IBACOS

HOME TO INNOVATION

Duct Designs in Low Load Houses: Challenges and Solutions

Lessons Learned from Building America

RESNET 2007

February 19, 2007

Duncan Prahl, RA and

Anthony Stamatopoulos

This session

- ***Challenges with Low Load Houses (Energy Star and the universe beyond it)***
- ***Comfort – what is it and why is it important?***
- ***Process Issues***
- ***Advanced Thermal Enclosure Mechanical Systems***
  - *Loads*
  - *Equipment*
  - *Ducts*
  - *Supply outlets*

Challenges

- *More efficient enclosure*
- *Lower and lower heating and cooling loads*
- *Higher latent to sensible load ratios (especially in south)*
- *More emphasis on “Right Sizing”*

Top Five Solutions

- ***Buy a Flux Capacitor and go back to the 50's***
- ***Get out of the business***
- ***Blame it on someone else***
- ***Rethink how the space conditioning system is designed and installed***
- ***Process needs to change***

A Few More Challenges

- ***Energy Efficiency ≠ Comfort***
- ***Builders typically have more comfort complaints than high bill complaints***
- ***If it ain't comfortable, energy efficiency will be set back 20 years (maybe we don't need a Flux Capacitor…)***
- ***Need to understand comfort fundamentals***

Thermal Comfort

Thermal Comfort Criteria – ASHRAE Std 55

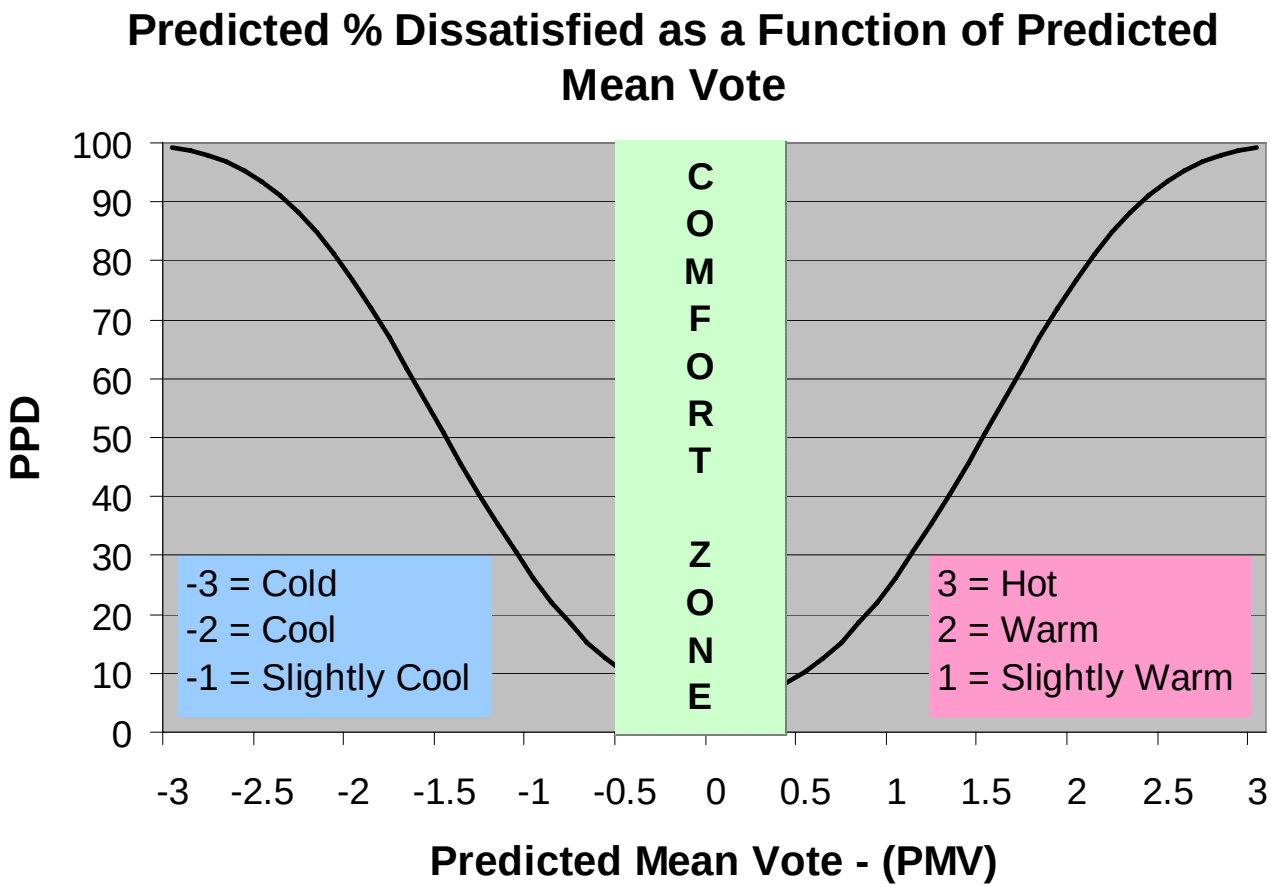
Items that determine human thermal comfort

1. **Metabolic Rate**
2. **Clothing Insulation**
3. **Air Temperature**
4. **Mean Radiant Temperature (MRT)**
5. **Air Speed**
6. **Humidity**

Examples of poor comfort

- ***Cold floor - Hot head***
  - *stratification*
- ***Air blowing on person***
  - *poor supply outlet location, selection, temperature, or throw*
- ***Cold or Hot Surfaces = Low / High MRT***
  - *poor choice of thermal enclosure elements*
- ***Floor to floor or room to room temperature variations***
  - *beyond +/- 2°F = poor design of distribution system, high variance in thermal characteristics of various rooms*

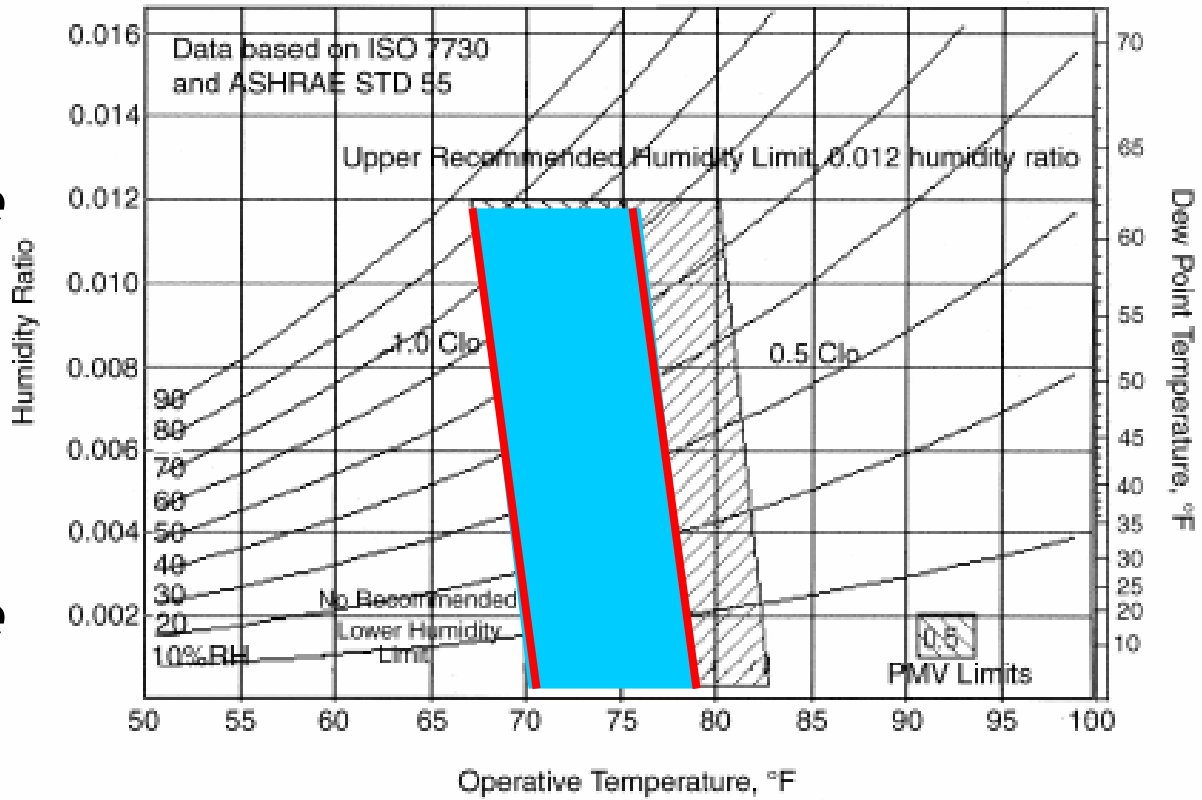
Thermal Comfort

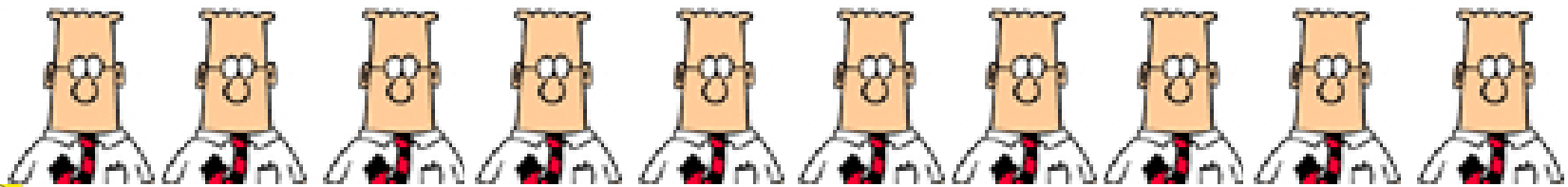


Thermal Comfort

Up to 20% are dissatisfied because they are too cold

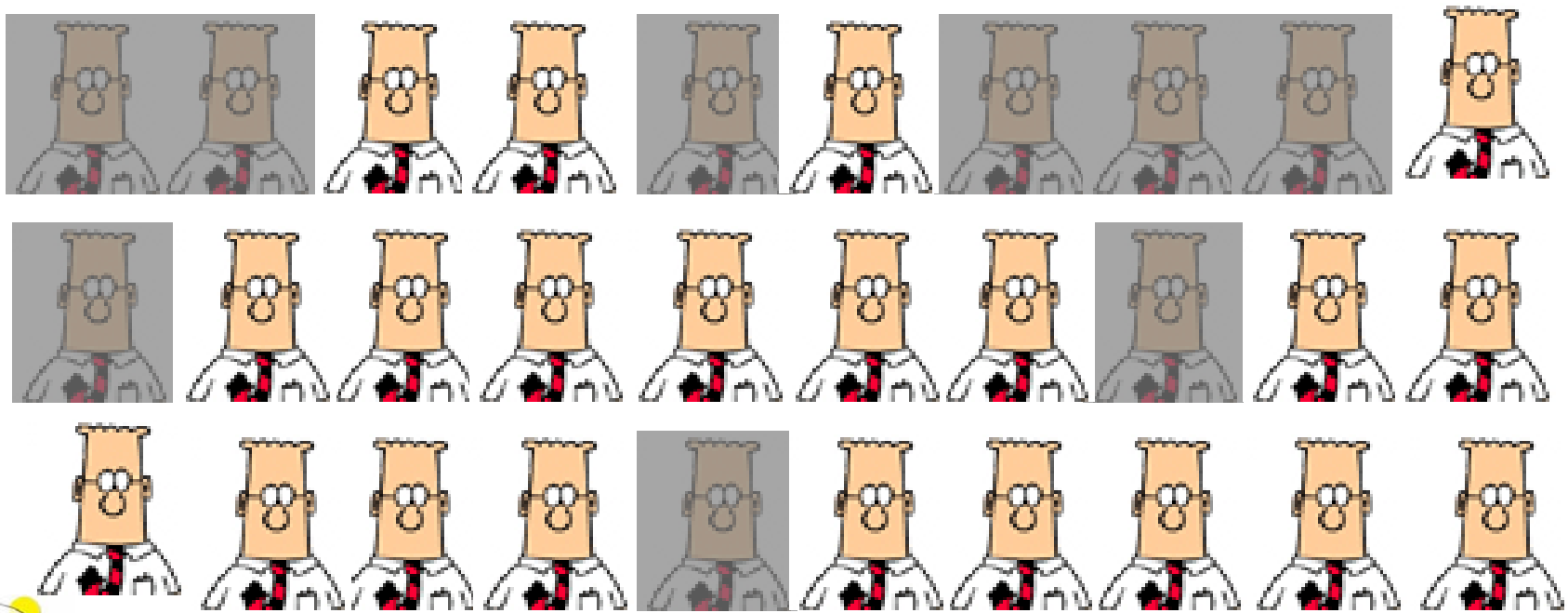
A different 10% are dissatisfied because they are too hot





Thermal Comfort

If all rooms within a home are within the thermal comfort zone, up to 30% of individuals may be uncomfortable in every room.

