Facilities Design and Planning for Extreme Snow Events

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Provider Number: J380
Course Number: SNOW90

10.14.2015 | Waltham, MA

Course Description

Following Boston's record snowfall last winter, now is a good time to discuss the lessons learned as we prepare for winter 2015-2016. We will begin this session by discussing snow loads on structures, including how design snow loads are determined in the building code, how those loads have changed over time, and how modifications to existing buildings can affect snow loading. Next, we will review how ice dams form, identify risk factors that make some buildings more susceptible to ice damming, and present several mitigation strategies. Throughout the presentation, we will use local project case studies to illustrate challenges posed by extreme snow events, while providing practical examples of solutions.

Learning Objectives

1. Understand the evolution of building code snow load provisions, how building vintage affects vulnerability to overloads, and how the nor'easter weather patterns created the heavy snow conditions in 2010 and 2015.
2. Recognize elements in new and existing buildings that aggravate snow load conditions in extreme snow events, and understand techniques and strategies to manage and prioritize snow removal during extreme snow events.
3. Understand how ice dams form and how to identify risk factors.
4. Identify various ice dam mitigation strategies and the appropriate applications for each.

Contents

1. WEATHER PHENOMENA
2. ASSESSMENT OF SNOW LOADS
3. ASSESSMENT OF STRUCTURAL CAPACITY
4. SNOW REMOVAL PLANS

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1. **WEATHER PHENOMENA**
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- 2015: ± 200 Roof Collapses in MA, more in NH, CT, and RI
- Sequence of:
  - Storms – Eastern MA
  - Northernly Winds
  - Persistent Cold

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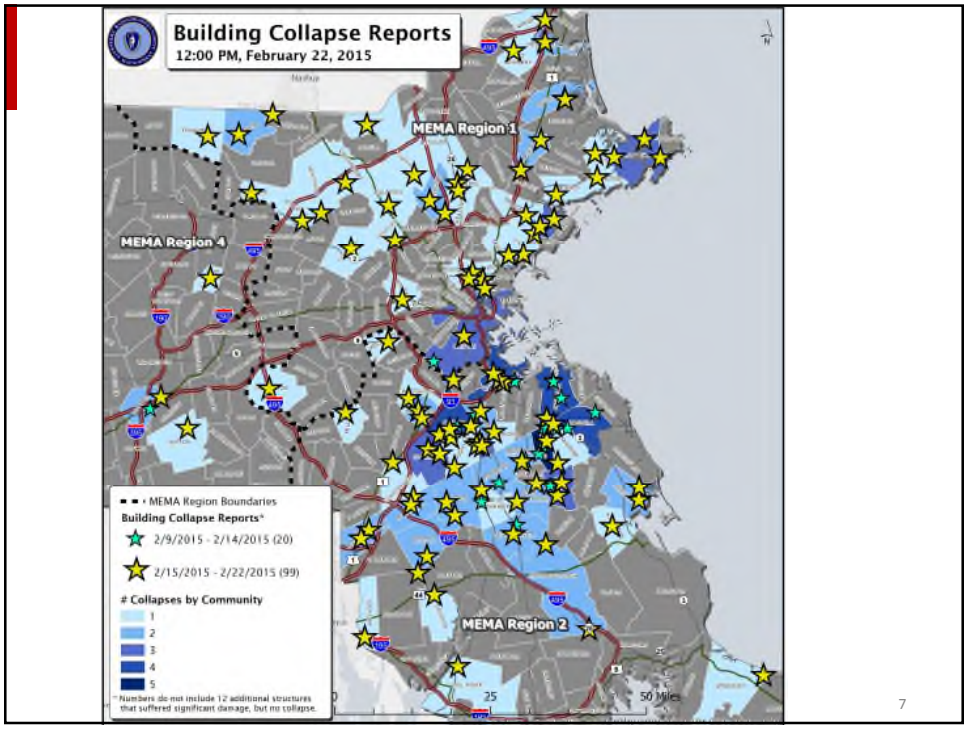
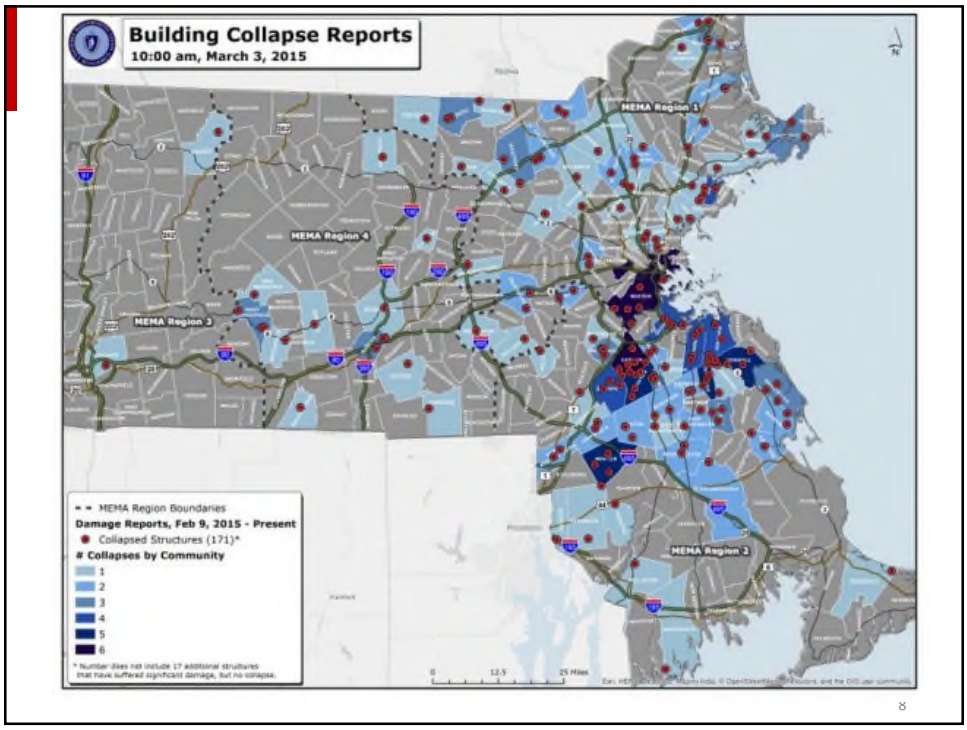

Building Collapse Reports
12:00 PM, February 22, 2015
MEMA Region 1
MEMA Region 4
MEMA Region 2
MEMA Region Boundaries
Building Collapse Reports*
2/9/2015 - 2/14/2015 (20)
2/15/2015 - 2/22/2015 (99)
Collapses by Community
1
2
3
4
5
* Numbers do not include 12 additional structures that suffered significant damage, but no collapse.
25
50 Miles
7


Building Collapse Reports
10:00 am, March 3, 2015
MEMA Region 1
MEMA Region 4
MEMA Region 3
MEMA Region 2
MEMA Region Boundaries
Damage Reports, Feb 9, 2015 - Present
Collapsed Structures (171)*
Collapses by Community
1
2
3
4
5
6
* Number does not include 17 additional structures that have suffered significant damage, but no collapse.
0
12.5
25 Miles
8

WEATHER PHENOMENA

- **Ingredient 1: Snow followed by cold**

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Partial List of 2015 Storms

Jan 24-25: Framingham – 8.3 in., East Boston 4.4 in

Jan 27-28: JUNO – Acton 34 in., So Boston 31 in.
Gusts: 49 to 78 mph

Feb 9-10: Sharon 25.5 in; East Boston 22.3 in.

Feb 14-15: Ipswich 22 in.; East Boston 16.2 in.
Gusts: 57 to 65 mph

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A Lot of Snow:

Source: http://boston.cbslocal.com/2015/02/27/the-most-extreme-winter-month-ever-observed-in-new-england/.

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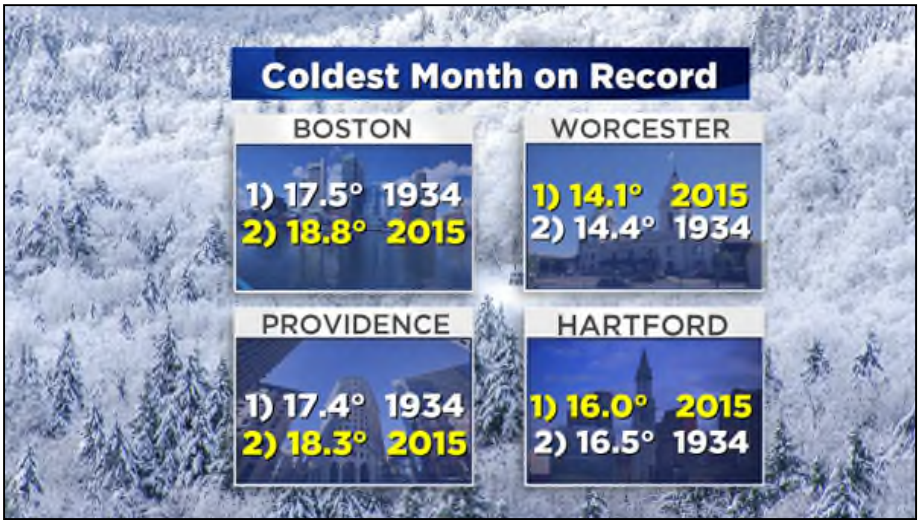
Cold…



Source: http://boston.cbslocal.com/2015/02/27/the-most-extreme-winter-month-ever-observed-in-new-england/.

