In accordance with the Department of Labor and Industry's statute 326.0981, Subd. 11,

"This educational offering is recognized by the Minnesota Department of Labor and Industry as satisfying **1.5 code/energy hours** of credit toward **Building Officials and Residential Contractors** continuing education requirements."

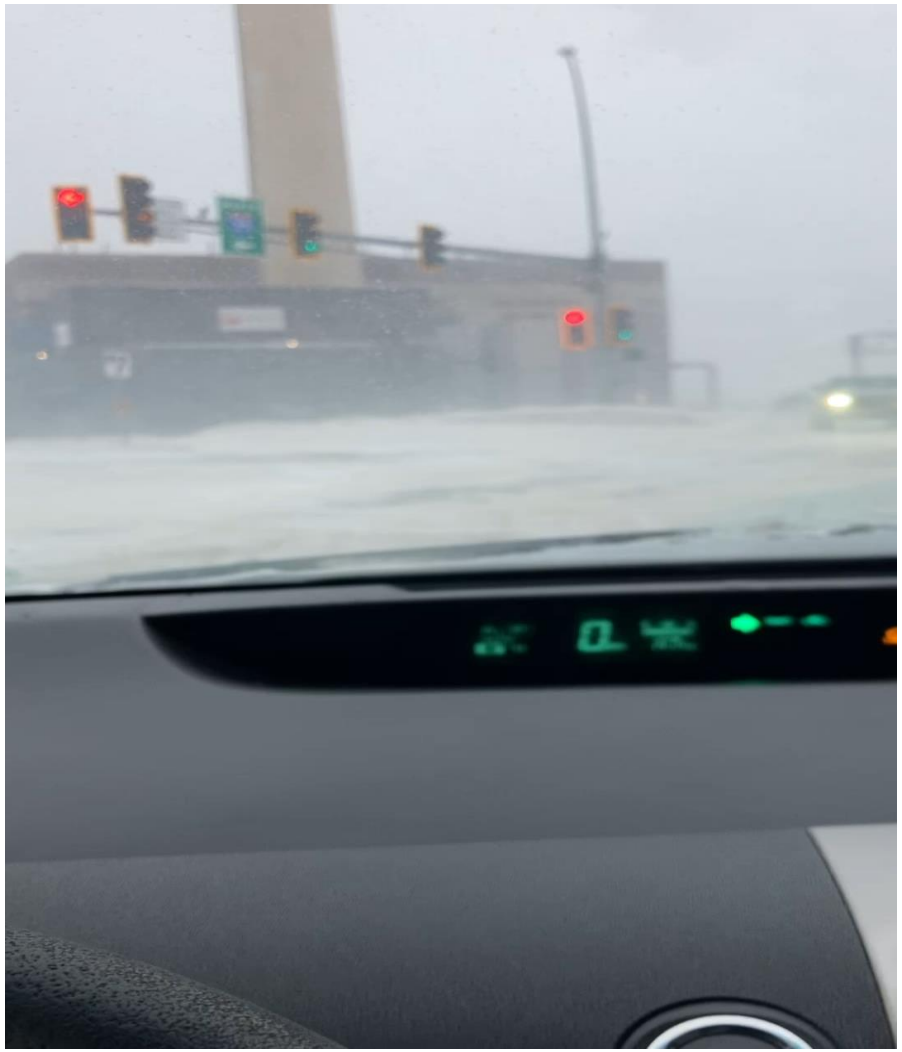
For additional continuing education approvals, please see the continuing education credit section in the conference agenda booklet.

ENERGY DESIGN
conference & expo

Improving Residential HVAC Performance and Energy Efficiency

Feb 21-22, 2023

Ah, Duluth in February…



Introduction

Bruce Stahlberg

- Owner of Affordable Energy Solutions, Inc (AES).
- Over 35 years experience, has performed over 8,000 energy audits on various building types.
- Focused on HVAC Quality Install Testing protocol including static pressure, air flow testing and Manual J calculations.

Who are you?

- Weatherization
- Utilities
- Government
- Builders/Remodelers
- HVAC Contractors
- Other?

- Anyone see this last year?

Agenda and Goals

- Mechanical HVAC forced air systems
  - Operation and delivery
- Manual J Sizing Calculations – Importance
  - Scrutinizing Manual J calcs
- Diagnosing in the field –
  - Recommended tests
- Set Up of Forced Air Systems
  - Size, Static Pressure and Air Flow
- Improving installations and performance
  - “Tweaking” Existing and New installations
  - Case Studies

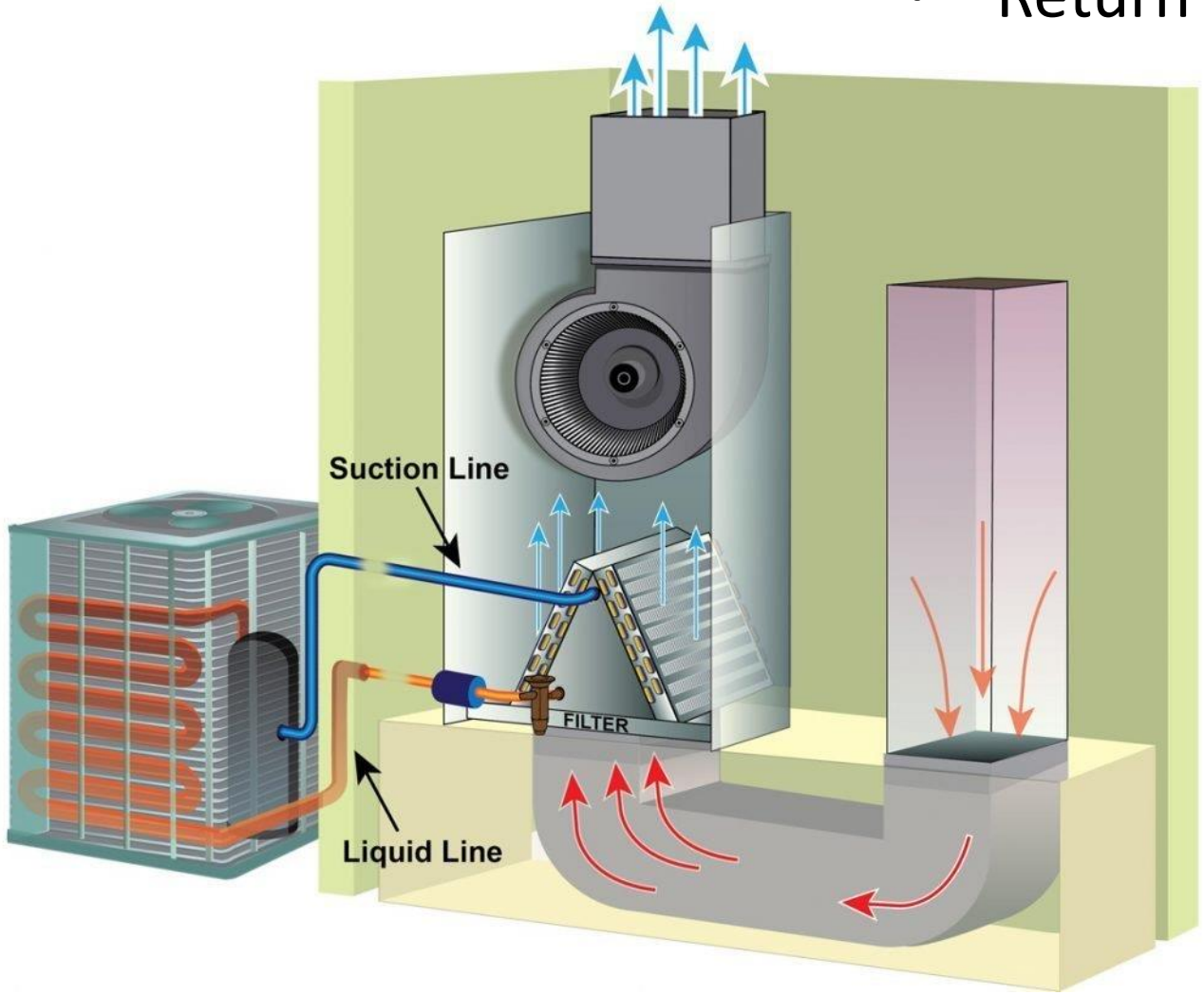
Terms and abbreviations

- Manual J Heat Loss (Load) Calculation in BTUs/hour
- BTUs = Heat Hour = time
- CFM = Flow of Air in Cubic Feet per minute
- TESP = Total External Static Pressure
- Output / Input = furnace BTU/hr rating
- K = 1000 Example: 10K = 10,000

- 10kBTUs = 10,000 BTUs

Mechanical FORCED AIR System

- Supply (blows)
- Return (sucks)



Needs to be set up correctly at installation

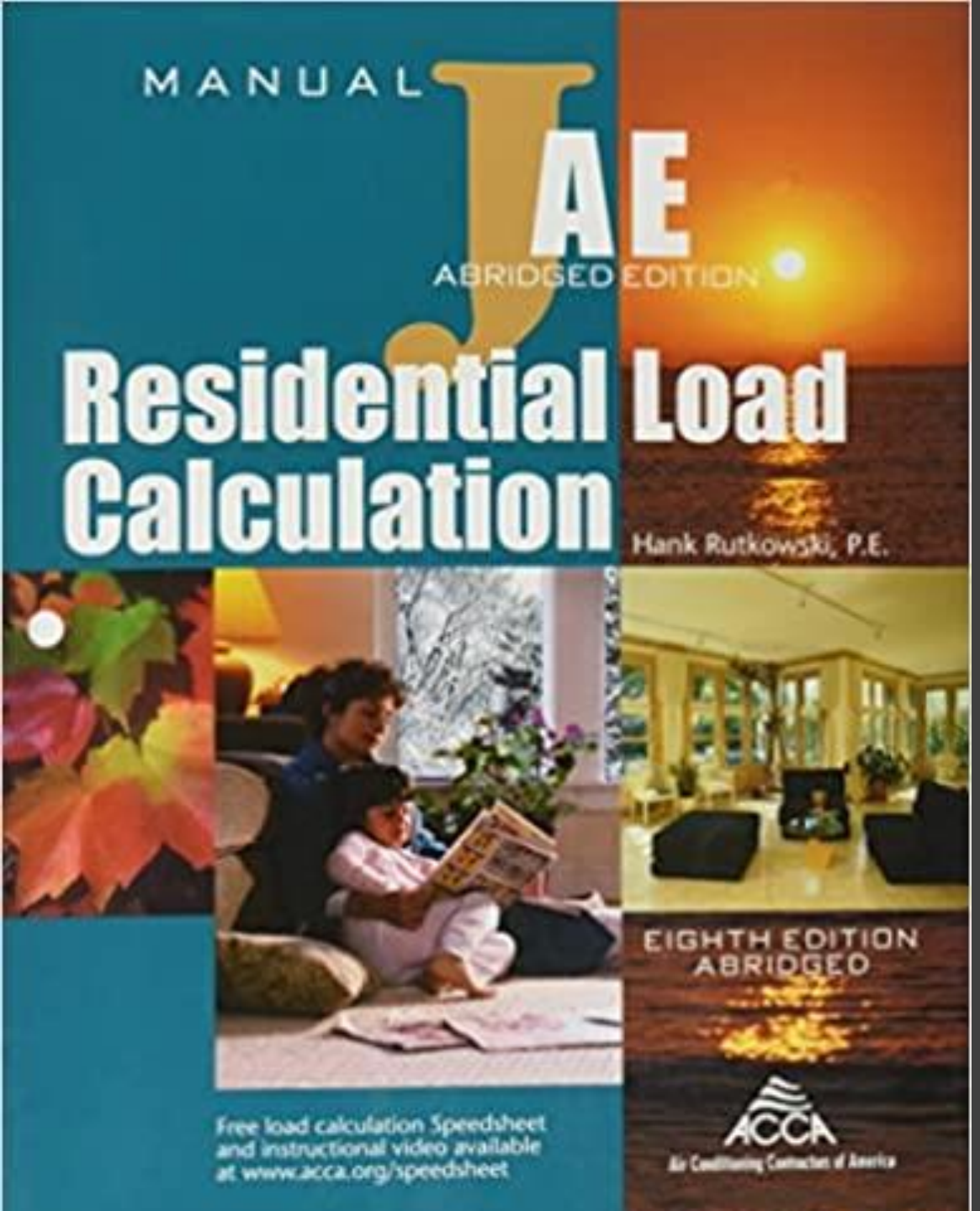
Photo from: *HVAC School for Techs by Techs, by Bryan Orr*

Why the need to heat our homes?

