Overview of Building Science Consortium Experience with Residential Mechanical Ventilation and Distribution

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Outline

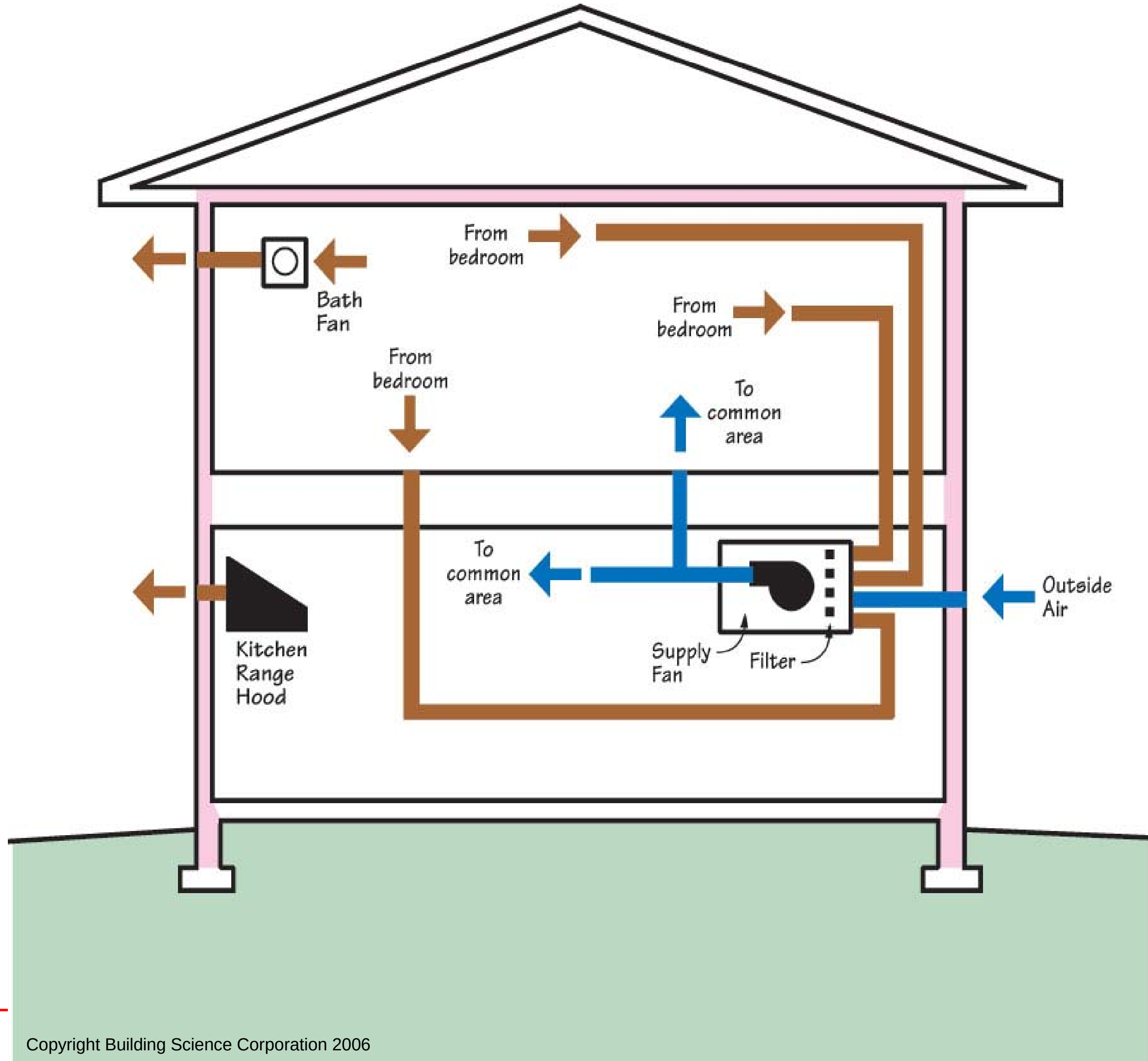
- Provide a chronology of our experience with residential mechanical ventilation in production homebuilding
  - Focus on above-code to high-performance home programs
- Discuss issues framing the development of our process
- Explain our current positions as a point of reference
- New research on ventilation air distribution

Phase 1

- Supply ventilation was identified as being a preferred whole-house ventilation strategy
  - Outside air comes from a known source, can be filtered and conditioned
  - Pressurizes rather than depressurizes interior of building with respect to outdoors
    - Helps rather than hinders combustion appliance drafting
    - Avoids drawing polluted air from garage, crawl space, attic
    - Avoids airflow related moisture/mold problems in humid climates under cooling conditions
    - Applicable in cold climates with airtight enclosure and insulated sheathing, or cavity spray foam insulation
  - Less expensive than balanced ventilation

Supply ventilation system
(multi-point, with 3:1 recirculation air for tempering)

- Separate duct system dedicated to ventilation air distribution
- Use 3:1 recirculation air for tempering
- Be careful to assure there is no condensation if injecting into cool central system ducts. Do not apply that system in warm, humid climates



Separate supply fan with filtration

- Higher cost than most production builders willing to pay
- Required tempering of outdoor air
  - 1 part outdoor air mixed with 2 to 3 parts recirculation air, less in mild-dry climates, more in cold and humid climates
  - Extra airflow for tempering means more energy consumption
- Separate ducting required at least two pickups and at least one supply
  - If single supply into main supply trunk of central system, then needed to make especially sure that mold in cool ducts would not occur
  - If supplied directly to conditioned space, then needed at least two supply points to avoid comfort complaints
- Required easy access to change another filter
- Some resistance to fan running continuously

Phase 1.5

- Some builders resistant to cost of separate supply fan ventilation chose to install single-point exhaust-only despite our reservations
- New problems arose
  - Lack of filtration
    - Dust marking on light carpets
    - Dirt/grit particles settling on horizontal surfaces
  - Lack of distribution
    - Moisture accumulation and odor buildup in rooms remote from exhaust fan
  - Objections to fan noise

Phase 1.5, cont.

- HVAC system right-sizing began to take hold facilitating energy efficiency goals and cost trade-off targets
  - Tight, well-insulated building with controlled air exchange
  - High-performance glass: reducing load, increasing comfort near outside walls, allowing more compact duct systems and ducts inside conditioned space
- Along with customer high satisfaction of energy efficiency performance came new higher expectations of very uniform comfort conditions throughout the conditioned space
- This would require more consistent air mixing for thermal comfort as the sun moves around the house and during light-load and no-load periods

Enter Phase 2

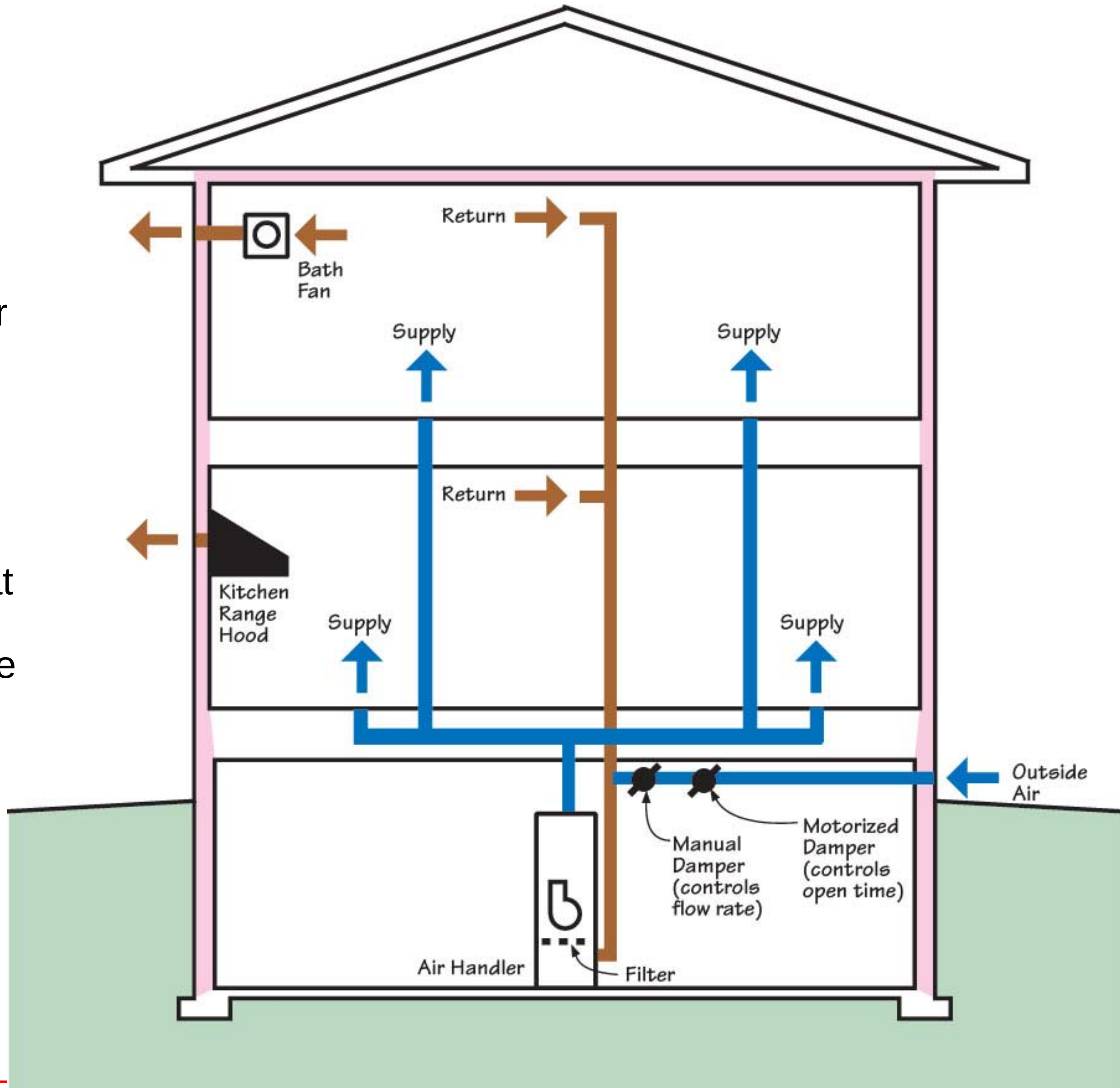
- Central-fan-integrated supply ventilation with smart timer to assure consistent ventilation and whole-house mixing
- First big communities in Chicago area
  - Started with 8” outside air duct, 10 cfm/person, operated central fan on minimum 33% duty cycle
  - Found that ventilation rate was higher than needed, interior RH going too low
  - Lowered ventilation rate, accounting for the small infiltration rate (0.1 ach) during the two-thirds time when not ventilating

