DOE Zero Energy Ready Home

Tech Training Webinar Series

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Low Load High Efficiency HVAC

ZERO ENERGY READY HOME
U.S. DEPARTMENT OF ENERGY

The Home of the Future….Today

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DOE Zero Energy Ready Home Resources

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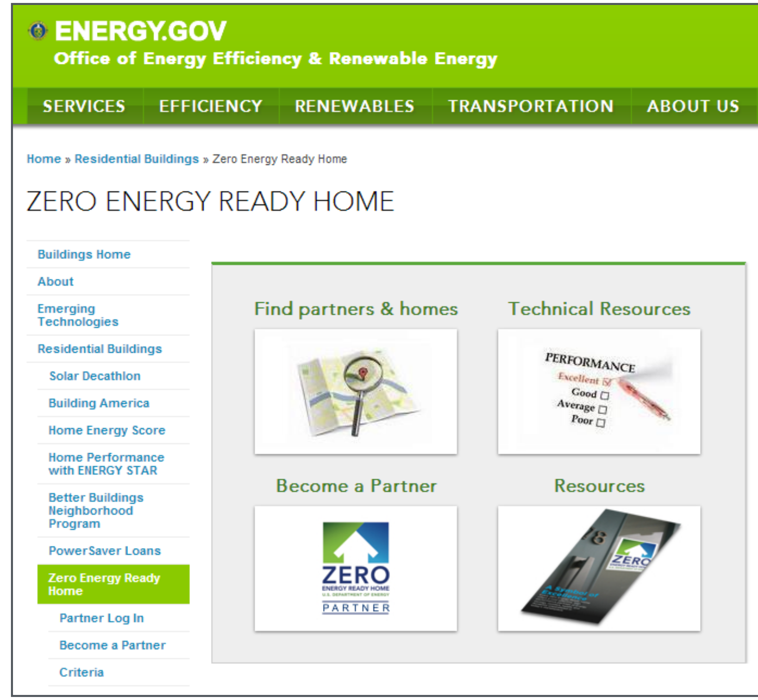
- www.buildings.energy.gov/zero/
- Events:
  - Upcoming in-person ZERH Trainings
  - Technical Training webinars
  - Conference Presentations
- Partner Locator
- Program Specifications
- Webinar Recordings



Building America Solution Center

- http://basc.pnnl.gov/

Thank You

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Zero Energy Ready Home Technical Solutions:
Low Load High Efficiency HVAC
Lessons Learned from Building America

Duncan Prahl, RA

May 27, 2014

Today's Session

- Zero Energy Ready Homes have advanced insulation and draft sealing that reduce energy consumption and enable the design and installation of an engineered comfort system that is significantly smaller than those installed in houses just 10 years ago. This webinar will discuss key issues associated with designing these systems, including the appropriate load calculations (an how they can be manipulated), selection of equipment, duct layout strategies, selection of supply and return air locations, and proper register selection for air mixing in rooms.

Challenges

- Challenges with HVAC in Zero Energy Ready Homes
- More efficient enclosure
- Lower and lower whole house heating and cooling loads
- Higher latent to sensible load ratios (especially in south)
- More emphasis on “Right Sizing”
- Load imbalances between summer and winter

Top Five Solutions

- Buy a Flux Capacitor and go back to the 50’s
- Blame it on someone else
- Rethink how the space conditioning system is designed and installed
- *Actually follow* Manual J, S, T and D
- Keep velocity up and Mix, Mix, Mix

A Few More Challenges

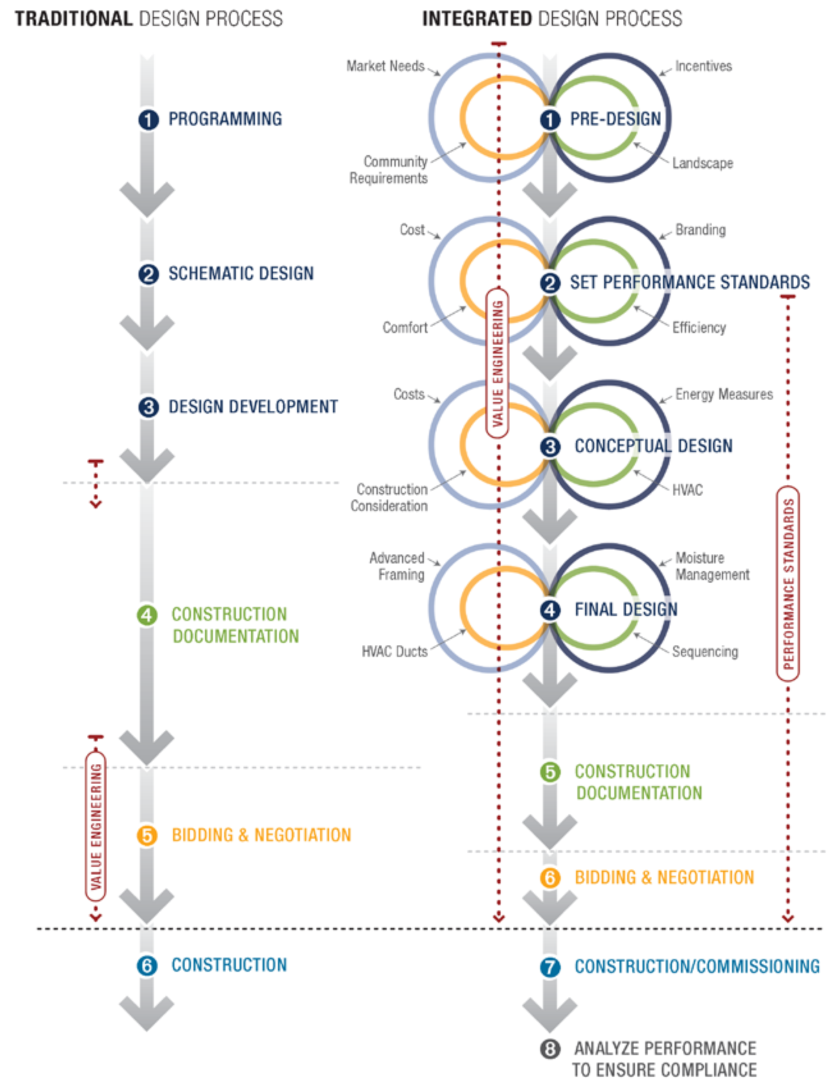
- Energy Efficiency ≠ Comfort
- Builders typically have more comfort complaints than high bill complaints
- If it isn't comfortable, energy efficiency will be set back 20 years

Examples of Discomfort

- 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
  - Not really an issue with ZERH enclosure
- Floor to floor or room to room temperature variations
  - Beyond +/- 3^{o}F (cooling) = poor design of distribution system, high variance in thermal characteristics of various rooms

It All Starts at the Design Phase

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



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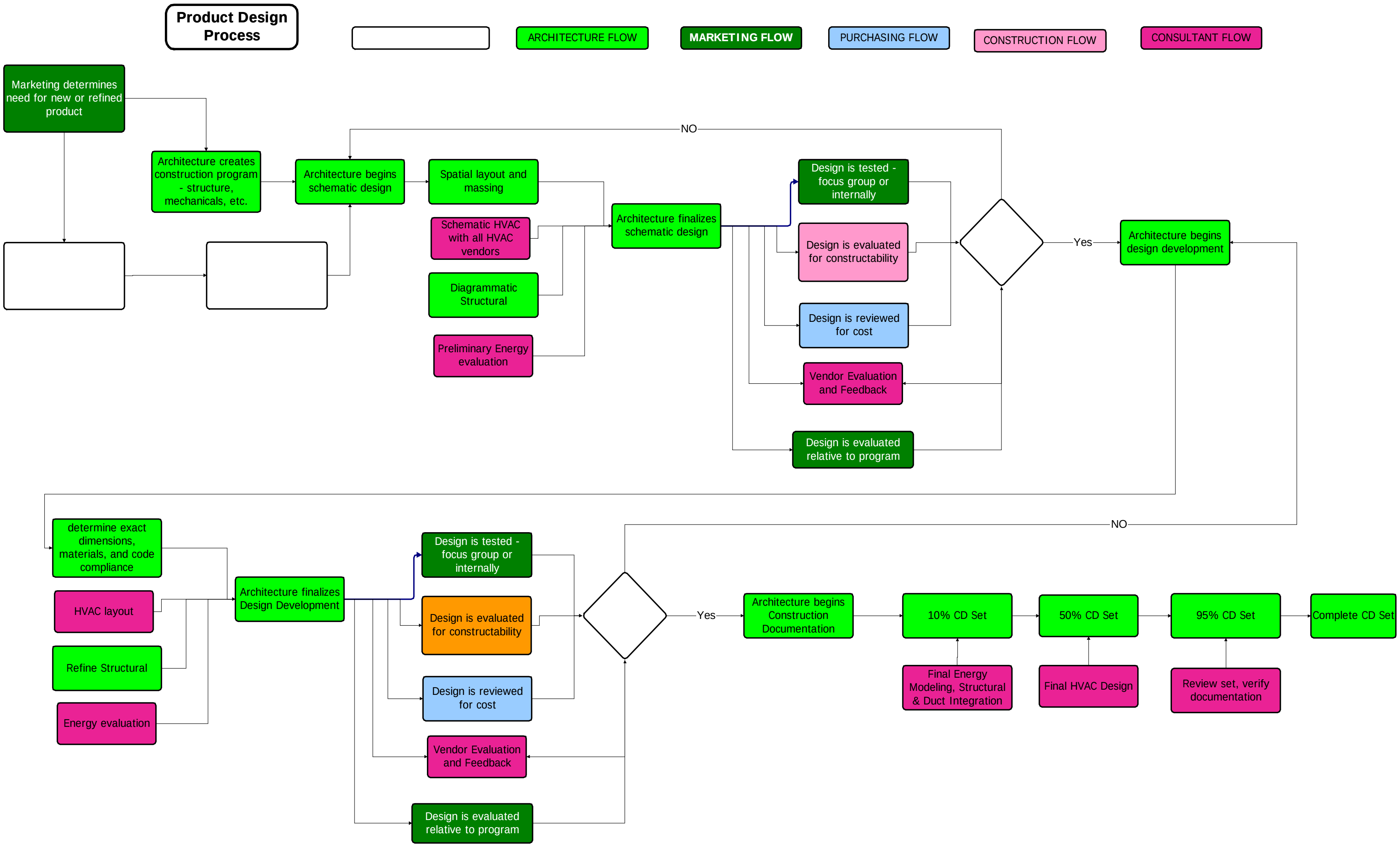
Integrated Design Process Map



