Introduction to Heating System Sizing

Heating Systems for Energy Auditors and Inspectors

Key Terminology

Air Changes per Hour (ACH)

Air Conditioning Contractors of America (ACCA)

Air leakage heat loss

British Thermal Unit (BTU)

British Thermal Unit per Hour (BTUH)

Conduction

Convection

Cubic feet (ft^3)

Cubic Feet per Minute (CFM)

Design Heat Load (DHL)

Exfiltration

Heat capacity of air

Infiltration

Internal gain

Lawrence Berkeley Laboratory (LBL) number

Manual J, Residential Load Calculation

National Energy Auditor Tool (NEAT)

N-factor

Pascal (Pa)

Radiation

R-value

Short cycling

Sizing multiplier

Solar gain

Surface heat loss

Thermal envelope

U-factor

Section Transition

Learning Objectives (Slide #2)

By attending this session, participants will gain an understanding of**:**

- The two main causes of heat loss in a dwelling: surface heat loss and air leakage heat loss.
- How to evaluate the heating system sizing calculations of system installers.
- The methods of heating system sizing used in *Manual J, Residential Load Calculation*.
- The disadvantages of oversizing a heating system.

It will be helpful if the trainer reviews Manual J, 7th edition before presenting this unit.

Calculating Heat Loss #1 (Slide #3)

- The heat loss of a dwelling is called the ***design heat load (DHL)***.
  - DHL is a new term in ***Manual J*, *Residential Load Calculation***, the standard resource for residential load calculation prepared by the ***Air Conditioning Contractors of America (ACCA)***.
- The DHL is always expressed in ***British thermal units per hour (BTUH)***.
  - A ***British thermal unit (BTU)*** is the amount of thermal energy required to increase the temperature of 1 pound of water by 1°F.
- Once the DHL is calculated, a ***sizing multiplier*** is used to increase the DHL by a small percentage to account for degradation of the efficiency of the heating system over time.
  - The sizing multiplier for gas-fired systems is 1.1.
  - The sizing multiplier for oil-fired systems is 1.2.
- Note that the sizing multiplier for oil-fired equipment is larger than for gas-fired equipment. This is because oil-fired equipment gets dirty faster, causing its efficiency to degrade faster. As efficiency decreases, the output of the heating system decreases. The slight oversizing that the sizing multiplier brings to the process ensures there will always be enough heat output to keep the dwelling warm.

Calculating Heat Loss #2 (Slide #4)

- For example, if the DHL of a house in a northern climate is found to be 50,000 BTUH, the gas-fired system installed would be the DHL times the sizing multiplier, or 50,000 BTUH x 1.1 = 55,000 BTUH.
  - A gas furnace or boiler with 55,000 BTUH output rate is appropriate for this dwelling.
  - If an oil-fired unit were installed in this house, the calculation would be 50,000 BTUH x 1.2 = 60,000 BTUH output.
  - For certified heating equipment, see www.ahridirectory.org/ahriDirectory/pages/home.aspx.
- If a distribution system is being installed, the heat loss for each room must be calculated to determine the appropriate size of the system.
  - Generally, only heating systems are being replaced in weatherization work, so it is not necessary to size the heat distribution for each room.
  - If room-by-room sizing is required, only the heat loss surfaces in each room are considered—that is, only the surfaces that are part of the ***thermal envelope***.
  - If a room has no surfaces that are part of the thermal envelope, it has no heat loss and does not need a heat distribution unit (a heat register for a furnace or a hot water unit for a hot water boiler).
  - For rooms with surfaces that are part of the thermal envelope, the ***air leakage heat loss*** is rather difficult to allocate to each room. *Manual J* assumes all the air leakage occurs through windows and doors, so it breaks down the total dwelling air leakage by the total square footage of windows and doors in the dwelling.