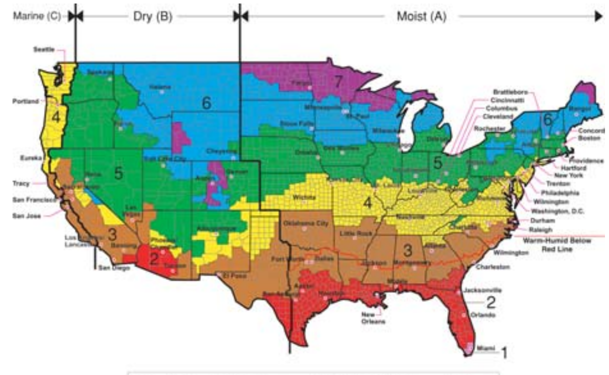
$$\dot{Q}_{in} = \frac{(\dot{Q}_{co}) - (\frac{I}{60} V(1 - f))}{f}$$

  - Reduced to 6” outside air duct, keep duty cycle at 33%, found this amount of outside air and whole-house mixing worked well for humidity, odor, and thermal control

Central-fan-integrated supply ventilation system (CFIS)

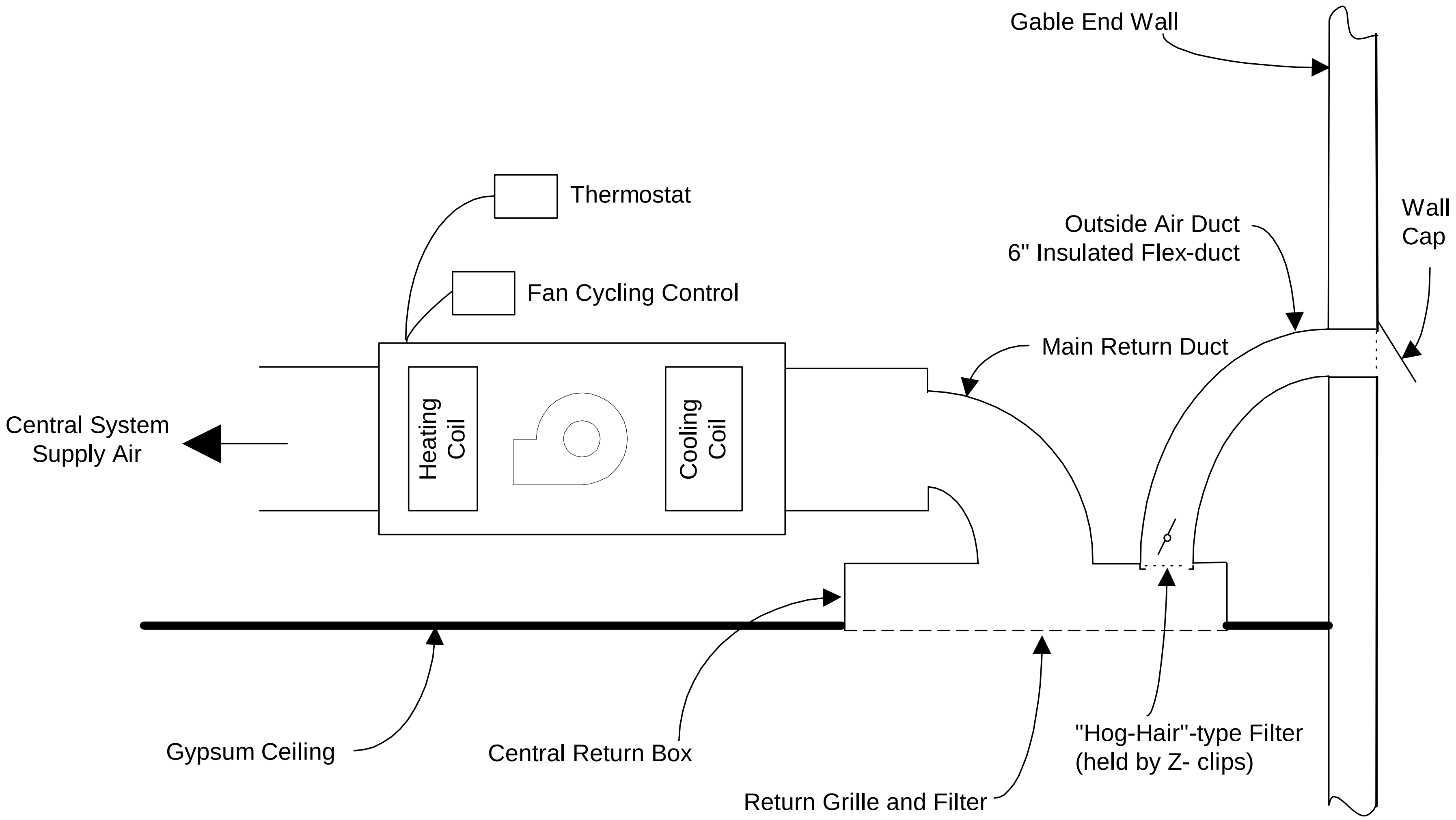
- Uses the existing central air handling system to fully distribute ventilation air
- Uses a fan cycling control to assure a minimum duty cycle to fill in the ventilation gaps during low or no heating and cooling demand
- Optional motorized damper and damper control limits the introduction of outside air to a maximum during periods of high heating and cooling demand, or if the occupant selects the thermostat constant fan setting
- Normal outside air fractions are 5% to 10%. For higher fractions, limit the mixed air return temperature to not less than 55 degrees
- Use available exhaust to increase air exchange for a time if desired



