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Water Entry Prevention and Moisture Control in Buildings

North Platte, Nebraska – April 5-6, 2016

Condensation Control in Low- and Steep-slope Roofing

NRCA

Mark S. Graham
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National Roofing Contractors Association
Rosemont, Illinois

About NRCA

- Not-for-profit trade association founded in 1886
- Rosemont (Chicago), IL and Washington, DC
- More than 3,500 members:
  - Roofing contractors and affiliate members
  - All 50 states and 53 counties
  - 97 local, state and regional affiliates organizations
  - Less than $1 M in volume to large companies
  - Both residential and commercial work
  - One-third in business for more than 50 years
- Assist roofing contractors and advance the roofing industry

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About me

- Raised in a third-generation, family-owned construction business
- Degree in Architectural Engineering
- Roof contracting business
- Consulting engineer
- NRCA…for the last 22 years

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

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.

Roof slope

"incline", not "pitch"

Low slope	Steep slope
2:12 or less	4:12 or greater
Hydrostatic	Hydrokinetic
Waterproof	Water shedding
Membrane roof coverings	Shingle-type roof coverings

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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Roof product/system choices – Steep slope



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Moisture sources in buildings

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

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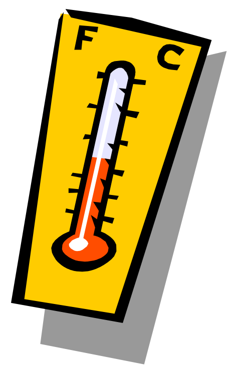
Phases of moisture

- **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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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.

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).

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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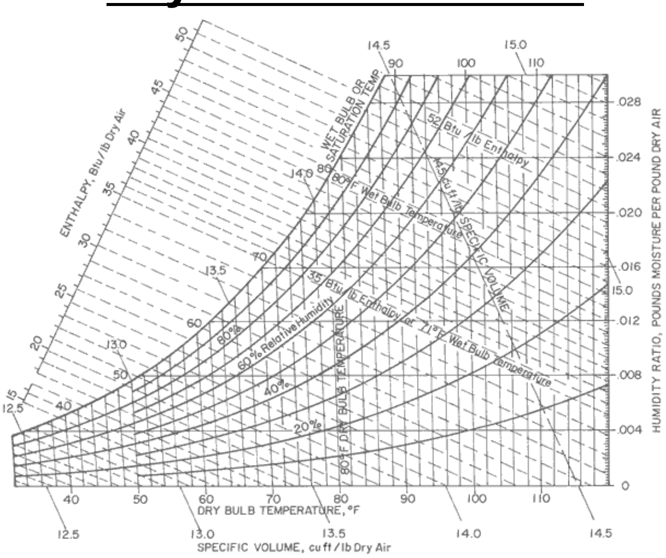
Psychrometric chart



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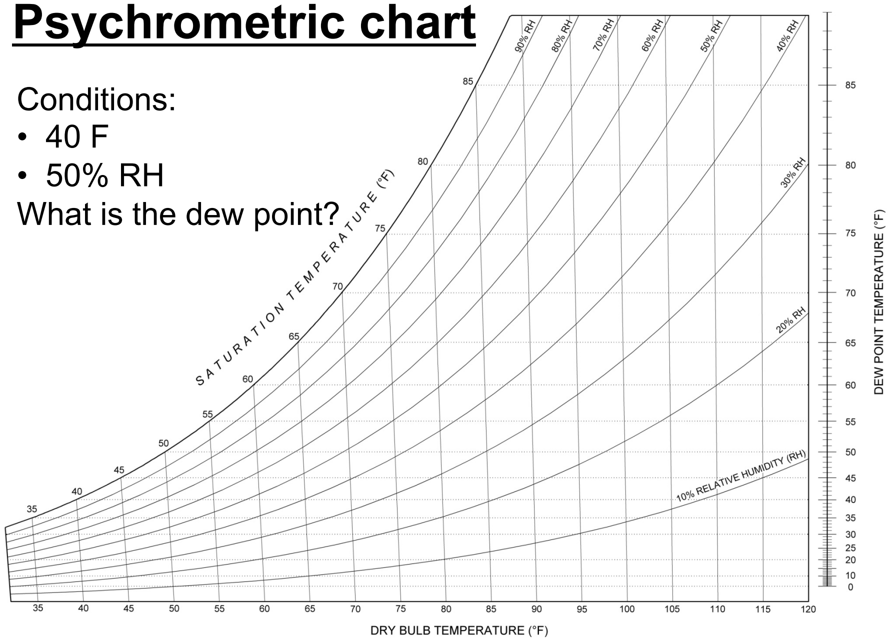
Psychrometric chart

Conditions:

- 40 F
- 50% RH

What is the dew point?



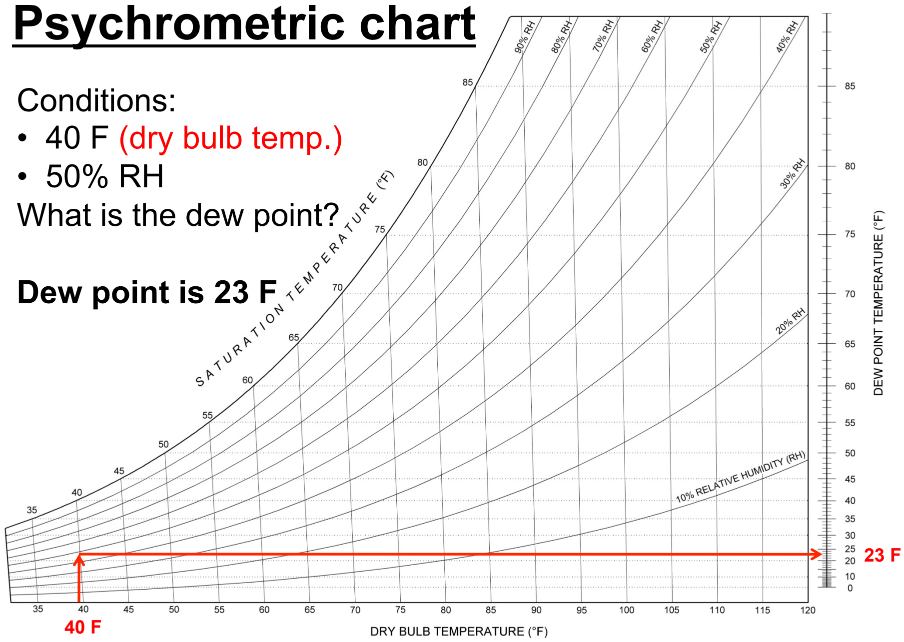
Psychrometric chart

Conditions:

- 40 F (dry bulb temp.)
- 50% RH

What is the dew point?

Dew point is 23 F



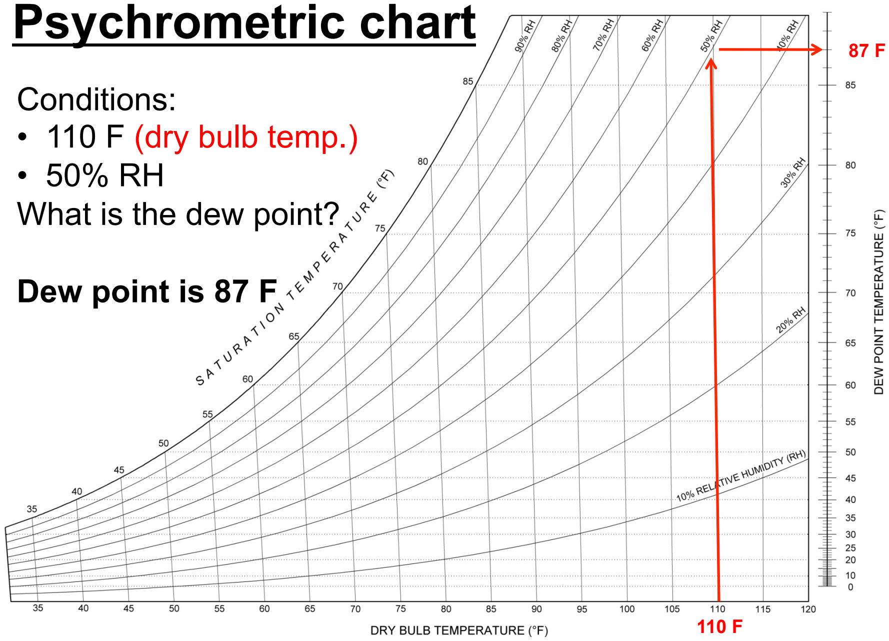
Psychrometric chart

Conditions:

- 110 F (dry bulb temp.)
- 50% RH

What is the dew point?

