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BUILDING TECHNOLOGIES PROGRAM

Strategy Guideline: Accurate Heating and Cooling Load Calculations

Arlan Burdick

IBACOS, Inc.

June 2011

Building America

U.S. Department of Energy

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Prepared for:

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Forward

The *Strategy Guideline: Accurate Heating and Cooling Load Calculations* report provides information for the following groups:

- Heating Ventilation and Air Conditioning (HVAC) Mechanical Contractors
- HVAC System Designers
- Builders
- House Remodelers.

This guide can be used as a point of entry for collaborative discussions between a builder, HVAC contractor, and other trade partners to understand the importance of appropriately calculating peak heating and cooling loads, as the first step of HVAC system design.

Accurate load calculations have a direct impact on energy efficiency, occupant comfort, indoor air quality, and building durability. The load calculation is the first step of the iterative HVAC design procedure, as a full HVAC design involves much more than just the load calculation. The loads modeled by the heating and cooling load calculation process will dictate the equipment selection and duct design to deliver conditioned air to the rooms of the house. This guide references the methodologies of the Air Conditioning Contractors of America (ACCA) publication *Manual J Residential Load Calculation Eighth Edition* (ACCA MJ8), which in turn references information provided by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). ACCA MJ8 only applies to single family detached dwellings, low-rise condominiums, and townhouses.

This guide is not a new method for performing load calculations, a substitute for established methods of performing load calculations, or step-by-step instructions on how to perform the load calculations. This guide presents the key criteria required to create accurate heating and cooling load calculations and offers examples of the implications when inaccurate adjustments are applied to the HVAC design process. The guide shows, through realistic examples, how various defaults and arbitrary safety factors can lead to significant increases in the load estimate. Emphasis is placed on the risks incurred from inaccurate adjustments or ignoring critical inputs of the load calculation.

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Definitions

ACCA	Air Conditioning Contractors of America
ACCA MJ8	Air Conditioning Contractors of America publication *Manual J Residential Load Calculation Eighth Edition*
ACH50	Air Changes per Hour at 50 Pascals
ACHn	Air Changes per Hour Natural
AED	Adequate Exposure Diversity
ALP	Average Load Procedure
ASHRAE	American Society of Heating, Refrigeration and Air-Conditioning Engineers
Btu	British Thermal Unit
Btu/h	Btu per hour
cfm	Cubic Feet per Minute
°Fdb	Degree Fahrenheit Dry Bulb
°Fwb	Degree Fahrenheit Wet Bulb
HVAC	Heating, Ventilation and Air Conditioning
PLP	Peak Load Procedure
RESNET	Residential Energy Services Network
RH	Relative Humidity
SHGC	Solar Heat Gain Coefficient

Executive Summary

The heating and cooling load calculation is the first step of the iterative HVAC design procedure; a full HVAC design involves more than the just the load estimate calculation. Right-sizing the HVAC system, selecting HVAC equipment and designing the air distribution system to meet the accurate predicted heating and cooling loads, begins with an accurate understanding of the heating and cooling loads on a space. The Air Conditioning Contractors of America (ACCA) Manual J Version 8 provides the detailed steps required to calculate the heating and cooling loads. The accurate heating and cooling loads are used to right-size the equipment with ACCA *Manual S Residential Equipment Selection*, then to design the air distribution system and ductwork with ACCA *Manual T Air Distribution Basics for Residential and Small Commercial Buildings* and ACCA *Manual D Residential Duct System Procedure*.

In the author's experience several factors have led to a general industry resistance to initially perform an accurate load calculation, which is necessary for the design of a right-sized HVAC system. Historically, energy codes did not address stringent levels of energy efficiency, and rules of thumb were developed for HVAC sizing that worked based on the construction at that time. Building enclosures have become more energy efficient as energy codes have become more stringent since 2000; however, these rules of thumb have not changed. Full credit should be taken for improvements such as better windows, enhanced air tightness strategies, and additional insulation.

ACCA MJ8 says of safety factors:

> *"Manual J calculations should be aggressive, which means that the designer should take full advantage of legitimate opportunities to minimize the size of estimated loads. In this regard, the practice of manipulating the outdoor design temperature, not taking full credit for efficient construction features, ignoring internal and external window shading devices and then applying an arbitrary "safety factor" is indefensible."*

> *"No additional safety factors are required when load estimates are based on accurate information pertaining to the envelope construction and duct system efficiency. Large errors are possible if there is uncertainty about insulation levels, fenestration performance, envelope tightness or the efficiency of the duct runs installed in the unconditioned space."*

Examples in this guide show the implications when inaccurate adjustments are applied to the heating and cooling load calculation process. In order to demonstrate the impact on the loads when common “safety factors” are applied to the load calculation process, two houses that meet the 2009 International Energy Conservation Code® (IECC) prescriptive path were modeled as the accurate baseline. One house was modeled in Chicago, IL, and one in Orlando, FL. Several common “safety factors” were applied to the baseline models to create examples of how and where load calculations can be inflated leading to system oversizing. The baseline load calculations were manipulated for:

- Outdoor/Indoor Design Conditions
- Building Components
- Ductwork Conditions
- Ventilation/Infiltration Conditions
- Worst Case Scenario (combining all the safety factors)

Seemingly small manipulations such as changing the outdoor/indoor design conditions can result in exaggerated loads. The Orlando House example (Figure 1) showed a 9,400 Btu/h (45%) increase in the total cooling load, which may increase the system size by 1 ton when the ACCA Manual S procedures are applied.

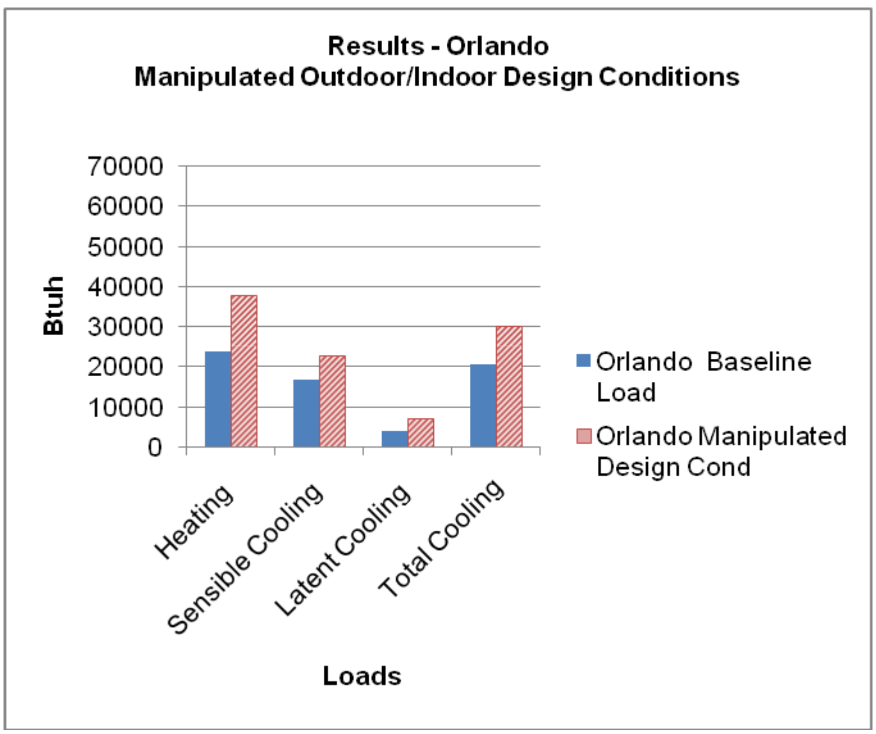

Figure 1. Results – Orlando House Manipulated Outdoor/Indoor Design Conditions

Combining several adjustments only compounds the inaccuracy of the calculation results. The results of the combined manipulations to outdoor/indoor design conditions, building components, ductwork conditions, and ventilation/infiltration conditions produce significantly oversized calculated loads. The Orlando House example (Figure 2) showed a 33,300 Btu/h (161%) increase in the calculated total cooling load, which may increase the system size by 3 tons (from 2 tons to 5 tons) when the ACCA Manual S procedures are applied. Not only does this oversizing impact the heating and cooling equipment costs, but duct sizes and numbers of runs must also be increased to account for the significantly increased system airflow.

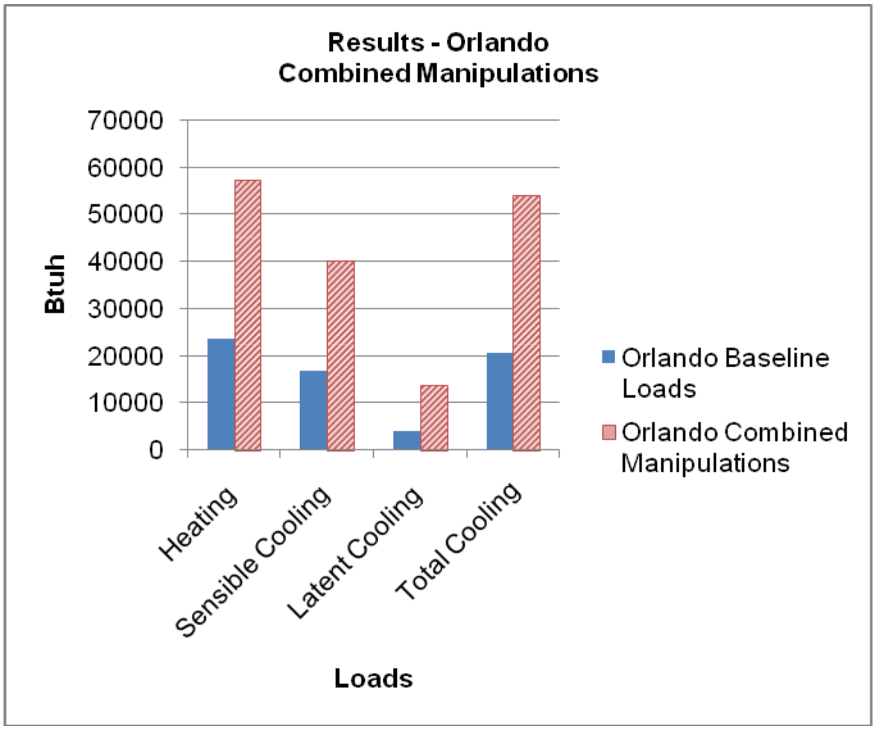

Figure 2. Results – Orlando House Combined Manipulations

Oversizing the HVAC system is detrimental to energy use, comfort, indoor air quality, building and equipment durability. All of these impacts derive from the fact that the system will be "short cycling" in both heating and cooling modes. To reach peak operational efficiency and effectiveness, a heating and cooling system should run for as long as possible to address the loads. An analogy is that of a car: highway driving at a steady speed will get the best fuel economy, while speeding up and slowing down puts undue wear and tear on the engine and braking systems, and reduces fuel efficiency.

An oversized HVAC system will have both a higher initial cost and a higher cost of operation. The frequent starting and stopping of short cycling can lead to premature failure of the equipment. Short cycling limits the total amount of air circulating through each room, and can lead to rooms that do not receive adequate duration of airflow. In the cooling season in humid climates, cold clammy conditions can occur due to reduced dehumidification caused by the short cycling of the equipment. The system must run long enough for the coil to reach the temperature for condensation to occur and an oversized system that short cycles may not run long enough to sufficiently condense moisture from the air. Excess humidity in the conditioned air delivered to a space may lead to mold growth within the house.

