Controls: Principles

Lesson 1 to 8

Course Content

Learning Objectives

This training course covers heating and cooling controls most often used in residential, apartment, and light commercial structures in which unitary package-type equipment and electric powered controls are installed.

After completing this course, a typical student should be able to:

1) Read and recite basic control terminology.

2) Identify basic control components and explain their function in the circuit.

3) Understand the basic steps in troubleshooting control problems.

Student mastery of these objectives will be demonstrated by successful completion of three 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.

Introduction: What Is An Automatic Control System?

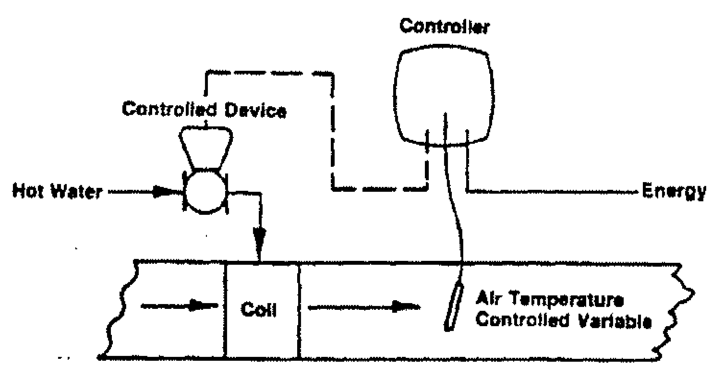
Before beginning your study of the individual components that make up a control system, let's first consider an overview of the necessary functions in any control system.

Very simply, a control system checks or regulates within clearly defined limits. Consider a car and driver on a winding road. The driver looks down the road and follows the lane markers and makes adjustments to the steering wheel, as he keeps the car between the road markers. One can drift a little to the right or left before making any adjustment to the wheel. This is manually controlling a car. There are also control systems that can do this automatically - as with an airplane and an automatic pilot.

So, an *automatic* control system means something - air temperature, for instance, is regulated automatically without any manual adjustment.

A control system must monitor a condition, say, the air temperature in a duct, and compare that observed value of perhaps 98° F with the desired value, or set point which might be 100° F. Then it must energize a controlled device like a water valve to increase (or decrease) the supply of hot water to a duct heating coil. As the air temperature increases to 100° F, the controller closes the hot water valve to reduce the hot water sent to the heating coil.

In the figure below, we have illustrated this simple automatic control system. Since there is *feedback* to the controller which measures the change in air temperature, this is called a closed loop control system.



The remainder of your lessons will be learning about the many controllers and controlled devices available to accommodate the exact requirements of modem heating and cooling systems.

Unit 1 Preview: Low Voltage Control Circuits

It is extremely important that the student understand at the outset exactly what this course is about and what it provides. Don't skip over these important first pages in the textbook.

Physically, the course contains twenty lessons, divided into five units or sections that are composed of from two to six closely-related lessons.

The first unit you are about to study is entitled *Low Voltage Control Circuits*. It contains three lessons. The material found in this first unit provides an overview of the design and performance of a control system. That is, effectively, Unit One touches on all aspects of a control system - but not in great detail.

Lesson I provides a review of basic electrical theory to help the student understand the operating principles behind the various control devices. Since this is a course on controls and not electricity, the lesson is intentionally brief and to the point, but nonetheless, it is thorough and complete.

Traditionally, low voltage control systems provide safer, more sensitive control operations than systems required to operate on high voltage power. Lesson 2 deals at some length with the electrical transformer, a simple, but important device that converts line voltage power to low voltage power --- so essential to convenient, low voltage control circuits.

How a transformer works, correct sizing, and proper connections to avoid burnout and other problems are discussed in detail.

In Lesson 3, the concept of a control circuit is introduced. How heating and cooling controls are wired together; the various types of circuit diagrams; and most importantly, the rules of the road to properly trace and understand control circuits are presented. Lesson 3 should be considered one of the key lessons in this course.

The value of this first unit is that it introduces the whole control system concept. It lays the foundation for what is to follow in the remaining lessons - namely, a myriad of component details, operating features, and troubleshooting procedures.

As a final thought: don't study the material just to get good grades. Study this unit (and all the others) with the objective of trying to understand all the information contained in the lessons. You'll be a better "controls" person as a result of this determination.

Lesson 1 Overview

Lesson 1, *Review of Basic Electricity,* explains the electrical theory behind the operation of controls and circuits used in automatic heating and air conditioning systems. The lesson is designed to be a comprehensive "refresher" on basic electrical concepts.

To fully and effectively conduct this review, you should try to achieve the following goals:

1. Name the two fundamental *classes* of electricity.
2. Identify the two common sources of current electricity.
3. Describe electrical resistance.
4. Distinguish between electrical *conductors* and *insulators.*
5. Define *volt, ohm,* and *ampere.*
6. Define a *Watt* and *kilowatt.*
7. Explain Ohm's Law.
8. Describe two types of current electricity (alternating and direct).
9. Explain the need for single-phase AC and three-phase AC.
10. Identify and describe two general types of circuits (series and parallel).
11. Understand the "right hand rule" for determining direction of magnetic field inside a coil.
12. Describe the function of an electromagnet.

Now read Lesson 1 which begins on the next page.

Lesson 1: A Review of Basic Electricity

To begin, electricity is a form of energy. And energy, you may recall, is merely the ability to do work --- quite basically, move a force a distance.

The Basics of Electricity

There are two fundamental classes of electricity --- *static* electricity and *current* electricity. Static electricity is of little consequence to us here, since it cannot be used to operate controls. However, current electricity is quite useful in a number of different ways.

Current electricity is a result of the flow of electrons through a substance. Electrons are an integral part of the substance itself. For example: each atom in a copper wire has 29 electrons that are said to be negatively charged relative to other particles making up the copper atom. Once some of these electrons get moving from atom to atom, electric energy, or just plain electricity, is produced. We can magnetize iron, turn a shaft, illuminate, etc.

Batteries and electric generators, the latter sometimes referred to as "electron pumps," are two common methods of producing current electricity.

Conductors and Insulators

All materials have a property, termed *resistance,* which opposes the flow of electric current - a consequence of internal forces holding electrons in place. Materials that offer low resistance to the passage of an electric current are called *conductors.* Materials that offer high resistance to the passage of electric current are called *insulators.* Table 1-1 lists common materials according to their ability to conduct electric current.

Volts, Ohms, and Amperes

The word *volt* is a term used to express electric pressure (potential or electromotive force), and is roughly analogous to the pressure head needed to force water through a pipe.

Ohm is the term used to express resistance to the flow of electricity.

Ampere is a term to express the volume flow of electricity - the electrical "gallons" per second. One "amp" is equivalent to the flow of 6.28 billion electrons per second.

Table 1-1. Electrical Conductivity of Common Mate·ials			
Good conductors	Fair conductors	Poor conductors	Insulators
Silver Copper Aluminum Iron	Carbon Acid solutions Alkali solutions Salt solutions	Linen Paper Wood	Glass Rubber Bakelite Slate

Resistance

The resistance of a specific conductor is fixed in value - resistance does not vary with changes in the amount of current flowing through a conductor. Resistance will vary with changes in the temperature of a conductor. Normally, as the temperature of a conductor increases, its resistance will also increase.

While the resistance of a specific conductor is a *fixed* value, resistance in an electric circuit does vary with the *size* and *type* of material used in the circuit:

1. Resistance will vary directly with the length of the conductor (wire). Doubling the length of a conductor doubles the resistance.

2. Resistance will vary inversely with the size of the conductor (wire). If one conductor has four times the cross-sectional area of another conductor of the same material, it will. have onefourth the resistance of the smaller conductor (e.g. ten ft of American Wire Gauge (AWG) No. 8 conductor offers less resistance than 10 ft of No. 12.)

3. Resistance in the circuit will vary with the type of material used in the conductor (wire). No general rules can be stated; however, the resistance of an alloy is greater than the resistance of any one of its components.

Power

The basic unit of electrical power is the Watt - named in honor of James Watt, a Scottish engineer. Electrical power can be measured with a wattmeter. Many times, (but not always as we'll see later) it can also be calculated by applying the following formula which expresses the relationship between power (P), volts (E) and amperes (I):

$$P = E \times I$$

For example: a household toaster plugged into a 110 volt (E) circuit and drawing 10 amps (I) consumes electricity at the rate of 110 x 10, or 1,100 Watts. A Watt is analogous to horsepower, and one hp equals 746 Watts.

Total electrical energy expended (W) is equal to the rate at which work is done (P) multiplied by the length of time (t) the rate is measured.

$$W = P \times t$$

If time (t) is expressed in hours, W will be in Watt hours. A Watt hour is the work equivalent to a current of one ampere at a pressure of one volt flowing for one hour. A kilowatt hour is 1,000 Watt hours. Electrical energy is usually bought and sold in units of kilowatt hours.

Ohm's Law

George Simon Ohm was a German physicist who discovered the relationship between current, voltage and resistance. Ohm's Law states that the current (in amperes) flowing in an electric circuit is equal to the electromotive force (in volts) divided by the total resistance (in ohms) of that circuit.

There are three forms in which this law can be expressed mathematically:

Amperes (I)	Volts (E)	Ohms (R)
$I = E/R$	$E = I \times R$	$R = E/I$

An easy way to remember the different forms in which Ohm's Law can be expressed is to remember the illustration in Figure 1-1. If any of the three letters is covered, the two left uncovered are in the proper form.

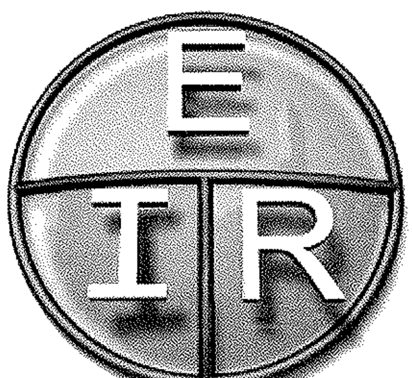


Figure 1-1: Ohm's Law in pictorial form.

