

# BBE 4414/5414

- Advanced Building Science: Fundamentals
  - Fall Semester
  - 4 Credits
  
- Instructor: Pat Huelman
  - 203 Kaufert Lab
  - 624-1286
  - [phuelman@umn.edu](mailto:phuelman@umn.edu)

# Advanced Building Science: Syllabus

## Course description

- An advanced course in the science of how houses work (and sometimes don't) with an emphasis on heat, air, and moisture flows.
- Applying building science principles (qualitative and quantitative) to resolve common energy, moisture, and air quality problems.

# Advanced Building Science - Syllabus

## Learning objectives

- Upon successful completion, you should be ...
  - fully versed in key building science principles
  - familiar with contemporary energy, moisture, and indoor air quality issues in housing
  - able to solve common heat, air, and moisture problems
  - able to comfortably communicate important principles through calculations, reports, and oral presentation.

# Advanced Building Science: Syllabus

## Textbooks

### – Required Texts

- ASHRAE Handbook of Fundamentals (HF)
- High Performance Enclosures – Straube (HPE)
- Builder’s Guide for Cold Climates – Lstiburek *eeba.org* (BG)

### – Supplemental Texts

- Building Science for Building Enclosure - Straube & Burnett (BSBE)
- Water in Buildings: Architects Guide to Moisture & Mold – Rose (WB)
- Building Science for a Cold Climate - Hutcheon & Handegord (BSCC)
- Understanding Psychrometrics – Gatley (UP)
- Principles of Heating, Ventilating, & Air Conditioning – Howell, Sauer, & Coad (VHA)

# Advanced Building Science: Syllabus

- Grading System
  - Point breakdown
    - assignments (5 points each) 15
    - first mid-term 15
    - second mid-term 15
    - third mid-term 15
    - lab assignments 25
    - final project: paper & presentation 15
  - Letter grades will be based on straight percentages
- Course Policies
  - Review syllabus

# Advanced Building Science: Syllabus

## Class Outline

### – Readings

- HF = Handbook of Fundamentals
- HPE = High Performance Enclosures
- BG = Builder's Guide for Cold Climates

### – Assignments

- Most assignments will be problems with some discussion
- Final project will include paper and presentation
  - general background of the topic
  - incorporate the pertinent building science principles
  - propose a solution to the assigned problem
  - prepared presentation to the class

# The House As a System

Building performance results from an interaction of

– People

- people priorities include health & safety, comfort, and affordability

– Building

- building priorities include durability, renewal, and disassembly

– Environment

- environmental priorities include local, regional, and global impacts

# The House As a System

It all begins with good design!

- Site planning
- House layout
- Basic structure
  - foundation type
  - ceiling/roof design
- Building enclosure
- Material selection
- Sub-systems
  - electrical/plumbing
  - heating, ventilation, air conditioning
- Finishes & Furnishings



# The House As a System

It all ends with proper execution!

– Contractor

- quality labor
- proper equipment
- ongoing training
- inspections
- quality control process

– Homeowner/Occupants

- user-friendly controls
- good operations and instructions
- proper maintenance schedules and information

# Wrap-Up

- Residential building science is about how houses work?
- On your notecard, describe a:
  - A. A building performance problem that has you perplexed and you would like to solve it.
  - B. A building science issue that you find intriguing and would like to understand it more fully.

# Introduction

- Good News
  - The quality of products and equipment that we use to build houses today is superior in almost everyway compared to homes built decades ago
- Bad News
  - The number of performance problems, product failures, and builder liability is at an all time high

# Introduction

- Good News
  - The overall quality of houses in Minnesota is arguably the best in the country.
- Bad News
  - We are not where we could be or should be given our climate, economy, and our environment.

# Introduction

- Good News
  - People are really beginning to focus on performance issues in new homes.
- Bad News
  - We spent the past two decades in a building boom where everyone was fixated on aesthetics, “sizzle”, size, and ultimately cost per square foot.

# Introduction

- Good News
  - We are finally talking about renewable energy for our homes.
- Bad News
  - Our current housing stock really isn't ready for it.
    - First, they need way too much energy.
    - Second, they haven't been built to easily integrate renewable technologies.

# Introduction

- Good News
  - Today, we have the know-how to build far more efficient, durable, healthier, and environmentally-sensitive homes.
- Bad News
  - We have been totally focused on relative and incremental improvements.
    - The planet doesn't care what percent we saved.
    - It only cares how much we use!

# Introduction

- **New Demands**
  - escalating consumer expectations
  - more stringent building and energy codes
  - rapid introduction of new building materials
- **New Problems**
  - increased moisture/building durability issues
  - heightened indoor air quality & health concerns
  - more environmental pressures on building materials
- **New Strategies**
  - emergence of building science
  - taking a systems approach



# What is Building Science?

- Study of the physical forces that act on buildings
  - gravity, wind, etc.
  - heat transfer
  - moisture transport
  - airflows
- Application of that knowledge to provide buildings that are
  - structurally sound
  - comfortable and efficient
  - durable and long lasting
  - healthy to live in
  - friendly to our environment

# What Is Total Building Performance?

- It is a deliberate integration of building enclosure, mechanical systems, and controls to provide a
  - comfortable, efficient, durable, and healthy home
- It demands a “systems approach” to the
  - dynamics of climate and occupants
  - interaction of building enclosure and mechanical systems
- It requires careful planning, teamwork and careful execution in
  - design, construction/installation, and operation

# How do We Measure Total Building Performance?

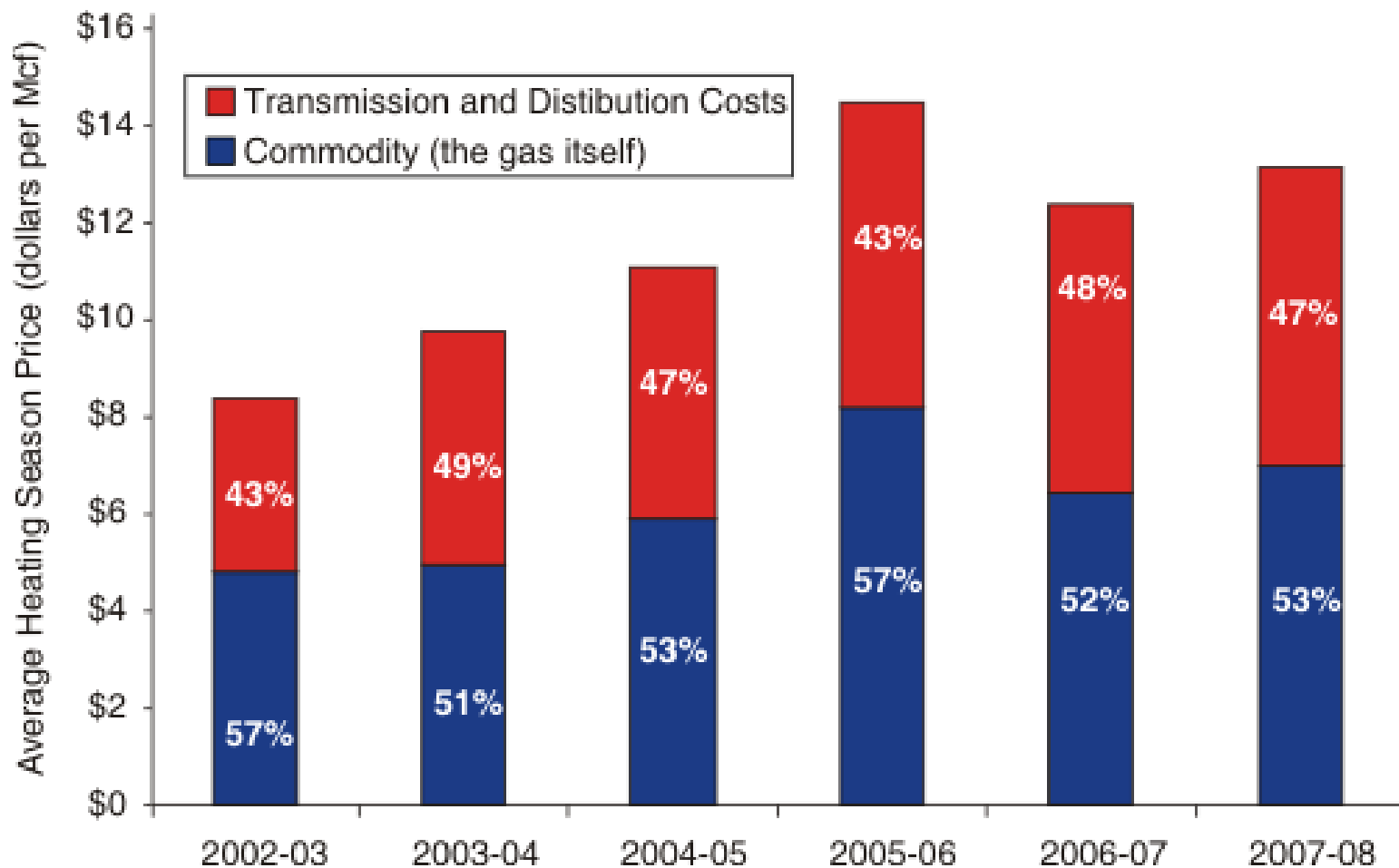
- Energy efficiency
  - Cost for space conditioning, water heating, refrigeration, lights, and appliances
- Moisture management & durability
  - Life of major structural components & products
- Healthy indoor environment
  - Quality of pollutant management & ventilation
- Environmental impacts
  - “Light” footprint and low long-term “costs”

# Total Building Performance: When Something is Missing

Some common performance issues in today's homes

- High energy bills
- Ice dams
- Wet foundations
- Window condensation
- Structural condensation
- Water intrusion
- Indoor air quality

# High Energy Bills



# Ice Dams



# Wet Foundations



# Window Condensation





# Structural Condensation



# Water Intrusion



# Indoor Air Quality



# Risky Mechanical Systems



# Can We Predict Total Building Performance?

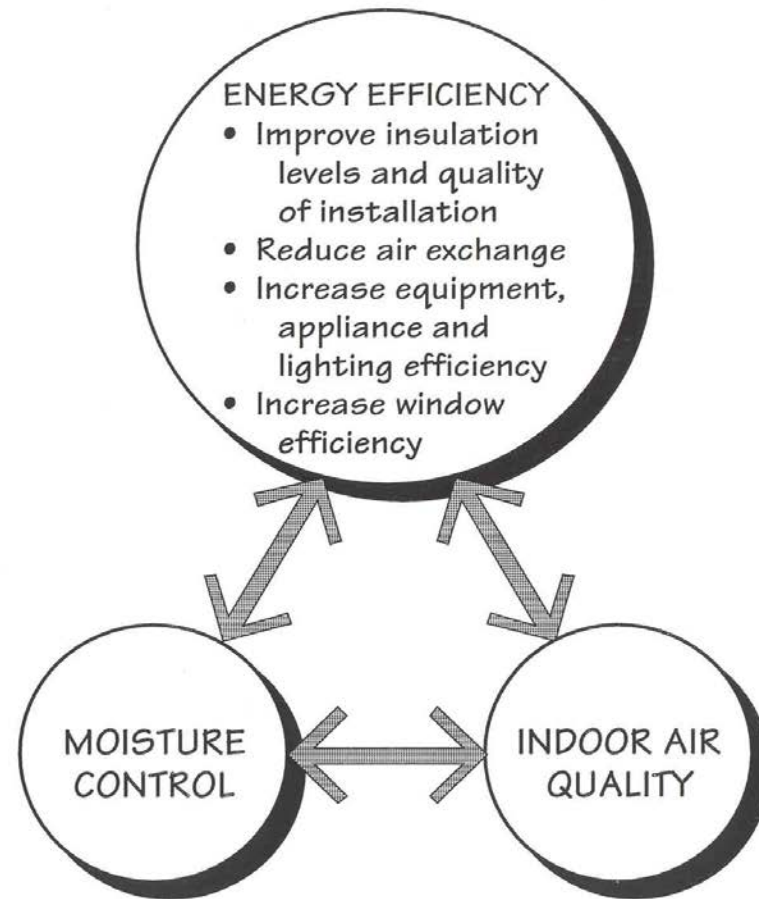
What's the best predictor of overall building performance?

