



Water Entry Prevention and Moisture Control in Buildings
Lincoln, Nebraska – October 28-29, 2015

Condensation Control in
Low- and Steep-slope Roofing



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My topics

- Principles/fundamentals (for roofing)
- Condensation control:
 - Low-slope roof assemblies
 - Steep-slope roof assemblies
- Thermal insulation
- Energy code

*Questions are welcome at any time...
continuing dialog is important*



Principles/fundamentals



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Some basic terminology


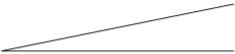
Roof assembly: an assembly of interacting roof components including the roof deck, air and vapor retarder (if present), insulation and membrane or primary roof covering designed to weatherproof a structure.

Roof system: A system of interacting roof components generally consisting of a membrane or primary roof covering and roof insulation (not including the roof deck) designed to weatherproof and sometimes improve the building's thermal resistance.




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Roof slope
"incline", not "pitch"

 <p>Low slope 2:12 or less Hydrostatic Waterproof Membrane roof coverings</p>	 <p>Steep slope 4:12 or greater Hydrokinetic Water shedding Shingle-type roof coverings</p>
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Roof slopes from 2:12 to 4:12 become somewhat of a "no person's land" and are best avoided



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Roof product/system choices – Low slope



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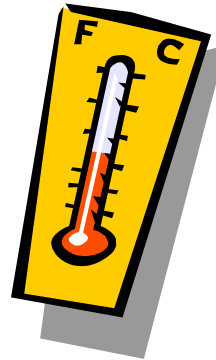
Moisture sources in buildings

- Construction moisture
- Building occupancy
- Building envelope infiltration
- Reflective roof coverings



Phases of moisture

- **Gas phase** -- moisture vapor
 - Above 212 F
- **Liquid phase** -- water
 - 32 F to 212 F
- **Solid phase** -- frost or ice
 - Below 32 F



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Humidity

The amount of water vapor in the air.

Relative humidity

Relative humidity is defined as the ratio of the partial pressure of water vapor in a parcel of air to the saturated vapor pressure of water vapor at a prescribed temperature.



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Condensation temperature

Dew point

The temperature at which the air can now longer hold all of its water vapor, and some of the water vapor must condense into liquid water.

At 100% relative humidity, the dew point temperature and real temperature are the same, and condensation begins to form.



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Comparing humidity & dew point

While relative humidity is a relative measure of how humid it is, the dew point temperature is an absolute measure of how much water vapor is in the air (how humid it is).



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Psychrometrics

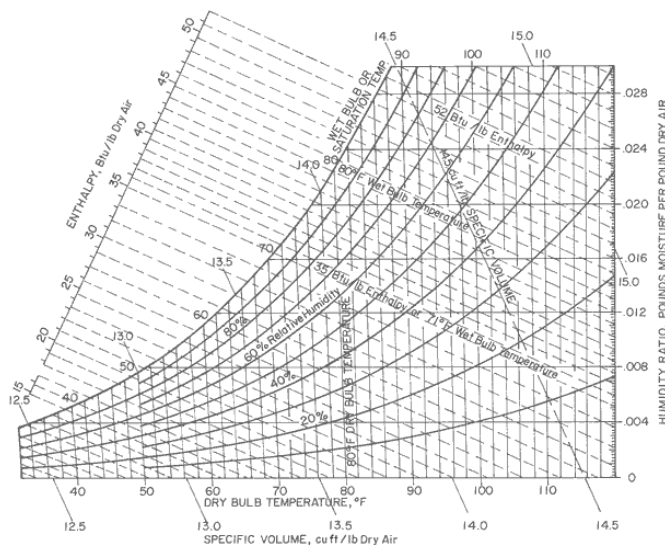
The field of engineering concerned with the determination of physical and thermodynamic properties of gas-vapor mixtures.

Derived from the Greek *psuchron* meaning "cold" and *metron* meaning "means of measurement".

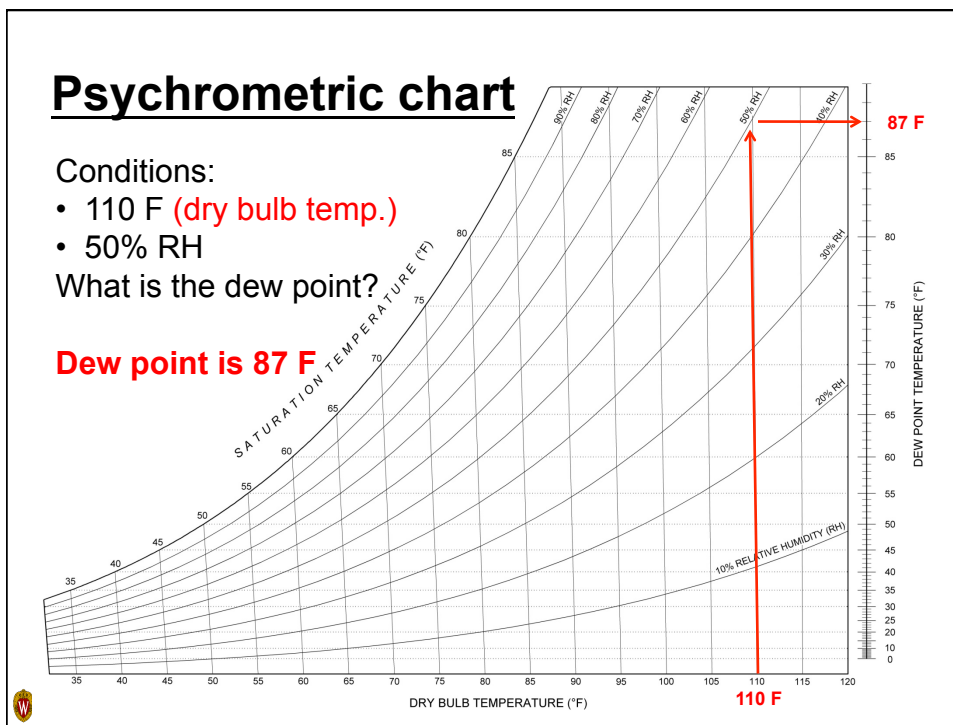
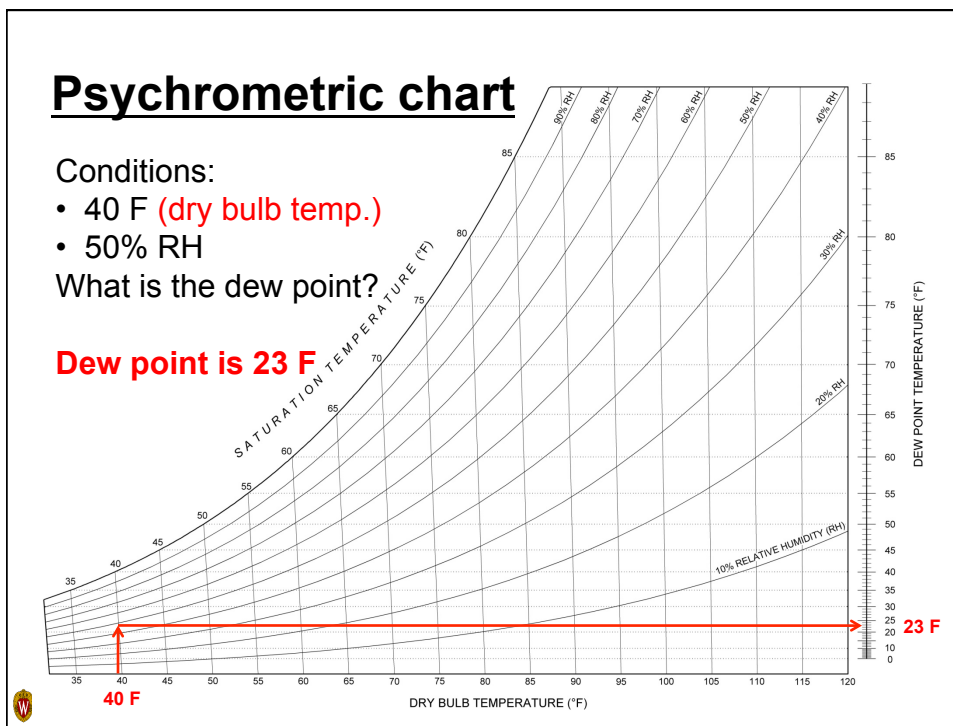


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Psychrometric chart



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Psychrometric “table”

Relative Humidity	Dew-Point Temperature (°F)															
	Design Dry Bulb (Interior) Temperature (°F)															
	32°F	35°F	40°F	45°F	50°F	55°F	60°F	65°F	70°F	75°F	80°F	85°F	90°F	95°F	100°F	
100%	32	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
90%	30	33	37	42	47	52	57	62	67	72	77	82	87	92	97	
80%	27	30	34	39	44	49	54	58	64	68	73	78	83	88	93	
70%	24	27	31	36	40	45	50	55	60	64	69	74	79	84	88	
60%	20	24	28	32	36	41	46	51	55	60	65	69	74	79	83	
50%	16	20	24	28	33	36	41	46	50	55	60	64	69	73	78	
40%	12	15	18	23	27	31	35	40	45	49	53	58	62	67	71	
30%	8	10	14	16	21	25	29	33	37	42	46	50	54	59	62	
20%	6	7	8	9	13	16	20	24	28	31	35	40	43	48	52	
10%	4	4	5	5	6	8	9	10	13	17	20	24	27	30	34	

Adapted from ASHRAE Psychrometric Chart, 1993 ASHRAE Fundamentals Handbook.



*Warm air can hold more moisture
than cold air*



Thermodynamics

In physics, the study of energy conversion between heat and mechanical work, and subsequently the macroscopic variables such as temperature, volume and pressure.

Derived from the Greek *therme* meaning "heat" and *dynamis* meaning "power".



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First law of thermodynamics

Energy can be transformed (changed from one form to another), but cannot be created or destroyed.

Law of conservation of energy



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Second law of thermodynamics

The entropy of an isolated system which is not in equilibrium will tend to increase over time, approaching a maximum value at equilibrium.

