Comfort Heating:

Introduction

Lessons 1 to 7

Your Course Materials

You are about to join thousands of other active people in the heating and air-conditioning industry who have found these workbooks a convenient way to continue their job-related training and education.

Your course materials have been specially prepared to make distance learning easy as well as convenient.

Your course materials include:

- A **text section**, which includes all of your learning information, drawings, tables, and charts. You will read assignments in the text section to expand your knowledge of the subject.

- **Self-check quizzes**, which are found in the text section at the end of each lesson. You should take these quizzes to monitor your progress toward learning the materials. An answer key provides all of the correct quiz answers, and can be found in the final appendix to the text section.

- **Online unit exams** are provided separately from the text section. Every workbook course has a specific number (2 to 4) of exams that will officially mark and track your learning progress. Unlike the self-check quizzes, the unit exams are intended to be an official record of your course completion.

- **Extra resources.** Some workbook courses may come with additional resources, such as additional workbooks, audio files, etc. These resources may be found in the appendixes or in separate files. These resources will be valuable to your learning, but the topics are usually not covered in the unit exams.

Course Content

Learning Objectives

This course is designed to provide an overview of the principles, products and systems used in modern small system heating for individuals having little or no knowledge about comfort heating.

Upon successful completion of all assignments and tests in this course, the student-employee should be able to:

1. Describe what is required to keep people comfortable in winter.

2. List the building characteristics and weather conditions that affect building heat loss.

3. Identify components in ordinary forced air heating systems and understand the function they perform.

4. Use and understand the meaning of selected technical terms encountered in the industry.

You will demonstrate accomplishing these objectives by successfully completing two written examinations during the training period.

Learning Tips

Many distance learning students might find these tips on how to study offered by Dr. Francis Robinson, The Ohio State University, worthy of consideration.

Dr. Robinson recommends the **SQ3R method.** The SQ3R method of reading assignments helps you to study more effectively. SQ3R is a formula that represents the words **Survey, Question, Read, Recite** and **Review.** This is how to use the formula.

1. **Survey** - Page through the lesson. Read the title, headings, sub-headings, the first paragraph or two, and the last paragraph. Study the illustrations, pictures, graphs, charts, and tables. Relate this information to what you already know.

Read notable notes found throughout the course. They are extended comments much as an instructor would offer when going over a lesson in class.

2. **Question** - Page through the lesson a second time. This time, ask questions about the material in the lesson. Turn the title, headings, and sub-heading into questions by adding who, how, what, where, when, and why. Form your own questions.

3. **Read** - Read the lesson and look for answers to your questions. Think along with the author; anticipate what the author is going to say. Use a dictionary to find the meaning of any words that you don't know.

4. **Recite** - Look away from the material and tell yourself what you have just read. Try to answer your questions from memory. Do this immediately after you finish each section of the lesson and immediately after you finish each lesson.

5. **Review** - Complete the self-check quizzes to see how much you remember. Use the answer key to see how well you did. Then, go back to the textbook to review the questions that you missed. The reference page where each answer can be found is also provided in the answer key.

If you follow the SQ3R formula method of reading and studying, you will be well-prepared to take each examination. Send only the examinations to the school for grading; do not send in the self-check quizzes.

Get Started Right Away. Turn to Lesson 1.

Lesson 1 Overview

We want to capture your interest. So, we decided to touch on all the key issues affecting comfort heating in this very first chapter. We call it ---**The Challenge.**

We're going to list the comfort conditions that must be controlled, describe the problems involved in moving air through a duct system, highlight the performance requirements of supply outlets, and name important design guides and safety standards.

Obviously, in subsequent chapters will go over each "issue" in greater detail.

Now read Lesson 1 which begins on the next page.

Lesson 1: The Comfort Challenge

"Leslie Andrews, your system is designed to maintain 75 degrees inside when it's 10 below zero outside and the wind is blowing at 15 mph. During the summer, it'll stay 75 inside when the hot sun is beating down on your house and its 100 degrees in the shade"

That's quite a feat when you really think about it. No matter what the weather, the Andrews' home, apartment, or office will be comfortable all year long.

Let's review in total the *comfort challenge* in this, your first lesson. *(Don't worry about remembering all of it. This is just to peak your interest.)*

It's been said that necessity is the mother of invention. Because the weather in North America is, or can be, extreme for extended periods of time, North Americans have by necessity produced reliable and economical whole-house heating and cooling systems.

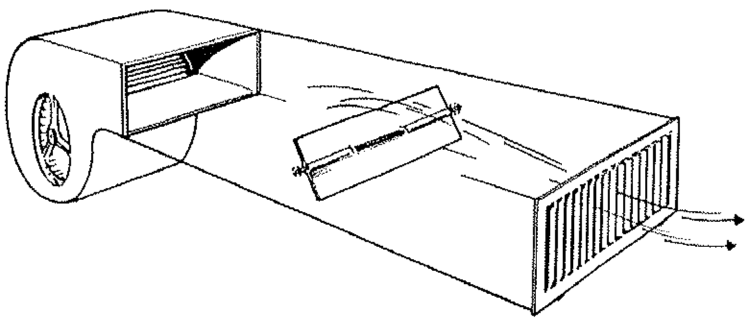
Certainly the beachcomber in some tropical Pacific "paradise" has no incentive to be concerned with furnace combustion problems when the temperature on his atoll is a breezy 77 degrees all year long. A major heating and air conditioning industry exists in North America because of a real need.

(If you haven't read "Overview — The Air Conditioning Industry" in the Introduction, you may want to pause and read it now.)

Control of Air -- The Key

What's the basic problem? We need surprisingly little air to sustain life. Relaxed, each of us consumes about 0.8 cubic foot of oxygen and produce 0.7 cubic foot of carbon dioxide per hour. An air supply of but one cubic foot per minute per person in an enclosure is quite adequate to replenish the oxygen consumed and to purge any build-up of exhaled *carbon dioxide.*

But while we need little air to survive, we do need considerable air, and properly treated air, to be made *comfortable.*



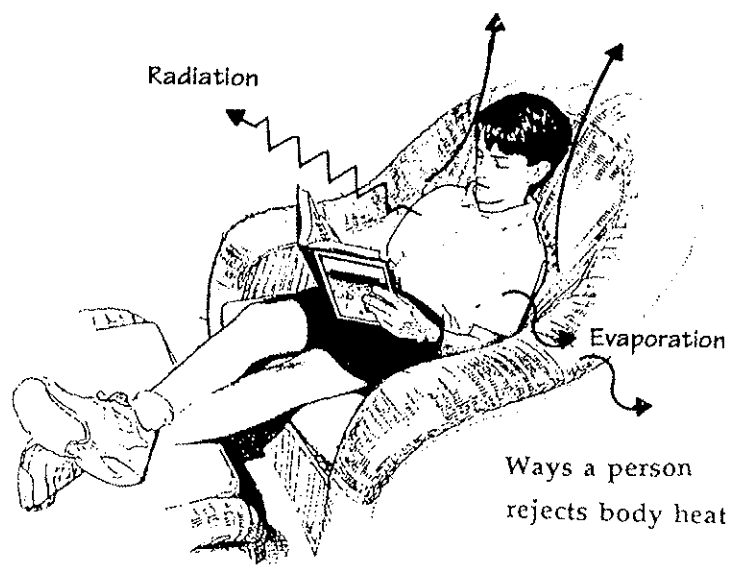
Air distribution systems (ductwork branches, transitions registers and grilles) must be customized for each building and situation.

Understanding how *air* interacts with human metabolism (heat rejection), how *air* behaves in a room, or how *air* flows in a duct is difficult to understand because air is invisible. Yet, *air distribution* is really the key to a successful heating installation.

The furnace, heat pump or other central "conditioning" unit is assembled, performance tested, and certified by the manufacturer. On the other hand, the heating contractor must *custom design* the air distribution system to fit in a building's structure, and then, satisfactorily heat it, be it a home, office, warehouse, or factory. *(Keeping people comfortable in a house is obviously far different than keeping people comfortable in a warehouse.)*

Keeping Warm

First of all, a heating system doesn't really warm people. The human body is already a heat producer — that's our metabolism. Our body is at a considerably higher temperature than a room at 70° F. Our deep body temperature is almost 100° and skin surfaces are in the 80s. Thus, heat flows *from* the body *to* the surroundings, not the other way around. A heating system produces an environment for each of us to *lose* heat comfortably — without shivering or perspiring.

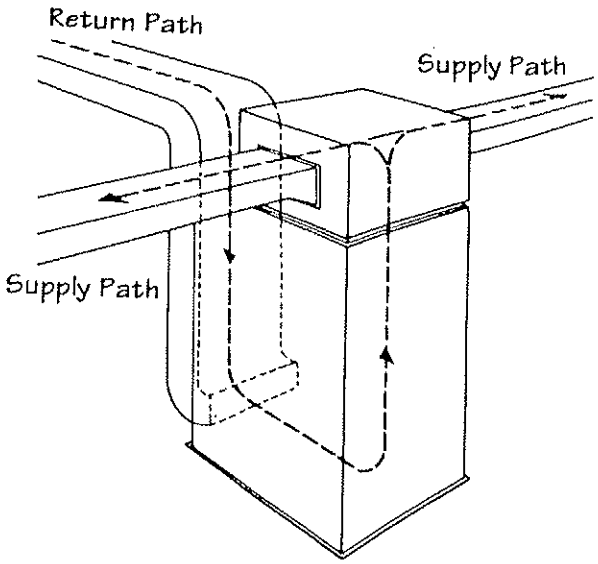


Ways a person rejects body heat

To do this, the designer must see that the heating system influences:

- *Air* and room surface temperatures
- *Air* movement — the "speed" of the air circulating in the room
- Humidity (moisture in the *air)* and *air* cleanliness

The Btu *(British thermal unit)* is our measure of heat in the *inch-pound* system. One Btu is about equal to the heat generated from burning a large wooden "kitchen" match.



Air carries heat energy through a network of supply and return ducts.

Consider a person sitting at home reading a paper. This individual loses body heat at the rate of some 400 Btu per hour (Btu/h) to his or her surroundings as follows:

- *About 100 Btu/h by evaporation — unnoticed perspiration picked up by room air*
- *Another 150 Btu/h by convection to air moving across our body*
- *And 150 Btu/h by radiation to cold walls and windows*

This last item, *radiant* heat loss to cold surfaces is often overlooked. It's why we get chilled in front of a large cold window. Think of it as the reverse of the radiant heat *gain* you feel when standing in front of a roaring fireplace.

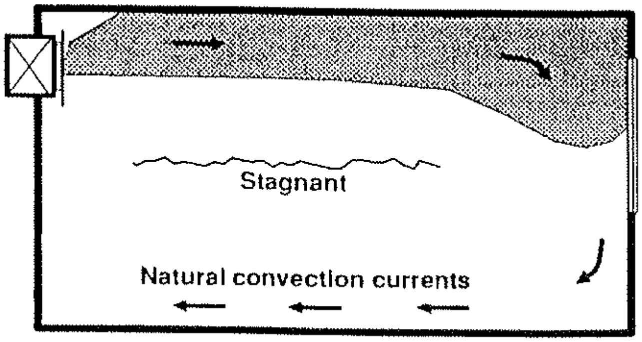
In a ducted air system, we process and circulate *air* to each room to affect comfort. The air is heated, humidified (when required) and filtered at the central equipment and then distributed throughout the building. *(In hydronic heating, water is heated and distributed to each room.)*

The air distribution (duct) system consists of *supply* and *return* paths formed by metal or fiber glass "ducts" connected to the heating unit. Both paths must be carefully sized to carry the correct amount of air.

Notable Note: A big help in reducing radiation loss is to use plenty of insulation in ceilings and walls and high quality storm windows. These steps help to raise inside wall, ceiling, and floor surface temperatures and ease the job on the heating system.

Room Air Motion

Air movement within a room is quite complex, but we need be aware of just a few elementary concepts.



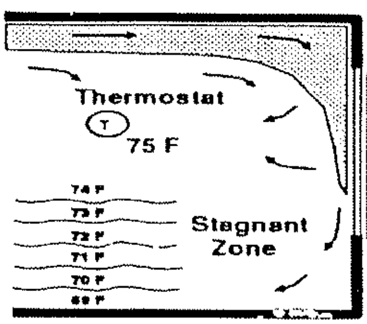
Let's start with the *occupied* zone — an imaginary region 2 feet out from each wall and extending between three inches and 72 inches above the floor which people "occupy."

Idealize air circulation in a room shows stagnant region and natural air currents. This is the cube in which we try to control the environment, keeping air temperatures in the 70s and assuring moderate air movement between 20 and 50 feet per minute (fpm).

Heated air discharging from an outlet pulls along (aspirates) considerable room air and projects the two streams into the room in a *spreading cone-like* fashion — mixing heated supply air and room air together as they move.

There are always *natural air currents.* During heating, if uninterrupted, room air naturally flows from the ceiling down the cold exterior walls and across the floor. The warmest and lightest air is at the ceiling. The air is cooled as it touches cold walls and glass which causes the now heavier air to descend to the floor.

Then there is always a *stagnant* zone — an area of a room where natural air currents have more influence than mixed air being moved by the supply outlet. We've all noticed how cigarette smoke drifts almost in slow motion in the center of many rooms, perhaps one-third of the way up from the floor — that's the stagnant zone.



Small temperature gradient in a room is an indication of good air distribution.

Also important is the room air temperature *gradient.* In the case of heating, a gradient might be a gradual increase in air temperature moving from the floor at, say 69° F up to 79° F near the ceiling — a 10 degree difference from top to bottom. The temperature gradient tells much about the comfort level in a room. The *smaller* the gradient, the greater the comfort level.

As might be expected, almost any excessive movement of cooler air will be detected by an occupant. The combination of low air temperature with high air velocity is what we call a *draft.* The *neck* is also more sensitive to drafts than the ankle.

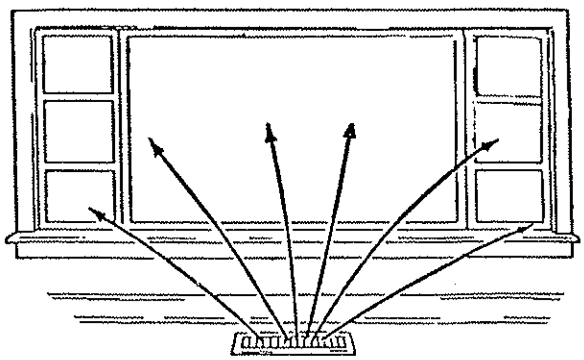
Pause for a moment. Can you see that we really have a difficult problem? We need air in the low 70s moving at 20 to 50 fpm, but the supply air we are delivering may well be at 100° or 110° F and moving at speeds up to 700 fpm — 15 to 40 times faster than what we desire.

Outlets Important

The solution is to introduce conditioned air into a room outside the occupied zone and do so through as many openings as possiblel to divide the fast moving hot air into small quantities that blend with room air very quickly. Generally speaking, using several smaller outlets is much more effective than one big one. A supply outlet is more than just a cover on the end of the duct.

What's involved in *sizing* outlets? Here are the key factors needed:

First, you must know the *volume* of air the outlet must handle. (This is determined from a heat loss calculation in Btu/h.) Outlet air capacity is often listed in cubic feet per minute (cfm) but may also be listed in Btu/h.



Throw --- how far the register projects supply air --- is a critical performance factor.

Next, the proper *velocity* of the air leaving the outlet must be established. Too high a velocity produces noise; too low a velocity may impede proper projection of the air stream. Residential grille velocities usually range from 500 to 700 feet per minute.

Third, the *pressure* or push behind the air is a consideration. The volume of air needed must be deliverable within the pressure capabilities of the fan that circulates the air through the duct system. This pressure is expressed in *inches of water column.* Typically a register should be able to deliver the needed air at a pressure of 0.03 inches of water column or less. *(One pound per square inch equals nearly 28 inches of water column, so you can see this is very small pressure.)*

With this information, a designer can select from manufacturers catalogs a number of adequate supply outlets with just one additional piece of information — the *throw* requirement.

Throw is simply the distance from the face of the outlet to some point where the moving air stream velocity falls to 50 feet per minute. For example, for good heating, a supply outlet with a *four foot throw* at the required volume, acceptable velocity and pressure limits is an appropriate selection.

Return Opening

A return has little influence on the overall air movement in a room. A return is not a giant vacuum cleaner. It only affects the air about 18 inches from the grille.

Undersized grilles and return ducts can starve the heating unit of air, hence the supply side air flow is reduced and performance affected. It is not the location of the return that's so important, it is adequate size.

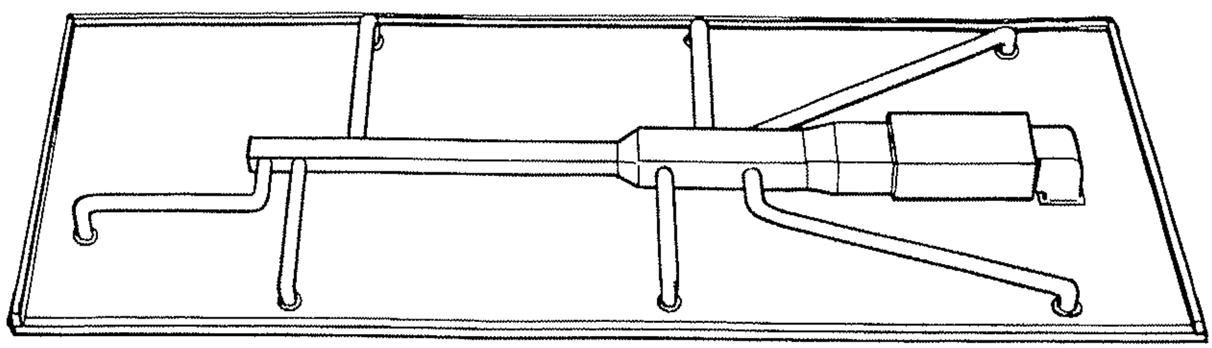
While location is less of a factor for returns, there are still some *preferred* locations.

For a heating system in cold climates, we usually place the supply outlets positioned low along outside walls. We should locate the return grilles *low* on an inside wall to bleed off the coolest room air along the floor.

In milder climates, where heating is secondary to cooling, supply outlets are often placed high in sidewalls, or in the ceiling to optimize cooling. Heating performance is sacrificed, but returns should still be placed *low* to be of as much help as possible to "bleed" off the cold air moving along the floor.

Flow in Ducts

The force required to move air through ductwork is provided by the heating unit blower (fan). This push you recall is measured in terms of inches of water column. A pressure of 0.2 inches of water column is very often the pressure used to move air through a duct system in a residence. Arithmetic shows that's just over 0.007 pounds per square inch (psi). It doesn't take much pressure to move air, but you can also use it up fast with poor design.



Fittings, more often than not, cause more resistance to air flow than the straight ducts themselves. Routing and sizing are critical to effective air flow.

Ductwork, like water pipes, offers resistance to flow. Both friction and dynamic losses are involved. Friction is the resistance caused by the air rubbing along the duct surfaces. Dynamic loss occurs when we turn air, increase or decrease air velocity, or cause unnecessary "eddy currents." The furnace blower must overcome the resistance of the duct system. As might be expected, blower capacity *decreases* as the duct resistance *increases.*

A surprising fact is that outlets and duct *fittings* offer higher resistance to flow than their "size" would suggest. That's because dynamic as well as friction losses are involved.

Losses, or the resistance of fittings and grilles, are reported in terms of *equivalent feet,* rather than in inches of water, in residential work. An equivalent foot refers to the number of feet of *straight* duct of the same diameter that would impose the same resistance or pressure loss for the same air flow rate.

An ordinary round elbow, for example, has a loss equivalent to ten feet of straight pipe.

In a typical home, branch duct runs may be only 10 or 12 feet long, so adding just one elbow to a branch can almost double the resistance of that branch. Two elbows in a branch could result in a 20 to 25% reduction in capacity. "Too many" elbows is very often the reason for the classic hard-to-heat room. And some fittings are worse than others.

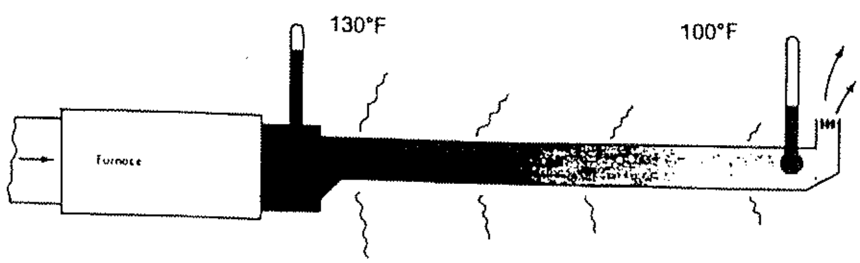
The penalty for poor fitting selection and convoluted system layout is increased pressure loss, noise, and higher fan electrical operating cost.

Duct Heat Loss

Proper duct design also requires an evaluation of *duct heat loss.*

Typically, the temperature of supply air decreases along the length of duct as heat is lost through the walls of the duct. We might start out with 130° F air, but deliver only 100° F air to the room. Then we must increase the amount of air delivered to a room to make up for the effect of duct heat loss. More air means increased system resistance and perhaps the need for a larger duct.

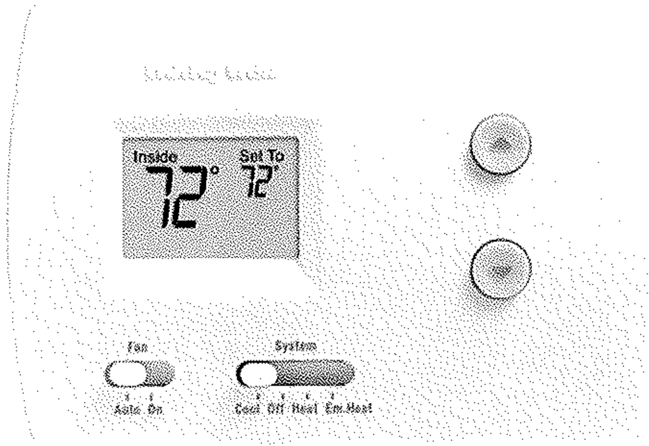
In compact systems, where the heating unit is centrally located, and branch runs relatively short and essentially the same length, the assumption that the supply air temperature at each register is the same is a reasonable one. But in larger systems, where the heating unit is remote from certain rooms, the temperature drop in the run of duct should be considered.



Supply air moving through heating duct runs can experience a significant drop in temperature. Ducts must be insulated and air tight.

When ductwork is not in a heated space, say ductwork routed through an attic or a ventilated crawl space, then the ductwork must be *insulated* to minimize this loss of heat energy. The central heating unit must also be *increased* in heating capacity to provide adequate Btus to warm the house to make up for duct losses. This adds to operating costs.

Controlling the System



A *thermostat* senses room air temperature and turns the equipment on and off. It should be placed on an inside wall, not more than five feet off the floor, in a place with good air circulation and not near appliances or lights.

The furnace blower should be adjusted to deliver the correct volume of air and the system *balanced* room by room. This is accomplished by adjusting *dampers* installed in each room duct. No matter how precisely sized each portion of a duct system may be, all systems must be balanced to assure the proper amount of air is delivered to each room.

Floor to ceiling temperature gradients are improved with constant or near constant blower operation to improve air circulation. There will be no drafts if the designer has located outlets correctly. Humidifiers work more effectively as do filters with constant air circulation.

The added cost of operating the blower can be justified by some reduction in heat loss caused by more uniform temperatures throughout the structure and extended motor life. *(Starting and stopping a motor is harder on electrical windings than letting it run continuously.)*

Finally, to assure proper air flow at all times, filters must be kept *clean.* Dirty filters will impose high resistance so that less air is circulated, and people begin to complain about inadequate capacity to heat the house. It may well be the most frequent cause of a no heating or poor heating complaint.

Restrictive air flow over the heating equipment such as a heat pump can wreak havoc on a compressor too.

Design and Safety

In designing the air distribution system, we must also consider safety and safe operation. All duct *materials* in most areas of the U.S. must comply with Underwriters Laboratories' standards.

Installation standards are covered in the National Fire Protection Association's Pamphlet 90-B for residential systems. Duct *construction* is covered under manuals published by The Sheet Metal and Air Conditioning Contractors' National Association, (SMACNA) Inc.

Most residential duct systems are assembled from prefabricated sheet metal items. The proper gauge of metal to use is established by code. The larger the duct system, the heavier the gauge that must be used. Manufacturers of prefabricated pipe and fittings publish catalogs from which fittings can be selected.

In addition to sheet metal, non-metal duct, such as fibrous glass in both flexible and rigid forms, is popular.

Residential *sizing* procedures are based on Manual J for estimating heat losses. For duct sizing, many technicians use Manual D. Both manuals are published by the Air Conditioning Contractors of America (ACCA).

There are also computer-based design programs available. These programs eliminate the arithmetic, but they cannot substitute for the designer's practical know-how.

Wow!

Have we demonstrated that comfort heating is a real challenge and requires an understanding of basic science as well as practical know-how? In subsequent chapters, we will examine these central heating issues one at a time and in detail.

Self-Check, Lesson 1 Quiz

You should have read all the material in Lesson 1 before attempting this review. Answer all the questions to the best of your ability before looking up the answers provided in the answer key.

Please indicate whether the following statements are true or false by drawing a circle around T (to indicate TRUE) or F (to indicate FALSE).

