Low-Load HVAC Systems for Single and Multifamily Applications

Anthony Grisolia
Managing Director
Innovation Programs

Andrew Poerschke
Specialist
Innovation Programs
Agenda

Basis for Thermal Comfort
Comparative Modeling
Newtown Townhouse Case Study
Plug and Play System
Future Work
How IBACOS Thinks About Comfort Risks
ASHRAE 55
Comfort

Home 24

Same Plan
Same Street
Same Orientation

Different Occupants

Home 25

Home 26

0.5 CLO
1.0 MET
Aggregate of 36 Homes

36 Homes, Month of September

Median setpoint: 75°F

47% of data within box

Humidity Ratio, \( \frac{\dot{m}_{\text{water}}}{\dot{m}_{\text{dry air}}} \)

Normalized Density

Dry Bulb Temperature, °F

0.000
0.005
0.010
0.015
0.020
0.025
0.030

0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
0.22
0.24
0.26
0.28
0.30
0.32
0.34
0.36
0.38
0.40
0.42
0.44
0.46
0.48
0.50
0.52
0.54
0.56
0.58
0.60
0.62
0.64
0.66
0.68
0.70
0.72
0.74
0.76
0.78
0.80
0.82
0.84
0.86
0.88
0.90
0.92

0.5 CLO
1.0 MET
ACCA Comfort, Cumulative Density, 36 Homes

95% of the time, homes are comfortable at a maximum room-to-room ΔT (°F) of 6.0.

ACCA Comfort Threshold:

36 Homes, Month of September
Callback Risk, Hypothetical Curve
Factors Impacting Comfort

Employment

Use of programmable thermostat
Impact of Number of Stories on Comfort
Key Lessons Learned

- “Comfortable” homes can have a wide range of temperatures
- Uniformity is a better metric for judging comfort
- Humidity maintained below 60% without active dehumidification
- Comfort guarantee has added upfront costs, but builders feel it is worth it
Comparative Modeling

TRNSYS Multizone Thermal Model
99 Models
  3 Home Geometries
  3 Climate Zones
  3 System Types
  5 Control Strategies
# Zero Energy Ready Home Enclosure

**MSHP, Traditional Central, Small Diameter**

<table>
<thead>
<tr>
<th></th>
<th>Scenario</th>
<th>Details</th>
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<tbody>
<tr>
<td>1</td>
<td>Single Zone, Single Thermostat</td>
<td>Standard set points: 71°F heating, 76°F cooling</td>
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<tr>
<td>2</td>
<td>Single Zone, Two Thermostats</td>
<td>System runs if one thermostat calls for conditioning. Determine ideal location for second thermostat (e.g., South Bedroom, West Bedroom).</td>
</tr>
<tr>
<td>3</td>
<td>Two Zone, Two Thermostats</td>
<td>Determine ideal location for second thermostat (e.g., South Bedroom, West Bedroom).</td>
</tr>
<tr>
<td>4</td>
<td>Single Zone, Single Thermostat, Fan On</td>
<td>Constant fan operation, conditioning supplied only as called for by the thermostat.</td>
</tr>
<tr>
<td>5</td>
<td>Clever Thermostat</td>
<td>Thermostat reads the weather forecast at the top of each hour and cycles fan during conditions that typically would result in asymmetric loads (e.g., sunny midseason day).</td>
</tr>
</tbody>
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**Single Story Slab**  
**Two Story Slab**  
**Two Story Basement**
Simple floorplan easy to condition