- Answer: Air flows and pressures
  - as a group – unplanned, unintentional, and unmanaged airflows are the primary cause of residential performance failures
  - air flow can carry with it a great deal of heat and moisture
  - air pressures can compromise mechanical system performance

Air management is critical for comfort, energy efficiency, durability, and indoor air quality!

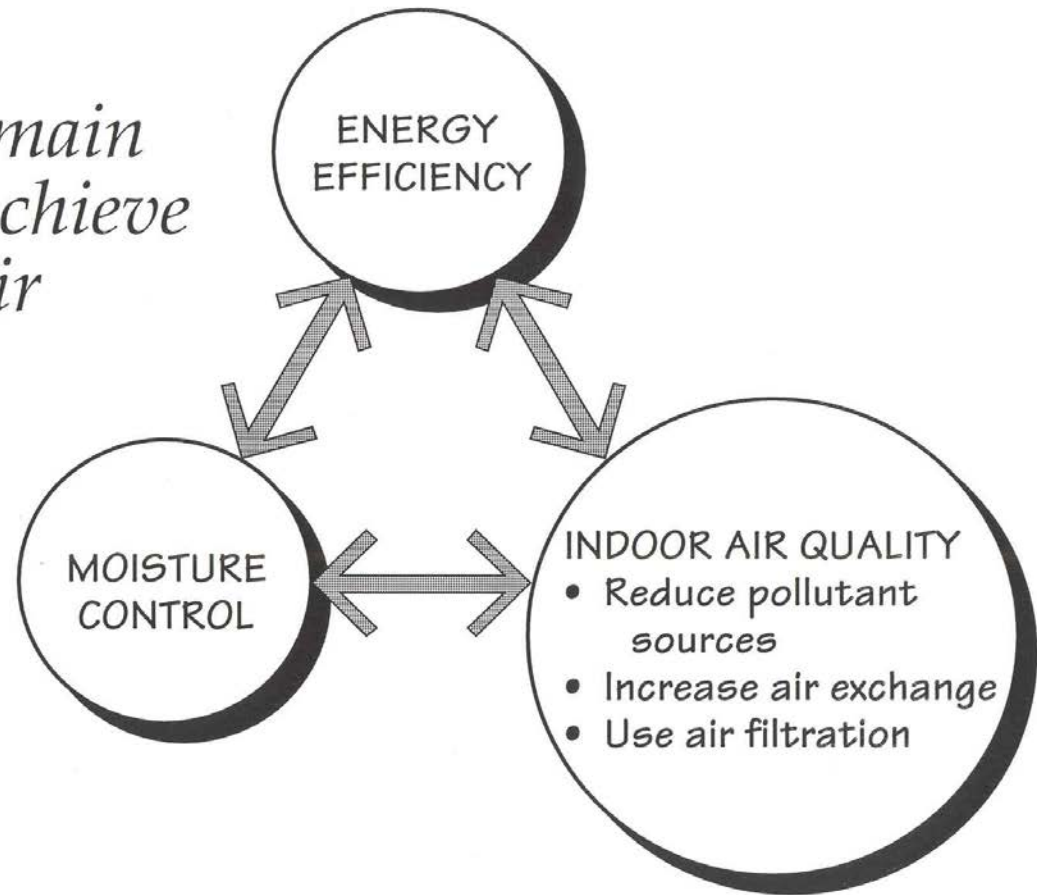
# Finding the Solution to Total Building Performance!

*What are the main strategies to achieve energy efficiency?*



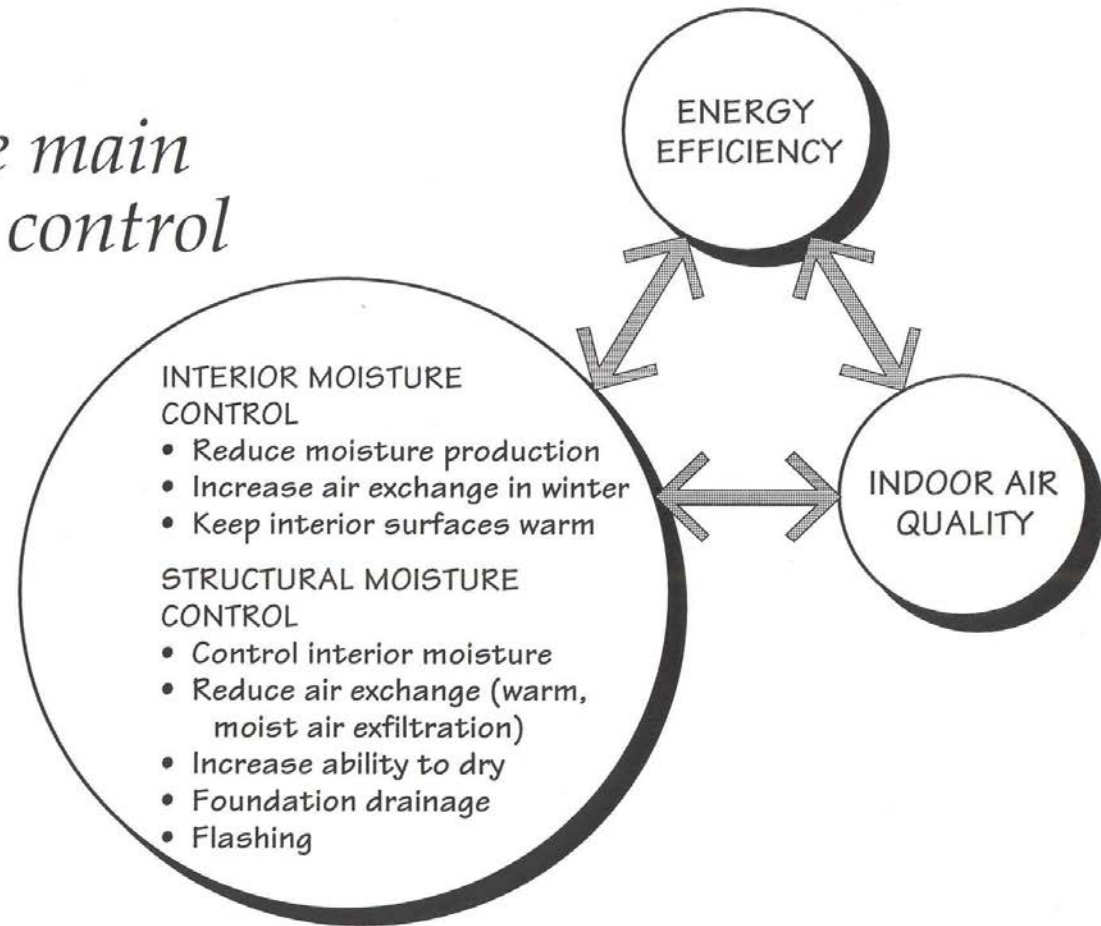
# Finding the Solution to Total Building Performance!

*What are the main strategies to achieve good indoor air quality?*



# Finding the Solution to Total Building Performance!

*What are the main strategies to control moisture?*

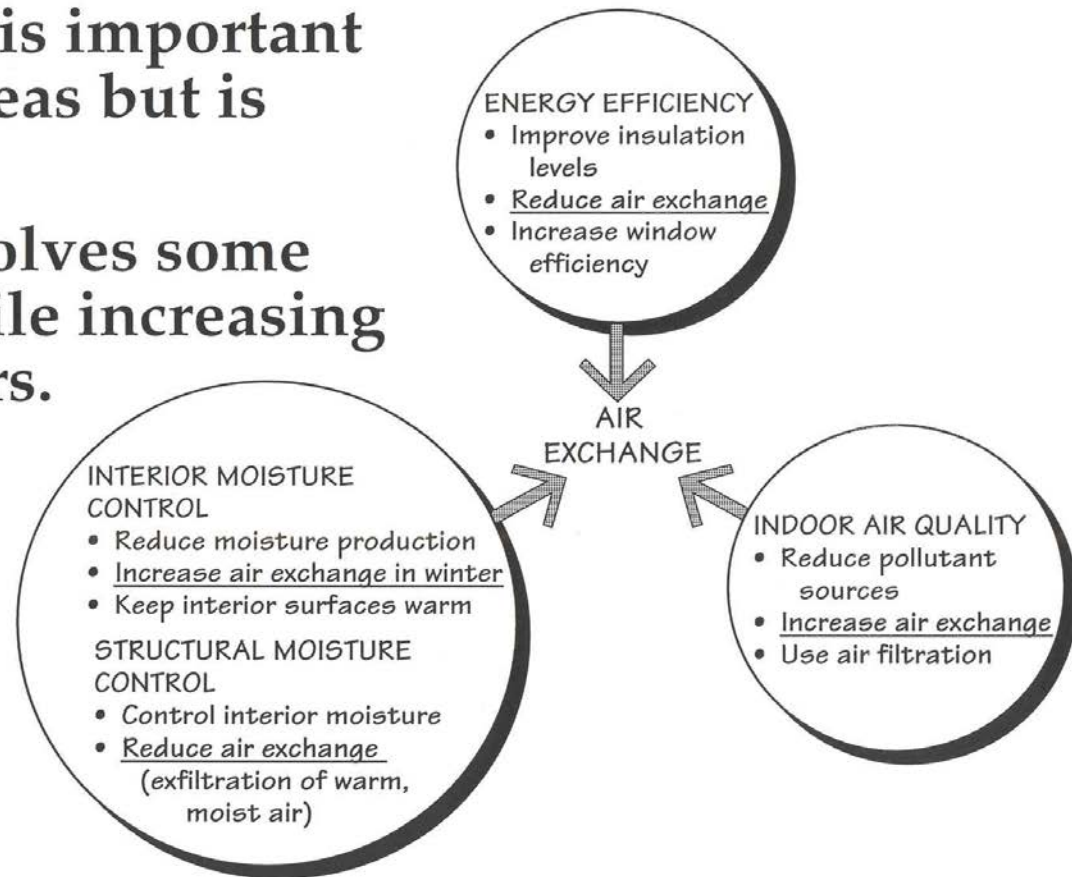




# Finding the Solution to Total Building Performance!

Air exchange is important in all three areas but is also complex.

Reducing it solves some problems while increasing it solves others.

































