Manual-J Calculation Walkthrough

by April Trostle

Part 1: Heat Loss (Winter) Estimation

Step 1: Defining Load Requirement

- To determine your home's peak winter conditions, refer to Table 1 for the 97.5th percentile values of temperature for the nearest major city
- Take 70 °F as the indoor design temperature
- Temperature Delta (TD) = Indoor Design Temperature - Outdoor Design Temperature

Table 1

OUTDOOR DESIGN CONDITIONS FOR UNITED STATES AND CANADA
DESIGN GRAINS BASED ON AN INSIDE DESIGN TEMPERATURE OF 75°F

Location	Latitude Degrees	WINTER 97½% Design db	WINTER Heating D.D. Below 65°F	SUMMER 2½% Design db	SUMMER Coincident Design wb	SUMMER Grains Difference 55% RH	SUMMER Grains Difference 50% RH	SUMMER Daily Range
ALABAMA								
Alexander City	33	22	....	93	76	37	44	21 M
Anniston AP	33	22	2810	94	76	35	42	21 M
Auburn	32	22	....	93	76	37	44	21 M
Birmingham AP	33	21	2710	94	75	30	37	21 M
Decatur	34	16	3050	93	74	25	32	22 M
Dothan AP	31	27	1400	92	76	39	46	20 M
Florence AP	34	21	3199	94	74	23	30	22 M
Gadsden	34	20	3000	94	75	30	37	22 M
Huntsville AP	34	16	3190	93	74	25	33	23 M
Mobile AP	30	29	1620	93	77	44	51	18 M
Mobile CO	30	29	1620	93	77	44	51	16 M
Montgomery AP	32	25	2250	95	76	33	40	21 M
Selma-Craig AFB	32	26	2160	95	77	38	47	21 M
Talladega	33	22	....	94	76	33	42	21 M
Tuscaloosa AP	33	23	2590	96	76	32	39	22 M
ALASKA								

Step 2: Door & Window Losses

- The next step will be to go through each exterior surface and calculate heat losses according to Q = U x A x TD (where U = 1/R, A in sq. ft, TD in F, and Q in BTU/hr)
- Test data has found that U-value is not always linearly independent from temperature delta, so we instead use the Heating Transfer Multiplier (HTM) = U x TD
  - Therefore, Q = HTM x A
- HTM curves for specific doors and windows are provided in Table 2, along with a U-value if that variable is preferred.
- Lookup the specific HTM curve, then lookup the HTM-value by linearly interpolating from the table.
- Calculate surface area
- Per surface: Q = HTM x A

Table 2

Heat Transfer Multipliers (Heating)

No. 1 Single Pane Window	Winter Temperature Difference																
	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	U
	HTM (Btuh per sq. ft.)																
Clear Glass																	
A. Wood Frame	19.8	24.8	29.7	34.7	39.6	44.6	49.5	54.5	59.4	64.4	69.3	74.3	79.2	84.2	89.1	94.1	.990
B. T.I.M. Frame	20.9	26.1	31.4	36.6	41.8	47.0	52.3	57.5	62.7	67.9	73.2	78.4	83.6	88.8	94.1	99.3	1.045
C. Metal Frame	23.1	28.9	34.7	40.4	46.2	52.0	57.8	63.5	69.3	75.1	80.9	86.6	92.4	98.2	104.0	109.7	1.155
Low Emittance Glass, e = 0.60																	
D. Wood Frame	18.4	23.0	27.5	32.1	36.7	41.3	45.9	50.5	55.1	59.7	64.3	68.9	73.4	78.0	82.6	87.2	.918
E. T.I.M. Frame	19.4	24.2	29.1	33.9	38.8	43.6	48.5	53.3	58.1	63.0	67.8	72.7	77.5	82.4	87.2	92.1	.96
F. Metal Frame	21.4	26.8	32.1	37.5	42.8	48.2	53.6	58.9	64.3	69.6	75.0	80.3	85.7	91.0	96.4	101.7	1.07
Low Emittance Glass, e = 0.40																	

Step 2: Door & Window Losses (Cont.)

- As you could see in the previous figure, there are a number of details about the surfaces which combine to create a unique curve. The details for windows and doors include:
- <u>WINDOWS:</u>
- Feature Type
    - Single-, Double-, Triple-Pane
        - w/ or w/o Storm (not for triple-pane)
        - w/ or w/o Inter-Pane Adjustable Blinds
    - Jalousie Window
        - Metal Frame & Single Pane Only
    - Skylight
        - Plastic Dome or Glass
- Frame Type
    - Wood, TIM (Thermal Break), Metal
- Glass Type
    - Clear
    - Low Emittance
        - If Single Pane, specify e = (0,6, 0.4, 0.2)

