We will be starting soon!

Thanks for joining us

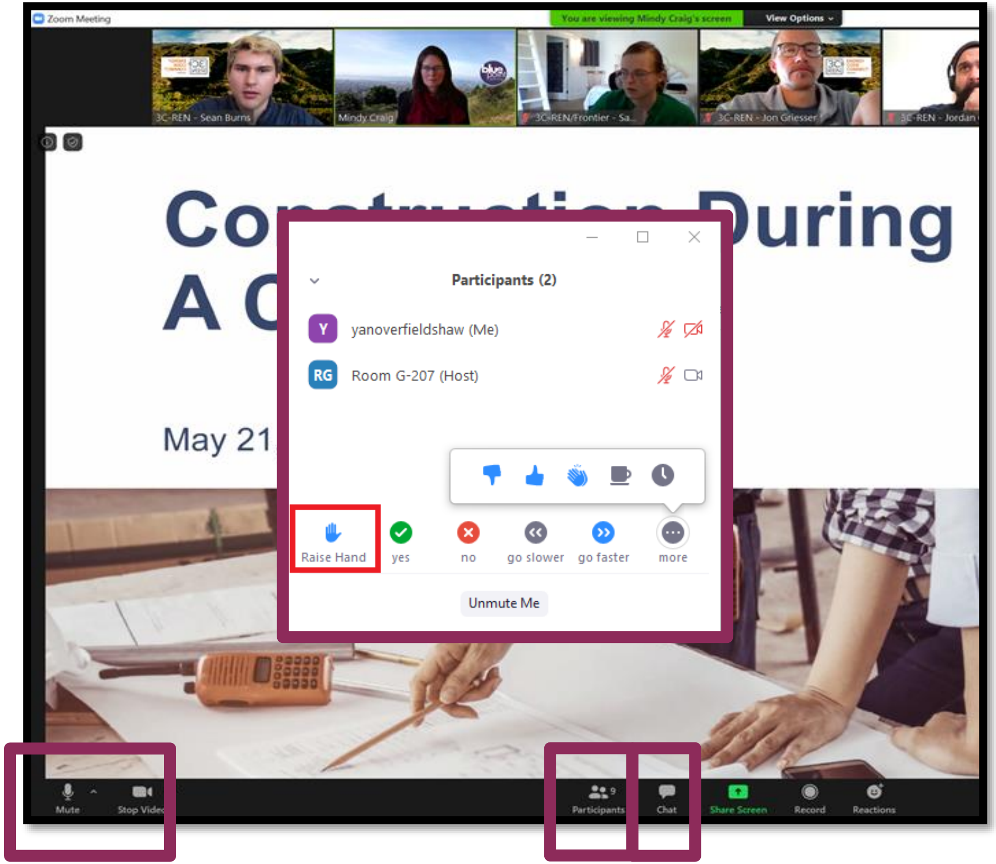
Diagnosing Heating and Cooling Comfort Problems in Homes

Russell King, ME – Coded Energy, Inc.

January 27, 2023

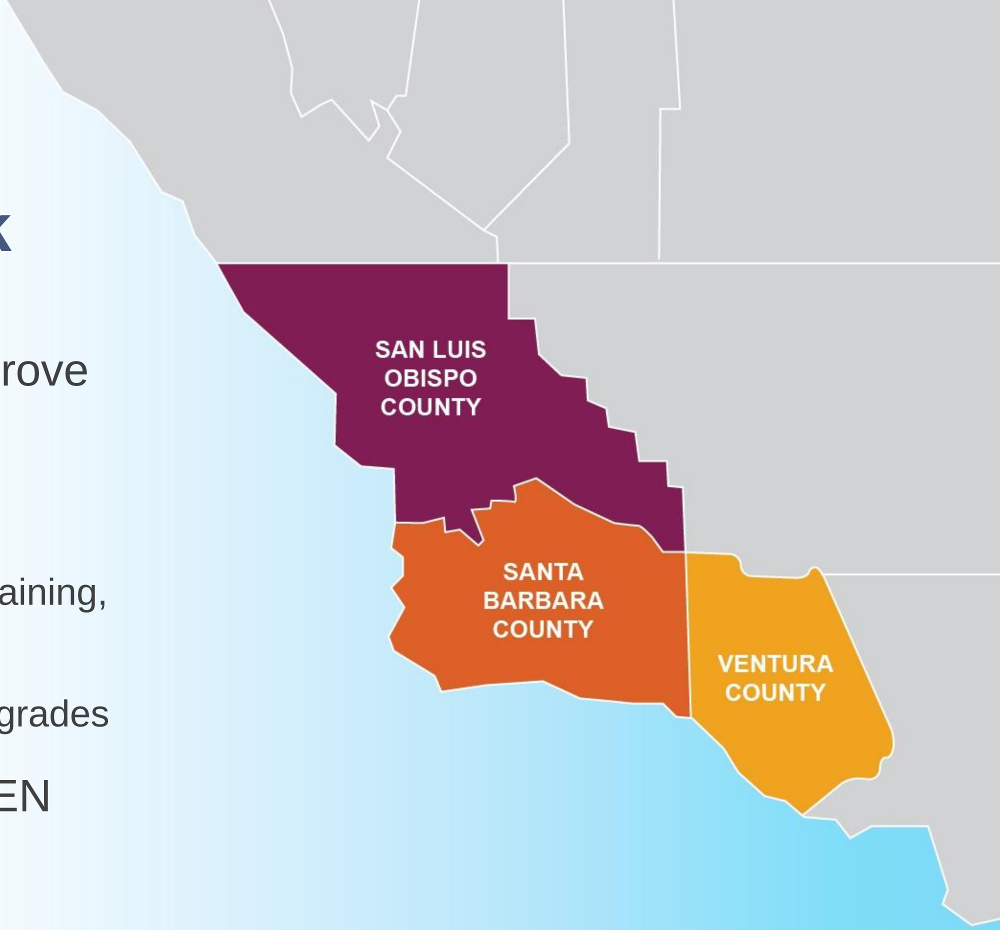
Zoom Orientation

- Please be sure your full name is displayed
- Please mute upon joining
- Use "Chat“ box to share questions or comments
- Under "Participant" select "Raise Hand" to share a question or comment verbally
- The session may be recorded and posted to 3C-REN's on-demand page. Feel free to ask questions via the chat and keep video off if you want to remain anonymous in the recording.



3C-REN: Tri-County Regional Energy Network

- Three counties working together to improve energy efficiency in the region
- Services for –
  - **Building Professionals:** industry events, training, and energy code compliance support
  - **Households:** free and discounted home upgrades
- Funded by ratepayer dollars that 3C-REN returns to the region



3C-REN
Staff Online

3C-REN ENERGY CODE CONNECT

3C-REN BUILDING PERFORMANCE TRAINING

3C-REN HOME ENERGY SAVINGS

3C-REN ENERGY CODE CONNECT

- Serves all building professionals
- Three services –
  - **Energy Code Coach**
  - **Training and Support**
  - **Regional Forums**
- Makes the Energy Code easy to follow

Energy Code Coach:
3c-ren.org/codes
805.220.9991

Event Registration:
3c-ren.org/events

3C-REN BUILDING PERFORMANCE TRAINING

- Serves current and prospective building professionals
- Expert instruction:
  - **Technical skills**
  - **Soft skills**
- Helps workers to thrive in an evolving industry

Event Registration:
3c-ren.org/events

3C-REN HOME ENERGY SAVINGS

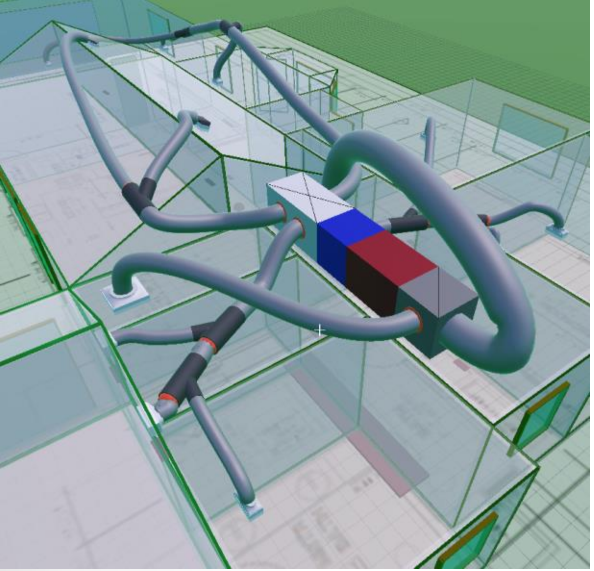
Multifamily (5+ units)

- No cost technical assistance
- Rebates up to $750/apartment plus additional rebates for specialty measures like heat pumps

Single Family (up to 4 units)

- Sign up to participate!
- Get paid for the metered energy savings of your customers

Enrollment:
3C-REN.org/contractor-participation



Introduction to *Residential Comfort Diagnostics*

By Russell King, ME
CEO/Founder of Coded Energy Inc.
Developers of Kwik Model 3D Software

KWIK MODEL3D

CODED ENERGY

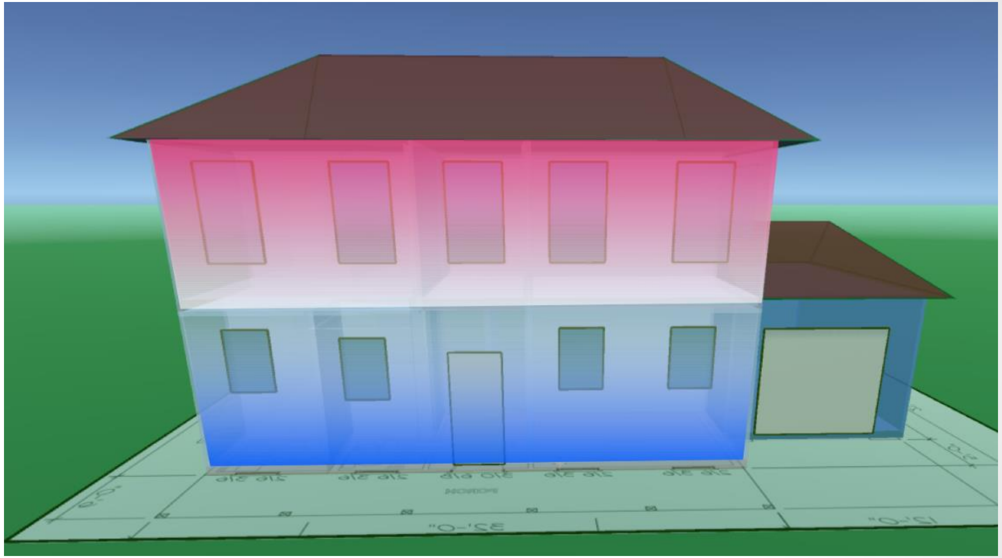
Types of Comfort Problems and Their Symptoms