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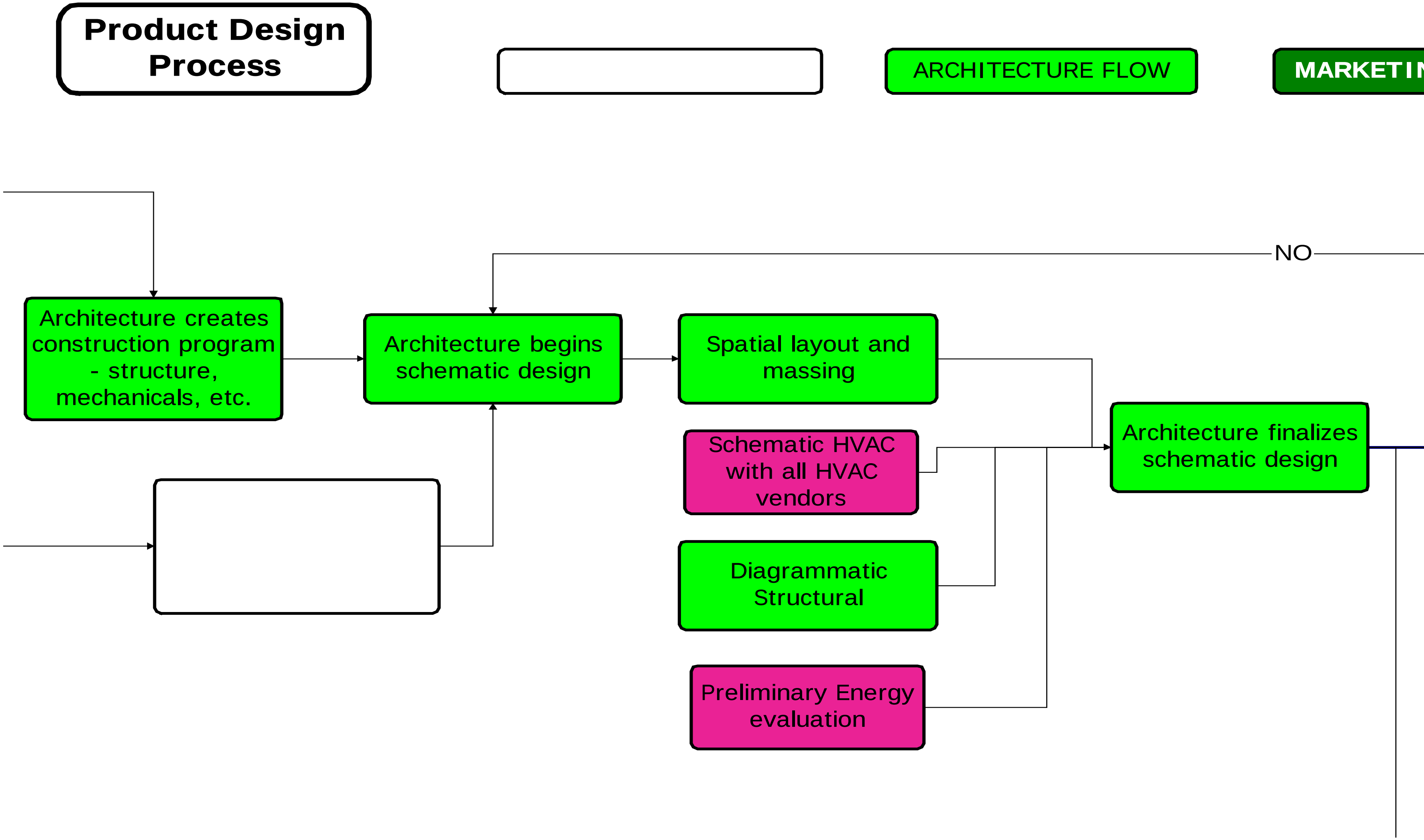
Schematic Design Phase



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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

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**	**0.37**	**0.31**
Zero Ready – Cold Climate	**1476**	**0.26**	**0.10**
Passive House	**2200 - 3200**	**0.08 – 0.18**	**.05**

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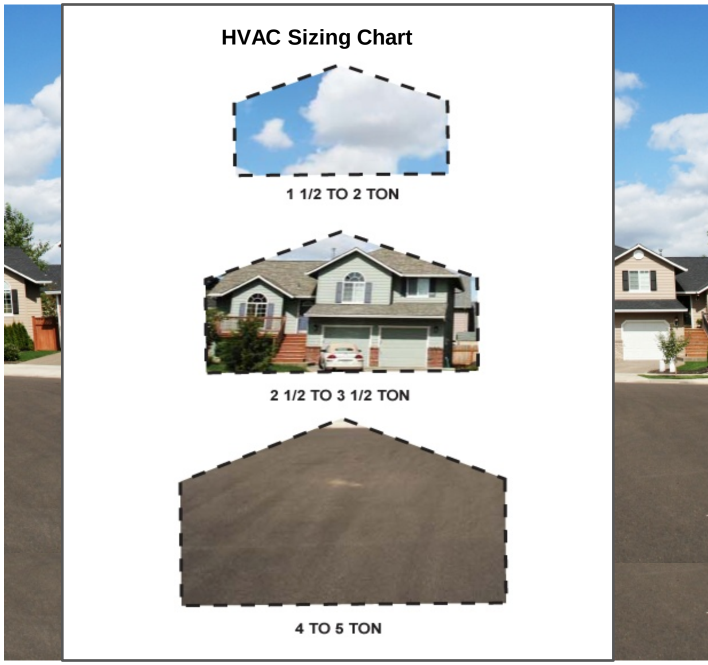
What's it all mean?

- 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 is important
- Long runs, less airflow, takes time to heat up duct mass, lower outlet temperatures at long runs on short cycles, t'stat location
- Register selection is critical

HVAC System Design Guides

- Right sizing being adopted by above code programs and by codes, but what does it really mean?
- Can't design by "Rule of Thumb"
- Implications of "knob twiddling" in load calculations can still lead to "right sized" systems that are grossly oversized
- More energy efficient enclosures with advanced systems can yield simplified strategies for duct layouts and supply outlet locations



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HVAC System Design Guides- Building America Publications

- Help “demystify” the HVAC design process for non HVAC professionals

http://www1.eere.energy.gov/library/default.aspx?page=2

Search “IBACOS HVAC”

Loads:
http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/hvac_load_calc.pdf

Sizing:
http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/strategy_guide_hvac_sizing.pdf

Compact Ducts:
http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/strategy_guide_compact_air_dist.pdf

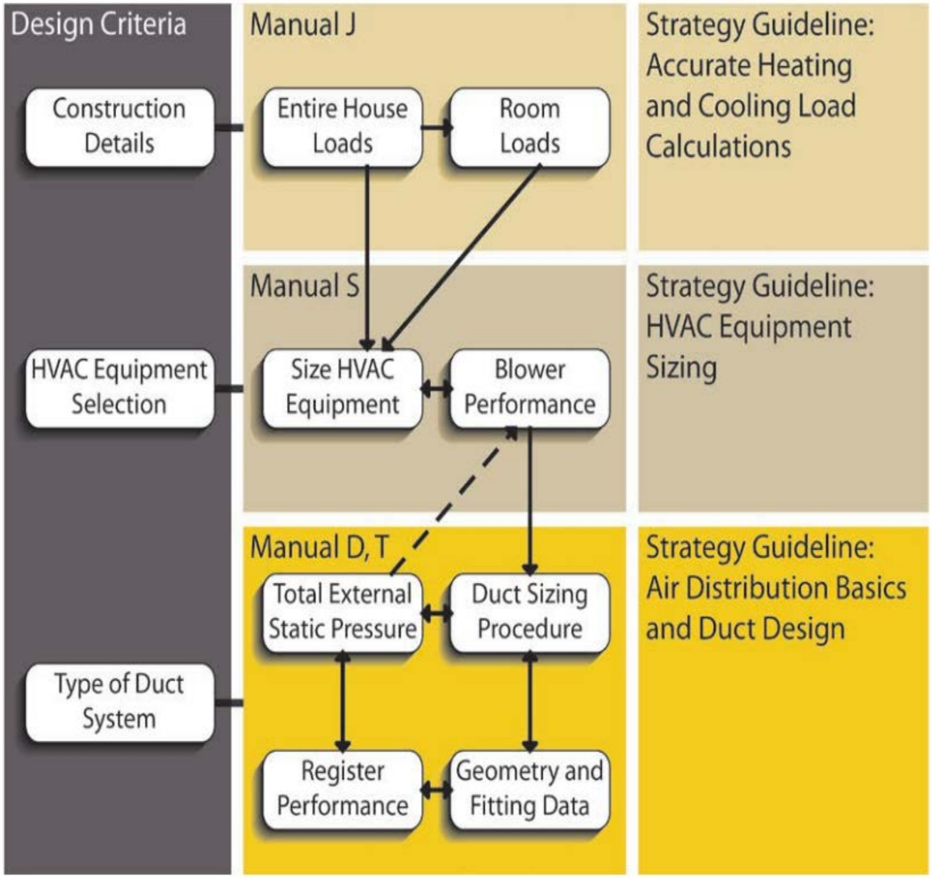
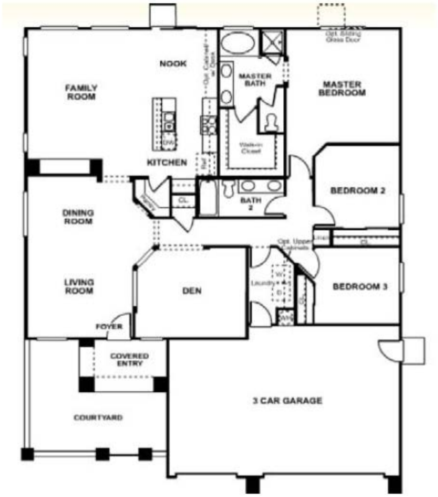


Figure 1. Design information from ACCA Manual J—Residential Load Calculation.

HVAC System Design Guides

- Demonstrate how easy it is to “right size” 2x the actual load
- Multiple runs through WrightSoft with common errors/safety factors
  - Altered outdoor/indoor design conditions
  - De-rated insulation, window performance, shading characteristics
  - Exaggerated infiltration and ventilation
  - Combined all safety factors for a grossly exaggerated load



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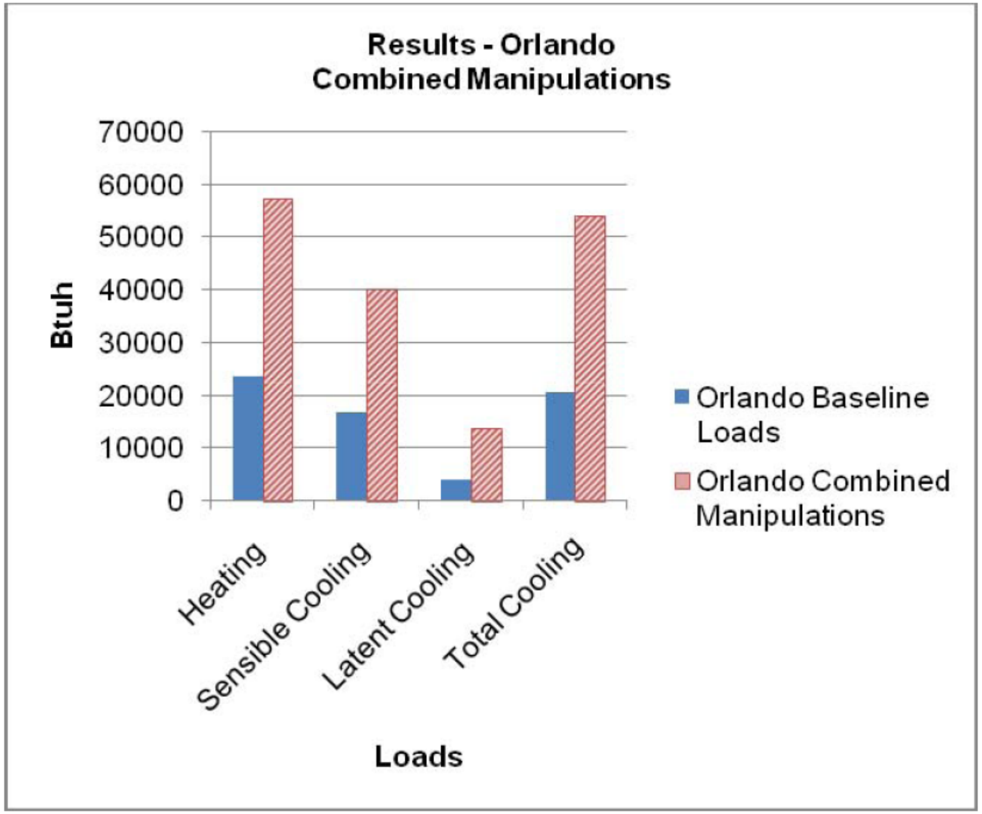
Combined Fudge Factors - FL