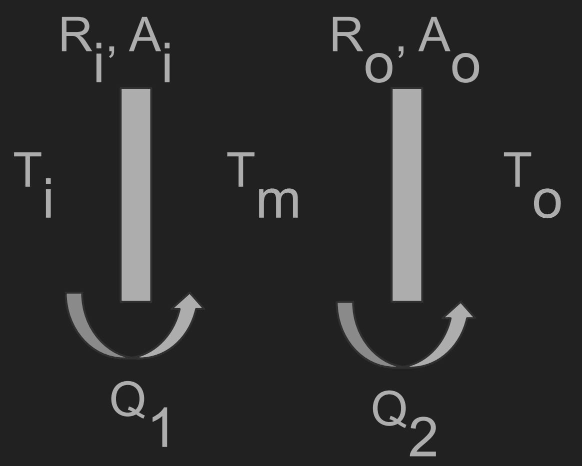
- <u>DOORS:</u>
- Glass (Left Criteria and …):
    - Sliding Glass, French Door
- Wood
    - Storm Type
        - None, Wood, Metal
    - Core Type
        - Hollow, Solid, Panel
- Metal
    - Storm Type
        - Yes or No
    - Core Type
        - Fiberglass, Polystyrene, Urethane

Step 3: Wall & Partition Losses

- Walls bordering other homes/conditioned spaces do not qualify!
- Net Wall Area = Gross Wall Area (Width x Height) - Window Areas - Door Areas
- Note: If a staircase lies along a partition, the staircase wall area should be included.
- Below-Grade Walls have different HTM curves.
  - Walls must extend 2' below grade to qualify, otherwise soil doesn't insulate enough
  - For area calculations, divide the wall area into above-grade and below grade portions, averaging the grade line if necessary
- Partitions are defined as walls between conditioned and unconditioned spaces (e.g. knee walls, garages)
  - Note that unconditioned spaces will not be the same temperature as the outside so the TD we use to find our HTM will be different.
  - The manual simply says to do so based off of "the expected temperature" in the unconditioned space, but why do that when we can solve for an intermediate temperature between plies of R-values?
  - Given interior/exterior temps and R-values:
  - How did I derive this? Check it out!

$$T_m = \frac{A_o R_i T_o + A_i R_o T_i}{A_i R_o + A_o R_o},$$

Step 3: Wall & Partition Losses (Cont.)



Finding Thermal Equilibrium:

$$Q_1 = Q_2 : \frac{A_i}{R_i}(T_m - T_i) = \frac{A_o}{R_o}(T_o - T_m),$$

$$\left(\frac{A_i}{R_i} + \frac{A_o}{R_o}\right)T_m = \frac{A_o}{R_o}T_o + \frac{A_i}{R_i}T_i,$$

$$\frac{A_iR_o + A_oR_i}{\cancel{R_iR_o}}T_m = \frac{A_oR_iT_o + A_iR_oT_i}{\cancel{R_iR_o}},$$

$$\boxed{T_m = \frac{A_oR_iT_o + A_iR_oT_i}{A_iR_o + A_oR_o},}$$

*Sometimes there are semi-conditioned spaces which are kept at specific non-indoor temperatures. If that's you, just use that temperature.

Step 3: Wall & Partition Losses (Cont.)

- Table 2 offers the following wall/partition options for curves:
- Grade Level
  - Above Grade
  - Below Grade (must extend below 2’ to qualify)
    - 2’-5’ below
    - >5’ below
- Construction
  - Wood Frame
    - Cavity Insulation
      - None, R-11, R-13, R-19, R-27 Wall, R-30 Wall, R-33 Wall
    - Sheathing
      - Gypsum, Asphalt, Bead, Extra Poly, R-8 Sheathing
  - Masonry Wall
    - Block Type
      - 8”-12” Block, 4” Brick + 8” Block
    - Insulation Type
      - None, R-5, R-11, R-19

Step 4: Ceiling & Roof Losses

- There are three possibilities for the combined insulation of the ceiling and roof:
  - 1. Attic is Vented
    - Ignore roof insulation, treat attic temperature as outdoor temperature
  - 2. Attic is Conditioned
    - Ignore ceiling insulation, treat attic temperature as indoor temperature
  - 3. Attic is Unvented & Unconditioned
    - Consider ceiling insulation only, using intermediate temperature formula
    - Table 2 provides HTM curves for specific roof-ceiling combinations to avoid that entirely
- A ceiling is defined as any layer immediately below a roof, attic, or unconditioned space.
- Note: Part of a first-story ceiling on a two-story house could qualify due to the nature of slanted roofs.

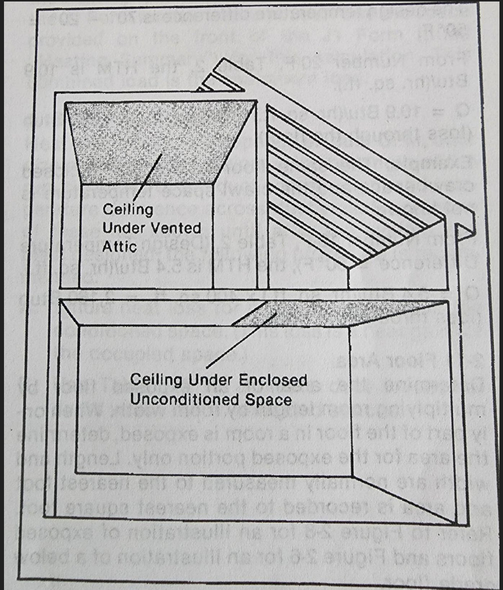


Figure 2-7 Exposed Ceiling

Step 4: Ceiling & Roof Losses (Cont.)

