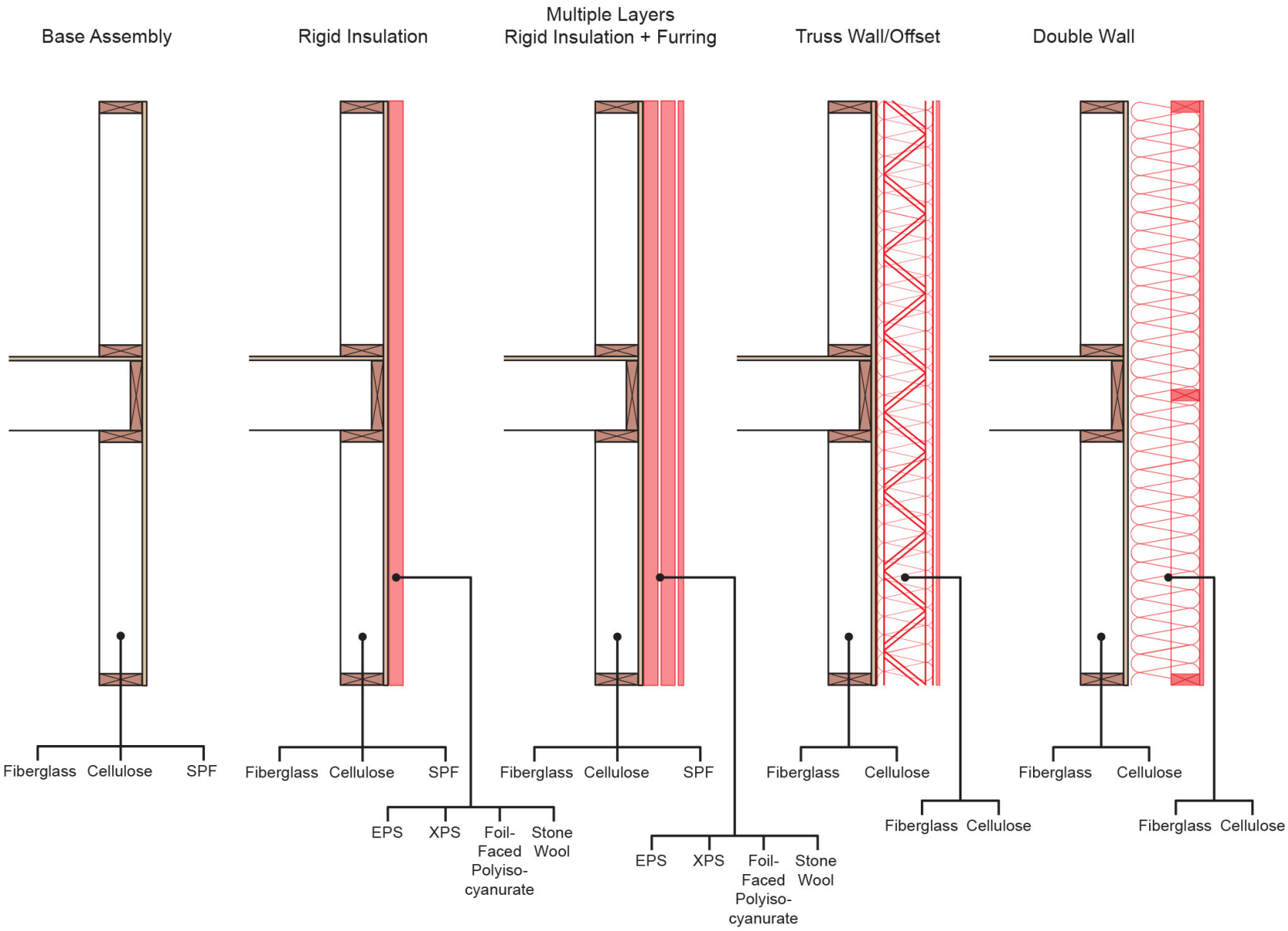
….Distributed Thermal Mass….

