# Ventilation: Best Practices for Tight Homes in Cold Climates

## Energy Design Conference

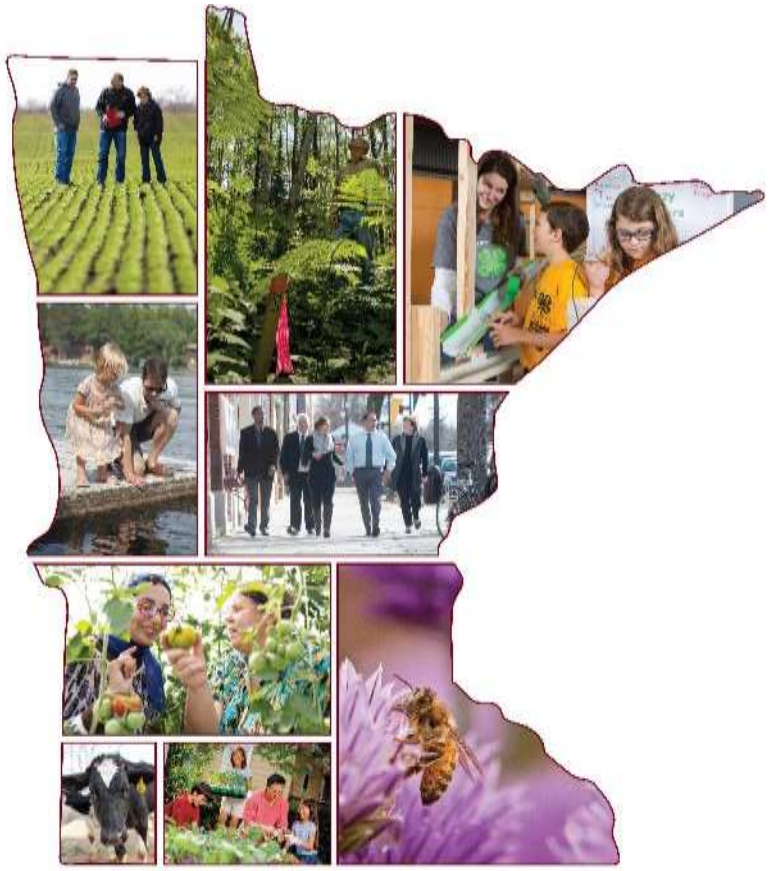
**February 26, 2019**

**Duluth, MN**

## Patrick Huelman

**University of Minnesota**

**Cold Climate Housing Program**



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# VENTILATION:
## BEST PRACTICES FOR TIGHT HOUSES IN COLD CLIMATES

- 1: Intro and Set-Up
- 2: Ventilation Basics
- 3. Ventilation Design
- 4. Ventilation Strategies
- 5. Ventilation Best Practices

=> Using building science and a systems approach to guide us towards more robust, high-performance mechanical systems!

# 1. INTRO: A STARTING POINT

- Today we are seeing many homes with remarkably efficient and airtight low-load enclosures.

- However, for some of theses homes, their mechanical systems are not delivering the desired outcomes (efficiency, comfort, air quality, etc.).

# REALITY CHECK #1

- Early logic said if you spent more money on the enclosure, you could get that money back on the heating/cooling system.
  - While the loads were smaller, the smaller equipment didn't save very much money.
  - Equipment needs actually became more demanding and system integration and control complexity increased.

# REALITY CHECK #2

- There was a though that once the enclosure was super-tight, you could just drop in a little fresh air and add a little heating/cooling and it would be perfectly comfortable and healthy.
  - Unfortunately, it isn't quite that simple!
  - Tight houses don't have natural air flow from bottom to top or side to side.

# 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.

# MAKING THE CASE FOR ROBUST

- 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 delivered!

# MODERN MECHANICAL CHALLENGES

- Has the typical single-zone, forced-air heating and cooling system hit the end of the road?
  - It continues to be difficult to match peak loads.
  - Part-load operation can be both ineffective (uncomfortable) and inefficient (energy).
  - Frequently provides poor zone control (temperature, humidity, fresh air) in high-performance homes.

# MODERN MECHANICAL CHALLENGES

- Can we justify two independent, high-end, sealed combustion, condensing plants for space and water heating?
  - Space heating isn't our most important problem.
  - For many homes, water heating represents a larger peak load.
  - It would makes sense to move towards integrated space and water heating systems.

# MODERN MECHANICAL CHALLENGES

- Should ventilation (fresh air for people) be an independent system?
  - It is difficult to control when integrated with other systems.
  - Airtight homes have very limited internal mixing.
  - It is critical to provide better distribution to all habitable spaces.

# MODERN MECHANICAL CHALLENGES

- How are we going to manage pressures (both negative and positive) in our new, airtight homes?
  - Exhaust flow rates for range hoods and clothes dryers are simply too large.
  - Active pressure management is needed now.
  - But current make-up air approaches and systems are clumsy at best!

# MECHANICAL SYSTEM COMPONENTS

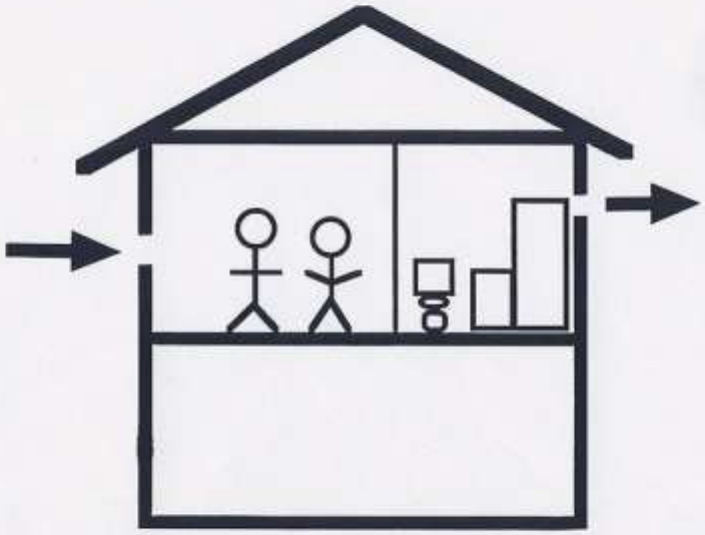
- Space Conditioning Components
  - Heating
  - Cooling
  - Filtration
  - Humidification/Dehumidification
- **Ventilation (whole house & spot)**
- Other Key Components
  - **Make-Up Air (MUA)**
  - Domestic Hot Water

# GETTING ON THE SAME PAGE

- For today's discussion, we are going to separate the four specific types of air:
  - Ventilation Air
  - Make-Up Air
  - Combustion Air
  - Circulation Air