Hint: heat loss happens

Heat loss is in BTUs/hour

Laws of nature will equalize both to room temperature



Step 1 – Manual J Design

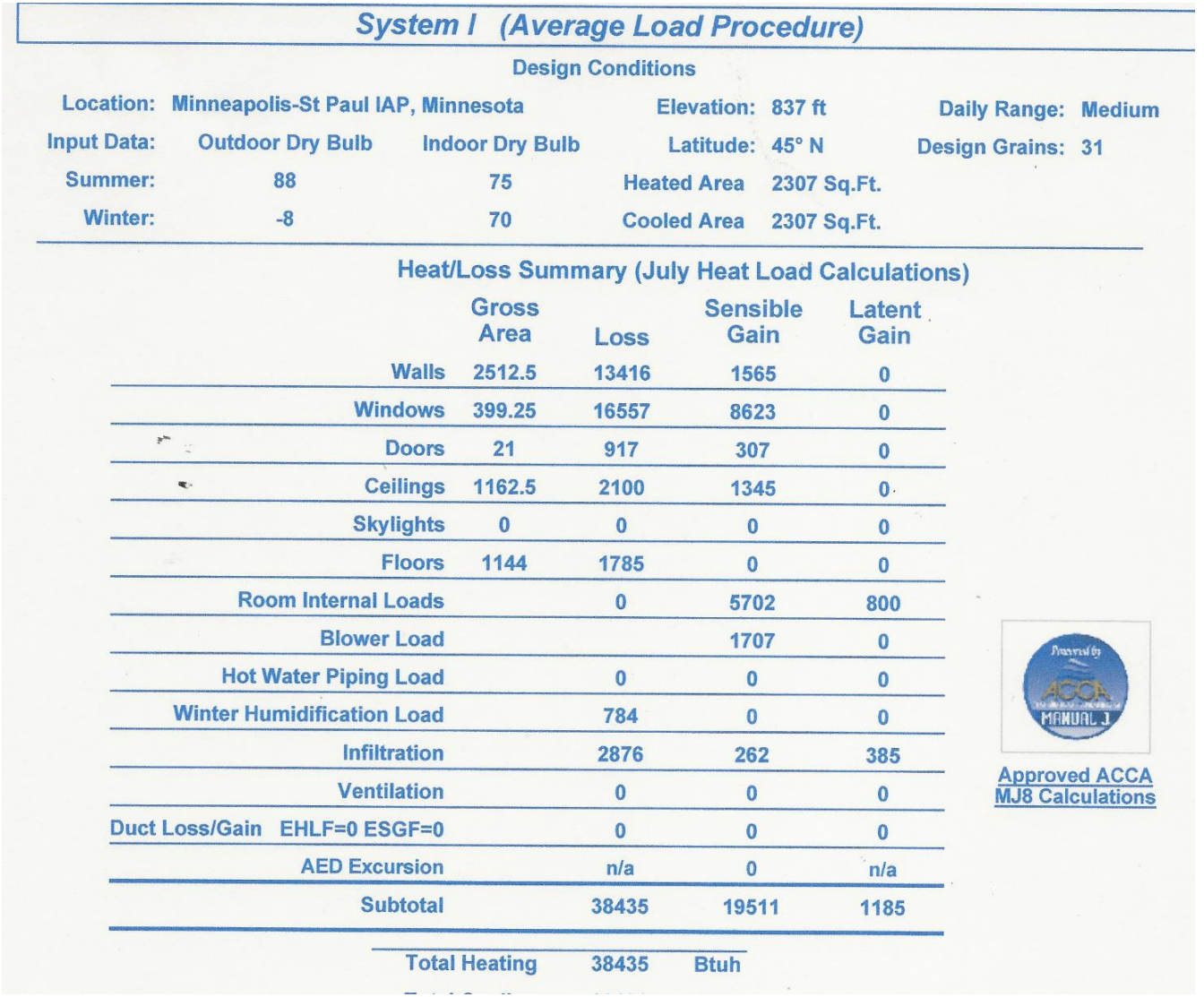
- Manual J Load Calculations
  - U-values (Insulation)
  - Square feet
  - Delta T –Temp change
  - BTUs/hour
  - Requires some effort (although not much)

Manual J software document

- Required with new install
- Not so for mobile homes

- Can vary widely
- Based on assumptions

- 36,435 *exact ESTIMATE*



System I (Average Load Procedure)

Design Conditions

Location:	Minneapolis-St Paul IAP, Minnesota		Elevation:	837 ft	Daily Range: Medium
Input Data:	Outdoor Dry Bulb	Indoor Dry Bulb	Latitude:	45° N	Design Grains: 31
Summer:	88	75	Heated Area	2307 Sq.Ft.	
Winter:	-8	70	Cooled Area	2307 Sq.Ft.	

Heat/Loss Summary (July Heat Load Calculations)

	Gross Area	Loss	Sensible Gain	Latent Gain
Walls	2512.5	13416	1565	0
Windows	399.25	16557	8623	0
Doors	21	917	307	0
Ceilings	1162.5	2100	1345	0
Skylights	0	0	0	0
Floors	1144	1785	0	0
Room Internal Loads		0	5702	800
Blower Load			1707	0
Hot Water Piping Load		0	0	0
Winter Humidification Load		784	0	0
Infiltration		2876	262	385
Ventilation		0	0	0
Duct Loss/Gain EHLF=0 ESGF=0		0	0	0
AED Excursion		n/a	0	n/a
Subtotal		38435	19511	1185

Total Heating 38435 Btuh

Approved ACCA MJ8 Calculations

It depends on several factors…

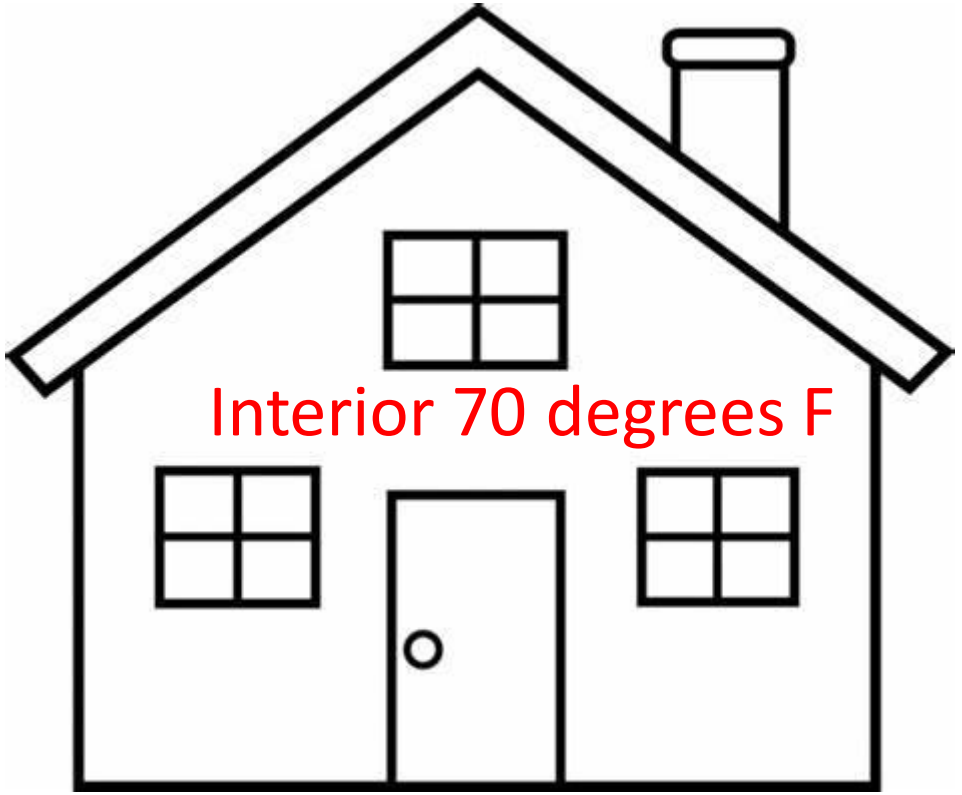
SIZE

INSULATION LEVELS

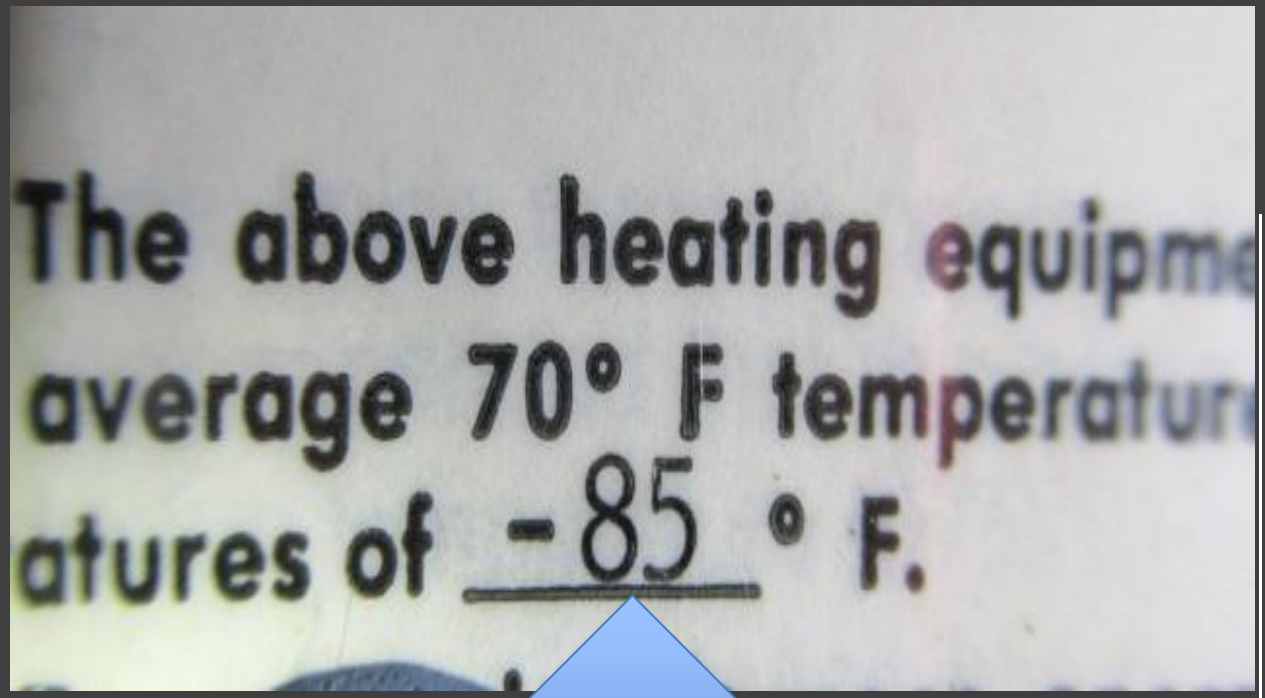
INFILTRATION (TIGHTNESS)