- Table 2 offers the following roof/ceiling options for HTM curves:
- Roof-Ceiling Combinations
  - No Insulation, R-11 Batts, R-19 “, R-22 “, R-26 “, R-30 “
- Roof
  - 1½” Wood Decking
    - None, R-4, R-5, R-6, R-8, R-13, R-19
  - Shredded Wood Planks
    - 2”, 3”
  - Fiber Board Insulation
    - 1½”, 2”
- Ceiling
  - Wood Decking w/o Insulation OR None, R-7, R-11, R-19, R-22, R-26, R-30, R-38, R-44, R-57

Step 5: Floor Losses

- An exposed floor is defined as any layer immediately below a basement, porch, or other unconditioned space.
- Note: Part of a second-story floor on a two-story house could qualify as an exposed floor due to porches, sunrooms, etc.
- If the unconditioned space below is vented to the outside, use the design temperature delta
- If the temperature of the unconditioned space is unknown and estimation is difficult (e.g. crawl space), the manual encourages us to be conservative and use the design temperature delta.
  - Maybe we can use that conservatism for partitions/attics too?
- Concrete Slab On Grade Floors have unique considerations to be explained on next slide.

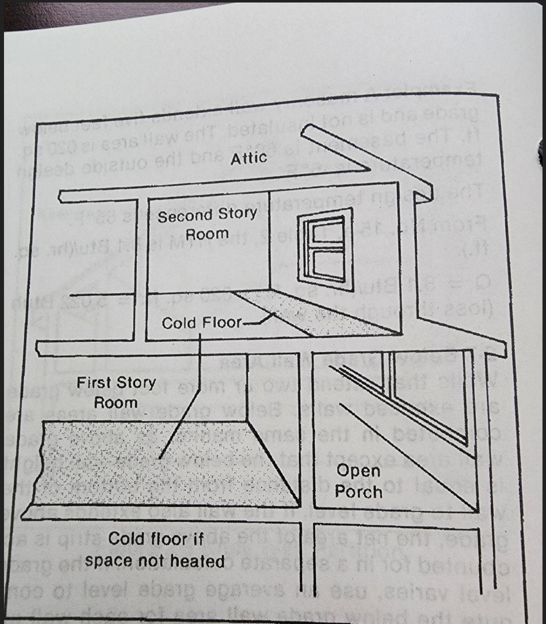


Figure 2-8 Exposed Floor

Step 5: Floor Losses (Cont.)

- Table 2 has the following options for HTM Curves:
- Space Type
  - Over Vented Space (Garage, Porch, Vented Crawl Space, etc.)
  - Over Unvented Space (Crawl Space, Cold Basement, Sunroom, etc.)
  - Under Conditioned Basement (Not Concrete Slab!)
    - No additional qualifiers needed
- Floor Type
  - Hardwood, Carpeted
- Insulation Type
  - None, R-11, R-13, R-19, R-30

Step 5: Floor Losses (Cont.) – Concrete Slab On Grade

- Concrete Slab On Grade Floors depend on the ground temperature, which varies substantially from the edges to the center.
- Since the majority of floor losses will be concentrated around the edges, for this calculation we instead multiply our HTM by the perimeter of the floors
- Table 2 has the following options for HTM (Btuh / ft) curves:
- Perimeter Warm Air Duct System OR None
- Edge Insulation Thickness
  - None, 1”, 1½”, 2”
- Insulation Value
  - None, R-5, R-8, R-11

Step 6: Infiltration Losses

- Infiltration concerns the winter air that is able to enter conditioned spaces, primarily through fireplace ventilation, exhaust fans in kitchens and bathrooms, and cracks in windows and doors.
- The exact infiltration flux is measured in cubic feet per minute (gotta love imperial units) and is thus called the infiltration CFM.
- We have a new formula for this heat loss component: Q = 1.08 x CFM x TD
  - 1.08 is a unit conversion
- CFM is a difficult quantity to estimate due to multiple sources of loss which are all rated to differing maximum infiltration levels (also dependent on outdoor windspeed).
- We start by finding the Winter Air Changes Per Hour using Table 5 which is based on a simple seal rating of “Poor”, “Average”, or “Best”.

Winter Air Changes Per Hour

Floor Area	900 or less	900-1500	1500-2100	over 2100
Best	0.4	0.4	0.3	0.3
Average	1.2	1.0	0.8	0.7
Poor	2.2	1.6	1.2	1.0
For each fire place add:		Best 0.1	Average 0.2	Poor 0.6

Step 6: Infiltration Losses (Cont.)