# VENTILATION AIR

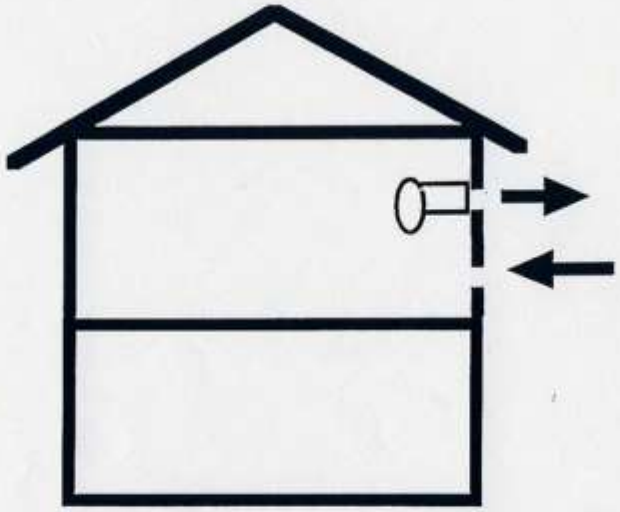
- **Ventilation Air**
  - Replacement, by direct or indirect means, of air in habitable rooms with fresh, outdoor air.



  - Ventilation air is intended to meet metabolic needs, manage indoor air pollutants, and control winter moisture.

# MAKE-UP AIR

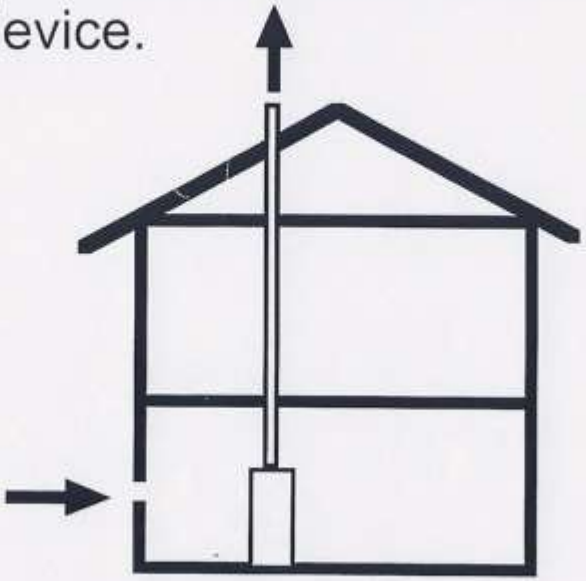
- **Make-Up Air**
  - Outdoor air needed to replace indoor air removed by mechanical exhaust device(s).



  - Makeup air is intended to limit the negative pressure in the home when exhaust devices are in operation.

# COMBUSTION AIR

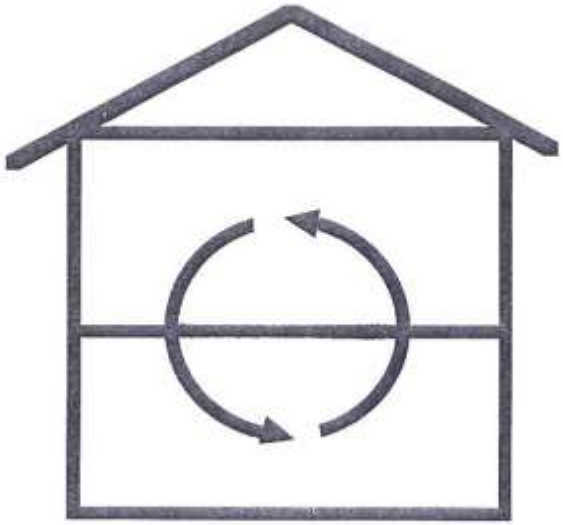
- **Combustion Air**
  - Air from the home (or directly from the outdoors) required to meet the combustion and dilution needs of a vented combustion device.



  - Combustion air is intended to ensure proper combustion and venting of combustion by-products.

# CIRCULATION AIR

- **Circulation Air**
  - Air taken from the home and recirculated back to the home using mechanical means.



  - Circulation air is intended to mix the indoor air for improved comfort and to provide more uniform indoor conditions.

# HIGH-PERFORMANCE VENTILATION

- Point 1: High-performance homes demand high-performance ventilation.
- Point 2: First and foremost, we must remember ventilation is for people!
- Point 3: Yet, we must recognize that ventilation has critical energy, building, and pressure connections.

# 2. VENTILATION BASICS

- A methodical and systematic way of looking at ventilation air (that does include a bit on circulation and make-up air, too).
  - Air in & air out
  - Building pressures
  - Internal flows
  - System operation

# VENTILATION 101

- (Bad) Air Out
  - Where is exhaust air picked up?
  - How is air being exhausted (% mechanical)?
- (Good) Air In
  - Where is intake air supplied?
  - How is air being supplied (% mechanical)?
  - Does this air need to be conditioned?

=> ***Ventilation effectiveness*** is all about the "concentration gradient" between in and out!

# VENTILATION 201

- Internal Flow Path(s)
  - What is the path from the supply location to the exhaust location?
  - Does the fresh air flow through the occupied zone?

=> ***Ventilation efficiency*** is all about getting adequate fresh air to people with the lowest possible energy consumption!

# VENTILATION 301

- Resultant House Pressure
  - If the mechanically exhausted and supplied air are not equal …
    - or the exhaust and supply air are not well connected
  - What will be the change in the house pressure?
    - too negative may impact venting, radon, garages
    - too positive can impact winter moisture migration

=> ***Pressure change*** can be profound in tight homes, especially with higher ventilation rates.

# VENTILATION 401

- System Controls & Operation
  - Is there a clear indicator when the system is operating properly?
  - Can the ventilation rate be easily increased or decrease as needed or desired?
  - Is the fresh air being distributed to all habitable spaces?
  - Can the system be shut down for maintenance?

=> ***Occupant role*** cannot be an afterthought!

# A QUALITY VENTILATION SYSTEM SHOULD:

- Provide a continuous, baseline ventilation.
- Have additional capacity available, when needed.
- Remove exhaust air from areas with highest contaminants.
- Provide the outdoor (fresh) air as clean as possible.
- Supply outdoor (fresh) air to all habitable rooms.
- Not impose serious pressure imbalances on the home.
- Have acceptable thermal and acoustical comfort.
- Be easy to operate and maintain.
- Be cost effective to install and operate.
  - Adapted from the R-2000 Design Guidelines (CHBA – 1994?)

# CODE COMMENTARY

- Our Minnesota Residential Energy Code (MN-REC) is pretty solid regarding ventilation rates and requirements.
- However, our MN-REC does not guarantee “effective and efficient” ventilation practices.
  - And furthermore, many homes today don’t even comply with all of the MN-REC requirements.

# CODE COMMENTARY

- Building codes frequently lead to a “race for the bottom”!
  - There’s an incentive to find the least expensive approach that will keep the code official happy.
  - But it may compromise the intended performance for the buyer.
- Today, we are focused on high-performance homes and beyond code approaches that will lead us “back to the top”.
  - While still meeting code minimums.

