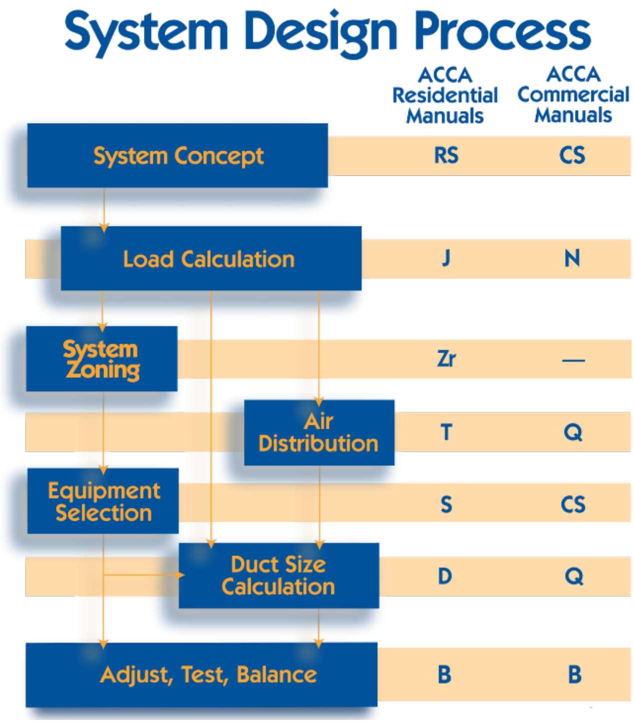
HVAC System Design

Air Conditioning Contractors of America (ACCA)

HVAC Design Protocols



HVAC design is more than ACCA Manual J. Most HVAC contractors, home energy raters, contractors and others in the residential construction field know about Manual J. Many non-builders even know about Manual D, which describes how to design the duct system. Not as many, however, know about the missing links - Manual S and Manual T. For a properly designed heating & cooling system, the designer must go through the whole process contained in all four protocols: J, S, T, and D.

Manual J

This manual is for determining how much heat the house loses in winter and gains in summer. Manual J is both a whole house and a room-by-room calculation, which allows you to determine how much conditioned air each room needs for both heating and cooling.

It factors in all the surfaces of the building envelope, with separate areas and insulation levels for each type of assembly. Each wall is given its proper orientation, because windows and doors are attached to them. Other important data include the location and tightness of the duct system, the infiltration rate of the house, the internal loads (appliances and people), and where the house is located.

The results specify the BTUs of heat lost by each room in the winter and gained in the summer. The heat gain is split into two parts: sensible (related to temperature) and latent (related to humidity). The heat gained or lost in a room then determines how much conditioned air that room needs in cubic feet per minute (cfm).

Manual S
Once the amount of conditioned air (cfm) necessary for each room is known, the designer reviews and selects a right-sized piece of equipment. Which air conditioner, heat pump, furnace, or boiler is a good fit for the calculated loads? With forced-air cooling systems, this selection is critical because every piece of equipment has different characteristics - sensible and latent capacities, the amount of air moved (cfm), and the static pressure delivered are the key attributes applied to the design in the next stages.

Manual T
With the room-by-room cfm requirements, the designer will determine how to distribute the air in the room to deliver enough to meet the needs (the higher of the heating and cooling cfm requirements from Manual J).

The questions answered here are: Where will the supply registers, diffusers, or grilles be located? Where will the return grilles be located? What type of register, diffuser, or grille will be used? How big does it need to be?

Good choices at this step eliminate drafts or inadequate mixing. It's possible to provide enough conditioned air to a room but still have comfort issues because of poor velocity at the register, which results in poor mixing or drafts from poor register placement.

Manual D
Finally, with all the data, the cfm needed for each room, the selected equipment, and how the air is distributed in the room, you can design the duct system.
At this stage the designer evaluates the path with the greatest friction, which may not be the longest path, by evaluating the ducts lengths, how many fittings and turns in the route, and how much air needs to be delivered.

The type of duct has a big impact on the results, as sheet metal ducts have a lower friction rate than flex duct or rigid fiberglass duct board.

The underlying principle of Manual D is to design a duct system which delivers the correct cfm to each room against the friction created by the ducts and fittings with the static pressure available from the blower.