# A Key to the Great Puzzle

- The greatest of these is airflow!
- Efficient, durable, and healthy homes require carefully managed airflows
  - We must control both holes and pressures.
- And to some extent, until we get this right we can't move on.

# High Performance Houses for Cold Climates

- The “Ten Key Components” that will ensure ...
  - Energy efficiency
  - Moisture control & durability
  - Good indoor air quality
- A formula for ...
  - How to have your cake and eat it too!!!

Components	The Ten Key Components	Energy	Moisture	IAQ
1. Full coverage optimal thermal insulation				
2. Continuous warm-side air barrier				
3. Full-coverage warm-side vapor retarder				
4. Continuous exterior-side weather barrier				
5. Energy efficient, condensation resistant windows				
6. Effective ground moisture / soil gas control				
7. Low toxicity materials, finishes, and furnishings				
8. Safe, efficient space heating and cooling				
9. Managed mechanical ventilation				
10. Efficient and safe appliances and lighting				



# **Key Components of a Cold Climate House**

**Putting it All Together  
to Achieve Total Building Performance**

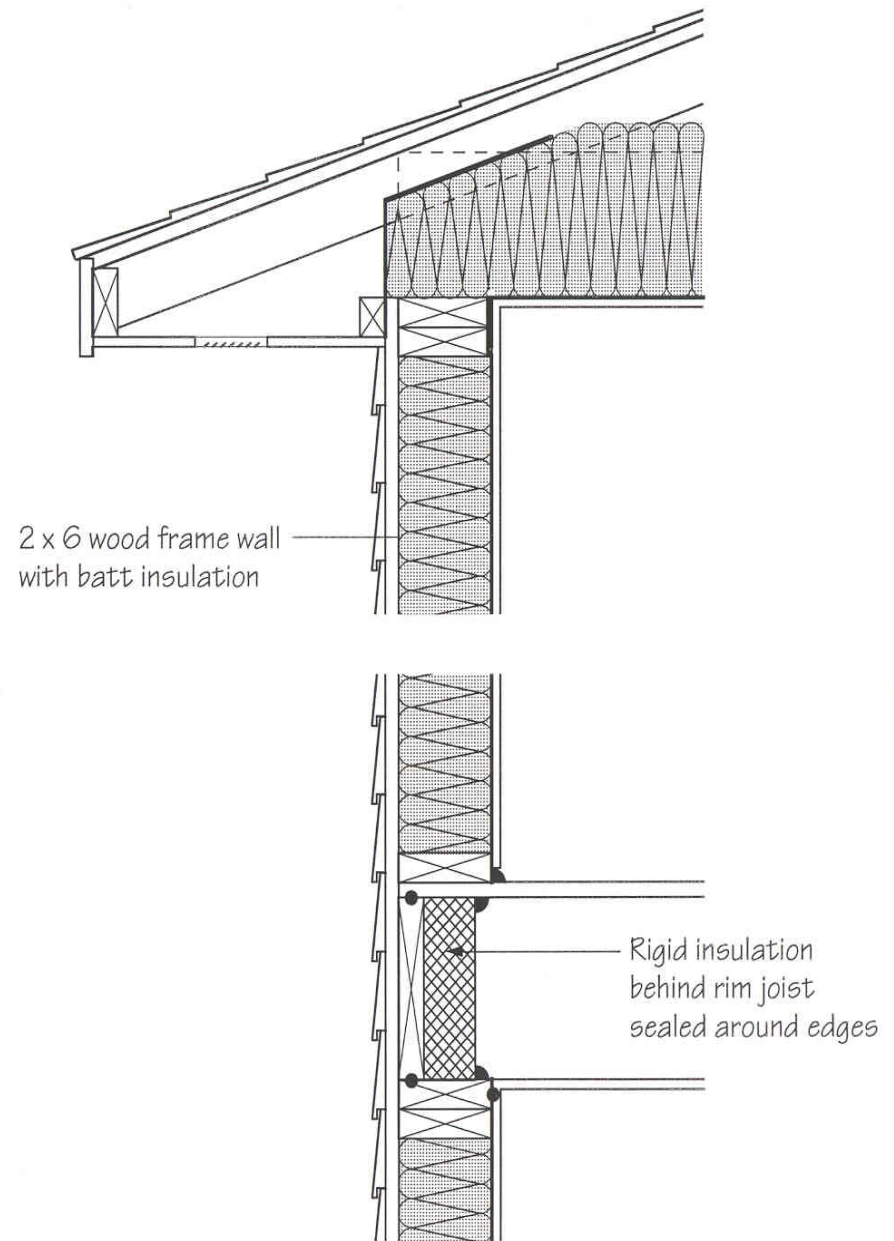
**1. Full coverage  
optimal thermal  
insulation**

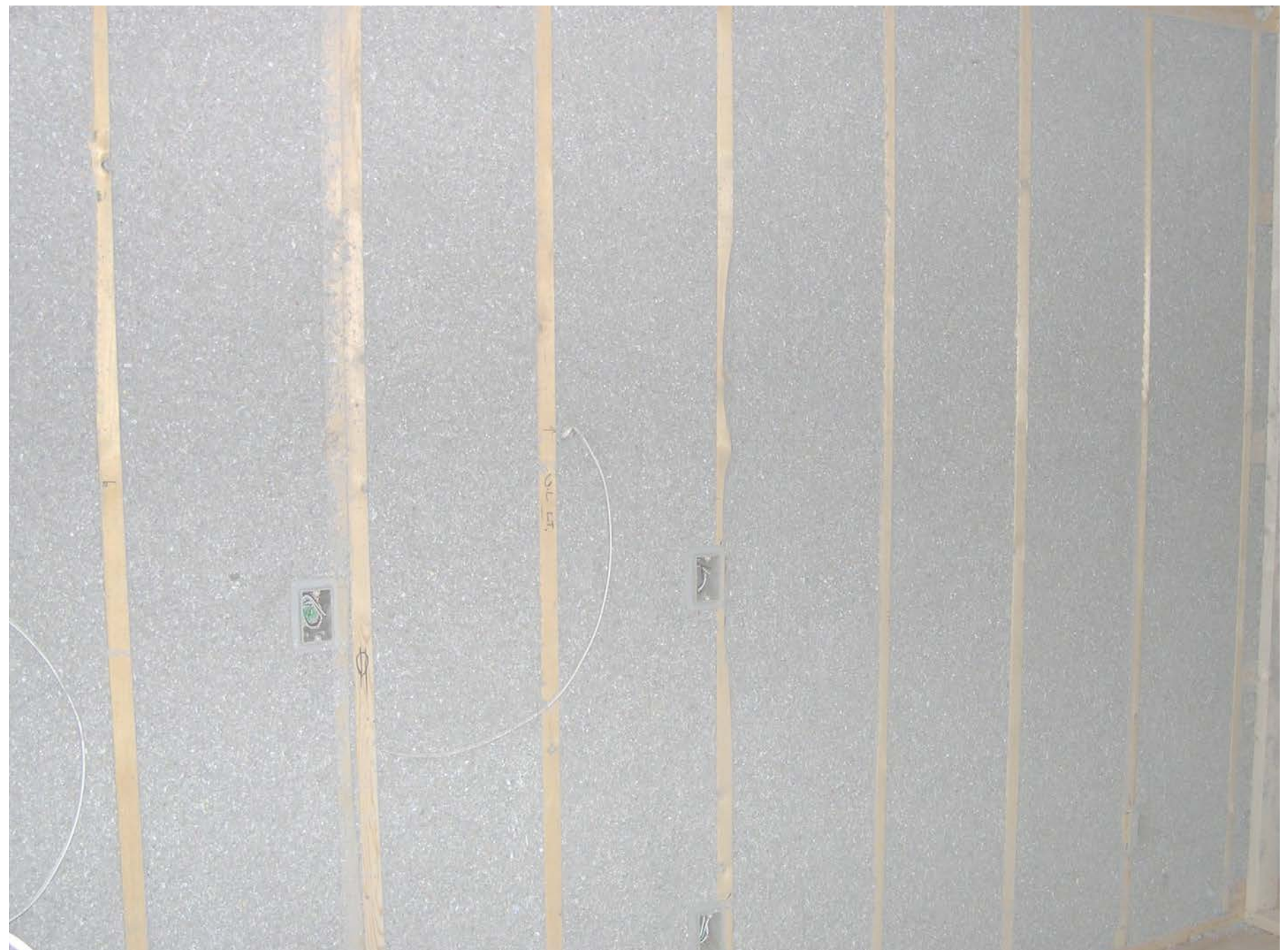


# **Key Components of a Cold Climate House**

**Putting it All Together  
to Achieve High Performance**

# Full-Coverage, Optimal Thermal Insulation





SL LF





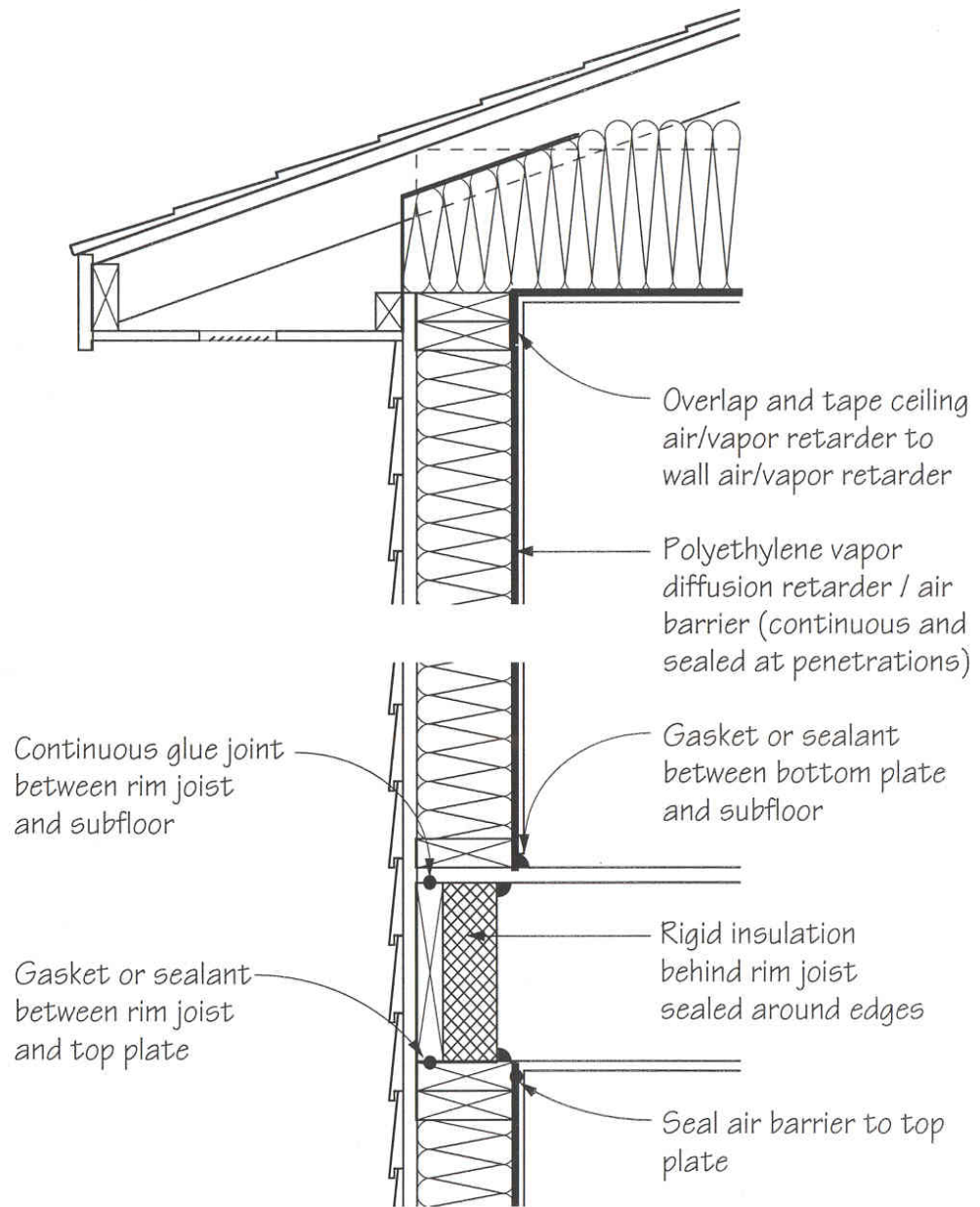
**1. Full coverage  
optimal thermal  
insulation**

