How does a home perform? Understanding basic building science

Field Fusion
Energizing the discussion around building efficiency.

Presented By Robby Schwarz

Agenda

Intro to Building science
- The connection to the IECC

- Systems Thinking

- Applied Building Science
  - Heat Flow
  - Air Flow
  - Moisture Flow

Change is Hard ... Change is Good... Change can be Made Easier
Expectation
Pathways through the 2015/18 IECC

• Prescriptive
  • Baseline but no code tool used for quantification

• UA Trade off
  • Area waited U-Value

• Simulated Performance
  • Annual Cost Compliance

• Energy Rating Index
  • HERS Index

Fundamental Questions

- Is It There?
- Does It Work?
Fundamental Questions

Is It There?  Does It Work?

[Images of a room with insulation and a duct system]
The Pathways and Mandatory sections of the IECC

- Lead us to sound applied building science and systems thinking
Look how houses have changed

1910 2018

The House as a System
(Quote from the EEBA Builders Guide) www.eeba.org

“Residential Construction is a complex operation including thousands of processes by dozens of industries, bringing together hundreds of components and sub-systems into a house.”
Applied Building Science

Systems Thinking

- Holistic approach rather than a component approach.
- Synergy
  - The various parts work together
  - Achieving what could not be achieved before!
- Meeting the Expectations
  - Safe
  - Comfort
  - Durable
  - Efficient
  - Environmental
Synergy = Systems Thinking

• 1+1 = 1
  ▪ Fan + Duct = Air flow
• 1+1 = 2
  ▪ Fan + Duct = Air flow + Ventilation
• 1+1 = 3
  ▪ Fan + Duct = Air flow + Ventilation + Durability
• 1+1 = 4
  ▪ Fan + Duct = Air flow + Ventilation + Durability + IAQ

House as a System and Applied Building Science

Must operate in Harmony in a particular environment
Codes Climate Map

Micro Climates

- Controlled environment
  - Consistent Comfort
  - Temperature
  - Humidity
  - Air Quality

- Predictability / Control
  - Tightness
  - Insulation
  - Mechanical System
  - Ventilation
What/Where is the Thermal Envelope?

- Control & Predictability
- Air Flow
- Moisture Flow
- Thermal Flow

R402.4 Air Leakage and Air Barriers (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.

- 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.
**Thermal Flow**

The Building Science
Broken down

[Images of heat transfer processes: Conduction, Radiation, Convection]

**Heat Flow**

[Diagram showing heat transfer from warmer to cooler object]

http://www.bpihomeowner.org/blog/technically-speaking/principles-heat-transfer
1\textsuperscript{st} Law of Thermodynamics

- Energy cannot be created or destroyed
- Energy moves and changes form
- Flow of heat is an energy transfer mechanism

2\textsuperscript{nd} Law of Thermodynamics

- Heat moves from high temperature regions to low temperature regions
  - Hot to Cold
- It never flows from low to high without adding additional energy
- No reaction is 100\% Complete, there is always energy loss
Temperature difference is the force that drives heat movement

- Delta = Difference = Δ
- Delta T = Temperature Difference

ΔT = 58°

Temperature vs. Heat

- Temperature is a measure of the internal energy of a system
  - A measure of how fast molecules are moving in a system

- Heat is a measure of how energy is transferred from one system (or body) to another
Heat

- Energy transferred from one body to another

- Things do not have to be hot to have heat
  - They only have to be hotter/have more heat than another body to transfer heat

Two Types of Heat

- Sensible heat
  - Heat able to be sensed by a thermometer
  - Heat absorbed (added) or released (taken away) by a substance during a change in temperature
  - This is the energy described by heat load calculations

- Latent heat
  - Heat released or absorbed by a substance during a change in phase
  - Phase changes
    - Solid to liquid / liquid to vapor
    - This is the energy that drives a heat pump or air conditioner
    - Condensation
Two Kinds of Energy

- Potential
  - Stored energy
    - Cord of wood, ice cub, Battery, hot water heater

Energy that can flow between Objects

- Kinetic Energy
  - This is the energy of motion
  - Atoms of molecules in motion are Kinetic energy
  - The temperature of energy is a description of faster moving atoms or molecules
  - Energy that is measured by a thermometer

BTU Measurement of energy

British Thermal Unit

The quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit

- Approximately the energy produced by burning one wooden match

- The term "BTU" is used to
  - Describe the heat value (energy content) of fuels,
  - To describe the power of heating and cooling systems, such as furnaces
  - BTU per hour (BTU/h) is understood, though this is often confusingly abbreviated to just "BTU".