Pulling It All Together
Utilizing the processes from all four ACCA manuals will result in a well-designed HVAC system. The result is a high-performance system that's more efficient and comfortable than typical installations.

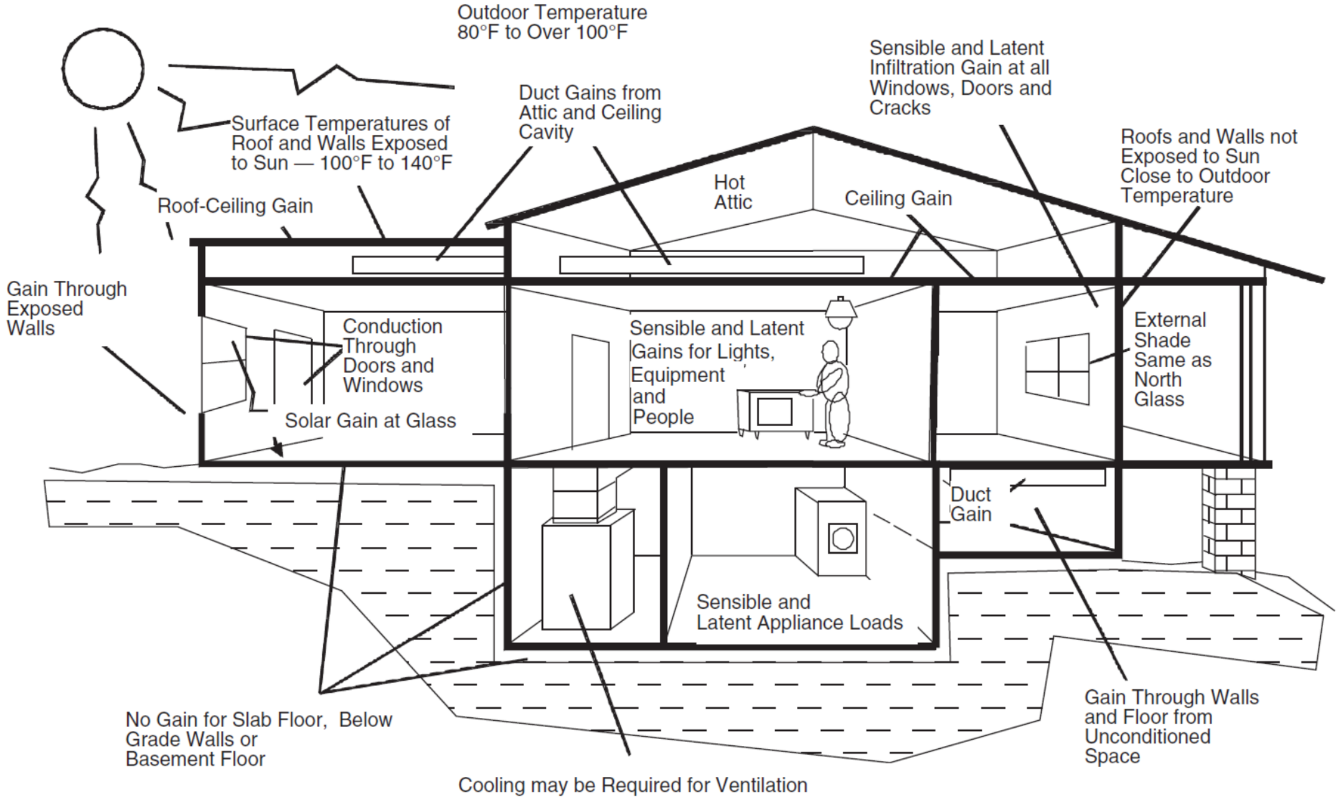
Even the best HVAC design in the world, if it's not installed as designed, will perform poorly. It's a good idea to have every new system tested and commissioned.