**2. Continuous  
warm-side air barrier**

# **Components of a Cold Climate House**

**Putting it All Together  
to Achieve High Performance**

# Continuous Warm-Side Air Barrier

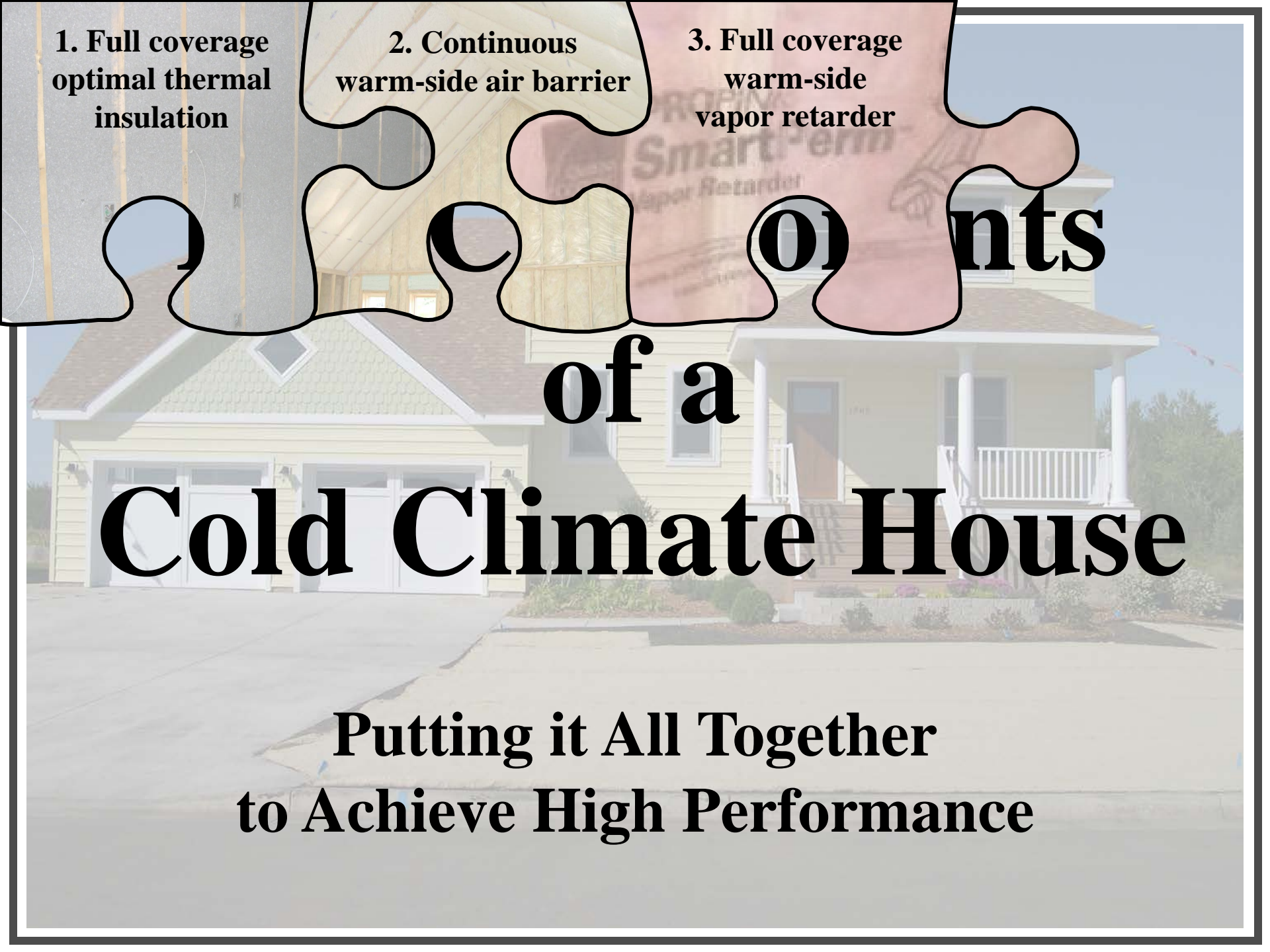




**1. Full coverage  
optimal thermal  
insulation**

**2. Continuous  
warm-side air barrier**

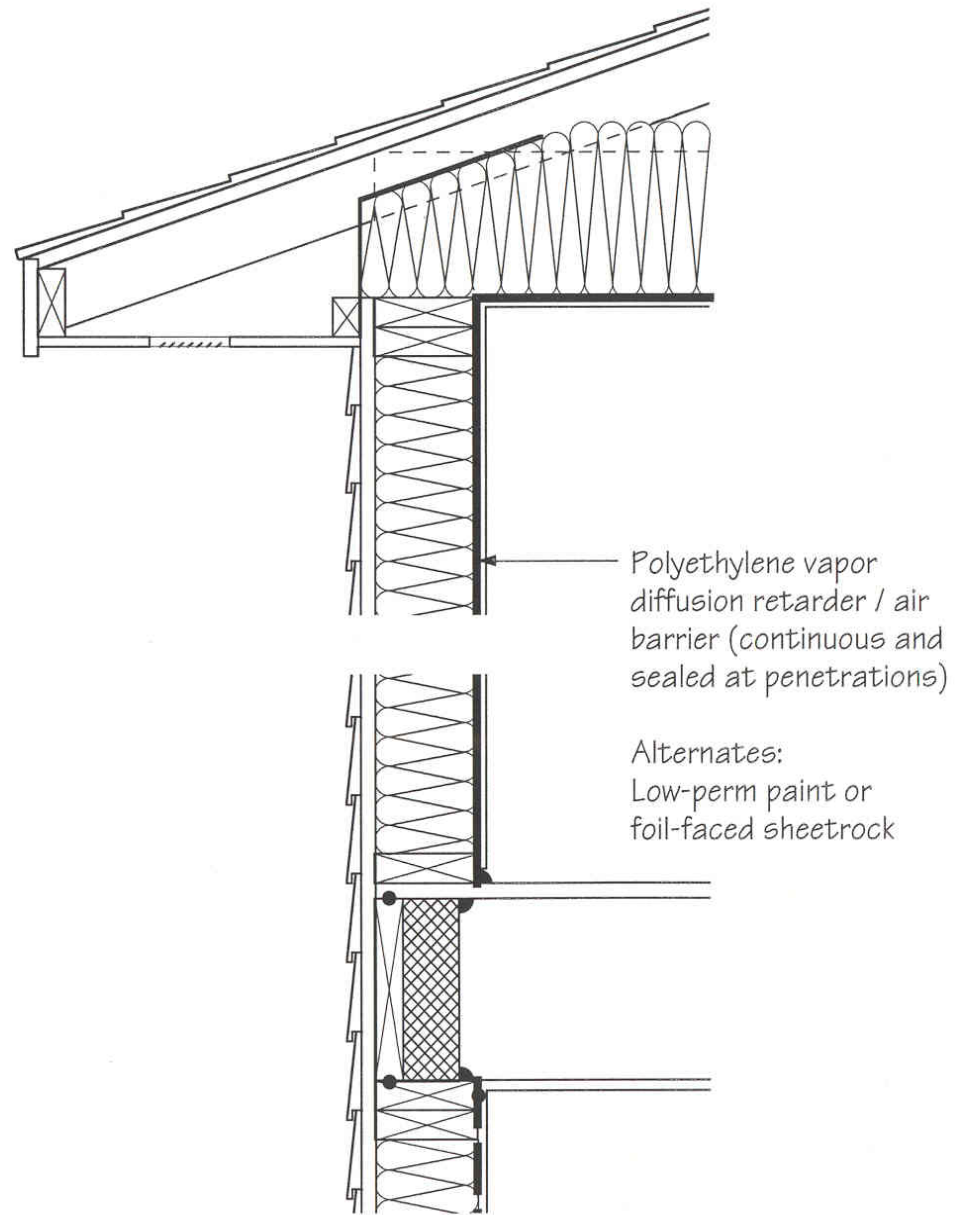
**3. Full coverage  
warm-side  
vapor retarder**



