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Air Management for High-Performance, Low-Load, Airtight Homes

For: Energy Design Conference

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AIR MANAGEMENT FOR HIGH-PERFORMANCE, LOW-LOAD, AIRTIGHT HOMES

- Part 1: Intro to Contemporary HVAC Challenges
- Part 2: Space Conditioning & Ventilation
- Part 3: Understanding Airflows & Pressures
- Part 4: Best Practice Guidance
- => Using building science to guide us towards more robust, high-performance enclosure systems!

OVERARCHING THEMES

- We can and must do better!
  - Challenge ourselves towards higher-performing buildings that are efficient, durable, healthy, robust, and resilient!
- Existing technology can get us there, but …
  - We need to reduce the focus on finding the perfect product.
  - We must embrace more robust approaches and systems.
  - We need major improvement in design & execution.
- For major advances in performance, we will need more robust designs, technologies, and processes.

FIVE FUNDAMENTAL CHANGES

- Increased 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!
  - Building enclosure must be airtight to control the unwanted movement of energy, moisture, and pollutants
  - Mechanical systems must be thoughtfully designed, installed, and operated to properly condition the air inside the home
    - heat, cool, filter, ventilate, dehumidify, humidify, etc.
    - manage air pressure differentials across the enclosure

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!

FIVE CONTEMPORARY HVAC CHALLENGES

- 1. Improper Heating & Cooling System Sizing
  - Excess capacity it leads to short cycling and increases part-load performance issues, esp. in cooling

- => We need:
  - Improve sizing procedures, protocols, and software
  - Move towards variable capacity heating/cooling equipment

FIVE 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 towards smarter, integrated control systems

FIVE 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

FIVE 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

FIVE CONTEMPORARY HVAC CHALLENGES

- 5. Unmanaged Building Pressures
  - In airtight houses, the pressures can fluctuate wildly
  - Impacting heat, air, moisture, and pollutant transport
  - Potentially affecting other devices and closure of doors/dampers

- => We need:
  - To limit items causing excessive pressures, especially negative
  - To actively manage the house to outdoor pressure with make-up air and relief air

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)

ALWAYS MANAGE THE POLLUTANT

- Safe pollutant levels
  - Avoid and/or encapsulate for material emissions
  - Use point source control, where possible
  - Then employ general ventilation
- Manage fine particulates
  - Whole house
  - Kitchen range
- Protection against biologicals
  - Humidity control
  - Particle filtration

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~~

SPACE HEATING – SPECIAL CONSIDERATIONS

- Focus on proper sizing and comfort
  - Variable capacity equipment can help reduce short cycling
  - Circulation/mixing is needed for more uniform temperatures

SPACE HEATING SYSTEM – PAT'S PICK

- Forced-air system
  - air-source heat pump
  - sized for cooling
  - w/ hot water coil to comfortably meet peak loads
- Storage water heater
  - sealed combustion
  - condensing; modulating
- Spot hot water radiant heat
  - bathrooms

SPACE COOLING – SPECIAL CONSIDERATIONS

- Heating really isn't the big problem any longer!
- Highly-insulative, airtight enclosures with unmanaged solar and internal gains can easily overheat when outdoor temperatures are well below your setpoint
  - If natural ventilation works for you, this is pretty easy
    - but it must be based on enthalpy, not temperature
  - If outside air causes issues (and it does for many), it would make sense to have an economizer cycle

SPACE COOLING – SPECIAL CONSIDERATIONS

- Heating balance points are very low
  - 40 to 45 degrees
- Space cooling today is very different
  - Loads may look lower
  - But cooling demand will be longer
  - Load diversity & ratios between spaces will be much higher

SPACE COOLING – SPECIAL CONSIDERATIONS

- To AC or not to AC?
  - For many reasons, this is changing fast
  - Cooling loads and hours are growing quickly
- Natural ventilation can work many days, but not all days for all people
  - May present outdoor IAQ issues including pollen, mold spores, and particulates
  - Can contribute to indoor moisture and mold issues, especially with cooler interior surfaces

SPACE COOLING SYSTEM – PAT'S PICK

- ASHP
  - Sized for cooling
  - Dehumidification mode
  - Possibly use hot water coil for reheat

HOUSE FILTRATION – SPECIAL CONSIDERATIONS

- Fine particulates are a significant health risk in our homes
  - kitchen cooking is a major source
  - Outdoor air is also a major contributor
- They can be managed with decentralized units
- But good filtration on a whole house forced air system can be very effective

HOUSE FILTRATION – PAT’S PICK

- Forced air system
  - 4” pleated media
  - MERV 13
- Ventilation air
  - Upgraded ERV filter
- Make-up air
  - MERV 8+