- Temperature issues
- Humidity issues
- High energy bills
- Noise
- Dust

Temperature Issues - Symptoms

Uneven temperatures floor to floor

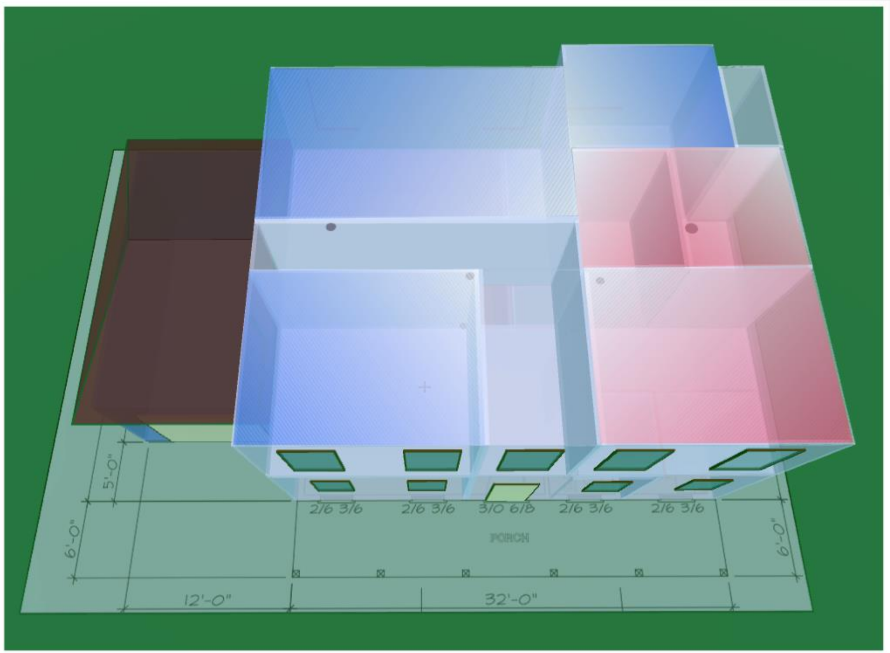
- Hot upstairs, cold downstairs
- Stratification – “Hot air rises”



Temperature Issues - Symptoms

Uneven temperatures room to room

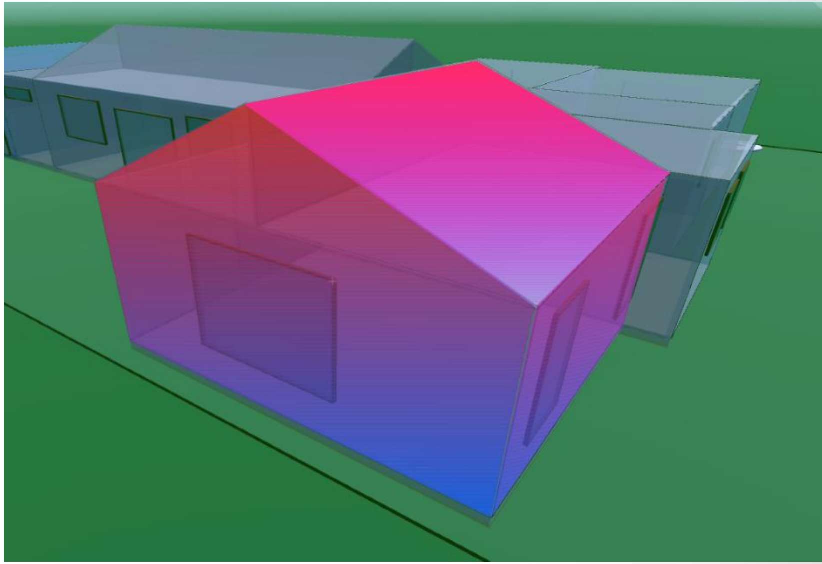
- Some rooms are hotter or colder than others, even on the same floor
- Bedrooms above the garage
- “The baby’s room is always freezing.”
- “The family room is like an oven in the afternoon”



Temperature Issues - Symptoms

Stratification within a room

- Cold at the floor but hot near the ceiling
- Bunk beds
- Vaulted Ceilings
- Lofts



Temperature Issues - Symptoms

System doesn't maintain set temperature

- Summer: System runs and runs but never cools off
- Winter: System runs and runs but never heats up

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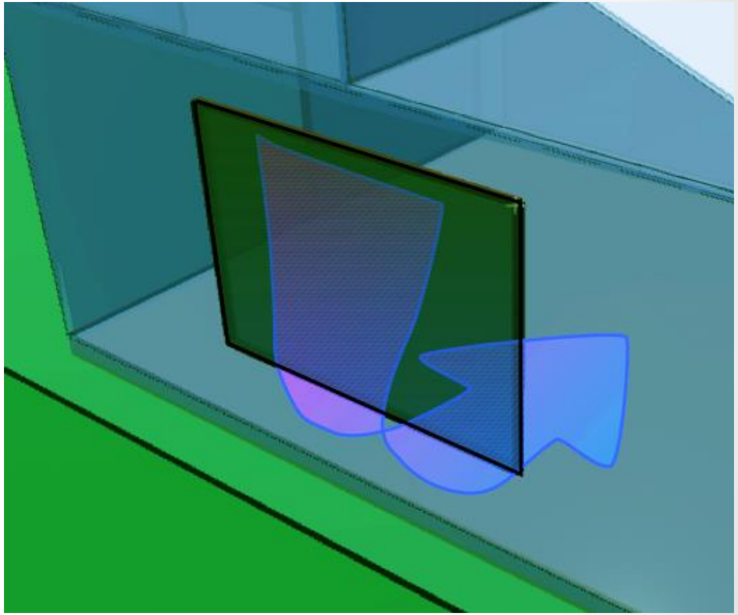
Temperature Issues - Symptoms

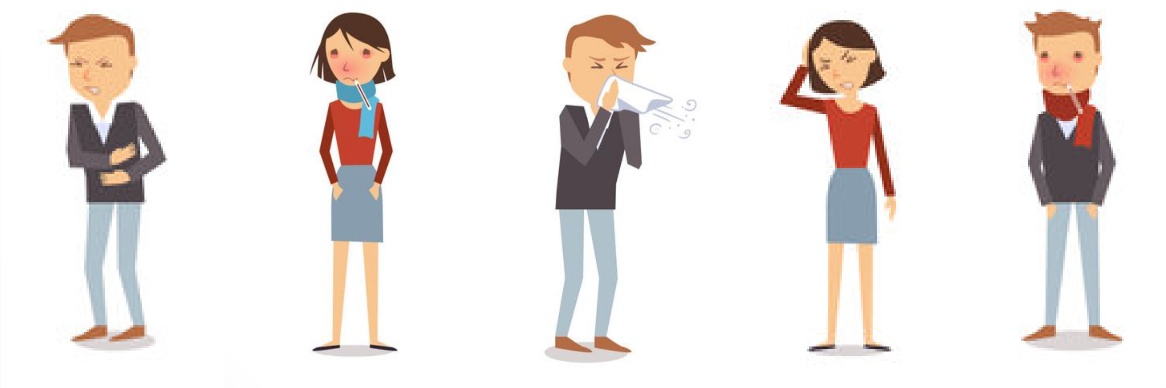
Drafts

- Cold air moving across one's body
  - Windows
  - Doors
  - Vaulted ceilings
  - Supply registers
    - Heated air feels too cold or too hot
    - Cooled air feels too hot or too cold



How to Interview the Homeowner

- It helps to have a set of interview questions prepared.
- Identify the <u>symptoms</u> of the problem before trying to identify the problem.
- Use precise terms when identifying the how they feel
  - Do you feel warm, cold, muggy, sticky, sweaty, dry nose/throat



How to Interview the Homeowner

- Ask them what seems to **resolve** the complaint
  - Sun goes down
  - Closing the drapes
  - Putting on a sweater
  - Closing off vents
- Find out what rooms in the house are the *most* comfortable.

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How to Interview the Homeowner

- Identify **<u>when</u>** the problems occur
  - Heating or cooling season
  - System on or system off
  - Mild days or extreme days
  - What time of day
  - Behavior related causes (watch for signs of poor t-stat operation)
- Identify **<u>where</u>** in the house the problems occur

Problems Caused by Poor Design

- Diagnosing comfort problems has to happen **after** all equipment issues have been resolved.
- In other words, the equipment is performing as it should, but the occupants are still not comfortable.

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Problems Caused by Poor Design

- Once faulty equipment has been ruled out the there are really only three things that cause the vast majority of comfort problems
  1. The occupants are behaving detrimentally to the performance of the system (leaving windows open, operating the t-stat wrong)
  2. The load of the house is higher than it should be (insulation has been removed, leaks have been added, wrong windows installed)
  3. The system is not designed well.
- The vast majority of comfort problems are caused by **poorly designed systems**.

Problems Caused by Poor Design

- The good news is that design problems are fairly easy to diagnose.
- If you do an **<u>after-the-fact design</u>** on the house based on the basic existing layout (e.g., register locations), you can use that to see where the differences are between the ***expected*** performance of the "good design" and the ***actual***, installed system:
  - Equipment size
  - Duct layout, register locations
  - Duct sizing and airflows

How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

Doing a *proper* design on a house is an important investment of time.

However, it is possible to do a quick-and-dirty evaluation, using basic design principles to determine the rough total airflow capacity of the system.

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How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

Assuming that “Good” airflow is believed to be around 400 cfm/ton, let’s use this as target.

Note: In humid climates lower airflow per ton may be desirable.

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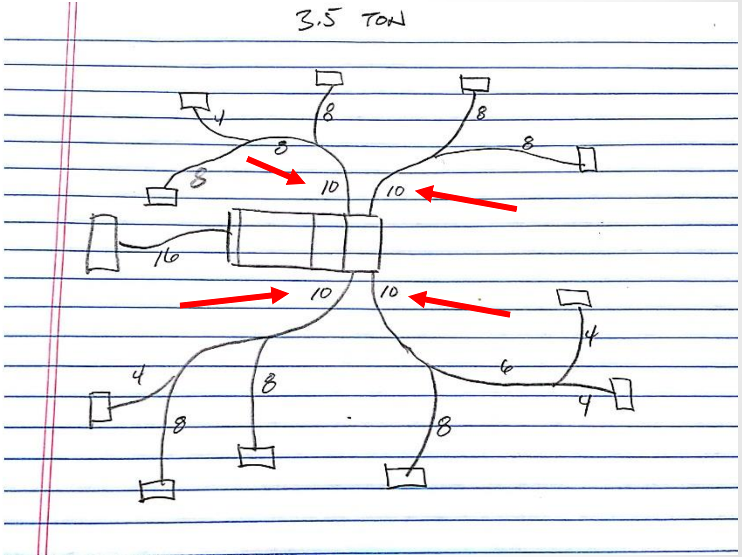
How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

Consider this simple sketch of a duct system.