True False

1. T F We need very little air to sustain life, but much more to be made comfortable.

2. T F The air distribution system is critical to the effective performance of a forced air heating system.

3. T F The basic purpose of a heating system is to warm the occupants.

4. T F The combination of high air temperature and low air velocity produces a draft.

5. T F Proper thermostat location is essential to the operation of the heating system.

In the following multiple-choice questions, choose the phrase that <u>most</u> correctly completes the statement, and check the appropriate box for the corresponding letter in front of the phrase.

6. An important way to reduce body heat loss by radiation to cold building surfaces is to:

☐ A. change the room air temperature. ☐ B. add insulation to walls, ceiling and floors.
☐ C. add more windows. ☐ D. lower the surface temperature of the walls.

7. The imaginary region within a room to be comfort conditioned is called the:

☐ A. occupied zone. ☐ B. center of living.
☐ C. functional area. ☐ D. performance zone.

8. A gradual increase in air temperature from floor to ceiling is referred to as a:

☐ A. temperature gradient.
☐ B. temperature inversion.
☐ C. temperature migration.
☐ D. temperature change.

9. As it leaves the supply outlet, heated air may enter a room at velocities up to:

☐ A. 700 feet per minute.
☐ B. 700 miles per hour.
☐ C. 50 feet per minute.
☐ D. 50 miles per hour.

10. The pressure required to move air through ductwork is measured in terms of:

☐ A. feet of head.
☐ B. inches of water.
☐ C. inches of mercury.
☐ D. pounds per square inch.

For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

Key Words

balancing large blend friction 90A
heat exchanger airflow dynamic Manual D small occupant
90-B reacting

11. The function of a supply outlet is to _______________ supply air and room air into a uniform mixture.

12. Return air intakes that are too ___________ can starve the central unit of air and affect the performance of the supply outlets.

13. The pressure loss due to air rubbing along the duct inside surface is called ___________ loss.

14. After a system is installed, the air flow to each space must be adjusted. This procedure is called ____________________ the system.

15. Heating system safety is covered in the National Fire Protection Association (NFPA) Standard ____________.

Check Your Answers!

Now compare your answers with those given in the answer key at the back of this book. The answer key also directs you to a page in the lesson to review the text for any questions you may have missed.

Lesson 2 Overview

So, do you think you know what heat is? After you've read this chapter and completed the selfcheck review, be honest and see if your explanation isn't significantly different.

We're going to talk about how heat moves, the difference between sensible and latent heat, define a Btu, and introduce you to metrics and heat.

Now read Lesson 2 that begins on the next page.

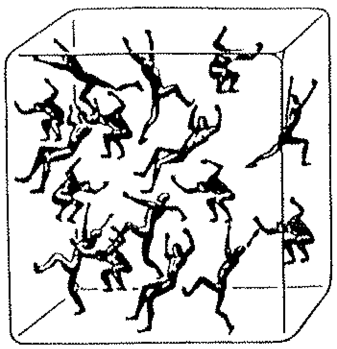
Lesson 2: What is Heat?

Energy is the ability to do work. We can categorize basic sources of energy as chemical, solar (or radiant), nuclear, mechanical, and electrical — all capable of releasing (producing) heat.

Heat is energy in *transit*. The *thermal* energy of a substance reflects the average energy level of its molecules in motion. The greater the molecular motion (energy), the greater the *thermal* energy of a substance. It is the movement or *exchange* of thermal energy between two substances that we call heat.

Heat transfer can raise the "temperature" of a substance, melt a solid, vaporize a liquid, cause a substance to expand and trigger a chemical change in a substance.

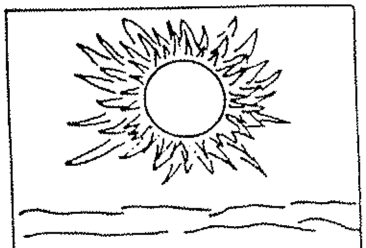
Heat can only be transferred from a substance at a *higher* temperature to another at a *lower* temperature.



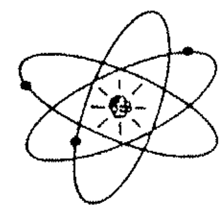
Thermal energy reflects molecular activity.

This increases the amount of thermal energy (molecular motion) in the lower temperature substance and raises its temperature. Temperature, therefore, is an indication of heat intensity, but not heat quantity. (*More on this later.*) Also, heat cannot move in the other direction — from a substance at a lower temperature to one at a higher temperature.

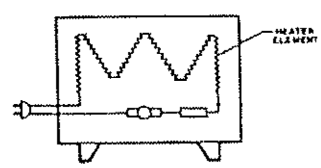
All sources of energy can release heat. The chemical energy stored in oil and natural gas converts to heat when the fuel is burned. Natural gas and oil are common energy sources for comfort heating.



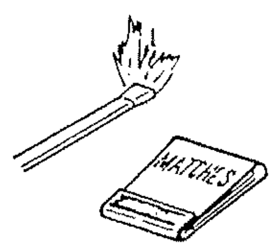
Solar Energy to Heat



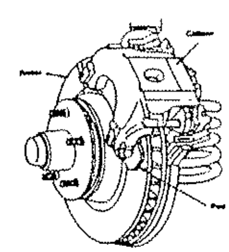
Nuclear Energy to Heat



Electrical Energy to Heat



Chemical Energy to Heat

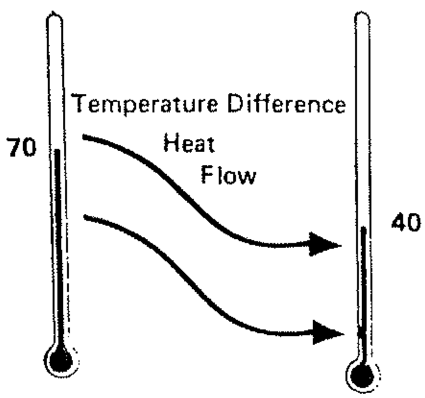


Mechanical Energy to Heat

In comfort heating, we are concerned with two effects caused by heat, and we have assigned names to the phenomena.

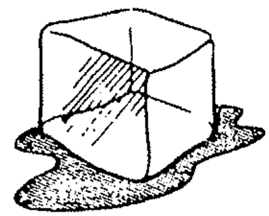
- *Sensible* heat is the heat that changes the temperature of a substance without changing its form. We add or remove sensible heat when we raise or lower the temperature of air.

- *Latent* heat changes the form of a pure substance *without* changing its temperature. For example: when heat changes ice to a liquid or transforms water into steam. (*Incidentally, a great deal of heat transfer is usually involved.*)



Heat can only flow from a high temperature source to a lower temperature source.

Latent heat changes the form of a substance such as melting ice into water.

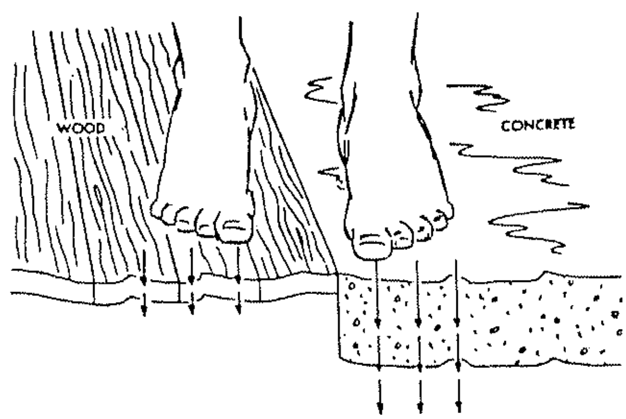


How Heat Moves

Heat can move from one material to another by three distinct mechanisms — by conduction, radiation and convection.

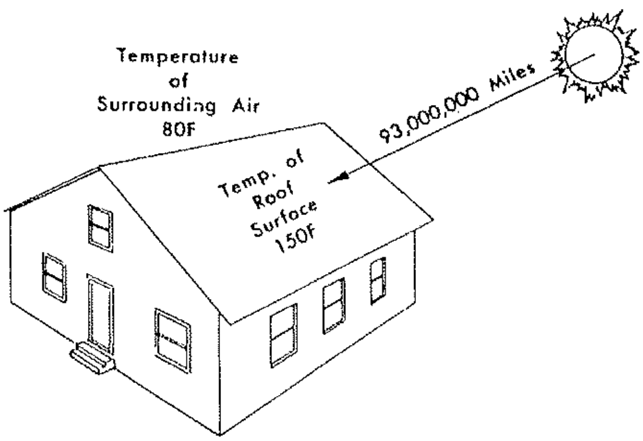
Conduction

Conduction is the transfer of heat through a single substance from a higher temperature area to a lower temperature area, or the transfer of heat between two different substances in contact with each other. Thermal energy moves when adjacent molecules collide.



Bare feet on a cold concrete floor is a good example of conduction heat transfer.

One example of conduction is movement of heat along an iron rod held over an open flame. The heat travels along the rod from the flame to the outer ends. Other examples are the electric iron and a spoon (particularly silver) in hot coffee.



Thermal energy can move through space in waves much as sound moves via radio waves. The waves strike an object and convert to thermal energy raising the temperature of the surface such as a roof.

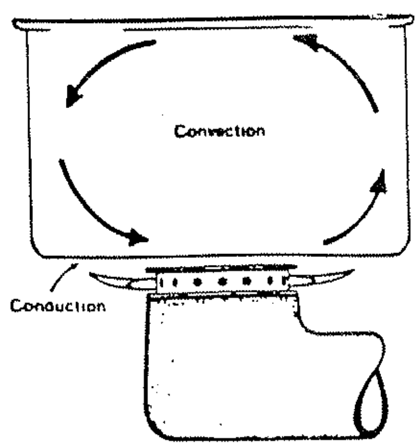
Radiation

Radiation is the transfer of thermal energy by electromagnetic waves moving through space from one substance to another substance. This mode of transfer brings solar energy to a roof, converts to thermal energy, and raises the roof temperature to 150° F or more, although the air surrounding the roof may be only 80° F. Other examples are infrared electric heat lamps and a fireplace.

The surfaces exchanging thermal radiation must "see" each other. That's why we feel relief stepping into the shade to avoid the heat "rays" of the sun.

Convection

Convection is the transfer of heat by moving fluids, such as the *circulation* of a gas or liquid, where moving currents of high temperature molecules exchange heat with molecules at lesser temperatures. Unlike conduction, there is a physical movement associated with convection.



Water in pan becomes uniformly warm via convection heat transfer. If circulation is forced by stirring, the heat transfer process speeds up.

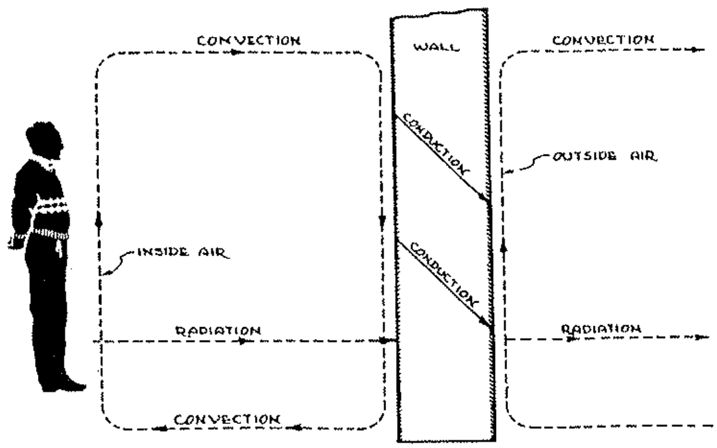
A classic example is heating a pan of water on a stove. The water at the bottom of the pan warms and expands, rising toward the surface. This causes the water to begin a natural circulation, transferring heat to all the water in the pan.

The ordinary clothes dryer is an example of heat transfer by forced convection. A space heater warms a room in large measure by causing natural convection air currents.

Very often, all three methods of heat transfer are involved. Consider an ordinary outside wall. Air currents in a room cascade down the wall to transfer heat by convection.

Then the heat moves through the wall by conduction. Outside the same thing occurs. In addition, radiation exchange occurs between the wall surfaces (both inside and out) and other surfaces the wall "sees."

A clothes dryer uses forced convection (air circulation) to dry clothing quickly.



In real situations, all three methods of heat transfer are usually involved. Consider the case of an ordinary exterior wall as depicted at left.

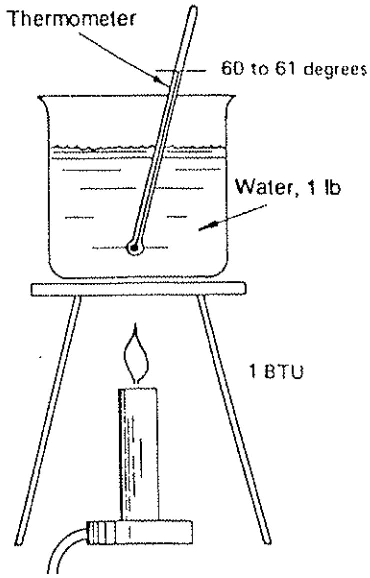
How Heat Is Produced

As we noted, all forms of energy can produce or release heat. A practical way to produce heat in quantity for comfort is by combustion. This is a chemical process emitting both heat and light, usually through the union of combustible materials such as wood, gas, coal, or oil with oxygen, and elevated to an ignition temperature. If the material is not heated to its "kindling" temperature, combustion will not occur. (*An example of heat triggering a chemical reaction.*)

Electric energy is also used to produce heat.

How Heat Is Measured

Frequently, there is some confusion between temperature and heat. Temperature indicates thermal intensity, not the quantity of heat. As a simple analogy, a yardstick inserted in a barrel of water would indicate how deep the water is, but not how many gallons of water are in the barrel. Temperature is measured in degrees Fahrenheit.



Definition: 1 Btu is the amount of heat required to raise 1 lb of water 1°F.

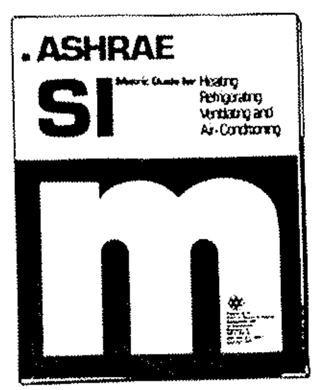
Heat is measured in terms of the Btu or British thermal unit. One Btu is defined as the amount of heat required to raise one pound of water one degree Fahrenheit. In a more practical term: A single large wooden match will produce about one Btu when it is completely burned.

This also equals the amount of heat needed to raise the temperature of about 55 cubic feet of air just one degree Fahrenheit. To heat 550 cubic feet of air one degree F would take 10 times as much heat or 10 Btu.

The heat-producing capacity or output of equipment is usually rated in Btu per hour (Btu/h). As will be discussed later in detail, the size of the heating equipment required is based on the heat loss characteristics of each building, and this, too, is expressed in Btu per hour.

Thus, a house with a 50,000 Btu per hour heat loss must be fitted with a heating unit capable of producing 50,000 Btus per hour or more.

Metric Measurements



The American Society of Heating, Refrigeration and AirConditioning Engineers (ASHRAE) publishes a metric guide for the heating industry. This is part of the overall program in the United States, and earlier in Canada, to convert from so-called "English" or inch-pound units of measurement to "SI" (Systeme International d'Unites) units, commonly referred to as metric units.

In the metric system, temperature is measured in degrees Celsius and heat rate (Btu/h) is measured in Watts; and just plain "Btu" is measured in Joules.

To convert Fahrenheit (F) to Celsius (C) we can use the formula:

$C = (F-32)\,(5/9)$

For example, if room temperature is 70°F, then the metric measurement would be:

$C = (70-32)\,(5/9) = 21°C$

To convert Btu per hour to Watts use this formula: W = Btu/h x 0.293

Thus, a 50,000 Btu per hour heat loss would be:
W = 50,000 x 0.293 W = 14,650 Watts

Finally, to convert Btu to Joules use this formula:

J = 1055 x Btu

Thus, 10,000 Btus would become:

J = 1055x10,000 J = 10,550,000 Joules

Btu, Btus, & Btu/hr or Btu/h?

Frequently, there is a casual reference to Btus when Btu per hour is correct and vice versa. Let's clear up this point.

Energy is the ability to do work. It is expressed simply Btu (or Joule). Power is the *rate* of doing work and it is time related. Thus, Btu per hour (or Watts) is heat power. It indicates how much heat energy is being expended over a specific time.

Heat power is written in many ways — Btu/per hour, Btus per hr., Btuh and Btu/h. According to the ASHRAE metric guide, Btu/h is the preferred notation.

It will no doubt take more time before metric measurements are in common use.

Metric Rules-of-Thumb:

If you can remember these first four rules-of-thumb, you will be able to read metric drawings. The rest are for specifications.

- 1 mm = about 1/25 inch = thickness of a dime
- 25 mm = about 1 inch
- 300 mm = about 1 foot
- 1000 mm = 1 m = about 3 feet +10% more (roughly, a yard)
- 1 m^2= roughly 10 square feet
- 1 L = about 1 quart
- 1 m^3 = about 35 cubic feet (about 30% more than a cubic yard)
- 1 kg = about 2.2 pounds
- 1000 kg = 1 Mg = 1 metric ton = about 2,200 pounds
- 10 kPa = about 1.5 psi

- Celsius temperature rhyme

30 is hot	(86°)
20 is nice	(68°)
10 is cool	(50°)
0 is ice	(32°)

Self-Check, Lesson 2 Quiz

You should have read all the material in Lesson 2 before attempting this review. Answer all the questions to the best of your ability before looking up the answers provided in the Answer Key.

Please indicate whether the following statements are true or false by drawing a circle around T (to indicate TRUE) or F (to indicate FALSE).

True False

1. T F Thermal energy is a form of energy reflecting internal molecular motion.

2. T F Heat is the movement of thermal energy between substances.

3. T F The transfer of heat by the movement of air or liquid is called convection heat transfer.

4. T F To transfer heat by conduction between two substances, the surfaces must be touching.

5. T F Thermal energy transfer by electromagnetic waves is called radiation heat transfer.

In the following multiple-choice questions, choose the phrase that <u>most</u> correctly completes the statement, and check the appropriate box for the corresponding letter in front of the phrase.

6. One British thermal unit (Btu) is defined as the heat required to:

☐ A. boil one pound of water. ☐ B. melt one pound of ice.
☐ C. increase the temperature of water 1° F. ☐ D. raise one pound of water 1° F.

7. In the metric system of measurement, "Btu" is the same as:

☐ A. Watts. ☐ B. Watt hours.
☐ C. Joules. ☐ D. Joules per hour.

8. Thermal energy transfer (heat) moves from one substance to another substance at:

☐ A. the same temperature. ☐ B. a different temperature.
☐ C. a lower temperature. ☐ D. a higher temperature.

9. The most common way to generate heat for comfort applications is:

☐ A. solar energy. ☐ B. chemical energy.
☐ C. electrical energy. ☐ D. mechanical energy.

10. Using the formula C = (F-32) (5/9), a temperature of 68° F would be equivalent to:

☐ A. 0° C. ☐ B. 10° C.
☐ C. 20° C. ☐ D. 30° C.

For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

Key Words

sensible solar convection contact combustion chemistry
conduction radiation latent transfer

11. A common chemical process that releases thermal energy for space heating is called ______________ and involves a fuel and oxygen.

12. The sun warming the roof of a building is an example of heat transfer by ______________.

13. Heat applied to a substance that changes its physical state is referred to as ______________ heat.

14. Heat that raises the temperature of a substance without changing its physical state is called ______________ heat.

15. Heat transfer from the air in a room through a wall to the outside air involves convection, radiation and ______________ heat transfer mechanisms.

Check Your Answers!

Now compare your answers with those given in the answer key at the back of this book. The answer key also directs you to a page in the lesson to review the text for any questions you may have missed.

When you are satisfied you understand the questions missed, proceed to your next assignment which starts on the next page.

Lesson 3 Overview

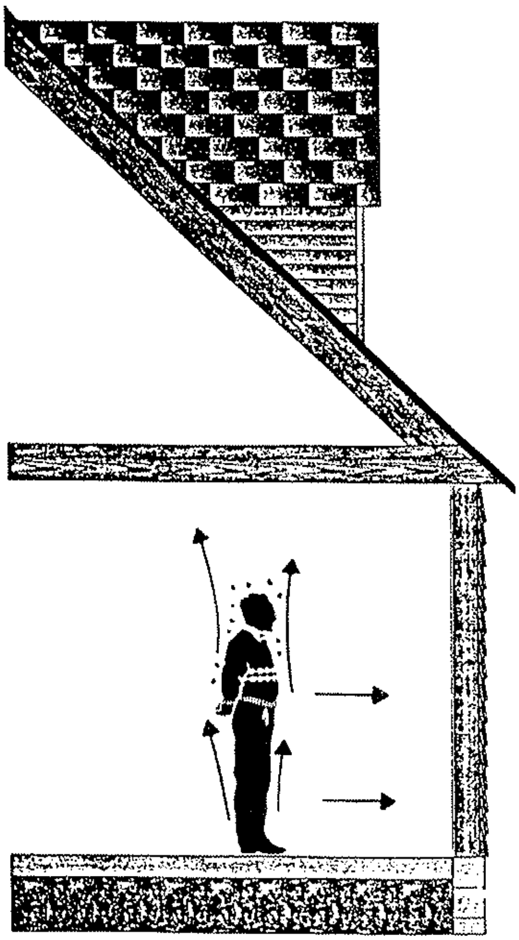
Someone once said "comfort is a lack of discomfort." Our everyday experience tells us that in a room with a consistent temperature, some people will be comfortable while others will not. This could be a result of different clothing, state of health, or even emotions.

Body temperature regulation is through our blood vessels. They expand to carry more blood to the skin to be cooled, and contract to keep blood in the interior of the body to conserve heat. This action of the blood vessels is under the control of the nervous system which responds to emotional factors as well as changes to temperature.

In heating, we limit our concerns to the factors directly affecting reaction to surrounding thermal conditions and air cleanliness. Basically, we'll be talking about the mechanisms of heat rejection by occupants in a room.

Now read Lesson 3 which begins on the next page.

Lesson 3: What It Takes to Be Comfortable



Humans reject heat by convection, radiation, and perspiration (evaporation).

Maintaining a comfortable indoor environment in winter depends on both *thermal* and non-thermal issues. Thermally speaking, it is necessary to control the temperature, humidity, and air motion in a room.

Indoor air quality is also a critical issue. You can be in a thermally correct building, but feel uncomfortable because rooms are "stuffy." Stuffiness can be the result of airborne contaminants as we'll see later on.

Today, Indoor *Environmental* Quality is the buzz word used to encompass all the key parameters affecting indoor comfort.

It was once thought that occupant discomfort was due solely to high levels of *carbon dioxide* which humans give off when exhaling (we take in oxygen and release CO_2). By supplying enough fresh air to offset the carbon dioxide, the early notion was that occupants of the room would be comfortable. Well, not exactly.

Researchers modified this theory through experiments that demonstrated the cooling effect of moving air across the skin. Studies showed that people in a test box were uncomfortable because body heat was not removed fast enough. The test subjects expressed a feeling of comfort only when body heat removal was increased by using fans.

Body Temperature

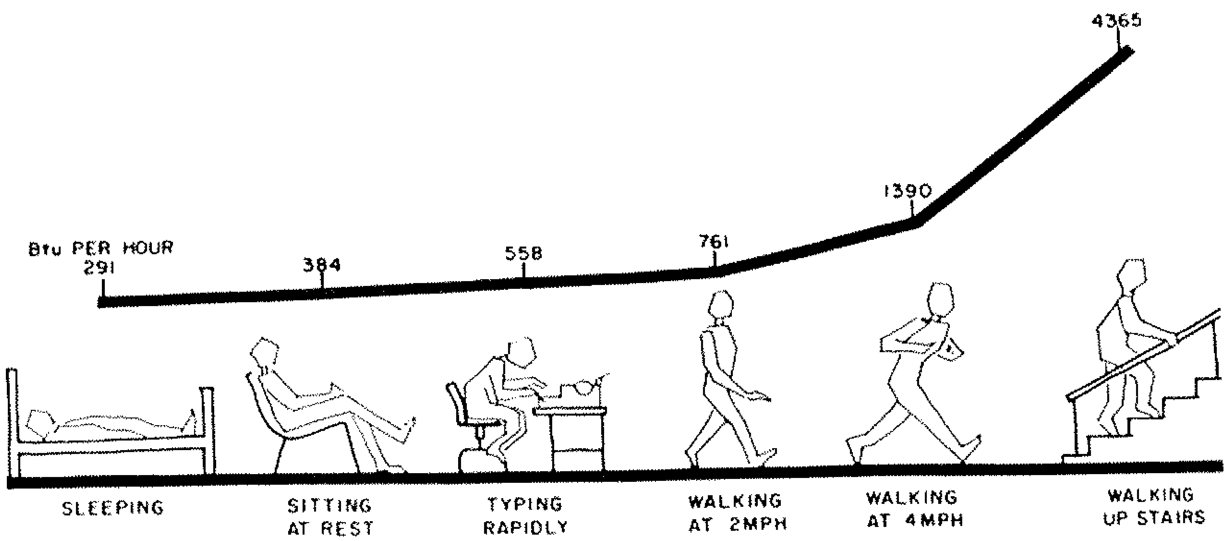
The human body must maintain an internal temperature between 98.2° and 98.6°F. To carefully regulate this temperature, the heat developed from the chemical processes resulting from eating, drinking, and breathing must be rejected by our body. If the rate of heat loss is too fast, we are uncomfortably cold (hypothermia). If the rate of heat dissipation is too slow, we feel hot (hyperthermia).

Notable Note: Many of us worry about our calorie intake. Calorie is taken from the French word "calor" which means heat. One calorie equals about 4 Btu. The oxidation of the food we consume is called metabolism, one byproduct of which is the release of heat.

