# MANAGING BUILDING PRESSURE DIFFERENTIALS IN HIGH-PERFORMANCE, LOW-LOAD HOMES

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# OVERARCHING THEMES

- We can and must do better!
  - Challenge ourselves towards better performance
- Existing technology can get us there, but …
  - We need to reduce the focus on products.
  - We must embrace more robust systems.
  - We need improvement in design & execution.
- For major advances in performance, we will need more robust designs, technologies, and processes.

# FIVE FUNDAMENTAL CHANGES

- Increase thermal resistance
  – more insulation => less heat flow => less drying!
- Changes in permeability of linings
  – while this may mean less wetting,
  – it also can lead to very slow drying!
- Increased water/mold sensitivity of materials
- Moisture storage and redistribution
- Complex 3-D airflow networks in buildings

# FIVE INEVITABLE TRENDS

- Building Airtightness
  - getting tighter everyday; not certain where it will stop
- Mechanical Ventilation
  - must include air distribution; moving towards balanced
- Exterior Control Layers
  - especially insulation with vented cladding
- Ducts in Conditioned Space
  - will drive use of conditioned crawl spaces/attics
- Active Pressure Management
  - integrated make-up air

# THE BIG PICTURE

- Ultra-efficient + high-performance homes are all about air management!
  - The building enclosure must be airtight to control the unwanted movement of energy, moisture, and pollutants.
  - The mechanical systems must be thoughtfully designed, installed, and operated to properly condition the air inside the home.
    - heat, cool, filter, ventilate, dehumidify, humidify, etc.
    - and manage air pressure differentials!

# THE BIG PICTURE

- It appears that some designs, systems, materials, and operations are falling short of our performance expectations.

- Specifically, our mechanical systems are lagging way behind the rest of the high-performance house in both the …
  – technology that is being used and
  – how the systems are being designed/delivered!

# 5 CONTEMPORARY HVAC CHALLENGES

- 1. Improper Heating & Cooling System Sizing
  - Increases part-load performance issues, esp. cooling

=> We need:

  - Improve sizing procedures, protocols, and software
  - Move to variable capacity heating/cooling equipment

# 5 CONTEMPORARY HVAC CHALLENGES

- 2. Lack of Proper Controls and Operation
  - Leads to poor comfort, ventilation, and moisture control

=> We need:

- User-friendly controls for heating, cooling, and ventilation
- Move to smart, integrated control systems

# 5 CONTEMPORARY HVAC CHALLENGES

- 3. Poor Latent Load Management
  - Especially in summer
  - Elevated humidity can cause mold and dust mite issues

=> We need:

- Improved cooling design and/or
- Dedicated whole house dehumidification

# 5 CONTEMPORARY HVAC CHALLENGES

- 4. Inadequate Ventilation Distribution
  - Tighter homes with less HVAC run time lead to stagnant spaces and rooms.

=> We must:

- provide fresh, filtered, tempered air to all habitable rooms
  - more strategic distribution
  - improve filtration of ventilation and recirculation air
- increase use of energy recovery units

# 5 CONTEMPORARY HVAC CHALLENGES

- 5. Unmanaged Building Pressures
  - In airtight houses, the pressures can fluctuate wildly
  - Impacting heat, air, moisture, and pollutant transport!

=> We need:

- To limit items causing excessive pressures, especially negative pressure
- To actively manage the house pressure with make-up air and relief air

# MECHANICAL SYSTEM COMPONENTS

- Space Conditioning Components
  - Heating
  - Cooling
  - Filtration
  - Humidification/Dehumidification
- Ventilation (whole house & spot)
- Other Key Components
  - ***Make-Up Air (MUA)***
  - Domestic Hot Water

# AIRFLOW: THE BASICS

- To have airflow* you must have a
  - Pathway
  - Pressure

  - * For today's discussion, I will focus on pressures and flows across the building enclosure and assume the building interior volume acts as a single zone.

# AIRFLOW: THE BASICS

- Pathways
  - Unintentional *
    - leaks and holes
  - Intentional
    - windows & doors
    - ports
    - ducts & vents

# AIRFLOW: THE BASICS

- Pressures
  - Natural *
    - wind
    - stack
  - Mechanical
    - combustion venting
    - exhaust fans/devices
    - supply fans/devices
    - forced air systems (leaks and imbalances)

# UNDERSTANDING BUILDING PRESSURES

- Historically we have focused on negative pressures caused by exhaust devices.
  - Combustion safety concerns
  - Radon (soil gas) entry
  - Garage gas transport
- And in cold climates we have fixated on avoiding positive pressure in heating mode.
  - Due to moisture migration into walls and attics

# UNDERSTANDING BUILDING PRESSURES

- The challenges increase exponentially with tighter enclosures and larger exhaust devices.
- Pressure Triangle
  - If we know the house tightness and exhaust flow,
  - It is easy to predict the resultant pressure.
  - For example: 2500 SF House at 2 ACH@50Pa
    - 150 cfm of exhaust will causes -5 Pa
    - 300 cfm of exhaust will cause -15 Pa