- Using a duct slide rule (aka, duct-u-lator) you can estimate the airflow capacity of the ducts.
- There are three important sets of ducts that affect overall airflow:
    1. Main supply trunks at the plenum
    2. Supply branches serving the registers
    3. Return ducts



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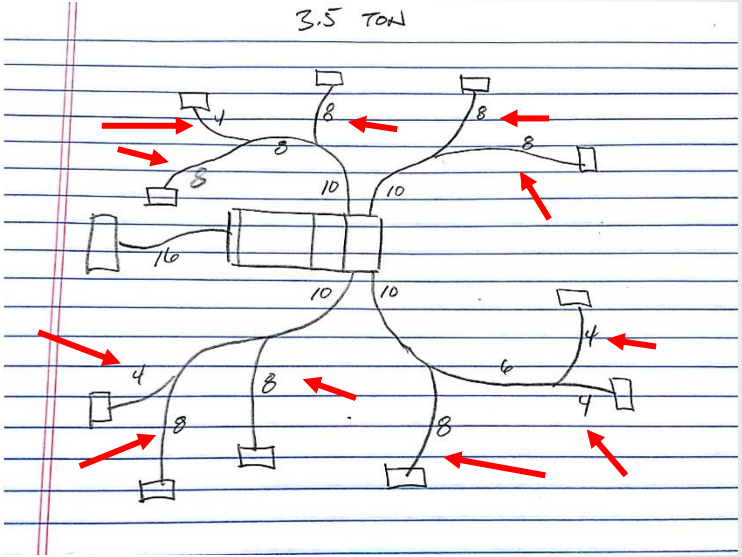

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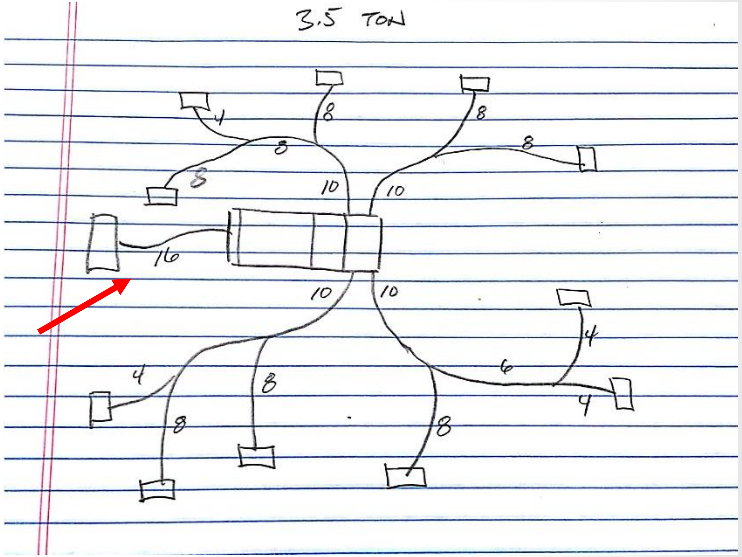

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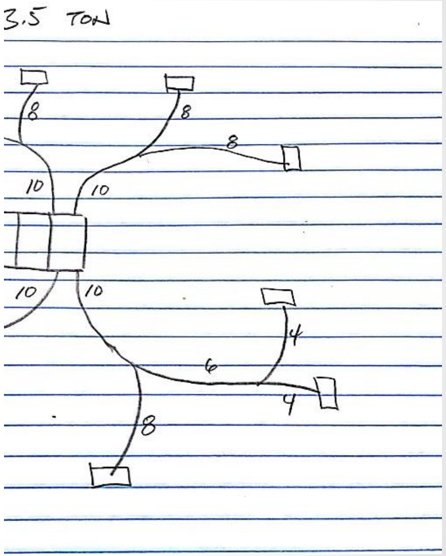
How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

- This table was created with a duct slide rule and shows the maximum airflow of various sizes of flex duct at a friction rate of 0.1 iwc/100’

Duct Diameter	Air Flow CFM
4”	20
5”	50
6”	80
7”	120
8”	170
9”	230
10”	300
12”	500
14”	740
16”	1050
18”	1400
20”	1875



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How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

- 0.1 iwc/100’ is a commonly used friction rate for examples, but the actual friction rate should be calculated for each design.
- Friction rate is discussed in more detail in another blog article called, ***“Friction Rate Explained – Maybe”***

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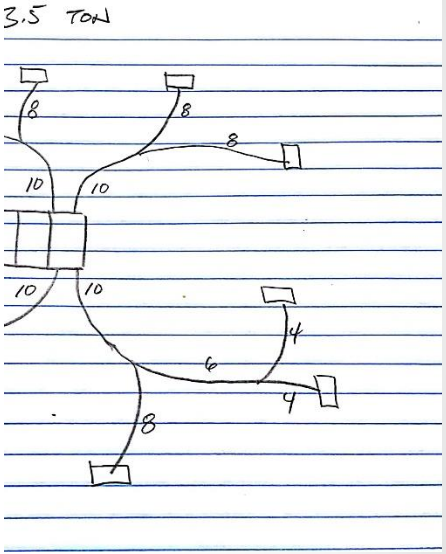

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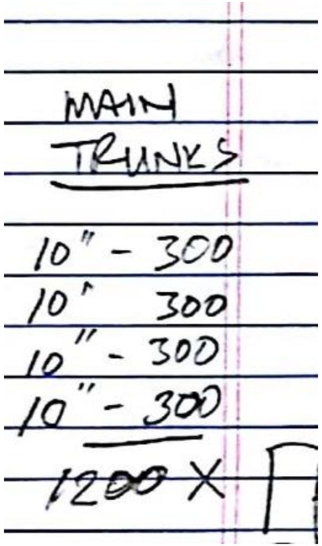
How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

- List all of the main trunk sizes and the airflow capacity of the ducts.
    - Then add them up
- Do the same for the supply branches.
- Do the same for the return side



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SUPPLY BRANCHES	
8	– 170 CFM
4	20
8	170
8	170
8	170
4	20
4	20
8	170
8	170
8	170
4	20
	1270 CF

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RETURN: 16" — 1050 CFM X

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How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

Compare those to the desired total. We'll use 400 cfm/ton as a target, but you could use 350.

3.5 tons x 400 = 1400 cfm

3.5 tons x 350 = 1225 cfm

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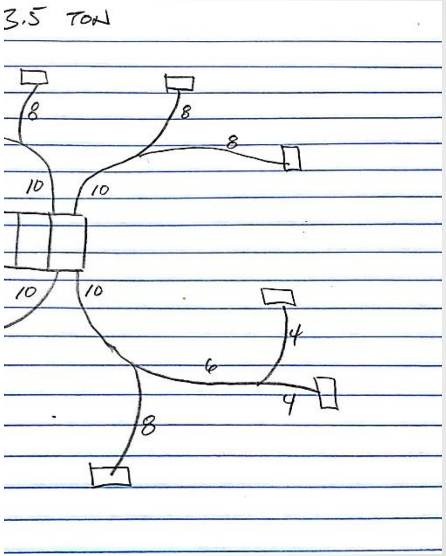

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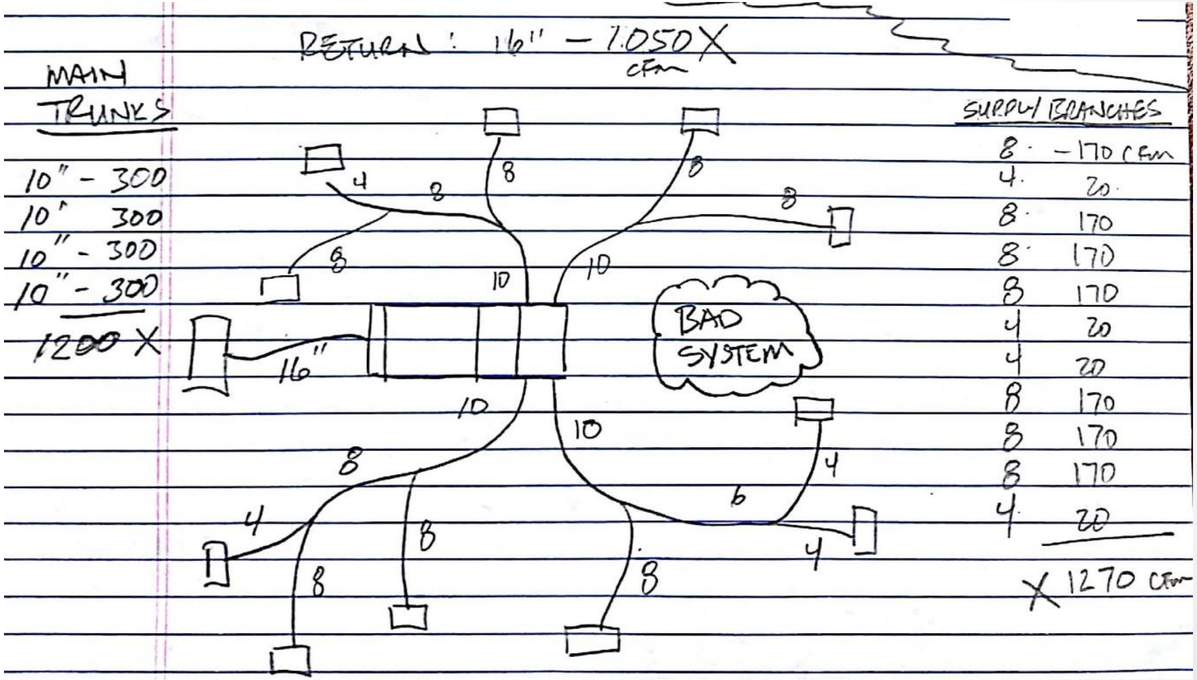

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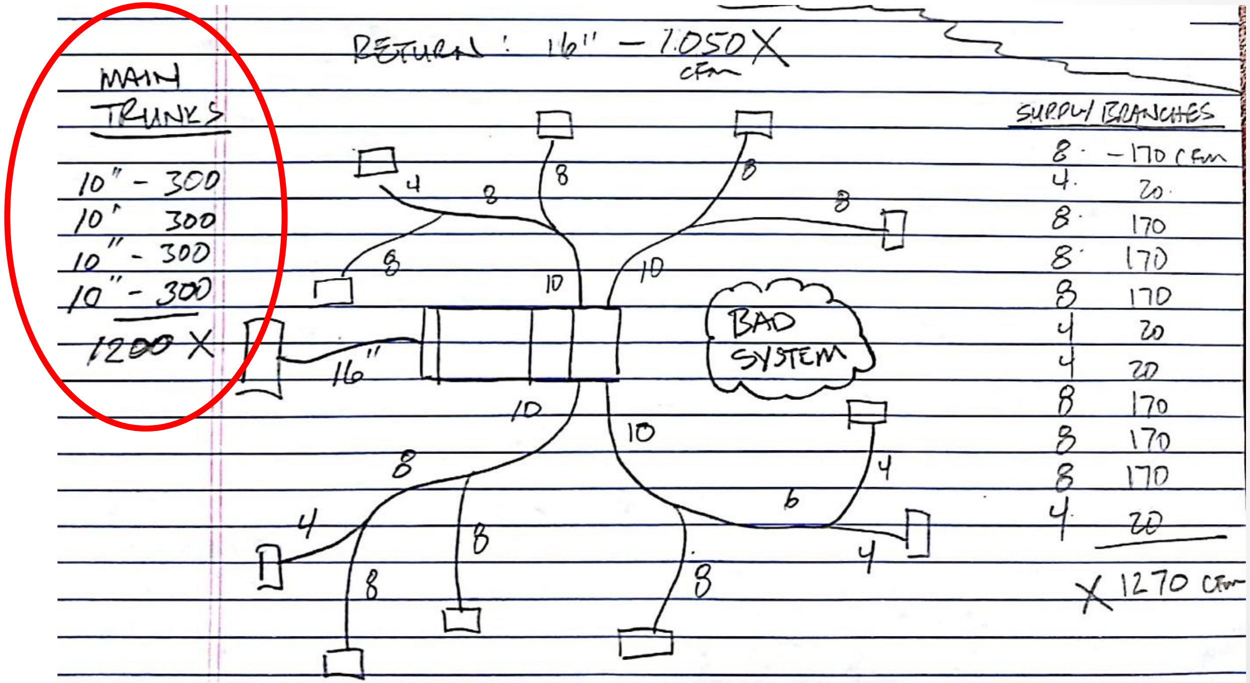

