Metal Building Systems:
Dealing with heat and moisture issues

Dr John F. Straube

Assistant Professor

Dept of Civil Engineering & School of Architecture

University of Waterloo

Ontario, Canada

jfstraube@uwaterloo.ca

www.balancedsolutions.com

Overview

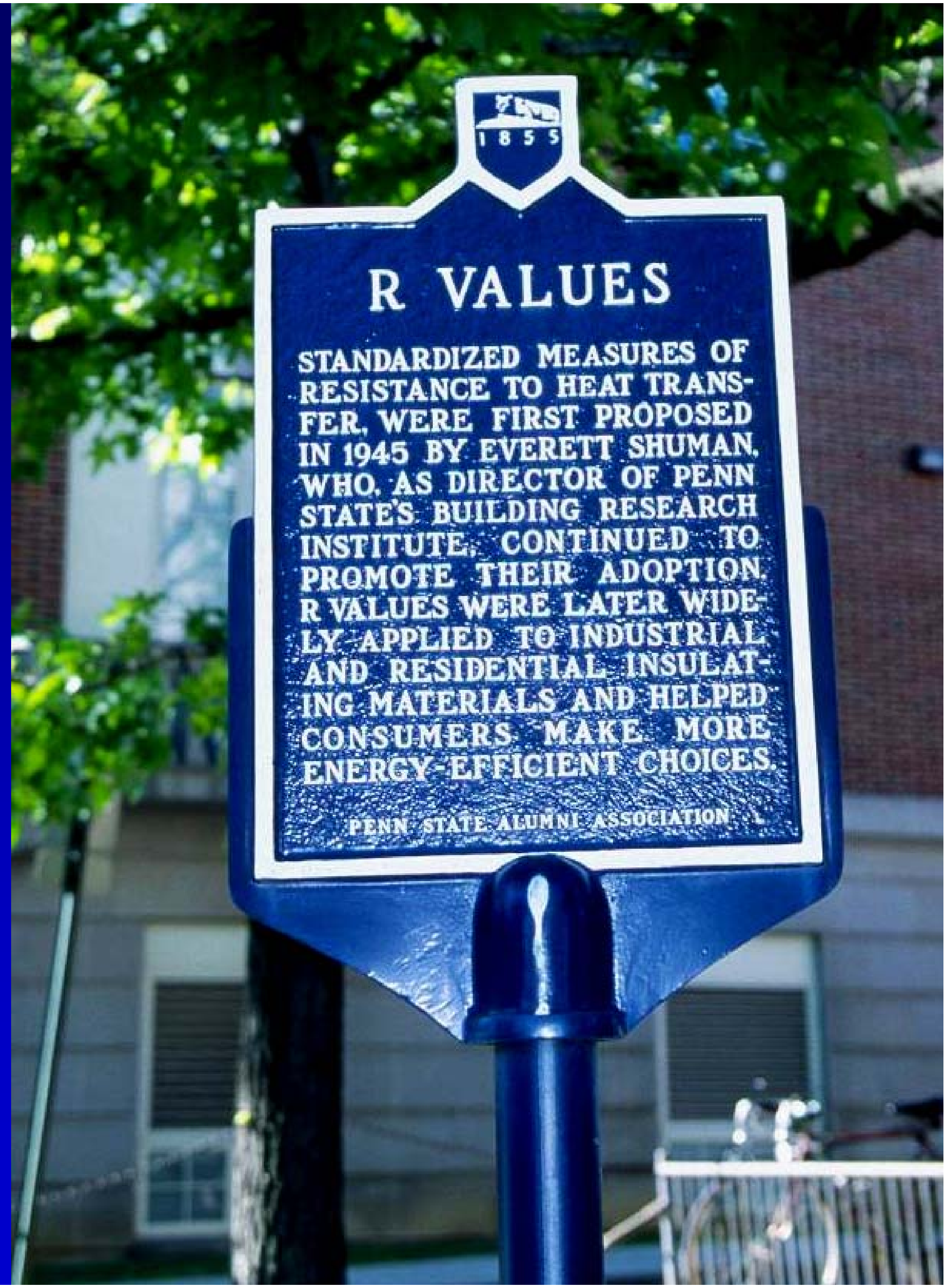
- Scope:
  - Commercial (some residential)
  - Light gauge steel stud
  - Pre-manufactured metal build
  - Roof s
- Thermal Control
  - mostly conduction
- Moisture
  - mostly condensation

Thermal

Why Thermal control?

- Save Energy
- Comfort
- Aesthetics
- Match competition
- Code Compliance

R Values


1855
R VALUES
STANDARDIZED MEASURES OF
RESISTANCE TO HEAT TRANS-
FER, WERE FIRST PROPOSED
IN 1945 BY EVERETT SHUMAN,
WHO, AS DIRECTOR OF PENN
STATE'S BUILDING RESEARCH
INSTITUTE, CONTINUED TO
PROMOTE THEIR ADOPTION.
R VALUES WERE LATER WIDE-
LY APPLIED TO INDUSTRIAL
AND RESIDENTIAL INSULAT-
ING MATERIALS AND HELPED
CONSUMERS MAKE MORE
ENERGY-EFFICIENT CHOICES.
PENN STATE ALUMNI ASSOCIATION

The Meaning of R-value

- Thermal Resistance
  - R-value
  - Thermal Bridging
- Airtightness
  - about 30 % of energy loss
- Mass
  - smooths peaks and valleys
  - takes advantage of heat within (sun, equipment)
- Buildability / Inspectability
  - do you get what you spec/design?

R-value

- Gives heat flow as equivalent conductance
  - Rarely includes thermal bridging
  - or three dimensions
- Never intended to include
  - airtightness
  - mass

Thermal Performance
R-values and *Real* R-values

- **Walls are three-dimensional and must be considered as such.**
- **Simple R-values are inadequate to describe thermal performance of some walls**
- **Dynamic behaviour and/or three-dimensional details greatly affect energy consumption.**

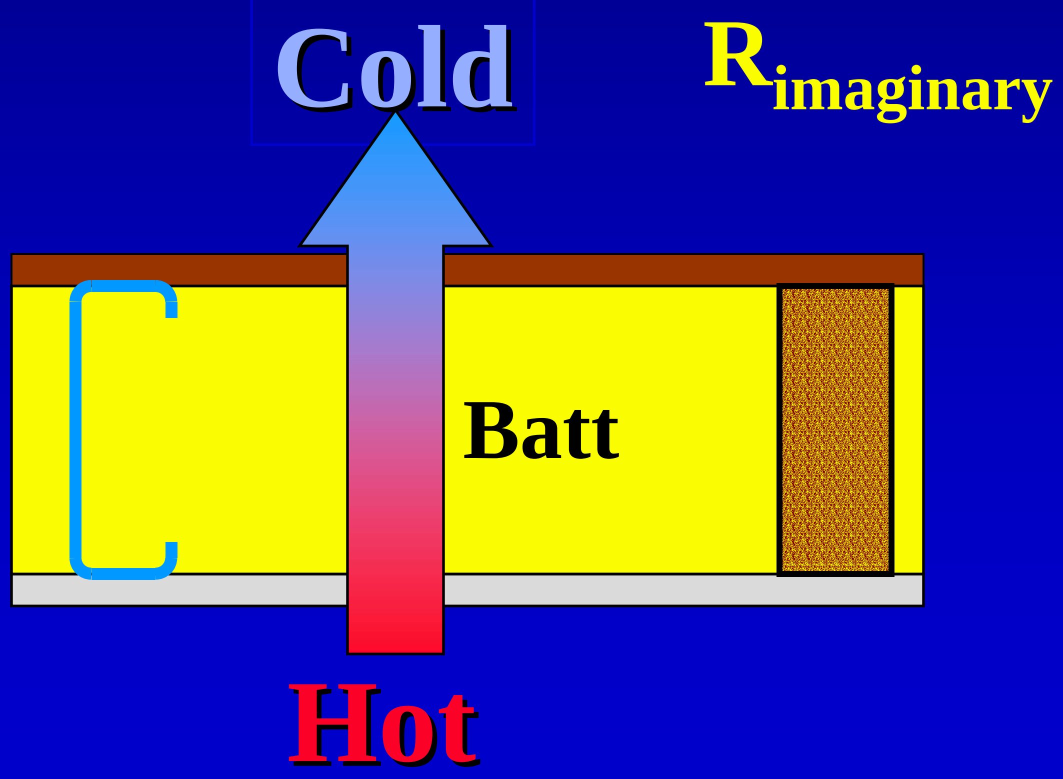
See "Toward a National Opaque Wall Rating Label", by Jeff Christian and Jan Kosny, *Proceedings of Thermal Performance of Exterior Envelope of Buildings VI*, pp. 221-239.

Different Types of R-values

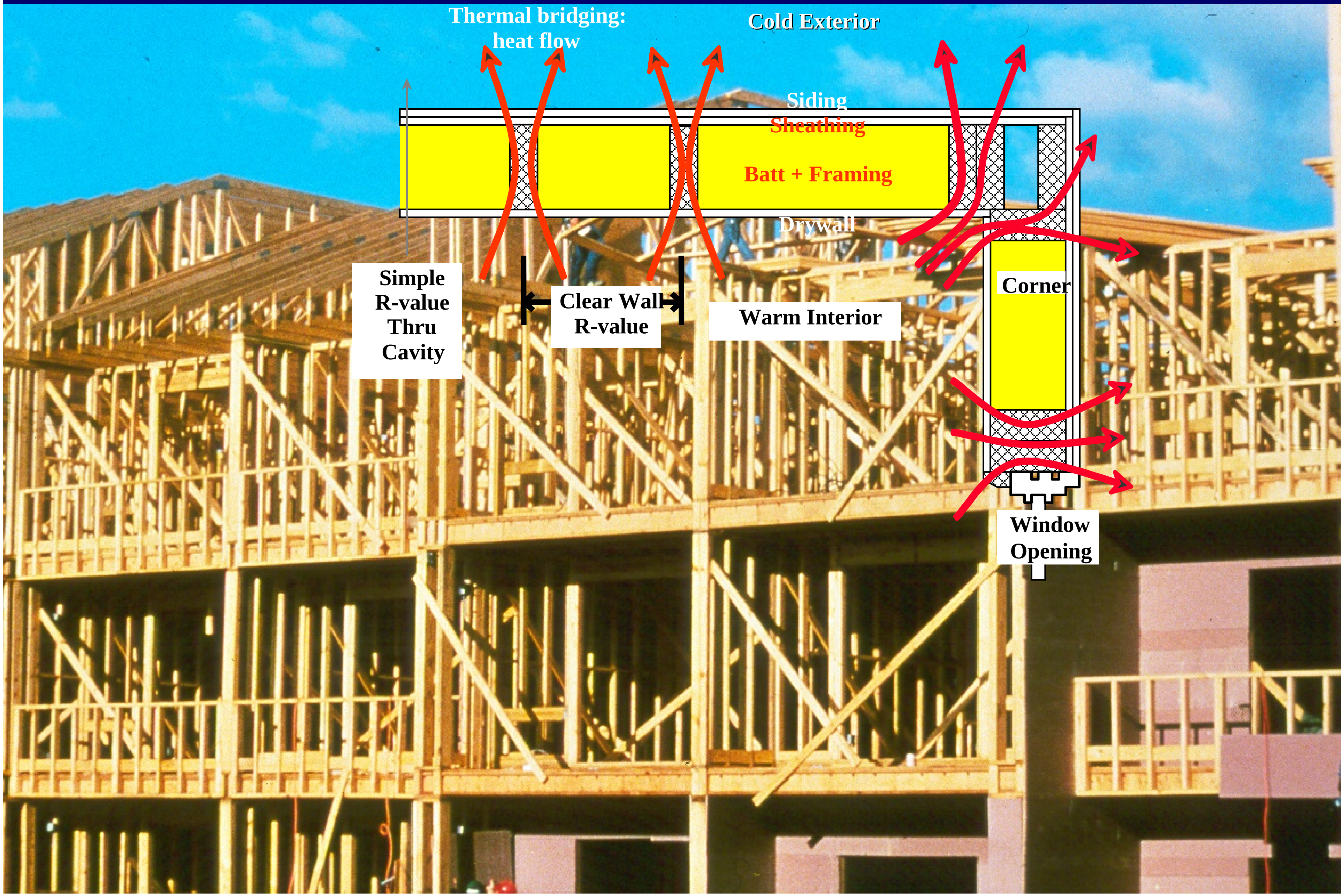
- Center-of studspace (R_{cs})
  - Typical value given. Calculated between framing members
- Clear-wall (R_{cw})
  - More realistic 2-D. Calculations/tests of a section of wall.
- Whole-wall (R_{ww})
  - Most realistic 3-D steady state. Calculations/tests
  - walls with interfaces, corners and openings, doors windows
- True Energy (R_{te})
  - Includes time effects, e.g., 4-D = "mass effect".
  - Dynamic Whole wall
  - Highly climate and building dependent.

Center of Studspace

- Ignores framing elements
- Accounts <u>only</u> for insulation, sheathing, etc.

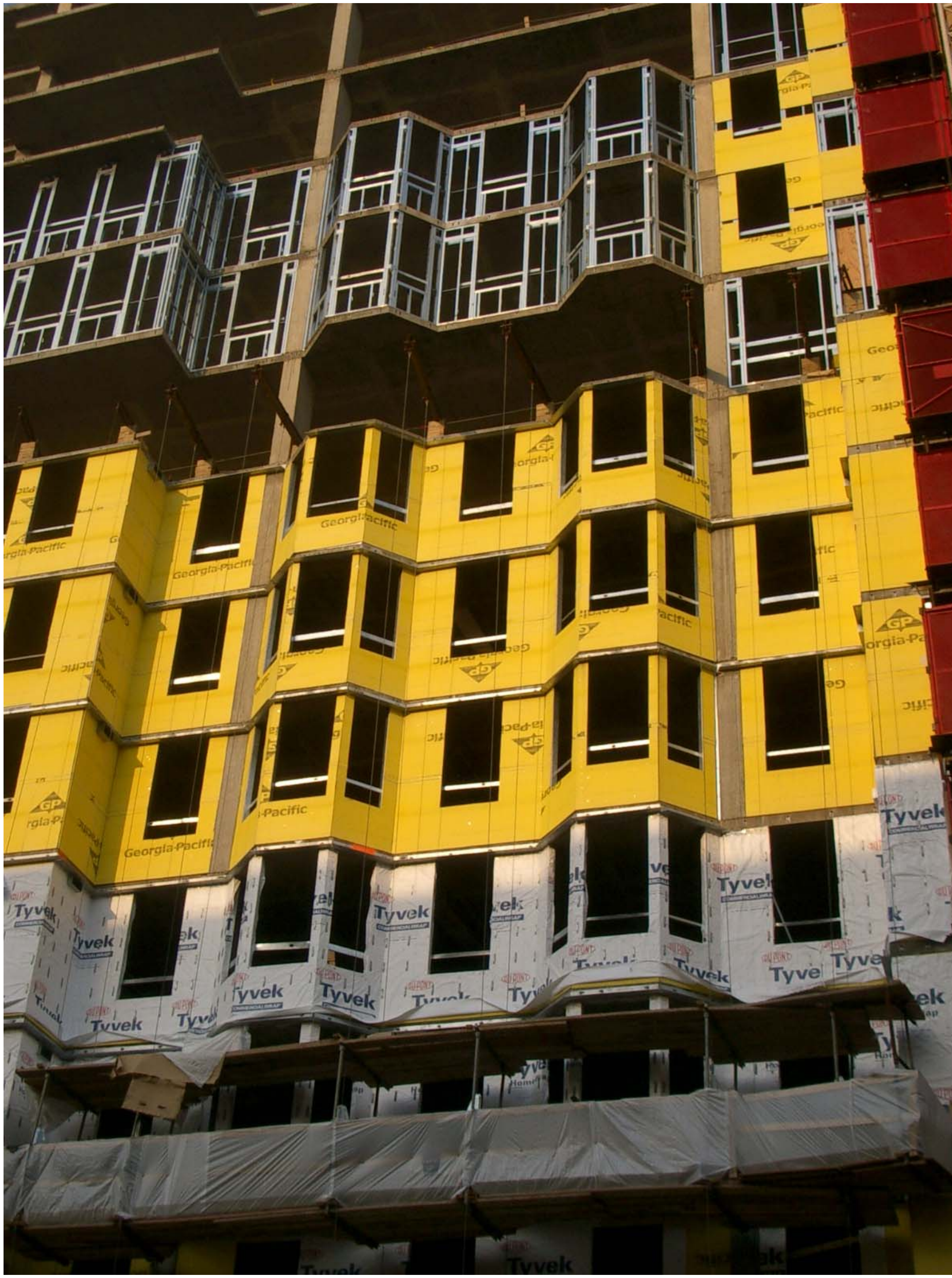
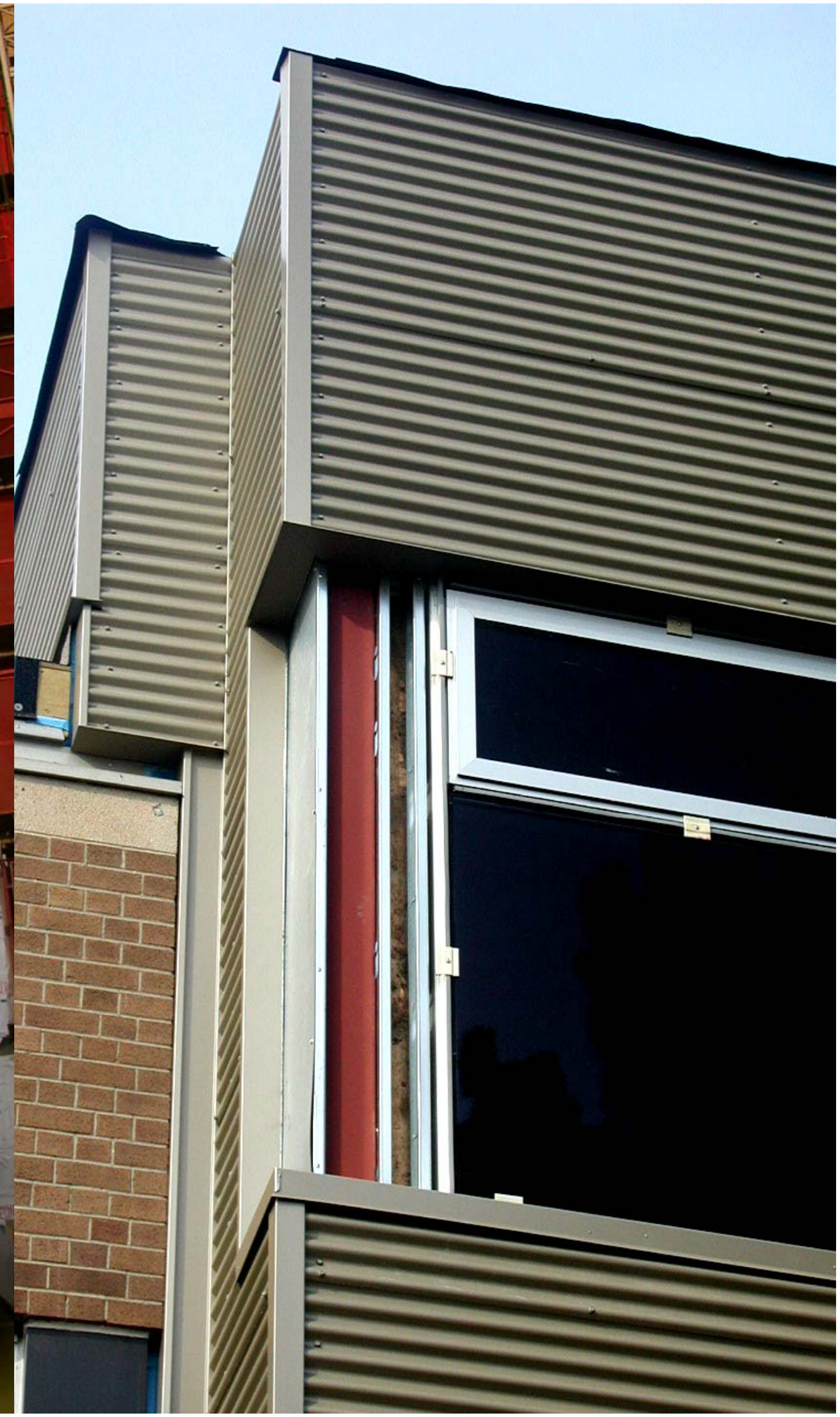