Introduction

Heating and cooling loads are the measure of energy needed to be added or removed from a space by the HVAC system to provide the desired level of comfort within a space. Right-sizing the HVAC system begins with an accurate understanding of the heating and cooling loads on a space. Right-sizing is selecting HVAC equipment and designing the air distribution system to meet the accurate predicted heating and cooling loads of the house. The values determined by the heating and cooling load calculation process will dictate the equipment selection and duct design to deliver conditioned air to the rooms of the house, right-sizing the HVAC system. The heating and cooling load calculation results will have a direct impact on first construction costs along with the operating energy efficiency, occupant comfort, indoor air quality, and building durability.

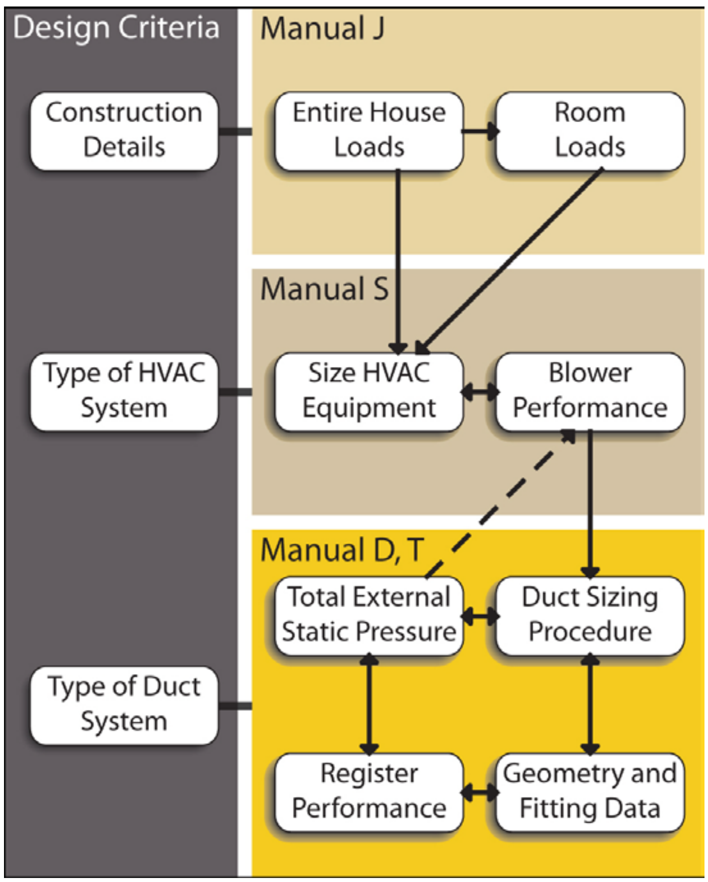

Figure 3. Residential HVAC Design Process

A full HVAC design involves more than the just the load estimate calculation; the load calculation is the first step of the iterative HVAC design procedure (Figure 3). The values calculated from the ACCA MJ8 procedures are then used to select the size of the mechanical equipment. Mechanical equipment selection is done with the aid of the ACCA *Manual S Residential Equipment Selection*. The conditioned air delivery to the space is controlled by the type and size of the air outlet. ACCA *Manual T Air Distribution Basics for Residential and Small Commercial Buildings* provides the guidance on selecting the air outlet size and type. The ductwork that carries the conditioned air to meet the load requirements of the space from the mechanical equipment to the air outlet is sized with the aid of the ACCA *Manual D Residential Duct System Procedure*. The iterative nature of the process involves balancing the blower performance of the mechanical equipment against the pressure losses of the ductwork and air outlets to deliver the conditioned air to the space in as unobtrusive manner as possible. The ACCA procedures have been written into commercial software packages to help the designer work through the many iterations required for a good design.

For the purposes of this guide, an energy-efficient house is defined as one that is designed and built for decreased energy use and improved occupant comfort through higher levels of insulation, more energy-efficient windows, high efficiency space conditioning and water heating equipment, energy-efficient lighting and appliances, reduced air infiltration, and controlled mechanical ventilation. Specification levels for energy-efficient houses have historically been prescribed by beyond code programs that set a percentage better than code for energy use, such as ENERGY STAR® that requires houses to be 15% more energy efficient than code. Beyond-code programs continue to set a percentage better than the improved codes for energy use, raising the bar for whole house energy efficiency. The 2009 International Energy Conservation Code® (IECC) establishes an estimated 15% improvement in energy efficiency over the previous 2006 IECC requirements. Ongoing code cycles are anticipated to incrementally further increase the minimum efficiency of a house. For example, the 2012 IECC achieves approximately 30% savings over the 2006 version. As the new codes are adopted and implemented, a house that was built under an above-code program in 2010 will likely be the code-mandated house in 2015. As the energy efficiency of the house is increased under code or above code programs, the peak heating and cooling loads are significantly reduced.

ACCA MJ8 says of safety factors:

> *"Manual J calculations should be aggressive, which means that the designer should take full advantage of legitimate opportunities to minimize the size of estimated loads. In this regard, the practice of manipulating the outdoor design temperature, not taking full credit for efficient construction features, ignoring internal and external window shading devices and then applying an arbitrary "safety factor" is indefensible."*

An accurate evaluation of the heating and cooling loads requires a complete understanding and accounting of the building components that make up the thermal enclosure along with the outdoor/indoor contributions to the load. The load calculation for a house where the building enclosure has been enhanced with added air tightness strategies, better windows, and additional insulation will be more sensitive to manipulation of the inputs. In the author’s experience, several factors have lead to a general industry resistance to initially perform an accurate load calculation, which is necessary for the design of a right-sized HVAC system. Historically, energy codes did not address stringent levels of energy efficiency, and rules of thumb were developed for HVAC sizing that worked based on the construction at that time. Building enclosures have become more and more energy efficient as energy codes have become more stringent since 2000, but these rules of thumb have not changed. Full credit should be taken by the HVAC system designer for improvements such as better windows, enhanced air tightness strategies, and additional insulation.

HVAC contractors are also not 100% convinced that the builder is managing all other trades to construct a thermal enclosure that truly achieves targeted performance levels. Typically, the HVAC installer will get the comfort complaint if the building enclosure has not met the builder's stated specifications, even though the HVAC system is designed and installed according to the stated specifications. Many HVAC companies rely on the "400 square feet per ton" rule for sizing systems. Even when a load calculation is required to be performed, the contractor may often manipulate the inputs to get a result that is close to the "400 square foot" rule of thumb. Overcoming this bias requires the builder and their trade base sharing an understanding of the importance of achieving the stated building enclosure specifications, and undertaking visual inspections and testing during construction to verify the building meets the intended level of performance. When these checks and balances are in place, the perceived need to add factors of safety during the heating and cooling load calculation process can be avoided. Appendix A contains suggested enhancements to the scope of work for the Mechanical Contractor or HVAC designer.

The critical inputs and their associated risks discussed in this guide are:

- Design Conditions
    - Location
        - Latitude
        - Elevation
        - Outdoor temperature and relative humidity
- Orientation
- Internal conditions
    - Indoor temperature and relative humidity
- Building Enclosure
    - Insulation levels of walls, ceilings, and floors
    - Window specification
        - Thermal conductivity
        - Solar Heat Gain Coefficient (SHGC)
    - Infiltration and ventilation levels
    - Interior and exterior shading
- Internal loads
    - Number of occupants
    - Electronics, lighting and appliances.

A concise checklist to aide in compiling the information required to accurately calculate loads is located in Appendix B of this document.

Baseline Load Calculation

In order to demonstrate the impact on the loads when common inaccurate adjustments (also known in the industry as "safety factors") are made to the house, ACCA MJ8 load calculations were performed on two houses (Figure 4) that meet the 2009 International Energy Conservation Code® (IECC) prescriptive path. The first ("Chicago House") is a one story 2,223 ft^2 (above grade) house with a full conditioned basement in Chicago, IL (IECC Climate Zone 5 - CZ5). The other ("Orlando House") is a 2,223 ft^2 one story slab-on-grade house in Orlando, FL (IECC Climate Zone 2 - CZ2). The input conditions used to model the two houses are listed in Table 1.

Figure 4. Typical 2223 ft^2 One Story House

Table 1. Baseline Model Parameters

Condition	Chicago House Climate Zone 5	Orlando House Climate Zone 2
Outdoor Design Conditions	89°Fdb 73°Fwb Temp Cooling 2°F Temp Heating	92°F db 76°Fwb Temp Cooling 42°F Temp Heating
Indoor Design Conditions	75°F Temp 50% RH Cooling 70°F Temp 30% RH Heating	75°F Temp 50% RH Cooling 70°F Temp 30% RH Heating
Roof Assembly	Vented R-38 Attic, Asphalt shingle roofing, 1/2 inch gypsum drywall ceiling	Encapsulated R-31 Attic (“cathedralized attic”), Tile Slate Concrete roofing, 1/2 inch gypsum drywall ceiling
Wall Assembly	9' height, 2x6 Framed walls, R-19, OSB exterior sheathing, Brick exterior, 1/2 inch interior drywall	9' height, Light weight 8" concrete block 3/4 inch interior XPS, R-4.8, one coat light color stucco, 1/2 inch interior drywall
Foundation Assembly	9' height, 8" poured concrete wall, 2" exterior XPS R10 6.5 feet below grade depth, Heavy damp soil type, concrete slab 8’ below grade	Heavy damp soil type, concrete slab-on-grade
Windows	U = 0.35, SHGC = 0.5	U = 0.65, SHGC = 0.30
Ducts	In Conditioned Space	In encapsulated R31 Attic (“cathedralized attic”), Tightness = Supply and Return 0.06 cfm/ft^2, Radial center of room outlets, R-8 insulation
Shading	Full credit for eaves, 50%exterior bug screens, light colored blinds at 45 degrees closed	Full credit for eaves, 50% exterior bug screens, light colored blinds at 45 degrees closed
Infiltration	0.10 ACHn (2.65 ACH50) Cooling 0.19 ACHn (5.03 ACH50) Heating	0.10 ACHn (2.65 ACH50) Cooling 0.19 ACHn (5.03 ACH50) Heating
Ventilation	Balanced supply and exhaust, 60 cfm to meet ASHRAE standard 62.2 with no energy or heat recovery	Balanced supply and exhaust, 60 cfm to meet ASHRAE standard 62.2 with no energy or heat recovery

The calculated loads are listed in Table 2. The peak heating and cooling load is in Btu/h (Btu per hour). The nominal size of the cooling equipment for these two houses is 2 tons, (1 nominal ton = 12,000 Btu/h) based on the calculated cooling loads of 20,600 Btu/h and 20,700 Btu/h for Chicago and Orlando respectively. The Load Dependencies section of this Guide shows the impact on the calculated loads (and therefore the nominal equipment size) when the baseline conditions listed in Table 2 are modified to apply "safety factors" in an effort to come closer to the industry standard sizing of 400 square feet per ton.