- This Table is based off of assumptions. If not met, refer to Appendix 5 for detailed per-feature calculation (could use for more accuracy, but may overwhelm user). These assumptions include:
  - <4 stories
  - Glass makes up 10-30% of wall area
  - ~3 exhaust fans, recessed lighting,
  - dryer vent, pipe & duct penetrations

Winter Air Changes Per Hour

Floor Area	900 or less	900-1500	1500-2100	over 2100
Best	0.4	0.4	0.3	0.3
Average	1.2	1.0	0.8	0.7
Poor	2.2	1.6	1.2	1.0
For each fire place add:		Best 0.1	Average 0.2	Poor 0.6

- Using the AC Changes per Hour (ACHR), we can calculate the CFM as follows:
- CFM = ACHR x V / 60
  - Where V is the volume of the above-grade conditioned space in cubic feet
- This gives us the complete formula:Q = 0.018 x ACHR x V x TD

Step 6: Duct Losses

- Ducts are imperfect at insulating air on its way to the rooms it is meant to condition.
- When that leakage happens within a conditioned area, it still is contributing to the total conditioning of the home, and so is inconsequential.
- But when a duct runs through an unconditioned space such as attics, basements, and garages, much of that heat is conducted away and lost.
- The exact heat loss will be a fraction of the heat loss belonging to the room which that duct serves.
  - Ex: Duct runs through attic into master bedroom, which has wall, ceiling, etc losses. Sum those up and multiply by our duct loss multiplier to get the duct loss.
  - Note: This is working off the assumption of a room-by-room calculation, which for our purposes is not required unless the space qualifies for duct losses.
  - I suggest that if our user specifies duct losses, then we will probe for a single-room calc of the targeted room and subtract that portion of loss from the overall calculation.

Step 6: Duct Losses (Cont.)

- Table 7A provides the possible options which combine to provide a duct loss multiplier:
- Supply Air Temperatures < OR > 120 °F
- Outdoor Design Temperature < OR > 15 °F
- Duct Location
  - Exposed to Outdoor Ambient (aka Vented Rooms)
  - Enclosed in Unconditioned Room
  - Buried In or Under Concrete Slab
    - Edge Insulation: None, R=3-4, R=5-7, R=7-9
- Duct Insulation
  - None, R-2, R-4, R-6

- **Step 7: Add up all the heat losses found above and you're done!**

Part 2: Heat Gain (Summer) Estimation

Step 1: Defining Load Requirement

- In summer, in addition to temperature deltas, part of our AC load will be dedicated to keeping indoor humidity lower than it may be outdoors
  - This portion of load is called Latent Load. All other loads are called Sensible.
- Summer loads are lessened due to the low temperatures at night providing passive cooling
  - Comparing lows to highs: L = <15°F, M = 15-25°F, H = >25°F
- To determine your home's peak summer conditions, refer to Table 1 for the following weather data for the nearest major city:
  - 2.5th Percentile Temperature
  - Grains Difference aka Indoor-Outdoor Humidity Delta (50% is conservative)
  - Daily Range: Degrees and Letter Category

Table 1

OUTDOOR DESIGN CONDITIONS FOR UNITED STATES AND CANADA
DESIGN GRAINS BASED ON AN INSIDE DESIGN TEMPERATURE OF 75°F

Location	Latitude Degrees	WINTER 97½% Design db	WINTER Heating D.D. Below 65°F	SUMMER 2½% Design db	SUMMER Coincident Design wb	SUMMER Grains Difference 55% RH	SUMMER Grains Difference 50% RH	SUMMER Daily Range
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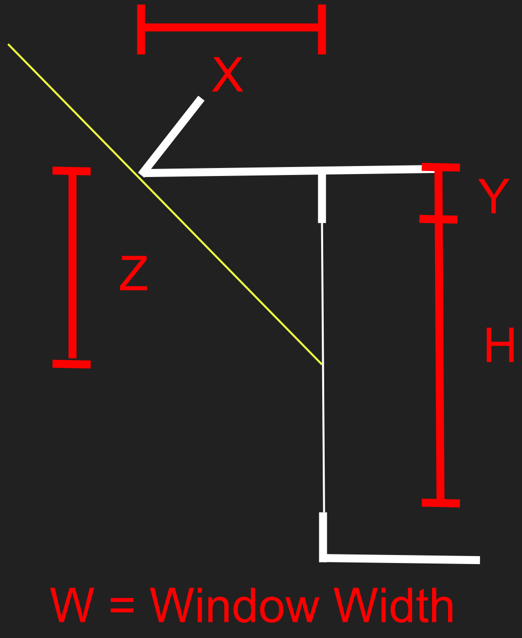
Step 2: Window & Glass Door Gains

- Summer heat gains come from a combination of conduction, radiation, infiltration and convection (acts as thermal inertia smoothing radiation gains).
- Luckily for us, Table 3 provides window/glass door HTM's which envelope them all for us.
- Table 3 provides the following options for its HTM curves:
- Direction
  - N, NE/NW, E/W, SE/SW, S
- Panes
  - Single, Double, Triple
  - Low-e Coating = +1 Pane
- Shading
  - None, Drapes, Roller Shades, Awning
  - Full Shading (Awning) Curve = Unshaded North-Direction Curve
- Tint Type
  - None, Tinted, Reflective
- External Shade Coefficient
  - 0, 0.15, 0.25, 0.35, 0.45
- Skylight
  - Inclination: 0°, 30°, 45°, 60°

Step 2: Window & Glass Door Gains (Cont.)