Calculating Heat Loss #3 (Slide #5)

- Energy auditors should know enough about the sizing procedure to check the installers' work.
    - The ***National Energy Auditor Tool (NEAT)*** calculates the hourly heat loss of a dwelling. This can be used to check the installer's sizing calculation.
- The installer should ALWAYS supply the energy auditor with a DHL (sizing) calculation document for the job.
    - If an installer will not submit a written sizing document, the energy auditor should seriously consider using a different installer. We have very few chances to size a heating system correctly; we must do it right when we have the chance.

Distribute the sample Manual J Load calculation for reference.

- The standard sizing procedure is based on *Manual J*. Most installers use computer software based on this method.
- The installer's equipment supplier commonly performs the actual sizing for the installer.
- Many equipment suppliers have a person on staff who sizes heating systems. This can work very well if this person receives the correct data for the dwelling.
- The energy auditor will likely supply the data. Be sure to provide clear, written documentation, including the relevant ***R-value***, ***U-factor*** (the inverse of R-value), and ***air changes per hour (ACH)***.

Provide examples of U-factor and R-value conversions:

1/R =U

1/14 =0.071

and

1/U=R

1/0.071=14

Calculating Heat Loss #4 (Slide #6)

- To determine the DHL of a dwelling, we must calculate the following for a 1-hour period at design temperatures:
    - ***Surface heat loss*** through all surfaces of the thermal envelope.
    - Air leakage through the thermal envelope (above grade only).
- ***Solar gain*** and ***internal gain*** are not calculated. Both reduce heat loss, but we cannot count on them as there is no sun on cloudy days and at night and we cannot depend on people being in the dwelling for internal gain. However, both are included when sizing cooling systems because they impose a load on cooling equipment.
- Design temperature is the difference between 70°F (the assumed indoor temperature) and the outdoor design temperature. For example, if the outdoor design temperature is 10°F, the design temperature is 70°F – 10°F = 60°F. Always assume the indoor temperature is 70°F.

- The outdoor design temperatures are available in *Manual J*. Normally, the outdoor design temperature is the "97½%" design temperature. If the 97½% design temperature is 10°F, it means that during the three coldest months of the heating season (December, January, and February), the outdoor temperature is 10°F or warmer 97½% of the time and colder than 10°F 2½% of the time. This method prevents oversizing of the heating system by making the system the correct size for all but the coldest days. Even on days colder than the 97½% design temperature, the heating system will supply enough heat because of internal gains and thermal energy stored in building materials and house furnishings.

- Designers of heating systems—especially if they are also the installers—tend to use a colder outdoor temperature for the calculation than *Manual J* states. This results in installation of an oversized system, which wastes energy and reduces the life of the system because of ***short cycling***. It is important to use *Manual J* to size systems.

Surface Heat Loss Components (Slide #7)

- There are always at least five heat loss surfaces in a dwelling: ceilings/roofs, walls, floors, windows, and doors.
    - The types of building components vary widely in many homes. For example, most houses have two or three different window types and at least two wall types (wood above grade and masonry below grade). While the minimum is five surface types, some houses have 10 to 15.
- If two parts of the ceiling in a house have different R-values, heat loss must be calculated for each one. The same is true for other building assemblies.
    - R-value is the resistance to heat transfer through a building surface.

Assembly R-values (Slide #8)

- Building envelopes generally consist of layers of materials. Each one resists heat flow.
- In addition, each layer that is not in physical contact with another layer has an air film that also resists heat flow.
- The pictured assembly has ½" drywall, 3½" fiberglass, 2" x 4" framing, ½" plywood, building wrap, and clapboard siding.
- The assembly has a total theoretical R-value of ≈ 14. In reality, it will test ≈ 20% lower at ≈ R-11.
    - The R-value for almost every material is listed in books and on websites.
    - To calculate the R-value of an assembly, find the R-value for each component and add the R-values together. Remember that the result is theoretical. Any audit protocol or software will de-rate an assembly by some percentage—the infamous fudge factor—to bring the calculated heat loss more in line with actual performance based on fuel use.
    - It is generally safe to rate an uninsulated wall assembly as R-3, a ceiling with no attic floor as R-1, and a ceiling with an attic floor as R-2.