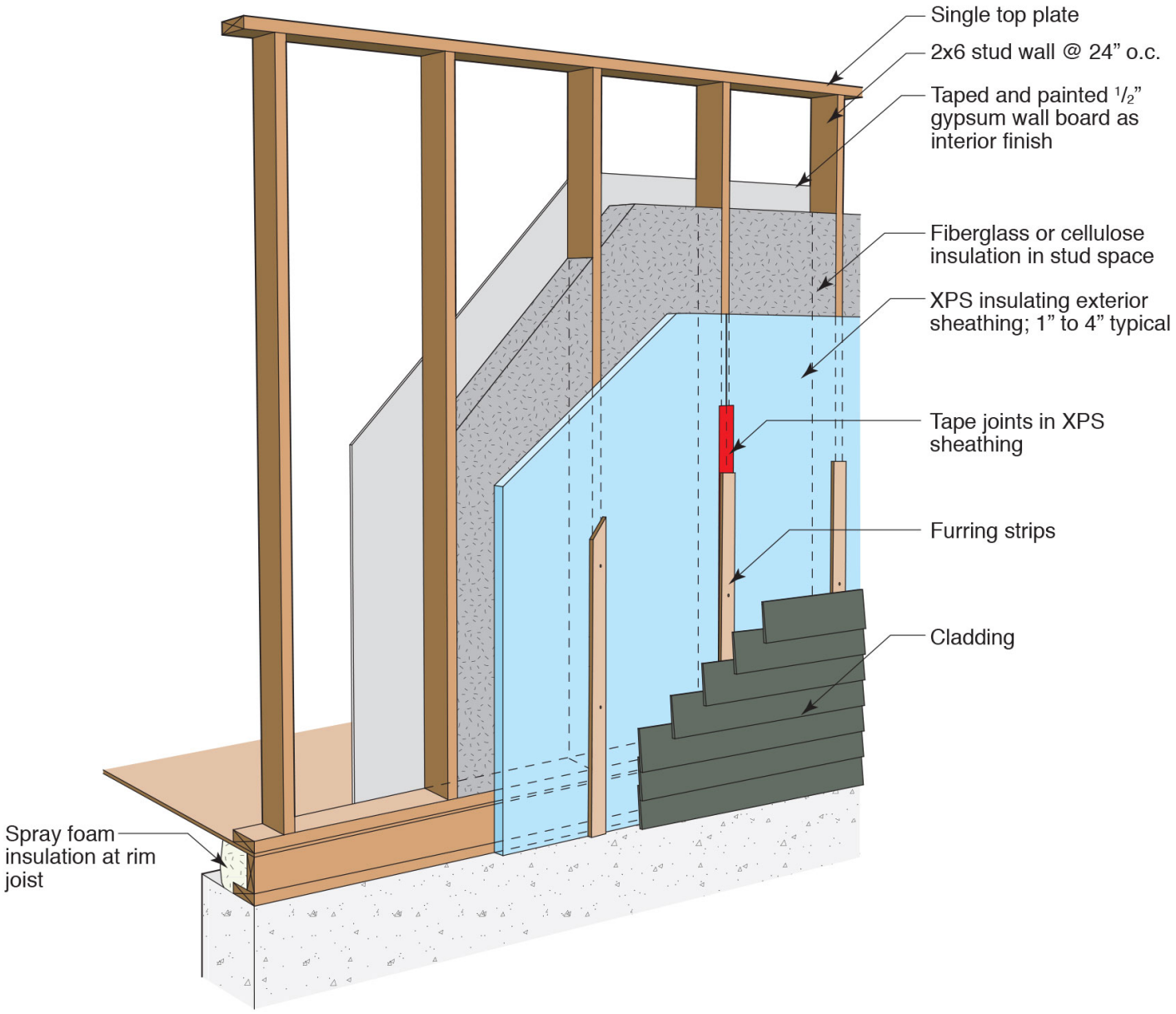
….Plus a Ford F-150 electric….

