UNIVERSITY OF MINNESOTA | EXTENSION

MAKING A DIFFERENCE IN MINNESOTA: ENVIRONMENT + FOOD & AGRICULTURE + COMMUNITIES + FAMILIES + YOUTH

High-Performance Homes Bring New Challenges for Mechanical Systems

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NEW DEMANDS ON MECHANICAL SYSTEMS:
PRINCIPLES AND BEST PRACTICES

- Part 1: Intro; Five Things; Why Robust?
- Part 2: Basic Service Requirements
- Part 3. Key System Components
- Part 4: System Packages That Make Sense

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

GOOD NEWS; BAD NEWS

- Good News
  - We are seeing some remarkably efficient and airtight low-load enclosures.

- Bad News
  - For many of theses homes, their mechanical systems are not delivering the desired outcomes (efficiency, comfort, air quality, etc.).

MORE BAD NEWS

- Original logic said if you spent more money on the enclosure, you could get that money back on the heating/cooling system.
  - That didn't turn out exactly the way we hoped!
- There was a thought that once the enclosure was super-tight, you could just drop in a little fresh air and add some heating/cooling and it would be perfectly comfortable.
  - It isn't quite that simple!

THE FIVE THINGS

- How did we get here
- What really changed?
- What does it mean for building design and construction practices?

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

FIVE CRITICAL SYSTEM CHANGES

- Step Back & Take a Broader Systems View
- Demand Performance Over Prescriptive
- Use Building Science, Engineered Approach
- Place a Premium on Robust
- Focus on Total Cost of Ownership

Building America Strategy

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Ultra-High Efficiency + High-Performance