The function of a comfort heating (or cooling) system is to create an environment in which the body loses heat at a rate that feels comfortable.

Body Heat Loss

The amount of heat generated by an individual depends on physical activity. At rest, an adult may reject 300 to 400 Btu/h. Working at a desk could double the rejection rate. Walking could nearly triple heat output.



Average heat rejection rates for an adult based on physical activity.

The body gets rid of excess heat by radiation, convection and evaporation. Heat loss by conduction is generally insignificant in ordinary comfort heating situations. (*Bare feet on a cold floor involve little heat transfer but can be very uncomfortable just the same.*)

As we know, heat transfer by *radiation* as we know is from a hot surface to a cold object that "see" each other. The difference in temperature between our skin surface and the surrounding room surfaces dictates the rate at which the body loses heat by radiation. The temperature of the air in the room is not a factor in the amount of radiation exchanged.

A person with a skin surface temperature in the 80s will radiate heat to cooler surrounding objects, such as a cold wall surface perhaps at 68°, or cold window glass, which often may be as cold as 35° or even less when frost appears.

The body loses heat by *convection* as air circulates across the skin — as long as the air is *cooler* than the temperature of the skin. Excessive air motion, however, can cause the body to lose heat at an uncomfortably high rate.

The common complaint of "sitting in a draft" may be an example of air motion which gives the feeling of a colder air temperature even though the air temperature may be the same as the rest of the room. Air in motion feels colder because it increases the rate of heat transfer from the skin by convection.

(*To compensate for a high radiation loss, say, to a large picture window on a cold day, we usually raise the air temperature in the room to reduce heat loss by convection.*)

Sweating

The third way in which the human body loses heat is by *evaporation*. The body constantly eliminates moisture through the skin. Usually, this moisture evaporates as rapidly as it comes to the skin surface. Perspiration appears when the moisture is produced faster than it can evaporate. By increasing air motion, we can increase the evaporation rate.

When skin moisture evaporates, heat is absorbed into the air from the body. This really helps cool the body, because a great deal of heat is dissipated when liquid perspiration changes into a vapor. (*After perspiring, we can easily get a chill if the evaporation rate increases too dramatically.*)

Humidity

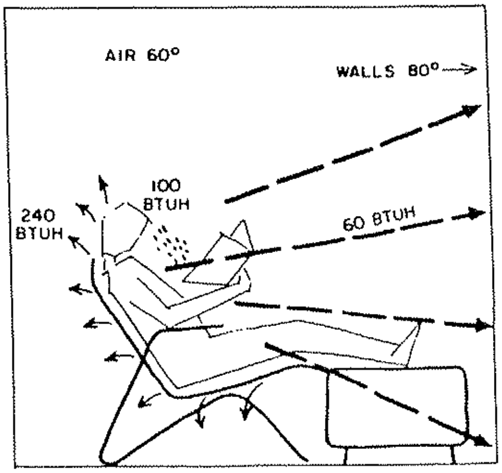
Air is made up of oxygen and nitrogen plus varying amounts of water vapor. We cannot see the water vapor, as it is pure steam. We call water vapor in air *humidity*. The humidity of the air affects the rate of evaporation of moisture from the skin.

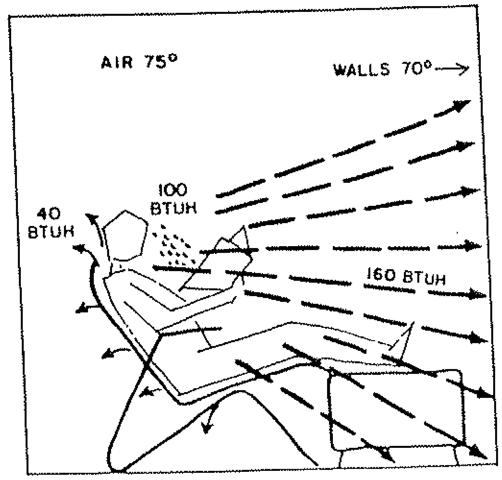
If the air is dry (low humidity), the air will absorb the moisture on the surface of the skin quite rapidly. Once again, rapid evaporation increases the rate of cooling of the skin surface and body heat loss increases.

If the air in contact with the body already contains a lot of moisture (high humidity), then the rate of evaporation and body cooling is much slower.

Humidity vs. Temperature

Studies have suggested that people are more sensitive to changes in temperature than humidity. However, many people report remaining comfortable in a home that has a slightly lower air temperature if the humidity of the air is high. *(We're increasing convection heat loss and decreasing evaporation heat loss, but keeping total body loss acceptable.*)





At right, a person reading could radiate 160 Btu/h to a wall at 70°, 40 Btu/h due to convection with air at 75° and 100 Btu/h by evaporation with humidity at 35%. At left, humidity is unchanged; radiation loss reduces to 60 Btu/h when wall is at 80° and convection loss increases to 240 Btu/h when air temperature is reduced to 70°.

Notable Note: The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 55 (Thermal Environmental Conditions for Human Occupancy) defines a range of temperatures and humidity that suggests at least 80% of the occupants would be comfortable.

For the same reason, occupants need a slightly higher air temperature in a dry environment. The dry air gives a faster rate of evaporation, with more rapid skin cooling, and must be offset by a higher air temperature to reduce convection heat loss. (We are talking here about perhaps a one degree change.)

Generally, for normal building occupancy with moderate window area, a room temperature around 70°F, a humidity level above 20%, and a gentle motion of room air (20 to 30 feet per minute) will permit most people to lose body heat comfortably. Because people dress differently in summer and winter, conditions for comfort between summer and winter do differ slightly.

The upper humidity level should never exceed 60% and in winter, building considerations usually limit humidity to around 35% or less. (The effect of humidity on health and furnishings is covered in Lesson 8 on humidifiers.)

Other Factors

There are other factors not directly related to the control of body temperature that must be considered when designing comfort heating systems. Objectionable equipment noise is one example. These are called non-thermal effects. Perhaps more difficult to resolve than noise are the following:

- A lack of fresh air. Occupants of a room constantly consume oxygen in the air and exhale carbon dioxide. If CO_2 is allowed to build-up, available oxygen decreases and the room air becomes "stale." People become quite uncomfortable. There is always the concern over body odor as well. Therefore, ventilation air — a source of fresh air — is often needed for comfort. (Our early heating experts were not exactly wrong about carbon dioxide and comfort.)

- Dirty air. Air laden with tobacco smoke, vapors, dust, emissions from building materials and bio-aerosols (viruses, pollen, and bacteria) can cause some discomfort for many people, but for persons with allergies it can become serious.

When poor air quality affects a large number of persons on short term basis,

People can be uncomfortable when CO_2 level rises; become sick when indoor air quality is affected by bio-aerosols and other emissions from building materials.

We refer to the situation as a Sick Building Syndrome. Leaving the building usually means ailments go away.

Filtration and ventilation are needed to reduce these problems. Sick Building concerns are usually identified with offices, and many problems involve how the building was constructed. But indoor air quality should be addressed in the design, installation, and operation of any heating system. And equally important is a well-maintained heating system. Good maintenance can go a long way toward preventing the occurrence of many indoor contaminants.

Self-Check, Lesson 3 Quiz

You should have read all the material in Lesson 3 before attempting this review. Answer all the questions to the best of your ability before looking up the answers provided in the Answer Key.

Please indicate whether the following statements are true or false by drawing a circle around T (to indicate TRUE) or F (to indicate FALSE).

True False

1. T F Occupant comfort is strictly a function of temperature, humidity and air motion.

2. T F A high level of carbon dioxide can be a factor affecting occupant comfort in a room.

3. T F Perspiration appears when body moisture is produced faster than it can be evaporated by room air.

4. T F Increasing air motion around the body can decrease heat loss by both convection and evaporation.

5. T F A person reacting to extreme cold and excessive heat loss is said to suffer from hypothermia.

In the following multiple-choice questions, choose the phrase which <u>most</u> correctly completes the statement, and check the appropriate box for the corresponding letter in front of the phrase.

6. The basic function of a heating system is to create an indoor environment in which the body:

☐ A. gains heat at a comfortable rate. ☐ B. loses heat at a comfortable rate.
☐ C. never perspires. ☐ D. exchanges heat with surfaces equally.

7. Evaporation is an important method of heat rejection by the body because it:

☐ A. has a high heat rejection capacity.
☐ B. can be easily controlled.
☐ C. has little effect on the sensation of comfort.
☐ D. is not affected by indoor humidity levels.

8. A reasonable estimate for the heat rejection rate for a person working at a desk is:

☐ A. 200 to 300 Btu/h. ☐ B. 300 to 400 Btu/h.
☐ C. 400 to 500 Btu/h. ☐ D. 600 to 800 Btu/h.

9. Body heat loss by convection occurs whenever room air:

☐ A. moves over the skin surfaces.
☐ B. is very dry.
☐ C. creates a draft.
☐ D. is at a temperature lower than the skin.

10. Raising indoor humidity and lowering the room air temperature:

☐ A. decreases heat loss by evaporation and convection.
☐ B. increases heat loss by evaporation and convection.
☐ C. decreases evaporation/increases convection heat loss.
☐ D. increases evaporation/decreases convection heat loss.

For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

Key Words

infiltration	bio-aerosols	convection	maintained	sick building
chemistry	ventilation	germ laden	conduction	filtration

11. Viruses, pollen and bacteria in room air are called ______________.

12. Ventilation and _______________ are needed to reduce air contaminants.

13. When poor indoor air quality affects a large number of occupants, the situation is called _________________________ Syndrome.

14. One technique to reduce carbon dioxide build-up is to introduce ________________ air.

15. A heating system must be well ____________ besides well designed and installed to reduce the build up of indoor contamination.

Check Your Answers!

Now compare your answers with those given in the answer key at the back of this book. The answer key also directs you to a page in the lesson to review the text for any questions you may have missed.

When you are satisfied you understand the questions missed, proceed to your next assignment which starts on the next page.

Lesson 4 Overview

Now that Lesson 3 helped us understand the people problem, we turn our attention to the building and its problems as a result of weather and people living inside.

We're going to study how energy escapes a building, moisture problems, and the interface between the building and the heating system.

Now read Lesson 4 which begins on the next page.

Lesson 4: Heating Problems & Construction

The performance of a heating system depends upon the construction of the building. The building and heating system must be considered together. Think of a drafty old barn; a heating system might make it warmer but never comfortable!

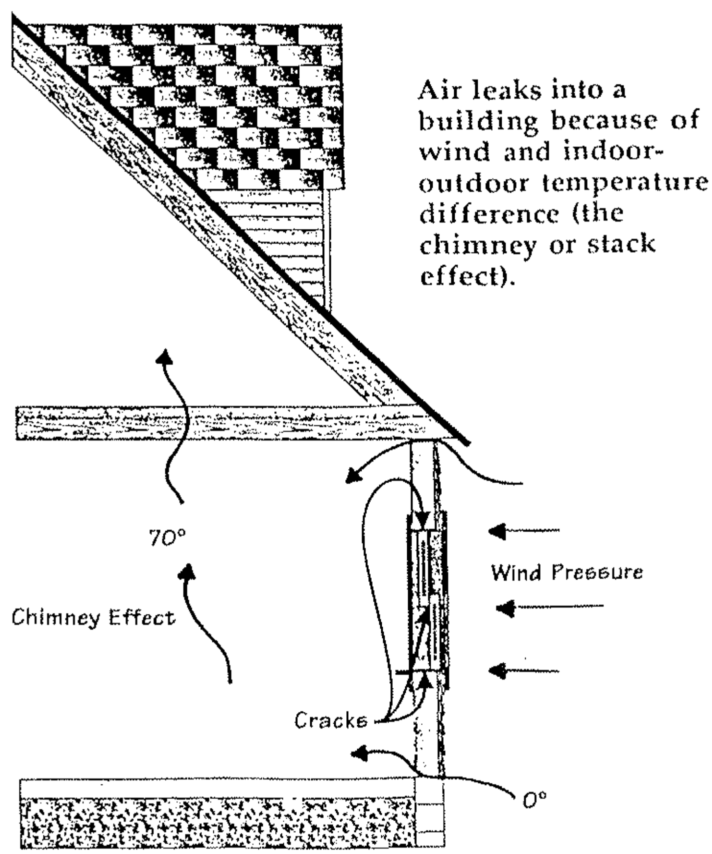
Sources of Loss

A house loses heat energy through all *exposed* surfaces — heat moves through the outside walls, ceiling or roof, windows, doors, and floors. Cold partitions, such as a wall adjacent to an unheated attached garage, provide a heat loss path as well.

A building also loses heat through the displacement of warm inside air by cold outside air entering building interior spaces. *Infiltration* is the term used for the natural leakage of air in and around windows and doors and through other cracks and construction joints found in a building. *Exfiltration* is when air leaves the building.

A combination of wind and "stack effect" forces the air into the building. The stack effect is caused by a difference in temperature between indoor air and outside air.

Lighter, warmer air rises up and out upper level openings while heavier outdoor air enters through lower cracks.



Older homes may have as many as three complete air changes every hour. However, because of the use of new building materials and techniques, homes built today may have only one air change every *two* hours.

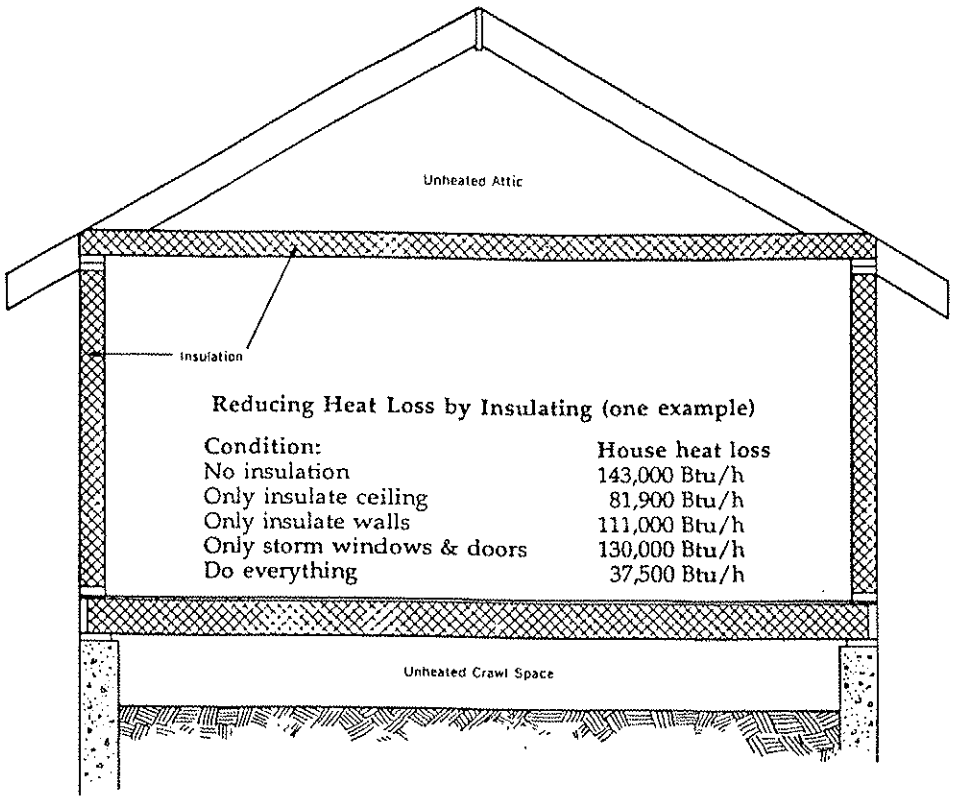
Obviously, the amount of heat escaping from a building must be replaced with "new" heat in order to maintain a comfortable indoor temperature.

Reducing Losses

The type and quality of construction has a direct bearing on the heat loss *rate* of the building and the comfort of the occupants.

As we learned in the previous lesson, one way the body loses heat is by radiation to cold surfaces. If exterior walls are poorly constructed with little insulation, or if there are large expanses of single pane glass, the occupants could well be uncomfortable in cold weather. The interior surface of an uninsulated wall may be 10° or more colder than the room air.

These large cold surfaces are also going to create rapidly moving currents of cold air which are bound to create drafts — a serious source of discomfort.



Reducing Heat Loss by Insulating (one example)

Condition:	House heat loss
No insulation	143,000 Btu/h
Only insulate ceiling	81,900 Btu/h
Only insulate walls	111,000 Btu/h
Only storm windows & doors	130,000 Btu/h
Do everything	37,500 Btu/h

It is certainly in the interest of the heating specialist to urge and recommend that buildings be well constructed and well insulated. This will result in the selection of a smaller heating unit, and owners will be more comfortable and save on fuel bills in the bargain.

The addition of full insulation, storm windows, and doors can reduce the heat loss of a structure by as much as 74%.

There are both *physical* (space) and *economic* (no payback) limitations to the amount of insulation that can be usefully added. Severity of local weather and local cost of energy are two important considerations. The U.S. Department of Energy (DOE) and many state energy offices specify insulation levels for new construction.

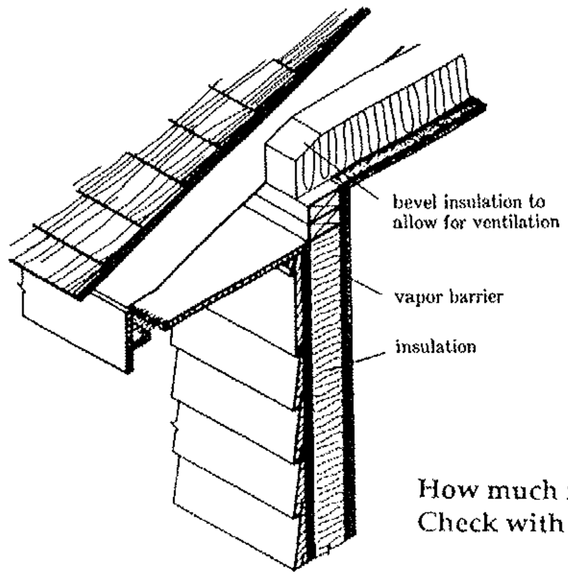
Effectiveness of insulation is measured in its R-value, not inch thickness.

The recommended level of thermal insulation used to be specified in terms of so many inches (thick) for walls, ceiling, and floor. Today, insulation manufacturers refer to recommended *R* numbers. The R value reflects the resistance to the flow of heat offered by the insulation. The higher the number, the greater the resistance or insulating quality. R-13 insulation provides more insulation value than an R-6 material.

Specifying inches has been abandoned because of the variety of products available today and the fact that each material varies in its heat conductivity per inch thickness. Thus, six inches of one type may not provide the same insulating effect as six inches of another.

Window Losses

So, heat loss through exterior walls can be reduced by using adequate insulation, but what about windows? A window loses 14 times more heat than an insulated wall. Many windows can be provided with *storm* sashes. This cuts heat loss by 50%.

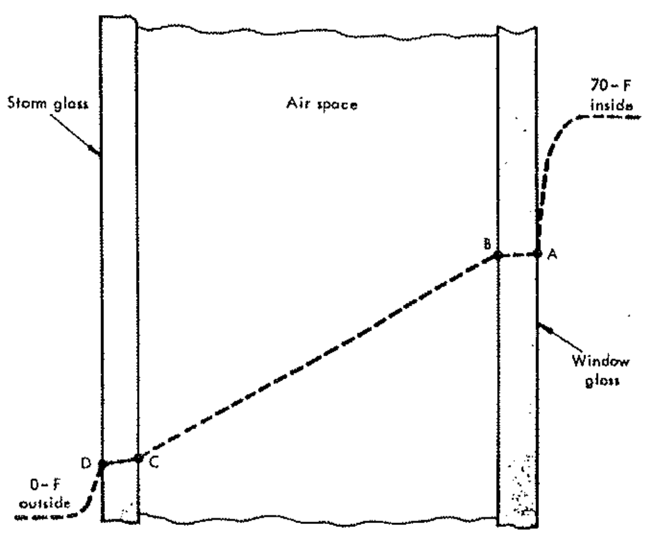


How much insulation?
Check with state energy office.

Another method of reducing heat loss through window glass is by installing *insulated* windows — double sheets of glass with an air space between them. Triple glazing is even recommended, as might be specially *coated* windows.

Moisture and Construction

Paint blisters showing up on walls and warped roofs are manifestations of moisture condensation inside building components. Under certain conditions of temperature and humidity, hidden condensation and frost buildup can occur on sheathing, siding, and other building members just as we observe it collecting on windows.



How important is a storm window or double glass? The air space between two panes of glass provides <u>half</u> the resistance to heat flow.

Humidity and comfort is covered in Lessons 3 and 8. Here we will focus on how moisture can affect building materials.

Again, considering the house as a system, the building must breathe. For much of a winter, the humidity level inside a building is higher than outside.

Ordinary air movement through building materials is the predominate cause of moisture migration from the inside out, but diffusion is also a factor.

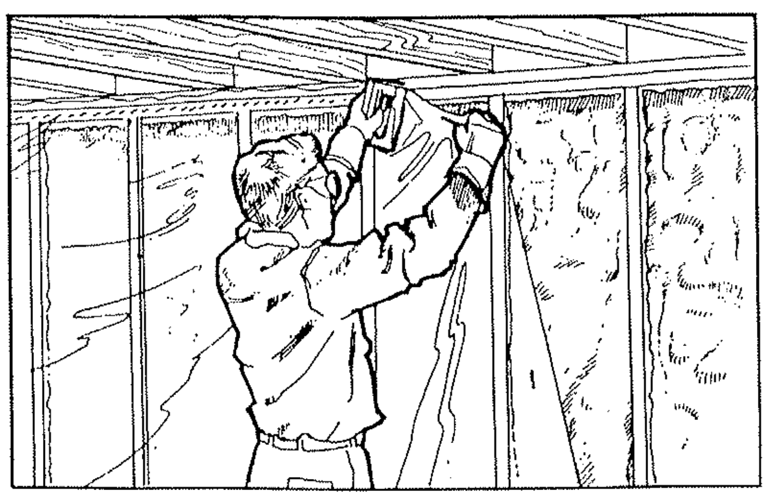
The water vapor pressure inside an occupied building during cold weather is more than it is outside. The reasons being, first, warm air can hold more moisture, and second, moisture is added to indoor air by people, plants and animals. Moisture is also added to the interior of buildings by any process which involves the use of hot water such as bathing, washing dishes, or cooking food.

This indoor-outdoor vapor pressure *difference* drives moisture through building components and we call this effect diffusion.

However driven, by air movement or diffusion, when the water vapor reaches a cold enough surface, it condenses. This may cause damage immediately or produce frost buildup, then thaw, and cause damage later on.

One answer to the condensation problem is to block passage using an air and vapor retarder (barrier). Condensation in walls, floors, and ceilings can be minimized by installing an air/vapor barrier such as heavy aluminum foil or special plastic film on the warm side of the walls, ceiling, and floor in the structure. By preventing the moisture from *reaching* cold surfaces, condensation can be prevented.

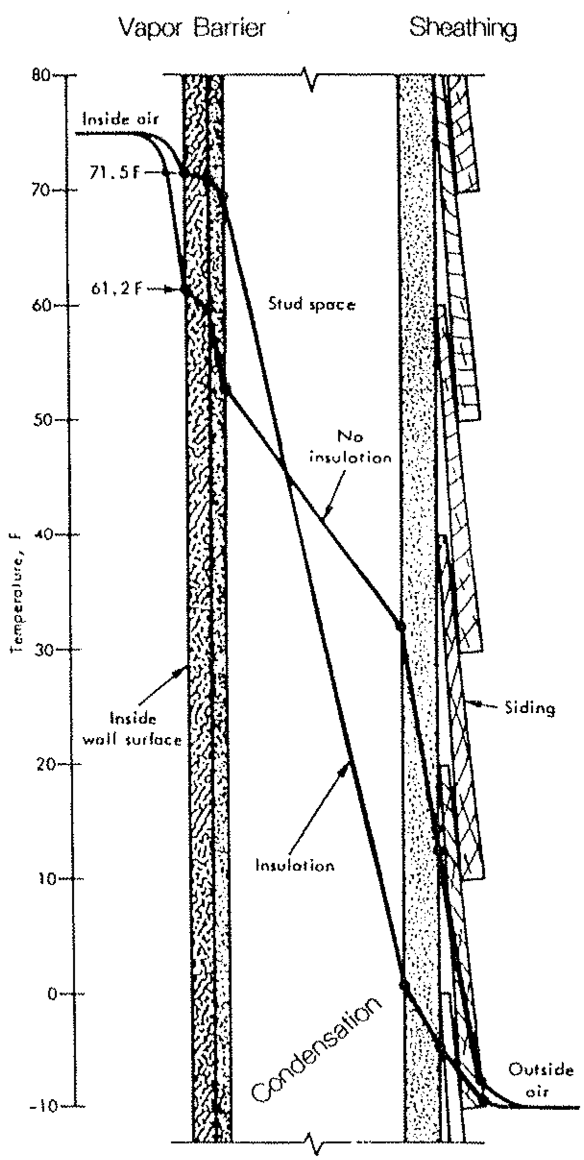
In spite of the fact that moisture migration is like heat transmission in many ways, there is no relationship between the thermal resistance of any particular substance to heat transmission and its ability to impede the migration of water vapor. Many substances which are excellent insulators against heat flow offer negligible resistance to the passage of water vapor and vice versa.



Vapor barrier (retarder) is installed on the warm side of an exterior wall.

In fact, the addition of wall and ceiling insulation — without a suitable vapor barrier — may increase the likelihood of condensation. How? In an *uninsulated* wall, so much heat is flowing into the interior wall cavity that the surface is too warm to cause condensation.

