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Engineering of Structures
and Building Enclosures

Balancing Waterproofing and Thermal Performance for Vegetative Roof Assemblies

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Vegetative Roofs

Why choose a vegetative roof?

- Appearance / use
- Rainwater harvesting / reduce runoff
- Shades roof in summer, absorbs heat in winter
- Reduces heat island effect
- Insulating value of growth media (soil)

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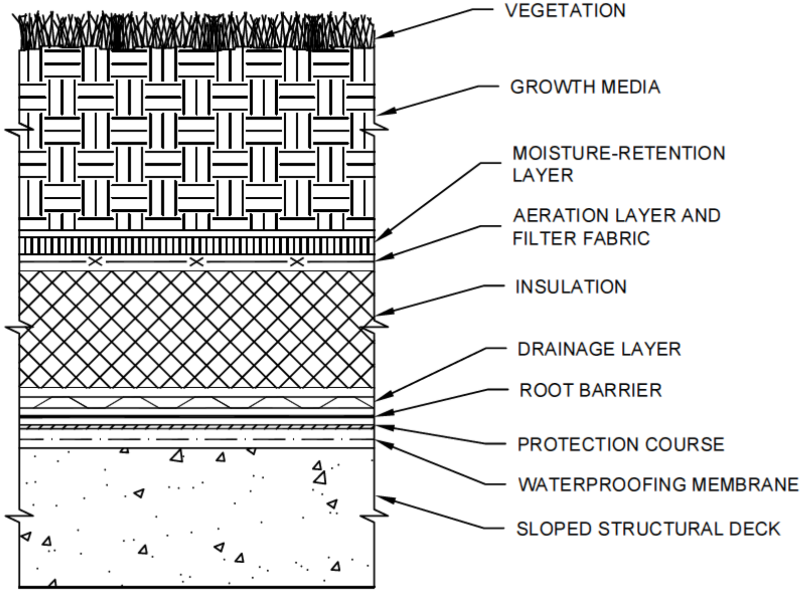
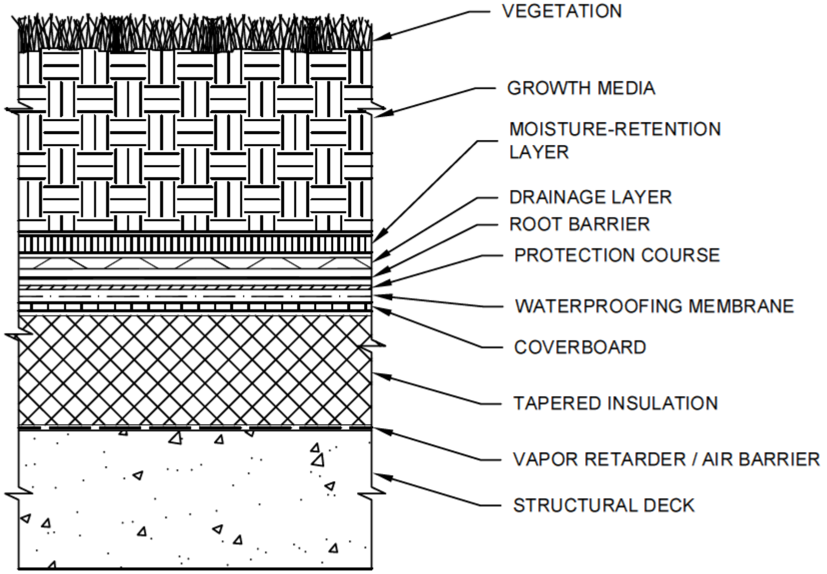
Vegetative Roof Assemblies