DEHUMIDIFICATION – SPECIAL CONSIDERATIONS

- Critical in low-load homes, as typical air-conditioning sizing, sensible heat ratios, and controls don't work very well
  - Many times you have high latent loads with no sensible load
  - Frequently you need high moisture removal under part-load cooling conditions
- Since summer ventilation does not equal humidity control, it is critical to provide systematic dehumidification
  - Independent control to control condensation, mold, and dust mites
  - Huge aid for summer comfort

DEHUMIDIFICATION – SPECIAL CONSIDERATIONS

- It takes 10+ minutes to wet the coil to the point that condensate is being removed
  - About the same to re-evaporate, though much shorter if the fan runs continuously
- It might be possible to downsize the AC and consider reheat to force longer run times
  - Two-stage or variable capacity AC can help!
- For best summer humidity control, consider a whole house dehumidifier

DEHUMIDIFICATION – PAT'S PICK

- ASHP Cooling system
  - Variable capacity with dehumidification mode
- Stand Alone Dehumidification
  - Efficient two-stage high capacity DH unit

VENTILATION – SPECIAL CONSIDERATIONS

- In high-performance, low-load, airtight homes, good is not good enough!
  - You are working within an incredibly tight enclosure
  - Start by managing pollutants (and moisture)
  - Humid outdoor air will create some special challenges, especially under part-load conditions

VENTILATION SUMMARY

- Must be balanced heat recovery ventilation
  - In most cases, an ERV is preferable
  - Filtration (MERV 11+) for supply air
  - Fresh air distribution to all habitable rooms
    - forced air system
    - separate dedicated duct system
- Spot ventilation can be exhaust-only if small and/or rarely used.

WHOLE HOUSE VENTILATION – PAT'S PICK

- High-Quality ERV
  - Fully-ducted source-point exhaust
    - bathrooms (no bath fans)
    - kitchen area (w/ independent range hood)
    - laundry room & basement
  - Supply air to forced-air return
    - Temper by mixing; second chance to filter; easy to distribute
  - Controls
    - medium continuous
    - button boost for high

TIME FOR A QUICK PAUSE

- Questions
- Thoughts
- Reflections
- Discussion

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 the heating mode
  - Due to moisture migration into walls and attics

UNDERSTANDING BUILDING PRESSURES

- 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

UNDERSTANDING BUILDING PRESSURES

- Before you worry about the magnitude, let's make sure you have the correct sign!
  - What is acceptable/unacceptable?
  - What is desired or preferred?

UNDERSTANDING BUILDING PRESSURES

- Optimal Pressures (house wrt outdoors/garage/ground)

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

ESTABLISHING PRESSURE DESIGN THRESHOLDS

- 1. Design Factors
- 2. Operating Conditions
- 3. Time Step
- 4. How Will the Target be Expressed

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. typical

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?
  - Unacceptable vs. Acceptable vs. Desirable
  - Design limits
    - 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

MAKE-UP AIR

- Key Equipment Concerns
  - Ventilation impact can be minimized by using a balanced ventilation strategy for both continuous and intermittent ventilation
  - Kitchen range 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
    - ventless heat pump or condensing dryer

MAKE-UP AIR

- Key Strategies
  - All closed, sealed-combustion equipment
  - Minimize exhaust flows
  - Passive make-up air
    - Is limited in size, is not tempered, and will be plugged
  - Blended make-up air
    - Mixes indoor air with outdoor air to increase the temperature of the air delivered to the house
  - Tempered make-up air
    - Outdoor air is tempered (temperature & humidity)

SUPPLY AIR SYSTEMS

- We need to rethink how we can embrace new supply air strategies to actively manage house pressure
  - Dedicated outdoor air units
  - Economizers
  - ???

- How do we condition that air simply and economically?