- Shading can do a lot to relieve load, so it's useful to analyze partially shaded windows in terms of a shaded portion and an unshaded portion.
- Table 8 provides the formula for those area estimations.
- The latitude and window direction combine to provide a Shade Line Multiplier (SLM), which effectively determines the sun's angle of attack
- In short:
  - Z = X * SLM
  - Shaded Area = (Z - Y) * W
  - Unshaded Area = (H - (Z-Y)) * W
  - …
  - **Shaded Area = (X * SLM - Y) * W**
  - **Unshaded Area = (H + Y - X * SLM) * W**



Steps 3-6: Doors, Walls, Ceilings, Roofs, and Floors

- Non-Glass Doors & Walls
  - HTM curves in Table 4. These use all the options in Table 2 plus the Daily Range Category from Table 1.
  - Below Grade (Basement) Walls do not contribute to Heat Gains
- Ceilings & Roofs
  - Same as above, but also an option between Light- and Dark-Colored Roofs.
  - Same rules from the Heating Load Estimation apply.
- Floors
  - Table 4 HTM's + Daily Range Option.
  - On-Grade Floors do not contribute to Heat Gains. Only floors above garages and crawl spaces count towards the total.
- **This means the total exposed area for walls and floors will differ between Heating and Cooling Estimations!**

Steps 7-9: Internal, Infiltration, and Ventilation Gains

- Internal Gains
  - 1200 Btuh Sensible for home (underestimate, but used intermittently)
  - Per person in home: 300 Btuh Sensible, 230 Btuh Latent
  - Place load in living room if doing room-by-room analysis
- Infiltration
  - Return to Table 5 to find the corresponding summer ACHR
  - Infiltration CFM = ACHR x V / 60
  - Sensible Q = 1.08 x CFM x TD
  - Latent Q = 0.67 x CFM x GR
    - GR = Grains Difference
    - 0.67 is, again, a unit conversion factor
- Ventilation (Exhaust fans)
  - If home has mechanical ventilation (required if summer ACHR < 0.35), then heat gains through those ducts are required
  - Vent CFM = Max(50, (.35 - ACHR)*V/60) + (100 PER Kitchen) + (50 PER Bathroom)
  - Sensible Q = 1.08 x Vent_CFM x TD
  - Latent Q = 0.68 x Vent_CFM x TD

Step 10: Duct Gains & Final Estimate

- If ducts run through unconditioned spaces, Table 7B gives summer Duct Gain Multipliers to apply to dedicated room load

- Rating & Temperature Swing Multiplier (RSM): Table 6 provides an extra factor to adjust for the fact that indoor temperatures will fluctuate due to daily variations outdoors.
  - If 4.5°F variation is allowed, RSM = 0.9.
  - If 3°F variation is allowed, RSM = 1.0. Better to use this value so as not to underestimate.

- Total Latent Load = Sum of Latent Loads
- Total Sensible Load = Sum of Sensible Loads * RSM (Unchanged if RSM = 1)
- Final Load Estimation is presented as Sensible and Latent Totals specified separately.

Part 3: Miscellaneous Analyses

Alternative Residences

- Mobile homes have a separate table of HTM's.
  - These tables are shorter due to fewer common building materials
  - These values are generally lower due to the lower thermal mass
- Multi-Family Structures (w/ Decentralized A/C)
  - Conditioning an entire home has the benefit of conditioning loads becoming more evenly distributed throughout.
  - When a single unit is only in charge of a couple rooms, summer loads will be somewhat higher
    - Due to solar radiation, winter loads unchanged
  - Table A2-1 has a list of Sensible Load Correction Factors to multiply final load totals by.
  - The factors are determined by % Glass Area on Walls and the primary direction these windows face.
  - Ex: If you have North and West-facing windows, pick the factor under "Northwest".
  - If you expect to neighbor unoccupied/unconditioned units, you may want to include partition (non-exposed walls) in your calculations.

Multi-Zone AC Systems

- Some homes have their AC systems divided into multiple sections, which take advantage of the fact that people tend to spend more time in living spaces during the day and bedrooms at night.
- Due to the partitioning this causes, those same Sensible Load Correction Factors apply to summer estimates for each room in the house
    - If we wish to avoid a full room-by-room analysis, these factors could be applied only to the windows rather than the entire room subtotal
- Each section of the house, after applying these factors, are summed to determine the peak capacity of the load going to that particular section
- There are three kinds of Multi-Zone AC Systems:
    - Single Unit Multi-Zone (75°F OR Off)
        - Single AC unit, but zones receive no conditioning during certain times
        - For these, the capacity of the unit only needs to be the maximum of the “Living” and “Sleeping” Subtotals (usually “Living”)
    - Multiple Unit Single-Zone (75°F OR Off)
        - Multiple AC units in charge of only a single zone of the house
        - For these, the capacity of each is simply the zone subtotal (with the load factors)

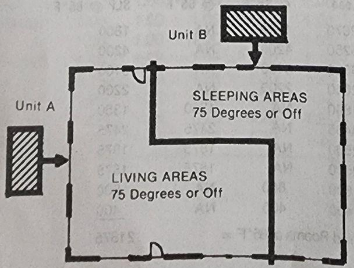
Multi-Zone AC Systems (Cont.)