Table 2. Baseline Calculated Loads Using ACCA MJ8

Chicago House		Orlando House	
Heating Load	41,700 Btu/h	Heating Load	23,600 Btu/h
Sensible Cooling	17,400 Btu/h	Sensible Cooling	16,600 Btu/h
Latent Cooing	3,200 Btu/h	Latent Cooing	4,000 Btu/h
Total Cooling	20,600 Btu/h	Total Cooling	20,700 Btu/h

Load Components

Heating and cooling load calculations are dependent on the building location, indoor design conditions, orientation, and building construction. The use of commercial software to calculate the heating and cooling loads greatly simplifies the process. Various software applications that provide results certified by ACCA to meet all requirements of MJ8 are available.

Peak Heating Load

The peak heating load represents the amount of heat lost to the outdoor environment at design outdoor and indoor conditions, which must be made up by the HVAC system to maintain occupant comfort (Figure 5). There is one relatively straightforward and uncomplicated heat loss calculation procedure used in ACCA MJ8. The components of the heating load calculation are covered in depth in Section 4 of the ACCA MJ8. The total estimated heat loss is a combination of the sensible heat loss through conduction, infiltration, and ventilation loads. No credit is taken for solar gains or internal loads in calculating the heating load because the peak heat loss occurs at night during periods of occupant inactivity.

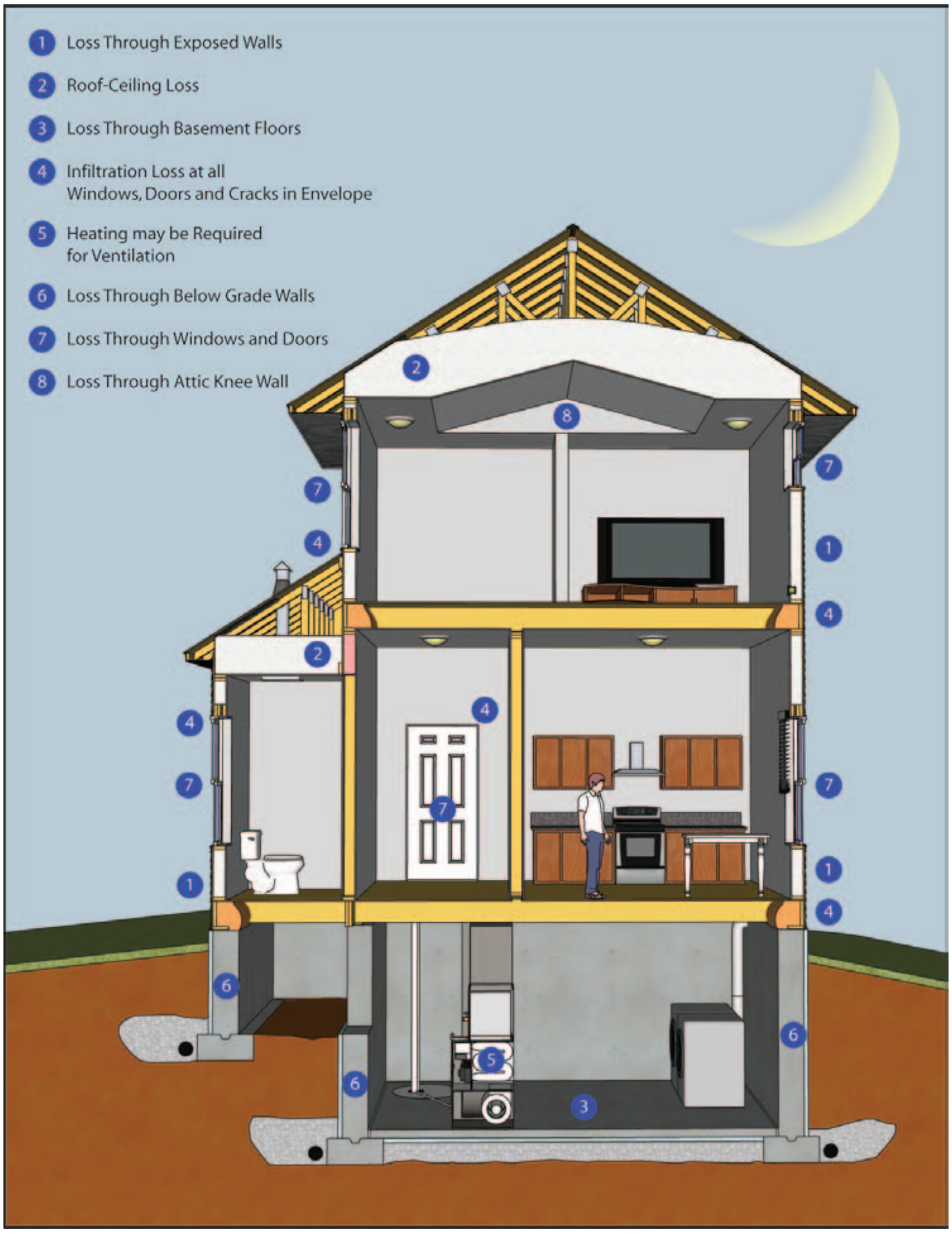

Figure 5. Heat Loss Locations

Peak Cooling Load

Peak cooling loads represent the amount of heat gained by the house from the outdoor environment at design conditions, which must be removed by the HVAC system to maintain occupant comfort. Cooling loads are made up of the sensible and latent heat gains. The mechanisms of heat gain are conduction, infiltration, ventilation, and radiation (Figure 6). The components of the cooling load calculation are covered in depth in ACCA MJ8.

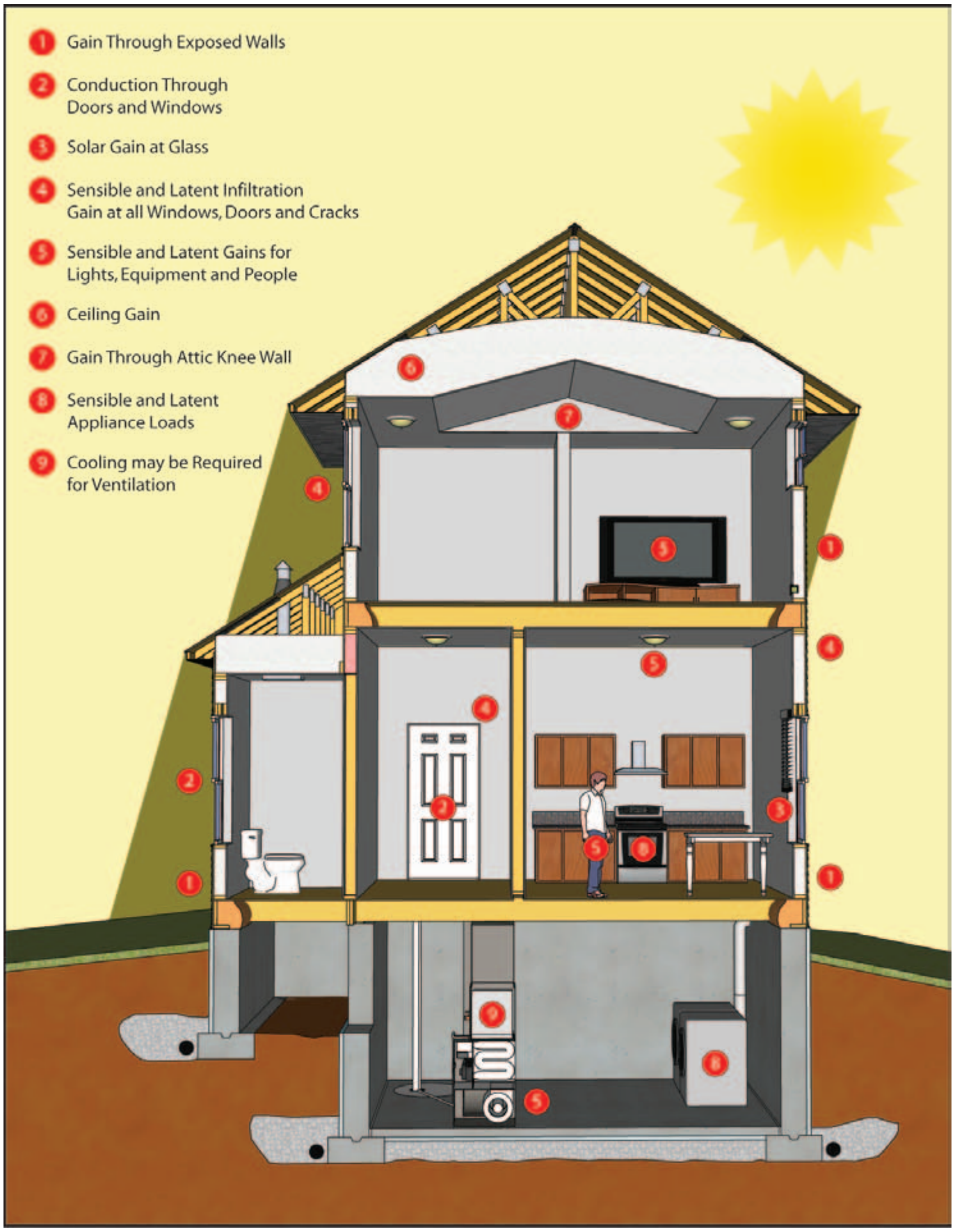

Figure 6. Heat Gain Locations

The cooling load calculation procedure in ACCA MJ8 is more complex than the heating load calculation procedure. ACCA MJ8 documents two cooling load calculation procedures in Section 5-1, the Average Load Procedure (ALP) and the Peak Load Procedure (PLP).

The ALP uses the conditions that are encountered in late afternoon during midsummer when solar gains and temperatures are expected to be highest. This is a simplified method to create dependable cooling load estimates for conventional single family detached houses with a central single zoned comfort system with Adequate Exposure Diversity (AED). See the Orientation section of this Guide for a description of the *Test for Adequate Exposure Diversity*. The ALP procedure minimizes the complexity of the calculations, however, it must be noted the values are averaged for room-to-room loads and approximate the peak block load for the structure.

The PLP looks at time of day sensitivities for midsummer conditions, recognizing that in some designs certain rooms may have significant solar gains during midday or the morning. An example might be a highly glazed sunroom on the south face of a house with considerable east, west and south glass, or a living room with lots of south facing glass and a moderate amount of west glass. The PLP is the residential equivalent to a commercial cooling load procedure, and should be used when a house does not have AED. It is used to estimate peak room loads for the midsummer season and the hour of day in which that room has its maximum solar gain. The whole house cooling load is the sum of the peak for each room.

Location – Design Conditions

The building location is described by its latitude and elevation. This location describes the values for the outdoor design conditions such as the elevation of the location, latitude, winter heating dry bulb temperatures, summer cooling dry bulb temperatures and relative humidity (RH) information. ACCA MJ8 Table 1A *Outdoor Design Conditions for the United States* has ASHRAE tabulated data for various cities throughout the United States. An example for Orlando, FL, is shown in Table 3. The outdoor design conditions are determined by choosing the city from the table closest to the project city.