**Points  
of a  
Cold Climate House**

**Putting it All Together  
to Achieve High Performance**

# Full-Coverage, Warm-Side Vapor Retarder





PROPINEC  
**SmartPerm™**  
Vapor Retarder



www.propinec.com  
1-800-368-7272

**1. Full coverage  
optimal thermal  
insulation**

**2. Continuous  
warm-side air barrier**

**3. Full coverage  
warm-side  
vapor retarder**

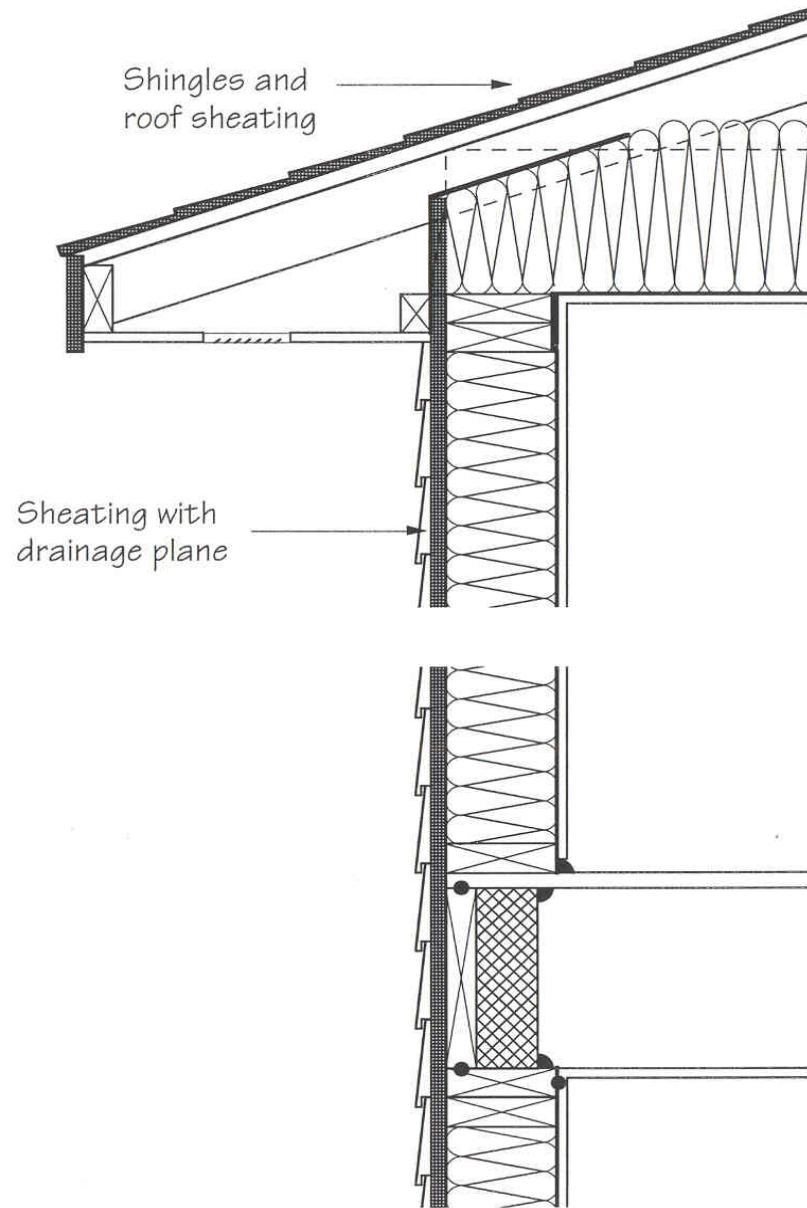
**4. Continuous  
exterior-side weather  
barrier**

**of a**

**Cold Climate House**

**Putting it All Together  
to Achieve High Performance**

# Full-Coverage, Exterior Weather Barrier





DU PONT

Tyvek  
Home  
Revestment

Call 1-800-4TYVEK

DU PONT

Tyvek  
Home



**1. Full coverage  
optimal thermal  
insulation**

**2. Continuous  
warm-side air barrier  
vapor retarder**

**3. Full coverage  
warm-side  
vapor retarder**

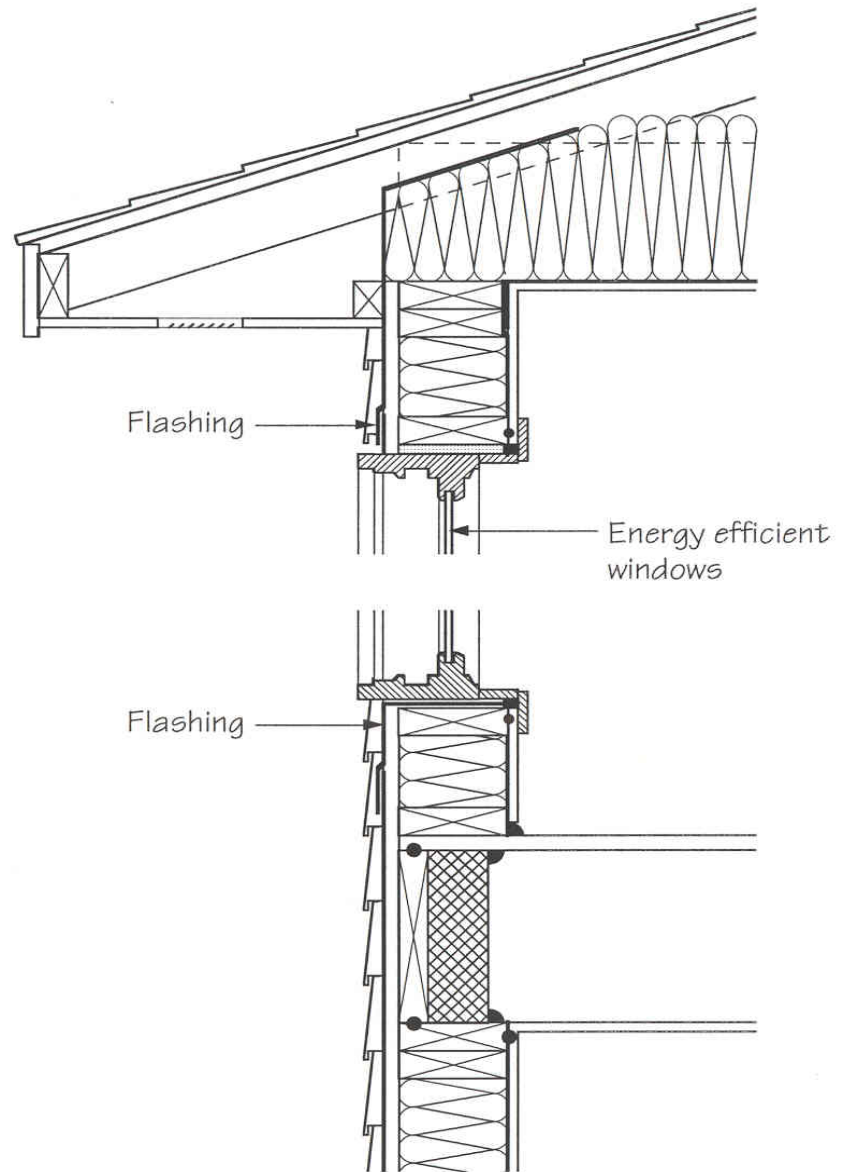
**4. Continuous  
exterior-side weather  
barrier**

**5. Energy efficient,  
condensation  
resistant windows**

# of a Cold Climate House

**Putting it All Together  
to Achieve High Performance**

# Energy-Efficient, Condensation- Resistant Windows





National Fenestration  
Rating Council

CERTIFIED

# ANDERSEN CORPORATION

**Tilt-Wash Double-Hung Window**  
Vinyl-Clad Wood Frame  
High-Performance™ Low-E<sup>2</sup> Gas-Filled Glazing

## ENERGY Performance

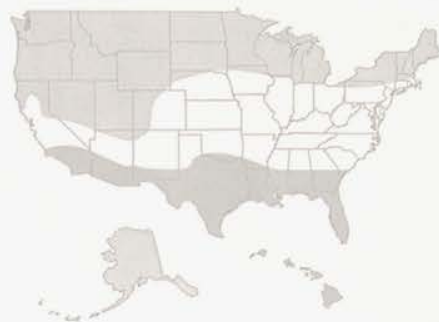
- Energy savings will depend on your specific climate, house and lifestyle
- For more information, call 1-888-888-7020 or visit NFRC's web site at [www.nfrc.org](http://www.nfrc.org)

### Technical Information

Res	U-Factor	<b>.34</b>	Solar Heat Gain Coefficient	<b>.32</b>	Visible Light Transmittance	<b>.51</b>
	Non-Res	<b>.33</b>	<b>.33</b>	<b>.53</b>		

Manufacturer stipulates that these ratings conform to applicable NFRC procedures for determining whole product energy performance. NFRC ratings are determined for a fixed set of environmental conditions and specific product sizes.

Meets or exceeds Model Energy Code & C.E.C. Air Infiltration Requirements.



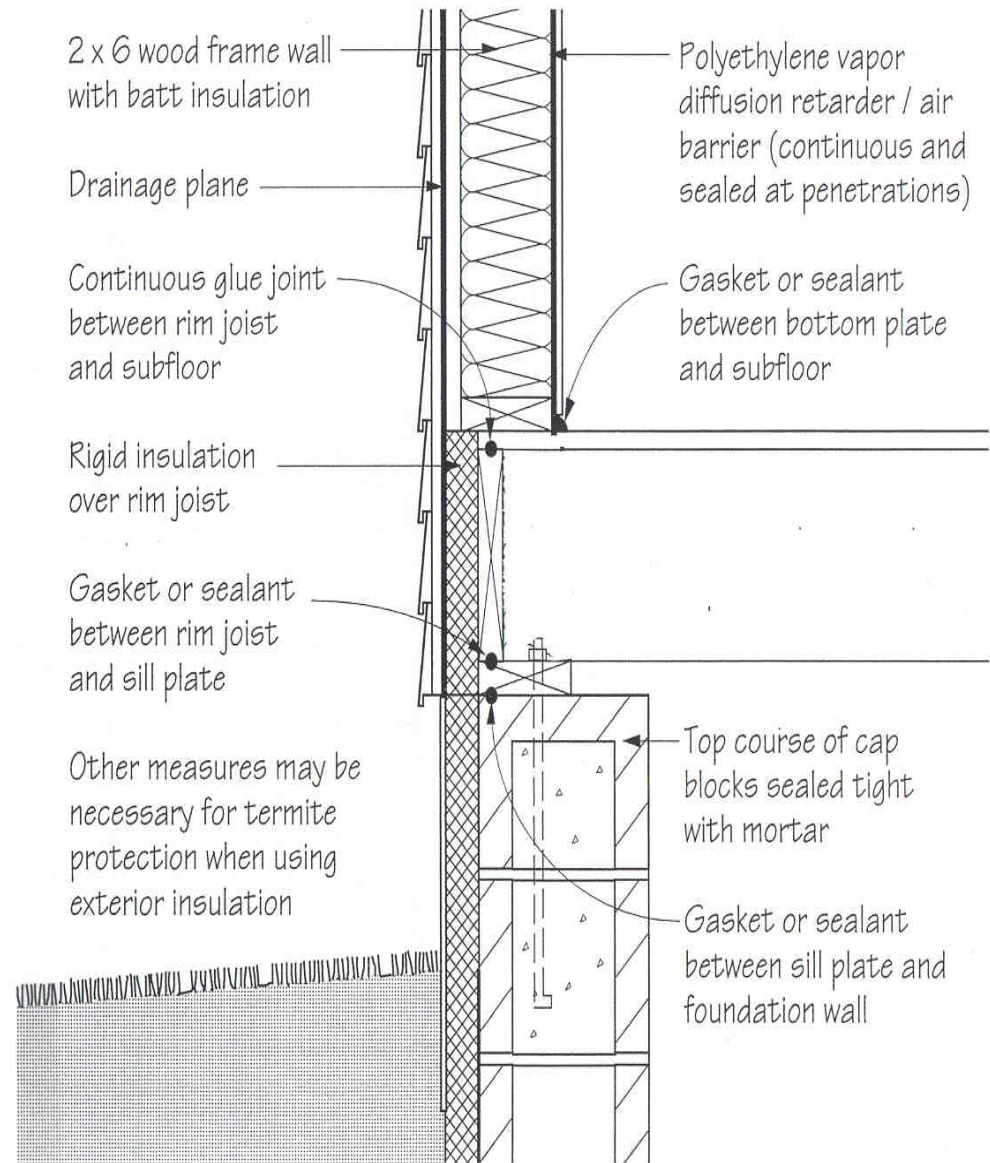
- = Northern  
Mostly Heating
- = Central  
Heating & Cooling
- = Southern  
Mostly Cooling

This product is ENERGY STAR® qualified for the regions indicated below: All regions- Northern, Central, and Southern