- A properly insulated wall or ceiling assembly will approximate the insulation R-value less 10%. So if there is R-11 insulation in the attic, the assembly would be rated at R-10 (11 – 10% = 9.9 ≈ 10).[1]

Surface Heat Loss (Slide #9)

- Surface heat loss = A x ΔT/R. This is the basic surface heat loss equation used by *Manual J.*
  - A = area in square feet.
  - ΔT = difference in temperature in °F.
  - R = total resistance of assembly to heat flow.
- Surface heat loss is calculated in BTUH.
- This equation must be used for each heat loss surface of the building envelope.
- The surface loss formula can also be written A x ΔT x t x U. This is useful for calculating heat loss through windows and mobile home insulation, which are always listed by U-factor rather than R-values. Doors are sometimes listed by U-factor. In this equation, the small t indicates time in hours.

Refer to the "Calculating Envelope Energy Loss" section of the Energy Auditor – Single family curriculum for more on these formulas.

  - U = U-factor or heat transmittance.
  - Because R-value is the inverse of U-factor (U = 1/R and R = 1/U), these equations are equivalent.
  - R-values can be added.
  - U-factors cannot be added.

Example: Wall Section Surface Loss (Slide #10)

Given the following characteristics, what is the heat loss?

- 8' x 12' wall with no windows = 96 sq. ft.
- 70°F inside, 30°F outside = 40°F ΔT.
- R-11 for the wall assembly.
  - The nominal R-value is the R-value (resistance to heat transfer) through the interior and exterior sheet materials and through the insulation.
  - The actual R-value is a weighted average of the R-value through the insulation and the framing members, considering the sheet materials.

Wall Section Surface Loss Calculation (in BTUH):

- (96 sq. ft. x 40°F x 1 hr)/11 ft^2, °F, hr/BTU= 349 BTUH

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[1] Krigger, John T., and Chris Dorsi. *Residential Energy Cost Savings and Comfort for Existing Buildings*. 4th ed. New York: Saturn Resource Management, 2004, p. 274.

Have students work through the problem on scrap paper.

Click to reveal answers to calculations on slide.

Air Leakage Heat Loss (Slide #11)

- This EPA ENERGY STAR illustration shows ***infiltration*** and ***exfiltration*** patterns in a typical single-family home before air sealing.
- Energy moves by ***conduction***, ***convection***, and ***radiation***.
  - Insulation deals with conduction and radiation by trapping tiny air pockets, which slow conductive and radiant energy flow.
  - Insulation has, at best, a minimal effect on convective (air-transported) energy flow. Air sealing in conjunction with insulation is necessary to control convective energy loss.
- Broadly speaking, the building industry has mastered insulation. Any reasonably competent tradesman can install insulation properly. (Quality control can be an issue, as "can" does not always equal "will.")
- On the other hand, few outside the weatherization program understand the value of air sealing.

Measuring Air Leakage (Slide #12)

- There are various methods for measuring or estimating the air leakage of a house during the heating season, but a blower door test is the most accurate.
  - Depressurize or pressurize a house to a pressure difference of 50 ***pascals (Pa)*** and then measure the flow through the blower door fan.
- There are a number of methods for translating the blower door test results into useful information. Most often, the ***cubic feet per minute (CFM)***$_{50}$ blower door result is changed into ACH, which is the number of times one house volume of air leaks through the house in 1 hour.

$$\text{ACH} = \frac{\text{CFM}_{50} \text{ x } 60 \text{ minutes/hour}}{\textbf{\textit{N-factor}} \text{ x volume}}$$

  - (2,500 CFM50 x 60 min/hr) / (14 N-factor x 10,500 cubic feet) = 1.02 ACH

Give students the house characteristics and have them work through problem on scrap paper.

Reveal answers to calculations.

  - The N-factor (sometimes called the ***Lawrence Berkeley Laboratory (LBL) number***) establishes the relationship between the house's leakage at 50 Pa with a blower door and its leakage on average during the heating season.
  - The volume is usually only the above-grade volume.