Dew point is 87 F



Psychrometric "table"

Dew-Point Temperature (°F)															
Relative Humidity	**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*.

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Warm air can hold more moisture than cold air

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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

Solid → Liquid → Gas → Liquid → Solid…

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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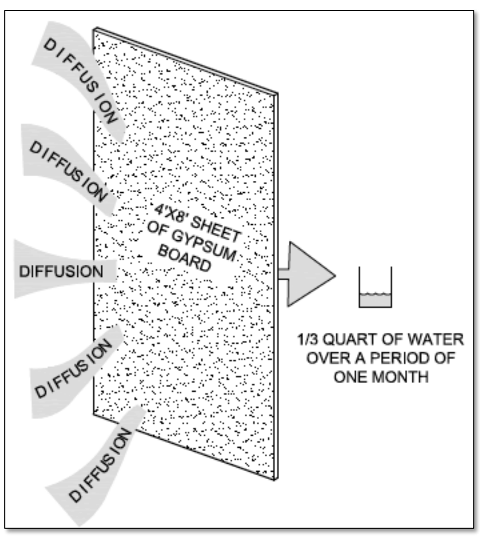
A practical application…

Is the glass "leaking"?

No! But we are studying thermodynamics

Diffusion



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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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Material	Permeance (perm)[1]	Permeability (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 (¾ in. thick)	15	
Plaster on wood lath	11	
Gypsum wall board (⅜ in. thick, plain)	50	
Hardboard (⅛ in. thick, standard)	11	
Built-up roof membrane (hot applied)	0.0	
Plywood (¼ in. thick, Douglas fir, exterior glue)	0.7	
Plywood (¼ 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

Classification	Permeance
Class I vapor retarder	0.1 per 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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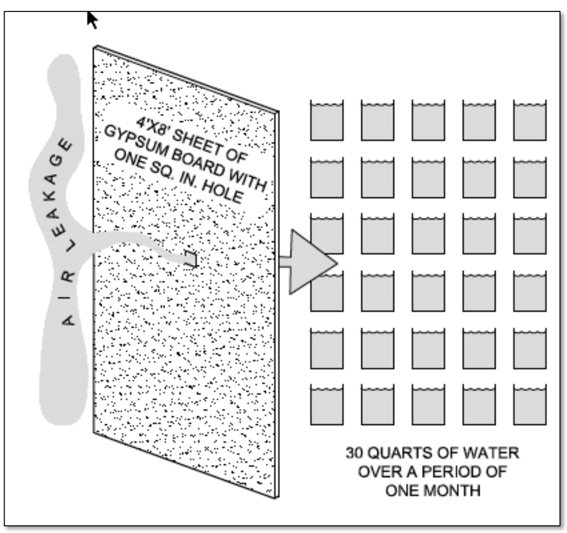
Continuity is critical.

Air leakage



Note: Compared to ⅓ quart by diffusion (~100 X)

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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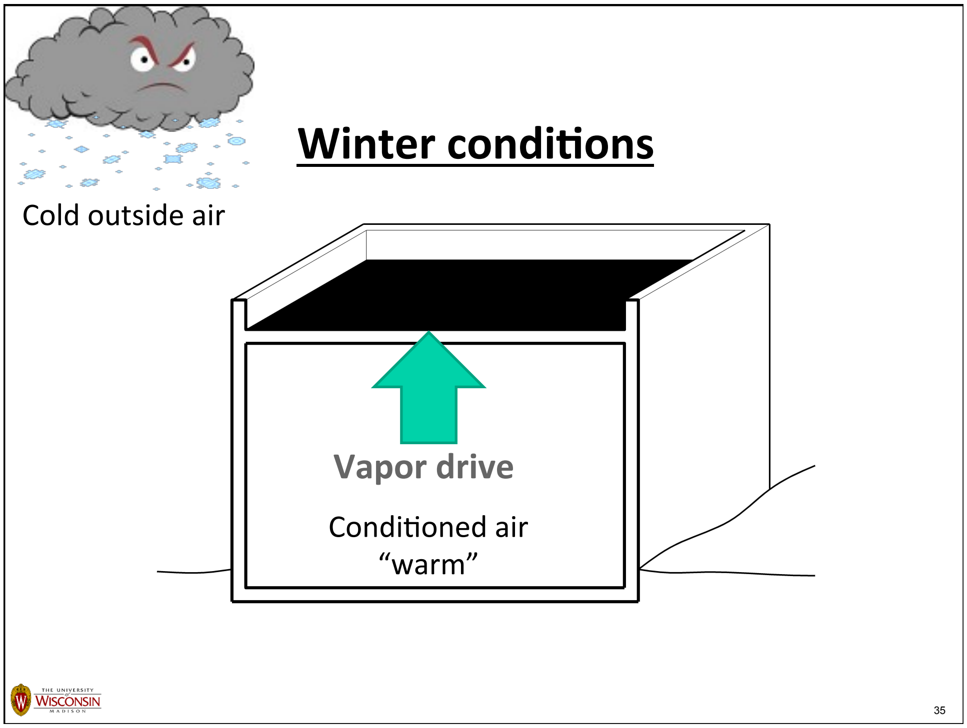
Winter conditions
Cold outside air
Vapor drive
Conditioned air
"warm"
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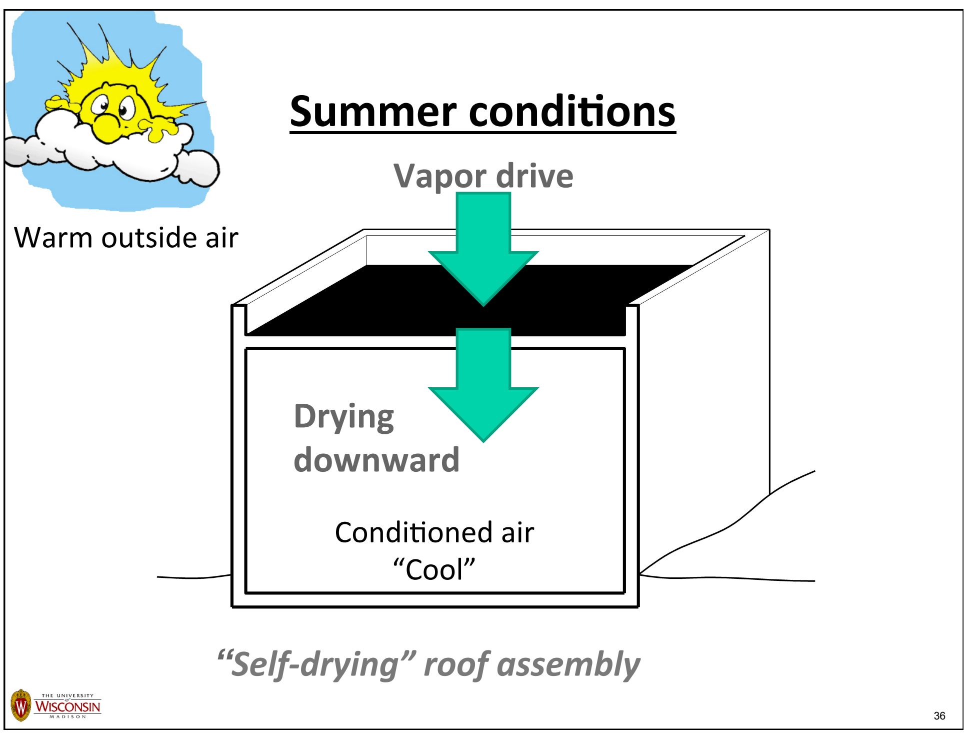
Summer conditions
Warm outside air
Vapor drive
Drying
downward
Conditioned air
"Cool"
"Self-drying" roof assembly
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Historically, most roof systems have effectively performed as "self-drying roofs"…

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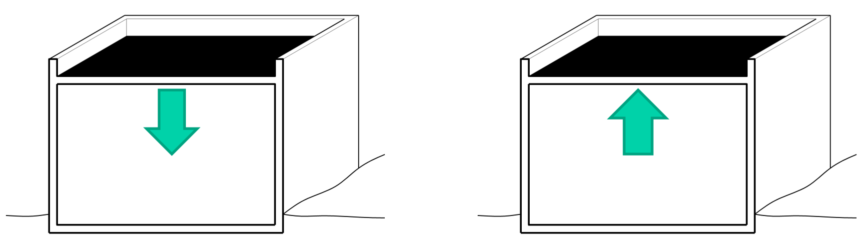
Self-drying roofs function properly if…