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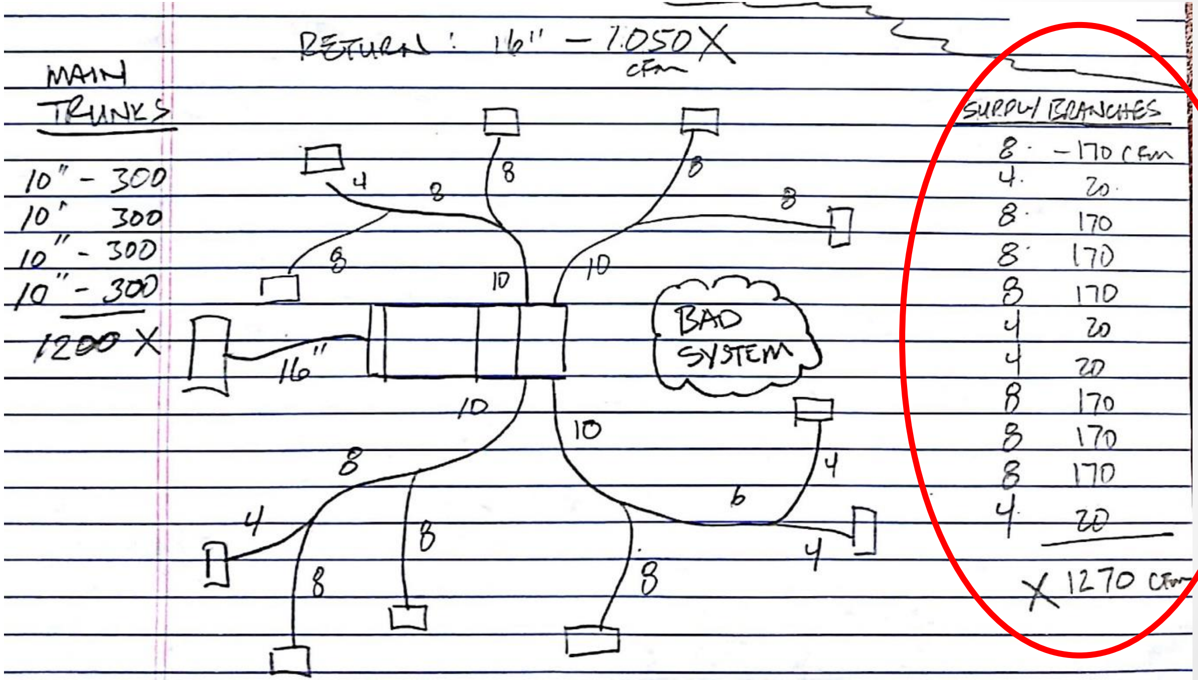

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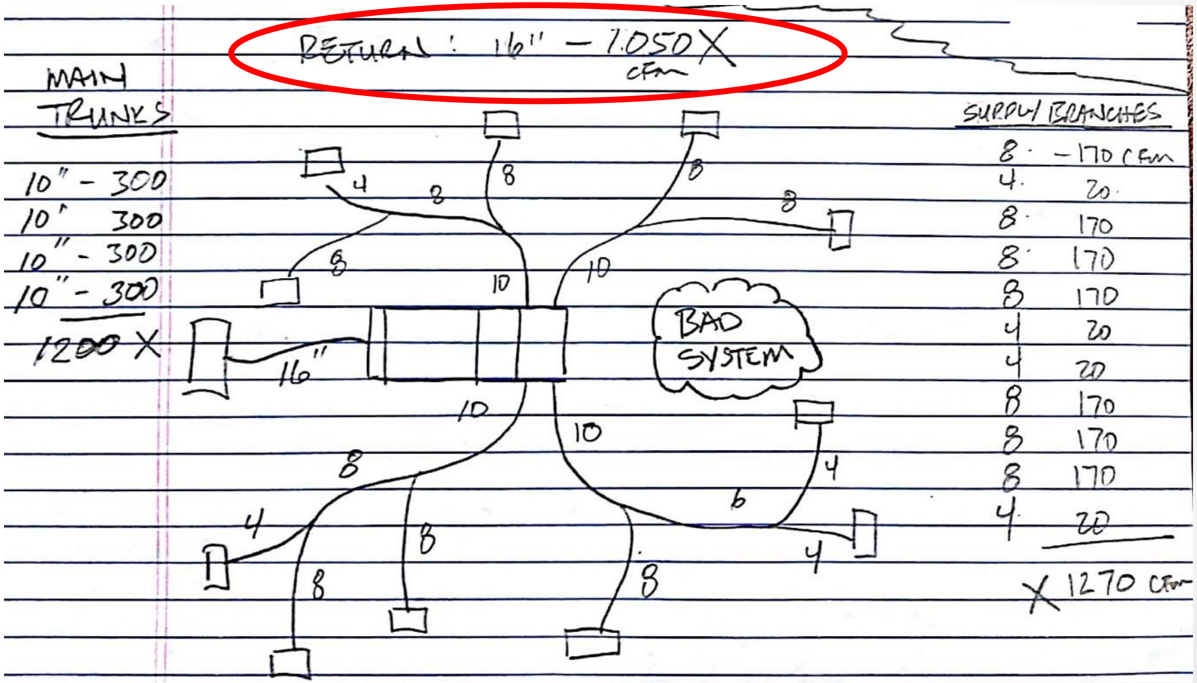

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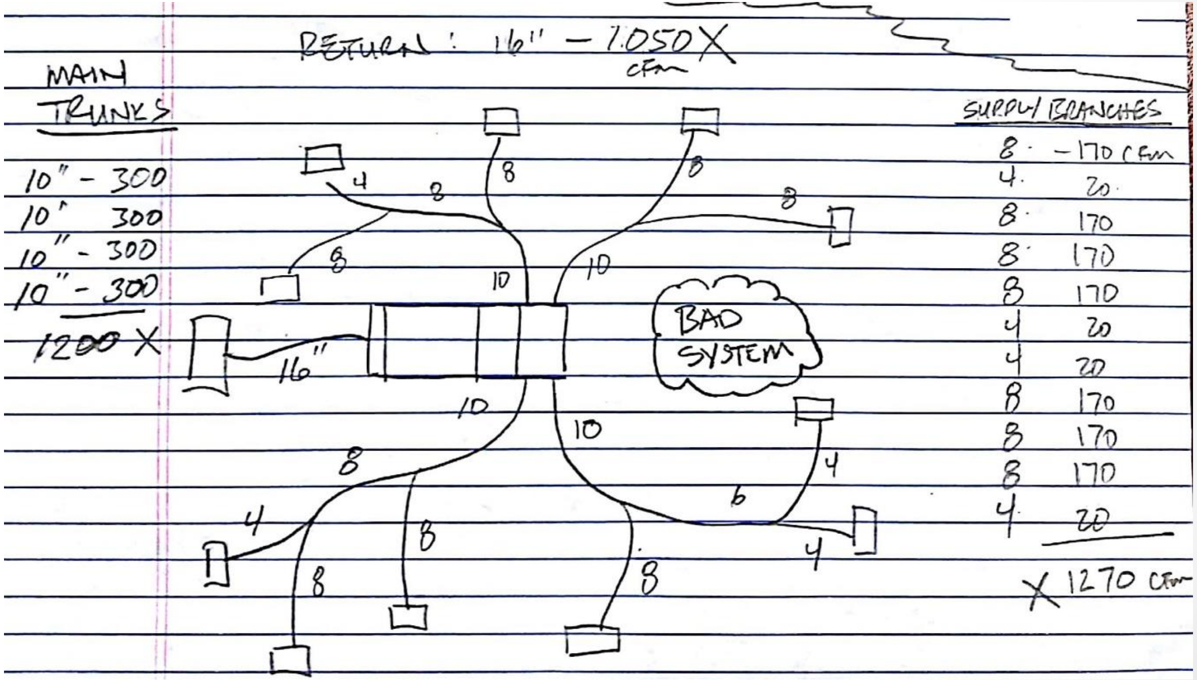
How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

As you can see, the ducts are well undersized for a target of 400 cfm/ton:

1400 cfm

This is especially true for the return, which is a common problem.



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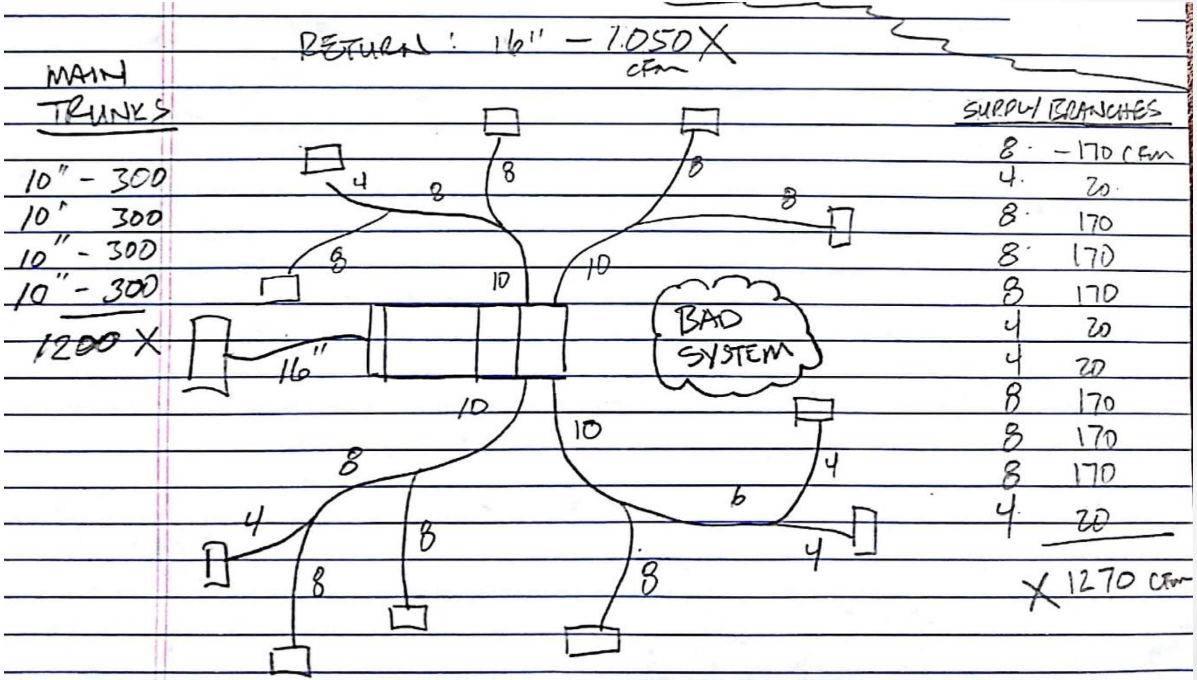
How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

A simple fix of increasing return capacity will make the system barely meet the code minimum of 350 cfm/ton.