# CODE COMMENTARY

- Don’t confuse good ventilation practice with code prescribed whole-house ventilation!
  - You can exceed the code.
  - Some key ventilation items can be used but might not be a part of the designated whole-house ventilation system.
    - Range ventilation (vented to outdoors) is very important, but usually independent.
    - Some additional bath exhaust might be desirable.

# CODE COMMENTARY

- We are going to talk about code related issues, but the focus is on best practices for a healthier indoor environment!
  - The most effective thing we can do for good indoor air quality is remove the pollutants.
  - That includes providing a very high MERV filter on your forced-air system.
  - Managing house pressure is key to pollutant control and ventilation success.

# 3. SYSTEM DESIGN & BEST PRACTICES

- Ventilation Flow Rates
- Ventilation Distribution
- Ventilation Strategies

# VENTILATION RATES

- How much ventilation do you need?
  - Trick question …
    - nobody knows for sure and every house, occupant, and situation would have a very different answer.
- However, …
  - Generally more is better for indoor air quality
    - unless there are external source issues
    - or a serious moisture penalty (generally summer)
  - Generally less is better for energy efficiency
    - unless ventilation also serves as an economizer

# VENTILATION RATES

- An important building physics factoid:
  - 1 cfm of exhaust ≠ 1 cfm of balanced ventilation
    - When you turn on a 100 cfm exhaust fan you will get approximately 60 to 70 cfm of new outdoor air.
    - When you turn on a 100 cfm balanced ventilation system you will get 100 cfm of new outdoor air.
  - No codes or standards deal with this difference at this time, but it has clear air exchange, air quality, and energy impacts.

# VENTILATION RATES: ASHRAE 62.2-’16

- Whole House Mechanical Ventilation

  **Qv = 0.03 x Floor Area + 7.5 (Bedrooms +1)**

- Source Point Ventilation
  - Kitchen
    - on demand: **100 cfm** or
    - continuous: **5 ACH**
  - Full bath:
    - on demand: **50 cfm** or
    - continuous: **20cfm**

# VENTILATION RATES: BSC-1501

- Whole House Mechanical Ventilation

  **$Q_v$ = 0.01 x Floor Area + 7.5 (Bedrooms +1)**

- **$Q_{fan}$ = Qv * Cs**

| System Coefficient | Distributed | Not Distributed |
|---|---|---|
| Balanced | **0.75** | **1.0** |
| Not Balanced | **1.0** | **1.25** |

- Source point ventilation similar to ASHRAE

# VENTILATION RATES: MN-REC ’15

- Total Ventilation

  **$Q_{tv}$ = 0.02 x floor area + 15 x (bedrooms + 1)**

- Continuous Ventilation

  **$Q_{cv}$ = total ventilation / 2**

  (but not less than 40 cfm)

- Intermittent Ventilation

  **total ventilation – continuous ventilation**

- Source point ventilation similar to ASHRAE

# MN REC'15: VENTILATION RATES

- The building shall be provided with a balanced mechanical ventilation system that is +/-10 percent of the system's design capacity and meets the requirements of Section R403.5.5, which establishes the continuous and total mechanical ventilation requirements …
  - Exception: Kitchen and bath fans ***that are not included*** as part of the whole-house mechanical ventilation system are exempt from these requirements.

# VENTILATION DISTRIBUTION: MN-REC ’15

- Ventilation (outdoor) air shall be delivered to each habitable space by a forced-air circulation system, separate duct system, or individual inlets.
  - In MN, this has been required since 2000 and until very recently, it was unique to MN.
  - But increasingly important as houses get much tighter …
    - because stack and wind forces don’t provide internal air movement and mixing.

# VENTILATION DISTRIBUTION: MN-REC ’15

- When the ventilation air is being distributed via the forced air circulation system …
  - If the outdoor air is supplied directly to the forced air system, provide a circulation flow rate of 0.075 cfm x conditioned floor area.
  - If the outdoor air is supplied indirectly to the forced air system, provide a circulation flow rate of 0.15 cfm x conditioned floor area.

# 4. VENTILATION SYSTEM DESIGN

- Step 1. Ventilation Type
  - Exhaust-Only
    - w/ limitations in MN, if part of the whole house system
  - Balanced Supply & Exhaust
    - Required in MN w/ an exception
  - Supply-Only (w/ limitations in MN)
    - w/ limitations in MN if part of the whole house system

# VENTILATION SYSTEM DESIGN

- Step 2. Exhaust Approach
  - Source => pick-ups in key source points
  - General => pick-ups from central living spaces
  - Volume => pick-up from return duct

# VENTILATION SYSTEM DESIGN

- Step 3. Fresh Air Distribution
  - Forced-air circulation system
    - directly into the return or supply trunk
  - Separate duct system
  - Individual inlets

# VENTILATION SYSTEM DESIGN

- Step 4. With or Without Heat Recovery
  - No heat recovery
  - Heat recovery
    - heat recovery ventilator (HRV)
    - energy (enthalpy) recovery ventilator (ERV)
    - heat pumps (to air or water)