	Baseline Load	Manipulated Load	Change In Load Btu/h	Change In Load %
Heating Load	23,600 Btu/h	57,200 Btu/h	33,600 Btu/h	142 %
Sensible Cooling	16,600 Btu/h	40,200 Btu/h	23,600 Btu/h	142 %
Latent Cooing	4,100 Btu/h	13,900 Btu/h	9,800 Btu/h	239%
Total Cooling	20,700 Btu/h	54,000 Btu/h	33,300 Btu/h	161 %



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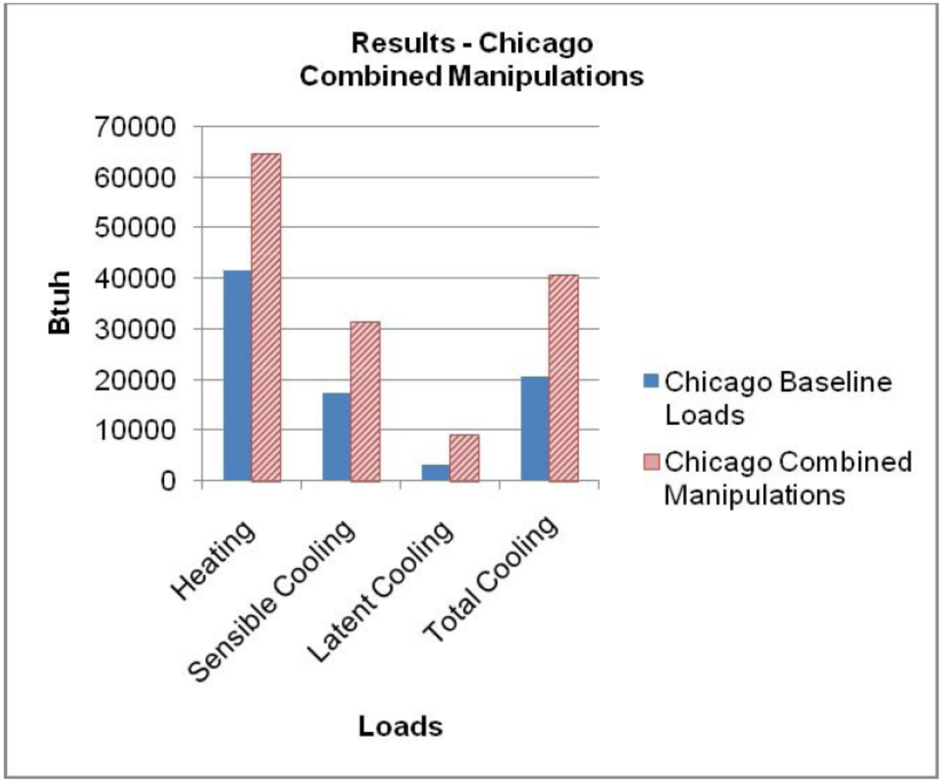
Combined Fudge Factors - IL

	Baseline Load	Manipulated Load	Change In Load Btu/h	Change In Load %
Heating Load	41,700 Btu/h	64,700 Btu/h	23,000 Btu/h	55 %
Sensible Cooling	17,400 Btu/h	31,600 Btu/h	14,200 Btu/h	82 %
Latent Cooing	3,200 Btu/h	9,100 Btu/h	5,900 Btu/h	184 %
Total Cooling	20,600 Btu/h	40,600 Btu/h	20,000 Btu/h	97 %



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Denver, CO House

	ZERH Home
Foundation	R-18 Basement & Crawlspace walls
Above Grade Walls	R-21 cavity, R-5 sheathing
Floors Over Unconditioned Space	R-46
Roof Insulation R-Value	R-54 & Vaulted Ceilings @ R-40
Windows	U-value 0.30 & SHGC 0.30
Exterior Doors	U-value 0.20
Building Air tightness	3.0 ACH50
Mechanical Ventilation	HRV: supply 84 cfm, exhaust 84 cfm, run-time 50%, power 100 watts, & efficiency 82%
Furnace	94.1 AFUE
AC	18.1 SEER

Columbus, GA House

	ZERH Home
Foundation	Slab-on-grade no insulation
Above Grade Walls	R-13 – Cavity, R-5 Sheathing
Floors Over Unconditioned Space	N/A
Roof Insulation R-Value	R-29 Unvented attic
Windows	U-value 0.35 & SHGC 0.35
Exterior Doors	U-value 0.20
Building Air tightness	3.0 ACH50
Mechanical Ventilation	ERV: supply 60 cfm, exhaust 60 cfm, run-time 50%, efficiency 80%
Heat Pump	9.3 HSPF
AC	18.6 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

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

		ZERH			Energy Star v.2	
	Area (ft²)	Htg load (Btuh)	Clg load (Btuh)		Htg load (Btuh)	Clg load (Btuh)
First Floor & Basement	3,492	26,112	21,554		42,436	29,312
Upper Bedrooms	936	8,928	6,387		12,911	8,845
Entire House	4,428	35,040	25,423		55,346	34,585
Other equip loads		2,007	558		5,017	1,139
Equip. @ 0.98 RSM			25,409			34,938
Latent cooling			0			0
TOTALS	4,428	37,047	25,409		60,363	34,938

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Cold Climate House
Manual J Part Loads

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

		ZERH			Energy Star V.2	
	Area (ft²)	Htg load (Btuh)	Clg load (Btuh)		Htg load (Btuh)	Clg load (Btuh)
First Floor & Basement	3,492	13,762	20,686		22,365	27,826
Upper Bedrooms	936	4,705	6,049		6,804	8,365
Entire House	4,428	18,467	24,217		29,169	32,618
Other equip loads		1,058	482		2,644	949
Equip. @ 0.98 RSM			23,464			31,889
Latent cooling			0			0
TOTALS	4,428	19,525	23,464		31,813	31,889

Cold Climate House Peak Airflow (cfm)

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

		ZERH				Energy Star v.2		
	Area (ft²)	Htg AVF (cfm)	Clg AVF (cfm)	% Diff		Htg AVF (cfm)	Clg AVF (cfm)	% Diff
Entry	212	31	25	21%		54	44	20%
Dining	168	70	100	-35%		100	153	-42%
Pantry	36	8	3	91%		14	5	95%
Powder	36	0	2	-200%		0	2	-200%
Master Bathroom	174	35	58	-49%		52	79	-41%
Master Bedroom	306	130	223	-53%		170	301	-56%
Kitchen / Nook	300	71	127	-57%		102	175	-53%
Laundry	68	32	19	51%		40	28	35%
Family	304	84	145	-53%		111	178	-46%
Bedroom	225	83	80	4%		127	102	22%

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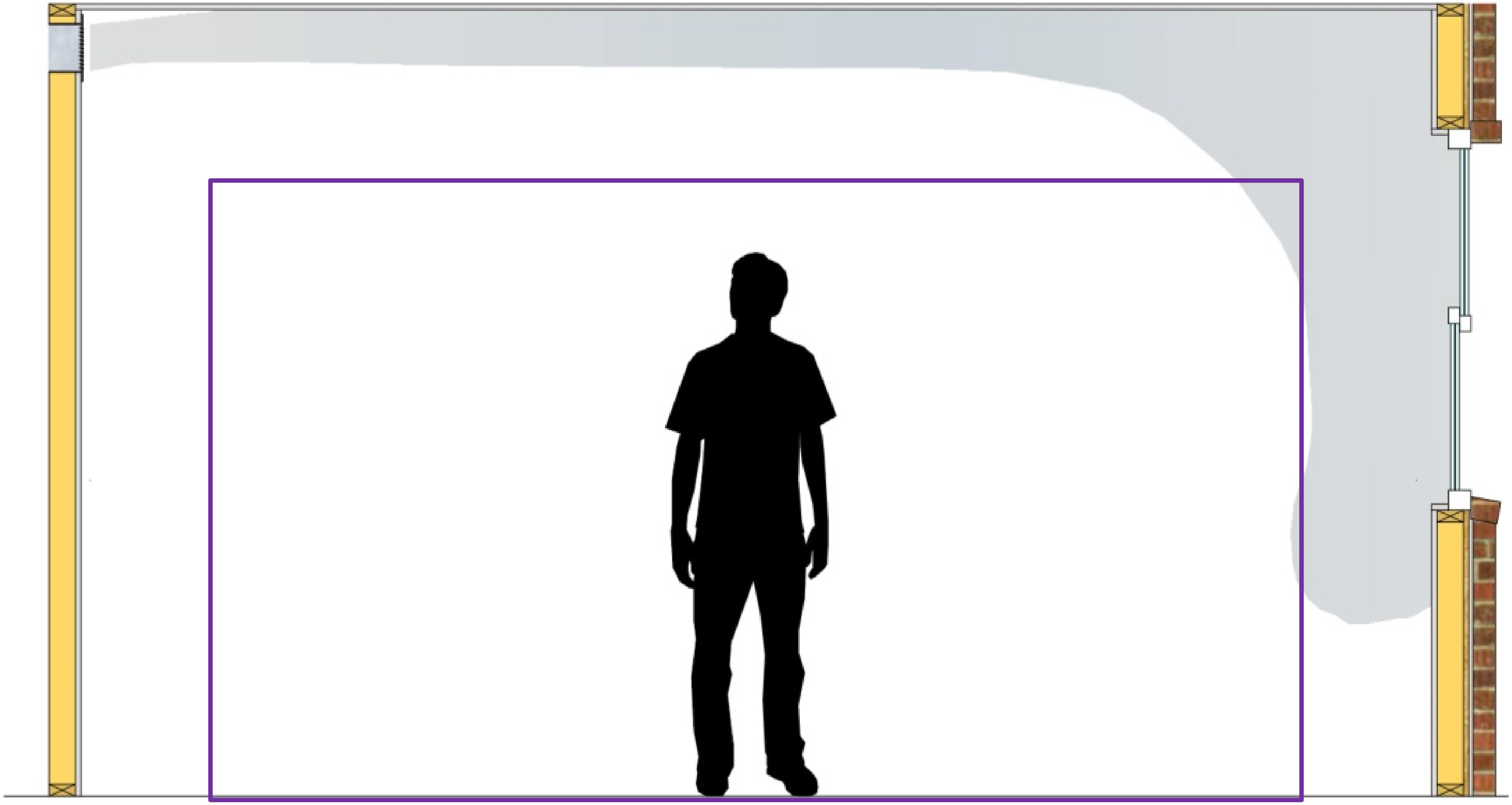
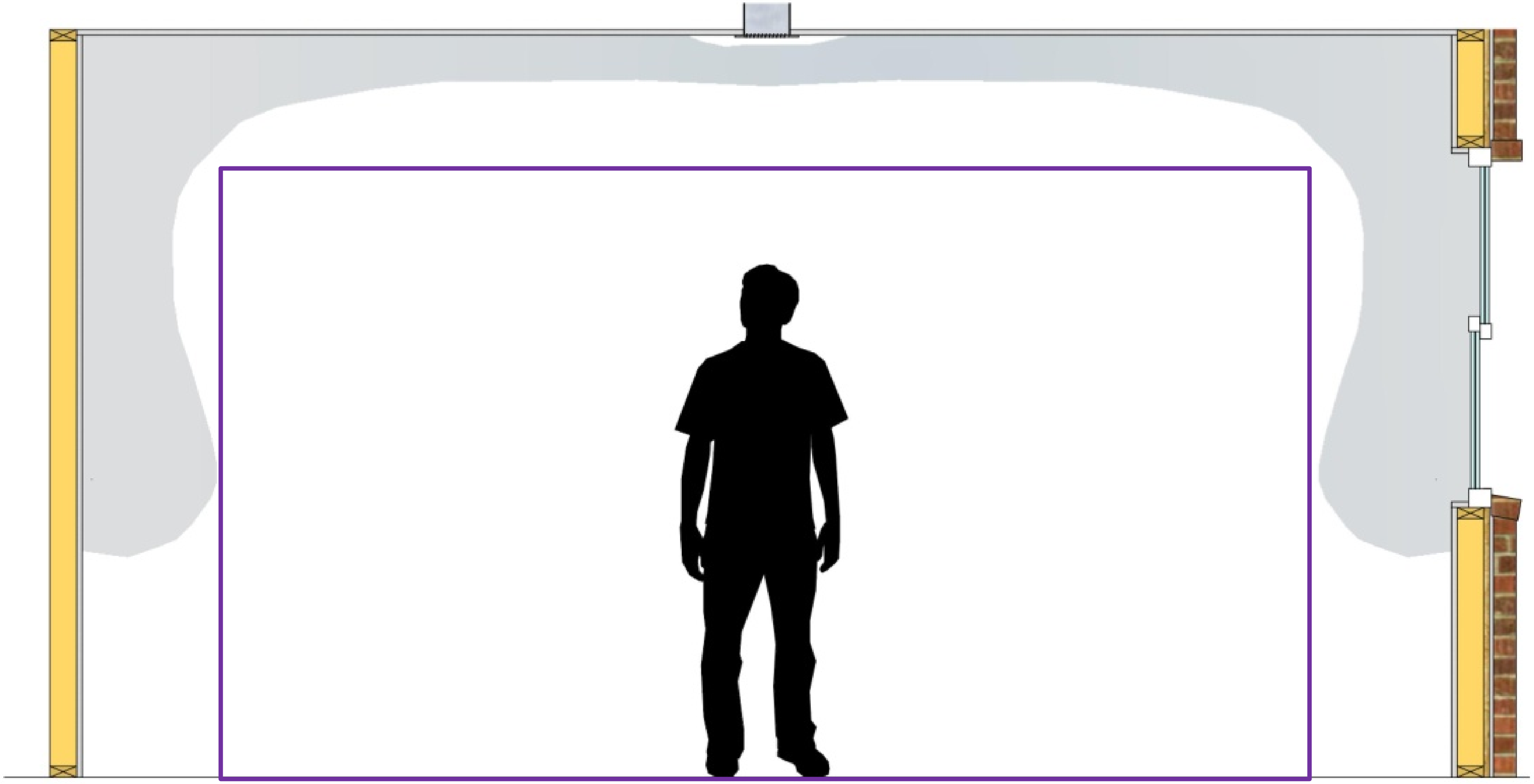
Supply Air Outlet
Design and Selection