Tilt-Wash Double-Hung Window  
Tested to NWWDA I.S. 2-87 Standard  
**DP 30**



# Effective Ground Moisture/Soil Gas Control





**1. Full coverage optimal thermal insulation**

**2. Continuous warm-side air barrier**

**3. Full coverage warm-side vapor retarder**

**4. Continuous exterior-side weather barrier**



**of a**

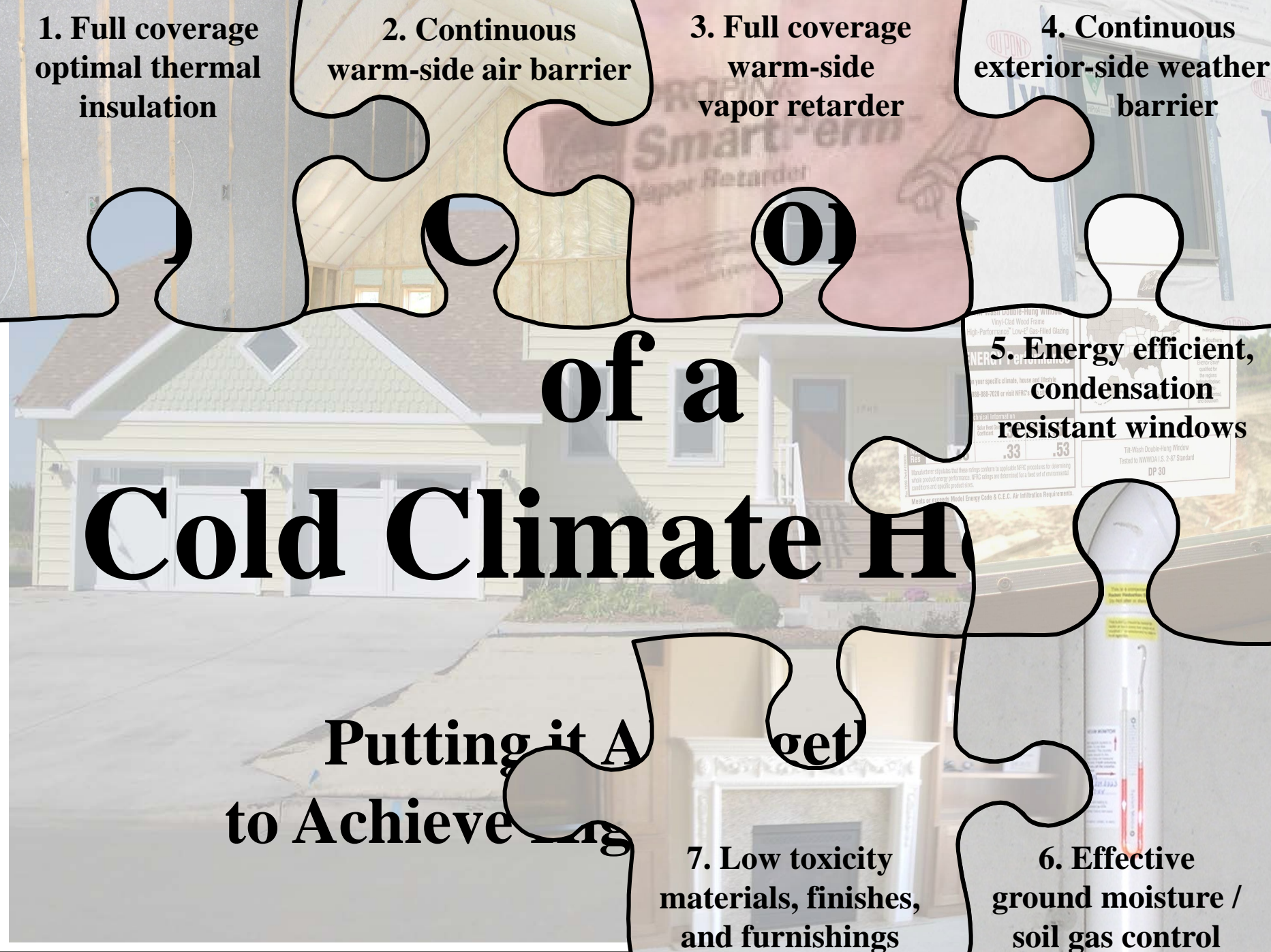
# **Cold Climate Home**

**5. Energy efficient, condensation resistant windows**

**Putting it All  
to Achieve**

**7. Low toxicity materials, finishes, and furnishings**

**6. Effective ground moisture / soil gas control**





# Low-Toxic Materials, Finishes, Furnishings

- Carpets
- Underlays
- Paints
- Household cleaning products
- Cooking odors
- Combustion gases
- Textiles
- Tobacco smoke
- Molds and fungi
- Hair spray
- Disinfectants
- Deodorants
- Glues
- Wood products

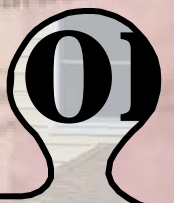


**1. Full coverage optimal thermal insulation**

**2. Continuous warm-side air barrier**

**3. Full coverage warm-side vapor retarder**

**4. Continuous exterior-side weather barrier**



# Cold Climate Home

**5. Energy efficient, condensation resistant windows**

ENERGY STAR	ENERGY STAR
U-Value: 0.33	U-Value: 0.53
SHGC: 0.25	SHGC: 0.40
Visible Transmittance: 0.70	Visible Transmittance: 0.70

ENERGY STAR Certified Product

to

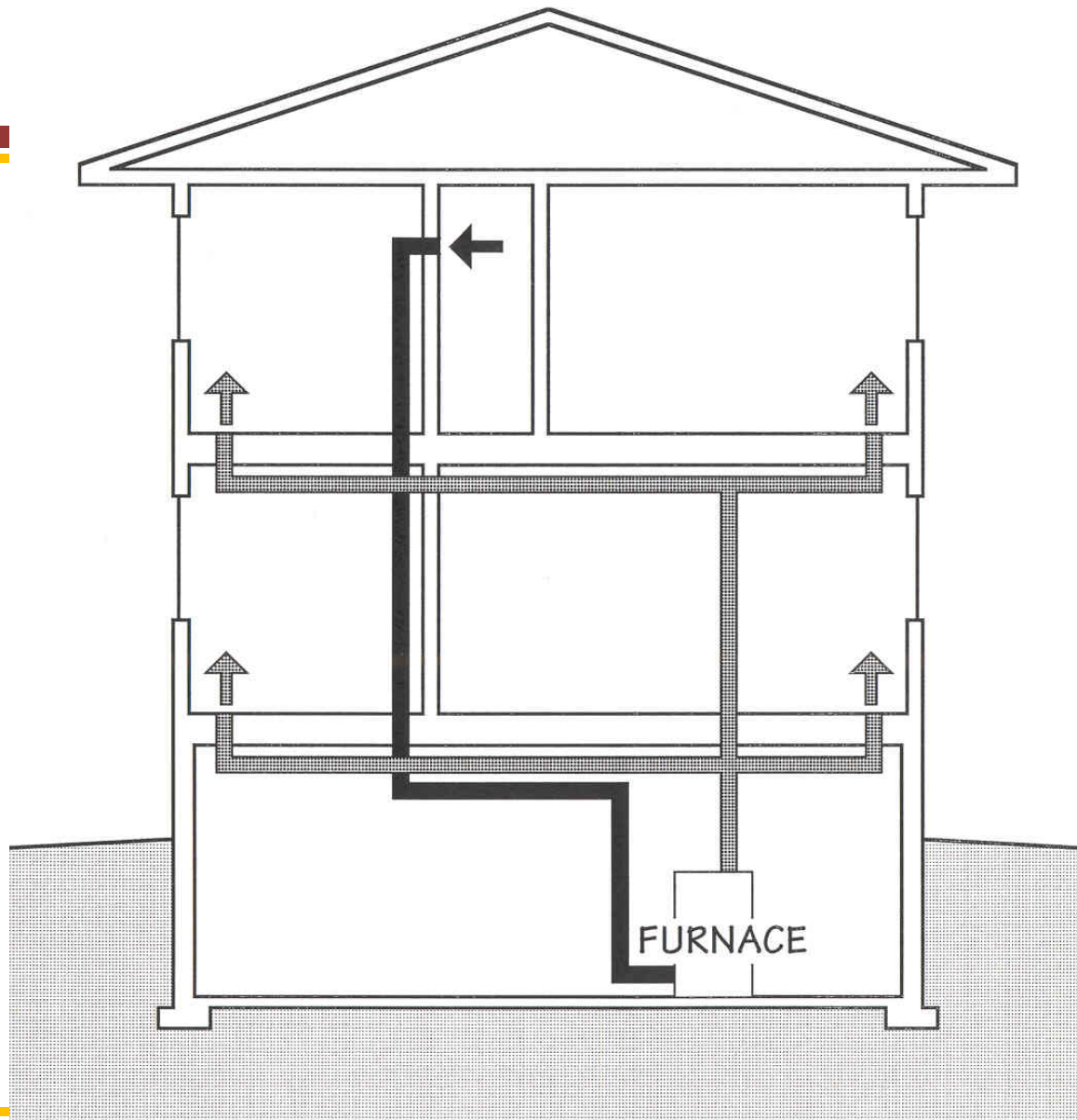
**8. Safe, efficient space heating and cooling**

**7. Low toxicity materials, finishes, and furnishings**

**6. Effective ground moisture / soil gas control**



# Safe, Efficient Space Heating and Cooling



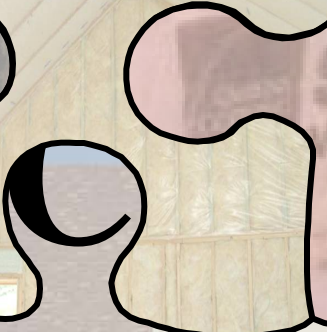


**1. Full coverage optimal thermal insulation**

**2. Continuous warm-side air barrier vapor retarder**

**3. Full coverage warm-side vapor retarder**

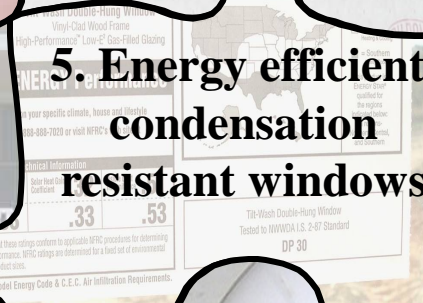
**4. Continuous exterior-side weather barrier**