Table 3. Outdoor Design Conditions for the United States - Manual J Version 8, Table 1A

Location	Elevation	Latitude	Winter	Summer					
	Feet	Degrees North	Heating 1% Dry Bulb	Cooling 1% Dry Bulb	Coincident Wet Bulb	Design Grains 55% RH	Design Grains 50% RH	Design Grains 45% RH	Daily Range (DR)
Florida									
Apalachicola	20	29	35	90	78	57	64	70	M
Belle Glade	17	26	44	91	76	42	49	55	M
Cape Kennedy AP	10	28	42	90	78	57	64	70	L
Daytona Beach AP	31	29	37	90	77	51	58	64	L
Fort Lauderdale	10	26	50	90	78	57	64	70	L
Fort Myers AP	15	26	47	93	77	46	53	59	M
Fort Pierce	25	27	42	90	78	57	64	70	M
Gainsville AP	152	29	33	92	77	47	54	60	M
Housestead, AFB	7	25	52	90	76	57	64	70	L
Jacksonville AP	26	30	32	93	77	46	53	59	M
Jacksonville/Cecil Field NAS	80	30	34	95	76	35	43	49	M
Jacksonville, Mayport Naval	16	30	39	92	78	54	61	67	M
Key West AP	4	24	58	89	79	66	73	79	L
Lakeland CO	214	28	41	91	76	42	49	55	M
Melbourne	15	28	43	91	79	62	69	75	M
Miami AP	11	25	50	90	77	51	58	64	L
Miami Beach CO	8	25	48	89	77	52	59	65	L
Miami, New Tamiami AP	10	25	49	91	78	56	59	65	L
Milton, Whiting Field NAS	200	30	31	93	77	46	53	59	M
Ocala	90	29	34	93	77	46	53	59	M
Orlando AP	100	28	**42**	**93**	76	39	46	52	M
Panama City, Tyndall AFB	18	30	37	89	79	66	73	79	L
Pensacola CO	30	30	32	92	78	54	61	67	L

Indoor design conditions for the cooling season design conditions of 75˚F 50% RH and heating season design conditions of 70˚F 30% RH are prescribed in MJ8 and based on the ASHRAE Comfort Zone Chart (Figure 7). These conditions represent the regions of the ASHRAE comfort zone (shaded areas) where, on average, people feel most comfortable. If local codes or regulations specify other design conditions, use those instead of the values in ACCA MJ8 and the ASHRAE tables.

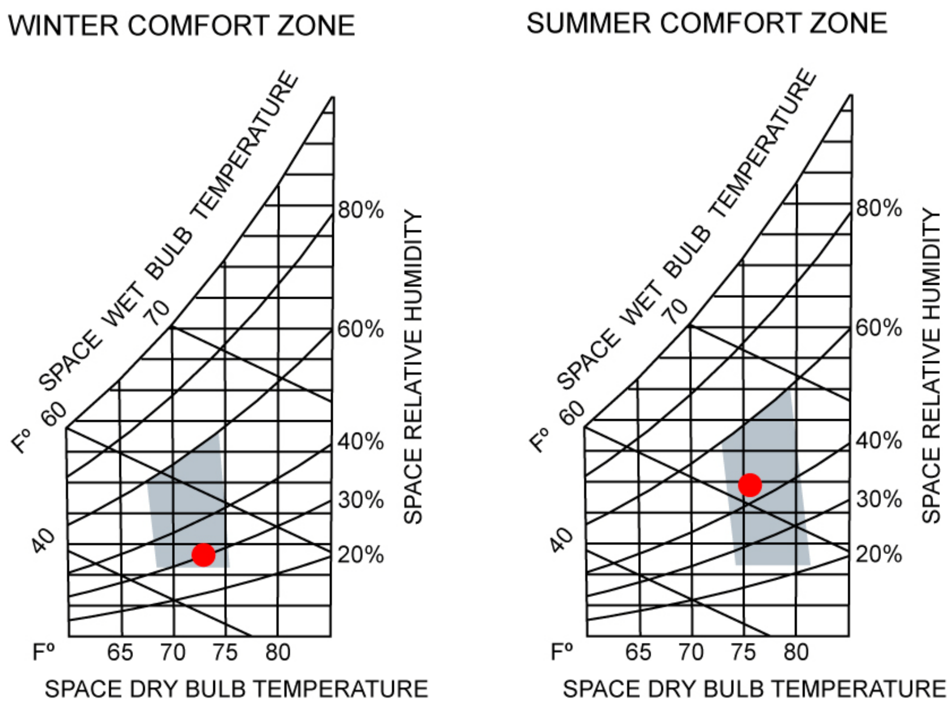

Figure 7. ASHRAE Winter and Summer Comfort Zones

The outdoor design conditions described by the ASHRAE tables represent long-term average temperatures that will not be exceeded more than a few hours per season. They do not represent the worst weather conditions ever experienced in a given location. Using the Orlando House as an example, Figure 8 shows the temperatures above the outdoor design temperature of 93˚F will occur only 13 hours out of the 8,760 hours in a year. The ASHRAE tabulated temperature data is adequate for calculating peak heating and cooling loads, and should not be increased as an additional safety factor.

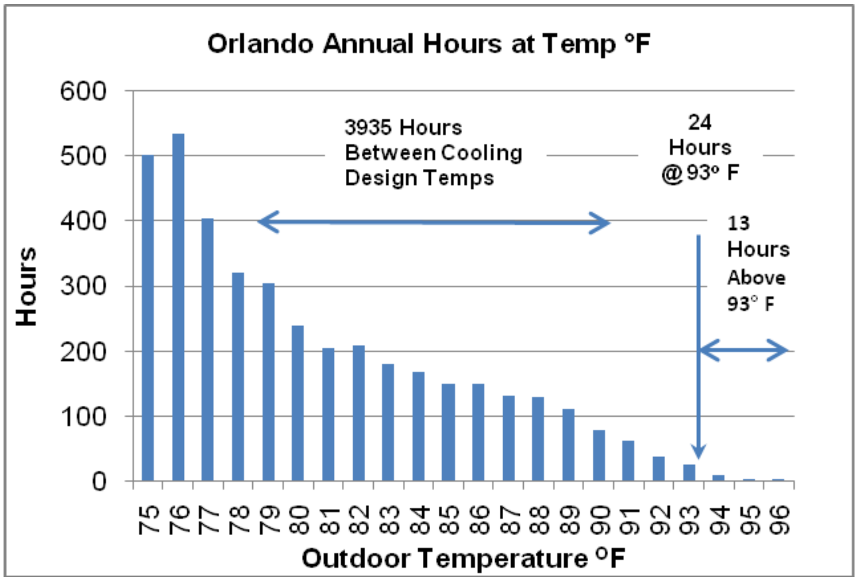

Figure 8. Outdoor cooling bin hours in Orlando, FL

A right-sized system will run close to 100% of the time at the outdoor design condition and proportionally less at temperatures closer to the inside design temperatures. Designing a system using peak heating and cooling loads based on extreme weather conditions that occur for only a few hours per season, such as the hottest day on record, will result in an oversized system. Oversized systems in humid climates may not run long enough under some part load conditions to achieve humidity removal from the air and keep the house within the ASHRAE comfort zone.

Orientation

The orientation of the house must be considered in the cooling load calculation due to changing solar heat gains at various times of the day (Figure 9) and the impact of those gains. North, Northeast, East, Southeast, South, Southwest, West, Northwest or North are typically the orientations used for undertaking load calculations for production housing, although the exact cardinal orientation can be used for houses specifically sited on a given lot. The orientation of the house can greatly affect the sensible heat gain on the house depending on the ratio of windows to opaque walls and the degree of shading from the sun.

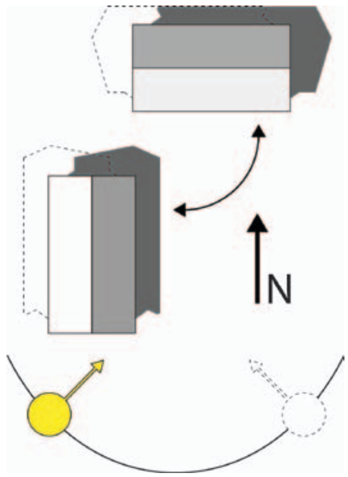

Figure 9. Building Orientation

For production homebuilding, all orientations for given house must be considered. Often times, the peak cooling load for the worst case orientation is acceptable for system sizing; however, if there is a significant difference between loads at various orientations, system sizing may vary for the same house. In the case of the Chicago House, the cooling load varies by 4,400 Btu/h between the worst case and best case orientations of the house (Figure 10). When the HVAC design moves to the system sizing step, Manual S, this variance may impact the system size.

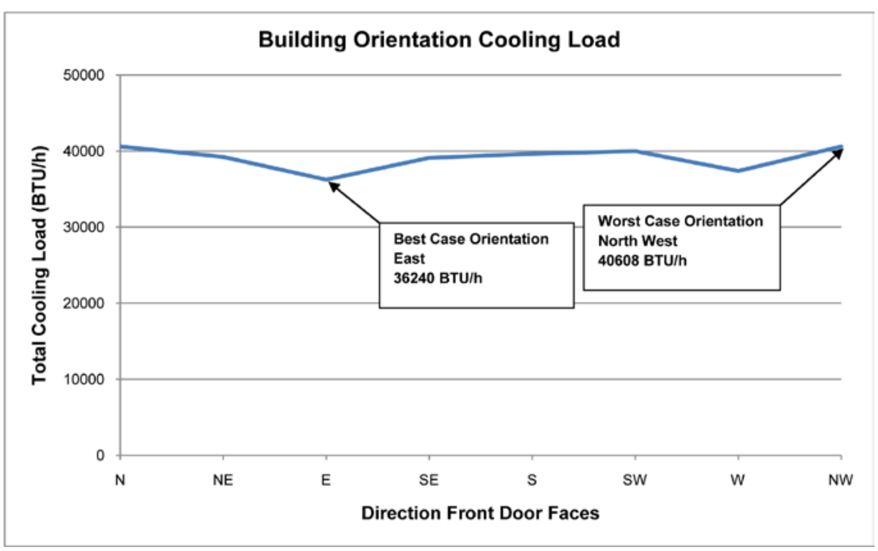

Figure 10. Building Orientation Cooling Load

The AED limit is an hourly load gain through glazing 30% greater than the average hourly load gain. If a dwelling does not have AED, the architectural features of the dwelling, such as a high percentage of windows in one orientation, will cause a spike in the block cooling load (heat gain) at a particular time of day. The *Test for Adequate Exposure Diversity* is a procedure that is best performed with the aid of software.

Figure 11 is a software-generated output that shows a house passing the *Test for Adequate Exposure Diversity* by not exceeding that maximum. Figure 12 shows a house that fails by slightly exceeding the AED limit late in the day. The results of the *Test for Adequate Exposure Diversity* require appropriate design judgment in the interpretation of the software output. Appendix 3 of the ACCA MJ8 describes the procedure to compensate for a house that does not pass the *Test for Adequate Exposure Diversity* by compensating for the load only in those rooms with the inadequate exposure diversity without oversizing the whole system. If the variance shown in the test is not addressed, there will likely be a comfort issue in the rooms with the high glazing load.