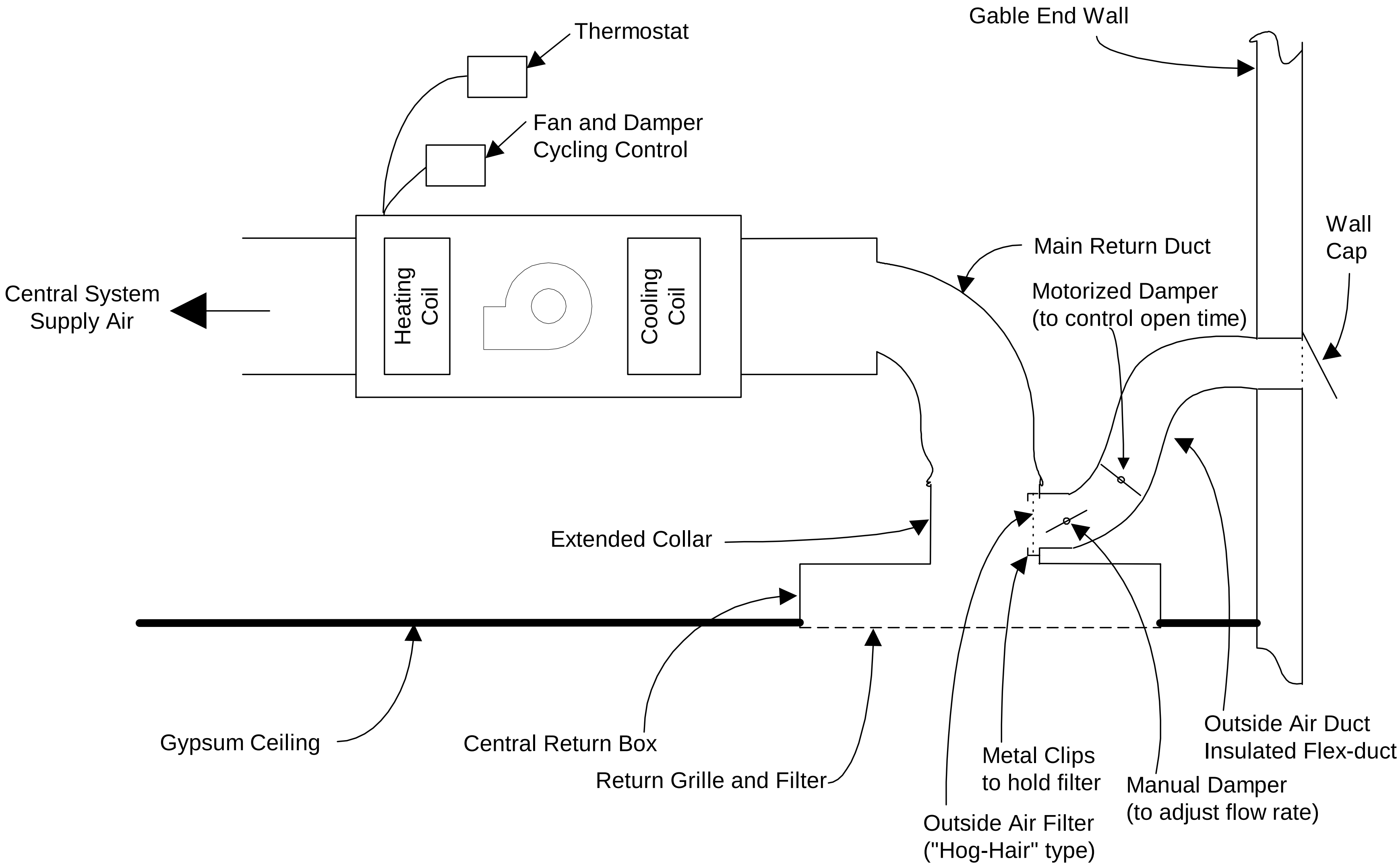


- Took to projects in Las Vegas, Tucson/Phoenix, Albuquerque, Houston, Oklahoma City, Minneapolis (combined with exhaust)
- Became a standard for BSC Building America projects
- And for the EFL national private sector program by Masco, with energy-use and comfort guarantee, about 150,000 such houses since 1996
- In common use in other above-code programs from the Southeast to Texas to Colorado

CFIS, Attic AHU, ceiling filter grille



CFIS, Attic AHU, ceiling filter grille, extended collar

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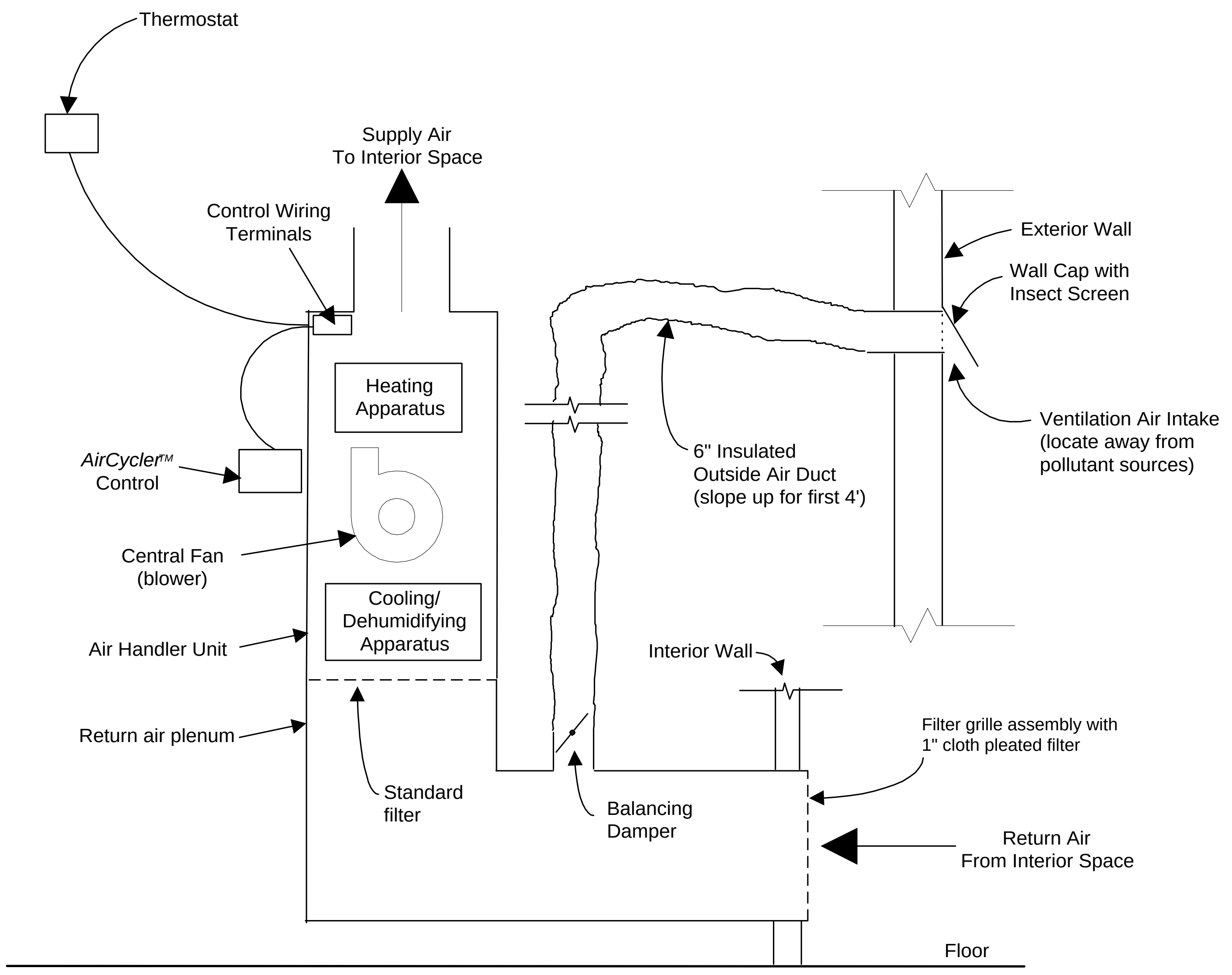
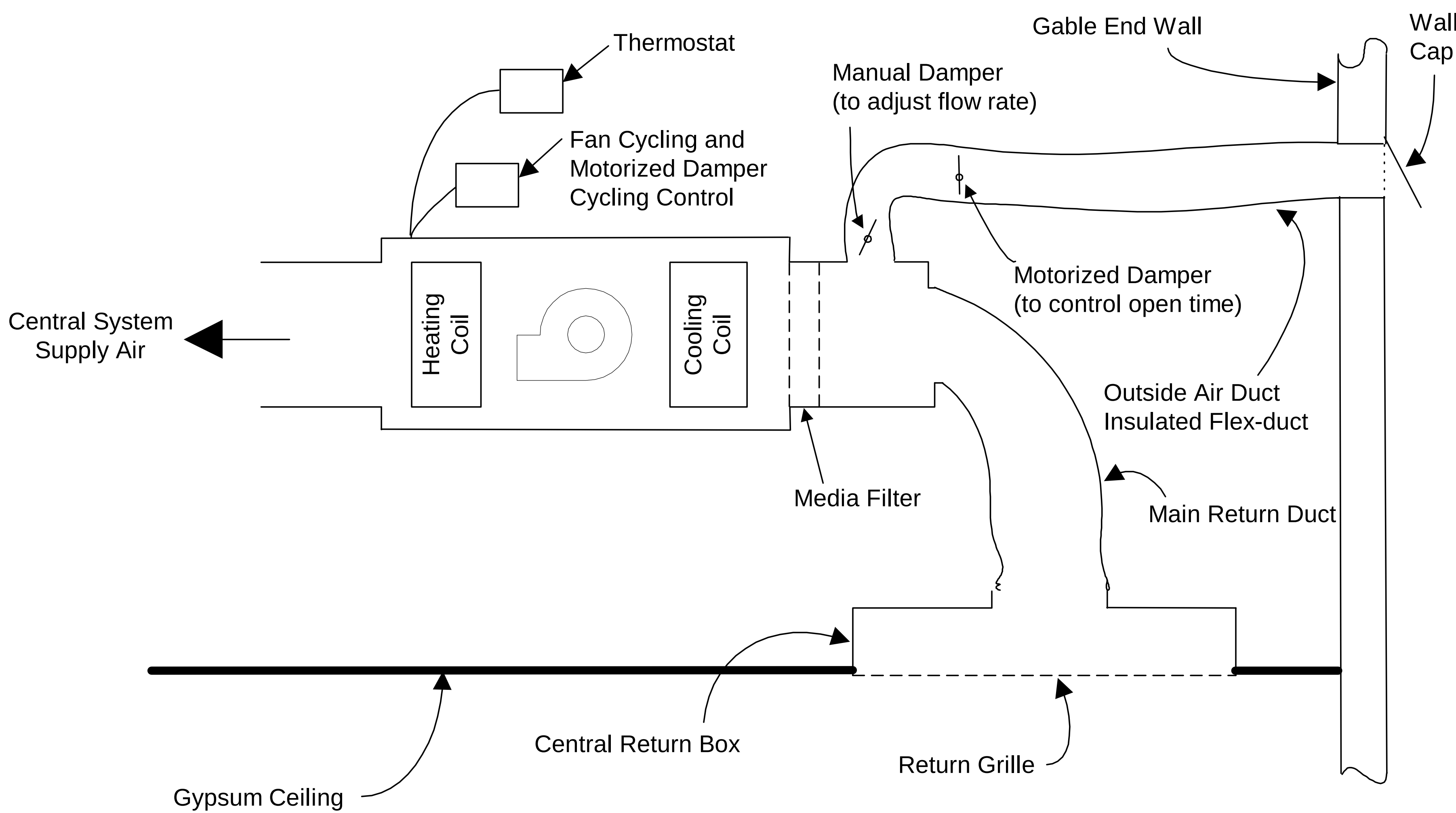
Central-fan-integrated supply ventilation