Heat → Cold



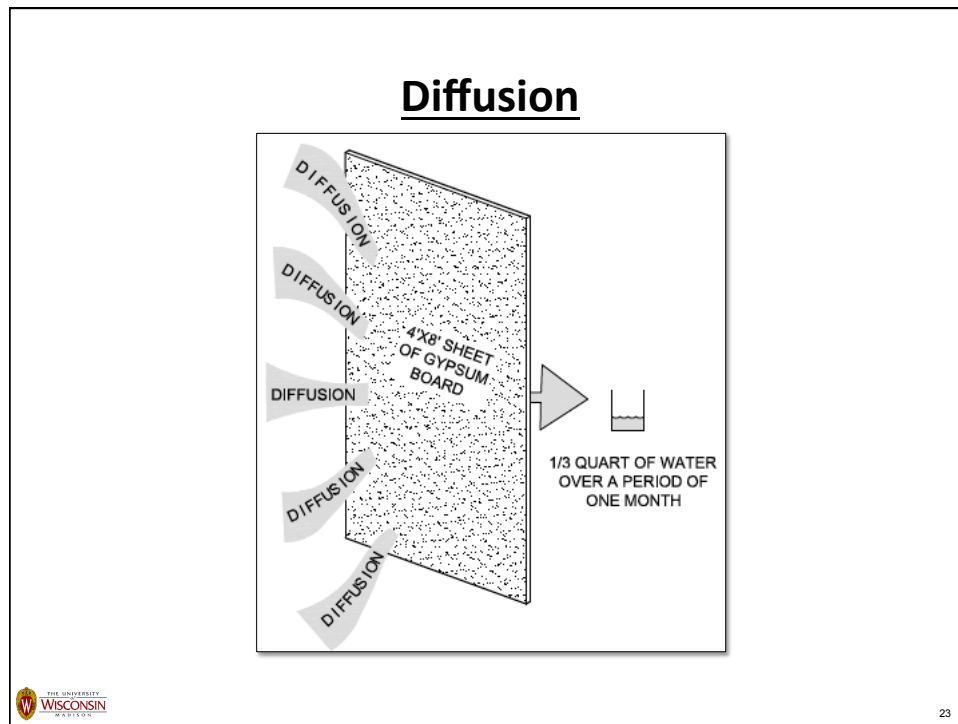
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A practical application of these principles

Water droplets (condensation) on the outside of a container of cold liquid



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Diffusion terminology

Permeability: the time rate of vapor transmission through a flat material of a unit thickness induced by vapor pressure difference between two specific surfaces under specified temperature and humidity.

Expressed as “perm-inch” units

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Diffusion terminology

Permeance: the time rate of vapor transmission through a flat material or construction assembly induced by vapor pressure difference between two specific surfaces under specified temperature and humidity.

Expressed as “perm” units



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<u>Material</u>	<u>Permeance</u> (perm) ¹	<u>Permeability</u> (perm-inch) ¹
Construction materials:		
Concrete (1:2:4 mix)		3.2
Brick masonry (4 in. thick)	0.8	
Concrete block (8 in. thick, cored)	2.4	
Plaster on metal lath (½ in. thick)	15	
Plaster on wood lath	11	
Gypsum wall board (½ in. thick, plain)	50	
Hardboard (¼ in. thick, standard)	11	
Built-up roof membrane (hot applied)	0.0	
Plywood (½ in. thick, Douglas fir, exterior glue)	0.7	
Plywood (½ in. thick, Douglas fir, interior glue)	1.9	
Thermal insulation materials:		
Air (still)		120
Cellular glass		0
Expanded polystyrene		2.0-5.8
Extruded polystyrene		1.2
Mineral wool (unprotected)		116
Plastic and metal foils and films:		
Aluminum foil (0.001 in. thick)	0.0	
Polyethylene (0.004 in. thick)	0.08	
Polyethylene (0.006 in. thick)	0.06	
Building paper, felts, roofing papers:		
Saturated and coated roll roofing (65 lbs./100 ft. ²)	0.05	
Kraft paper and asphalt laminated, reinforced (6.8 lbs./100 ft. ²)	0.3	
15-lb. asphalt felt	1.0	
15-lb. tar felt	4.0	
Asphalt (2 oz./ft. ²)	0.5	
Asphalt (3.5 oz./ft. ²)	0.1	
Self-adhering polymer-modified bitumen membrane (0.040 in. thick)	0.1 ²	



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Vapor retarders

<u>Classification</u>	<u>Permeance</u>
Class I vapor retarder	0.1 perm or less
Class II vapor retarder	1.0 perm or less, and greater than 0.1 perm
Class III vapor retarder	10 perm or less, and greater than 1.0 perm
Permeance determined according to ASTM E96, Test Method A (desiccant method or dry cup method)	

*NRCA recommends effective vapor retarders
have perm-ratings of 0.5 or less*

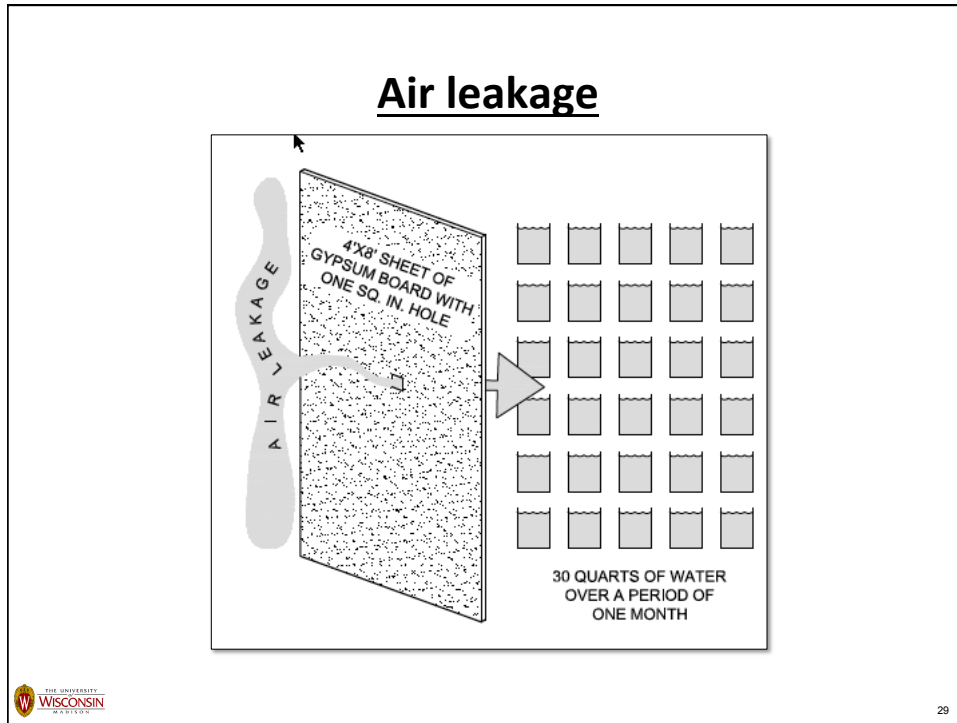


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Vapor retarder continuity is critical.



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Air leakage, not vapor diffusion, can and does cause most of the moisture problems building envelopes suffer.

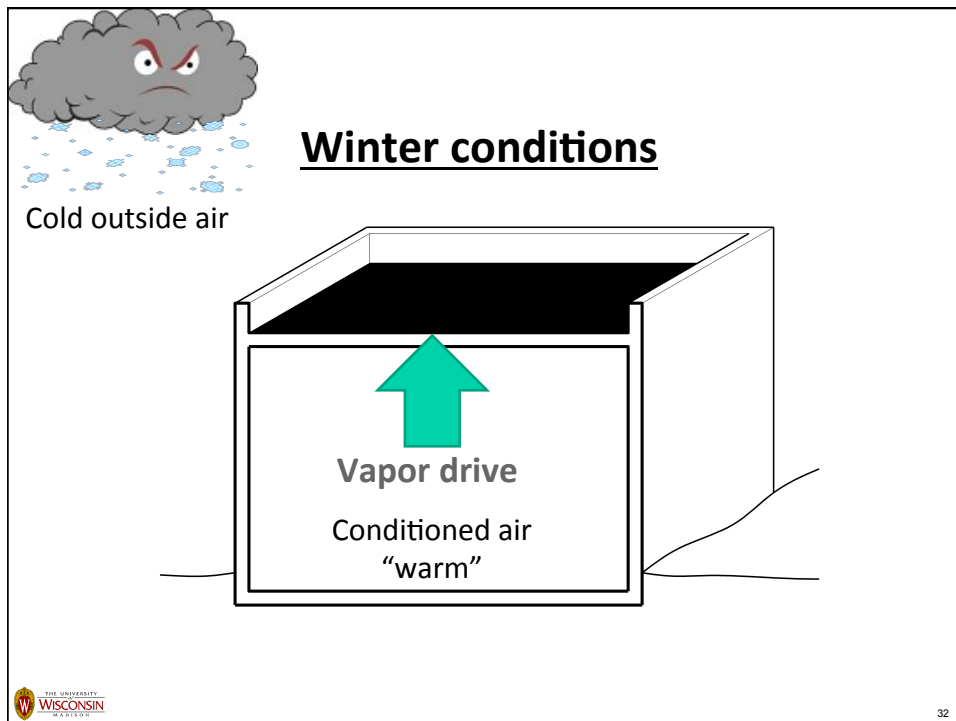


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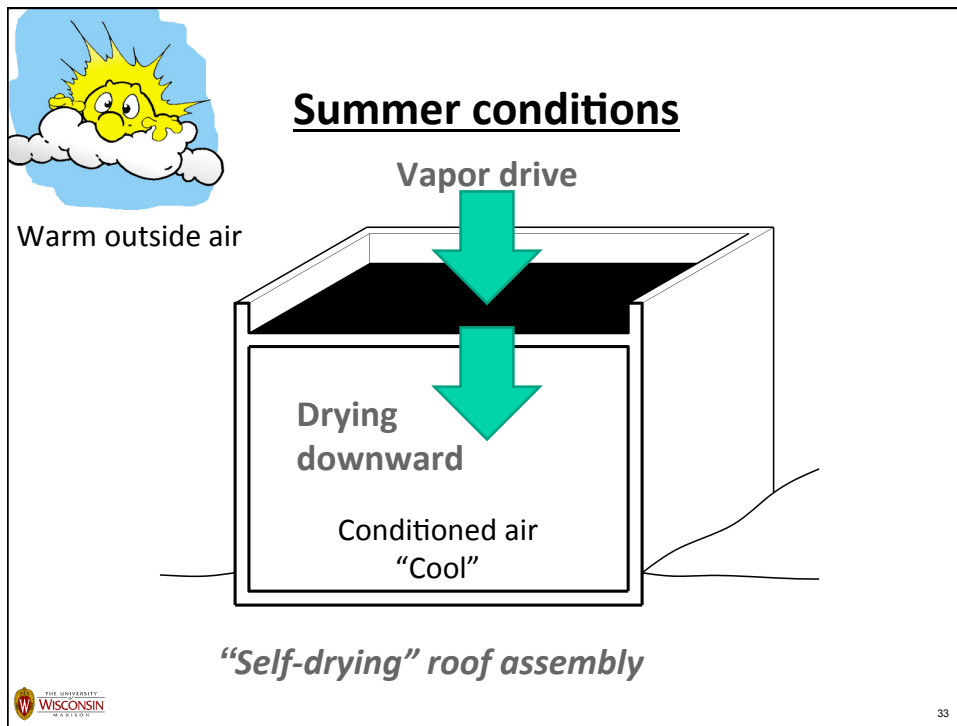
Now, pulling all these principles and fundamentals together into a roofing-specific example....



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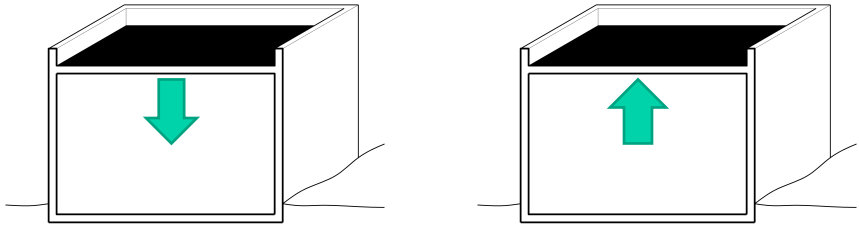


Historically, most roof systems have effectively performed as "self-drying roofs"...