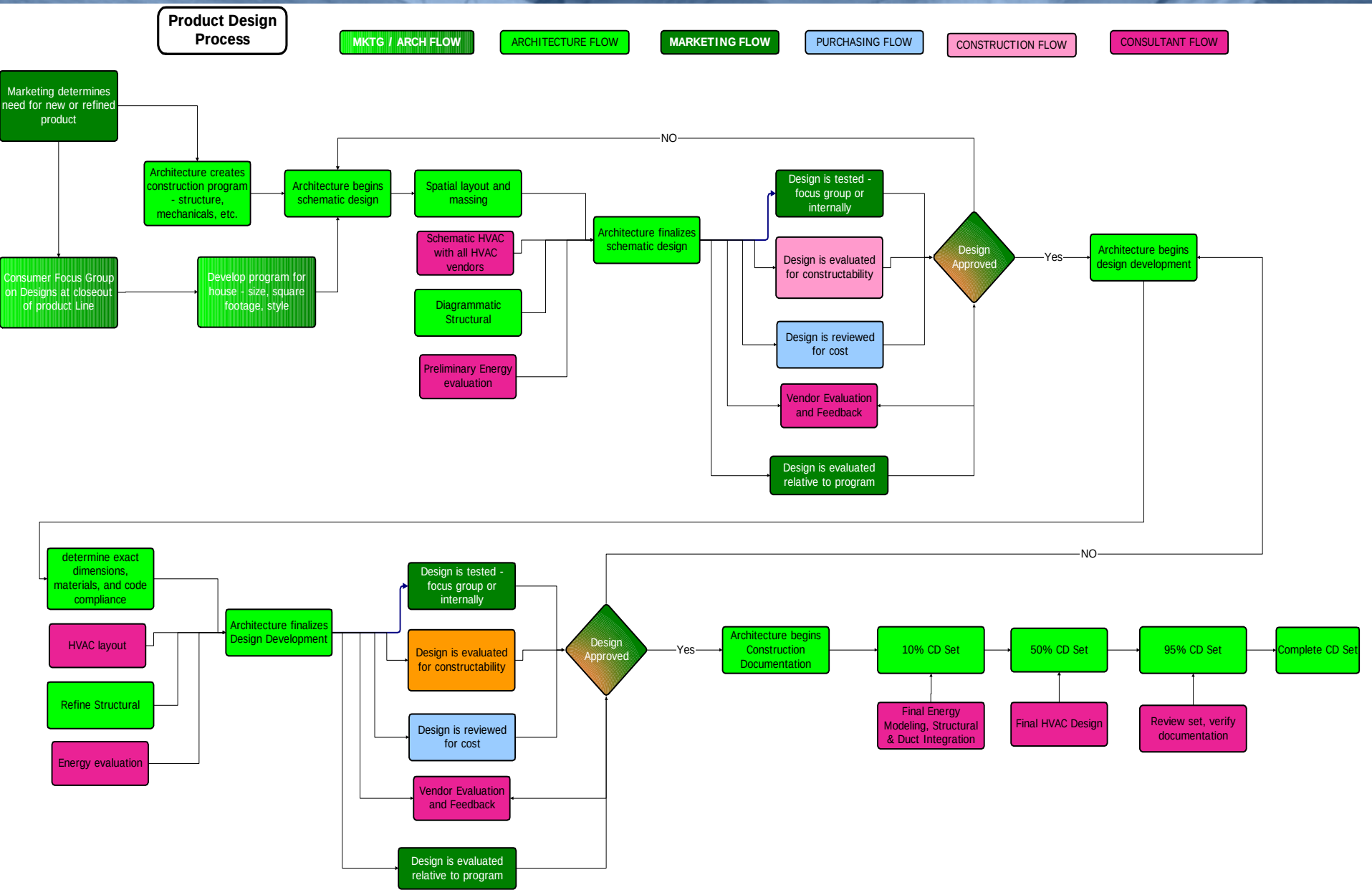


Before you Begin – Process, Process, Process

- ***Set performance goals and responsibilities***
- ***What is acceptable and what is not?***
- ***What is the energy and system performance criteria?***
- ***What are the aesthetic criteria?***
- ***Determine expectations - builder, trades, manufacturers, consumer***
- ***What is the process for accountability***
- ***Testing and verification process (Commissioning)***

IBACOS

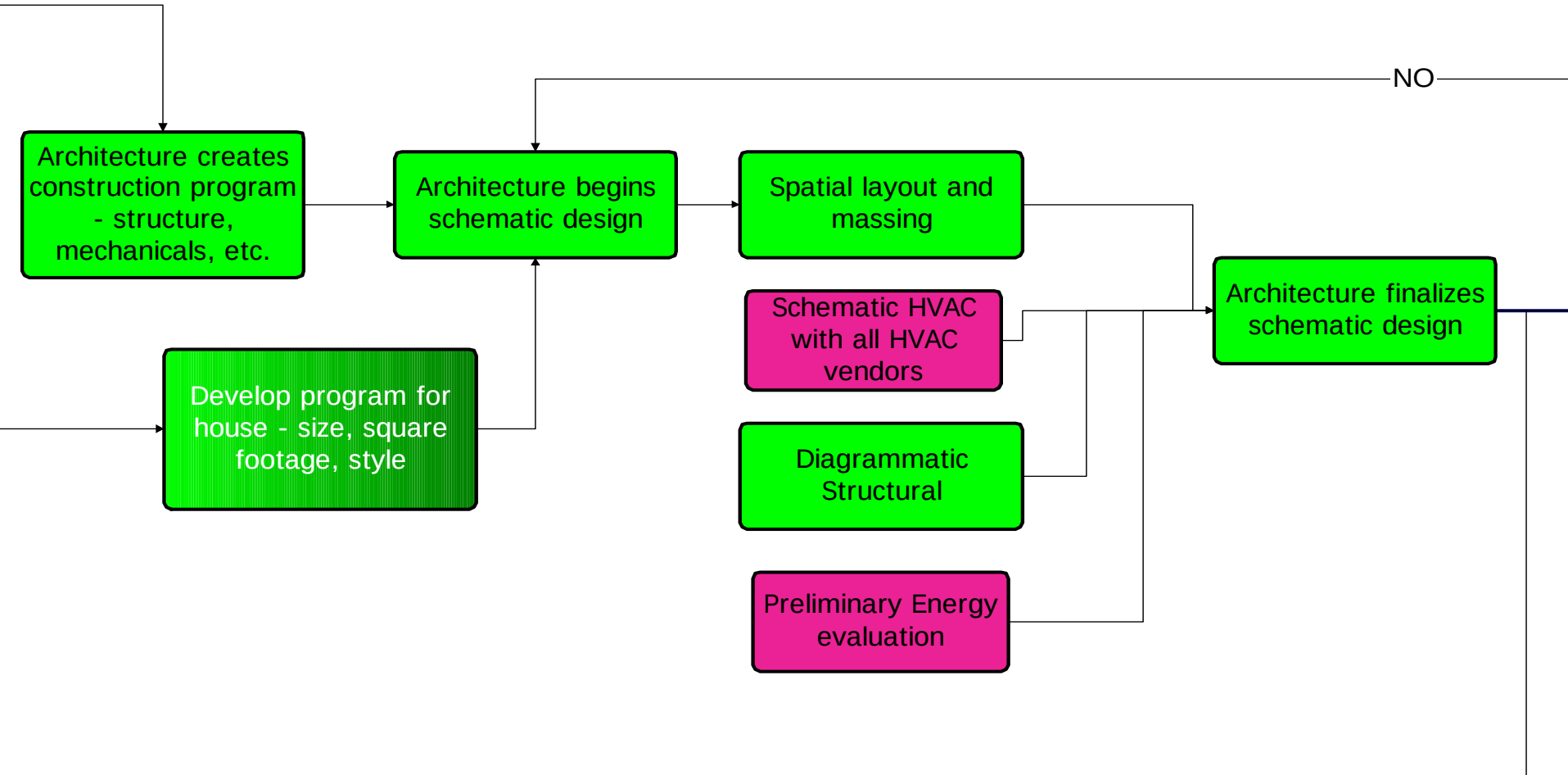
Integrated Design process map



Schematic Design Phase

Product Design Process

MKTG / ARCH FLOW | ARCHITECTURE FLOW | MARKETIN



What does an ideal forced air system do?

- *Delivers or removes energy from space (heats or cools)*
- *Mixes air in room to maintain temperature and fresh air uniformity*
- *Maintains humidity levels in comfort zone*
- *Is unnoticed by the occupants*
- *Is energy efficient*

IBACOS

Sizing Trends

	System size sf/ton	Air flow cfm/sf	Air exchange rate ACH nat
Historic “Rule of Thumb”	**400**	**1.0**	**0.5 - 0.75**
Energy Star – Cold Climate	**1107**	**0.35**	**0.31**
Energy Star – Mixed Humid Climate	**1124**	**0.34**	**0.34**
40% BA – Cold Climate	**1476**	**0.26**	**0.10**
40% BA – Mixed Humid Climate	**1311**	**0.27**	**0.19**

What's it all mean?