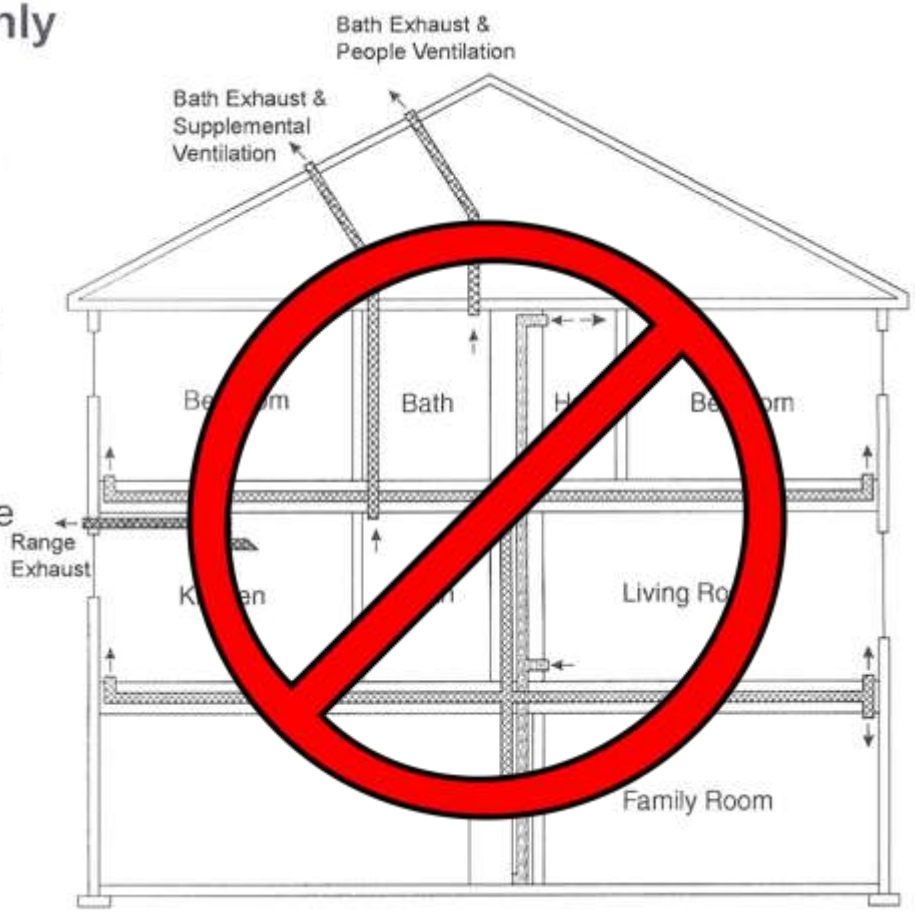
# GENERAL VENTILATION DESIGN

- Step 5. Controls
  - Continuous should be continuous
    - but could be turned off when there is extended period of no occupancy or windows are wide open
    - needs a code-compliant shut-off for maintenance
  - Intermittent (high speed or additional fan)
    - generally occupant controlled
    - frequently in source point areas

# DECENTRALIZED EXHAUST-ONLY

- **1. Decentralized Exhaust-Only**
  - source point approach
  - no heat recovery
  - with forced air

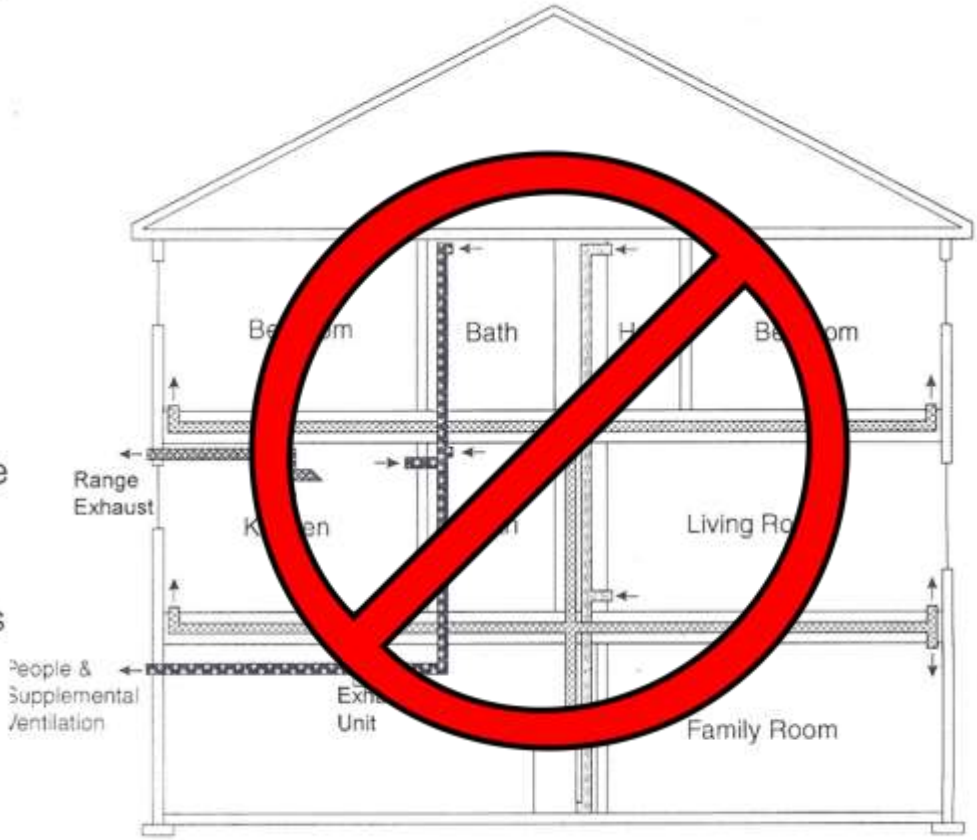
  - This option will depressurize the home and may cause undesired infiltration.
  - The force-air fan must run intermittently to provide adequate distribution of fresh air.
  - All RVS fans must have flow measured and verified.
  - Controls for people ventilation must be clearly marked in a central location.
  - Continuous venting to the roof may cause ice dams.



# CENTRALIZED EXHAUST-ONLY

- **3. Centralized Exhaust-Only**
  - source point approach
  - no heat recovery
  - with forced-air

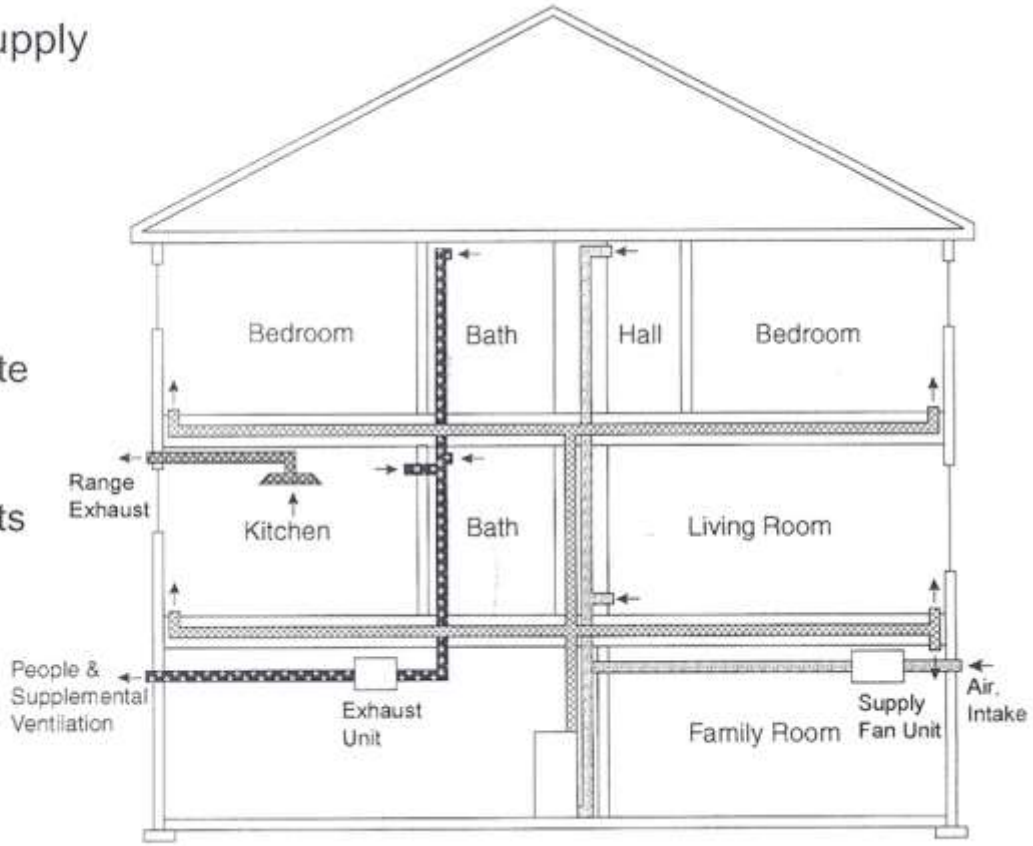
  - This option will depressurize the home and may cause undesired infiltration.
  - The force-air fan must run intermittently to provide adequate distribution of fresh air.
  - This fan must meet both people and total ventilation requirements
  - All RVS fans must have flow measured and verified.
  - Controls for people ventilation must be clearly marked in a central location.