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Weather Phenomena

- Ingredient 1: Snow followed by cold
- **Ingredient 2: Wind**

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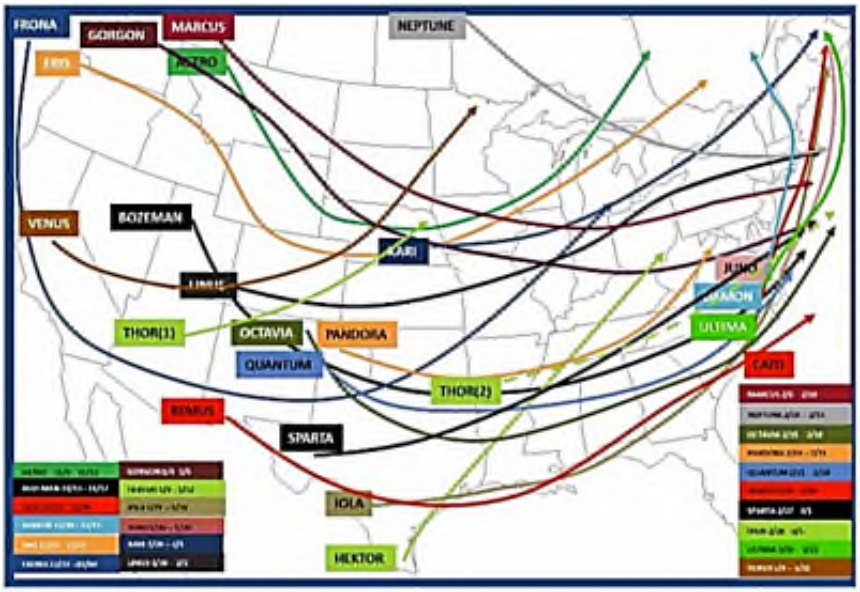
Named Storms 2014-2015



Source: http://www.weather.com/storms/winter/news/winter-weather-watch-2014-2015-20140930

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Source: http://kb1ijv.tripod.com/weatherwithaspin/id16.html

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Radar Image of Jan 27-28 Storm:

Source: http://wqad.com/2015/01/28/the-eric-factor/

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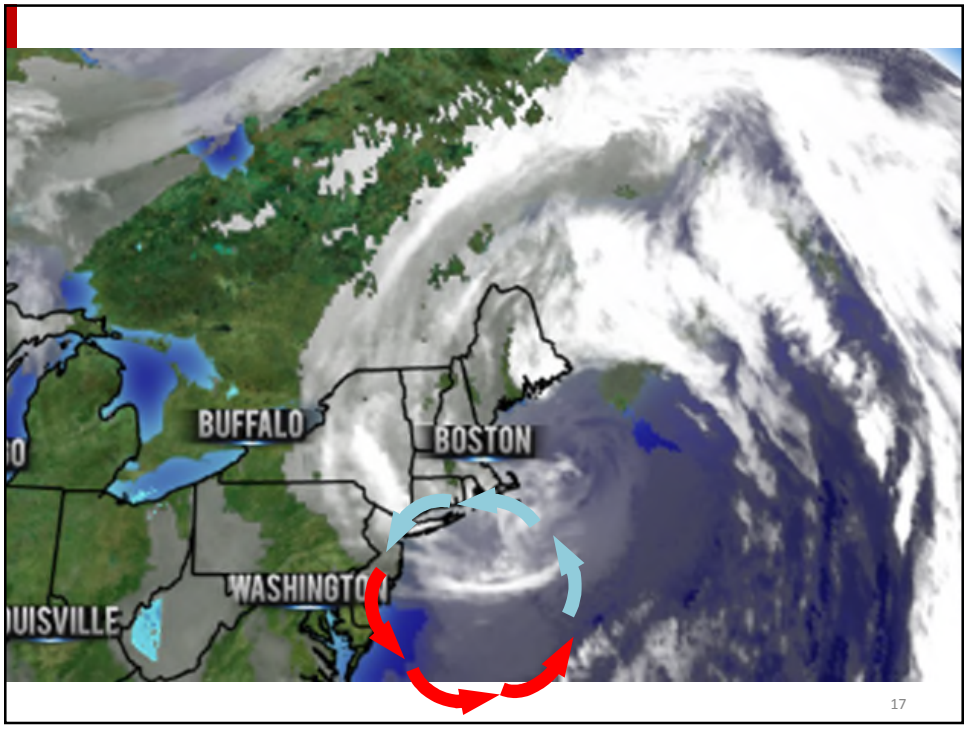
BUFFALO
BOSTON
WASHINGTO
UISVILLE
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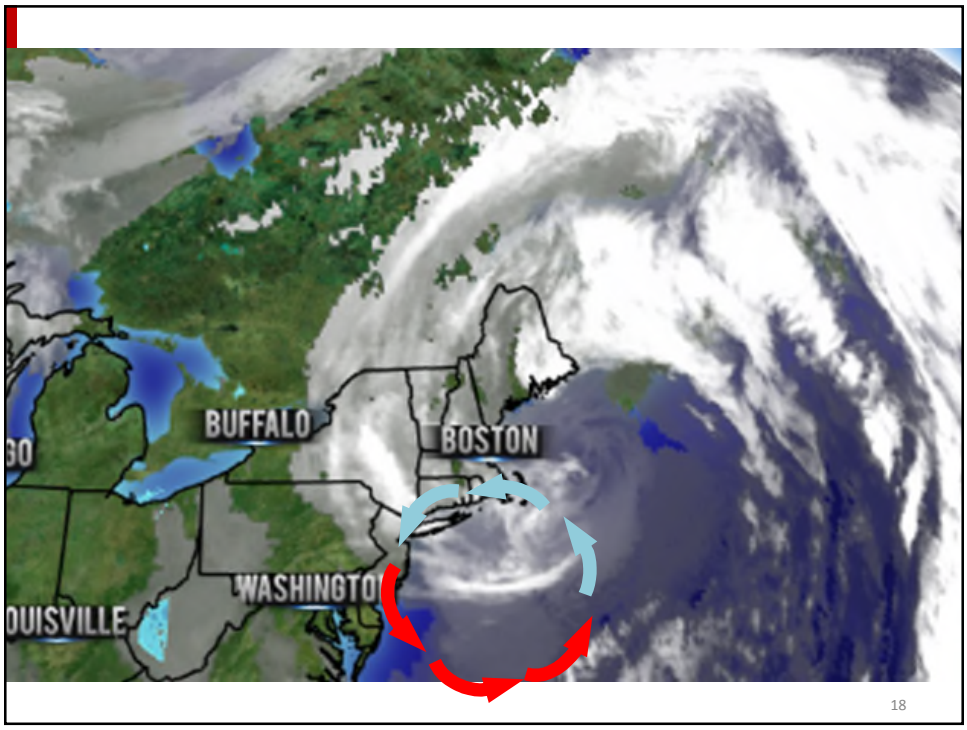
BUFFALO
BOSTON
WASHINGTO
UISVILLE
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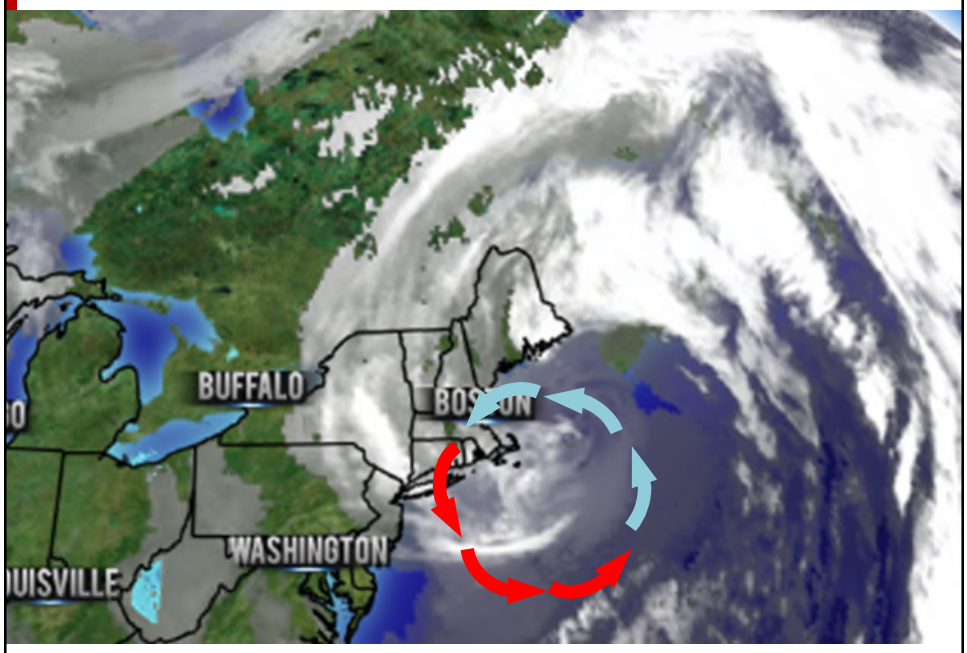

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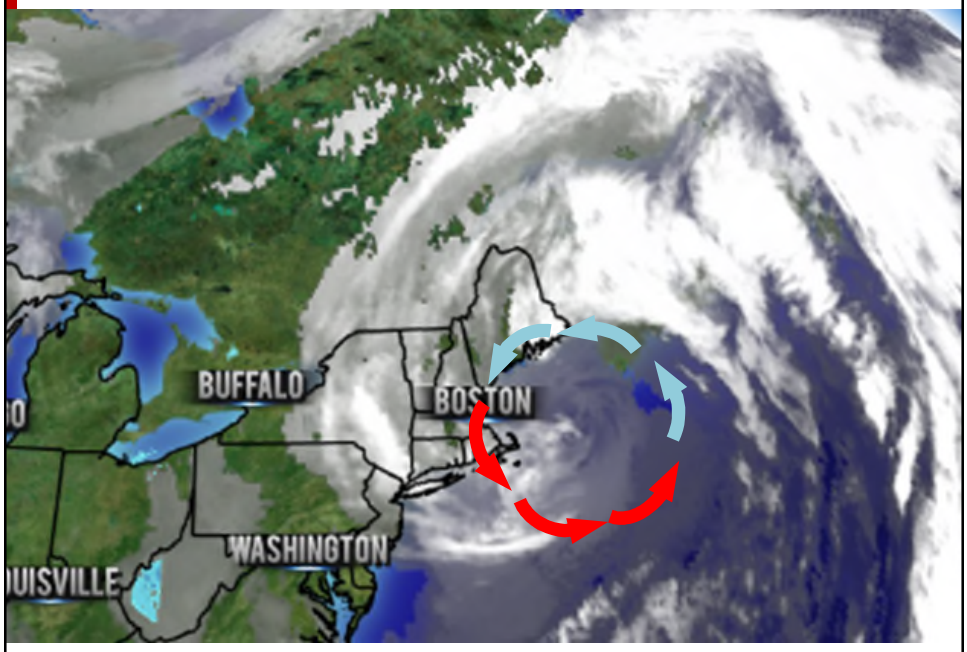