Thermal Bridging



Different Types of R-values

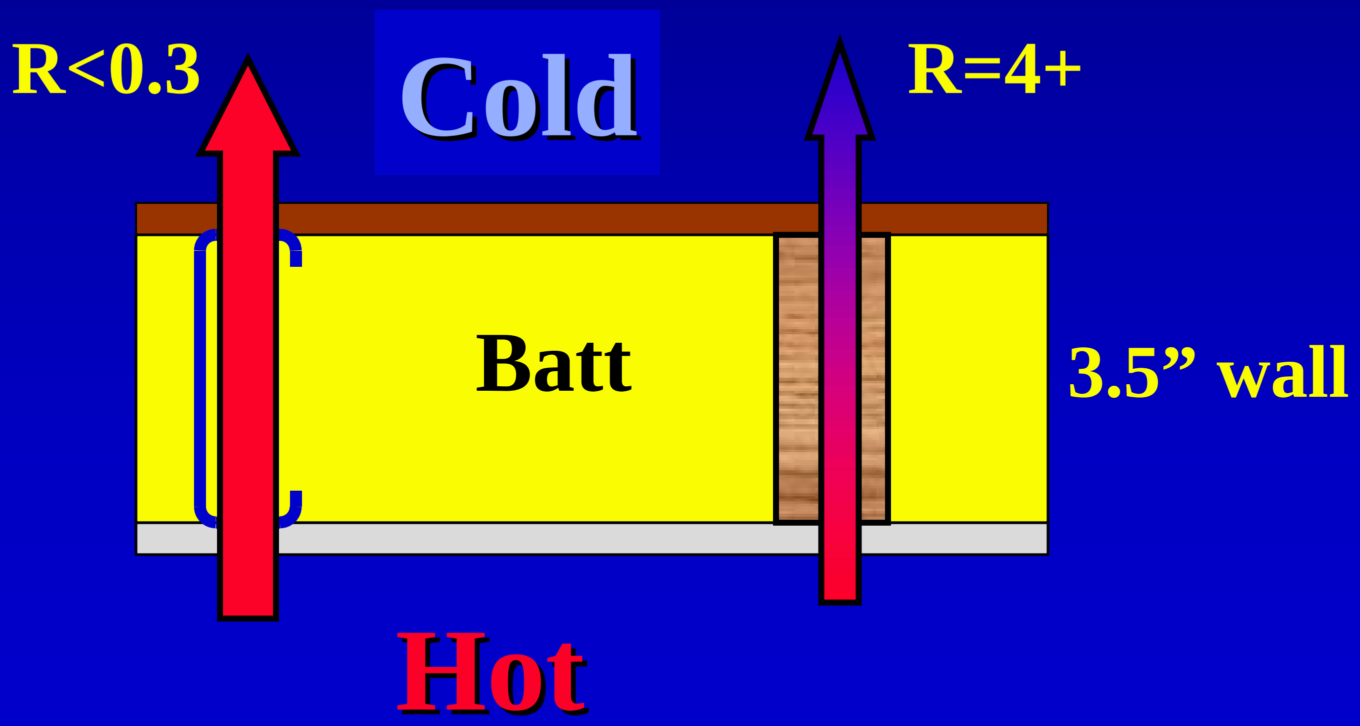
- **Center-of studspace (R_{cs})**
  - **Typical value given. Calculated between framing members**
- **Clear-wall (R_{cw})**
  - **More realistic 2-D. Calculations/tests of a section of wall.**
- **Whole-wall (R_{ww})**
  - **Most realistic 3-D steady state. Calculations/tests**
  - **walls with interfaces, corners and openings, doors windows**
- **True Energy (R_{te})**
  - **Includes time effects, e.g., 4-D = “mass effect”.**
  - **Dynamic Whole wall**
  - **Highly climate and building dependent.**

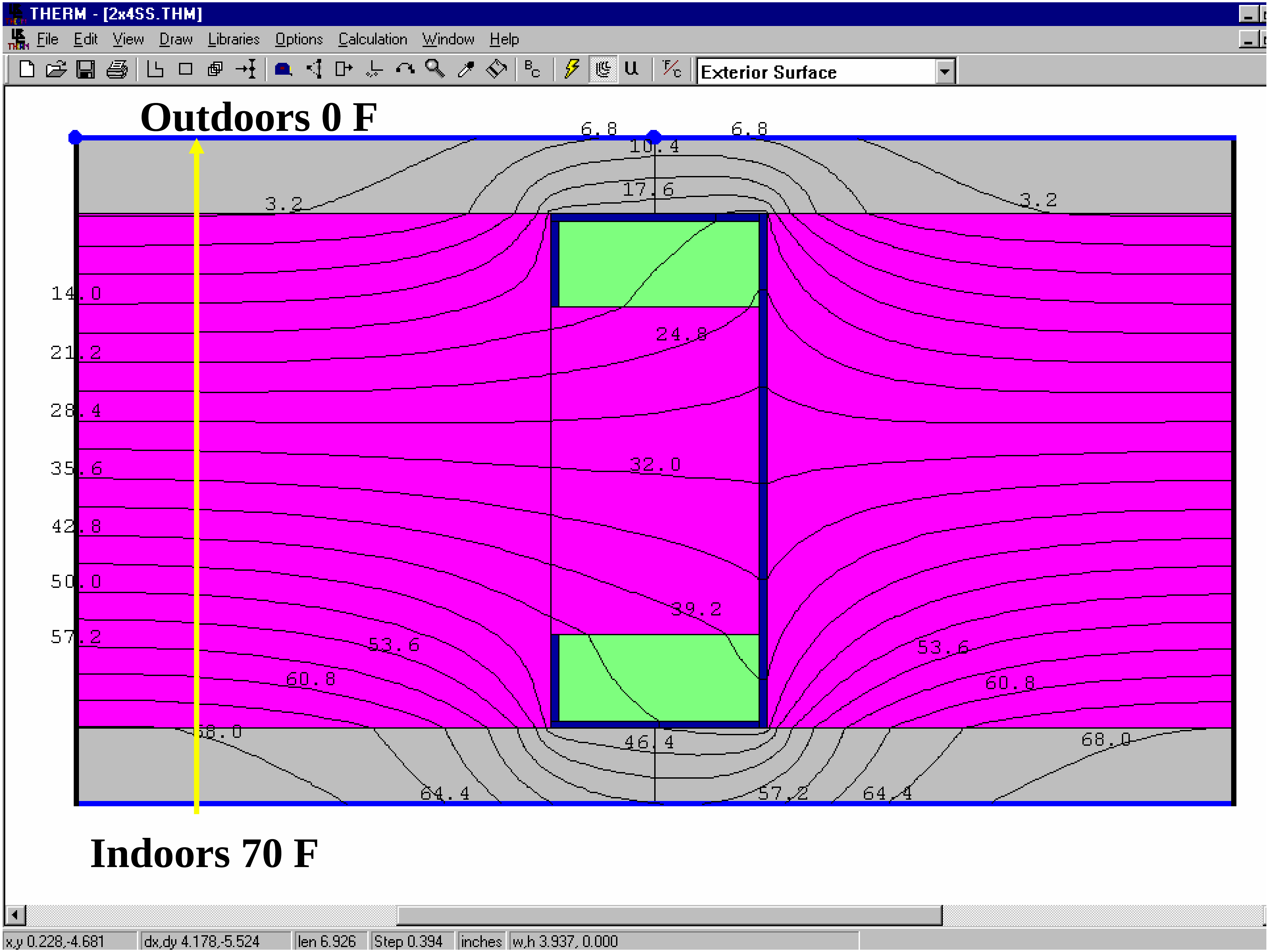

Georgia-Pacific
Tyvek



Genie S-40
A5
C1-003
WEST

Thermal Bridging

- Steel is 400 times more conductive than wood
- Steel studs are about 40 times thinner

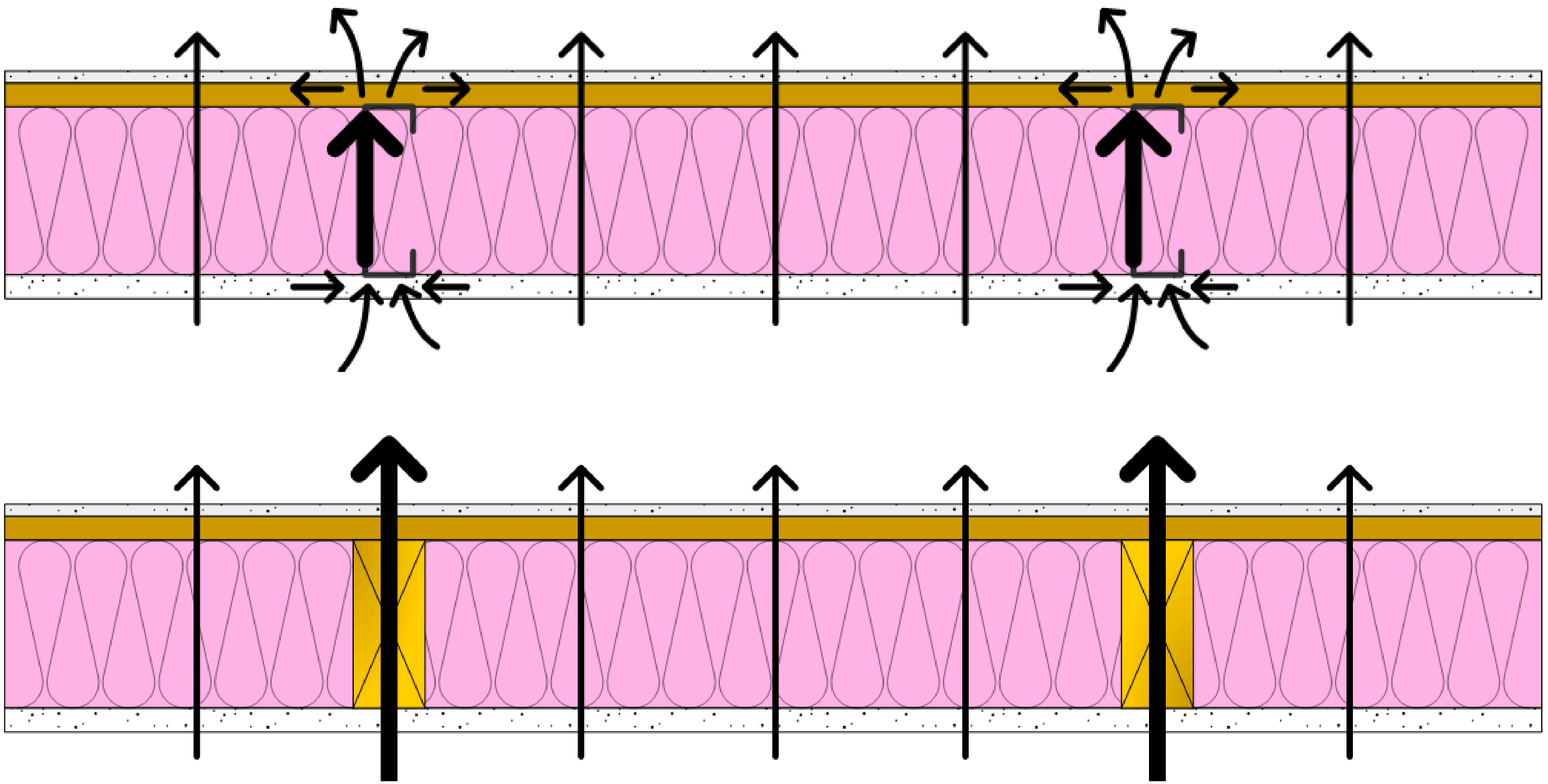


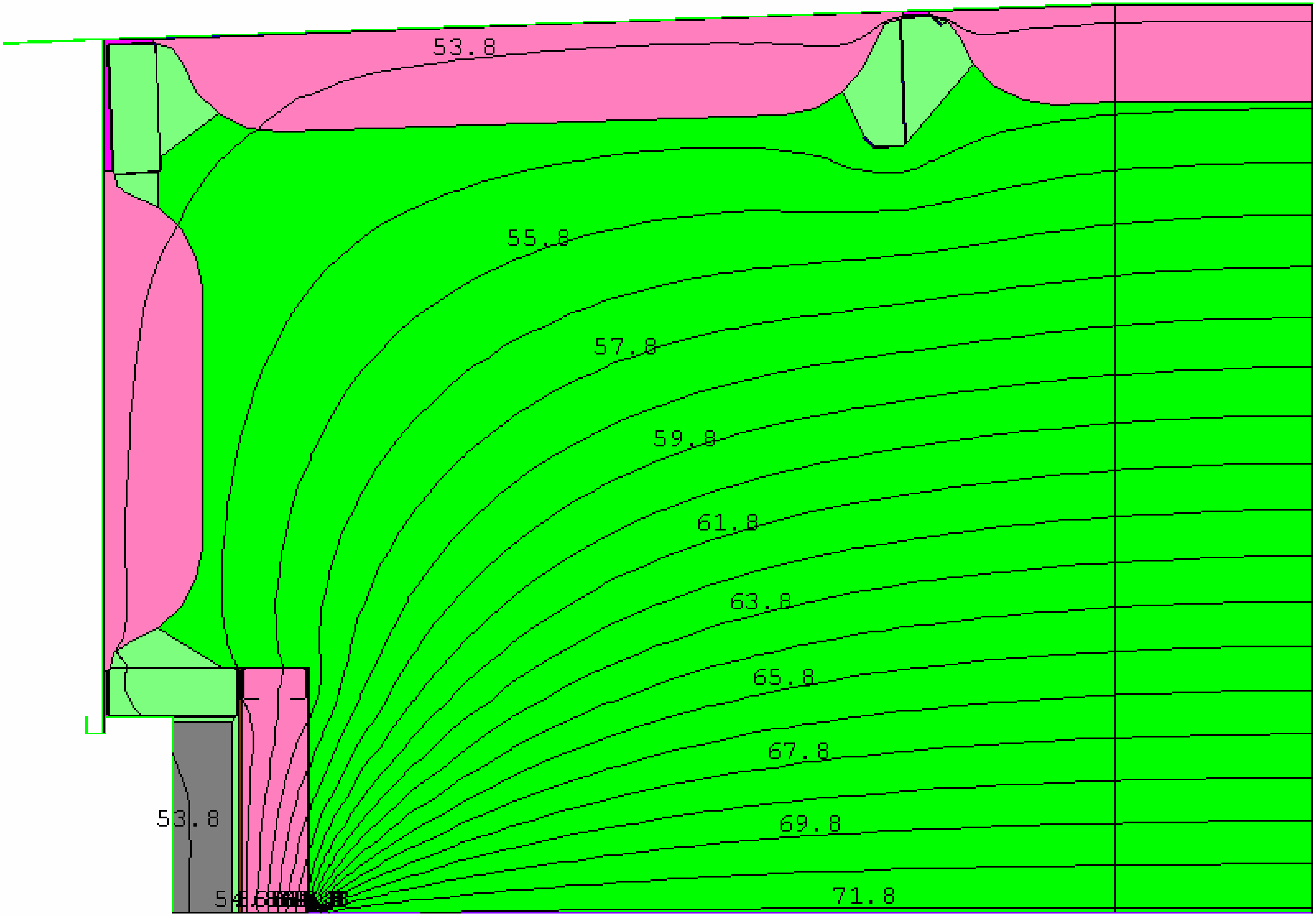

THERM - [2x4SS.THM]
File Edit View Draw Libraries Options Calculation Window Help
Exterior Surface
Outdoors 0 F
6.8
10.4
17.6
3.2
14.0
21.2
28.4
35.6
42.8
50.0
57.2
24.8
32.0
39.2
53.6
60.8
68.0
46.4
64.4
57.2
Indoors 70 F
x,y 0.228,-4.681
dx,dy 4.178,-5.524
len 6.926
Step 0.394
inches
w,h 3.937, 0.000

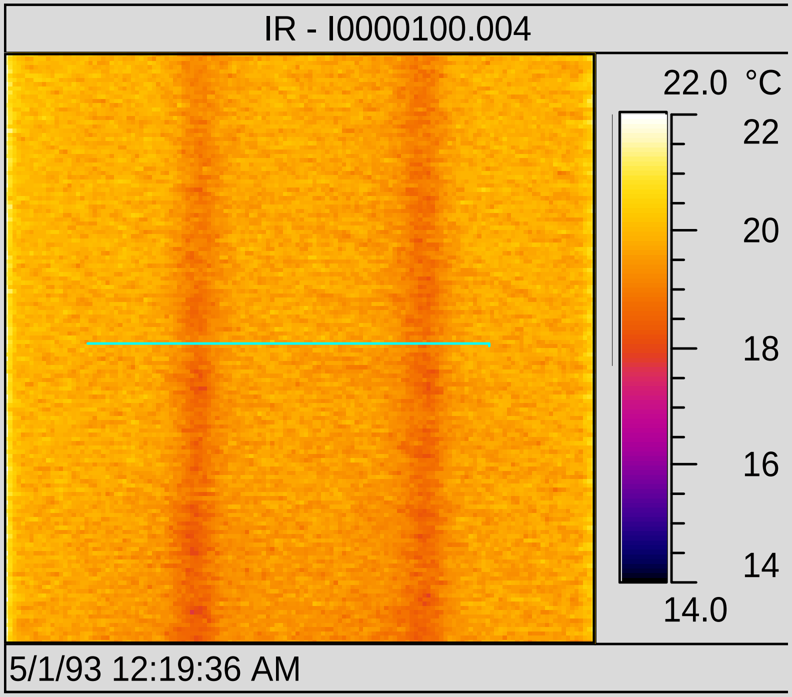
Condensation

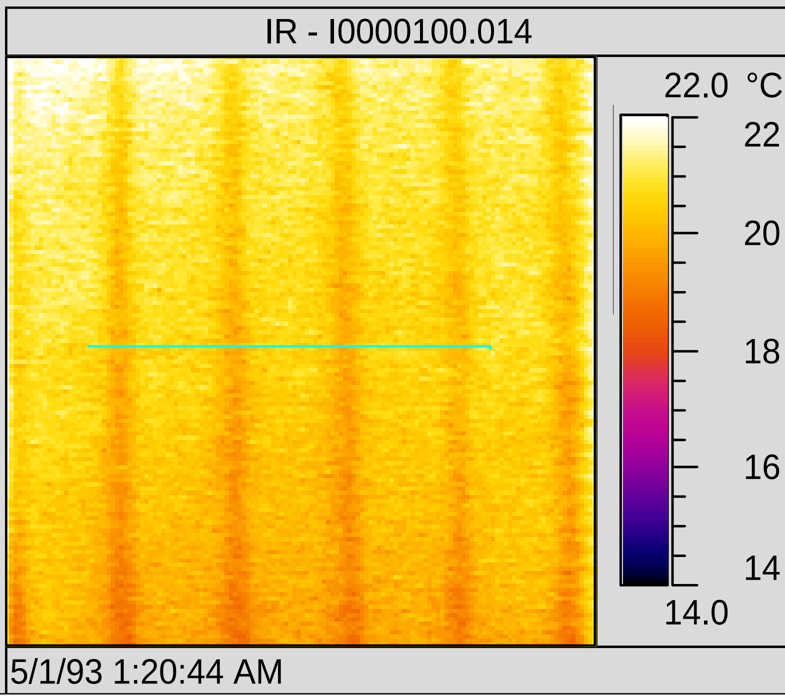
RH	Condensation Temperature
20%	28 F
30%	37 F
40%	45 F
50%	50 F
60%	54 F