Two General Approaches



Inverted Roofing Assembly



“Conventional” Roofing Assembly

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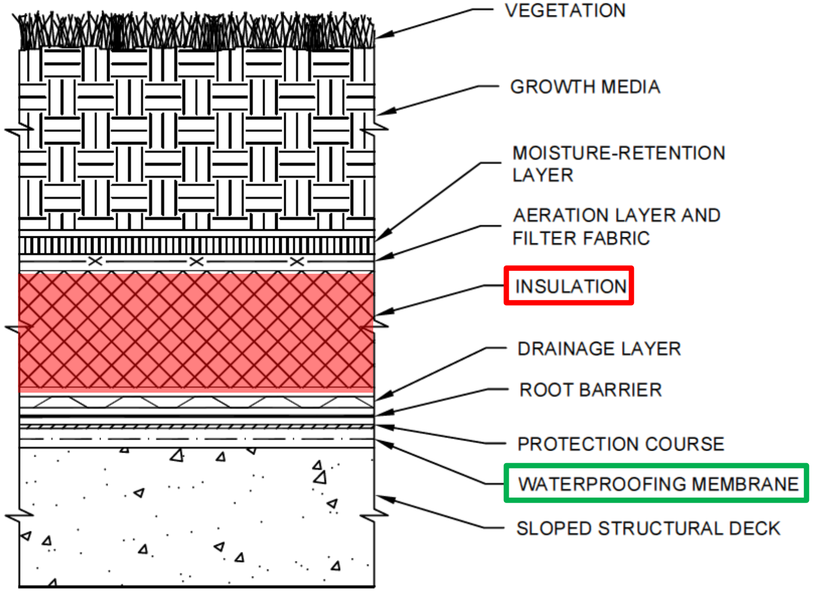
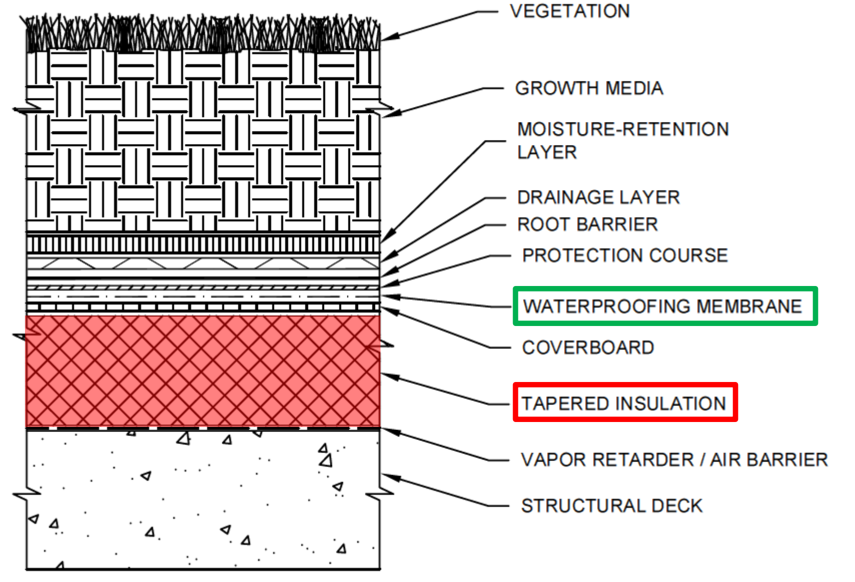
Vegetative Roof Assemblies

Position of insulation and waterproofing membrane



Inverted Roofing Assembly



“Conventional” Roofing Assembly

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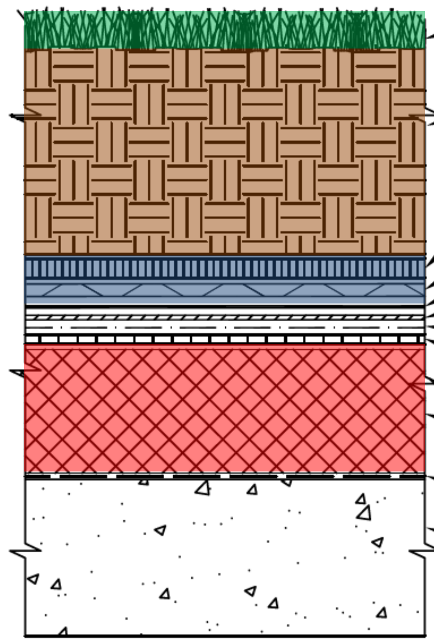
Conventional Assemblies

Advantages

- Similar to conventional roofing approach
- Separates membrane from irregularities and movement in deck
- Higher R-value insulation can be used (i.e. polyisocyanurate, compared to extruded polystyrene, XPS)
- Improved thermal performance of insulation