DESIGN TEMPERATURES

*Exterior -6 to -26 degrees F



*ACCA Manual J Load Calculation for MN



Actual Design temp from Mobile Home Data Plate

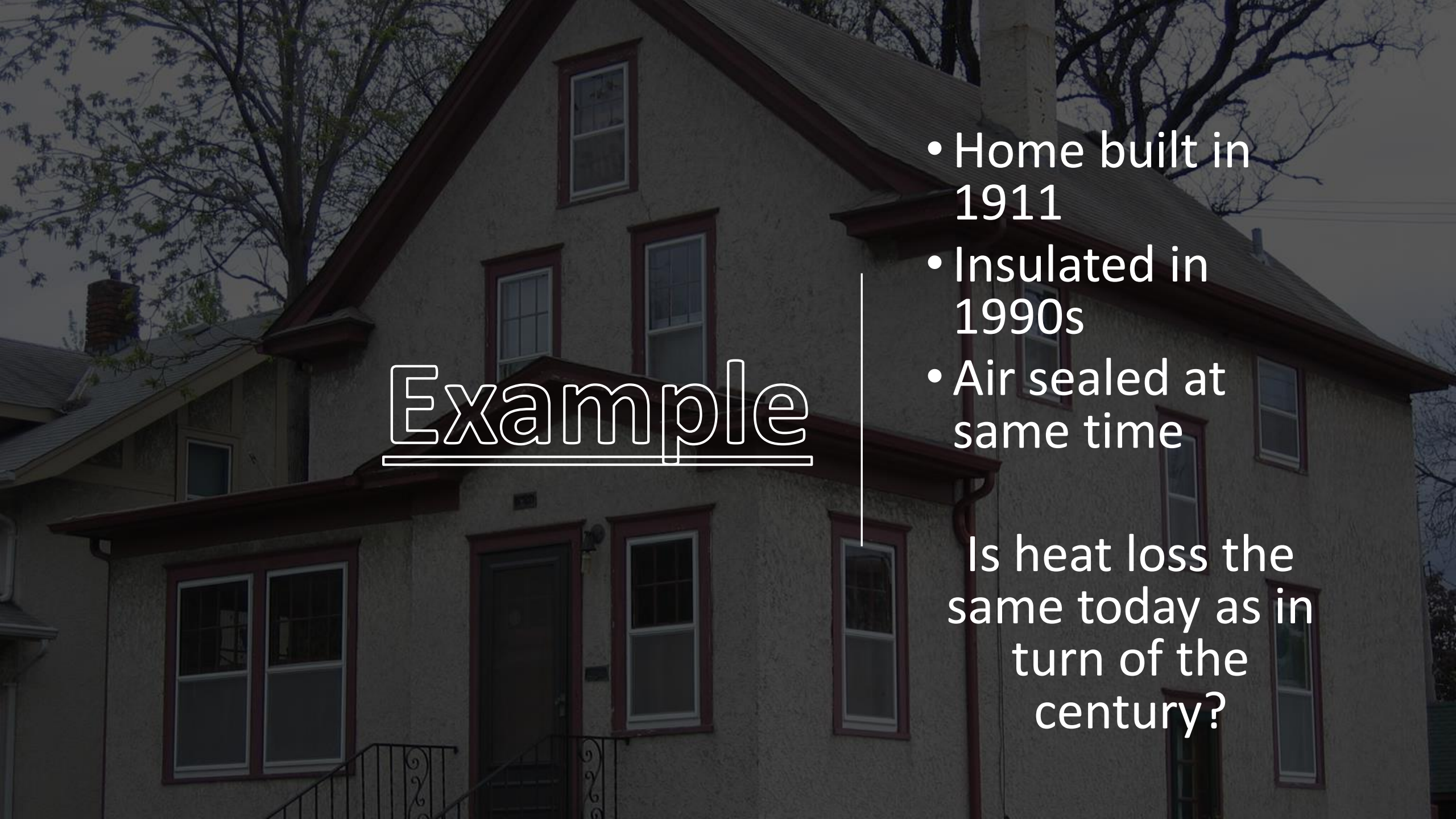
Delta T Design Inputs

- Examples: Winter, Summer

- Tofte: -6 F, 75 F
- Winona: -10 F, 88 F
- Fergus Falls: -17 F, 88 F
- Bemidji: -26 F, 85 F
- Minneapolis: - 11 F, 88 F
- Blaine: -4 F (adjusted?)

- We design for ***Worst Case***, the coldest day of the year

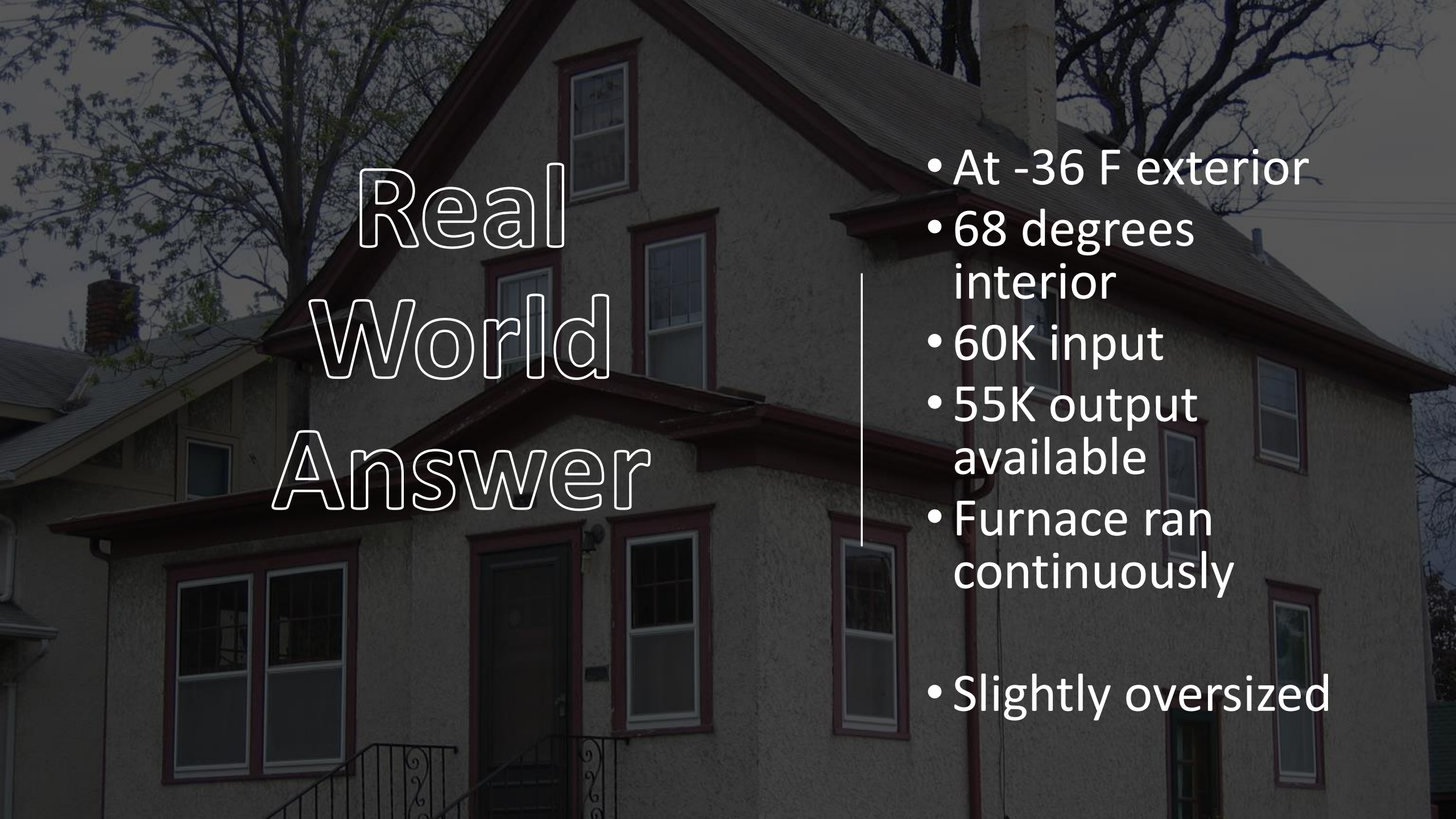
What is the HEAT LOSS demand for these homes?



Example

- Home built in 1911
- Insulated in 1990s
- Air sealed at same time

Is heat loss the same today as in turn of the century?



Real World Answer

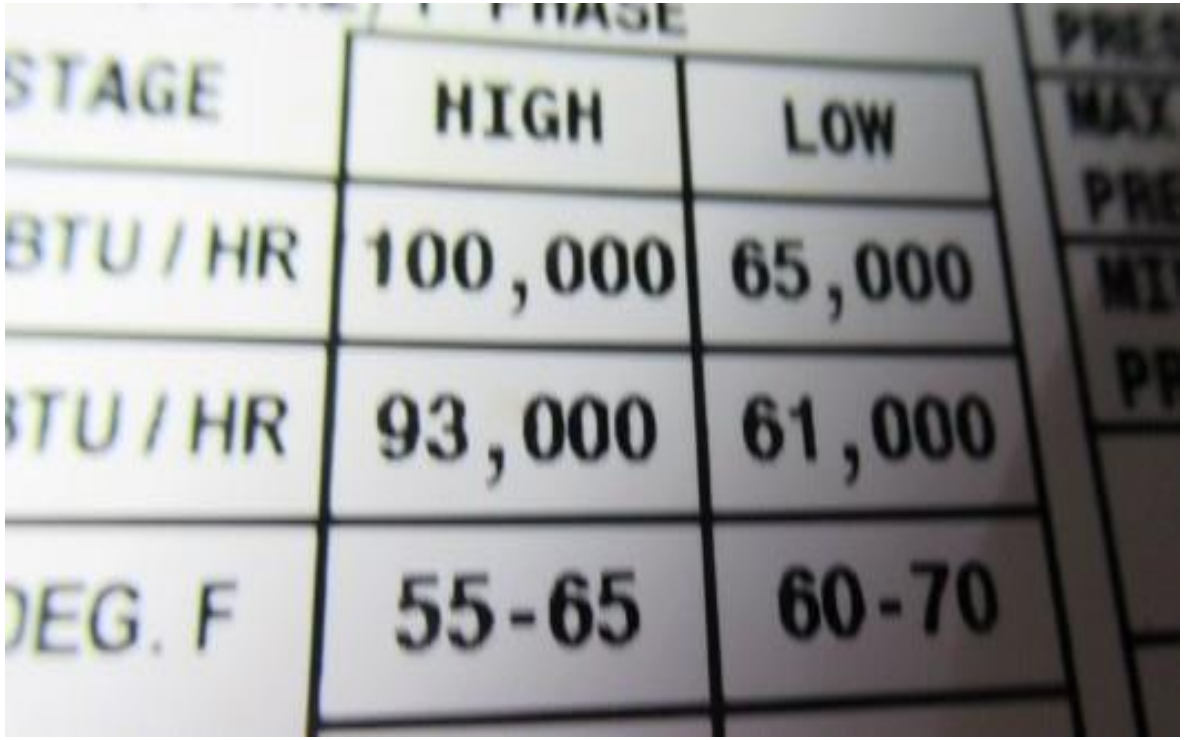
- At -36 F exterior
- 68 degrees interior
- 60K input
- 55K output available
- Furnace ran continuously

- Slightly oversized

Nameplate Information

- Size found on nameplate
- Proposed size found on contractor’s bid

- Furnace Sizes
  - 40K
  - 60K
  - 80K
  - 100K



Nameplate Information

- Size
- Output/input = efficiency
- Temp rise

HEAT STAGE		HIGH	LOW
INPUT / ENTREE	BTU / HR	100,000	65,000
OUTPUT / SORTIE	BTU / HR	93,000	61,000
AIR TEMPERATURE RISE	DEG. F	55-65	60-70
AUGMENTATION DE LA TEMPERATURE DE L'AIR	DEG. C	31-36	33-39

Replacing to more efficient systems

From this...