- *Lower loads, lower airflow (cfm) per room*
- *Lower airflow = less air available to mix for the same volume room*
- *Same size house, same length ducts, lower airflow, duct tightness critical*
- *Long runs, less airflow, takes time to heat up duct mass, lower outlet temperatures at long runs on short cycles*
- *Register selection is critical*

IBACOS

Denver CO House

	Building America 40%	Energy Star Specs
Foundation	R-18 Basement & Crawlspace walls	R-10 Basement & Crawlspace walls
Above Grade Walls	R-21 - Exterior Sheathing R-5	R-18
Floors Over Unconditioned Space	R-46	R-21
Roof Insulation R-Value	R-54 & Vaulted Ceilings @ R-40	R-38
Windows	U-value 0.30 & SHGC 0.30	U-value 0.35 & SHGC 0.60
Exterior Doors	U-value 0.20	U-value 0.50
Building Air tightness	ACH nat 0.10	ACH nat 0.31
Mechanical Ventilation	HRV: supply 84 cfm, exhaust 84 cfm, run-time 50%, power 100 watts, & efficiency 82%	84 cfm Fresh air intake only
Furnace	94.1 AFUE	92.1 AFUE
AC	18.1 SEER	13.0 SEER

IBACOS

Columbus GA House

	Building America 40%	Energy Star Specs
Foundation	Slab-on-grade no insulation	Slab-on-grade no insulation
Above Grade Walls	R-13 – Cavity, R-5 Sheathing	R-13
Floors Over Unconditioned Space	N/A	N/A
Roof Insulation R-Value	R-29 Unvented attic	R-30 Unvented attic
Windows	U-value 0.38 & SHGC 0.35	U-value 0.65 & SHGC 0.50
Exterior Doors	U-value 0.20	U-value 0.50
Building Air tightness	ACH nat 0.19	ACH nat 0.34
Mechanical Ventilation	ERV: supply 60 cfm, exhaust 60 cfm, run-time 50%, power 90 watts, & efficiency 80%	60 cfm Fresh air intake only
Heat Pump	9.3 HSPF	7.7 HSPF
AC	18.6 SEER	13.5 SEER

Heating and cooling Bin Hours

Boulder, CO			Columbus GA	
DB (°F)	Total Hrs		DB (°F)	Total Hrs
90 to 100	118		90 to 98	155
78 to 90	673		78 to 90	1532
32 to 68	5307		32 to 68	3911
2 to 32	1610		14 to 32	181
-10 to 2	77			

Cold Climate house Manual J Peak Loads

		Building America 40%			Energy Star	
	Area (ft^2)	Htg load (Btuh)	Clg load (Btuh)		Htg load (Btuh)	Clg load (Btuh)
First Floor & Basement	3,492	26,112	21,554		42,436	33,397
Upper Bedrooms	936	8,928	6,387		13,004	10,367
Entire House	4,428	35,040	25,423		55,440	38,952
Other equip loads		2,007	558		5,017	1,139
Equip. @ 0.98 RSM			25,409			39,209
Latent cooling			0			0
TOTALS	4,428	37,047	25,409		60,457	39,209

Outdoor Design Temps: -3°F & 93°F,
Indoor Design Temps 71 & 76

IBACOS

Cold Climate house Manual J Part Loads

		Building America 40%			Energy Star	
	Area (ft^2)	Htg load (Btuh)	Clg load (Btuh)		Htg load (Btuh)	Clg load (Btuh)
First Floor & Basement	3,492	13,762	20,686		22,365	31,911
Upper Bedrooms	936	4,705	6,049		6,853	9,887
Entire House	4,428	18,467	24,217		29,218	36,985
Other equip loads		1,058	482		2,644	949
Equip. @ 0.98 RSM			23,464			36,038
Latent cooling			0			0
TOTALS	4,428	19,525	23,464		31,862	36,038

Outdoor Design Temps: 32 °F & 90°F
Indoor Design Temps 71°F & 76°F

IBACOS

Cold Climate house Peak Airflow (cfm)

		Building America 40%			Energy Star	
	Area (ft^2)	Htg AVF (cfm)	Clg AVF (cfm)		Htg AVF (cfm)	Clg AVF (cfm)
Entry	212	31	25		50	43
Dining	168	70	100		93	159
Pantry	36	8	3		13	4
Powder	36	0	2		0	2
Master Bathroom	174	35	58		48	74
Master Bedroom	306	130	223		158	294
Kitchen / Nook	300	71	127		95	172
Laundry	68	32	19		37	27
Family	304	84	145		103	156
Bedroom	225	83	80		118	83

Outdoor Design Temps: -3°F & 93°F,
Indoor Design Temps 71 & 76

IBACOS

Mixed Humid house Manual J Peak Loads

Peak		Building America 40%			Energy Star	
	Area (ft^2)	Htg load (Btuh)	Clg load (Btuh)		Htg load (Btuh)	Clg load (Btuh)
Entire House	3,934	27,730	22,880		4,8015	34,307
Other equip loads		1,107	535		2,362	923
Equip. @ 0.95 RSM			22,993			34,596
Latent cooling			4,134			6,890
TOTALS	3,934	28,838	27,128		50,377	41,486

Outdoor Design Temps: 27°F & 93°F
Indoor Design Temps 71°F & 76°F

Mixed Humid house Manual J Part Loads

		Building America 40%			Energy Star	
	Area (ft^2)	Htg load (Btuh)	Clg load (Btuh)		Htg load (Btuh)	Clg load (Btuh)
Entire House	3,934	24,579	21,678		42,559	31,630
Other equip loads		981	455		2,093	751
Equip. @ 0.95 RSM			21,026			30,763
Latent cooling			4,555			7,705
TOTALS	3,934	25,561	25,581		44,652	38,467

Outdoor Design Temps: 32°F & 90°F
Indoor Design Temps 71°F & 76°F

IBACOS

Mixed Humid house Peak Airflow (cfm)

		Building America 40%			Energy Star	
	Area (ft^2)	Htg AVF (cfm)	Clg AVF (cfm)		Htg AVF (cfm)	Clg AVF (cfm)
Laundry	63	91	121		81	95
Office	150	95	158		119	166
Mstr Bed	265	186	164		198	176
Mstr Bath	182	90	77		64	75
Bedroom 2	195	166	111		139	101
Bedroom 3	209	132	130		217	175
Family-Dining	650	277	404		400	448

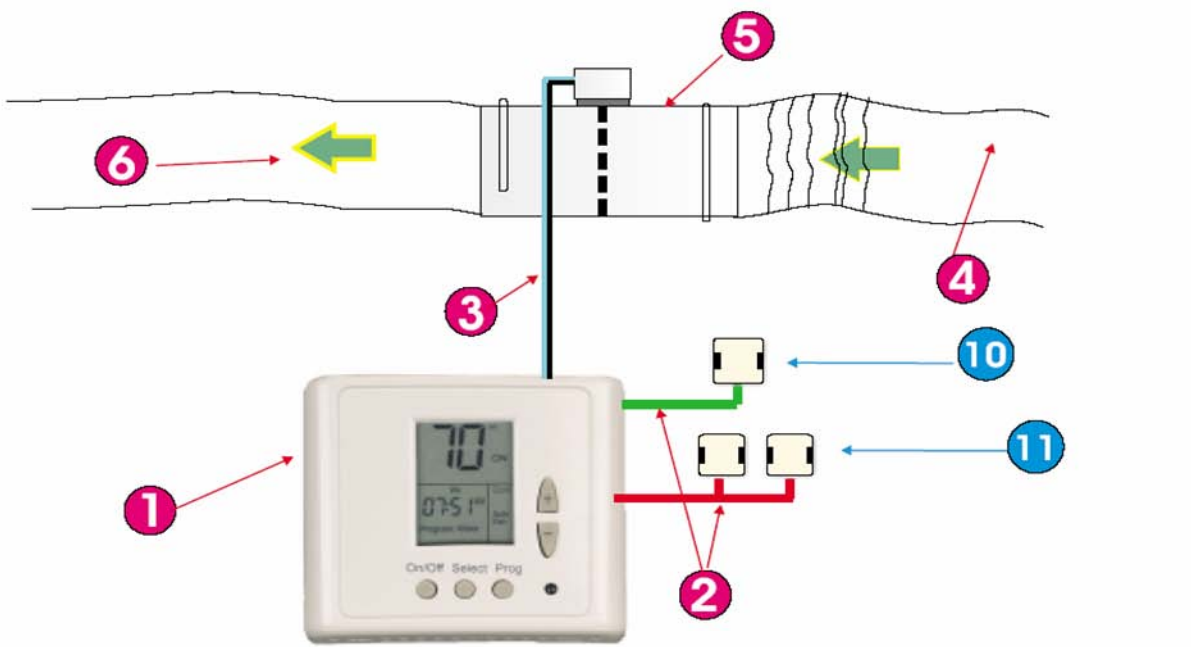
Outdoor Design Temps: 27°F & 93°F
Indoor Design Temps 71°F & 76°F

San Diego RESNET 2007 Conference

Building America U.S. Department of Energy
Research Toward Zero Energy Homes

Single Unit, Zoned or Unzoned Solution

- ***Fan cycling unit incorporated into simple T-stat.***
- ***Master – With Remote Slave(s)***
- ***Maybe back to two systems….***



Mechanical Design

- ***Advanced Thermal Enclosure Mechanical Systems***
  - *Loads & cfm (done)*
  - *Equipment*
  - *Ducts*
  - *Supply outlets*

Equipment Options

- ***Single Speed Challenges***
  - Poor dehumidification
  - Room to room temperature differences
  - Longest duct run may not heat up or cool down
  - Zoning and matching part load performance
- ***Multi-Speed Benefits***
  - Part load performance
  - Assists in meeting heating and cooling flow variations
  - Can accommodate combinations of flow and resistance

Generic External System Pressure Drops

DEVICE	PRESSURE DROP
Standard Filter	.10 Clean
High Efficiency Filter	.20 Clean
Humidifiers/Electric Heaters	.10 to .20
Supply Outlet	.03
Return Grille	.03
Balancing Damper	.03 Open
Coil	.15 to .45 wet coil
Duct System	……..

Example Pressure Drop

DEVICE	PRESSURE DROP
Supply Register	.03
Return Grille	.03
Balancing Damper	.03
Coil	.33 wet coil
Total EXCLUDING DUCTS	.42

IBACOS Equipment Pressure Gain

AIR DELIVERY—CFM (With Filter)*

UNIT SIZE CARRIER	RETURN-AIR SUPPLY	SPEED	EXTERNAL STATIC PRESSURE (In. wc)							
			0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
060-12	1 side or bottom	High	1490	1450	1400	1345	1275	1190	1080	960
		Med-High	1190	1180	1155	1120	1070	1005	915	810
		Med	1015	1010	995	985	920	875	800	715
		Med-Low	870	860	840	820	780	735	670	580
		Low	685	670	645	620	[illegible]	[illegible]	495	420
080-12	1 side or bottom	High	1605	1560	1510	1450	1380	1300	1195	1045
		Med-High	1305	1290	1265	1225	1175	1100	995	895
		Med	1135	1125	1110	1080	1030	965	885	800
		Med-Low	990	980	965	930	880	825	760	685
		Low	805	780	745	700	660	630	575	495
		High	1810	1755	1690	1640	1565	1495	1410	1330
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

0.55 IWC at 1200 cfm

RESNET 2007 Conference

Building America U.S. Department of Energy Research Toward Zero Energy Homes

Static for Duct System

For 1200 cfm System

External System Pressure Drop = 0.55 IWC

Equipment Pressure Gain -0.42 IWC (for Devices)

