HVAC SIZING AND DESIGN PRINCIPLES
ABOUT SOUTHFACE

Southface promotes sustainable homes, workplaces and communities through education, research, advocacy and technical assistance.

www.southface.org
WHO ARE YOU?

• Name
• Organization/company
• How long have you been in the design, construction, contractor or enforcement industry?
LEARNING OBJECTIVES

• Identify code requirements regarding sizing, design, and selection of HVAC equipment and ducts
• Explain how the ACCA Manual J, S and D load calculation standards are used to determine appropriate sizing and design of ducts and HVAC equipment
• Describe the role the HVAC system plays in moisture control and the effect excessive moisture has on building durability and occupant comfort and health
• Define sensible and latent heat
• Review a completed load calculation printout for common errors and intentional inputs of incorrect data and identify examples of such errors
• Compare installed HVAC and duct systems to outputs of Manual J, S, and D to verify proper sizing and design
• Describe the consequences of improperly sized HVAC systems
AGENDA

Morning:
1. Introduction
2. The systems approach
3. HVAC Overview

LUNCH

Afternoon:
• How HVAC systems are sized & selected
• Distribution
• Practical applications

Please set phones to silent! We will have breaks!
A house is a system made up of interrelated parts:

- The building envelope
- Heating & cooling
- Ventilation (controlled)
- Water heating & distribution
- Lighting & appliances
THE BUILDING ENVELOPE

Building Thermal Envelope
  • Continuous Air Barrier (Pressure Boundary)
  • Complete Insulation Coverage (Thermal Boundary)

Thermal and Pressure Boundaries Make up the Building Envelope
Houses are systems

How do the following factors affect the performance of the HVAC system?

- Air tightness of building envelope
- Insulation installation
- Lighting & appliances
- Others?

*KY code requires 50% high efficacy lighting*
HVAC effectiveness is affected by other building components!
QUALITY COUNTS!

Improper HVAC design & installation can severely affect home performance!

- Poor comfort
- High energy consumption & cost
- Unhealthy IAQ
- Equipment & building durability
- Combustion safety
THE FUTURE IS NOW!

Proper design and installation are becoming increasingly important as standards & technology become more advanced.

- Codes require envelope & duct sealing measures.
- Sophisticated equipment choices require knowledgeable design & installation.
HVAC OVERVIEW

- Purpose
- Function
- Design (sizing)
The purpose of the HVAC system is to provide the occupants with a comfortable & healthy living environment

- It does more than just control air temperature
- It also provides moisture control
- Controlling relative humidity is important for comfort, IAQ, and building durability
MOISTURE AND COMFORT

Human Thermal Comfort:

• Humans make poor thermometers
• Our sense of hot or cold is based on the rate heat is leaving or entering our bodies
• This is affected by a variety of factors – not just ambient air temperature
• Since we regulate our body temperature by perspiration, our comfort level is affected by the moisture level in the air around us
Relative humidity levels have a significant impact on a variety of IAQ issues.

Indoor air quality issues occur at high and low relative humidity; optimum range is 40%-60%.

Source: BPI Building Science Principles Reference Guide
VENTILATION – THE “V” IN HVAC

HVAC is not just heating & cooling
• Spot ventilation is used primarily to remove moisture & pollutants at the source
• Whole house ventilation is used to ensure occupants have fresh air provided in a controlled manner
• Air exchanges through leaks are irregular, ineffective, inefficient, and unhealthy!
VENTILATION

- Mechanical ventilation is required by code if the tightness of the home is <5 ACH50
- Ventilation should be sized to comply with table in code

<table>
<thead>
<tr>
<th>DWELLING UNIT FLOOR AREA (square feet)</th>
<th>NUMBER OF BEDROOMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 - 1</td>
</tr>
<tr>
<td>&lt; 1,500</td>
<td>30</td>
</tr>
<tr>
<td>1,501 - 3,000</td>
<td>45</td>
</tr>
<tr>
<td>3,001 - 4,500</td>
<td>60</td>
</tr>
<tr>
<td>4,501 - 6,000</td>
<td>75</td>
</tr>
<tr>
<td>6,001 - 7,500</td>
<td>90</td>
</tr>
<tr>
<td>&gt; 7,500</td>
<td>105</td>
</tr>
</tbody>
</table>