To this…

Major change in heating system, no change in ductwork

Available heat (BTUs) increases by 15%

***DOWNSIZE by at least that amount**

***already oversized originally**

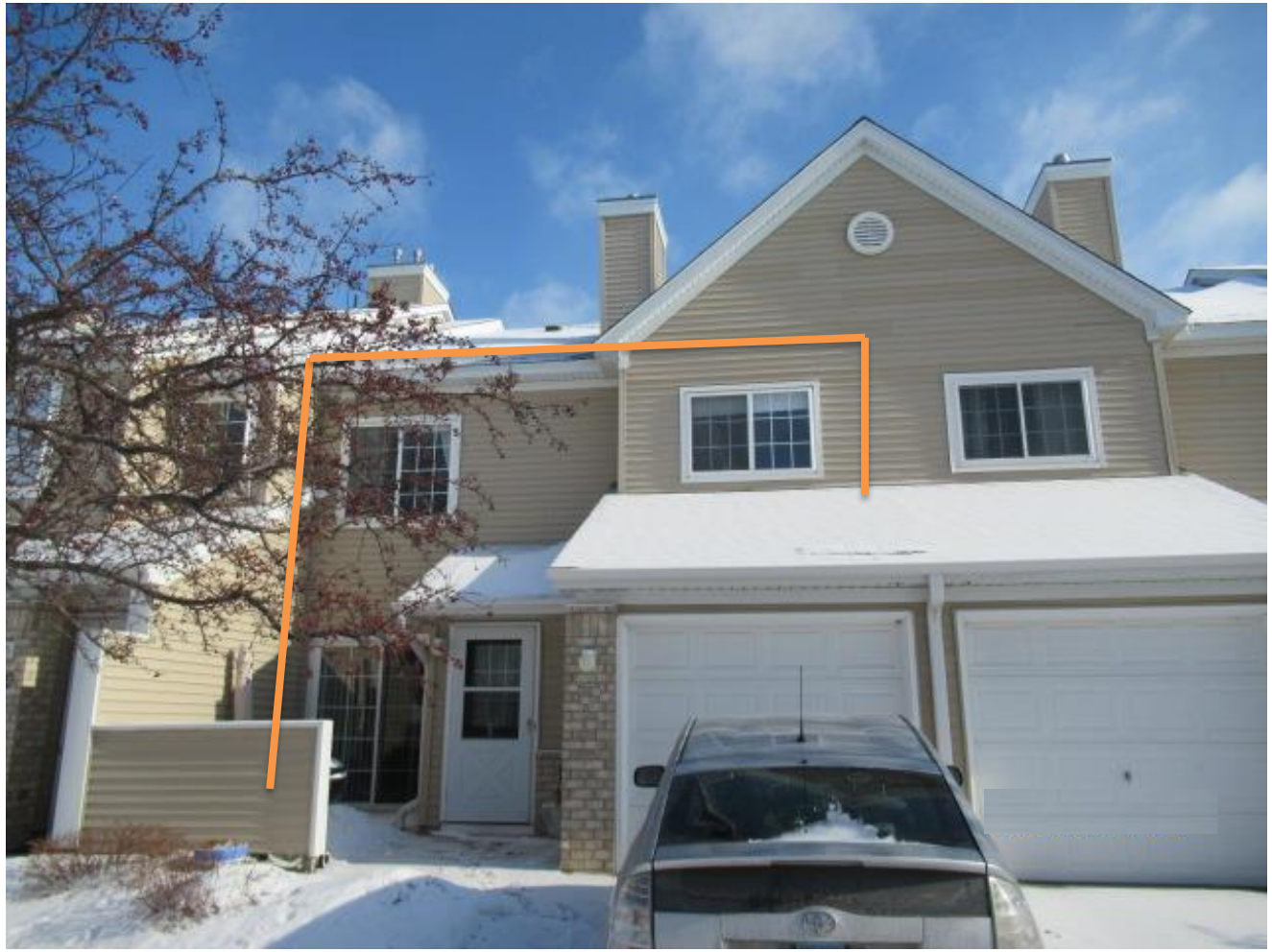
Same Input, larger Output

More heat

- 80K input, 64K output

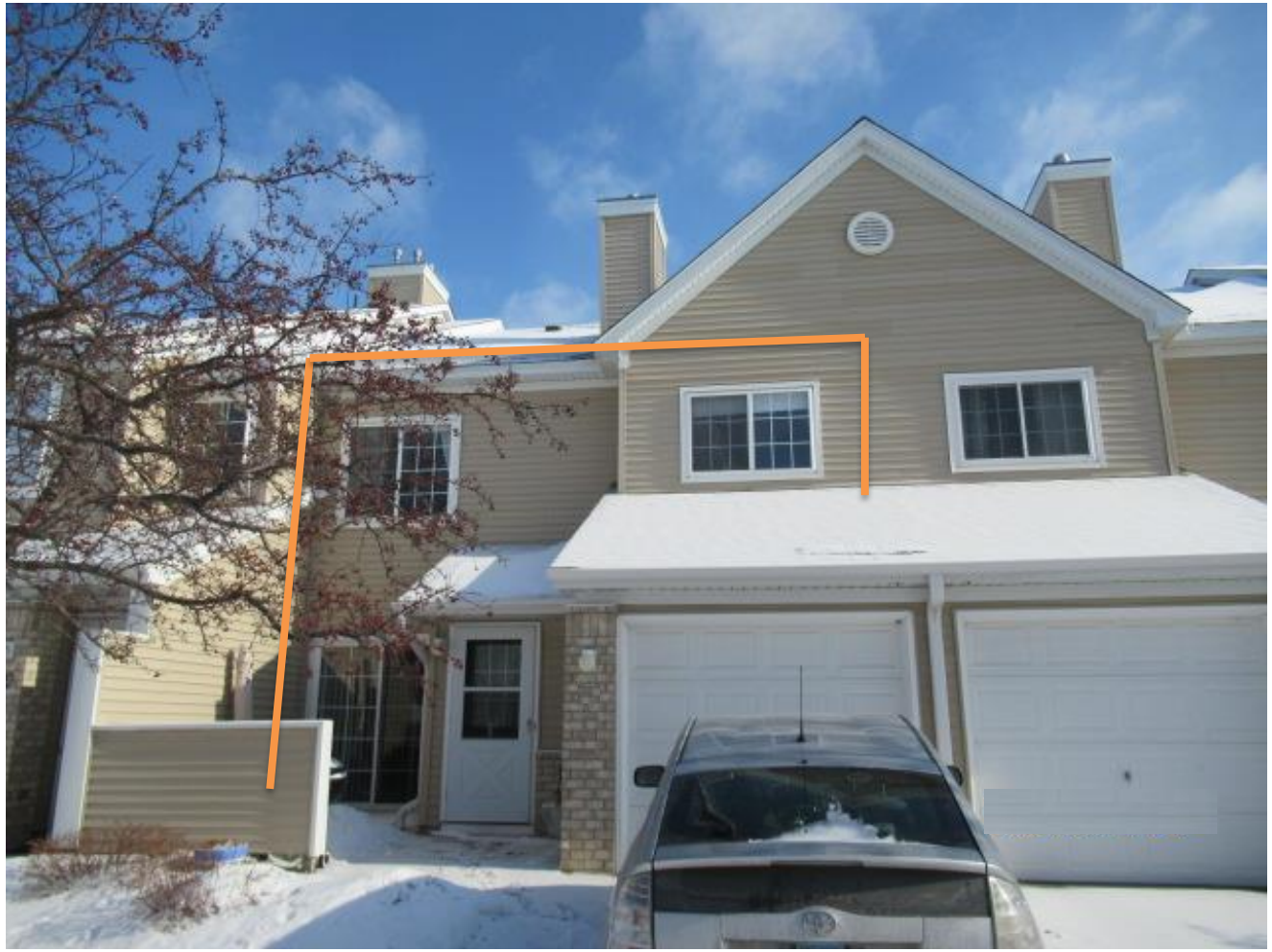
80K input, 77K output

What is the heat loss of this home?



- 1995 construction
- 2” x 6” walls
- 1,080 sq. ft.
- Weatherized home
- Middle unit, heated on both sides
- Plus gas fireplace

Several Estimates for the same home



- 20,000 BTUs/hr
- 32,000 BTUs/hr
- 36,000 BTUs/hr
- 53,000 BTUs/hr

Depends on who you ask...

- Weatherization energy modeling = 20 KBTUs
- CoolCalc.com energy modeling = 32 KBTUs
- Contractor proposed - 2017 = 36 KBTUs
- Manual J calculation - 2021 = 52 KBTUs (several errors)

And the winner is...

- 1st stage only

- New Furnace installed – 2021 = 35 KBTUs (1st stage)
  Outputs = 53 KBTUs (2nd stage)

Rated TESP = 0.5”
Measured TESP = **.68”**
Measured TESP = **.96”**

Overall End Result

- Erroneous Manual J
- System oversized
- High pressure, loud
- Requested set at 1st stage
- Contractor replaced furnace with smaller one (profit?)

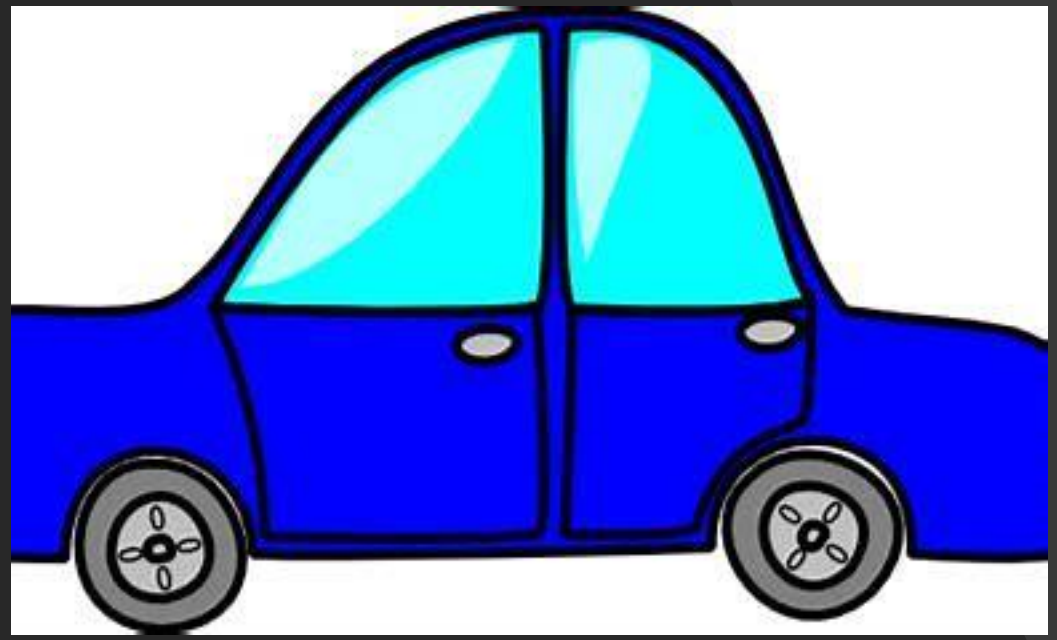
Static pressure dropped from .96” to .56”
Survived several cold snaps <-15 F

Impact of Oversizing

- Noisy operation
- Short cycling (on, off, on, off)
- Increased pressure
- Reduced efficiency
- Likely shorter life expectancy
- Less comfortable

Ideal Optimization = Long Run time

- Gets to Steady State
- More comfort
- Less wear and tear on system
- It runs “all the time” – when cold….that is perfect
- Use Car analogy with customers



Manual J – www.CoolCalc.com

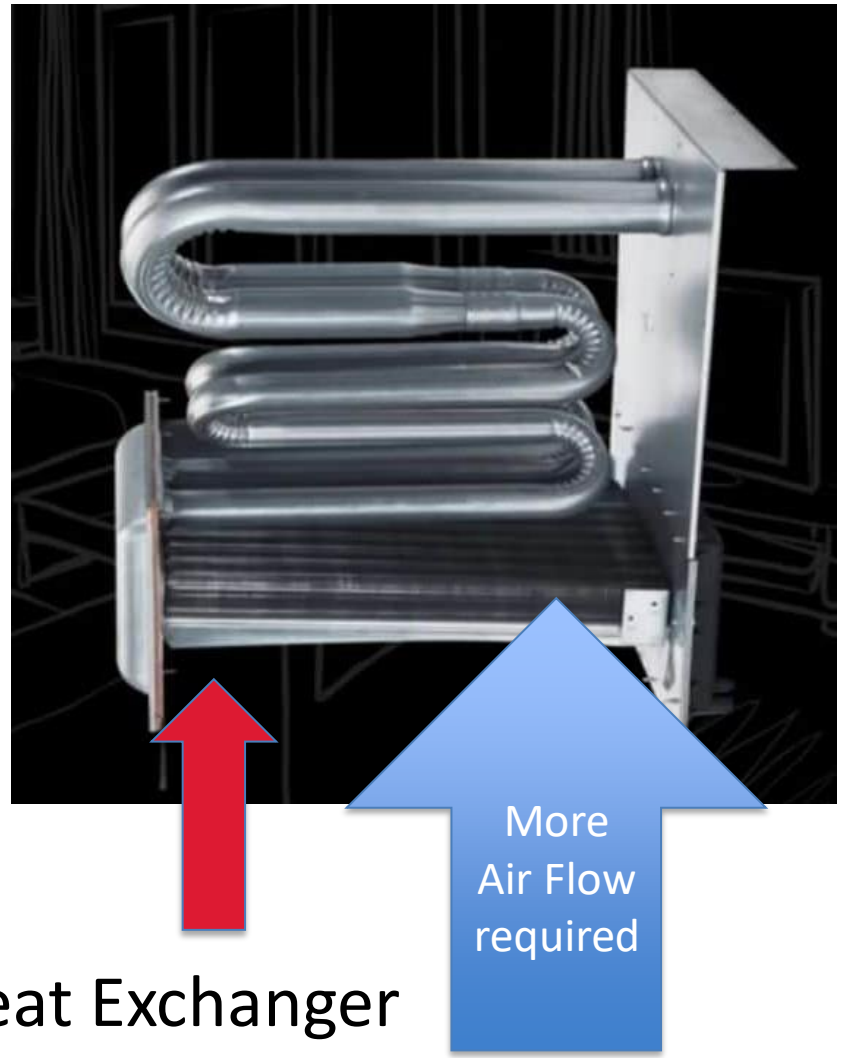
- Use or Compare with CoolCalc.com
  - ACCA approved
  - Cool Calc Manual J – YouTube
  - Need some building info:
    - Location, Age of building

  - ***Has Limitations!***
  - ***Does not replace actual measurements!***
  - ***Leans towards oversizing!***
  - ***Not designed for Mobile Homes***