In an insulated wall, less heat escapes, and surfaces on the opposite side of the insulation are very near the same as the cold outdoor temperatures. This is why insulating older homes without effective air/vapor retarders sometimes causes condensation problems.



Temperature of sheathing in an insulated wall can approach that of the outdoor temperature. Condensation can occur on the sheathing and in the insulation. Note that the inside wall surface temperature of an uninsulated wall is nearly 14° colder (75 - 61.2°) than room air.

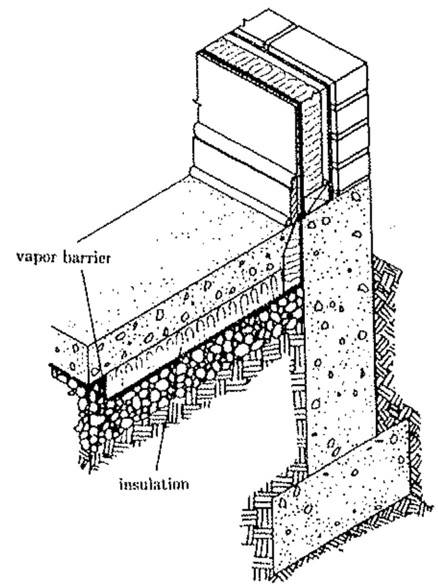
If after insulating an older building, condensation problems develop, one or more of the following may help to alleviate the problem:

- Paint the interior wall and ceiling surfaces with a paint that produces a film having a high resistance to the migration of water vapor.
- Make certain there are no unintentional sources of water vapor such as an unvented clothes dryer or a bare earth floor in a crawl space. (More on this later.)
- Provide mechanical ventilation of the building if the relative humidity is high after all possible extraneous sources of moisture have been eliminated.

Slab Floors

In a slab floor, the edge of the slab should be well insulated. Ground water problems must also be taken into consideration. It is important that the area under the slab be thoroughly waterproofed so that moisture will not rise through the slab, or ground water will not seep into any ductwork installed in the slab.

Use of unheated slab construction should *not* be considered for homes in cold climates. Only when the perimeter of the slab is heated directly by embedded ductwork can cold floor complaints be eliminated. Many owners have experienced heavy frosting along the perimeter edge extending as much as three feet into the room when unheated, uninsulated slabs were used in cold climates.

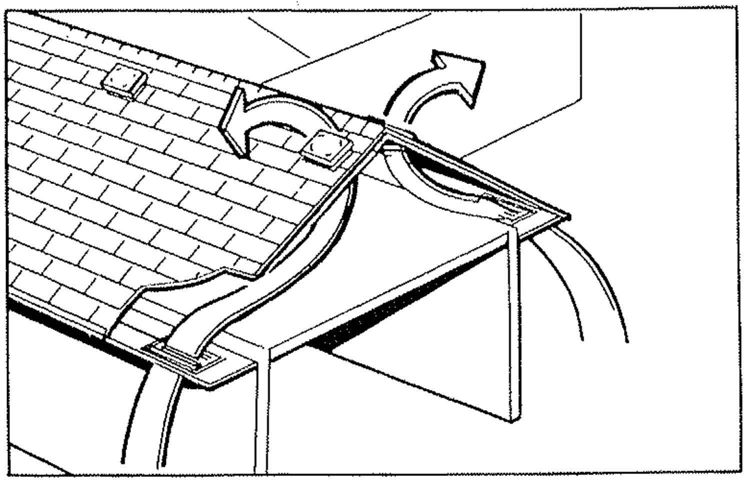


Edge of slab must be well insulated.

To heat a concrete slab floor successfully and economically, the edge of the slab must be well insulated along the entire perimeter. Both vertical and "L" shaped insulation is used.

When a concrete patio is made part of the construction, the highly conductive mass acts like a giant heat transfer fin and heat can readily escape in winter. Again, insulation should be added to produce a thermal "break" to minimize heat loss through the concrete.

Ventilated attic spaces are important too. Adequate vent openings purge the attic space of any moisture that may have penetrated through the ceiling before it condenses or even freezes. Without good attic venting, moisture buildup, in the form of ice crystals, will eventually thaw and damage insulation and even ceiling surfaces.



Left: Attic spaces must be vented to purge internal moisture.

A good vapor barrier in the ceiling minimizes this danger, but no vapor barrier is perfect so it's a combination of vapor barrier and vent openings that eliminates this problem.

Crawl Spaces

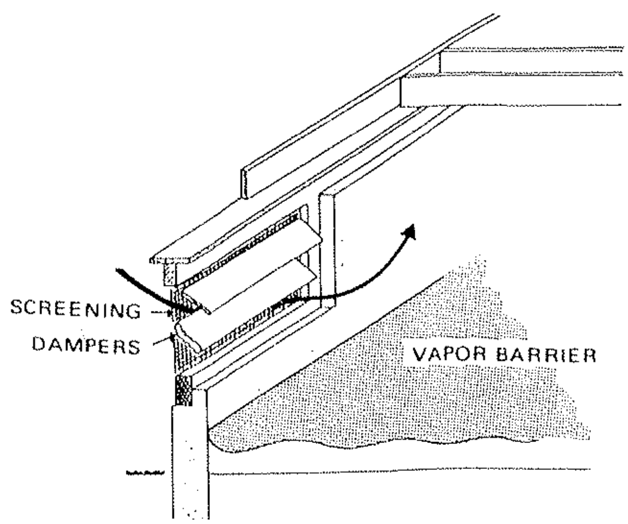
In houses over crawl spaces, it is important that the crawl space floor be covered with a moisture barrier. Even dry-looking ground will have moisture evaporating from it. This moisture can damage the house structure through excessive humidity.

Still controversial as to the real need, most building codes require crawl spaces to be fitted with ventilation grilles. Any ventilation openings to the outside should be equipped with effective closures to be used during the time the heating system is in operation.

Crawl space *walls* may be insulated to protect water pipes and heating ducts routed through the space. This is identified as a *conditioned* crawl space.

Crawl spaces with no insulation along the perimeter but with insulation in the floor above are termed unconditioned and fitted with open vents.

Many codes still require open vents in crawl spaces.



Evaporation of water from crawl space floor		
Bare Earth, High Moisture Content		16.25 Gallons
Free Water Surface		14.8 Gallons
Bare Earth, Average Moisture Content		10.3 Gallons
Earth Covered by Vapor Barrier		0.24 Gallons

Each can represents a gallon of water that evaporates from the ground in an 850 sq ft crawl space with and without ground cover. The second row represents the evaporation rate for free standing water. The crawl space must be covered.

Supplying Fresh Air

In the last lesson, we noted that occupants may complain about the lack of adequate "fresh air" during the heating season. They may complain about lingering odors, excessive humidity and a general "stuffiness."

Fresh air is needed in the house to replace air contaminated by cigarette smoke, by exhalation of carbon dioxide and by cooking odors.

Notable note: Evaporation of moisture in an uncovered crawl space can increase cooling costs considerably during the summer, since all of the moisture evaporates into the home and must be removed by the cooling system.

Very importantly, we are in need of fresh air to replace that which is consumed by gas or oil furnaces during combustion.

The question is how shall we provide it?

We already noted that outside air *leaks* into a structure around windows and doors, but also through holes for wiring, plumbing and penetrations for other services, electrical outlets, recessed lighting, sill and top plates — in fact, anyplace there is an intersection with other building components.

Reducing infiltration reduces heat loss and energy consumption. But, as buildings become more tightly constructed, new problems may arise.

To be certain of an adequate supply of combustion air, it may be necessary to duct outside air *directly* to gas or oil-fired heating equipment. *(A gas furnace may require 3,000 cu ft of air each hour of continuous operation.)*

Energy conservation has fostered tighter houses.

Kitchen and bathroom exhaust fans may not operate effectively. Venting clothes dryers may also be impeded, since you cannot exhaust air from a building without replacing it with an equal amount of outdoor "make-up" air.

Furnace and fireplace chimneys may not vent properly. Downdrafts (reverse flows) may even occur in unusual circumstances. The chimney actually becomes a make-up air duct, especially if exhaust fans are operating.

Forced Ventilation

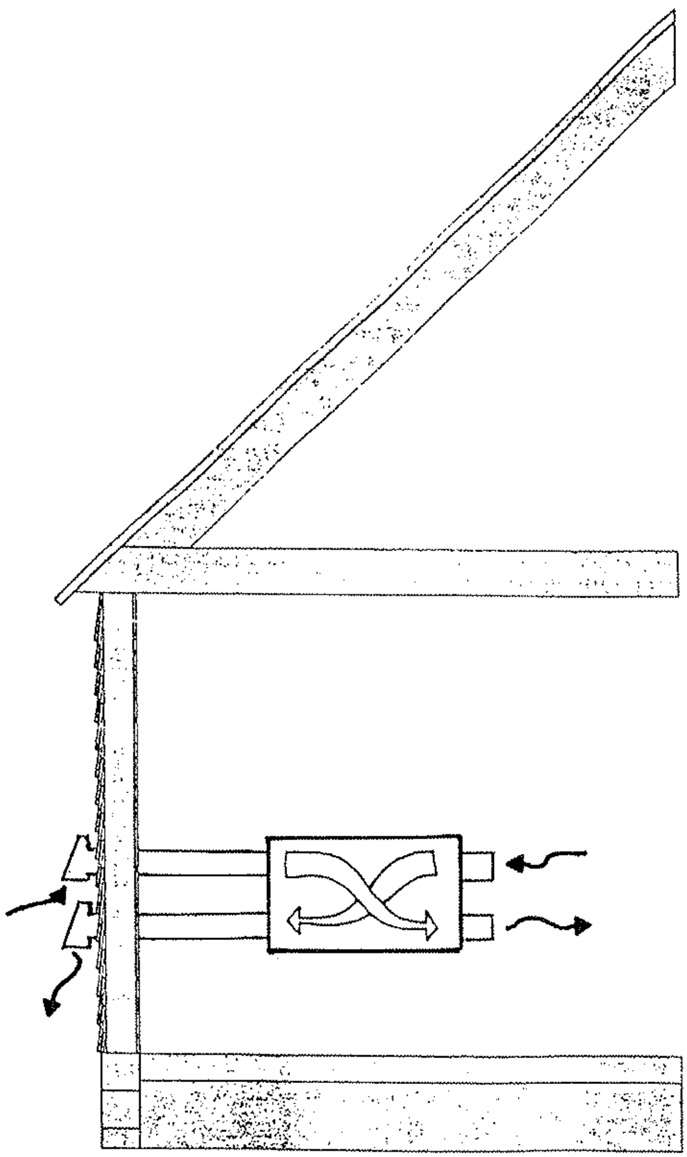
One solution to the "tight" house is to provide *positive ventilation.* This can be accomplished by installing an outdoor air intake opening and ducting it to the return side of the heating unit. The volume of outside make-up air supplied must be carefully regulated since the amount of "fresh" air introduced must, of course, be heated. This requires additional fuel and therefore increases the cost of operating the heating system.

To reduce this cost, an air-to-air *Heat Recovery Ventilator (HRV)* can be used. This device preheats cold incoming air using the heat available in stale room air being exhausted to the outof-doors. *(For more on HRV's, see Lesson 8.)*

The effectiveness of such a device to also purge other pollutants found in tight homes has not been clearly documented. It is recognized that small units would probably be ineffective since such small quantities of air are processed.

A house with a *fireplace* poses a unique problem to the heating specialist. One can imagine the heat loss if a door or a window were left open during the heating season! Well, an open fireplace flue can allow large amounts of warm air to leak out of the house.

A roaring fire in the fireplace only increases draft. Most of the fireplace heat goes right up the chimney, causing an even greater flow of indoor air. The warm air lost is, of course, replaced by infiltration of cold outside air around windows and doors.



A Heat Recovery Ventilator may be required to provide economical outdoor (fresh) air.

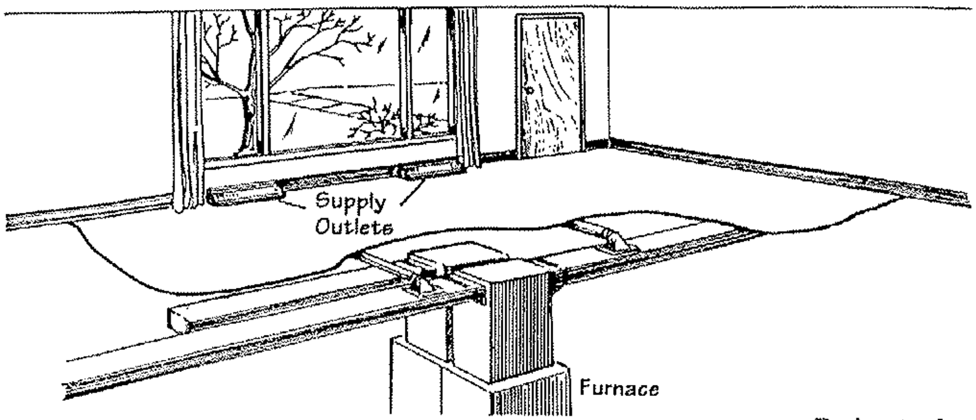
It is very important that the fireplace have a *damper* that can be easily and tightly closed when the fireplace is not being used, along with fireplace doors that can be opened and closed during operation.

System Interface

By now, we should understand sources of building heat losses and methods to reduce losses. Let's turn to the heating system interface. We'll start with a bit of history.

Before furnace fans were introduced, warm air heating systems were all *gravity* systems. A gravity warm air heating system operated on a very basic physical law. When air is heated, it expands and becomes lighter. Therefore, heated air rises in relation to adjacent colder or unheated air. Hence, the "theory" behind the hot air balloon or the chimney.

Since the force available to move air in a gravity system is very small, the furnace and ducts must offer very little resistance to the flow of air. The large gravity furnace was always installed in a basement as near to the center of the house as possible. The greater the height the heated air had to rise; the greater would be the gravity force, much as a tall chimney creates more draft than a short one.



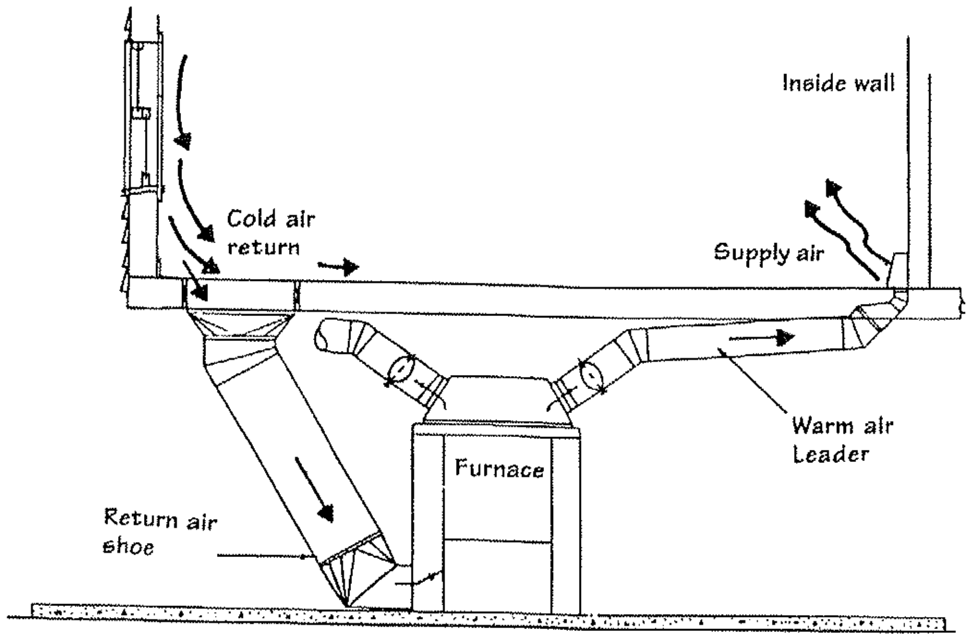
Perimeter heating.
Note supply outlets
are under windows.

Gravity Ductwork

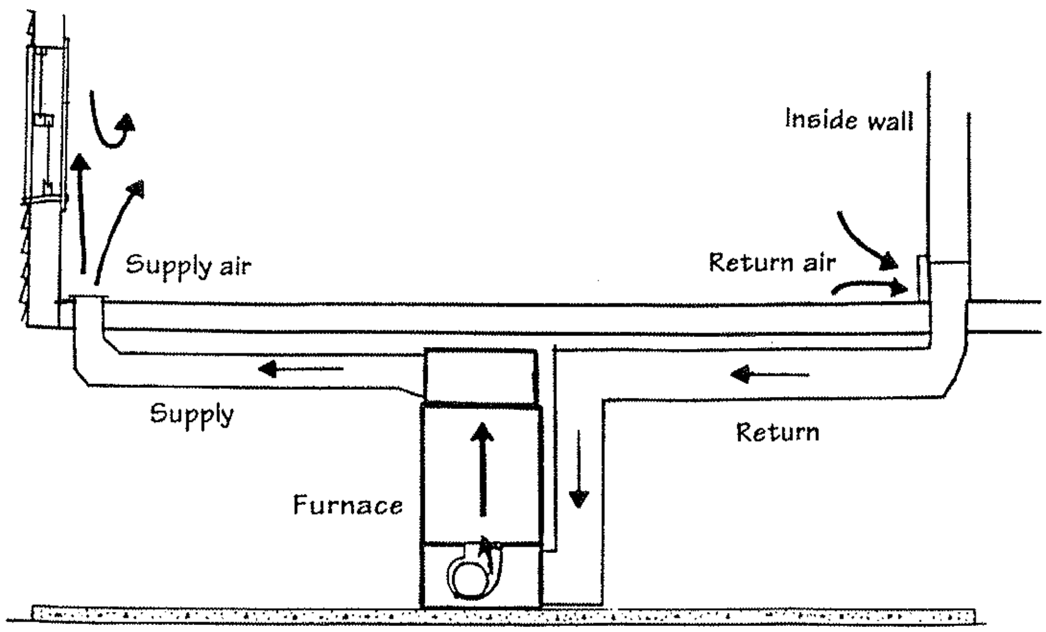
The sheet metal piping (now we say ductwork) for a gravity system had to be very large and as short and direct as possible.

The warm air supply outlets were usually located on *inside* walls. This resulted in the shortest horizontal run.

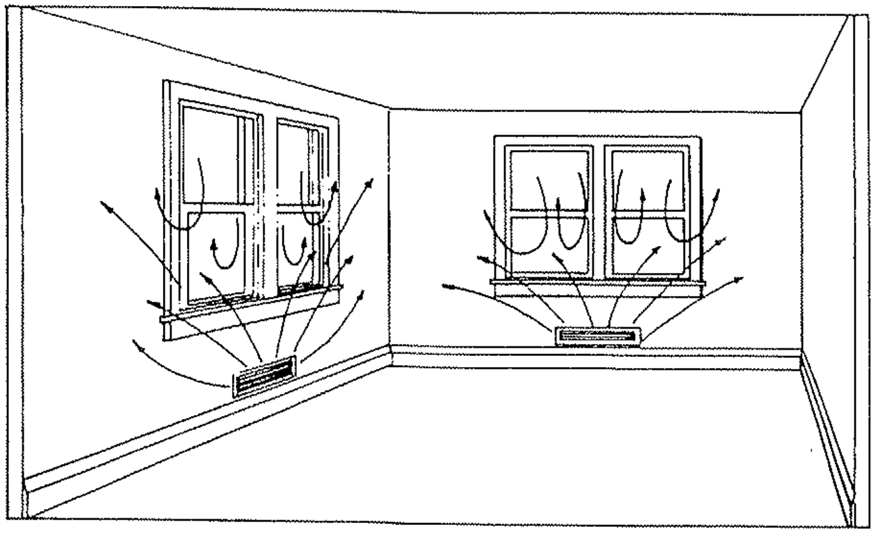
Cold air return grilles were usually placed along outside walls under windows where the coldest air would be "captured" and enter the return duct. This also helped to produce a large temperature difference between hot air leaving the furnace and cold air returning back to the furnace.



In a gravity system, hot supply air was introduced from registers near the inside wall. Cold air returns were placed beneath windows to "capture" cold air cascading down the window. When forced air furnaces were introduced, the supply/return locations remained essentially unchanged for some time.



Research led to the introduction of *perimeter* heating. This reversed the conventional configuration. Supply air was now introduced beneath windows to counter the cold air and return air was captured along inside walls. The heat was delivered at the point of greatest loss.



Perimeter heating introduces heated air at the point of greatest heat loss and counteracts cold air moving down the cold walls and cold glass.

Forced Warm Air

Well-designed gravity systems could and did perform well in homes with *basements.* They were not suited to other styles.

In a forced warm air system, the heated air is mechanically circulated by an electric powered blower — sometimes we say furnace *fan.* Ductwork is much smaller and can be routed horizontally for considerable distances. Furnaces can be placed anywhere — in a basement, attic or in a small room without regard to the elevation of the supply registers and return grilles.

Countering Heat Loss

As we now know, windows lose more heat than exposed wall surfaces because the heat conduction of glass is greater than other types of building materials. In addition, cracks around windows (and doors) are a source of cold air leakage, as we just learned.

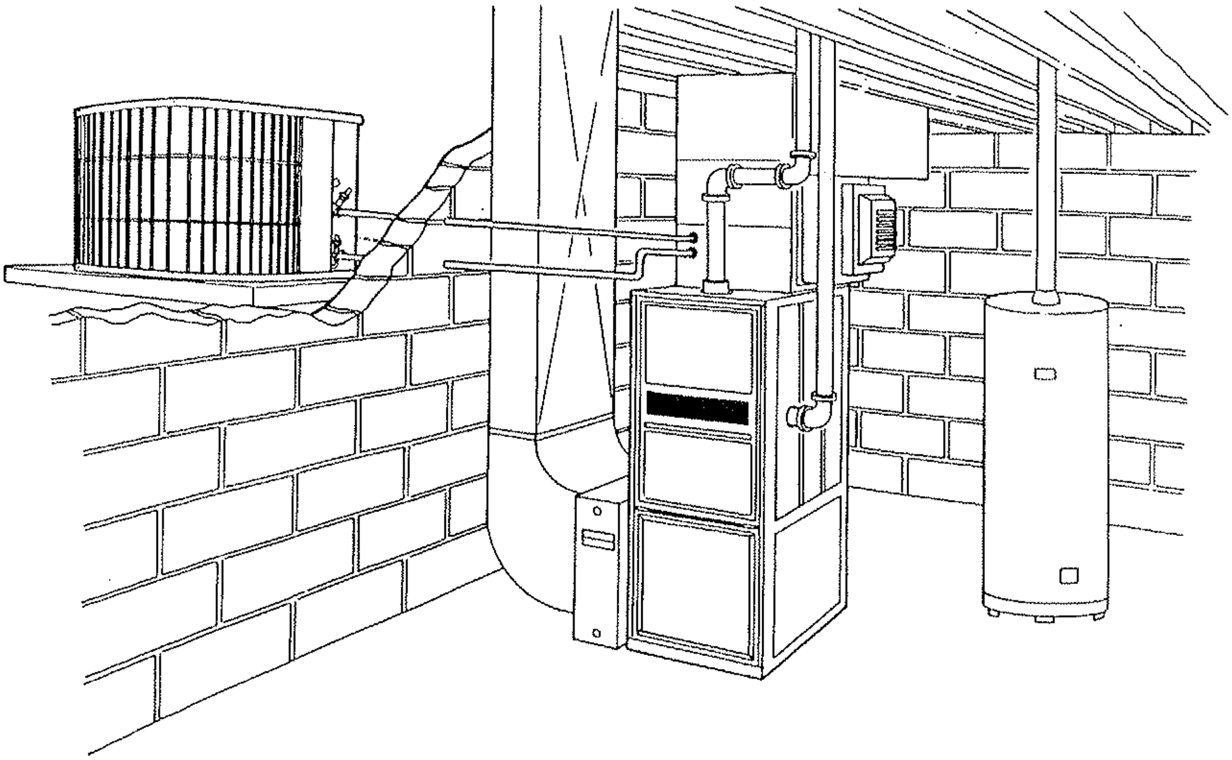
We also know that our bodies lose heat by radiation to any cold outside surfaces, and occupants "see" exposed walls and windows quite readily in every room.

These two phenomena led to the introduction of the *perimeter* heating system. In this system, the supply registers are positioned *under* windows whenever possible and/or along *outside* walls, thus supplying the heat where the loss is *greatest.*

Introducing heated air in this manner offsets the cool air falling from the windows and reduces radiation loss by warming the surfaces of the outside walls and windows.

House construction impacts the size and selection of the furnace and where the furnace, ducts, and outlets will be placed — and how well the system performs!

The architectural style of the building affects the amount of labor and material that goes into a complete heating installation. Two buildings can have exactly the same heat loss and exactly the same number of outlets and still have widely different installation problems.



Size, type and location of heating equipment are all influenced by architectural and construction features of the building.

Self-Check, Lesson 4 Quiz

You should have read all the material in Lesson 1 before attempting this review. Answer all the questions to the best of your ability before looking up the answers provided in the Answer Key.

Please indicate whether the following statements are true or false by drawing a circle around T (to indicate TRUE) or F (to indicate FALSE).

True False

1. T F The quality of construction is a factor in the performance of the heating system.

2. T F Air leakage through cracks, windows and doors can be a source of heat loss.

3. T F Installing insulation of an outside wall decreases the temperature of the inside wall surface.

4. T F The appropriate level of insulation for a given area of the country is specified in thickness of insulating material in inches.