Ultra-High Efficiency

- Enclosure
- Low-Load HVAC
- Components

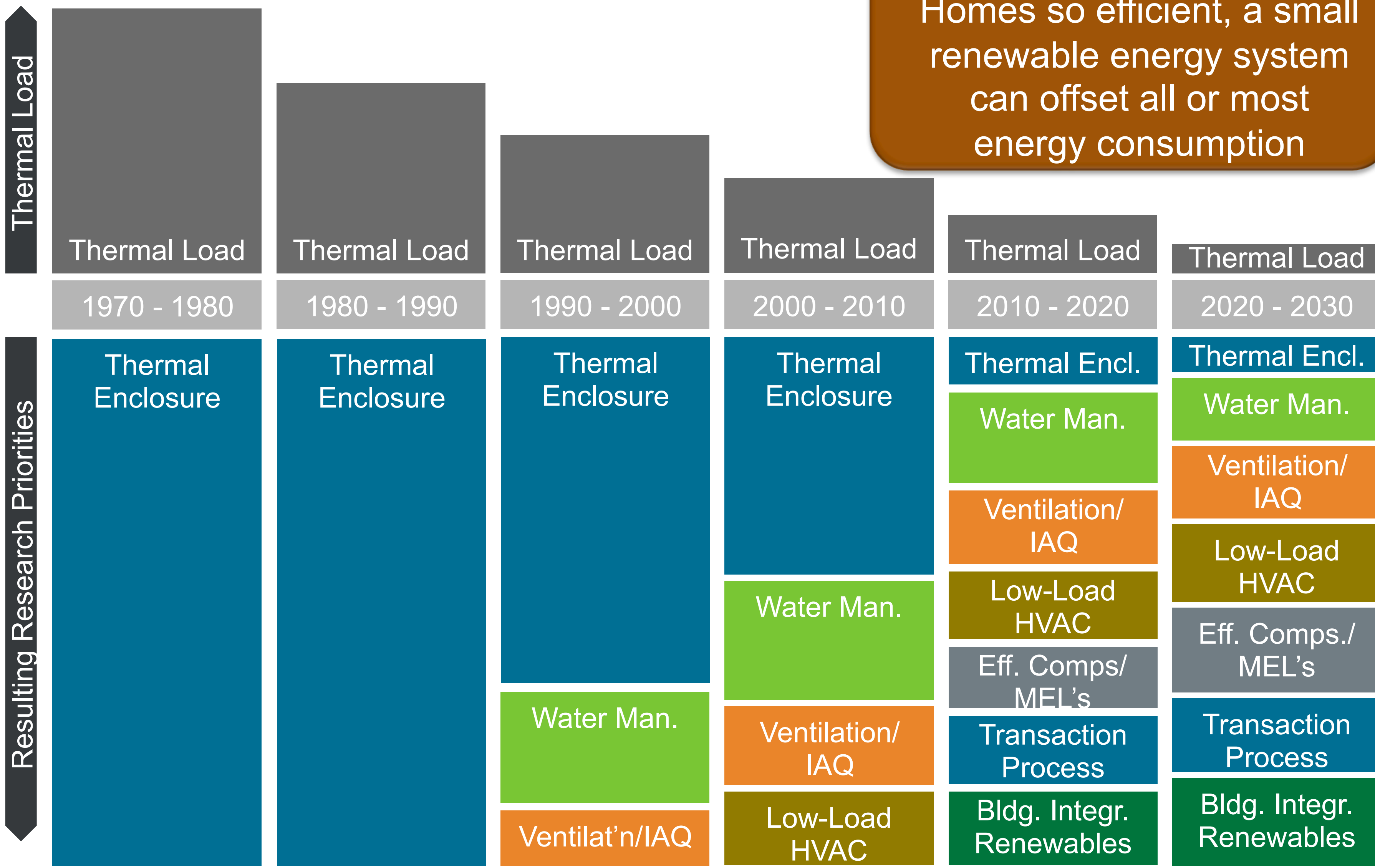
High-Performance

- Affordable
- Comfort
- Health
- Durability
- Renewable Readiness
- Water Conservation
- Disaster Resistance

Building America Strategy

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Goal:
Homes so efficient, a small renewable energy system can offset all or most energy consumption



MAKING THE CASE FOR ROBUST

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

- High-performance houses will push our current approach. Therefore, we must …
  - design and engineer (not just build) our homes.
  - build forgiveness/tolerance into all systems.
  - build redundancy into critical materials.
    - or make it easy to repair and/or replace key components
  - develop a more predictable delivery system.
  - provide continuous feedback to the occupant.

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 CONUNDRUM

- 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 CONUNDRUM

- 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 CONUNDRUM

- 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 represent a larger peak load.
  - We probably need to move towards integrated space and water heating systems.

MODERN MECHANICAL CONUNDRUM

- 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!

2. BASIC SERVICE (MEP) SYSTEMS

- Mechanical System
  - HVAC will be the primary focus for today!
- Electrical System
  - Limited discussion on this one for today!
- Plumbing System
  - Some discussion as it overlaps HVAC!

BASIC SERVICE REQUIREMENTS

- Comfortable Interior Conditions
- Healthy Indoor Air
- Convenient Warm Water
- Minimize Building Enclosure Impacts
- Affordability of Systems

INTERIOR SPACE CONDITIONS

- Thermal Comfort (operative temperature)
  - Temperature
    - ambient air
    - mean radiant
  - Humidity
  - Airflow

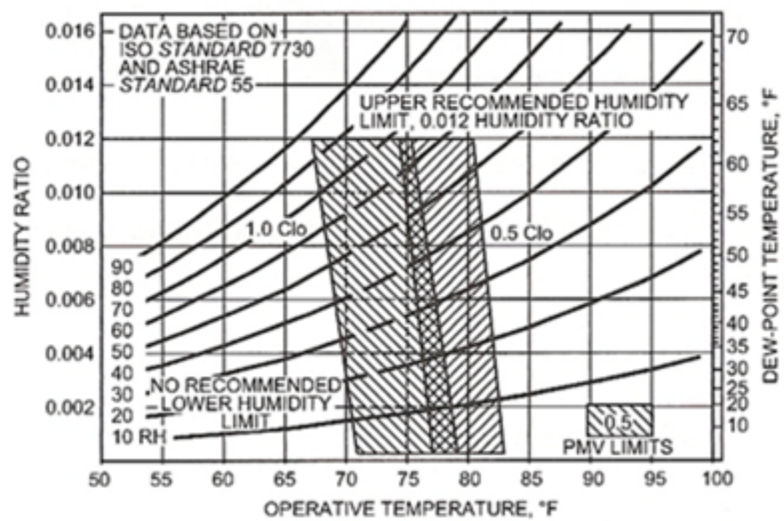


Fig. 5 ASHRAE Summer and Winter Comfort Zones
[Acceptable ranges of operative temperature and humidity with air speed ≤ 40 fpm for people wearing 1.0 and 0.5 clo clothing during primarily sedentary activity (≤1.1 met).]