# BALANCED W/O HEAT RECOVERY

- **4. Balanced**
  - separate exhaust and supply
  - source point approach
  - without heat recovery
  - with forced-air

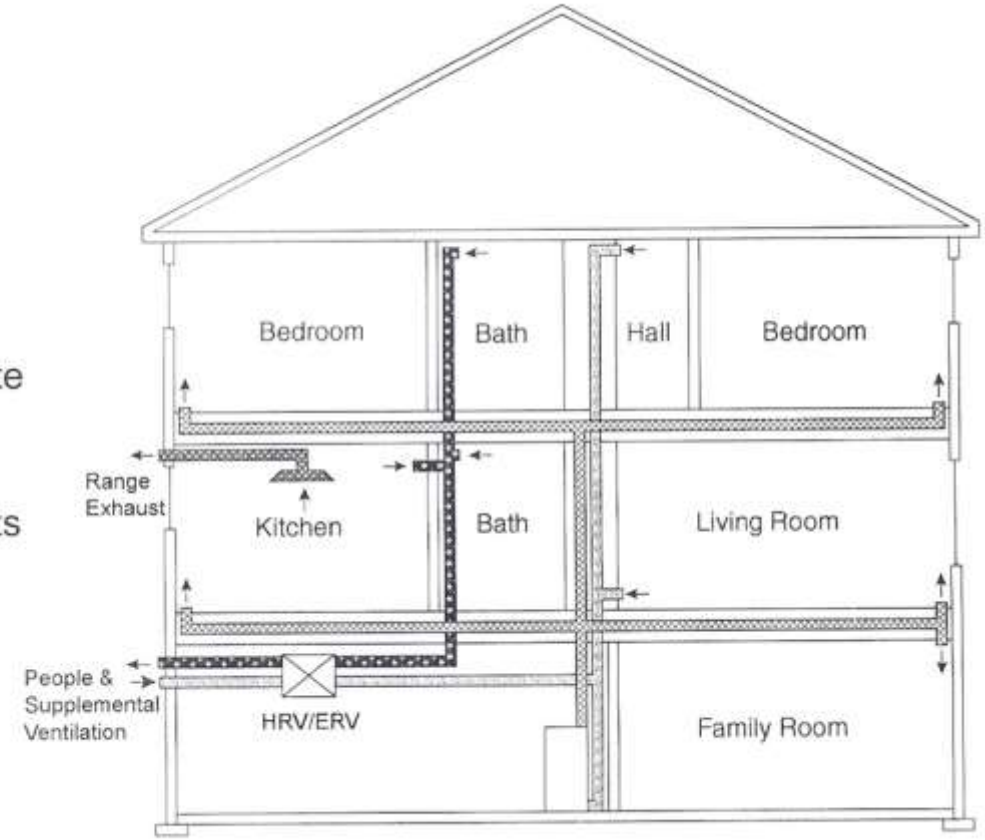
- The force-air fan must run intermittently to provide adequate distribution of fresh air.
- This fan must meet both people and total ventilation requirements
- All RVS fans must have flow measured and verified.
- Controls for people ventilation must be clearly marked in a central location.
- Supply air may need to be tempered by preheat or blending.



# BALANCED W/ HEAT RECOVERY

- **6. Balanced**
  - source point approach
  - with heat recovery
  - with forced-air

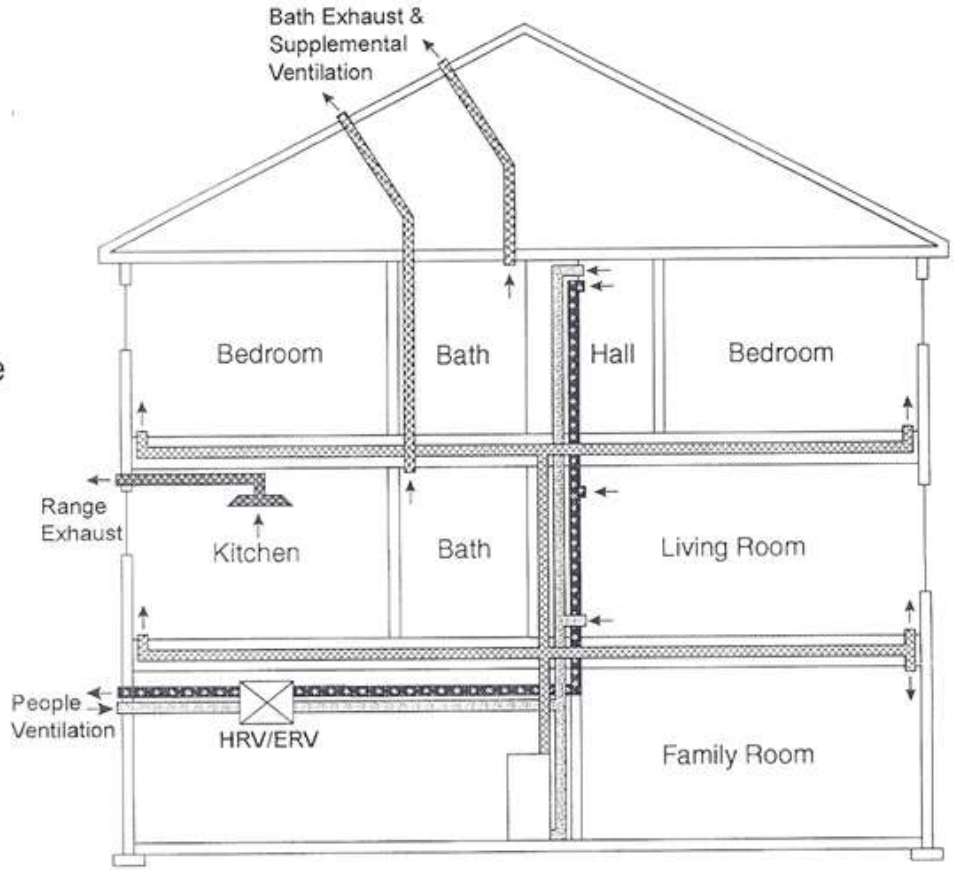
  - The force-air fan must run intermittently to provide adequate distribution of fresh air.
  - This fan must meet both people and total ventilation requirements
  - All RVS fans must have flow measured and verified.
  - Controls for people ventilation must be clearly marked in a central location.
  - Airflow must be adjusted for defrost & low temp. reduction.