TABLE M1507.3.3(1) CONTINUOUS WHOLE-HOUSE MECHANICAL VENTILATION SYSTEM AIRFLOW RATE REQUIREMENTS
TYPES OF WHOLE HOUSE VENTILATION

There are a variety of whole house ventilation strategies:

- Exhaust only
- Supply only
- Balanced
FUNCTION – HEATING & COOLING

- There are a variety of types of heating and cooling systems
- We will focus on forced air ducted systems
- Furnaces & heat pumps essentially replace heat that is lost across the building envelope
- Air conditioning removes heat & moisture (sensible & latent)
HOW AIR CONDITIONING REMOVES MOISTURE

- Warm humid indoor air is blown across a cold coil
- Water vapor in the air condenses on the coil, collects, then exits the home through the condensate line
- This process takes time
- Oversized systems reach the thermostat set point before moisture is removed from home

http://www.youtube.com/watch?v=L5jQqmaFKOE
https://www.youtube.com/watch?v=14MmsNPtn6U
SECTION 403.1 - HVAC CONTROLS

Mandatory Requirement

**Programmable** thermostat required for furnace
Heat Pump requires lockout capability to prevent unnecessary strip heat
The temperature at which the heat pump can deliver exactly the same amount of Btu’s that the house is losing.
TYPES OF COOLING LOAD

Sensible Load

Latent Load

Total = Sensible + Latent

AHRI CERTIFIED
www.ahridirectory.org

Certificate of Product Ratings

AHRI Certified Reference Number: 3251832  Date: 3/9/2011

Product: Split System: Air-Cooled Condensing Unit, Coil with Blower
Outdoor Unit Model Number: 24ABB442(A,W)30
Indoor Unit Model Number: CNPH*421A**
Furnace Model Number: 58CV(LK)070-12
Manufacturer: CARRIER AIR CONDITIONING
Trade/Brand name: BASE 14 PURON AC

Manufacturer responsible for the rating of this system combination is CARRIER AIR CONDITIONING

Rated as follows in accordance with AHRI Standard 210/240-2008 for Unitary Air-Conditioning and Air-Source Heat Pump Equipment and subject to verification of rating accuracy by AHRI-sponsored, independent, third party testing.*

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooling Capacity (Btu/h)</td>
<td>36500</td>
</tr>
<tr>
<td>EER Rating (Cooling)</td>
<td>12.00</td>
</tr>
<tr>
<td>SEER Rating (Cooling)</td>
<td>14.00</td>
</tr>
</tbody>
</table>

* Ratings followed by an asterisk (*) indicate a rating made using test data and/or test results provided by the manufacturer. Ratings not followed by an asterisk indicate a rating made using calculation procedures provided in the Standard.

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www.ahridirectory.org
# HVAC AND MOISTURE

## It's Not the Heat, It's The Humidity..

<table>
<thead>
<tr>
<th>Bin Temperature</th>
<th>70-75</th>
<th>75-80</th>
<th>80-85</th>
<th>85-90</th>
<th>90-95</th>
<th>95-100</th>
<th>100-105</th>
<th>105-110</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td># of Hours of Occurrence</td>
<td>1188</td>
<td>880</td>
<td>620</td>
<td>361</td>
<td>172</td>
<td>23</td>
<td>2</td>
<td>0</td>
<td>3246</td>
</tr>
<tr>
<td>%</td>
<td>37%</td>
<td>27%</td>
<td>19%</td>
<td>11%</td>
<td>5%</td>
<td>1%</td>
<td>0%</td>
<td>0%</td>
<td>83%</td>
</tr>
<tr>
<td>Manual J Design, Load based on Temperature</td>
<td>92°</td>
<td>99 gr/lb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASHRAE Humidity Design, Load based on Moisture</td>
<td>82°</td>
<td>133 gr/lb</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Approximate Extra Moisture Added per 100 CFM Of O.S.A.</td>
<td>3.9 pts/hr</td>
<td>or 93.9 pts/day</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[Image of HVAC equipment]
HVAC EQUIPMENT SIZING