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Self-drying roofs function properly if...




Downward drying \geq **Moisture pick-up**



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Condensation control guidelines
Low-slope roof assemblies



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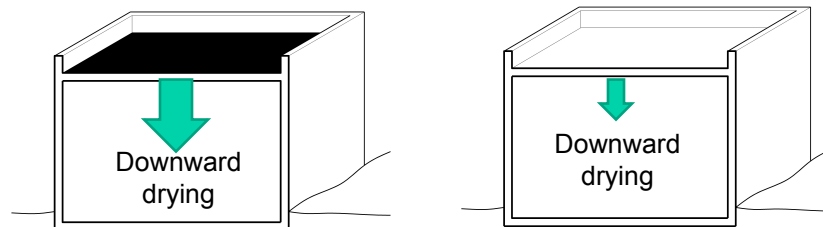
Unintended consequences

Unintended consequences are outcomes that are not the results originally intended by a particular action.

The unintended results may be foreseen or unforeseen, but they should be the logical or likely results of the action



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Conventional roof

“Cool” roof

Cool roofs do not dry-down as efficiently as conventional roofs



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Recommendations

Self-drying “cool” roofs

- Adhered roof covering (membrane)
 - 2 or more layers of insulation
 - Off-set board joints on insulation
- or--
- Don't rely on the “self-drying” concept:
 - Consider providing for a properly-placed vapor retarder



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Vapor retarder guidelines for condensation control

Low-slope roof assemblies



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Vapor retarders should be considered

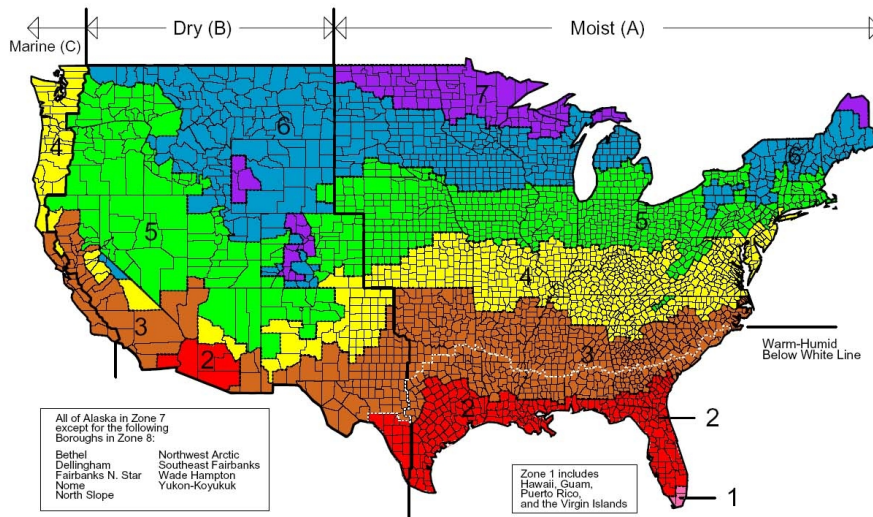
Low-slope roof assemblies

- Climate Zones 6A, 7 or 8
- High interior humidity occupancies (swimming pools)
- Coldest month < 40 F, interior RH ≥ 45%
 - US Army CRREL method enhancement
- Cold storage/freezer buildings (vapor retarder will function as an air barrier)

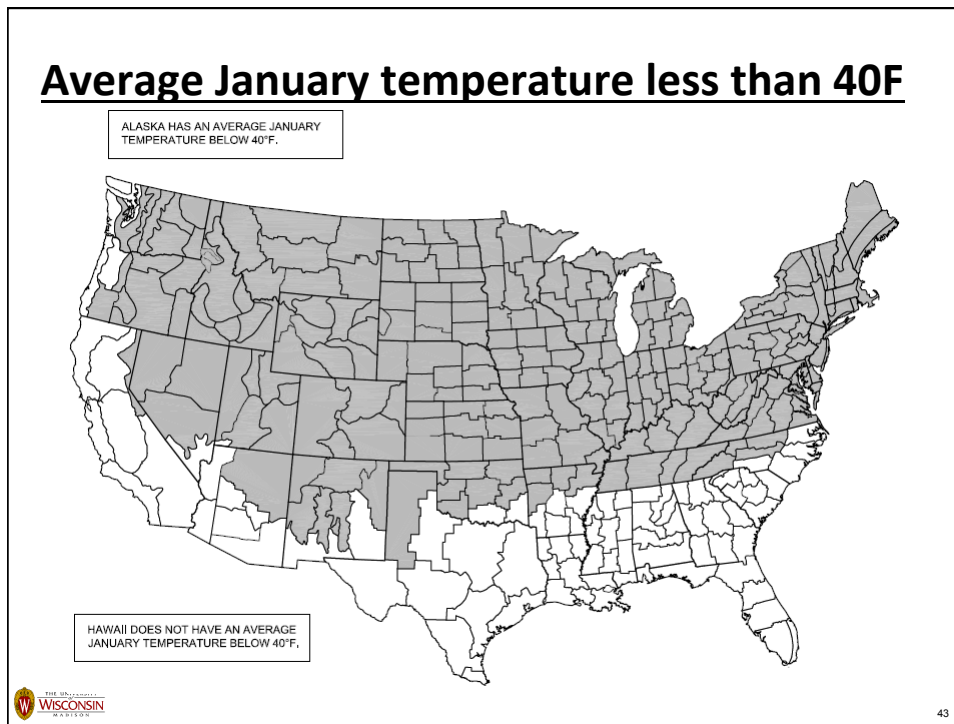


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Climate zone map



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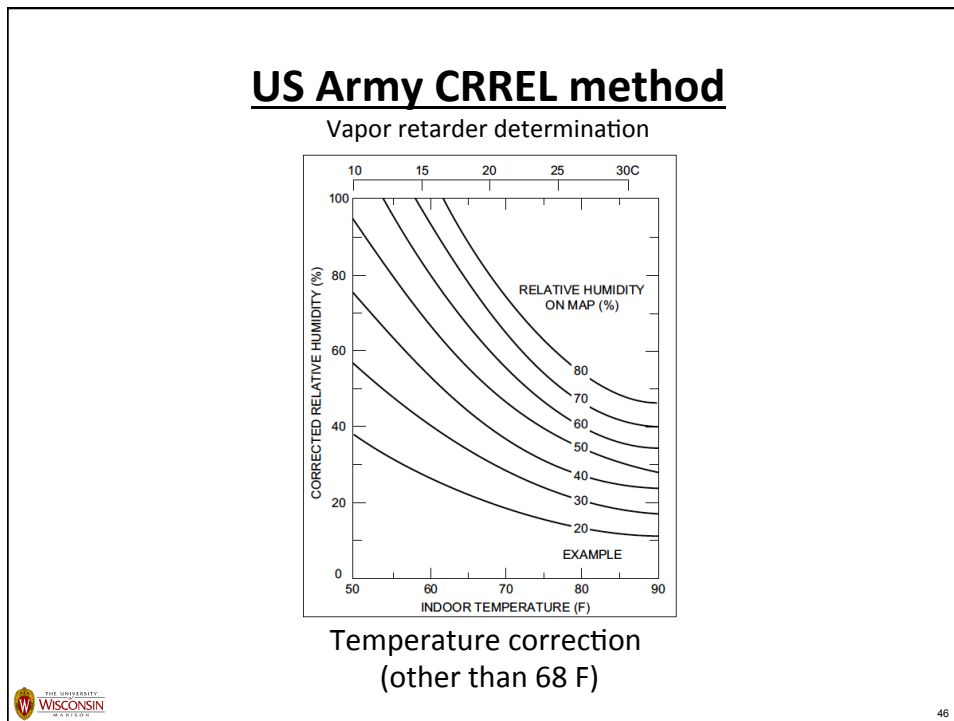
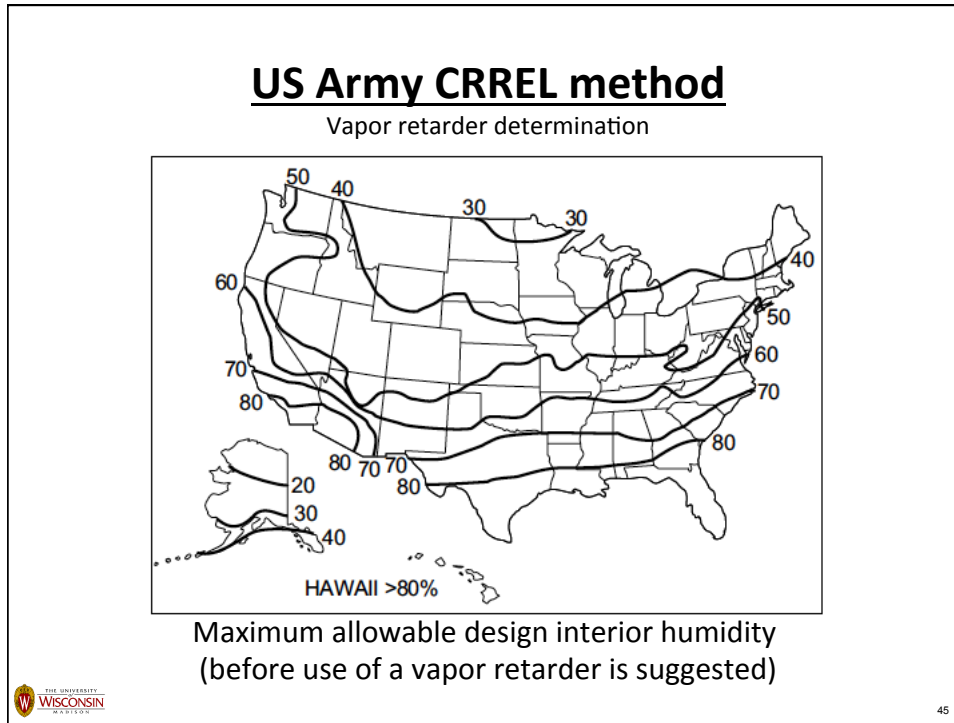
US Army CRREL method

Vapor retarder determination
(CRREL: Cold Regions Research and Engineering Laboratory)

Enhances the “Coldest month < 40 F, interior RH ≥ 45%” guideline:

- Applies to adhered roof coverings (only)
- Provides interior RH thresholds for throughout the U.S. (based upon a 68 F design interior temperature)
- Provides RH threshold corrections for design interior temperatures other than 68 F


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Vapor retarder fundamentals

- Evaluate the dew point temperature during winter design conditions (in North America)
- To prevent the formation of condensation on the interior side of a vapor retarder, the temperature at the vapor retarder level must be warmer than the dew point temperature.

Position the vapor retarder as close to the “warm side” as possible.