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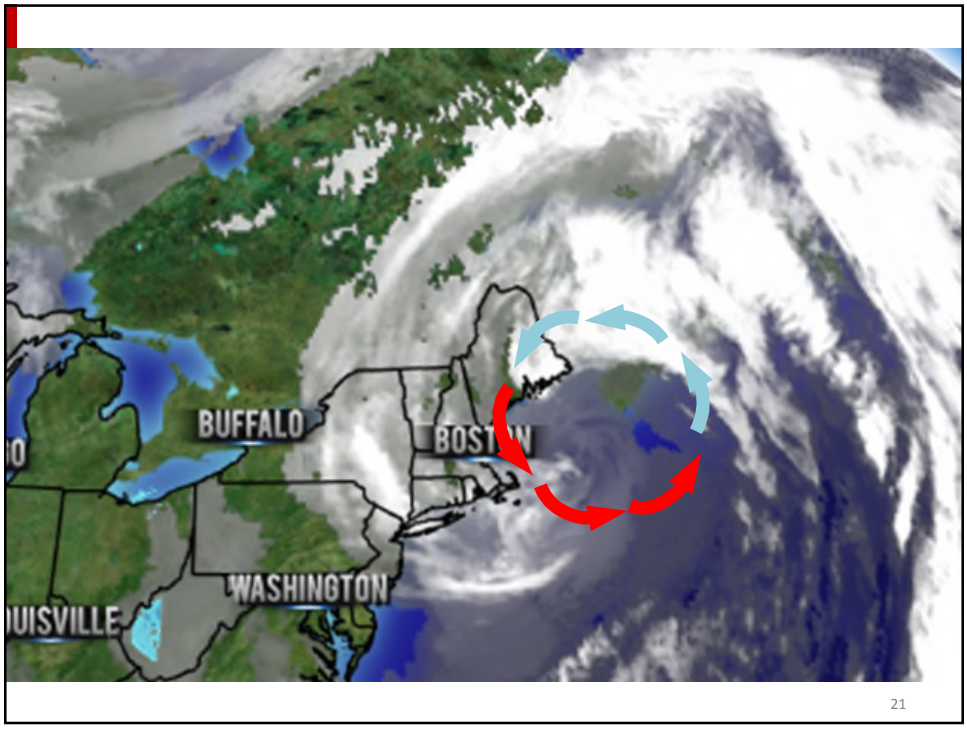
BUFFALO
BOSTON
WASHINGTON
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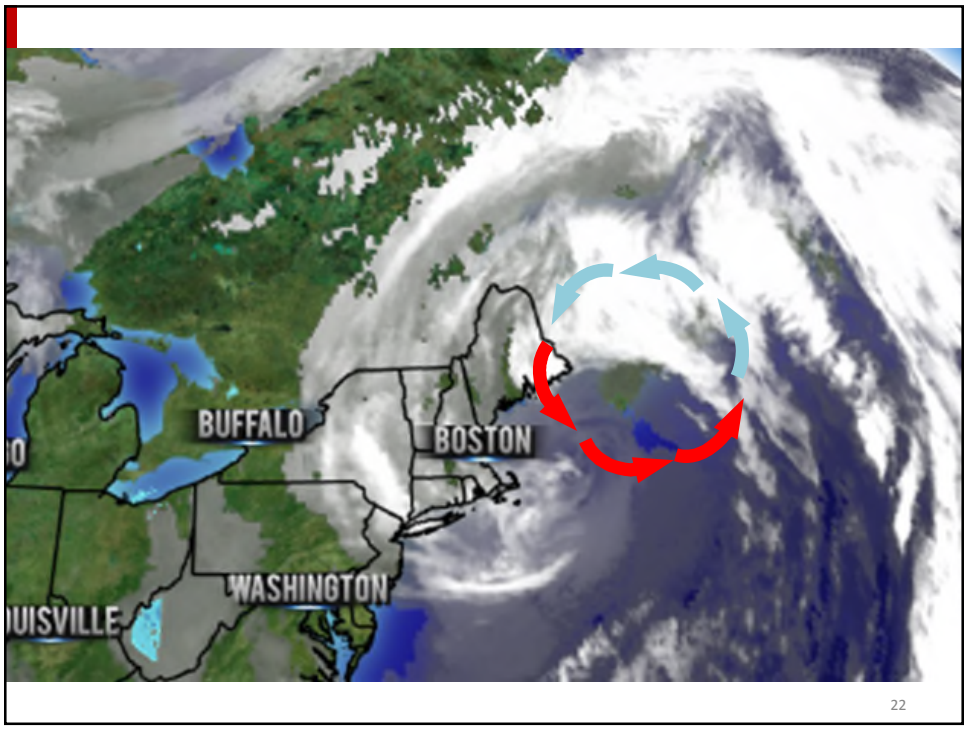
BUFFALO
BOSTON
WASHINGTON
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Weather Phenomena

- Ingredient 1: Snow followed by cold
- Ingredient 2: Wind
- **Ingredient 3: Drifts**

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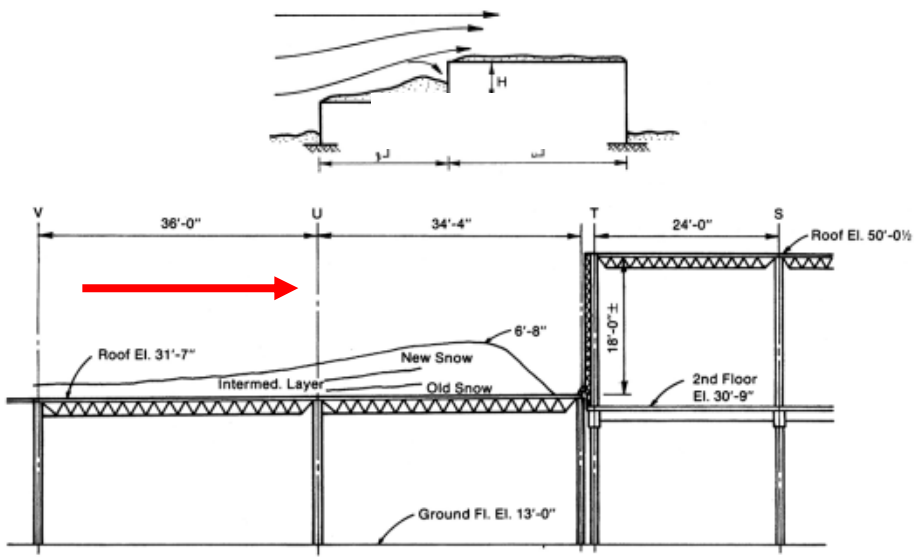

Source: Roof Snowdrifts die to Blizzards, ASCE Journal of Structural Engineering, Vol. 116, No. 3, March 1990.

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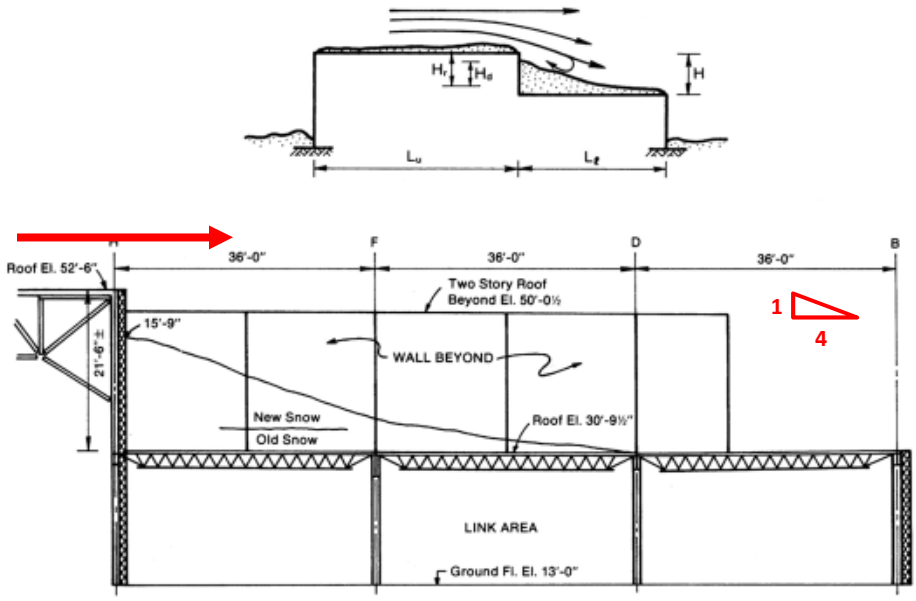

Source: Roof Snowdrifts die to Blizzards, ASCE Journal of Structural Engineering, Vol. 116, No. 3, March 1990.

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- Snow drifts require:
  - Aerodynamic irregularity (i.e., “step”)
  - Driftable snow upwind – in the “fetch” area
  - Strong enough wind
- Snow is “driftable” when the following apply:
  - Snow not followed by rain, sleet, or freezing rain
  - Snow followed by < 32˚ F
  - Wind within 3 days since last snow fall, i.e., wind acting on young snow

Source: M. O’Rourke and J. Wikoff, *Snow Related Roof Collapse and Implications for Building Codes*, Structure Magazine, January 2013.