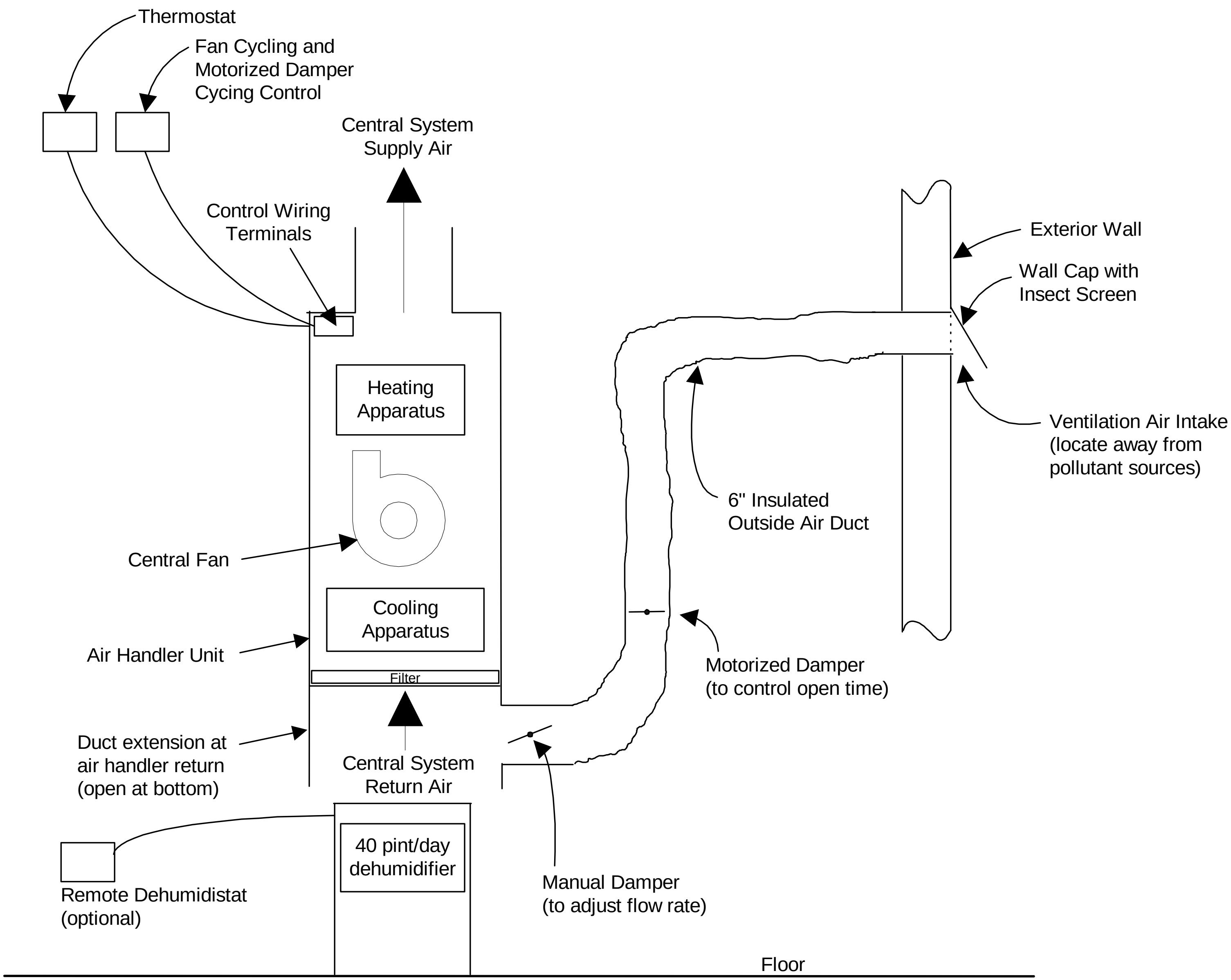
Interior closet configuration



Central-fan-integrated supply ventilation
Attic AHU, media/electronic filter



CFIS with dehumidification separate from cooling hot-humid climate, interior mechanical closet configuration

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- Field monitoring and simulations show that the extra central fan operation amounts to about 15% to 20% of annual hours
  - $0 to $20 annual cost in climates with relatively long (dominant) heating season and low electric rates (Minnesota, Seattle, Kansas City) (fan heat contributes to heating)
  - $40 to $60 annual cost in climates with significant heating and cooling (Charlotte, Atlanta)
  - $60 to $80 annual cost in climates with dominant cooling and high electric rates (Phoenix, Houston) (fan heat adds to sensible cooling)

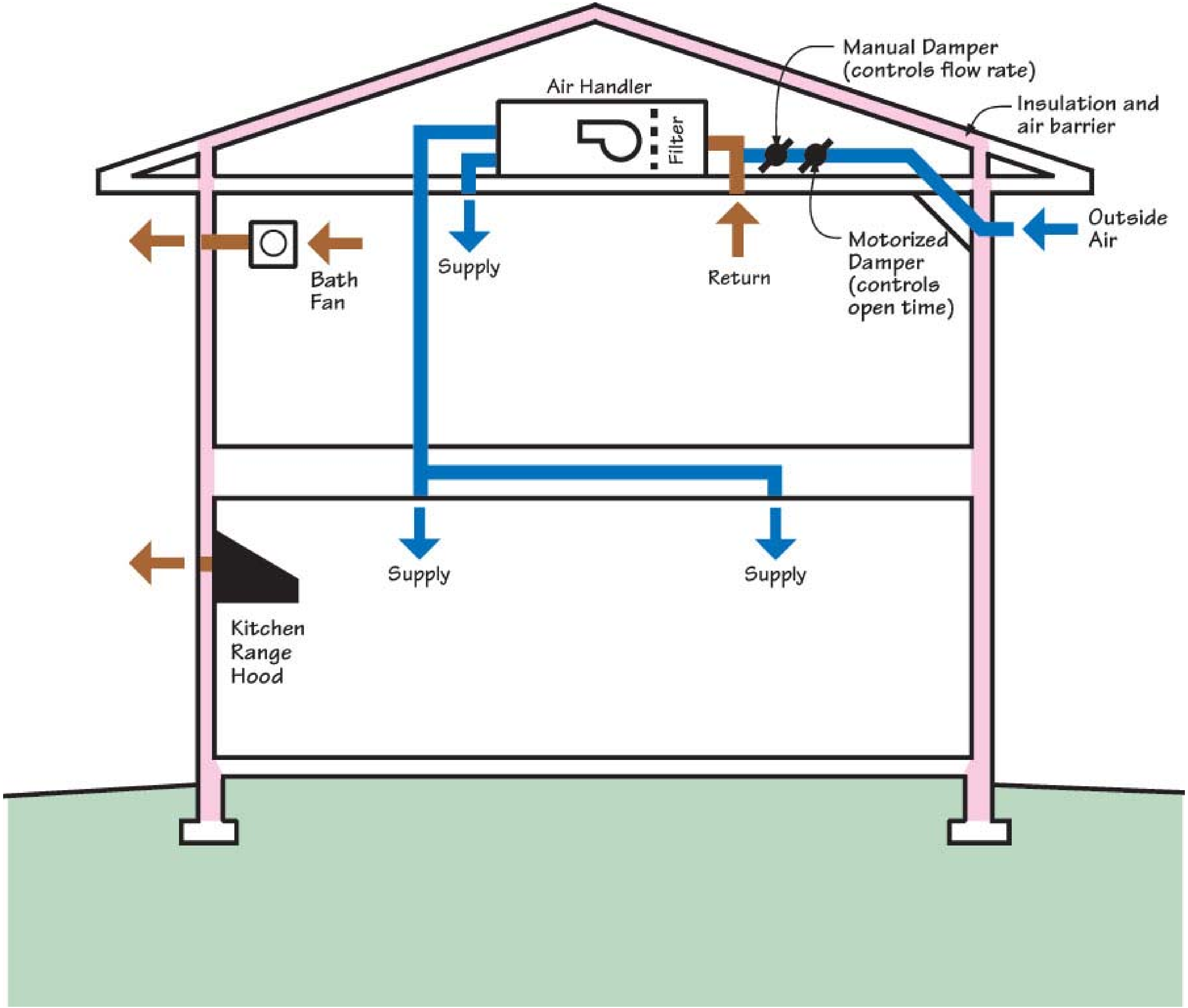
Enter ASHRAE Standard 62.2-2003

- 62.2 required about 2 times the mechanical ventilation airflow that we had been successfully using