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Determining necessary R-value above a vapor retarder layer

Fundamental equation:

$$R_o = \frac{R_i (T_{dp} - T_o)}{(T_i - T_o) - (T_{dp} - T_o)}$$

where:

R_o = R-value on the exterior side of the vapor retarder

R_i = R-value on the interior side of the vapor retarder

T_{dp} = Design dew point temperature

T_o = Design outside temperature

T_i = Design inside temperature



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Determining necessary R-value above a vapor retarder layer

Steps:

1. Determine T_o using the winter design dry bulb
2. Determine T_{dp} using T_i and the design RH
3. Determine R_o and R_i , and solve for R_{INSUL}



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An example

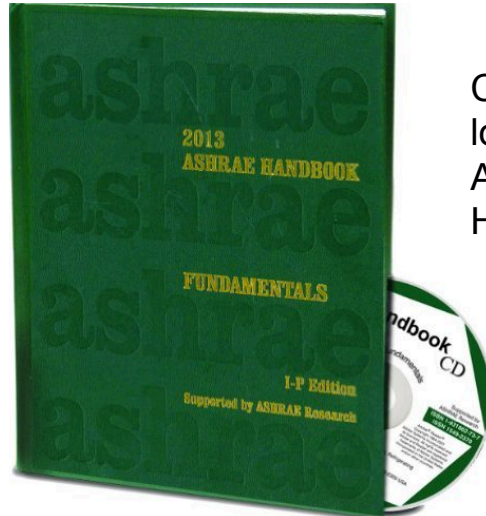
Scenario:

- Lincoln, NE ($T_o \approx 0$ F)
- Interior design conditions: 75 F and 60% RH
- Roof assembly:
 - Single-ply roof membrane
 - Rigid board insulation (R_{INSUL})
 - Kraft paper vapor retarder
 - 2½-inch-thick wood plank deck



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Determine T_o using the winter design dry bulb



Climatic data for 1,445 locations is provided in ASHRAE's Fundamentals Handbook



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$T_o \approx 0 F$

2013 ASHRAE Handbook - Fundamentals (F) LINCOLN MUNICIPAL, NE, USA WMO#: 725510

Lat: 40.83N Long: 96.76W Elev: 1188 StP: 14.08 Time Zone: -6 (NAC) Period: 86-10 WBAN: 14939

Annual Heating, Humidification, and Wet Bulb Design Conditions											
Year	DB	WB	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)
1	-3.5	1.5	-11.1	3.2	-2.4	-6.3	4.1	3.0	30.9	27.6	27.0

LINCOLN MUNICIPAL, NE, USA WMO#: 725510

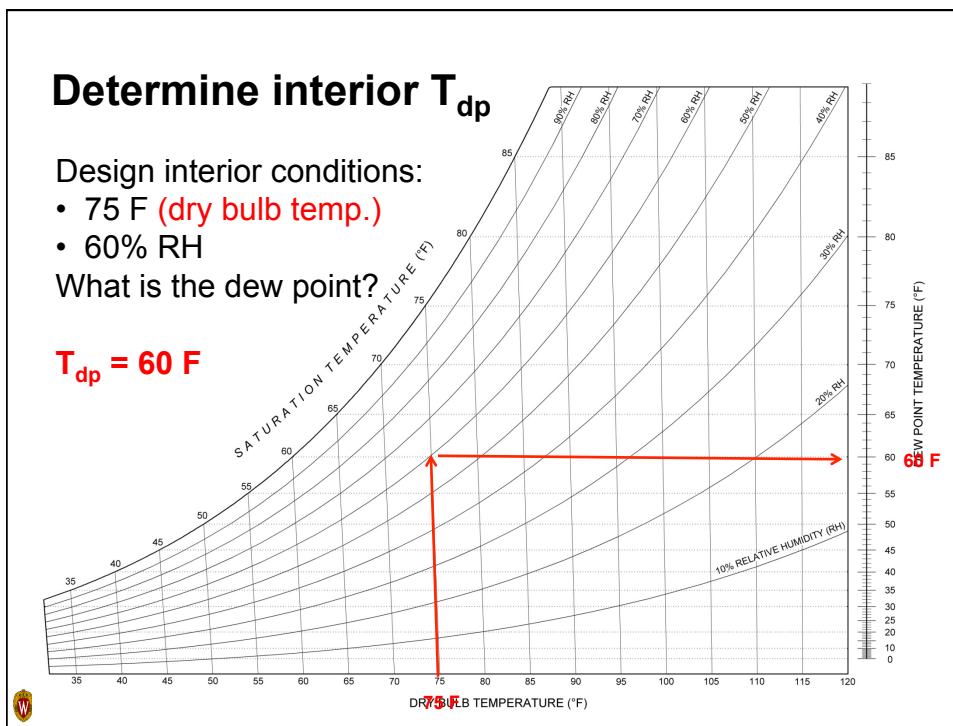
Lat: 40.83N Long: 96.76W Elev: 1188 StP: 14.08 Time Zone: -6 (NAC) Period: 86-10 WBAN: 14939

Annual Heating and Humidification Design Conditions														
Coldest Month	Heating DB			Humidification DPMcDB and HR				Coldest month WSMcDB			MCWS/PCWD to 99.6% DB			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
1	-3.5	1.5	-11.1	3.2	-2.4	-6.3	4.1	3.0	30.9	27.6	27.0	26.4	7.3	340

Annual Cooling, Dehumidification, and Enthalpy Design Conditions														
Hottest Month	Hottest Month DB Range	Cooling DB/McWB				Evaporation WBMcDB				MCWS/PCWD to 0.4% DB				
		0.4%	1%	2%	MCWB	WB	0.4%	1%	2%	MCWB	MCWS	PCWD		
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)
7	21.3	96.9	93.2	74.5	90.4	73.5	78.3	90.6	76.9	89.1	75.4	86.6	14.5	180



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Determine R_o and R_i

Component	R_o	R_i
Outside air film (f_o)	0.17	--
Membrane	0.24	--
Insulation	Unknown (R_{INSUL})	--
Kraft paper vapor retarder	0.12	--
2½ inch wood deck	--	2.32
Inside air film (f_i)	--	0.62
Total	0.53 + R_{INSUL}	2.94

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Solve for R_{INSUL}

$$R_o = \frac{R_i (T_{dp} - T_o)}{(T_i - T_o) - (T_{dp} - T_o)}$$

$$0.53 + R_{INSUL} = \frac{2.94 (60 - 0)}{(75 - 0) - (60 - 0)}$$

$$R_{INSUL} = 11.76$$

Insulation with an R = 11.76 (or greater) is needed above the vapor retarder to prevent condensation



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Vapor retarder materials

- Bituminous vapor retarders:
 - Two plies of ASTM D2178, Type IV felt in moppings of hot asphalt
 - Polymer-modified bitumen sheet
- Non-bituminous vapor retarders:
 - Plastic sheets or films
 - Kraft paper or aluminum foil combinations



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Some additional considerations

Vapor retarder placement

- Board joints in rigid board insulation
- Mechanical fasteners



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Board joints

Heat loss through gaps at the joints between insulation boards can represent up to a 10% reduction in effective R-value

A two-layer application of rigid board insulation with staggered and offset board joints is recommended



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Mechanical fasteners

Mechanical fasteners through the cross-section of rigid board insulation can represent 3% to 8% losses in effective R-values.

Mechanically-attach the bottommost layer and adhere subsequent layers with offset board joints.



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Cooler and freezer buildings

TECH TODAY

Design challenges

Cooler and freezer building designs present unique situations for roof system designers

by Mark S. Graham

Unlike most building types where interior conditions are relatively constant, interior conditions in cooler and freezer buildings often are the same or worse than typical exterior winter conditions. As a result, roof system designers of cooler and freezer buildings are presented with some unique design challenges and decisions.

Sound engineering is necessary when designing cooler and freezer buildings

Design considerations

In addition to typical considerations for conventional buildings, there are at least three fundamental design considerations that need to be resolved when designing buildings for low-temperature operations, such as cooler or freezer buildings:

- Compensating for building thermal movement and avoiding potential damage to the roof system caused by thermal contraction and expansion
- Determining how much thermal insulation (R-value) is needed
- Controlling air and water vapor movement within a roof assembly and deciding whether to use one or more air and vapor retarders

Thermal movement

The conditions under which a cooler and freezer building will be constructed and subsequently operate need to be considered. For example, suppose a freezer building is 100 feet long and 200 feet wide with walls 20 feet high. If the building's structural framework is erected during the summer when the outdoor temperature is 75 F, the building's framework may be approx. 1/8 inch

When the building is put into operation and its interior structural framework cools to the building's normal operating temperature, which can be about 20 F, the lateral framework may contract about 1/4 inch because of thermal movement and longitudinal members may contract about 1/8 inches. Also, the stress created by these movements are considerable and typically will be greatest at the building's corners.

Thermal movement and stress also can significantly affect a roof system if not properly addressed.

Sound engineering judgment is necessary when designing the structural framework for cooler and freezer buildings to address thermal movement and stress. NRCA suggests placing structural expansion joints to divide the building envelope into relatively square laid-out rectangular segments. Also, the design of expansion joints can be critical.

Thermal insulation

Determining how much thermal insulation (R-value) is necessary within a roof system also needs to be closely evaluated. In typical situations, roof surface temperatures during summer months can be as high as 140 F depending on the cooler or freezer building geographic location and roof color. Interior temperatures in cooler or freezer buildings may be held at 20 F for months, or the space may not be in use and the refrigerating equipment may not be operating. The resulting interior-to-exterior temperature differential through a roof assembly may be as high as 180 F.

Calculating the temperature and vapor pressure gradients across a roof assembly (and wall assembly) may be useful.

When selecting specific insulation types to achieve necessary R-values, designers also need to consider the insulation's average temperature within the assembly's temperature gradient. Polyisocyanurate insulation, for example, has a relatively high R-value at 75 F but notably decreased R-values at lower or higher temperatures.

Air and vapor retarders

Also, designers need to consider the placement of a vapor retarder and possibly a separate air retarder.

For cooler and freezer buildings, there is no question the most effective location for a vapor retarder is on the outside of the insulation—a continuous, adhered roof membrane can serve this purpose. The only time there will be a potential vapor drive direction when the exterior temperature drops below the interior temperature, these conditions would need to exist for long time periods before a reverse vapor pressure differential could cause vapor migration damage.

Special considerations also need to be given to designing roof-to-wall junctions, building expansion joints and air and vapor seal penetrations to ensure air and vapor seal conditions. The roof-to-wall vapor sealable layer should be made continuous with the membrane to the vapor retarder of the wall system.

Failure to provide a continuous vapor barrier at air and wall would increase infiltration and accumulation of air on interior surfaces.

NRCA recommendations designers provide detailed specifications and drawings to ensure their design intentions are known to builders and installers. ♦♦♦

MARK S. GRAHAM is NRCA's vice president of national services.

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Professional Roofing, August 2015



Condensation control guidelines

Steep-slope roof assemblies



Historically, condensation control for steep-slope roof assemblies has been addressed with attic ventilation

Historic guidelines:

- 1:150 ratio: (1 sq. ft. of ventilation for every 150 sq. ft. of horizontally-projected ceiling area)
- 1:300 ratio exception allowed if a ceiling vapor retarder is included in the roof assembly



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Research has shown there is little or no technical basis for these historic attic ventilation guidelines



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Also, more isn't necessarily better...