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Density of Snow Varies

- Ice = 58 lb/cf
- Frosty/Slushy Snow = 25 – 40 lb/cf
- Dense Snow = 10 – 20 lb/cf
- Fresh, Light, Fluffy = 5 – 10 lb/cf

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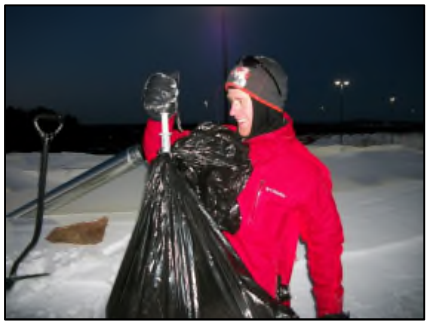

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Evaluating a Single Building or Inventory

- Evolution of the Building Code
- Vulnerabilities and Risk Factors
- Fragility or Robustness of the Structural System

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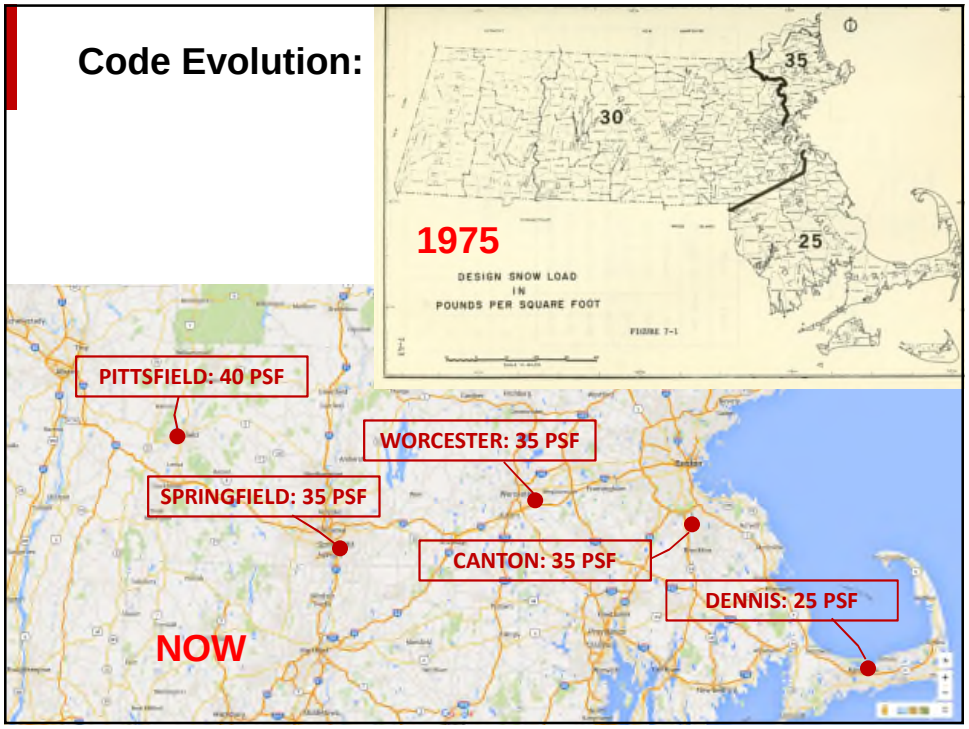
Code Evolution:



CODE	DESIGN FLAT ROOF SNOW LOADS					DRIFT	COLD/ WARM	EXPOSURE
	PITTSFIELD	SPRINGFIELD	WORCESTER	CANTON	DENNIS			
CITY OF BOSTON 1964	30					x	x	x
MA 1ST ED. Jan. 1975	30	30	30	30	25	√[1]	x	x
MA 2ND ED. Feb. 1975	30	30	30	30	25	√[1]	x	x
MA 3RD ED. Jun. 1979	30	30	30	30	25	√[1]	x	x
MA 4TH ED. Sept. 1980	40	35	35	35	25	√[1]	x	x
MA 5TH ED. Sept. 1990	40	35	35	35	25	√	x	x
MA 6TH ED. Feb. 1997	40	35	35	35	25	√	x	x
MA 7TH ED. Sept. 2008[2]	45	40	40	40	25	√	√	√
MA 8TH ED. Jan. 2014[3,4]	40	35	35	35	25	√	√	√

1. Drift calculations did not account for length of upwind fetch.
2. The 7th Edition prescribes ground snow loads (P_g). Numbers are the rounded flat roof snow load, $P_f=0.7C_eC_tIP_g$ assuming C_e, C_t, and I=1.0.
3. Table was amended several times. Values reported were effective as of 1/31/14.
4. The 8th Edition prescribes ground snow loads (P_g) and minimum flat roof snow load, (P_f). Numbers in parentheses are the smaller of $P_f=0.7C_eC_tIP_g$ and the tabulated P_f.

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Vulnerabilities and Risk Factors

- Blocked Drains
- Improper Slopes to Drains
- Non-Engineered Alterations

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Vulnerabilities and Risk Factors

- Blocked Drains
- Improper Slopes to Drains
- Non-Engineered Alterations
- Latent Design Defects
- Latent Construction Defects
- Added Suspended Loads

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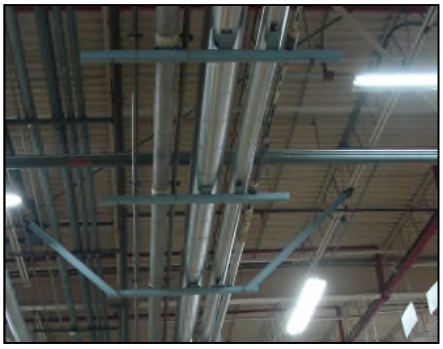

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Vulnerabilities and Risk Factors

- Blocked Drains
- Improper Slopes to Drains
- Non-Engineered Alterations
- Latent Design Defects
- Latent Construction Defects
- Added Suspended Loads
- Material Deterioration
- Snow Drifts
- Added Insulation
- Added Topside Loads
- Additions or Alterations that Create a “Step”

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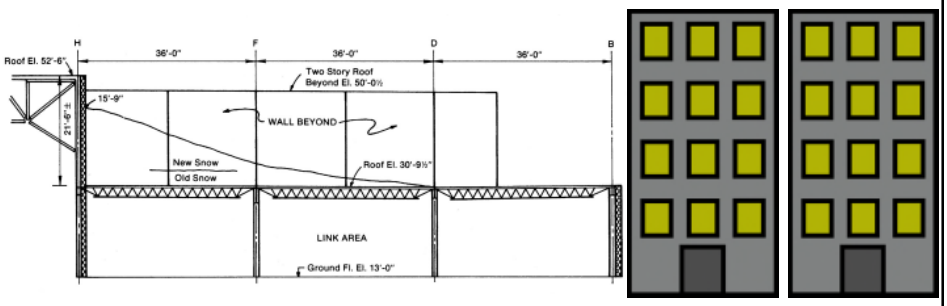

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System Fragility-Robustness

Robustness = How much residual overstrength a structural system provides.

Robustness in the face of snow loads generally correlates with system dead weight.

A structural system that is properly designed to the loads required by the building code, with all of the required safety factors, is fragile if the overstrength beyond the **DESIGN LOADS + SAFETY FACTORS** is low.

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From Fragile to Robust:

- Metal Buildings
- Wood or Metal Trusses
- Open Web Joists
- Engineered or Sawn Lumber
- Precast Concrete
- Steel Framed
- Steel-Concrete Composite
- Reinforced Concrete

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Fragility/Robustness ↔ Code Design Load

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CODE	DESIGN FLAT ROOF SNOW LOADS					DRIFT	COLD/ WARM	EXPOSURE
	PITTSFIELD	SPRINGFIELD	WORCESTER	CANTON	DENNIS			
V-1								
CITY OF BOSTON 1964			30			x	x	x
MA 1ST ED. Jan. 1975	30	30	30	30	25	√[1]	x	x
MA 2ND ED. Feb. 1975	30	30	30	30	25	√[1]	x	x
V-2								
MA 3RD ED. Jun. 1979	30	30	30	30	25	√[1]	x	x
MA 4TH ED. Sept. 1980	40	35	35	35	25	√[1]	x	x
MA 5TH ED. Sept. 1990	40	35	35	35	25	√	x	x
V-3								
MA 6TH ED. Feb. 1997	40	35	35	35	25	√	x	x
MA 7TH ED. Sept. 2008[2]	45	40	40	40	25	√	√	√
V-4								
MA 8TH ED. Jan. 2014[3,4]	40	35	35	35	25	√	√	√

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SYSTEM	CODE VINTAGE			
	V-1	V-2	V-3	V-4
MORE FRAGILE				
	P1		P3	
	P2		P4	
MORE ROBUST				

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Nonstructural Vulnerabilities

→ Impact of Deflections on Interior Finishes

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Snow Removal Plans

- **Insurance**

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Insurance

Coverage for emergency snow removal?

If so, what are the terms and due diligence required?

Coverage in the event of a failure – personal injury, loss of function?

Coverage often linked to building code requirements.

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INSURANCE Building Code

SUBSTANTIAL STRUCTURAL DAMAGE. A condition where:

1. In any story, the vertical elements of the lateral-force-resisting system have suffered damage such that the lateral load-carrying capacity of the structure in any horizontal direction has been reduced by more than 20 percent from its predamaged condition; or

2. The capacity of any vertical gravity load-carrying component, or any group of such components, that supports more than 30 percent of the total area of the structure's floor(s) and roof(s) has been reduced more than 20 percent from its predamaged condition and the remaining capacity of such affected elements, with respect to all dead and live loads, is less than 75 percent of that required by the *International Building Code* for new buildings of similar structure, purpose and location.

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Substantial Structural Damage
Paraphrased Definition

Either of:

Shear walls or braces in any story have suffered capacity reduction of 20% or more.

Columns and walls supporting 30% or more of the roof area have capacity reduction of more than 20%.

Mass Code, Chapter 34, IEBC Chapter 2 Section 202.0 Definitions

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Substantial Structural Damage
Paraphrased Definition

Either of:

Shear walls or braces in any story have suffered capacity reduction of 20% or more.