- The unit MBTU was defined as one thousand BTU presumably from the Roman numeral system where "M" stands for one thousand (1,000).
  - Many companies and engineers use MMBTU to represent one million BTU.
  - Alternatively a therm is used representing 100,000 or 10^5 BTU
How Heat Moves

- Heat Moves/transfer by:
  - Conduction
  - Convection
  - Radiant energy movement

- All heat transfer mechanisms occur simultaneously

Conduction

- Energy conducts through solid objects
- Always from warm to cold until a balance is reached
Conductive Heat Loss

Exterior at 20°

The more lumber in a wall system, the greater amount of thermal bridging is taking place. A 16” o.c. wall typically is 25% wood.

Rigid insulation adds a continuous thermal break

Heat flow through solid objects

Interior at 72°

Convection

• Energy transferred by a moving fluid such as:
  • Air
  • Water
Convective Heat Loops

Exterior at 20°

Hollow wall cavities must be completely filled with insulation to discourage convective heat loops.

Interior at 72°

Convection loops circulate near walls. During the heating season, warm air is cooled by exterior walls and falls toward the floor, creating a convective loop. Convective loops can also happen within framing cavities if the insulation doesn't completely fill the space.
Radiation

• Radiant heat energy flies through open space
  • From an object of high temperature
  • To an object of lower temperature.

Human Comfort

Mean Radiant temperature

90°F

35°F
Thermal Transmittance

- Heat flow through building assemblies, simultaneously, by conduction, convection, and radiant heat flow.

Controlling Thermal/Heat Flow

[Diagrams showing methods to control thermal/heat flow]
**Air sealing and insulation**

**2015 IECC R402.4**

- The components of the thermal envelope as listed in Table R402.4.1.1 shall be installed in accordance with the manufacture's instructions and the criteria listed in table R402.4.1.1 as applicable to the method of construction.

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**Insulation**

- Insulation traps pockets of air
- Stagnate Air Pockets create the R-value

**Air Barrier**

- Stopping the movement of air from scrubbing away the stagnate air pocket
- Now it works
Two Functions of an Air Barrier

• Interior vs. Exterior air barrier
• At its simplest form
  • Interior drywall
  • Exterior sheathing
    • House Wrap?
    • Drainage Plan

• Function
  • Enclosing Insulation
    • 6 sided encapsulation
    • Air control

CONTROLLING THERMAL FLOW

Most insulation is NOT an air barrier

Resists Conduction

Does not resist Air Flow:
That is the job of the air barrier

* An Air Barrier is any solid material that blocks air flow including sealing at edges and seams

What is the biggest insulation Myth:
Insulation Stops the movement of air!
Air Flow

The Building Science
Broken down

How does air move in a house?
Freight Train

Can a House Be Too Tight?

NO!
- Wrong question
- Control air flow
- In order to control the air

Real question .............
- Can houses be under-ventilated?

YES!

Build Tight and Ventilate Right
Control

Predictability
The important forces affecting air leakage in homes

- Stack
- Wind
- Mechanical

Stack Effect: warm air rising

(+ Positive pressure
(- Negative pressure

Neutral pressure plane

(+) Positive pressure

(-) Negative pressure

Neutral pressure plane

Stack Effect
Taller houses have greater stack!

- 2 – 3 stories
- Chimneys
- Stair Wells

Exfiltration

Infiltration

Wind - powerful but not constant
Mechanical

- HVAC Systems
- Fans
  - Room Pressures
  - House pressure

Return Side Leakage (Winter)

Supply Side Leakage (Summer)
**Mechanical effect**

**Return Leaks**

Dominant leakage on the return ducts sends the basement zone negative

**Mechanical Effect**

**Supply Leaks**

If you have dominant leakage on the supply ducts
**Air Flow Summary**

- Air is a fluid and will move if there is a path and a pressure present
  - Hole and driving force

If either is missing air will not move
Air in = Air out
CFM = Cubic foot of air

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**Moisture Flow**

The Building Science
Broken down

[Source](http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/four-ways-water-gets-buildings)
Vapor + Air

- Air = transport mechanism
- Vapor travels with air
- Move air, move moisture
- Summary
  - Hole / driving forces
  - If one or the other is missing, no flow
  - Equilibrium: No air in, No air out

Control the air by building tight!