Heat Loss in Buildings - Building Heating Load

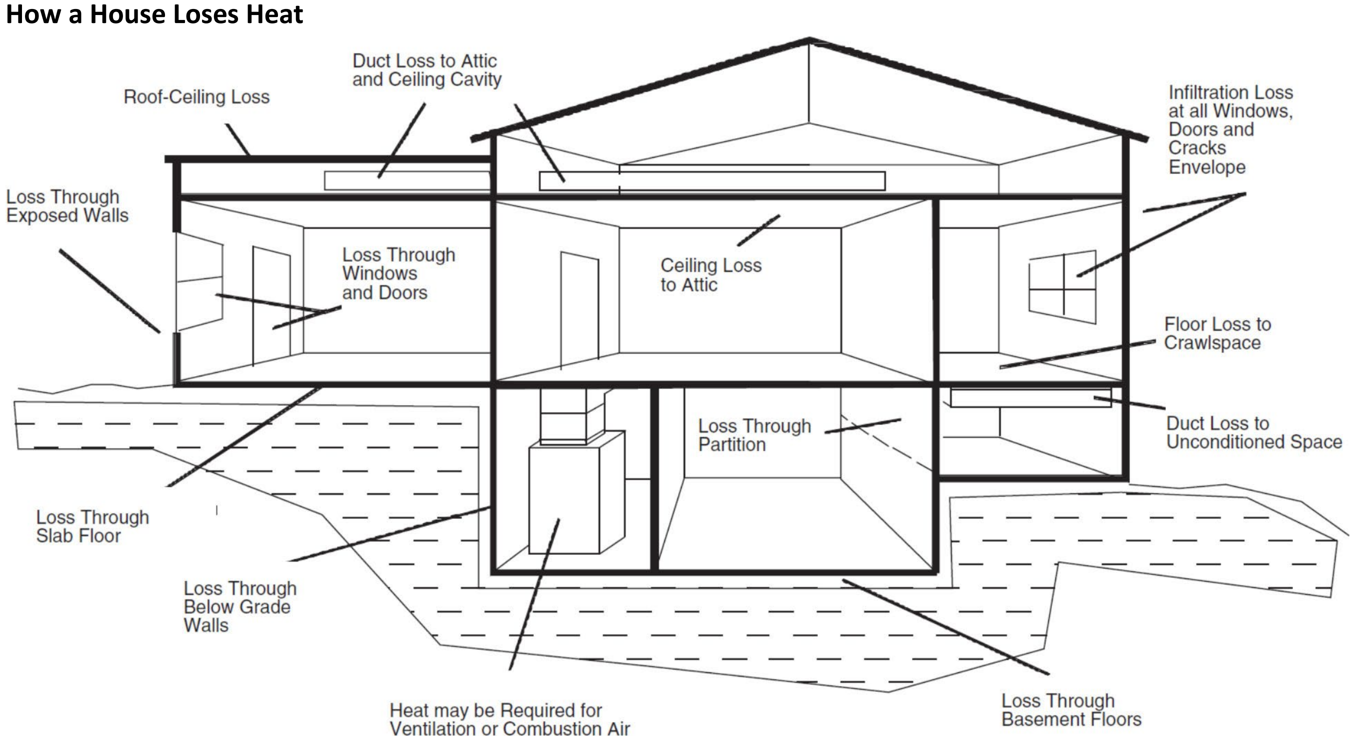
Heat Gain in Buildings - Building Cooling Load

Root Cause → Heat Transfer – flow of heat

How a House Gains Heat



How a House Loses Heat



Applied Heat Transfer

Summer

- Heat flows INTO the home
- Sensible heat – dry heat (dry bulb; thermometer)
- Latent heat – wet heat (wet bulb; humidity)

Heat Gain so we need cooling

Winter

- Heat flows OUT OF the home
- Sensible heat only

Heat Loss so we need heating

2nd Law of Thermodynamics:

- ❑ Over time, differences in temperature and pressure will decrease, leading to thermodynamic equilibrium
- ❑ Nature doesn't like temperature differences, so heat flows from a region of high temperature to a region of lower temperature until both are equal
- ❑ But we humans do like temperature differences, so we've designed objects and processes to slow this physical phenomenon down or combat it outright.