**of a**

# **Cold Climate Home**

**5. Energy efficient, condensation resistant windows**



**get!**

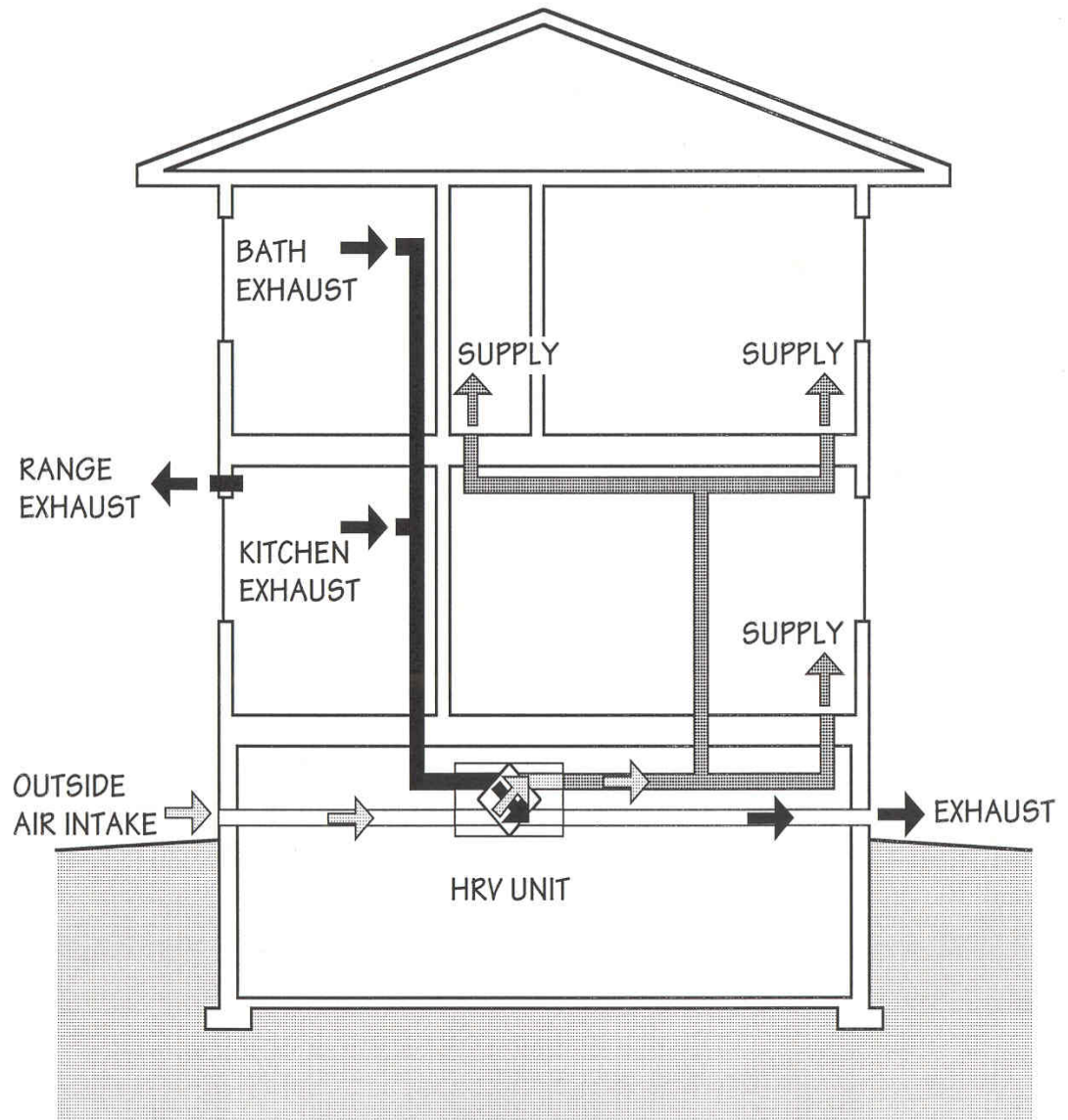
**9. Managed mechanical ventilation**

**8. Safe, efficient space heating and cooling**

**7. Low toxicity materials, finishes, and furnishings**

**6. Effective ground moisture / soil gas control**

# Managed Mechanical Ventilation





Logsnay



**1. Full coverage optimal thermal insulation**

**2. Continuous warm-side air barrier vapor retarder**

**3. Full coverage warm-side vapor retarder**

**4. Continuous exterior-side weather barrier**

**10. Efficient and safe appliances and lighting**

# 10 of a Dozen Climate H

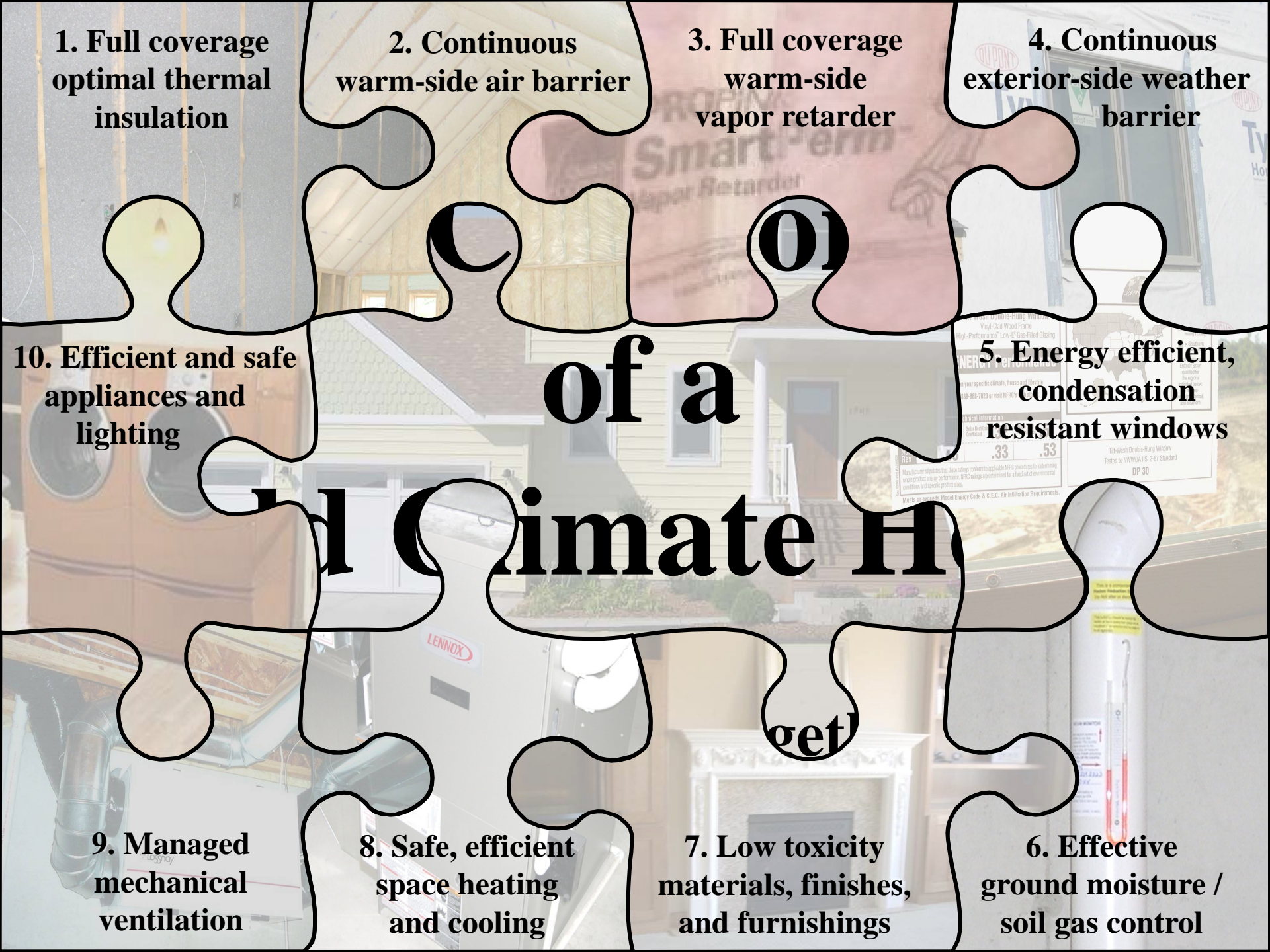
**5. Energy efficient, condensation resistant windows**

**9. Managed mechanical ventilation**

**8. Safe, efficient space heating and cooling**

**7. Low toxicity materials, finishes, and furnishings**

**6. Effective ground moisture / soil gas control**





## Efficient, Safe Appliances and Lighting



4  
PACK





**1. Full coverage optimal thermal insulation**

**2. Continuous warm-side air barrier vapor retarder**

**3. Full coverage warm-side vapor retarder**

**4. Continuous exterior-side weather barrier**

**10. Efficient and safe appliances and lighting**

**11. User friendly controls**

**5. Energy efficient, condensation resistant windows**

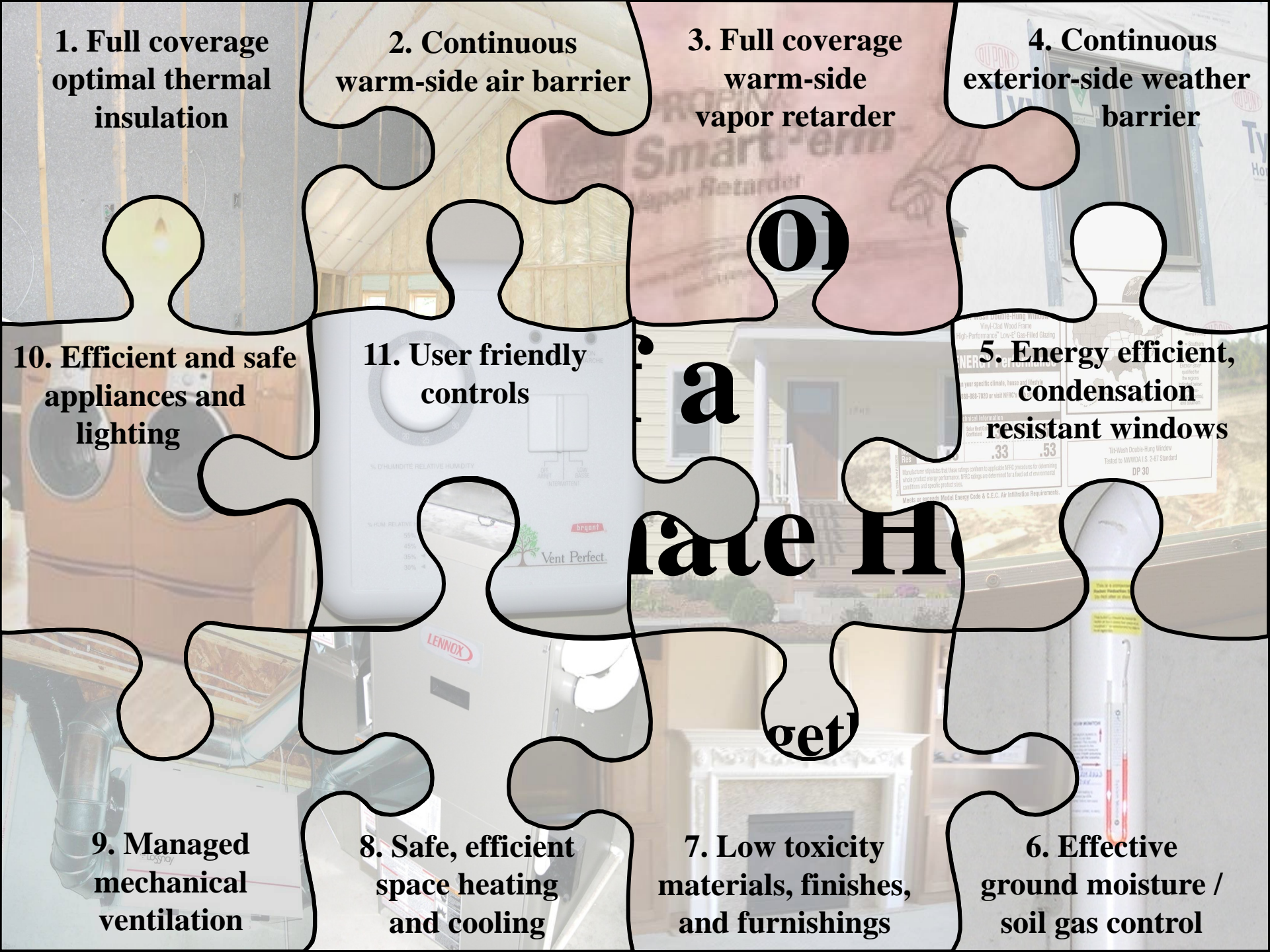
**9. Managed mechanical ventilation**

**8. Safe, efficient space heating and cooling**

**7. Low toxicity materials, finishes, and furnishings**

**6. Effective ground moisture / soil gas control**

# 101 a rate H get



# User-Friendly Controls

- Set-back thermostat
- Dehumidistat
- Ventilation
  - more or less





% D'HUMIDITÉ RELATIVE HUMIDITY

AIR EXCHANGE  
ÉCHANGE D'AIR

ON  
MARCHÉ



OFF  
ARRET

LOW  
BASSE

INTERMITTENT

% HUM. RELATIVE HUM.	EXT. TEMP. EXT.
55% ◀ ▶	10° C / 50°F
45% ◀ ▶	0° C / 32°F
35% ◀ ▶	-10° C / 14°F
30% ◀ ▶	-20° C / -4°F



**bryant**

Vent Perfect.

