The House as a System

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What’s a house?
The Job of a House:

Keep out:
- rain, snow, wind, animals, insects, etc.
  (Roofing system)

Let in:
- sunlight, fresh air
  (Window system)

Let out:
- indoor air pollutants, high moisture levels, etc.
  (Ventilation system)

Keep in:
- conditioned air (that we pay for)
  (Insulation and Air barrier systems)
Other Systems Within The House

- Heating
- Cooling
- Humidification and Dehumidification
- People
House as a System

A house is a system of interdependent parts.
- The operation of one part affects many others.
- When they all work together, the house is comfortable, safe, efficient, and durable.

A house will experience problems when its house parts don’t work together properly.
- Some obvious, some invisible.
- Some now, some years down the road.
How a home performs is determined by the interaction between the:

- Environment
- Building
- People
Building Science: is the study of the physical forces that impact of house.

- Heat transfer
- Moisture movement
- Air flows
- Pressure
- Gravity
- Capillary action
The House as a System

The rise of Building Science has lead to the realization that the house is a set of interrelated parts that interact and affect each other. This can have a direct effect on the health of the occupants.

Building Science gives us the tools to diagnose housing problems HOLISTICALLY, so we can treat the root cause and not just the symptom.
Old vs New

Older Home:
- Balloon-framed two-story home (lots of stack effect)
- Boards, plaster & lathe
- No insulation
- Construction style and materials inherently leaky

Newer Home:
- Low (little stack effect)
- Plywood & drywall
- Construction style and materials inherently tighter than older home
Old vs New

**Older Home:**
- Uses more energy
- Drafty in winter
- Humid in summer
- Leaks allowed for good ventilation during certain times of the year

**Newer Home:**
- Uses less energy
- More comfortable
- Less natural ventilation

The old house got wet in the summer (humid) & dried in the winter (low humidity).

The new house gets just as wet but can’t dry; therefore poor IAQ and mold/mildew.
When looking at a housing problem think of HAM!

- Heat flow
- Air flow
- Moisture flow
Basics of Heat Flow

In the absence of other forces, heat will always move from HOT to COLD.
Basics of Heat Flow

Heat can be transferred in 3 ways

Conduction
- two solid objects in physical contact

Convection
- two fluids in contact (air is a fluid)

Radiation
- two objects in a line of sight
Basics of Heat Flow

Air Temp
70

Building Science
135

65

I ❤️ 98
Basics of Heat Flow

I love Building Science

Air Temp
70

Conduction

65
Basics of Heat Flow

Convection

Air Temp

Building Science

135

75

75

135

65

70

I love Building Science

98
Basics of Heat Flow

Building Science

Air Temp
70

I

Heart

Radiation
65

75

135
Basics of Heat Flow

- Conduction
- Convection
- Radiation

Air Temp: 70

Building Science

Heart

135

75

65

98
Basics of Moisture Flow

In the absence of other forces, moisture will always move from WETTER to DRYER.
Basics of Moisture Flow

Moisture has 3 states
- Solid
- Liquid
- Gas

Moisture moves as
- Liquid
- Vapor
Moisture Movement

**Diffusion Through Surface**
- Air molecules are blocked
- Water vapor molecules are passed

**Convection Through Holes**
- Both water vapor and air molecules pass through
Diffusion

Test Period was One Cold Climate Heating Season

1/3 quart of water
Air Transported Moisture

Test Period was One Cold Climate Heating Season

30 quarts of water

Air Leakage

4x8 sheet of gypsum board with 1 in² hole
Interior at 70° F And 40% RH
High humidity leaking around electrical outlet with air leakage from outside wall causing condensation and mold.
Moisture – Bulk Water

Bad window installation
Moisture – Bulk Water

High Ground water and/or poor drainage
Dirt floors allow moisture and soil gases into the house
Condensation

Liquid water forms when water vapor comes in contact with a sufficiently cold surface

The study of condensation/vapor formation is called psychrometrics
According to psychrometrics, the water vapor in the air will begin to condense at a temperature of 57 degrees.
According to the psychrometric chart, the water vapor in the air will condense at a temperature of 57 degrees.
Window Condensation

- Common factors:
  - Indoor relative humidity
  - Insulation factors of the window
  - Outside temperature

- Source of much misinformation and misconception
  - Need for window replacement
  - Humidifiers
  - Other moisture sources
Condensation Chart

The chart illustrates the relationship between indoor relative humidity and outdoor temperature for different levels of insulation. The curves are labeled as follows:

- **R-1; U=1.0**
- **R-2; U=0.50**
- **R-3; U=0.33**
- **R-4; U=0.25**

The chart shows how the indoor relative humidity increases with decreasing outdoor temperatures, especially for lower levels of insulation (R-1 and R-2). For higher levels of insulation (R-3 and R-4), the increase is less pronounced at lower temperatures, indicating better protection against condensation.
What’s the problem here?
It could be a condensation issue
Lack of ventilation

Steve’s bathroom

Jake’s, bathroom
Mold on walls indicates serious moisture issues in the home.
Basics of Air Flow

Air flow requires both a PRESSURE and a PATH.

In the absence of other forces, Air will always move from HIGH PRESSURE to LOW PRESSURE.
Basics of Air Flow

Pressures

Natural
- wind effect
- stack effect

Mechanical
- exhaust fans
- duct imbalances

Paths
- holes and leak
- windows, doors, ductwork
Air Flow: Temperature

$\Delta T = \text{Temperature Difference}$

Winter

Flow is from _____ to _____

The higher the $\Delta T$, the ____more____ heat and air want to escape or enter the building.