But are you satisfied with a D- system?



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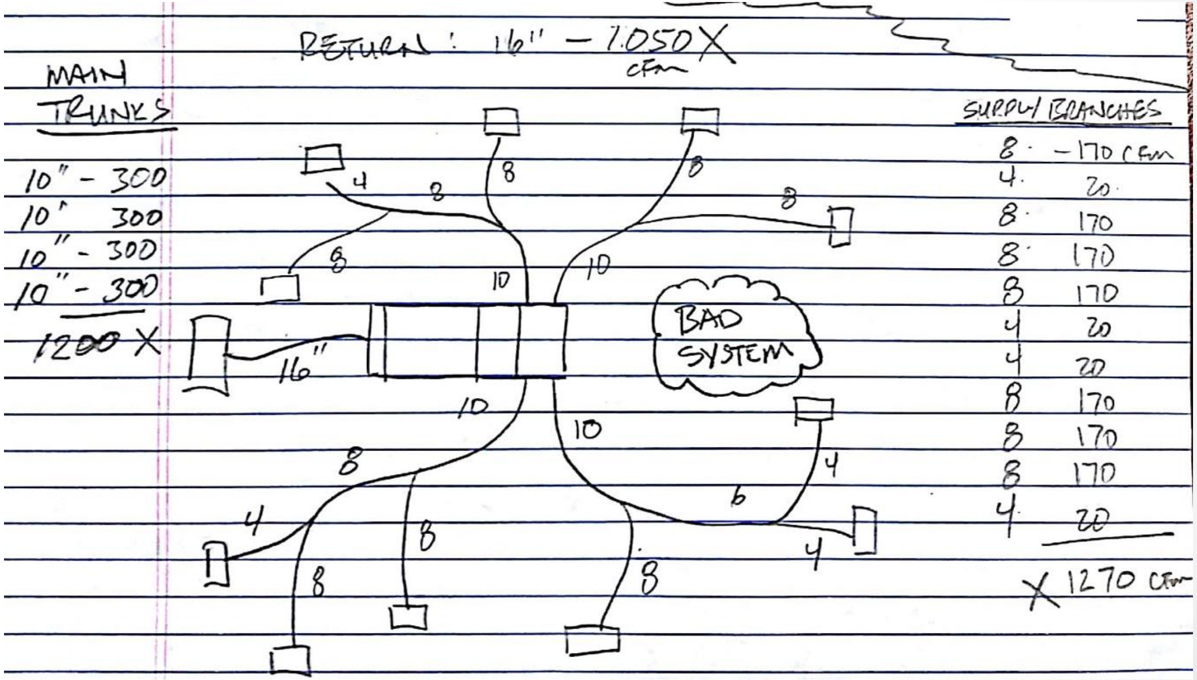
How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

Note that this does not address room by room air balance.

To do that, you need to do room by room load calculations.

To do that, you need to learn ACCA's Manuals J, S, and D



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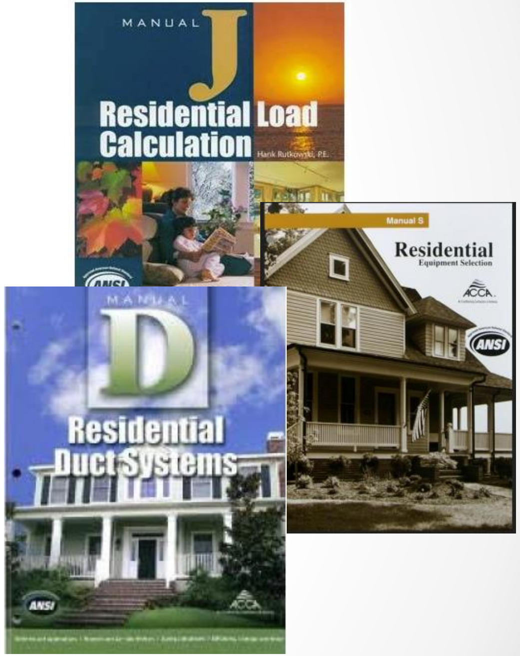
How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

- Basic Design Manuals
  - Manual J – Residential Load Calculations
  - Manual S – Equipment Selection
  - Manual D – Duct Design
- Other Related Manuals
  - Manual RS – Residential System Design (overview)
  - Manual T – Terminal Selection (registers)
  - Manual H – Heat Pumps
  - Manual LLH – Low Load Homes
- Other Standards and Checklists. (QI, QM, etc.)
- www.acca.org



How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

Load Calculations are critical to properly sized heating and cooling equipment.

For **Air Conditioners**:

- ***Undersizing*** may cause house not to cool (or heat) well on very hot (or cold) days.
- ***Oversizing*** can cause excess stratification, uneven temperature distribution. Plus, higher electric bills and shortened equipment life.

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How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

- The negative impacts of ***Oversized Equipment*** can be reduced by using multi-stage or variable capacity units.
- The negative impacts of both ***Oversized and Undersized Equipment*** can be reduced with <u>good duct design and good system airflow</u>.

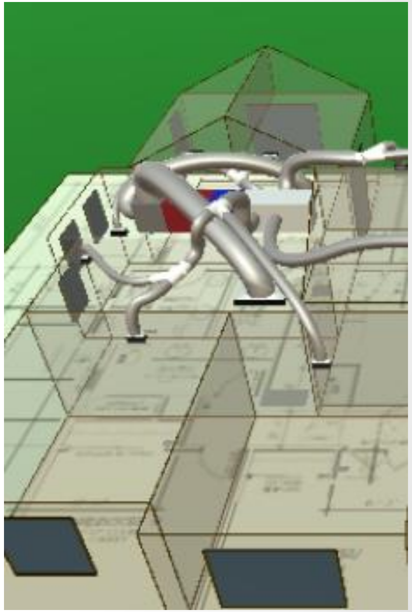
How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

- Historically, the most common method of equipment sizing was rules of thumb and trial and error.
- This almost always led to oversized equipment (and undersized ducts).

How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

The Importance of Good Design: Duct Sizing

- Since the temperature of the ***entire house*** (or zone) is determined by ***one location*** (at the thermostat) it is important for even temperature distribution that conditioned air be distributed evenly throughout the home.
- This is done by sizing the ducts to deliver the **proper airflow** to each room (register).



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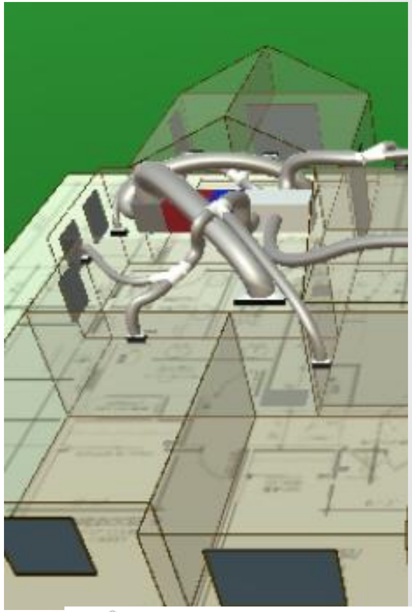
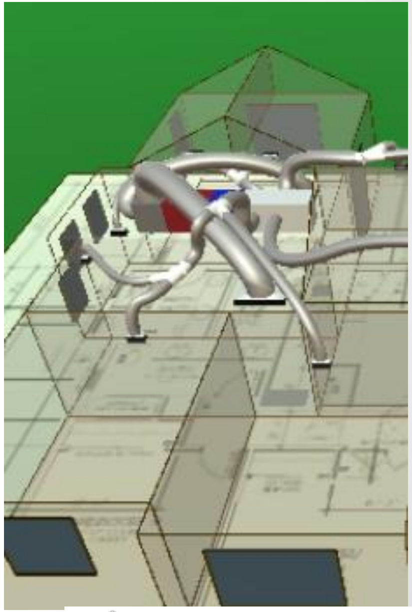
How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

- Target room airflows need to be determined from **room-by-room loads** – you need to know what the load of a room is relative to other rooms.
- Overall undersizing of all ducts, especially return ducts, will reduce total system fan flow, which will reduce <u>**capacity and efficiency**</u> of system.



How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

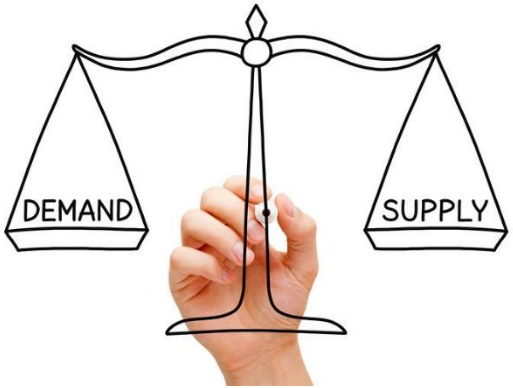
- Undersizing one or two ducts relative to the other ducts in the house will cause poor **air balance.**
- This will result in uneven temperature distribution in the house (some rooms warmer or cooler than others)
- This is made even worse by low overall airflow.



How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

Remember:

- Equipment cannot be properly sized unless you know the **load** of the house. (Demand)
- **Manual J**
- Equipment cannot be properly sized unless you can accurately determine the **capacity** at design conditions. (Supply)
- **Manual S**



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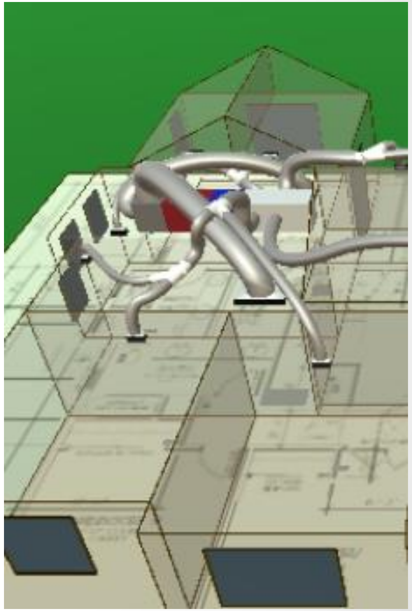
How to Evaluate an Existing System for Proper Equipment Sizing and Duct Sizing

Remember:

- Individual **ducts** cannot be properly sized unless you know how to distribute the air.
- To know how to distribute the air, you need **room by room** load calculations.