Systems are sized in order to best fulfill their function

- Heating is sized at a rate to replace lost BTUs
- AC sized for both sensible & latent
- Climate is important (design temps)

Used courtesy of ACCA
HAZARDS OF IMPROPER SIZING

Improper sizing can create a variety of problems This is especially important for air conditioning!

Tendency to oversize AC results in:
- Ineffective moisture removal
- Poor comfort
- IAQ concerns
- Durability issues

Heating:
- Too small – poor comfort
- Too big – short cycling
Proper system airflow rates are essential for effective HVAC performance

- Too fast – poor comfort & ineffective moisture removal
- Too slow – poor comfort and equipment issues
BEST OF BOTH WORLDS

Variable speed systems:
- Provide effective strategies for consistent performance
- But performance can be compromised by poor duct design, sizing & installation (also filters)
- Proper design & installation is essential for advanced equipment
ACCA Manual J & S are the code required methods used to size and select heating & cooling equipment

• Manual J – used to determine heating & cooling loads of home
• Manual S – used to select equipment based upon Manual J
ACCA MANUAL J

- Required by code
- Determines heating and cooling loads (room by room for new construction)
- Necessary for selection, but not intended to be solely used for such

Used courtesy of ACCA
HOW DOES MANUAL J WORK?

- Location
- Orientation
- Envelope
- Duct & envelope tightness
- Internal gains

Used courtesy of ACCA
LOAD CALCULATION PROCESS

• Select Design Conditions
  • Weather location
  • Indoor conditions

• Fill out Building Description
  • Building Type
  • Construction Materials
  • Construction Tightness
LOAD CALCULATION PROCESS

• Choose System Type
  • Example: Split system AC with gas furnace
  • May be generic or specific systems

• Select Distribution Preferences
  • Duct Materials
  • Registers, register locations
LOAD CALCULATION PROCESS

• Draw the room-by-room floor plan
  • As this is completed, the software generates the load calculation

• Select equipment type
  • Choose type of system: split AC with furnace, heat pump, etc.

• Draw ducts
  • Select basic layout (e.g. trunk and branch or radial)

• Generate report
ACCA MANUAL S

- Required by code (2012 IRC)
- Uses load information from Manual J to select equipment
ACCA MANUAL S - SIMPLIFIED

• Heating
  • Between 100% - 140% capacity of Manual J

• Cooling
  • Equipment must meet both sensible & latent heat loads
  • No greater than 115% of specified size or next nominal size

Used courtesy of ACCA
The actual capacity of air conditioning equipment depends upon:

- Outdoor temperature
- Indoor temperature
- Indoor humidity
- System airflow

*Actual capacity may differ from equipment data plate!*

ACCA Manual S is necessary to properly select equipment based upon local conditions!
DISTRIBUTION

- Duct design (Manual D)
- Installation
ACCA MANUAL D

- Used to design duct system
- Duct layout
- Duct diameters & cfm

*Used courtesy of ACCA*
FLOW TESTING

- Each room has a specific airflow requirement
- Flow rates should be field verified (best practice)
DUCT SEALING IS CRITICAL!

- Duct sealing & testing are required by code
- Ducts should be sealed regardless of location
- Mastic is the preferred material for sealing
Leaky Return Ducts
House pressure goes (+)
Leaky Supply Ducts
House pressure goes (-)
DUCT TESTING REQUIREMENTS

• Kentucky code requires leakage testing of ducts (unless located within conditioned space)
• Even if ductwork is exempt from testing, it still must be sealed
DUCT TESTING REQUIREMENTS

Duct leakage must meet one of the following:

• Post-construction duct leakage to outdoors ≤ 8 cfm per 100 ft²
• Post-construction total duct leakage ≤ 12 cfm per 100 ft²
• Rough-in total duct leakage w/AHU ≤ 6 cfm per 100 ft²
• Rough-in total duct leakage without AHU ≤ 4 cfm per 100 ft²
WHAT DOES IT MEAN?

