House as a System

Weatherization Energy Auditor Single Family

Key Terminology

Aldehydes	Dropped soffit
Backdraft	Indoor Air Quality (IAQ)
Bypass	Spauling
Carbon Monoxide (CO)	Stack effect
Chimney chase	Vapor retarder

Section Transition

Learning Objectives (Slide #2)

By attending this session, participants will:

- Become aware of the potential for interaction among building components and mechanical systems.
- Understand how air sealing a home can negatively affect indoor air quality.
- Be able to recognize typical air leakage sites and know how to deal with them.

House as a System (Slide #3)

A house is a system of interdependent parts: Mechanical and physical components.

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

Approaching the house as a system of interactive parts, the savings mount and we avoid creating health and safety issues.

Air sealing and insulating a home reduces the heating and cooling load. A replacement furnace in a sealed and insulated home can be smaller than the existing furnace. The initial price of the smaller unit is lower, and the long-term operating costs will be less.

A house will experience problems when its house parts don't work together properly.

- Some problems are obvious, some invisible.
- Some problems appear now, some years down the road.

Building failures are symptoms of failures in the house as a system. As weatherization workers, we need to find the underlying problem, not just replace the rotted wood.

House as a System (Slide #4)

Click to highlight arrows pointing to various elements, as outlined in list below.

- Buildings are systems. Everything in a building has the potential to interact with everything else:
  - Moisture through concrete, grading, landscaping, gutters, and downspouts.
  - Moisture from cooking, showering, and faucet aerators.
  - Air infiltration at windows and doors.
  - Air exfiltration at cathedral ceilings and recessed light fixtures, i.e., "can lights" or "pot lights."
  - Garages and ***carbon monoxide (CO)***.
  - Atmospheric combustion appliances.
  - Occupants and how they use the home.
- The tighter the building, the stronger the interaction will be.
- Codes that control trades practices were, for the most part, written when this potential was essentially insignificant. Consequently, individual tradesmen performing code-compliant work can create potentially harmful situations without realizing they have done so.
  - Example: Heating codes commonly ensure sufficient combustion air by requiring so many cubic feet of space per BTU/hr input of the appliance. These codes were established when basements were commonly rubble stone or granite slabs. Concrete is inherently tighter, but the codes haven't changed to reflect that.
- Energy auditors are the only people commonly trained in House as a System Science!

Examples – House as a System (Slide #5)

- An uninsulated attic or other failure in the thermal boundary or air barrier makes the heating and/or cooling system work harder.

Examples - House as a System (Slide #6)

- Leaky recessed light fixtures increase heat loss and gain, and can cause ice dams and moisture problems.

Examples - House as a System (Slide #7)

- Fans that exhaust into the attic or crawl space cause moisture to condense on the roof deck and trusses, weakening the structure. This problem could exist unnoticed for years, causing poor ***indoor air quality (IAQ)*** and expensive structural damage.

Ventilation and Air Change (Slide #8)

Click to reveal arrows indicating air leaking in, and again to reveal air leaking out.

- Plugging the holes and then putting in fans is counterintuitive to most people.
- The "old-timers" believed that "houses have to breathe," so left them loose, but leaving houses leaky enough to provide good indoor air quality in spring and fall also leaves them drafty, which makes them expensive to heat in the winter and cool in the summer.
- The first energy crisis inspired a wave of insulating without considering moisture build-up or IAQ. The result was odors, rot, and mold.
- A house that is properly air sealed and mechanically vented has the correct amount of air exchange all the time. Heating properly air-sealed homes is also significantly cheaper than "letting the house breathe!"
- The blue arrows represent infiltration, the red arrows, exfiltration. Because holes at the top and bottom are the ones most involved with the ***stack effect***, sealing them is the first priority.
- Intermediate-level holes - those around living space windows and doors - are more of a comfort issue than an energy conservation issue simply because the stack effect has little effect on them.
    - Wind-driven air leakage, which can occur at windows and doors, is mostly a function of building exposure. Unless the building is severely exposed to the wind, window and door leakage will have little effect on the air change rate. In homes with normal exposure, it is acceptable to only weatherstrip and air seal the windows and doors the homeowner complains about.

In the Attic (Slide #9)

- Small holes in the attic floor - at pipes, wires, and the ***chimney chase*** - allow heated air from the living space to enter the attic.
- The entering air will be relatively warm and wet.
- Moisture from the warm-wet air condenses on the first cold surface it contacts - typically, the most northerly walls and the underside of the roof deck.
- The water reacts to gravity, runs down to stain the ceiling, and looks like a roof leak.

Pipe/Wire Bypasses (Slide #10)

- Dirty insulation - particularly fiberglass - can help you pinpoint air ***bypasses***.