Thus, E (if covered) = IR or $I \times R$
I (if covered) = E/R or $E \div R$
R (if covered) = E/I or $E \div I$

If current, potential, and resistance are expressed in amperes, volts, and ohms, respectively, the equation are valid for all direct current circuits.

Types of Current Electricity

There are two common types of current electricity *direct current* (DC) and *alternating current* (AC).

A direct current is one which is fixed in value and constant in direction while the circuit is closed. Direct current is generally produced by a battery.

Alternating current flows first in one direction, then reverses and flows in the opposite direction. There is not only a repeated change in the direction of flow, but also a constant change in potential. The voltage starts at 0 volts, increases until it reaches a positive maximum, reduces to 0 volts, then increases until it reaches a negative maximum, and reduces again to 0 volts. The period covered in this change from 0 volts to a positive maximum, to a negative maximum, and back to 0 volts is called a cycle. If this cycle is repeated 60 times per second, the current is 60 cycle AC current. Alternating current is generally produced by an alternating current generator.

In AC circuits, the electric power is equal to E x I only when the voltage and current are alternating in unison.

If the AC current peaks before or after the AC voltage reaches its maximum, due to components such as motors, coils and capacitors in the circuit, the product E x I must be multiplied by a factor termed the power factor - to obtain the precise wattage in the circuit.

And for the same reason, Ohm's Law must be modified slightly for AC circuits. The term impedance (Z) replaces pure resistance (R) in the various formulas. This new term combines resistance with reactance - an additional effect due to motors, coils and capacitors in AC circuits.

Normally, electrical control equipment designed for use in AC circuits cannot be used in DC circuits.

Single and Polyphase AC

Alternating currents can be either single phase or polyphase currents. Polyphase current (usually three-phase current) is commonly supplied to industrial and commercial customers. Polyphase service allows several economies to be realized in generating the electricity, in delivering it, and in the equipment using it. Single phase current is used in residences. In fact, polyphase current is not likely to ever be encountered in homes and all standard domestic equipment is built for single phase current. Normally, electrical equipment designed for single phase current cannot be used with polyphase current.

Electrical Circuits

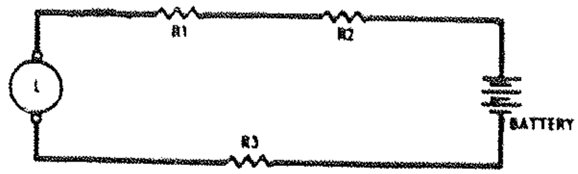
Electrical circuits are generally classified as *series* or *parallel* circuits, depending on the method used to connect equipment into the circuit (Figure 1-2 and 1-3). The two general types of circuits can also be combined, forming a series-parallel circuit or compound circuit (Figure 1-4).

In parallel circuits, the voltage across each piece of equipment will be equal to the supply voltage; however, the current flowing through each piece of equipment will vary. For example, if two motors, one rated at 5 amps and one rated at 10 amps, are connected in parallel, each motor will draw its rated current and the total current in the circuit will equal the sum of the two currents (15 amps).

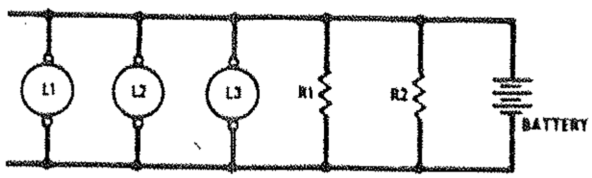
A parallel circuit will be *overloaded if* the sum *of* the *designed current ratings* for the equipment connected to the circuit exceeds the available supply. If a system is overloaded, the voltages and currents in the equipment connected to the circuit will drop. Normally, the fuse protecting the circuit will burn out or the overload switch will open if an overload condition exists. However, if the circuit is not properly fused or if the fuse is shorted out, the equipment will burn out. "Overloading a circuit or system" is a dangerous practice; it could cause fires.

In a *series* circuit, the voltage across each piece of equipment will vary; however, the sum of the individual voltage drops must always equal the supply voltage. Since there is only one path for current to flow in a series circuit, the total current is the same in all parts of the circuit. Furthermore, the amount of current flowing in a series circuit is determined by the resistance of the equipment in the circuit. The total resistance in the circuit will be equal to the sum of the resistances of the individual parts of the circuit.

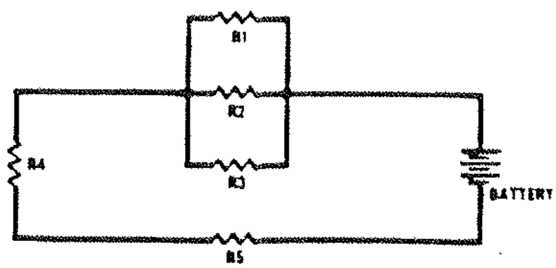
Series vs. Parallel Circuits



1-2 SERIES circuit.



1-3 PARALLEL circuit.



1-4 COMBINATION circuit

The characteristics of series and parallel circuits can best be illustrated by an example.

Assume an electric toaster and a electric iron are rated at 1,100 Watts. Each has a fixed resistance of 11 ohms due to the heating element inside. Now let's connect these appliances, first in series, then in parallel, into a 110 volt source.

In series, the total resistance R, in the circuit equals the sum of the resistances of each appliance. Thus:

$R_T = 11 + 11 = 22$ ohms.

From Ohm's Law, the current in the circuit would be:

$I = E/R = 110/22 = 5$ amps.

The voltage drop across each appliance would be:

$E = E \times R = 5 \times 11 = 55$ volts.

In parallel, the voltage across each appliance is 10 volts. Thus, the current flow through each appliance is

$I = E/R = 110/11 = 10$ amps.

And in parallel, the reciprocal of the combined circuit resistance (Rc) is equal to the sum of the reciprocals of the resistance of each appliance. Thus:

$$I = 1/11 + 1/11 = 2/11 \text{ or}$$
$$Rc = 5.5 \text{ ohms.}$$

(Note that the combined resistance is less than the individual resistances in a parallel circuit.)

The total current flow in the circuit is from Ohm's Law:

$I = E/R = 110/5.5 = 20$ amps.

This is, by necessity, exactly equal to the sum of the current flow through each appliance.

Summed up, the voltage, current and power for these two appliances are:

	In Series	**In Parallel**
Voltage	55 volts	110 volts
Current	5 amps	10 amps
Power	275 Watts	1100 Watts

Which way do you think the appliances should be connected to work best - in series, or in parallel?

Short Circuit

Since an electric circuit is simply a path through which electrons can flow, electrons will always follow the path of least resistance. Therefore, a short circuit is simply that part of a circuit in which the resistance is less than the total resistance of the circuit. A circuit can be "shorted" either accidentally or intentionally.

Magnetism, Electromagnets, and Induced Potential

Electric current flowing in a conductor will create a *magnetic field* around the conductor if the conductor is a piece of coiled wire, a concentrated magnetic field will be created inside the coil - the strength of this magnetic field will depend on the amount of current flowing through the coil and on the number of turns in the coil. When the current ceases to flow, the coil loses most of its magnetism. If the right hand is placed around a coil with the fingers pointing in the direction of current flow, the thumb will point in the direction of the flow of the magnetic lines of force *inside* the coil and also point to the "north" pole of the two pole magnetic coil. (Figure 1-5.) The flow of the magnetic lines of force inside the coil will be from the south pole to the north pole; and on the outside of the coil, the flow will be from the north pole to the south pole.

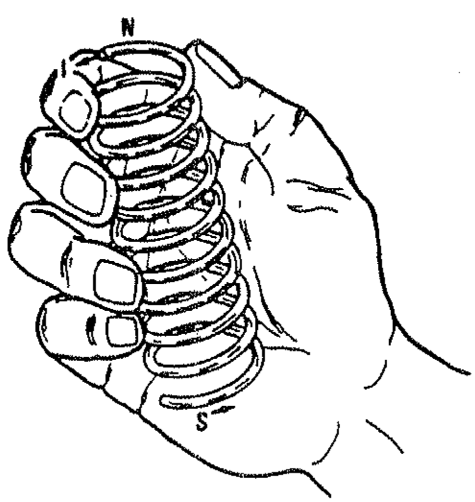


Figure 1-5: Right-hand rule to find "north" pole of a coil. If fingers point in direction of current flow through coil, thumb points to north pole of coil.

A substance is said to be a magnet if it has the property of magnetism - that is, if it has the power to attract such substances as iron, steel, nickel, or cobalt, which are known as *magnetic materials.*

Magnets may be conveniently classified into three groups - 1) natural magnets which are found in their natural state in the form of a mineral called magnetite; 2) permanent magnets, bars of hardened steel (or some form of alloy) that have been permanently magnetized; or 3) electromagnets, composed of soft iron cores around which are wound coils of insulated wire. The addition of the soft iron core increases and intensifies the magnetic field or force since the magnetic lines of force are more easily established in the soft iron than in air.

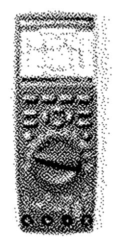
All magnets have two poles or points of magnetic attraction, known as the north pole and the south pole. A magnetic field exists around a simple magnet. The field consists of imaginary lines along which a *magnetic force acts*. These imaginary lines emanate from the north pole of the magnet and enter the south pole, returning to the north pole through the magnet itself. A magnetic circuit is a complete path through which magnetic lines of force may be established. Magnetic circuits are similar to electric circuits and a close relationship exists between electricity and magnetism. Knowledge of this relationship is important in understanding the operation of transformers, solenoids, motors, and relays.

We have just considered how the flow of electric current creates a magnetic field around the conductor. It is also possible to establish an electrical potential (voltage) in a conductor by moving it through a magnetic field (the ordinary generator, where the conductors on the rotating shaft are moved through the poles of a magnet is an example). The voltage induced in the conductor will depend on the strength of the magnetic field through which it is moved and upon the speed of the movement. Electrical potential can also be established in a conductor without actual movement if the conductor is placed in a magnetic field and the strength of the field is increased and decreased rapidly. This is the principle behind the operation of the AC transformer. The AC current applied on one side causes a fluctuating magnetic field, which induces a voltage on the other side of an iron core. Transformers are discussed in detail in Lesson 2.