What's left for the duct system? = 0.13 IWC ASP

For 1200 cfm System

External System Pressure Drop = 0.50 IWC

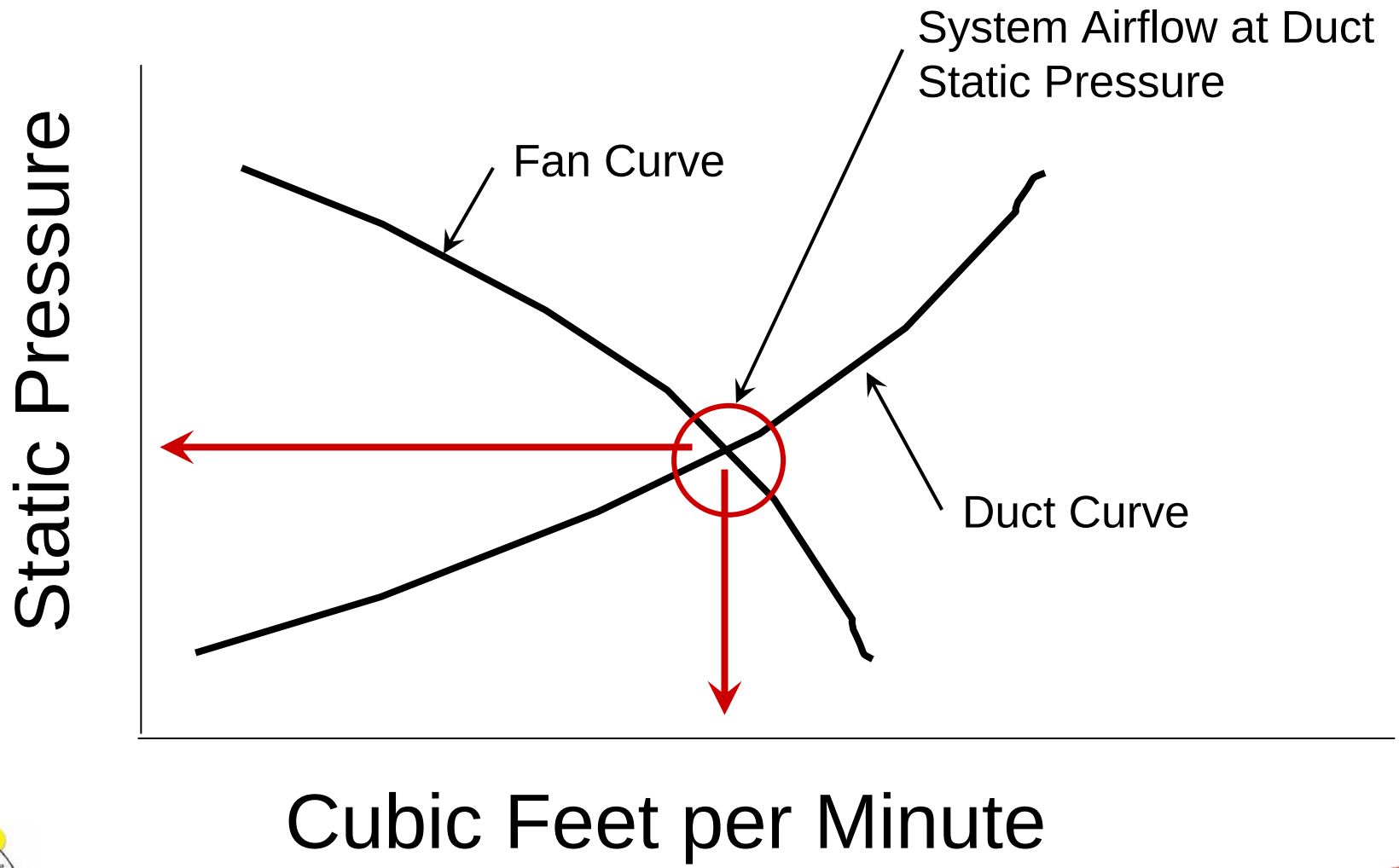
Equipment Pressure Gain -0.42 IWC (for Devices)

What's left for the duct system? = 0.08 IWC ASP

From Here to There

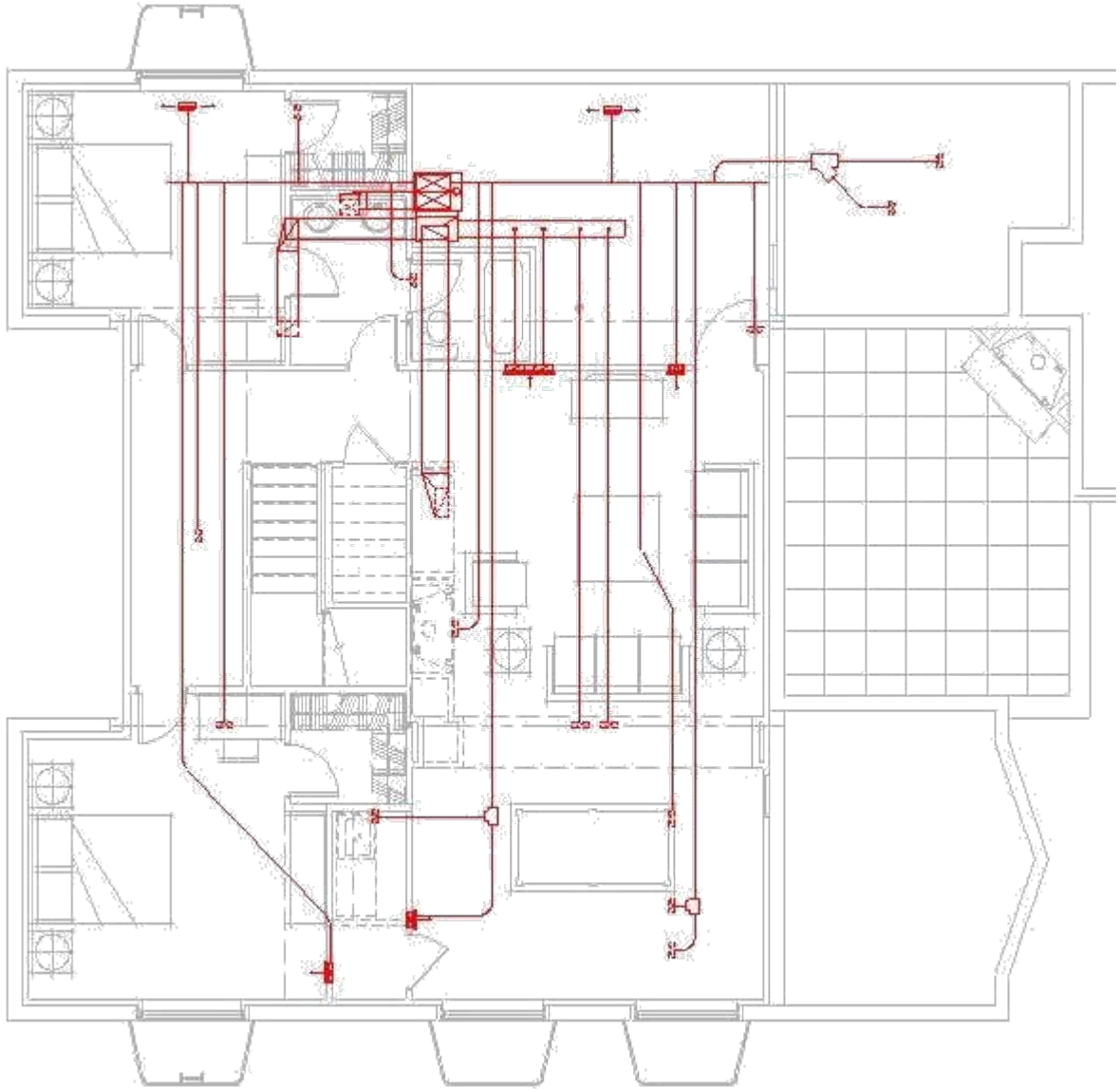
- ***Duct Design – Critical Factors***
  - *Assume Tight Ducts*
  - *Available Static Pressure & CFM*
  - *Determine Equivalent Lengths*
  - *Design using "Variable Friction" (Combination of Static Regain & Constant Velocity)*
  - *Iterate Design (Duct sizes & Routing)*