- There are three kinds of Multi-Zone AC System (Cont.):
  - Central Ducted VAV (75°F OR 85°F)
    - Single AC unit and a single connected duct system, but different rooms have more lenient temperature settings (85°F in summer, 65°F in winter, say)
    - To analyze these, calculate a Design Load @ 75°F for the living spaces with added LCF’s. Then, calculate a Design Load @ 85°F for the bedrooms with added LCF’s. Then, sum these.
      - While the LCF’s will increase the load, the lower setpoint should provide a higher knockdown for a lower overall total

Multi-Zone AC Systems (Cont.)

When two multi-zone systems are used they can be arranged so that one cools the living areas and the other cools the sleeping areas or they can be arranged so that each system cools part of each area. The physical arrangement is important if the equipment is designed to cool either the living areas or the sleeping areas but not both.

	Primary Exposure	Manual J Load @ 75°F	Zone Load Factor	Adjst'd Load @ Design	Manual J Latent Load
Unit A					
Living Room	N & W	1800	1.15	2070	Infil't
Dining Room	West	4200	1.25	5250	Plus
Kitchen	S & W	5100	1.30	6630	Eight
Family Room	South	2200	1.20	2640	People
Total Loads =		13300		16590	2880
Unit B					
Master Bedroom	North	1800	1.00	1800	
Bedroom 3	S & E	3300	1.05	3465	Infil't
Bedroom 2	East	2500	1.00	2500	Plus
Bedroom 1	East	2500	1.00	2500	Eight
Bath 1	North	600	1.00	600	People
Bath 2	North	400	1.00	400	
Total Loads =		11100		11265	2400



Units "A" and "B" are arranged so that unit "A" cools the living areas and unit "B" cools the sleeping areas. In this case the total sensible capacity is equal to the sum "A" and "B" capacities: 16590 + 11265 = 27855 Btuh.

Compare the total design load 27855 Btuh for this arrangement with the design load 17590 Btuh for the arrangement shown by Figure A2-6.

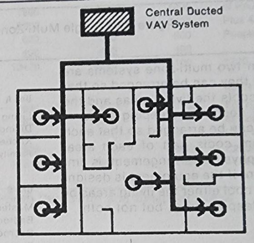
Figure A2-5 Two Multi-Zone Units Arranged to Cool Living or Sleeping Areas

When a central ducted VAV system cools the entire house, all exposures are of equal importance and the total load on the central equipment can be estimated by summing the uncorrected Manual J room loads.

The design sensible cooling load is equal to 24,400 Btu/Hr. Notice that the total sensible load is reduced if the cooling loads for rooms which are usually unoccupied during the day time are calculated at the set up temperature.

The correction factors are used to estimate the room loads and to determine the room CFM.

The design latent load is 3,440 Btuh and is equal to the latent load that was calculated for the entire house by the standard Manual J procedure.



	Primary Exposure	Manual J Load @ 75°F	Room Load Factor	Room Design Load	Manual J Load @ 75°F	Manual J Load @ 85°F	Liv @ 75°F Bath @ 75°F SLP @ 85°F
Living Room	N & W	1800	1.15	2070	1800	NA	1800
Dining Room	West	4200	1.25	5250	4200	NA	4200
Kitchen	S & W	5100	1.30	6630	5100	NA	5100
Family Room	South	2200	1.20	2640	2200	NA	2200
Master Bedroom	North	1800	1.00	1800	NA	1350	1350
Bedroom 3	S & E	3300	1.05	3465	NA	2475	2475
Bedroom 2	East	2500	1.00	2500	NA	1875	1875
Bedroom 1	East	2500	1.00	2500	NA	1875	1875
Bath 1	North	600	1.00	600	600	NA	600
Bath 2	North	400	1.00	400	400	NA	400
Total Sensible Load =		24400		Unoccupied Rooms at 85°F =			21875

*Glass area equals 15% of wall area.

Figure A2-3 Central Ducted VAV System Cools Entire House

When a single multi-zone system is sized to cool either the living areas or the sleeping areas (but not both simultaneously) the design sensible cooling load is equal to 17,590 Btu/Hr. Note that the room load correction factors are required because the living areas and the sleeping areas are associated with specific exposures.

The design latent load is equal to the latent load that is associated with the living areas which equals 2880 Btuh (1040 for infiltration and 1840 for occupants).