# BALANCED W/ HEAT RECOVERY

- **7. Balanced**
  - general approach
  - with heat recovery
  - with forced-air

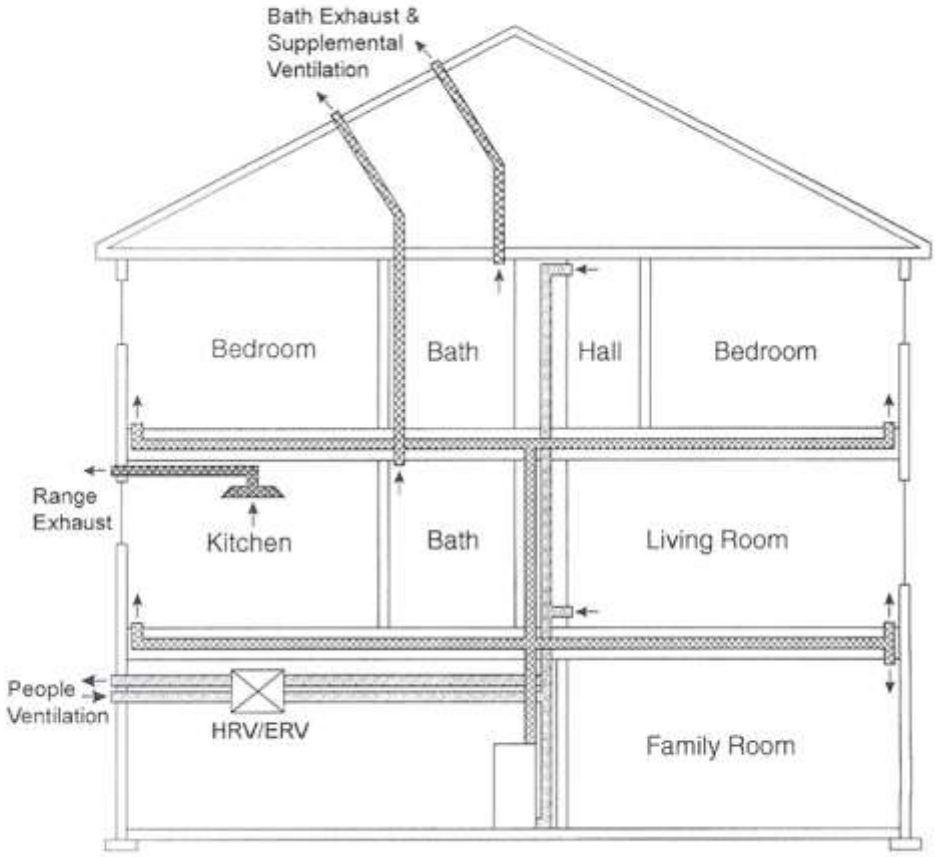
  - The force-air fan must run intermittently to provide adequate distribution of fresh air.
  - This fan might meet the people ventilation requirements only
  - All RVS fans must have flow measured and verified.
  - Controls for people ventilation must be clearly marked in a central location.
  - Airflow must be adjusted for defrost & low temp. reduction.



# BALANCED W/ HEAT RECOVERY

- **8. Balanced**
  - volume approach
  - with heat recovery
  - with forced-air

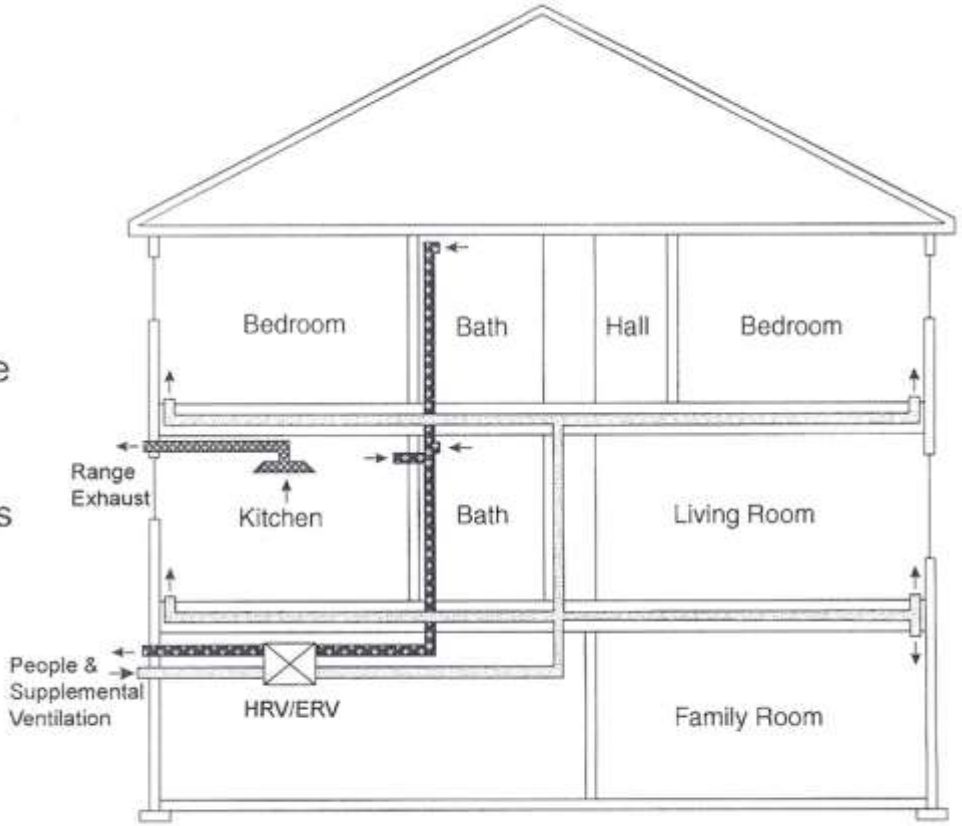
  - The force-air fan must run continuously to meet ventilation requirements and provide adequate distribution of fresh air.
  - This fan might meet the people ventilation requirements only
  - All RVS fans must have flow measured and verified.
  - Controls for people ventilation must be clearly marked in a central location.
  - Airflow must be adjusted for defrost & low temp. reduction.



# BALANCED W/ HEAT RECOVERY

- **10. Balanced**
  - source point approach
  - with heat recovery
  - without forced-air

  - The ventilation fan must run continuously to provide adequate distribution of fresh air
  - This fan must meet both people and total ventilation requirements
  - All RVS fans must have flow measured and verified.
  - Controls for people ventilation must be clearly marked in a central location.
  - Airflow must be adjusted for defrost & low temp. reduction.



# 5. VENTILATION BEST PRACTICES

- General Design
- Commissioning the System
- Role of Balanced Ventilation
- Should it be HRV/ERV?
- Don’t Forget Space Cooling/Dehumidification
- Filtration Targets
- What About Make-Up Air?