Downward drying ≥ 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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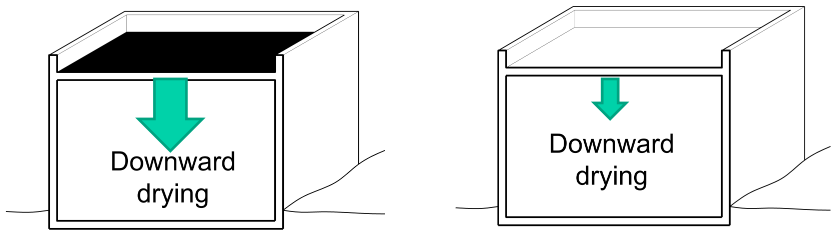

"Non-cool" roof

"Cool" roof

Cool roofs do not dry-down as efficiently as "non-cool" 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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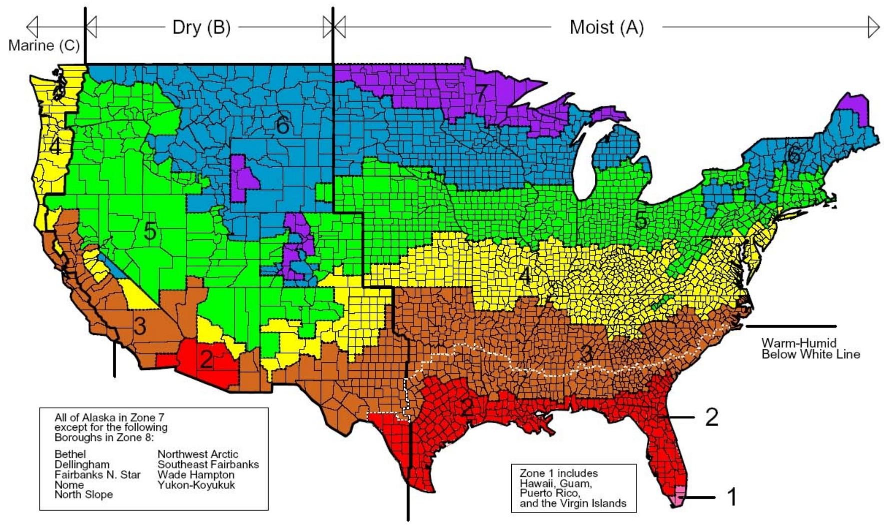
Climate zone map



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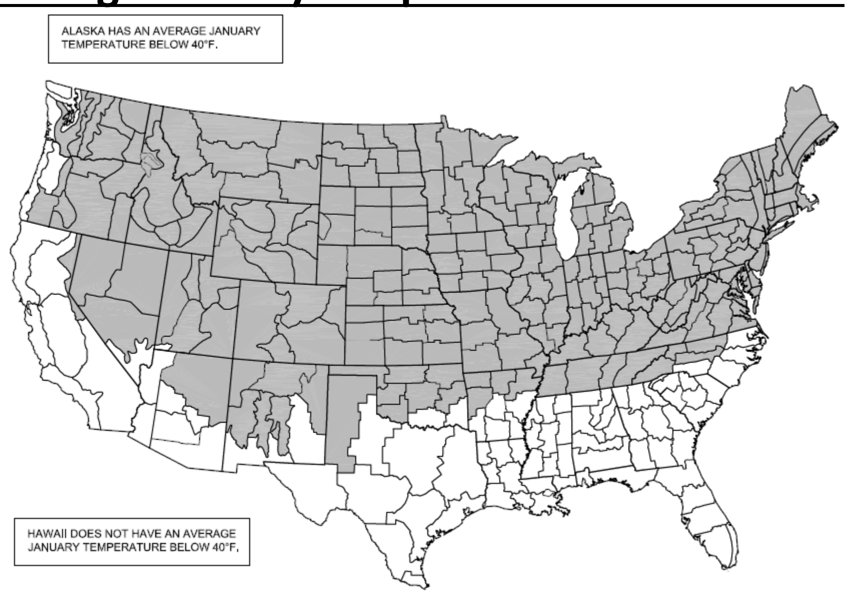
Average January temperature less than 40F



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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. (68 F design interior temperature)
- Provides RH threshold corrections for design interior temperatures other than 68 F

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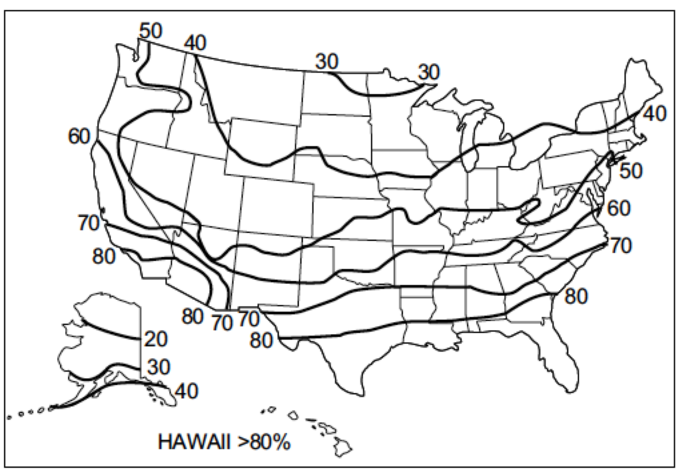
US Army CRREL method

Vapor retarder determination



Maximum allowable design interior humidity
(before use of a vapor retarder is suggested)

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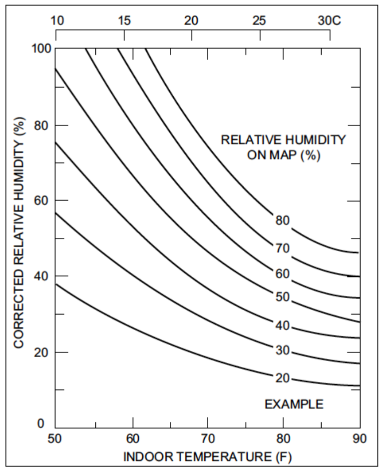
US Army CRREL method

Vapor retarder determination



Temperature correction
(other than 68 F)

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.

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:

- North Platte, NE (T_o = 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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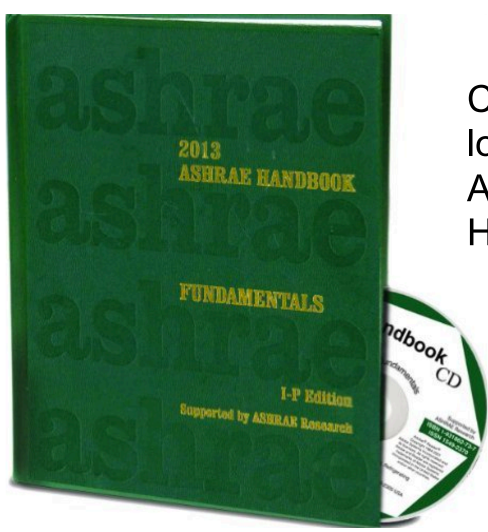
Determine T_o using the winter design dry bulb



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

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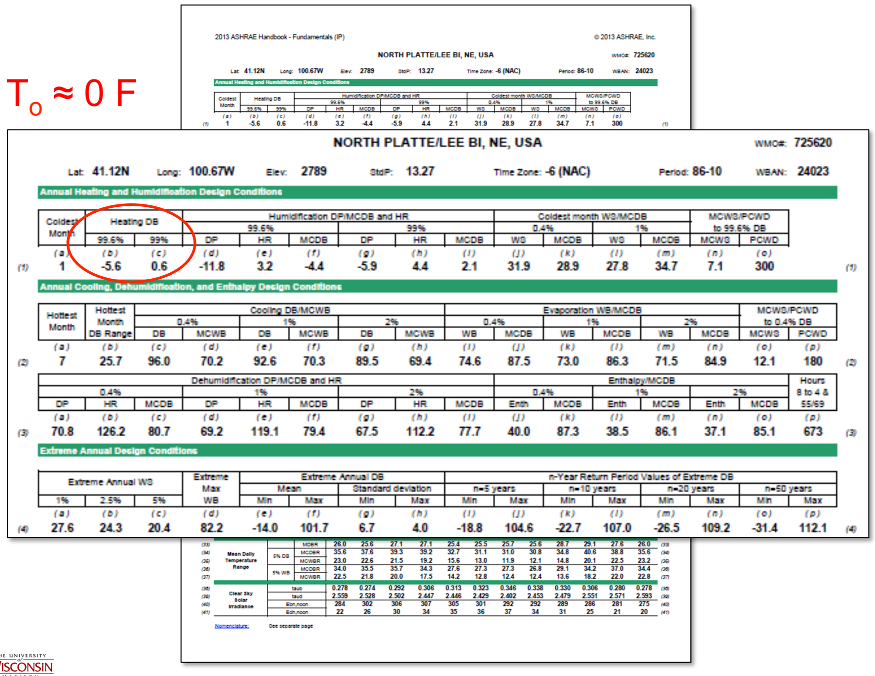
$T_o \approx 0$ F