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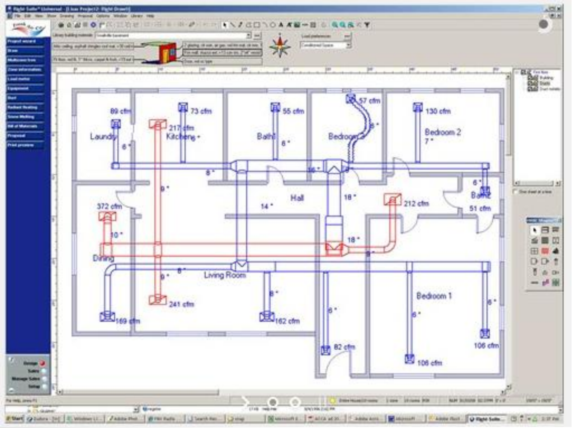
Diagnostic Testing: Room-by-Room Airflows

- To obtain the load calcs, you will need to take a Manual J class and learn how to use some (ACCA certified) load calculation software.
- There are several ACCA approved ***software programs*** available to help you through this process.

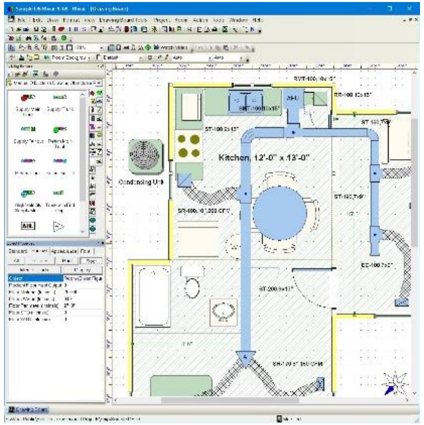
Diagnostic Testing: Room-by-Room Airflows

Examples:

Right-Suite® by Wrightsoft



RHVAC by Elite Software



Kwik Model® with *EnergyGauge Loads*

Diagnostic Testing: Room-by-Room Airflows

Measuring Actual Airflows

- Supply and return airflows must be measured.
  - Passive Flow Hood
  - Powered Flow Hood
  - Velometer
  - Plastic Bag and stop watch
  - Other
- See “LBNL 47382” regarding supply measurements.
- For air balance, it’s more important to be accurate relative to each other.

Diagnostic Testing: Room-by-Room Airflows

Identifying Balance Problems

- Should we compare actual measured flows to target flows?
- Only if the measured **total** flow and target **total** flow the same. This is usually not the case.
- Compare measured **percent of totals** to target **percent of totals**.

- Example . . .

Equipment and Airflow Report

System name: **Upstairs** — this system # **2** of **2** systems in this house

Equipment Info	FAU Make	Coil Make	Condenser Make
Describe location and	**Carrier**	**ADP**	**Carrier**
configuration:	FAU Model	Coil Model	Condenser Model
attic mounted	**58MXA040-12**	**HDD03336D**	**38BRC036**
horizontal			Condenser Type
	nace	**w/TXV**	**split AC**

Sub-Zone nam… — …s sub-zone # 1 of 1 sub-zones in this system

Measured Flows

Target Flows

Room Name-Register #	Measured CFM	% of total	Target CFM	% of total	variance
stairs	0	0.0%	257	21.4%	-100.0%
gameroom	195	19.7%	186	15.5%	27.3%
bed 2	163	16.5%	160	13.3%	23.7%
bath 3	34	3.4%	20	1.7%	106.5%
bed 3	196	19.8%	179	14.9%	33.0%
bonus (2)	215	21.8%	230	19.2%	13.5%
bed 4	153	15.5%	158	13.2%	17.6%
bath 2	32	3.2%	10	0.8%	288.7%
Total	988	100.0%	1200	100.0%	

Equipment and Airflow Report

System name:	Upstairs			this system # **2** of **2** systems in this house		
Equipment Info	FAU Make		Coil Make		Condenser Make	
Describe location and	**Carrier**		**ADP**		**Carrier**	
configuration:	FAU Model		Coil Model		Condenser Model	
attic mounted	**58MXA040-12**		**HDD03336D**		**38BRC036**	
horizontal	FAU Type		Coil Type		Condenser Type	
	horiz gas funace		**horiz cased w/TXV**		**split AC**	
Sub-Zone name:			this sub-zone # 1 of 1 sub-zones in this system			
			Cooling Mode			
Room Name-Register #	Measured CFM	% of total	Target CFM	% of total	variance	
stairs	0	0.0%	257	21.4%	-100.0%	
gameroom	195	19.7%	186	15.5%	27.3%	
bed 2	163	16.5%	160	13.3%	23.7%	
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Notice Difference!

Equipment and Airflow Report

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	horiz gas	**horiz cas**	**plit AC**
Sub-Zone name:			f 1 sub-zones in this system
		Cooling Mc	

Measured % of total

Target % of total

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horizontal	FAU Type		Coil Type		Condenser Type	
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bath 2	32	3.2%	10	0.8%	288.7%	
Total	988	100.0%	1200	100.0%		

Compares
% of total

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One system serving multiple floors

Equipment and Airflow Report

System name:	Entire house		this system # 1 of 1 systems in this house
Equipment Info	FAU Make	Coil Make	Condenser Make
Describe location and	Goodman		Goodman
configuration:	FAU Model	Coil Model	Condenser Model
attic mounted	GMP075-4		CKT42-A
horizontal	FAU Type	Coil Type	Condenser Type
	horiz gas furn.	horiz cased	split AC, 3.5 ton

Downstairs

Sub-Zone name:	Downstairs			this sub-zone #1 of 2 sub-zones in this system	
Room Name-Register #	Measured CFM	% of total	Target CFM	% of total	variance
LIV	132	9.2%	230	14.4%	-36.0%
FAMILY	196	13.7%	181	11.3%	20.8%
KIT	263	18.3%	317	19.8%	-7.4%
BED4	91	6.3%	110	6.9%	-7.7%
BA3	71	5.0%	17	1.1%	366.0%
LAU	39	2.7%	7	0.4%	521.6%
Total	792	55.2%	862	53.9%	

Sub-Zone name:	Upstairs			this sub-zone # 2 of 2 sub-zones in this system	
Room Name-Register #	Measured CFM	% of total	Target CFM	% of total	variance
BONUS	128	8.9%	221	13.8%	-35.4%
MBED	157	10.9%	155	9.7%	13.0%
MBATH	78	5.4%	85	5.3%	2.4%
BA2	77	5.4%	36	2.3%	138.6%
BED2	114	7.9%	98	6.1%	29.8%
BED3	88	6.1%	143	8.9%	-31.3%
Total	642	44.8%	738	46.1%	
Zone Total	1434	100.0%	1600	100.0%	

Equipment and Airflow Report

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Equipment Info	FAU Make		Coil Make	Condenser Make	
Describe location and	Goodman			Goodman	
configuration:	FAU Model		Coil Model	Condenser Model	
attic mounted	GMP075-4			CKT42-A	
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Total	642	44.8%	738	46.1%	
Zone Total	1434	100.0%	1600	100.0%	

One system serving multiple floors

Upstairs

Diagnostic Testing

- There are many very useful diagnostic tests.
- Some of them require fairly expensive equipment, but none are extremely difficult.
- Without testing, you are just guessing.
- Diagnosing problems by trial and error is more expensive and time consuming in the long run.

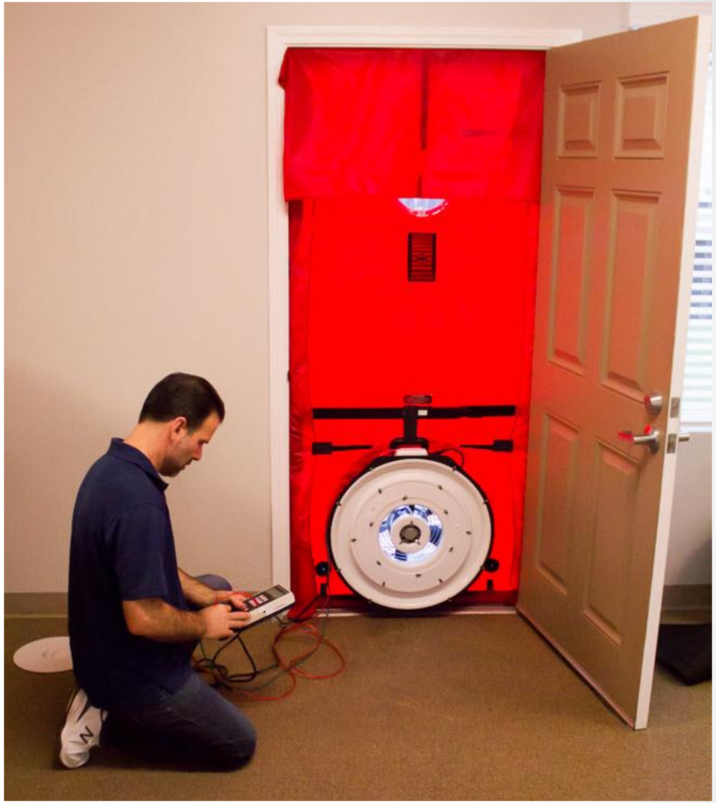

Photo Courtesy of CalCERTS, Inc.

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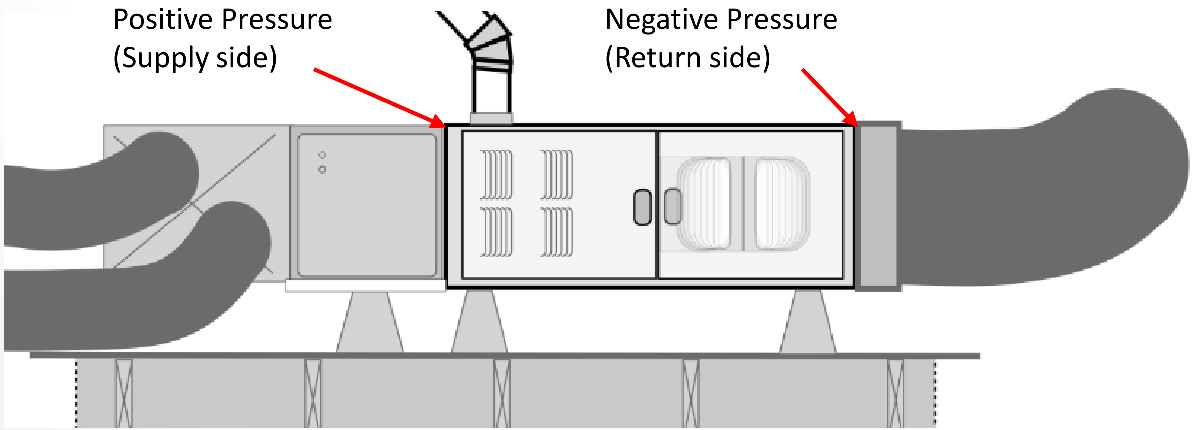
Diagnostic Testing: Static Pressure

- Static pressure across the air handler fan, often referred to as "external static pressure" (ESP), is one of the easiest diagnostic tests to do and for the effort, one of the most informative.
- It gives a good indication of duct sizing and system airflow.