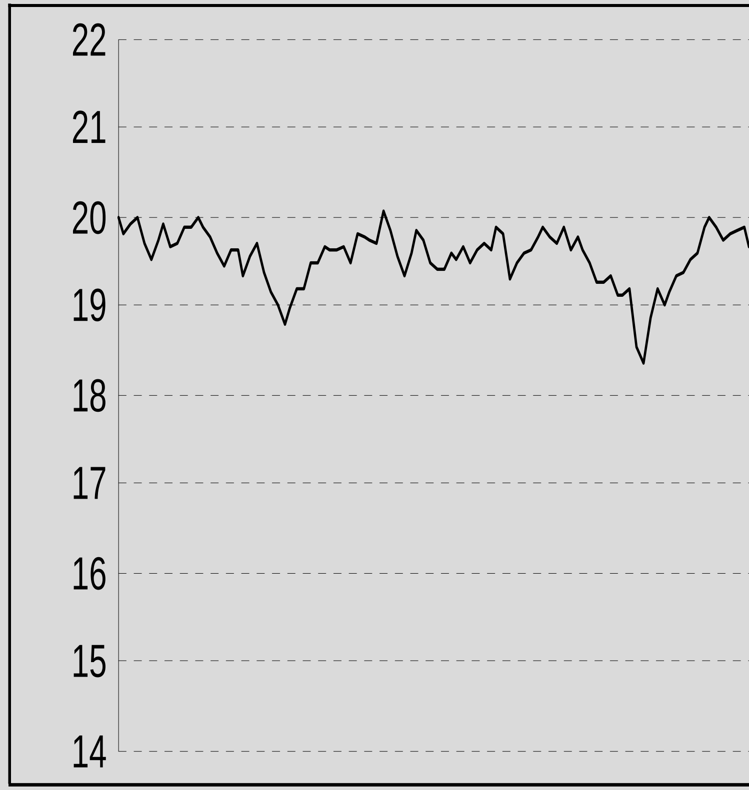
Wood vs Steel



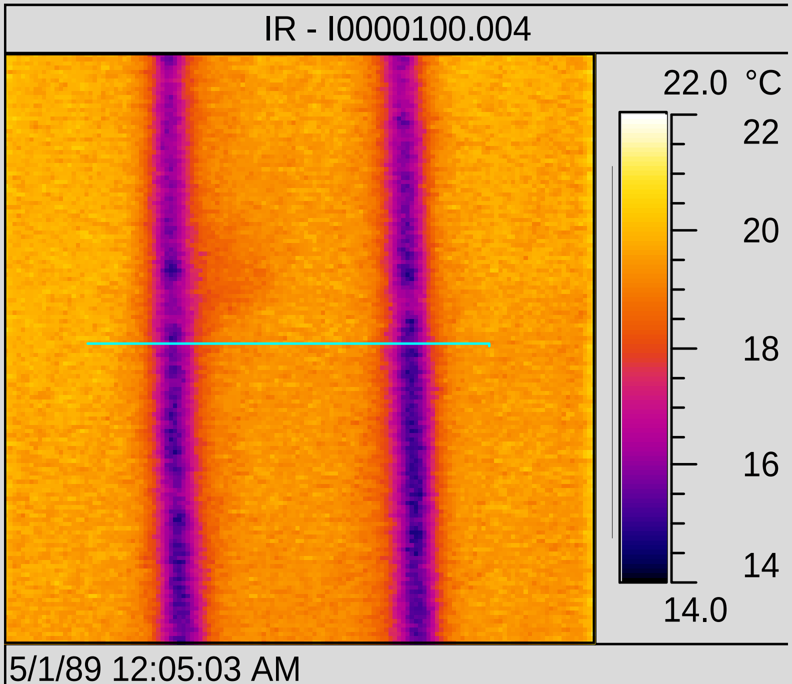

53.8
55.8
57.8
59.8
61.8
63.8
65.8
67.8
69.8
71.8
53.8

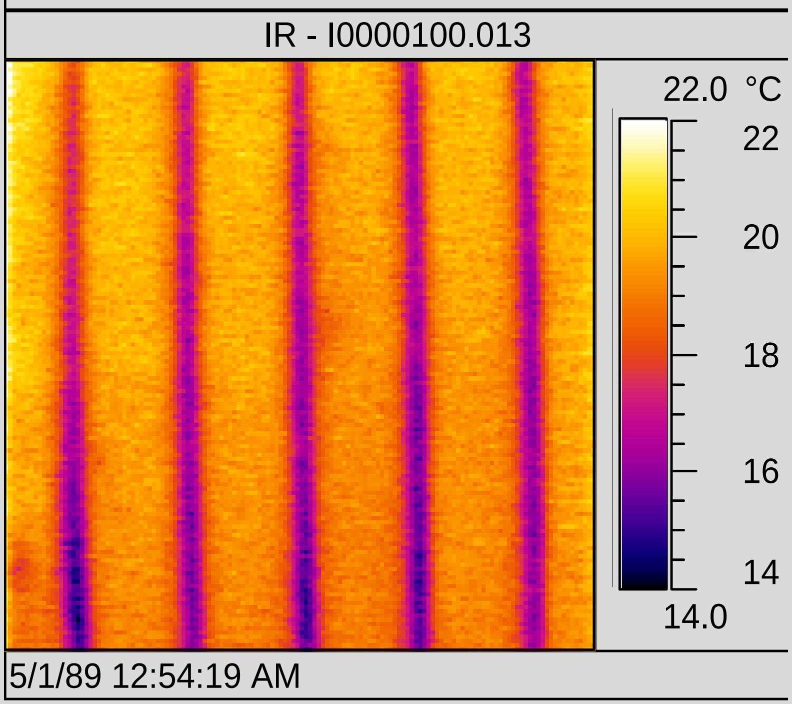






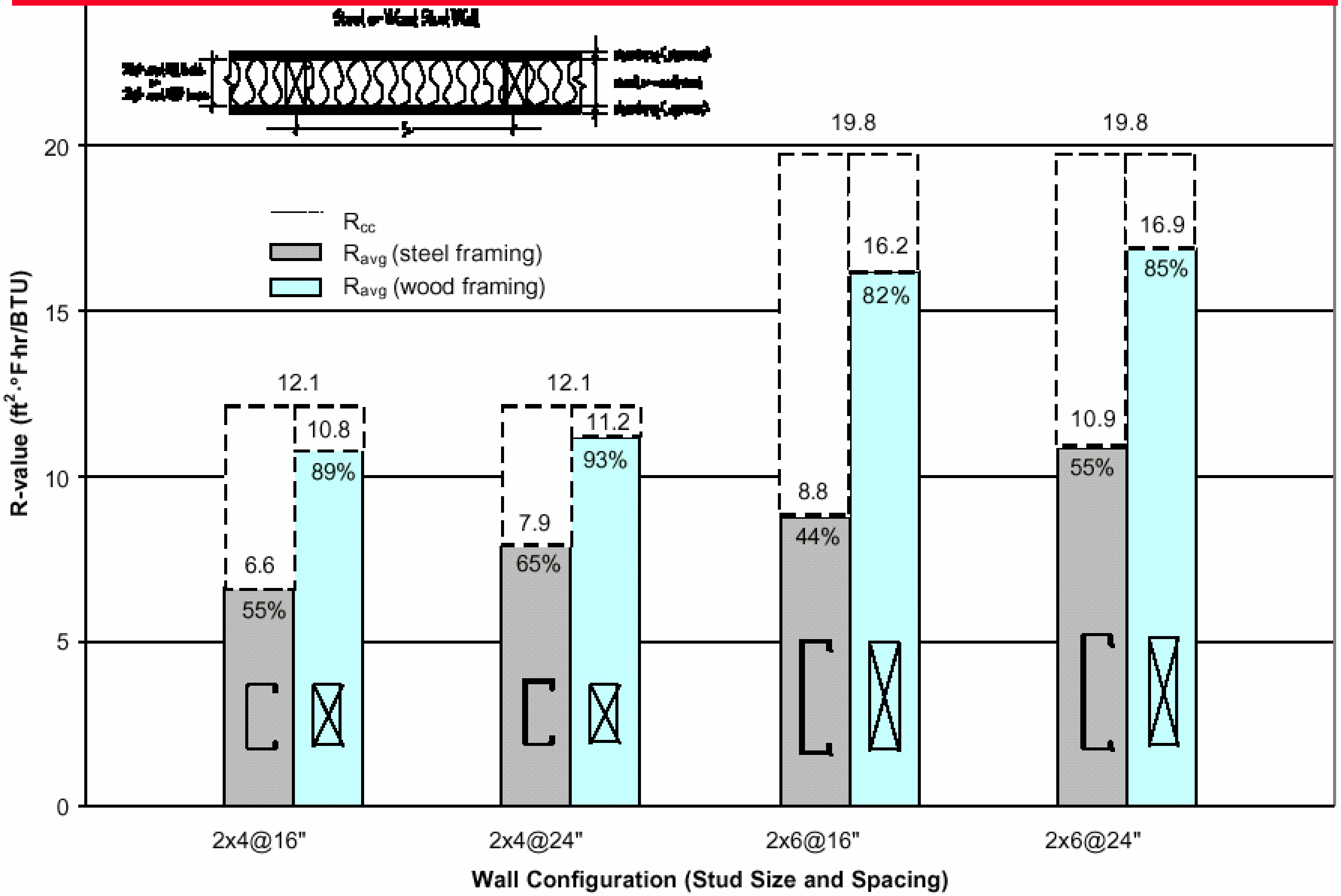
2x4 wood stud w/R12 batt



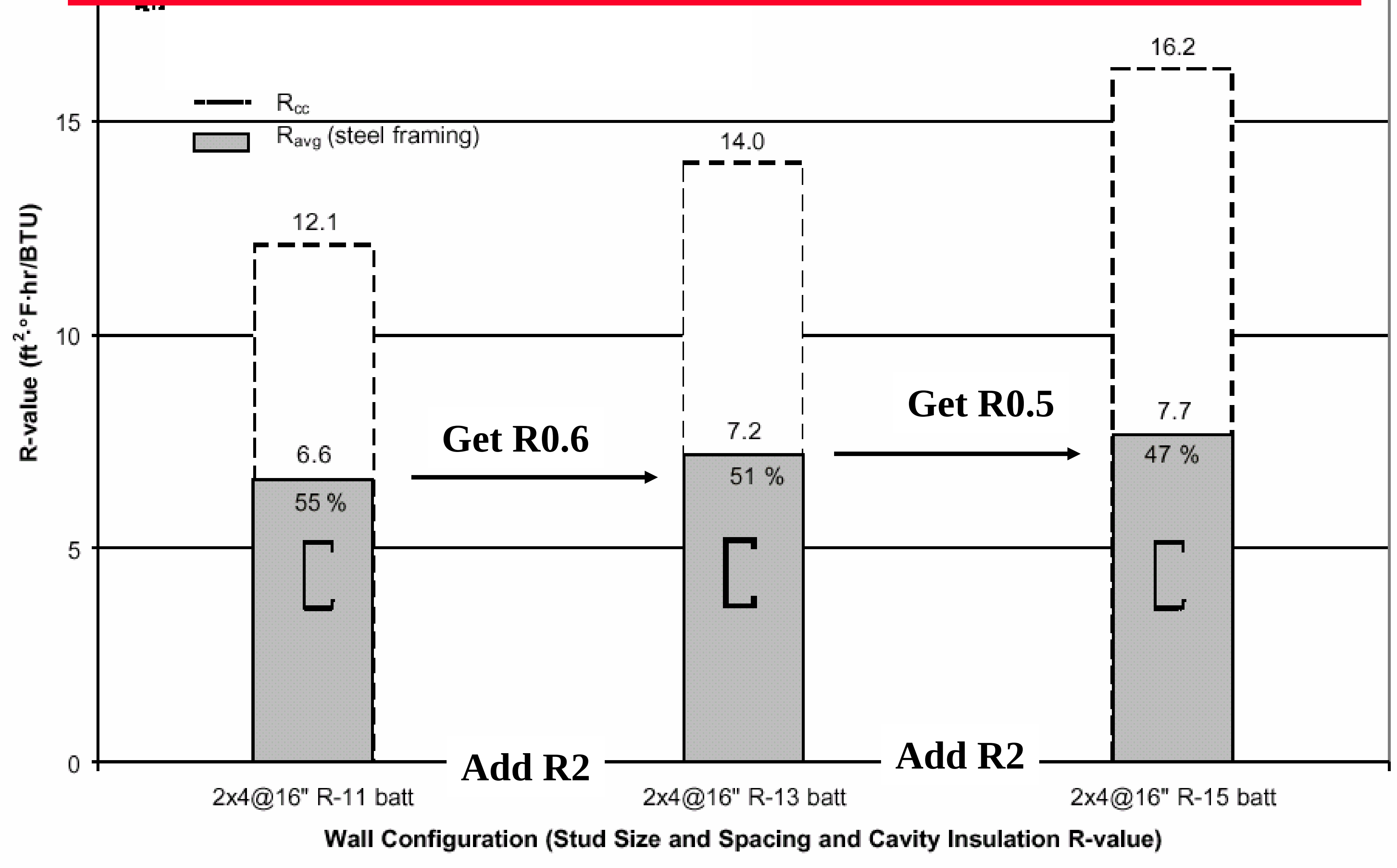


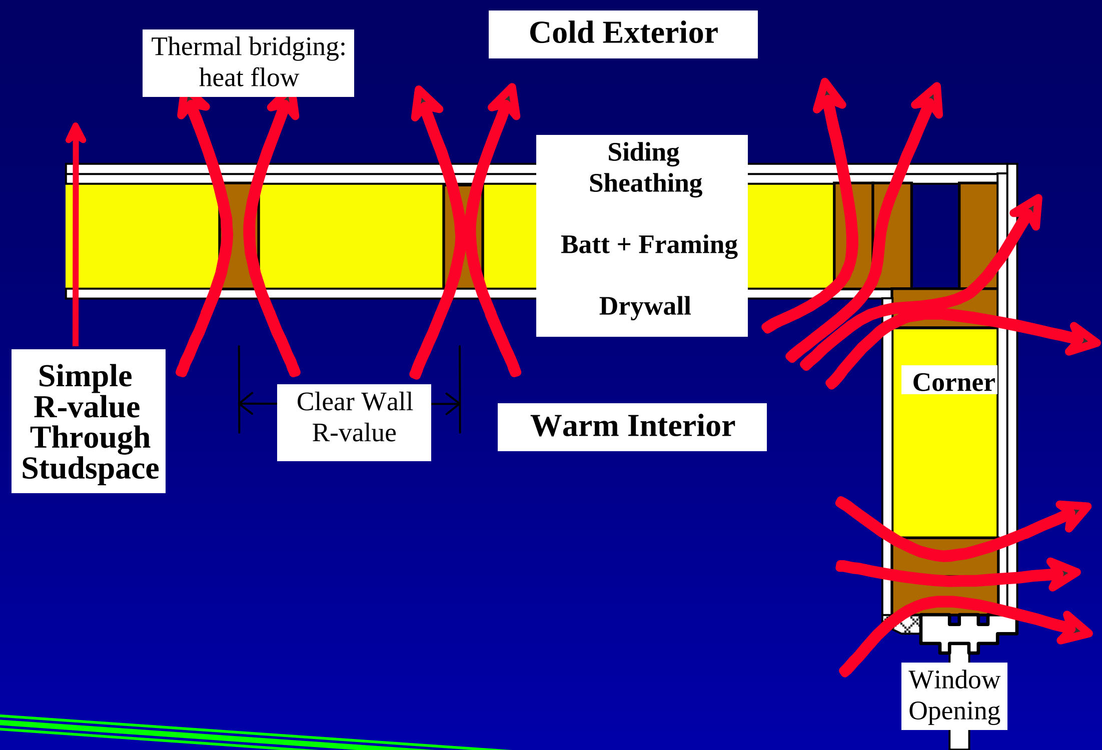
2x4 steel stud w/R12 batt

R-value Comparison

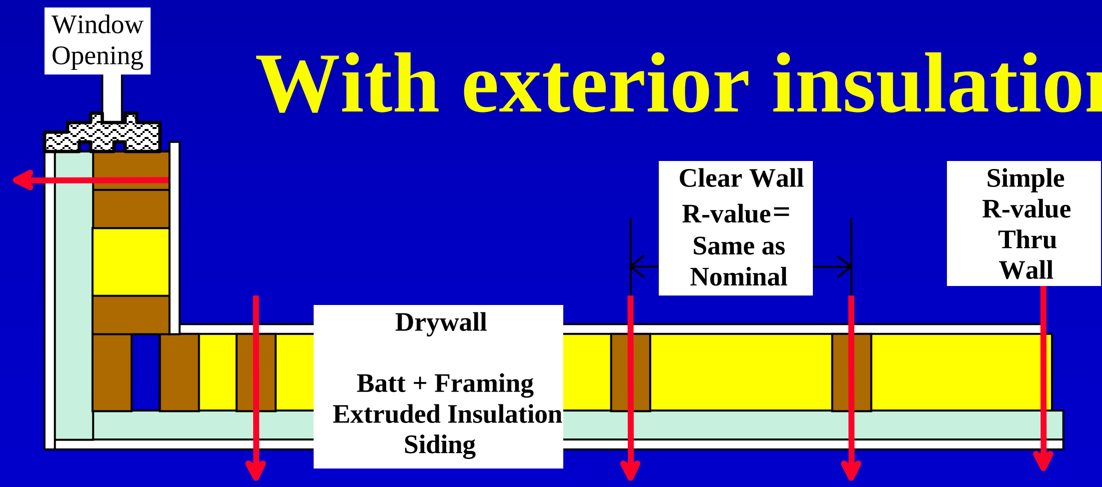


Adding batt is not helpful!