- Once again – Peak vs. Part Load
- It’s not just cfm
- Location, Location, Location
- Throw
- Face Velocity
- Terminal Velocity
- Air volume (cfm)
- Pressure drop
- Noise

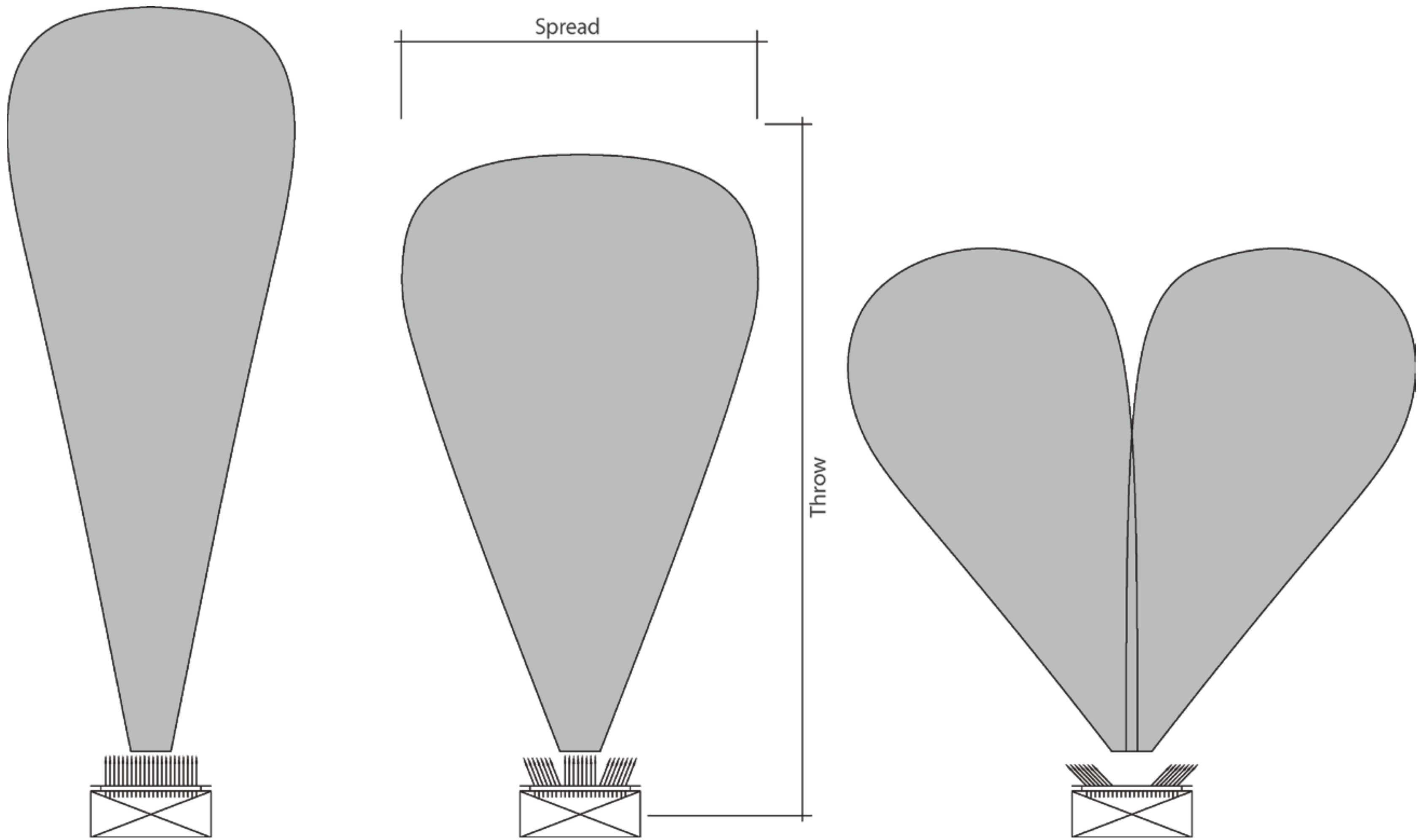
Diffuser Placement – Occupied Zone



Diffuser Placement – Occupied Zone



Register Throw and Spread



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Register Characteristics

Face Velocity		400	500	600	700	800	900	1000	1100
Pressure Loss		.010	.016	.022	.031	.040	.050	.062	.075
8 x 4	cfm	65	80	100	110	130	145	160	175
Ak .160	Throw	6.5	8.0	10.0	11.0	13.0	15.0	16.0	18.0
10 x 4	cfm	80	100	120	140	160	180	200	220
Ak .202	Throw	7.0	9.0	11.0	13.0	14.0	16.0	18.0	20.0
12 x 4	cfm	100	120	145	170	195	220	245	270
Ak .244	Throw	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0
14 x 4	cfm	115	145	170	200	230	255	285	315
Ak .286	Throw	8.5	11.0	13.0	15.0	17.0	19.0	22.0	24.0
12 x 5	cfm	125	155	190	220	250	280	310	345
Ak .312	Throw	9.0	11.0	14.0	16.0	18.0	[illegible]	[illegible]	[illegible]
10 x 6	cfm	125	155	190	220	250	[illegible]	[illegible]	[illegible]
Ak .314	Throw	9.0	11.0	14.0	16.0	18.0	[illegible]	[illegible]	[illegible]

Ak= net area in square feet

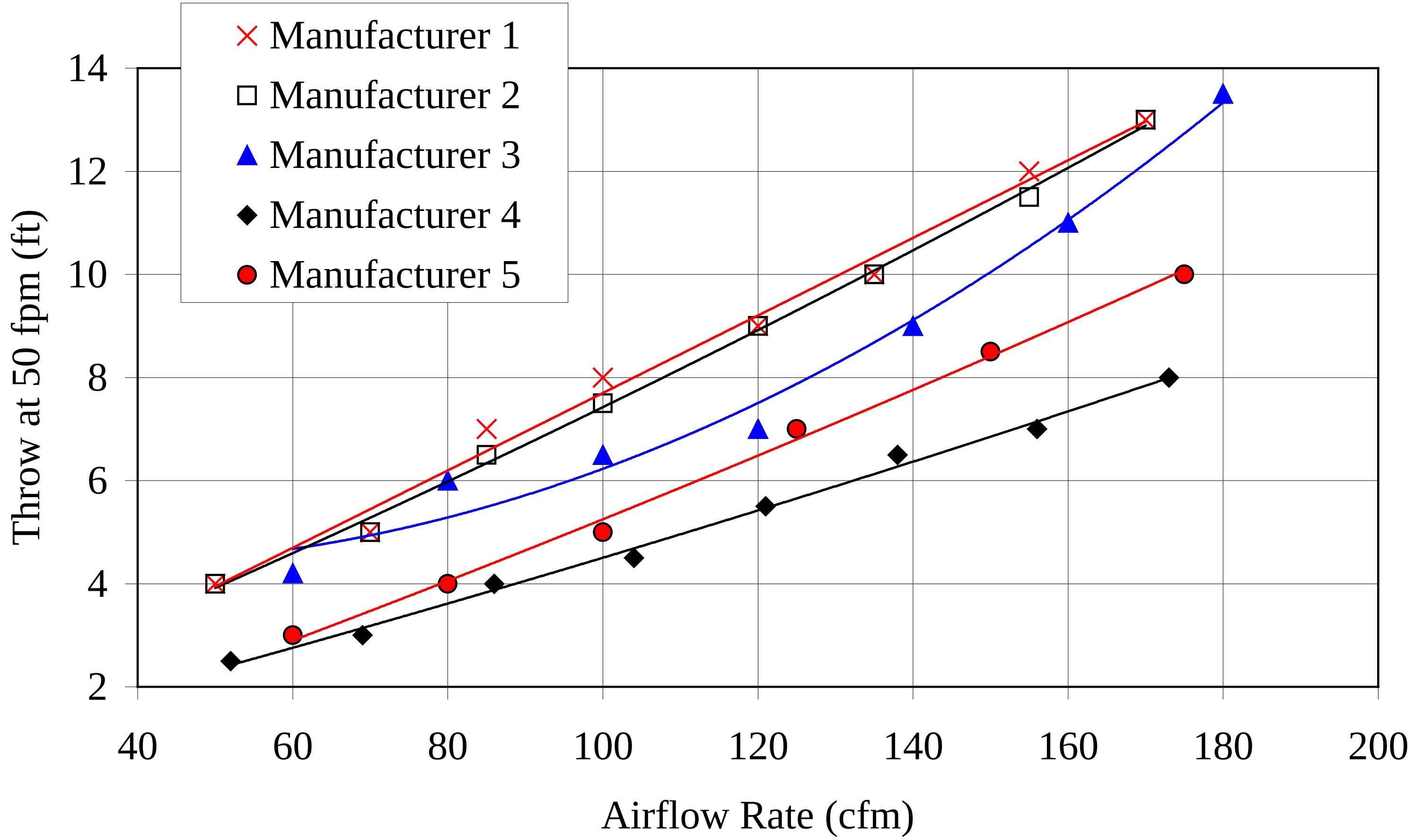
Face Velocity
Pressure Loss
Delivery cfm

*NC 30 NC 35 — Noise Criteria

*less than or equal to

FOOTNOTE C:
NOISE CRITERIA: NC "A" scale.
(1) Below NC25 extremely quiet.
(2) Below NC30 Quiet Office.
(3) Below NC35 Conference Rooms; normal voice 10-30 ft.
(4) Below NC40 Conference Rooms; 6-12 ft. normal voice.
(5) NC45 Conference Rooms; 3-6 ft. normal voice.