• Theory is nice, but how does this relate to the real world?
• Practical applications
THE REAL WORLD

• Manual J & S are both necessary & required for selection
• However, Manual J is typically the most available document
• Is there a way to make practical decisions with limited information?
There are a variety of ways to perform a Manual J

Software packages are increasingly being used

ACCA approved software is listed on ACCA’s website

Some software packages also incorporate Manuals S & D

Software typically generates a variety of reports

www.acca.org/standards/approved-software
EXAMPLE MANUAL J SCENARIO

• You are performing a field inspection
• You are only provided with some type of Manual J documentation (summary, complete printout, etc.)
• How can you tell if this is a legitimate Manual J and if the equipment was selected properly?
EXAMPLE MANUAL J SCENARIO

Available information:
• Manual J summary (see example report in course materials)
• Data plates on installed equipment (photos on slides)
This method is presented solely as a means to perform a very basic quality control check in the field!

Equipment capacities (sizes) listed on data plates are based upon a specific set of operating conditions, which likely differ from local conditions (outdoor & indoor temperatures and RH)!

More detailed manufacturer data is necessary to accurately determine the actual capacity of a given cooling system!
EXAMPLE MANUAL J SCENARIO

1. Locate heating and cooling loads on Manual J
2. Determine maximum equipment size by multiplying loads from Manual J by factors derived from Manual S (table)
3. Locate equipment capacities (data plates)
4. Equipment capacities should meet loads from Manual J, but not exceed the results of calculations from step 2
1. The heating load from the Manual J is 55342 Btuh
2. 140% of the heating load is 77,479 Btuh (1.4 x 55342)
3. The output capacity of the installed furnace is 61,000 Btuh
4. The installed furnace meets the heating load from the Manual J, but is not larger than 140% of this load (55k < 61k < 77k Btuh)
5. The furnace appears to be sized appropriately
1. The total cooling load from the Manual J is 42,242 Btuh & 4.0 tons is specified.
2. 115% of the cooling load is 48,578 Btuh (1.15 x 42,242).
3. The installed air conditioner is ~48,000 Btuh (4 tons) based upon model number.
4. The unit meets the total cooling load from the Manual J, but does not appear to be larger than 115% of this load.
5. This is VERY simplified & should only be used to identify major red flags!
COMMON PROBLEMS WITH MANUAL J INPUTS

• Manual J’s are often not correct – both unintentionally & intentionally
• The results of a Manual J are only as meaningful as the input data (GIGO)
• There are several common input errors that are often found
THE USUAL SUSPECTS

- Design temperatures
- Building orientation
- Number of occupants
- Window area & U-value
- Air leakage
The location & design temperatures should be accurately entered into the software.

Typically, city is selected from a menu.
OUTDOOR DESIGN CONDITIONS

- Outdoor design temps are listed in a table in Manual J & within approved software databases
- The 99% design conditions should be used
- Technicians often override inputs to adjust results
ACCA specifies 70° for heating and 75° & 50% RH for cooling.

These numbers are often subjectively adjusted!

<table>
<thead>
<tr>
<th>Winter Design Conditions</th>
<th>Summer Design Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside db</td>
<td>26 °F</td>
</tr>
<tr>
<td>Inside db</td>
<td>70 °F</td>
</tr>
<tr>
<td>Design TD</td>
<td>44 °F</td>
</tr>
<tr>
<td></td>
<td>92 °F</td>
</tr>
<tr>
<td></td>
<td>72 °F</td>
</tr>
<tr>
<td></td>
<td>20 °F</td>
</tr>
<tr>
<td></td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>43 gr/lb</td>
</tr>
</tbody>
</table>
The heating & cooling loads on a house are dependent on the orientation, especially for windows.