Table 402.4.1.1 Air Barriers and Insulation Installation
(Mandatory)

- R103.2 Information on Construction documents
- Details shall include but are not limited to:
  - Insulation location and R-values
  - Window U-value & SHGC
  - Mechanical System design criteria
  - Mechanical and water heater Type, size and efficiency
  - Duct sealing, insulation and location
  - Air sealing details
Moisture Flow

Moisture Migration Priorities
Significantly more water vapor travels through a wall by air leakage than by diffusion

Vapor diffusion:
- 1/10 pint of water per heating season

Air leakage (1/8 inch hole):
- 50 pints of water per heating season

https://portlandenergy.save.com/energy-logic-moisturemovement.php

Why is this a 100 year old house?

Drafty, uncomfortable, yet very durable houses

- Why?

Expectation?

We have changed the way we build so we need to understand moisture flow
Building Perspective

- Things get wet / Let them dry
  - Wet from the outside
  - Wet from the inside
  - Wet from the start

- Moisture flow transport mechanisms
  - Gravity
  - Capillary action
  - Diffusion
  - Air

Gravity – Bulk Water
Wind Driven Rain, Snow, Ice…..

- Layer the materials so that water is:
  - Directed down
  - Directed out
  - Directed way
- Utilize gravity
**Capillary Action**

- Water drawn upward or sideways
- Capillary Beak
- What is sill seal?

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**Air leakage vs. Capillary break**
What is Vapor Diffusion?

- Moisture moving directly through a material
- What is Vapor Pressure?
  - It is the pressure exerted by water in air.

- It is a function of:
  - TEMPERATURE and
  - RELATIVE HUMIDITY

Vapor Diffusion a slow process

4x6 sheet of gypsum board
Interior at 70°F and 40% RH

1/3 quart of water

32 Square feet

From EEBA Builder's Guide to Cold Climates by Joseph Lstiburek
The Problem is Air and the 4 M’s

- Much
- More
- Moisture
- Movement

Diffusion vs. air leakage

- 1 Quart = 4 Cups
- 4 Quarts = 1 Gallon
- 30 Quarts = 7.5 Gallons

- Diffusion
  - 1/3 Quarts
- Air leakage
  - 30 Quarts
### First Condensing Surface

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*Courtesy of DOW Building Materials*

### Dew-Point Condensation

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*70° Temp + 35% RH = 40° Dew-Point Temp*

*Courtesy of DOW Building Materials*
Air Barrier or Vapor Barrier: What is the Question?

- Insulation Resists Heat Flow
- Insulation does not Stop Air Flow
- Air barrier Stops Air Flow
- Solid materials are best at blocking air flow: OSB, Drywall, T-ply

What We Don't Do:

- [Images of various construction details]
5 key Air Barriers Attributes

What we can do....

• **Continuity:** The most important element in 3D structures with so many different components to ensure alignment between insulation and the air ABS

• **Impermeability:** The ABS must be impermeable to Air after installation.

• **Strength:** The ABS must be designed to transfer the full designed wind load, stop external or internal air movement into the assembly, and continue to be impermeable

• **Durability:** The ABS must continue to be impermeable throughout its service life, or at the IECC says, “over the useful life of the building.”

• **Stiffness:** The ABS must be stiff enough so that irregularities in the building found at installation of the ABS do not change its permeance

6 Recommendations for Vapor Management

What we should do.....

• **Encouraging** drying mechanisms over wetting prevention mechanisms

• **Avoid** using vapor barriers where vapor retarders will provide satisfactory performance

• **Avoid** using vapor retarders where vapor permeable materials will provide satisfactory performance

• **Avoid** the installation of vapor barriers on both sides of assemblies

• **Avoid** the installation of vinyl wall coverings on the inside of air-conditioned assemblies

• **Encourage** ventilation meeting ASHRAE Standard 62.2 or 62.1
  • Now a mandatory part of Code
Conclusion
Understanding Building Science

• Systems thinking
  • Synergy
• Applied Building Science
  • Control and Predictability
    • Heat Flow
    • Air Flow
    • Moisture Flow
• Sound/well defined building envelope
  • Insulation and Air barrier

Tunnel House
Thank you!
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