Absolutely best method is to be on-site to get accurate inputs

System Design: Condensing Furnace

- Secondary Heat Exchanger
- More heat / BTUs available
- Requires more air flow
- Adds blockage in flow path



Required Air Flow increases with ductwork staying the same size = Higher Pressure

100 CFM

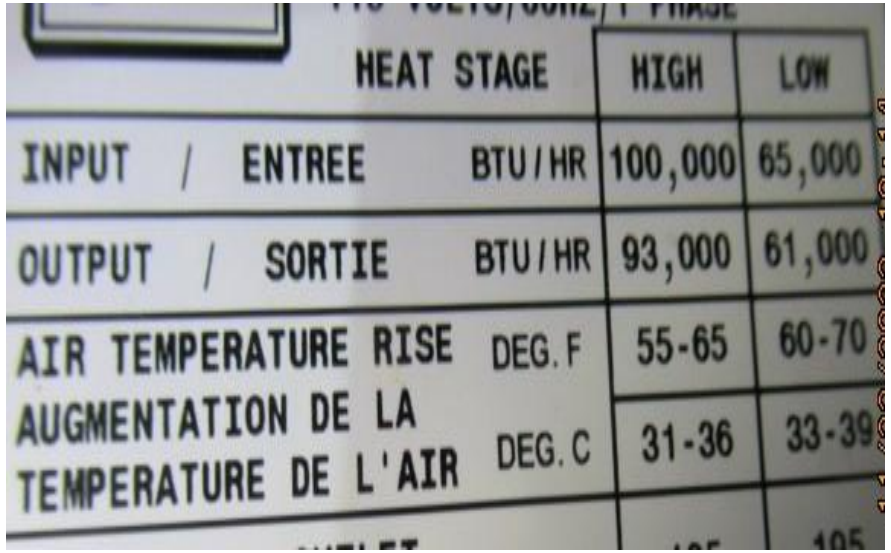
130 CFM

150 CFM

Recommended CFM per 10,000 BTUs

Tweaking an Existing System

- Oversized System, 15 years
- Two-stage (luckily)
- Owner complained about noise
- Set to run on 1st stage only
- 61K BTU vs. 93KBTU
- Temps dropped to -12 and -15° F.



HEAT STAGE		HIGH	LOW
INPUT / ENTREE	BTU/HR	100,000	65,000
OUTPUT / SORTIE	BTU/HR	93,000	61,000
AIR TEMPERATURE RISE	DEG.F	55-65	60-70
AUGMENTATION DE LA TEMPERATURE DE L'AIR	DEG.C	31-36	33-39

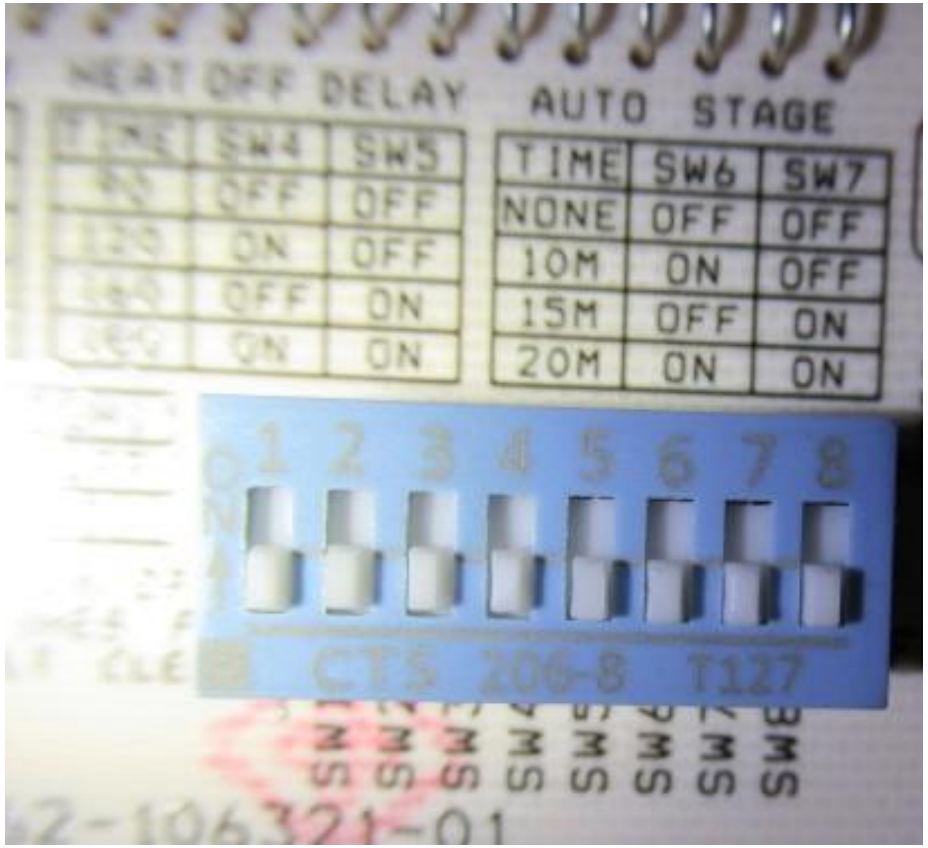
System Design: Control Board

- Controls operations
- Stage control
- Blower Motor Speed
- Blower Motor On/Off time

- Dipswitches
- Menu options – push button
- Low voltage wiring

System Design: Dip Switches

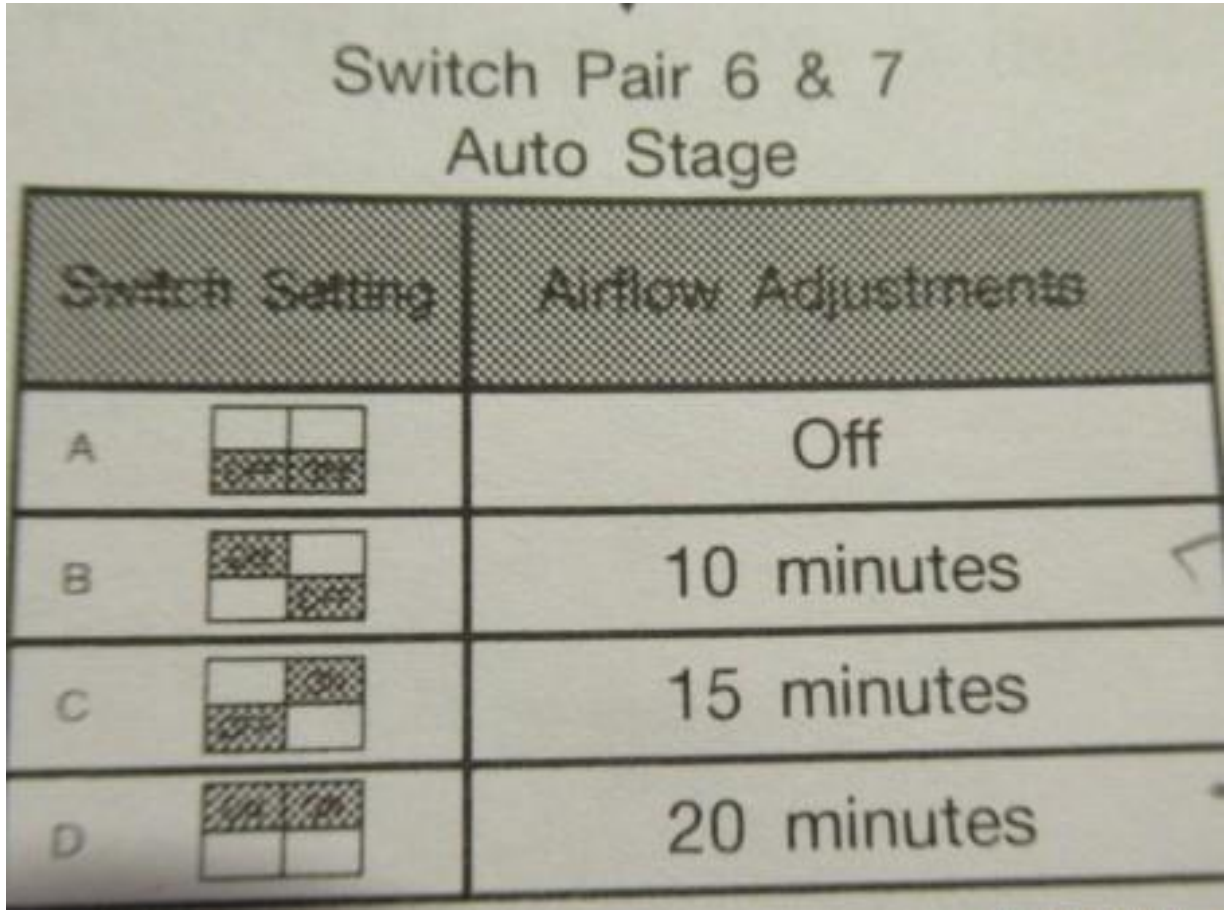
- Used by some manufacturers
- Dip Switch settings control various operations



System Design: Dip Switches

- Can change auto switch to 2nd stage
- (or not)

- Varies by manufacturer
- One has 60 minutes

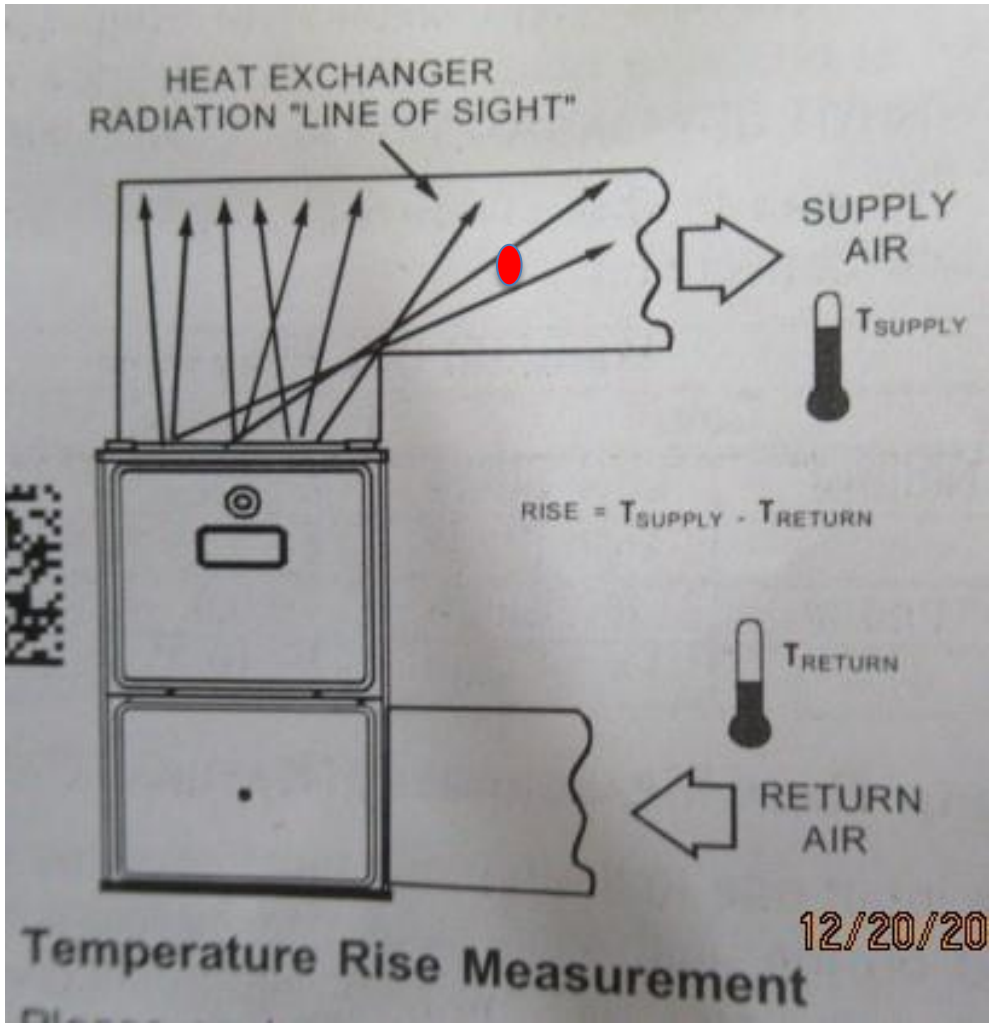


Switch Pair 6 & 7
Auto Stage

Switch Setting	Airflow Adjustments
A	Off
B	10 minutes
C	15 minutes
D	20 minutes

RECOMMENDED TESTS IN THE FIELD

- Temp Rise (in proper location!)