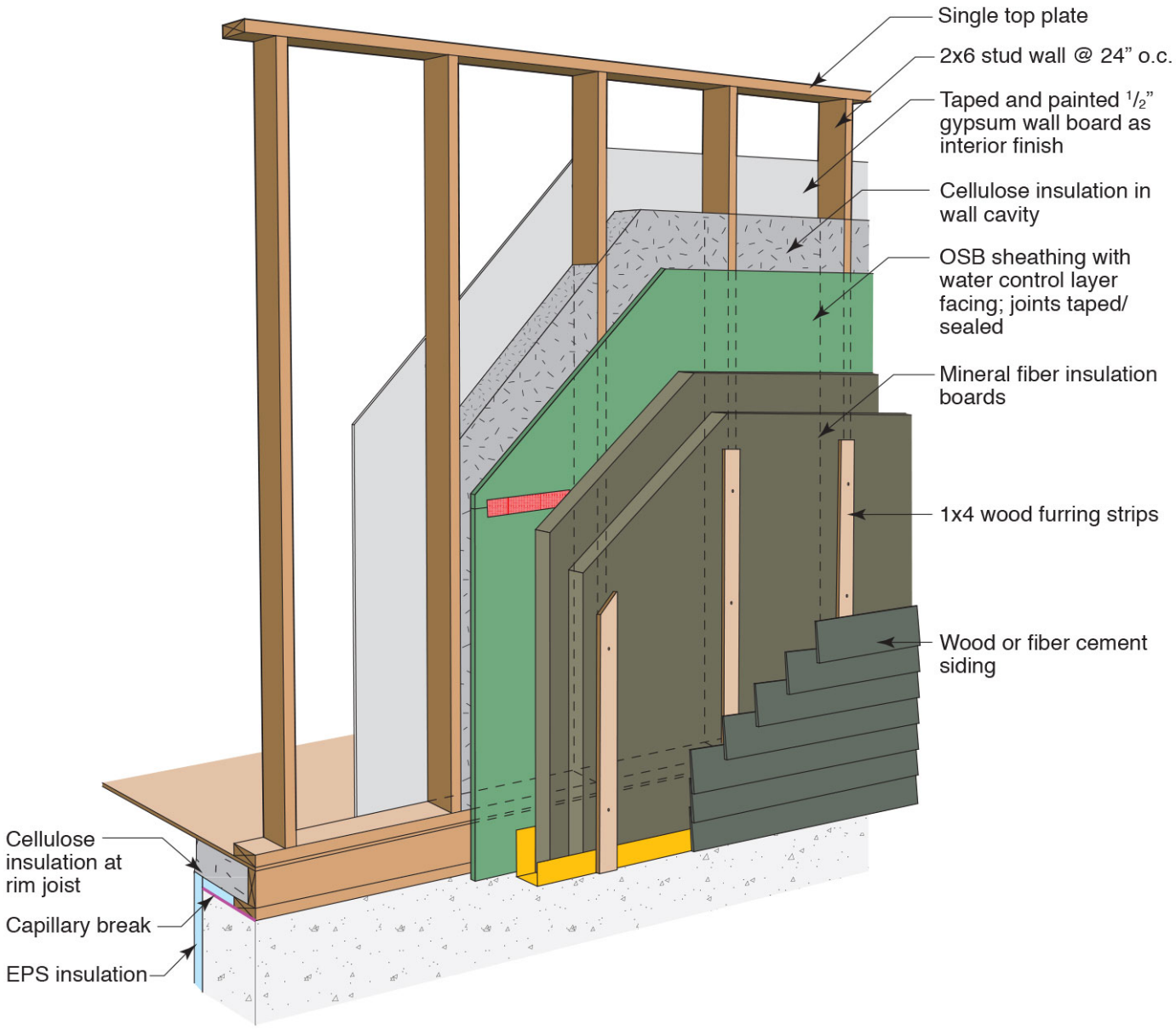

Cladding
Control layers
Structure

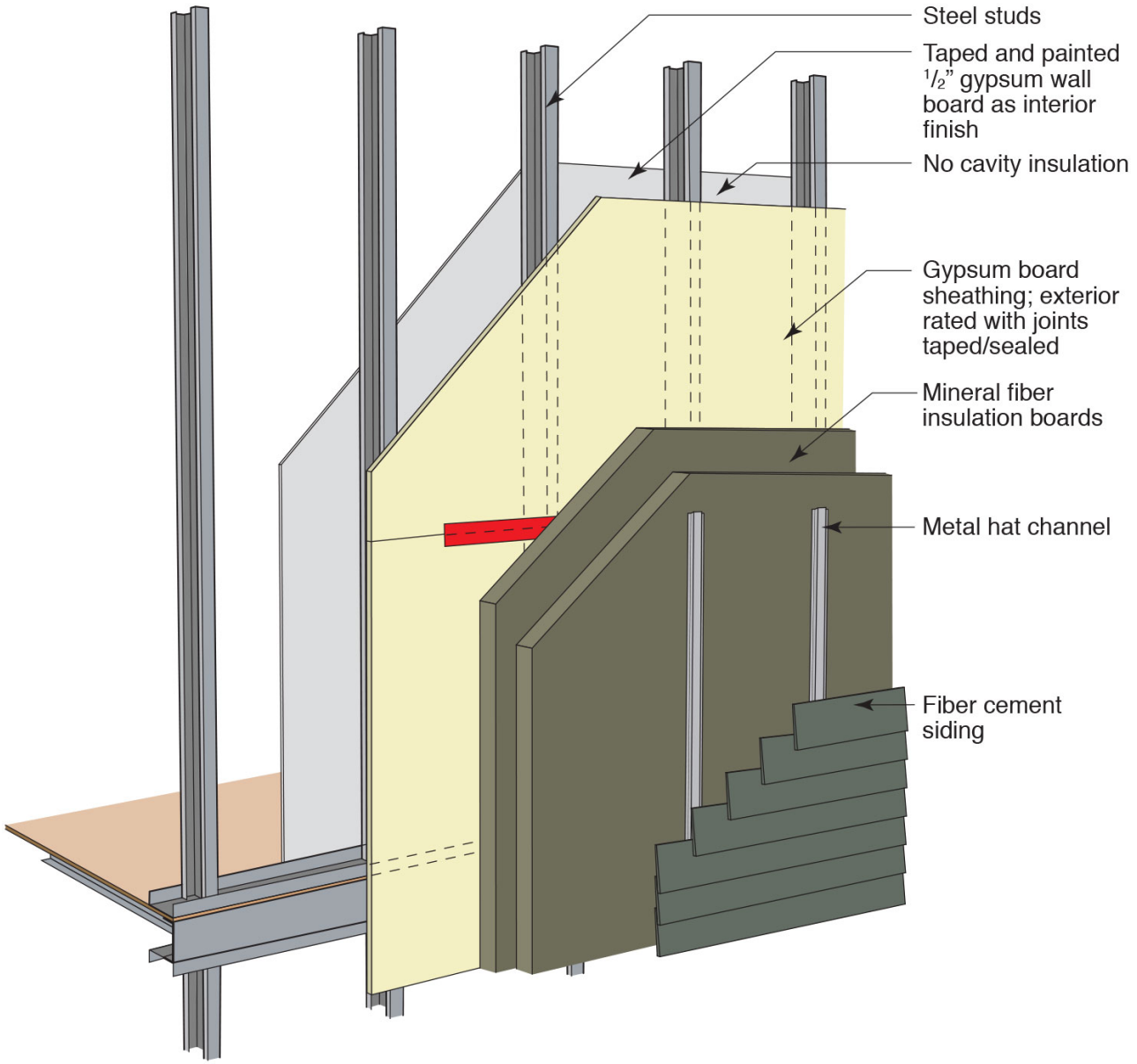


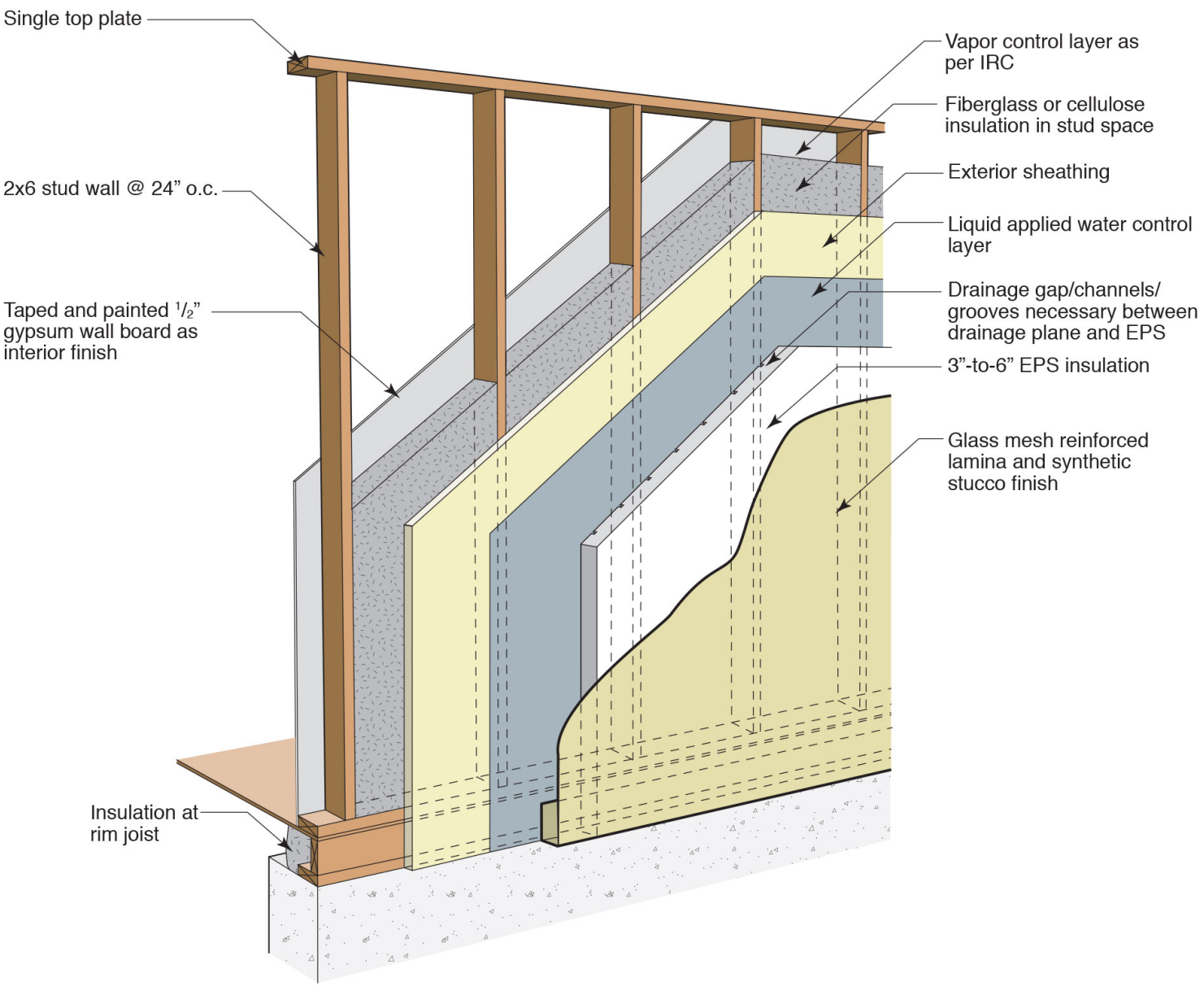
WATER THAT PENETRATES
IS DIVERTED OUTWARD
BY FLASHINGS