Chimney Chases (Slide #11)

- Chimney chases are almost universally ignored during initial construction. There is little differentiation between new and old construction.
- From an energy perspective, the area around the chimney is absolutely the worst place to have a vertical hole in a house.
  - It is the only hole that's guaranteed to be a bypass between the basement and the attic. The chimney's heat causes the air column around it to suck air from the basement and pressurize the attic.
  - Many a prematurely failed roof is solely attributable to an unsealed chimney chase simply because the air pulled from the basement is often very humid. The resulting condensation on the underside of the roof deck can cause it to rot and load the underside of the shingles with moisture, causing them to expand and curl up at the ends. As the sun dries, the shingles contract back to their normal shape. The constant flexing causes premature shingle failure.

Treating the Chimney Chase (Slide #12)

- Dirty fiberglass around the chimney points to an air leak from below.
- Clearances are important. Fire code requires a 2" clearance around combustibles.
- The air seal from the chimney to the ceiling below must be complete.

Note the "shine" below the tape to the left of the chimney in the upper right of the picture. That's a light reflecting off the boiler smoke pipe in the basement.

Sealed Chimney Bypass (Slide #13)

- The red line between the chimney and the metal air barrier is high-temperature caulk, which is required by code.
- The underside of the metal is caulked to the ceiling framing.
- Scrap pieces of drywall complete the air seal from new framing to the existing ceiling.
- The last step is installing a metal dam to keep insulation at least 2" away from the chimney.

An Alternative Method (Slide #14)

Diagram from Maine's DOE WAP Manual.

- With an exposed chimney, it is permissible to create the air seal in the living space at the ceiling if 1) it matches the general style and construction quality of the home, and 2) the homeowner agrees.
- The insulation dam is still required in the attic.

In the Basement (Slide #15)

Notice the ***spauling*** (the white, chalk-like coating on the concrete caused by water picking up salts as it migrates through the concrete, then leaving them on the surface when it evaporates) as well as the high water mark and standing water. The sewer cleanout is plugged with a wood stopper. There is minor mold on the cement blocks and floor stringers.

> *Q. Square foot for square foot, what evaporates more water vapor into the air: standing water or concrete without a vapor barrier?*
>
> *A. Concrete, because it has more surface area.*

- Without a ***vapor retarder*** in, on, or below the concrete floor, ground moisture is constantly radiated into the basement.
- Even with a vapor retarder, ground moisture will enter the basement through cracks and holes.
- Soil gasses will enter with the moisture.
- Mechanical appliances can produce airborne pollutants.
- Many things stored in the basement can off-gas. Typically, we find detergents, paint, hobby chemicals, cleaning solvents, etc.
- Dirt floors and crawl spaces are even more problematic.
- Basements are typically well connected to the living space. Whatever is in the basement, occupants breathe in the living space.
- Duct leaks can have many consequences:
  - The heat that leaks out of the ducts warms an area you don't want heated.
  - Cold air is pulled into the heating system from the basement.
  - Heated air is forced out of the home.
  - Basement pollutants are delivered to the living space.
- Remember: Whatever is in the basement, occupants breathe in the living space.

Plumbing and Wire Opening (Slide #16)

- All types of holes give basement air free access into first-floor wall cavities. They will be connected in turn to upper floor cavities and the attic.

Under the Tub (Slide #17)

- This opening under the tub looks innocent enough. It is almost certainly connected to vertical chases behind the tub/shower that are, in turn, connected to upper floor cavities and the attic.

Another Tub (Slide #18)

- This is a similar situation in an older home.

More in the Basement (Slide #19)

- The installer couldn't fit his arm into the space between the plenum and the ceiling so he didn't bother finishing this job.
- This situation pressurizes the basement, forcing air out along the sill. It can "power rot" the basement box sill assembly, while wasting significant energy.
- The "cure" was drywall mesh tape, a good quality duct mastic such as RDC # 6, and a short stick.

More in the Basement: Danger! (Slide #20)

- The picture to the left shows a grille cut into the return plenum to prevent the duct from banging when the air handler started up. The air handler fan now sucks directly on the barometric damper. This house has, in effect, a power vent chimney. All combustion byproducts are being delivered to the occupants to breathe. THIS IS EXTREMELY DANGEROUS!
    - Even oil units can produce CO under these conditions. Oil combustion also produces ***aldehydes*** - toxic byproducts of oil combustion - and other pollutants.
- On the right, we see the top of an atmospheric gas water heater. Because the vent system ***backdrafted*** repeatedly to the point of burning the paint off the water heater, someone installed thermocouples to shut down the gas flame whenever backdrafting occurred. The real culprit was leaky return ductwork on a warm air furnace (not pictured) sucking on the basement.