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Diagnostic Testing: Duct Leakage

- Duct leakage can have a dramatic impact on the heating and cooling loads that a system must deal with.
- It also directly reduces the amount of heating and cooling delivered to the home.

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Diagnostic Testing: Blower Door Test

- Infiltration is the leakage of unconditioned air into a home and the corresponding leakage of conditioned air to the outside.
- To measure infiltration, we induce a known pressure on the house using fans. Actual infiltration is caused by much smaller natural pressure differentials (wind and temperature).

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Diagnostic Testing: Blower Door Test

- Infiltration can have a huge impact on house load, especially in older homes.
- Infiltration is measured using a diagnostic tool called a “blower door”.

Diagnostic Testing: Infrared Camera

- Infrared thermography is a way to see temperature differences. I
- It is a very impressive visual tool, however.
- It can be used to find locations of air or water leaks.
- It can be used to find missing or poorly installed insulation.
- It can be used to confirm hot ceilings caused by poor attic ventilation.
- The limitations include that it should be used during more extreme conditions (very cold or very hot) for best results.

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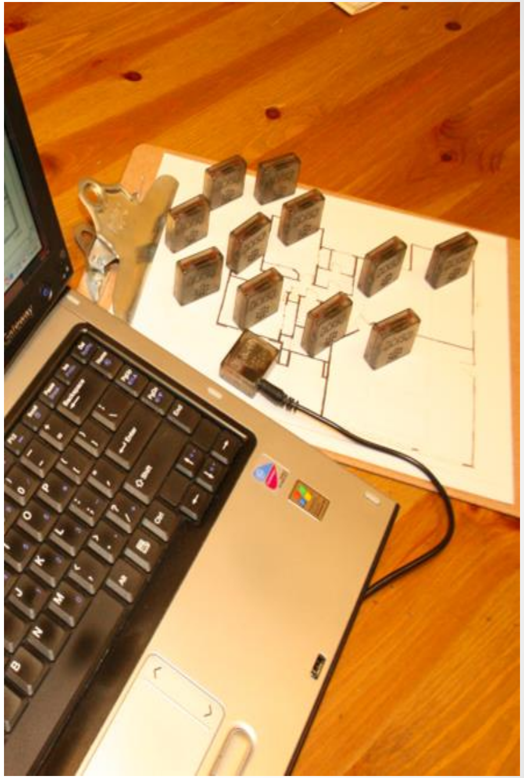
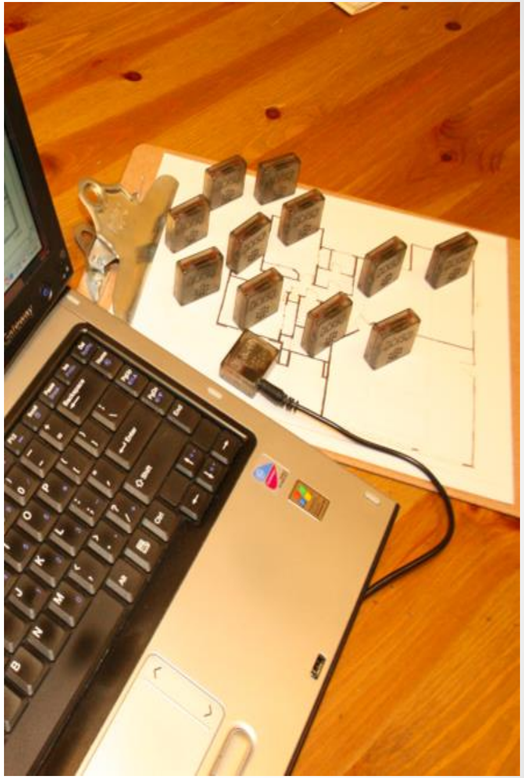
Diagnostic Testing: Data loggers

- Data loggers are small devices that record temperature and or humidity at specified intervals over a specified period of time.

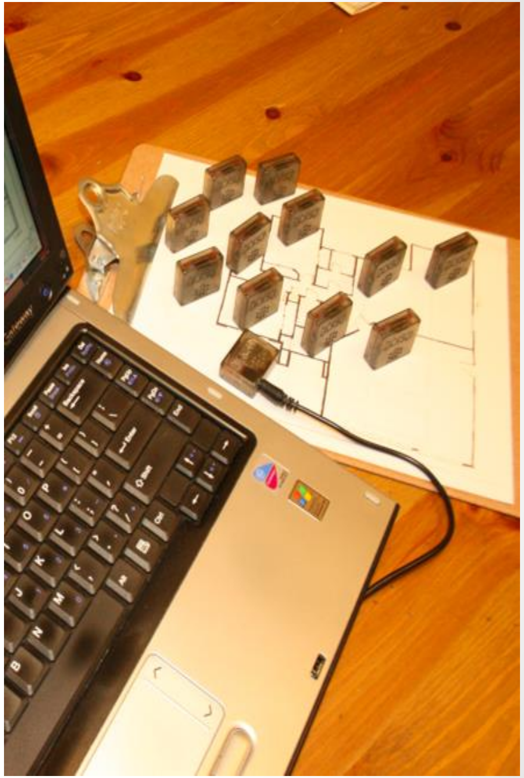


Diagnostic Testing: Data loggers

- With this information, you can diagnose:
    1. Equipment sizing relative to load
    2. Air balance
    3. Occupant behavior
- The limitations include that they must be used during extreme conditions for best results.



Diagnostic Testing: Data loggers



- For best results, data loggers should be placed in the following locations:
    1. Outside the house, on the north side or in the shade. This is to measure outdoor temperature.
    2. Right next to the thermostat.
    3. On a supply register. This will tell you when the system turns on and off.
    4. In at least one “comfortable” room, about 5’ from the floor out of any direct sunlight or supply air streams. This will be the reference for comparing the problem rooms to.
    5. In several “uncomfortable” rooms

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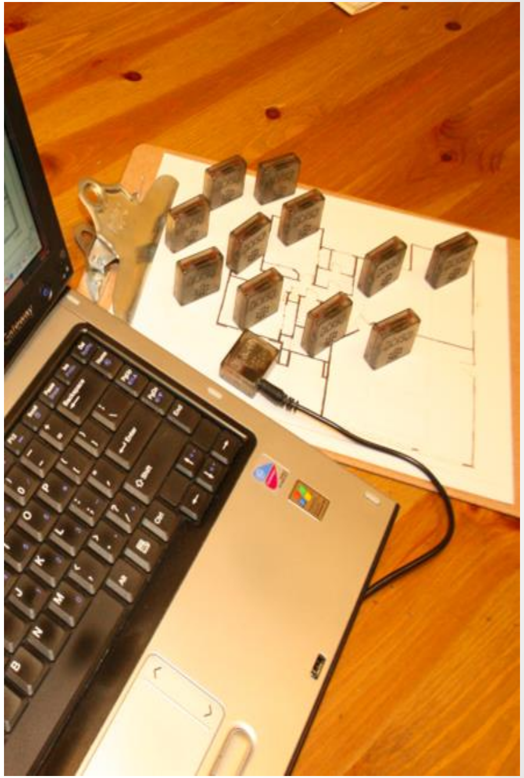
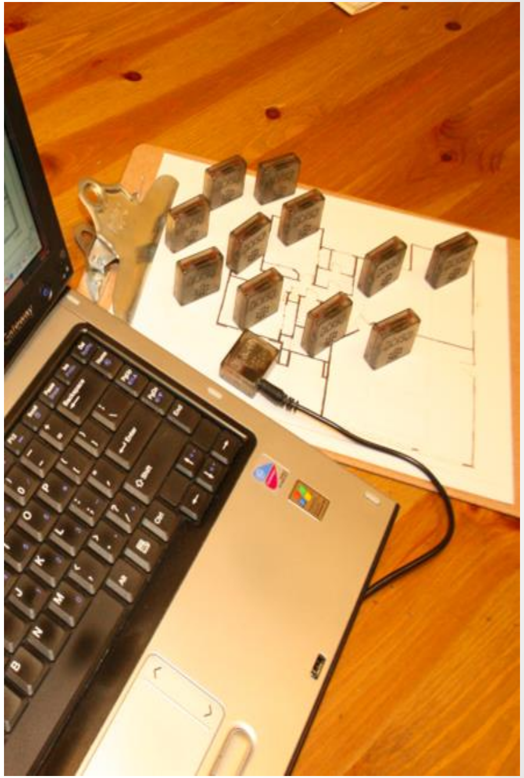
Diagnostic Testing: Data loggers

- Have the homeowners agree to and sign a set of instructions saying that:
  - They will leave the thermostat at an agreed to setpoint, unless it gets really uncomfortable.
  - They will not tamper with the data loggers or cause unusual temperatures near them.
  - They will operate doors, windows, window coverings, and exhaust fans normally