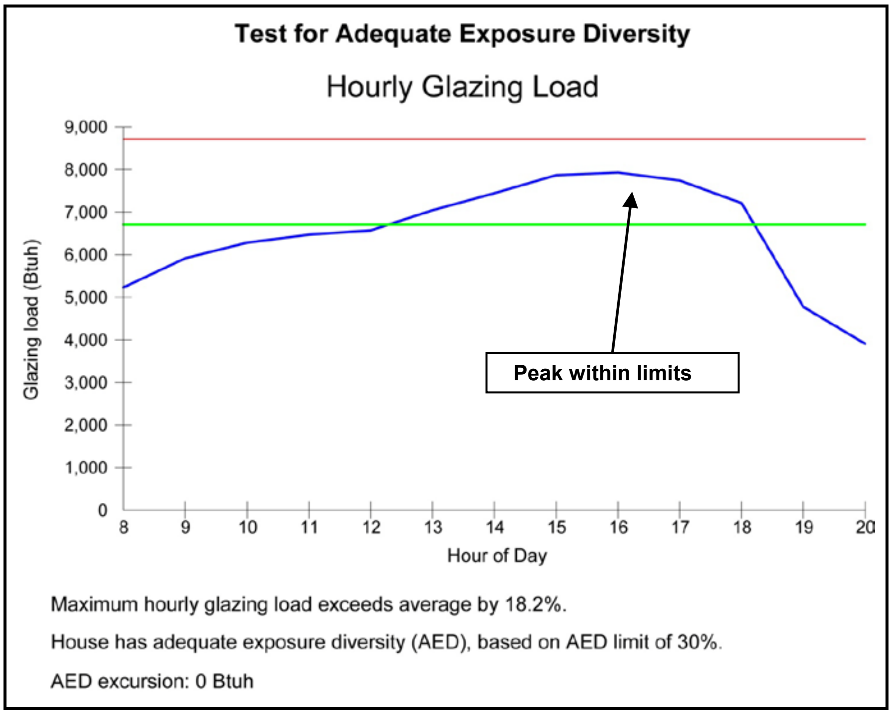

Figure 11. Test for Adequate Exposure Diversity – Pass

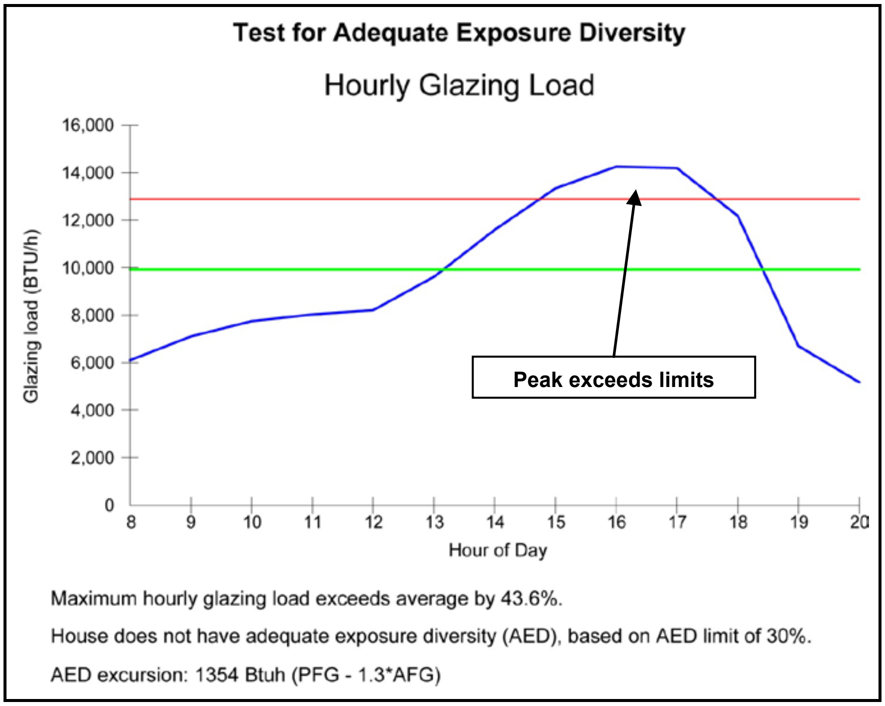

Figure 12. Test for Adequate Exposure Diversity – Fail

Building Components

Building construction, proper details, and materials are critical components of the heating and cooling load calculations. The R-value of the building wall, roof, and foundation construction components can be accurately calculated using the insulation levels specified combined with the remainder of the components that make up the construction assembly (i.e. drywall, sheathing, exterior siding materials, structural framing system, roofing materials, etc.). The window performance, described by the U-value and SHGC, must be known and accurately represented by the data input. Shading provided by the overhang of eaves, insect screens, and internal blinds or shades will reduce the sensible heat gain. If shading is ignored in the load calculation the cooling load will be inflated.

Heating and Cooling System Location and Duct Leakage

Best practice for HVAC design is to keep all ductwork within the conditioned space in order to eliminate the duct losses/gains to and from the outside conditions. Scenarios, such as the one-story slab-on-grade Orlando House, present challenges in keeping all ductwork inside conditioned spaces. In a slab-on-grade house, it is typical for an installer to put the HVAC system completely in the attic. Because it has a basement, the Chicago House does not present the same challenges to keeping the ductwork inside conditioned space. In a single-story house with a basement, the duct system is typically run in the basement, which is considered conditioned space provided the basement walls are insulated or there are supply registers in the basement. For ducts outside conditioned space, the heating and cooling loads are more sensitive to duct leakage and R-values of the duct insulation.

Ventilation/Infiltration

Ventilation and infiltration brings outside air into the conditioned space, impacting the heating and cooling load. The target ventilation and infiltration rate must be accurately represented in the data input of the load calculation. In humid climates, the impact on the latent cooling load added by ventilation/infiltration can be significant.

Risks Associated with Oversizing

Oversizing the HVAC system is detrimental to energy use, comfort, indoor air quality, building, and equipment durability. All of these impacts derive from the fact that the system will be "short cycling" in both the heating and cooling modes. To reach peak operational efficiency and effectiveness, a heating and cooling system should run for as long as possible to meet the loads. An analogy is that of a car: highway driving at a steady speed will get the best fuel economy, while speeding up and slowing down puts undue wear and tear on the engine and braking systems, and reduces fuel efficiency.

First Cost, Energy Costs and Durability

An oversized HVAC system will have both a higher initial cost and a higher cost of operation. The frequent starting and stopping of short cycling can also lead to premature failure of the equipment.

Comfort - Space Temperatures

Short cycling limits the total amount of air circulating through each room, and can lead to rooms that do not receive adequate duration of airflow. Short cycling of an oversized system can lead to comfort complaints when the spaces located further from the thermostat do not change temperature as quickly as spaces near the thermostat. Even in an energy-efficient house with an enhanced thermal enclosure, this can lead some rooms being colder during the heating season and warmer in the cooling season. In attempt to make the spaces further from the thermostat more comfortable, the occupant may set the thermostat set point higher, requiring additional energy.

Comfort - Humidity Control

The risks associated with oversizing the cooling system, particularly in more humid climates, are also a concern. In the cooling season in humid climates, cold clammy conditions can occur due to reduced dehumidification caused by the short cycling of the equipment. The cooling system removes moisture from the air by passing the air across a condensing coil. The system must run long enough for the coil to reach a temperature where condensation will occur and an oversized system that short cycles may not run long enough to sufficiently condense moisture from the air. Excess humidity in the conditioned air delivered to a space may lead to mold growth within the house.

Load Dependencies

Several common safety factors were applied to the baseline models to create examples of how and where load calculations can be inflated leading to system oversizing.

The baseline load calculations used in this Guide were manipulated for:

- Outdoor/Indoor Design Conditions
- Building Components
- Ductwork Conditions
- Ventilation/Infiltration Conditions
- Worst Case Scenario (combining all safety factors).

Outdoor/Indoor Design Condition Dependencies

To illustrate the effects on the load calculation of manipulating the outdoor/indoor design conditions, the indoor conditions were reversed and the outdoor conditions manipulated to the mean extreme temperatures (Tables 4 and 5). Outdoor temperatures for the manipulated models were taken from the Outdoor Mean Extreme temperatures listed in the ASHRAE 2009 Fundamentals handbook. These changes are representative of those the author has observed from designers wishing to bump the system size up for added cushion.

Table 4. Chicago House Manipulated Outdoor/Indoor Design Conditions

Baseline	Manipulated
Outdoor Design Conditions 89°Fdb 73°Fwb Temp Cooling 2°F Temp Heating	*Outdoor Design Conditions* 97°Fdb 78°Fwb Temp Cooling -11°F Temp Heating
Indoor Design Conditions 75°F Temp 50% RH Cooling 70°F Temp 30% RH Heating	*Indoor Design Conditions* 70°F Temp 30% RH Cooling 75°F Temp 50% RH Heating

Table 5. Orlando House Manipulated Outdoor/Indoor Design Conditions

Baseline	Manipulated
Outdoor Design Conditions 93°Fdb 76°Fwb Temp Cooling 42°F Temp Heating	*Outdoor Design Conditions* 96°Fdb 79°Fwb Temp Cooling 30°F Heating
Indoor Design Conditions 75°F Temp 50%RH Cooling 70°F Temp 30% RH Heating	*Indoor Design Conditions* 70°F Temp 30% RH Cooling 75°F Temp 50%RH Heating

The results of changing the outdoor/indoor design conditions while keeping all other parameters for the Chicago House the same are shown in Table 6 and Figure 13. When the system is selected, this manipulation would effectively oversize the cooling system by 1 ton.

Table 6. Results – Chicago House Manipulated Outdoor/Indoor Design Conditions

	Baseline Load	Manipulated Load	Change In Load Btu/h	Change In Load %
Heating Load	41,700 Btu/h	52,700 Btu/h	11,000 Btu/h	26 %
Sensible Cooling	17,400 Btu/h	24,100 Btu/h	6,700 Btu/h	39 %
Latent Cooing	3,200 Btu/h	6,800 Btu/h	3,600 Btu/h	113 %
Total Cooling	20,600 Btu/h	31,000 Btu/h	10,400 Btu/h	51%

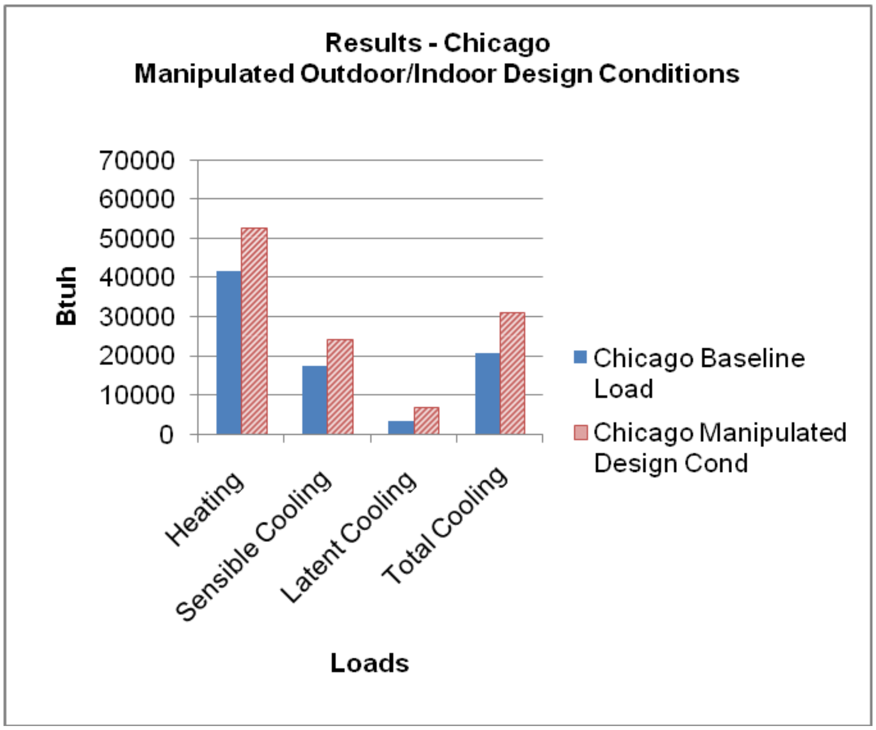

Figure 13. Chicago House Change in Loads, Manipulated Outdoor/Indoor Design Conditions

The results of changing the outdoor/indoor design conditions while keeping all other parameters for the Orlando House the same are shown in Table 7 and Figure 14. When the system is selected, this manipulation would effectively oversize the cooling system by 1 ton.