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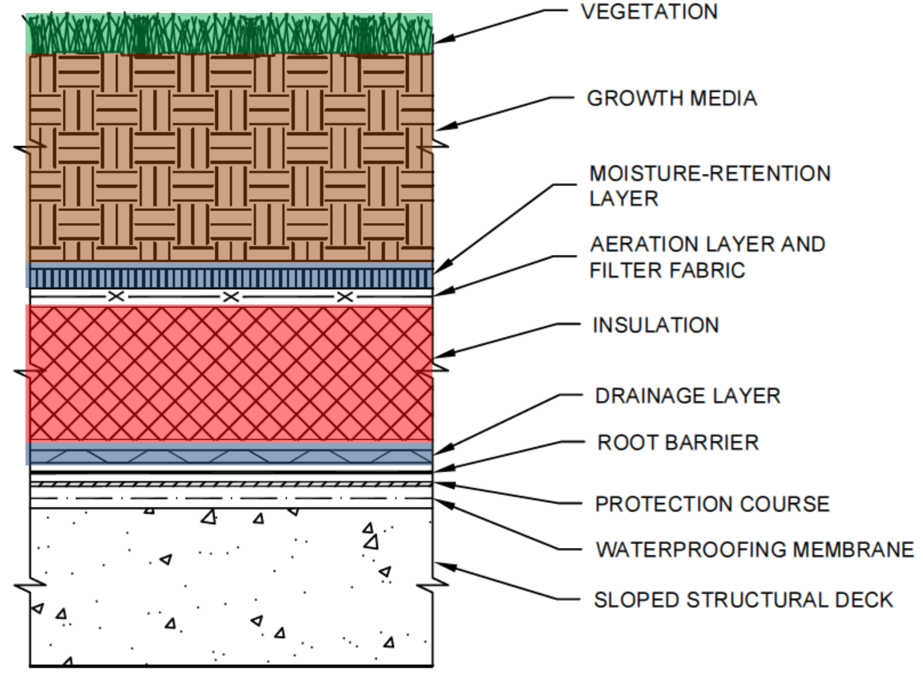
Inverted Assemblies

Advantages

- Allows fully-adhered / compartmentalized membrane systems
  - Easier leak detection and repairs (conventional system leak can show remote from breach in membrane)
- Reduced membrane temperature cycling / long term membrane durability
- Rigid substrate => Fully supported (versus insulation deflection)
- Membrane acts as vapor retarder and air barrier
- Additional membrane protection



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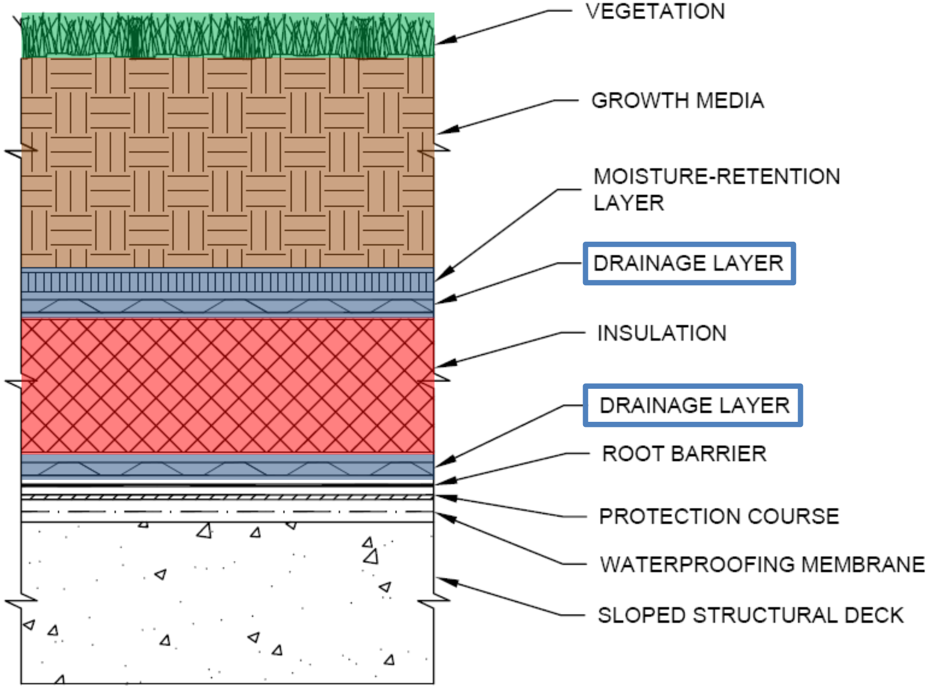
Inverted Assemblies

Drainage Layer Location

- Insulation manufacturers typically recommend drainage layer above insulation to improve thermal performance
- Drainage layer above insulation is not generally watertight; water travels to membrane:
  - Butt joints in plastic drainage composite sheets
  - Insulation joints
- Drainage layer below insulation improves waterproofing performance
  - Drains water at lowest level
  - Negatively affects thermal performance
- Drainage above and below insulation improves performance