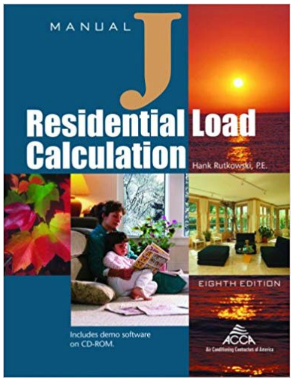
Purpose of a Load Calculation

- ❑ First step in designing a mechanical system that can add or remove heat energy at a rate that will provide the acceptable level of comfort for the occupants.
- ❑ An account of the total heat flow into and out of a home, depending on the time of year.
- ❑ Using the load calculation, the designer will be able to choose equipment that has acceptable capacity.

Manual J Load Calculation Method

Two sets of design conditions.

The peak loads.



Heat loss (winter)

- ❑ Outdoor design temperature – heating 99% dry bulb (db)
- ❑ Indoor design temperature – 70°F db

Heat gain (summer)

- ❑ Outdoor design temperature – cooling 1% db
- ❑ Indoor design temperature – 75°F db

Design Temperatures

Outdoor Design Temperature

- ❑ Must be for the home's specific location
- ❑ 30-year average compiled by ASHRAE
- ❑ Manual J – Tables 1A and 1B (free download)
- ❑ Updated in 2014

Indoor Design Temperature

- ❑ Within the ASHRAE comfort zone charts (per ANSI/ASHRAE 55 Thermal Environmental Conditions for Human Occupancy Standard)

Manual J Outdoor Design Temperatures

Table 1A
Outdoor Design Conditions for the United States

Location	Elevation	Latitude	Winter	Summer					
	Feet	Degrees North	Heating 99% Dry Bulb	Cooling 1% Dry Bulb	Coincident Wet Bulb	Design Grains 55% RH	Design Grains 50% RH	Design Grains 45% RH	Daily Range (DR)
Alabama									
Alexander City	686	33	22	93	76	39	46	52	M
Anniston AP	612	33	24	93	76	39	46	52	M
Auburn	776	32	22	93	76	39	46	52	M
Birmingham AP	644	33	23	92	75	34	41	47	M
Decatur	592	34	16	93	74	27	34	40	M
Dothan AP	401	31	32	93	76	39	46	52	M
Florence AP	581	34	21	94	75	31	38	44	M
Gadsden	569	34	20	94	75	31	38	44	M
Huntsville AP	629	34	20	92	74	28	35	41	M
Mobile AP	218	30	30	92	76	41	48	54	M
Mobile CO	26	30	29	93	77	46	53	59	M
Montgomery AP	221	32	27	93	76	39	46	52	M
Ozark, Fort Rucker	356	31	31	94	77	44	51	57	M

In a load calculation, the designer is going to account for every source of heat gain or heat loss. These sources are what we call loads.

Loads That Must Be Accounted For

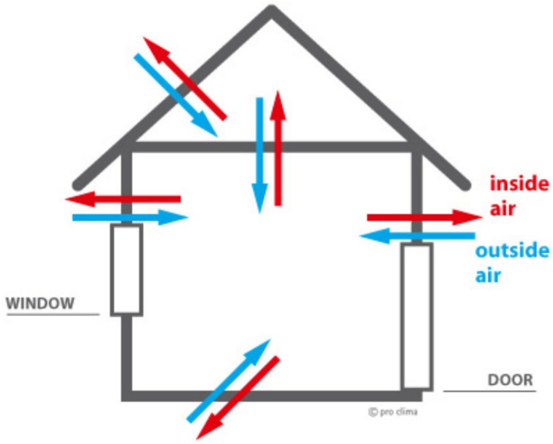
As applicable for the specific home:

- Fenestration (windows, glass doors, skylights)

Orientation – Important for Fenestration

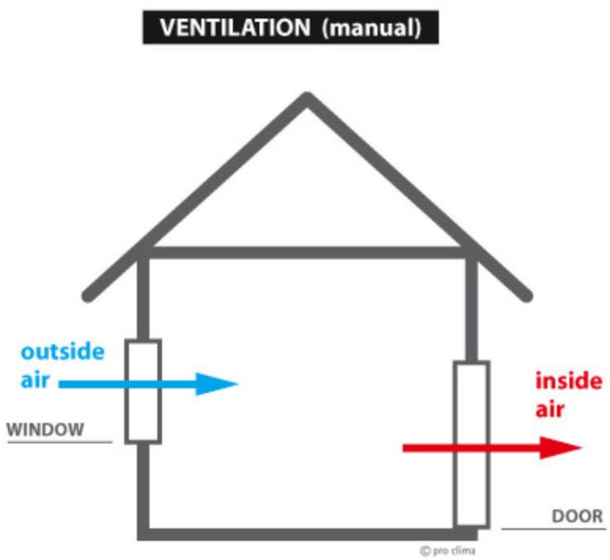
- ❑ What direction does the front door face? (Orientation)
- ❑ This is important because of the movement of the sun throughout the day, and it will have a huge effect on loads from windows, glass doors, and skylights.