Few Tips on Test Instruments

A single device that can do all the jobs in testing controls and circuits is every technician's dream. Reality has it that more than one meter will be necessary. What follows are a few suggestions on the selection and protection of electrical test instruments.

Good meters may appear to be a sizable investment but they save you time and money in the long run if carefully selected, properly used, and maintained.



One “multi-purpose” meter is handy if it isn’t too bulky, but it may be complex to use.

Using several special purpose meters may be easier to read and use, may be less expensive per unit, and may offer greater dependability (when a multi-purpose meter breaks down, you have no test capability). Any meter should be kept in a protective case and not just tossed in with the wrenches. For electronic diagnosis, select a high impedance meter - 20,000 ohms per volt or greater should be used.

Meter scales are either linear or non-linear. Linear scale means evenly spaced divisions and easier to read as compared to non-linear scales.

Select a meter where the readings will be at or near mid-scale for most of your work. Accuracy is lost at either end of the scale.

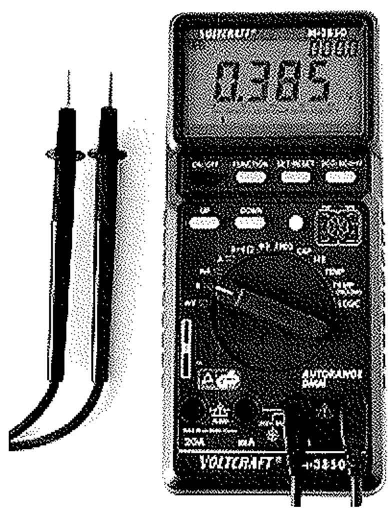
A digital meter is easier to read than an analog (moving pointer) type. They are excellent for finding the precise value of voltage, current or resistance. On the other hand, an analog meter is usually less expensive and is excellent for observing the trends of slowly changing voltage, current or resistance.

Keep the users manual with any meter and review it periodically. Even with meters kept for a long time, we tend to forget some features.

If you are not going to learn to use a meter properly or use it infrequently, it is probably best not to buy it.

All meters should be checked for accuracy over time. Send it back to the factory if you cannot re-calibrate the device yourself.

Use only the best quality batteries in a test meter, if required.



We have been considering the basic electrical concepts necessary and sufficient for an understanding of heating and cooling controls. For those interested in a more comprehensive review of electrical theory, numerous excellent texts on basic electricity can be found in local libraries. The student is always encouraged to do additional reading and reference work.

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 A magnetic field around a conductor is created by the electric current flowing in that conductor.

2. T F The sum of resistance of each piece of electric equipment determines the value of the current in a series circuit.

3. T F Reducing the length of a conductor reduces the resistance of that conductor.

4. T F An insulator strongly resists the flow of electrical current.

5. T F Both acid and alkali solutions are fair conductors of electricity.

6. T F Wood is a good conductor of electricity.

7. T F Permanent magnets may not be made of an artificial substance.

8. T F Unlike magnetic poles repel each other.

9. T F Electrical equipment designed for single-phase current can be used for polyphase current as well.

10. T F The rate at which electrical work is done, multiplied by the length of time the rate is measured, is equal to total energy expended.

11. T F Direct current is fixed in value and constant in direction.

12. T F There is no scientific relationship between volts, ohms, and amperes.

13. T F Ohm's Law states that the current in a circuit is equal to the electromotive force (in volts) divided by the total resistance (in ohms) of the circuit.

14. T F The material of which a conductor is composed has little effect on resistance.

15. T F Virtually all substances have some property which resists the flow of electrical current.

16. T F A good conductor offers substantial resistance to the passage of electrical current.

17. T F Magnetic lines of force inside a coil will be from the south to the north pole, but from the north to the south pole on the outside.

18. T F Three-phase current is the most common polyphase current.

19. T F If two pieces of equipment are connected in parallel, the voltage across each piece will vary.

20. T F Alternating current is generally produced by a bank of batteries.

In the following multiple choice questions, choose the phrase that most correctly completes the statement and circle the corresponding letter in front of the phrase.

21. Two common types of electrical current are:

a. direct and alternating.
b. direct and single phase.
c. alternating and polyphase.
d. single phase and polyphase.

22. The Watt is a unit used to measure:

a. ohms.
b. low voltage.
c. electrical power.
d. amperes.

23. In Ohm's Law, I =

a. ER.
b. RE.
c. R/E.
d. E/R.

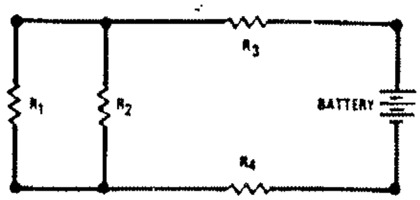
24. Overloading an electrical system may result if the rated loads of all the pieces of equipment added together exceed:

a. the total power supply available.
b. 1,000 Watts.
c. 100 amperes.
d. the recommendation of the utility company.

25. A short circuit is that part of a circuit that always has resistance:

a. more than the total circuit.
b. the same as the total circuit.
c. less than the total circuit.
d. apart from the circuit.

26. The figure at right is an illustration of a:



a. series circuit.
b. parallel circuit.
c. series-parallel circuit.
d. short circuit.

27. In alternating current, there is a repeated change in the:

a. resistance.
b. amount of wattage.
c. heat produced.
d. direction of current flow.

28. The unit used to measure resistance is a(n):

a. ampere.
b. Watt.
c. ohm.
d. volt.

29. The term volt expresses:

a. air pressure.
b. water pressure.
c. current pressure.
d. electrical pressure.

30. An electrical potential is set up in a conductor when that conductor is moved through a:

a. helix.
b. magnetic field.
c. coil.
d. solenoid.

31. Resistance is the property of a substance to oppose the flow of:

a. electricity
b. acid.
c. water.
d. alkaline solutions.

32. A substance which offers low resistance to the flow of electricity is a(n):

a. insulator.
b. resistor.
c. conductor.
d. converter.

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

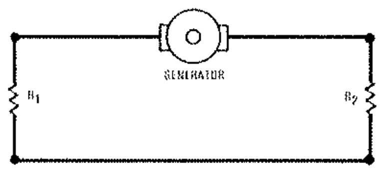
33. Two common sources to produce current electricity are ____________ and a/an ___________.

34. Alternating current may be provided as ______________ or _____________ power.

35. An iron core inserted into a coil is a/n ______________________.

36. The voltage across each piece of electrical equipment will vary if two pieces are connected in _________________________.

37. A current of one ampere at a pressure of one _____________ flowing for one hour is a Watt hour.



38. The figure above is an illustration of a/an ________________________ circuit.

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 2 Overview

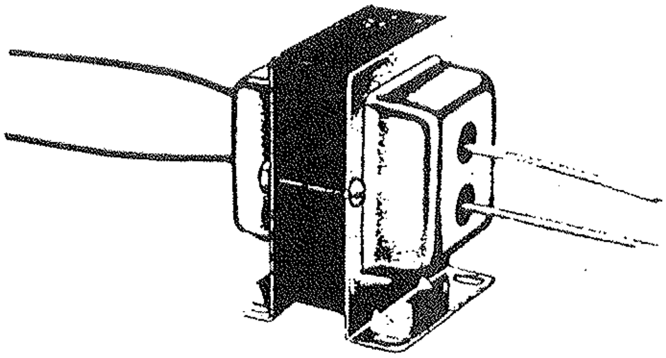
A transformer is an electrical device that reduces or raises voltage levels at practically no loss in power. It is a vital component of a low voltage control system. Lesson 2, *The Transformer,* describes the function of a transformer and explains in detail how it operates in relation to the electrical load.

Study this lesson carefully so that you can:

1. Define an electric transformer and describe how and why it is used to change voltage.
2. Describe the function of a step-down transformer in a control circuit.
3. List the factors involved in determining primary voltage.
4. List the steps followed to determine transformer capacity.
5. State the formula for determining transformer size when serving pure resistive loads.
6. Explain the relationship between transformer size and contactor or motor starter loads.
7. State and explain the formula for determining transformer size when serving solenoid and relay loads.
8. Define NEC Class 2 and power type transformers.
9. Understand how to overcome "phasing" problems.

Now read Lesson 2 which begins on the next page.

Lesson 2: The Transformer



Heating and air conditioning control circuits can be designed to operate on either line voltage (115-120 volts) or low voltage which is usually less than 30 volts. However, a low voltage control circuit can readily be made superior to a line voltage circuit because: first, wiring is simplified; and secondly, because low voltage thermostats can be made to provide closer temperature control than line voltage thermostats.

Transformers

Essential to the development of low voltage controls is the economical AC transformer. A stepdown or low voltage transformer is used in heating and air conditioning control systems to reduce line voltage to operate the control components. Almost all of the transformers used in the heating and air conditioning industry reduce incoming voltage to 24 volts.

Inside, a simple step-down transformer consists of two unconnected coils of insulated wire wound around a common iron core (Figure 2-1). The coil connected to the power supply is called the primary coil (PRI) and the coil which provides low voltage for the control circuit is called the secondary coil (SEC). In step-down transformers, the ratio of primary to secondary voltage (120 to 24, 240 to 24, or 208 to 24) is directly proportional to the ratio of primary turns to secondary turns wound around the iron core (5 to 1, 10 to 1, or 8 to 1). For instance: if there are five turns on the primary side for every turn wound on the secondary side, then the ratio of primary to secondary turns is 5 : 1, and the voltage measured on each side would be in the same proportion. If we applied 120 volts on the primary side, we would measure 1/5 or 24 volts on the secondary side. (It is also possible to step-up the voltage using a transformer with more turns on the secondary than on the primary side.)