Columns and walls supporting 30% or more of the roof area have capacity reduction of more than 20%.

Per Section 304.4 (Prescriptive Provisions) and 506.2 (Repairs) – Less Than Substantial Structural Damage Does not Require Rebuilding to Current Code

Mass Code, Chapter 34, IEBC Chapter 3 Sections 304.0 and 506.0

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Snow Removal Plans

- Insurance
- **Gold Standard Plan**

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With Drawings, History of Alterations, and Study of Vulnerabilities and Risk Factors:

- Blocked Drains
- Improper Slopes to Drains
- Non-Engineered Alterations
- Latent Design Defects
- Latent Construction Defects
- Added Suspended Loads
- Material Deterioration
- Snow Drfits
- Added Insulation
- Added Dead Load
- Additions or Alterations that Create a “Step”

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With Drawings, History of Alterations, and Study of Vulnerabilities and Risk Factors:

- Prescribe Snow Removal in Therms of Feet or in Terms of Snow Weight
- Clear Drains
- Clear RTUs and Service Lines
- Map Hazards
- Prescribe Removal Sequence Where Warranted

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Snow Removal Plans

- Insurance
- Gold Standard Plan
- **Ad Hoc Plan**

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Without Drawings, or History of Alterations, or Thorough Assessment

- Perform Expedited Assessment
- Cognizant of Structure Vintage and Degree of Fragility
- Cognizant of Nonstructural Vulnerabilities
- Cognizant of Weather Forecast – Snow and Wind Direction…
- → Clear Drains
- → Map/flag Hazards
- → Clear Service Lines

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Rooftop Units – Gas Fired

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Rooftop Units – Gas Fired

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Rooftop Units – Gas Fired

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Without Drawings, or History of Alterations, or Thorough Assessment

- Perform Expedited Assessment
- Cognizant of Structure Vintage and Degree of Fragility
- Cognizant of Nonstructural Vulnerabilities
- Cognizant of Weather Forecast – Snow and Wind Direction……
- → Clear Drains
- → Map/Flag Hazards
- → Clear Service Lines
- → Prescribe Partial or Total Removal of Snow...
- → …and thin down drifts.

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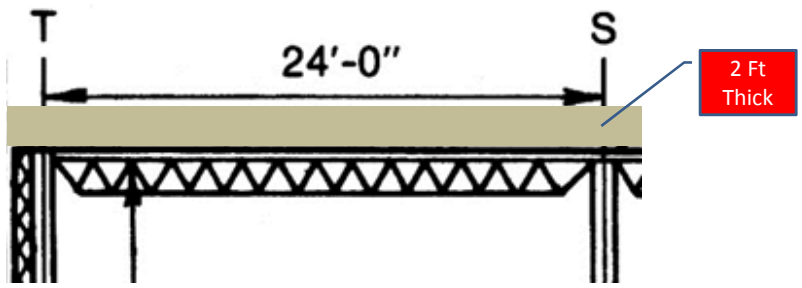

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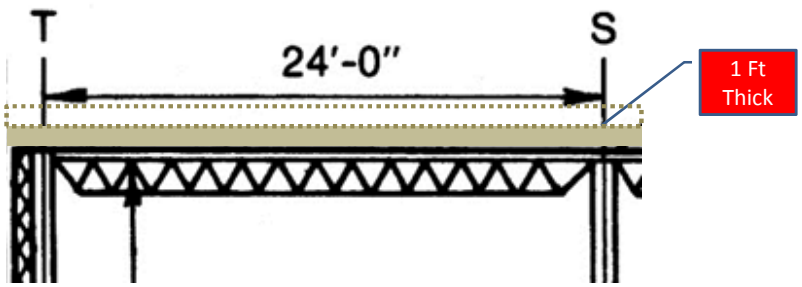

Removed 24 cubic ft/ft
Flexural Forces Reduced to 50%
Shear Forces Reduced to 50%

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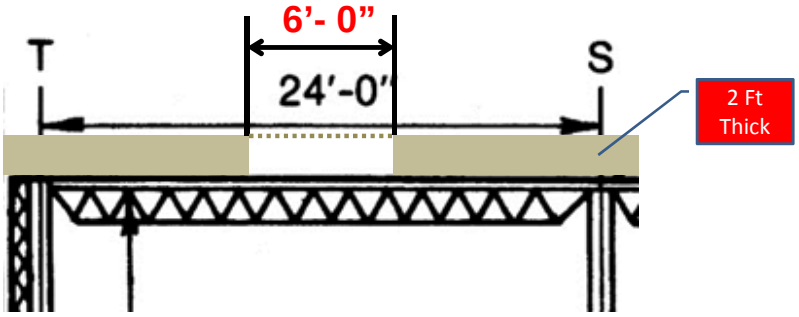

Removed 12 cubic ft/ft
Flexural Forces Reduced to 56%
Shear Forces Reduced to 75%

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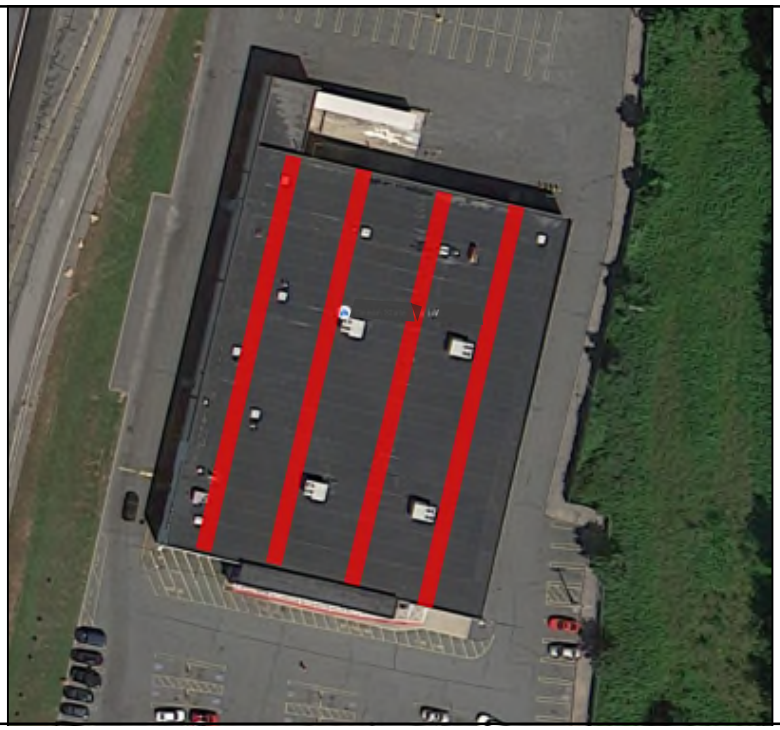

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Snow Removal Plans

- Insurance
- Gold Standard Plan
- Ad Hoc Plan
- **Other Considerations**

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Be Aware Of The Hazards

E-Pak

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Snow Removal Plans

- Insurance
- Gold Standard Plan
- Ad Hoc Plan
- Other Considerations
- **And Let's Not Forget: Fire Control and Pump Rooms, Hydrants, and Gas Meters**

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SIMPSON GUMPERTZ & HEGER
Engineering of Structures and Building Enclosures

Facilities Design & Planning for Extreme Snow Events

Part 2 – Ice Dams: Causes and Solutions

Phil Moser, P.E. (MA)
Simpson Gumpertz & Heger Inc.