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

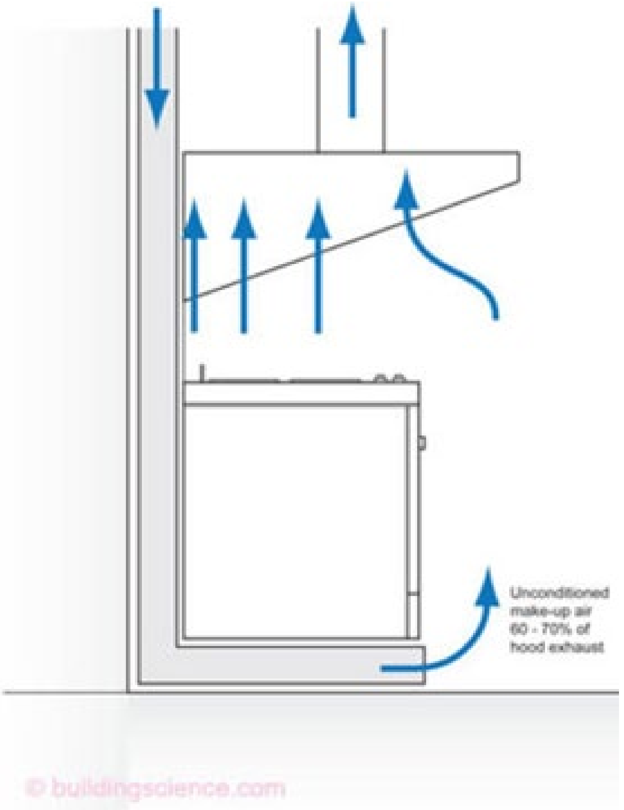
- Using the balanced ventilation system
  - Shunt the exhaust side back to the indoors;
  - Supply air continues to provide make-up air for exhaust devices (range, clothes dryer, etc.)
- There can be a few challenges …
  - The defrost cycle may interrupt the supply air
  - If ventilation is source-point,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

- 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?

RANGE HOOD VENTING & MAKE-UP AIR*

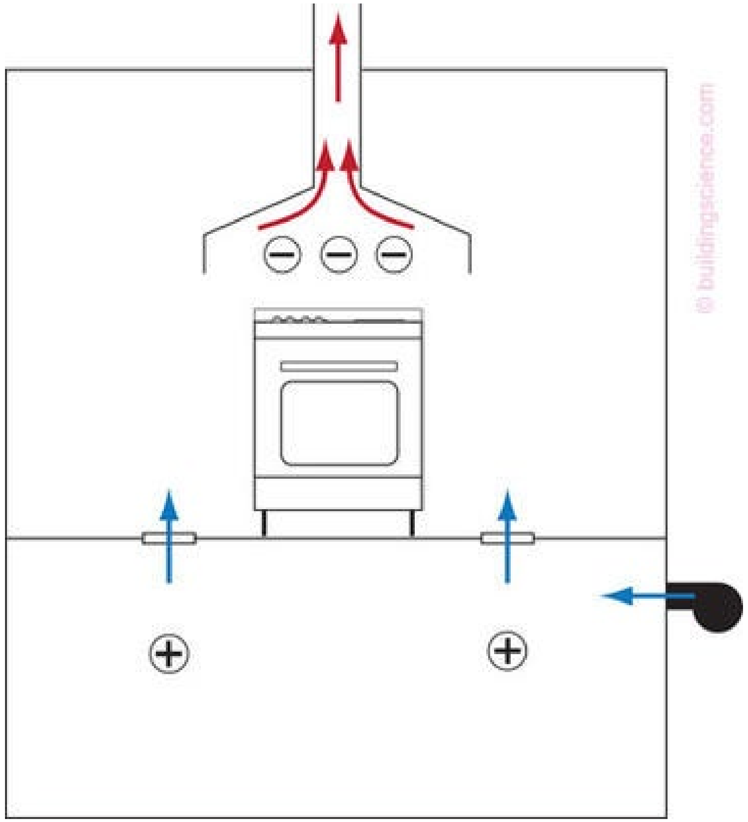
- Capture the Pollutants
  - Large front overhang
  - Side panels
- Supply Make-Up Air (MUA)
  - 60 to 70% at the stove
  - 30 to 40% at the kitchen perimeter



* BSI-070: First Deal with the Manure and Then Don't Suck

RANGE HOOD VENTING & MAKE-UP AIR*

- For Smaller Hoods (200 cfm)
  - Size make-up air at 10% greater than the exhaust
  - Provide the make-up air to the basement
    - temper, as needed
  - Use floor grills to introduce the make-up air to the kitchen perimeter



* BSI-070: First Deal with the Manure and Then Don't Suck

RANGE HOOD & CLOTHES DRYER – PAT'S PICKS

- Range Hood
  - 160 to 200 cfm
  - extended front w/ side panels

- Clothes Dryer
  - condensing
  - ventilation pick-up

MAKE-UP AIR / SUPPLY AIR SYSTEM – PAT'S PICKS

- 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
- BSI-070: First Deal with the Manure and Then Don't Suck
  – Joseph Lstiburek
- EEBA Ventilation Guide
  – Armin Rudd, 2011
- Getting Enclosures Right in ZERH
  – Joe Lsitburek, 2016
  – https://www.energy.gov/eere/buildings/downloads/zerh-webinar-getting-enclosures-right-zero-energy-ready-homes

BUILDING AMERICA SOLUTION CENTER

TIME FOR A QUICK PAUSE

- Questions
- Thoughts
- Reflections
- Discussion

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