- So, with a desire to support the standard in principle, should we increase minimum fan duty cycle?
  - doesn't make a lot of practical sense, at least without an ECM blower, and at least not in humid (wet-coil) climates
  - occupants would likely complain
- Or, increase size of outside air duct to increase flow rate?
  - can negatively impact cooling system size
  - 8” or 10” wall cap looks ugly, and snow can blow in easier

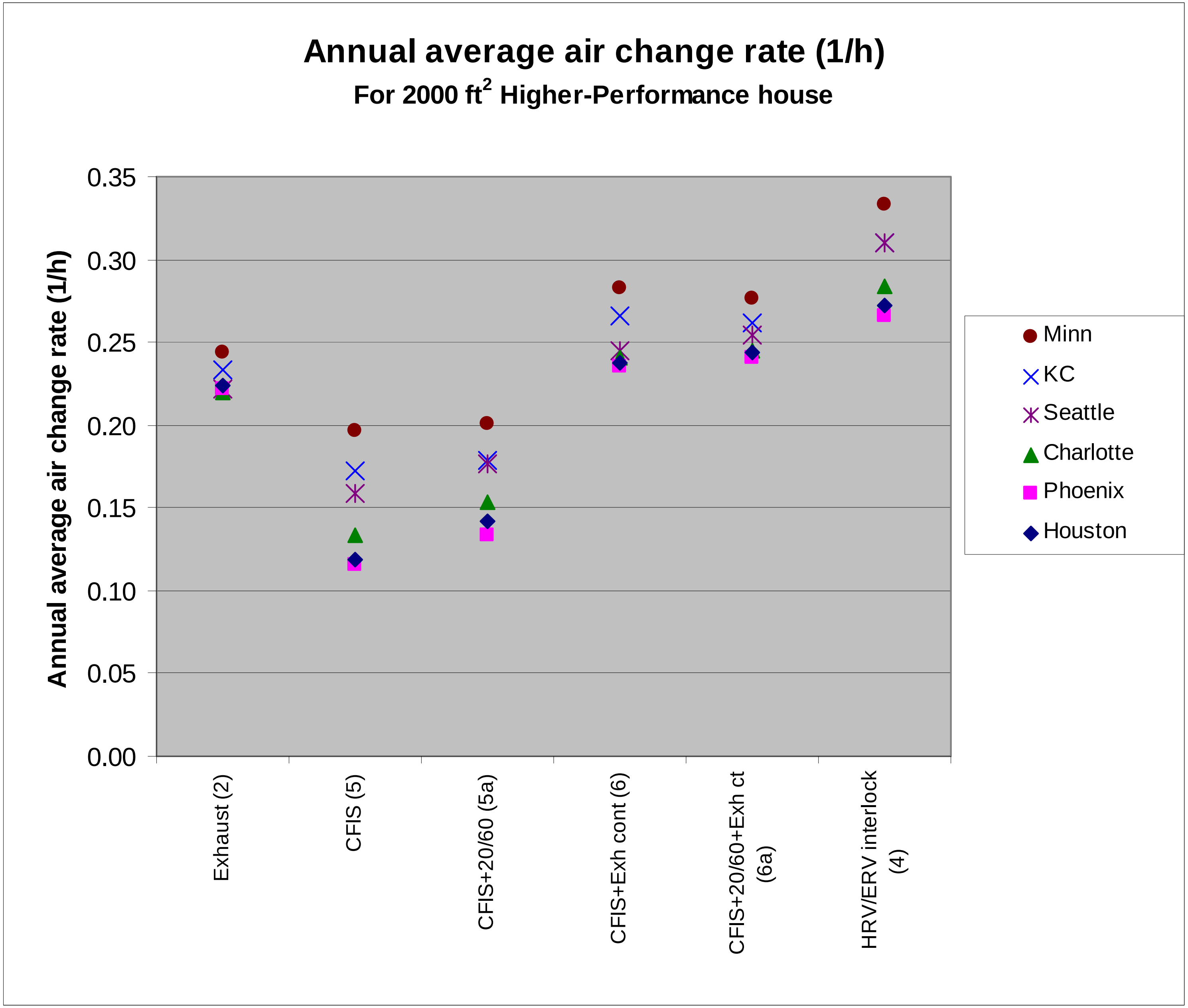
Phase 3

- Successful solution was to upgrade any bathroom fan in the house to meet the 62.2 air flow and sone requirements
- That is the ventilation system of record for ratings or otherwise


Manual Damper
(controls flow rate)
Air Handler
Filter
Insulation and
air barrier
Outside
Air
Supply
Return
Motorized
Damper
(controls
open time)
Bath
Fan
Supply
Supply
Kitchen
Range
Hood