Temp Rise – Location Matters

- Varies greatly on location
- Is everyone in the same location?
- Easy to hit 30 degree range

RECOMMENDED TESTS IN THE FIELD

- Total External Static Pressure (TESP)

Total External Static Pressure - Nameplate

	IN. W.C.
MAX. EXTERNAL STATIC PRESS. PRESS. STATIQUE EXTÉRIEURE MAX.	0.5

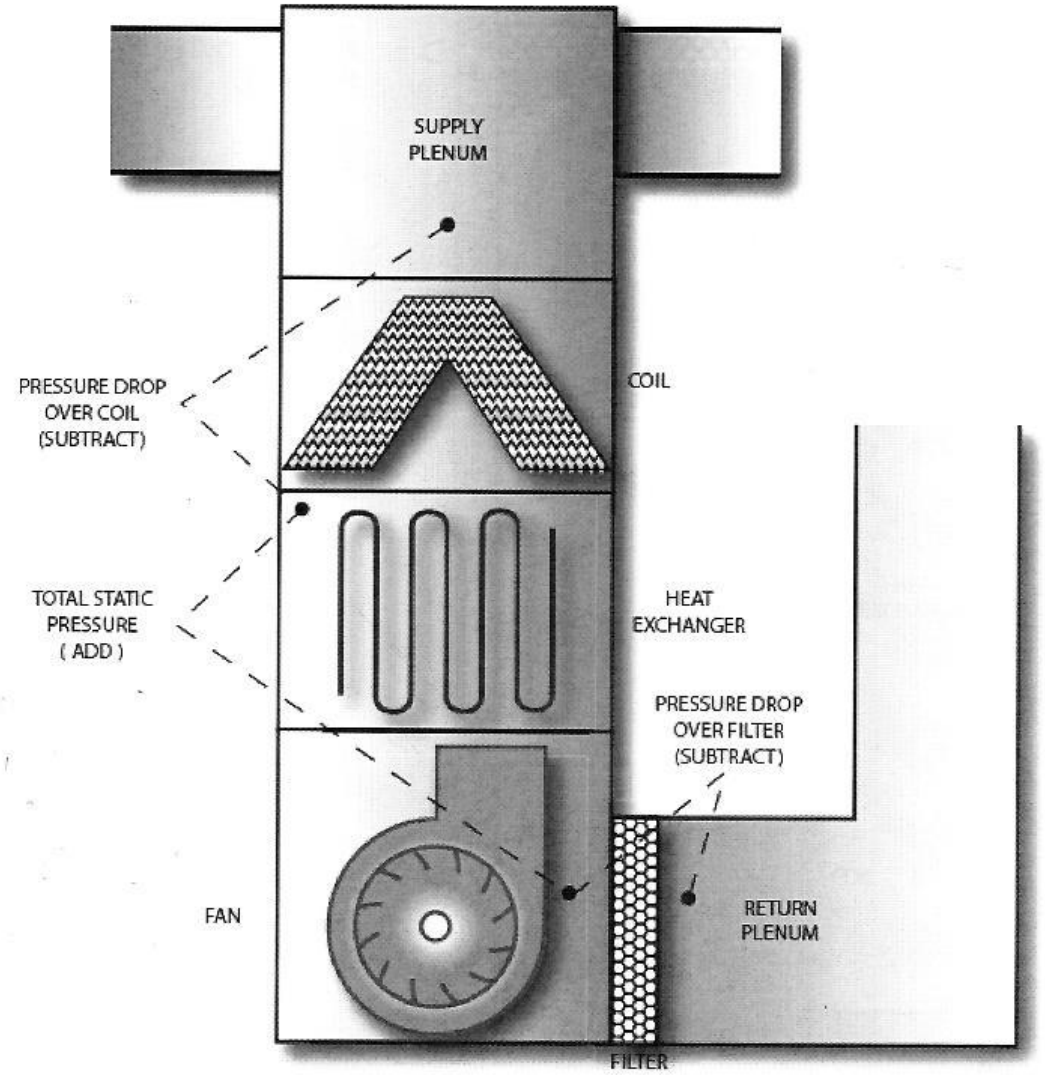
- Often 0.5” w.c
- Can be 0.8” wc
- For Mobile Homes 0.3” wc

Total External Static Pressure: Tools Needed to Measure

- Step drill bit
- Static Pressure Probe w/magnet
- Manometer
- Plugs or aluminum tape

Testing Total External Static Pressure: The Basics

- We drill *"TEST PORTS"*
  - We do not drill "*holes*"
- Use a step drill bit
  - Not a regular bit
- TESP readings help us:
  - ✓ Troubleshooting distribution issues
  - ✓ Measure air flow
  - ✓ Compare with manufacturer rated



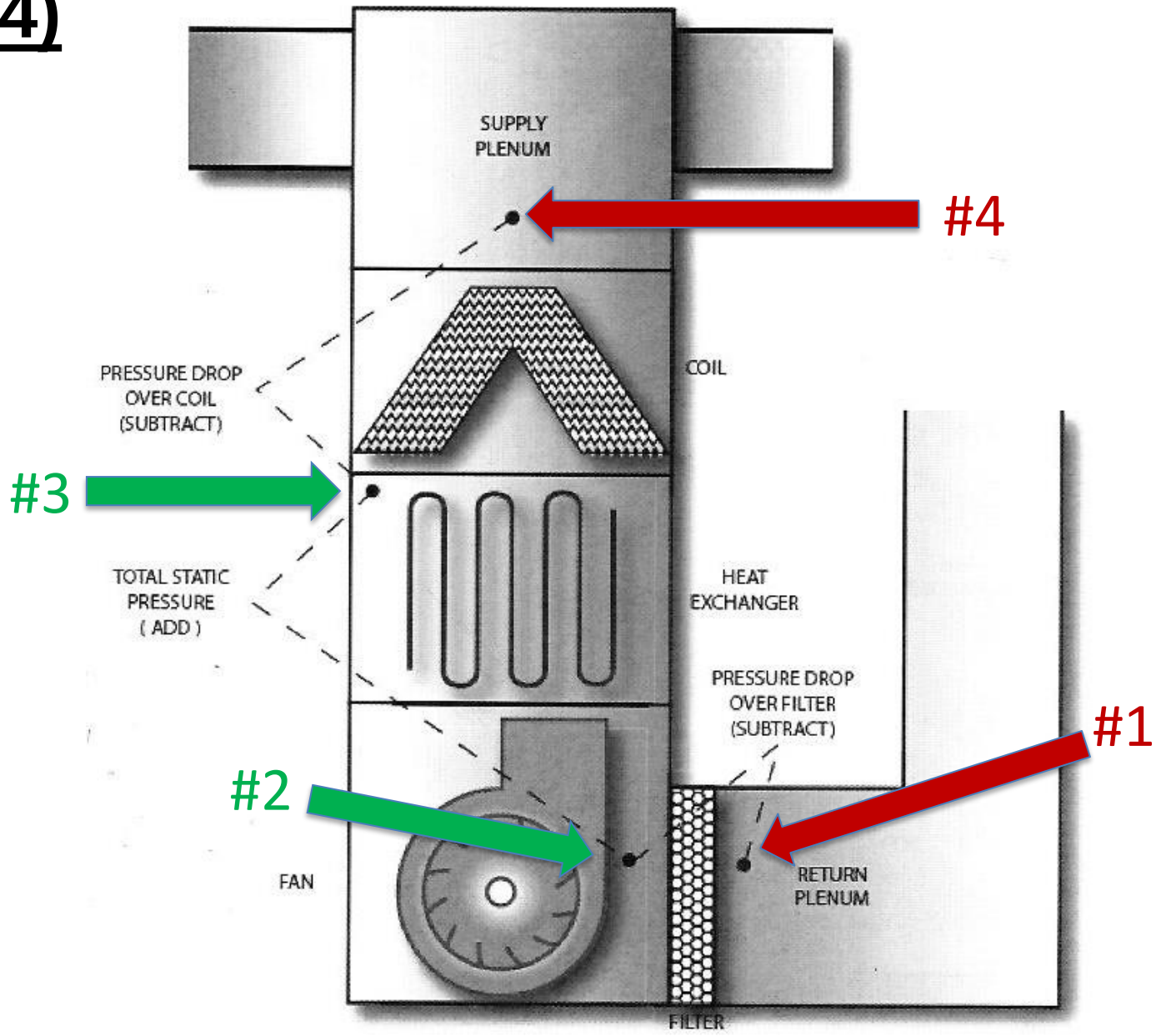
TESP Test Ports Location (4)

1. Before Filter

2. After Filter
   & before blower

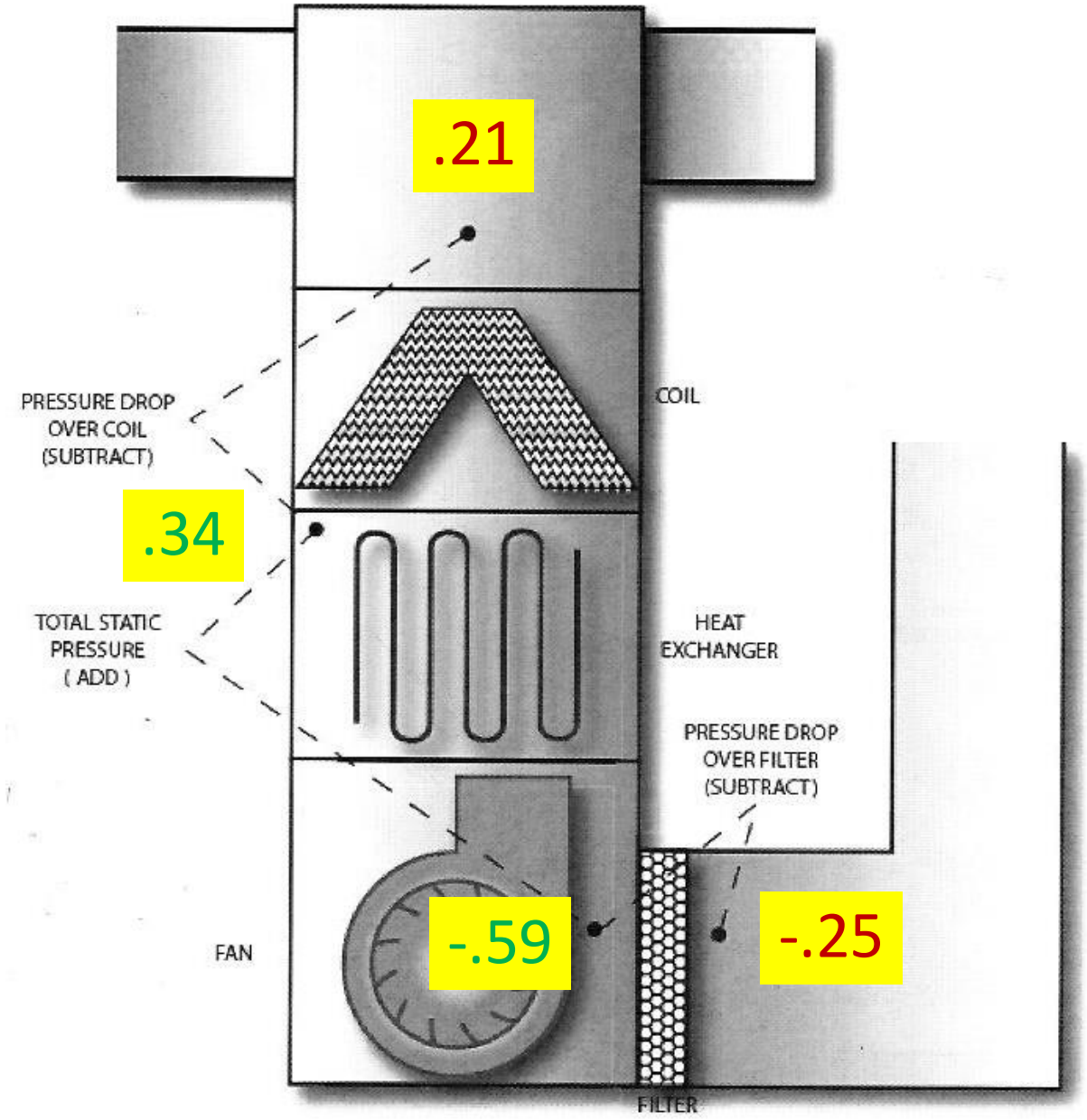
3. After heat exchanger
   & before the AC coil

4. After AC coil



Static Pressure Example #1

I. Pressure drop across filter
   I. -Red to Green = subtract
   II. 59-25=34
   III. “Budget” = 10
II. Pressure drop across ac coil
   I. -Red to Green = subtract
   II. 34-21=13
   III. “Budget” = 20
III. TESP
   I. Green to Green = add
   II. 59+34=93
   III. Manufacturer's Specs = 50