2013 ASHRAE Handbook - Fundamentals (IP)

NORTH PLATTE/LEE BI, NE, USA WMO#: 725620

Lat: 41.12N Long: 100.67W Elev: 2789 StdP: 13.27 Time Zone: -6 (NAC) Period: 86-10 WBAN: 24023

Annual Heating and Humidification Design Conditions

(1) 1 -5.6 0.6 -11.8 3.2 -4.4 -5.9 4.4 2.1 31.9 28.9 27.8 34.7 7.1 300 (1)

NORTH PLATTE/LEE BI, NE, USA WMO#: 725620

Lat: 41.12N Long: 100.67W Elev: 2789 StdP: 13.27 Time Zone: -6 (NAC) Period: 86-10 WBAN: 24023

Annual Heating and Humidification Design Conditions

	Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB		
				99.6%			99%			0.4%		1%				
		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)	1	-5.6	0.6	-11.8	3.2	-4.4	-5.9	4.4	2.1	31.9	28.9	27.8	34.7	7.1	300	(1)

Annual Cooling, Dehumidification, and Enthalpy Design Conditions

	Hottest Month	Hottest Month DB Range	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB		
			0.4%		1%		2%		0.4%		1%		2%				
			DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(2)	7	25.7	96.0	70.2	92.6	70.3	89.5	69.4	74.6	87.5	73.0	86.3	71.5	84.9	12.1	180	(2)

	Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Hours 8 to 4 & 55/69	
	0.4%			1%			2%			0.4%		1%		2%			
	DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB		
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(3)	70.8	126.2	80.7	69.2	119.1	79.4	67.5	112.2	77.7	40.0	87.3	38.5	86.1	37.1	85.1	673	(3)

Extreme Annual Design Conditions

	Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB								
					Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years		
	1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	
	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)	(i)	(j)	(k)	(l)	(m)	(n)	(o)	(p)	
(4)	27.6	24.3	20.4	82.2	-14.0	101.7	6.7	4.0	-18.8	104.6	-22.7	107.0	-26.5	109.2	-31.4	112.1	(4)

(33)	Mean Daily Temperature Range		MDBR	26.0	25.6	27.1	27.1	25.4	25.5	25.7	25.6	28.7	29.1	27.6	26.0	(33)
(34)		5% DB	MCDBR	35.6	37.6	39.3	39.2	32.7	31.1	31.0	30.8	34.8	40.6	38.8	35.6	(34)
(35)			MCWBR	23.0	22.6	21.5	19.2	15.6	13.0	11.9	12.1	14.8	20.1	22.5	23.2	(35)
(36)		5% WB	MCDBR	34.0	35.5	35.7	34.3	27.6	27.3	27.3	26.8	29.1	34.2	37.0	34.4	(36)
(37)			MCWBR	22.5	21.8	20.0	17.5	14.2	12.8	12.4	12.4	13.6	18.2	22.0	22.8	(37)
(38)	Clear Sky Solar Irradiance	taub		0.278	0.274	0.292	0.306	0.313	0.323	0.346	0.338	0.330	0.306	0.280	0.278	(38)
(39)		taud		2.559	2.528	2.502	2.447	2.446	2.429	2.402	2.453	2.479	2.551	2.571	2.593	(39)
(40)		Ebn,noon		284	302	306	307	305	301	292	292	289	286	281	275	(40)
(41)		Edh,noon		22	26	30	34	35	36	37	34	31	25	21	20	(41)

Nomenclature: See separate page

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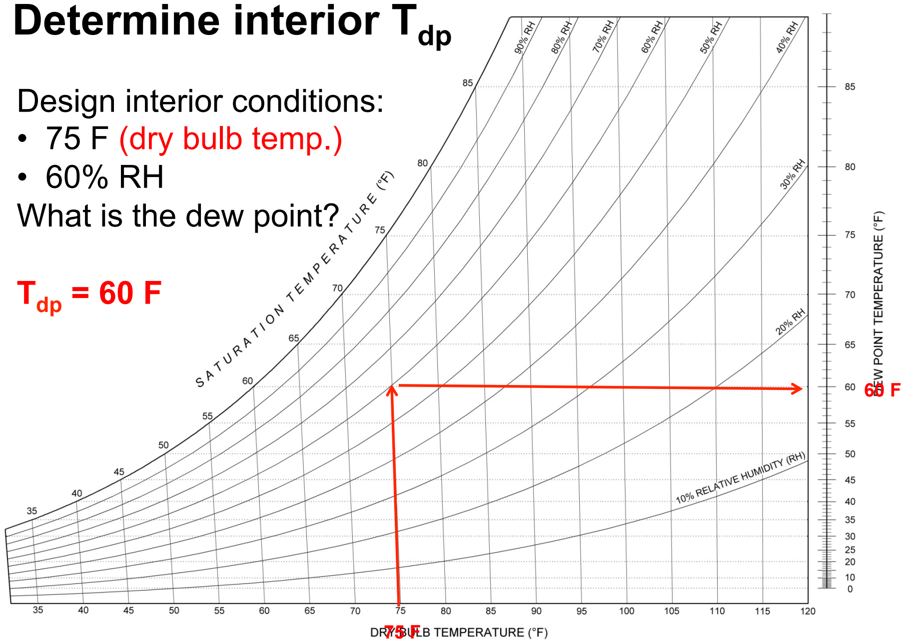
Determine interior T_{dp}

Design interior conditions:

- 75 F (dry bulb temp.)
- 60% RH

What is the dew point?

$T_{dp} = 60$ F



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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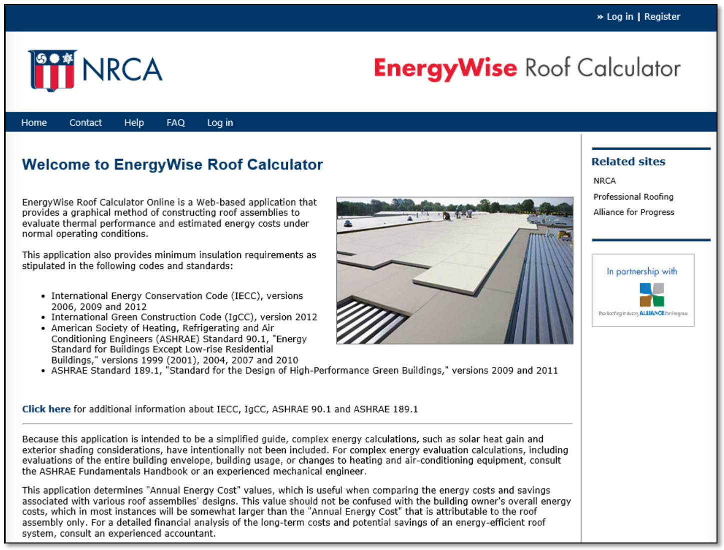
energywise.nrca.net



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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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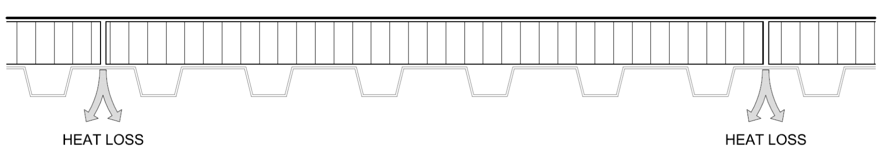
Board joints



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

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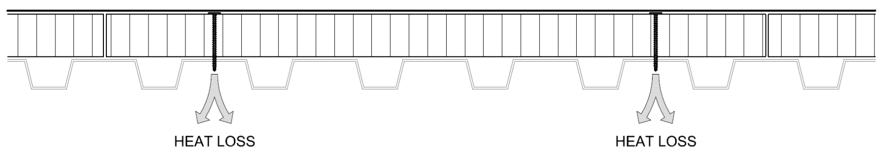
Mechanical fasteners



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

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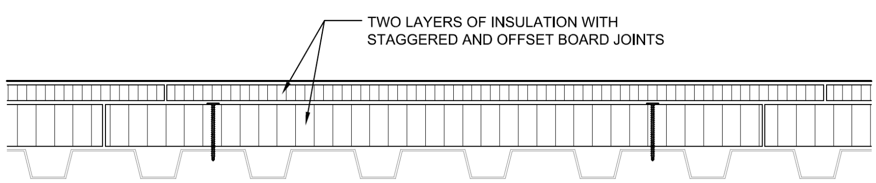
So,… use two layers of insulation, off-set the board joints, mechanically-attach the bottom layer and adhere the top layer(s)



Referred to as "screw one, mop one"

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 environments are relatively moderate, 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 coolers or freezers:

- 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 70 F, the building's framework may be square and true.