Duct Sizing Procedure



IBACOS

BA 40% Cold Climate

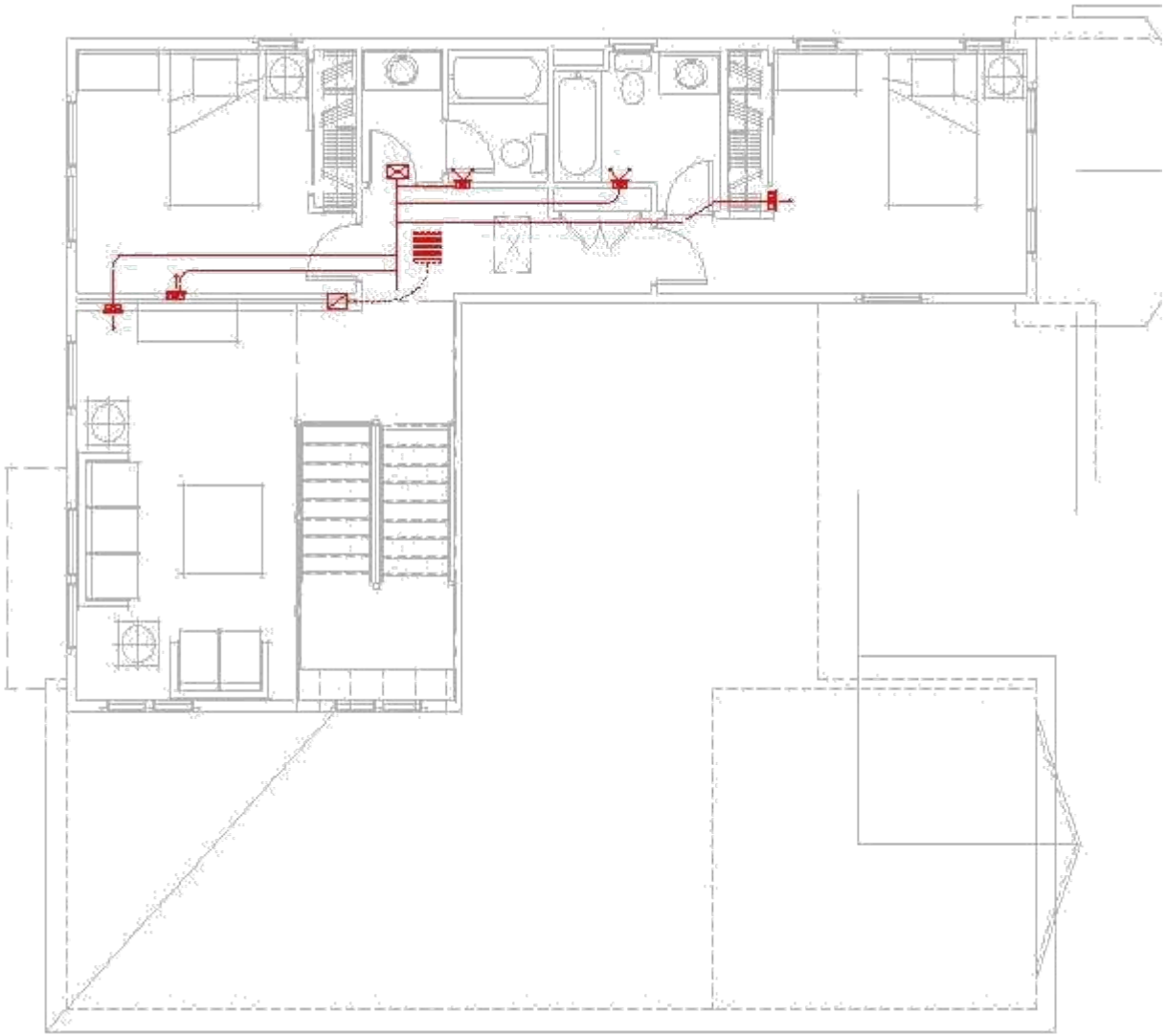


RESNET 2007 Conference

Building America
U.S. Department of Energy
Research Toward Zero Energy Homes

IBACOS

BA 40% Cold Climate

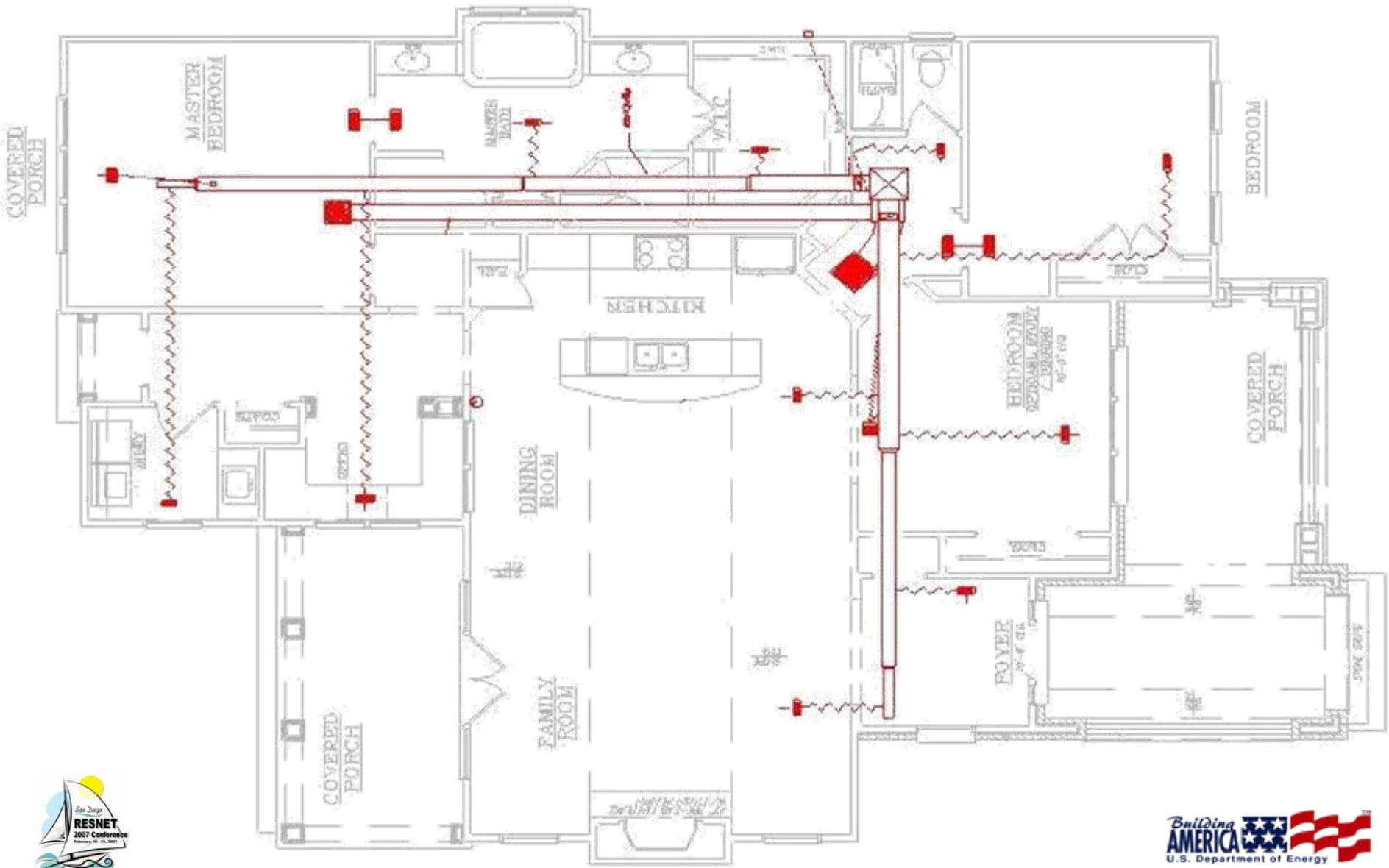


RESNET 2007 Conference

Building America
U.S. Department of Energy
Research Toward Zero Energy Homes

IBACOS

40% BA Mixed Humid



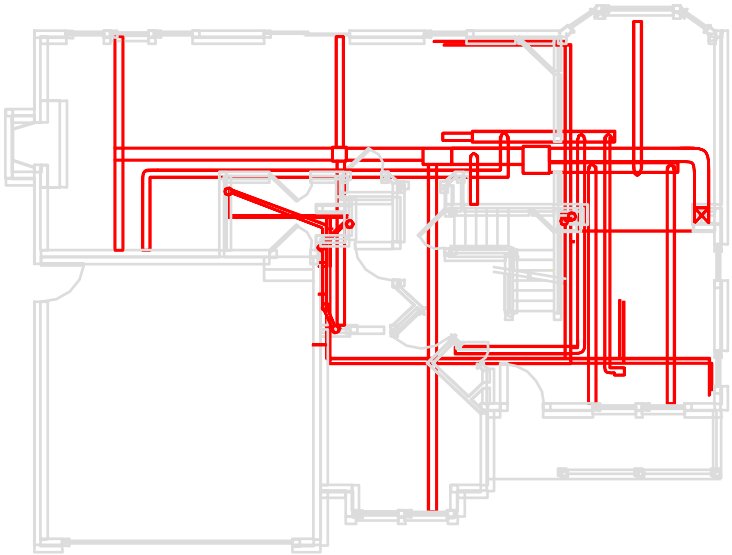
RESNET 2007 Conference

Building America
U.S. Department of Energy
Research Toward Zero Energy Homes

Variable Friction Method

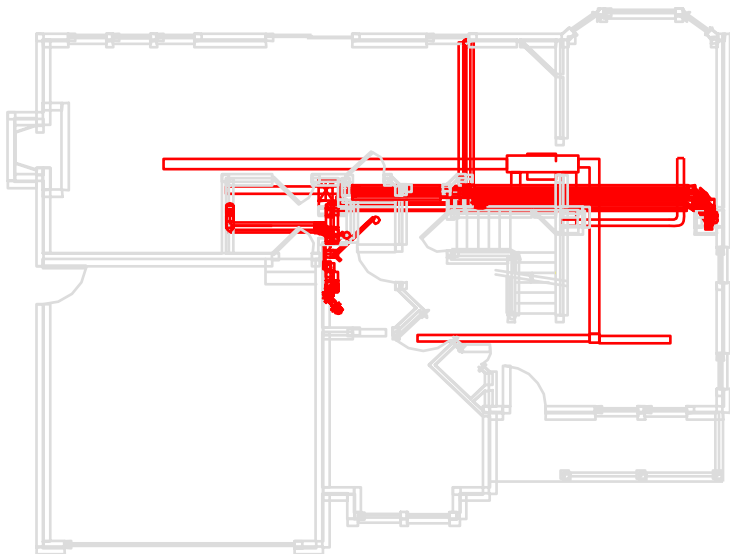
- **Static Regain and Constant Velocity**
  - Every duct run in the system needs to be calculated
  - Maintain constant static pressure throughout the air distribution system
  - Design to ensure constant air velocity in trunk and branches.
    - If you loose velocity, can't get it back
  - Ensure volume *and* velocity at supply outlets
  - (ASHRAE HVAC and Fundamentals Handbooks)

Supply Air Temperature



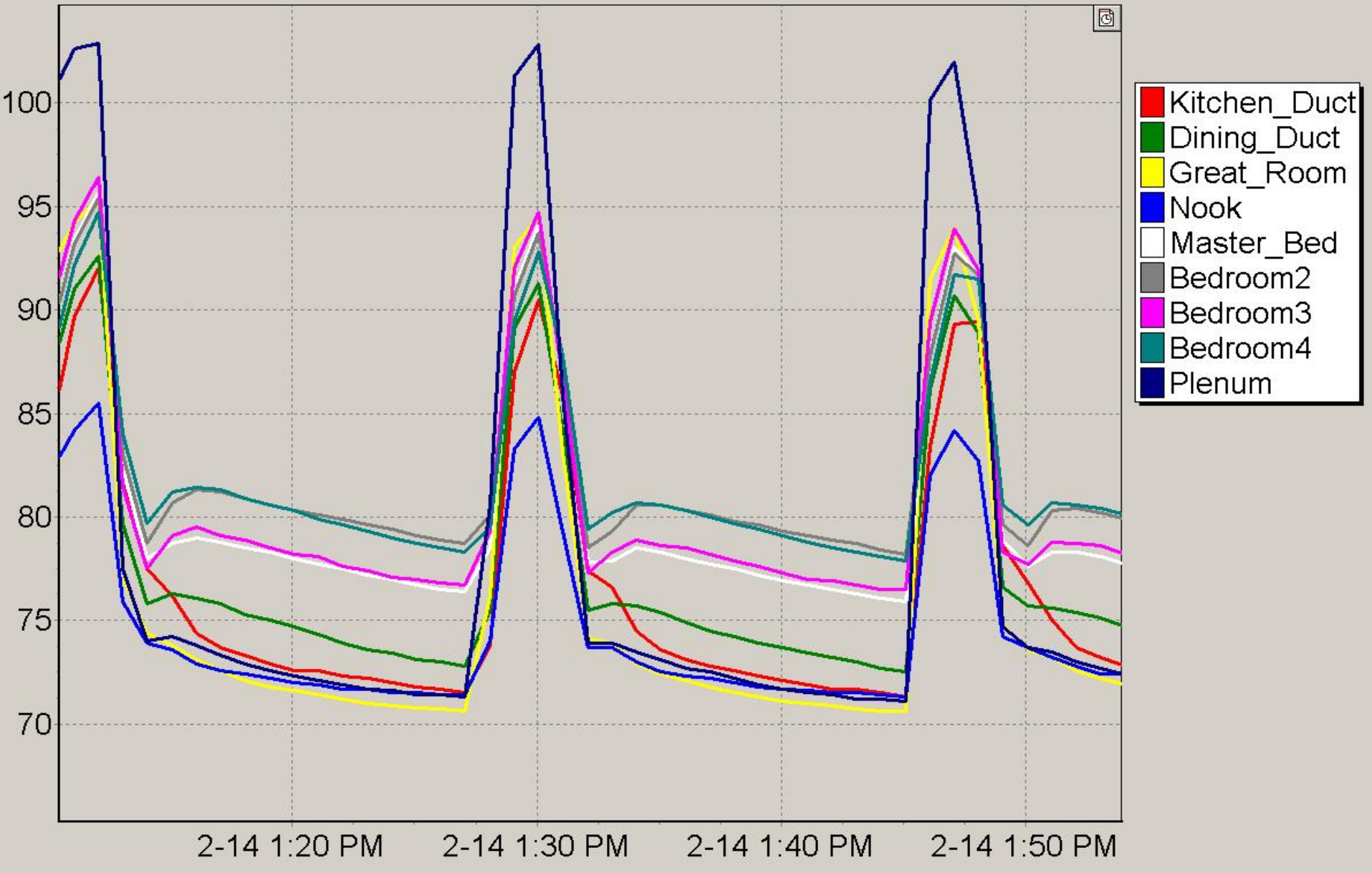
- Compact vs. perimeter distribution
- High mass vs. low mass

