Residential HVAC Systems and Strategies:

Line of Sight and Horizons
Speaking Today

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• 20+ years of commercial and institutional HVAC design experience with a major A/E design firm
• A background in residential energy and performance research, systems design and integration, project management and delivery, building diagnostics and building commissioning
• Member of ASHRAE’s Residential Building Systems Technical Subcommittee
• Recently rejoined IBACOS
Diffuser research work with IBACOS in 1997
IBACOS Is About…
Collaborative Innovation for the Homebuilding Industry

• Innovation in the homebuilding industry must be embraced and driven strategically. Game-changing innovation cannot be achieved alone.

• IBACOS connects the right mix of people, intelligence and tools to drive the research of new ideas and to develop meaningful value propositions for new products and technologies.

• Innovation involves and impacts consumers, builders, suppliers, policy makers and the world.
Key Tenets

Seek to make homes:
- Safe
- Healthy
- Durable
- Comfortable
- Efficient
- Responsible
- Affordable
Learning Objectives

- Outline common performance issues that persist with conventional residential HVAC systems despite ongoing improvements in home energy efficiency.
- Recognize current residential sector trends and practices that impact HVAC system selection and performance, and ultimately influence customer expectations.
- Identify some of the latest residential HVAC systems solutions and strategies that can be implemented today to raise the bar towards high performance.
- Recognize ways that the residential construction market is changing and how residential HVAC systems and strategies can be expected to evolve over the next 5-10 years.
Topics for Today

• Common residential HVAC performance issues

• Residential trends impacting design and practices

• Latest high-performance HVAC programs, strategies and systems

• Evolving markets and expected HVAC impacts, with some glimpses of what may be on the horizon.
Common Residential HVAC Performance Issues

- Struggles to save energy
- Lack of comfort
- Poor indoor air quality (IAQ)
- Intrusive noise
- Excessive cost to operate
- Ongoing reliability issues

These are homeowner experiences, and builders risks, but what are contributing root issues and causes?
Root Causes for Performance Issues

1. Inaccurate load assessments
   - Calculations and reality don’t match
2. Incorrect equipment or setup
3. Incorrect system airflows
4. Duct system leakage
   - Less air to spaces
   - Space loads unmet
   - Temperature excursions
   - Longer run time possible if Tstat impacted
   - Less mixing into space
   - Excessive heating /cooling to unintended areas
   - Energy loss to outdoors
Root Causes for Performance Issues

5. Duct design
   • Supply or return

6. Inadequate duct insulation
   • Excessive supply air temperature gain or loss “in transit”
   • Space loads unmet
   • Temperature excursions
   • Cooler supply air in winter may cause feeling of draftiness

7. Improper or inadequate balancing

8. Refrigerant charge

9. Mixing issues impact space temperatures and ventilation effectiveness

10. Unbalanced exterior loads
Residential Trends Impacting Design and Practices

• What drives trends?
• What are some trends and impacts to HVAC systems?
What Drives Housing Industry Trends?

1. Consumer demand, values, beliefs and preferences
   A. Dollar value (microeconomic)
   B. Convenience
   C. Health
   D. Sustainability
   E. Happiness and peace of mind
What Drives Housing Industry Trends?

2. Demographics - Widening range of demands
   A. Family types
   B. Millennials
   C. Gen X
   D. Boomers
   E. Aging in place
What Drives Housing Industry Trends?

3. Technology developments
   A. Materials
   B. Equipment and systems
   C. Home automation and sensors
   D. Information systems, including user interfaces
   E. Other industries
What Drives Housing Industry Trends?

4. Economic factors (macroeconomic)
   A. Overall (sense of) health of the economy = consumer confidence
   B. Relative housing costs
   C. Interest rates and lending environment
   D. Energy costs
What Drives Housing Industry Trends?

4. Economic factors *(continued)*

E. Competition (opportunity)
   - Among builders
   - Among manufacturers and suppliers
   - Results in marketing and advertising strategies

F. Risks for builders and contractors
What Drives Housing Industry Trends?

5. Government, utilities, and standards organizations
   A. Policy and codes
   B. Programs
   C. Subsidies and credits
   D. Consumer guidance
   E. Standards
Trends Impacting HVAC Systems and Strategies

1. Homebuyers are generally more savvy
   A. Society: Information-rich
   B. Use of gadgets & measurements
   C. Desire for user interaction
   D. Connectivity & smart technologies
   E. Seeking forward compatibility
   F. Cost-consciousness
   G. Verification of added value
   H. Choices: important
   I. Some demographics shun complexity
Information-Rich Society
Gadgets & Measurements

BMI Body Mass Index

EnergyGuide

IBACOS

9/29/2016 20
User Interaction, Controllability
Eager for Connectivity, Smart(er) Homes, Internet of Things