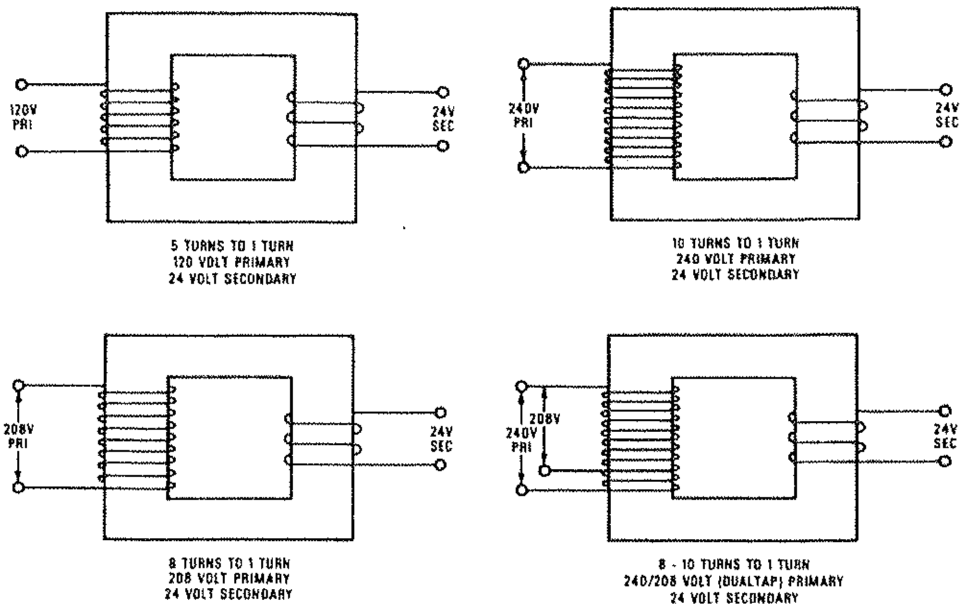
Is all this magic? Did some energy disappear? Not really; the value of the current on the secondary side would be 5 times higher than on the primary side, so that the power on both sides of the transformer remains the same --- assuming a 100 percent efficient transformer. If there were 1.67 amps on the secondary side, then the primary circuit would carry only 0.334 amps. To prove there is no magic or lost energy involved, we can balance the power on both sides:

Volts x Amps = Volts x Amps
(Primary) = (Secondary)

.120 x 0.334 = 24 x 1.67 = 40 VA

An actual transformer is not 100 percent efficient so there would be some small loss of energy in an actual installation.

How is AC voltage and current conveyed between two circuits that are not directly connected? Actually, the iron core "connects" the circuits by means of electromagnetic *induction,* which was mentioned and defined in Lesson 1. Current electricity can produce magnetism; and, conversely, magnetism can produce current electricity. However, to produce continuous flow current electricity from magnetism, the magnet must be moved repeatedly across the wire. In the case of a transformer, the "movement" is created by the alternating nature of the magnetic field about the iron core; in turn, by the applied AC voltage.



2-1 INSIDE an ordinary transformer are two coils of wire linked together by a common iron core. The number of times the wire in each coil loops around the iron core affects the ratio of voltage input to voltage output as shown by these four examples. Note: PRI refers to the primary or input side of the transformer, SEC refers to the secondary or low voltage side.)

The transformer as described here will not work in a DC circuit since there would be no induction.

The first step in selecting a transformer to use in a control circuit is to determine the voltage which will be applied to *the primary coil.* The applied voltage must agree with the primary voltage marked on the transformer.

Determining the Primary Voltage

Transformers are available in a number of "nominal" primary voltages.

<table>
<tr><th colspan="2">Transformers with these "nominal" rated primary voltages:</th><th>May be used with these common line voltages.</th></tr>
<tr><td colspan="2">NEMA Standard</td><td rowspan="6">110, 115 or 120 volts
208 volts
220, 230 or 240 volts
440, 460 or 480 volts</td></tr>
<tr><td>OLD</td><td>NEW</td></tr>
<tr><td>115</td><td>120</td></tr>
<tr><td>208</td><td>208</td></tr>
<tr><td>230</td><td>240</td></tr>
<tr><td>460</td><td>480</td></tr>
</table>

In selecting transformers, always match the primary voltage rating of the transformers with the supply line voltage. If the voltage applied to the primary coil exceeds the rated primary voltage by 10%, the transformer will burn out.

"Oversizing" transformers - using a 240V transformer with 120V supply -will result in insufficient secondary voltage. If a 240V transformer is connected to a 120V supply line, the secondary voltage will be only 12 volts instead of the 24 volts required for the control circuit. If a 240V transformer is used with a 208V supply line, the secondary voltage would be 240/208 x 24 or 20.8 volts, rather than the required 24 volts.

After determining the required primary voltage rating, the next step in selecting a transformer is to determine the size or capacity of the transformer needed to carry the electrical load of the secondary circuit.

Determining Transformer Size (Capacity)

Low voltage transformers are manufactured in a number of sizes or capacities. A transformer's capacity refers to the amount of electrical current (amps) that the transformer can handle through its primary and secondary coils without unacceptable voltage drops. A transformer for a control circuit must have a capacity rating sufficient to handle the current (amperage) requirements of the loads connected to the secondary circuit.

The capacity ratings of transformers are expressed in "Volt-Amperes" (VA). *VA is the product of volts x amperes.*

The amount of power the transformer can handle is determined by the number of turns in the wire, the size of the wire and the number of laminations in the core of the transformer. Generally the VA (Volts x Amps) capacity rating of the transformer increases as the number of turns decreased and the wire diameter increases.

Electrical Loads

Pure resistance electrical loads such as heating coils have a 100% power factor. Therefore, the wattage in pure resistance loads is determined by applying the following formula:

Watts (purely resistance load) = Volts x Amps x 1 (100%)

Obviously, a transformer used in a secondary circuit with pure resistance loads must have a capacity rating (VA rating) equal to the wattage of the circuit.

Solenoid and Relay Loads

Electrical devices containing a coil and iron, such as solenoid valves and relays, have a power factor of approximately 50%. Therefore, the wattage in circuits with common inductive loads such as solenoid valves and relays is determined by applying the following formula:

Watts (inductive loads) = Volts x Amps x 0.5 (50%)

Since transformers are rated in Volt-Amps (Volts x Amps), the formula for calculating the wattage in circuits with inductive loads can be re-arranged into a more convenient form for use in determining transformer capacity required, as follows:

Volts x Amps = 2 x Watts (inductive loads)

Therefore, for typical inductive loads, the transformer capacity required is determined as follows:

VA (transformer capacity required) = 2 x total wattage of the connected load

Contactor and Motor Starter Loads

For circuits with contactors and motor starters, the solenoid and relay rule *does not* strictly apply.

Contactor is the generic term given to relays with contact ratings equal to or greater than 20 amperes. A motor starter is a contactor with built-in thermal overload protection.

Since contactors and motor starters generally have relatively large inrush currents, the specific characteristics of the device must be known before a transformer of the required capacity can be selected for secondary circuits containing these devices. The transformer capacity required for proper operation of contactors and motor starters must equal the initial inrush volt-amps of the contactor in the secondary circuit. The initial inrush VA valve of the device is used because this is the amount of power required to pull in the contactor contacts with a quick positive action. If less than initial inrush is available, the contactor may close slowly or chatter, causing damage to the contacts.

For example: a 60 amp contactor might have a sealed (closed) continuous VA of 25, but its inrush may be as high as 165.

Usually a combination of contactors and motor starters in a secondary circuit are powered from a single transformer. The transformer capacity must be large enough to handle the total connected load; therefore, the initial inrush VA values for all of the individual components connected in the circuit are added together to determine the required capacity (VA value) for the transformer.

If the contactors and motor starters are designed to pull in at less than rated voltage ("nominal" voltage), a transformer can be selected to take advantage of this design feature. For example, if a contactor designed to pull in at 75% of nominal voltage is used in the secondary circuit and the inrush amperage of the contactor is 1 ampere, transformer capacity required would be calculated as follows:

- "nominal" voltage is 24 volts
- 75% of 24 is 18 volts
- 18 x 1 = 18 watts inrush load
- 2 x 18 = 36 VA (minimum) transformer size using inductive load formula.

NEC Class 2 and Power Transformers

Low voltage control transformers are designed and manufactured to meet National Electric Code (NEC) Class 2 specifications of Underwriters' Laboratories. NEC Class 2 specifications are protective specifications which require the transformer to limit current and heating in the event of prolonged overload conditions.

Power Transformers which carry greater loads and are, therefore, of higher capacity than NEC Class 2 low voltage transformers, should be protected by a *fuse* in the transformer circuit. A properly fused power transformer will usually meet codes which specify NEC Class 2 or equivalent transformers.

Note: Transformers used in control circuits may have a greater capacity than the total connected load in the secondary circuit; however, the transformer should never have a capacity rating which is less than the total connected load.

Phasing

Before discussing transformer "phasing," let's review some of the things we know about battery powered direct current circuits. In many cases, a battery-powered device may require more electrical energy than one battery cell can provide. The device may require either a higher voltage or more current, and in some cases both. Under these conditions, it may be necessary to combine or interconnect enough batteries to meet the load requirements.

If batteries are connected in series (negative electrode of the first cell to positive electrode of the second cell, etc.) and the power take off terminals are the positive electrode of the first cell and the negative electrode of the last cell, the voltage produced by the interconnected batteries equals the number of cells times the voltage output per cell. For example, four 1.5 volt batteries connected in series will produce 6 volts. The current flowing through the circuit will equal the voltage divided by the resistance. However, connecting batteries in series does not boost the *available* amperage. The cells in our circuit, for example, might have a constant current capacity rating of 1/8 ampere. If the series wired batteries in this circuit are expected to supply current constantly for several hours, the current in the circuit should be limited to 1/8 ampere.

If a number of batteries are connected in parallel (all the positive electrodes are connected to one line, and all the negative electrodes are connected to the other) and no more than one cell is connected between the lines at any one point, the voltage available between the lines will equal the voltage available from a single cell.

For example, four 1.5 volt batteries connected in parallel will produce 1.5 volts. However, each cell may contribute its maximum allowable current to the line. So the line current available is equal to the amperage output of each cell multiplied by the number of cells in the circuit. Four cells wired in parallel have enough capacity to supply a load requiring 4 x 1/8 or 1/2 ampere at 1.5 volts.