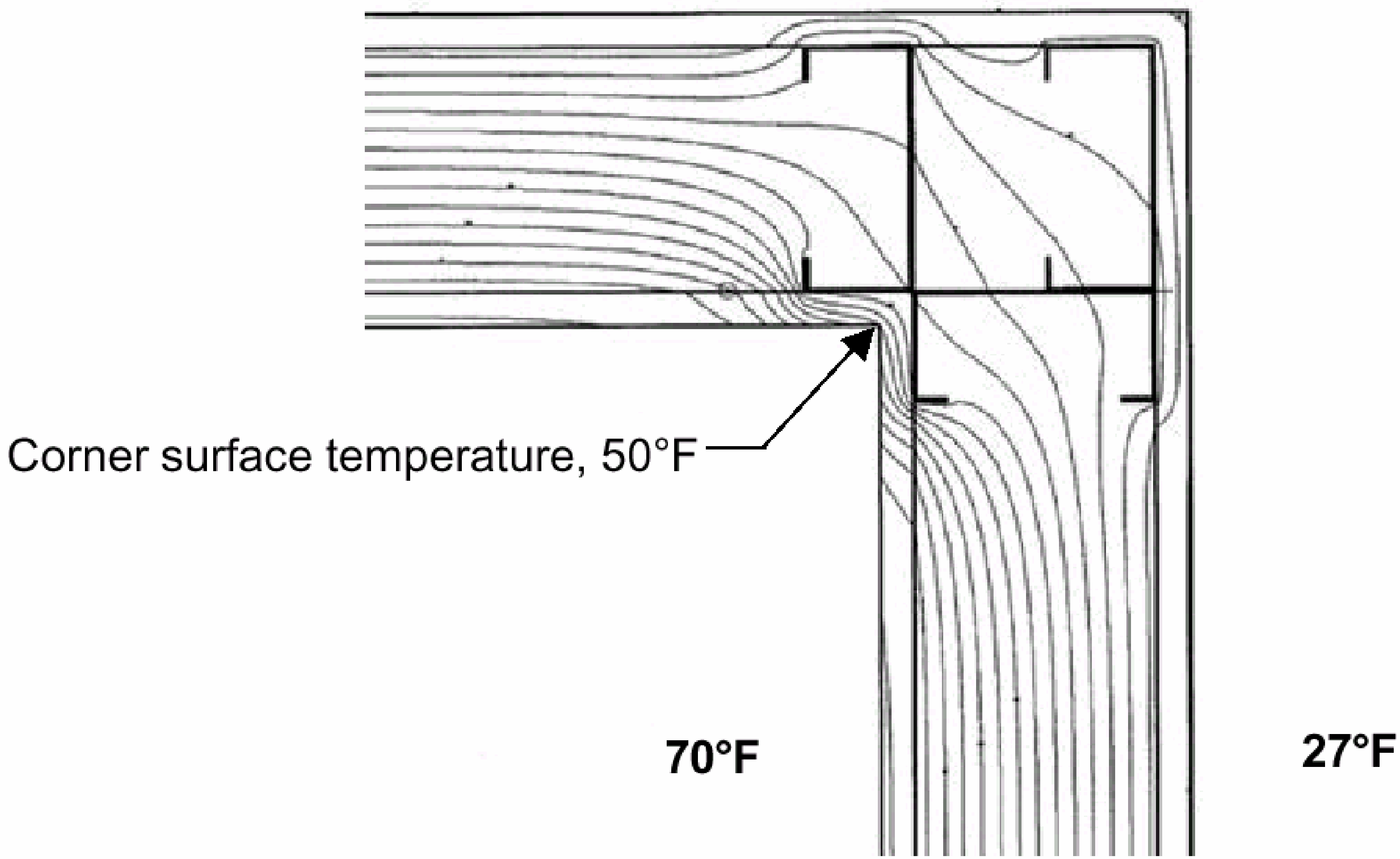




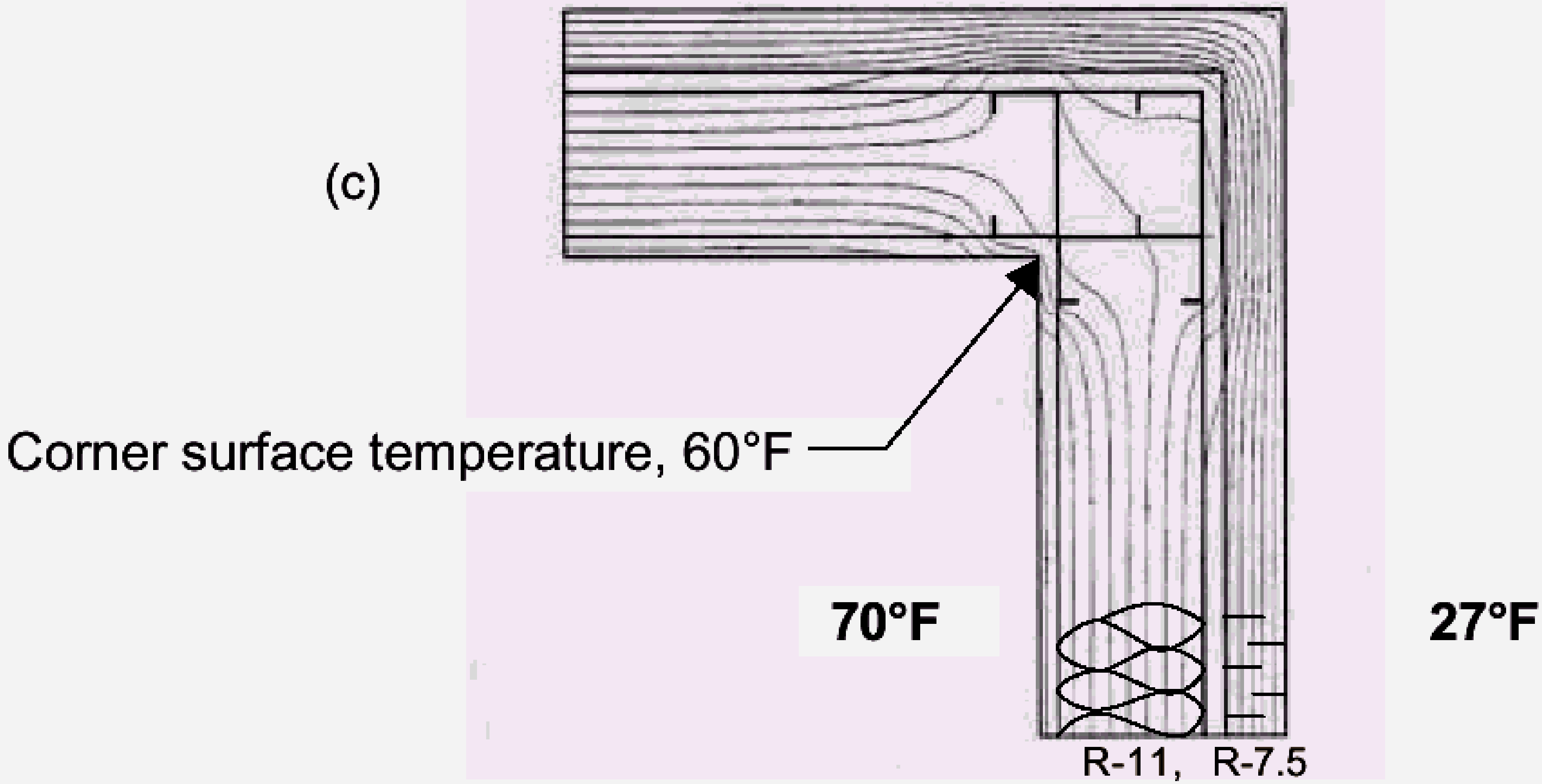
With exterior insulation



Cold Corners

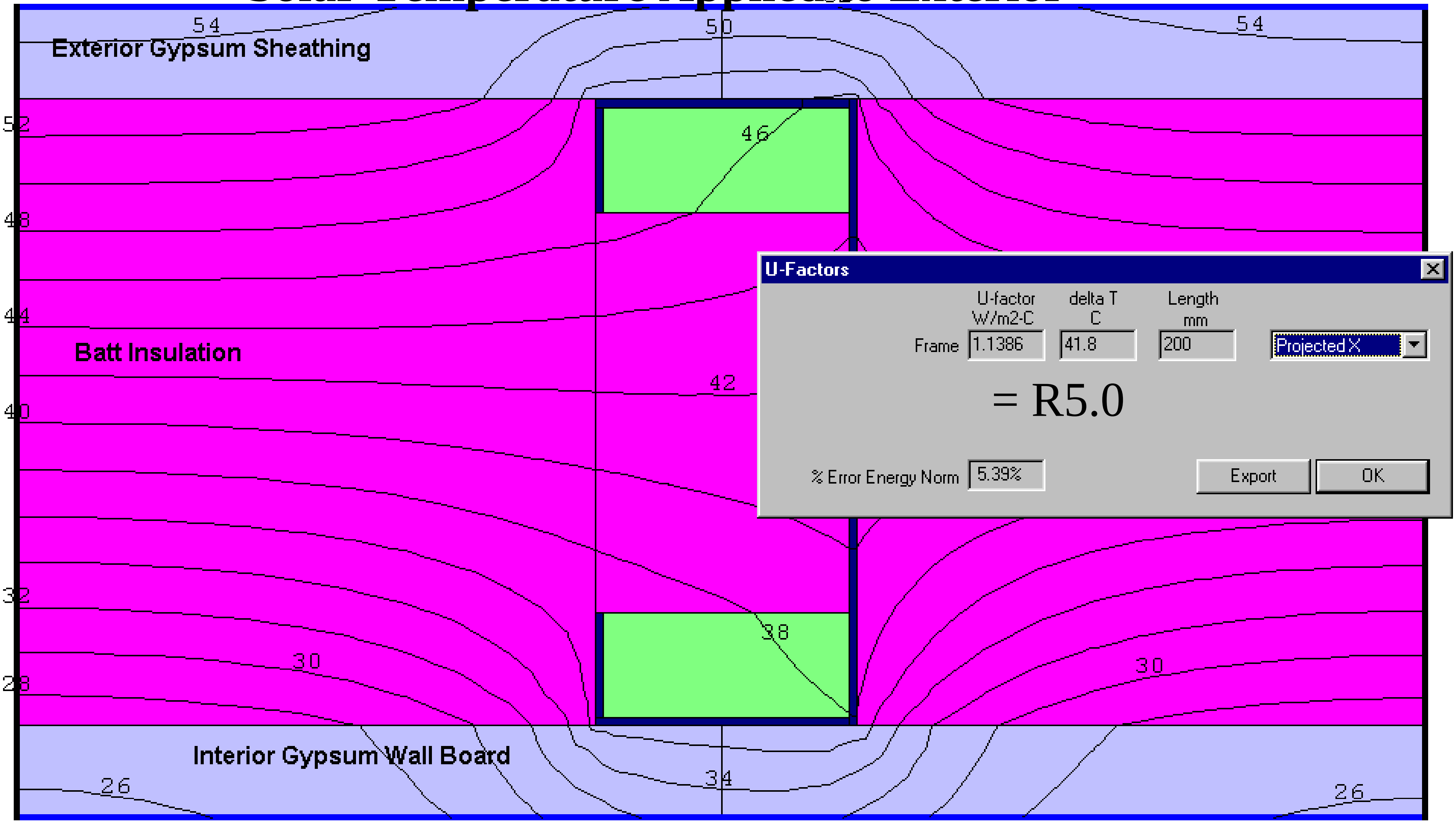


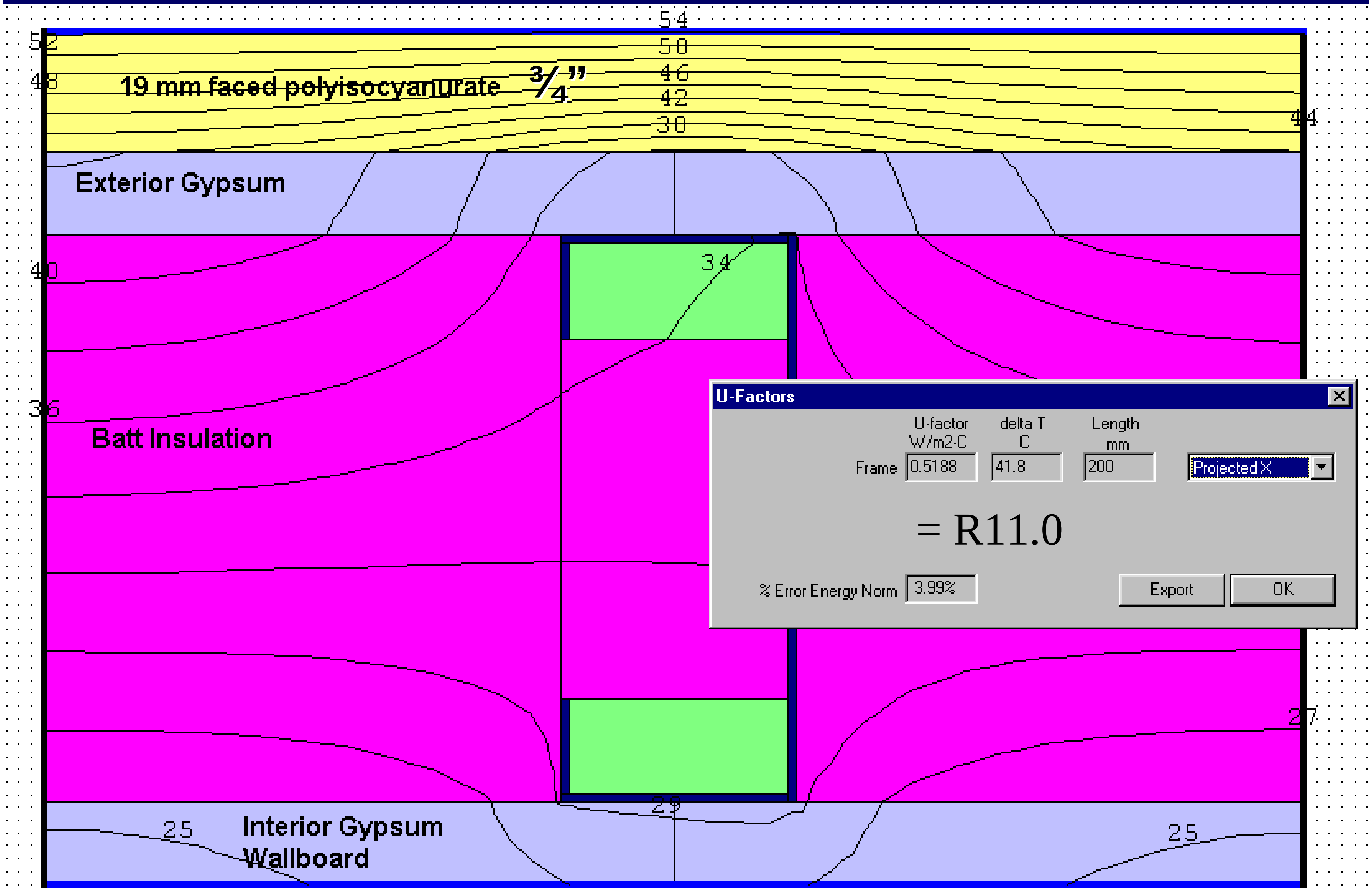
Cold Corners - Answer



Therm can calculate 2-D values - Free!

Solar Temperature Applied to Exterior

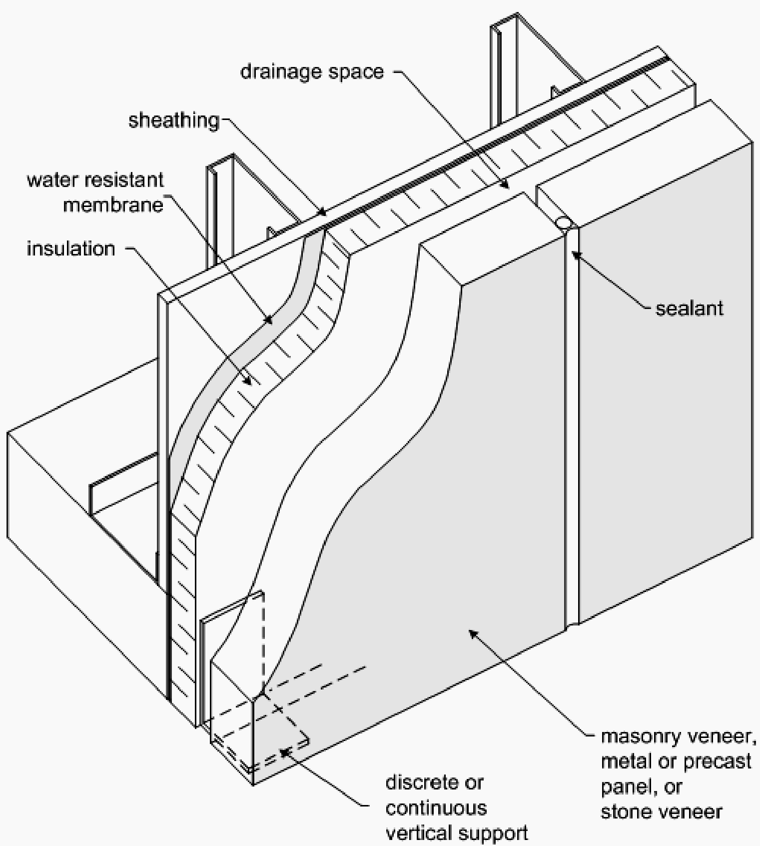



54
50
46
42
38
52
48
19 mm faced polyisocyanurate ¾"
44
Exterior Gypsum
40
34
36
Batt Insulation
27
29
25
Interior Gypsum Wallboard
25
U-Factors
U-factor W/m2-C
delta T C
Length mm
Frame
0.5188
41.8
200
Projected X
= R11.0
% Error Energy Norm
3.99%
Export
OK

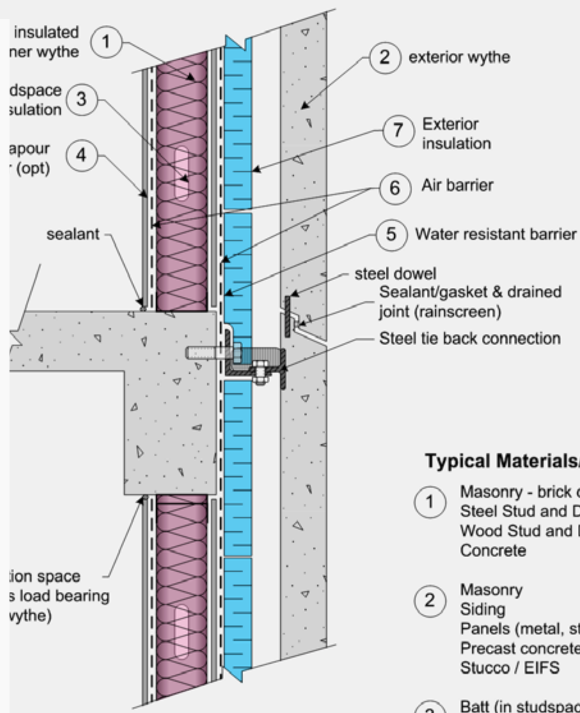
Insulated on the outside

- Often easiest, simplest, safest to put all of the insulation on the outside!!

Heavy Cladding System



Typical Insulated Inner Wythe Cavity Wall w/ Insulating Sheathing



Typical Materials/Sub-systems

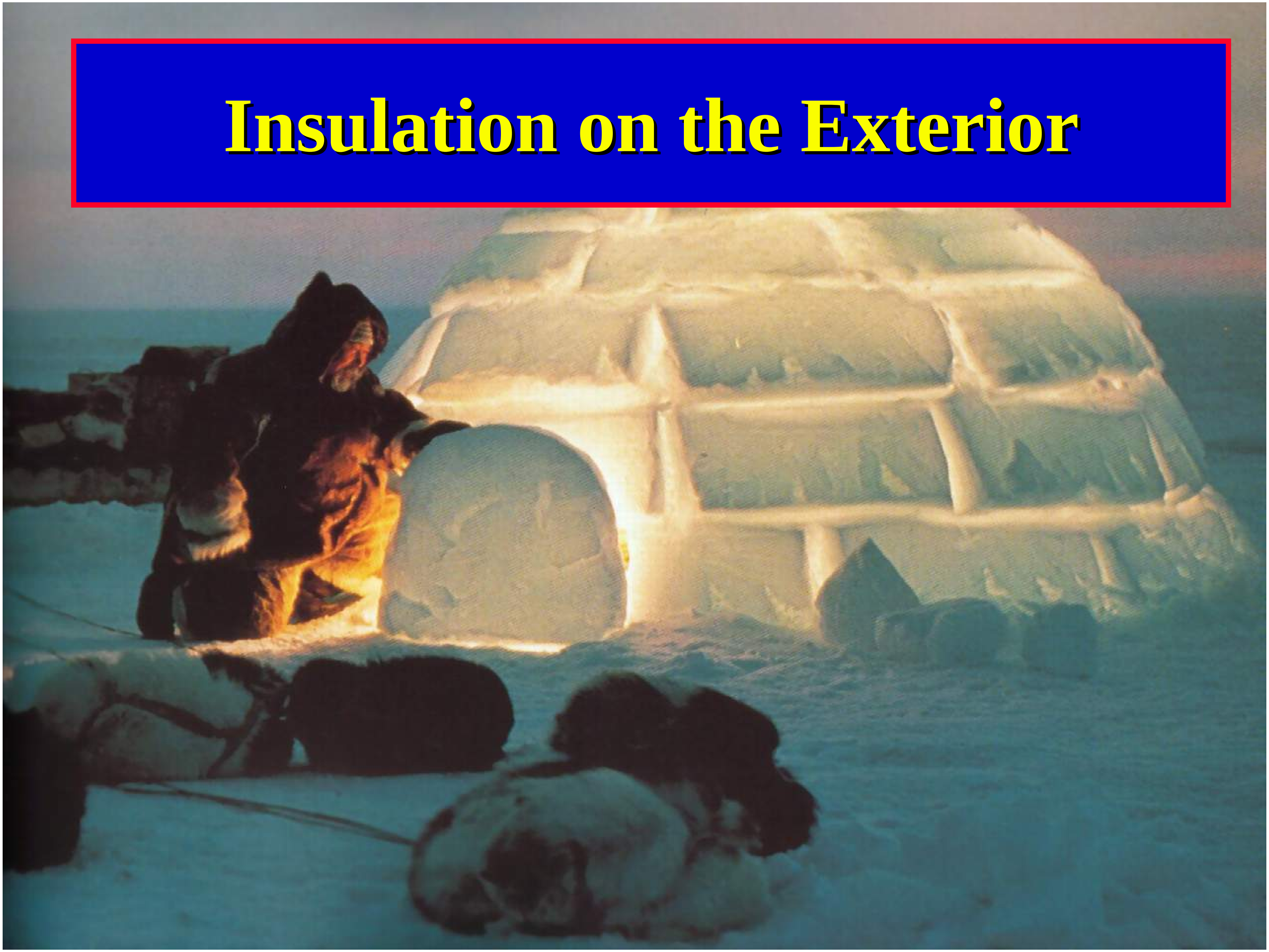
1. Masonry - brick or block; Steel Stud and Drywall (shown); Wood Stud and Drywall; Concrete
2. Masonry; Siding; Panels (metal, stone, ceramic, etc); Precast concrete (shown); Stucco / EIFS
3. Batt (in studspace); Cellulose; Spray Foam
4. Paint or vinyl wallpaper on drywall; Polyethylene; foil-backed drywall; Kraft facing on batt
5. Spray-foam; Trowel- / spray- applied membrane; Sheet membrane

6. terior sheathing; terior sheathing or sheet; ray-foam; owel- / spray- applied; embrane; eet membrane

7. Rigid Fibrous; Expanded Polystyrene; Extruded Polystyrene; Polyurethane Products; Wood Fibreboard; Polyisocyanurate

All on the exterior

Insulation on the Exterior

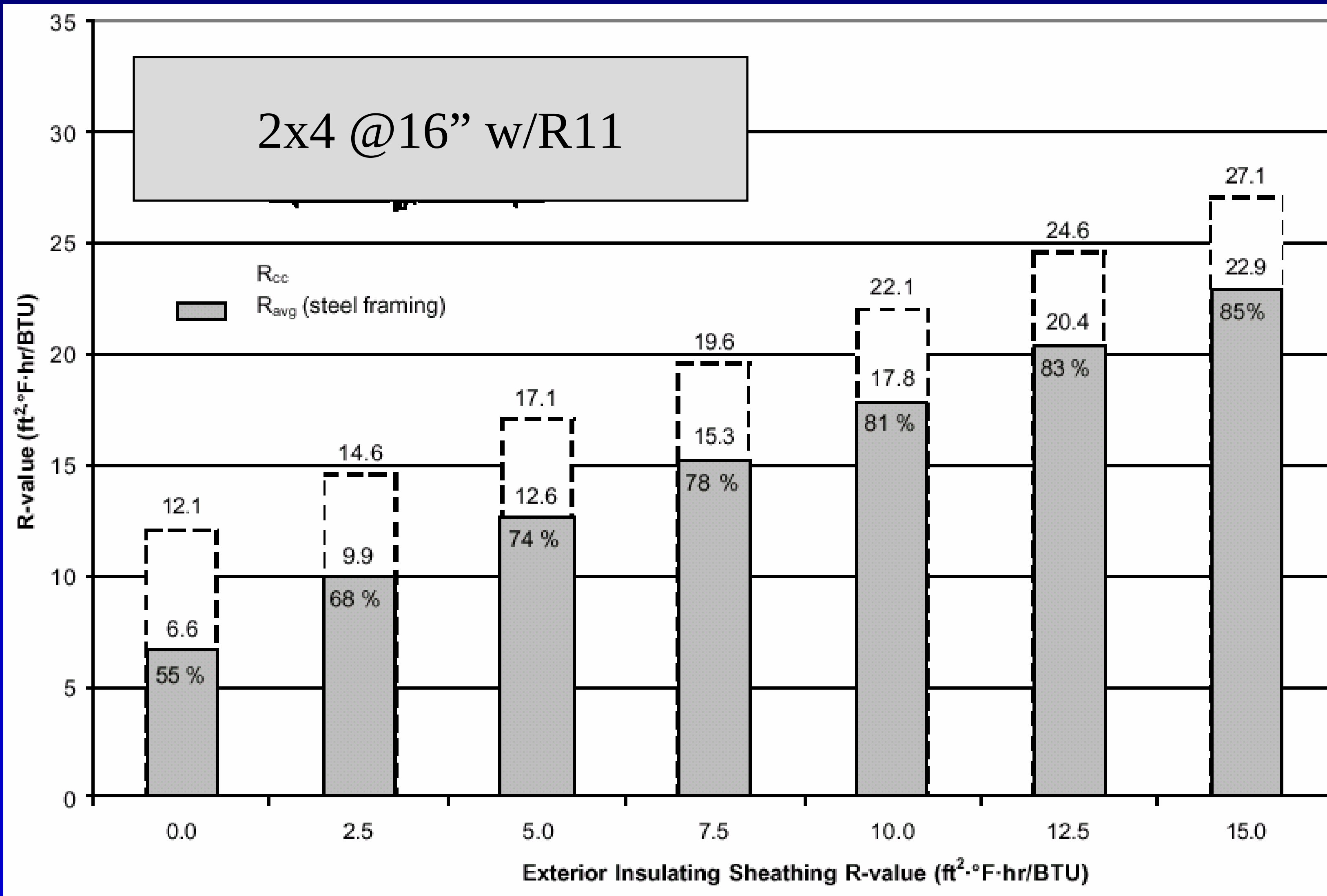



CLADMATE
STYROFOAM

Insulated Sheathing

- Blunts thermal bridges
- Get more R-value than you pay for
- Easiest is to add rigid foam
  - can be EPS, XPS, or PIC, even MFI