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International Building Code, 2009 Edition

1203.4 Attic Spaces. Enclosed attics and enclosed rafter spaces formed where ceilings are applied directly to the underside of roof framing members shall have cross ventilation for each separate space by ventilating openings protected against the entrance of rain and snow. Blocking or bridging shall be arranged so as not to interfere with the movement of air. A minimum of 1 inch (25 mm) of airspace shall be provided between the insulation and the roof sheathing. The net free ventilating area shall not be less than 1/300 of the space ventilated with 50 percent of the required ventilating area provided by ventilators located in the upper portion of the space to be vented at least 3 feet (914 mm) above the eave or cornice vents with the balance of required ventilation provided by eave or cornice vents.



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International Residential Code, 2009 Edition

R806.2 Minimum area. The total net free ventilation area shall not be less than 1/150 of the area of the space ventilated except that a reduction of the total area to 1/300 is permitted, provided a least 50 percent and not more than 80 percent of the required ventilation area is provided by ventilation located in the upper portion of the space to be ventilated at least 3 feet (914 mm) above the eave or cornice vents. As an alternative, the net free cross-section ventilation area may be reduced to 1/300 when a vapor retarder having a transmission rate not exceeding 1 perm (5.7×10^{-11} kg/s m² Pa) is installed on the warm-in-winter side of the ceiling.



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Attic ventilation

*IBC 2009 and IRC 2009 are not consistent
...and conflict to some extent.*

*IBC 2009 and IRC 2009 are also not consistent
with industry guidelines.*



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Steep-slope roof assemblies

Condensation control guidelines

- Attic ventilation
- Unvented attics



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Attic ventilation components



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Suggested guidelines

Static ventilation configuration

- Balanced
- 1:150 ratio
- Jan. \leq 30 F:
 - Vapor retarder
- Slope 8:12:
 - Increase ventilation

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Suggested guidelines

Mechanical ventilation

- 1 CFM \approx 1:150 ratio
- Eave/soffits vents req'd
- Jan. \leq 30 F:
 - Vapor retarder
- Slope 8:12:
 - Increase ventilation

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Average January temperature less than 30F

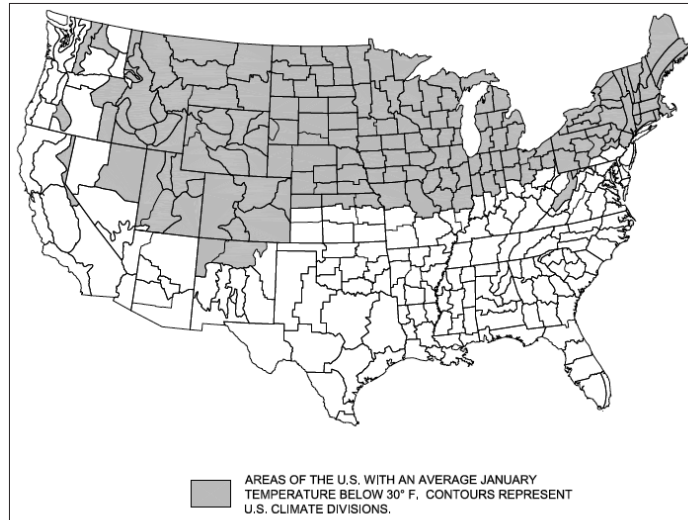
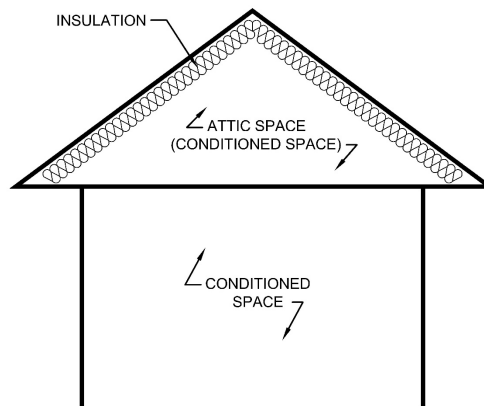


Figure 2-3: Areas of the U.S. with an average January temperature below 30 F, composite 1981-2012 data. Map is based on data provided by NOAA/ESR, Physical Sciences Division, Boulder, Colo., from its website, www.cdc.noaa.gov. Contours represent U.S. Climate Divisions.



An alternative: Unvented, conditioned attic



International Residential Code, 2009 Edition

R806.4 Unvented attic assemblies. Unvented attic assemblies (spaces between the ceiling joists of the top story and roof rafters) shall be permitted if all of the following conditions are met:

1. The unvented attic space is completely contained within the building envelope.
2. No interior vapor retarders are installed on the ceiling side (attic floor) of the unvented attic assembly.
3. When wood shingles or shakes are used, a minimum $\frac{1}{4}$ inch (6 mm) vented air space separates the shingles or shakes and the roofing underlayment above the structural sheathing.
4. In climate zones 5, 6, 7 and 8, any air impermeable insulation shall be a vapor retarder, or shall have a vapor retarder coating or covering in direct contact with the underside of the insulation.



-Continued-

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International Residential Code, 2009 Edition

5. Either Items 5.1, 5.2 or 5.3 shall be met, depending on the air permeability of the insulation directly under the structural sheathing.
 - 5.1 Air-impermeable insulation only. Insulation shall be applied in direct contact to the underside of the structural sheathing.
 - 5.2 Air-permeable insulation only. In addition to the air-permeable installed directly below the structural sheathing, rigid board or sheet insulation shall be installed directly above the structural roof sheathing as specified in Table 806.4 for condensation control.
 - 5.3 Air-impermeable and air-permeable insulation. The air-impermeable insulation shall be applied in direct contact to the underside of the structural roof sheathing as specified in Table R806.4 for condensation control. The air-permeable insulation shall be installed directly under the air-impermeable insulation.



-Continued-

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International Residential Code, 2009 Edition

TABLE R806.4
INSULATION FOR CONDENSATION CONTROL

CLIMATE ZONE	MINIMUM RIGID BOARD OR AIR-IMPERMEABLE INSULATION VALUE ^a
2B and 3B tile roof only	0 (none required)
1, 2A, 2B, 3A, 3B, 3C	R-5
4C	R-10
4A, 4B	R-15
5	R-20
6	R-25
7	R-30
8	R-35

^a Contributes to but does not supersede Chapter 11 energy requirements.



The conditioned, unvented attic is considered a viable alternative to attic ventilation



Vaulted (cathedral) ceilings

Wayne Tobiasson/CRREL research:

- Ventilation has a role in reducing ice-dam and icicle formation
- When it is warmer than 22 F, melted water seldom refreezes at eaves
- Size ventilation to keep the bottomside of the roof deck below freezing when it is 22 F outside
- When it is colder than 22 F, it is easier to ventilate with outside air



79

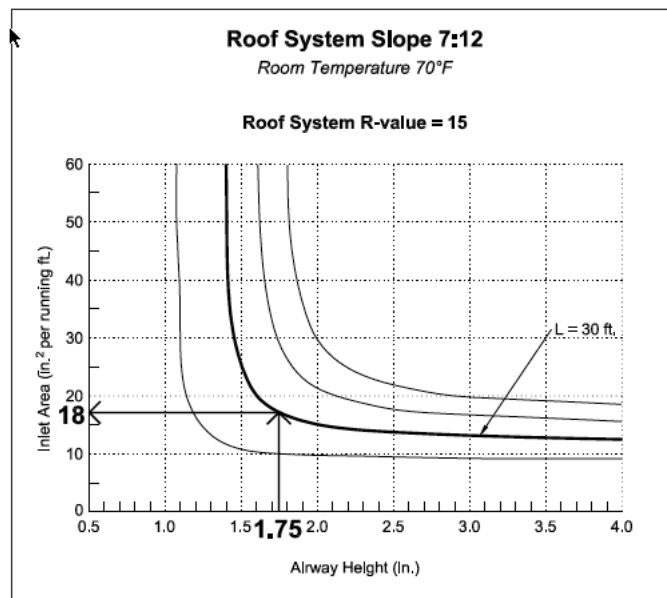
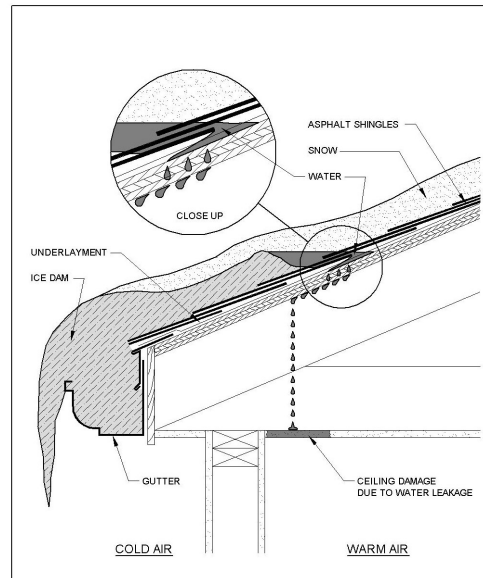


Figure 14: Example calculation for airways 1.75 inches in height with a rafter length of 30 feet and an R-value of 15, slope of 7:12



80

Additional considerations for ice damming



81

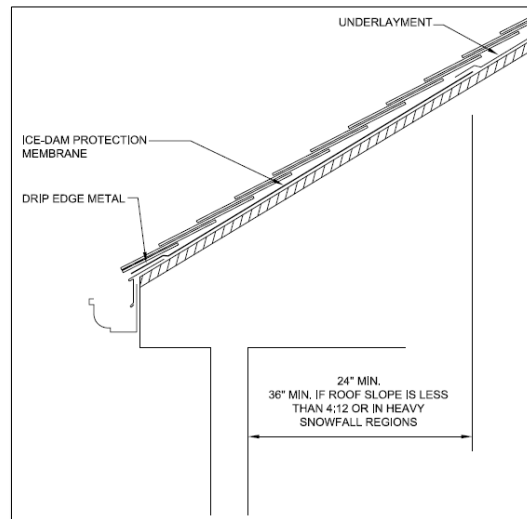
Ice damming guidelines

- Applies to all steep-slope water-shedding roof systems (including tile and architectural metal panels)
- Include anytime “...the January mean temperature is 30 F or less....”
- ASTM D1970 self-adhering underlayment
- Extending upslope a minimum of 24 inches—measured in the horizontal plane—from the inside of a building’s exterior wall line



82

Placement of ice dam membrane



Thermal insulation

Principles of thermal insulation

British thermal unit (Btu): the energy required to raise the temperature of 1 pound of water 1 degree Fahrenheit (F).