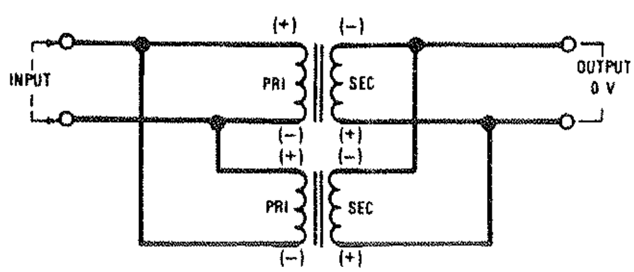


Figure 2-2: Primary leads of two interconnected transformers are crossed; secondary leads are in parallel. Result: zero voltage in secondary.

Obviously, if the load in a circuit requires more voltage and more current than a single cell can produce, the batteries can be connected in a series/parallel network to boost both voltage and current output

Whenever batteries are interconnected, they must be wired correctly. In a series circuit, a positive to positive cell connection will not provide a difference in electrical potential and no current will flow. In a parallel circuit, on the other hand, if cell electrodes are connected positive to negative, one battery will short to the other and there will be a heavy current flow until the batteries are completely discharged.

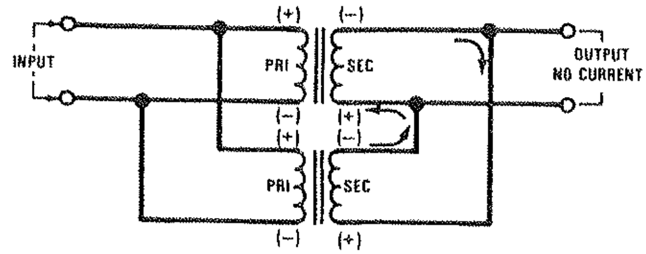


Figure 2-3: Primary leads of two interconnected transformers are wired in parallel. Secondary leads are crossed. Result: short circuit.

Although the output of a transformer is alternating current, the "polarity" of the transformer secondaries must be considered whenever two or more transformers are wired in parallel.

If it were possible to stop the alternations of a transformer secondary at any given instant of time and still observe the induced voltage, one end of the secondary winding would be positive and the other end would be negative. In other words, at any one instant of time, the output of the transformer can be compared to the output of a battery. This is referred to as *phasing.*

Various forms of the phasing problem are illustrated in Figures 2-2, 2-3, 2-4 and 2-5. The polarities shown are instantaneous.

Figure 2-2 shows two interconnected transformers. The primary input leads are crossed, and the secondary leads are connected in parallel. The net result is no voltage available in the secondary or control circuit.

In Figure 2-3, the primary leads of the same transformers are now connected in parallel and the secondary leads are crossed. This causes currents very nearly that of short circuit currents across the secondary terminals of each transformer and the ultimate burnout of one or both transformers in 6 to 8 minutes. No current will flow to the control system wiring.

Figure 2-4 shows the primaries leading to two transformers connected in parallel. The secondaries of the transformers are in series with the connected lead, say one or more relays. (*Note: this is not the same situation as in Figure 2-3.*) In this arrangement, the voltage across the load is twice that of each transformer alone, and there is no increase in VA.

In Figure 2-5, with primaries unchanged, the transformer secondaries are connected in parallel with other, and are in series with the load. Now the secondary voltage is the same as either transformer alone, but the VA capacity is doubled.

Figure 2-6 shows a practical example of the phasing problem illustrated in Figure 2-4. Figure 26 is a diagram representing a *single* thermostat controlling a *heating* relay and a *cooling* relay each with its own transformer. Although the voltage that could be measured across either transformer secondary is 24 volts, a voltage of 48 volts would exist between one thermostat lead from the heating relay and one from the cooling relay. Unless the maximum current that can be supplied by the transformers is definitely limited to 1.6 amperes, this condition violates the NEC voltage-current limits for Class 2 remote-control systems.

Testing on the Job

A voltmeter can be used to detect the presence of abnormally high open-circuit voltage. Leave unconnected one of the two thermostat terminals of one relay-transformer combination, or connect the thermostat wiring at the relays but not at the thermostat; then take a voltage reading (1) between the unconnected wire and terminal at the relay, or (2) between one wire and each of the others in turn, at the thermostat location. A voltage reading noticeably higher than 30 volts indicates wrong phasing. Reverse the two thermostat wiring connections at the two wire control relay or reverse the terminal connections at one of the transformer secondaries, as shown, or at the primaries to correct the problem.

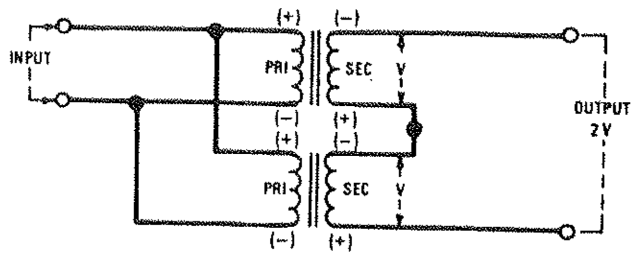


Figure 2-4: Primary leads of two interconnected transformers are in parallel; secondary leads are wired in series. Result: twice the secondary voltage of one transformer.

For many years it was common practice to phase transformers in the field - particularly when adding cooling to an existing heating system which was already fitted with a transformer made too small with the addition of cooling.

Changes to the National Electrical Code now prohibit paralleling or otherwise interconnecting Class 2 transformers.

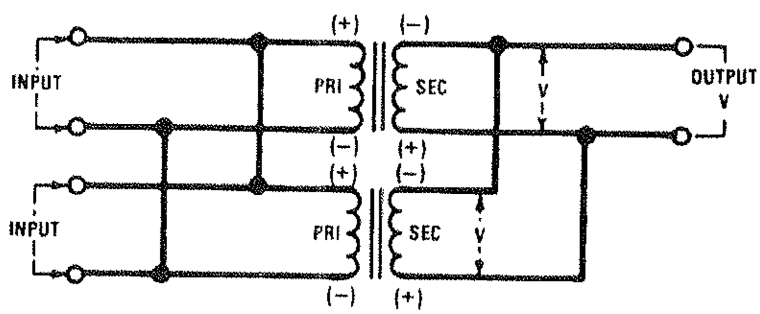


Figure 2-5: Primary and secondary leads of two interconnected transformers are connected in parallel. Result: voltage is the same as with one transformer, but VA capacity is doubled.

There are three basic approaches to avoid interconnecting transformer secondaries and thus comply with modem safety requirements.

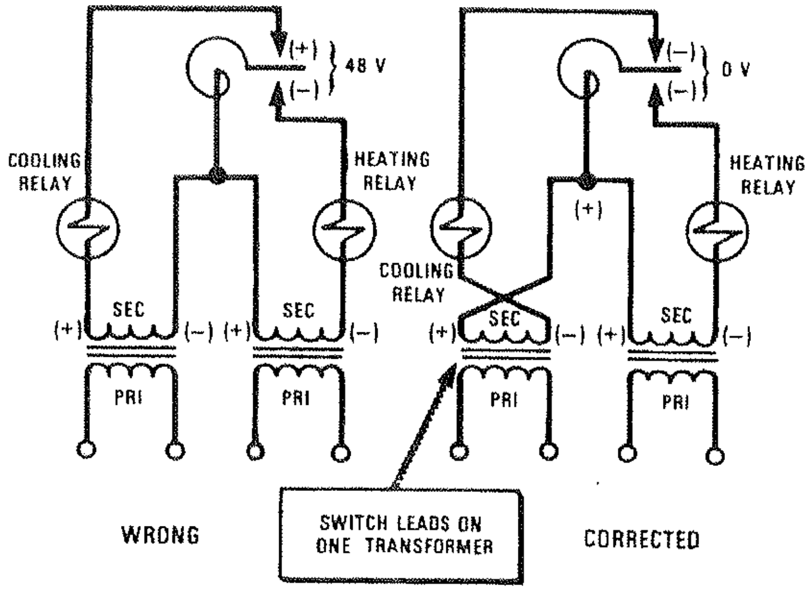


Figure 2-6: wiring above violates NEC code for class 2 transformers. Leads must be switched (right side of picture) to reduce "high" voltage across thermostat junctions.

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 A transformer may have greater capacity than the total connected load.

2. T F A transformer may have less capacity than the total connected load.

3. T F Power type transformers are rated higher in capacity than NEIC Class 2 transformers.

4. T F Motor starter contacts may chatter and cause damage if less than initial inrush power is provided to contactor.

5. T F There is no advantage to using a contactor that can work (close) below its rated voltage.

6. T F A contactor with thermal overload protection is called a motor starter.

7. T F Because of the wide variation in the design of contactors mid motor starters, it is impossible to state a general rule regarding specific electrical characteristics.

8. T F Load requirements of the secondary control circuit determine the size of transformer to be selected.

9. T F Line voltage controls give better temperature control than low voltage devices.

10. T F Low voltage comes from the secondary coil.

11. T F The size of the coil wire and amount of iron in the core both affect the ability of the transformer to handle electrical current.

12. T F Changes in the National Electric Code now permit paralleling of Class 2 type transformers to increase the capacity of the secondary circuit.

13. T F There is no need to determine the voltage that will be applied to the primary of the transformer before selecting a transformer.

14. T F The low voltage control transformer is available in only one size.

15. T F The term "size" refers to the outside dimensions of the transformer.

16. T F If two transformers of equal size are correctly wired in parallel, the voltage is the same but the current in the secondary circuit is doubled.

In the following multiple choice questions, choose the phrase that most correctly completes the statement and circle the corresponding letter in front of the phrase.

17. If a 240 volt transformer is connected to a 120-volt supply the secondary voltage will be:

a. 3 volts. b. 6 volts.
c. 12 volts. d. 24 volts.

18. Capacity of the transformer refers to:

a. number of amperes. b. physical size of the transformer.
c. both of the above. d. none of the above.

19. The product of volts times amperes is expressed as:

a. AV. b. VA.
c. A. d. V.

20. Pure resistance loads have a power factor of:

a. 25%. b. 50%.
c. 75%. d. 100%.

21. The formula for common inductive loads of solenoid valves and relays is W =:

a. V x A x 1.3. b. X x A x 1.0.
c. V x A x 0.5. d. V x T x 1.3.