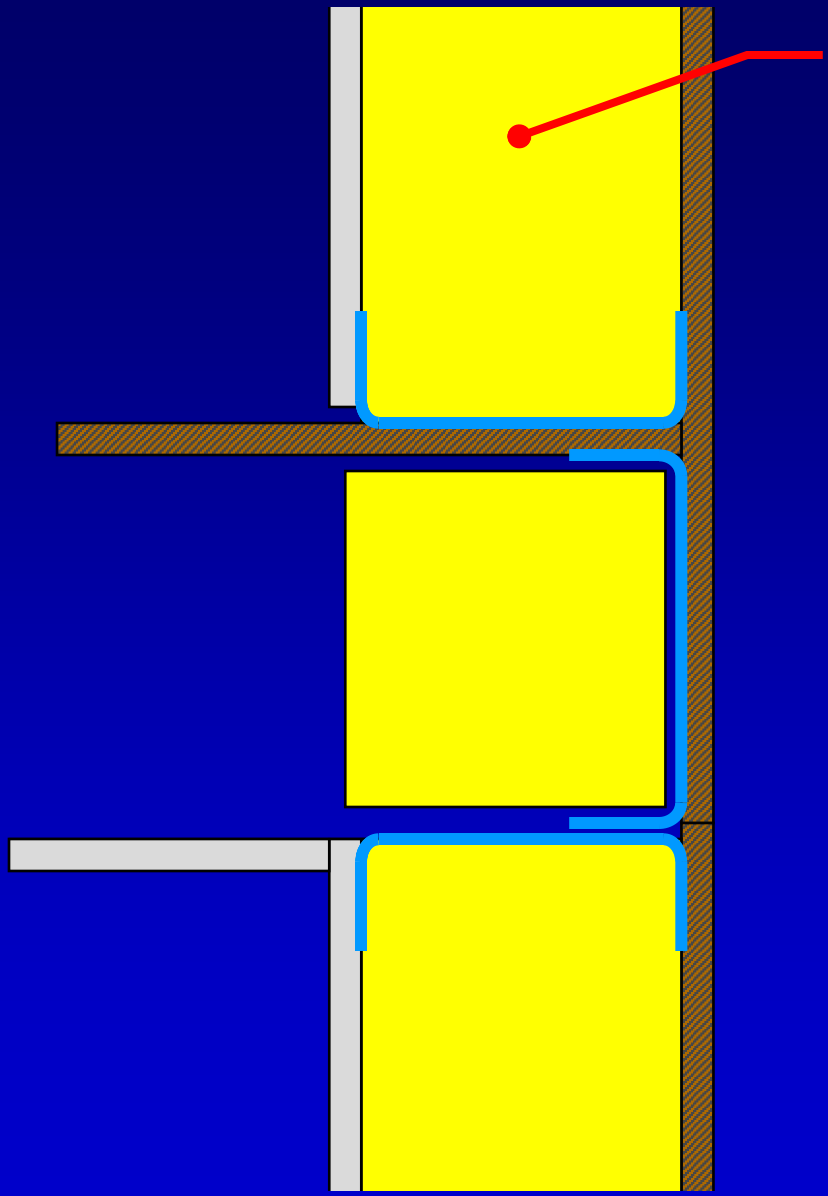
Impact of Insulating Sheathing



traube 2004

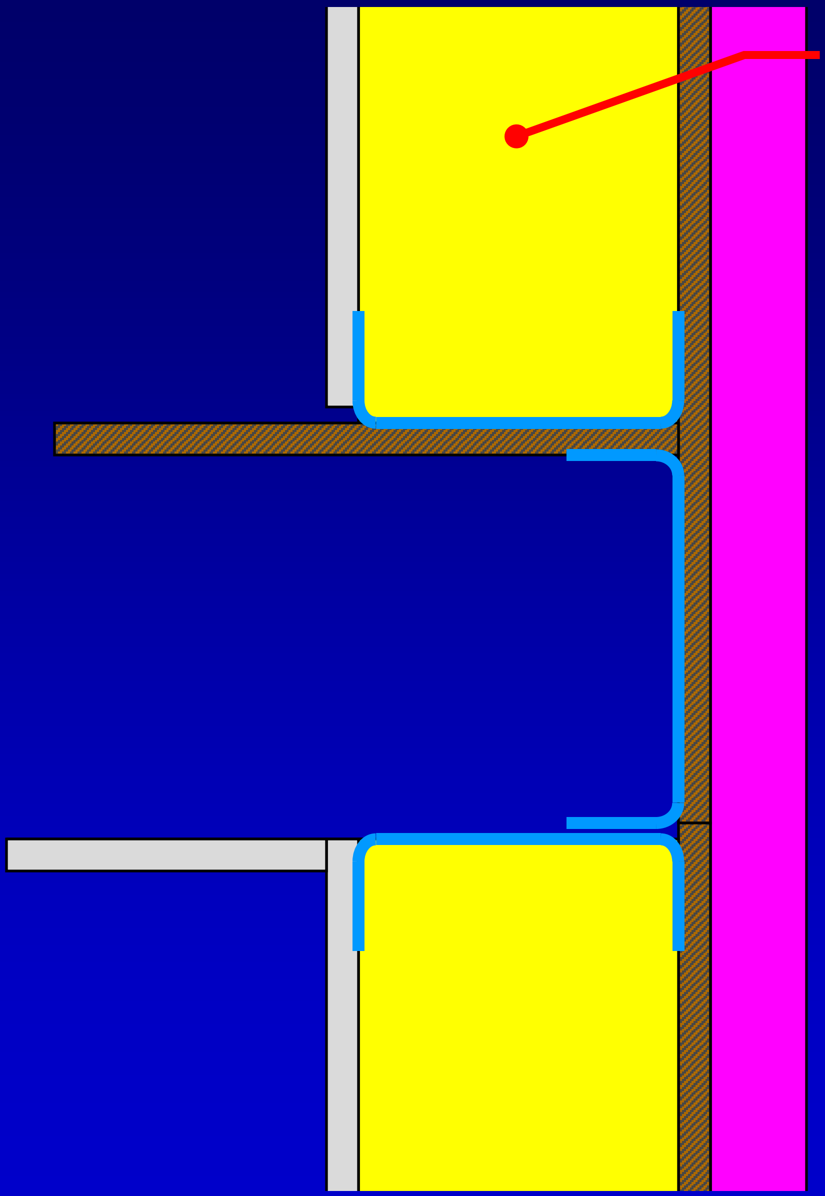
Different Types of R-values

- Center-of studspace (R_{cs})
  - Typical value given. Calculated between framing members
- Clear-wall (R_{cw})
  - More realistic 2-D. Calculations/tests of a section of wall.
- Whole-wall (R_{ww})
  - Most realistic 3-D steady state. Calculations/tests
  - walls with interfaces, corners and openings, doors windows
- True Energy (R_{te})
  - Includes time effects, e.g., 4-D = "mass effect".
  - Dynamic Whole wall
  - Highly climate and building dependent.



E.g. Rim Joists

- Uninsulated Rim Joist
- = thermal nightmare
- Stuffing batts helps little



E.g. Rim Joists

- •Uninsulated Rim Joist
- •= thermal nightmare
- •Stuffing batts helps little

Steel Truss Roofs

- Danger, danger!!

Different Types of R-values

- **Center-of studspace (R_{cs})**
  - **Typical value given. Calculated between framing members**
- **Clear-wall (R_{cw})**
  - **More realistic 2-D. Calculations/tests of a section of wall.**
- **Whole-wall (R_{ww})**
  - **Most realistic 3-D steady state. Calculations/tests**
  - **walls with interfaces, corners and openings, doors windows**
- **True Energy (R_{te})**
  - **Includes time effects, e.g., 4-D = “mass effect”.**
  - **Dynamic Whole wall**
  - **Highly climate and building dependent.**

Typical R-values

Wall Description	$R_{imagine}$	Center of cavity R_{cc}	Clear wall R_{cw}	Whole wall R_{ww}
3.5” SS@16 o.c. R12	12-13	12	7.4	6.1
3.5” SS@16 o.c. R12 + 1” EPS	16-18	16	11.8	9.5
2x6 WS@24 in. o.c., R19 batt	20	19	16.4	13.7
2x4 WS@16 in o.c., R12 batt	12-13	12	10.6	9.6
EPS block forms	15.2	15.2	15.2	15.7
Stressed Skin 6” core	25	25	24.7	21.6

With information from Oak Ridge National Labs

Codes and R-values

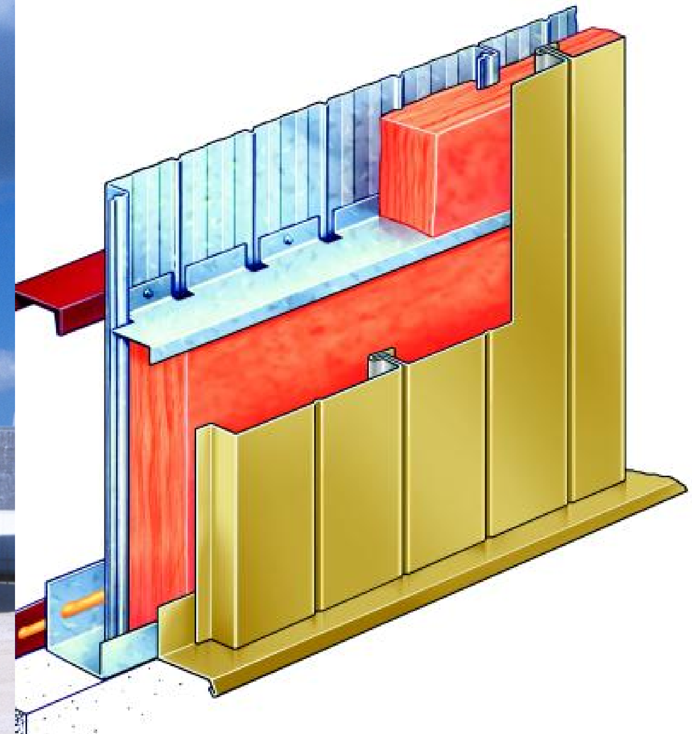
- **Implications: traditional framed walls have usually over-reported R-values**
- **New ASHRAE 90.1 uses clear-wall *plus* mass effect**
- **Most local codes do not consider**

True energy equivalent R-values will vary with climate and building type, but *consumption will always be lower for walls with thermal mass*, and lowest for walls with thermal mass on the inside.

Data Sources

- Oak Ridge National Labs
  - www.ornl.gov/roofs+walls
- Penn Housing Research Center
  - www.phrc.org Phone 814 865 2341
  - Report #58
- AISI
  - Thermal Design Guide for Exterior Walls

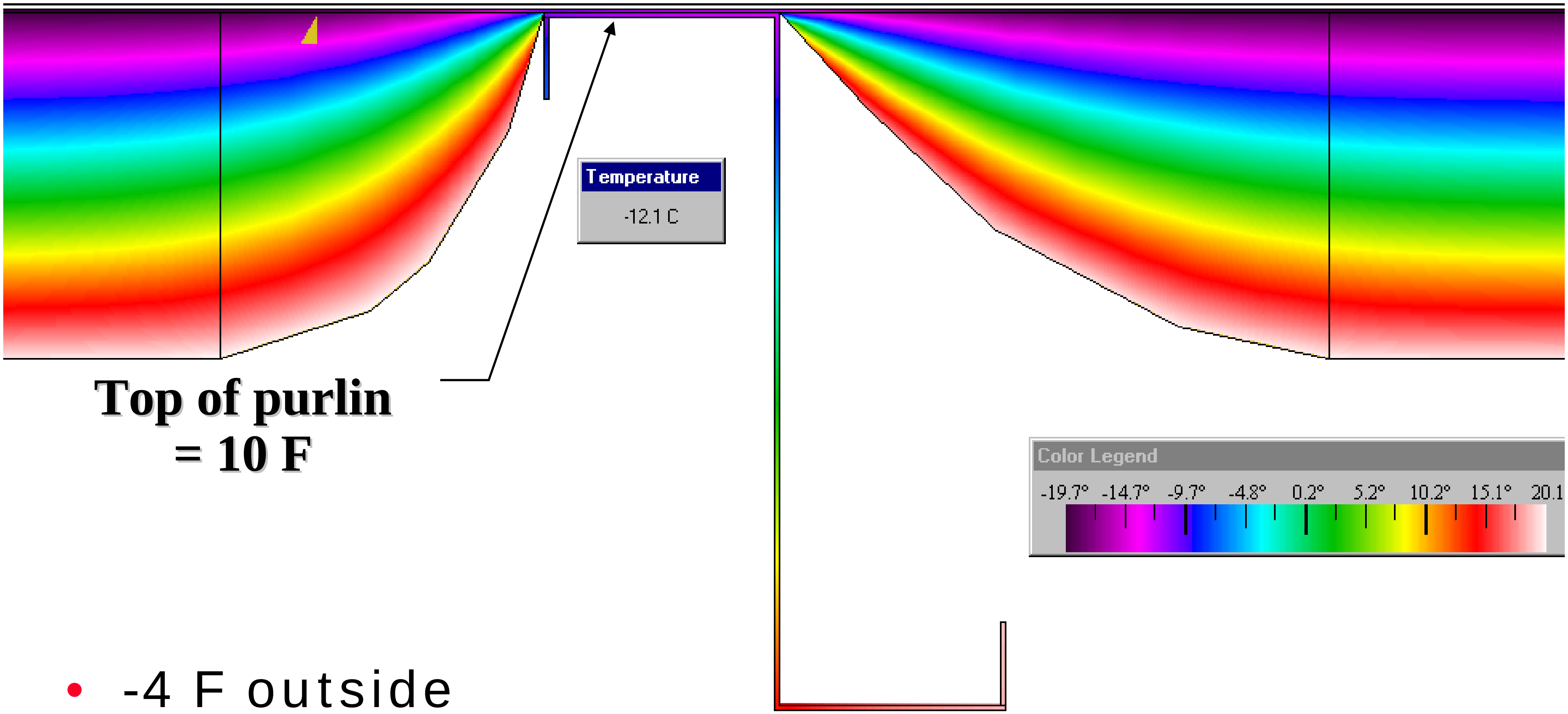
Metal Building Systems




SKY TRAK
SKY TRAK
8042
Legacy
Series

Metal Building Systems

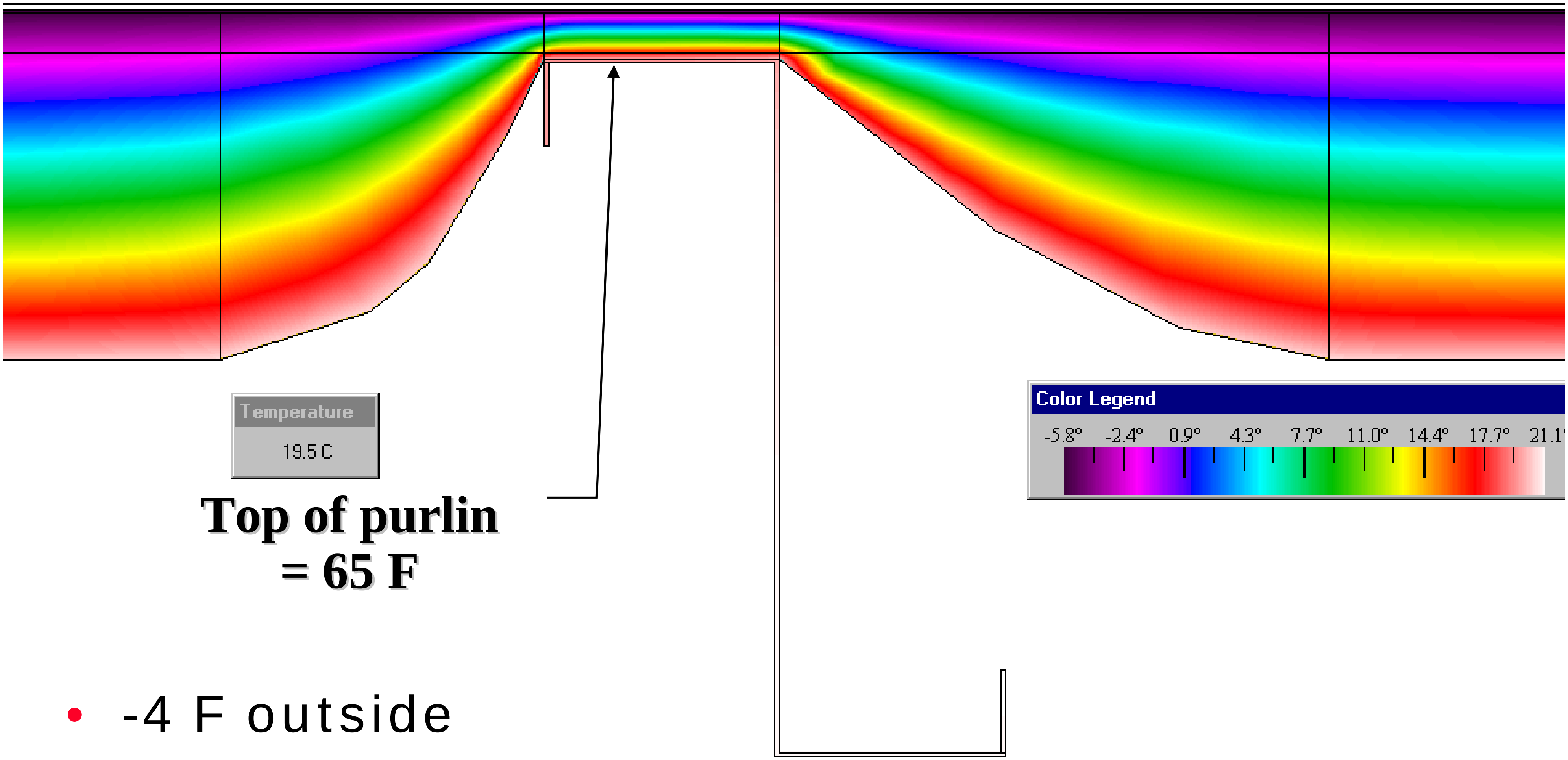
- Metal Building System
  - heavy gauge or hot-rolled structure
  - light gauge purlins, studs
  - “bagged” insulations
- Serious Thermal Bridges
  - related problems with comfort and moisture
  - Mainframing
  - At fnd
  - Purlins
- Consume lots of Energy
  - owners may accept this



Top of purlin = 10 F

- -4 F outside
- 71 F inside

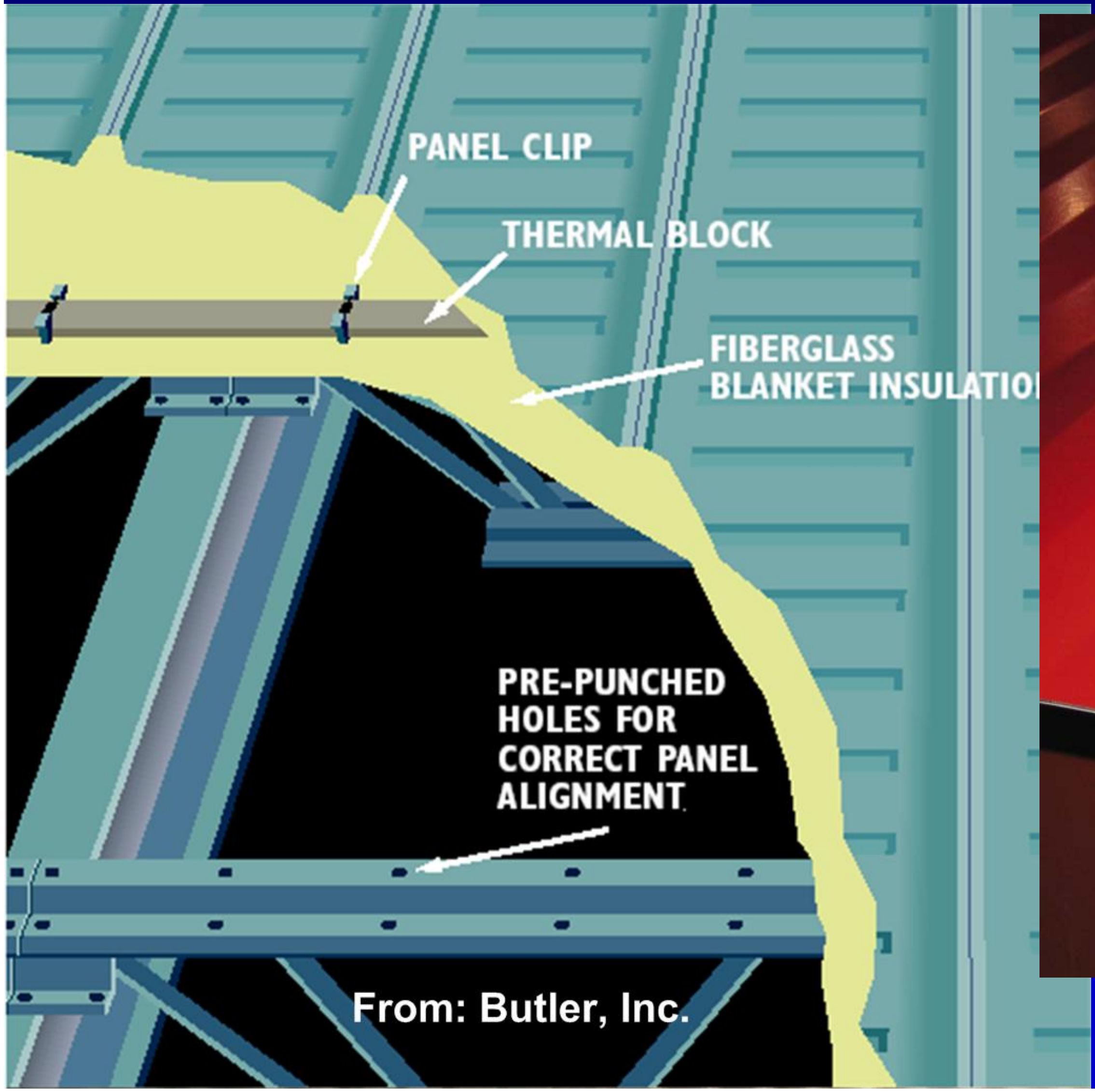
•Two-D steady state temperature and heatflow calculation