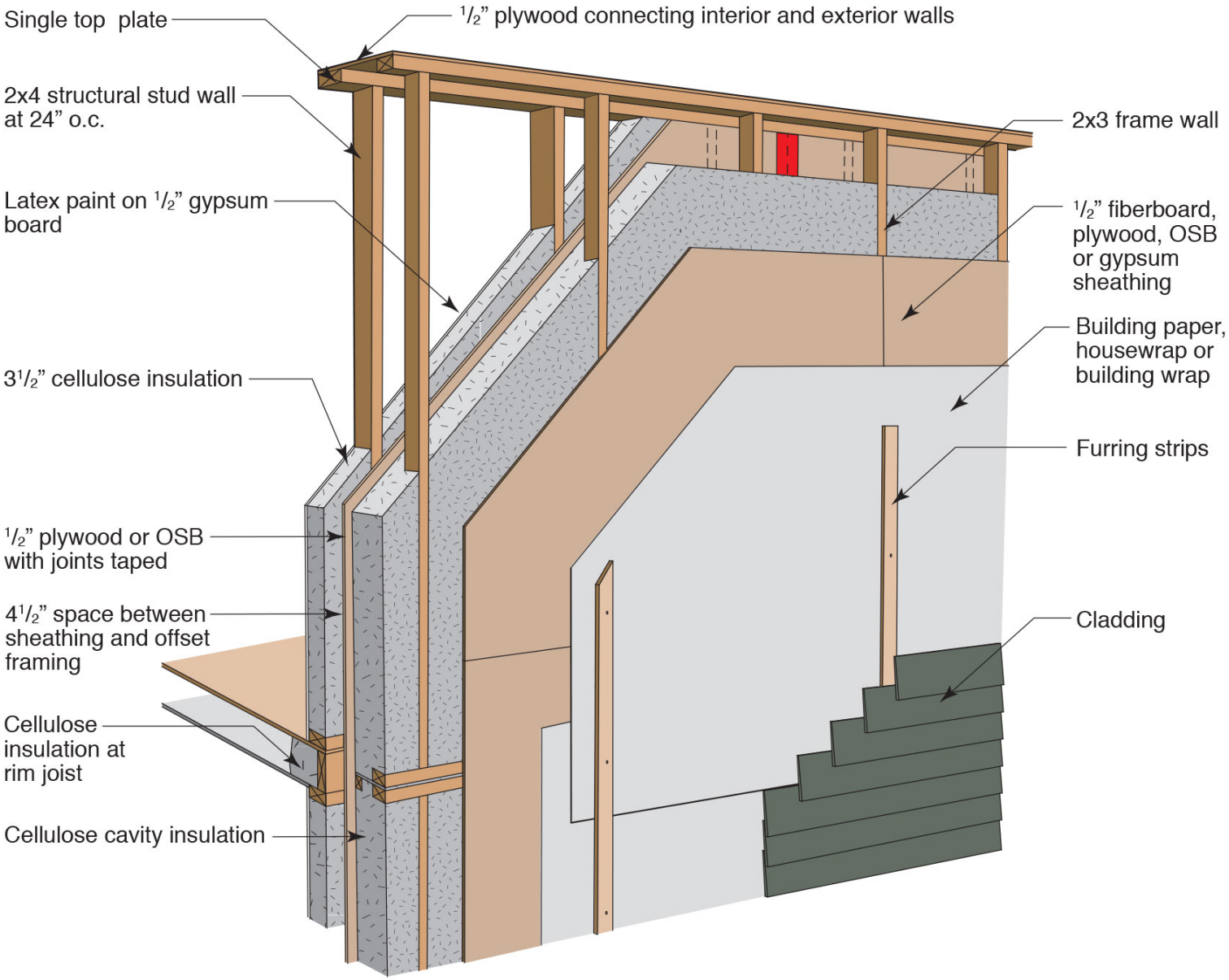

Base Assembly
Rigid Insulation
Multiple Layers
Rigid Insulation + Furring
Truss Wall/Offset
Double Wall
Fiberglass
Cellulose
SPF
EPS
XPS
Foil-Faced Polyiso-cyanurate
Stone Wool