- Terminal outlet temperature
- Less margin for error



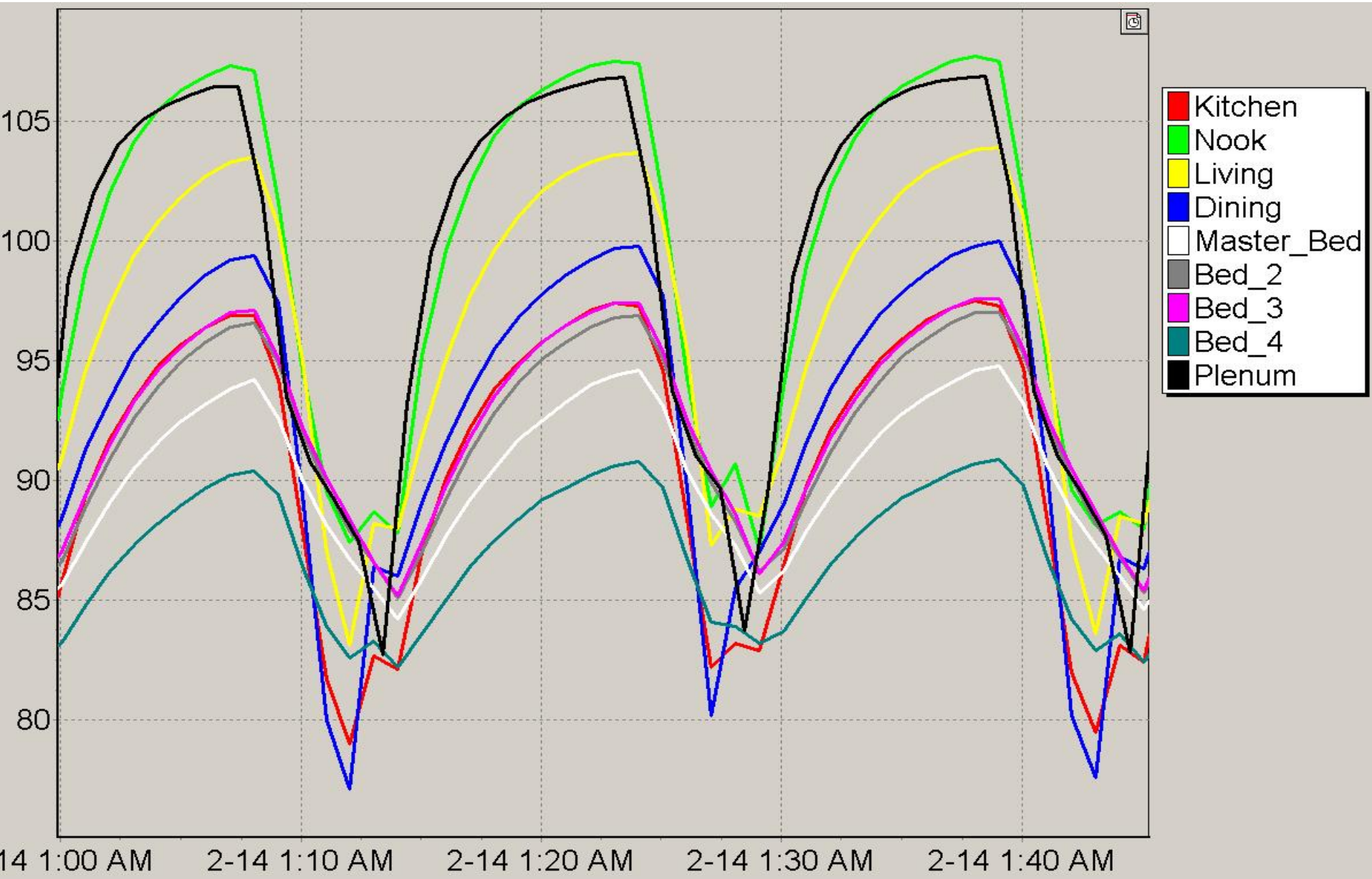
IBACOS

Terminal Air Temperature
Low Mass, compact System



IBACOS

Terminal Air Temperature
High Mass, perimeter System



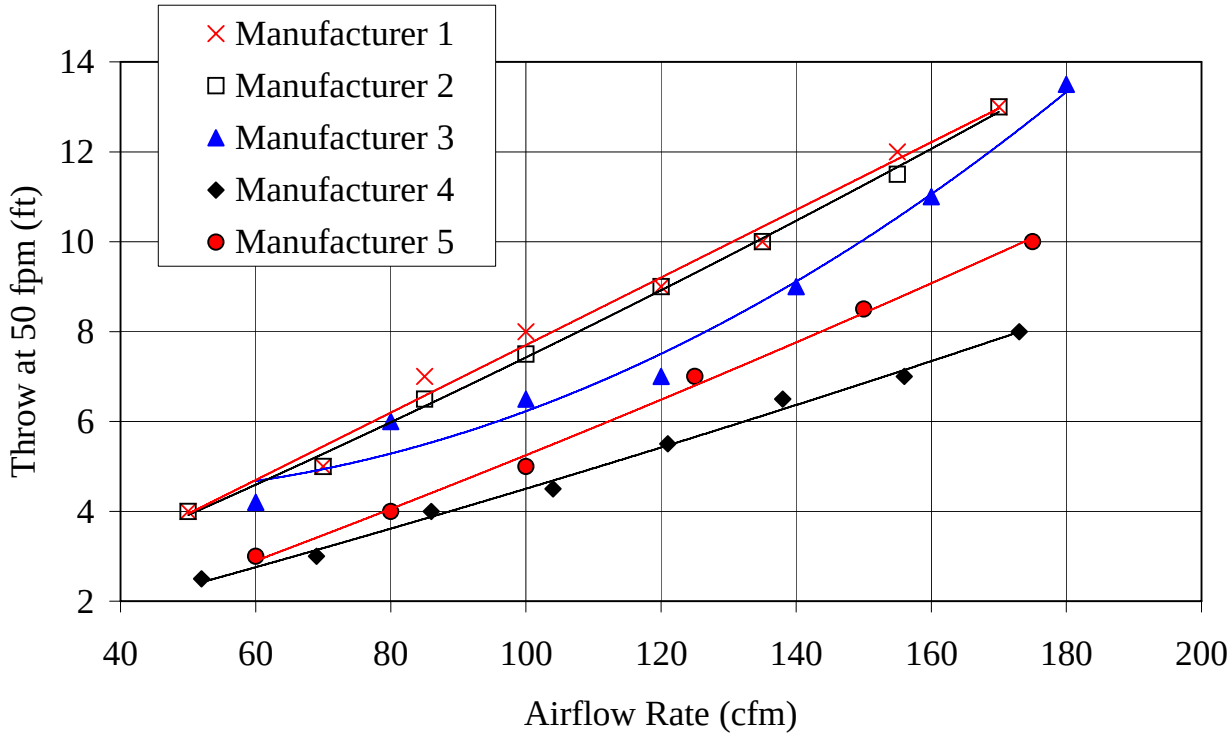
Supply air outlet design & Selection

- *Once again – Peak vs. Part Load*
- *Throw*
- *Face Velocity*
- *Terminal Velocity*
- *Air volume (cfm)*
- *Pressure drop*
- *Noise*
- *Location, Location, Location*

Room Air Distribution

Register Selection Criteria

- *Throw*
- *Pressure Drop*
- *Noise*



Floor Register Performance (10x4)

Selection and Design

1. Calculate adjustment	
CFM	80
Ak	0.118
K	3.3
Vt	75
Throw	9
Adjustment	0.777

2. Enter design parameters	
CFM	48
K	3.3

Terminal Velocity	Throw (feet)
50	6.5
100	4.1
150	2.7

Recommended K Values		
Outlet Type	Discharge Pattern	K
High sidewall grille	0° deflection	5.0
High sidewall grille	wide deflection	3.7
High sidewall linear	core < 4" high	3.9
High sidewall linear	core > 4" high	4.4
Low sidewall	up wall, no spread	4.4
Low sidewall	wide spread	2.6
Baseboard	up wall, no spread	3.9
Baseboard	wide spread	1.8
Floor	no spread	4.1
Floor	wide spread	1.4
Ceiling circular	360°	1.0
Ceiling square	4-way, little spread	3.3
Ceiling square	1-way, little spread	4.4
Ceiling linear	1-way, horizontal	4.8

Life is never simple:

Most registers are rated at 75fpm throw boundary and tested at 100 plus cfm.