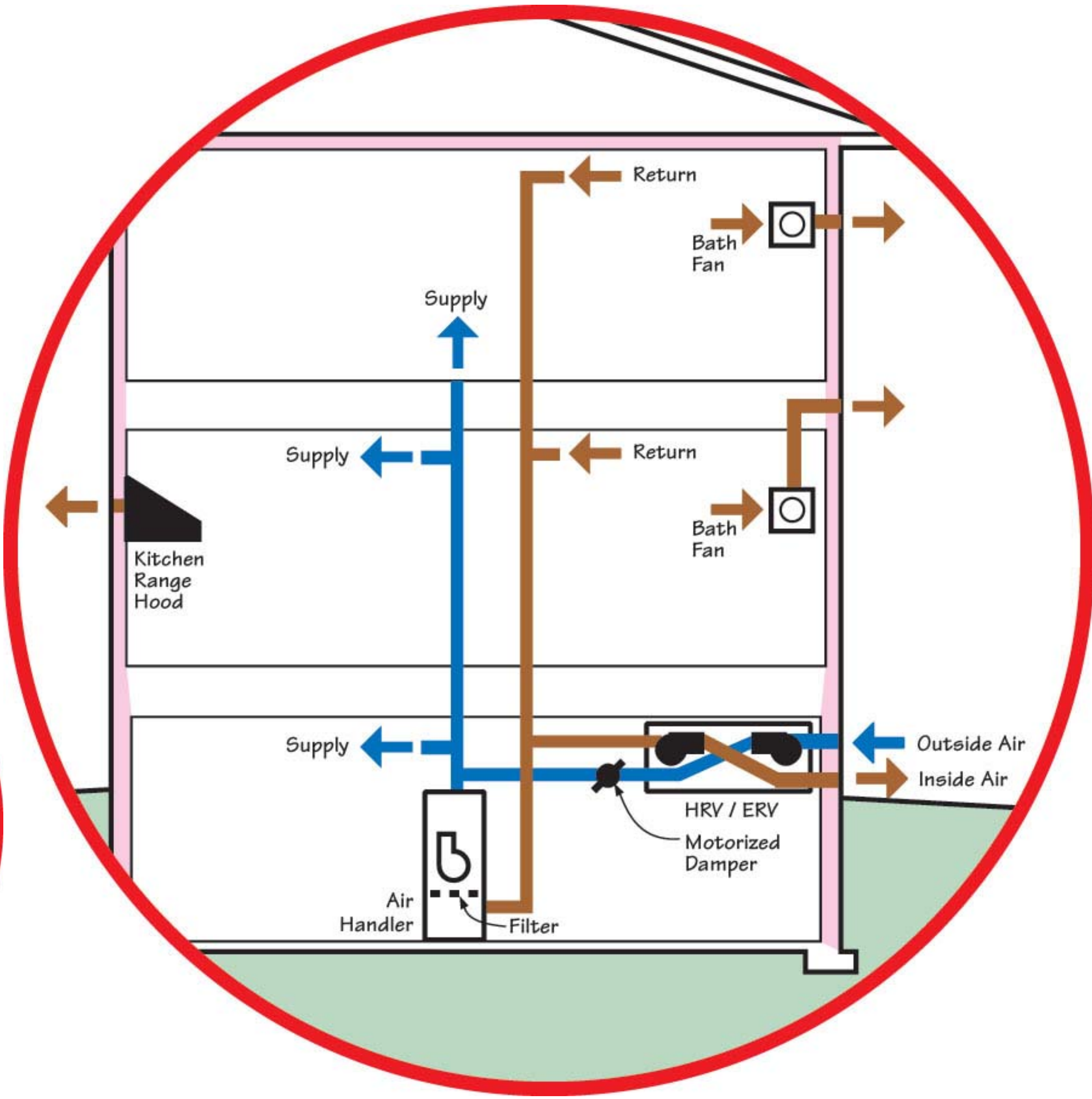
Phase 3

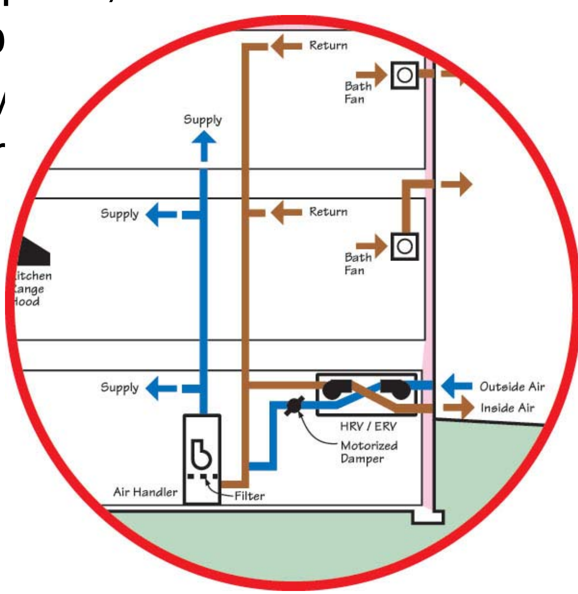
- Successful solution was to upgrade any bathroom fan in the house to meet the 62.2 air flow and sone requirements
- That is the ventilation system of record for ratings or otherwise
- The occupant controls the fan on/off status. To meet 62.2, the compliant fan only needs to be there and be capable of being turned on as much or as little as desired.
- Then, outside of 62.2 requirements, and outside of an energy rating, and regardless of whether the occupant chooses to run the exhaust fan or not, the 6" outside air duct with central fan cycling is cheap insurance to protect the builder against complaints of thermal comfort and odor or moisture buildup.
- From an energy rating perspective, that should not be handled any differently than the FAN ON switch capability on every thermostat. Occupants can turn the central fan to ON at will and that would use far more energy than fan cycling.

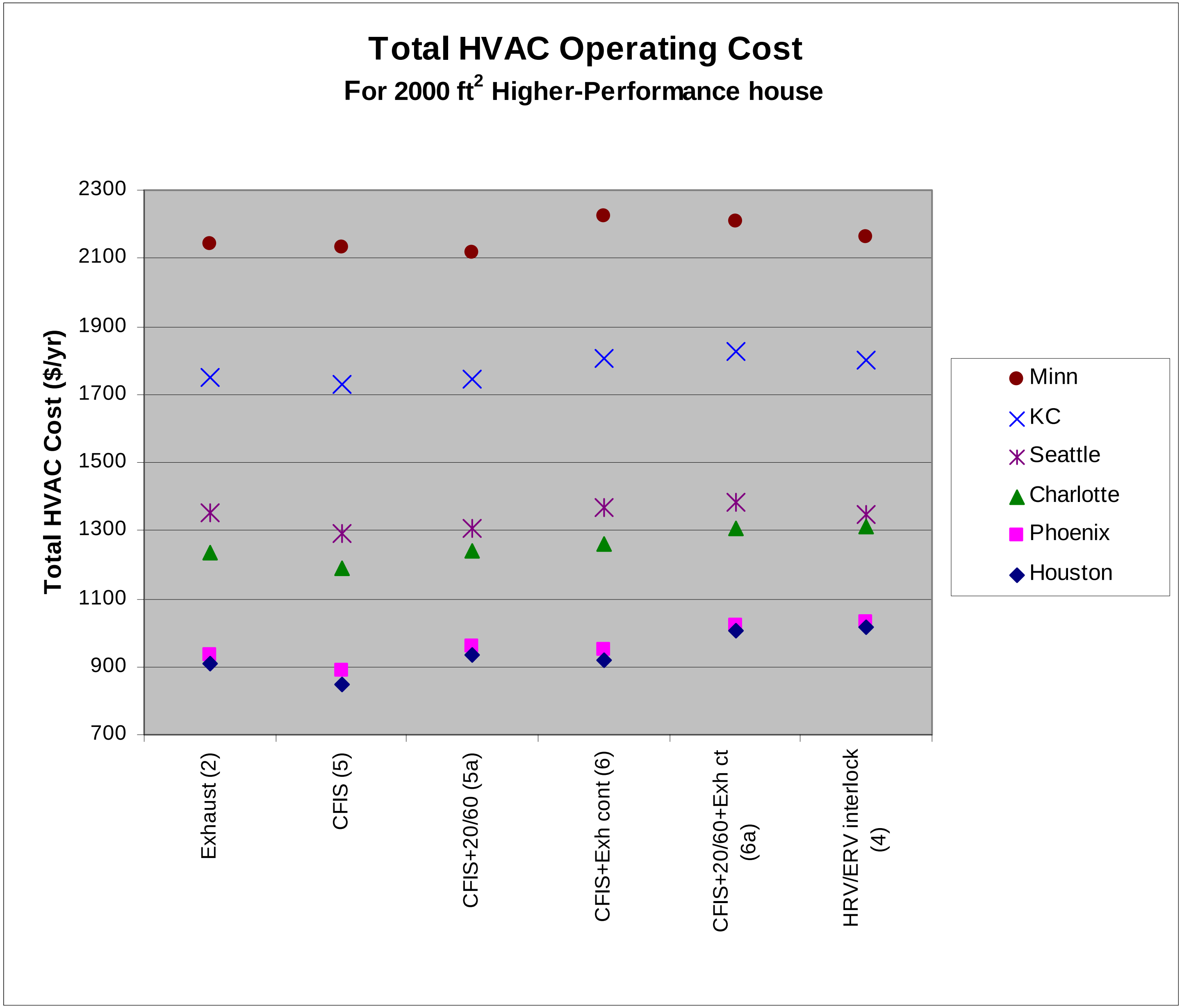

Annual average air change rate (1/h)
For 2000 ft2 Higher-Performance house
Annual average air change rate (1/h)
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Exhaust (2)
CFIS (5)
CFIS+20/60 (5a)
CFIS+Exh cont (6)
CFIS+20/60+Exh ct (6a)
HRV/ERV interlock (4)
Minn
KC
Seattle
Charlotte
Phoenix
Houston

Balanced ventilation with heat or energy recovery (both sides integrated with central system ducts)

- Remote mounted ventilator pulling from the central system return plenum and injecting into the central supply plenum
- Requires coincident operation of the central air handler
- Increases fan energy consumption, and constant operatio
humidity
summer