	Primary Exposure	Manual J Load @ 75 F	Zone Load Factor	Adjst'd Load @ Design	Liv @ 75 Bath @ 75 SLP-Off	Liv-Off SLP @ 75 Bath @ 75
Living Room	N & W	1800	1.15	2070	2070	0
Dining Room	West	4200	1.25	5250	5250	0
Kitchen	S & W	5100	1.30	6630	6630	0
Family Room	South	2200	1.20	2640	2640	0
Master Bedroom	North	1800	1.00	1800	0	1800
Bedroom 3	S & E	3300	1.05	3465	0	3465
Bedroom 2	East	2500	1.00	2500	0	2500
Bedroom 1	East	2500	1.00	2500	0	2500
Bath 1	North	600	1.00	600	600	600
Bath 2	North	400	1.00	400	400	400
Total Sensible Loads =		24400		27855	17590	11265

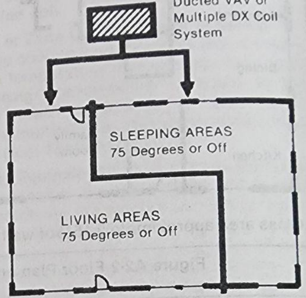
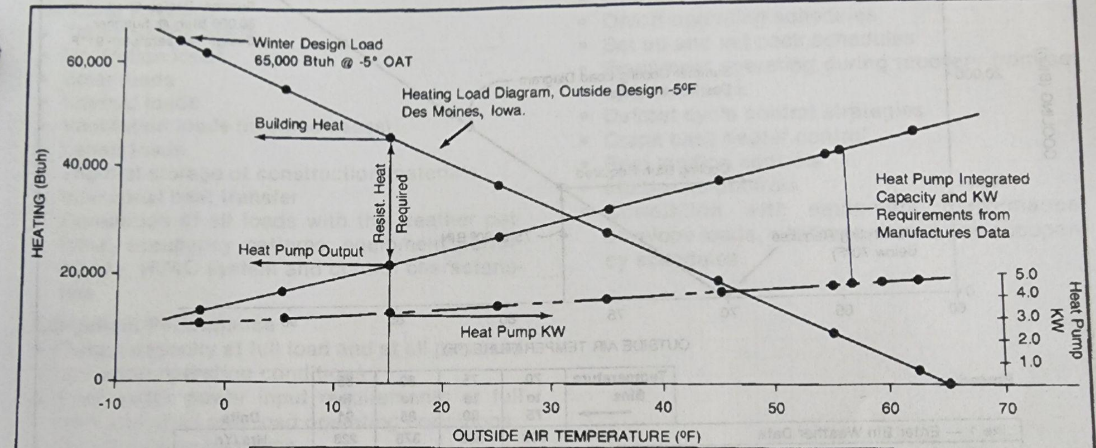


Figure A2-4 Single Multi-Zone System Sized to Cool Part of the House

Energy Consumption Estimates

- An important part of this project is the ability to point to cost savings from a downsized AC unit and especially the money that can be saved from switching to a heat pump, which has a much better coefficient of performance. Additionally, these calculations will be necessary for determining AC unit sizing based off of the capacity required.
- Appendix A-4 has involved graphs showing year-long heating and cooling costs.
  - They start by collecting histograms of hours-per-year spent in different temperature bins.
  - A linear plot can then graph the heating load based on the outdoor temperature.
    - 1st Point: Peak Load @ Outdoor Design Temperature
    - 2nd Point: 0 Btuh @ 5 degrees below Indoor Design Temperature
  - Heat pumps have an additional graph (based on OEM data) showing output as a function of temperature, as heat pumps are less efficient at lower temperatures
  - When the heat pump overperforms, factor in the duty cycle fraction to only count the time it spends running.
  - When the heat pump cannot meet the required heating load, resistive heating must fill in the gaps.
  - Multiply by the bin weather data along the entire curve to find the total KWh/Yr of the system.

Energy Consumption Estimates (Cont.)