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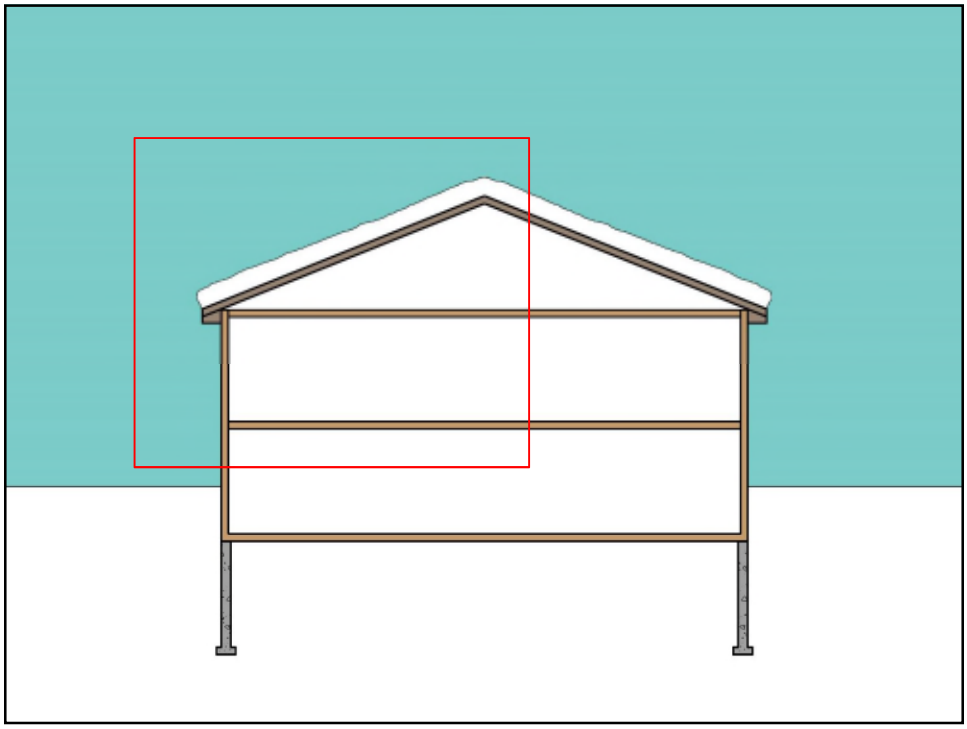
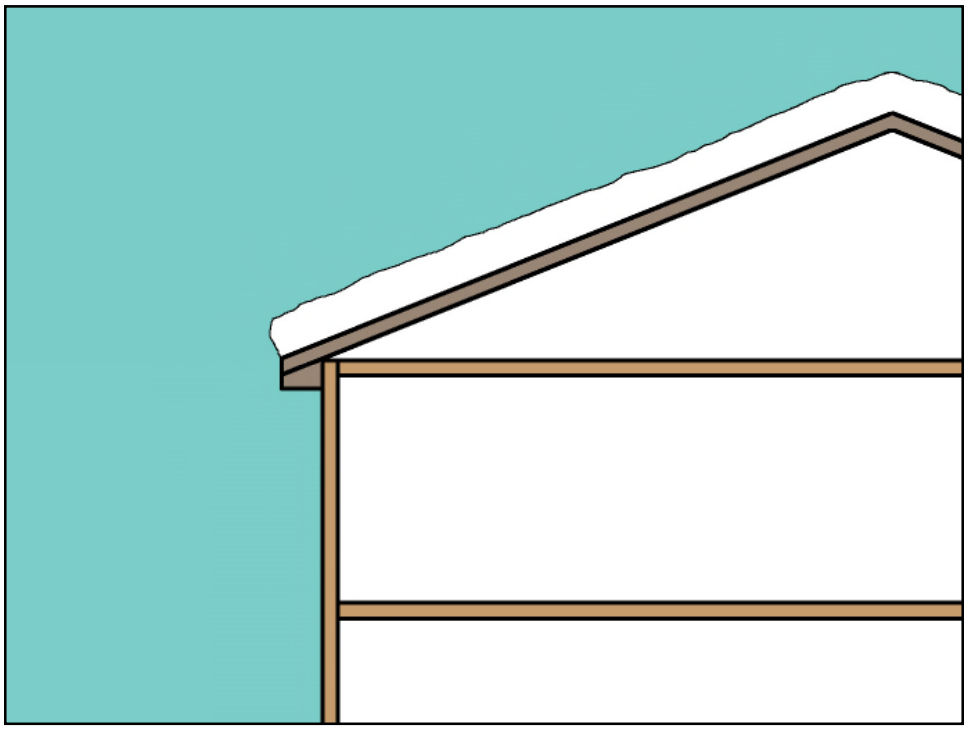
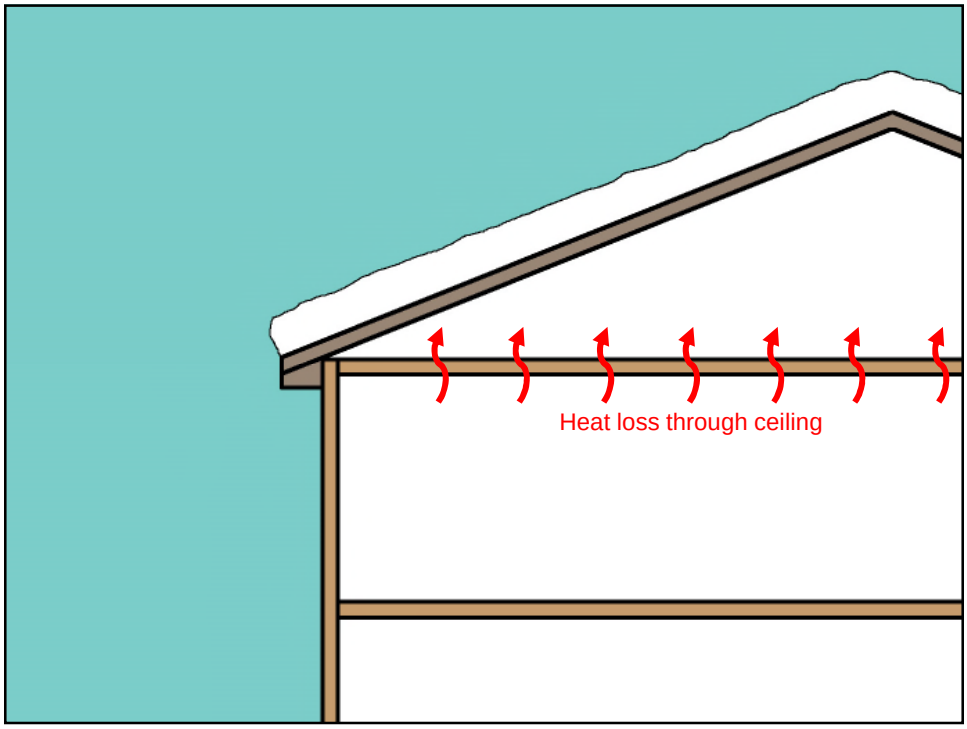
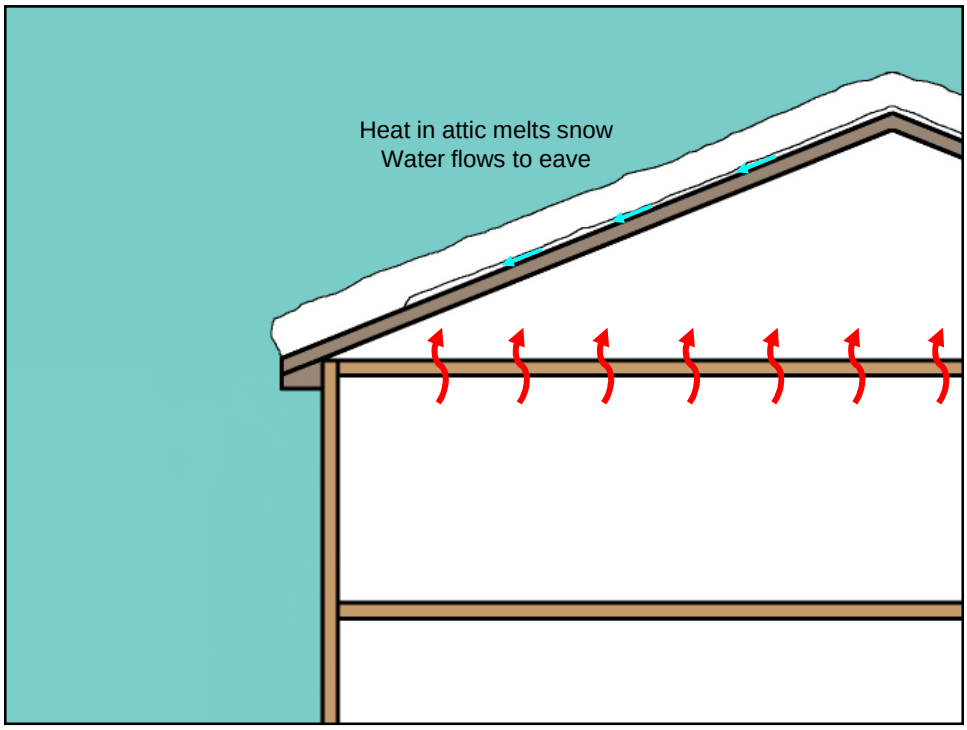
Outline

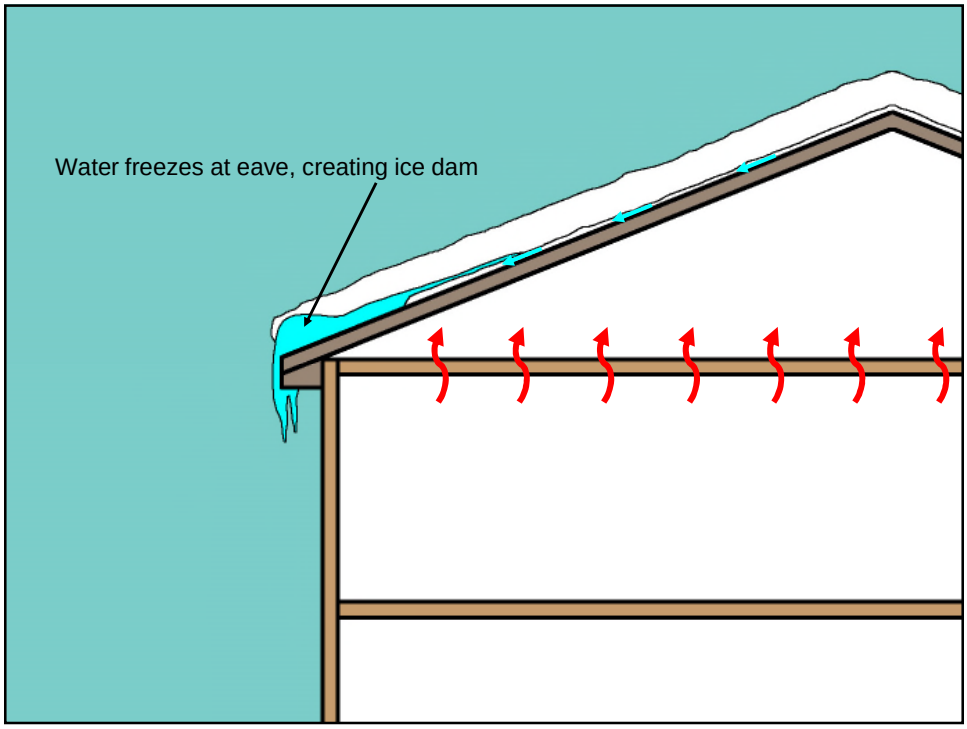
- Why do ice dams form?
  - How can they be minimized
- Why do ice dams result in leakage?
  - How to protect against leakage