85

Principles of thermal insulation

Thermal conductivity (k): the amount of heat is transmitted by conduction through 1 square foot of 1-inch-thick homogenous material in 1 hour where there is a difference of 1 degree Fahrenheit (F) across the two surfaces of the material.

$$k = \text{Btu} \cdot \text{inch} / \text{ft}^2 \cdot \text{hr} \cdot \text{F}$$



86

Principles of thermal insulation

Thermal conductance (C): the amount of heat is transmitted by conduction through 1 square foot of a specified thickness of material in 1 hour where there is a difference of 1 degree Fahrenheit (F) across the two surfaces of the material.

$$C = \text{Btu} / \text{ft}^2 \cdot \text{hr} \cdot F$$



87

Principles of thermal insulation

Thermal transmittance (U): the amount of heat is transmitted by conduction through 1 square foot of an assembly and its boundary layers in 1 hour where there is a difference of 1 degree Fahrenheit (F) across the two surfaces of the assembly.

$$U = \text{Btu} / \text{ft}^2 \cdot \text{hr} \cdot F$$



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Principles of thermal insulation

Thermal resistance (R): a relative measure of a material's or an assembly's resistance to heat flow; the reciprocal of the material's thermal conductance (C) or an assembly's thermal transmittance (U).

$$R = 1 / C \text{ or } R = 1 / U$$

R-values are readily additive (unlike k-values and C-values). Therefore $R_T = R_1 + R_2 + R_3 = \dots$



89

R-value rule

US Federal Trade Commission 16 CFR Part 460

The thermal resistance (R-value) of insulation shall be determined in accordance with the U.S. Federal Trade Commission R-value rule (CFR Title 16, Part 460) in units of $\text{h} \times \text{ft}^2 \times \text{°F}/\text{Btu}$ at a mean temperature of 75°F (24°C).



90

Polyisocyanurate



- Polyisocyanurate foam and facers
- ASTM C1289 (multiple types, grades and classes)
- 4' x 4' and 4' x 8'
- Thicknesses range from 1" to 4"
- R = 5.0-6.0 per inch
- R-value decreases with aging
- LTTR = 5.6 to 5.9 per inch



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Long-term thermal resistance (LTTR)

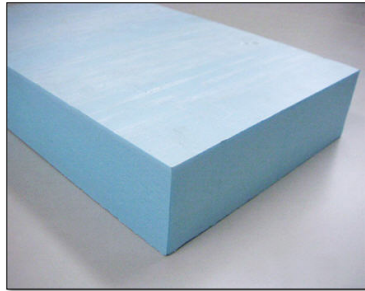
Determined using ASTM C1303 or CAN/ULC-S770

R-value estimate based upon a 15-year time-weighted average, corresponding to the product's estimated R-value 5-years after manufacturing



92

Extruded polystyrene (XPS)



- Polystyrene polymer is heated and extruded
- ASTM C578 (many types)
- 2' x 4' and 2' x 8'
- 1", 1½", 2", 2½", 3" & 4"
- R = 4.6 to 5.0 per inch



93

Expanded polystyrene (EPS)



- Polystyrene polymer, foaming agent and heat
- ASTM C578 (many types)
- 4' x 4' and 4' and 8'
- ⅜" to 24" and tapered
- R = 3.1 to 4.3 per inch based upon density



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Insulation R-values

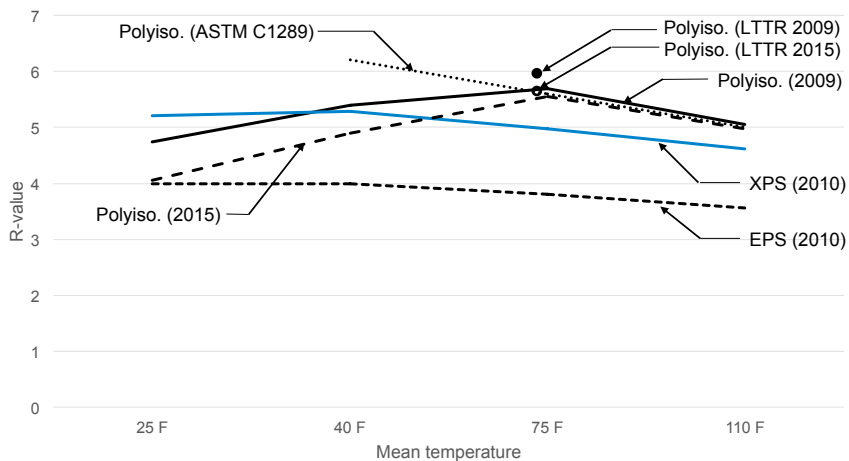
NRCA R-value testing:

- Polyisocyanurate (2009 and previous)
- Expanded polystyrene (2010)
- Extruded polystyrene (2010)
- Polyisocyanurate (2015)



95

NRCA R-value testing



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Design R-value recommendation

Polyisocyanurate insulation

1986-2011:


- R = 5.6 per inch thickness

2012-2015:


- R = 5.6 per inch thickness (cooling climates)
- R = 5.0 per inch thickness (heating climates)

Beginning in 2016:

- R = 5.0 per inch thickness



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Analyzing R-value Requirements

Cost paybacks to increases in R-values may not be practical

November 2014

Recent increases to the model energy code's building energy performance requirements have resulted in increased R-values being specified for many buildings' exterior envelopes, including roof systems.

Adoption of the *International Energy Conservation Code, 2012 Edition* (IECC 2012), which includes significant R-value increases for most roof systems, has been limited. The R-value increases were implemented into the code with minimal to no consideration of the added initial construction costs and long-term payback to building owners.

Energy code requirements

The building envelope thermal (prescriptive) requirements contained in IECC 2012 include roof assemblies minimum R-value requirements as shown in Figure 1. These R-values apply to all buildings, including roof system replacements, classified by the code as being for "commercial" buildings. IECC 2012 identifies all buildings as commercial except detached one- and two-family dwellings and multiple single-family dwellings (townhouses), as well as Group R-2, R-3 and R-4 buildings three stories or fewer in height above grade plane.

Comparing IECC 2012's minimum prescriptive R-values with those in the *International Energy Conservation Code, 2009 Edition* (IECC 2009) reveals minimum required R-values for roof assemblies have increased from R-5 to R-10 depending on specific climate zones and building (roof) assembly configurations.

In May 2012, the Department of Energy (DOE) issued a determination indicating IECC 2012 provides greater energy efficiency to buildings than IECC 2009. DOE indicated IECC 2012 makes substantial progress with achieving DOE's goal to provide a 30 percent overall improvement in building energy efficiency compared with the code's previous editions.

Code adoption

Also included in DOE's May 2012 determination is a requirement for individual states to review their current codes and certify by May 17, 2014, that residential energy efficiency requirements meet or exceed the levels established in IECC 2012. In the past, this type of certification standard resulted in individual states upgrading their building energy code to the latest edition of the model code.

To determine the status of individual states' energy code

adoption, NRCA conducted a comprehensive survey of states' adoption and plans for future code updates. From this survey only seven states were discovered to have updated their energy code to IECC 2012: Iowa by Iowa's May 17 certification deadline; Illinois, Iowa, Maryland, Montana, North Carolina, Rhode Island and Washington.

Four additional states—California, Florida, Massachusetts and New York—will upgrade to IECC 2012's code by Jan. 1, 2015. The remaining states reported they have no immediate intention of upgrading their energy codes; some states have no state-mandated energy code.

NRCA considers the findings of its energy code adoption survey to be significant. High R-value advocates, including some insulation manufacturers, trade associations and special interest groups, are leading designers and building owners to believe 2012 IECC R-values are required throughout the U.S. One roof system manufacturer and one special interest group are going as far as implying compliance with the *International Energy Conservation Code, 2015 Edition* already is required. NRCA's survey reveals these high R-value claims are misleading; in fact, most states do not yet require compliance with IECC 2012.

NRCA "Industry Issue Update," November 2014

Payback analysis:

- 100 sq. single story building
- Costs per R+5 increases
- Energy savings per R+5 increases
- Local energy costs
- Cost ÷ Savings = Payback
- 16 cities in 8 climate zones


Payback results (Lincoln, NE):

- R-10 to R-15: 3.3 yrs.
- R-15 to R-20: 11.1 yrs.
- R-20 to R-25: 20.5 yrs.
- R-25 to R-30: 54.7 yrs.

Climate zone	Roof assembly configuration ^a		
	Insulation entirely above	Roof buildings (with 8-9 thermal shields)	Attic and other
1	R-20(1)	R-10 + R-11.15	R-20
2	R-20(1)	R-10 + R-11.15	R-20
3	R-20(1)	R-10 + R-11.15	R-20
4	R-25(1)	R-10 + R-11.15	R-20
5	R-25(1)	R-10 + R-11.15	R-20
6	R-25(1)	R-25 + R-11.15	R-40
7	R-25(1)	R-20 + R-11.15	R-40
8	R-25(1)	R-20 + R-11.15	R-40

a. - Continuous insulation
b. - Low-slope is continuous membrane installed below the joists and ceiling, used for thermal separation, movement, control moisture rates or both of the membrane system.

Figure 1: Minimum prescriptive thermal insulation requirements for commercial buildings



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Energy code requirements



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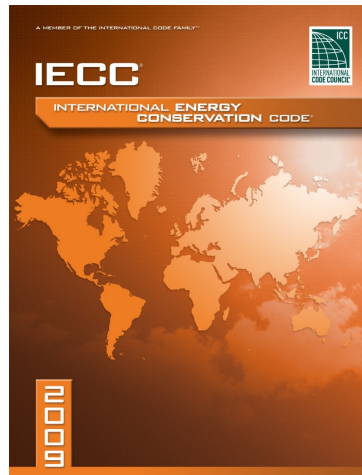
Some history...

Energy efficiency of buildings

- 1973: Arab oil embargo
- 1974: NBS Interim Report 74-452 (prelim. criteria)
- 1975: ASHRAE 90-75 (energy-efficiency std.)
- 1977: BOCA/ICBO/SBCCI code (CABO MEC)
- 1980: ASHRAE 90-80
- 1989: ASHRAE 90.1-89
- 1992: Energy Policy Act (EPAAct)
- 1998: *International Energy Conservation Code*
- 1999: ASHRAE 90.1-99



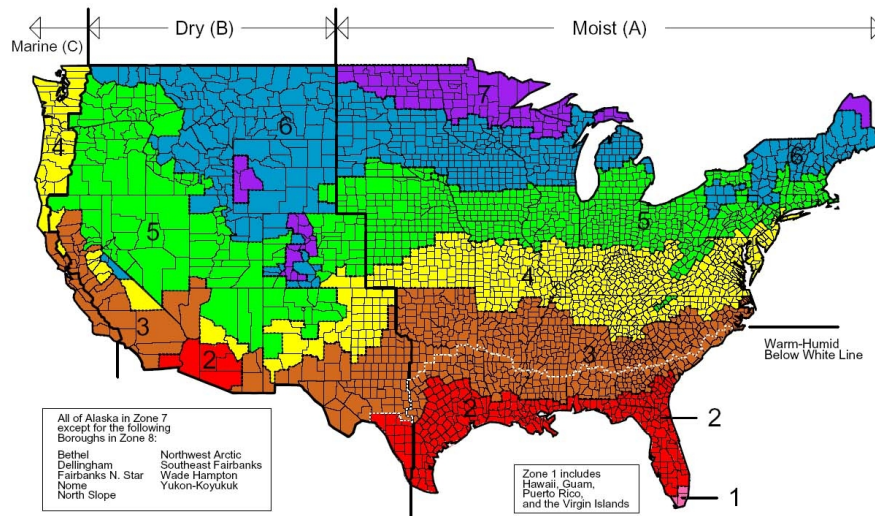
International Energy Conservation Code, 2009 Edition (IECC 2009)