Note: Acoustical comfort is important, too.

INDOOR ENVIRONMENTAL QUALITY

- 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

DOMESTIC HOT WATER

- Safe
  - No backdrafting
  - No scalding
- Comfortable
  - Proper temperature at fixtures
- Convenient
  - Quick delivery to reduce water/energy waste

BUILDING ENCLOSURE IMPACTS

- Manage Pressures
- Mitigate Pollutants
- Prevent Critter Entry

BUILDING ENCLOSURE: PRESSURE

- Optimal Pressures (house wrt outdoors)

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

BUILDING ENCLOSURE: POLLUTANTS

- Soil Gases
  - Radon, water vapor, etc.
- Garage Gases/Particulates
  - Engine by-products, stored chemicals, etc.
- Structural Cavities
  - VOCs, particulates, mold, etc.

BUILDING ENCLOSURE: CRITTERS

- Screens on ventilation hoods
- Filters (inline) on intake air
- Quality dampers
  - Exhaust side of ventilation
  - Kitchen range hood
  - Clothes dryer

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.

SPECIAL NOTE ON ZEROING IN*

- Net Zero Energy Today
  - It is clearly possible to get to NZE where …
    - the total amount of energy consumed is equal to the total amount of energy generated on-site.
  - However, the whole building solution might look a bit different than you imagine.

* Zeroing In: BSI-081 by Joseph Lstiburek

ZEROING IN*

- Don’t bother with passive solar!
  - The heat gain in the winter is not needed.
  - The heat gain in the summer will hurt you.
  - But people want windows -- so pay attention and use good judgement on the window orientation, placement, and type.
- Ultra-efficiency crushes super-insulated.
- Collect the solar energy with PV.

ZEROING IN*

- Ultra-tight is critical, but it has real consequences!
  - Large exhaust devices require a new approach and/or make-up air.
    - clothes dryer: consider a condensing unit
    - range hood: high capture rate with make-up air
  - Interior wood fireplaces/stoves …
    - don't even think about it!

ZEROING IN*

- Ventilation system must be top-drawer!
  - Balance with heat/energy recovery is not optional.
  - Run the bathroom exhaust through the HRV/ERV.
  - Provide fresh air to the bedrooms …
    - generally with the forced-air conditioning system.

ZEROING IN*

- You must have air circulation!
  - Air isn't moving bottom to top or side to side.
  - You need mixing for thermal comfort.
  - You must distribute fresh/filtered air for IAQ.

- You can choose to do this with your space conditioning or ventilation system.

ZEROING IN*

- The greatest challenge is latent load management!
  - In the swing seasons and under part-load conditions.
- Do you think you can do this with your space conditioning or ventilation system?
  - It is tougher than it sounds.
  - Dehumidification may need to be an independent system.

3. MECHANICAL SYSTEMS

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

SPACE HEATING

- Fuel Costs
- Key Parts of the System
  - Delivery Approach
    - Forced air
    - Hydronic
  - Plant Choices
  - Controls
- System Costs

SPACE HEATING: FUEL COSTS

- Cost per Delivered Million Btu
  - NG = 10.0 x $/therm / efficiency
    - 10.0 x $0.80 / 0.65 = $ 12.31
    - 10.0 x $0.80 / 0.94 = $ 8.51
  - LPG = 11.0 x $/gallon / efficiency
    - 11.0 x $1.65 / 0.94 = $ 19.31
  - Elec = 293 x $/kWh / COP
    - 293 x $0.12 / 1.0 = $ 32.23
    - 293 x $0.12 / 3.2 = $ 10.07
    - 293 x $0.07 / 3.2 = $ 6.41