Static Pressure Example – Using Whole Numbers

TESP Rated = .50”	Before Filter	After Filter	Before AC	After AC
Static Pressure	.25” w.c.	.59” w.c.	.34” w.c.	.21” w.c.
Pressure Drop Filter & AC	59 – 25 = 34		34 – 21 = 13	
Pressure Drop recommended	20% of TESP = 10		40% of TESP = 20	
TESP Total		59 + 34 = 93		
Manufacturer TESP recommended		50		

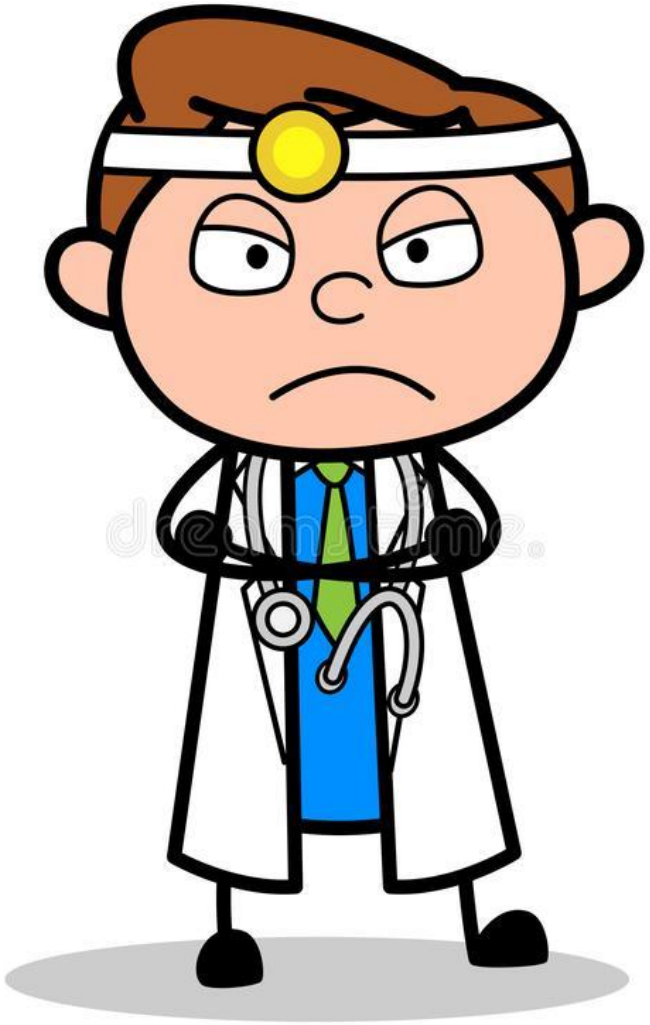
How does an Upgrade to High Efficiency impact Static Pressure and Desired Flow?

System Efficiency (Type)	Input BTUs	Output BTUs	Desired Flow CFM	Static Pressure Inches of water column
Existing natural draft	80,000	64,000	640	.60
Two Scenarios for New Installation				
High Efficiency Condensing 96%	60,000	56,000	840	.79
High Efficiency Condensing 96%	45,000	43,200	648	.61

Note: Typically rated at 0.50” wc

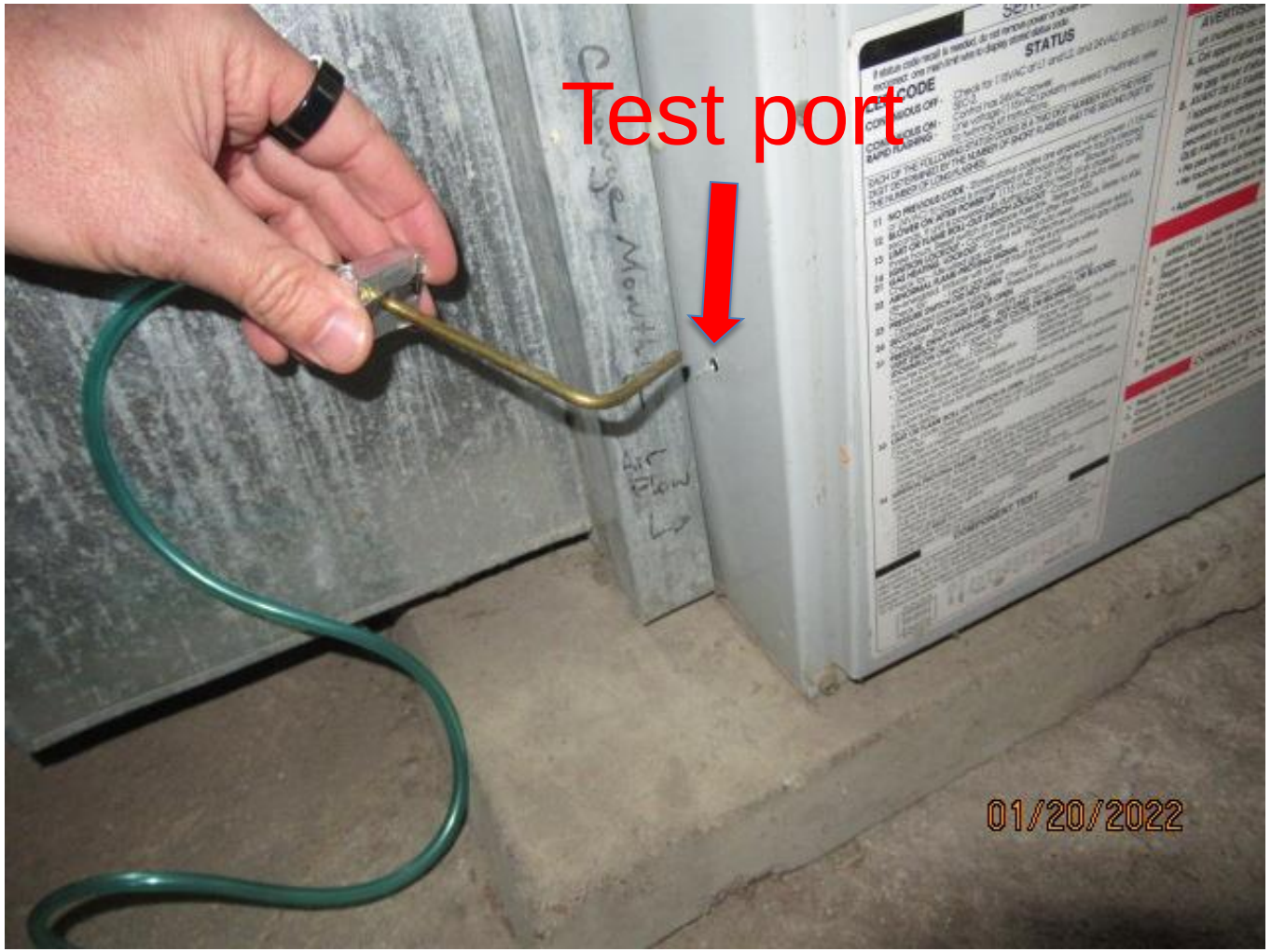
How Much Pressure is “too much”?

Who	Recommended or desired	Action needed
Manufacturer	*0.5” typically	Great, nothing needed
Contractors	0.5” to 0.75”	Not great but acceptable
Contractors/ Manufacturers	0.75” to 1.0”	Bad, consider tweaking if possible
Contractors/ Manufacturers	Over 1.0”	Very bad, need corrective action, educate contractor



What if Filter Rack is directly against Furnace Cabinet?

- Drill into side of the cabinet
- Static Pressure Probe towards ductwork

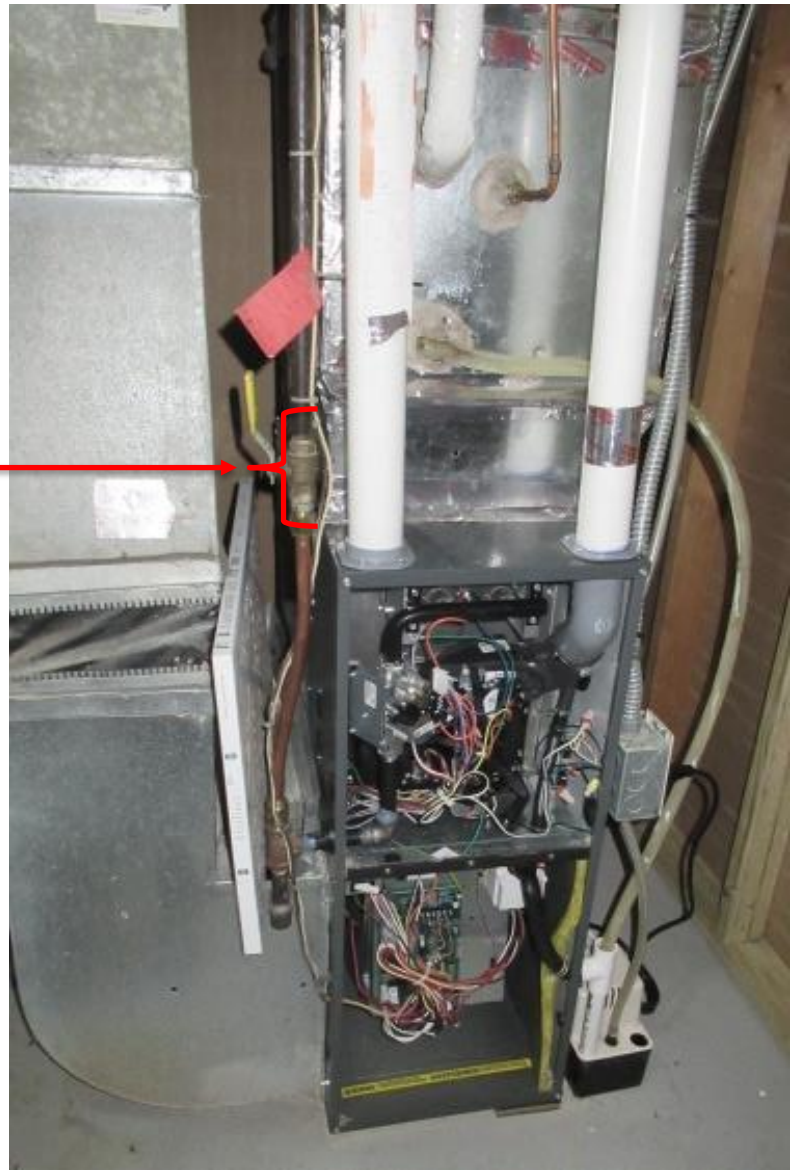


What if AC Coil is installed directly on top of Furnace Cabinet?

- Drill into cabinet
- About 1” below top for supply side reading
- Above is AC drain pan
- Static Pressure Probe points into air flow

New Installations provide free space

- New furnaces are often shorter which creates a “free space” for supply side reading



HINTS FOR STATIC PRESSURE CONVERSATIONS

- Use whole numbers, not “inches of water column”
- 0.50 inches of water column = 50
- Compare to blood pressure
- High numbers are bad, restrictive
- Drill test ports, not “holes”

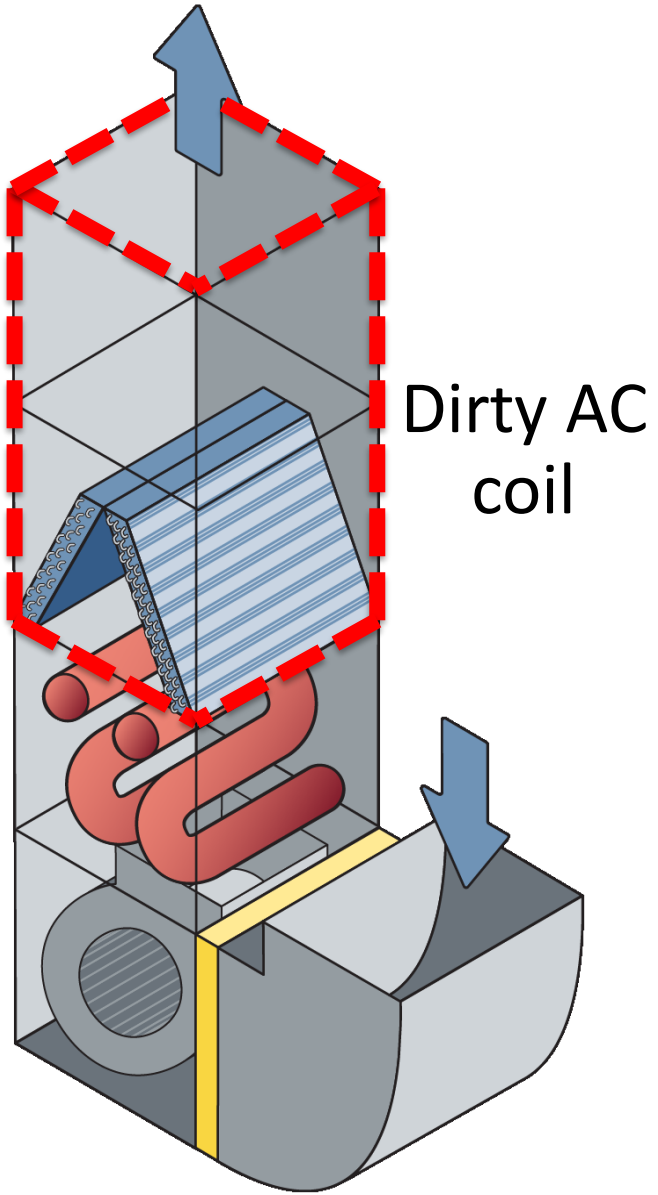
High Static Pressure = lower system air flow