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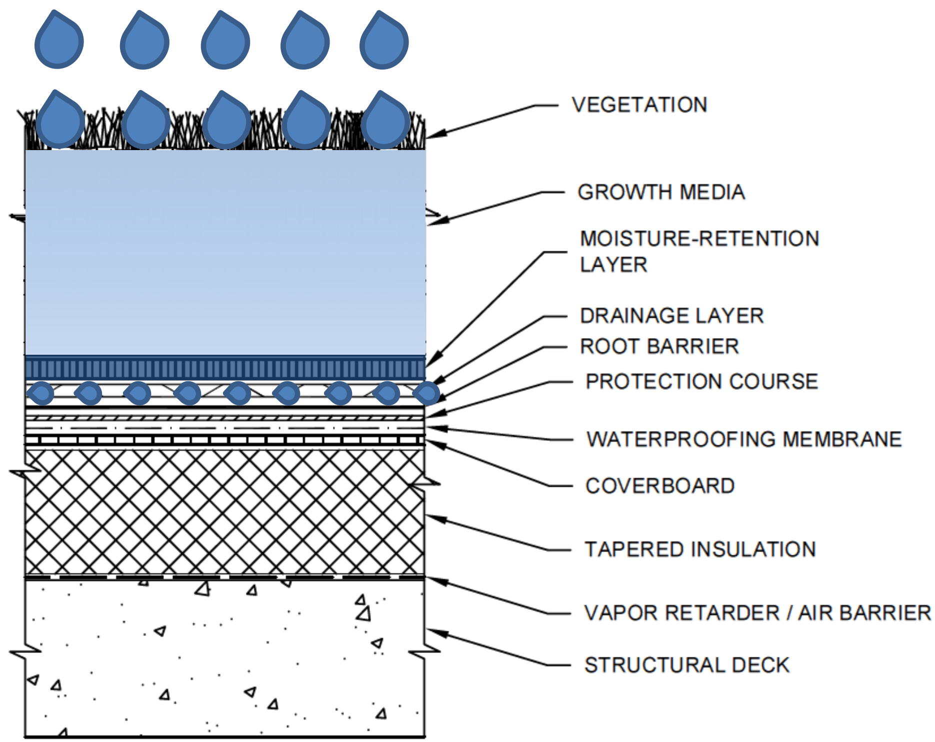
Thermal Analysis
Outline

- Developed mathematical thermal model for heat transfer between drainage layer / waterproofing and roof deck.
- Water reaching membrane below insulation depends on:
  - Roof type (conventional vs. inverted)
  - Growth media
  - Retention and watertightness above insulation
  - Drainage layer(s) and location(s)
- Thermal effect depends on:
  - Water volume / flow rate below insulation
  - Distance water travels below insulation (i.e. to drains)
  - Water temperature (exterior air temperature)
  - Insulation thermal resistance (i.e. total R-value)

Thermal Analysis

Conventional Assembly: Moisture Flow

- Incident rainfall rate
  - From weather file in energy analysis
- Water migrates through soil
  - Assumed rate to be lesser of calculated value from Darcy's Law (10^{-6} m/s) and weather file rainfall rate
- Collects in moisture-retention layer
- Enters drainage layer
- Travels to drain



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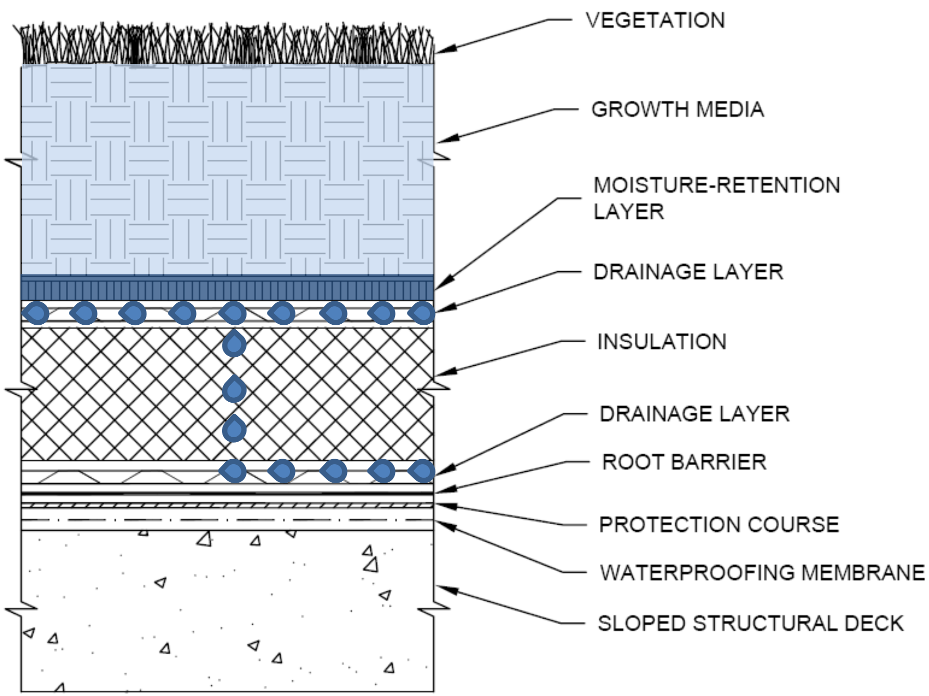
Thermal Analysis