IBACOS

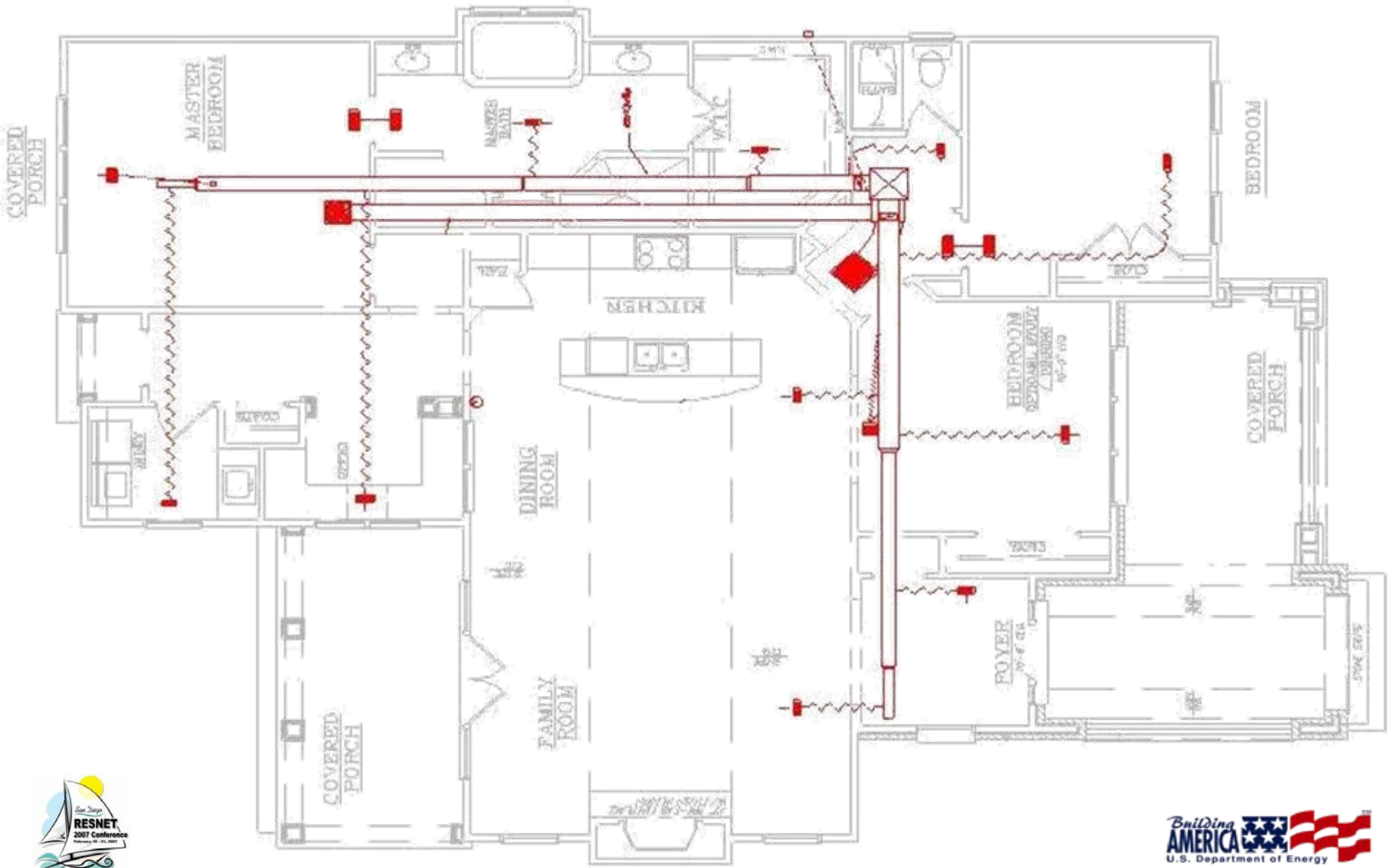
Diffuser Selection and Design

Diffuser Comparisons

Room Designation	Throw Desired	CFM	Desired Selection VHO & HVO		Contractor Selection 6" x 10" & 6" x 12"		Generic Selection RZ682	
			Size	Throw	Size	Throw	Size	Throw
Laundry	4'	55	8 x 4	6.6'	6 x 10	3.6'	8 x 4	6.6'
Bedroom/Study	4.5'	110	8 x 4	13.3'	6 x 10	9.6'	6 x 10	9.1'
Family Rm	16'	142	10 x 4	15.8'	6 x 10	12.4'	6 x 10	9.1'
Family Rm	16'	142	10 x 4	15.8'	6 x 12	10.9'	6 x 10	9.1'
Mstr. Bath	7.5'	72	6 x 4	9.7'	6 x 10	6.3'	6 x 6	8.1'
Mstr. Bed	7.8'	142	10 x 4	12.3'	6 x 10	9.6'	8 x 8	11.2'
Office	7'	120	10 x 4	13.4	6 x 10	10.5'	12 x 4	11.5

IBACOS

40% BA Mixed Humid



RESNET 2007 Conference

Building America
U.S. Department of Energy
Research Toward Zero Energy Homes

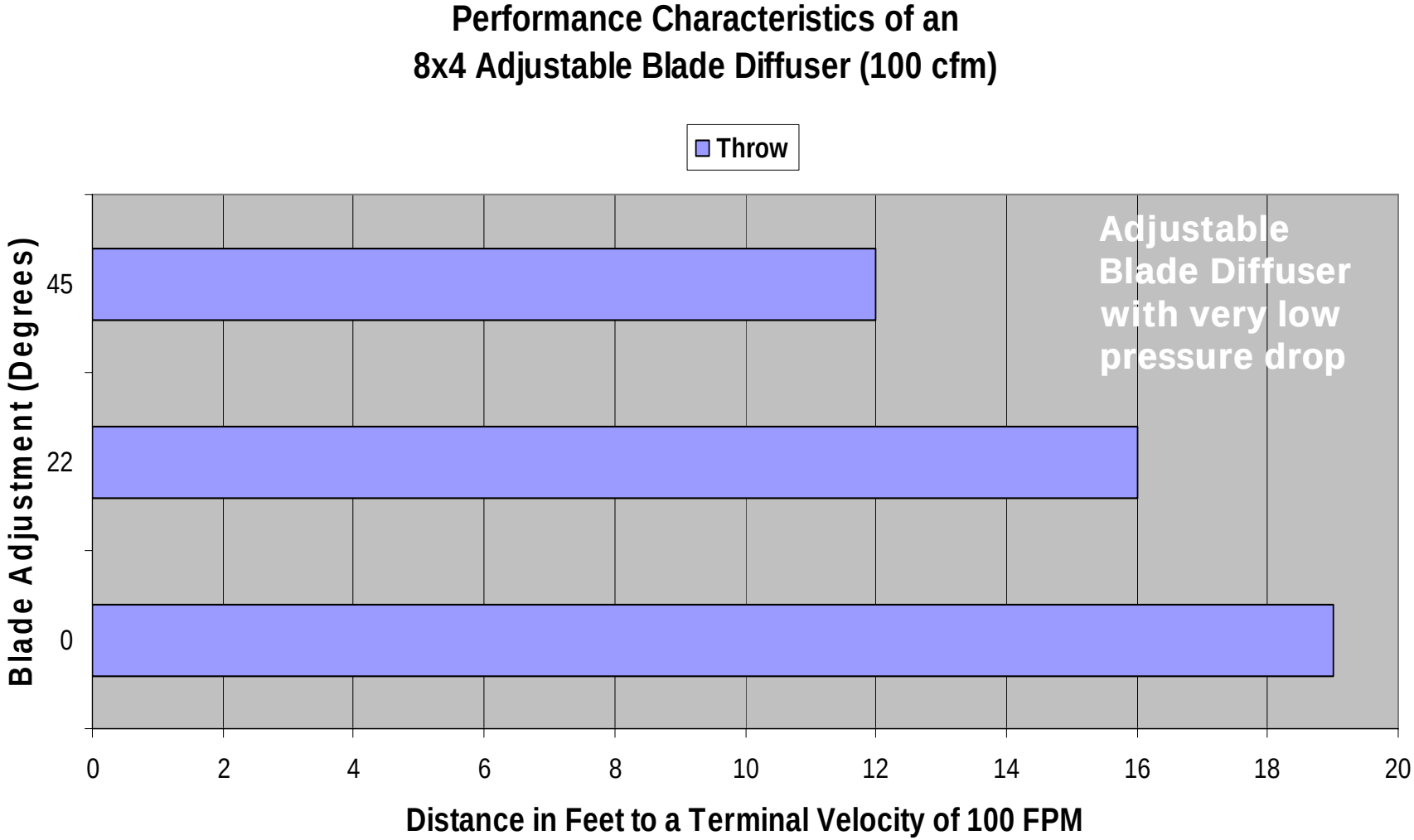
IBACOS

Diffuser Selection and Design

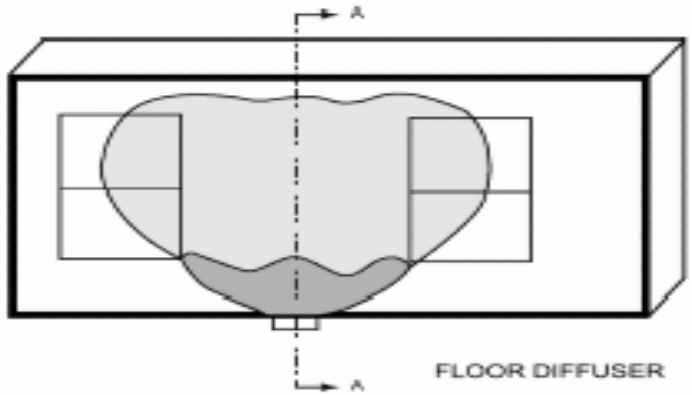
Diffuser Comparisons

Room Designation	Throw Desired	CFM	Desired Selection VHO & HVO		Contractor Selection 6" x 10" & 6" x 12"		Generic Selection RZ682	
			Size	Throw	Size	Throw	Size	Throw
Laundry	4'	55	8 x 4	6.6'	6 x 10	3.6'	8 x 4	6.6'
Bedroom/Study	4.5'	110	8 x 4	13.3'	6 x 10	9.6'	6 x 10	9.1'
Face Velocity			660		352		352	
Family Rm	16'	142	10 x 4	15.8'	6 x 10	12.4'	6 x 10	9.1'
Family Rm	16'	142	10 x 4	15.8'	6 x 12	10.9'	6 x 10	9.1'
Face Velocity			681		378		454	
Mstr. Bath	7.5'	72	6 x 4	9.7'	6 x 10	6.3'	6 x 6	8.1'
Mstr. Bed	7.8'	142	10 x 4	12.3'	6 x 10	9.6'	8 x 8	11.2'
Office	7'	120	10 x 4	13.4	6 x 10	10.5'	12 x 4	11.5