MSHP among best performers, zone system

In some cases continuous fan made improvements

Differences between small diameter and traditional systems not captured in model
<table>
<thead>
<tr>
<th></th>
<th>Single Story Ranch</th>
<th>Two Story Slab</th>
<th>Two Story Basement</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSHP</td>
<td>Orlando</td>
<td>Fresno</td>
<td>Denver</td>
</tr>
<tr>
<td>Winter Overheating</td>
<td>88.5% 1.66°F 0.15°F</td>
<td>96.3% 1.04°F -0.19°F</td>
<td>94.4% 1.15°F -0.56°F</td>
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<tr>
<td></td>
<td>Orlando</td>
<td>Fresno</td>
<td>Denver</td>
</tr>
<tr>
<td></td>
<td>85.3% 1.40°F 1.05°F</td>
<td>96.4% 1.05°F -0.31°F</td>
<td>95.1% 1.17°F -0.56°F</td>
</tr>
<tr>
<td></td>
<td>Orlando</td>
<td>Fresno</td>
<td>Denver</td>
</tr>
<tr>
<td></td>
<td>81.3% 2.23°F 0.65°F</td>
<td>82.8% 2.08°F 0.56°F</td>
<td>82.8% 2.20°F 0.56°F</td>
</tr>
</tbody>
</table>

|                | Traditional 1 Zone 1 Zone 2 Zone 2 Systems Continuous Responsive |
|                | Orlando    | Fresno    | Denver             |
|                | Orlando    | Fresno    | Denver             |
|                | Orlando    | Fresno    | Denver             |
|                | Orlando    | Fresno    | Denver             |
|                | Orlando    | Fresno    | Denver             |
|                | Orlando    | Fresno    | Denver             |
|                | Orlando    | Fresno    | Denver             |
|                | Orlando    | Fresno    | Denver             |
|                | Orlando    | Fresno    | Denver             |
|                | Orlando    | Fresno    | Denver             |

Legend: winter green spring yellow summer red fall
Animated Plan: Summer
Animated Plan: Winter
Animated Plan: All Homes
Lessons Learned

Geometry design and HVAC design are highly interdependent. In a low load home, you can’t drop in a system and hope it works.

Single floor plan with central connecting space easiest to condition

Window orientation and percentage of wall area significantly impacted comfort. In these cases two thermostats or two systems necessary.

Climate zones with large diurnal swings greater challenge to condition, thermal mass may help. Continuous fan can also help by mixing top and bottom floors.

What works in one home might not work in another.
Shrinking Thermal Loads

2,000 SQ. FT.  5 tons – 2,000 CFM
Past  400 SQ. FT. / TON

2,000 SQ. FT.  3 tons – 1,200 CFM
Present  667 SQ. FT. / TON

2,000 SQ. FT.  1.5 tons – 600 CFM
Future  1333 SQ. FT. / TON
Challenge:
Providing comfort and efficiency in low load homes
Air Delivery is Key
Multifamily Case Study
Comparing Small Diameter to Traditional Ductwork

Denver, CO
Stapleton Community
Newtown Builders
3 Unit Town Homes
Cooling Season Data
Project Overview

Unico
- Small Diameter
- MSHP

Standard
- Central DX

A1  A2  A3

B3  B2  B1
# Home Specifications

<table>
<thead>
<tr>
<th>Design Cooling Load (kBtu/h)</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
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</thead>
<tbody>
<tr>
<td>16</td>
<td>13</td>
<td>18</td>
<td>16</td>
<td>13</td>
<td>18</td>
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</table>

<table>
<thead>
<tr>
<th>Air Conditioner Rated Capacity (kBtu/h)</th>
<th>24</th>
<th>24</th>
<th>36</th>
<th>24</th>
<th>18</th>
<th>24</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Outdoor Unit Model</th>
<th>IS24G065</th>
<th>IS24G065</th>
<th>IS36G110</th>
<th>CA13NA24</th>
<th>CA13NA18</th>
<th>CA13NA24</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>Air Handling Unit Model</th>
<th>M2430BL1-EA2</th>
<th>M2430BL1-EA2</th>
<th>IS12MPA</th>
<th>59SC2C040S17</th>
<th>59SC2C040S17</th>
<th>59SC2C040S17</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Ductwork Location</th>
<th>Conditioned space</th>
<th>Conditioned space</th>
<th>Conditioned space</th>
<th>Conditioned space</th>
<th>Conditioned space</th>
<th>Conditioned space</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Air Handling Unit Location</th>
<th>Second floor</th>
<th>Second floor</th>
<th>High wall fan coil</th>
<th>First floor</th>
<th>First floor</th>
<th>First floor</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Building Measured Air Leakage (ACH 50)</th>
<th>2.97</th>
<th>3.49</th>
<th>3.98</th>
<th>2.15</th>
<th>2.73</th>
<th>3.18</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Building Measured Air Leakage (CFM 50)</th>
<th>857</th>
<th>750</th>
<th>993</th>
<th>632</th>
<th>585</th>
<th>792</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Ductwork Measured Air Leakage (CFM @ 25 Pa)</th>
<th>54</th>
<th>47</th>
<th>N/A</th>
<th>5</th>
<th>5</th>
<th>na</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>Floor Area</th>
<th>1,300 ft²</th>
<th>1,100 ft²</th>
<th>1,600 ft²</th>
<th>1,300 ft²</th>
<th>1,100 ft²</th>
<th>1,600 ft²</th>
</tr>
</thead>
</table>