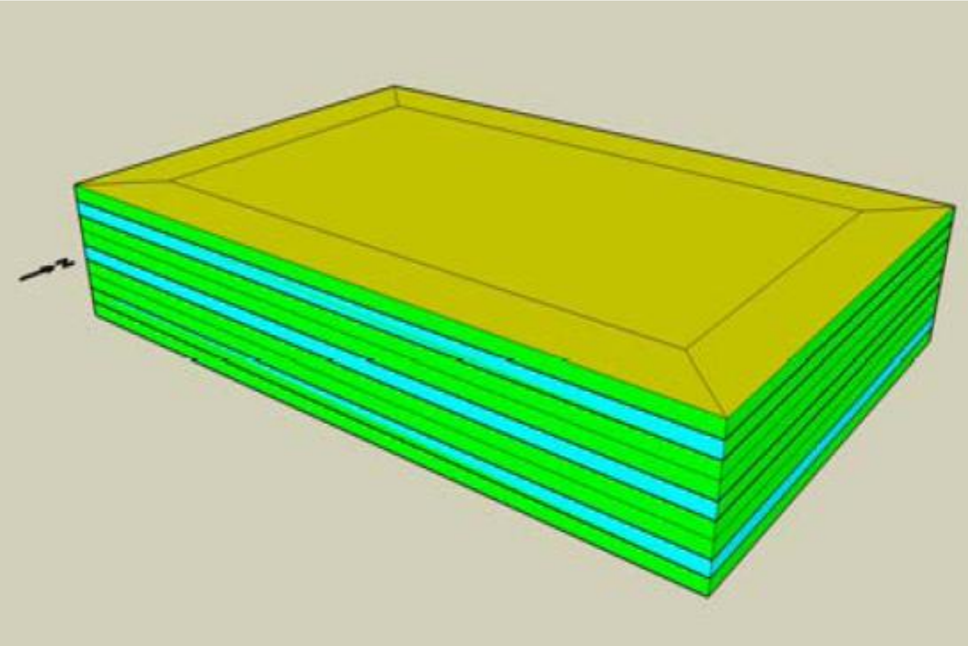
Inverted Assembly: Moisture Flow

- Travels through discontinuities to lower drainage layer
  - Butt joints in plastic composite sheets
  - Insulation joints
- Previous study showed 1-5% of water reaches membrane level
  - Set 1% as “Low” case
  - Set 5% as “High” case
- Total heat transfer between drainage water and roof deck based on transient analysis for flat surface in contact with fluid flow



Energy Analysis
Base Model

- Incorporated thermal model into whole building energy model
  - EnergyPlus Version 6.0
- U.S. Department of Energy Reference Building: Medium Office
  - Meets prescriptive requirements of ASHRAE Standard 90.1-2004



Energy Analysis
Weather Data

- Time-varying annual weather data for 3 locations
  - Miami, Florida – Baltimore, Maryland – Chicago, Illinois
  - Temperature, solar radiation, wind
  - Precipitation

Location	Total Annual Precipitation (in.)	Days With Precipitation
Miami	63.9	124
Baltimore	44.6	129
Chicago	38.2	159