Register Characteristics



Floor Register Performance (10x4)

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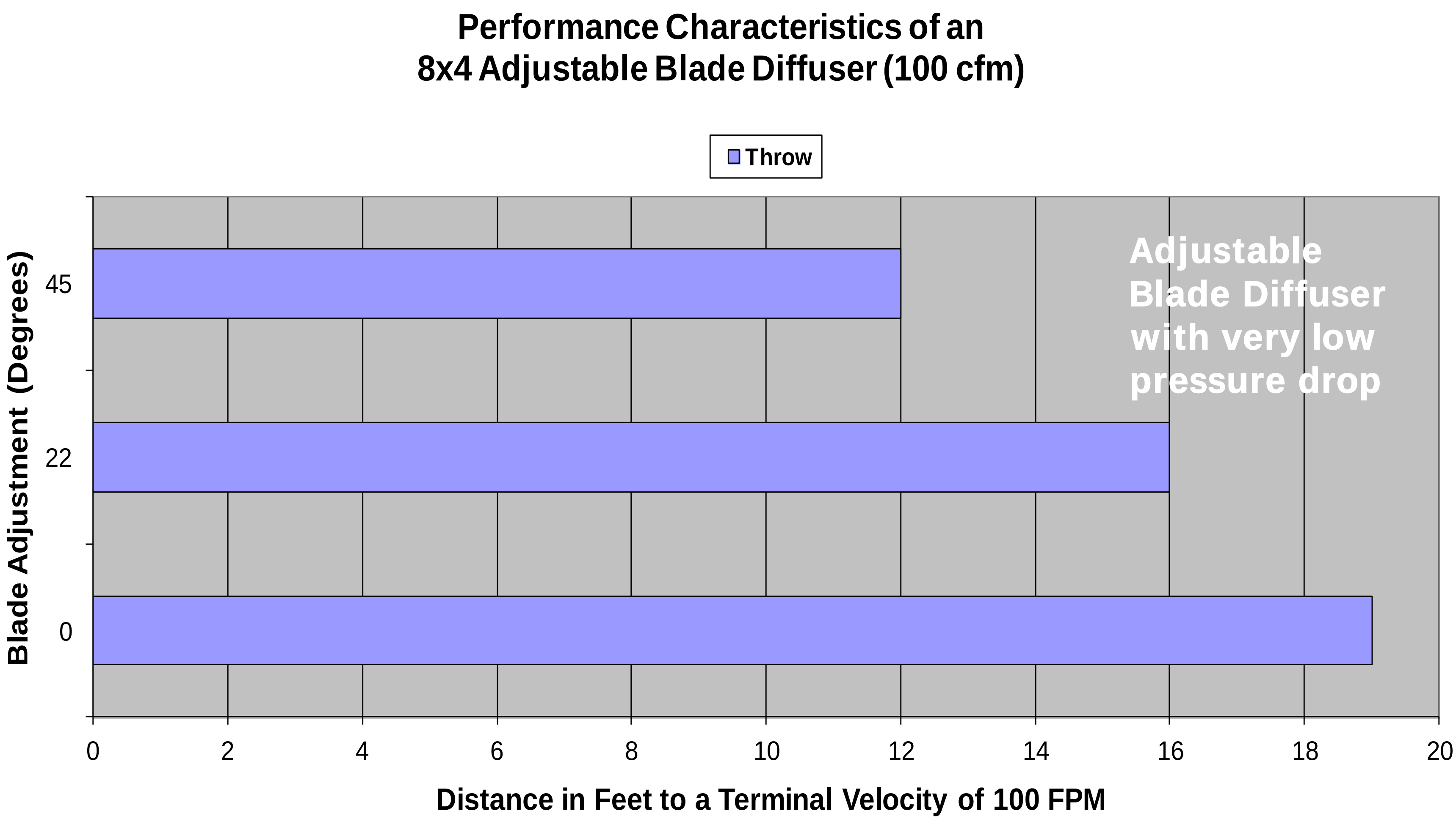
Register Throw



Calculating Register Performance

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	0º 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	360º	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:

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

See ASHRAE 2009 Handbook—Fundamentals, Chapter 20, Space Air Diffusion

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CFM, Diameter, Velocity

Manual D Ductsize Data - Duct System 1 - Supply (cont'd)

---Duct Name, etc.			
Type	Roughness	Diameter	Velocity
Upstream	Temperature	Width	Loss/100
Shape	Length	Height	Fit.Eq.Len
Sizing	CFM	Area	SP.Avail

---Duct Name: SR-160, Supplies: Dining (in Zone 1), Fittings: 8-A2, 4-G, 2-I, 8-A2, Effectiv

Runout	0.0003	7	378
Up: ST-240	55	5.4	0.035
Rnd	43.3	7.7	88.1
Presize	101	79.4	0.232

---Duct Name: SR-130, Supplies: Entry (in Zone 1), Fittings: 2-I, 4-H, Effective Length: 30.6

Runout	0.0003	4	367
Up: ST-280	118	3.1	0.062
Rnd	3.8	4.4	26.7
Presize	32	4	0.259

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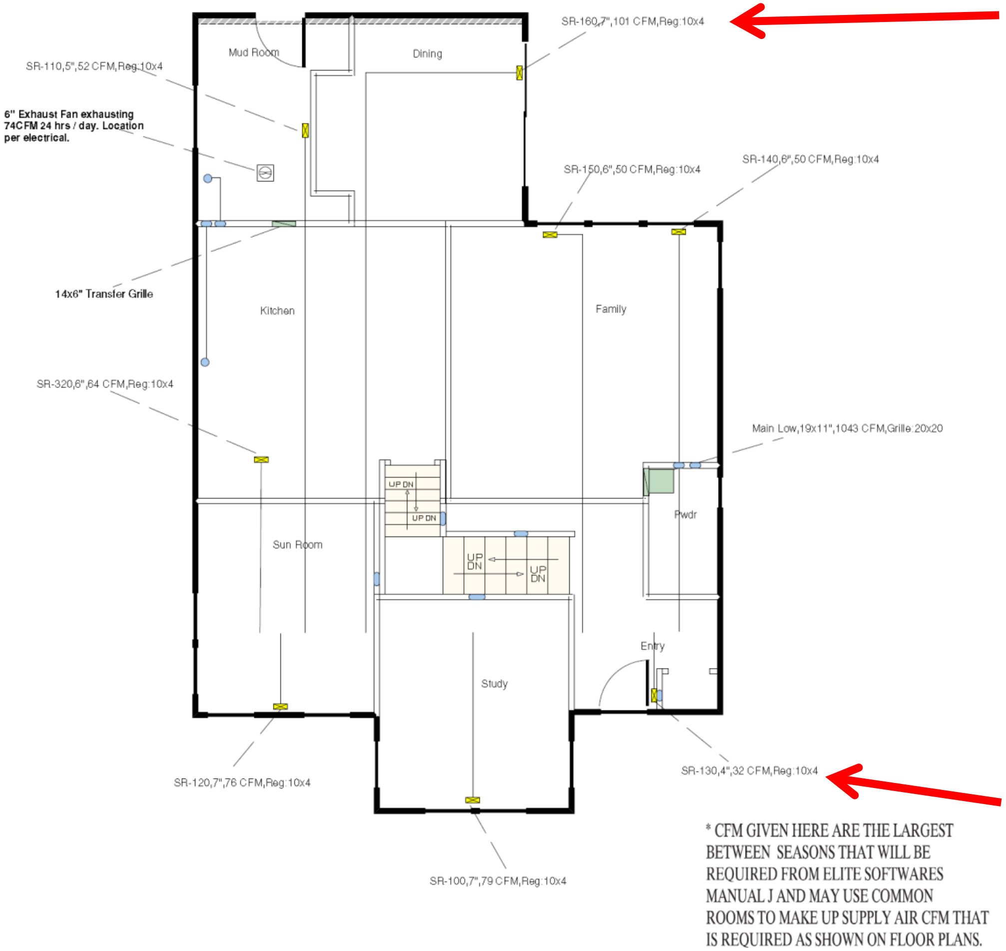
What Really Happens…



SR-160,7",$\boxed{\text{101 CFM,Reg:10x4}}$

"We use Shoemaker Model 325 - 4"x10" supply floor registers"

SR-130,4",$\boxed{\text{32 CFM,Reg:10x4}}$

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Supply Outlet Selection

FOOTNOTE C:
NOISE CRITERIA: NC “A” scale.
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(3) Below NC35 Conference Rooms; normal voice 10-30 ft.
(4) Below NC40 Conference Rooms; 6-12 ft. normal voice.
(5) NC45 Conference Rooms; 3-6 ft. normal voice.