| SF / Ton | 977 | 1018 | 1067 | 977 | 1018 | 1068 |
Traditional Ductwork Layout

Floor 1

Floor 2

Floor 3
Small Diameter Ductwork Layout
Small Diameter Ductwork

Register not yet installed

2.5” Branch Duct

Bend to cause restriction and balance airflow.

8” Trunk
Room-to-Room Temperature Performance

Small Diameter  MSHP  Central DX

max room to room
- A1
- A2
- A3
- B1
- B2
- B3
CO2 in Main Living Space of Each Home

A3 - Unoccupied
Psychrometrics and ASHRAE 55 Comfort Box

Data from 9 days plotted
“Hair” Plot Explanation

Balanced System Should Maintain Temperature Uniformity
Small Diameter System Hair Plots

A1

Short System Cycles

Median duration = 9 minutes
% above 6 °F = 1%

A2

Median duration = 10 minutes
% above 6 °F = 0%
Traditional System Hair Plots

B1

System Off — System On
Median duration = 17 minutes
% above 6°F = 0%

B2

System Off — System On
Median duration = 15 minutes
% above 6°F = 21%

B3

System Off — System On
Median duration = 28 minutes
% above 6°F = 57%

R-to-R gets worse during system on cycle
Room-to-Thermostat Temperature

Drift during unoccupied period

Entry slightly warmer, balancing risk during winter

Humidifier?

May perform better in winter
Room-to-Room Temperature Difference

Red indicates $\Delta T$ beyond 6°F
Cumulative Energy Use

Unoccupied MSHP uses most energy? - no shades - no natural ventilation

Would use more energy if normalized for occupancy

Unoccupied MSHP uses most energy?
- no shades
- no natural ventilation
# System Performance Summary

<table>
<thead>
<tr>
<th></th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total HVAC Energy (kWh)</td>
<td>109</td>
<td>103</td>
<td>140</td>
<td>116</td>
<td>90</td>
<td>104</td>
</tr>
<tr>
<td>Average Daily Runtime (min)</td>
<td>297</td>
<td>562</td>
<td>N/A</td>
<td>415</td>
<td>358</td>
<td>324</td>
</tr>
<tr>
<td>Average Thermostat (°F)</td>
<td>74.6</td>
<td>72.1</td>
<td>72.8</td>
<td>72.5</td>
<td>76.1</td>
<td>73.3</td>
</tr>
<tr>
<td>Average Room-to-Room ΔT (°F)</td>
<td>2.4</td>
<td>2.1</td>
<td>6.4</td>
<td>2.6</td>
<td>4.8</td>
<td>6.6</td>
</tr>
</tbody>
</table>

![Diagram showing system layout and energy consumption](image)

*Small Diameter, MSHP, Central DX*
Tips for Success for Small Diameter Systems

Evenly space take-offs from plenum
Branch ducts 6 – 10 ft long.
Commission system at rough in stage
1.2-1.8 in. w.c. target. 1.5 in. optimal
Home Run Manifold System