22. A contactor is a relay with contact rating of _________ amperes or more.

a. 20 b. 25
c. 60 d. 100

23. Contactors are often designed for proper pull-in at or below ____ % of the rated voltage.

a. 25
b. 50
c. 75
d. 100

24. The primary voltage must match:

a. line voltage.
b. low voltage.
c. a magnetic field.
d. the secondary coil.

25. The capacity rating of a transformer increases as the wire diameter increases and the number of turns:

a. increases.
b. decreases.
c. remains constant.
d. none of the above.

26. The maximum number of transformers that can be used in parallel as long as polarity and code requirements are maintained is:

a. 2.
b. 3.
c. 7.
d. none.

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

27. In order for contractors and motor starters to operate properly, the transformer capacity is determined by the value of the initial ______________ volt amperes of the contactor.

28. The transformer capacity for solenoid valves and relays must be equal to or greater than _____________ times the total wattages of the connected load.

29. A relay is a device with contact ratings of less than _____________ amperes.

30. Capacity rating of transformers is expressed in __________________.

31. The formula for wattage is ______________________.

32. Once the required primary voltage is determined, one must next determine the ________________ of the secondary circuit.

33. Interconnecting two or more transformers with regard to the polarity of each transformer is referred to as the correct __________________ of transformers.

34. A/an ______________ can be used to detect excessive open circuit ___________ when a single thermostat is wired to operate two relays each with its own 24 volt ____________________.

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

The full concept of a control circuit is introduced in Lesson 3. The various types of control diagrams or field and factory wiring schematics are explained. The use of symbols and abbreviations and finally the basic rules to follow in circuit analysis are presented.

After studying this lesson, you should:

1. Know the basic elements in a circuit.
2. Know the characteristics of series, parallel, and compound circuits.
3. Know how ammeters and voltmeters are connected.
4. List the various types of control diagrams and know the advantages of each method.
5. Explain how to trace a control circuit using the four "Rules of the Road."
6. Recognize several common industry circuit symbols and component abbreviations.
7. Be able to isolate simple circuit elements for analysis.

Now read Lesson 3 which begins on the next page.

Lesson 3: The Basic Control Circuit

A basic electrical control system consists of a circuit with a power source, at least *one switch* and *one load* connected together by electrical *wiring*. A *closed* or completed circuit is a system of wires, loads, and switches that *converts* electrical energy into another useful form of energy such as light, heat, rotary motion (motor) or linear motion (solenoid). A completed circuit is one in which the flow of electrical energy can be followed or "traced" from the power source, through a switch, through a load, and back to the power source. (Figure 3-1).

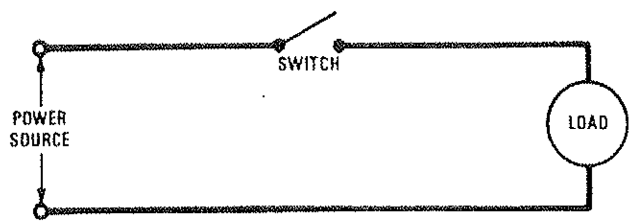


Figure 3-1: A basic electrical circuit.

The switches in a control system may be either manually operated or automatic. The loads in the circuit may be valves, relays, lights, motors, or other electrical devices. In low voltage systems the power source is a transformer. The loads in the system respond to the presence or absence of electric current; therefore, the operation and location of the switches in the circuit determine the load reactions (Figure 3-2).

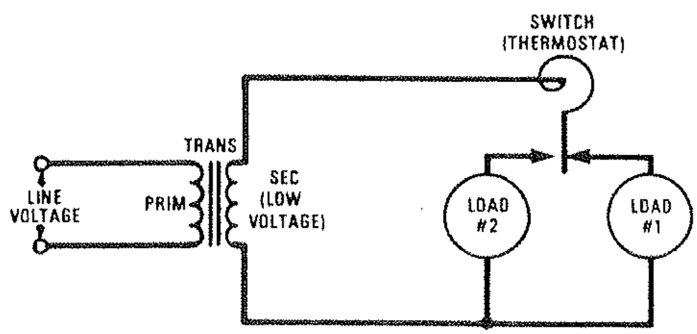


Figure 3-2: A basic low voltage circuit.

Series Circuits

When a power source, switches and loads are connected together to provide only one path for the current to flow, the wiring loop is called a series circuit. (Figure 3-3.) When the thermostat in Figure 3-3) closes, electric current can flow from the power source, through the thermostat, the coil of the solenoid valve, the closed limit control contacts, and back to the power source. The closed circuit converts electrical energy into linear motion to open or close the valve.

In working with series circuits, remember that:

1. A break in the continuity of the circuit will stop the flow of current at all points of the circuit.

2. The current flow in all parts of the circuit is the same.

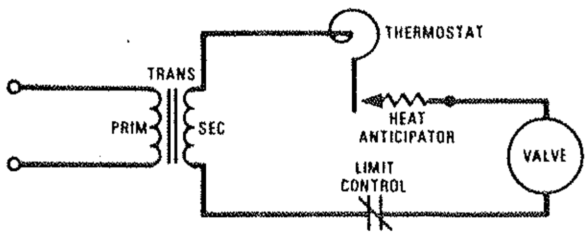


Figure 3-3: Series arrangement of a limit switch, valve and thermostat.

3. Ammeters are always connected in series with the loads when taking meter readings. (Figure 3-4).

4. The voltage across each load in the circuit will vary; however, the sum of the individual voltage drops will always equal the supply or applied voltage.

5. Voltmeters are always connected across the load --- or in parallel with the load - when taking meter readings (Figure 3-5).

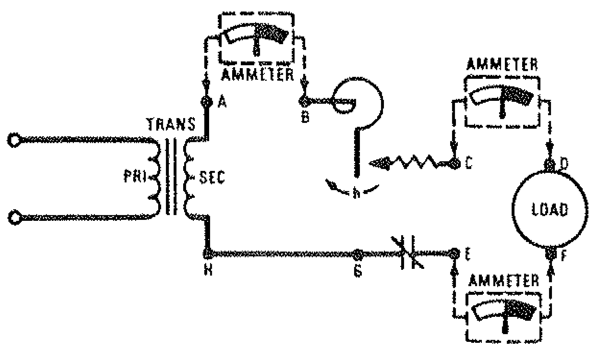


Figure 3-4: Ammeters are connected in series with the circuit to measure current.

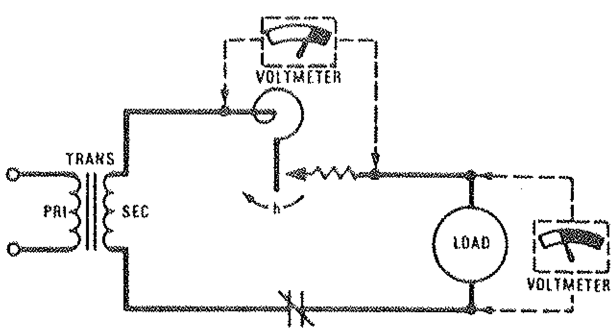


Figure 3-5: Voltmeters are connected in parallel with a load to measure voltage drop.

Parallel Circuits

When a power source, switches and loads are connected together to provide two or more paths for current flow, the wiring loop is called a parallel circuit (Figure 3-6).

If the high limit switch and the thermostat in Figure 3-6 are closed, current will flow from the power source through both legs (A to B and C to D). However, either leg will function independently. The operative valve is affected only by the switching action of the thermostat, and the manual reset valve is controlled by the action of the high limit switch.

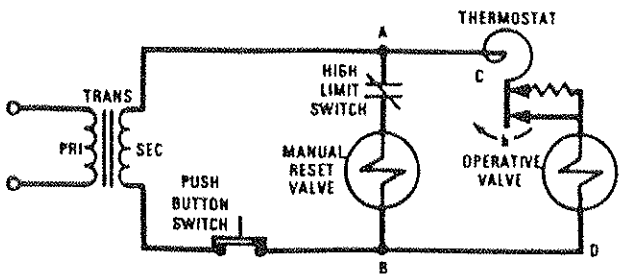


Figure 3-6: Parallel arrangement between a high limit switch and thermostat - and the valves they serve

In working with parallel circuits, remember that:

1. The total current flow is the sum of the currents flowing in the individual legs. In Figure 3-7, the current in leg A to B plus the current in leg C to D is equal to the current draw for the total circuit which is measured between points E and A.

2. The voltage across each piece of equipment in a parallel circuit will be equal to the supply voltage which is measured between points E and F in Figure 3-7.

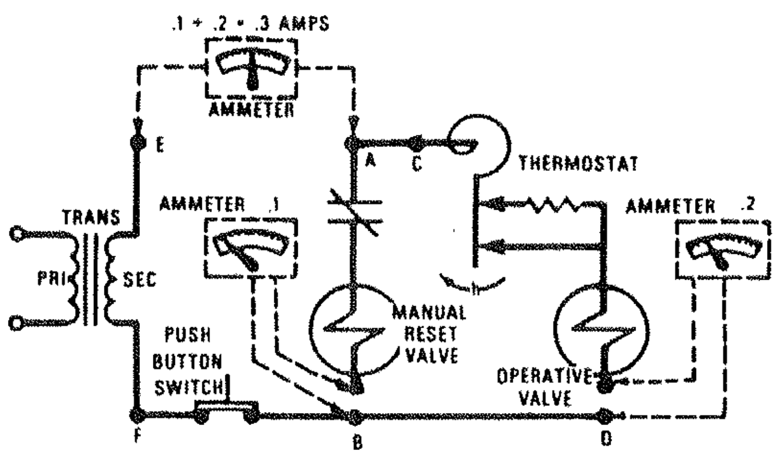


Figure 3-7: Total current in a parallel circuit equals the sum of the current flow in each leg.

Compound Circuits

Most heating and air conditioning control circuits are compound circuits - a combination of both series and parallel circuits.

Circuit Diagrams

Control circuits may be illustrated or diagramed using one of **three** methods - a *block* diagram, a *schematic* diagram, or a pictorial diagram. Figure 3-8 shows how a low voltage thermostat controlling an air conditioning compressor might appear using each method.