In the Garage (Slide #21)

Q. What are some pollutants typically stored in the garage?

Click to reveal selection of pollutants typically found in the garage.

- The garage floor has the same moisture characteristics as the basement floor.
- Garages are even more likely than basements to contain stored "off-gassers," such as automobiles, lawn mowers, and other fossil-fueled machines.
- Catalytic converters in cars emit low levels of CO for approximately four hours after the car is shut off!
- Garages typically have a low "air-feed" (the lower edge of the overhead door) and high "relief" (pipe and wire penetrations near the ceiling). Or they are totally open to the living space attic. Anything breathable in the garage is soon inside the home.
- It is extremely important to isolate the garage from the living space to the greatest degree possible to ensure that our weatherization activities - particularly measures that reduce the natural air change rate in the living space - do not concentrate pollutants that previously escaped. A post-weatherization check of any isolation measures using pressure diagnostics is imperative!

In the Kitchen and Bathroom (Slide #22)

- Showering creates large amounts of airborne moisture.
- ….as does cooking without using pot lids.
- Existing vent fans are typically underpowered and noisy.
- Often, they're not vented to the exterior.
- When they are, the ducts often leak or restrict airflow.
- Even a good fan does nothing if it isn't used.
- Remember when evaluating homes with gas ranges or cooktops that gas code requires they be vented to the building exterior through a hard-ducted vent hood. Recirculating models do not satisfy the code requirement. Always consider installing good quality CO detectors in homes with gas appliances.

With a properly functioning ventilation system, moisture and other pollutants are kept from entering the home. Any pollutant - and moisture is considered a pollutant for the purposes of this discussion - created in the home is transported safely outside through exhaust ventilation and ductwork. However, in many homes, the fans or ducts are loud, leaky, non-existent or otherwise not up to the job. Moisture created within the home condenses on cool building surfaces, both in the living space and in the attic, and causes mold, mildew, poor IAQ, and structural damage.

Dropped Soffits (Slide #23)

- Ceiling drywall isn't typically extended over cabinet ***dropped soffits***.
- Even if the attic is insulated, attic air has free access to the cavity, cooling the walls and cabinet.

Dropped Soffits (Slide #24)

- If you see soffit-mounted cabinets, remember to investigate during attic inspection

In the Living Room (Slide #25)

- An "open-burn" fireplace (one without glass doors) pulls so much heated air from the living space it actually may cool the surrounding space.
    - Of interest: Wing chairs and footstools were invented to shield people from the rush of air heading to open fireplaces in castles.

Unvented Space Heaters (Slide #26)

This is a photo of a kerosene wick burner heater, the predecessor of the Kerosun and other unvented space heaters.

- Kerosene wick burner heaters are almost universally illegal because of their unhealthy emissions and because of the likelihood of fire. Vent-free gas fireplaces are illegal in many states because they tend to produce high levels of CO.
- Instructions for vent-free fireplaces usually say to set the gas flame to blue with a yellow tip for low CO production. Further on, the instructions often say to close the air gate down for a more realistic yellow flame. A yellow flame indicates high CO production.

Outside (Slide #27)

The house as a system concept doesn't stop at the walls. Factors outside the home that affect structural integrity and home performance include:

- Roof leaks – Water leaking into the attic damages insulation, reducing the effective R-value and increasing heating and cooling bills.
- Gutters (or lack of) – Poorly installed or clogged gutters can cause moisture to drip down exterior surfaces, infiltrating cracks and crevices. This can cause structural damage and reduce effective R-values of wall insulation.
- Landscaping
  - Ground slope – Any landscaping that guides moisture toward the home, rather than away, is poor landscaping.
  - Vegetation
    - Good design: A deciduous tree planted on the south side of the house can shade it in summer, and allow low winter sun to warm the home during the heating season.
    - Bad design: Trees and bushes of any type that reduce air movement around the building retard drying of building components and can promote building rot.
- Building design
  - Any building design - low slope or flat roof additions, abutting dormers, etc. - that allows water to puddle or channels it toward other building components is a poor design.

Mechanical Ventilation (Slide #28)

- Mechanical ventilation is essential in today's homes to balance good indoor air quality and energy conservation. Homes left loose enough for moisture and odor control without using mechanical ventilation waste energy.
- Types of mechanical ventilation include:
  - Bathroom and kitchen fans.
  - Clothes drier.
  - Central vacuum.
  - Whole-house ventilation.
  - Central heating and cooling systems.
- Mechanical ventilation can pull moist exterior air into wall and ceiling assemblies in cooling environments. It may also cause backdrafting in any environment.

Occupant Behavior (Slide #29)

Occupant behavior is the most arbitrary factor in the IAQ and energy use of all homes. When you conduct the initial interview, find out how your clients use their home.