Energy Analysis

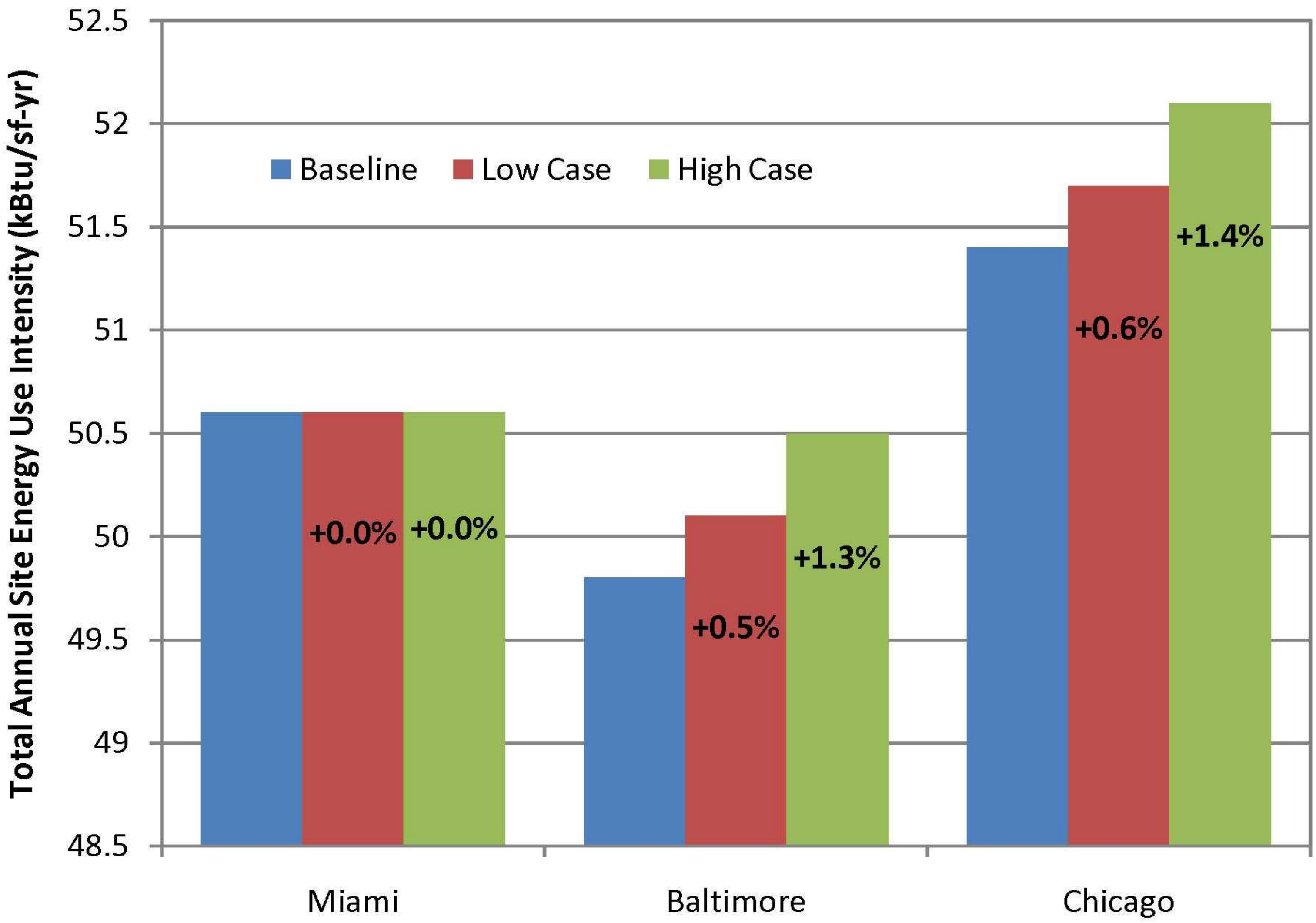
Roof Construction

- Roof insulation values based on minimum prescriptive requirements of 2009 IECC
  - Equivalent to ASHRAE Standard 90.1-2007
- Three drainage cases (for inverted assembly)
  - No water below insulation
  - Low Case: 1% water below insulation
  - High Case: 5% water below insulation