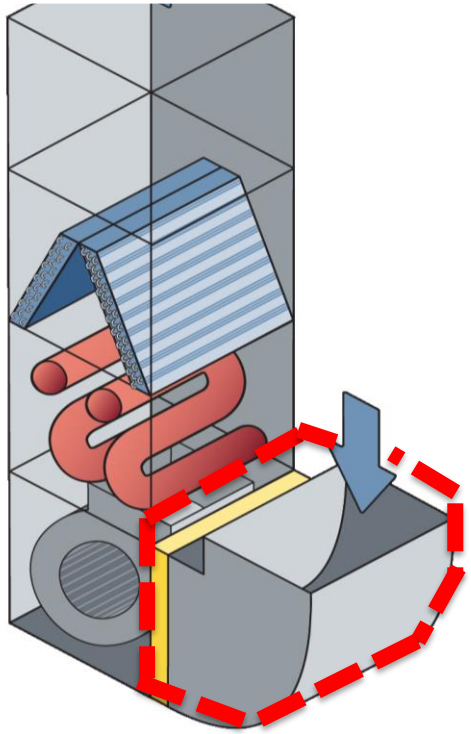
- Restrictions can negatively impact operation
- Filters, coils, elbows, etc. all add restriction

Common Causes of high pressure on SUPPLY side

- Restricted ductwork
- Plugged coils
- Transitions in ductwork
  - Changes in size
  - Round to rectangular

Common Causes of High Static on the *Supply* Side

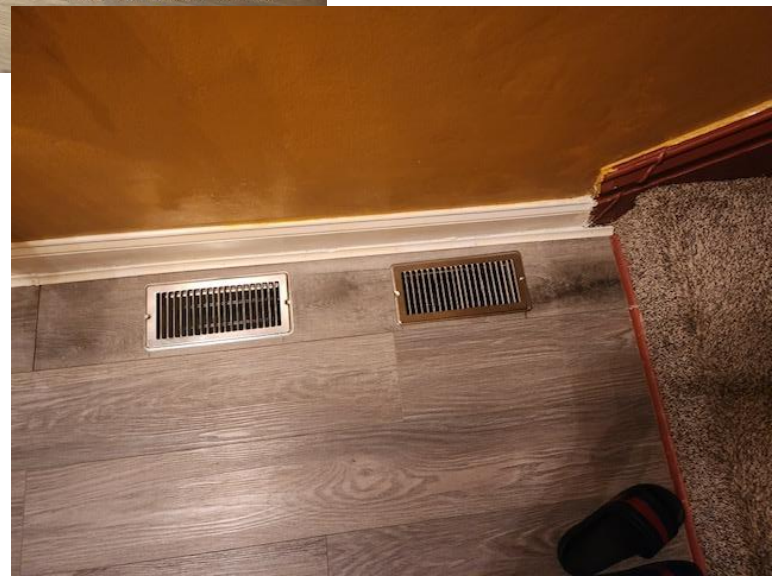




Common Causes of High Static on the Return Side

Short on RETURN – most common

- Owner added new floor
- Covered up return registers
- Testing showed a RETURN issue
- Return reading
  - With filter .86” wc
  - W/out filter .71” wc
- Supply reading
  - .21
  - New furnace installed



Which Filter is Right?

Varying units of filtration (and restriction)

RECOMMENDED TESTS IN THE FIELD

- Measuring Air Flow (CFM)
- Extremely valuable info
- ~~Never~~ Rarely done

- The Next Frontier

TESP and Fan Curve Chart

TESP	Rating	Comments
Overall Value	★★★☆☆	Cost-effective method, provides good measurement on new clean systems with proper OEM chart. Is not accurate if system is dirty.
ACCA 310	Yes	Recognized by ANSI/ACCA/RESNET
Residential Accuracy	★★☆☆☆	Good accuracy if using a Magnehelic on new systems with right OEM table. Per 310: Accuracy of ± 1% of the reading or ± 0.25 Pa (0.001 inH2O) required for manometer, whichever is greater.
Consistency	★★★☆☆	Inconsistent readings if condition of equipment is not clean (matching the OEM table).
Equip. Cost	$$	Cost-effective, can start very low (<$100, to about $600)
Time (Min)	5 to 10	Process is straightforward. NCI is a good resource for this method.

Meets Standard 310

Does not meet Standard 310

Correlation between Static and Fan Settings

G51MP-48C-090 PERFORMANCE (Less Filter)

External Static Pressure		Air Volume / Watts at Different Blower Speeds										
		High			Medium-High			Medium-Low			Low	
in. w.g.	Pa	cfm	L/s	Watts	cfm	L/s	Watts	cfm	L/s	Watts	cfm	L/s
0.00	0	2180	1030	930	1835	865	790	1520	715	630	1280	605
0.10	25	2135	1005	885	1825	860	750	1510	710	610	1275	600
0.20	50	2085	985	840	1810	855	720	1505	710	580	1270	600
0.30	75	2030	955	800	1775	835	685	1500	705	565	1265	595
0.40	100	1940	915	760	1735	820	650	1480	700	535	1250	590
0.50	125	1855	880	725	1660	785	600	1430	675	505	1215	575
0.60	150	1740	820	670	1590	750	575	1380	650	475	1175	555
0.70	175	1645	775	640	1475	695	520	1290	610	450	1105	520
0.80	200	1540	725	600	1340	630	465	1175	555	405	1020	480
0.90	225	1335	630	540	1170	555	440	1070	505	375	950	450

NOTES - All air data is measured external to unit without filter (not furnished - field provided).
Air volume based on bottom air return air. Actual air volume may vary on side return air applications.

Example from Manufacturer

To determine total external duct static pressure, proceed as follows:

1. With clean filters in the furnace, use a manometer to measure the static pressure of the return duct at the inlet of the furnace. (Negative Pressure)
2. Measure the static pressure of the supply duct. (Positive Pressure)
3. The difference between the two numbers is .4" w.c.

   Example:

   static reading from return duct = -.1" w.c.

   static reading from supply duct = .3" w.c.

   total external static pressure on this system = .4" w.c.

TESP and Manufacturer Fan Curve Chart

- Advantages:
  - Low cost
  - Only need pressure gauge and fan curve chart
  - Quick and easy (if table available)
  - Can be good for troubleshooting

- Disadvantages:
  - Accuracy can be dramatically impacted by conditions (dirty blowers, coils, filters, etc.)
  - Not reliable for existing equipment
  - Can’t always find curve table

Hot Wire Anenometer

- Advantages
  - Easy to use
  - Does the math for you

- Disadvantages
  - Needs long straight ductwork to stabilize air
  - Cost of equipment

Digital True Flow Tool

- Advantages
  - Uses four static pressure data points
  - Digital with Bluetooth connection
  - Accurate measurement
  - WX agencies already have digital gauge
- Disadvantage
  - Cost
  - Must buy equipment

Digital True Flow tool 1 minute, 33 seconds

- TEC Digital TrueFlow Solution Overview - YouTube

CASE STUDIES – Real World Testing

- What is the best way to VERIFY the calculated Manual J estimates?

Condensing 90%+ to Condensing 96%

- 1300 sq.ft. (w/bsmt) Built in 1917
- Attic, walls, bsmt and crawl insulated
- Kitchen remodeled
- Furnace 15 years old, red tagged

	Existing	Installed	Manual J calc
Input	80K	42K / 60K	54,473 BTUs
Output	74K	38K / 58K	
TESP 1st		.77”	
TESP 2nd		1.5”	Set to 1st stage only
Rated		0.5”	Survived -15 F

Second stage not needed or used

New 2-stage Condensing 90%

- 700~ sq.ft. 2 story Built in 2000~
- Habitat for Humanity home, 2” x 6” walls (not 2x4)
- Twin Home, no heat loss on one full side

	Existing	Installed	Manual J calc
Input		39K / 56K	41K BTUs/hr
Output		38K / 54K	Contractor went with next largest size
TESP 1st		.94”	Loud, set at 1st stage only
TESP 2nd		1.15”	Survived -15 F
Rated		0.5”	Still high static

MH 80% to 2-stage Condensing 90%

- 870~ sq.ft. Built in 1978, original furnace, design temp -24 F

Not helping

	Existing	Installed	Manual J calc
Input	80K	47K / 72K	“not needed”
Output	64K	45K / 69K	**35K CoolCalc
TESP 1st	.41”	.84” 3X	Loud!!
TESP 2nd		 1.39” 4.6X!	Recommend 1st stage only
Rated	0.3”	0.3”	Plus reduce blower speed

**CoolCalc not designed for Mobile Home Manual J

Mobile Home 2-stage Condensing 90%

- 914~ sq.ft. Built in 1984, design temp -28 F

Not helpling

	Existing	Installed	Manual J calc
Input	70K	39K / 60K	“not needed”
Output	56K	37K / 58K	52,590 BTUs Coolcalc
TESP 1st		.49”	Loud!!
TESP 2nd		.87”	Recommend 1st stage only
Rated	0.3”	0.3”	Plus Clean and Tune

Draft-assisted 80% to 2-stage Condensing 90%

- 700~ sq.ft. Built in 1920~
- Furnace 21 years old
- Crazy loud on 2nd stage

	Existing	Installed	Manual J calc
Input	80K	42K / 60K	45K BTUs Contractor estimate
Output	64K	40K / 58K	5K BTUs Difference
TESP 1st	.78”	.77”	Contractor went to next larger size to cover
TESP 2nd	n/a	1.5” 3X over!	Set on 1st stage for 60 min
Rated	0.5”	0.5”	Tested at -15 degree F

Draft-assisted 80% to 2-stage Condensing 90%

- 1,500~ sq.ft. 1992 built 2” x 6” walls, tight, 5-level home

	1st install	2nd install	Manual J calc
Input	100K	29K / 42K	67K BTUs Contractor estimate
Output	80K	28K / 40K	No 2nd stage fired
TESP 1st	n/a	.53”	No 2nd stage needed
TESP 2nd	.99	no 2nd Stage	Tested at -15 degree F
Rated	0.5”	0.1” / 0.9”	*Contractor had to install two furnaces*

CONCLUSIONS

Now what?

Start installing more Appropriately sized Furnaces

CONCLUSIONS

Did you hear that?

Stop installing oversized Furnaces!

Recommended Testing - in the field

- Verify ductwork size and condition (look at it)
- Listen to it (under returned can be heard)
- Especially return, commonly under sized
- Make sure dampers are open
- Add *static pressure testing* to standardized tests
- Add *air flow testing* to your in-field testing

Recommended Additions for Inspections

- Add *static pressure testing* to standardized tests
- Add *air flow testing* to your in-field testing
- Learn about furnace control boards
- Learn how to tweak the installation (if needed)
- Can be done for both existing and new installs

- Get training – manufacturer or HVAC testing

Recommended changes in the office

- If a weatherization program, **provide** the size to the contractor
- **When replacing, require the contractor supply you with:
  - Age, Input/output, Efficiency of existing
  - With condensing, NEVER install same size
- Compare that with what is being proposed
- *Scrutinize* the Manual J for accuracy
- Perform a Manual J on CoolCalc for comparison only
- When close, error on the smaller size (don't be afraid)

Common Manual J errors to check

- 2” x 6” wall construction, contractor uses 2” x 4”
- Square footage (verify by auditor, Google Maps, CoolCalc)
- Furnace proposed is higher efficiency but same size as old one
- Basement given same weight as above grade
- Bigger is ***not*** better
- Smaller size will ~~likely~~ heat home with less problems

Questions?