Table 7. Results - Orlando House Manipulated Outdoor/Indoor Design Conditions

	Baseline Load	Manipulated Load	Change In Load Btu/h	Change In Load %
Heating Load	23,600 Btu/h	37,800 Btu/h	14,100 Btu/h	60 %
Sensible Cooling	16,600 Btu/h	22,900 Btu/h	6,300 Btu/h	38 %
Latent Cooing	4,100 Btu/h	7,100 Btu/h	3,000 Btu/h	73 %
Total Cooling	20,700 Btu/h	30,100 Btu/h	9,400 Btu/h	45 %

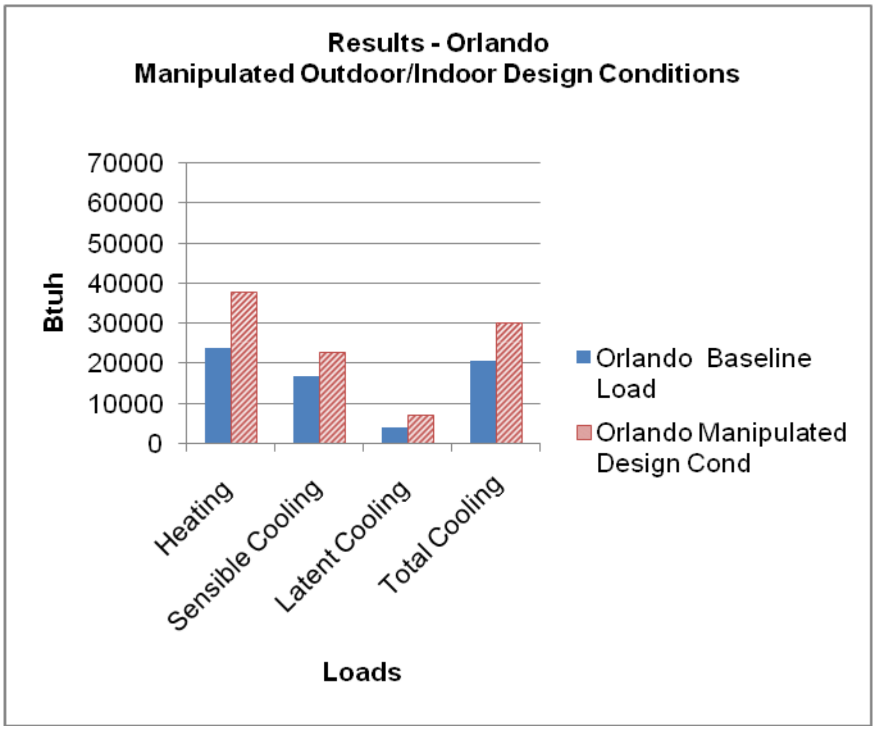

Figure 14. Orlando House Change in Loads, Manipulated Outdoor/Indoor Design Conditions

Building Components Dependencies

To illustrate the effects on the load calculation of adding a safety factor by manipulating or ignoring known building component values and ignoring shading, the building component specifications were changed as shown in Tables 8 and 9.

Table 8. Chicago House Building Component Manipulations

Baseline	Manipulated
Windows U = 0.35, SHGC = 0.5 *Walls* R-19 *Attic* R-38 Full credit for eaves, 50% exterior bug screens, light colored blinds at 45 degrees closed	*Windows* U = 0.45 SHGC = 0.5 *Walls* R-17 *Attic* R-30 No credit for eaves, no bug screens, no blinds

Table 9. Orlando House Building Component Manipulations

Baseline	Manipulated
Windows U = 0.65, SHGC = 0.30 *Walls* Light weight concrete block w/ .75 inch XPS, R-4.8 *Attic* R-31 sealed Full credit for eaves, 50% exterior bug screens, light colored blinds at 45 degrees closed	*Windows* U = 0.65 SHGC = 0.40 *Walls* Light weight concrete block no XPS R-1 *Attic* R-30 vented No credit for eaves, no bug screens, no blinds

The wall R-value downgrade for the Chicago House is equivalent to the designer attempting to account for a poor installation based on the RESNET Grade 3 installation quality level or ignoring the XPS for the Orlando House. The attic insulation and window downgrade are equivalent to the designer not resetting default values or using values lower that the IECC 2009 levels. These changes are representative of those the author has observed from designers wishing to bump the system size up to for added cushion.

The results of manipulating the building components and shading while keeping all other parameters for the Chicago House the same are shown in Table 10 and Figure 15. When the system is selected, this manipulation would effectively oversize the cooling system by ½ ton.

Table 10. Results - Chicago House Building Component Manipulations

	Baseline Load	Manipulated Load	Change In Load Btu/h	Change In Load %
Heating Load	41,700 Btu/h	46,300 Btu/h	4,600 Btu/h	11%
Sensible Cooling	17,400 Btu/h	22,400 Btu/h	5,000 Btu/h	28 %
Latent Cooing	3,200 Btu/h	3,200 Btu/h	0 Btu/h	0 %
Total Cooling	20,600 Btu/h	25,700 Btu/h	5,100 Btu/h	24 %

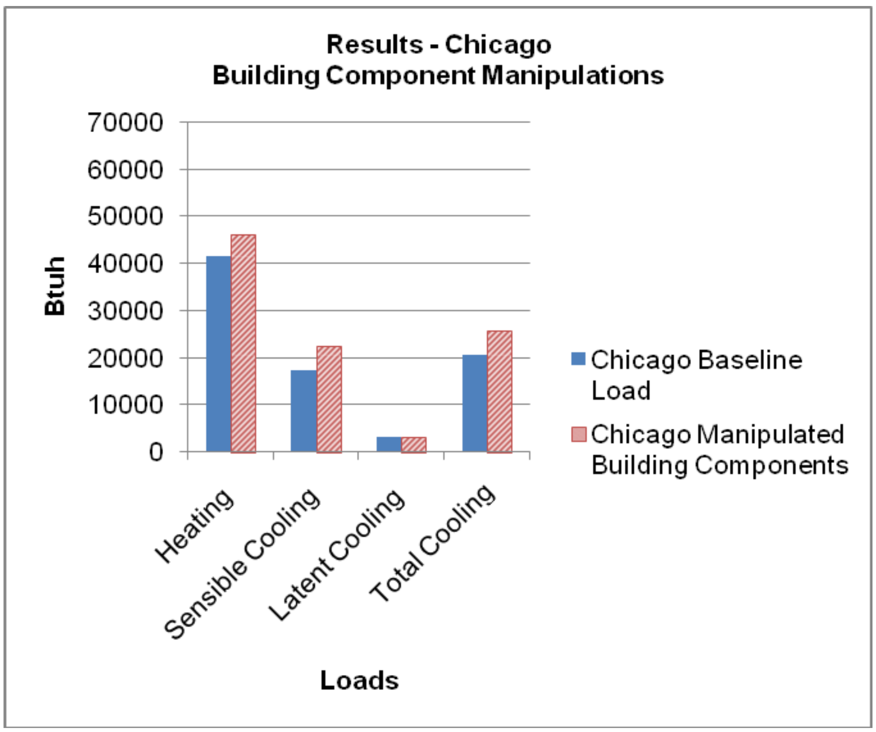

Figure 15. Chicago House Change in Loads, Building Component Manipulations

The results of manipulating the building components and shading while keeping all other parameters for the Orlando House the same are shown in Table 11 and Figure 16. When the system is selected, this manipulation would effectively oversize the cooling system by ½ ton.

Table 11. Results - Orlando House Building Component Manipulations

	Baseline Load	Manipulated Load	Change In Load Btu/h	Change In Load %
Heating Load	23,600 Btu/h	26,600 Btu/h	3,000 Btu/h	12 %
Sensible Cooling	16,600 Btu/h	23,000 Btu/h	6,400 Btu/h	39 %
Latent Cooing	4,100 Btu/h	4,200 Btu/h	100 Btu/h	2 %
Total Cooling	20,700 Btu/h	27,100 Btu/h	6,400 Btu/h	31 %

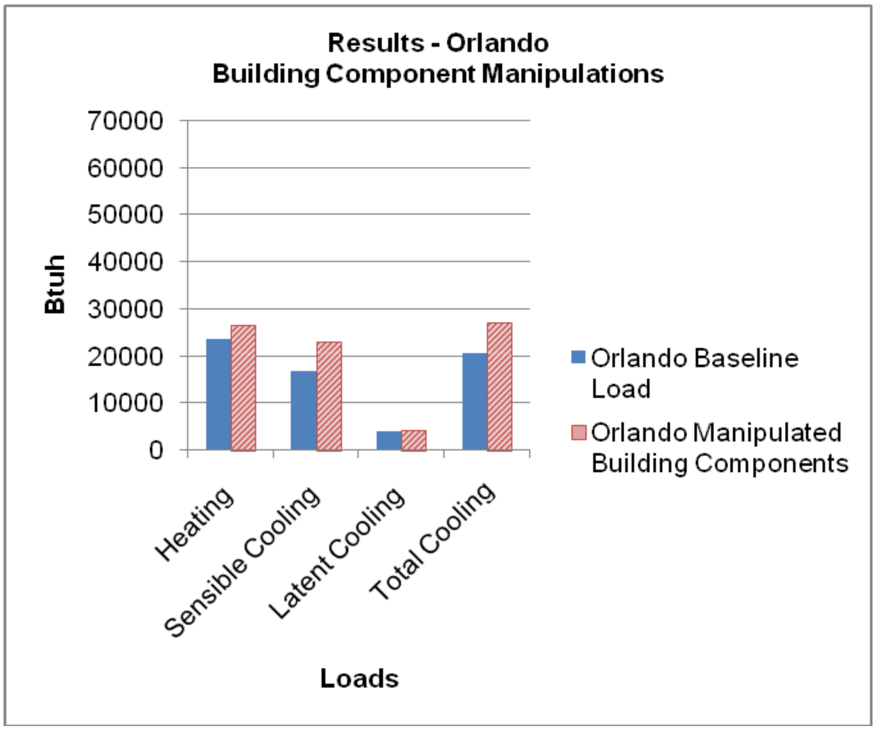

Figure 16. Orlando House Change in Loads, Building Component Manipulations

Ductwork Conditions Dependencies

To illustrate the effects on the load calculation of adding a safety factor by manipulating or ignoring the ductwork conditions, the specifications were changed as listed in Table 12. This manipulation was not performed on the Chicago House since the Chicago House has an insulated basement and duct work in conditioned space. As discussed in the Heating and Cooling System Location and Duct Leakage section of this Guide, the duct systems in single story houses are typically located in conditioned basements. Basements are considered conditioned space provided the basement walls are insulated or they have supply registers. The manipulated duct tightness values used for the Orlando House are the ACCA MJ8 average duct tightness default values.