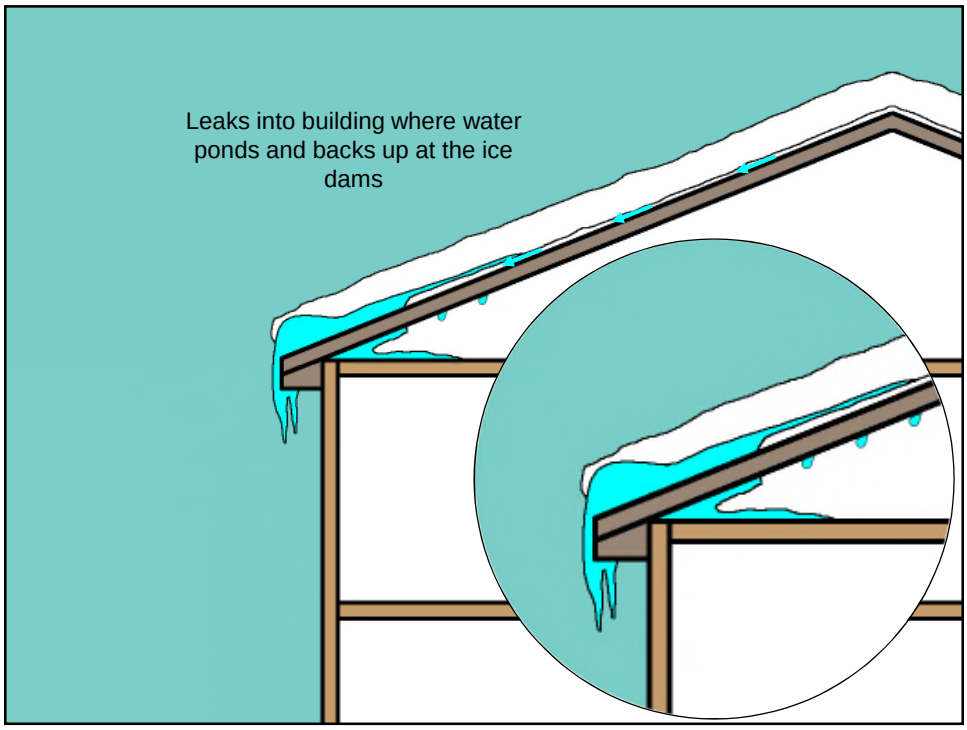





Heat loss through ceiling


Heat in attic melts snow
Water flows to eave


Water freezes at eave, creating ice dam


Leaks into building where water ponds and backs up at the ice dams

Risk Factors for Ice Dams

- Roof geometry that funnels precipitation into concentrated areas

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Risk Factors for Ice Dams

- Roof geometry that funnels precipitation into concentrated areas
- Gutters

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Risk Factors for Ice Dams

- Roof geometry that funnels precipitation into concentrated areas
- Gutters
- Lower-sloped roofs

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Risk Factors for Ice Dams

- Roof geometry that funnels precipitation into concentrated areas
- Gutters
- Lower-sloped roofs
- Large overhangs

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Risk Factors for Ice Dams

- Roof geometry that funnels precipitation into concentrated areas
- Gutters
- Lower-sloped roofs
- Large overhangs
- Mechanical equipment in attics

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Risk Factors for Ice Dams

- Roof geometry that funnels precipitation into concentrated areas
- Gutters
- Lower-sloped roofs
- Large overhangs
- Mechanical equipment in attics
- Snow retention devices

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Risk Factors for Ice Dams

- Roof geometry that funnels precipitation into concentrated areas
- Gutters
- Lower-sloped roofs
- Large overhangs
- Mechanical equipment in attics
- Snow retention devices
- Poorly insulated attics

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Risk Factors for Ice Dams

- Roof geometry that funnels precipitation into concentrated areas
- Gutters
- Lower-sloped roofs
- Large overhangs
- Mechanical equipment in attics
- Snow retention devices
- Poorly insulated attics
- Interior air leakage into attics

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Risk Factors for Ice Dams

- Roof geometry that funnels precipitation into concentrated areas
- Gutters
- Lower-sloped roofs
- Large overhangs
- Mechanical equipment in attics
- Snow retention devices
- Poorly insulated attics
- Interior air leakage into attics
- Unvented or poorly ventilated attics

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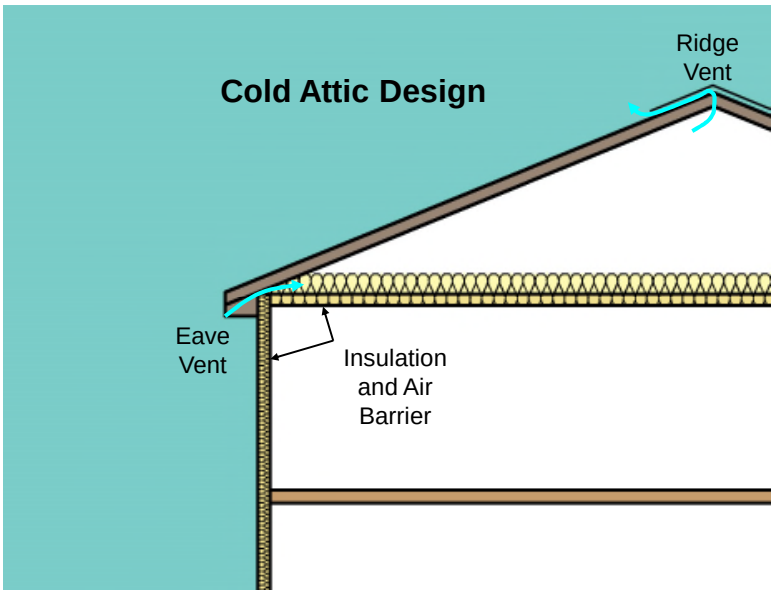
Attic Ventilation



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Other Benefits from Attic Ventilation

- Evacuate moisture from attic
  - Reduce condensation on sheathing
- Reduce roof deck temperatures
  - Shingle warranty requirement
  - Perceived increase in asphalt shingle longevity (disproven by SGH)

Attic Ventilation - Limitations

- Roof geometry controls effectiveness of the ventilation system
- Ice dams can still occur at critical locations, even with proper ventilation

Sometimes the Problem is Obvious

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Fiberglass Insulation, No Eave Vent

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Design of Attic Ventilation

- Building Codes - use “Rule of Thumb”:
  - 1 sf vent opening / 300 sf roof area with a vapor retarder
  - 1 sf vent opening/ 150 sf roof area without a vapor retarder
  - No scientific basis; used for condensation control
  - May be suitable for typical residential buildings with simple geometry, steep slope roofs
  - Inadequate for large buildings with insufficient slope (not enough stack pressure)
  - Does not account for roof geometry

Design of Attic Ventilation

- Calculation of Required Ventilation
  - Based on research by CRREL*
  - Studied ice dams on buildings in Ft. Drum, NY
  - Provides guidelines for critical attic and outside temperatures needed for ice damming

* Army Corps of Engineers Cold Regions Research and Engineering Laboratory; Tobiasson, Buska, and Greatorex, “Interface”, January 1998

Attic Temp. vs. Exterior Temp. – No Ice Dams

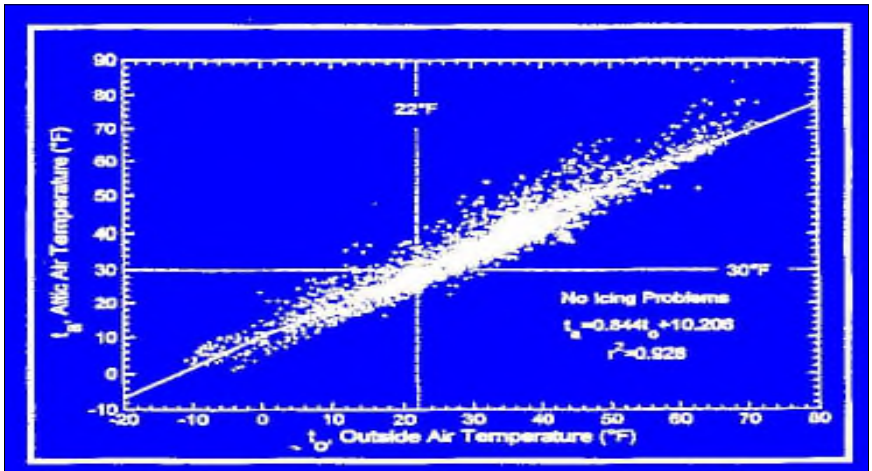

Figure 5: Attic temperature vs. outside air temperature for a roof experiencing no icing problems.

111

Attic Temp. vs. Exterior Temp. – Some Ice Dams

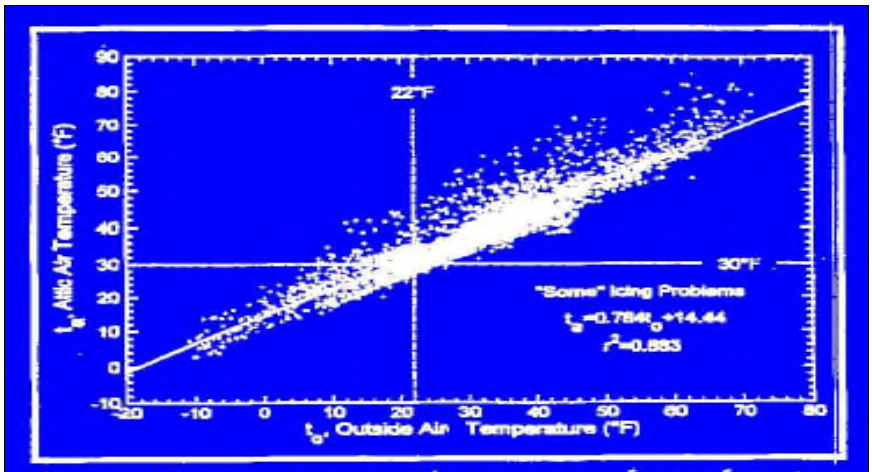

Figure 6: Attic temperature vs. outside air temperature for a roof experiencing "some" icing problems.