Impact on housing?
Forward Compatibility in a World of Change
Cost Conscious Consumers
Verification of Value
Choice Is Important, Don’t Want to Compromise
Complex User Interfaces Not Universally Preferred
Industry Trends Impacting HVAC Systems and Strategies

2. Lower heating and cooling loads
   A. Code and program driven
   B. Insulation
   C. Airtightness
   D. Windows
   E. Appliance and lighting efficiency standards

Source: US DOE Zero Energy Ready Home Program literature
Industry Trends Impacting HVAC Systems and Strategies

3. Emphasis on performance beyond energy use: lots of “-ilities”
   A. Comfort quality
   B. Indoor air quality
   C. Sound quality
   D. Maintainability
   E. Adjustability (individualized control)
   F. Reliability
   G. Durability
   H. Installability
Industry Trends Impacting HVAC Systems and Strategies

4. Marketing benefits more than features
   A. Builders
   B. Manufacturers
   C. Retrofit Contractors

5. Labor issues – availability and quality of workforce
Industry Trends Impacting HVAC Systems and Strategies

6. Energy conservation and environmental standards for equipment manufacturers, such as:
   A. Emerging new Fan Efficiency Rating (FER) requirements for residential furnaces, as mandated by the Energy Policy and Conservation Act (EPCA), to take effect in 2019
   B. Overall furnace energy conservation standards being amended
   C. Amended test procedures for energy performance of central AC units and air source heat pumps (ASHPs).
   D. Continued emphasis on refrigerants (EPA).
Industry Trends Impacting HVAC Systems and Strategies

7. Progressive construction and business models
   A. Modularized and manufactured construction
   B. Customer-for-life models
   C. Energy-efficient mortgages
Industry Trends Impacting HVAC Systems and Strategies

8. Responsible focus on renewables and community
   A. Recognize strains on resources
   B. Increased self-sufficiency at the home or community level
   C. Move toward carbon neutral
   D. Low embodied energy materials and systems with low life-cycle impact
Community-Based Self-Sufficiency

Vauban sustainable model district near Freiburg, Germany
Move Toward Carbon Neutral
# Reduced Embodied Energy and Life-Cycle Impact

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<th>Material</th>
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![Diagram of life cycle impact](image.png)
Latest High-Performance HVAC Programs, Strategies and Systems
Programs

Latest High-Performance HVAC Programs, Strategies and Systems
Strategies
Right Sizing

- Affects energy cost, comfort, IAQ, noise and reliability
- Shorter run times reduce mixing, increase remote room temperature float, and provide less effective latent removal

Advanced Thermostats

- Affect energy cost +; comfort +
- Dead band between heating and cooling
- Programmable
- “Smart”
- Equip with adaptive recovery for air source heat pumps to save energy
- Feedback on energy use, runtime, filter and humidifier maintenance

https://basc.pnnl.gov/resource-guides/thermostat-controls#quicktabs-guides=0
Duct System Sealing and Testing

- Impacts: energy cost, IAQ and comfort
- Seal all seams, gaps, and holes of all trunk duct connections before insulating duct
- Mastic seals well and is visible
- Seal blower cabinet seams, leave tape behind
- Perform visual inspection before pressure test
Duct System Sealing and Testing (continued)

• Duct blaster: target leakage age to outdoors is $\leq 4 \text{ cfm}^2/100 \text{ sf}$ of conditioned floor area (5 cfm$^2$ for homes $<1200 \text{ sf}$)
• Max total leakage is $8 \text{ cfm}^2$ per 100 sf
• Injected aerosol spray sealant is another option

https://basc.pnnl.gov/resource-guides/duct-leakage-outdoors#quicktabs-guides=6

https://basc.pnnl.gov/resource-guides/total-duct-leakage-tests

https://basc.pnnl.gov/resource-guides/total-duct-leakage-tests
Bring Ducts and Equipment into Conditioned Space

- Impacts: comfort; energy cost
- Sealed crawlspace or basement
- Unvented attic space
- Integrated with interior framing system: stud bays, open web joists, etc.
- Furr-downs, soffits, bulkheads, dropped ceilings
- Inverted soffits
Compact Ducts

- Impacts comfort, energy costs
- Saves material, time, cost
- For better enclosures, better diffusers
Compact Ducts (continued)


https://basc.pnnl.gov/resource-guides/compact-air-distribution
Zoned Ducted HVAC

• Impacts: comfort; energy cost
• Adds convenience, individualized control, flexibility for occupants
• But can increase energy use if constant setpoints are applied across zones
• Can increase noise, reduce moisture control, or cause system instability if misapplied
Zoned Ducted HVAC (continued)

• Adds some complexity and limitations for designer to provide a system that performs well overall