SPACE HEATING: COMMON SYSTEMS

- Gas Forced-Air
- Radiant (Electric or Gas)
- Air Source Heat Pump (ASHP)
- Ground Source Heat Pump (GSHP)

SPACE HEATING: GAS FORCED-AIR

- Traditional Single (or Dual) Zone Furnace
  - Most common system used for many decades
  - Easily adapted for space cooling
  - Current gas prices make this very attractive
- Current Challenges
  - Proper sizing
  - Poor part-load efficiency
  - Poor space by space comfort and control

SPACE HEATING: RADIANT

- Infloor or Room Radiators/Convectors
  - Electric radiant tends to be inexpensive to install and provides easy zoning controls, but may be quite expensive to operate.
  - Boiler and hot water has lost market share, in general, but has seen a small resurgence with high-end clients for comfort-focused spaces.
  - Upside is the boiler can provide both space and water heat.

SPACE HEATING: ASHP

- Traditional Split System
  - Uses an outside compressor/condenser unit with an indoor evaporator coil
  - Provides heating and cooling
  - May need back-up for peak heating loads
- Ductless or Ducted Mini-splits
  - Similar outdoor unit, but indoor units are located within each space or a unit with limited ducting.
  - Improved capacity and high part-load efficiency.

SPACE HEATING: GSHP

- Indoor unit looks similar to and functions like an ASHP (or GF-A system with an AC coil).
- There must be an outside loop-field.
- With desuperheater, it can provide hot water.
- With proper installation and operation, the GSHP can be efficient and provide competitive operational costs.
- However, initial costs continue to be high.

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 COOLING

- Traditional AC on a GF-A Unit
  - Very common, but has similar sizing, zoning, and part-load efficiency issues.
- Ductless (or Ducted) Mini-splits
  - Improved part-load efficiency and better zoning.
- Room (or window) AC Units
  - Lower cost, but frequently poor performance

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 to 20 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.

SPACE FILTRATION

- Pleated media filter
- Electrostatic
- Electronic
- Turbulence (not readily available)

WATER HEATING

- Combustion Safety
  - Must be power-vented
  - Preferably two-pipe direct power-vented
- Type
  - Storage tank
  - Tankless

WATER HEATING

- Storage Tank
  – Provides instant access to hot water
  – Gives buffer capacity for widely varying draws
  – Easier maintenance
- Definitely would go this way for combination space and water heating
  – Condensing sealed combustion (90+% CAE)

WATER HEATING

- Tankless
  - Must be a modulating unit
  - Better with predictable draws
  - Good water quality

WATER HEATING

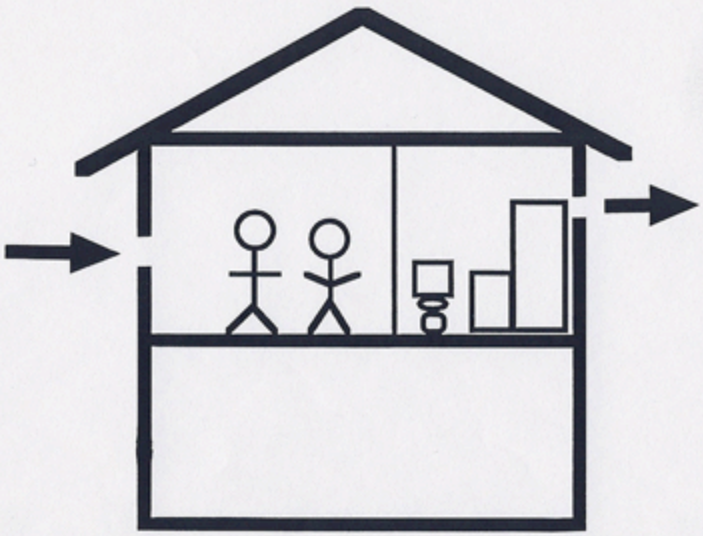
- Delivery system is very important.
- Insulate the pipes.
- No more than ½ gallon between source (water heater or recirc line) and any fixture.
  - This is required for the EPA WaterSense and DOE-ZERH programs.