Table 12. Orlando House Ductwork Conditions Manipulations

Baseline	Manipulated
Tightness level Supply = 0.06 cfm/ft^2 Tightness level Return = 0.06 cfm/ft^2 Insulation = R-8	Tightness level Supply = 0.12 cfm/ft^2 Tightness level Return = 0.24 cfm/ft^2 Insulation = R-6

The results of manipulating the ductwork characteristics while keeping all other parameters for the Orlando house the same are shown in Table 13 and Figure 17. When the system is selected, this manipulation would effectively oversize the cooling system by ½ ton.

Table 13. Results - Orlando House Ductwork Conditions Manipulations

	Baseline Load	Manipulated Load	Change In Load Btu/h	Change In Load %
Heating Load	23,600 Btu/h	26,700 Btu/h	3,100 Btu/h	13 %
Sensible Cooling	16,600 Btu/h	19,100 Btu/h	2,500 Btu/h	15 %
Latent Cooing	4,100 Btu/h	5,100 Btu/h	1,000 Btu/h	24 %
Total Cooling	20,700 Btu/h	24,200 Btu/h	3,500 Btu/h	17 %

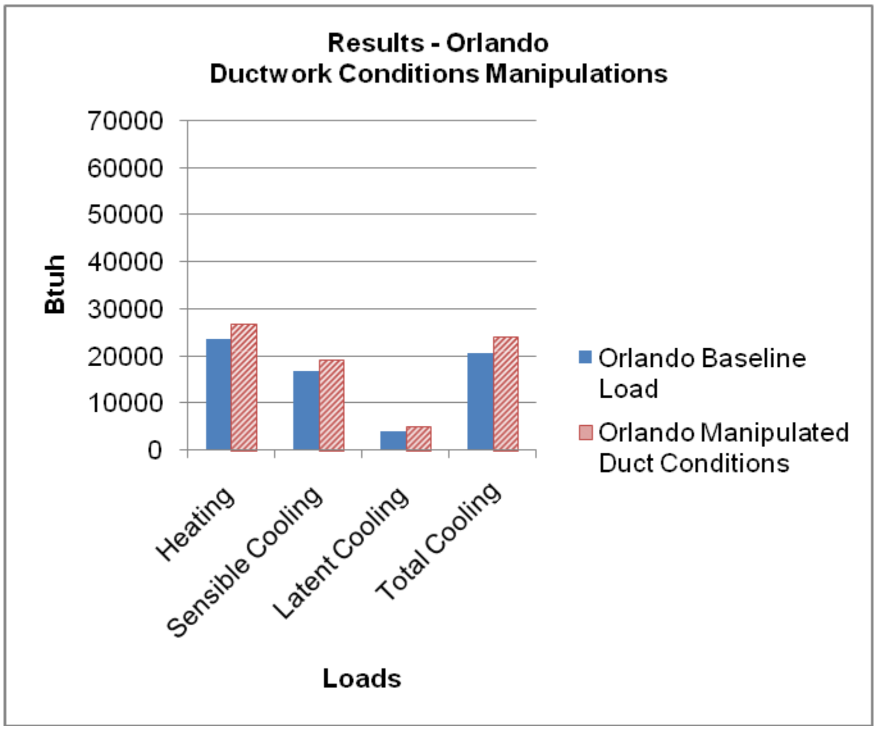

Figure 17. Orlando House Change in Loads, Ductwork Conditions Manipulations

Ventilation/Infiltration Conditions Dependencies

To illustrate the effects on the load calculation of adding a safety factor by manipulating or ignoring the ventilation/infiltration, Tables 14 and 15 show the specification changes using the ACCA MJ8 default infiltration rate of "semi-loose construction" and a ventilation rate of an arbitrary continuous 100 cfm that may have been determined by looking at the combined effect of simultaneously running all the exhaust fans in the house.

Table 14. Chicago House Ventilation/Infiltration Manipulations

Baseline	Manipulated
Heating season infiltration = 0.19 ACHn (5.04 ACH50)	Heating season infiltration = 0.43 ACHn (11.39 ACH50)
Cooling season infiltration = 0.10 ACHn (2.65 ACH50)	Cooling season infiltration = 0.23 ACHn (6.09 ACH50)
Ventilation balanced 60 cfm to meet ASHRAE standard 62.2 without energy or heat recovery	Ventilation exhaust only 100 cfm

Table 15. Orlando House Ventilation/Infiltration Manipulations

Baseline	Manipulated
Heating season infiltration = 0.19 ACH (5.03 ACH50)	Heating season infiltration = 0.43 ACH (11.39 ACH50)
Cooling season infiltration = 0.10 ACH (2.65 ACH50)	Cooling season infiltration = 0.23 ACH (6.09 ACH50)
Ventilation balanced 60 cfm to meet ASHRAE standard 62.2 without energy or heat recovery	Ventilation exhaust only 100 cfm

The results of manipulating the ventilation/infiltration rates while keeping all other parameters for the Chicago House the same are shown in Table 16 and Figure 18. This manipulation alone is not enough to increase the cooling system size.

Table 16. Results - Chicago House Ventilation / Infiltration

	Baseline Load	Manipulated Load	Change In Load Btu/h	Change In Load %
Heating Load	41,700 Btu/h	46,600 Btu/h	4,900 Btu/h	12 %
Sensible Cooling	17,400 Btu/h	17,900 Btu/h	500 Btu/h	3 %
Latent Cooing	3,200 Btu/h	4,100 Btu/h	900 Btu/h	28 %
Total Cooling	20,600 Btu/h	22,000 Btu/h	1,400 Btu/h	7 %

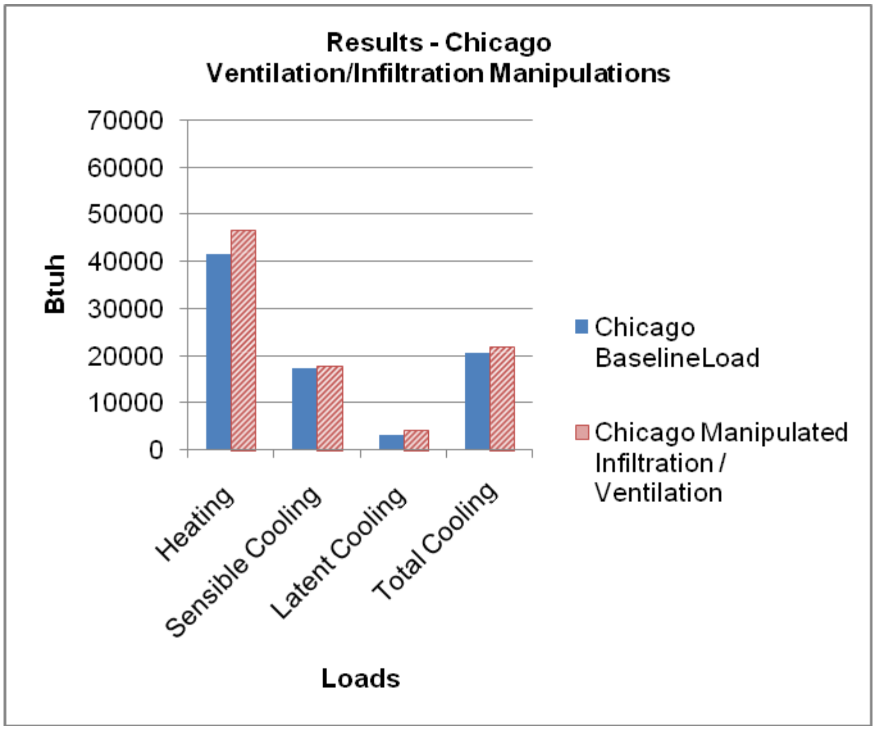

Figure 18. Chicago House Change in Loads, Ventilation/Infiltration Manipulations

The results of manipulating the ventilation/infiltration rates while keeping all other parameters for the Orlando House the same are shown in Table 17 and Figure 19. This manipulation alone is not enough to increase the cooling system size.

Table 17. Results – Orlando House Ventilation/Infiltration

	Baseline Load	Manipulated Load	Change In Load Btu/h	Change In Load %
Heating Load	23,600 Btu/h	25,600 Btu/h	2,000 Btu/h	9 %
Sensible Cooling	16,600 Btu/h	17,300 Btu/h	700 Btu/h	4 %
Latent Cooing	4,100 Btu/h	5,200 Btu/h	1,100 Btu/h	27 %
Total Cooling	20,700 Btu/h	22,500 Btu/h	1,800 Btu/h	9 %

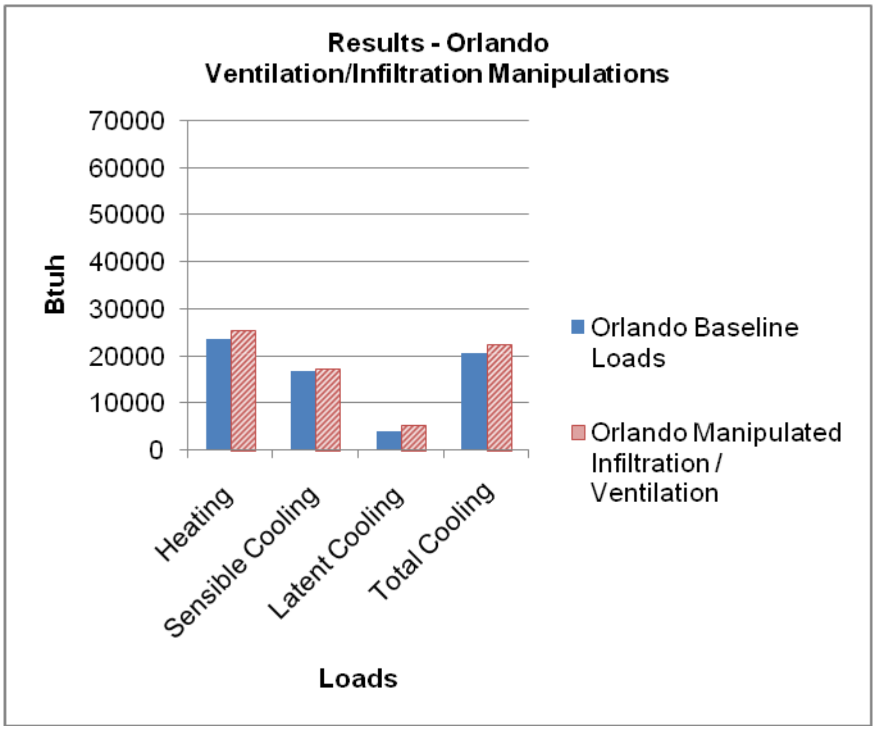

Figure 19. Orlando House Change in Loads, Ventilation/Infiltration Manipulations

Combined Dependencies

Each of the safety factors applied to the outdoor/indoor design conditions, building components, ductwork conditions, or ventilation/infiltration conditions outlined above has its own impact on the heating and cooling loads. But, a more significant impact occurs when the safety factors are combined. The compounding of safety factors will result in an inflated load that cannot be relied upon for the remaining steps of the HVAC design process. To illustrate the effects on the load calculation of the compounded safety factors, all of the individual impacts were applied to the baseline models.

The results of combining the manipulations while keeping all other parameters for the Chicago House the same are shown in Table 18 and Figure 20. When the system is selected this manipulation would effectively oversize the cooling system by 1½ tons.