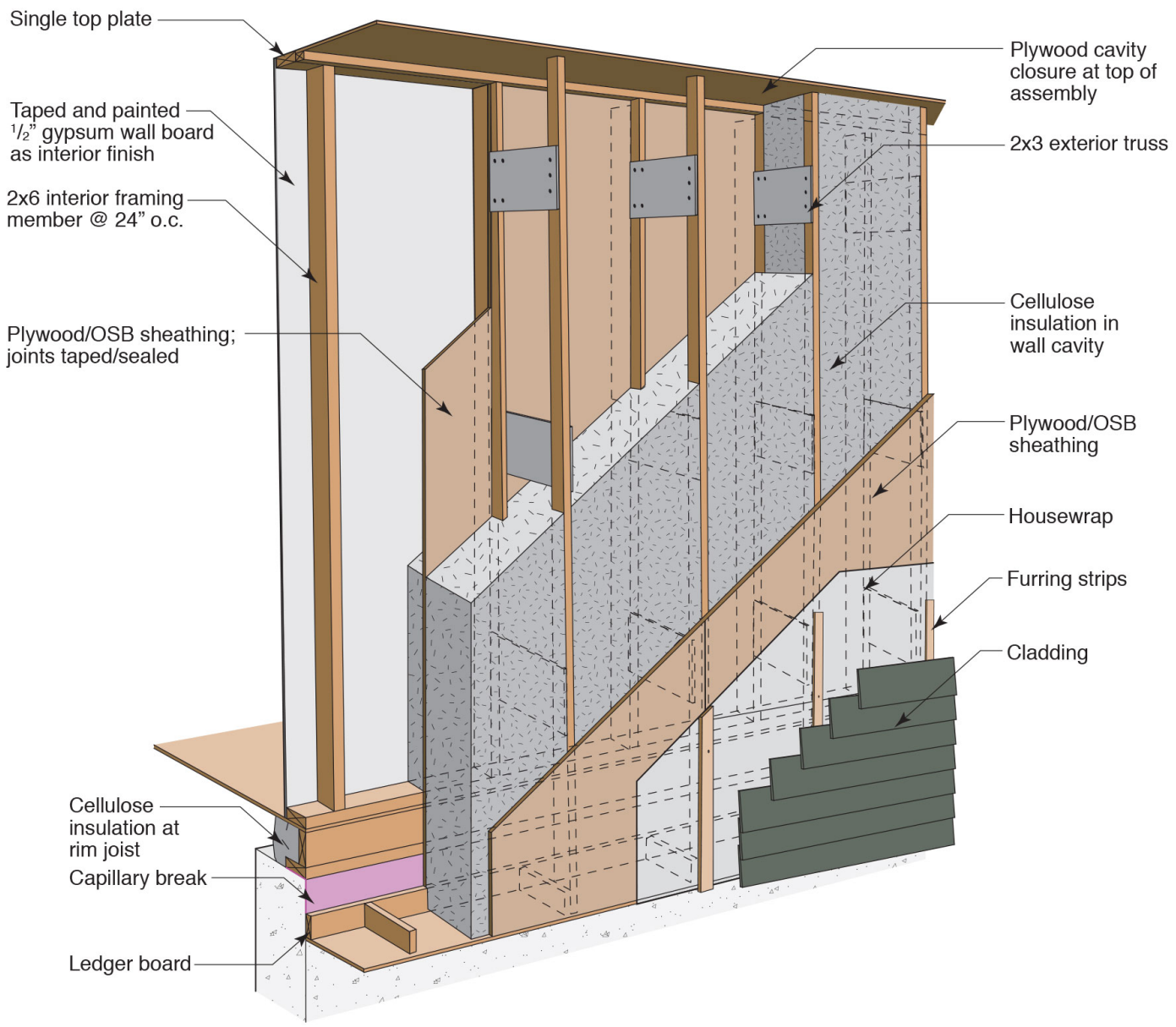

Single top plate
2x6 stud wall @ 24” o.c.
Taped and painted ½” gypsum wall board as interior finish
Fiberglass or cellulose insulation in stud space
XPS insulating exterior sheathing; 1” to 4” typical
Tape joints in XPS sheathing
Furring strips
Cladding
Spray foam insulation at rim joist