- Opaque panels (wood/metal doors, above & below grade walls, partition walls, ceilings, floors)
- Infiltration

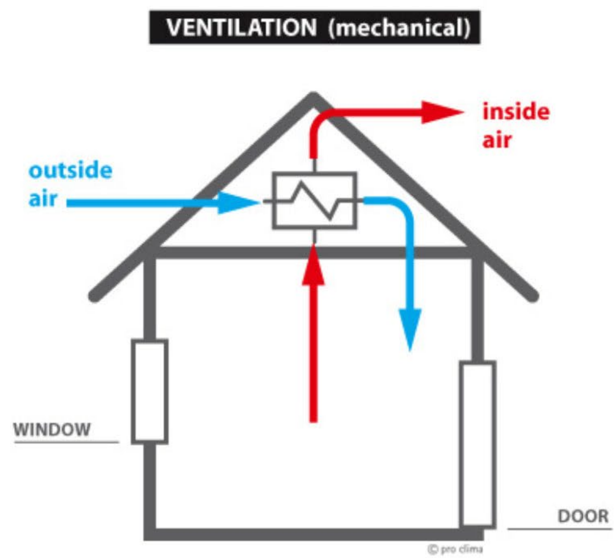


Uncontrolled air movement through the building envelope.

- Ventilation



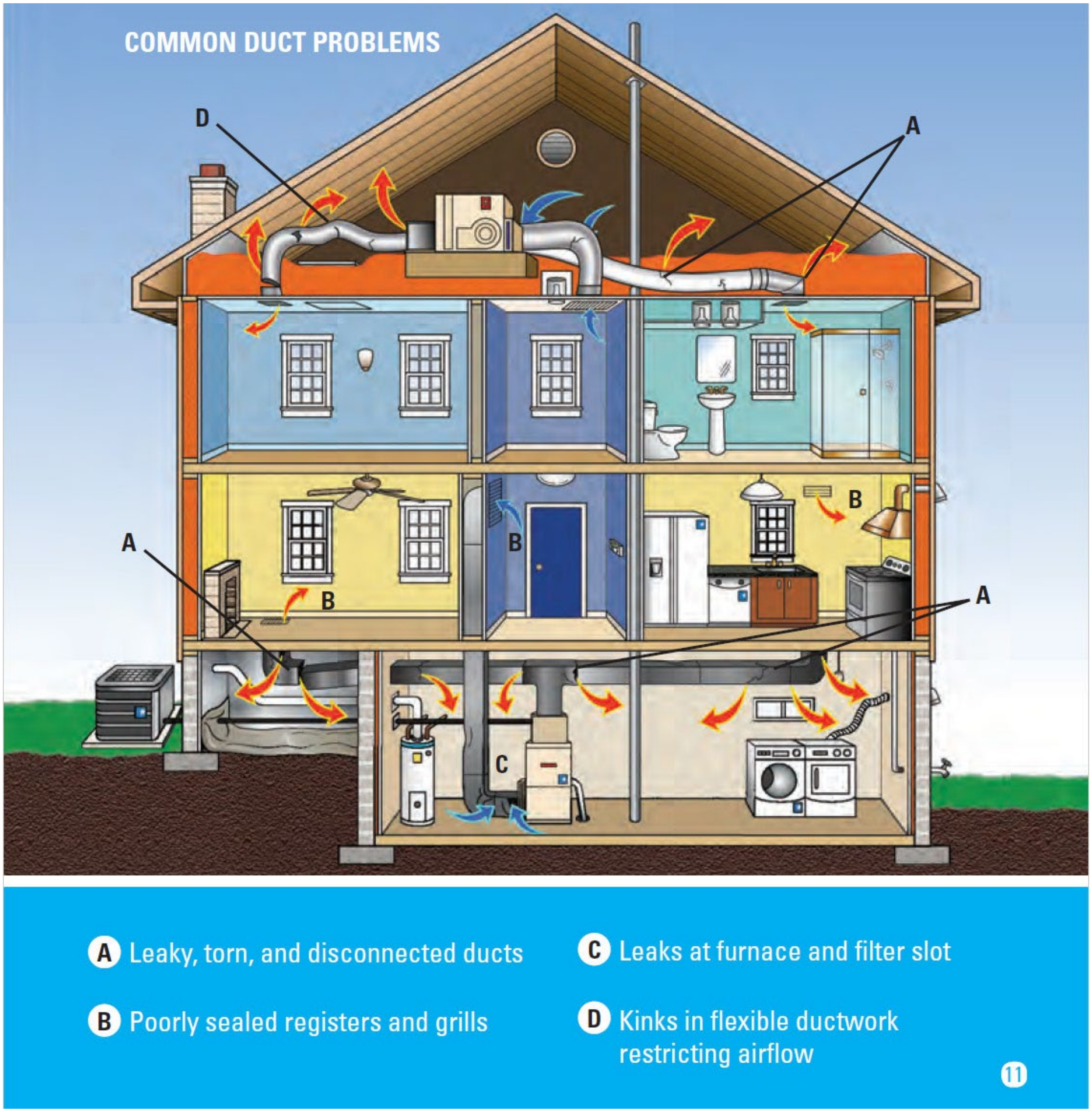
Replacing stale air on the inside with outside air through windows and doors.