Summer

$\Delta T = 60^\circ$  
$\Delta T = 20^\circ$
Air Flow: Pressure

\[ \Delta P = \text{Pressure Difference} \]

Flow is from positive (high) to negative (low) pressure.

For every CFM that enters, one CFM exits.

Flow takes the path of least resistance.
Air Flow: Wind Effect

Wind creates a positive pressure on the windward side of the building . . .

Which creates a negative pressure on the other sides of the house.
Driving Forces: Stack Effect

Stack Effect

Warmer air rises and escapes out of the top of the house. . .

Which creates a suction that pulls in outside air at the bottom of the house.
Crawlspaces may contain mold, pests, pesticides, asbestos, lead paint and sewer gas. An apparently dry crawlspace can add excessive water vapor to a house.
Why a Holistic Approach?
Why a Holistic Approach?
Why a Holistic Approach?

Moisture / Water Intrusion → Mold → Asthma Exacerbation
Structural Damage

Moisture / Water Intrusion
Structural Damage

- Pests
  - Rodents
  - Cockroaches

- Lead Poisoning

- Fire

- Injuries
Structural Damage

- Pests
  - Rodents
  - Insects

- Lead Poisoning
- Fire
- Injuries

Asthma Exacerbation
Pesticide
Pesticide
The Systems of a House and How they Work
Weather Barrier System

Components:
- Roof
- Flashing
- Drainage Plain
- Gutters
- Windows/Doors
- Grading
- Drain Tile
Bad roof System = Water Leaks
Effects of the Defect

- Reduces the R-value of the insulation, may cause more ice dams on the roof
- Soaks the insulation, may cause the ceiling to collapse, could case injury
- Could increase humidity levels – dust mites
- Lead to mold growth – respiratory problems
Is There A Problem??
Windows and Doors
Effects of the Defect

- Bad installation or lack of maintenance will lead to moisture intrusion
- Structural damage
- Mold – respiratory problems
Insulation System

Components
- Attic Insulation
- Wall insulation
- Windows/Doors
- Foundation
Infrared camera are used to find missing insulation and air leaks
Effects of the Defect

- Uncomfortable
- Higher energy bills
- Over work HVAC system
- Cold surfaces = condensation = potential for mold/respiratory problems
Air Barrier System

Components
- Sheetrock
- Plastic Air Barrier
- Windows/Doors
- Fan Dampers

Common Leaks
1. Attic Bypasses
2. Wall Tops
3. Faulty Damper
4. Door Sweeps
Dropped Soffits

Attic insulation can hide dropped soffits
Changes in Ceiling Height

OPEN WALL CAVITY
Attic Bypass

Furnace Vent (chimney)  Top of soffit – air sealed
Effects of the Defect

- Allows conditioned air into unconditioned areas
- Causes ice dams
- Causes condensation on the roof deck and/or in walls
- Air Barrier and Insulation must be aligned
Heating System

Components
- burner
- fan
- supply ducts
- return ducts
Cooling System

Components
- condenser
- evaporative coil
- compressor
- pump
- fans
- supply ducts
- return ducts
OLD vs NEW

65% EFFICIENT

92% efficient
Effects of the Defect

• Uncomfortable
• Higher energy bills
• Oversized heating system = short cycling
• Oversized cooling system = less dehumidification
• Higher humidity = condensation = potential for mold/respiratory problems
• Replacement systems and duct work must be sized to work together as a systems.
Ventilation System

Components
- Exhaust Fans
- Makeup Air (leaks)
- Filtration
- Distribution
Today’s Houses Have (Bigger) Fans
Natural Draft Appliances
Effects of the Defect

Not enough Ventilation = Poor I.A.Q.

- Indoor contaminants, allergens, VOC’s
- Could increase humidity levels too much
- Driving moisture into the wall assembly
- Mold, increase of dust mites – respiratory
Effects of the Defect

To much Ventilation

- Outdoor air entering at higher levels
- Down drafting of naturally vented combustion appliances or fireplaces
Effects of the Defect

Back Drafting

• Combustion gases spill into the home
  – CO, NOX, CO2
  – Water vapor

• Health effects
  – Many deaths each year
Show Little Red Video
Using a Systems Approach

Solutions need to:

- Increase the durability of the house
- Promote a healthy indoor environment
- Insure that systems work together and do not create heat, air, and moisture imbalances
Remember that the house is a system and changes in one part of the house can have negative effects in another part.

Solutions can be complex, so don’t guess.

If you don’t measure, you don’t know!
Thank You

Questions?
Local Resources

- Minnesota Department of Commerce, Division of Energy Resources. [www.energy.mn.gov](http://www.energy.mn.gov)

- Minnesota Department of Health

- Minnesota Building Performance Association [www.mbpa.us](http://www.mbpa.us)

- Sustainable Resources Center [www.src-mn.org](http://www.src-mn.org)
National Resources

• Department of Energy [www.energy.gov](http://www.energy.gov)

• EPA [www.epa.gov](http://www.epa.gov)

• National Center for Healthy Housing [www.nchh.org](http://www.nchh.org)

• Building Performance Institute [www.bpi.org](http://www.bpi.org)  
  (Finding a certified contractor)
References

- Weatherization Assistance Program Standardized Curricula WAPTAC 2011
- National Center for Healthy Homes: “Essentials for Healthy Homes Practitioner’s” Course
- Energy Related Mold and Moisture Produced by: Montana State University Housing and Environmental Health Program and D.O.E. Weatherization Program