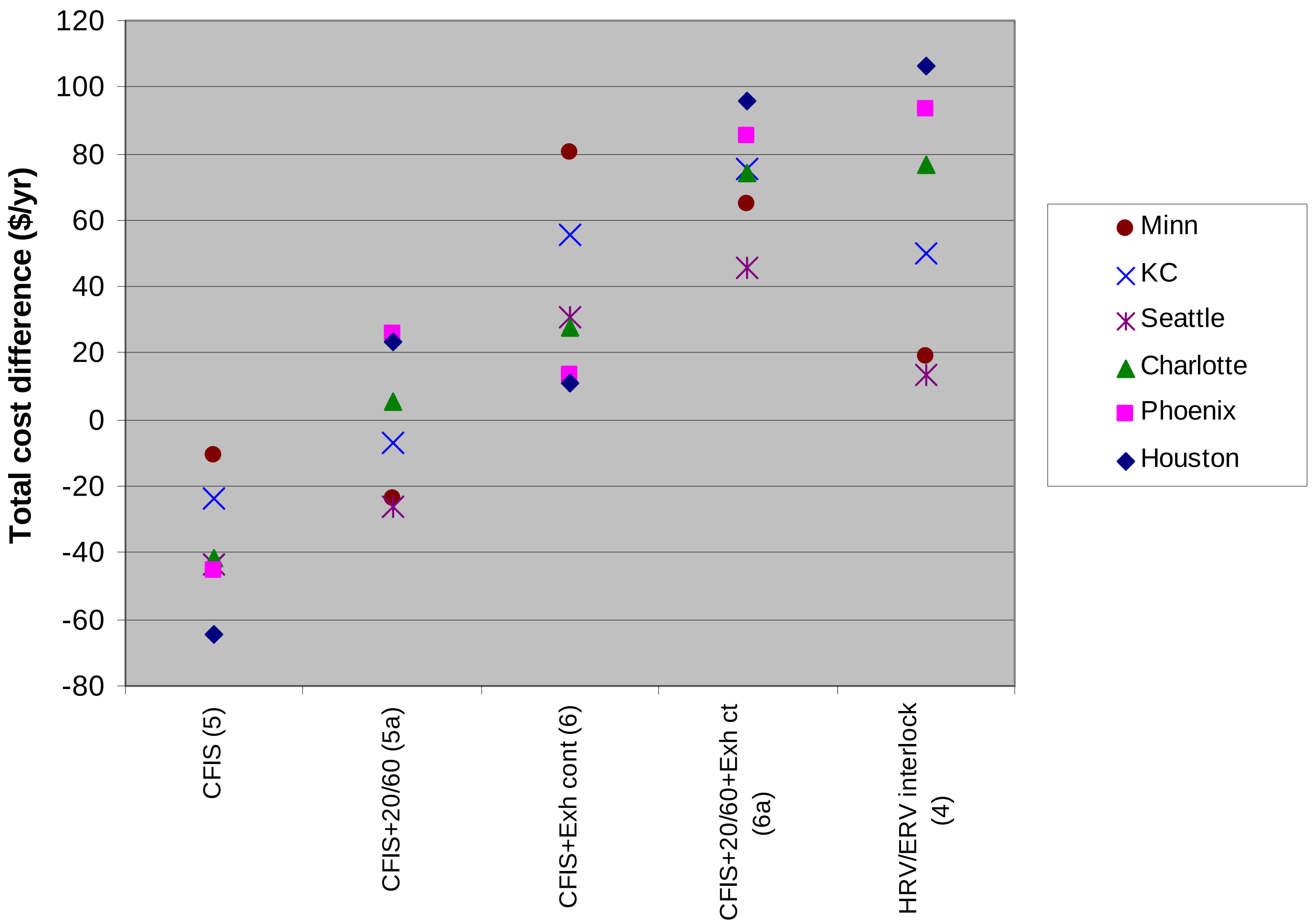


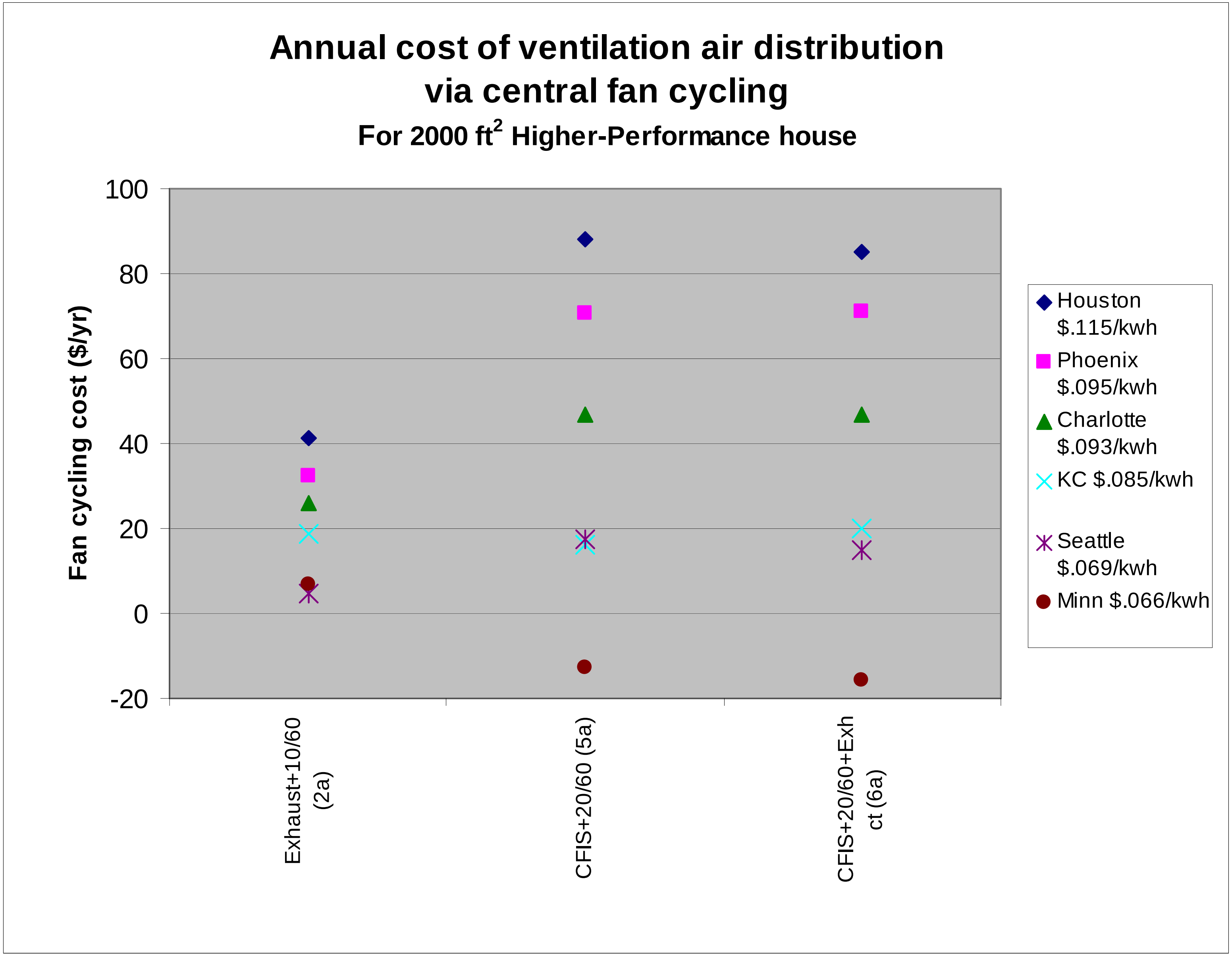


Total HVAC Operating Cost
For 2000 ft2 Higher-Performance house
Total HVAC Cost ($/yr)
2300
2100
1900
1700
1500
1300
1100
900
700
Exhaust (2)
CFIS (5)
CFIS+20/60 (5a)
CFIS+Exh cont (6)
CFIS+20/60+Exh ct (6a)
HRV/ERV interlock (4)
Minn
KC
Seattle
Charlotte
Phoenix
Houston

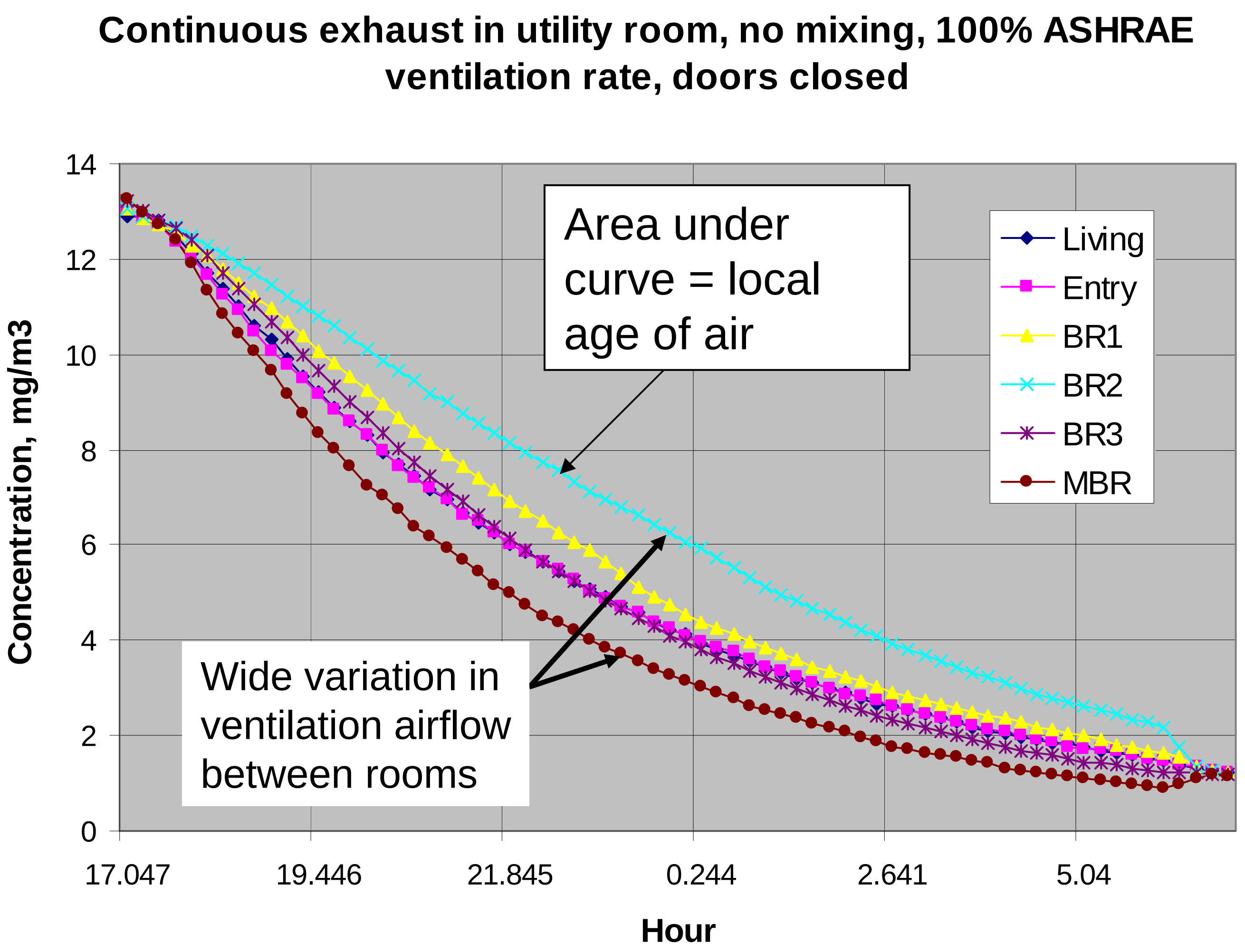
Total HVAC cost difference from System 2 (single-point exhaust)