When the building is put into operation and its interior and structural framework cools to the building's internal operating temperature, which can be about -20 F, the lateral framework may contract about ¾ of an inch because of thermal movement and longitudinal members may contract about 1½ inches. Also, the stresses created by these movements are considerable and typically will be greatest at the building's corners. Thermal movement and stresses also can significantly affect a roof system if not properly addressed.

Sound engineering judgement is necessary when designing the structural framework for cooler and freezer buildings to address thermal movement and stresses. NRCA suggests placing structural expansion joints to divide the building envelope into relatively square (and not 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 160 F depending on the cooler or freezer building's geographic location and roof color. Interior temperatures on 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 in-service 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 reversal of vapor drive direction is 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 consideration also needs to be given to designing roof-to-wall junctures, building expansion joints and any roof system penetrations to ensure air and vapor seals are continuous. The roof system's vapor retarder layer should be made continuous with and be interconnected to the vapor retarder of the wall system.

Failure to provide a continuous vapor barrier and air seal will result in moisture infiltration and accumulation of ice on interior surfaces.

NRCA recommends designers provide detailed specifications and drawings to ensure their design intentions are known to bidders and installers.

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

14 www.professionalroofing.net AUGUST 2015

Professional Roofing, August 2015

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Condensation control guidelines

Steep-slope roof assemblies

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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 x 10^{-11} kg/s m^2 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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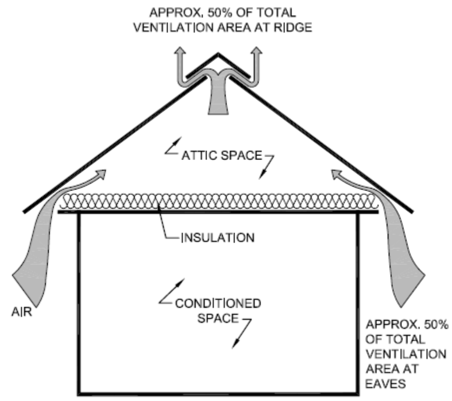
Suggested guidelines

Static ventilation configuration

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



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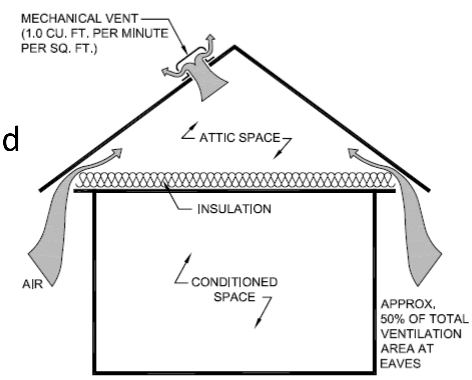
Suggested guidelines

Mechanical ventilation

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



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Average January temperature less than 30F

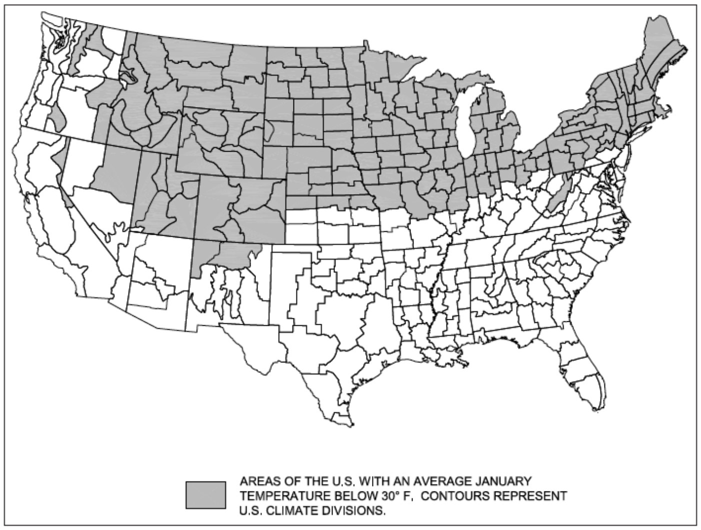

Figure 2-3: Areas of the U.S. with an average January temperature below 30 F, composite 1981-2012 data. Map is based on data provided by NOAA/ESRL Physical Sciences Division, Boulder, Colo., from its website, www.cdc.noaa.gov. Contours represent U.S. Climate Divisions.

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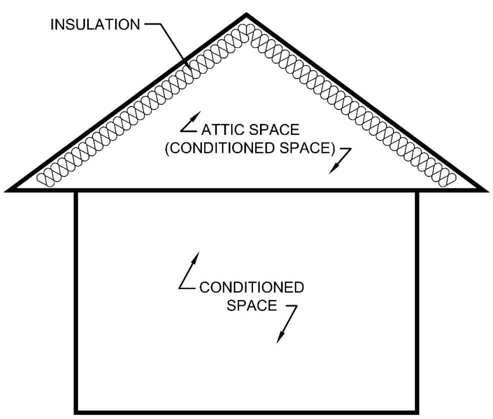
An alternative: Unvented, conditioned attic



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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 ¼ 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 contract with the underside of the insulation.

-Continued-

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-

International Residential Code, 2009 Edition

TABLE R806.4 INUSLATION 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.	

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

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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 bottom-side 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

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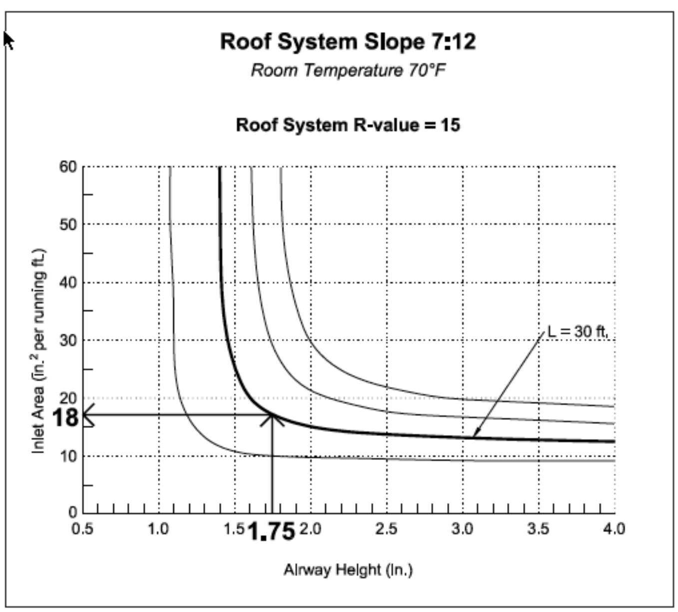

Figure 14: Example calculation for airways 1.75 inches in height with a rafter length of 30 feet and an R-value of 15, slope of 7:12

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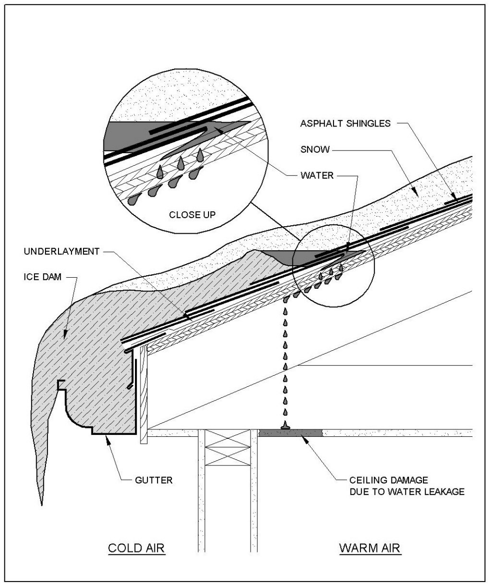
Additional considerations for ice damming



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Ice damming guidelines

- For 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

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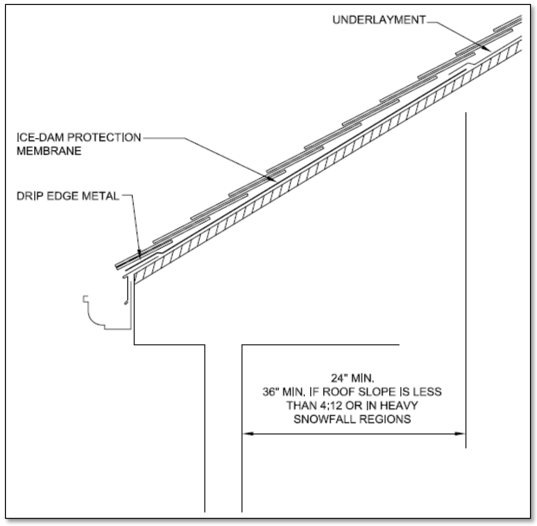
Placement of ice dam membrane



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Thermal insulation

88

Principles of thermal insulation

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

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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.

$$k = Btu \bullet inch / ft^2 \bullet hr \bullet F$$

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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.

$$C = Btu / ft^2 \bullet hr \bullet F$$

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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.

$$U = Btu / ft^2 \bullet hr \bullet F$$

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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 $R_T = R_1 + R_2 + R_3 = \ldots$

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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 h x ft^2 x °F/Btu at a mean temperature of 75°F (24°C).