**1. Full coverage optimal thermal insulation**

**2. Continuous warm-side air barrier vapor retarder**

**3. Full coverage warm-side vapor retarder**

**4. Continuous exterior-side weather barrier**

**10. Efficient and safe appliances and lighting**

**11. User friendly controls**

**12. Proper homeowner operation and maintenance**

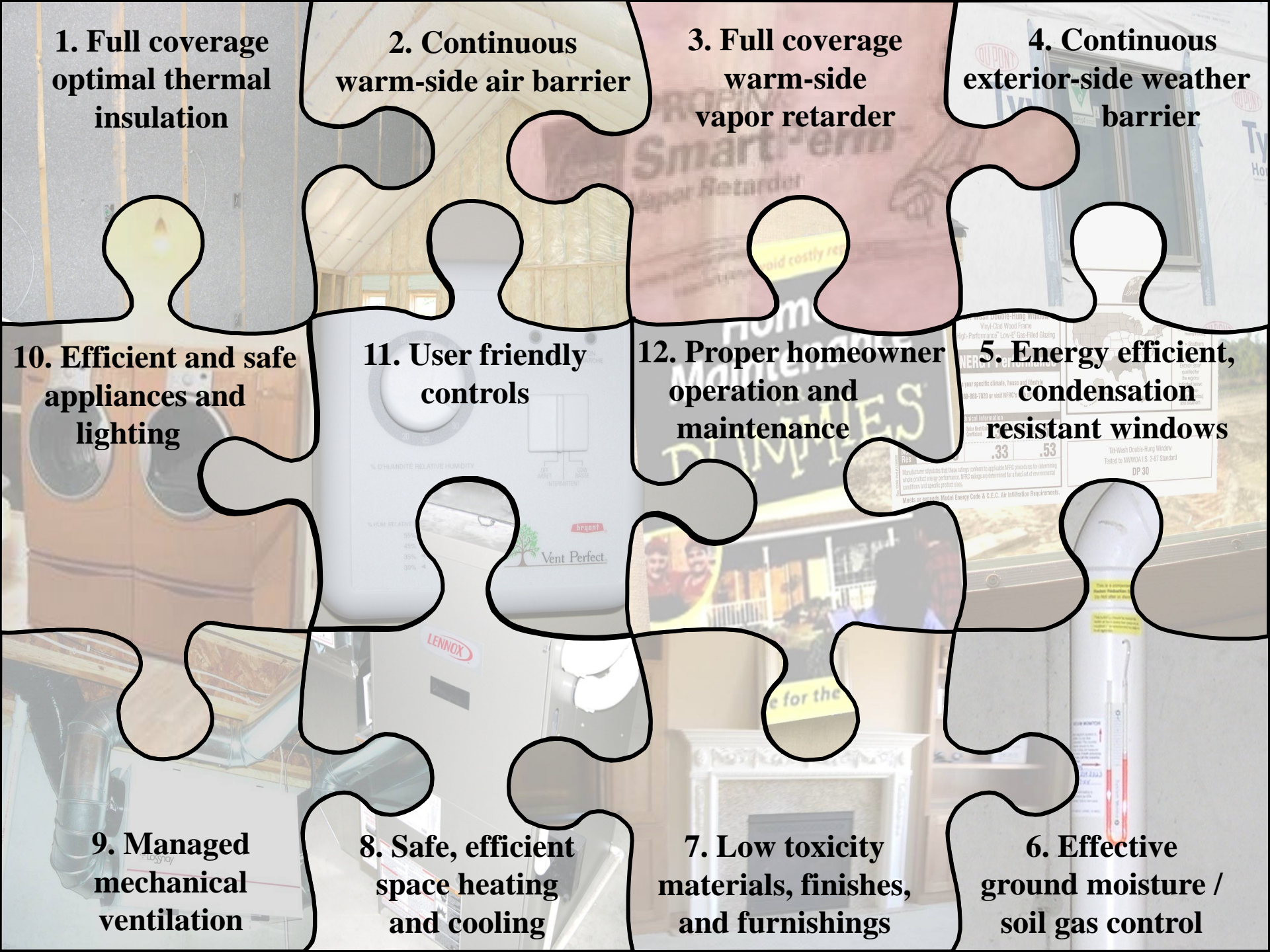
**5. Energy efficient, condensation resistant windows**

**9. Managed mechanical ventilation**

**8. Safe, efficient space heating and cooling**

**7. Low toxicity materials, finishes, and furnishings**

**6. Effective ground moisture / soil gas control**



# Proper Operation & Maintenance

- Homeowners manual with product information and guide to operation
- Preventive maintenance checklist
- Maintenance log



Save your home in  
top-top shape and avoid costly repairs

# Home Maintenance FOR DUMMIES



A Reference for the Rest of Us!



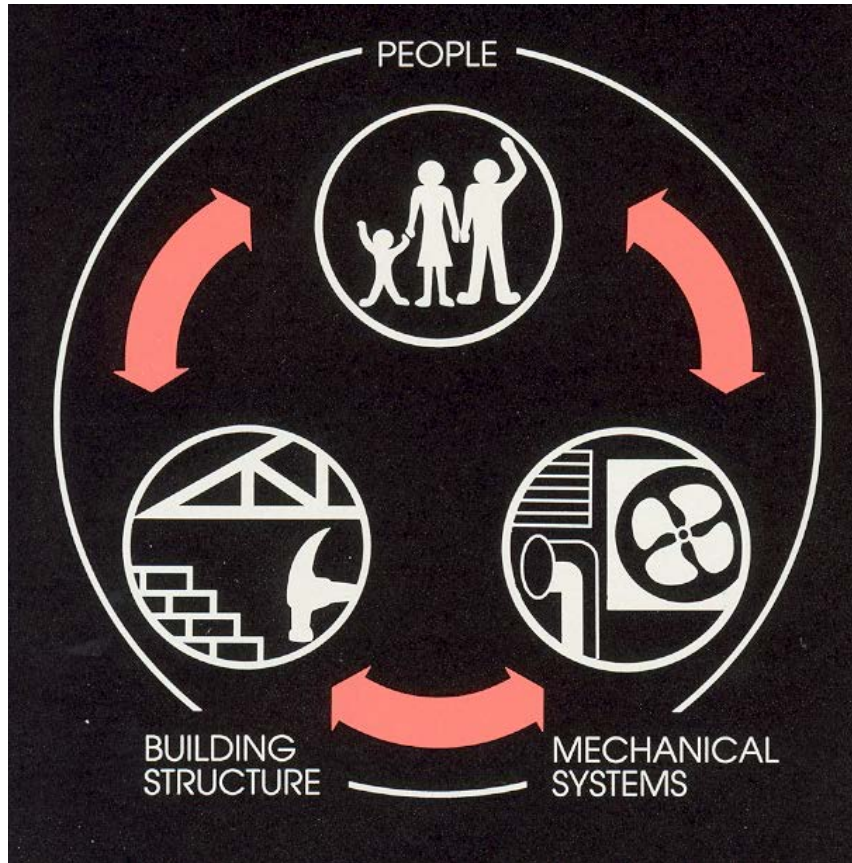
# Total Building Performance: When It All Comes Together

- Well-insulated envelope
  - slab, foundation, walls, ceiling
- Highly efficient windows
- Extremely airtight
- High quality mechanicals
  - efficient, sealed combustion furnace and water heater
  - properly sized, high-efficiency air-conditioning
  - well-designed, sealed ductwork
  - dedicated and distributed mechanical ventilation system
  - high-efficiency air filtration
  - proper make-up air for exhausts
  - user-friendly controls



- Very comfortable home
- Durable & low-maintenance
- Healthy indoor environment
- Heating: \$140 - 350 /yr
- Cooling: \$80 - 200/yr
- Water heating: \$ 60 - 100/yr

# Total Building Performance: In Summary



Always keep a holistic view of how houses work

- Must acknowledge the interaction of ...
  - structure & building envelope
  - mechanical equipment
  - occupants
- Within the context of the ...
  - climate
  - site

# Total Building Performance: In Summary

- Building a home or remodeling today is
  - not just parts, but **practices**
  - not just materials, but **methods**
  - not just products, but **process**
- The whole should be more than the sum of the parts
  - We must move from simple assembly to system integration and ultimately synergy

# Total Building Performance: In Summary

- We can and must do better!
  - Controlling airflow is critical to building performance
- Existing technology can get us there!
  - It's not about products - it's all about execution
- New technologies will be important
  - Must be systematic in their evaluation & application

# In Summary

## Questions and Discussion

# Preview for Next Class

- Introduction to HAM
  - Heat flows
  - Air flows
  - Moisture flows
  
- Readings
  - HF: Chapter 2 => 2.1 to 2.3
  - HF: Chapter 4 => 4.1 to 4.21
  - HPE: Chapter 2 & 3 (intro only)



# Building Science Review (for next class)

- Key Building Science Principles
  - Heat goes from \_\_\_\_\_ to \_\_\_\_\_ .
  - Water vapor goes from \_\_\_\_\_ to \_\_\_\_\_ .
  - Water vapor goes from \_\_\_\_\_ to \_\_\_\_\_ .
  - Air in \_\_\_\_\_ \_\_\_\_\_ air out ( and vice versa).
  - Air must have a \_\_\_\_\_ and a \_\_\_\_\_ to flow.
  - \_\_\_\_\_ the rain (and the soil)
  - Most of the action is at \_\_\_\_\_ and \_\_\_\_\_ .
  - Gas concentration (pollutants, water vapor, etc.) is a function of \_\_\_\_\_ \_\_\_\_\_ and \_\_\_\_\_ \_\_\_\_\_ .
- In the end -- \_\_\_\_\_ , \_\_\_\_\_ , and \_\_\_\_\_ flows will drive the performance of the system!