# HOUSE TIGHTNESS, FLOWS & PRESSURES

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | House Tightness - Blower Door CFM @ 50Pa (& Hole Size with 0.65 exponent) | | | | | | | | | |
| **Flow (cfm)** | 100 | 200 | 300 | 400 | 500 | 600 | 800 | 1000 | 1250 | 1500 | 2000 | 3000 |
| **Hole (sq. in.)** | 7 | 15 | 22 | 29 | 37 | 44 | 59 | 73 | 92 | 110 | 147 | 220 |
| **ACH (20,000 cf)** | 0.3 | 0.6 | 0.9 | 1.2 | 1.5 | 1.8 | 2.4 | 3.0 | 3.8 | 4.5 | 6.0 | 9.0 |
| | | | | | | | | | | | | |
| **Δ Pressure (Pa)** | | | | | **Unbalanced Flow in CFM** | | | | | | | |
| 100 | 157 | 314 | 471 | 628 | 785 | 942 | 1255 | 1569 | 1961 | 2354 | 3138 | 4708 |
| 75 | 130 | 260 | 390 | 521 | 651 | 781 | 1041 | 1302 | 1627 | 1952 | 2603 | 3905 |
| 50 | 100 | 200 | 300 | 400 | 500 | 600 | 800 | 1000 | 1250 | 1500 | 2000 | 3000 |
| 40 | 86 | 173 | 259 | 346 | 432 | 519 | 692 | 865 | 1081 | 1297 | 1730 | 2595 |
| 30 | 72 | 143 | 215 | 287 | 359 | 430 | 574 | 717 | 897 | 1076 | 1435 | 2152 |
| 25 | 64 | 127 | 191 | 255 | 319 | 382 | 510 | 637 | 797 | 956 | 1275 | 1912 |
| 20 | 55 | 110 | 165 | 220 | 276 | 331 | 441 | 551 | 689 | 827 | 1102 | 1654 |
| 15 | 46 | 91 | 137 | 183 | 229 | 274 | 366 | 457 | 572 | 686 | 914 | 1372 |
| 12 | 40 | 79 | 119 | 158 | 198 | 237 | 316 | 395 | 494 | 593 | 791 | 1186 |
| 10 | 35 | 70 | 105 | 141 | 176 | 211 | 281 | 351 | 439 | 527 | 703 | 1054 |
| 9 | 33 | 66 | 98 | 131 | 164 | 197 | 262 | 328 | 410 | 492 | 656 | 984 |
| 8 | 30 | 61 | 91 | 122 | 152 | 182 | 243 | 304 | 380 | 456 | 608 | 912 |
| 7 | 28 | 56 | 84 | 111 | 139 | 167 | 223 | 279 | 348 | 418 | 557 | 836 |
| 6 | 25 | 50 | 76 | 101 | 126 | 151 | 202 | 252 | 315 | 378 | 504 | 756 |
| 5 | 22 | 45 | 67 | 90 | 112 | 134 | 179 | 224 | 280 | 336 | 448 | 672 |
| 4 | 19 | 39 | 58 | 77 | 97 | 116 | 155 | 194 | 242 | 290 | 387 | 581 |
| 3 | 16 | 32 | 48 | 64 | 80 | 96 | 128 | 161 | 201 | 241 | 321 | 482 |
| 2 | 12 | 25 | 37 | 49 | 62 | 74 | 99 | 123 | 154 | 185 | 247 | 370 |
| 1 | 8 | 16 | 24 | 31 | 39 | 47 | 63 | 79 | 98 | 118 | 157 | 236 |
| | | | | | | | | | | | | |
| **By Patrick Huelman, University of Minnesota** | | | | | | | | | | | | **March 5 ,2018** |
| | | | | | | | | | | | | |
| | | | | | | | | | (blue) | Clothes dryer @ 130 cfm | | |
| | | | | | | | | | (red) | Small range hood @ 250 cfm | | |
| | | | | | | | | | (yellow) | Large range hood @ 500 cfm | | |

# BUILDING PRESSURE GUIDANCE

- Before you worry about the magnitude, let's make sure you have the correct sign!