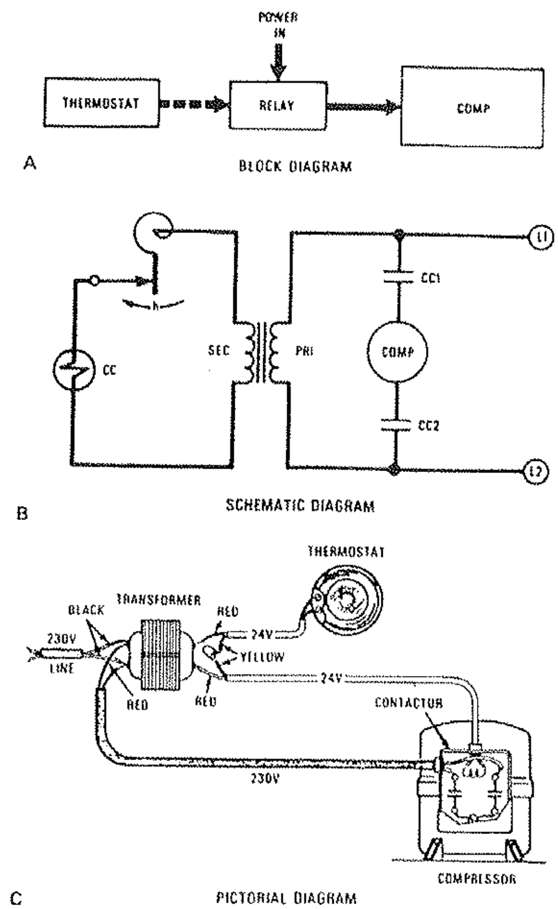
The *block* diagram (A) is purposely simple, showing essential concepts and sequences only. Block diagrams are often used as an introductory step to explaining complex control systems such as electronic circuit boards where the technician might immediately become bogged down with a myriad of details before understanding basic organizational concepts and priorities.

The *schematic diagram* (B) shows every wiring detail and component using a code - a kind of circuit shorthand. This is also known as the *ladder* or *elementary diagram*.

The pictorial or connection diagram (C) attempts to show the control circuit as it really is.

Both of these latter diagrammatic methods have advantages and disadvantages. Each serves a particular need. Sometimes pictorializing is impossible because of the numerous crisscrossings of wires made necessary, and the resultant spaghetti bowl effect thus pictured. On the other hand, even simple schematic diagrams often frighten less experienced men, and schematics supplied with new equipment are often redrawn in the shop as pictorial diagrams for field use – hence are frequently called field wiring diagrams.

Schematics are considered more "scientific" and are used more often by manufacturers and control specialists. In fact, they are often referred to as factory diagrams.



Schematics are used throughout this course.

Figure 3-8: Control circuit can be illustrated by one of the three methods shown --- block diagram, schematic, or pictorial.

WHAT FOLLOWS IS VERY IMPORTANT

Interpreting schematic circuit diagrams is simplified if the following "Rules of the Road" are applied:

1. Review the diagram to be certain you understand the meaning of the symbols used.

2. Start your trace at the *uninterrupted* power source. A complete or closed circuit consists of an unbroken trace from the uninterrupted power source, through the wiring, switches and loads and back to the power source. A break in the wiring, an open switch, or an open relay contact will break the continuity of the circuit and stop the flow of electrical energy at that point.

3. All circuit components are shown in the "non powered" condition unless stated otherwise.

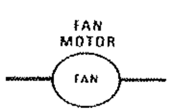
4. If two traces are possible (parallel circuits), the current will divide and follow both paths. The amount of current flowing in a circuit will depend on the resistance in the circuit the greater the resistance the less current flow in that section of the circuit.

Circuit Analysis

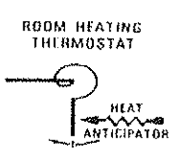
Figure 3-9 is a wiring diagram for a typical gas fired warm air heating system. The symbols used in the diagram are:

The fan control contacts are normally open, the switch will close on a temperature rise. (Same symbol is also used for other component contacts, e.g. compressor contacts.)

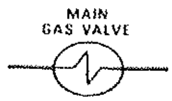
The limit control contacts are normally closed, the switch will open on a temperature rise. (Same symbol is also used for other normally closed circuits.)



The fan motor drives the blower to distribute the heated air through the system. (Same symbol is also used to represent other components, only letter F is replaced with suitable identification.)

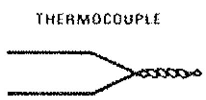


The room heating thermostat (equipped with a heat anticipator) will close on a temperature fall and open on a temperature rise.



The main gas valve is normally closed. When the thermostat calls for heat, the valve will be energized, permitting gas to flow to the main burner. (Same symbol is also used to identify other solenoids, relay coils, etc.)

The manual reset pilot safety valve is energized by power supplied from the thermocouple in the pilot burner flame. (How electrical voltage is generated by the thermocouple will be discussed in another lesson.)



The voltage generated by the thermocouple 1) holds the valve seat in the open position so that gas will flow to the pilot burner, and 2) holds the contacts closed to complete the secondary circuit to the transformer. The thermocouple senses the presence of the pilot flame and energizes the pilot safety, valve as long as a safe pilot flame is present.

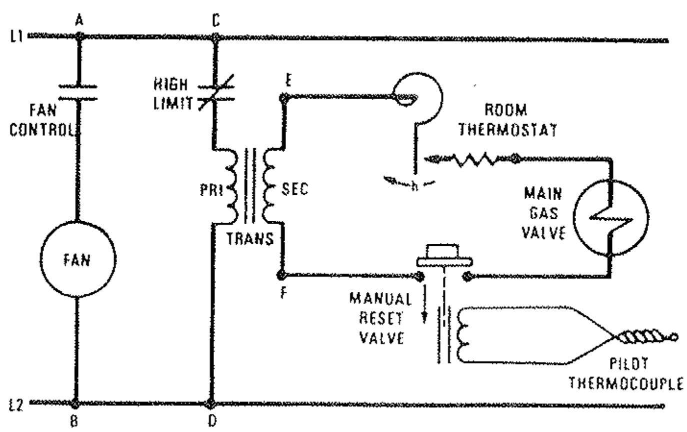


Figure 3-9: Typical control schematic for a gas-fired warm air heating system.

Review the diagram to be sure the meaning of all the symbols used is clearly understood. Start your trace of the circuits diagramed in Figure 3-9 at the uninterrupted power source.

The fan function is isolated in Figure 3-9A, which is leg A to B in Figure 3-9. The *normally open* fan control switch in this leg breaks the continuity of this circuit; therefore, the fan motor will not run. However, the fan switch will close on a temperature rise in circulating furnace air, completing the circuit from Ll through the fan motor and back to L2. Therefore, the component operations in this circuit can be summarized as follows:

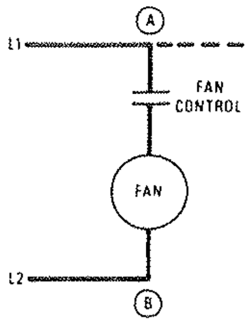


Figure 3-9A: Fan control segment of basic heating circuit originally shown in Figure 9.

1. The fan control contacts will close on a temperature rise. At a preset air temperature, the furnace fan motor will operate.

2. Fan or blower operation will not be affected by any component in the control circuit other than the fan control switch.

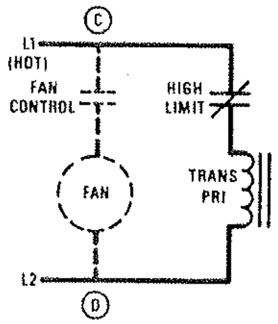


Figure 3-9B: High limit leg of basic heating circuit shown in its entirety in Figure 9.

The *high* limit function in the control circuit is isolated in Figure 3-9B which is leg C to D in Figure 3-9. In this circuit, electrical energy flows from L1 through the normally closed high limit switch and the primary coil of the transformer and back to the power source (L2). Since the continuity of the circuit is not interrupted, component operations in this circuit can be summarized as follows:

1. The primary coil of the transformer will be energized unless a high air temperature condition in the furnace opens the high limit switch.

2. When the high limit contacts open, electrical current will not reach the primary coil of the transformer and the power supply for the secondary circuit will be de-energized.

3. When a high temperature condition occurs and the high limit switch opens, electrical energy will continue to flow through the fan circuit and the blower will continue to operate until the supply air temperature decreases enough to open the fan control contacts.

The *secondary* control circuit is isolated in Figure 3-9C, which is leg E to F in Figure 3-9. The power source for the secondary circuit is the secondary coil of the transformer. Tracing this secondary circuit indicates that:

1. When the thermostat closes, the secondary circuit is completed from the power source, through the thermostat, the main gas valve, and the manual reset contacts and back to the power source.

2. When the thermostat calls for heat, the main gas valve will open, permitting gas to flow to the main burner which is ignited by the pilot flame.

3. The pilot thermocouple in the pilot flame generates voltage to keep the pilot valve seat open and its contacts closed. If a safe pilot flame is not present, the contacts will open and break the continuity of the secondary circuit.

4. When the main burner is ignited, the furnace air temperature will rise and the fan switch will close, permitting the blower to operate.

5. If a high air temperature condition occurs, the high limit switch will open and the transformer will be de-energized. The main gas valve will close, since there is no power in the secondary circuit, shutting off the flow of gas to the main burner. However, the blower will continue to operate until the fan control contacts open.

6. As long as a safe pilot flame is present, the pilot valve seat will remain open and the pilot flame will provide ignition whenever the main gas valve opens.

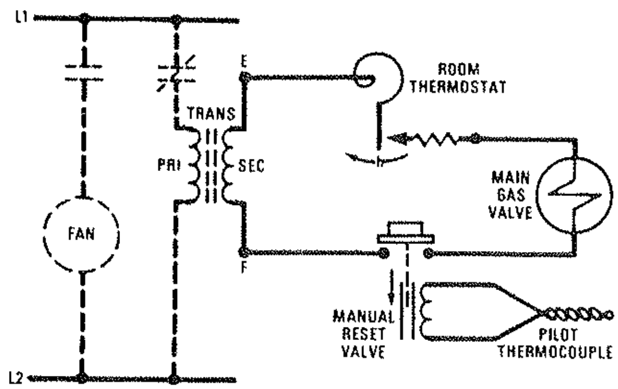


Figure 3-9C: Low voltage segment of basic heating control circuit shown in Figure 9.