Table 18. Results - Chicago House Combined Manipulations

	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 %

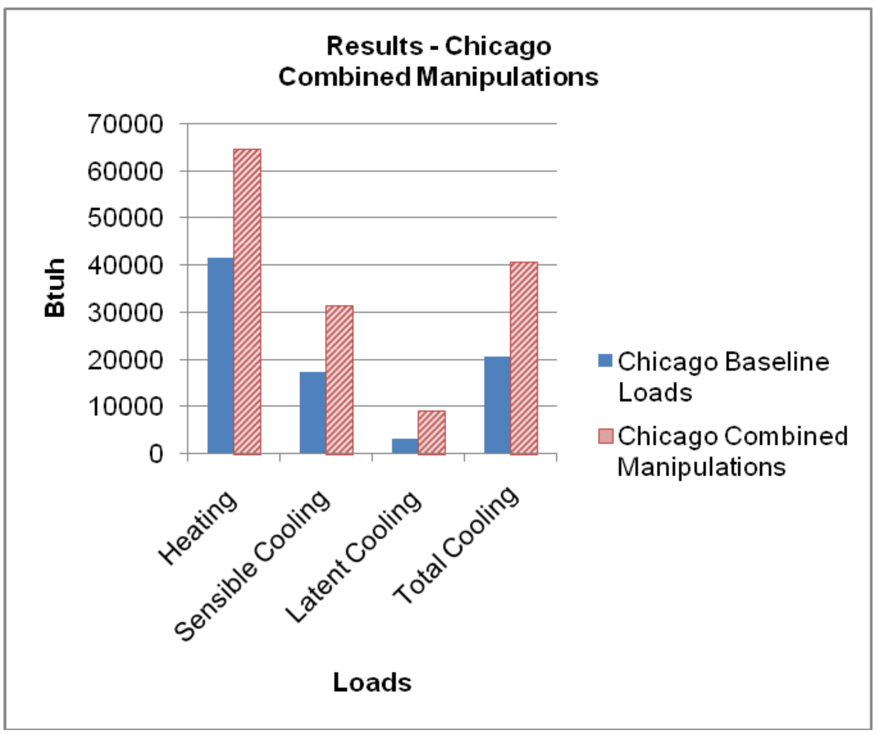

Figure 20. Chicago House Change in Loads, Combined Manipulations

The results of combining the manipulations while keeping all other parameters for the Orlando House the same are shown in Table 19 and Figure 21. When the system is selected, this manipulation would effectively oversize the cooling system by 3 tons.

Table 19. Results - Orlando House Combined Manipulations Results

	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 %

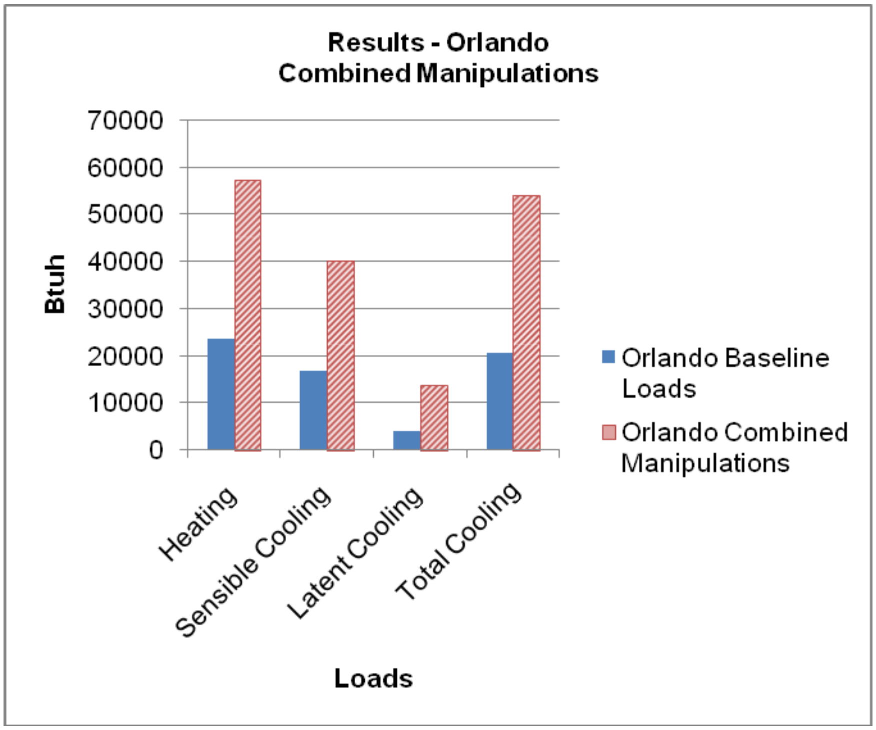

Figure 21. Orlando House Change in Loads, Combined Manipulations

Conclusion

Right-sizing the HVAC system begins with an accurate understanding of the heating and cooling loads on a space. The values determined by the heating and cooling load calculation process dictate the equipment selection and the duct design needed to deliver conditioned air to the rooms of the house to meet the occupant's comfort expectations.

Examples in this guide showed the implications when inaccurate or inappropriate adjustments are applied during the heating and cooling load calculation process. Seemingly small manipulations such as changing the outdoor/indoor design conditions can result in exaggerated loads. For example, the Orlando House manipulations of outdoor/indoor design conditions showed a 9,400 Btu/h (45%) increase in the total cooling load, which may increase the system size by 1 ton when the ACCA Manual S procedures are applied.

Combining several adjustments only compounds the inaccuracy of the calculation results. The results of the combined manipulations to outdoor/indoor design conditions, building components, ductwork conditions, and ventilation/infiltration conditions produce significantly oversized calculated loads. The Orlando House example showed a 33,300 Btu/h (161%) increase in the calculated total cooling load, which may increase the system size by 3 tons (from 2 tons to 5 tons) when the ACCA Manual S procedures are applied. Not only does this oversizing impact the heating and cooling equipment costs, but duct sizes and numbers of runs must also be increased to account for the significantly increased system airflow.

Again, ACCA MJ8 says of compounding safety factors:

> *"Research studies and the experience of multiple system designers indicate that aggressive use of Manual J procedures provides adequate accuracy. No additional safety factors are required when load estimates are based on accurate information pertaining to the envelope construction and duct system efficiency. Large errors are possible if there is uncertainty about insulation levels, fenestration performance, envelope tightness or the efficiency of the duct runs installed in the unconditioned space."*

The compounding of arbitrary safety factors must be avoided in the load calculation process. The HVAC design industry's practice of using extreme outdoor design conditions, de-rating the insulation value, and over-estimating the infiltration rate render the calculated load values meaningless.

References

O'Neal, Dennis L. et.al. ASHRAE 2009 Fundamentals Volume. Atlanta, GA: ASHRAE. 2009.

Rutkowowski P.E., Hank. Manual J Residential Load Calculation Eighth Edition Version Two. Arlington, VA: ACCA. 2006

National Renewable Energy Laboratory (NREL). Typical Meteorological Year 3 Data Set. NREL Website. http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/. 2008.

Appendix A: Enhancements to Scope for Mechanical Contractor/HVAC Manual J Designer

Design Analysis to be completed by Engineer or Contractor, also known as the "Designer"

Calculations to be performed using ACCA Manual J Version 8 Prerequisites:

- All inputs/defaults/building characteristics used for the ACCA Manual J Version 8 calculations must be verified by the HVAC contractor/Mechanical designer in the field and/or must be verified and signed off by the builder that is what is being built consistently across all of the builder's houses in that community or division.
- Design conditions as listed in Table 1A of ACCA Manual J version 8 for the following city shall be used <insert city>. Indoor conditions shall be 75°F Temp 50% RH Cooling and 70°F Temp 30% RH Heating

The "Designer" shall provide the following information to the builder and HVAC installer:

- Provide room-by-room and building heat gain/loss demand loads based on installed lights and equipment, envelope heat transfer, occupants, required ventilation and all other factors normally considered in these calculations. Loads are to be determined by analysis of actual load calculations performed using ACCA Manual J Version 8 and not by "rules of thumb".
- Determine room supply, return or exhaust air requirements based on the heat gain/loss calculations, total and outside air change requirements, and temperature, humidity, ventilation, and pressurization criteria for each room or space.

Appendix B: ACCA Manual J8 Input Checklist

House Location (city, state)... ____________________

House Orientation... ____________________

*Complete set of construction drawings including all options are necessary to properly perform a Manual J8 analysis.

Insulation R-Values

Foundation

- Basement Depth below grade .... ____________________
- Crawlspace Depth below grade .... ____________________
- Soil Type .... ____________________
- Wall Type (concrete, ICF, CMU, brick, stone, AWW, metal frame) ..... ____________________
- Foundation Wall Thickness .... ____________________
- Insulation Type .... ____________________
- Insulation Location .... ____________________
- Insulation R-Value .... ____________________

Walls

Stud Walls

- Stud Spacing .... ____________________
- Stud Depth .... ____________________
- Drywall Thickness .... ____________________
- Exterior Sheathing Type .... ____________________
- Insulation Type .... ____________________
- Insulation Location .... ____________________
- Insulation R-Value .... ____________________

Non-Stud Walls

- Wall Thickness .... ____________________
- Drywall Thickness .... ____________________
- Insulation Type .... ____________________
- Insulation Location .... ____________________
- Insulation R-Value .... ____________________

Floors Over Unconditioned Space

- Sheathing Type .... ____________________
- Insulation Type .... ____________________
- Insulation Location .... ____________________
- Insulation R-Value .... ____________________

Attic

- Insulation Location .... ______________________
- Insulation R-Value .... ______________________
- Roofing Type .... ______________________
- Sealed or Ventilated.. ______________________

Windows

- U–value .... ______________________
- SHGC .... ______________________
- Low-E or Clear Glazing .... ______________________
- Number of Panes .... ______________________

Air Infiltration

- Building Envelope Leakage Rate .... ______________________

Ductwork

- Insulation Value .... ______________________
- Location .... ______________________
- Leakage Rate .... ______________________

Ventilation

- Ventilation Rate .... ______________________
- Continuous or Intermittent Ventilation.. ______________________

Space Conditioning Zoning

- Multi Zone .... ______________________
- Single Zone .... ______________________

Stop Work – Do Not Proceed If:

IF there is not a complete set of construction drawings clearly identifing areas and dimensions of all exterior surfaces.	**THEN** obtain from the builder a complete set of construction drawings clearly identifing areas and dimensions of all exterior surfaces.
IF the exact specifications for roof/attic assembly i.e. roofing material, radiant barrier, insulation levels are not known.	**THEN** obtain from the builder the exact specifications for roof/attic assembly i.e. roofing material, radiant barrier, insulation levels.
IF the exact specifications for wall assembly i.e. cladding material, insulation levels are not known.	**THEN** obtain from the builder the exact specifications for wall assembly i.e. cladding material, insulation levels.
IF the exact specifications for windows/doors i.e. U-value, SHGC are not known.	**THEN** obtain from the builder the exact specifications for windows/doors i.e. U-value, SHGC.
IF the exact specifications for air tightness, duct tighness and location, infiltration and ventilation rates are not known.	**THEN** obtain from the builder the exact specifications for air tightness, duct tightness and location, infiltration, and ventilation rates.

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