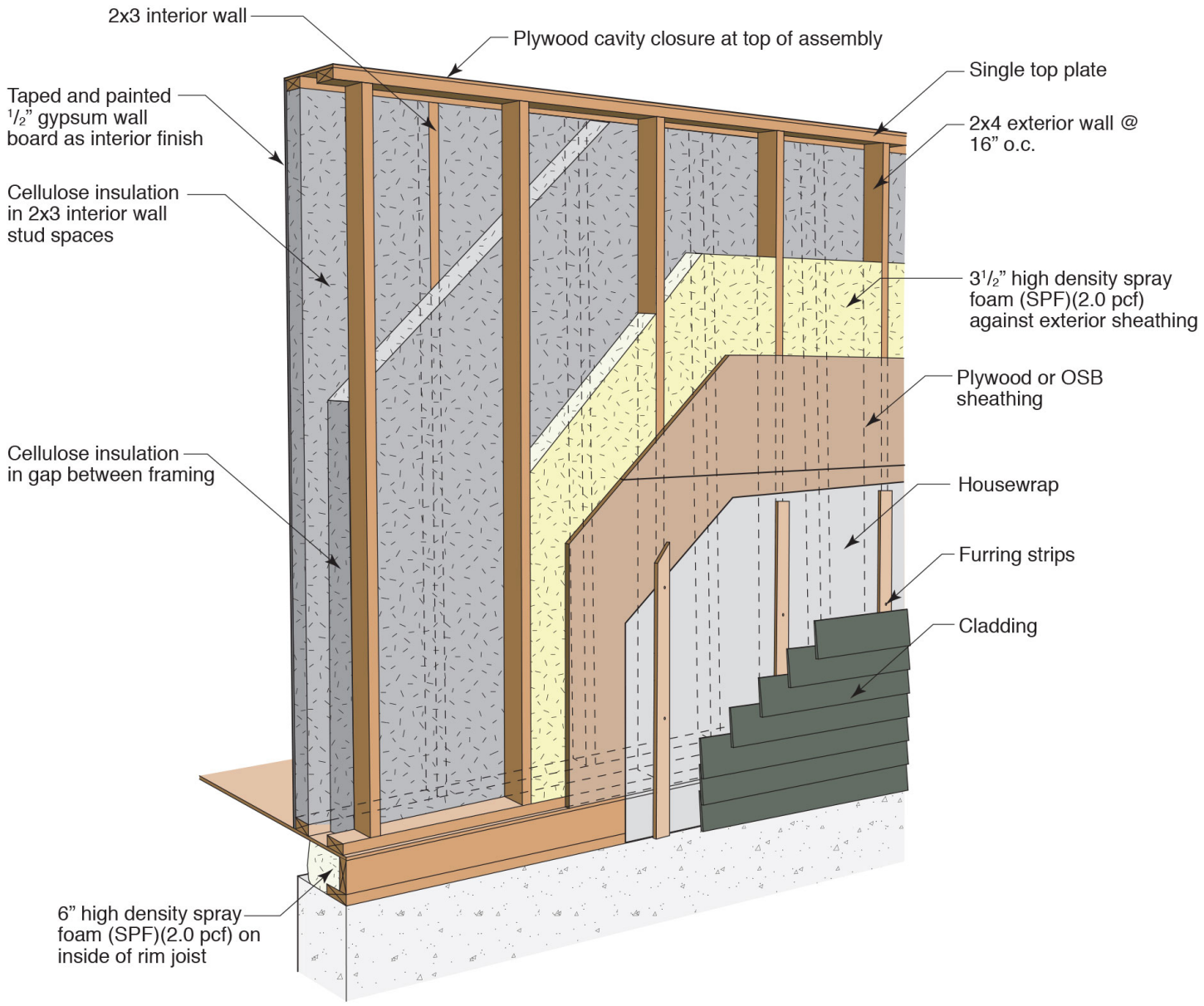

Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted 1/2" gypsum wall board as interior finish
Cellulose insulation in wall cavity
OSB sheathing with water control layer facing; joints taped/ sealed
Mineral fiber insulation boards
1x4 wood furring strips
Wood or fiber cement siding
Cellulose insulation at rim joist
Capillary break
EPS insulation