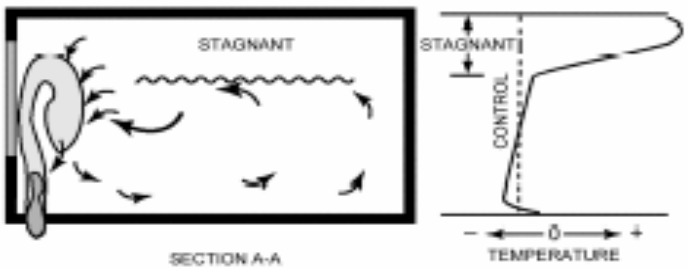
Register Throw



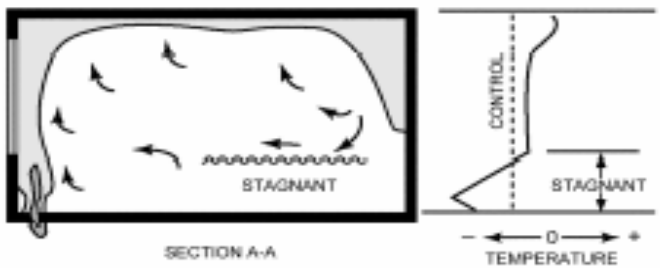
Diffuser Selection and Design

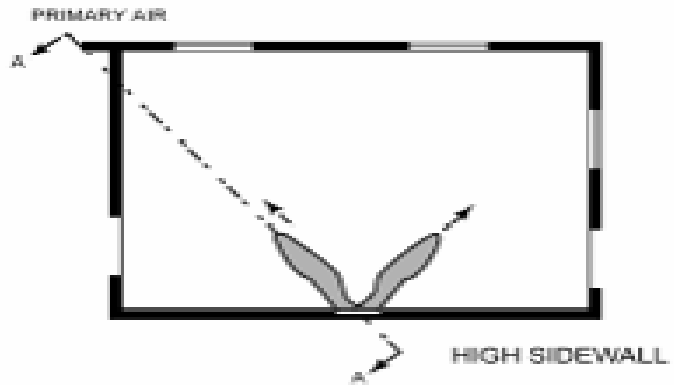


COOLING



HEATING



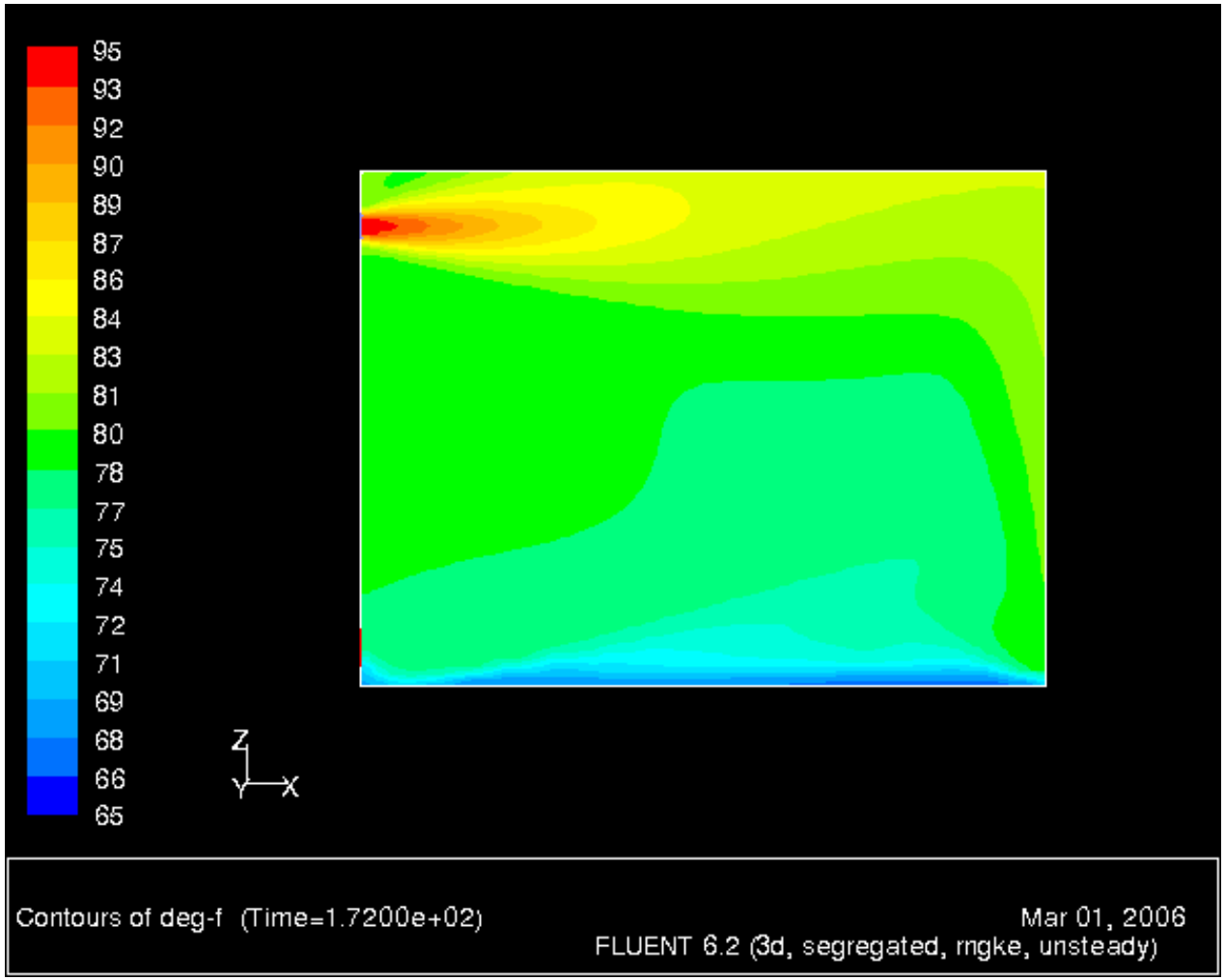


COOLING

HEATING

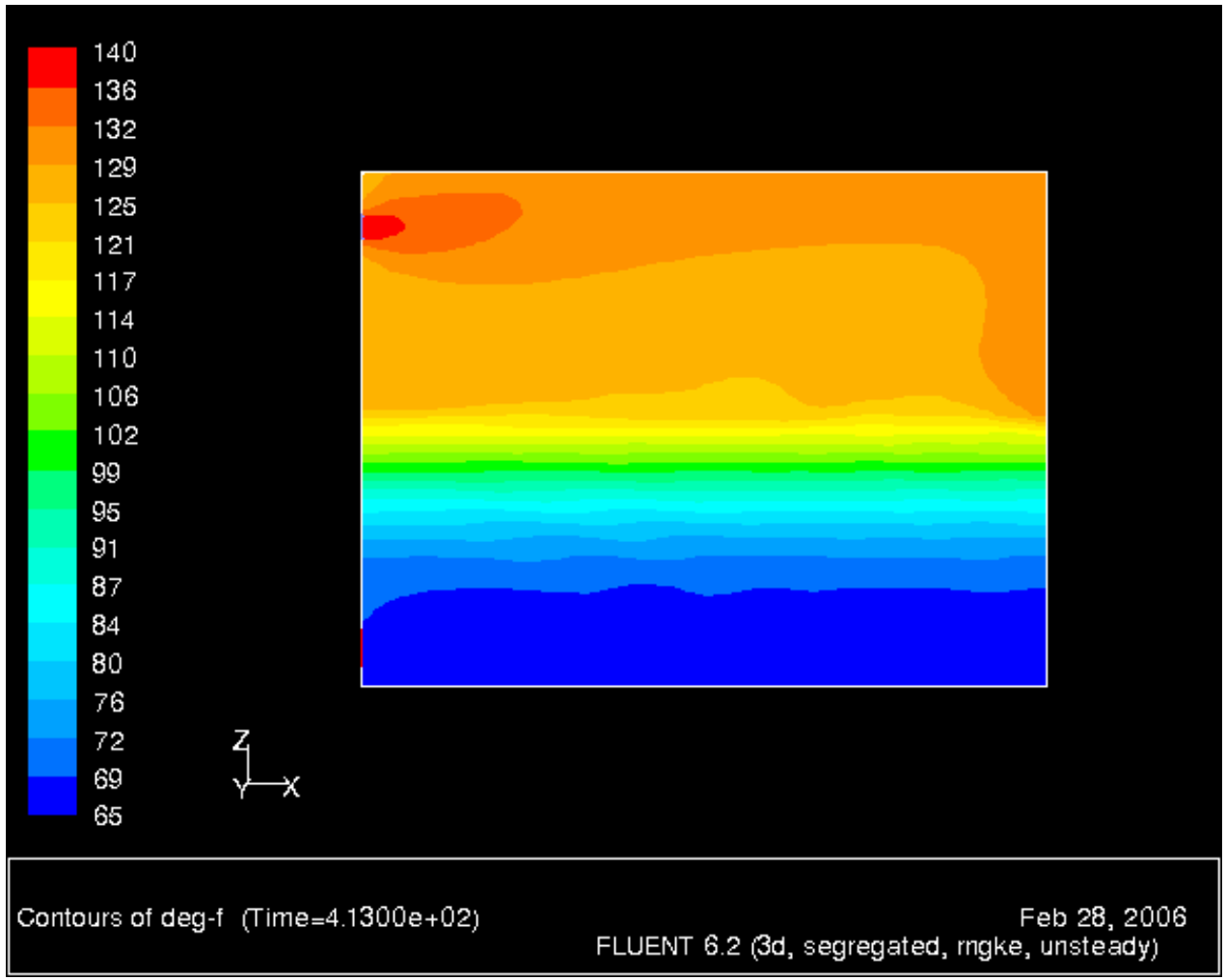
Room Air Distribution

With air entering at 95°F and 790 ft/min, the room has good mixing.



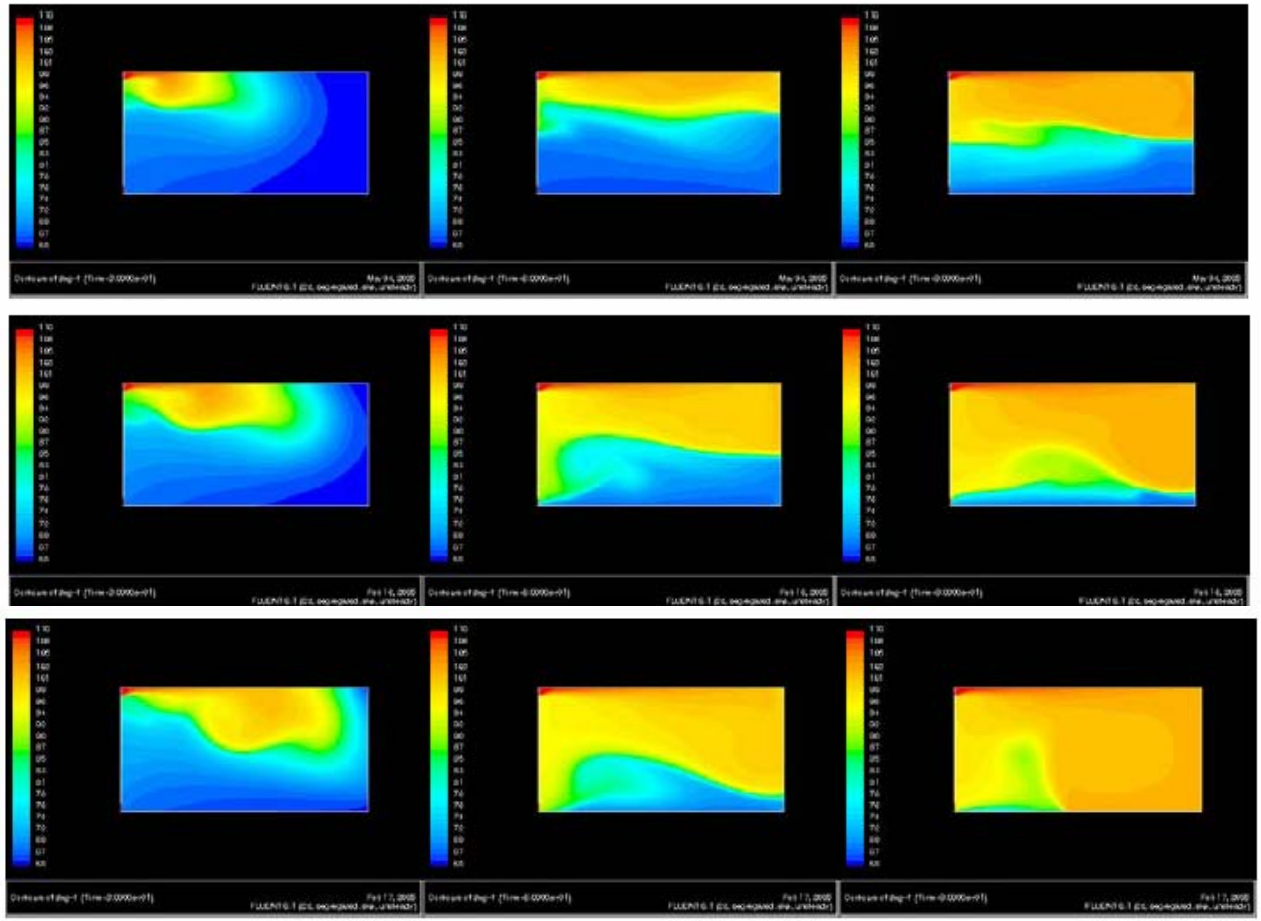
Room Air Distribution

With air entering at 140°F and 330 ft/min, the room shows stratification.



110 F Supply Air Temperature

- **Supply air Velocity**
  - **394 f/m**
  - **591 f/m**
  - **787 f/m**



time = 30 sec time = 60 sec time = 90 sec

So what do you do?

- ***Equipment selection is critical***
- ***DO a duct design***
- ***Consider designing each duct run (Variable friction method – ASHRAE HVAC & Fundamentals Handbooks)***
- ***Supply outlets designed, not what's on the truck***
- ***Trending towards***
  - *Higher air velocity at outlet*
  - *Lower supply air temperature in heating mode*
  - *Longer run time*
  - *Be aware of air speed in occupied zone.*

IBACOS

Thank You

US DOE Building America Program

Best Practices Research Alliance

Cardinal Glass Industries

Carrier Corporation

National Renewable Energy Laboratory

RESNET 2007 Conference

Building America U.S. Department of Energy Research Toward Zero Energy Homes

Thank You

Questions?

dprahl@ibacos.com

astamatopoulos@ibacos.com