GETTING ON THE SAME PAGE

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

VENTILATION AIR

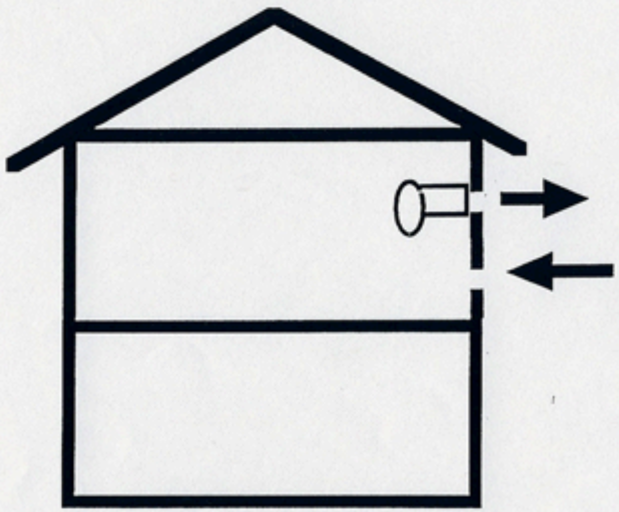
- **Ventilation Air**
  - Replacement, by direct or indirect means, of air in habitable rooms with fresh, outdoor air.



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

MAKE-UP AIR

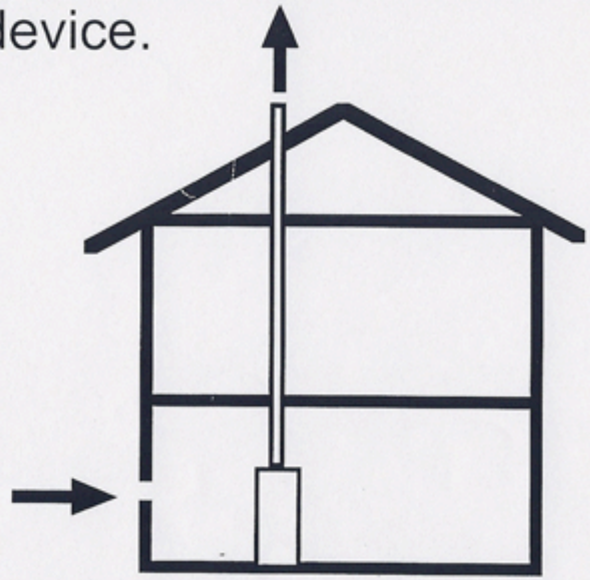
- **Make-Up Air**
  - Outdoor air needed to replace indoor air removed by mechanical exhaust device(s).



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

COMBUSTION AIR

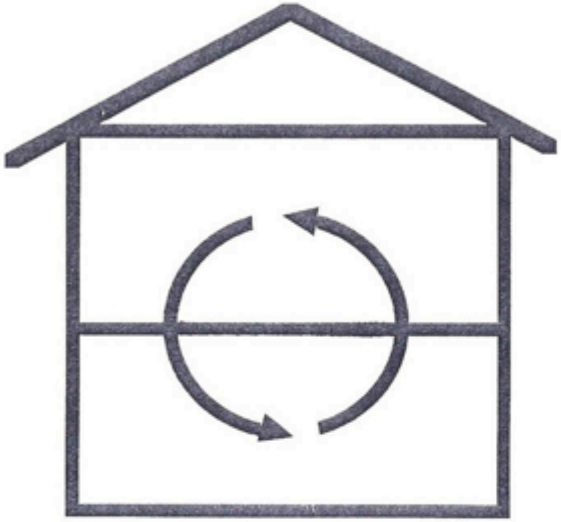
- **Combustion Air**
  - Air from the home (or directly from the outdoors) required to meet the combustion and dilution needs of a vented combustion device.



  - 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.

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"!

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 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?)

SYSTEM DESIGN & BEST PRACTICES

- Ventilation Flow Rates
- Ventilation Distribution
- Ventilation System Design

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
  Q_v = 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 conditioned 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

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.
  - This is currently 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 system …
  - If the outdoor air is supplied directly to the forced air circulation system, provide a flow rate of 0.15 cfm x conditioned floor area.
  - If the outdoor air is supplied directly to the forced air circulation system, provide a flow rate of 0.075 cfm x conditioned floor area.