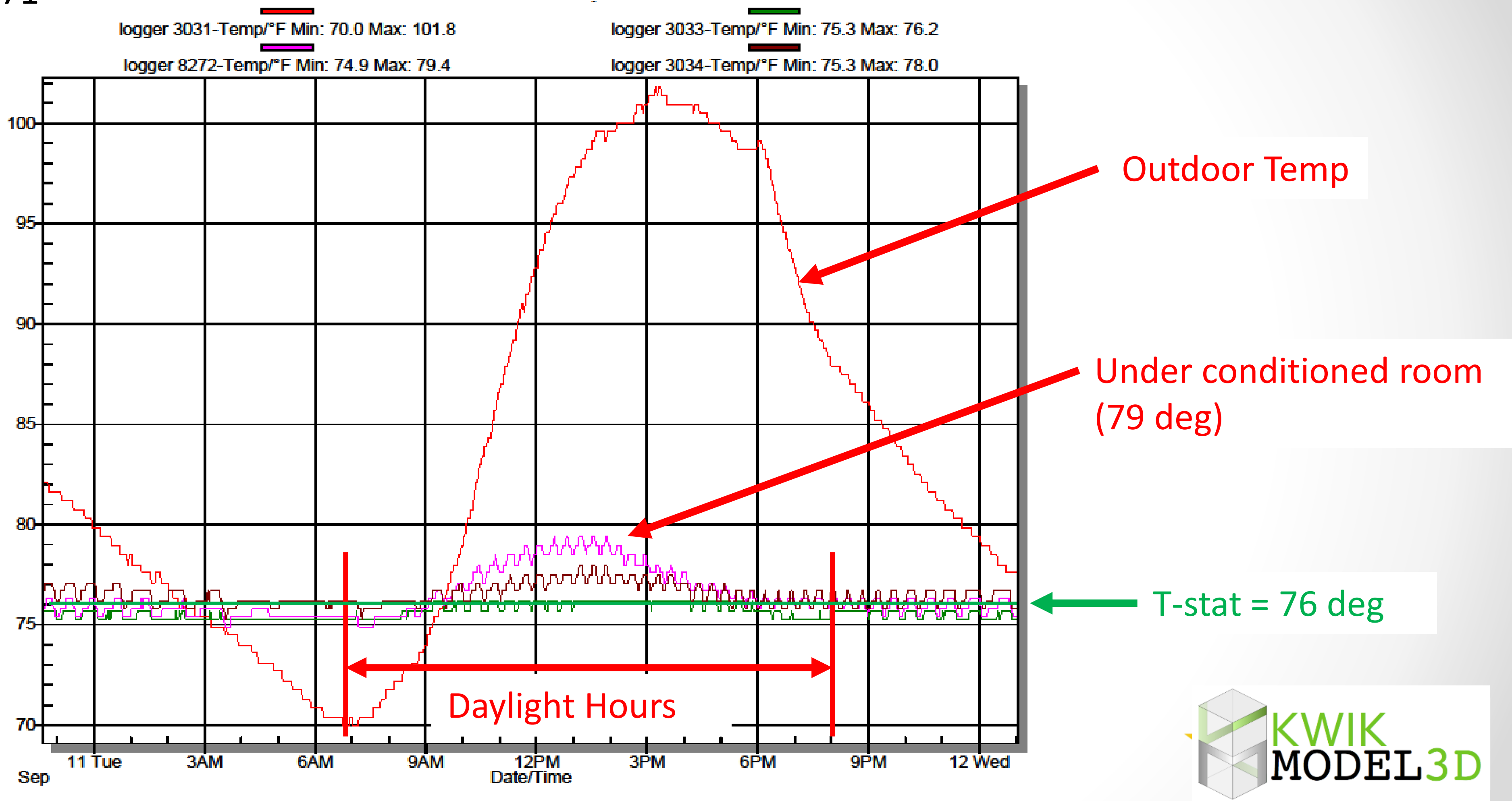


Diagnostic Testing: Data loggers

- Try to monitor the house for about a week.
- When done, collect the loggers, compile and graph the data from all data loggers onto a single graph.
- Good software will allow you to turn certain data on and off and change the time periods and scale of the graph.
- Examples . . .



Temperature Data Logger Results (24 hrs)



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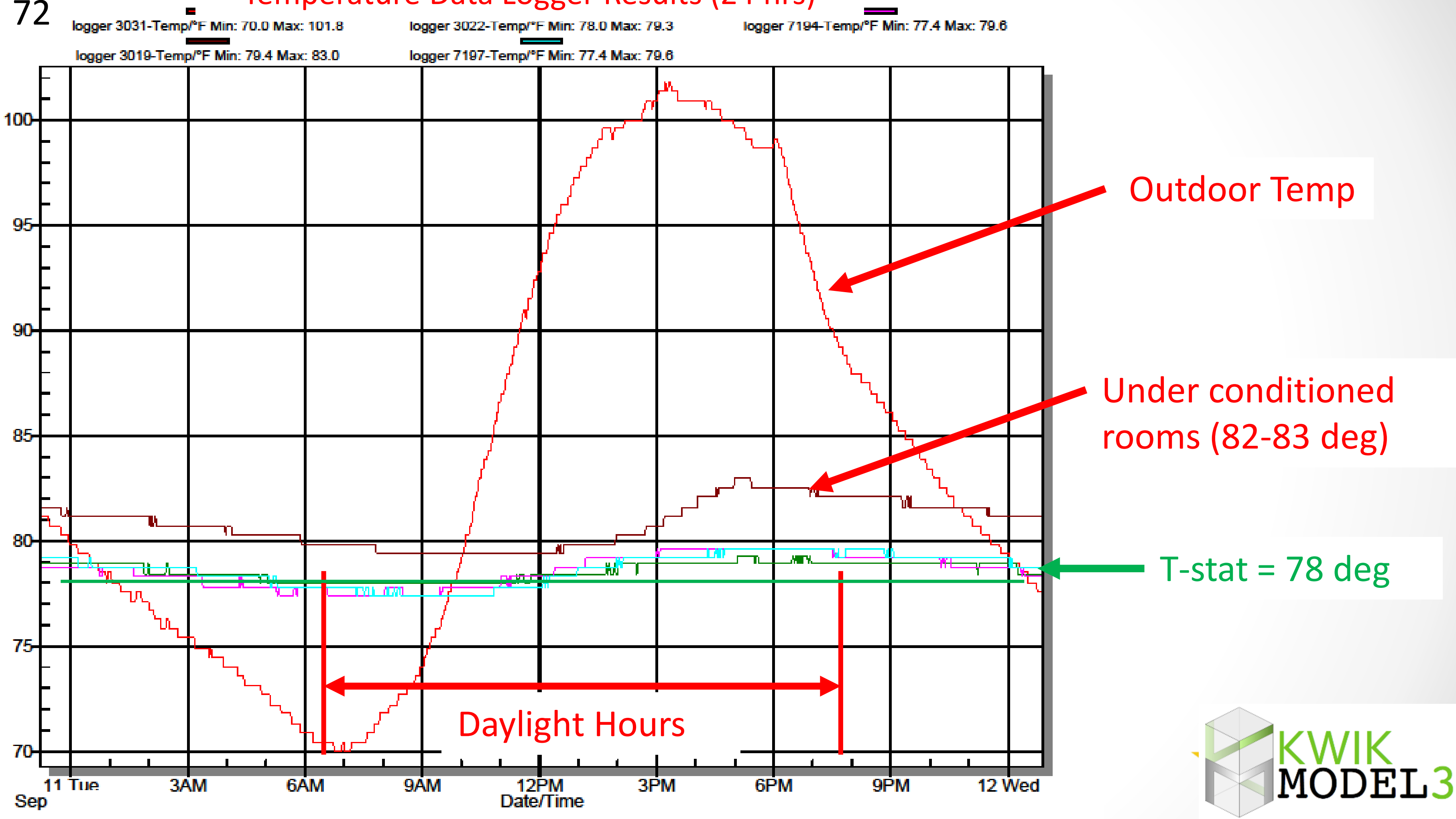

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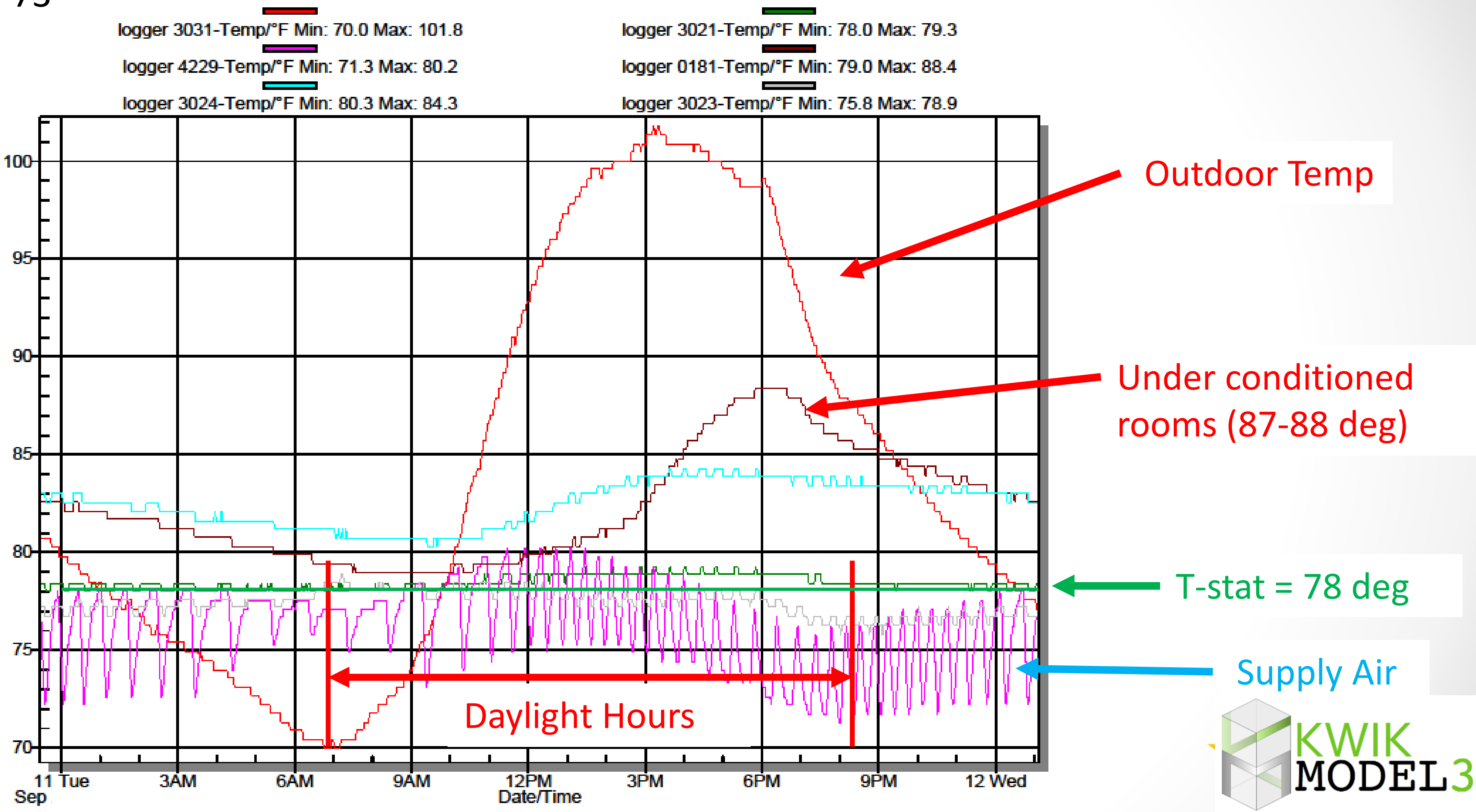

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Conclusions From This Training

- There is an entire arsenal of diagnostic tests that can be used to identify comfort problems.
- The most important “tool” is an understanding of the design process.
- Carefully and precisely identifying the symptoms that are causing the homeowner complaints is critical.
- Once the symptoms have been identified, the source can be confirmed using the appropriate diagnostic tests.
- Tests take time, but having real, tangible measurements is far more convincing to homeowners to take your recommended repairs and can be cheaper for them in the long run.
- The knowledge and skills to do these tests will set you apart from your competition.

The End

Thank you

russ@coded-energy.com

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