5. T F The air space between window panes is critical to reducing the heat loss through glass.

In the following multiple-choice questions, choose the phrase that <u>most</u> correctly completes the statement, and check the appropriate box for the corresponding letter in front of the phrase.

6. The predominate mechanism for moisture in air to move from inside a building through building materials is:

☐ A. air movement. ☐ B. diffusion.
☐ C. moisture difference. ☐ D. temperature difference.

7. Water vapor condenses on windows and inside wall surfaces because the moisture:

☐ A. contacts a warm surface. ☐ B. contacts a cold surface.
☐ C. is trapped between the surfaces. ☐ D. cannot circulate freely.

8. Older homes may experience moisture condensation problems because of:

☐ A. high infiltration rates. ☐ B. low ventilation.
☐ C. inadequate vapor barriers. ☐ D. leaky windows.

9. Heavy frosting along the edge of a floor slab in a cold climate is generally the result of

☐ A. no ground cover under the slab. ☐ B. excessive indoor humidity.
☐ C. a high water table. ☐ D. lack of perimeter slab heat.

10. Attic spaces must be well ventilated in winter to:

☐ A. release any heat trapped between roof and ceiling.
☐ B. purge any water vapor migrating through the ceiling.
☐ C. increase the building chimney effect.
☐ D. reduce under shingle surface temperature.

For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

Key Words

infiltration	perimeter	absorber	make-up	barrier
open	combustion	dilution	preheat	conventional

11. The earth floor of a crawl space must be covered with a moisture ________________.

12. Fresh air is needed to reduce air contaminants and to provide ______________ air for gas and oil furnaces.

13. Exhaust fans need an adequate supply of ________________ air.

14. A heat recovery ventilator reduces the cost to _________________ ventilation air in the wintertime.

15. A _______________________ heating system features supply outlets along outside walls with return air intakes along inside walls.

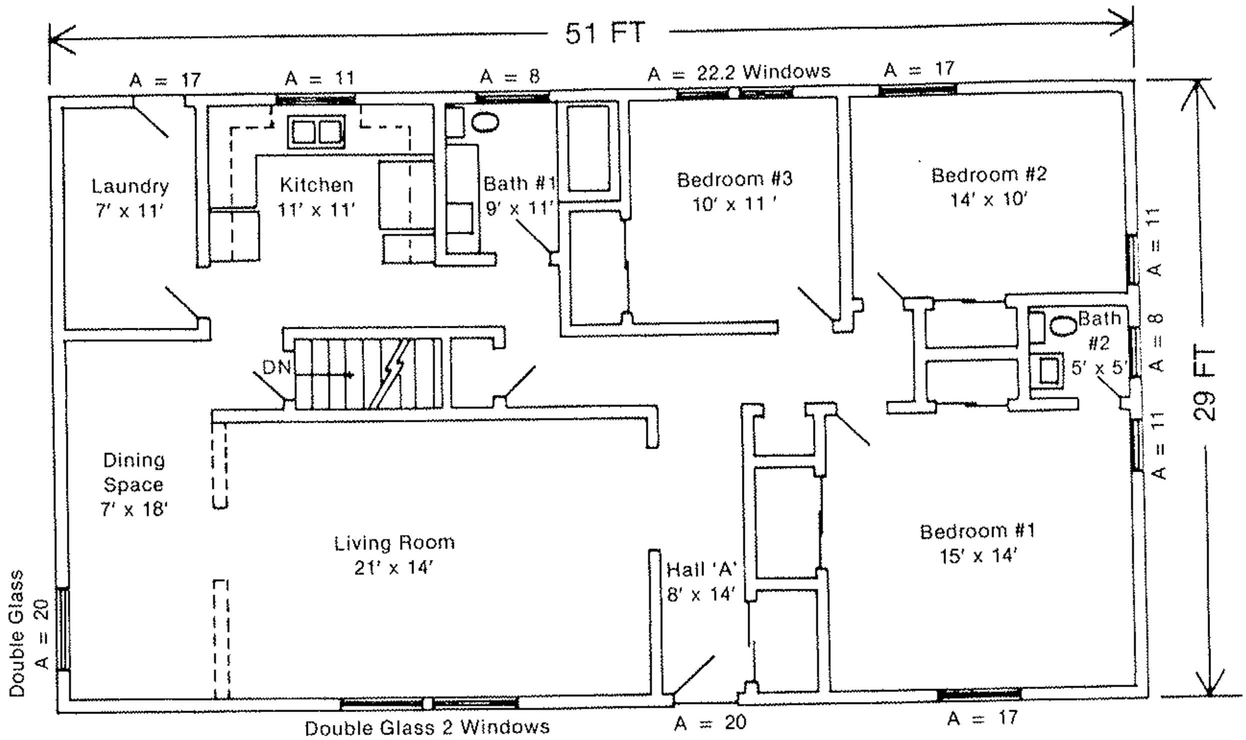
Check Your Answers!

Lesson 5 Overview

There are a number of small system heat loss calculating manuals used in the industry. So, we are not going to teach a specific heat loss procedure in this chapter. (There is separate course material on load calculations based on Manual J, published by the Air-Conditioning Contractors of America @ ACCA.org) What we intend to do here is provide the technical background common to most procedures — selecting design weather conditions, heat loss formulas, and physically what to measure.

Now read Lesson 5 which begins on the next page.

Lesson 5: Estimating Heat Loss



FIRST FLOOR
Ceiling Height 8' 0"

An estimate of a building's heat loss rate in Btu/h is necessary to determine the size of the heating system. The importance of this step cannot be over-emphasized.

Other names for this exercise are heat loss survey, comfort survey, or load calculation.

Furthermore, the heating load must be determined on a *room-by-room* basis in order to size the duct system and the supply outlets and return air grilles.

You cannot select equipment based on some rule of thumb estimate. This often leads to over sizing and comfort may be affected by installing a unit that is grossly oversized. Besides, a careful load calculation will often point out places where it is more desirable to *reduce* the heat loss for improved comfort than to size a furnace to handle the existing load.

As described in the last chapter, the key factor affecting the rate at which a structure loses heat is its *construction.* This includes not only the materials used and level of insulation provided, but also the quality of construction which may affect the *infiltration* load.

A load calculation also involves consideration of *wind speed.* Obviously, as wind speed increases, so does the heat loss rate of the structure. Most industry estimating procedures assume a 15 mph wind speed, but special cases may require using another value.

Another issue affecting heat loss rate is the *design outdoor temperature*. Logically, a house located in the South with a heating outdoor design temperature of 30° would have a much smaller heat loss than the exact same house built in Cleveland, Ohio with a design temperature of 0° F.

The outside design temperature is based on a careful study of weather bureau records. It is *not* the coldest temperature ever recorded, but a temperature that will not be exceeded for more than just a few hours in a typical year.

Take Chicago, Illinois for example. A design temperature of -6° F would cover 99.6% of the hours in a typical year. If only a 99% "coverage" were chosen, the design temperature is -1° F

Whatever outdoor design temperature selected, reality is that temperature *extremes* usually occur late at night, and therefore would have minimal impact on occupant comfort.

ASHRAE publishes the most referenced listing of recommended design temperatures for key cities in the United States and Canada. Industry procedures most often use the ASHRAE data. However, local weather bureaus can also assist anyone searching for this information for cities not included in the ASHRAE tabulation.

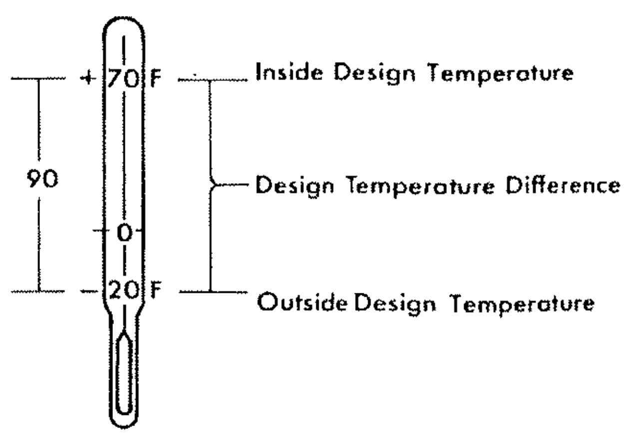
It is the design temperature *difference* between indoors and outdoors that is used to actually compute the heat loss through building materials.

Over time, common practice has been to use, 68°, 70°, and even 75° F for the *inside* design temperature. The *local building code* for public buildings and apartments may also specify a required minimum inside temperature at a specific outdoor temperature. Typically, 70° F is used in most calculation procedures.

The design temperature difference is merely a subtraction of the outside design temperature from the inside design temperature.

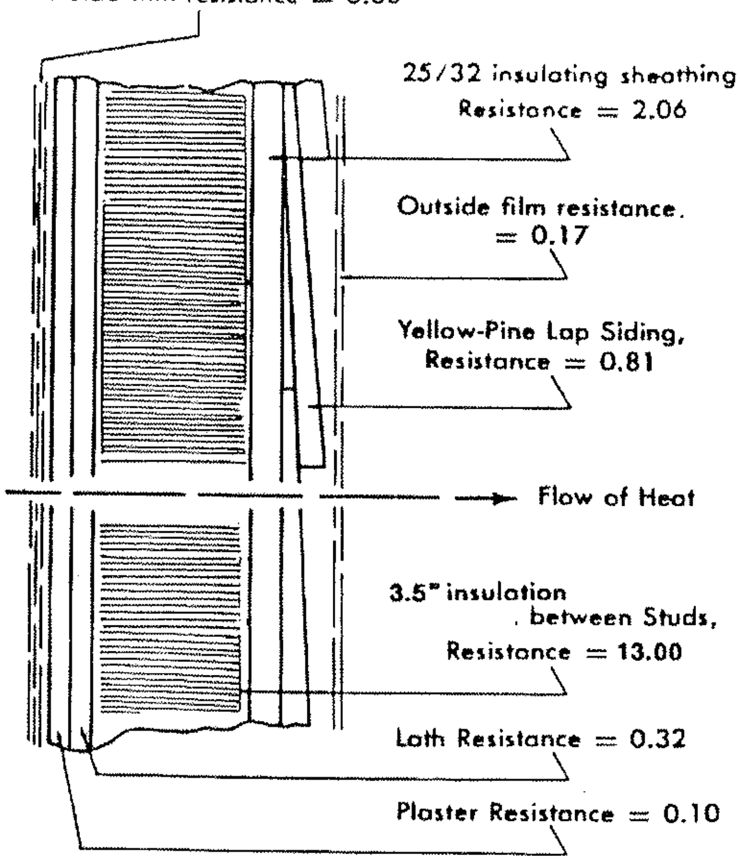
Example: Inside 70° and outside 30°. Difference is 70 - 30 or 40 degrees. This Design Temperature Difference is often called *Delta T,* DTD or just TD.

For outdoor temperatures *below zero,* it is necessary to change the minus sign to plus and *add* to indoor temperature. To the right is an example when outdoor temperature is -20º F.



***Notable note: Selecting a design outdoor temperature at the 99.6% level means that possibly 35 hours in a typical year would be colder. At 99%, all but 88 hours would be expected to be handled by the equipment without experiencing a slight drop in indoor temperature. This also assumes no internal heat benefit from lights, people and appliances.*"U" Factor**

Most building components are a composite of several different materials — dry-wall, studs, insulation, sheathing, siding, etc. The rate at which heat flows through a combination of materials is called the "U" factor or *overall* coefficient of heat transfer. The "U" factor is expressed in terms of Btu per hour per square foot per degree temperature difference.



Remember the "R" value of insulation? Well, the "U" factor for a wall is actually computed from the individual *resistances* of each piece that goes into making up the wall, including the insulation. The resistance of each material is added together to arrive at a *total* resistance. The "U" factor is the reciprocal of the total resistance.

Without going in extensive detail, assume the resistances of the individual wall materials were the following (see wall section) —

0.68 + 2.06 + 0.17 + 0.81 + 13.00 + 0.32 + 0.10 = 17.14 total resistance.

Then, the "U" factor for the wall would be 1/17.14 or 0.058 Btu/h/sq ft/°F.

Calculating Heat Loss

The *conduction* heat loss in Btu/h through a wall, window, door, ceiling or floor exposed to outdoor temperatures is the product of the design temperature difference times a specific "U" factor times the area of the exposed building surface.

Mathematically: H = U x A x Delta T where H equals heat loss, A is surface area, and Delta T is inside temperature minus the outside temperature.

For example: Assume a room's exposed wall has a *net* area of 112 sq. ft. Suppose the "U" factor is 0.058 for the type of wall construction and insulation added; and the Delta T is 80 degrees based on 70° inside and -10° outside. The wall heat loss would be — 0.058 x 112 x 80 = 520 Btu/h.

The *sum* of the individual heat losses through all the *exposed* walls, ceiling, floor, doors, and windows in each room becomes the conduction heat loss of the building.

Design manuals include tables of "U" factors for different wall, floor, and ceiling construction plus door and window types (single pane, double pane, etc.).

One procedure pre-calculates the "U" factor and Delta T to form tables of Heat Transfer Multipliers (HTM). This is simply multiplying the various "U" factors by various Delta T's and tabulating the results.

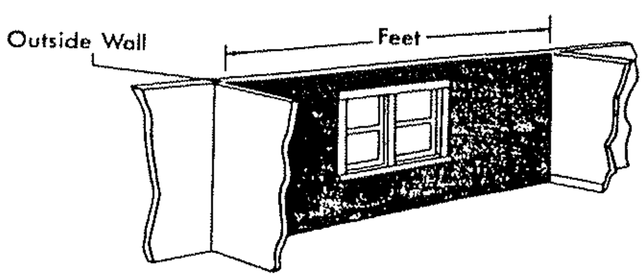
For instance: from our previous example, "U" was 0.058 and Delta T was 80°. The HTM would be — 0.058 x 80 or HTM = 4.64.

Now all the designer would have to do is select the correct HTM from the table and multiply it by the measured wall areas of the building.

What to Measure

The area of any building surface that is *exposed* to outdoor temperatures or temperatures significantly below inside design temperature must be determined.

In existing structures, actual measurements can be taken.

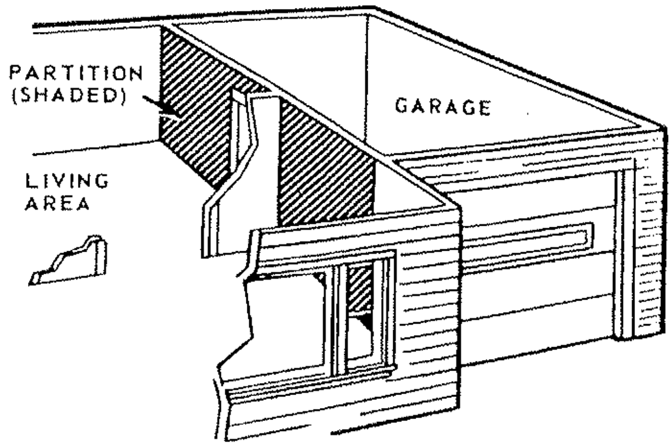


<u>Gross</u> wall area is length x width. <u>Net</u> wall area is gross area - window area.

In new construction, building plans are used to find lengths, widths, and heights needed.

Window and door areas in outside walls are determined and then *deducted* from gross wall areas, since doors and windows have *different* HTM's than walls and their heat losses are figured separately.

Example of a cold partition which must be included in wall heat loss calculations, along with walls fully exposed to the outside.



For example: If the *gross* exposed wall area of a room was 136 sq ft and a window in the wall was 24 sq ft, then the *net* wall area for heat loss purposes would be — 136 - 24 = 112 sq ft. (same as our previous example).

We would find the window HTM in a manual (say 44) and compute the heat loss just through the window — 44 x 24 = 1,056 Btu/h

We would then add the 1,056 Btu/h to the wall loss of 520 Btu/h (see previous example) to find the total heat loss through the wall assembly— 1,056 + 520 = 1,576 Btu/h.

An outside door in a wall would be treated separately in the same manner.

Walls exposed to unheated garages or unheated rooms are identified as *cold partitions* and must be part of the heat loss calculation. Ceilings exposed to unheated attics are also included.

Floor Heat Loss

Is the finished floor over a basement or crawl space? If it is in direct contact with the ground, then it is termed a slab floor?

Floors over *unheated* basements or crawl spaces are considered a source of heat loss and must be measured.

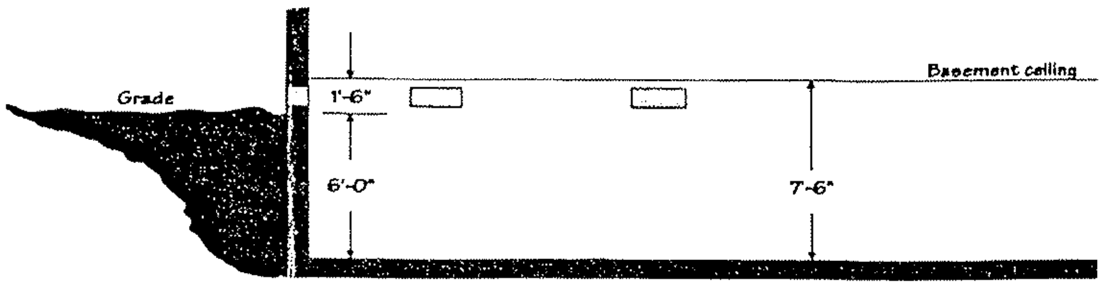
Notable note: When measuring for heat loss, lengths and widths are usually figured to the nearest foot (14 ft., 6 inches becomes 15 feet.) Heights are usually taken to the nearest half foot (7 ft., 9 inches would become 8 feet; 7 ft., 4 inches would be 7.5. ft.)

The heat loss for a slab floor on grade is high, because the edge of the slab is exposed to, and directly affected by, outside air temperature. The heat loss is much greater near the edge than at the center. Actually, slab floor heat loss is proportional to the perimeter length of the slab. Most procedures provide an HTM on a per foot basis rather than on a per square foot basis.

Basements

Basement heat loss is usually a result of the following —

- The wall *above* grade level (above the outside ground level)
- Basement windows
- The wall *below* grade level
- The *basement* floor



Basement wall loss is divided between above grade and below grade wall surfaces, as the heat loss rates are different.

Each is usually treated separately. The wall above grade follows standard practice. The "U" value and the temperature difference between inside and outside are multiplied by the net area of the exposed wall. (Any windows are once again determined separately.)

The portion below grade is estimated differently because the temperature of the ground below grade is warmer than the outside air temperature. The "U" factor between the wall and ground is also different. The effect is *less* heat loss per square foot below grade than above grade. And, as the basement gets deeper, the wall loss declines. Most load calculation procedures account for these differences.

Basement floors usually have a very small heat loss, and in many procedures, the basement floor loss is neglected. If not neglected, a simplified estimate may be required, such as 2 times the floor area is the estimated heat loss.

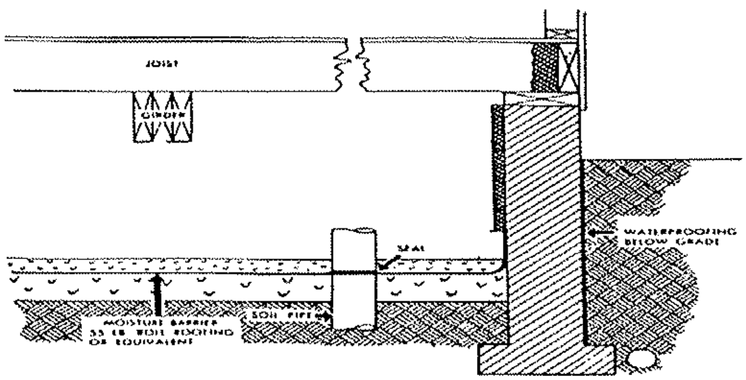
A crawl space is simply considered a shallow basement. However, because it is closer to grade, a crawl space floor will lose heat more rapidly around its perimeter and less rapidly near its center — similar to a slab floor. A perimeter measurement (distance around, in feet) or an adjusted floor area may be used to determine a crawl space floor loss.

There are a number of heat loss calculating procedures used in the industry, and each may offer a slightly different approach to a solution for crawl space heat loss. Thus, the particular procedure used should be learned so that the proper measurements are "plugged in" to arrive at a reasonable estimate of heat loss.

Infiltration

So far, we have considered accounting for the ways in which a building loses heat by conduction through the outside shell of the structure. A building, as we know, can also lose heat by having cold outside air enter and displace warm air.

Providers of load calculation manuals vary in their approach to estimating infiltration. Two traditional methods used to estimate infiltration are the ***crack*** and the ***air change*** methods. In the traditional crack method, the actual feet of crackage around windows and doors are measured and multiplied by a listed air leakage rate per foot of crack for the type of window.



Crawl space shown at left is treated like a shallow basement.

The length of crack in a double hung window, for example, would be twice the window height and three times the window width. At 15 miles per hour, air might leak in at 20 cubic feet per hour *per foot of crack.*

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

Summer Air Changes Per Hour

Floor Area	900 or less	900-1500	1500-2100	over 2100
Best	0.2	0.2	0.2	0.2
Average	0.5	0.5	0.4	0.4
Poor	0.8	0.7	0.6	0.5

Envelope Evaluation

Best - Continuous infiltration barrier, all cracks and penetrations sealed, tested leakage of windows and doors less then 0.25 CFM per running foot of crack, vents and exhaust fans dampered, recessed ceiling lights gasketed or taped, no combustion air required or combustion air from outdoors, no duct leakage.

Average - Plastic vapor barrier, major cracks and penetrations sealed, tested leakage of windows and doors between 0.25 and 0.50 CFM per running foot of crack, electrical fixtures which penetrate the envelope not taped or gasketed, vents and exhaust fans dampered, combustion air from indoors, intermittent ignition and flue damper, some duct leakage to unconditioned space.

Poor - No infiltration barrier or plastic vapor barrier, no attempt to seal cracks and penetrations, tested leakage of windows and doors greater than 0.50 CFM per running foot of crack, vents and exhaust fans not dampered, combustion air from indoors, standing pilot, no flue damper, considerable duct leakage to unconditioned space.

One example of tabulated infiltration rates in air changes per hour based on size of house and quality of construction. Example: An average 1500 to 2100 square foot house would experience 0.8 changes/hr.

Knowing the air leakage rate, crack length and the Delta T, the heat loss due to infiltration could be estimated.

In the air change method, infiltration is determined by simply assuming an hourly *air change rate* based on the number of exposures a room might have. The greater number of exposures, the higher the air change rate assumed.

For example, a room with one exposed wall — a wall with windows and an outside door on one side only — might be listed as having infiltration equal to 1/2, air change per hour. That is: outside air equivalent to 1/2 the volume of air in the room leaks into the room each hour. Again, knowing the Delta T, it is possible to determine the room heat loss due to infiltration.

With improvements in our knowledge about infiltration and the discovery that most infiltration occurs through openings other than windows and doors (about 20% occurs through windows and doors), the air change and basic crack methods have in a sense been blended.

The latest procedure is based on estimates of the crackage area or crack length for all possible construction openings, not just windows and doors. This leads to an estimated hourly infiltration rate. Since the computations are extremely lengthy, most procedures provide typical leakage rates in terms of *air changes per hour,* based on good, better, and best construction evaluation. A sample is shown above.

The whole house CFM formula: *Floor area x ceiling height x air change rate/60.*

Ventilation

In residences and other lightly-constructed buildings, the introduction of reasonable rates of mechanical ventilation does not reduce natural infiltration. Therefore, ventilation becomes an *additional* heating load.

If ventilation air is introduced through the furnace system via an outdoor air intake, the amount of air introduced in CFM can be used to estimate the added heating load using the design Delta T. The formula is: 1.08 x CFM x Delta T (1.08 is a constant to account for the air density and convert minutes to hours.)

If it were necessary to mechanically supply 50 CFM of outside air, the added load for the 80° Delta T would be:

1.08 x 50 x 80 = 4,320 Btu/h.

As mentioned previously, super-insulated homes probably require some level of controlled, mechanical ventilation. If the estimated infiltration is less than 0.25 air changes per hour, ventilation is probably needed; if a Heat Recovery Ventilator (HVR) is installed, the ventilation heating load will be substantially reduced.

Account for Duct Loss

If ductwork is not located in heated spaced, then the loss of heat from the ductwork must be calculated and *added* to the building heat loss. Exposed but insulated ductwork can add 10% to 20% to the total heating load the furnace must satisfy.

Total Heat Loss

Total heat loss, then, is the sum of the heat losses of all the individual rooms, including the heat loss through a basement or crawl space, air infiltration and ventilation (if used) and any exposed duct loss. From this Btu/h figure, the size of the heating equipment required is determined.

As mentioned, there are a number of simplified heat loss calculation manuals, as well as computer software programs, used in the industry. One example is Manual J, published by Air Conditioning Contractors of America.

Manual J and manufacturer provided manuals include design temperature information for various localities, tables of "U" factors or HTM's for doors, windows and building components and infiltration factors. Step-by-step procedures with worksheets and sample problems are also provided.