- -4 F outside
- 71 F inside

- **Add 1”/25 mm (R6.5) polyiso to exterior**

Thermal blocks

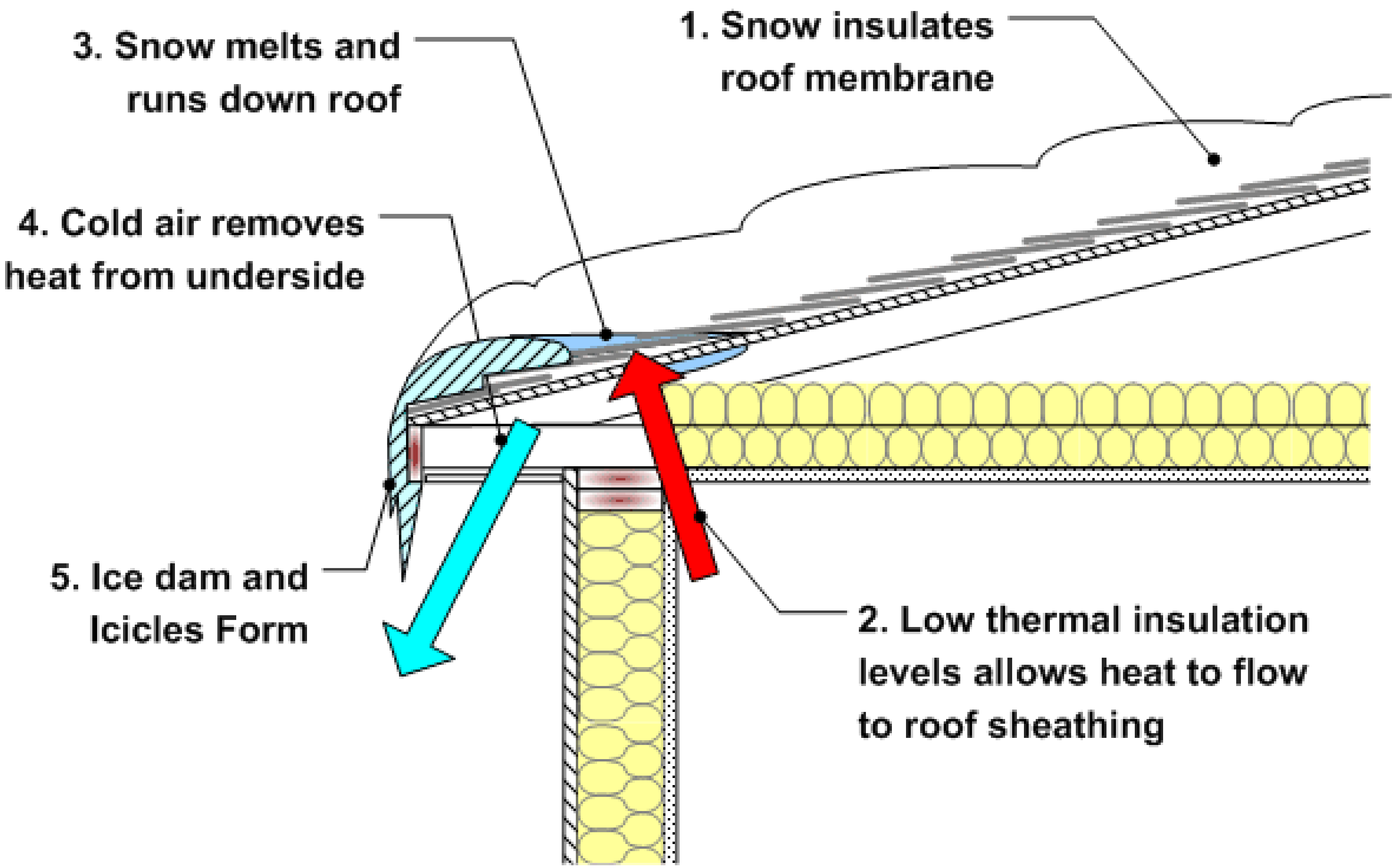


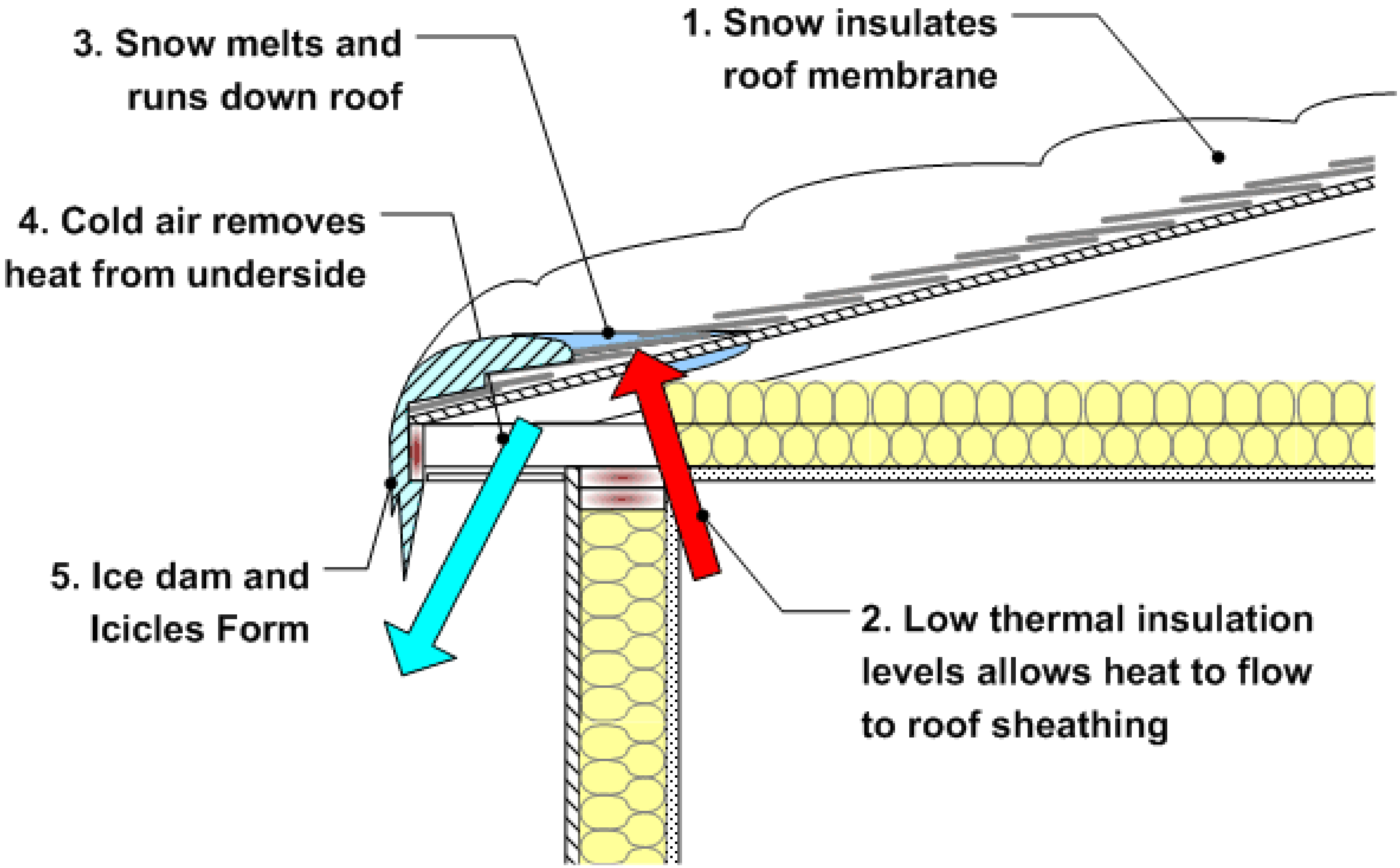
Vermont Code

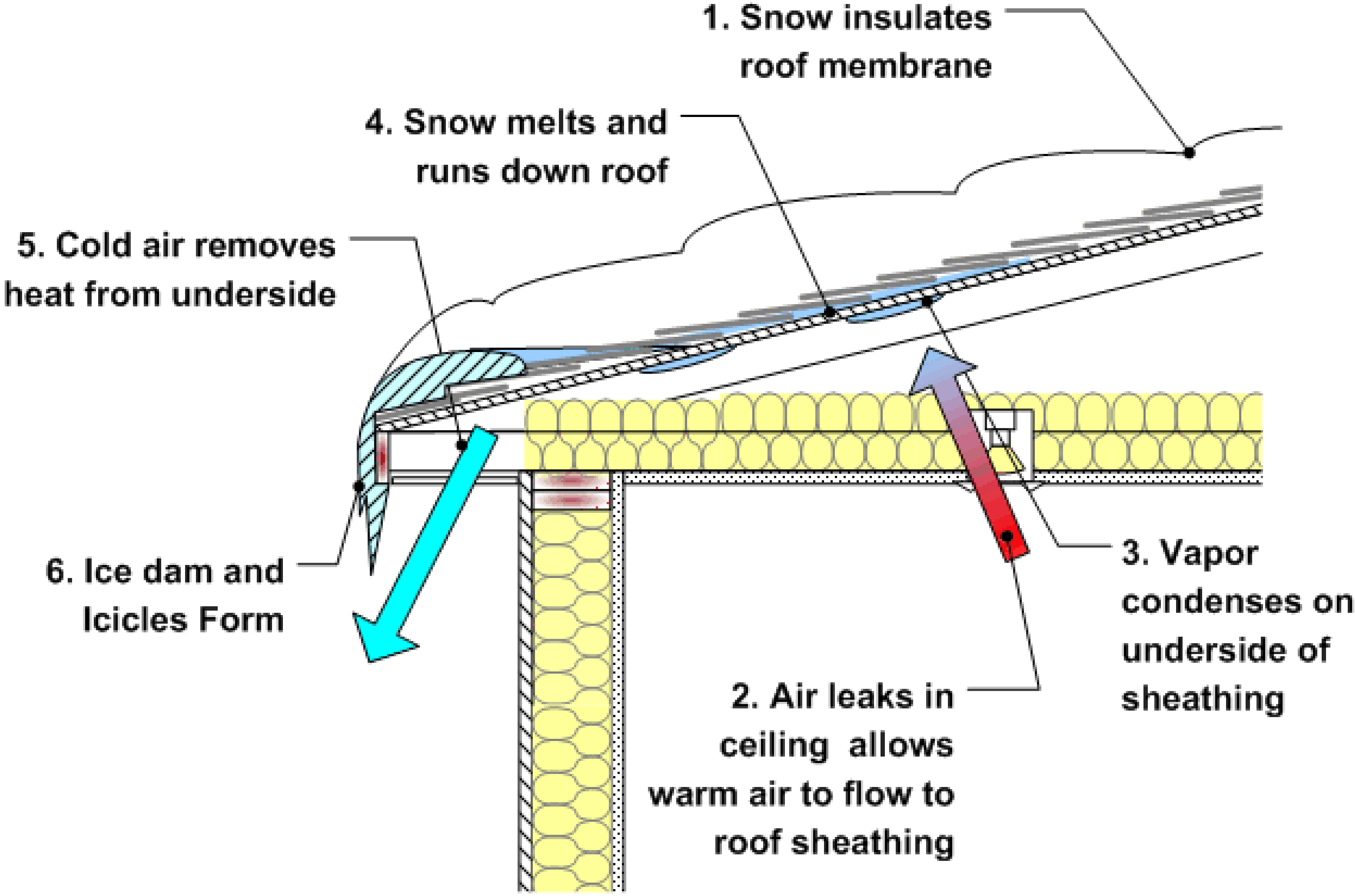
- Requires a thermal block between roof purlin and a metal roof
- This saves lots of energy, but also avoids condensation and ice dams

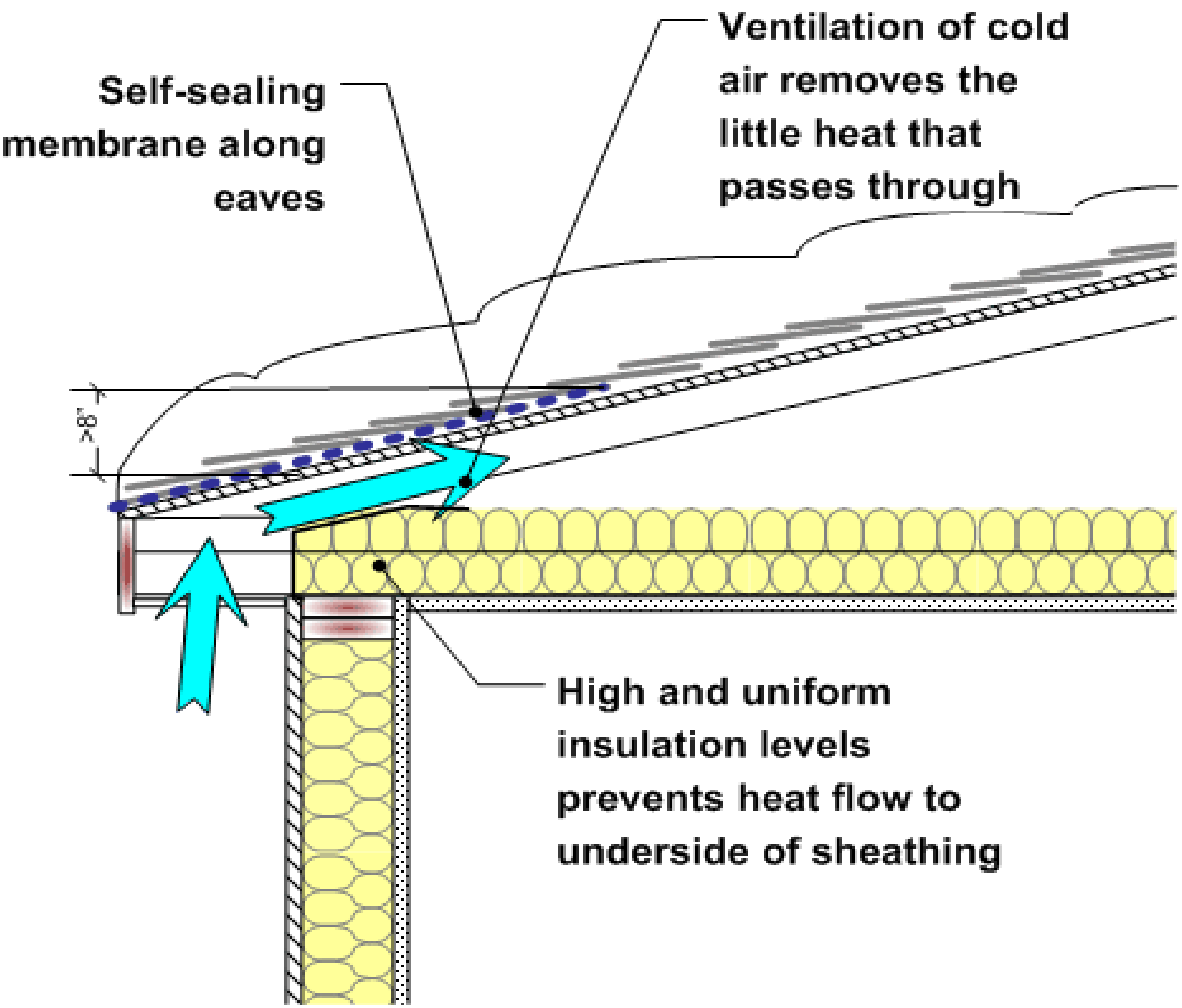
#54

Ice Dams


1. Snow insulates roof membrane
2. Low thermal insulation levels allows heat to flow to roof sheathing
3. Snow melts and runs down roof
4. Cold air removes heat from underside
5. Ice dam and Icicles Form


3. Snow melts and runs down roof
1. Snow insulates roof membrane
4. Cold air removes heat from underside
5. Ice dam and Icicles Form
2. Low thermal insulation levels allows heat to flow to roof sheathing


1. Snow insulates roof membrane
4. Snow melts and runs down roof
5. Cold air removes heat from underside
6. Ice dam and Icicles Form
3. Vapor condenses on underside of sheathing
2. Air leaks in ceiling allows warm air to flow to roof sheathing

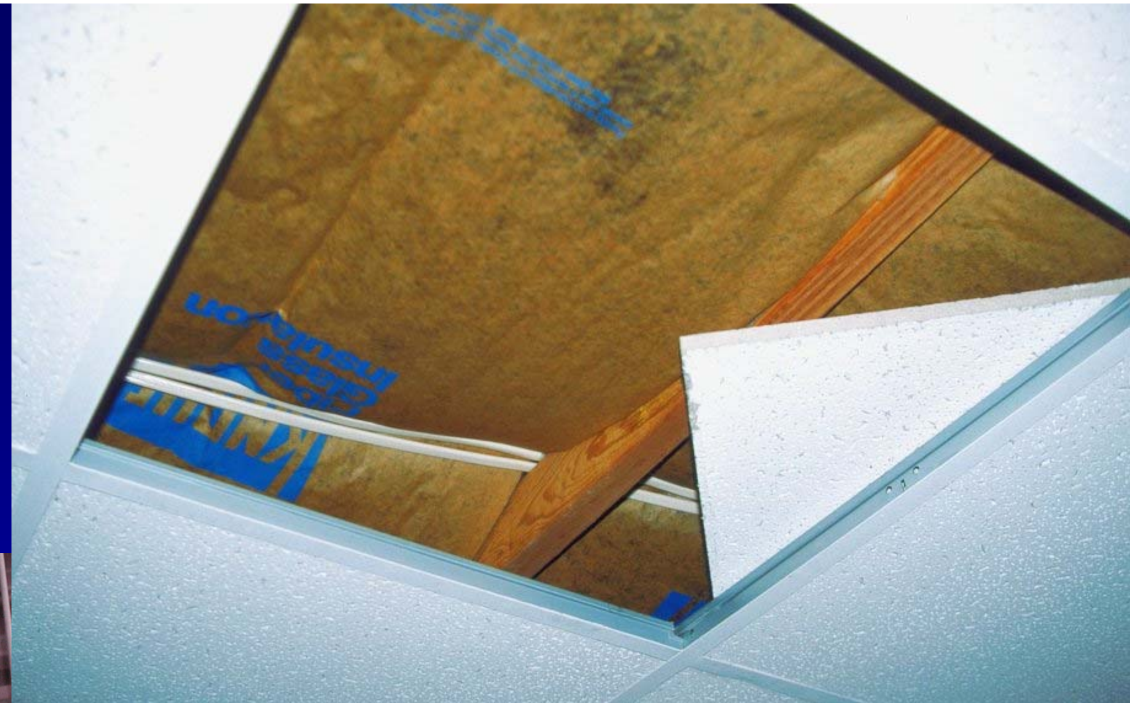

Self-sealing membrane along eaves
Ventilation of cold air removes the little heat that passes through
>8"
High and uniform insulation levels prevents heat flow to underside of sheathing