Replacing stale air on the inside with outside air through a balanced mechanical ventilation system with heat recovery to retain the energy on the inside of the building.

- Internal (number of people and appliances)

- System (ducts and blower)



Basic Load Equation

Load = U x A x ΔT

U is the heat transfer performance index (how well, a material transfers heat; it's the reciprocal of R- value)

- A is the Area
- ΔT is the Temperature Difference (TD)
- Load units are Btu/h

Can be simplified as Load = HTM x A

- HTM is the heat transfer multiplier
- HTM = U x ΔT

Table Values
Manual J 8th Edition (MJ8) has tables that contain specific values used in calculating individual loads.

Example: Table 4A (Heating and Cooling Performance for Opaque Panels) contains:

- Construction numbers,
- U values, or
- CLTD (cooling load temperature difference)

Heating and Cooling Performance for Opaque Panels

Construction Number 16A through 16F
Insulated Ceiling Under Attic or Attic Knee Wall (see Table 4E for encapsulated attic)

Ventilation options: Unvented or vented to FHA specifications, or attic fan, or extra attic vent area.
Roofing material options: Asphalt shingles, wood shakes, tile, slate, metal, concrete, tar and gravel or membrane.
Roof color options: Dark, red or solid bold color; light color, light gray, silver or unpainted metal and white (see absorptivity notes).
Reference Area = Gross Area - Skylight Area (SqFt)

Number	Construction Notes	Insulation R-Value	U-Value	CLTD Values Ceilings Under an Attic or Attic Knee Wall											
16A	Attic temperature = 150°F when outdoor temperature = 95°F Unvented Attic, No Radiant Barrier, Any Roofing Material, Any Roof Color														
16A-0	**16A** Unvented attic over ceiling or same type of air space behind an attic knee wall.	None	0.408	**Design Temperature Difference and Daily Range**											
16A-7		R-7	0.112	**10**		**15**			**20**			**25**		**30**	**35**
16A-11		R-11	0.081	**L**	**M**	**L**	**M**	**H**	**L**	**M**	**H**	**M**	**H**	**H**	**H**
16A-13		R-13	0.070	69	65	74	70	65	79	75	70	80	75	80	85
16A-15		R-15	0.061	Roofs and ceilings do not have a group number.											
16A-19		R-19	0.049	**16A** Roofing material code: None required											
16A-21		R-21	0.044	Roof color code: None required											