103

Climate zones

IECC 2009 and IECC 2012



104

Roofing-specific adaptation of Table 402.1.1

International Energy Conservation Code, 2009 Edition (Residential buildings)

Insulation and Fenestration Requirements by Component ^a	
Climate zone	Ceiling R-value
1	30
2	
3	
4	38
5	
6	49
7	
8	

^a R-values are minimums. ...
[Other footnotes omitted for clarity]



105

Roofing-specific adaptation of Table 502.2(1)

International Energy Conservation Code, 2009 Edition (Commercial buildings)

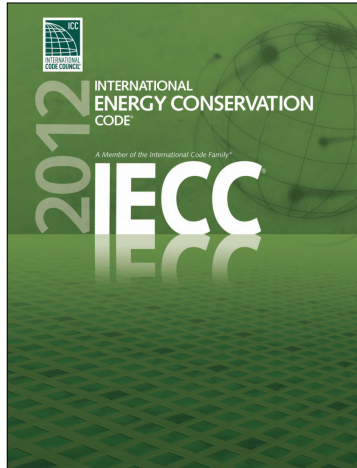
Opaque Thermal Envelope Assembly Requirements			
Climate zone	Roof assembly configuration		
	Insulation entirely above deck	Metal buildings (with R-5 thermal blocks)	Attic and other
1	R-15ci	R-19	R-30
2	R-20ci	R-13 + R-13	R-38
3			
4			
5			
6	R-25ci	R-13 + R-19	R-49
7			
8			

ci = Continuous insulation
LS = Liner system (a continuous membrane installed below the purlins and uninterrupted by framing members; uncompressed, faced insulation rests on top of the membrane between the purlins)



106

International Energy Conservation Code, 2012 Edition (IECC 2012)



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Format of IECC 2012

IECC – Commercial

Ch. 1[CE]: Scope and Admin.
Ch. 2[CE]: Definitions
Ch. 3[CE]: General Req.
Ch. 4[CE]: Commercial Energy Efficiency
Ch. 5[CE]: Referenced Stds.
Index

IECC – Residential

Ch. 1[RE]: Scope and Admin.
Ch. 2[RE]: Definitions
Ch. 3[RE]: General Req.
Ch. 4[RE]: Residential Energy Efficiency
Ch. 5[RE]: Referenced Stds.
Index



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Commercial vs. Residential

- Commercial unless Residential
- R202-General Definitions:
Residential Building. For this code, includes detached one- and two-family dwellings and multiple single-family dwellings (townhouses) as well as Group R-2, R-3 and R-4 buildings three stories or less in height above grade plane



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IECC – Residential Provisions



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Ch. 4[RE]—Residential Energy Efficiency

International Energy Conservation Code, 2012 Edition

- Sec. R401—General
- Sec. R402—Building Thermal Envelope
- Sec. R403—Systems
- Sec. R404—Electrical Power and Lighting Systems
- Sec. R405—Simulated Performance Alternative



111

Minimum thermal insulation requirements

IECC 2012, Section R402-Building Thermal Envelope

R402.1 General (Prescriptive). The *building thermal envelope* shall meet the requirements of Sections R402.1.1 through R402.1.4.

R402.1.1 Insulation and fenestration criteria. The building thermal envelope shall meet the requirements of Table R402.1.1 based upon the climate zone specified in Chapter 3.

R402.1.2 R-value computation. Insulation material used in layers, such as framing cavity insulation and insulated sheathing, shall be summed to compute the component R-value. The manufacturer's settled R-value shall be used for blown insulation. Computed R-values shall not include an R-value for other building materials or air films



112

Roofing-specific adaptation of Table R402.1.1

International Energy Conservation Code, 2012 Edition

Insulation and Fenestration Requirements by Component^a	
Climate zone	Ceiling R-value
1	30
2	38
3	
4	49
5	
6	
7	
8	

^a R-values are minimums. ...
[Other footnotes omitted for clarity]



113

R402.2 Specific insulation requirements (Prescriptive). In addition to the requirements of Section R402.1, insulation shall meet the specific requirements of Sections R402.2.1 through R402.2.12.

R402.2.1 Ceilings with attic spaces. When Section R402.1.1 would require R-38 in the ceiling, R-30 shall be deemed to satisfy the requirement for R-38 wherever the full height of uncompressed R-30 insulation extends over the wall top plate at the eaves. Similarly, R-38 shall be deemed to satisfy the requirement for R-49 wherever the full height of uncompressed R-38 insulation extends over the wall top plate at the eaves. This reduction shall not apply to the U-factor alternative approach in Section R402.1.3 and the total UA alternative in Section R402.1.4.



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R402.2.2 Ceilings without attic spaces. Where Section R402.1.1 would require insulation levels above R-30 and the design of the roof/ceiling assembly does not allow sufficient space for the required insulation, the minimum required insulation for such roof/ceiling assemblies shall be R-30. This reduction of insulation from the requirements of Section R402.1.1 shall be limited to 500 square feet (46 m²) or 20 percent of the total insulated ceiling area, whichever is less. This reduction shall not apply to the U-factor alternative approach in Section R402.1.3 and the total UA alternative in Section R402.1.4.

R402.2.3 Eave baffle. For air permeable insulations in vented attics, a baffle shall be installed adjacent to soffit and eave vents. Baffles shall maintain an opening equal or greater than the size of the vent. The baffle shall extend over the top of the attic insulation. The baffle shall be permitted to be any solid material.



115

Air retarders

IECC 2012, Section R402.4-Air Leakage (Mandatory)

R402.4 Air leakage (Mandatory). The building thermal envelope shall be constructed to limit air leakage in accordance with the requirements of Sections R402.4.1 through R402.4.4.

R402.4.1 Building thermal envelope. The building thermal envelope shall comply with Sections R402.4.1.1 and R402.4.1.2. The sealing methods between dissimilar materials shall allow for differential expansion and contraction.

R402.4.1.1 Installation. The components of the building thermal envelope as listed in Table R402.4.1.1 shall be installed in accordance with the manufacturer's instructions and the criteria listed in Table R402.4.1.1, as applicable to the method of construction. Where required by the code official, an approved third party shall inspect all components and verify compliance.

R402.4.1.2 Testing. The building or dwelling unit shall be tested and verified as having an air leakage rate of not exceeding 5 air changes per hour in Climate Zones 1 and 2, and 3 air changes per hour in Climate Zones 3 through 8. Testing shall be conducted...



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Roofing-specific adaptation of Table R402.4.1.1

International Energy Conservation Code, 2012 Edition

Air Barrier and Insulation Installation	
Component	Criteria
Air barrier and thermal barrier	A continuous air barrier shall be installed in the building envelope. Exterior thermal envelope contains a continuous air barrier. Breaks or joints in the air barrier shall be sealed. Air-permeable insulation shall not be used as a sealing material.
Ceiling/attic	The air barrier in any dropped ceiling/soffit shall be aligned with the insulation and any gaps in the air barrier sealed. Access openings, drop down stair or knee wall doors to unconditioned attic spaces shall be sealed.



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IECC – Commercial Provisions



118

Ch. 4[CE]—Commercial Energy Efficiency

International Energy Conservation Code, 2012 Edition

- Sec. C401—General
- Sec. C402—Building Envelope Requirements
- Sec. C403—Building Mechanical Systems
- Sec. C404—Service Water Heating
- Sec. C405—Electrical Power and Lighting Systems
- Sec. C406—Additional Efficiency Package Options
- Sec. C407—Total Building Performance



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Ch. 4—Commercial Energy Efficiency

International Energy Conservation Code, 2012 Edition

C401.2 Application. Commercial buildings shall comply with one of the following:

1. The requirements of ANSI/ASHRAE/IESNA 90.1
2. The requirements of Sections C402, C403, C404 and C405. In addition, commercial buildings shall comply with either Section C406.2, C406.3 or C406.4
3. The requirements of Section C407, C402.4, C403.2, C404, C405.2, C405.3, C405.4, C405.6 and C405.7. The building energy cost shall be equal to or less than 85 percent of the standard reference design building.

[Continued...]



120

C401.2.1 Application to existing buildings. Additions, alterations and repairs to existing buildings shall comply with one of the following:

1. Sections C402, C403, C404 and C405; or
2. ANSI/ASHRAE/IESNA 90.1



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Minimum thermal insulation requirements

IECC 2009, Section C402.2—Specific insulation Requirements (Prescriptive)

C402.2 Specific insulation requirements (Prescriptive). Opaque assemblies shall comply with Table C402.2. Where two or more layers of continuous insulation board are used in a construction assembly, the continuous insulation boards shall be installed in accordance with Section C303.2. If the continuous insulation board manufacturer's installation instructions do not address installation of two or more layers, the edge joints between each layer of continuous insulation boards shall be staggered.



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C402.2.1 Roof assembly. The minimum thermal resistance (*R-value*) of the insulating material installed either between the roof framing or continuously on the roof assembly shall be as specified in Table C402.2, based on construction materials used in the roof assembly. Skylight curbs shall be insulated to the level of roofs with insulation entirely above deck or R-5, whichever is less.

Exceptions:

1. Continuously insulated roof assemblies where the thickness of insulation varies 1 inch (25 mm) or less and where the area-weighted *U-factor* is equivalent to the same assembly with the *R-value* specified in Table C402.2.
2. Unit skylight curbs included as a component of an NFRC 100 rated assembly shall not be required to be insulated.

Insulation installed on a suspended ceiling with removable ceiling tiles shall not be considered part of the minimum thermal resistance of the roof insulation.



Roofing-specific adaptation of Table C402.2

International Energy Conservation Code, 2012 Edition

Opaque Thermal Envelope Assembly Requirements			
Climate zone	Roof assembly configuration		
	Insulation entirely above deck	Metal buildings (with R-5 thermal blocks)	Attic and other
1	R-20ci	R-19 + R-11 LS	R-38
2			
3			
4	R-25 ci	R-25 + R-11 LS	R-49
5			
6	R-30ci	R-30 + R-11 LS	
7	R-35ci	R-30 + R-11 LS	
8			

ci = Continuous insulation
 LS = Liner system (a continuous membrane installed below the purlins and uninterrupted by framing members; uncompressed, faced insulation rests on top of the membrane between the purlins)



R-value determination

IECC 2012, Section C303.1.4-Insulation Product Rating

C303.14 Insulation product rating. The thermal resistance (R-value) of insulation shall be determined in accordance with the U.S. Federal Trade Commission R-value rule (CFR Title 16, Part 460) in units of $h \times ft^2 \times ^\circ F/Btu$ at a mean temperature of 75°F (24°C).

What about tapered insulation?



125

Tapered insulation

International Energy Conservation Code, 2012 Edition (IECC 2009 is similar)

C402.2.1 Roof assembly. The minimum thermal resistance (R-value) of the insulating material installed either between the roof framing or continuously on the roof assembly shall be as specified in Table C402.2, based on construction materials used in the roof assembly. Skylight curbs shall be insulated to the level of roofs with insulation entirely above deck or R-5, whichever is less.

Exceptions:

1. Continuously insulated roof assemblies where the thickness of insulation varies 1 inch (25 mm) or less and where the area-weighted *U-factor* is equivalent to the same assembly with the *R-value* specified in Table C402.2.
2. ...