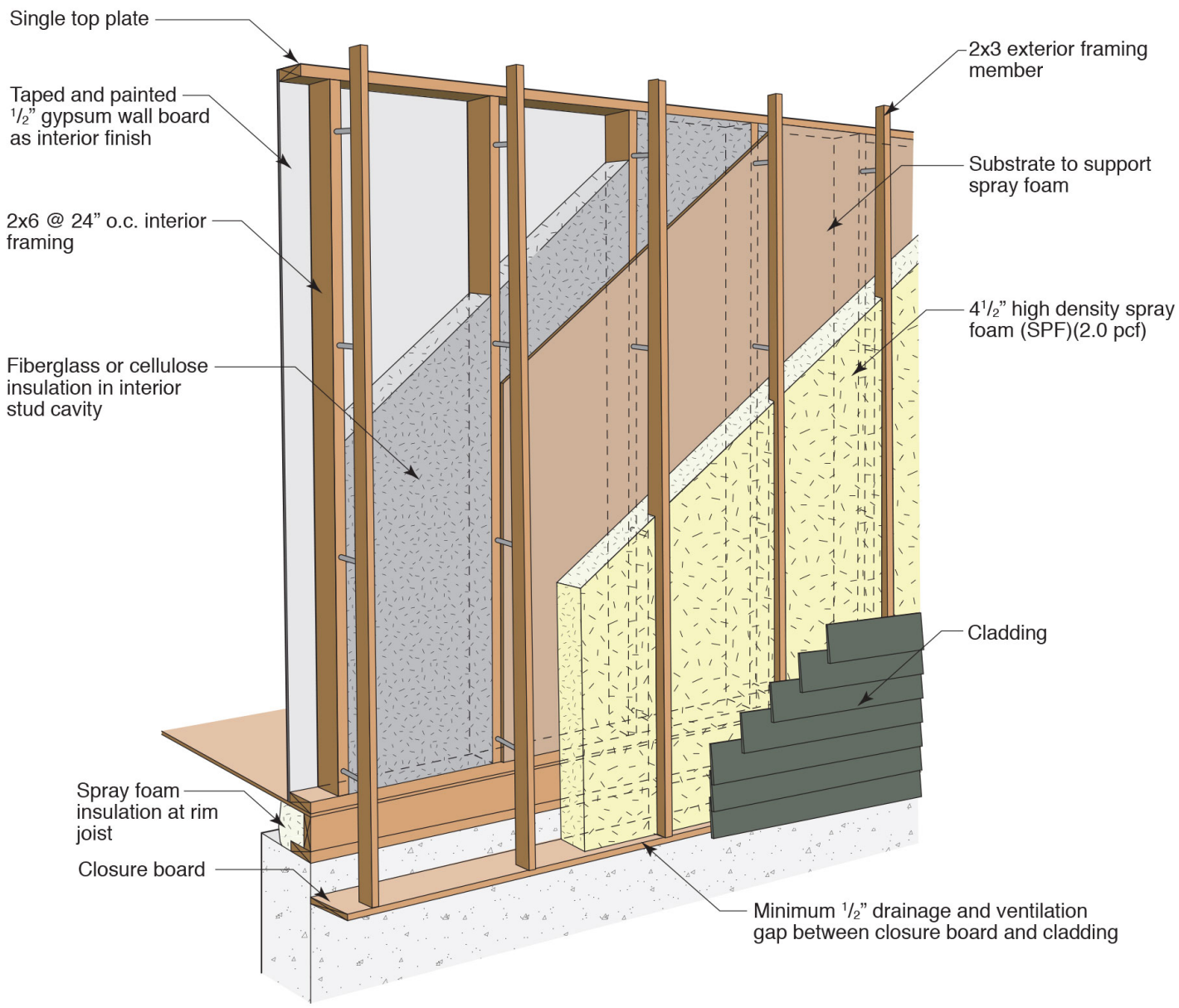

Steel studs
Taped and painted ½" gypsum wall board as interior finish
No cavity insulation
Gypsum board sheathing; exterior rated with joints taped/sealed
Mineral fiber insulation boards
Metal hat channel
Fiber cement siding

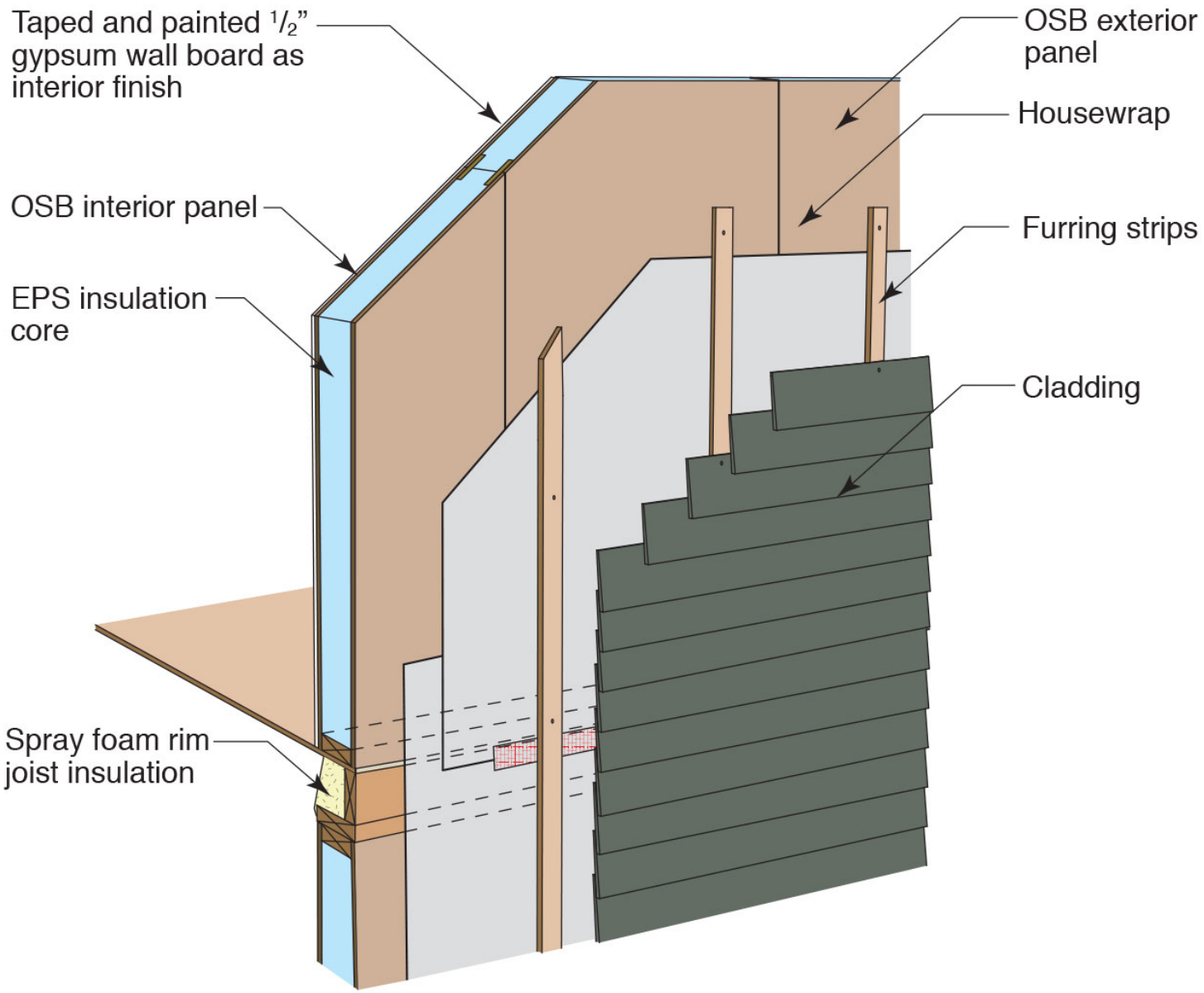

Single top plate
2x6 stud wall @ 24" o.c.
Taped and painted 1/2" gypsum wall board as interior finish
Insulation at rim joist
Vapor control layer as per IRC
Fiberglass or cellulose insulation in stud space
Exterior sheathing
Liquid applied water control layer
Drainage gap/channels/ grooves necessary between drainage plane and EPS
3"-to-6" EPS insulation
Glass mesh reinforced lamina and synthetic stucco finish