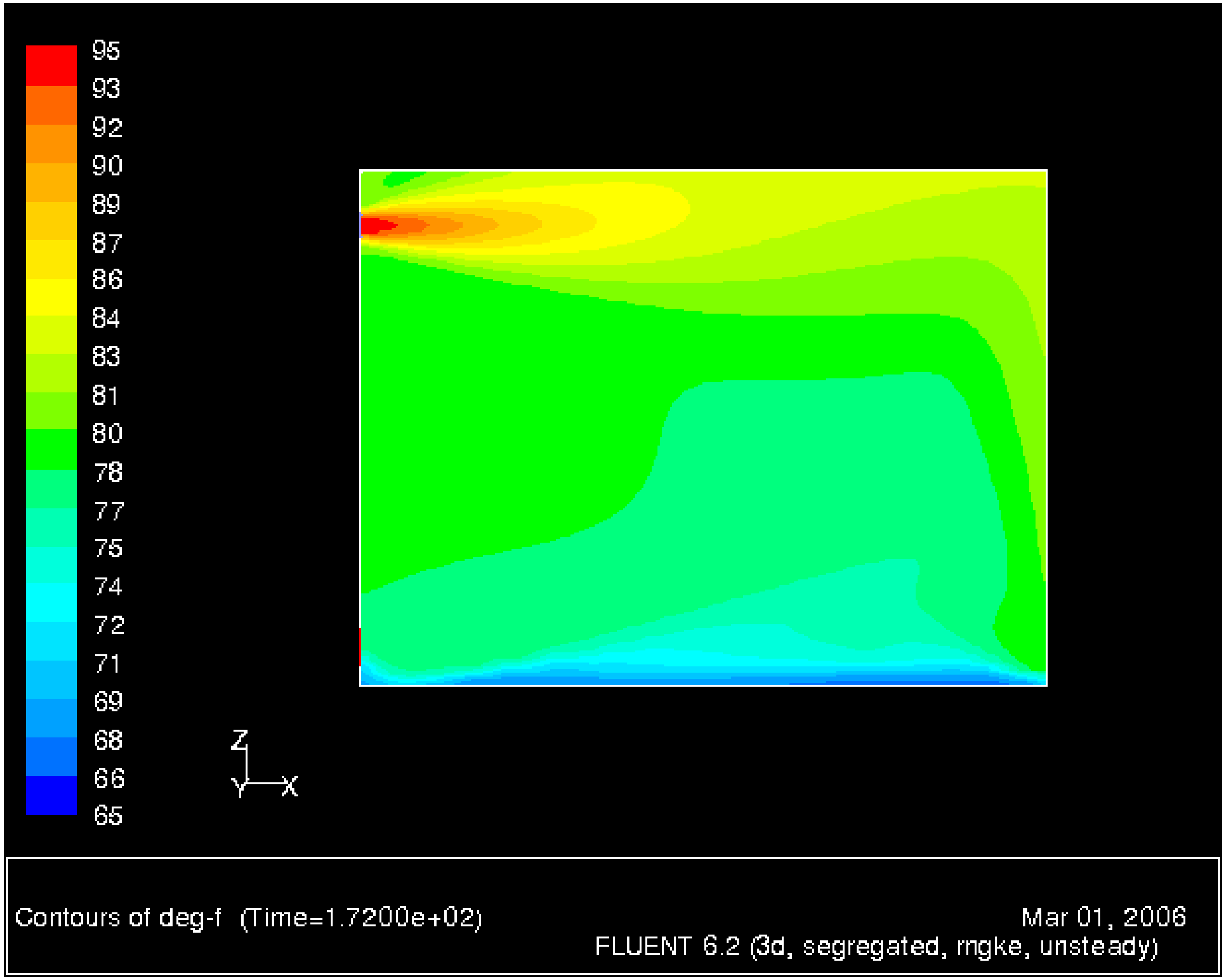
350 Series

Please refer

Size	Velocity	300	400	500	600	700	800
Effective Area	**Duct Pt**	**0.007**	**0.011**	**0.017**	**0.024**	**0.034**	**0.044**
2x10	**CFM**	**26.9**	**35.8**	**44.8**	**53.8**	**62.7**	**71.7**
.089 ft²	Throw	1.5/2/3	2/2.5/3.8	3/[illegible].5/5	3/4/5.5	3.5/5/6.5	4/5.5/7.5
	Spread	2.5	3	4	5	5.5	6
	NC	<20	20	25	25	30	30
4x10	**CFM**	**48.9**	**64.5**	**81.1**	**96.7**	**113.4**	**129.0**
.171 ft²	Throw	3.5/4/4.5	5/5.5/6	6.5/7.5/8.5	7/8.5/9.5	8.5/10.5/12	9.5/11.5/13
	Spread	3	4	5	6	7	8
	NC	<20	20	25	25	30	35

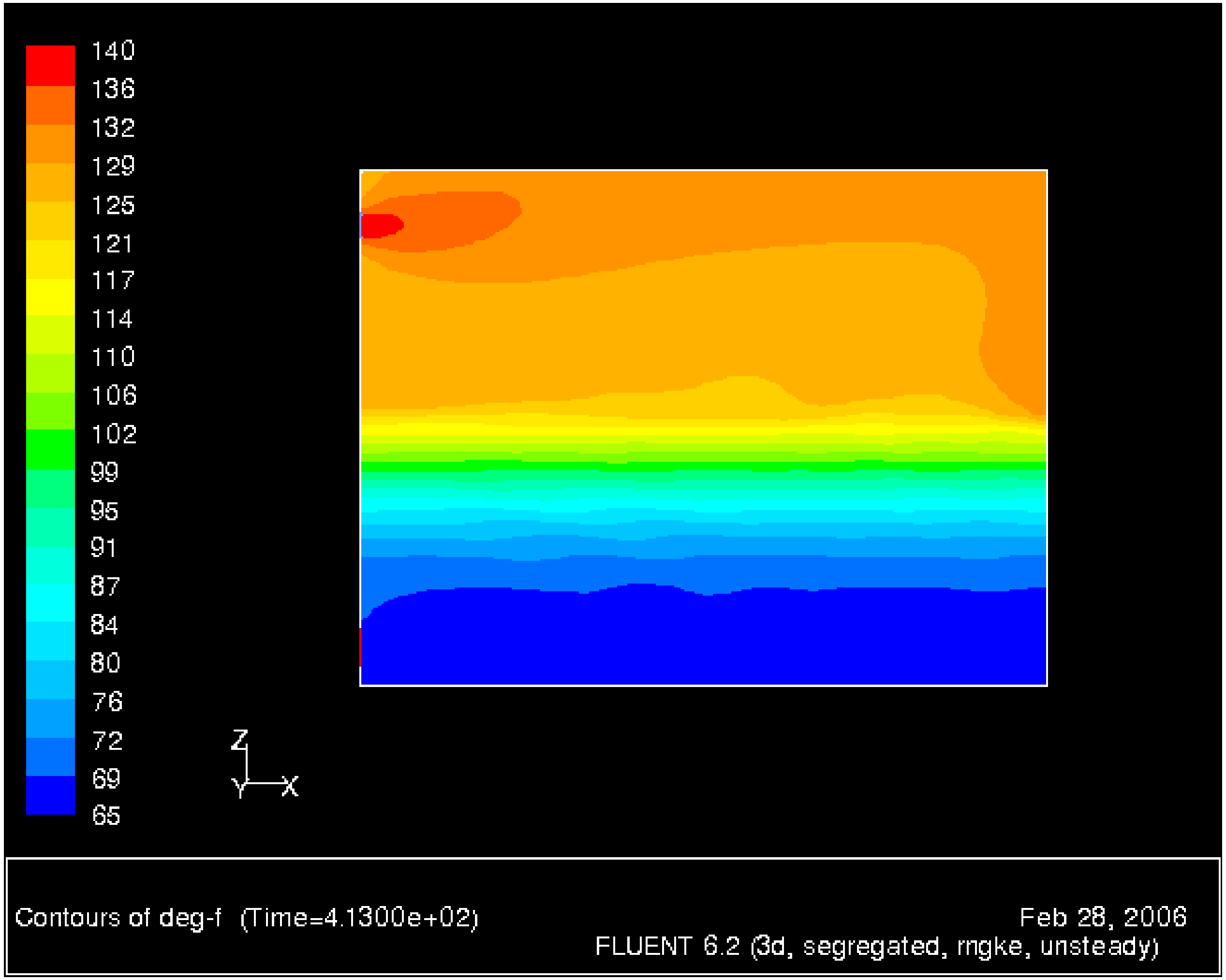
Room Air Distribution

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



Room Air Distribution

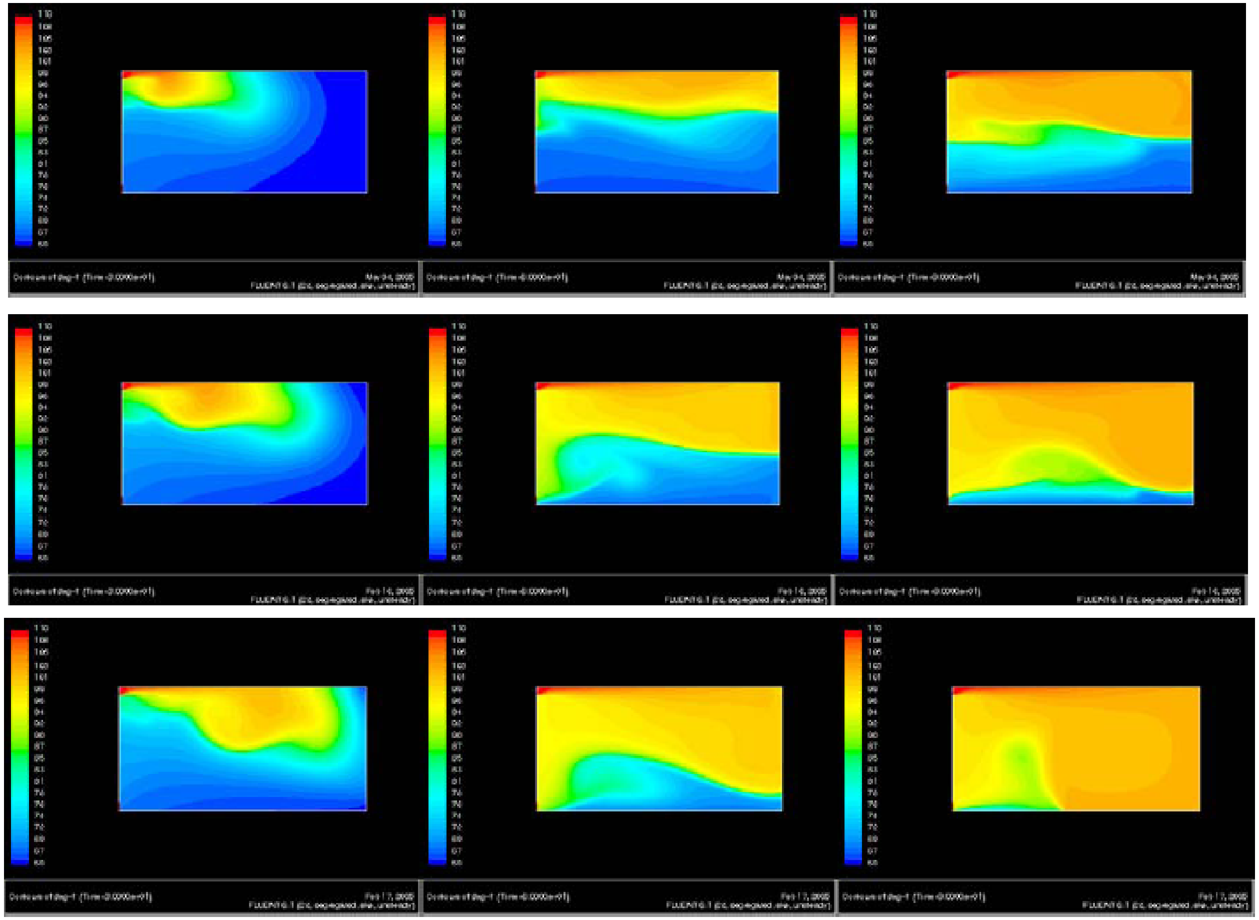
With air entering at 140°F and 330 ft/min, the room shows stratification.