Location	Roof Insulation R-Value
Miami	R-15
Baltimore	R-20
Chicago	R-20

Energy Analysis Results

Total Annual On-Site Energy Use



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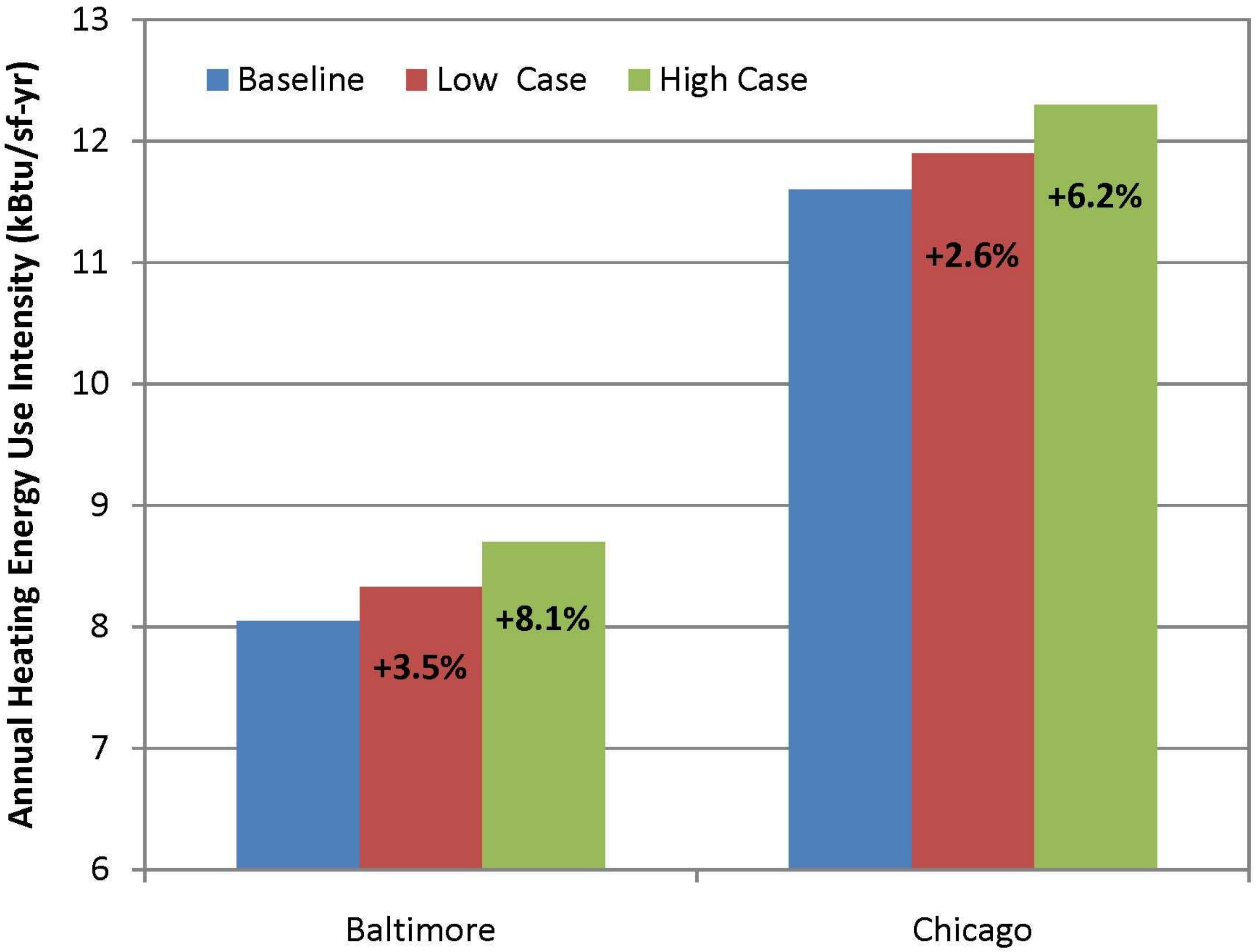
Energy Analysis Results