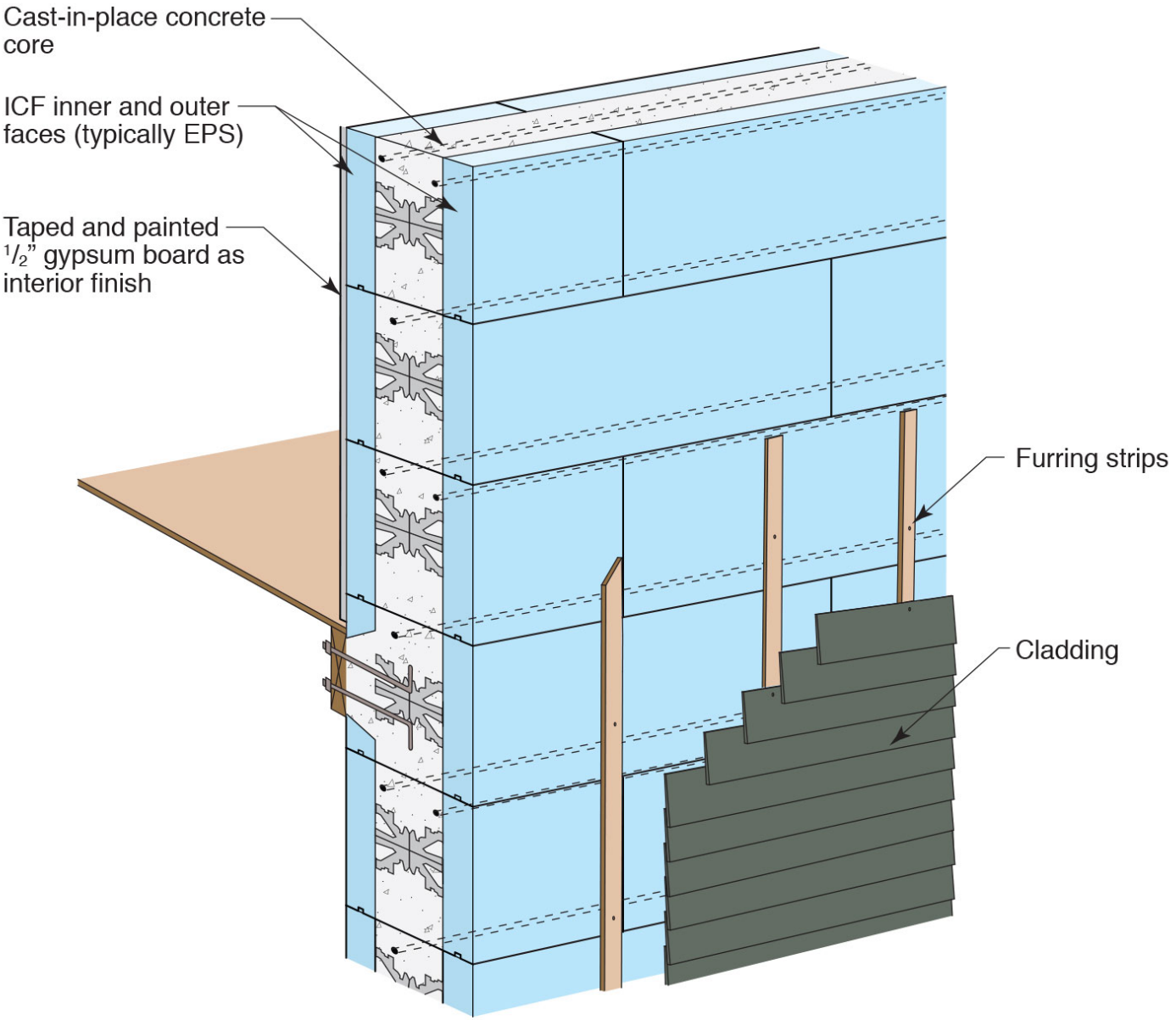

Single top plate
½" plywood connecting interior and exterior walls
2x4 structural stud wall at 24" o.c.
2x3 frame wall
Latex paint on ½" gypsum board
½" fiberboard, plywood, OSB or gypsum sheathing
Building paper, housewrap or building wrap
3½" cellulose insulation
Furring strips
½" plywood or OSB with joints taped
4½" space between sheathing and offset framing
Cladding
Cellulose insulation at rim joist
Cellulose cavity insulation


Single top plate
Taped and painted ½" gypsum wall board as interior finish
2x6 interior framing member @ 24" o.c.
Plywood/OSB sheathing; joints taped/sealed
Cellulose insulation at rim joist
Capillary break
Ledger board
Plywood cavity closure at top of assembly
2x3 exterior truss
Cellulose insulation in wall cavity
Plywood/OSB sheathing
Housewrap
Furring strips
Cladding


2x3 interior wall
Plywood cavity closure at top of assembly
Single top plate
Taped and painted ½" gypsum wall board as interior finish
2x4 exterior wall @ 16" o.c.
Cellulose insulation in 2x3 interior wall stud spaces
3½" high density spray foam (SPF)(2.0 pcf) against exterior sheathing
Plywood or OSB sheathing
Cellulose insulation in gap between framing
Housewrap
Furring strips
Cladding
6" high density spray foam (SPF)(2.0 pcf) on inside of rim joist


Single top plate
Taped and painted ½" gypsum wall board as interior finish
2x6 @ 24" o.c. interior framing
Fiberglass or cellulose insulation in interior stud cavity
Spray foam insulation at rim joist
Closure board
2x3 exterior framing member
Substrate to support spray foam
4½" high density spray foam (SPF)(2.0 pcf)
Cladding
Minimum ½" drainage and ventilation gap between closure board and cladding


Taped and painted 1/2" gypsum wall board as interior finish
OSB interior panel
EPS insulation core
Spray foam rim joist insulation
OSB exterior panel
Housewrap
Furring strips
Cladding


Cast-in-place concrete core
ICF inner and outer faces (typically EPS)
Taped and painted 1/2" gypsum board as interior finish
Furring strips
Cladding