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Polyisocyanurate

- Polysiocyanurate 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

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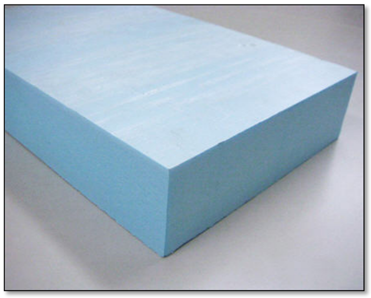
Extruded polystyrene (XPS)



- 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

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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)

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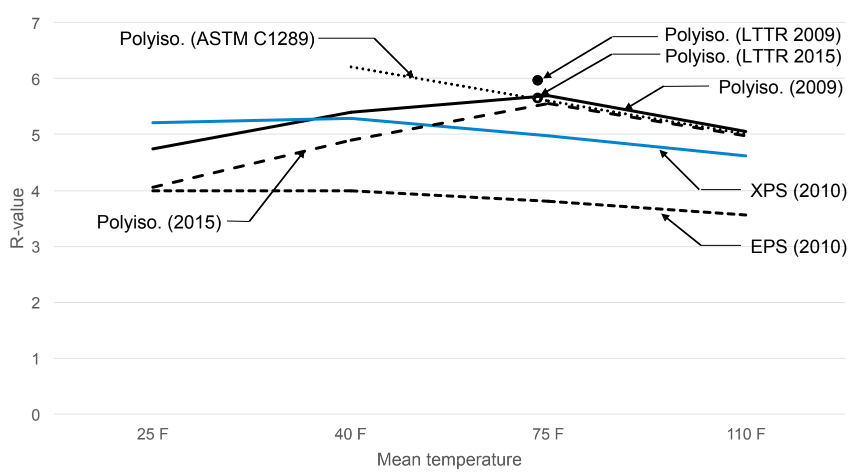
NRCA R-value testing



100

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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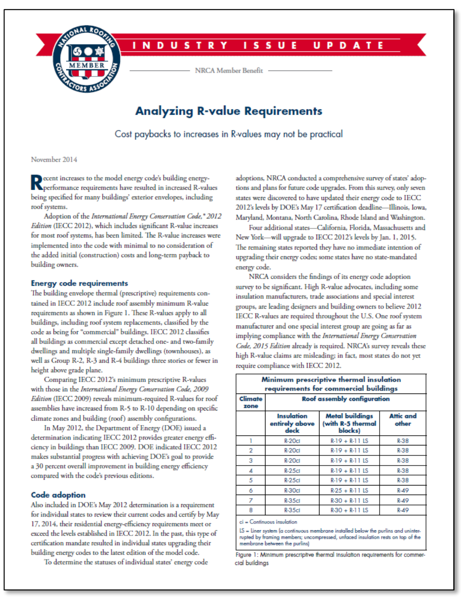

INDUSTRY ISSUE UPDATE

NRCA Member Benefit

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 assembly 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 classifies 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 in 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, their residential energy-efficiency requirements meet or exceed the levels established in IECC 2012. In the past, this type of certification mandate resulted in individual states upgrading their building energy codes to the latest edition of the model code.

To determine the statuses of individual states' energy code adoptions, NRCA conducted a comprehensive survey of states' adoptions and plans for future code upgrades. From this survey, only seven states were discovered to have updated their energy code to IECC 2012's levels by DOE'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 levels 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.

Minimum prescriptive thermal insulation requirements for commercial buildings

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	R-20ci	R-19 + R-11 LS	R-38
3	R-20ci	R-19 + R-11 LS	R-38
4	R-25ci	R-19 + R-11 LS	R-38
5	R-25ci	R-19 + R-11 LS	R-38
6	R-30ci	R-25 + R-11 LS	R-49
7	R-35ci	R-30 + R-11 LS	R-49
8	R-35ci	R-30 + R-11 LS	R-49

ci = Continuous insulation

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

Figure 1: Minimum prescriptive thermal insulation requirements for commercial buildings

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.

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Energy code requirements

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Some history…

Energy efficiency of buildings

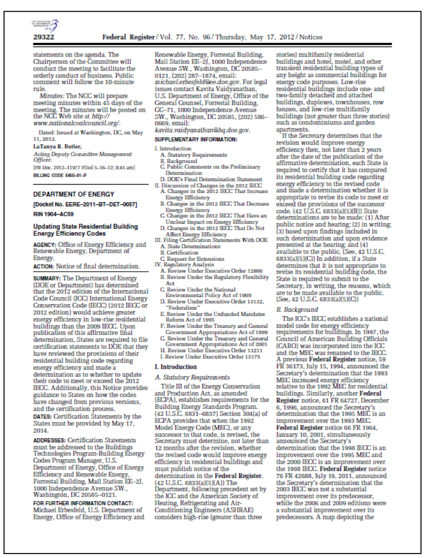
- 1973: Arab oil embargo
- 1974: NBS Interim Report 74-452 (prelim. criteria)
- 1975: ASHRAE 90-75 (energy-efficiency std.)
- 1977: BOCA/ICBO/SBCCI code (CABO *MEC*)
- 1980: ASHRAE 90-80
- 1989: ASHRAE 90.1-89
- 1992: Energy Policy Act (EPAct)
- 1998: *International Energy Conservation Code*
- 1999: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

More recent history…

Energy efficiency in buildings

- 2004: ASHRAE 90.1-04
- 2006: *International Energy Conservation Code, 2006 Edition*
- 2007: ASHRAE 90.1-07
- 2009: *International Energy Conservation Code, 2009 Edition*
- 2009: ASHRAE 189.1-09
- 2010: ASHRAE 90.1-10
- 2011: *International Energy Conservation Code, 2012 Edition*
- 2013*:* ASHRAE 90.1-13
- 2014: *International Energy Conservation Code, 2015 Edition*

Federal Register, May 17, 2012


29322 Federal Register / Vol. 77, No. 96 / Thursday, May 17, 2012 / Notices

Key points:

- US DOE has determined IECC 2012 will achieve greater energy efficiency in low-rise residential buildings than IECC 2009
- States must certify by 5/17/14 their energy code meets or exceeds the levels of IECC 2012

This triggers most states to update their state energy code

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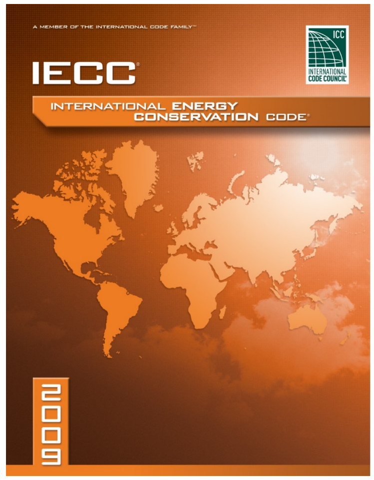
International Energy Conservation Code, 2009 Edition (IECC 2009)



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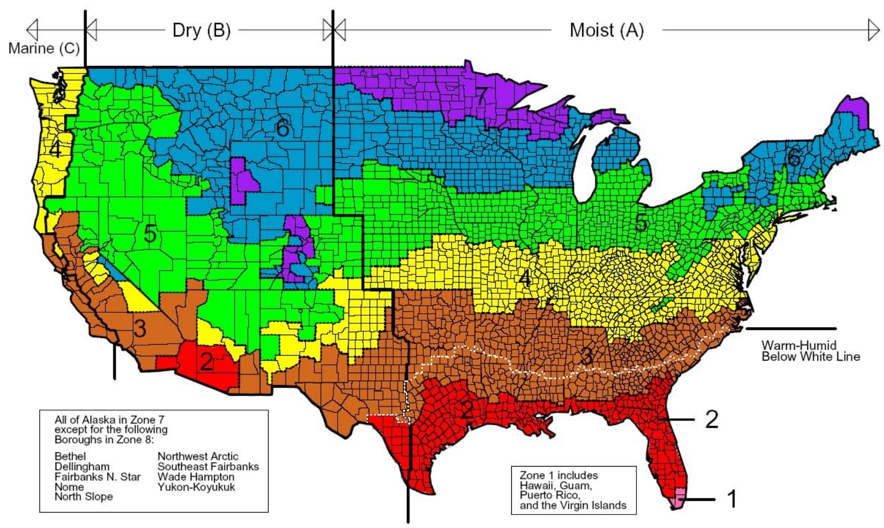
Climate zones