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

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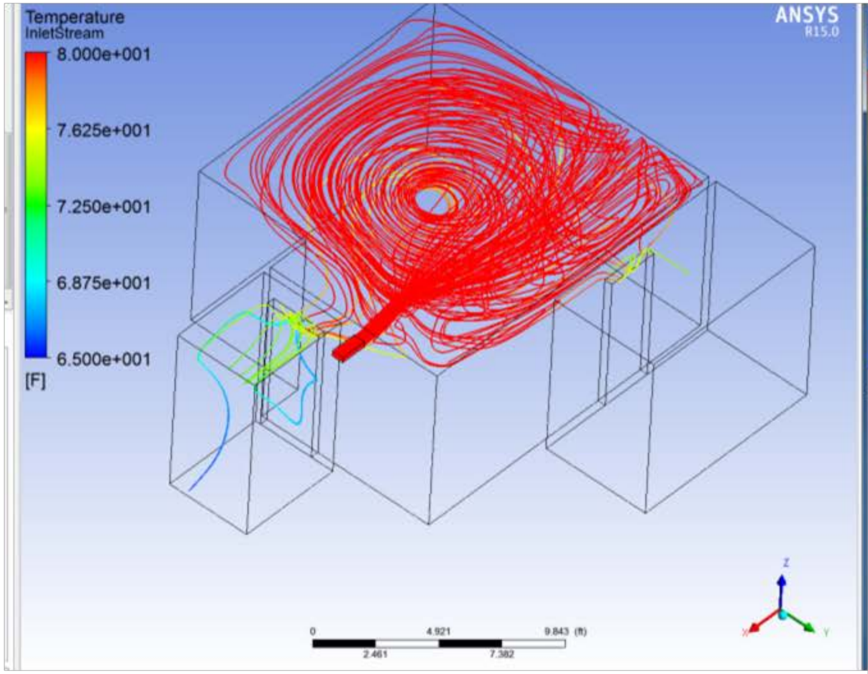
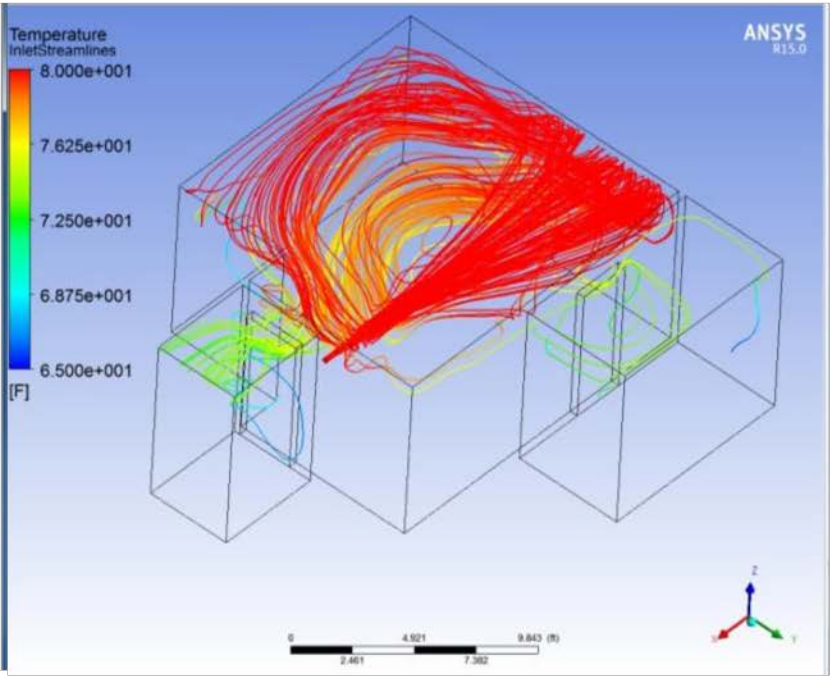
Air mixing - high sidewall interior register heating



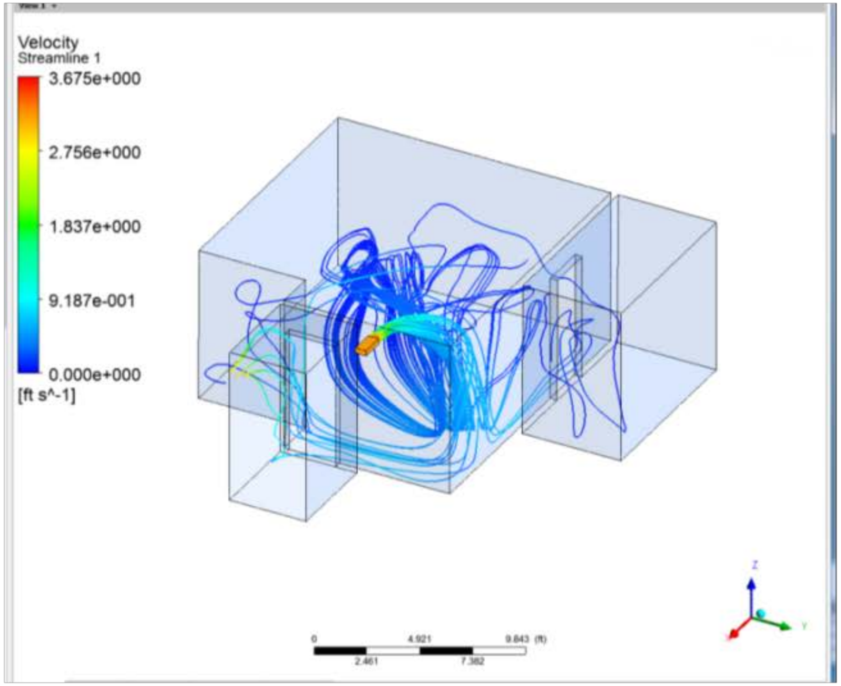
Standard register



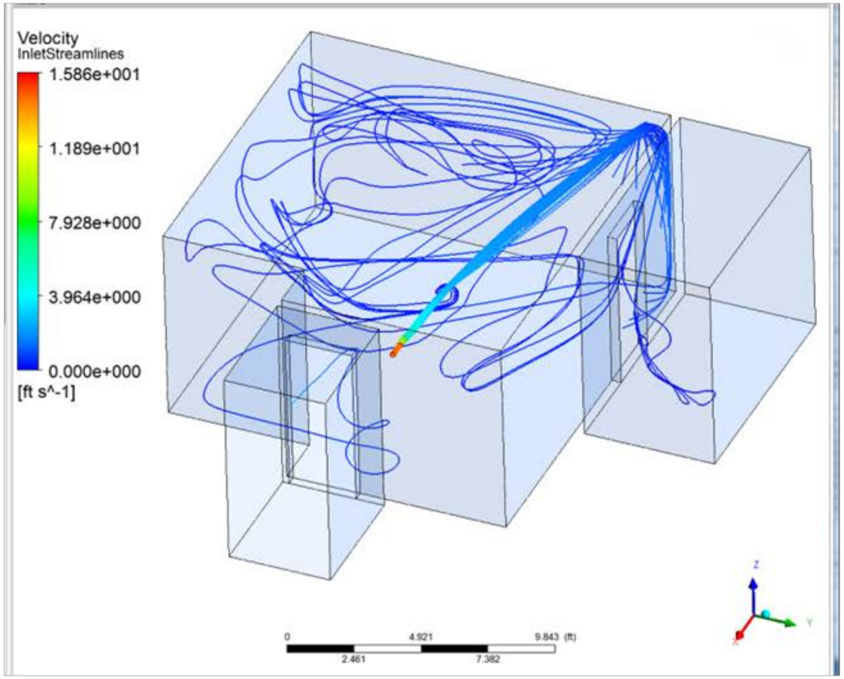
3 inch diameter diffuser

Air mixing - high sidewall interior register cooling

Standard register



3 inch diameter diffuser



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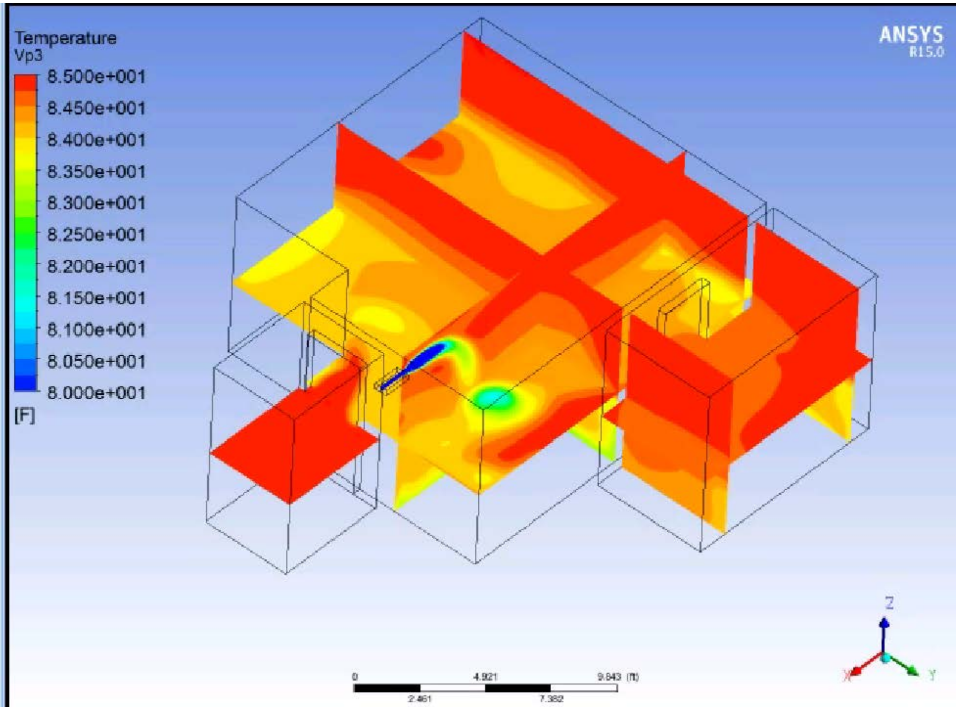
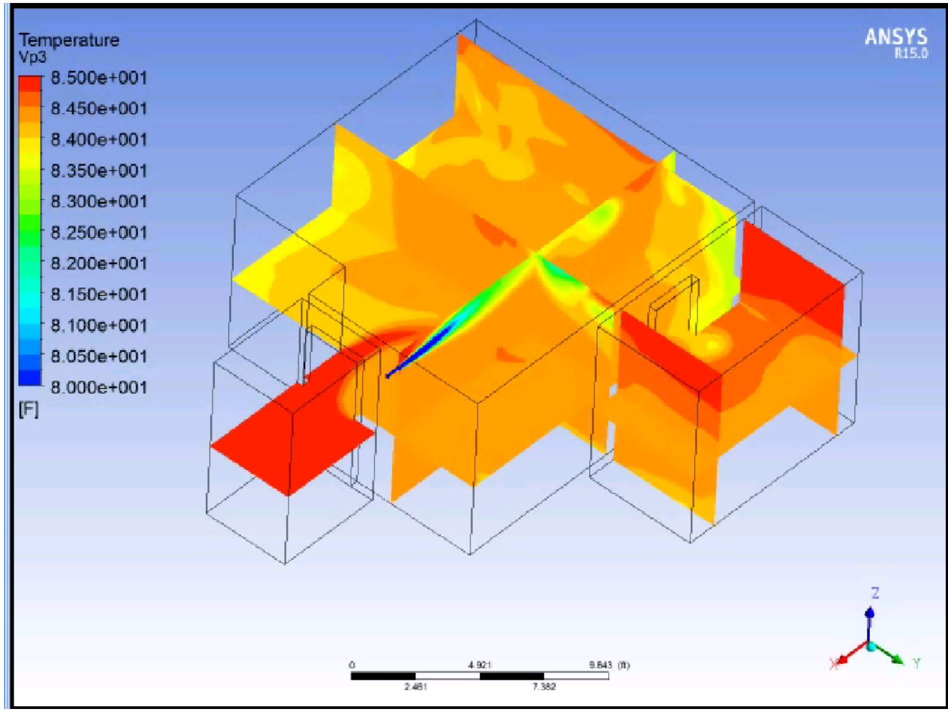
Another way to visualize it - cooling