Generic Fenestration

Default U-value and SHGC **Generic Windows and Glass Doors — Continued** Low-e Glass, Jalousie, Projected and Glass Block Load Area = Area of Rough Opening (SqFt)	**Metal No Break**		**Metal with Break**		**Wood, Wood with Metal Clad or Vinyl**		**Insulated Fiberglass**	
	U	**SHGC**	**U**	**SHGC**	**U**	**SHGC**	**U**	**SHGC**
Number 2 — Double Pane Low-e Glass Designed for Cold Climate (Emissivity of Low-e coating = 0.60)								
2A Operable window or sliding glass door	0.84	0.61	0.63	0.61	0.55	0.56	0.47	0.56
2B Window with fixed sash	0.67	0.61	0.60	0.61	0.54	0.66	0.51	0.66
2C Products rated and labeled by the NFRC (see Table 2B-1)	See label, NFRC Directory or manufacturer's engineering data.							
Number 3 — Double Pane Low-e Glass Designed for Cold Climate (Emissivity of Low-e coating = 0.40)								
3A Operable window or sliding glass door	0.82	0.61	0.61	0.61	0.53	0.56	0.45	0.56
3B Window with fixed sash	0.64	0.61	0.58	0.61	0.51	0.66	0.49	0.66
3C Products rated and labeled by the NFRC (see Table 2B-1)	See label, NFRC Directory or manufacturer's engineering data.							

HTM for Generic Window and Glass Door

Table 3A-3 — Reflective Glass

No Internal Shade

Default Assembly Performance	Single Pane						Double Pane						Triple Pane					
	U-Value		SC		SHGC		U-Value		SC		SHGC		U-Value		SC		SHGC	
	0.98		0.40		0.35		0.56		0.34		0.30		0.42		0.29		0.25	
Design CTD	10	15	20	25	30	35	10	15	20	25	30	35	10	15	20	25	30	35
Exposure	HTM for Rough Opening						HTM for Rough Opening						HTM for Rough Opening					
North	17	21	26	31	36	41	11	14	17	20	23	25	9	11	13	15	17	20
NE or NW	32	36	41	46	51	56	24	27	30	33	35	38	20	22	24	26	28	30
East or West	43	48	53	57	62	67	34	37	40	42	45	48	28	30	32	34	36	38
SE or SW	37	42	47	52	57	62	29	32	35	38	40	43	24	26	28	30	32	34
South	24	29	34	39	44	49	18	21	24	26	29	32	18	17	19	21	23	25

Vertical or Horizontal Blinds with Slats At 45 Degrees

Default Assembly Performance	Single Pane						Double Pane						Triple Pane					
	U-Value		SC		SHGC		U-Value		SC		SHGC		U-Value		SC		SHGC	
	0.98		0.33		0.29		0.56		0.30		0.26		0.42		0.25		0.22	
Design CTD	10	15	20	25	30	35	10	15	20	25	30	35	10	15	20	25	30	55
Exposure	HTM for Rough Opening						HTM for Rough Opening						HTM for Rough Opening					
North	13	18	23	28	33	38	9	11	14	17	20	23	7	9	11	13	15	17
NE or NW	24	29	34	39	44	49	19	21	24	27	30	33	15	17	19	21	23	26
East or West	33	38	43	47	52	57	27	29	32	35	38	41	22	24	26	28	30	32
SE or SW	29	34	38	43	48	53	23	26	28	31	34	37	19	21	23	25	27	29
South	18	23	28	33	38	43	13	16	19	22	24	27	11	13	15	17	19	21

Infiltration Defaults

When measuring is not possible.

Default Air Change Values for Single Story Construction

Construction	Air Changes per Hour — Heating Floor Area of Heated Space (SqFt)					Infiltration [1] Cfm for One Fireplace
	900 Or Less	901 to 1500	1501 to 2000	2001 to 3000	3001 or More	
Tight	0.21	0.16	0.14	0.11	0.10	0
Semi-Tight	0.41	0.31	0.26	0.22	0.19	13
Average	0.61	0.45	0.38	0.32	0.28	20
Semi-Loose	0.95	0.70	0.59	0.49	0.43	27
Loose	1.29	0.94	0.80	0.66	0.58	33

1) For one additional fireplace, add 7 CFM to the above fireplace values. For two or more additional fireplaces, add 10 CFM (total) to the above.