To protect IAQ, advise clients to avoid:

- Storing firewood inside (or outdoors right next to the home).
- Air drying clothes inside – even in the basement.
- Having numerous plants.
- Using chemicals indoors without adequate ventilation.
- Using "energy conservation" gadgets such as a drier draft diverter which will dump wash chemicals into the home along with any reclaimed heat from the drier.

Energy use is affected by lifestyle:

- Sleeping with windows open.
- Under or over dressing.
- Leaving any windows and doors open when the heat or A/C is on.

As an auditor, you must assess the impact of occupant behavior on your recommendations. It is extremely difficult to get someone to change a habit, and what makes sense to you may not make sense for your client.

What's Going On? (Slide #30)

- Side windows are double glazed; the center window is single glazed.
- Plant watering. All water poured into plant soil eventually evaporates into the room.
- Evaporated water is condensing on the cold, single-paned center window.

What Should Be Done? (Slide #31)

- Choices:
  1. Add a storm window – Relatively inexpensive with fair return (improves existing R-1 to R-2).
  2. Replace the window unit – More expensive with better return (R-1 to ≈ R-3.5).
  3. Run the ceiling fan – No initial cost and will raise the glass temperature over dew point, but will increase heat loss through windows and use electricity.
  4. Eliminate the plants – Free but interferes with client lifestyle and doesn't reduce space heat consumption.
- Any of the four will work.
- In the private sector, the decision would rest on homeowner resources and motivations. With DOE funding, the auditor must make the best choice for each house, considering 1) the client, 2) the future use of the building, and 3) the SIR.

Something to Think About (Slide #32)

This slide lists the four reasons why John Tooley, a leading building scientist, believes House as a System Science should dominate energy conservation retrofit decisions.

This slide and the next six were created using information from a presentation given by John Tooley in Portland, Maine.

Today's Houses Are Tighter (Slide #33)

- Plywood and drywall vs. boards and plaster.
- Platform vs. balloon framing.
- Concrete vs. granite slabs or rubble stone and brick.
- Concrete vs. dirt floors.
- Vinyl thermo pane windows vs. wood sash and storms.
- Insulated doors vs. wooden doors.
- Modern caulks.

Today's Houses Have More and Bigger Fans (Slide #34)

- More and stronger exhaust appliances.
- 400+ CFM Jenn-aire (upper left) vs. 50 CFM kitchen paddle fan hood (right).
- Direct through-the-wall fan (below).
- Clothes driers vs. drying rack or clothes line.
- Central vacuum.
- Air handlers.
- Central AC.
- Stronger furnace fans.
- Whole house ventilation fans.
- Bigger and more powerful fans in general.

Today's Houses Have Weaker Draft Appliances (Slide #35)

Click to reveal the progression of appliances from open fireplaces to fireplaces with glass doors to air tight woodstove to coal boiler to 80% drybase boiler and finally to a 90%+ furnace. Ask students to name an appliance with weaker draft each step of the way.

- Heating efficiency ratings are simply the percentage of consumed energy that goes up the chimney, i.e., as efficiency increases, less heat and air go up the chimney.
- As we increase heating appliance efficiency, we reduce draft, which in turn moves less air through the building, reducing its drying capability.
- The final step in efficiency improvement is a sealed combustion unit, which gets its combustion air from the outside and consequently does nothing to dry the building at all.

Today's Houses Have Less Drying Potential (Slide #36)

- Air moves readily through uninsulated walls and ceilings. Cavities filled with insulation slow or stop air movement.
- Years ago, houses were designed to cycle wet to dry annually. That is, they got wet in humid times and dried out when the humidity dropped.
- Energy savings measures generally interfere with this cycle and require moisture mitigation.
- These circumstances led to the common belief that cellulose rots buildings. When cellulose first gained popularity after the first energy crisis, installers were not aware of the necessity for moisture control. The result was a large number of damaged buildings. We now know that moisture control is essential when insulating and air sealing buildings.
- Modern homes generally spread out rather than up (think “ranch” vs. Victorian”), reducing the stack effect.
- Better caulks and sealants, tighter construction details, and man-made materials all help keep moisture in.

Lifestyle Changes (Slide #37)

- We've transformed from an agrarian society to an industrialized one, and from an active outdoor lifestyle to a sedentary indoor one.
- Daily showers vs. weekly baths.
- Water "sports" include hot tubs, multiple showerheads, saunas, and indoor pools.

Summary (Slide #38)

- We build very differently than we did as little as 40 years ago.
- Economic pressure is driving the move to tighter houses with smaller margins of safety.
- The tighter a house is, the more influence individual components have on the others.
- All pollutants inside the pressure boundary will eventually be dispersed throughout the entire living area.
- Altering a building or its mechanical system can have unexpected consequences.