IECC 2009 and IECC 2012



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Roofing-specific adaptation of Table 402.1.1

International Energy Conservation Code, 2009 Edition (Residential buildings)

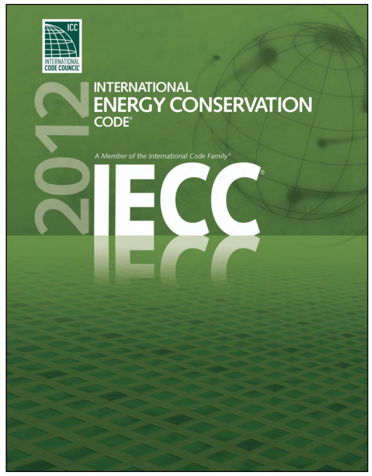
<table>
<tr><th colspan="2">Insulation and Fenestration Requirements by Component[a]</th></tr>
<tr><th>Climate zone</th><th>Ceiling R-value</th></tr>
<tr><td>1</td><td rowspan="3">30</td></tr>
<tr><td>2</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td><td rowspan="2">38</td></tr>
<tr><td>5</td></tr>
<tr><td>6</td><td rowspan="3">49</td></tr>
<tr><td>7</td></tr>
<tr><td>8</td></tr>
<tr><td colspan="2">[a] R-values are minimums. …
[Other footnotes omitted for clarity]</td></tr>
</table>

Roofing-specific adaptation of Table 502.2(1)

International Energy Conservation Code, 2009 Edition (Commercial buildings)

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

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.
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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

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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

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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]

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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 m^2) 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.

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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

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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…]

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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.

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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		
5			
6	R-30ci	R-25 + R-11 LS	R-49
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)

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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 x ft^2 x °F/Btu at a mean temperature of 75°F (24°C).

What about tapered insulation?

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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. <u>This type of insulation referred to as tapered insulation is where the roof insulation varies to provide slope for drainage</u>…."

[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; <u>it simply does not allow the additional thickness to be factored into the average insulation values</u>. 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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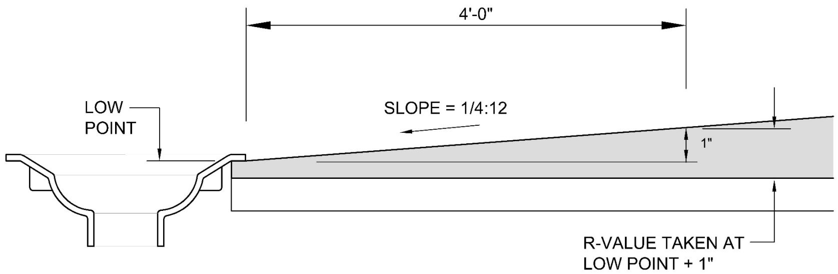
What about tapered insulation…?

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



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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…]

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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]

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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…]

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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….]

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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 ½ 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…]

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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 L/s · 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 L/s · 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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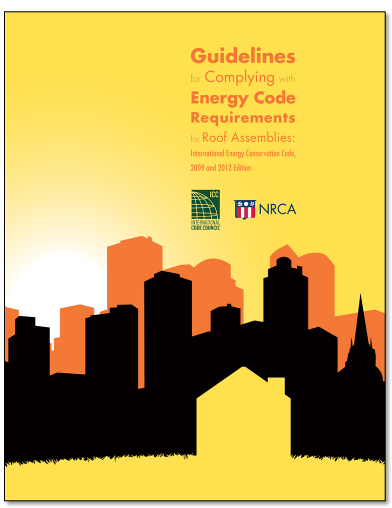
Energy Codes Manual (2009 & 2012 Codes)



- 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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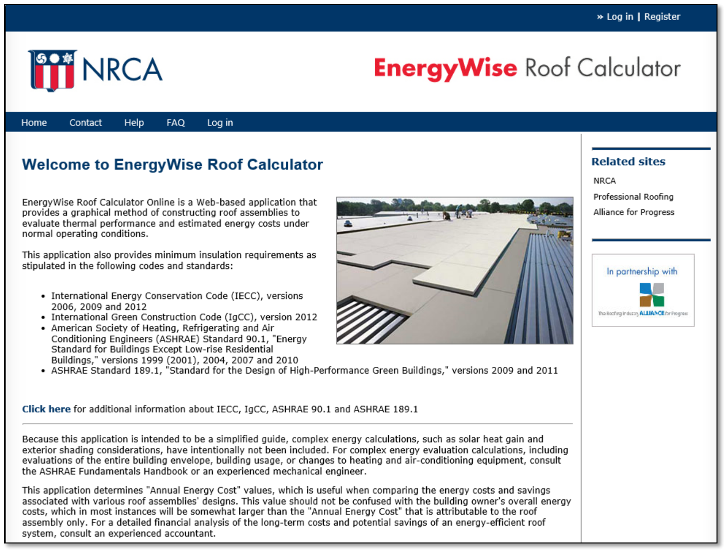

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Summary

- 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
  - An unvented attic is an 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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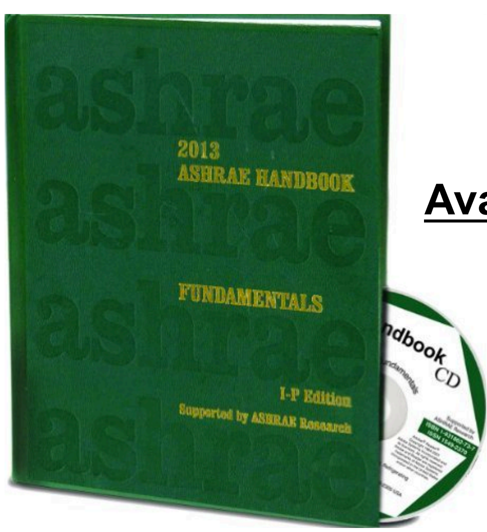
Reference documents



Available from ASHRAE
www.ashrae.org

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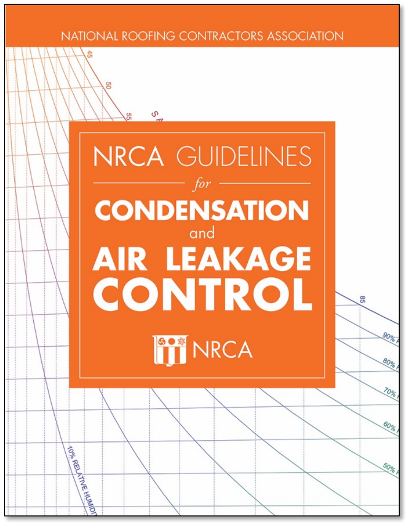
Reference documents



Available from NRCA

shop.nrca.net

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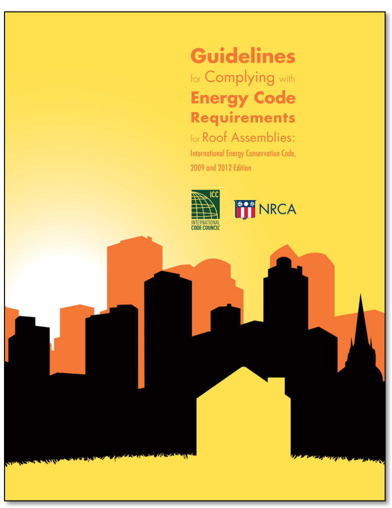
Energy Codes Manual (2009 & 2012 Codes)



- 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

Acknowledgement to the "founding fathers"

Moisture control in roof assembles

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U.S. Army Corps of Engineers (retired)

Joe Lstiburek
Building Science Corp. ("semi"-retired)

Bill Rose
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Design challenges

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

by Mark S. Graham

Unlike most building types where interior environments are relatively moderate, 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 coolers or freezers:

- 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 70 F, the building's framework may be square and true.

When the building is put into operation and its interior and structural framework cools to the building's internal operating temperature, which can be about -20 F, the lateral framework may contract about ¾ of an inch because of thermal movement and longitudinal members may contract about 1½ inches. Also, the stresses created by these movements are considerable and typically will be greatest at the building's corners. Thermal movement and stresses also can significantly affect a roof system if not properly addressed.

Sound engineering judgement is necessary when designing the structural framework for cooler and freezer buildings to address thermal movement and stresses. NRCA suggests placing structural expansion joints to divide the building envelope into relatively square (and not 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 160 F depending on the cooler or freezer building's geographic location and roof color. Interior temperatures on 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 in-service 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 reversal of vapor drive direction is 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 consideration also needs to be given to designing roof-to-wall junctures, building expansion joints and any roof system penetrations to ensure air and vapor seals are continuous. The roof system's vapor retarder layer should be made continuous with and be interconnected to the vapor retarder of the wall system.