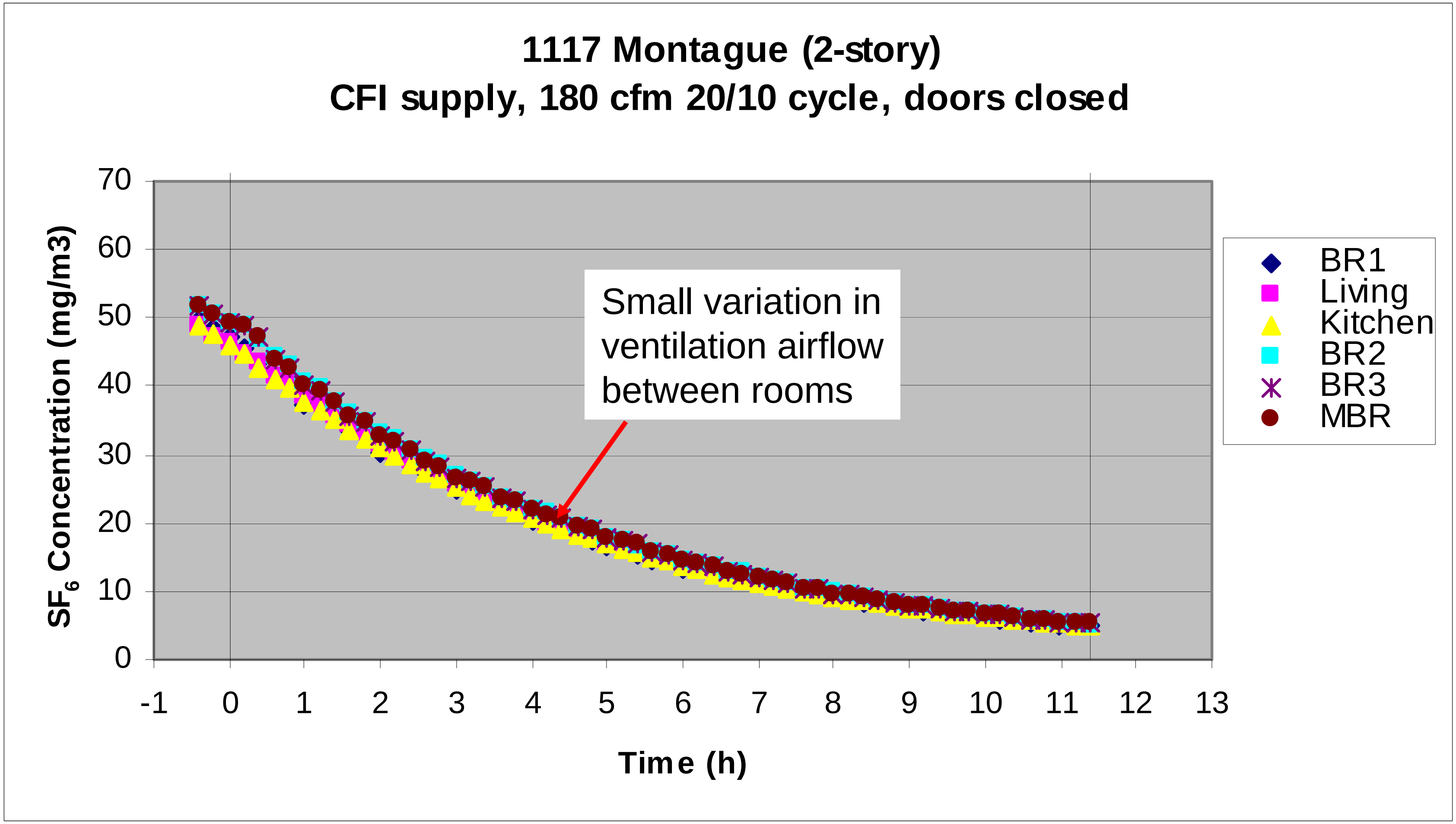
For 2000 ft^2 Higher-Performance house



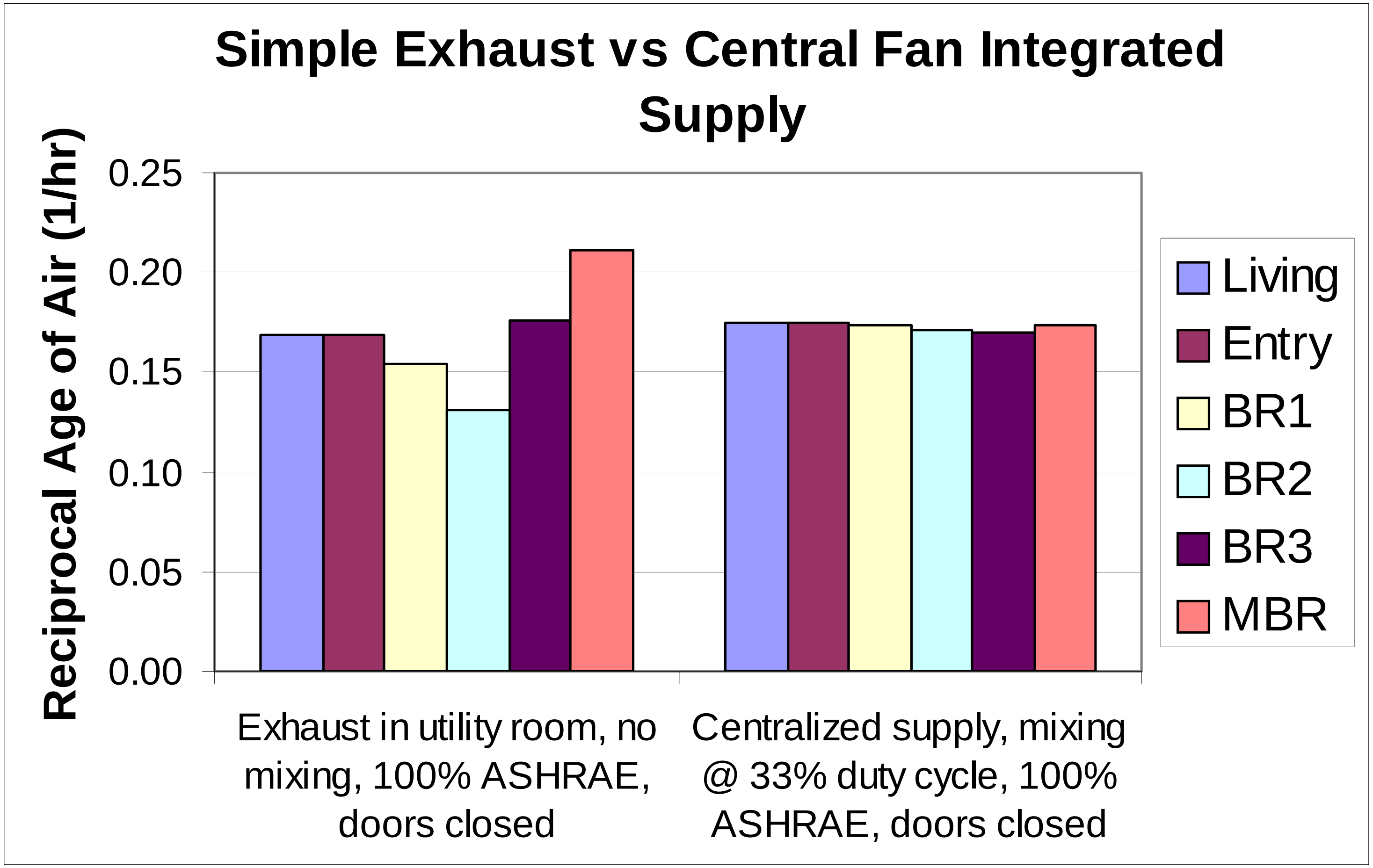

Annual cost of ventilation air distribution
via central fan cycling
For 2000 ft2 Higher-Performance house
Fan cycling cost ($/yr)
100
80
60
40
20
0
-20
Exhaust+10/60 (2a)
CFIS+20/60 (5a)
CFIS+20/60+Exhct (6a)
Houston $.115/kwh
Phoenix $.095/kwh
Charlotte $.093/kwh
KC $.085/kwh
Seattle $.069/kwh
Minn $.066/kwh

Age-Of-Air Calculation




1117 Montague (2-story)
CFI supply, 180 cfm 20/10 cycle, doors closed
Small variation in ventilation airflow between rooms
SF6 Concentration (mg/m3)
Time (h)
70
60
50
40
30
20
10
0
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
BR1
Living
Kitchen
BR2
BR3
MBR

Reciprocal Age-of-Air Comparison



Reciprocal Age-of-Air Comparison