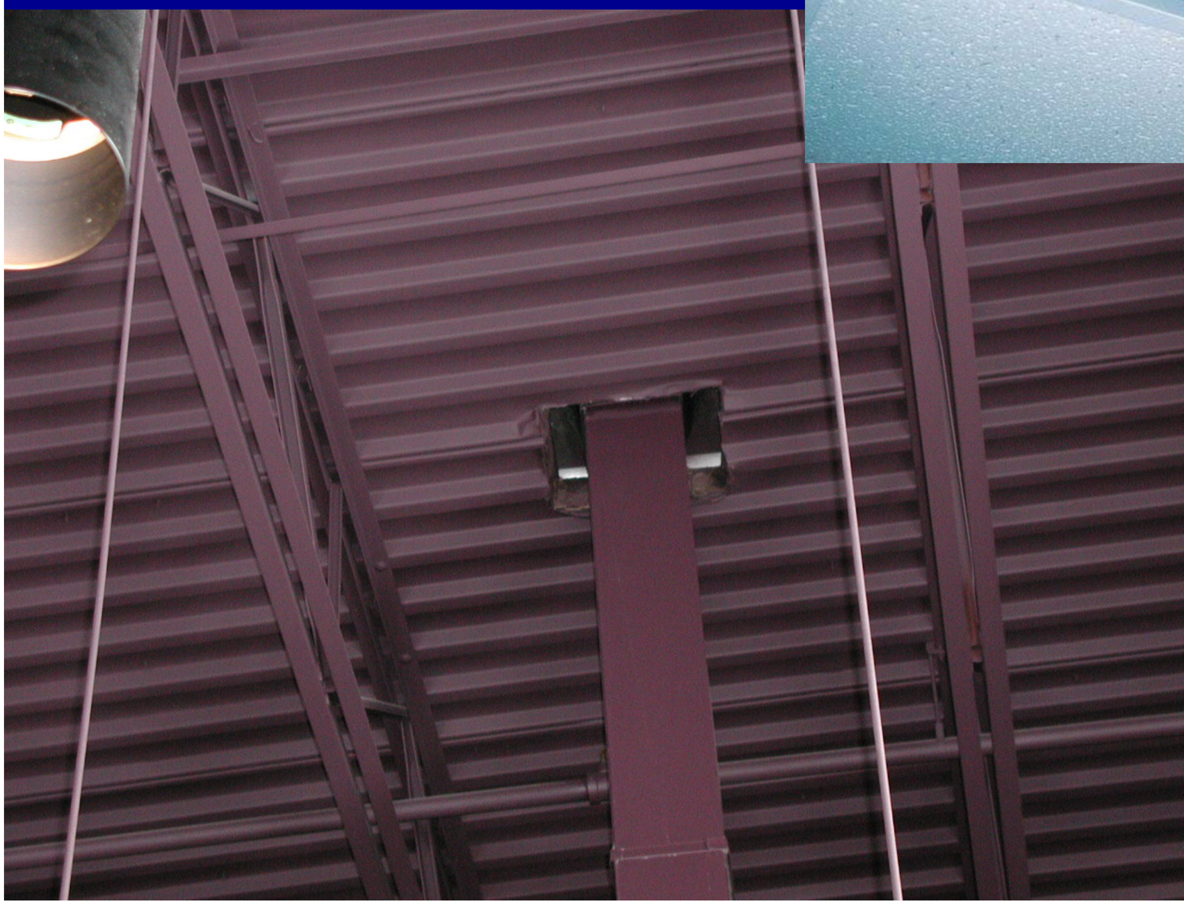

Tyvek
HomeWrap
Tyvek
HomeWrap
Tyvek
HomeWrap

Air flow control

- Bagged insulation allows easy airflow
- Cracks and openings allow
- Small cracks are bad, big holes are worse
- Wind, stack and mechanical equipment generate the pressures

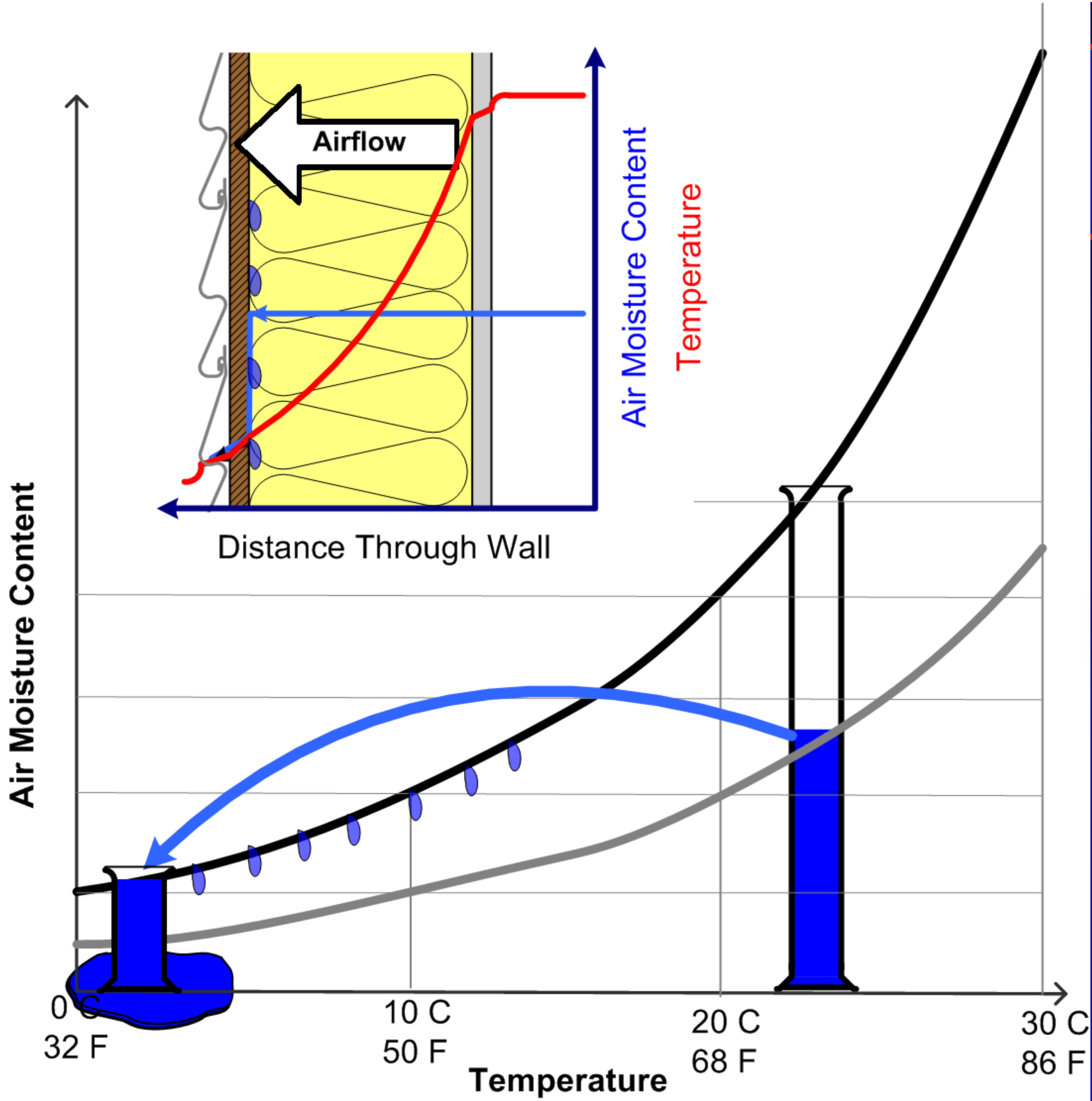
Bigholes

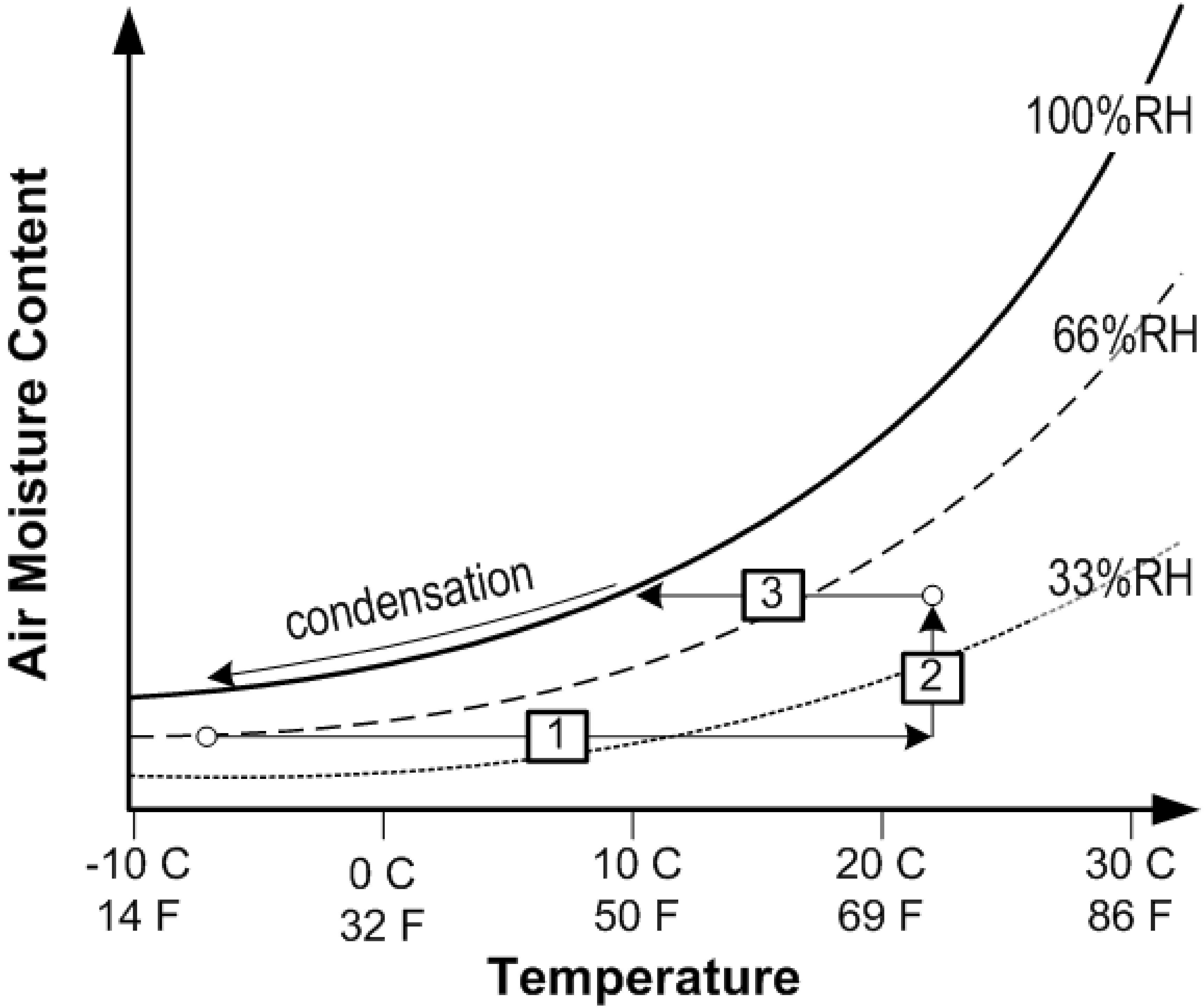




Bigholes

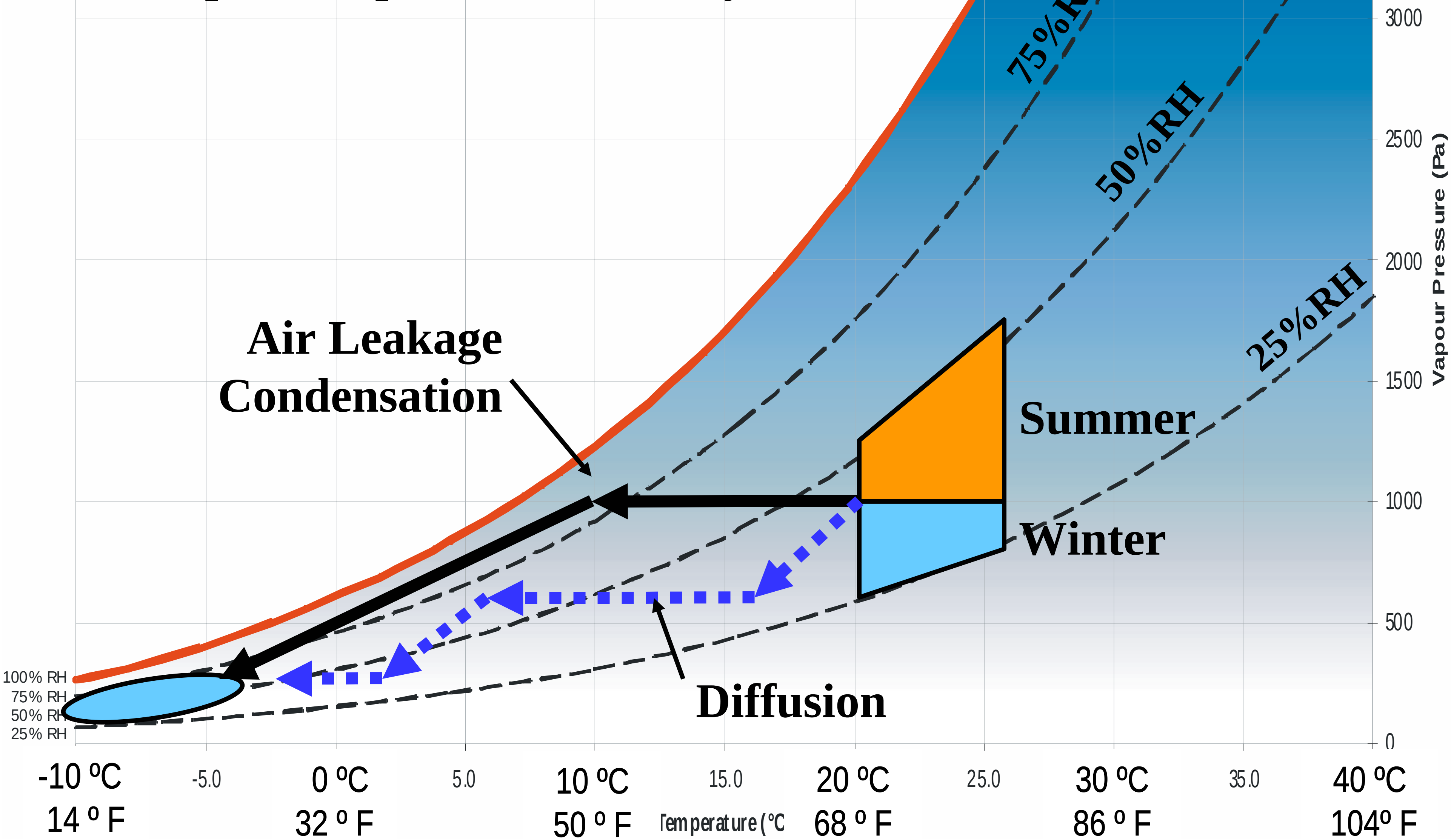
Airsealing


Airflow
Air Moisture Content
Temperature
Distance Through Wall
Air Moisture Content
0 C
32 F
10 C
50 F
20 C
68 F
30 C
86 F
Temperature

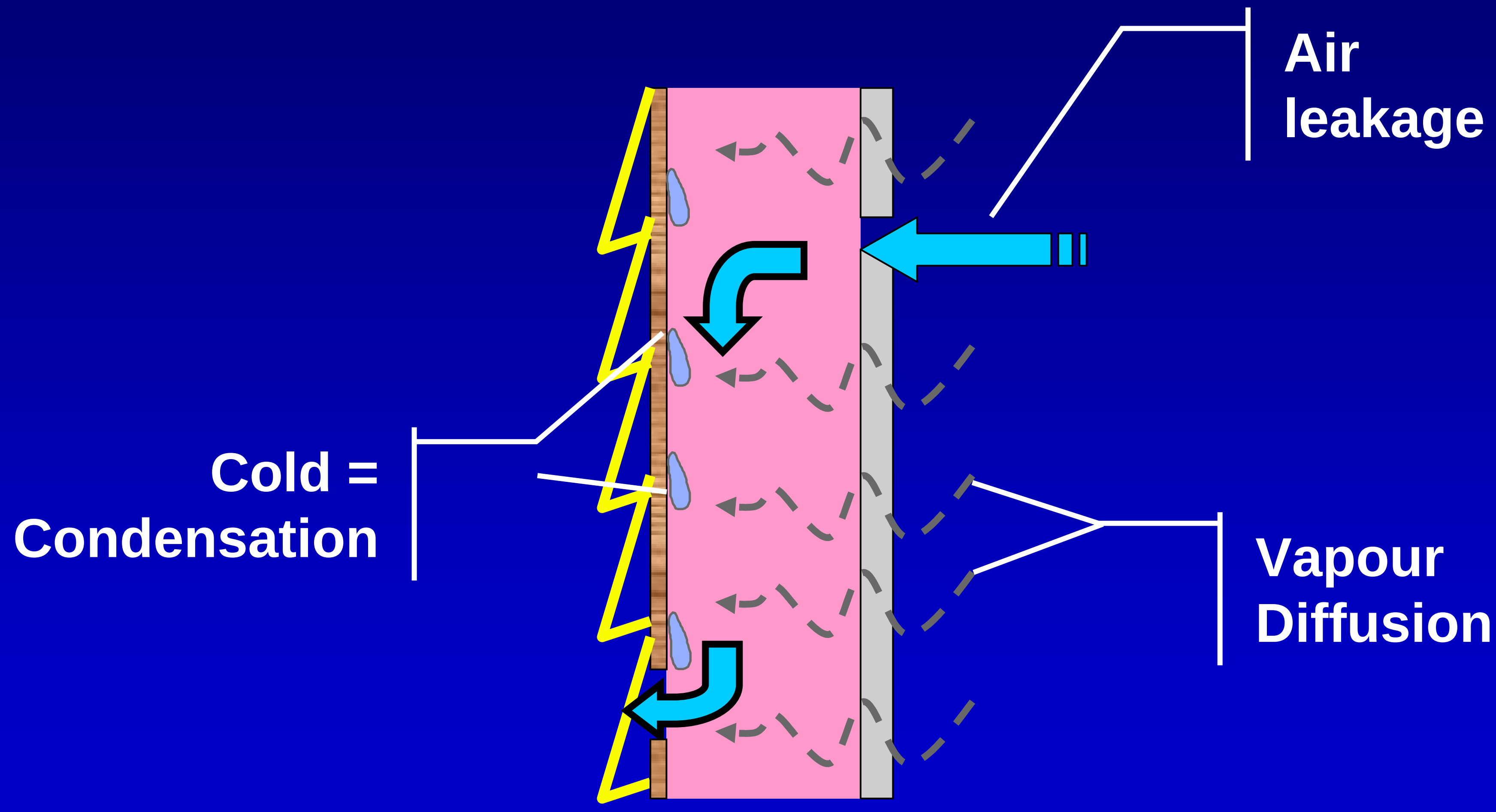

100%RH
66%RH
33%RH
condensation
3
2
1
Air Moisture Content
-10 C
14 F
0 C
32 F
10 C
50 F
20 C
69 F
30 C
86 F
Temperature

Air Leakage vs Diffusion

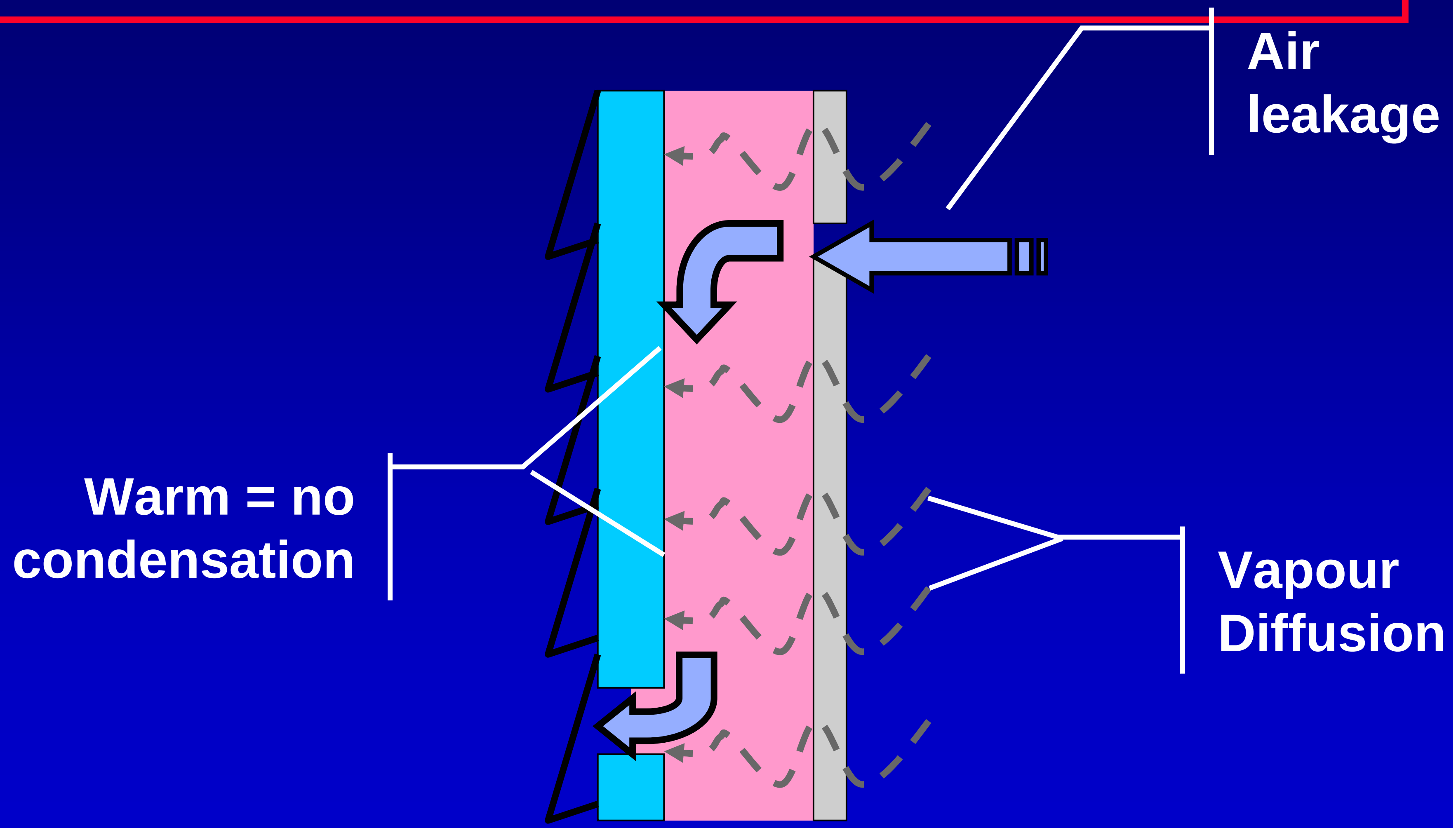
- Air barrier systems essential
- Low perm vapor barrier rarely needed