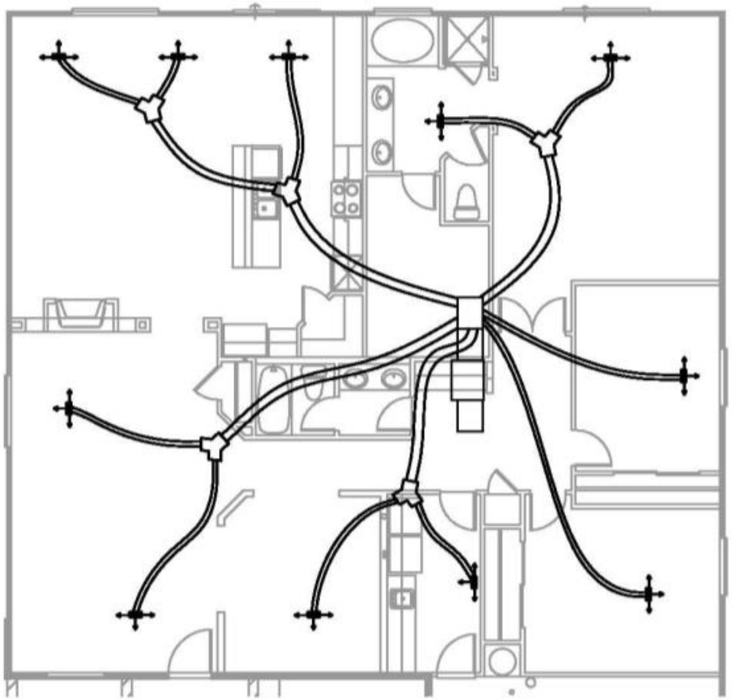
Standard Diffuser



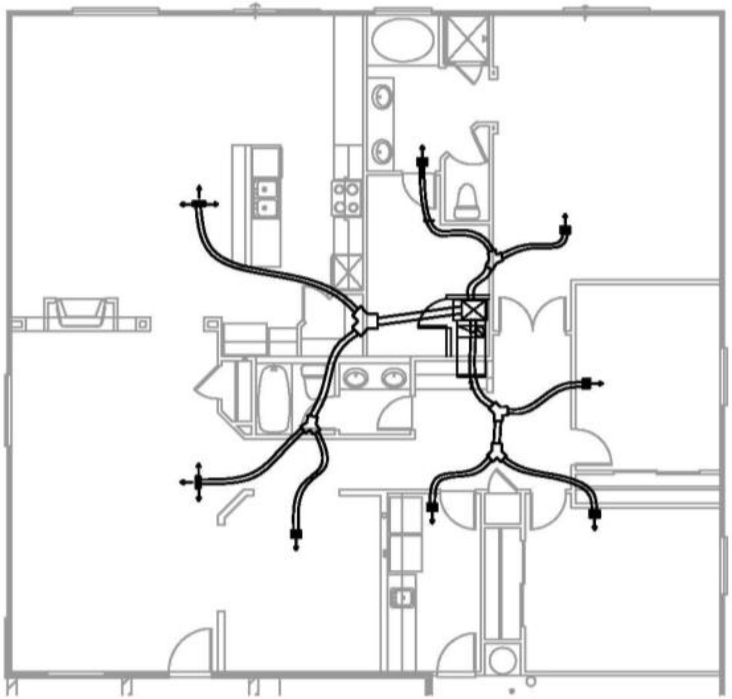
3 inch diameter diffuser

Supply Air Temperature Variables

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

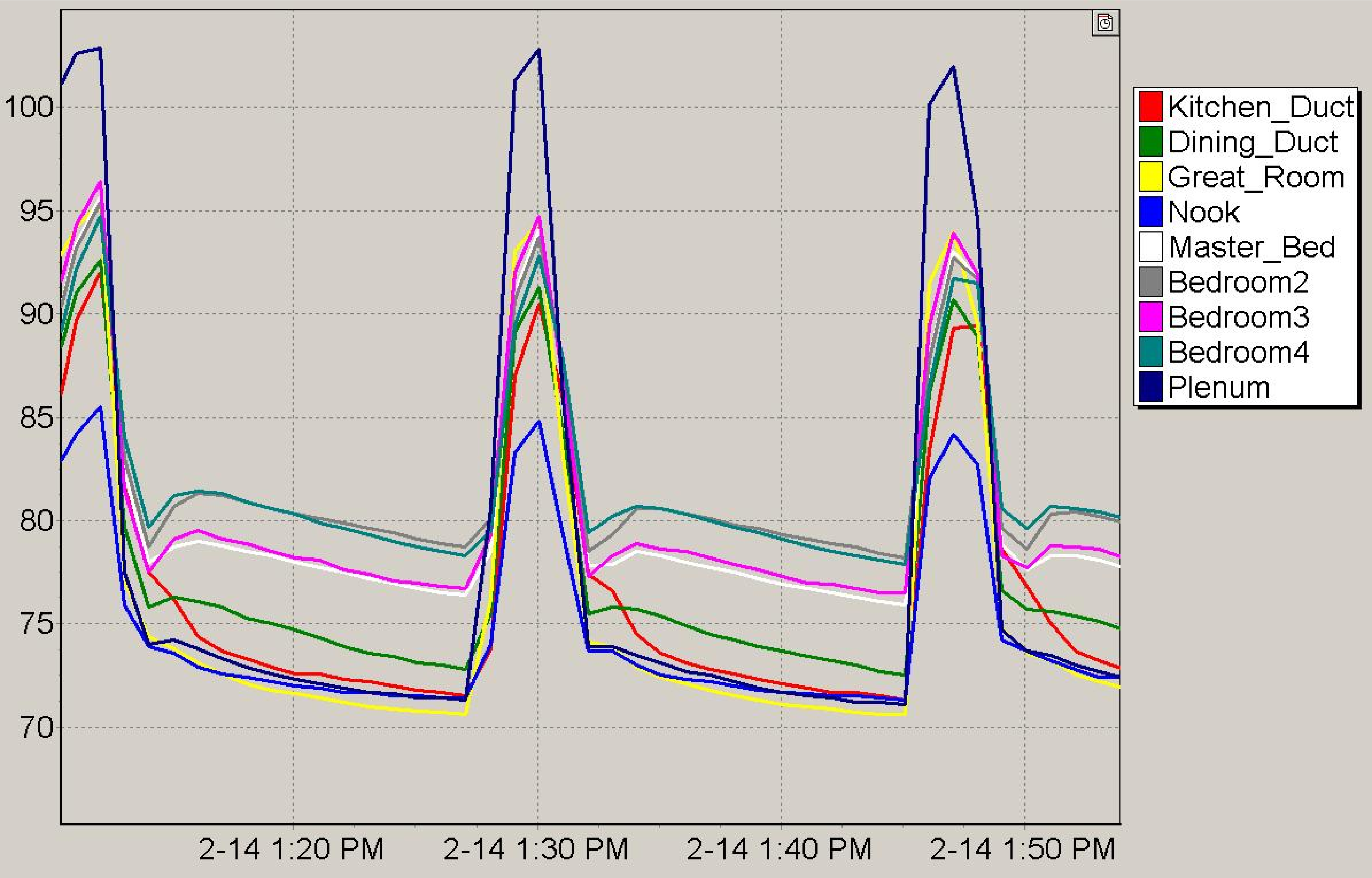


Traditional Layout (11 outlets)

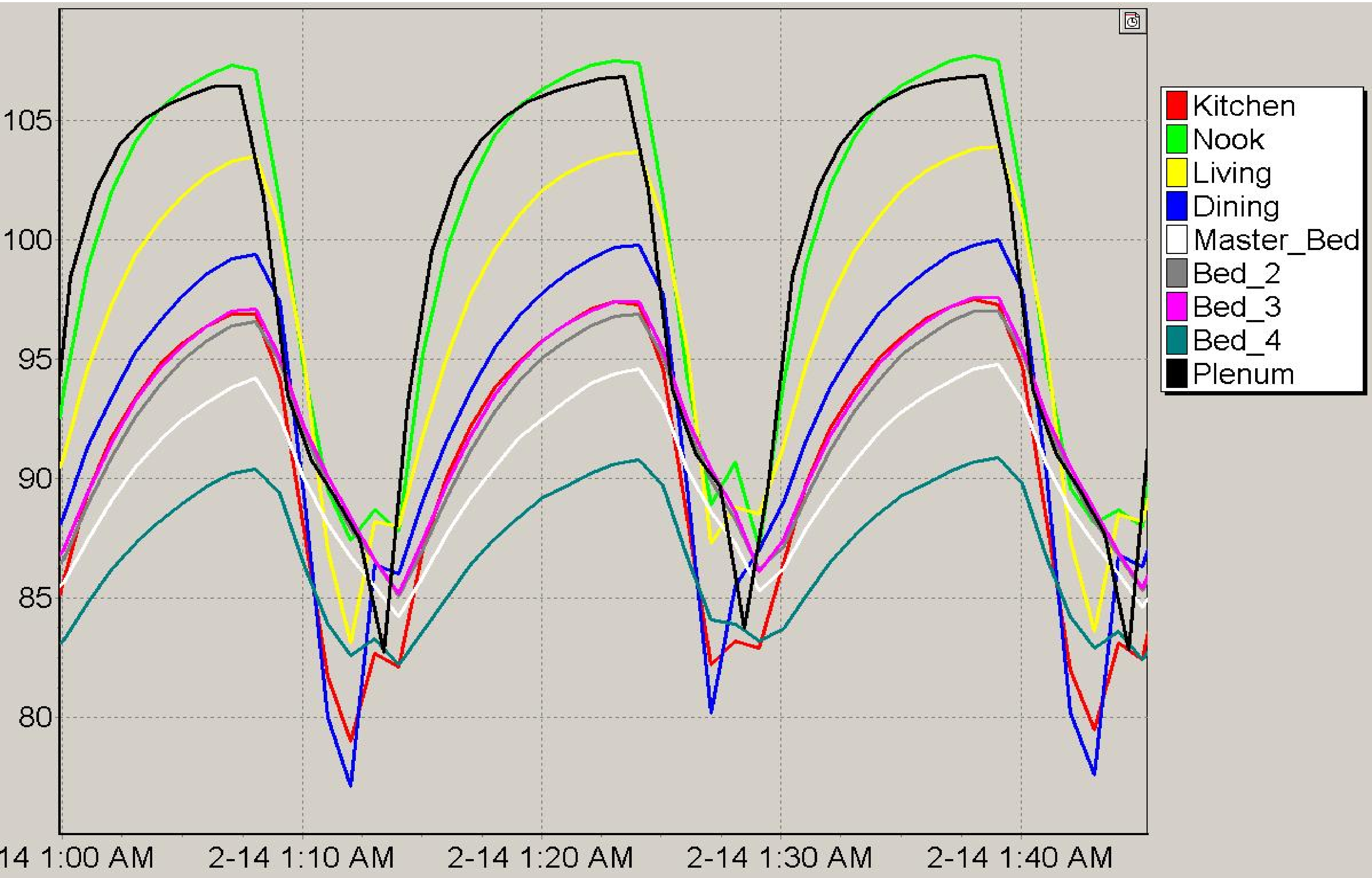


Compact Design (9 outlets)

Terminal Air Temperature
Low Mass, Compact System



Terminal Air Temperature
High Mass, Perimeter System



So what do you do?

- Equipment selection is critical
  - Total CFM is also critical
- DO a duct design, verify it is installed per the design
- Consider designing each duct run with higher velocities to get throw / mixing at supply outlet (Variable friction method – ASHRAE HVAC and Fundamentals Handbooks)
- Select supply outlets, don't just use 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

Thank You

US DOE Building America Program

Best Practices Research Alliance

Cardinal Glass Industries

Carrier Corporation

National Renewable Energy Laboratory

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Thank You

Questions?

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