VENTILATION SYSTEM DESIGN

- Step 1. Ventilation Type
  - Exhaust-Only
  - Balanced Supply & Exhaust
  - Supply-Only

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
  - 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 no occupancy or windows are wide open
    - does need a shut-off for maintenance
  - Intermittent (high speed or additional fan)
    - generally occupant controlled
    - frequently in source point areas

BALANCED VENTILATION: WHY???

- Whole building energy efficiency?
- Ventilation effectiveness and/or efficiency?
- Potential for heat recovery?
- Reduce possible pressure concerns?

BALANCED VENTILATION

- Generally a really 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 most ERVs) have defrost cycles
  - If connected to a forced air system, is it with circulation fan on or fan off?
    - Is the ventilation fan on low or high?

BALANCED VENTILATION

- Also keep in mind all of the other things that aren't balanced?
  - Clothes dryer
  - Kitchen hood/exhaust
  - Other exhaust fans (not part of the ventilation)
- In ultra-tight homes, pressure management is the most important reason to keep the ventilation balanced
  - or perhaps, increase the supply over exhaust!

BALANCED VENTILATION

- Furthermore,
  - 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.

HEAT RECOVERY – GOOD IDEA???

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

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
- Cost, complexity, and maintenance of these systems vary widely.
- But for most new homes, go with the ERV.

VENTILATION SUMMARY*

- 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

MAKE-UP AIR

- As houses get tighter and the exhaust flows get bigger, things get “tricky” in a hurry!
- 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

DESIRABLE HOUSE PRESSURES

- Optimal Pressure (House wrt Outdoors)

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

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.

4. BASE (MINIMUM) SYSTEM

- High-efficiency gas furnace (90% AFUE)
- High-efficiency air-conditioning (13 SEER)
- Deep-pleated media filter (MERV 8)
- Ducted HRV/ERV for continuous ventilation
- Limit the exhaust-only spot ventilation
  - careful high-capture range design and sizing
  - use a ductless/condensing clothes dryer to avoid MUA
- High-EF storage water heater (0.65 EF)

SYSTEMS PACKAGE 1: BETTER

- High-efficiency 2-stage gas furnace (94+% AFUE)
- High-efficiency air-conditioning (15+ SEER)
- Deep-pleated media filter (MERV 10+)
- Ducted ERV for continuous ventilation rate
  - source point pick-ups, distributed fresh air
- Limit exhaust-only spot ventilation
  - careful high-capture range design and sizing
- Tempered make-up air for dryer & range
- High-EF storage water heater (0.67+ EF)

SYSTEMS PACKAGE 3: BETTER

- Multi-head ducted VRF mini-split ASHP
  - high efficiency heating, cooling, and dehumidification
- Deep-pleated media filter (MERV 10+)
- Ducted ERV for continuous ventilation rate
  - source point pick-ups, distributed fresh air
- Limit exhaust-only spot ventilation
  - Carefully designed and sized high-capture range
- Blended make-up air for clothes dryer/range
- High-EF storage water heater (0.68+ EF)

SYSTEMS PACKAGE 4: BETTER

- Ground-source heat pump (COP 3.6+)
  - Water to air
  - Desuperheater for hot water (DHW + radiant)
  - Zoned cooling designed for dehumidification
- Deep pleated media filter (MERV 10+)
- Fully-ducted, two-speed ERV
  - source point pick-ups, distributed fresh air
- Blended make-up air for dryer & range
- On-demand recirc hot water distribution

SYSTEMS PACKAGE 5: BETTER

- Integrated space and water heating system
  - 92+% CAE condensing, storage-tank hot water
  - Fan-coil with ECM motor & 3 row hot water coil
  - Deep-pleated media filter (MERV 10+)
- ASHP (17+ SEER) using fan-coil unit
  - Provides heating, cooling, and dehumidification
- Fully-ducted, two-speed ERV
  - Source point pick-ups, distributed fresh air
- Blended or tempered make-up air for dryer & range
- On-demand recirc hot water distribution

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
  - 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

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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

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- Discussion & Questions

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