1	Name of Room					Entire House			1 Living			2 Dining			3 Laundry		
2	Running Ft. Exposed Wall					160			21			25			18		
3	Room Dimensions Ft.					51 x 29			21 x 14			7 x 18			7 x 11		
4	Ceiling Ht. Ft	Directions Room Faces				8			8	West		8	North		8		
TYPE OF EXPOSURE			Const No.	HTM Htg.	HTM Clg.	Area or Length	Btuh Htg.	Btuh Clg.	Area or Length	Btuh Htg.	Btuh Clg.	Area or Length	Btuh Htg.	Btuh Clg.	Area or Length	Btuh Htg.	Btuh Clg.
5	Gross	a	12-d			1280			168			200			144		
	Exposed	b	14-b			480											
	Walls &	c	15-b			800											
	Partitions	d															
6	Windows	a	3-A	41.3		60	2478		40	1652		20	826				
	& Glass	b	2-C	48.8		20	976										
	Doors Htg.	c	2-A	35.6		105	3738										
		d															
7	Windows		North														
	& Glass		E&W														
	Doors Clg.		South														
8	Other Doors		11-E	14.3		37	529								17	243	
9	Net	a	12-d	6.0		1078	6468		128	768		180	1080		127	762	
	Exposed	b	14-b	10.8		460	4968										
	Walls &	c	15-b	5.5		800	4400										
	Partitions	d															
10	Ceilings	a	16-d	4.0		1479	5916		294	1176		126	504		77	308	
		b															
11	Floors	a	21-a	1.8		1479	2662										
		b															
12	Infiltration HTM			70.6		222	15673		40	2824		20	1412		17	1200	
13	Sub Total Btuh Loss = 6+8+9+10+11+12						47808			6420			3822			2513	
14	Duct Btuh Loss			0%		—			—			—			—		
15	Total Btuh Loss = 13 + 14						47808			6420			3822			2513	
16	People @ 300 & Appliances 1200																
17	Sensible Btuh Gain = 7+8+9+10+11+12+16																
18	Duct Btuh Gain				%												
19	Total Sensible Gain = 17 + 18																

Load calculation manuals include custom worksheets to organize calculations.

Computer Methods

Despite the introduction of simplified manual heat loss calculating procedures for small structures, the advent of the low cost computer has prompted software developments to determine building heat loss. In addition to saving time and drudgery, computer programs can provide rapid *analysis* of proposed changes to insulation, building orientation, window sizes, etc., and the economic benefits that may accrue.

Whether calculations are done by computer or manually, someone must still make a building *survey* either from floor plans, in the case of a new building, or an on-the-site inspection for an existing one. The building survey form below is just one example of the type of information required to determine a building's heat loss.

Building Thermal Factors Survey

Design Conditions
Dry Bulb ________ Summer ________ Winter __________
Indoor °F ________ ________ __________
Outdoor °F ______ ________ __________

General Conditions:

1. Direction house faces: N NE E SE S SW W NW
2. House type: 1-story 2-story Split level
3. House age: New Planned Under construction
   Existing Approximate age __________

Construction:

1. Walls: Frame ________ Brick Veneer ______ Masonry __________
Insulation type __________ thickness __________ Interior partitions: Single _________
Double ____________ Color: Dark ________ Light _________

2. Ceiling heights: 1st floor ________ Vaulted ________ 2nd floor ___________
Other ________ Basement __________ Crawl space ___________

3. Roof: Pitched _______ Flat ______ Vented ______ Unvented ________
Color: Dark ________ Light _________

4. Ceiling: Attic above ______ Under occupied space ______ Insulation ________
Thickness ________ Natural vent ______ Attic fan ______ Whole house fan ______

5. Floors: Over basement ______ Over garage ______ Car port ______ Over crawl space ______ Vented ______ Unvented ______ Moisture barrier on ground

6. Insulation: None _____ Type ______ Thickness ______

7.. Windows Single pane ______ Double pane or storm sash ______ Moveable ______
Fixed ______ Double hung ______ Plain ______ Weatherstripped ______ Casement ______
Glass block _______ Certified ______ Non-certified ______

8. Exterior doors: Type _____________ Insulated _______ Storm door __________
Weatherstripped ________

9.. Shading: Type: Location:

Type	E	SE	S	SW	W
Roof overhang feet					
Awnings					
Trees					
Garage, carport, porch					
Inside shades					
No shading					

10. Miscellaneous: Number of people ______ Kitchen exhaust fan ______
Clothes dryer ______ Vented _____ Not vented ______

11. Special considerations: Frequent entertaining ________ summer temperature __________
Winter temperature __________

12. Special room treatment: Workshop ____ Game room ____ Other ______
Unusual lighting or appliance loads ______

Even computer load calculation procedures require building measurements and a physical survey of existing buildings.

Self-Check, Lesson 5 Quiz

You should have read all the material in Lesson 5 before attempting this review. Answer all the questions to the best of your ability before looking up the answers provided in the Answer Key.

Please indicate whether the following statements are true or false by drawing a circle around T (to indicate TRUE) or F (to indicate FALSE).

True False

1. T F The basic purpose for estimating building heat loss is to size the heating unit and the air distribution system.

2. T F Because of their small size, windows and outside doors can be safely neglected when estimating heat loss.

3. T F The outside design temperature is based on the coldest local temperature occurring in the last five years.

4. T F Industry load calculation procedures usually assume a local design wind speed of 5 mph for winter heating.

5. T F The "U" factor for a wall is the same as the "R" value for insulation.

In the following multiple-choice questions, choose the phrase that <u>most</u> correctly completes the statement, and check the appropriate box for the corresponding letter in front of the phrase.

6. The design temperature difference for a 70° F inside temperature and a -5° F outside temperature is:

☐ A. 65° DTD. ☐ B. 70° DTD.
☐ C. 75° DTD. ☐ D. 80° DTD.

7. The heat loss for a wall with a U factor of 0.10, a net area of 100 sq. ft. and a TD of 60° is:

☐ A. 6 Btu/h. ☐ B. 60 Btu/h.
☐ C. 600 Btu/h. ☐ D. 6,000 Btu/h.

8. The HTM for a ceiling with a "U" factor of 0.04 for TD's of 40° and 60° is:

☐ A. 1.6 and 2.4 Btu/h/sq ft respectively.
☐ B. 1.2 and 0.4 Btu/h/sq ft respectively.
☐ C. 1.6 and 2.4 Btu/sq ft respectively.
☐ D. 1.2 and 0.4 Btu/sq ft respectively.

9. An exposed wall has a gross area of 207 sq. ft. with a 36 sq. ft. window and a 21 sq. ft. exterior door. The net wall area is:

☐ A. 207 sq. ft. ☐ B. 186 sq. ft.
☐ C. 171 sq. ft. ☐ D. 150 sq. ft.

10. A tight 8,000 cubic foot house (1,000 sq ft with 8 ft ceiling height) has an estimated air change rate of 0.4 AC/h. How much air is leaking into the house per minute?

☐ A. 2,000 CFM. ☐ B. 3,200 CFM.
☐ C. 53.3 CFM. ☐ D. 107 CFM.

For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

Key Words

above center duct cold partitions preheat edge
partially exposed unheated dilution below

11. Walls or ceilings exposed to unheated spaces are referred to as ________________.

12. Floors over ________________ basements or crawl spaces are included in a heat loss estimate.

13. The heat loss of a slab floor is high because the ________________ is exposed to the outside air.

14. Basement wall loss is a combination of losses for __________ grade and __________ grade exposures.

15. The total heat loss of a structure is the sum of the individual room or below grade losses (including infiltration) plus any ______________ loss and ventilation load.

Check Your Answers!

Lesson 6 Overview

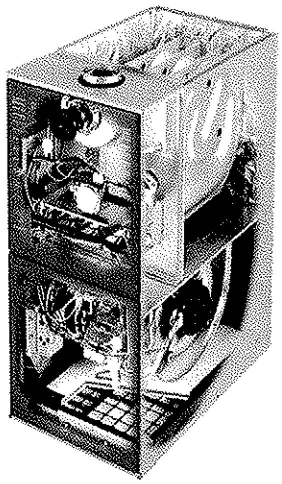
After completing this reading assignment and the self-check review quiz, you will be able to answer these questions.

- What are the essential parts of a forced air furnace?
- Is there more than one model of furnace?
- How are furnaces rated and by whom?
- What are the basic parts of an oil burner?
- What's covered under in-space heating equipment?

Now read Lesson 6 which begins on the next page.

Lesson 6: Forced Air Heating Units

With the launch of the U.S. Department of Energy minimum efficiency standards, furnace manufacturers introduced a series of new furnace designs in the 1990s.



Many years ago, cast iron or steel pipe less coal furnaces were quite common. However, with the introduction of gas and oil for heating fuels, the ducted gravity system soon followed. Today, of course, central furnaces circulate warm air by mechanical means and are referred to as forced air furnaces.

Basic Furnaces Classes

Residential furnaces are defined as any unit producing 250,000 Btu/h or less. Larger furnaces are considered to be *commercial* furnaces.

While residential furnaces can be installed in commercial buildings, commercial units are seldom installed in ordinary homes, since they would be oversized. In the case of very large custom homes, two or more residential furnaces are preferred to a single large commercial unit.

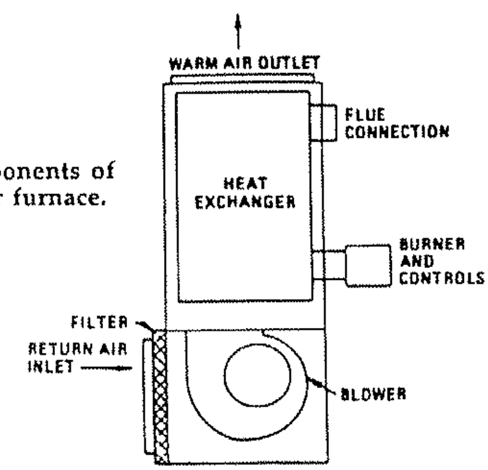
The basic components of a furnace are:

1. The heat exchanger (usually made of steel)
2. A combustion or fuel burning section
3. The casing (or cabinet)
4. Blower assembly and motor
5. A filter
6. Accessories (humidifier/high efficiency air cleaner/UV light/programmable thermostat.)

Using these basic components, furnaces, can be configured relative to supply air movement to be upflow or downflow (also known as counterflow) units and even horizontal flow.

In addition, there are outdoor furnaces, duct furnaces, electric furnaces and a few dual-fuel furnaces. The most common units will be described in detail later.

Basic components of a forced-air furnace.



Testing Furnaces

Most communities have established building codes to protect the health and safety of residents. In most instances, only furnaces that have passed certain recognized tests and are "certified" by a recognized testing agency may be installed.
The International Approval Services (formerly AGA Laboratories) is a recognized organization that can certify that a manufacturer's furnace has been tested in compliance with established safety standards. Products that pass can feature the American Gas Association (AGA) Blue Star Seal of Certification, and be listed in a directory that is available to city building departments and others. Other recognized testing organizations may also certify by the same established standards.

Similarly, oil furnaces are tested in compliance with specific standards and Underwriters' Laboratories publishes a listing of UL labeled oil furnaces. Again, many regulating bodies recognize UL as a valid testing agency, and therefore approve furnaces for installation that bear the UL label. UL also tests electric furnaces.

Furnace Ratings

Traditional industry furnace performance ratings had been based on "steady-state" operating conditions — everything hot and running at peak performance. Output was reported in Btu per hour.

While this was valuable for sizing furnaces, steady-state efficiencies are not very useful in determining energy consumption over an entire heating season. With concern over conserving energy, the U.S. Department of Energy (DOE) prepared new furnace test procedures. Steadystate bonnet capacity was replaced with *DOE heating capacity*, which is now used to size equipment.

In addition, DOE test procedures include an attempt to account for on-off operating losses. The non-steady state efficiency is termed the *annual fuel utilization efficiency (AFUE)*. It is defined as the annual output of useful energy delivered to the building divided by the annual fuel energy input to the furnace. Utilization efficiency is a smaller number than steady-state efficiency.

As an aid to consumers, the Federal Trade Commission (FTC) requires "Energy Guide" labels affixed to furnaces, and consumers must have access to an Energy Guide Fact Sheet. This fact sheet compares particular furnace utilization efficiency with industry best/worst models.

Furthermore, yearly heating cost information in *dollars per year* must be included, using utilization efficiency. Only furnaces with input ratings less than 225,000 Btu/h are covered by the DOE regulations.

The Gas Appliance Manufacturers Association (GAMA) conducts a voluntary performance certification program for gas and oil furnaces. Manufacturers who participate in this program have advertised DOE heating capacity and AFUE verified by test by an independent testing laboratory. A directory of certified efficiencies can be downloaded at www.AHRInet.org since GAMA and ARI consolidated to form Air-conditioning Heating & Refrigeration Institute.

Higher Efficiency Furnaces

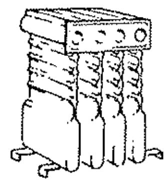
As of January 1992, no gas furnace has been manufactured with an AFUE less than 78 percent. Previously, some gas furnaces operated with annual fuel utilization efficiencies in the 60s and 70s. To improve on gas furnace performance, equipment manufacturers have introduced various models of mid and high efficiency furnaces that extract more heat from the burning gas. With a few exceptions, such as pulse combustion, higher efficiency furnaces obtain their increased efficiency through improved heat exchanger designs.

Usually some type of forced draft is required: first, because the heat exchanger imposes more resistance to the flow of combustion gases, and second, because there may be inadequate buoyancy to push the gases out the vent, especially if vented horizontally.

This mechanical or fan-assisted draft is usually provided by a small electric blower positioned on the outlet side of the heat exchanger and called *induced draft*. It may be called forced draft if the blower is on the inlet side of the combustion process..

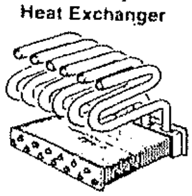
Standard gas furnaces discharge combustion products at temperatures from 275° F up to 550° F. Thus, considerable useful heat is lost up the flue — although some of this heat is needed to provide the push to force the combustion gases up the vent. These are non-condensing, midefficiency furnaces with AFUE's between 78% and 82%.

High efficiency gas furnaces may extract heat from the combustion gases to the point where the flue gas temperature is as low as 100° F. When a furnace extracts enough heat to cause the water vapor formed during the combustion process to condense (turn to water), the furnace is referred to as a condensing furnace. About 10% of the heat energy in natural gas is in the form of water vapor. So when this vapor condenses, latent heat can be captured. Condensing furnaces feature a secondary heat exchanger to capture this low temperature heat and operate with an AFUE between 88% and 96%.

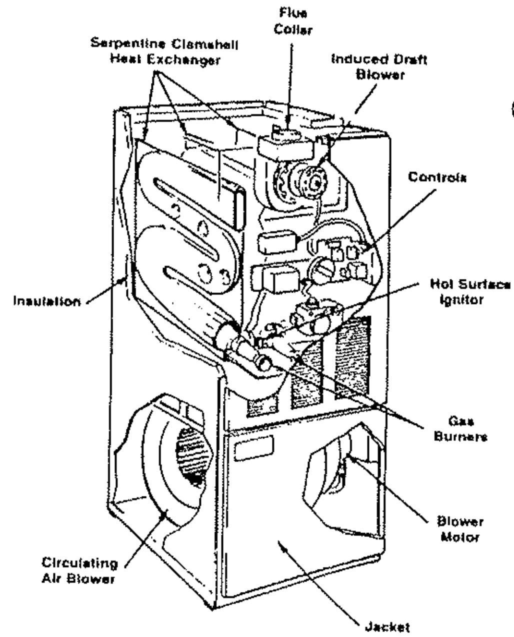


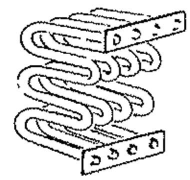
Clamshell Heat Exchanger

Primary Heat Exchanger



Secondary (Condensing) Heat Exchanger



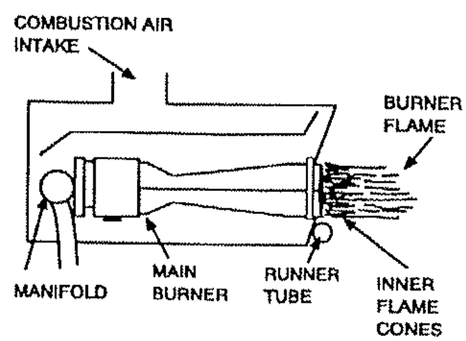


Tubular Heat Exchanger

The furnace blower is typically a dual inlet forward curved wheel driven by a permanent split capacitor (PSC) motor between 1/5 and 3/4 horsepower. Newer furnaces incorporate an ECM motor that provides for varying degrees of air flow at a lower operating cost.

Burners

Furnaces using a serpentine clamshell or tubular heat exchanger typically use an in-shot gas burner that produces a single, large flame. Traditional clamshell heat exchangers are fitted with multiport burners. These burners distribute a large number of small flames over a large area.

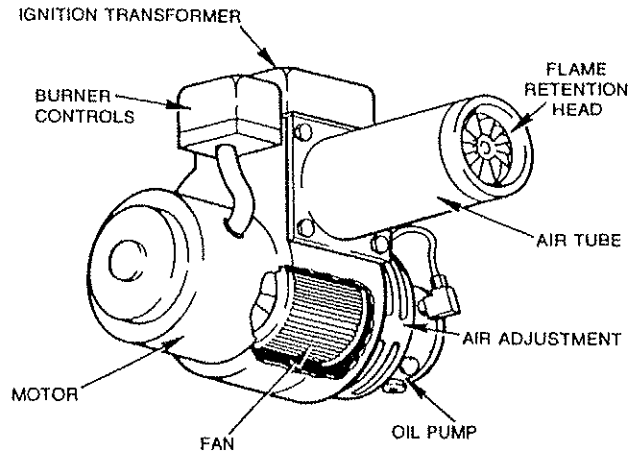


Most current furnaces use a hot surface igniter (HSI) to start combustion. A few may use intermittent ignition in which a spark system ignites a pilot flame to provide main burner ignition. The continuous standing pilot continuous standing pilot has slowly been abandoned. This switch has increased furnace efficiency by 1 to 2% alone.

Oil Burners

The most common oil burner used in modern furnaces is the high pressure "gun type" burner.

A pump on the burner draws oil from the fuel oil storage tank, builds up a pressure of approximately 100-140 pounds per square inch and pushes the oil through an atomizing nozzle that breaks the oil up into a fine mist. Combustion air is supplied by a burner blower and mixes with the oil mist.



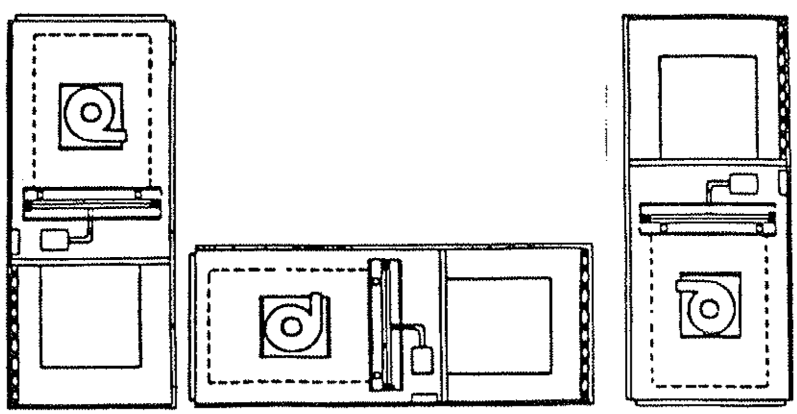
Good, clean combustion depends on the blending of atomizing oil and air. Special turbulator heads are used to swirl the air to increase mixing. Electrodes near the nozzle create a 10,000 volt spark for ignition. The ignition spark can be either constant or intermittent. Intermittent spark is supplied only at the time of ignition.

The oil furnace firebox is lined with refractory material or stainless steel to contain the heat and improve the combustion process. Burners are designed to use Number 1 or Number 2 fuel oil.

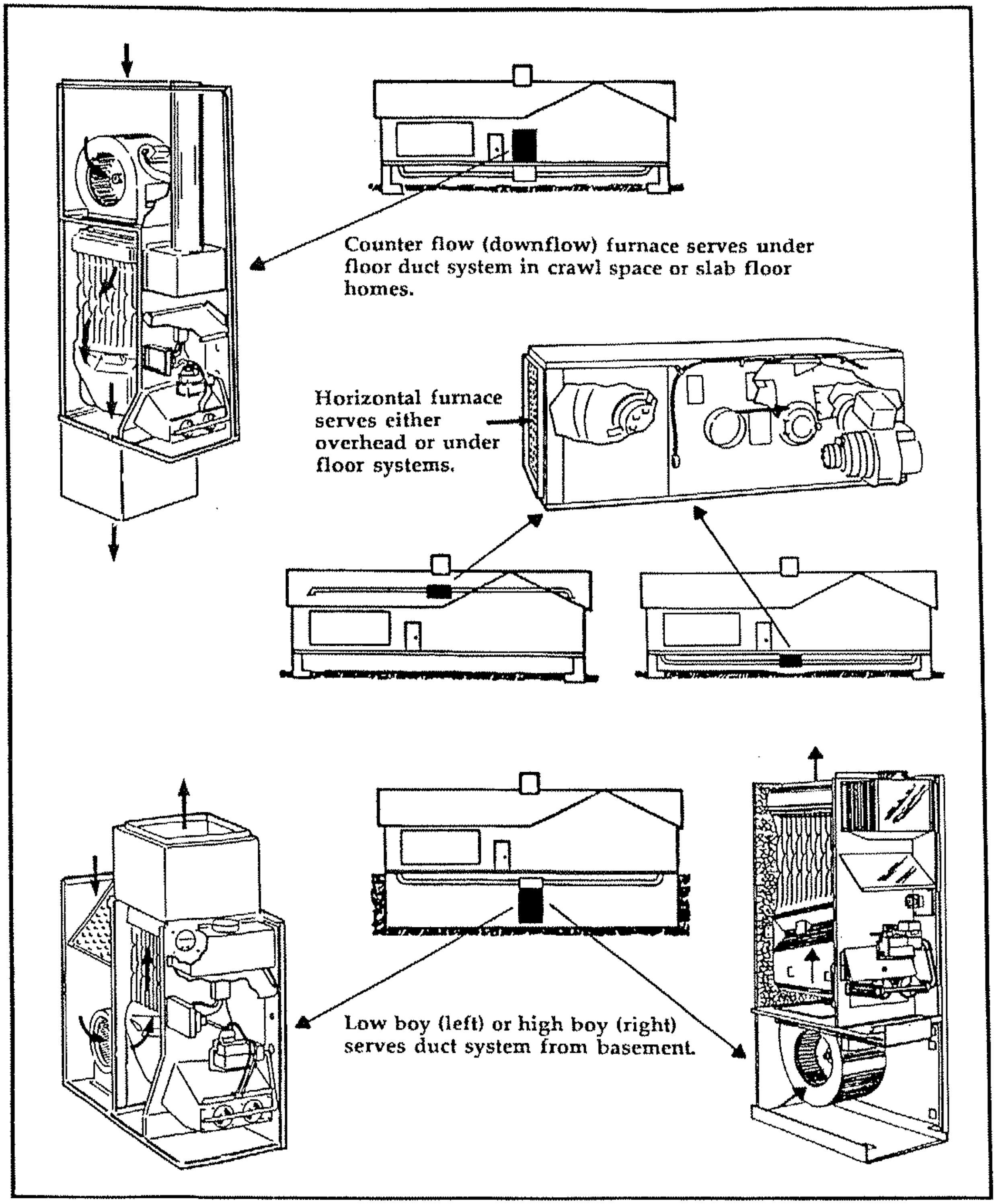
There have been other types of burners in use to burn oil for space heating, and may still be encountered in small furnaces or space heaters. Examples are a low pressure version of the gun burner, a vaporizing pot and rotary flame burner.

Furnace Configurations & Applications

There are a number of popular furnace design configurations to meet specific installation problems — no basement, tiny alcove or closet, etc. What follows is a brief description of each of the most widely available designs. Obviously, manufacturers may develop very unique designs for very specific applications, so not every available design will be illustrated.



The hi-boy or upflow furnace is perhaps the design most widely manufactured. The blower compartment is positioned beneath the heat exchanger and air is circulated up over the heat exchanger and out the top of the unit.



Traditional Furnace Configurations

Hi-boys can be installed in closets, basements and utility rooms.

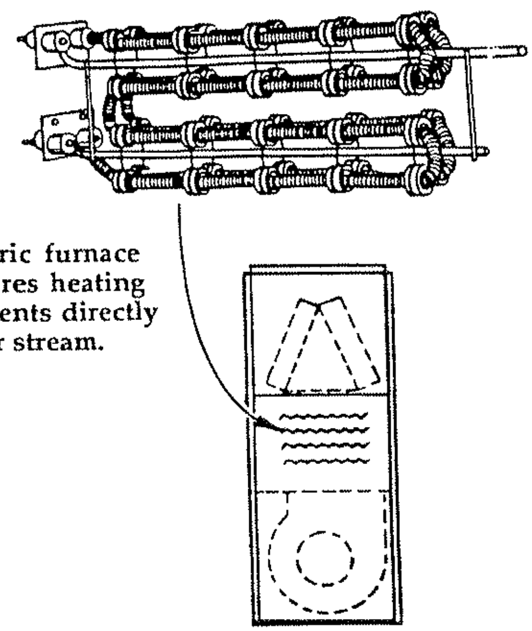
The lo-boy was originally designed for shallow basements and features the blower at the side of the heat exchanger. Lo-boys were traditionally from 12 to 18 inches shorter than hi-boys, but with the advent of low profile furnaces, this feature is of no consequence.

The downflow or counter-flow unit features the blower compartment above the heat exchanger. Air flows downward through the heat exchanger and out the bottom of the unit. This design was developed to provide perimeter (floor level) heating in buildings with crawl spaces or slab floor construction.

The horizontal furnace features the blower and heat exchanger in the same plane. The unit is often installed in crawl spaces or in attics where headroom is inadequate for other designs.