# VENTILATION BEST PRACTICE: DESIGN

- Plan on a balanced ventilation system
  - Low speed continuous; high speed, as needed
- Use source point exhaust
  - On top 3 or 4 source points (one per floor)
- Place intake (fresh air) into the forced air system
  - Return provides an opportunity for some mixing and additional filtration
  - MERV 8 on intake air and MERV 10+ on the forced air system

# VENTILATION BEST PRACTICE: DESIGN

- Don’t use volume ventilation
  - Poor effectiveness
  - Generally inefficient
  - Air handler must run continuously
  - Introduces damper issues

# COMMISSIONING VENTILATION SYSTEMS

- Make sure the installation follows the design.
- Verify the ducts are sealed, preferably with duct mastic.
- Verify the dampers are in place and functional.
  - Are there dampers on both intake and exhaust?
- Verify the exterior hoods are properly separated, screened, and labeled.

# COMMISSIONING VENTILATION SYSTEMS

- Verify the flow rates to outdoors.
  - Are the actual flow rates meeting the designed flow rates within +/-10%?
  - For a balanced system, are the flow rates for the exhaust and supply within +/-10%?
- Verify internal flow rates.
  - If connected to a forced air system, is circulation control set to provide proper air distribution?
  - If it is source point, are the interior intakes (bath, kitchen, etc.) moving the required air flow?

# COMMISSIONING VENTILATION SYSTEMS

- Do the fans meet the sound requirements?
  - Surface mounted fans for continuous less than 1.0 sone
  - Surface mounted fans for intermittent less than 2.5 sone
- Verify the intake filtration.
  - Is the filter equal to or better than MERV 4?
  - Is the filter readily accessible?
- Verify measures have been followed to minimize transmission of noise/vibration.

# COMMISSIONING VENTILATION SYSTEMS

- Verify the controls.
  - Are the controls readily accessible?
  - Are the controls clearly labeled?
  - If both the ventilation exhaust and supply are connected to the forced air distribution, are there controls to ensure the distribution fan is running whenever the ventilation system is on?
- Is the documentation for operation and maintenance provided in a readily accessible location.

# BALANCED VENTILIATION : WHY???

- To meet the code?
- To maximize building energy efficiency?
  - Provide an easy opportunity for heat recovery!
- To improve ventilation effectiveness and/or efficiency?
- Reduce possible pressure concerns?

# BALANCED VENTILATION

- Generally a good idea, but …
- In reality, it is virtually impossible to be balanced (within 10%) at all times.
  - Multiple fans/speeds is a control nightmare
  - HRVs (and many ERVs) have defrost cycles where the intake is shutdown or reduced
  - If connected to a forced air system, is it with circulation fan on or fan off?
    - Is the ventilation fan on low or high for balancing?

# BALANCED VENTILATION

- And so,
  - There are times where balanced ventilation might not make sense …
    - when other exhausting devices are operating, it might make sense to shunt the ventilation exhaust.
  - In fact, for much of the year it might actually be desirable to be out of balance …
    - other than mid-winter, a slight positive pressure might be good for the enclosure and indoor air quality.

# VENTILATION TYPE: MN-REC ’15

- An HRV or ERV intended to comply with both the continuous and total ventilation rate requirements shall meet the rated design capacity of the continuous ventilation rate specified in Section R403.5.3 under low capacity and meet the total ventilation rate specified in Section R403.5.2 under high capacity.
  - Exception: The balanced **HRV/ERV** system may include **exhaust fans** to meet the intermittent ventilation rate. Surface mounted fans shall have a maximum 1.0 sone per HVI Standard 915.

# BALANCED HRV/ERV CONTINUOUS W/ INTERMITTENT EXHAUST

- Essentially, this code exception allows for intermittent exhaust if a balanced system with HRV/ERV is used for the continuous ventilation.
- This is a fortuitous exception and can be a good opportunity for …
  - improved code compliance and
  - best ventilation practice.

# BALANCED HRV/ERV CONTINUOUS W/ INTERMITTENT EXHAUST

- I would consider this option for:
  - Homes that are large and/or low occupancy
  - Homes with high-production source points
  - Homes with long runs to source points
  - Homes with “iffy” wintertime enclosures

# BALANCED HRV/ERV FOR BOTH CONTINUOUS AND INTERMITTENT

- I would recommended this option for:
  - Smaller, high occupancy homes
  - Extremely tight homes
  - Zero Energy Ready Homes

# HEAT RECOVERY – GOOD IDEA???

- From an energy and comfort perspective, it is a must as it tempers the incoming air!
  - However, it might only be cost effective for the continuous ventilation.
- It is critically important to bring the occupant into this decision,
  - As it requires extra maintenance.
- Probably better as an incentive, rather than as a requirement.

# SHOULD I USE AN HRV OR ERV???

- Strictly from an energy perspective …
  - Generally use an HRV in heating only climates
  - Generally use an ERV in cooling or mixed climates
- From an indoor humidity perspective …
  - HRV can over-dry a leaky or low $H_2O$ load home
  - ERV may not dry down a tight & high $H_2O$ load home
- For H-P new homes w/AC, go with the ERV
  - Since summer moisture is much more troublesome
- Cost, complexity, maintenance vary widely.

# VENTILATION SUMMARY*

- Use balanced continuous ventilation with an HRV/ERV.
- In tight homes, the intermittent ventilation should be balanced, too.
- Spot ventilation could be exhaust-only if small and/or rarely used.
- Don’t forget the distribution!

*Get the EEBA Ventilation Guide by Armin Rudd

# 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

# SPACE FILTRATION

- Variety of filtration types
  - Pleated media filter
  - Electrostatic
  - Electronic
  - Turbulence (not readily available)
- Use high quality filters
  - MERV 8 minimum on intake air
  - MERV 10 or higher for circulation air

# SPACE COOLING

- To AC or not to AC?
  - For many reasons, this is changing fast.
  - And for many it isn't an option any longer.
- Natural ventilation can work many days, but not all days for all people.
  - It might present outdoor IAQ issues including pollen, mold spores, and particulates.
  - It can contribute to indoor moisture and mold issues, especially with cooler interior surfaces.

# SPACE HUMIDIFICATION

- In some instances it is necessary for winter-time comfort in cold climates, especially in
  - houses with very low moisture loads and/or
  - houses with high winter ventilation rates.
- But frequently it can be managed without intentional humidification. If not …
  - it should be a steam humidifier system
  - or wetted drum/pad w/ exceptional maintenance
  - or cool mist using clean, distilled water.

# SPACE DEHUMIDIFCATION

- This is critical in low-load homes, as typical air-conditioning doesn't work.
  - Many times you have high latent loads when there is no significant sensible load.
  - Frequently you need more moisture removal under part-load conditions.
- It takes 15 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.