Compare the orientation listed on Manual J documentation to the actual orientation of the home.

Current Orientation: Front Door faces East

Highest Cooling Load: Front Door faces Southwest
NUMBER OF OCCUPANTS

- Occupants represent internal gains
- ACCA specifies to use the number of bedrooms plus one
- For example, a three bedroom house should have four occupants entered into the Manual J

Q: How many Btuh does Manual J assume for each person?
CONSTRUCTION COMPONENTS

• Manual J requires detailed entry of construction data (R-value, U-value, etc.)
• If available, compare the listed components to what is actually in the house
• Pay particular attention to window areas and specifications

<table>
<thead>
<tr>
<th>Construction descriptions</th>
<th>Or</th>
<th>Area m²</th>
<th>U-value Btu/h·F°</th>
<th>Insul R ft²·F/Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Walls</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12C-0bw: Frm wall, brk 4&quot; ext, 1/2&quot; wood shib, r-13 cav ins, 1/2&quot;</td>
<td>n</td>
<td>545</td>
<td>0.091</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>e</td>
<td>17</td>
<td>0.091</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>613</td>
<td>0.091</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>w</td>
<td>486</td>
<td>0.091</td>
<td>13.0</td>
</tr>
<tr>
<td></td>
<td>all</td>
<td>2174</td>
<td>0.091</td>
<td>13.0</td>
</tr>
<tr>
<td>15A-4s3oc: 4: Bg wall, light dry soil, empty core, concrete block wall, r-4 ins, 8&quot; thk</td>
<td>n</td>
<td>63</td>
<td>0.102</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>e</td>
<td>305</td>
<td>0.093</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>232</td>
<td>0.102</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>w</td>
<td>350</td>
<td>0.093</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>all</td>
<td>630</td>
<td>0.093</td>
<td>4.0</td>
</tr>
</tbody>
</table>

| **Partitions**            |    |         |                 |                 |
| (none)                   |    |         |                 |                 |

<table>
<thead>
<tr>
<th>Windows</th>
<th>Or</th>
<th>Area m²</th>
<th>U-value Btu/h·F°</th>
<th>Insul R ft²·F/Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td>U30 S24: U30 S24; NFRC rated (SHGC=0.24); 50% blinds 45°, light; 50% outdoor insect screen; 2 ft overhang</td>
<td>n</td>
<td>18</td>
<td>0.300</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>e</td>
<td>9</td>
<td>0.330</td>
<td>0</td>
</tr>
<tr>
<td>U32 S29: U32 S29; NFRC rated (SHGC=0.29); 50% blinds 45°, light; 50% outdoor insect screen; 2 ft overhang</td>
<td>e</td>
<td>41</td>
<td>0.320</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>s</td>
<td>41</td>
<td>0.320</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>all</td>
<td>83</td>
<td>0.320</td>
<td>0</td>
</tr>
</tbody>
</table>
AIR LEAKAGE

- Software typically has generic tightness categories that are selected from a menu
  - Tight
  - Semi-tight
  - Average
  - Semi-loose
  - Loose

- More detailed options allow input of the actual infiltration (blower door)
- Using the actual (tested) infiltration will result in a more accurate Manual J
DUCT INSTALLATION - INSPECTION

• Compare duct layout and diameters to Manual D
• If Manual D not available, look for red flags
• Crimps, length, inadequate supports, etc.
DUCT INSTALLATION - INSPECTION
DUCT INSTALLATION - INSPECTION
DUCT INSTALLATION - INSPECTION

- Compare installed duct insulation with code requirements
- R-8 required for attics & exterior
- R-6 for other locations
SUMMARY

• Proper HVAC design and installation is not only code required, but important for quality construction
• As technology improves, this is becoming even more crucial
• Design and installation issues can lead to all sorts of problems
SUMMARY

• Man J, S, and D are established protocols that should be performed
• Although things can be complicated, there are practical methods to verify installed components and identify red flags
• Field inspection methods should be used in an appropriate context
QUESTIONS OR COMMENTS?