Plug and Play Design Methodology
Predictable airflows
Easily fits within conditioned space
Mock Duct Layout
### Performance Results

<table>
<thead>
<tr>
<th>Duct Number</th>
<th>Airflow (CFM)</th>
<th>Length (ft)</th>
<th>Number of Bends</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>1</td>
<td>17</td>
<td>19</td>
<td>19</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>16</td>
<td>16</td>
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<td>3</td>
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<td>16</td>
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<td>4</td>
<td>12</td>
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<td>14</td>
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<td>5</td>
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<td>15</td>
<td>15</td>
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<td>6</td>
<td>14</td>
<td>15</td>
<td>15</td>
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<td>7</td>
<td>18</td>
<td>20</td>
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<td>8</td>
<td>16</td>
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<td>10</td>
<td>21</td>
<td>23</td>
<td>24</td>
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</tbody>
</table>

| Power (Watts) | 26.3 | 32.6 | 39.2 |
| Total CFM     | 160  | 172  | 176  |
| Watt/CFM      | 0.16 | 0.19 | 0.22 |
| Static Pressure (Pa) | 43.0 | 48.4 | 51.5 |

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![Graph showing percent difference from median against duct length (ft). The graph includes data points for Duct Length (ft) on the x-axis and Percent Difference from Median on the y-axis. Different fan settings are represented by different colors: 176, 172, and 160 (CFM).](image)
Duct System and Fan Curves

Intersection represents point of operation

y = 6E-05x^{1.5459}
R^2 = 0.9985

Manifold system could be compatible with many systems on the market
Summary of Findings

Manifold system shows predictable airflow

Static pressure minimized by using smooth pipe, and compact duct layout

Can supply enough airflow to meet thermal demand of low load homes, may need two systems for larger homes

Potential for easy seasonal balancing from centralized location
Where are we going?

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<thead>
<tr>
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<tbody>
<tr>
<td><strong>System Design</strong></td>
<td><strong>System Design, Installation/Commissioning, &amp; Maintenance</strong></td>
<td><strong>Assess Load Profiles/Market Demand for Low-Load Homes</strong></td>
<td><strong>Manufacturers Develop Low-Load HVAC and Dehumidification for whole house comfort. Address design &amp; installation issues</strong></td>
<td><strong>Clear Design Standards. Address comfort criteria in Low-Load Homes (e.g., ACCA, ASHRAE)</strong></td>
<td><strong>I-Codes Adopt Low-Load Design and Performance Standards</strong></td>
</tr>
<tr>
<td><strong>Develop System Design Procedures/Tools &amp; Comfort Metrics/Criteria for Low-Load Homes</strong></td>
<td><strong>Validate/Demonstrate Comfort System Solutions in Low-Load Homes using Comfort Metrics/Criteria</strong></td>
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<tr>
<td><strong>Smart Systems</strong></td>
<td><strong>Best Practice Guidance/Training/Tools on System Design</strong></td>
<td><strong>Manufacturers Develop Automated FDD &amp; Optimization Controls</strong></td>
<td><strong>FDD, Sensors/Controls, Metrics &amp; Performance Validation Standards (e.g., ACCA, ASTM)</strong></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td><strong>Address equipment &amp; distribution/comfort performance, learning &amp; wireless sensors/controls</strong></td>
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**Note:** CONFIDENTIAL 11/18/2015
Where Are We Going?
Plug and Play System

Further evolve the plug and play system in unoccupied field tests.

Exhaustive bench testing to develop design methodology.

Time and cost comparison with traditional systems.

Modeling exercise to understand risks and opportunities of manifold system.
Where are we going?
Thermal Comfort Rating Method

1. Focus is to score a home’s ability to deliver thermal comfort
2. Identify industry need for a Thermal Comfort rating for homes
3. Minimize risk to builders from comfort callbacks
4. Work with existing standards organizations to develop methodology
5. Give home buyers tools to compare the performance of homes and weight comfort with energy
Questions?

Anthony Grisolia  
agrisolia@ibacos.com

Andrew Poerschke  
apoerschke@ibacos.com