# SPACE DEHUMIDIFCATION

- In our climate, it might be possible to downsize the AC and consider reheat to force longer run times.
  - variable capacity AC can help, too!
- But for best summer humidity control, consider a whole house dehumidifier.

# SPACE DEHUMIDIFCATION

- Whole House Dehumidification
  - Since ventilation does not equal humidity control, it is critical to provide systematic dehumidification.
  - Independent control for indoor humidity for condensation, mold, and dust mites.
  - Huge aid for summer comfort.

# BUILDING ENCLOSURE: PRESSURE

- Optimal Pressures (house wrt outdoors)

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

# MANAGING BUILDING PRESSURES

- This becomes increasingly harder 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: 2200 SF House at 2 ACH@50Pa
    - 150 cfm causes -6 Pa
    - 300 cfm causes -18 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**

Clothes dryer @ 130 cfm

Small range hood @ 250 cfm

Large range hood @ 500 cfm

# MAKE-UP AIR

- How much negative pressure for how long?
- 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.

# 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 with a heating element.

# AFFORDABILITY OF SYSTEMS

- Pay Me Now or Pay Me Later!
  - Initial (capital) costs
  - Operational (energy) costs
  - Ongoing maintenance costs
  - Time to replacement

# AFFORDABILITY OF SYSTEMS

- We must educate the consumer to think beyond costs!
  - Comfort
  - Convenience
  - Robustness
  - Resale
- And the builder must use these assets as his/her competitive edge.

# FINAL NOTES & CAUTIONS

- High-performance houses will require new enclosure strategies and systems:
  - Higher insulation levels
  - Improved water, air, and vapor control layers
  - Better drying strategies
  - More robust delivery systems

# FINAL NOTES & CAUTIONS

- High-performance enclosures will demand a new approach to the mechanical systems:
  - Integrated systems approach to low-load HVAC+DHW
  - Increased attention to indoor air quality
    - source control
    - ventilation
    - filtration
    - distribution
  - Improved make-up air solutions

# KEY RESOURCES

- Your New Partners
  - Utility Programs
  - Home Energy Raters
  - Home Performance Consultants
  - Other Resources
    - DOE Building America
    - Building Science Corporation
    - Green Building Advisor

# KEY RESOURCES

- DOE Building America Resources
  - General Energy Information (EERE)
  - DOE Zero Energy Ready Home (ZERH)
    - Tour of Zero
  - Top Innovations “Hall of Fame”
  - Building America Solution Center

# World-Class Research…

Building America Solution Center

BASC.energy.gov

…At Your Fingertips

# KEY RESOURCES

- BSI-039: The Five Things
  - Joseph Lstiburek
- BSI-022: The Perfect HVAC
  - John Straube
- BSI-016: Top Ten Issues in Ventilation
  - Armin Rudd
- BSI-017: Solving IAQ Problems
  - Joseph Lstiburek
- EEBA Ventilation Guide
  - Armin Rudd

- Discussion & Questions

## Contact Information

Patrick H. Huelman
203 Kaufert Lab; 2004 Folwell Ave.
St. Paul, MN 55108
612-624-1286
phuelman@umn.edu

# BONUS SLIDES FROM:

- Top 10 Issues in Residential Ventilation Design (and Installation)
  - BSI-016 (buildingscience.com)
  - By Armin Rudd
  - 2009 (rev. 2013) but still excellent!!!

# 1. DUCTS, FITTINGS, GRILLES

- Change airflow direction as infrequently and smoothly as possible
- For flex duct, pull the inner liner taut and provide adequate supports to prevent bends and sags
- Use the proper duct size; in general
  - Same size as fan outlet if very short (< 10’)
  - Increase one duct size for short runs (10 - 25’)
  - Increase two duct sizes for long runs (> 25’ w/ fittings)
  - Step up one additional size when using flex duct
  - Seal all joints with UL181 mastic
- Use grilles with curved blades & balancers

# 2. CONDENSATION & MOLD CONTROL

- Don’t put ventilation supply air into the central forced-air supply plenum, especially under humid conditions
  - Supply air may go into the forced-air return plenum, if a high MERV filter is between supply and forced-air fan
  - Or run the forced-air fan to promote mixing, but this causes re-evaporation of the AC coil when cooling
- Ducts must be insulated to avoid condensation
  - All exhaust ducts going through a cold space in winter
  - All supply air ducts within a conditioned space

# 3. SHORT CIRCUITING

- When ventilation air enters and leaves a duct or space before it has a chance to adequately mix
  - Don’t locate ventilation supplies and returns in close proximity
- Biggest concern is volume ventilation with supply and exhaust air connected to the central forced-air ductwork
  - Must interlock fan with the ventilation device.

# 4. LACK OF DISTRIBUTION

- Avoid short circuiting (see #3.)
- Duct ventilation air to each room or operate central forced-air fan to promote mixing
  - This is required by our code.

# 5. AIRFLOW FOR COMFORT

- Primarily a supply air issue
- Air from a central forced-air system (in circulation mode) can feel uncomfortable
- Uncomfortable direct contact is best avoided by:
  - supplying smaller amounts of air to more locations
  - avoid grille placement near sedentary occupants
  - use grilles that ensure mixing with room air
- Educate the customer and set expectations on the importance of the ventilation system and operation

# 6. GOOD OUTSIDE AIR?

- Ventilation air should be planned and executed to be as fresh as possible
  - At least 10’ from combustion vents, plumbing vents, and exhaust fans
  - At least 10’ away from flammable vapors, street, alley, driveway, or sidewalk
  - Avoid intakes near shingled or asphaltic roofing

# 7. FAN FLOW RATINGS

- Rated airflows for fans are commonly given for 0.10” w.c. and sometimes 0.25” w.c.
  - Typical duct system would rarely be <0.10” w.c.
  - Try to use fans with 0.25” w.c. ratings
  - Properly designed and installed systems should keep the static pressure below 0.25” w.c.

# 8. FAN FLOW VERIFICATION

- After installation, the actual air flow should be verified
  - Can be done with a flow hood or flow grid
  - Some devices have flow measurement ports
  - Measuring air velocity can be difficult and uncertain
- This has been required (for all flows over 30 cfm) by our code since 2000.

# 9. NOISE

- Sound levels for ventilation fans are generally measured in sones
  - 1 sone is like a quiet refrigerator in a quiet room
  - Direct mount ventilation fans should be 1 sone or less
- A low sone fan can be noisy, if improperly installed
  - Keep static pressures below 0.3” w.c.
  - No fittings at least 18” from the discharge side of the fan
  - For remote fans, use isolation straps, hangers, or sound/vibration dampening materials

# 10. MAINTENANCE

- Keep it easy or it won't get done!
- Filters must be easy to access to clean or replace
  - Easy to purchase, too
- Do not put outdoor intakes <12" off the grade
  - Make sure they are easy to access for cleaning
- Provide ongoing verbal and written communication to ensure ventilation system maintenance is done