Annual Heating Energy Use



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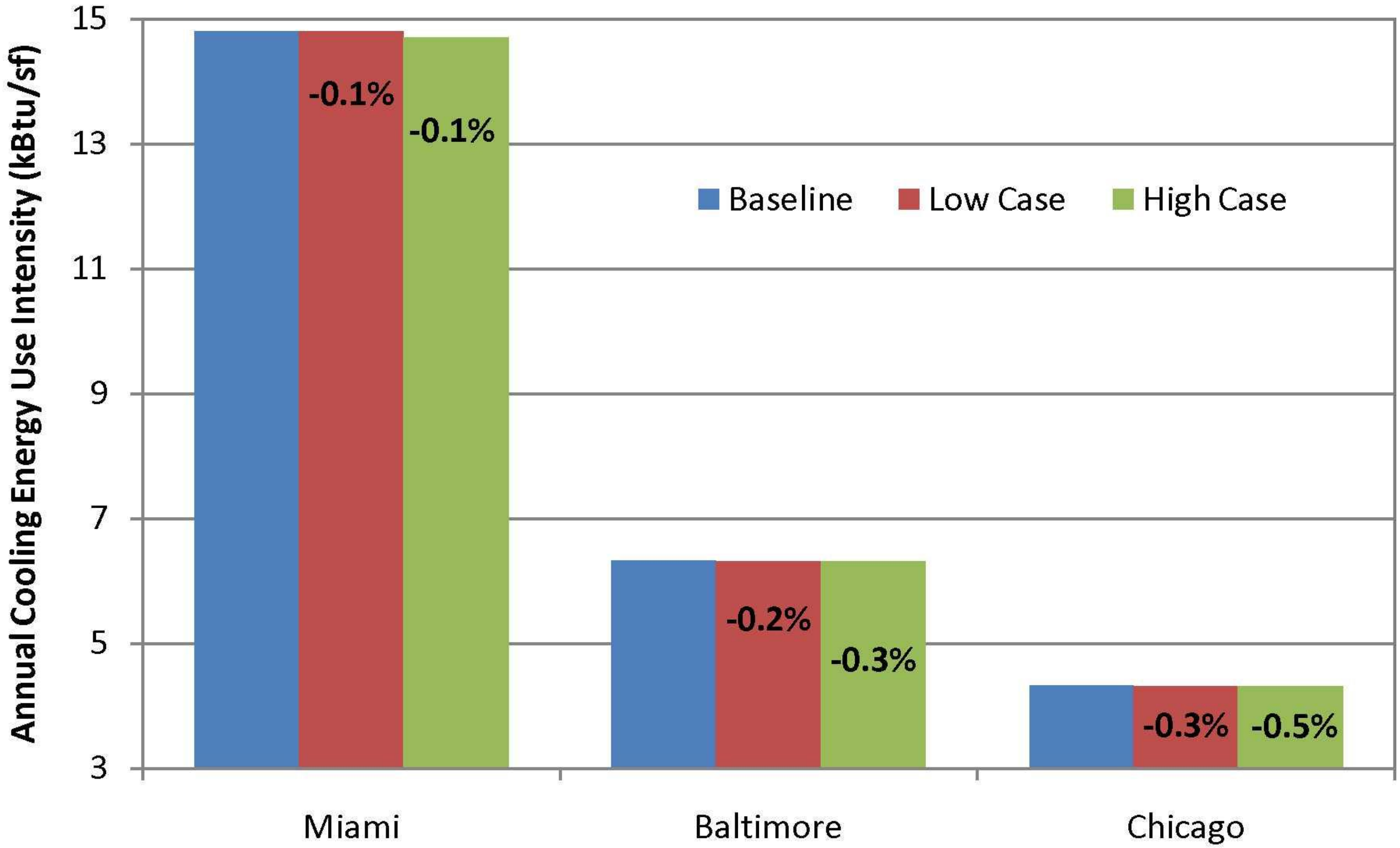
Energy Analysis Results

Annual Cooling Energy Use



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Energy Analysis Results

Increased Insulation – Total Annual Energy Use – Chicago

Insulation R-Value	Total Energy Use Per Square Foot (kBtu/sf-yr)			Percent Increase	
	Baseline	Low	High	Low	High
R-20	51.4	51.7	52.1	0.6%	1.4%
R-25	N/A	51.5	51.9	0.2%	1.0%
R-30	N/A	51.3	51.7	-0.1%	0.7%

Energy Analysis Results

Increased Insulation – Annual Heating Energy Use – Chicago

Insulation R-Value	Heating Energy Use Per Square Foot (kBtu/sf-yr)			Percent Increase	
	Baseline	Low	High	Low	High
R-20	11.6	11.9	12.3	2.6%	6.2%
R-25	N/A	11.7	12.1	1.0%	4.6%
R-30	N/A	11.6	12.0	-0.2%	3.4%

Conclusions

- Energy use due to drainage below insulation in inverted vegetative roof assemblies can be significant.
- This effect is due to increased roof heat loss and the associated increased mechanical heating requirements
- Effective drainage above the insulation decreases heat loss and energy use associated with the inverted system
- Increasing insulation thickness can reduce the effects of drainage below insulation, but may not eliminate the increase in annual building energy usage
- The effect of drainage layer location on both waterproofing and thermal/energy performance should be considered

Thank You

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