IECC Commentary indicates Exception 1 applies to tapered insulation systems.



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2012 IECC Code and Commentary

Tapered insulation

“...The exception to this section permits a roof that is “continuously insulated” to have areas that do not meet the required R -values, provided that the area-weighted values are equivalent to the specified insulation values. This type of insulation referred to as tapered insulation is where the roof insulation varies to provide slope for drainage....”

[continued...]



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2012 IECC Code and Commentary

Tapered insulation

“...This 1-inch (25 mm) limitation does not prevent the provisions from being applied to roofs that have a greater variation; it simply does not allow the additional thickness to be factored into the average insulation values. Where the variation exceeds 1 inch (25 mm), it would be permissible to go to the thinnest spot and measure the R -value at that point (for the example call this Point “a”). Then go to a point that is 1 inch (25 mm) thicker than Point “a” and measure the R -value there (for the example, call this Point “b”). The remaining portions of the roof that are thicker than the additional 1-inch (25 mm) portion (Point “b”) would simply be assumed to have the same R -value that Point “b” had. All portions of the roof that meet or exceed the Point “b” R -value would simply use the Point “b” R -value when determining the area weighted U -factor for the roof. “



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What about tapered insulation...?

IBC 2012, Sec. C402.2-Roof Assembly , Exception 1
allows a 1-inch insulation thickness variation

R-VALUE TAKEN AT
LOW POINT + 1"

THE UNIVERSITY OF WISCONSIN MADISON

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Solar reflectance and thermal emittance

IECC 2012, Section C402.2.1.1

C402.2.1.1 Roof solar reflectance and thermal emittance. Low-sloped roofs, with a slope less than 2 units vertical in 12 horizontal, directly above cooled *conditioned spaces* in Climate Zones 1, 2, and 3 shall comply with one or more of the options in Table C402.2.1.1.

Exceptions: The following roofs and portions of roofs are exempt from the requirements in Table C402.2.1.1:

1. Portions of roofs that include or are covered by:
 - 1.1 Photovoltaic systems or components.
 - 1.2 Solar air or water heating systems or components.
 - 1.3 Roof gardens or landscaped roofs.
 - 1.4 Above-roof decks or walkways.
 - 1.5 Skylights.
 - 1.6 HVAC systems, components, and other opaque objects mounted above...

[Continued...]

THE UNIVERSITY OF WISCONSIN MADISON

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TABLE C402.2.1.1
MINIMUM ROOF REFLECTANCE AND EMITTANCE OPTIONS^a

Three-year aged solar reflectance ^b of 0.55 and three-year aged thermal emittance of 0.75
Initial solar reflectance ^b of 0.70 and initial thermal emittance ^c of 0.75
Three-year-aged solar reflectance index ^d of 64
Initial solar reflectance index ^d of 82

[Footnotes omitted for clarity]



Air retarders

IECC 2012, Section C402.4-Air Leakage (Mandatory)

C402.4 Air leakage (Mandatory). The thermal envelope of buildings shall comply with Sections C402.4.1 through C402.4.8.

C402.4.1 Air barriers. A continuous air barrier shall be provided throughout the building thermal envelope. The air barriers shall be permitted to be located on the inside or outside of the building envelope, located within the assemblies composing the envelope, or any combination thereof. The air barrier shall comply with Sections C402.4.1.1 and C402.4.1.2.

Exception: Air barriers are not required in buildings located in Climate Zones 1, 2 and 3.

[Continued...]



C402.4.1.2 Air barrier compliance options. A continuous air barrier for the opaque building envelope shall comply with Section C402.4.1.2.1, C402.4.1.2.2, or C402.4.1.2.3.

C402.4.1.2.1 Materials. Materials with an air permeability no greater than 0.004 cfm/ft² (0.02 L/s · m²) under a pressure differential of 0.3 inches water gauge (w.g.) (75 Pa) when tested in accordance with ASTM E 2178 shall comply with this section. Materials in Items 1 through 15 shall be deemed to comply with this section provided joints are sealed and materials are installed as air barriers in accordance with the manufacturer's instructions.

1. Plywood with a thickness of not less than 3/8 inch (10 mm).
2. Oriented strand board having a thickness of not less than 3/8 inch (10 mm).
3. Extruded polystyrene insulation board having a thickness of not less than 1/2 inch (12 mm).
4. Foil-back polyisocyanurate insulation board having a thickness of not less than 1/2 inch (12 mm).
5. Closed cell spray foam a minimum density of 1.5 pcf (2.4 kg/m³) having a thickness of not less than 1-1/2 inches (36 mm).

[Continued....]



6. Open cell spray foam with a density between 0.4 and 1.5 pcf (0.6 and 2.4 kg/m³) and having a thickness of not less than 4.5 inches (113 mm).
7. Exterior or interior gypsum board having a thickness of not less than 1/2 inch (12 mm).
8. Cement board having a thickness of not less than 1/2 inch (12 mm).
9. Built up roofing membrane.
10. Modified bituminous roof membrane.
11. Fully adhered single-ply roof membrane.
12. A Portland cement/sand parge, or gypsum plaster having a thickness of not less than 5/8 inch (16 mm).
13. Cast-in-place and precast concrete.
14. Fully grouted concrete block masonry.
15. Sheet steel or aluminum.

[Continued...]



C402.4.1.2.2 Assemblies. Assemblies of materials and components with an average air leakage not to exceed 0.04 cfm/ft^2 ($0.2 \text{ L/s} \cdot \text{m}^2$) under a pressure differential of 0.3 inches of water gauge (w.g.) (75 Pa) when tested in accordance with ASTM E 2357, ASTM E 1677 or ASTM E 283 shall comply with this section. Assemblies listed in Items 1 and 2 shall be deemed to comply provided joints are sealed and requirements of Section C402.4.1.1 are met.

1. Concrete masonry walls coated with one application either of block filler and two applications of a paint or sealer coating;
2. A Portland cement/sand parge, stucco or plaster minimum 1/2 inch (12 mm) in thickness.

C402.4.1.2.3 Building test. The completed building shall be tested and the air leakage rate of the *building envelope* shall not exceed 0.40 cfm/ft^2 at a pressure differential of 0.3 inches water gauge ($2.0 \text{ L/s} \cdot \text{m}^2$ at 75 Pa) in accordance with ASTM E 779 or an equivalent method approved by the code official.



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IECC 2012's air barrier requirements significantly limit roof system designs in "commercial buildings" (as defined by IECC 2012)



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Air retarder exception added

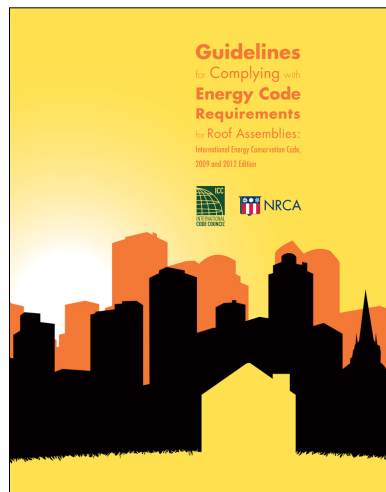
IECC 2015, Sec. C503 - Alterations

6. *Air barriers* shall not be required for *roof recover* and roof replacement where the *alterations* or renovations to the building do not include renovations or *repairs* to the remainder of the building envelope.



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Energy Codes Manual (2009 & 2012 Codes)



- Based upon IECC 2009 with ASHRAE 90.1-07 option and IECC 2012 with ASHRAE 90.1-10 option
- Includes roofing-related code text and NRCA commentary on each section
- Appendix has county-specific prescriptive R-value tables
- Co-branded with ICC; NRCA promotes to industry and ICC promotes to code officials



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energywise.nrca.net

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NRCA EnergyWise Roof Calculator

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Welcome to EnergyWise Roof Calculator

EnergyWise Roof Calculator Online is a Web-based application that provides a graphical method of constructing roof assemblies to evaluate thermal performance and estimated energy costs under normal operating conditions.

This application also provides minimum insulation requirements as stipulated in the following codes and standards:

- International Energy Conservation Code (IECC), versions 2006, 2009 and 2012
- International Green Construction Code (IgCC), version 2012
- American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 90.1, "Energy Standard for Buildings Except Low-rise Residential Buildings," versions 1999 (2001), 2004, 2007 and 2010
- ASHRAE Standard 189.1, "Standard for the Design of High-Performance Green Buildings," versions 2009 and 2011

[Click here](#) for additional information about IECC, IgCC, ASHRAE 90.1 and ASHRAE 189.1

Because this application is intended to be a simplified guide, complex energy calculations, such as solar heat gain and exterior shading considerations, have intentionally not been included. For complex energy evaluation calculations, including evaluations of the entire building envelope, building usage, or changes to heating and air-conditioning equipment, consult the ASHRAE Fundamentals Handbook or an experienced mechanical engineer.

This application determines "Annual Energy Cost" values, which is useful when comparing the energy costs and savings associated with various roof assemblies' designs. This value should not be confused with the building owner's overall energy costs, which in most instances will be somewhat larger than the "Annual Energy Cost" that is attributable to the roof assembly only. For a detailed financial analysis of the long-term costs and potential savings of an energy-efficient roof system, consult an experienced accountant.

Related sites
NRCA
Professional Roofing
Alliance for Progress

In partnership with
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Summary

- Remember the fundamentals:
 - Relative humidity varies with temperature
 - Dew point is condensation temperature
 - Vapor drive: Hot → Cold
- “Self-drying” roofs:
 - Downward drying ≥ moisture up-take
 - Additional considerations for “cool” roofs
- Vapor retarders

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Summary - continued

- Attic ventilation
 - Unvented attics alternative
- Thermal insulation
 - FTC R-value rule
 - Polyisocyanurate: R = 5.0 per inch
- Energy code
 - Watch for edition updates
 - Comply with the code
 - Air retarder requirements



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Previously, we said...

~~“When in doubt, leave it out...”~~



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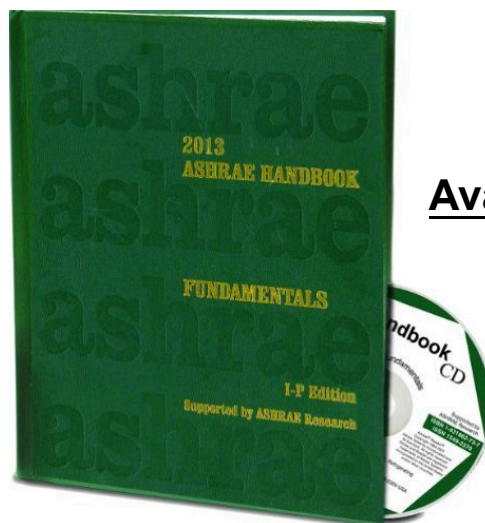
Now we can say...

“When in doubt, think it out...”



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Reference documents



Available from ASHRAE
www.ashrae.org



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Reference documents



Available from NRCA
shop.nrca.net



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The “ol’ guys” of condensation control

(Roof assemblies)



Wayne Tobiasson
U.S. Army Corps of Engineers (retired)



Joe Lstiburek
Building Science Corp. (“semi”-retired)



Bill Rose
University of Illinois at Urbana-Champaign (retired)



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