# BUILDING PRESSURE GUIDANCE

- Optimal Pressures (house wrt outdoors)

| | Winter | Summer |
|---|---|---|
| – Combustion Safety | + (or =) | + |
| – Garage Gases | + (or =) | = (or +) |
| – Radon (Soil Gases) | + | = (or +) |
| – Exterior Pollutants | + | + |
| – Thermal Comfort | + | + |
| – Building Enclosure | - | + |

# PRESSURE DESIGN THRESHOLDS

- 1. Design Factors
- 2. Operating Conditions
- 3. Time Step

# PRESSURE DESIGN THRESHOLDS

- 1. Critical Design Factors
  - House Type: detached vs. attached
  - Climate Zone:  CZ 1 to 7 (U.S.)
  - Interior Humidity Conditions: low, medium, high
  - Combustion:  sealed, power-vent, natural draft
  - Garage:  attached vs. detached
  - Soil Contact: Basement, crawl, slab, pier
  - Occupancy IAQ Goals: typical vs. sensitive

# PRESSURE DESIGN THRESHOLDS

- 2. Critical Operating Conditions
  – Season or Mode: heating vs. cooling
  – Load Condition: peak vs. normal

# PRESSURE DESIGN THRESHOLDS

- 3. Critical Time Step
  - Minutes
  - Hours
  - Days
  - Weeks
  - Continuous

# PRESSURE DESIGN THRESHOLDS

- 4. How will the design guidance or threshold be expressed?
  - Maximum negative or positive pressure differential
  - Acceptable range of pressure differentials

# BEST PRACTICE GUIDANCE

- A. Implement passive pressure management strategies to limit risk of pressure differentials
  - Use sealed combustion equipment
    - space heating
    - domestic hot water
    - no wood stoves or fireplaces
  - Use sound radon-resistant practices for below grade components
  - Verify airseal/isolation between house and garage

# BEST PRACTICE GUIDANCE

- B. Next, reduce the risk of generating troublesome pressure differentials
  - Mechanical systems
    - Sealed ductwork
    - Balanced supplies and returns
  - Avoid compartmentalization
    - Transfer grilles etc.
  - Limit size and quantity of exhaust devices
    - Exhaust fans, range hood, clothes dryer

# BEST PRACTICE GUIDANCE

- B. Next reduce the risk of generating troublesome pressure differentials
  - Ventilation impact can be mitigated by using a balanced ventilation strategy
  - Kitchen range flow must be carefully managed
    - designed for improved capture at lower flow rates
  - Clothes dryer is critical because of the flow rate and potential for extended run times
    - move to ventless condensing dryer

# BEST PRACTICE GUIDANCE

- C. Last, execute active pressure management strategies, as needed
  - Option 1: Passive make-up air opening
    - it must be limited in size
    - where do you put it
    - it must be mechanically dampered
    - filtration is difficult
    - if not tempered, it will be likely be disabled

# BEST PRACTICE GUIDANCE

- C. Last, execute active pressure management strategies, as needed
  - Option 2: Blended make-up air
    - mixes indoor air with outdoor air to increase the temperature of the air delivered to the house
    - modest filtration can be used
    - where is it introduced; probably in forced-air system

# BEST PRACTICE GUIDANCE

- C. Last, execute active pressure management strategies, as needed
  - Option 3: Tempered make-up air
    - filtration is generally included
    - outdoor air is tempered with a heating element
    - could incorporate dehumidification
    - generally introduced into the forced-air system

# MAKE-UP AIR / SUPPLY AIR SYSTEM

- We need to rethink how we can embrace new supply air strategies to actively manage house pressure.
  - Dedicated outdoor air units
  - Central fan integrated supply
  - Independent economizers
- How do we condition that air simply and economically?

# MAKE-UP AIR / SUPPLY AIR SYSTEM

- Using the balanced ventilation system
  - Shunt the exhaust side back to the indoors;
  - Supply air continues to provide make-up air for exhaust devices (range, clothes dryer, etc.)
- There can be a few challenges …
  - The defrost cycle may interrupt the supply air
  - If ventilation is source-point, bath exhaust requirements are unmet and bath air is reintroduced to the indoors which could be a code violation

# MAKE-UP AIR / SUPPLY AIR SYSTEM

- Make-Up Air Unit
  - 150 - 200 cfm variable-speed supply fan
  - MERV 8+ filter
  - Tempering
    - blended w/ house air ???
    - electric resistance / dehumidification
- Can also be used for
  - supply air ventilation (provide positive pressure)
  - summer economizer (provide free cooling)

# ACHIEVING HIGH-PERFORMANCE

- We must ensure our high-performance houses meet our expectations today and in the future?

- High-performance houses will push the enclosure, mechanical systems, and occupants.
  - This will require more robust designs.
  - It will demand systems with forgiveness/tolerance.
  - Build redundancy (or easy repair) into critical systems.
  - We must have a more predictable delivery system.
  - The owners/occupants will need to be in the loop.

# KEY RESOURCES

- BSI-081: Zeroing In [Handouts]
  - Joseph Lstiburek
- High-Performance Enclosures
  - John Straube, 2012
- Getting Enclosures Right in ZERH
  - Joe Lsitburek, 2016
  - https://www.energy.gov/eere/buildings/downloads/zerh-webinar-getting-enclosures-right-zero-energy-ready-homes
- EEBA Ventilation Guide
  - Armin Rudd, 2011

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- Discussion & Questions

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