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Attic Temp. vs. Exterior Temp. – Severe Ice Dams

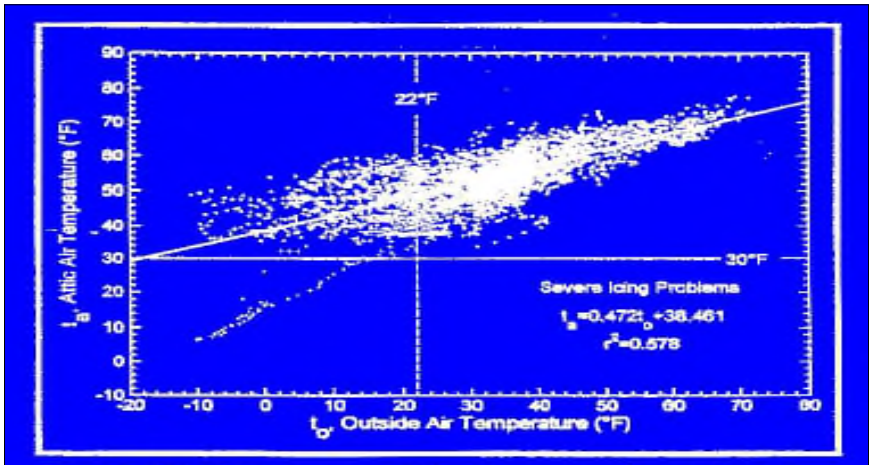

Figure 7: Attic temperature vs. outside air temperature for a roof experiencing severe icing problems.

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Icing Envelope

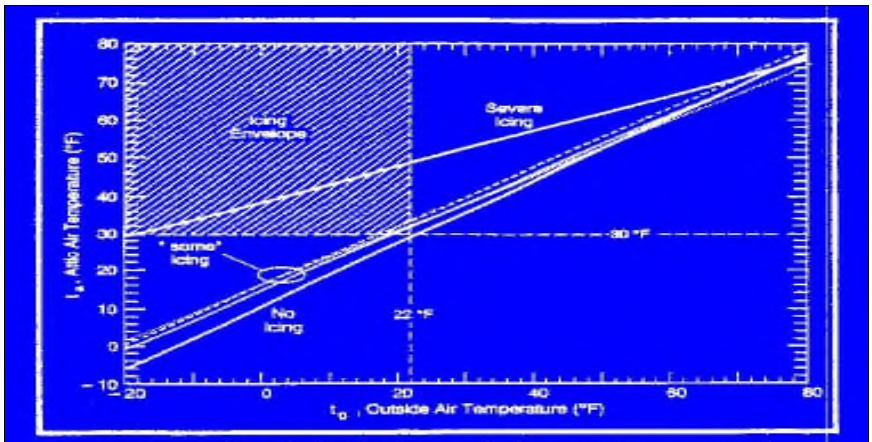

Figure 8: Lines of best fit for the three roofs shown in Figures 5–7, along with similar lines (dashed) for two other roofs also having "some" icing problems.

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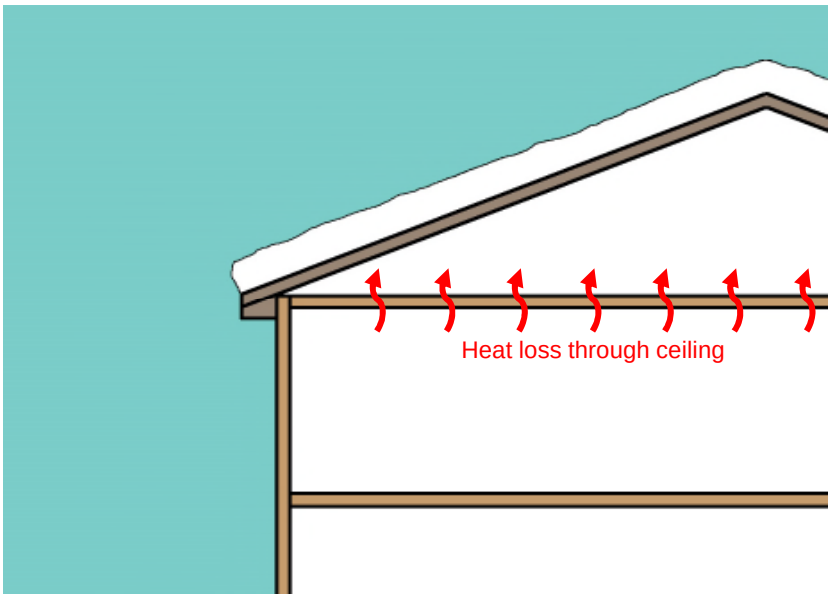
Design of Attic Ventilation

- Design Criteria to Prevent Snow Melting (Tobiasson):
  - If outside temperature is 22° or below,
  - Attic temperature should be 30° or below
- Using these guidelines, perform calculation of ventilation rate required
  - Equations vary depending on whether there is an attic or a cathedral ceiling
  - Calculations require making an estimate of the heat flow into the attic

Potential Sources of Heat in Attic



Potential Sources of Heat in Attic

- Heat loss through conduction, especially through
  - Areas with thin insulation
  - Gaps in insulation
- Air leakage from building interior
- Solar heat gain through roofing
- Losses in HVAC ducts and HVAC in attics

Cold Roof, Warm Roof

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Summary - Ice Dams can be decreased by:

- Using cold ventilated attics (or compact ventilated roofs)
- Increasing the slope of the roof
- Not using gutters or snow retention devices (if site can be designed accordingly)
- Reducing large eave overhangs
- Simplify the roof geometry

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Protecting Against Leakage from Ice Dams

- Ice dams can still occur at critical locations, even with proper ventilation
- Install self-adhered membrane underlayment at eaves, valleys, and other critical areas
  - How far upslope from the eave should it extend?
  - Workmanship at seams is critical
  - Turn up at penetrations, rising walls, etc.

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Self-Adhered Membrane Underlayment

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Tips for Successful Ice Barrier Installation

- How far upslope from the eave should it extend?
- Workmanship at seams is critical
- Turn up at penetrations, rising walls, etc.

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Building Code – IBC 2009

1507.2.8.2 **Ice Barrier**. In areas where there has been a history of ice formation along the eave causing a backup of water, an ice barrier that consists of at least two layers of underlayment cemented together or of a self-adhering polymer modified bitumen sheet shall be used in lieu of the normal underlayment and extend from the lowest edge of the roof surface to a point at least 24 inches (610mm) inside the exterior wall line of the building.

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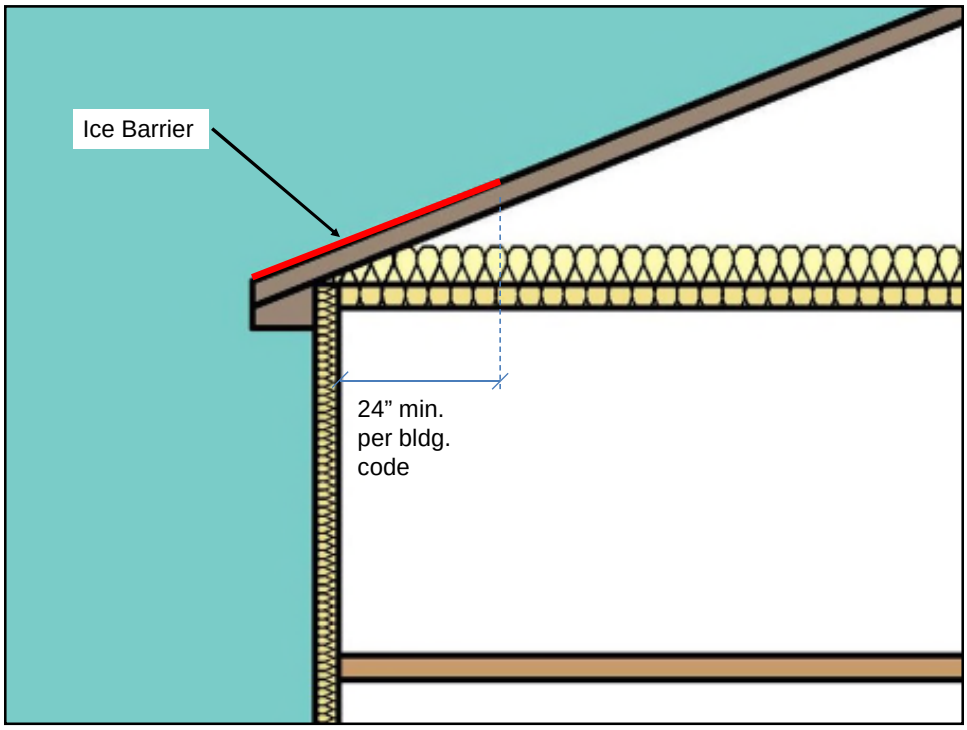

Detailing Issues

Water coming out of clapboards from ice dam leak.

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Underlayment Doesn't Turn Up Wall

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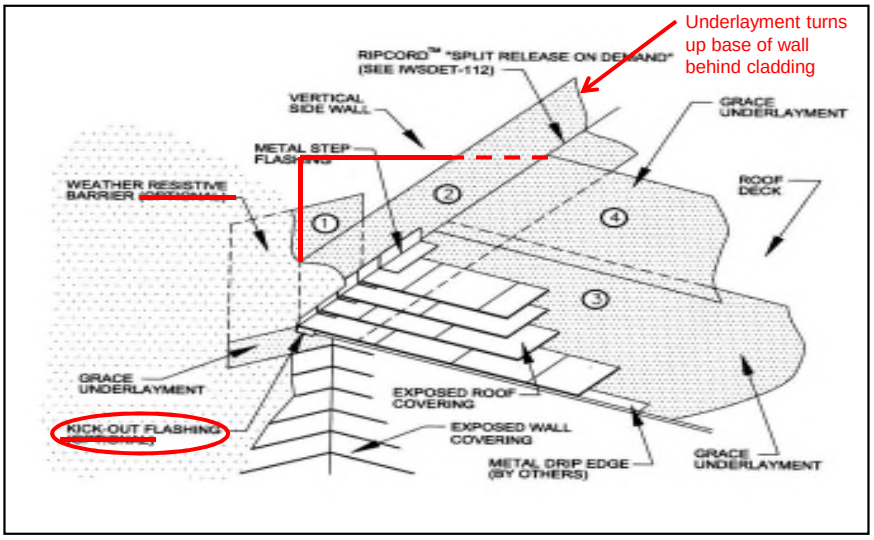
Underlayment Detailing



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