Horizontal furnaces are also suspended from ceilings in garages and factories where floor space is at a premium and damage to the furnace might easily occur.

An electric furnace features electric resistance elements inserted directly in the air stream. Because of its simplicity, a single model electric furnace can often be used as an upflow, counter-flow or horizontal design.



Electric furnace features heating elements directly in air stream.

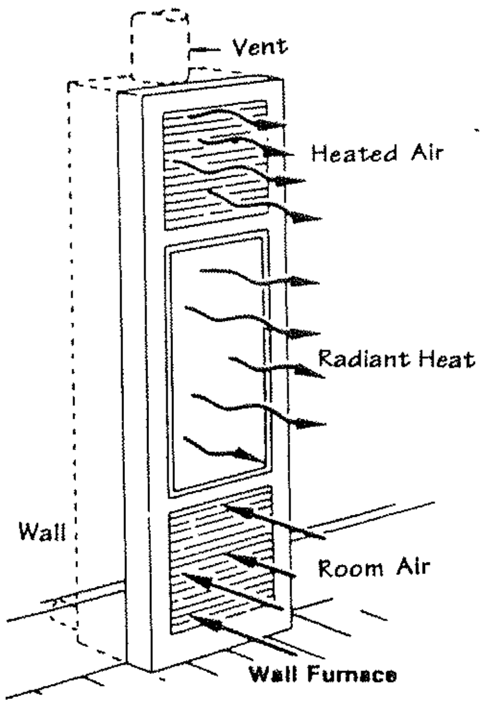
Multi-position gas and oil furnaces are also manufactured today. A few simple changes to the induced draft blower position and to the cabinet and an upflow furnace can be installed as a downflow or horizontal unit.

In some geographic areas, furnaces may be installed outdoors, on the roof of a commercial building or residence and even on a pad at ground level. In general, outdoor furnaces are similar to horizontal units and are usually gasfired. An outdoor furnace is carefully weatherized and features a special draft hood and ignition controls that are not readily affected by gusts of wind. Very often the outdoor furnace is packaged with an air conditioner in a single housing.

In-Space Heating Equipment

Under the category "space heaters," there are wall and floor furnaces and vented and unvented heaters. They are designed to heat one or two rooms or perhaps serve in small homes located in mild climates where heating requirements are quite modest.

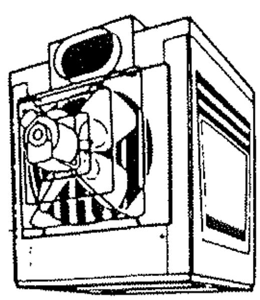
As the name implies, the wall furnace fits between studs in a common interior wall and, by gravity, circulation of heated air can warm adjacent rooms. Wall furnaces are used in many small apartments, room additions, and summer homes. Units are gas-fired.



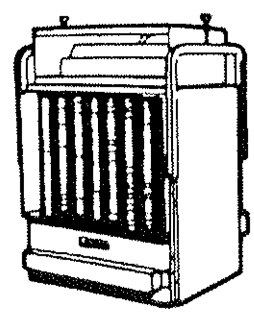
The floor furnace is inserted in a crawl space with a large opening protruding through the floor. This is covered with a register. The interior of the register provides for the supply of heated air and the perimeter or edge areas are return air inlets. Again, the floor furnace is usually gas-fired and the air circulation is by gravity.

Still another space heater is the suspended unit heater. This device is often used in multiples to heat large warehouse areas and factories etc. The unit can be gas or oil-fired, and air circulation is provided by a fan or at times a centrifugal blower. Smaller versions may be used to heat residential two and three car garages.

A duct unit heater has no integral blower but can be installed in an air distribution system. Such a unit is also called a duct furnace.



Unit Heater



Duct Furnace

Self-Check, Lesson 6 Quiz

You should have read all the material in Lesson 6 before attempting this review. Answer all the questions to the best of your ability before looking up the answers provided in the Answer Key.

Please indicate whether the following statements are true or false by drawing a circle around T (to indicate TRUE) or F (to indicate FALSE).

True False

1. T F New furnace designs were prompted by Department of Energy minimum efficiency standards.

2. T F Furnace Btu/h input rate is now used to size furnaces for a specific building.

3. T F A furnace AFUE can be used to estimate annual energy consumption and energy cost.

4. T F High efficiency furnaces actually extract heat from the water vapor in vent gases to increase efficiency.

5. T F A furnace oil burner must use a continuous spark to assure continuous combustion of the oil-air mixture.

In the following multiple-choice questions, choose the phrase that most correctly completes the statement, and check the appropriate box for the corresponding letter in front of the phrase.

6. Furnaces are termed residential for Btu/h output capacities of less than:

☐ A. 60,000 Btu/h. ☐ B. 100,000.
☐ C. 150,000. ☐ D. 250,000.

7. The federal Trade Commission consumer information label affixed to furnaces is called:

☐ A. Blue Star Seal. ☐ B. Safety Sticker.
☐ C. Energy Guide. ☐ D. Fact sheet.

8. A mid-efficiency furnace has an AFUE between:

☐ A. 86-96%.
☐ B. 85-36%.
☐ C. 78-82%.
☐ D. 68-75%.

9. Mid efficiency gas-fired furnaces most often use:

☐ A. an in-shot gas burner.
☐ B. a multi-port drilled burner.
☐ C. a slotted port burner.
☐ D. a single port upshot burner.

10 A downflow or counter flow furnace is most likely to be used to supply perimeter heating in a house built:

☐ A. over a basement.
☐ B. with a large attic space.
☐ C. over a crawl space.
☐ D. with a large glass area.

For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

Key Words

gas	certified	oil	"space"	high
UL	single room	mid	weatherized	heating capacity

11. A floor furnace is an example of ________________________ heating equipment.

12. Steady state furnace bonnet capacity has been replaced with DOE ________________ ____________ as the accepted output of a residential furnace.

13. A voluntary performance certification for all furnaces is operated by the ________________ Appliance Manufactures Association.

14. Furnaces that operate with AFUE's in the 88-96% range are called _________ efficiency furnaces.

15. An outdoor furnace must be ______________________ to operate successfully.

Check Your Answers!

Lesson 7 Overview

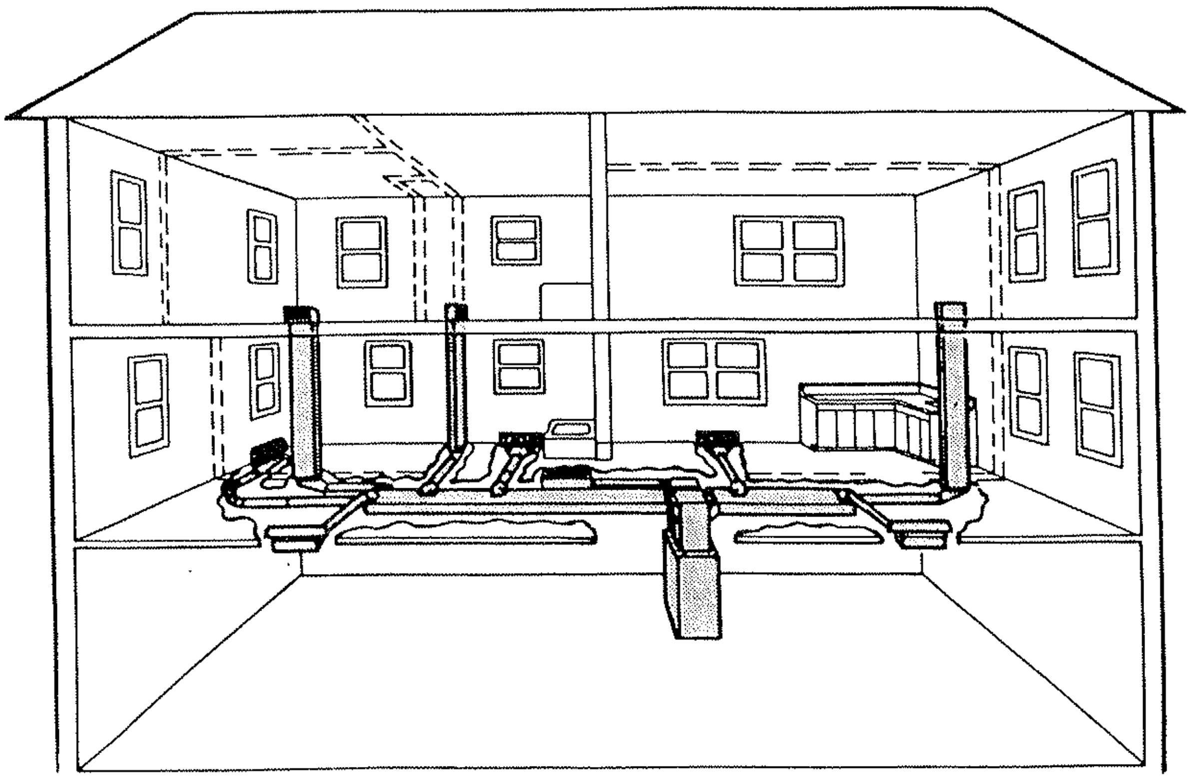
Is there logic and purpose to the maze of heating "pipes" routed through a home or office building? Information in Lesson 7 will explain the basics of duct systems and registers.

After completing this reading assignment and the self-check review quiz, you should be able to identify the basic types of duct systems. In addition, you will know the definitions of register, grille, and diffuser, and where they should be placed in a room for optimum comfort performance. You'll also get a start toward duct design with an introduction to resistance to air flow and blower selection. However, learning a complete duct design process must be left to another more advanced course.

Now read Lesson 7 which begins on the next page.

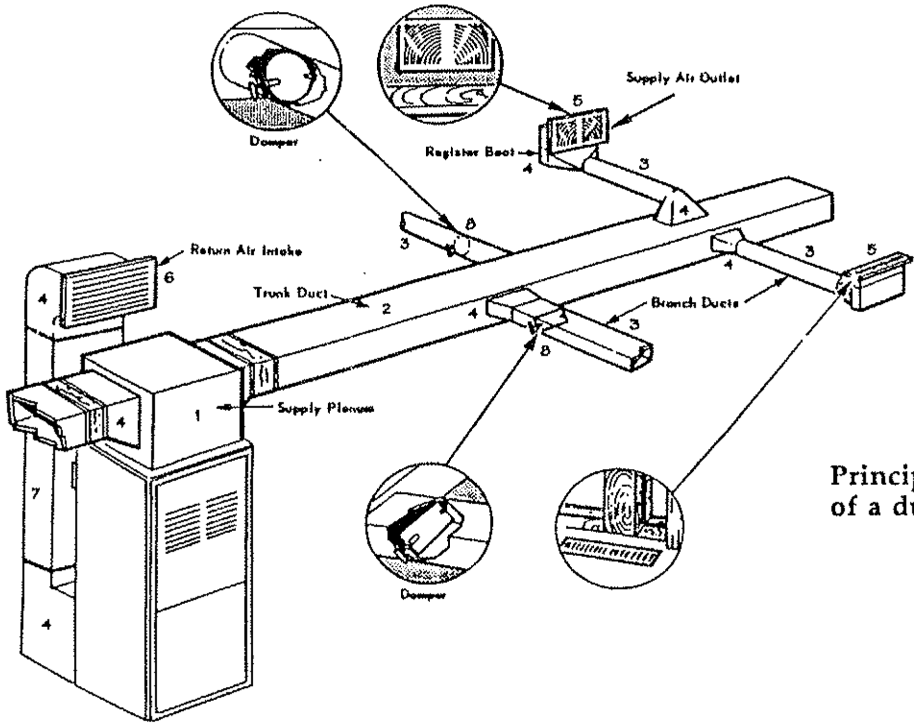
Lesson 7: Duct Systems & Registries

The air distribution system may well be the single most important part of a heating system. This importance stems from the fact that the installer must personally design and fit the air distribution system to the needs of each building. If done incorrectly, heating comfort will be compromised.



Duct system must be custom fitted to the building

The actual air carrying conduit called *ductwork* may be custom fabricated out of galvanized sheet metal or fiberglass material in a contractor's own shop or from prefabricated, factorymade pieces purchased from a wholesaler. In either case, the various pieces are connected together at the building site to form a closed path for the conditioned air.



Principle parts
of a duct system.

Duct Terms

The following are some of the more typical pieces of a duct system. Refer to the figure above to see where each item fits into a completed system.

1. ***Supply Plenum*** (sometimes called the Bonnet) is the central collecting chamber for the conditioned air leaving the furnace. The plenum should be as large as the supply opening on the equipment and as high as possible to permit mixing of the supply air before it enters the duct system.

2. ***Trunk Duct*** (sometimes called the main duct) carries the air to be distributed to more than one supply outlet. A main duct may not be necessary in some small systems, while in other systems, more than one main (or trunk) duct may be required.

3. ***Branch Ducts*** carry the air from the main duct to the individual supply outlets (sometimes called run-outs). If the branch is routed through a wall and rectangular, that portion is called a wall stack. Branch ducts are almost always formed as round duct but may be rectangular as well.

4. ***Fittings*** include the elbows, boots, take-offs, angles, and other items used to change the direction of air flow and cross sectional area of any duct. Fittings account for much of the resistance in a small duct system.

5. ***Supply Outlets*** project the conditioned air into the rooms.

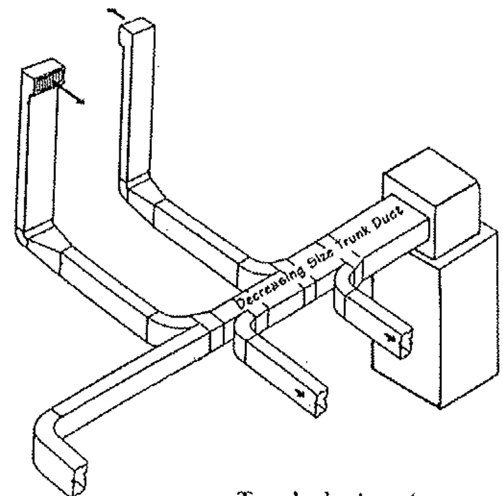
6. ***Return Air Intakes*** permit the air to pass from the room into the return duct system.
7. ***Return Ducts*** are the pipes that carry room air back to the furnace unit. Often, wood joists spaces are sealed with sheet metal "panning" to form a closed path for return air. This practice is being discouraged.

8. ***Volume Dampers*** in supply ducts or outlets are used to adjust the quantity of air to each space and thus "balance" the system.

Types of Systems

For residential and small commercial installations, there are really just four basic duct arrangements in common use:

- A Trunk Duct System
- An Extended Plenum System
- A Radial System
- A Perimeter Loop System

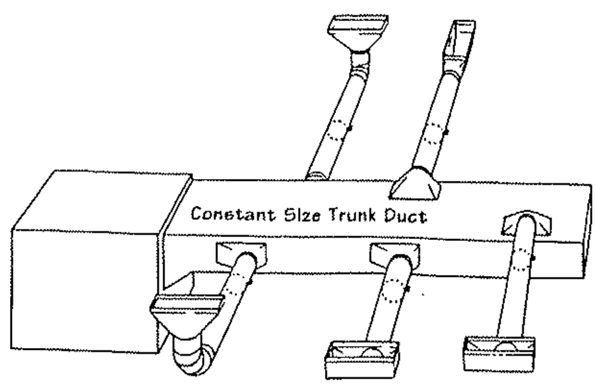


Trunk duct system

Why are there multiple duct configurations? Simply, because no one type of system can fit every type of building, considering space requirements, floor plan, cost, and performance.

System Features

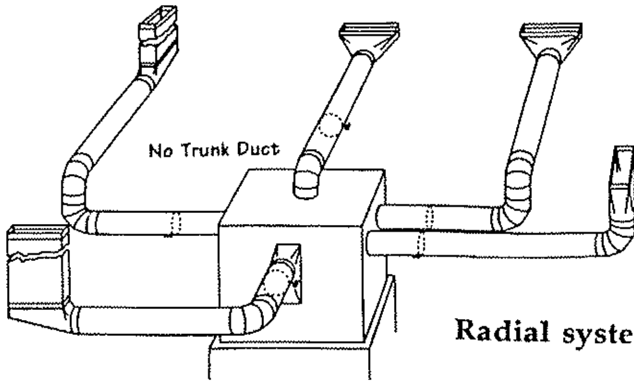
The *trunk duct* system is characterized by a *decrease* in main duct size after each (or several) branch connection. The fabrication costs are usually high, compared to other systems. The trunk duct system is usually a good choice when the furnace is not centered among the rooms to be conditioned. This system is often used in long custom ranch homes and long corridors with office spaces. The main duct may be routed through a basement, crawl space, attic, or above a suspended ceiling.



Extended plenum

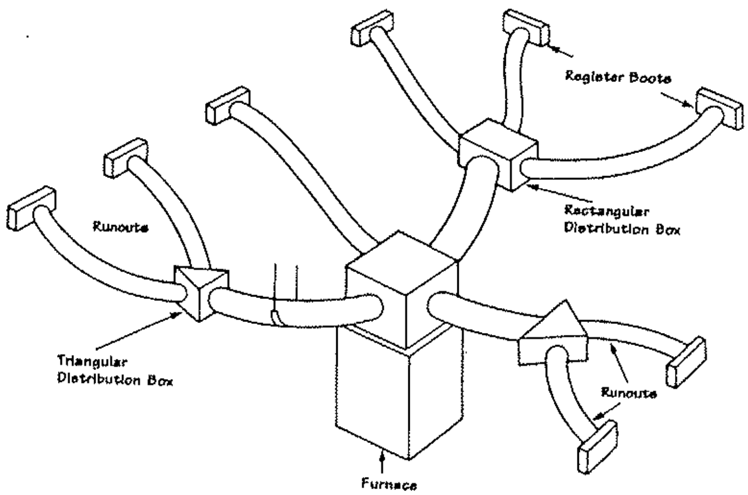
The *extended plenum* system is probably the most common main and branch arrangement used today in small buildings. It is easily fabricated, as the main duct has a constant cross-sectional area for its entire length. The branch take-off fittings are usually factory fabricated.

More material may be required, but assembly costs are low. A variation of the extended plenum includes one or perhaps two reductions in main size for longer mains.

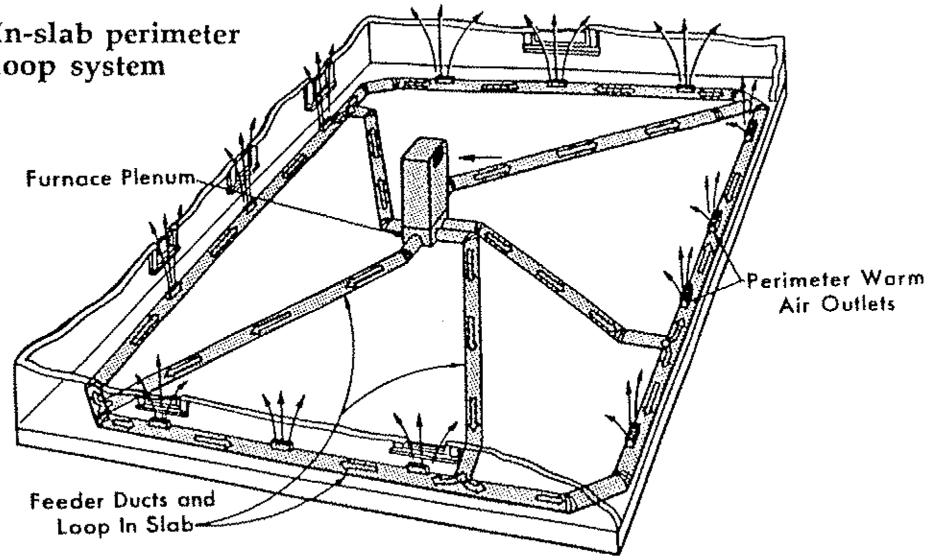


Radial system

Radial system with distribution box



In-slab perimeter loop system

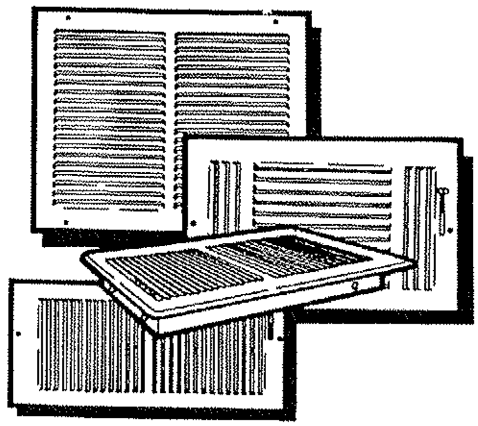


The *radial system* is characterized by *individual* duct runs from the central heating unit to each register. There is no main or trunk duct. This system is used when all heating outlets are about equally distant from the furnace plenum. When routed overhead through an attic, branch duct runs are often *flexible* fibrous duct material, rather than metal. A *distribution box* may be used to split a branch into two run outs, each serving a supply register.

The perimeter loop system was designed especially for in-slab applications in cold climates. While radial systems are also used, improved comfort is provided by the loop system, since it assures more uniformly warm floors, especially around the perimeter edge.

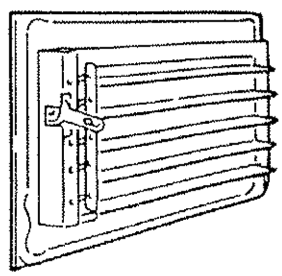
Registers, Diffusers & Grilles

The duct system is the connecting link between the central conditioning equipment and the supply outlets in the heated spaces.

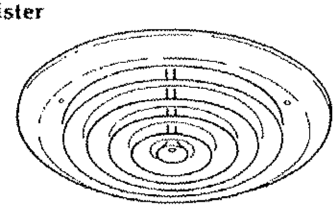


Registers and Grilles

Radial system with distribution box



Back dampers on grille makes it a register



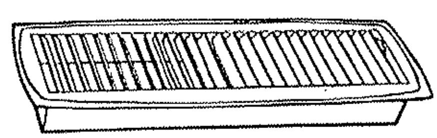
Ceiling diffuser

Proper supply outlet selection and location is essential to good room air motion and uniform temperatures in each room. To adequately satisfy the heating needs of various types and sizes of rooms, there are different *types* of supply outlets with several installation options. Architectural requirements may also influence outlet selection and location.

Baseboard diffuser

What's the difference between grilles, registers and diffusers?

A *grille* is any louvered or perforated covering over a supply or return duct opening.



Floor diffuser

A *register* is a grille with an air volume control damper. Registers are almost always rectangular in shape. Registers

may be found placed almost anywhere — in a ceiling, high or low in walls, and even at times in a floor.
Registers may have fixed or adjustable blades (louvers) to control the direction and spread of the discharging supply air.

A *diffuser* is a special outlet designed specifically to provide a spreading or fan-shaped air pattern.

Typical examples are *ceiling* diffusers which most often are round or square; *floor* diffusers which are rectangular and sometimes very narrow; and finally *baseboard* diffusers that are shaped to blend somewhat with baseboard moldings.

Supply outlets are usually made from steel, aluminum, or high quality plastic. Most manufacturers make a clear distinction between their residential and commercial line of registers and diffusers. Commercial register catalogs usually provide far more performance data for the engineer.

Location

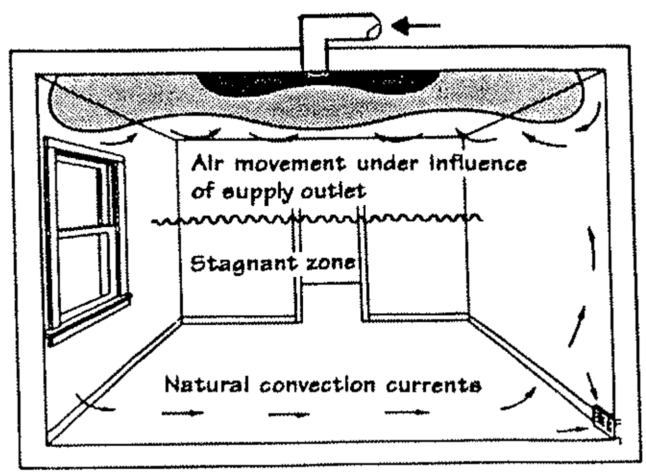
Understanding how supply outlets perform and how air moves within a heated space is made difficult because we cannot see air. This is also true for how air moves through a duct system.

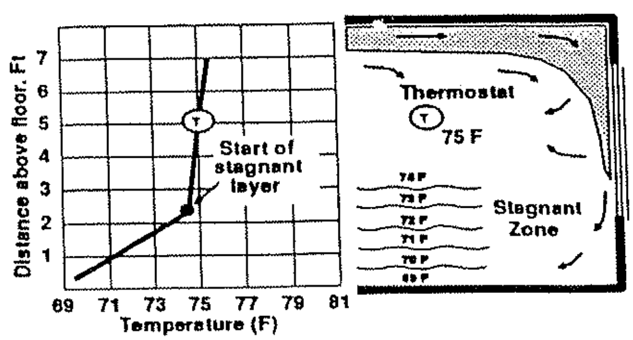
Studies conducted at the University of Illinois determined that, in any heated space, there is a region or zone where the room air is *not* influenced by the fast moving air discharging from supply outlets. This region is called the *stagnant zone or stagnant layer.* Only *natural convection air currents* move in this part of the room.

One visible manifestation of the presence of a stagnant zone is the manner in which cigarette smoke will hang suspended in the center of a room, drifting along in slow motion.

More scientifically, the stagnant zone is detected by measuring the room air

Simplified air movement within a room being serviced by a ceiling diffuser.