Internal Load Defaults

Appliance, Equipment and Lighting Loads

Default Appliance Load	Sensible Btuh	Latent Btuh	Notes
Refrigerator and range with vented hood.	1,200	~	1,200 Btuh applied to the kitchen.
Scenario Options			
1) Refrigerator, range with vented hood, dish washer, clothes washer and vented clothes dryer, electronic equipment and lighting allowance.	2,400	~	1,000 Btuh for the kitchen, 500 Btuh for the utility room, 900 Btuh allowance for a TV or computer and a few lighting fixtures.
2) Two refrigerators or one refrigerator and one freezer, dish washer, range with vented hood, clothes washer and vented clothes dryer, electronic equipment and lighting allowance.	3,400	~	2,000 Btuh for the room or rooms equipped with a refrigerator, 500 Btuh for the utility room, 900 Btuh allowance for a TV or computer and a few lighting fixtures.
Adjustment Options			
A) Cooking range not equipped with a hood that is vented to outdoors, or an unvented dishwasher operating during the late afternoon in mid summer, or simultaneous use of unvented range and dishwasher.	+ 850	+ 600	Light duty cooking, 25 percent of the available range capacity used for 15 to 20 minutes. One dishwasher-cycle load spread over a two hour recovery period.

Duct Load Scenarios

Duct Load Tables

Location	Supply System Geometry [1]	Return System Geometry [1]	Table Number
Unvented attic or attic knee wall space above 16A ceiling (150° attic when OAT = 95°F).	Radial with outlets in center of rooms.	Radial, 400 CFM per return, returns close to air handler.	7A-R
	Trunk and branch with outlets in center of rooms.	Trunk and branch, 400 CFM per return, returns close to air handler.	7A-T
Vented attic or attic knee wall space above 16B ceiling (130°F attic when OAT = 95°F).	Radial with outlets in center of rooms.	Radial, 400 CFM per return, returns close to air handler.	7B-R
	Trunk and branch with outlets in center of rooms.	Trunk and branch, 400 CFM per return, returns close to air handler.	7B-T
	Radial with outlets in center of rooms.	Single ceiling return close to air handler.	7A-AE
	Radial with outlets in center of rooms.	Closet air handler, return in closet door.	7B-AE
	Trunk and branch with outlets in center of rooms.	Grille at floor of conditioned space, return riser to attic air handler.	7C-AE
Vented attic or attic knee wall space above 16C ceiling (120°F attic when OAT = 95°F).	Radial with outlets in center of rooms.	Radial, 400 CFM per return, returns close to air handler.	7C-R
	Trunk and branch with outlets in center of rooms.	Trunk and branch, 400 CFM per return, returns close to air handler.	7C-T

Designer Options

Simple load calculation – MJ8AE (Abridged Edition)

- Dwelling must be 100% compatible with AE Checklist
- Can be done by hand or using ACCA MJ8 speedsheet

Full load calculation – Full MJ8

- Can be done by hand, but extremely time consuming
- Usually use third party software

Example - Accu-Size Heating & Cooling Home Analysis Form
How to Perform a Quick Load Calculation (Residential)

Step 1. Measure the Home, location of the windows, orientation (North-South- East-West) and draw it fairly accurately. Grid paper is helpful. Measure each window (sf) and enter on the drawing.

Step 2. Complete the Accu-Size Heating & Cooling Home Analysis Form

Cooling Load (heat gain) – 95 degree day

Enter in the square Footage of the Windows by orientation and single or double

Enter the square footage of the doors (exclude crawl space doors)

Enter in the square footage of the walls (total perimeter x ceiling height). Vaulted ceilings use an average of the height, for example if the vaulted height is 12 feet use 9 ft or 10 ft based on the distance.

Determine what type of insulation is in the walls, attic, and floor and enter the square footage of the net walls, ceiling and floor.

Enter in the home's total square footage in Infiltration/Ventilation and use the 3.5 multiplier (for a certified tight home 3.5 is not used)

Enter in the number of people (bedrooms) under Internal Gains

Step 3. Calculate the heat gain for each entry and add to get the Subtotal BTU/h heat gain

Step 4. Calculate the Gains for Ductwork

Step 5. Add to get the Total BTU/h Heat Gain

Heating Load (heat Loss) – 0 degree day

Repeat similar steps