Failure to provide a continuous vapor barrier and air seal will result in moisture infiltration and accumulation of ice on interior surfaces.

NRCA recommends designers provide detailed specifications and drawings to ensure their design intentions are known to bidders and installers.

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

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 assembly 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 classifies 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 in 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, their residential energy-efficiency requirements meet or exceed the levels established in IECC 2012. In the past, this type of certification mandate resulted in individual states upgrading their building energy codes to the latest edition of the model code.

To determine the statuses of individual states' energy code adoptions, NRCA conducted a comprehensive survey of states' adoptions and plans for future code upgrades. From this survey, only seven states were discovered to have updated their energy code to IECC 2012's levels by DOE'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 levels 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.

Minimum prescriptive thermal insulation requirements for commercial buildings			
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	R-20ci	R-19 + R-11 LS	R-38
3	R-20ci	R-19 + R-11 LS	R-38
4	R-25ci	R-19 + R-11 LS	R-38
5	R-25ci	R-19 + R-11 LS	R-38
6	R-30ci	R-25 + R-11 LS	R-49
7	R-35ci	R-30 + R-11 LS	R-49
8	R-35ci	R-30 + R-11 LS	R-49

ci = Continuous insulation

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

Figure 1: Minimum prescriptive thermal insulation requirements for commercial buildings

NRCA's theoretical energy savings and cost payback analysis				
Climate zone	**City**	**R-value increase**	**Btu savings (heating and cooling)**	**Payback**
1	Miami	R-10 to R-15	14,094,020 Btu	10.8 years
		R-15 to R-20	7,870,571 Btu	22.1 years
		R-20 to R-25	4,561,644 Btu	35.4 years
		R-25 to R-30	3,232,756 Btu	76.7 years
2	Phoenix	R-10 to R-15	17,587,010 Btu	18.5 years
		R-15 to R-20	9,743,286 Btu	38.1 years
		R-20 to R-25	5,620,822 Btu	61.3 years
		R-25 to R-30	3,969,578 Btu	133.0 years
	New Orleans	R-10 to R-15	21,213,494 Btu	15.0 years
		R-15 to R-20	11,760,541 Btu	30.9 years
		R-20 to R-25	6,787,331 Btu	49.7 years
		R-25 to R-30	4,794,863 Btu	107.8 years
3	Atlanta	R-10 to R-15	32,188,755 Btu	7.8 years
		R-15 to R-20	17,795,916 Btu	16.2 years
		R-20 to R-25	10,253,829 Btu	26.1 years
		R-25 to R-30	7,234,929 Btu	56.7 years
	Los Angeles	R-10 to R-15	16,585,533 Btu	11.6 years
		R-15 to R-20	9,175,377 Btu	23.8 years
		R-20 to R-25	5,288,761 Btu	38.2 years
		R-25 to R-30	3,732,720 Btu	83.0 years
	Dallas	R-10 to R-15	27,291,307 Btu	15.2 years
		R-15 to R-20	15,107,897 Btu	31.4 years
		R-20 to R-25	8,711,683 Btu	50.5 years
		R-25 to R-30	6,150,345 Btu	109.6 years
4	Seattle	R-10 to R-15	41,511,732 Btu	10.0 years
		R-15 to R-20	22,875,846 Btu	20.9 years
		R-20 to R-25	13,155,552 Btu	33.7 years
		R-25 to R-30	9,268,949 Btu	73.5 years
	Philadelphia	R-10 to R-15	45,256,460 Btu	7.5 years
		R-15 to R-20	24,967,532 Btu	15.5 years
		R-20 to R-25	14,368,027 Btu	24.9 years
		R-25 to R-30	10,128,298 Btu	54.3 years
4	Kansas City, Mo.	R-10 to R-15	51,295,159 Btu	9.4 years
		R-15 to R-20	28,314,737 Btu	19.4 years
		R-20 to R-25	16,299,591 Btu	31.3 years
		R-25 to R-30	11,492,733 Btu	68.0 years
5	Boston	R-10 to R-15	49,647,013 Btu	6.7 years
		R-15 to R-20	27,375,148 Btu	13.8 years
		R-20 to R-25	15,748,557 Btu	22.3 years
		R-25 to R-30	11,098,822 Btu	48.5 years
	Denver	R-10 to R-15	52,120,379 Btu	12.1 years
		R-15 to R-20	28,732,017 Btu	25.1 years
		R-20 to R-25	16,526,782 Btu	40.4 years
		R-25 to R-30	11,646,024 Btu	88.2 years
	Chicago	R-10 to R-15	58,340,933 Btu	7.5 years
		R-15 to R-20	32,175,508 Btu	15.6 years
		R-20 to R-25	18,512,379 Btu	25.2 years
		R-25 to R-30	13,047,818 Btu	54.7 years
6	Milwaukee	R-10 to R-15	63,370,658 Btu	9.4 years
		R-15 to R-20	34,933,522 Btu	19.4 years
		R-20 to R-25	20,093,821 Btu	31.4 years
		R-25 to R-30	14,159,572 Btu	68.3 years
	Minneapolis	R-10 to R-15	68,995,466 Btu	9.1 years
		R-15 to R-20	38,033,780 Btu	18.8 years
		R-20 to R-25	21,876,909 Btu	30.4 years
		R-25 to R-30	15,415,978 Btu	66.1 years
7	Sault St. Marie, Mich.	R-10 to R-15	78,807,463 Btu	8.5 years
		R-15 to R-20	43,428,492 Btu	17.6 years
		R-20 to R-25	24,975,104 Btu	28.4 years
		R-25 to R-30	17,596,619 Btu	61.8 years
8	Nome, Alaska	R-10 to R-15	119,135,728 Btu	3.7 years
		R-15 to R-20	65,648,986 Btu	7.7 years
		R-20 to R-25	37,752,688 Btu	12.4 years
		R-25 to R-30	26,598,690 Btu	27.0 years

Figure 2: Results of NRCA's theoretical energy savings and cost payback analysis

NRCA is committed to providing accurate and up-to-date information addressing energy code adoption. You can check the status of your state's energy code adoption by accessing the Energy Codes page of the Technical section of NRCA's website at www.nrca.net/technical/energycodes.

Energy savings and payback

NRCA has conducted an energy-savings and payback analysis for roof assembly R-value increases in 16 cities representative of the energy code's eight U.S. climate zones.

A hypothetical project that consisted of insulation above a roof deck assembly on a 10,000-square-foot single-story building was considered. Construction cost increases and corresponding theoretical energy-savings information were developed for changing the hypothetical roof assembly in each city from R-10 to R-15, R-15 to R-20, R-20 to R-25 and R-25 to R-30. City-specific current energy costs (natural gas for heating and electricity for cooling) were used in the analysis. Payback length is determined by dividing the incremental increased cost for adding R-value by the calculated theoretical energy cost savings. The results of NRCA's analysis are shown in Figure 2.

NRCA's 16-city analysis reveals insulation increases from R-10 to R-15 have the relatively shortest paybacks ranging from 3.7 years to 12.1 years. Conversely, increases from R-20 to R-25 and R-25 to R-30 have paybacks ranging from 12.4 years to 133 years. Payback lengths vary by a city's climatic conditions and heating and cooling energy costs. For example, energy costs significantly vary between Boston and Denver, resulting in wide variances in paybacks even when comparing cities in the same climate zone.

Considering current heating and cooling energy costs, NRCA's analysis concludes R-value increases resulting in payback lengths approaching or beyond a roof assembly's anticipated life span are not financially justifiable for building owners. A 2004 study conducted by The Roofing Industry Alliance for Progress revealed the average life span for a commercial low-slope roof system in the U.S. is about 17.4 years.

As heating and cooling energy costs increase, shorter payback lengths will occur and may better justify the current model energy code's high minimum-required R-values.

You can determine theoretical heating and cooling costs (and savings) for roof assembly configurations in specific cities using NRCA's EnergyWise Roof Calculator accessible at http://energywise.nrca.net.

NRCA recommendations

NRCA considers a roof assembly's thermal performance to be an important attribute to overall roof system performance.

NRCA recommends roof assembly designers provide designs that comply with the minimum requirements of the specific energy code applicable to the jurisdiction where a building is located.

Additional information about complying with the roofing-related requirements of IECC 2009 and IECC 2012 is provided in NRCA's *Guidelines for Complying With Energy Code Requirements for Roof Assemblies: International Energy Conservation Code, 2009 and 2012 Editions,* available by accessing shop.nrca.net or contacting NRCA's Customer Service Department at (866) ASK-NRCA (275-6722) or info@nrca.net.

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