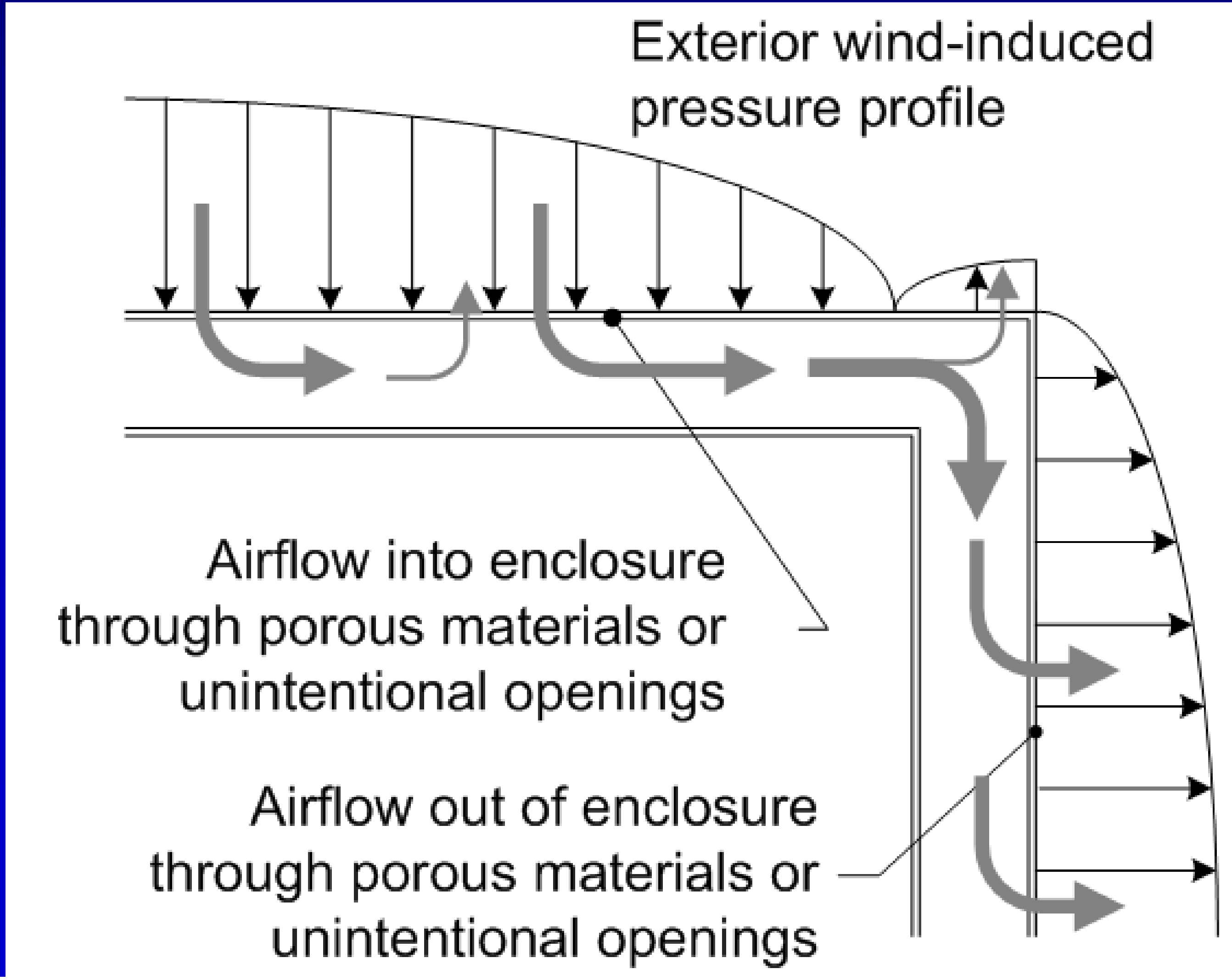
Wall w/o Insulated Sheathing



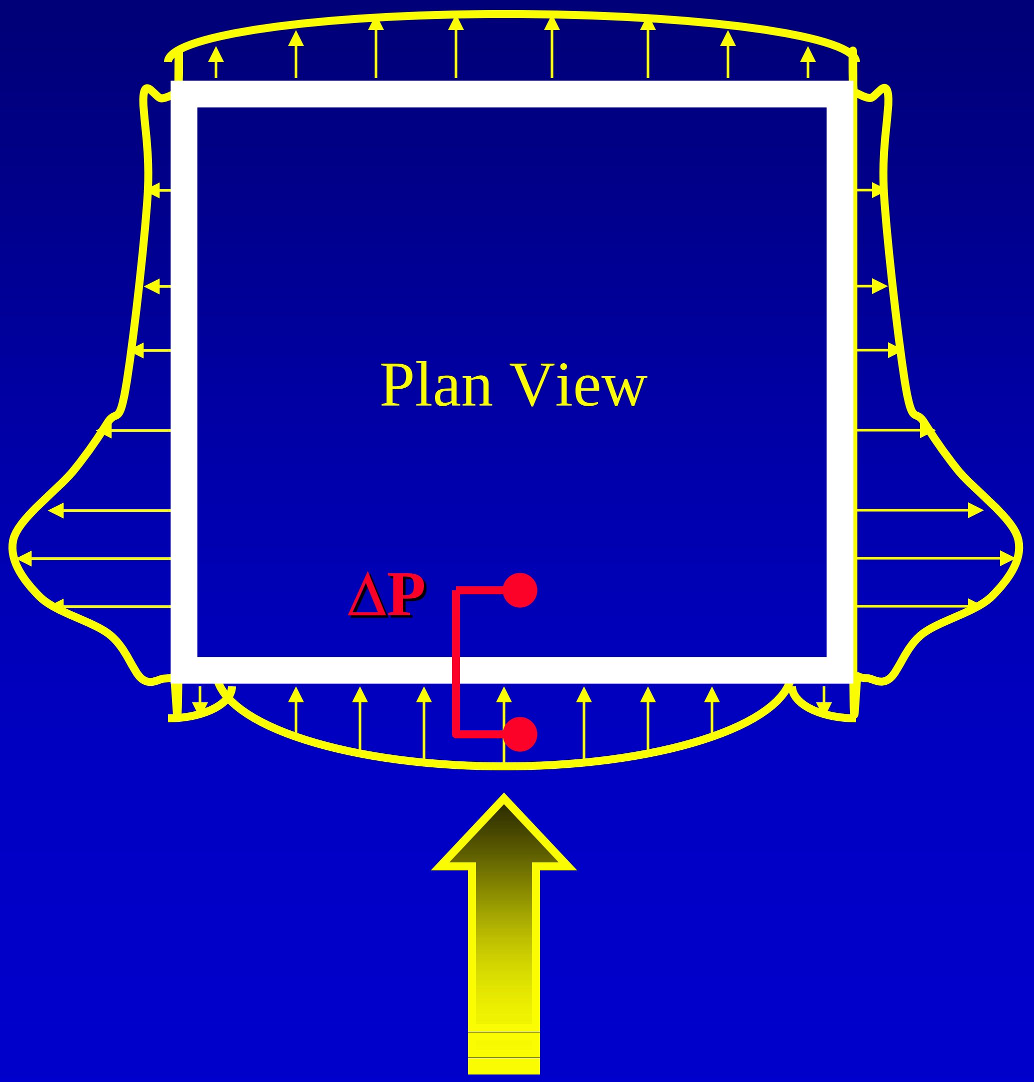
Wall with Insulated Sheathing



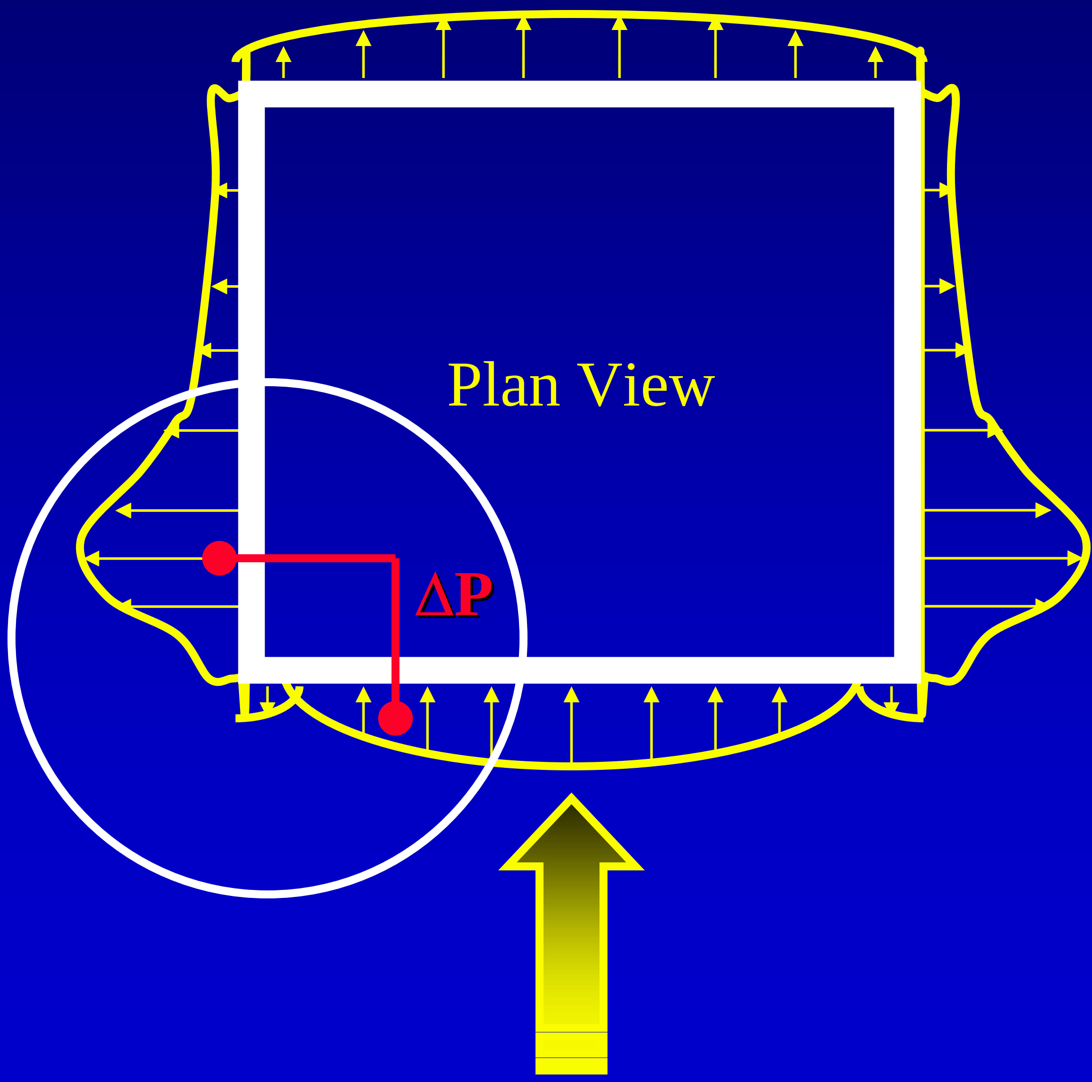
Windwashing



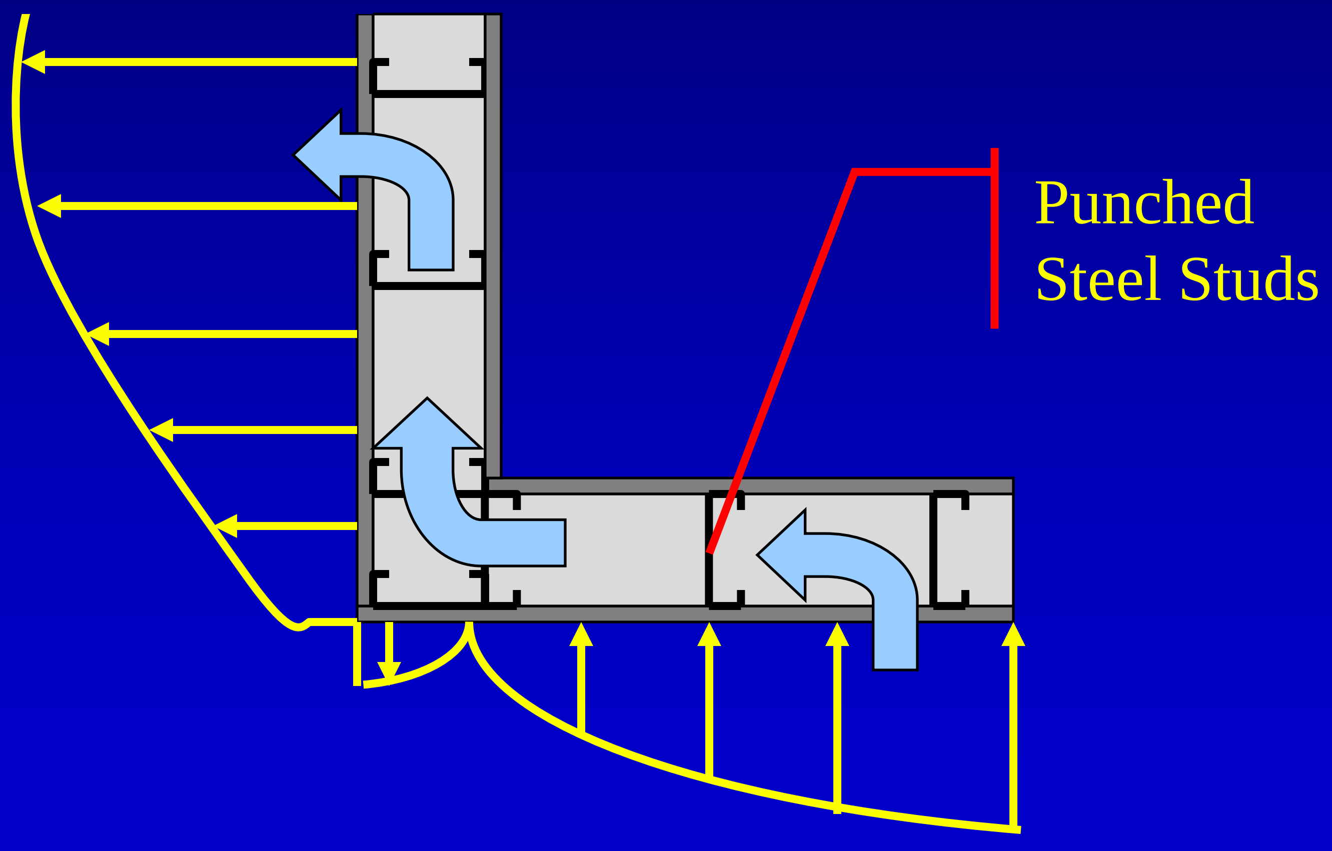
Pressure Distribution



Pressure Distribution

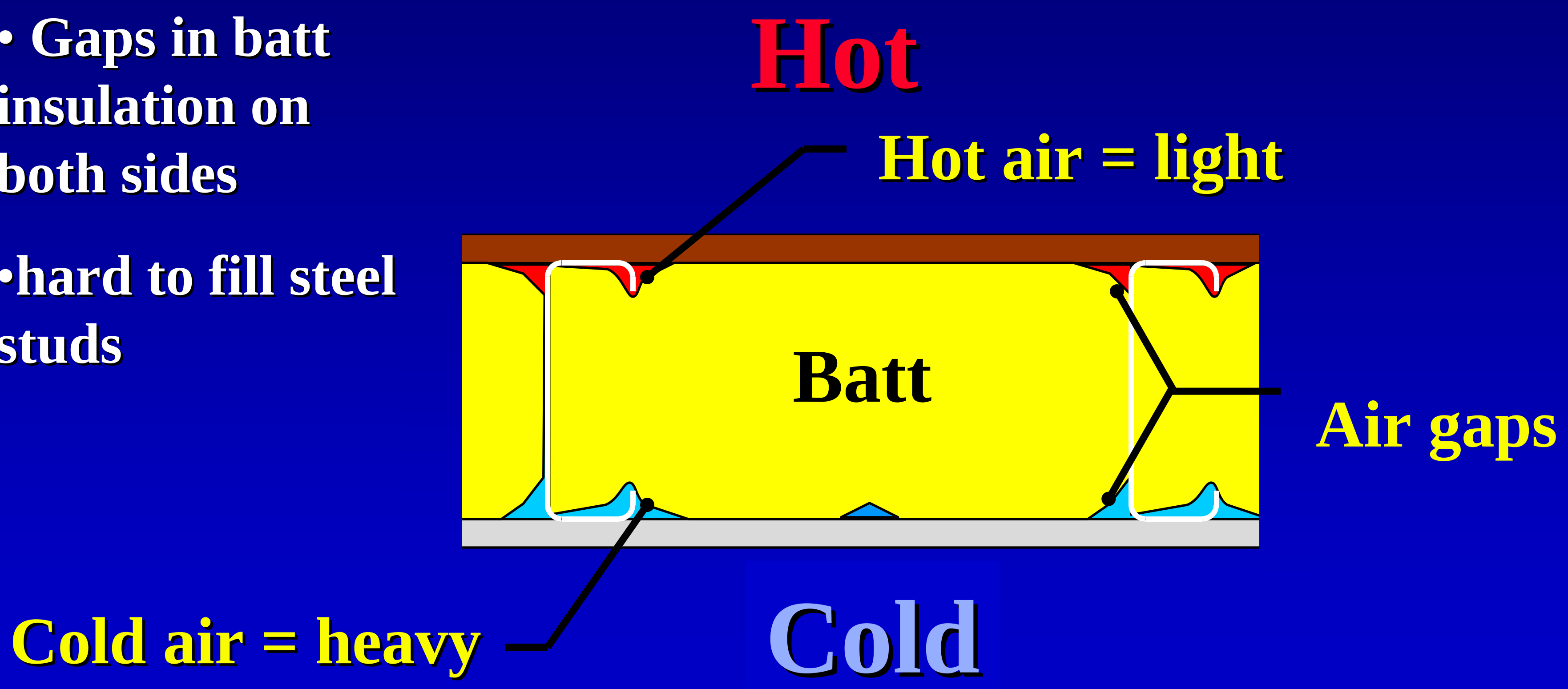


Lateral Airflows - windwashing



Internal Stack Effect & Insulation

- Gaps in batt insulation on both sides
- hard to fill steel studs



Common performance problem

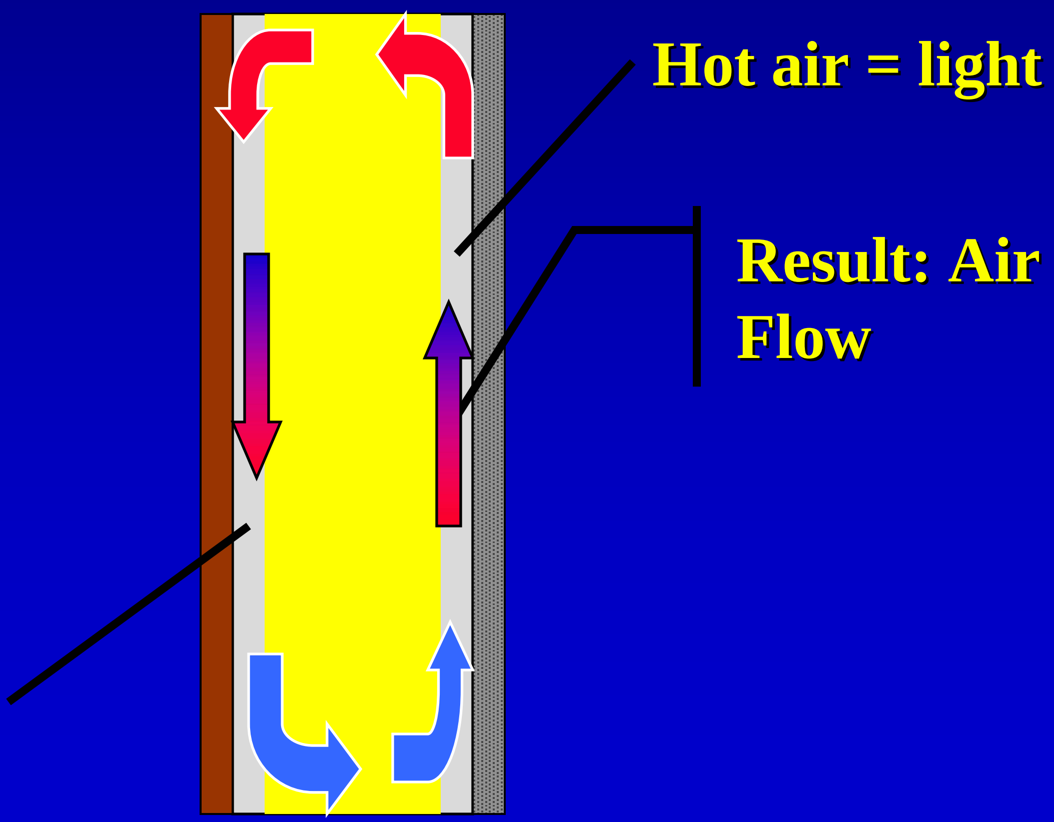
Internal Stack Effect

• Gaps in batt insulation on both sides

• closed circuit

• energy cost

• cold surfaces



Conclusions

- Metal enclosures can be energy-efficient and control condensation BUT, this requires
  - Exterior Insulation
  - Air barrier system (as for other systems)
  - Rain Control (as for other systems)