• Better systems have no bypass, 350 cfm/ton in all modes, \( \leq 0.58 \text{ watt}/\text{cfm} \)

• ACCA Manual Zr and CA Title 24 offer guidance

https://www.acca.org/store?webproductid=f878500f-bc20-e511-80fa-c4346bacebf4

Zoned Ducted HVAC (continued)

• At a minimum, coordinate the duct system design to permit access to seasonal adjustment dampers
• Indicate summer and winter damper positions
• Don’t leave homeowner with hands tied from making adjustments
Designed Return Air Paths

- Affect comfort, IAQ, noise
- Over-the-door transfer
- Offset privacy transfer
- Jump duct
- Dedicated return
- Door undercut is traditionally inadequate

https://basc.pnnl.gov/resource-guides/jump-ducts
https://basc.pnnl.gov/resource-guides/transfer-grilles
Ventilation

- Impacts IAQ, energy cost
- Install mechanical ventilation
- Tighten house to threshold
- Confirm flow
- Positive
- Negative
- Balanced
- Climate dependent
- Distribute
- Consider scheduling
Air Filtration

- Affects IAQ, energy cost
- MERV = Minimum Efficiency Reporting Value
- Filtration in air handler requires efficient air distribution and controls
- Don’t need HEPA
  - MERV16 almost as good
  - MERV13 gets you most of the benefit – use for filtering outdoor air
Air Filtration (continued)

• Be careful about supply filtration
  • Run-time vent systems may only operate when heating/cooling
  • MERV-6 generally accepted
  • MERV-8 required for ZERH per EPA Indoor airPLUS program
• Airtight shell serves like MERV13 or better

https://basc.pnnl.gov/resource-guides/high-merv-filter
Energy Recovery Ventilators

- Impact: comfort, IAQ, energy cost
- Up to 93% efficient heat (temperature) recovery between exhaust and ventilation airstreams – claims of higher
- ~80% efficient total energy recovery
- Options for energy recovery including moisture exchange using enthalpic cores
- Typically a fixed-plate cross-counterflow heat exchanger core arrangement – low leakage
Energy Recovery Ventilators (continued)

- ECM motors
- 75 – 300+ cfm capacities
- Single point and ducted distribution units available
- Switchable modes: HRV to ERV
- Tight homes in humid climates – consider dehumidifiers over ERV for better performance
Ceiling Fans

• Impact comfort, energy cost, noise
• Simple, inexpensive, convenient, multi-speed, quiet, efficient designs, remote controlled
• Soon can be integrated into a connected home’s control system

https://basc.pnnl.gov/resource-guides/ceiling-fans-energy-star
“Commissioning”

- A collection of tasks that are presently each a part of high performance home delivery, i.e.:
  - System checks
  - Startup
  - Airflow, refrigerant charge
  - Balancing?
  - Rater evaluations
  - Verify program requirements
“Commissioning”

- Impacts: comfort; IAQ; noise; energy cost; reliability
- Overall quality control opportunities

https://basc.pnnl.gov/information/energy-star-hvac-commissioning-checklist-3-indoor-hvac-fan-airflow

https://basc.pnnl.gov/information/energy-star-hvac-commissioning-checklist-2-refrigerant-charge

https://basc.pnnl.gov/information/energy-star-hvac-commissioning-checklist-4-air-balancing-supply-registers-return-grilles
“Aftermarket” In-Room Zoning System

• Adds room-by-room airflow and temperature control
• Intelligent, automatic adjusting vents replace room supply air registers
• In-room temperature sensors, plug into wall outlet
• Hub to network all sensors and actuators
• Controls central HVAC system
• Senses system pressure to avoid equipment damage
• DIY install if desired
• Mobile app
Small Capacity Equipment

- Furnaces
  - 18,000 btuh
- Condensing units
  - 1 ton
- Helps zoning
  - Analogous to distributed instantaneous water heaters
- Small ducts
  - High velocity
  - Medium velocity
  - Metal
  - Flexible
  - Acoustic
Variable Speed and Capacity

- ECM Motors
- Blowers
- Multistage and variable capacity furnaces
- Multistage and variable capacity condensing units and heat pumps
- Can help right sizing issues and latent removal
- Good with latent-based control algorithms
Mini-Split Heat Pumps

- Small capacity
  - 9,000, 12,000, and 15,000 btuh
  - Multiple indoor head units per outdoor unit
  - Each room has its own air handler connected to a compact outside unit
  - Good for low loads, low square footage
  - No ductwork required but optional: ductless and ducted
- Help stratification issues
Mini-Split Heat Pumps

- Traditionally unsightly but improving
- Low ambient air source heat pumps
  - Higher COP’s at lower outdoor temperatures than in past
- Ducted versions can be concealed
Ground Source Heat Pumps