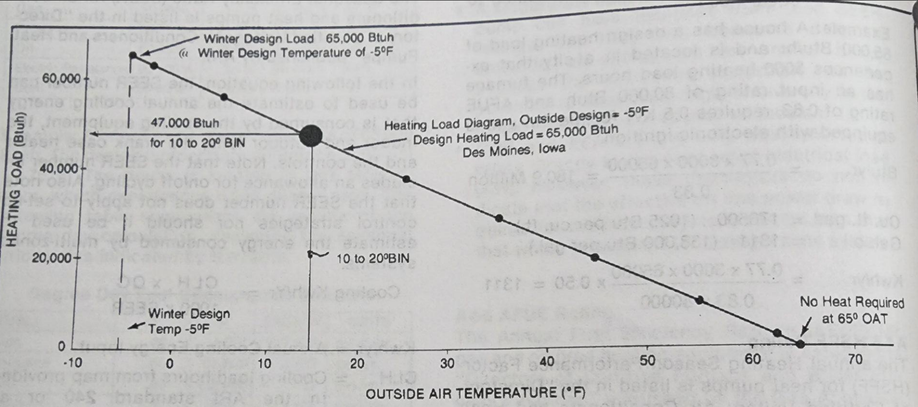


See Text for Procedure

Temperature Bins	-5 to 0	0 to 10	10 to 20	20 to 30	30 to 40	40 to 50	50 to 60	60 to 65	Totals	Units
Line 1 — Bin Weather Data	56	212	475	992	1,393	1,007	1,118	694		Hr./Yr
Line 2 — Building Heat Required ÷ 1,000	62	55	47	37	28	18	10	2		Btuh
Line 3 — Heat Pump Capacity ÷ 1,000	13	17	22	27	32	37	42	50		Btuh
Line 4 — Resistance Heat Required ÷ 1,000	49	38	25	10	0	0	0	0		Btuh
Line 5 — Heat Pump Power	2.8	3.0	3.3	3.6	3.8	4.1	4.4	4.7		KW
Line 6 — % Time Heat Pump Runs	1.0	1.0	1.0	1.0	.875	.486	.238	.040		—
Line 7 — Heat Pump Energy ÷ 1,000	157	636	1,567	3,571	4,631	2,006	1,171	130	13,869	Kwh/Yr.
Line 8 — Resistance Heating Power	14.4	11.1	7.3	2.9	0	0	0	0		KW
Line 9 — Resistance Heating Energy ÷ 1,000	806	2,353	3,468	2,877	0	0	0	0	9,504	Kwh/Yr.
Total Energy Required = Line 7 + Line 9 =									23,373	Kwh/Yr.

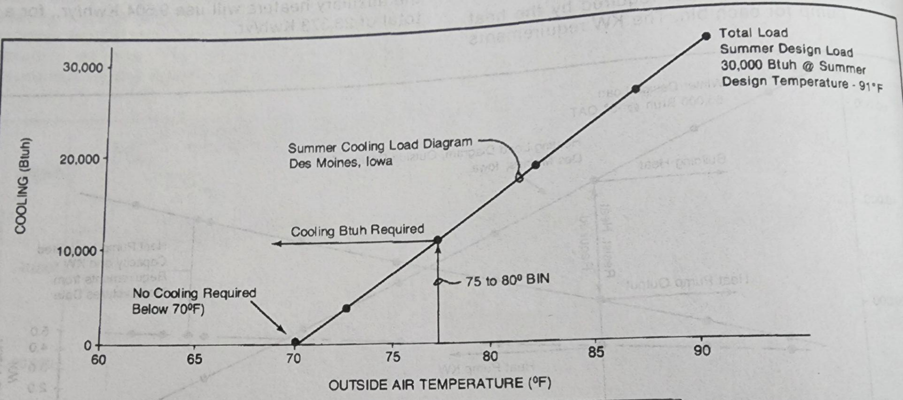
Figure A4-2 Bin Method for Heat Pump Heating Energy.

Energy Consumption Estimates (Cont.)



Procedure	Temperature Bins →	-5 to 0	0 to 10	10 to 20	20 to 30	30 to 40	40 to 50	50 to 60	60 to 65	Units
Line 1 — Enter Bin Weather Data		56	212	475	992	1,393	1,007	1,118	694	Hours per Year
Line 2 — Enter the Bin Heating Load		64	56	47	37	28	19	10	3	1,000 Btuh
Line 3 — Multiply Line 1 × Line 2		3,584	11,872	22,325	36,704	38,004	19,133	11,180	2,082	1,000 Btu
Sum up the numbers entered on Line 3 and Multiply by 1000 to Find the Yearly Heating Btu.		145,884 × 1000 = 145,884,000								$\frac{\text{Btu}}{\text{Year}}$
Calculate Fuel Consumption $F = \frac{\text{Btu/yr.}}{E \times P}$		For Gas Heat $F = \frac{145{,}884{,}000}{0.60 \times 1{,}025} = 236{,}000$								$\frac{\text{cu. ft.}}{\text{Year}}$

Figure A4-1 Bin Method for Furnace Energy



Procedure	Temperature Bins →	70 to 75	75 to 80	80 to 85	85 to 91	Units
Line 1 — Enter Bin Weather Data		709	562	378	223	Hrs./Yr.
Line 2 — Enter the Bin Cooling Load		4	11	18	25	1,000 Btuh
Line 3 — Line 1 × Line 2 = Energy per yr.		2,836	6,182	6,804	5,575	1,000 Btu/Yr.
Sum up the numbers on Line 3 and Multiply by 1,000 to find the Yearly Btu.		21,397,000				Btu/Yr.
Calculate Electrical Energy Required $\frac{\text{Cooling Kwh}}{\text{Yr}} = \frac{\text{Btu/Yr.}}{1{,}000 \times \text{Seer}}$		For Seer = 9.5 $\frac{\text{Kwh}}{\text{Yr}} = \frac{21{,}397{,}000}{1000 \times 9.5} = 2{,}252 \frac{\text{Kwh}}{\text{Yr.}}$				

Figure A4-3 Bin Method Cooling Energy