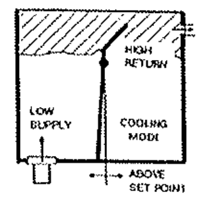


Temperature gradient showing temperature layers in stagnant zone.

temperature every few inches, starting at the center of the ceiling and working down toward the floor.

In the heating mode, measurements will indicate very uniform temperatures for several feet down from the ceiling — for example, not varying more than 2° say, from 76° to 74° F, when about five feet down from the ceiling. Then, about 30 inches above the floor, temperatures start to decrease rapidly, dropping 4° --- say, to 69° just a few inches above the floor. The height above the floor at which this dramatic change starts to take place is the top of the stagnant zone (30 inches above the floor in this example.). A typical floor to ceiling temperature pattern during heating is shown above.

Notable note: For cooling, the stagnant zone is near the ceiling, not the floor, with temperatures rising quickly as one nears the ceiling.

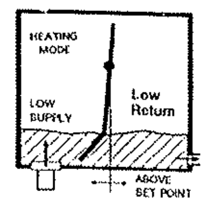


In a heat-cool system with low supply use high returns.

Note that the stagnant zone is from the floor up during heating. This concept is very important when deciding where to locate supply outlets and return inlets.

The number, type, and location of *supply* outlets have the greatest influence on the size of the stagnant zone. The object, of course, is to have the smallest possible stagnant zone. For example, the stagnant zone for ceiling diffusers during heating will be much larger than for floor diffusers in the same room.

In cold climates, keep supply and returns low in a heating only system.



Return air inlet locations have minimal effect, but can be of some help by quickly bleeding off the cooler room air moving in the stagnant zone. This can be accomplished by simply locating returns *in* the stagnant zone.

For heating: *low* supply outlets and *low* returns minimize the stagnant zone and therefore are the preferred locations for heating systems.

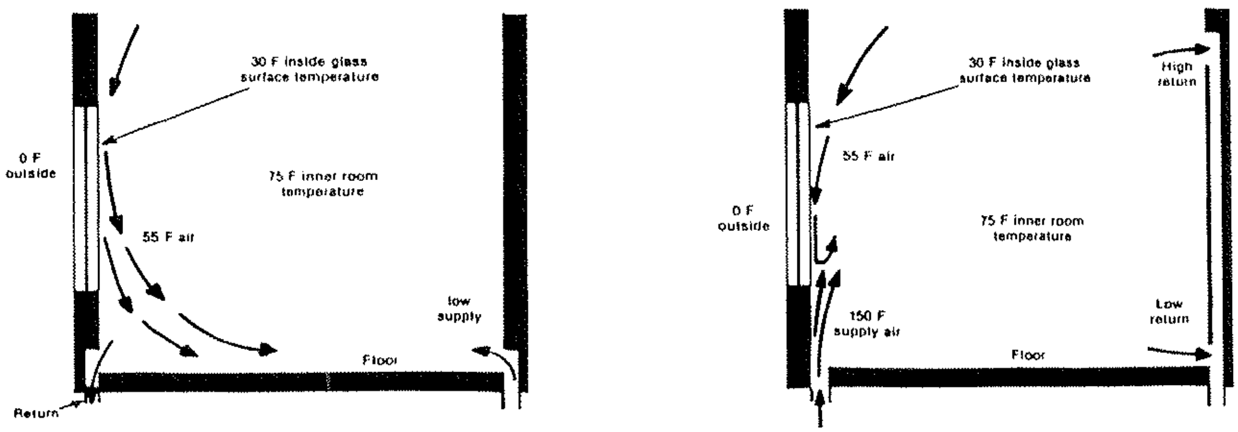
Return Grille

If summer cooling is also provided with the supply outlets still placed *low* to provide best heating performance in cold climates, then the returns are placed *high*. Why? The largest stagnant zone will occur during cooling and near the ceiling with low supply outlets, so high returns are most helpful. In this case, by bleeding off the warmer, ceiling-level room air cools quickly in summer.

It is also preferred to position heating supply outlets along *outside* walls and importantly underneath windows, if at all possible. This approach was first introduced in Lesson 4.

In the early days of warm air heating, contractors usually installed the supply outlets on inside walls and placed returns beneath windows, in keeping with the old gravity heating tradition. The thought was that the return air intake right under the window would capture any cold air cascading down the wall — hence the phrase *"cold air return."*

Notable note: To complete the story, for cooling-only systems, ceiling or high wall-supply and high return locations are preferred. If cooling is the most critical performance requirement but some heating is needed for a very short, mild heating period, then high supply outlets are still used, but returns are placed low. Since the high supply outlets will not do well on heating, the low returns will be of maximum benefit.



Old gravity and early forced air systems (left) placed supply registers on inside walls and returns under windows. Research in the 1950s (right) showed improved comfort with supply registers placed on outside walls and returns on inside walls.

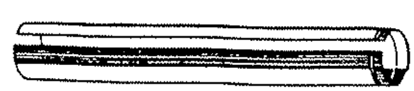
Research proved that by reversing the arrangement — placing supply outlets beneath windows and returns on inside walls, comfort levels could be substantially improved. Thus, in the 1950s, perimeter heating became the preferred approach to residential heating installations and continues today, perhaps less rigorously, as buildings are more heavily insulated and sealed.

Duct Materials

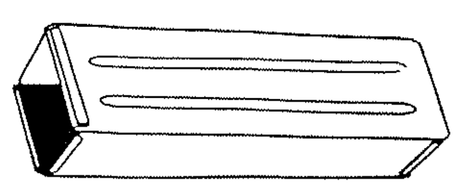
Materials used to make duct systems are covered by performance standards established by Underwriters' Laboratories regarding fire hazard classification, corrosion, erosion, rupture, collapse, and other physical characteristics. *(For a detailed discussion of codes, see Lesson 11.)*

The National Fire Protection Association (NFPA) establishes standards for fire-safe installation of ductwork and furnaces. *(For more on installation, see Lesson 12.)*

Presently, ductwork is fabricated from galvanized steel and both rigid and flexible fibrous glass materials. Fabrication standards most often referenced include NFPA, the Sheet Metal and Air



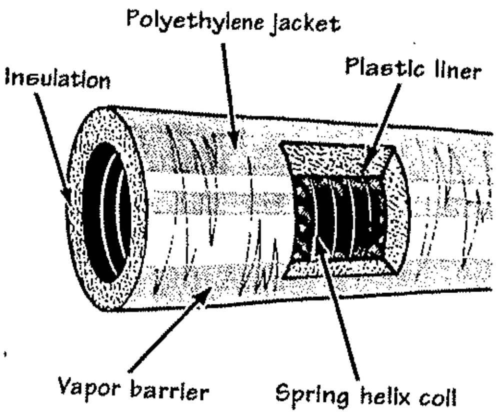
Galvanized steel is used to fabricate ductwork.



Conditioning Contractors National Association (SMACNA), and the North American Insulation Manufacturers Association (NAIMA).

Resistance to Air Flow

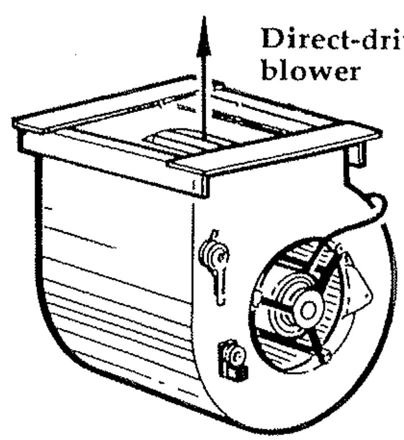
Air, like water, is subject to resistance as it attempts to flow through a piping system. Regardless of how the duct system is designed, resistance is always present. The best that a designer can do is keep resistance to a minimum.



Typical construction of round flexible duct

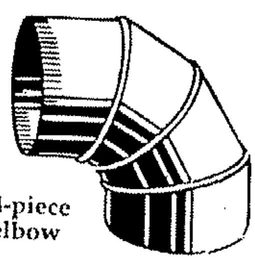
The job of the furnace blower is to move the air against the resistance offered by:

- the supply ductwork
- supply air outlets
- the return air intakes
- the return ductwork
- dampers and filters
- the internal passages of the equipment



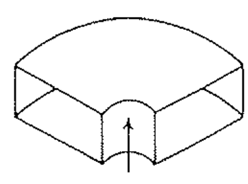
Direct-drive blower

Blowers should operate quietly and at speeds that are not excessive. The greater the resistance, the harder the blower must operate and the more electrical energy used to circulate the air.



4-piece elbow

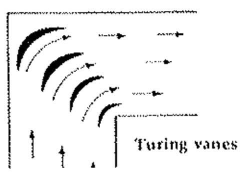
Each part of the duct system imposes a specific resistance to air flow. Turns offer *more* resistance than straight lengths of duct. For example: a 4-piece elbow imposes the same resistance as 20 feet of straight duct — and that's how fitting losses are often reported. It is



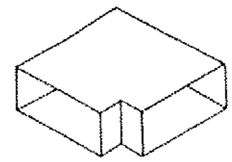
Radius elbow

important to minimize the number of elbows, and other fittings in a system to keep air resistance to a minimum.

Obviously some turns are necessary. In these instances, it is important to avoid *sharp* turns. If so-called 90° *miter* elbows are necessary because of space limitations, *turning vanes* should be inserted to lower the resistance of the mitered elbow.

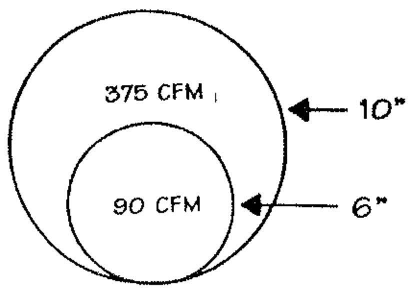


How much reduction can turning vanes achieve? A single hard bend miter elbow imposes a loss equal to 80 ft of duct. Add turning vanes and the miter elbow loss reduces to 10 ft — less than an ordinary radius elbow.



Miter elbow

Size is obviously very important. A six inch diameter duct imposes more resistance than a 10 inch duct of the same length and for the same volume of air flowing. Selecting the right "size" of straight duct is important.



Look at it this way --- you can push 375 cubic feet of air per minute (CFM) through a 10 inch duct for the same pressure loss penalty that moves only 90 CFM through a 6 inch duct.

At left: Air delivery for same pressure loss in round pipe.

Furnaces arrive with a "built-in" blower. Therefore, duct systems must be sized to match known blower performance.

(In very large systems, the blower may be selected separately.)

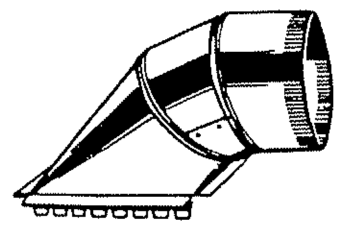
Blower capacity is given in terms of so many cubic feet of air per minute (CFM) against an external resistance of so many inches of water column static pressure (IWC). Inches of water pressure is used instead of pounds per square inch because the pressures involved in air flow are quite small. One inch of water is equivalent to a tiny 0.0361 psi.

Here's an example of a blower performance table:

External Static (IWC)			
CFM	High	Med	Low
1150			0.45
1200			0.30
1250		0.49	0.05
1300		0.37	
1350	0.69	0.25	
1400	0.62	0.14	
1450	0.55	0.04	
1500	0.47		
1550	0.39		
1600	0.31		
1650	0.23		

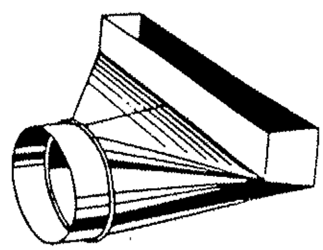
Note there are three columns for three different motor speeds and then a series of rows for different air flow rates — from 1150 to 1650 CFM. If a system required an air flow rate of 1300 CFM and we selected a medium speed (always a good idea), the fan would produce 0.37 IWC of pressure. This is available to size the complete duct system at that CFM. If the system is undersized — that is, imposes a higher resistance, the CFM would drop and not meet requirements.

Once the system is laid out, lengths measured and all fittings accounted for, a designer may turn to special charts to actually size the ductwork knowing the performance of the furnace blower.



Adjustable take-off
50-75 equivalent ft.

The resistances of specific fittings are listed in design manuals, such as Manual "D" published by the Air Conditioning Contractors of America (ACCA). Manual D also includes an accurate sizing procedure using engineering "friction" charts.



Register angle boot
80 equivalent ft.

Some manufacturers construct simplified sizing *tables* to ease the designer's job. The assumptions and limitations of any table are usually footnoted and should be *thoroughly understood* before using one.

Duct Heat Loss

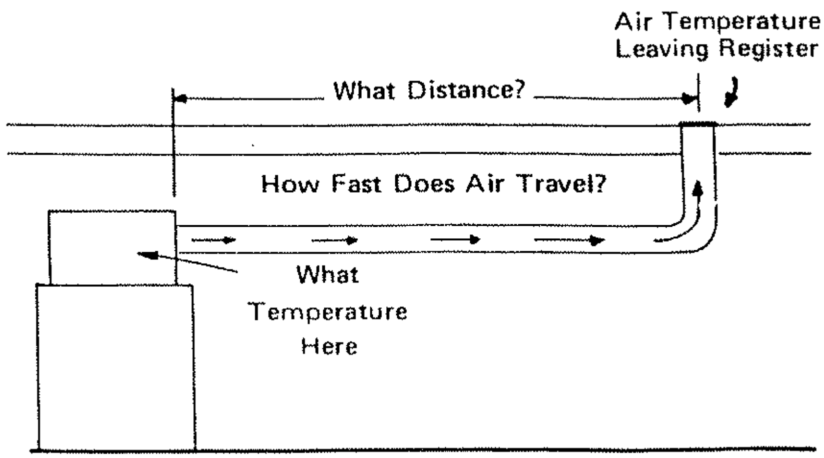
Another important factor in proper duct design is to account for any heat loss through the duct system between the heating equipment and supply outlets. Duct heat loss, hence air temperature drop, is affected by:

- how *much* heat is in the air as it leaves the furnace bonnet or plenum
- the *rate* of heat loss from the duct (metal pipe loses more heat than an insulated one)
- the *distance* from the furnace to the supply outlet
- how *fast* the air travels through the duct

It is essential to insulate ductwork that passes through any unconditioned spaces. A large drop in supply air temperature could cause "cold room" complaints. Excessive loss may require an increase in air delivery and a resulting larger branch duct.

Know About Construction

Everyone connected with the heating business should be familiar with house construction practices. You can acquire this knowledge by studying house plans and examining houses under construction. Visualize the problems related to the installation of the duct system and observe the ways these problems are solved. We'll return to these issues in Lesson 12 on installation.



Excessive heat loss from ducts can create problems such as a *hard to heat* room. For example: if a room heating load was 2,700 Btu/h, it would take 51 CFM of 130° (3304.8 = 1.08 x (13070) x 51) air to satisfy the load. If the supply air at the register was only 100° due to temperature drops in the duct, 100 CFM would have to be delivered to the room (3240 = 1.08 x (100-70) x 100).

New building materials and new construction practices are constantly appearing on the market. The wise heating specialist keeps himself up to date on these developments and learns the effects that they have on the heating system.

Self-Check, Lesson 7 Quiz

You should have read all the material in Lesson 7 before attempting this review. Answer all the questions to the best of your ability before looking up the answers provided in the Answer Key.

Please indicate whether the following statements are true or false by drawing a circle around T (to indicate TRUE) or F (to indicate FALSE).

True False

1. T F The air distribution system is critically important to heating comfort because it must be custom fitted to the structure.

2. T F NFPA establishes performance standards for duct materials regarding corrosion, rupture and fire hazard classification.

3. T F Smooth metal ducts offer no resistance to air flow.

4. T F The stagnant zone in a room during heating is always near the floor.

5. T F Turning vane are inserted in miter elbows to increase air resistance and stabilize the flow of air as it turns.

In the following multiple-choice questions, choose the phrase that most correctly completes the statement, and check the appropriate box for the corresponding letter in front of the phrase.

6. Blower performance is presented in terms of air flow rate in CFM versus:

☐ A. External static pressure (IWC). ☐ B. Internal static pressure (IWC).
☐ C. Total pressure (IWC). ☐ D. Velocity pressure (IWC).

7. A practical way to express the resistance of duct fittings for small systems is in terms of:

☐ A. friction loss in inches of water. ☐ B. dynamic loss in pounds per square inch.
☐ C. equivalent length of straight duct in ft. ☐ D. feet of head.

8. Btu/h heat delivery to a room is a consequence of both the volume of air supplied and air:

☐ A. velocity. ☐ B. density.
☐ C. pressure. ☐ D. temperature.

9. To optimize heating performance in cold climates, supply outlets should be placed:

☐ A. low, on the inside wall opposite windows.
☐ B. low, on the outside wall under windows.
☐ C. high, in the ceiling in the center of the room.
☐ D. opposite the position of the return grille.

10. In addition to fiber glass, ordinary ductwork is fabricated using:

☐ A. aluminized steel. ☐ B. stainless steel.
☐ C. galvanized steel. ☐ D. low lead steel.

For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

Key Words

inverted	register	extended	spreading	grille
plenum	radial	converging	distribution	splitter

11. A floor diffuser is a supply outlet that delivers air in a rapidly _______________ air pattern.

12. A _____________ is any louvered or perforated covering over a duct opening.

13. A common duct arrangement featuring a constant area main supply is called a/an ____________________ system.

14. A duct arrangement that does not feature a main or trunk duct is the ________________ duct system.

15. A _________________ box splits a branch into two run outs to serve two registers.

Check Your Answers!

YOU ARE NOW READY TO TAKE YOUR ONLINE UNIT EXAMINATION, EXAM #1.

GOOD LUCK!

Appendix A: Answer Key to Self-Check Quizzes

The answer to each quiz question is grouped by lesson number. For each answer, there is also a page number in the lesson text for reference. The student is encouraged to refer back for those questions missed and reread the material.

Self-Check Lesson 1	***Reference Page***
1. True	2
2. True	3
3. False	3
4. False	5
5. True	8
6. B	4
7. A	4
8. A	5
9. A	5
10. B	6
11. blend	5
12. small	6
13. friction	7
14. balancing	8
15. 90B	9

Self-Check Lesson 2	***Reference Page***
1. True	1
2. True	1
3. True	4
4. True	2
5. True	4
6. D	6
7. C	6
8. C	1 & 2
9. B	5
10. C	6
11. combustion	5
12. radiation	4
13. latent	3
14. sensible	3
15. conduction	5

Self-Check Lesson 3	*Reference Page*
1. False	2
2. True	2 & 5
3. True	4
4. False	3
5. True	2
6. B	2
7. A	4
8. D	3
9. A	3
10. C	4
11. bio-aerosols	5
12. filtration	5
13. sick building	5
14. ventilation	5
15. maintained	5

Self-Check Lesson 4	*Reference Page*
1. True	2
2. True	2
3. True	2
4. False	3
5. True	4
6. B	5
7. B	5
8. C	5
9. D	6
10. B	7
11. barrier	7
12. combustion	9
13. make-up	9
14. preheat	9
15. perimeter	12 & 13

Self-Check Lesson 5	***Reference Page***
1. True	2
2. False	4
3. False	3
4. False	2
5. False	4
6. C	3
7. C	4
8. A	5
9. D	5
10. C	8
11. cold partitions	6
12. unheated	6
13. edge	6
14. above/below	6
15. duct	9

Self-Check Lesson 6	***Reference Page***
1. True	2
2. False	3
3. True	3
4. True	4
5. False	5
6. D	2
7. C	3
8. C	4
9. A	4
10. C	6
11. space	7
12. heating capacity	3
13. gas	3
14. high	4
15. weatherized	7

Self-Check Lesson 7	*Reference Page*
1. True	2
2. False	9
3. False	9
4. True	8
5. False	10
6. A	11
7. C	10
8. D	12
9. B	8
10. C	9
11. spreading	7
12. grille	6
13. extended plenum	4
14. radial	6
15. distribution	6

Self-Check Lesson 8	*Reference Page*
1. False	2
2. False	3
3. True	3
4. True	4
5. False	6
6. A	5
7. B	5
8. C	5
9. C	6
10. D	8
11. humidistat	9
12. decrease	3-4
13. condensation	7
14. gallons/day	8
15. defrost	10

Appendix B: Glossary

A Selected List of Terms

ABSORPTION SYSTEM: A refrigerating system in which the refrigerant gas from the evaporator is chemically absorbed in another liquid, which is pumped to a higher pressure and released in a generator upon the application of heat.

ACOUSTICAL: Pertaining to sound.

ACOUSTICAL DUCT LINING: Duct with a lining designed to control or absorb sound and prevent transmission of sound from one room to another.

AIR CLEANER: A device designed for the purpose of removing airborne impurities such as dust, gas vapor, fumes, and smoke. Air cleaners include air washers, air filters, electrostatic precipitators, and charcoal filters.

AMPERE: The strength of an electrical current. The current produced by an electromotive force of one volt acting through a resistance of one ohm.

BLOW (THROW): The distance an air stream travels from the face of a supply oudet to a point from the face at which air motion is reduced to a velocity of 50 feet per minute.

BTU, BRITISH THERMAL UNIT: The quantity of heat required to raise the temperature of 1 lb. of water 1°F.

CHARGE: Amount of refrigerant in a system; or to put refrigerant into a system.

COMFORT AIRCONDITIONING: The process of treating air so as to control simultaneously its temperature, humidity, cleanliness, and distribution to meet the comfort requirements of die occupants of the conditioned space.

COMPRESSOR: That part of a mechanical refrigeration system that receives the refrigerant vapor at low pressure and compresses it into a smaller volume but at higher pressure.

CONDENSATION: The process of changing a gas into a liquid by removal of heat, as when water vapor is condensed into water on a cold surface.

CONDENSER: That part of a mechanical refrigeration system that receives the refrigerant vapor at high pressure and temperature and condenses it into liquid refrigerant at high pressure and temperature.

CONDUCTION: The transfer of heat from a warmer body to a cooler substance by direct contact.

CONVECTION: The transfer of heat by the circulation of a liquid or gas. such as water or air.

DEGREE DAY: A unit used to estimate fuel consumption and to specify the heating load in winter, based on temperature difference and time. There are as many degree days for any one day as there are degrees F. difference in temperature between the average [1] temperature for the day and 65
°F.

DEHUMIDIFY: To reduce or remove moisture from the air.

DEW POINT: The temperature at which the air can hold no additional water vapor and begins to form visible liquid droplets on cool surfaces.

DOUBLE GLAZING: Glazing consisting of two thickness of glass with an air space between them.

EVAPORATION: Change of state from a liquid to a gas. At 70° about 1,054 Btus are required to evaporate one pound of water.

GAS, NON-CONDENSABLE: Gas in a refrigerating system, such as air which does not condense at the temperature and partial pressure at which it exists in the condenser, and therefore imposes a higher head pressure on the system.

HEAD PRESSURE: Operating pressure measured in the discharge line at a compressor outlet.

HEAT, LATENT: A term used to express the energy involved in a change of state such as from a liquid to a gas.

HEAT, SENSIBLE: A term used in heating and cooling to indicate any portion of heat which changes the temperature of the substance involved without changing its physical state.

HEAT, SPECIFIC: The ratio of the quantity of heat required to raise (or lower) the temperature of one pound of a substance one degree F. to the amount required to raise the temperature of one pound of water one degree (Btu/lb°F).

HERMETIC UNIT: A compressor which has its motor sealed inside of the compressor housing and cooled by refrigerant vapor.

HIGH SIDE: Parts of a refrigerating system maintained at the pressure of the condenser.

HUMIDIFY: To add moisture to the air.

HUMIDISTAT: A control device activated by a change in humidity used for automatic control of relative humidity.

HUMIDITY, ABSOLUTE: The quantity of water actually in the air. Given as the weight of water vapor per unit volume (pounds or grains) of moisture per cubic foot of dry air.

HUMIDITY, RELATIVE: The ratio of the quantity of water vapor actually in the air to the water vapor the air could possibly hold at the same temperature and barometric pressure.

INFILTRATION: Air flowing into a house through cracks, loose construction, or other openings.

LOW SIDE: Parts of a refrigerating system at the evaporator pressure.

OHM: The unit of resistance. The resistance of a conductor in which one volt produces a current of one ampere.

PLENUM: A supply air compartment maintained under pressure and connected to one or more distributing ducts.

RADIATION: Transmission of energy by means of electromagnetic waves. Heat so transmitted increases temperature of objects it strikes in its path without increasing temperature of air through which it passes.

REFRIGERANT: A coolant that produces a useful refrigerating effect by its absorption of heat while expanding or vaporizing at practical pressures.

SHORT CYCLES: Refers to short and more frequent periods of on/off time when a system is delivering conditioned air.

TEMPERATURE, DEW POINT: The temperature at which the condensation of water vapor in the air begins.

TEMPERATURE, DRY BULB: The temperature indicated by an ordinary thermometer.

TEMPERATURE, WET BULB: The temperature read on a wet bulb psychrometer constructed and used according to specifications.

THERMOSTAT: An instrument which responds to changes in temperature to control (turn off/off) components in a cooling or heating system.

TON, OF REFRIGERATION: Quantity of heat required to melt one ton, 2,000 pounds, of ice in twentyfour hours. This is equivalent to 12,000 Btu's per hour.

VALVE, EXPANSION: A device which regulates the flow of refrigerant from the liquid line into the evaporator. It also separates high side from low side of a system.

VELOCITY: In heating and cooling, velocity usually refers to the rate of flow of the air in the ducts or rate of flow of the air through the registers and grilles. It is almost always expressed in feet per minute.

VOLT: The unit of electromotive force, or potential difference, equal to that force or difference