- Can provide heating and cooling
- Uses basic refrigeration cycle for heating and cooling
- Earth, ground water or surface water is the heat sink
- Can be used for heat only in colder climates
- Getting lots of press, additional research, creative financing and ownership models for loop field
- Possible opportunities for loop as a community utility
Evolving Markets and Expected HVAC Impacts

• Look to California for changes: Zero Energy by 2020
• Net Positive Homes – Homes that Give Back
• Site Manufactured Homes
Refrigerant Changes

• Natural refrigerants, Hydrofluoroolefins (HFO’s)
• Zero ozone depletion, low to no global warming potential
• Balance environmental benefits with energy efficiency
• Ripple effect: lubricants, manufacturing, service protocols, equipment characteristics
Connected-Home HVAC Services

- Comprehensive HVAC monitoring service
- Real-time information provided to help occupant manage the heating and cooling systems
- Expert system to predict and diagnose problem conditions in home or with equipment
- Offers equipment protection, optimizes effectiveness and efficiency
- Monitoring service, homeowner, and service professional networked together
- Live data, regular reporting, alerts as needed
Smart Whole House Ventilation (IAQ) Management Systems

- All air transferred in or out of home is managed
- Constant or interval air delivery
- Knowledge of ventilation provided over recent hours
- Knowledge of occupancy status
- Respond to intermittent exhausts: dryer, bathroom fans, kitchen hood
- Respond to outdoor temperature and moisture levels to minimize loads to house
- Sense contaminants and respond: particulates, CO2, VOC’s etc.
- Incorporate energy recovery
Commissioning 2.0

• Commissioning is a quality-focused process for enhancing the successful delivery of a building or retrofit project. Focus on Process.
• The process focuses upon verifying and documenting that the home and its systems and assemblies are planned, designed, installed, tested, to meet the Project Requirements set forth by the Project Initiator, and the Design Intent.
• It also establishes a guidance program for operation and maintenance to reflect the Design Intent.
• It is a Managed, Systematic, and well-documented Process where communication is key
• It is not just a series of testing activities or a set of checklists
• What systems can be cx’d?
  • HVAC, Electrical, Plumbing, Architectural
  • Basically any System or Assembly that has performance characteristics and performance expectations
• Systems that directly utilize (and thus could waste) energy can benefit from Commissioning
Horizon Items

- Variable refrigerant flow (VRF)
  - Extension of the mini-split heat pump concept
  - Simultaneous heating and cooling?
- Wearables
  - Sensing personal comfort and health
  - Thermally responsive clothing, devices
  - Optical head-mounted display
    - Opportunities for service and communication with customers
Horizon Items

- Dedicated Outdoor Air (DOAS) Systems for Homes
- Community Scale Heating / Cooling / Power
- 3D printing technology for customized solutions
- Simplified system packages requiring less labor
- Building-integrated HVAC systems and sensors
- Return of natural ventilation
- Occupant sensing system response
- Biological integration
  - Systems that scrub the air for example
Plug-n-Play Duct System

- Project Goal is to develop a simplified small-diameter residential air delivery system as a solution to the air distribution and comfort delivery issues in low-load production-built homes.
- System is assembled in a homerun arrangement from a kit-of-parts with a limited number of components.
- A straight-forward design methodology and companion guidance document accompany the system.
- Success Metrics: Duct system is easily integrated within the home’s conditioned space, installed with less cost, error and waste, and offers predictable performance to help deliver comfort in low-load homes.
Evolving Markets and Expected HVAC Impacts

Thermal Comfort Rating Metric (TCRM)

• Evaluate the need for, and feasibility of, a Thermal Comfort Rating Method (TCRM) for the residential sector.

• The TCRM is envisioned as an asset rating system that represents, in simple terms, a home’s overall ability to provide thermal comfort to its occupants under varying conditions and demands.

• The metric would give builders and homeowners a tool to make value-based decisions regarding thermal comfort performance in the context of energy efficiency.

• Vision: A comfort performance metric similar to, and able to work with, the Home Energy Rating System (HERS) index for energy efficiency and other developing residential sector asset ratings (IAQ, water efficiency, etc.)

• Use as a consistent comfort-based metric to evaluate and demonstrate value of concepts in Building America projects
The U.S. Department of Energy Building America Program has been a source of innovations in residential building energy performance, durability, quality, affordability, and comfort for more than 20 years.

This world-class research program partners with industry to bring cutting-edge innovations and resources to market.
Where can I find resources?

**Building America Solution Center**
Proven Innovations from World-Class Research...
at Your Finger Tips
[https://basc.pnnl.gov](https://basc.pnnl.gov)

**Building America Website**
Research Projects, Webinars, Monthly Newsletter,
Funding Opportunity Announcements
[www.buildingamerica.gov](http://www.buildingamerica.gov)

**Zero Energy Ready Home Program**
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