Measuring Air Leakage Heat Loss (Slide #13)

- Values required for measuring air leakage heat loss are:
  - The temperature difference between the indoors and outdoors at design conditions (outdoor design temperatures are available in *Manual J*).
  - The ***cubic feet (ft^3)*** of air leakage through the house for a given time period.
- The important part of the house for this calculation is the above-grade volume within the thermal envelope.
- To find the number of cubic feet of air moving through a dwelling in 1 hour, multiply the volume above grade by ACH.

Air Leakage Heat Loss (Slide #14)

- The basic *Manual J* equation for calculating heat loss due to air leakage is:

$$V \text{ x } ACH \text{ x } 0.0182 \text{ BTU/ft}^3, \text{°F x } \Delta T$$

  - V = volume of the building.
  - ACH = air changes per hour.
  - 0.0182 BTU/ft^3,°F = ***heat capacity of air***.
  - ΔT = the difference between the indoor temperature and the outdoor design temperature.
- Air leakage heat loss is calculated in BTUH.
- The heat capacity of air (0.0182 BTU/ft^3, °F at sea level) is the number of BTUs needed to raise the temperature of 1 cubic foot of air 1°F. This is a constant. One cubic foot of air is about the size of a basketball.
- This equation is used only once for each dwelling.

Example: Uninsulated ranch – Heat loss through air infiltration

- Volume = 4,800 ft^3
- ΔT = 40°F.
- ACH = 1.25.

How many BTUH are lost through air infiltration?

- V x ACH x 0.0182 x ΔT
  - 4,800 cu. ft. x 1.25 ACH x (0.0182 BTU/ft^3, °F) x 40°F = 4,368 BTUH

Have students work through the problem on scrap paper.

Reveal answers to calculations.

Calculating Volume (Slide #15)

- To calculate heat loss through air infiltration, we need to calculate the volume within the thermal envelope that is above grade.
- Volume = length x width x height.

Q: What is the volume of this rectangular prism?

A: 30 ft. x 20 ft. x 8 ft. = 4,800 ft^3

Let students do calculations themselves on scrap paper.

Click to reveal the volume within the rectangle.

Putting It All Together (Slide #16)

- This simplified form shows how the final heating system output value is derived.
- These nice round numbers are representative in magnitude, but they are not derived from an actual house.
- Because all the individual calculations for surface heat loss and air leakage heat loss have the same mathematical units, they can all be added together to get the total of 42,300 BTUH.
  - The yellow cells indicate surface heat loss.
  - The pink cells indicate air leakage heat loss.
- For this example, a heating system of 46,530 BTUH or a bit larger would be selected.
- Of course, it is necessary to be practical. What if no systems for 46,530 BTUH are available? The installer must then move up to the next larger size.
- If an installer has only an 80,000 BTUH system in the warehouse (oversized by more than 40%), look for another supplier or installer. A system should never be oversized by more than 25%.
- Note that air leakage heat loss is about 47% of the total heat loss (20,000 BTUH/42,300 BTUH). Air leakage generally accounts for 30%-50% of the total.

Load Calculation Manual #1 (Slide #17)

- As of early 2011, the 7th edition is the best resource for the *Manual J* method. It is much less expensive than the 8th edition and much easier to understand. This manual includes enough information for the energy auditor to check the work of the person doing the calculation.

Load Calculation Manual #2 (Slide #18)

- The 8th edition of *Manual J*, both the abridged and unabridged versions, are significantly more expensive and complex than the 7th edition. The advantages of the 8th edition are primarily in the area of sizing cooling systems, rather than sizing heating systems.

Summary (Slide #19)

- Energy auditors need to understand proper sizing of heating systems to ensure that new heating systems are not oversized.
- Oversizing the heating system wastes energy and shortens the life of the system.
- The two main reasons for heat loss in dwellings are surface heat loss and air leakage heat loss.
- *Manual J* is the standard for sizing heating systems for dwellings. This method is the basis for most of the computer software programs available.