Figure 3-10 is a control diagram for a heating cooling control circuit. While the diagram is complex, the "Rules of the Road" can still be applied to determine circuit functions. The heating portion is similar, to the control circuit shown before in Figure 3-9 except the limit control has been moved. The operation of the cooling portion of the control circuits can be summarized as follows.

1. When the manual system switch is in the "cool" position, the continuity of the secondary heating control circuit is broken and the thermostat will control the cooling system components only.

2. The thermostat contacts will close on a temperature rise, completing the low voltage secondary control circuit from one side of the transformer to the other. The cooling contactor (CC) relay coil will be energized and the cooling anticipator (CA) will be de-energized, since electrical current will follow the path of least resistance through the thermostat contacts. (The operation of cooling anticipators will be discussed in a later lesson.)

3. Whenever the cooling contactor coil is energized, its three contacts (CCI, CC2, and CC3) will close and the fan and the compressor will operate.

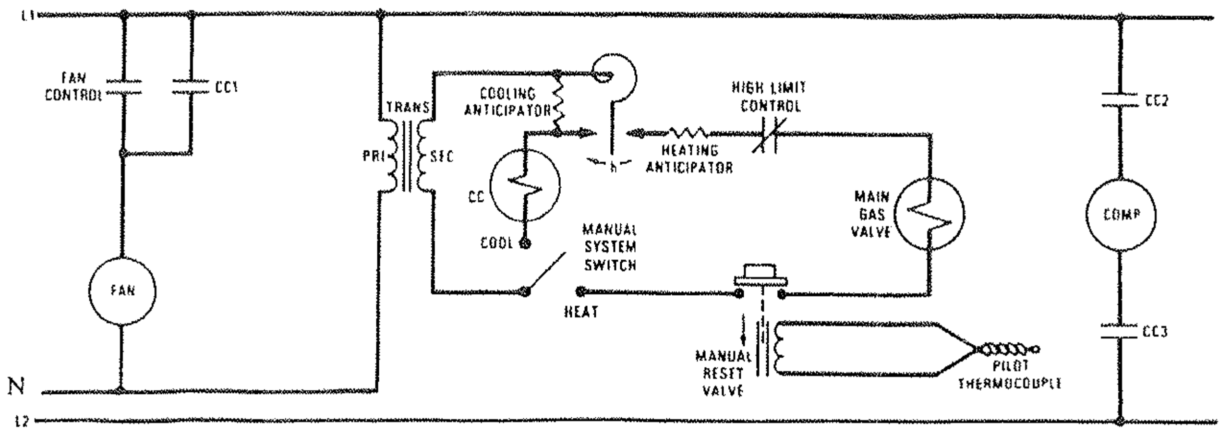


Figure 3-10: Typical control schematic for a gas-fired cooling added.

4. The thermostat contacts will open on a fall in temperature and the fan and the compressor will stop. When the thermostat contacts open, the cooling anticipator (CA) will be energized, since the open contacts offer more resistance to the flow of current than the resistance in the anticipator.

Figures 3-9 and 3-10 are extremely simplified control diagrams. A full and complete control system diagram would include a number of components which were not covered in this lesson. However, regardless of the complexity of the systems, a circuit diagram can be studied and circuit functions can be determined by following the "Rules of the Road" contained in this lesson.

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 Schematic wiring diagrams are also known as block diagrams.

2. T F Electrical switches may be controlled (opened and closed) automatically by a thermostat.

3. T F A break in continuity in a series circuit will not stop the flow of current to all loads.

4. T F A parallel circuit is one in which the power source is connected to two or more conducting paths containing loads and switches.

5. T F Tracing of a circuit must start at the uninterrupted power source.

6. T F The main gas valve is normally closed but, upon energizing, permits flow of gas to the main burner.

7. T F Basic principles of tracing circuits are the same for all circuits no matter how complex.

8. T F Factory schematics show controls according to function, not how they look.

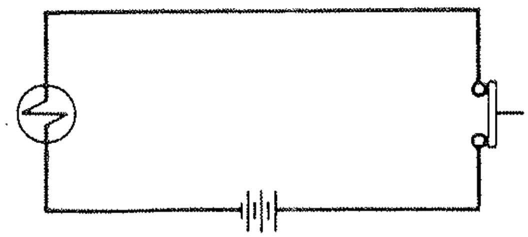
9. T F The acronym (abbreviation) CC refers to Cooling Contactor relay.

10. T F Most heating and cooling control circuits are series circuits.

11. T F Pictorial type control diagrams are more scientific since they show controls exactly as they appear.

12. T F Circuit components are usually shown in the energized or powered condition.

In the following multiple choice questions, choose the phrase that most correctly completes the statement and circle the corresponding letter in front of the phrase.



13. The figure show above illustrates a:

a. completed circuit. b. broken circuit.
c. short circuit. d. solenoid.

14. In a low voltage circuit the immediate power source is:

a. thermostat. b. relay coil.
c. transformer. d. battery.

15. A solenoid converts electric energy into:

a. heat. b. power.
c. pressure. d. linear motion.

16. Furnace fan control contacts open when circulating air:

a. cools down. b. heats up.
c. stops flowing. d. none of the above.

17. Pilot flame heats a thermocouple that energizes a:

a. pilot safety shutdown valve. b. thermostat switch.
c. cooling contactor. d. heat anticipator.

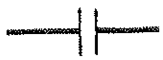
18. When a high limit switch opens, electrical energy still flows to the:

a. gas valve. b. cooling relay.
c. fan circuit. d. thermostat.

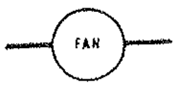
For the completion-type questions, fill in the blanks with the word (or words) that most accurately completes the thought.

19. A relay, indicator lamp, valve, and damper motor are examples of ____________________ that might be found in a control system.

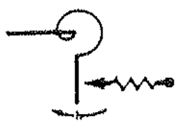
20. Identify the proper control for each of the following symbols.


= normally ______________ contacts


= normally ______________ contacts



= fan _____________


= room heating _______________ with heat __________________

21. Ammeters are always connected in ____________ with a load when taking meter readings.

22. A/an ___________ ___________, and a/an ______________ and one ______________ connected by wires constitute a control circuit.

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.

Unit 2 Preview: Thermostats and Humidistats

Now that you have reviewed basic electric theory, studied about the transformer, and considered the essentials of, at least, a simple control circuit, you will begin to study individual control components in some detail.

To start, this unit of study focuses on the room *thermostat* and *humidistat.* Lessons 4, 5, 6, and 7 involve specific areas of study relative to the thermostat and the last lesson in this unit, Lesson 8, takes up the subject of the humidistat.

Without the extremely sensitive room thermostat, automatic heating and cooling would, of course, be impossible. The thermostat is a control that, thermally speaking, must react like a human - be as sensitive to heat and cold. The thermostat is very often all that a building occupant ever notices or handles relative to a heating and air conditioning system. And perhaps, rightly so: the thermostat, more than any other single component that makes up a complete heating-cooling system - and this includes the furnace, boiler, cooling unit and registers - has the most influence on overall system performance. A cheap thermostat can make even the best heating and cooling system perform very poorly.

The thermostat senses changes in room air temperature and electrically turns equipment on or off to offset the change. The objective is to maintain a uniform or steady temperature under varying load conditions.

The humidistat is much like the thermostat in terms of its basic function. However, rather than sensing changes in temperature, a humidistat senses changes in humidity or moisture levels in room air, and turns equipment on and off accordingly. As you are already aware human comfort requires the control of both temperature and humidity (plus a third variable - air motion).

The learning goals that you should strive for are listed separately for each of the five lessons comprising Unit 2. Carefully review these learning goals so that you may have some insight as to what you will be studying and learning in each lesson. Your success at this stage of learning will have a definite impact upon your future success and progress in subsequent lessons.

Lesson 4 Overview

The first lesson in Unit 2 introduces you to the ordinary low voltage thermostat. It should help familiarize you with the basic elements that comprise a thermostat: what they are called and how they work together to provide automatic control in response to changes in room air temperature.

After studying this lesson, you should:

1. List the important parts of a thermostat.
2. Describe how a thermostatic bimetal sensing element works.
3. Recognize the basic forms bimetals can take.
4. Explain the function of electrical contacts and how they operate.
5. Explain the use of control switches that are built into room thermostats and also the means used to adjust thermostats.

Now read Lesson 4 which begins on the next page.

Lesson 4: The Low Voltage Thermostat

Thermostats are probably the most commonly used automatic control instruments in the world today. Room thermostats, which are used as the principal comfort control instrument in residential heating and air conditioning systems, measure changes in room air temperature and turn the heating or cooling equipment "on" or "off" so that the temperature within the building is maintained at a comfortable level. Room thermostats usually contain the following components:

1. A temperature-sensing element or bimetal.
2. Electrical contacts used to convert temperature changes sensed by the bimetals into electrical signals.
3. A means of manually adjusting the temperature control or set point.
4. Switches to control the heating and/or cooling system such as the "On-Off" switch, the "Heat-Cool" changeover switch, and the "Fan" or blower control switch.
5. Heat and/or cold anticipators (covered in the next session).
6. A base and a protective cover which usually contains a thermometer.

Thermostatic Bimetals

The temperature sensing element is the heart of the thermostat. There are several types of temperature sensing elements; however, the thermostatic bimetal is used in almost all room thermostats. The thermostatic bimetal is composed of two or more metallic alloys which are welded together. Since the metallic alloys used in the bimetal have different coefficients of expansion (when exposed to heat, one metal will expand more rapidly than the other), the thermostatic bimetal will change curvature when it "feels" a change in temperature.

The thermostatic bimetal used in room thermostats is generally constructed in one of three basic forms - the cantilever, the U-shaped, or the spiral (Figure 1). The U-shaped and the spiral bimetals provide greater movement and necessary force into a smaller space; therefore, they are in more common use.

The room thermostat must be sensitive to temperature changes in the room air - as sensitive as the human body. Therefore, the bimetal selected for the thermostat must have enough surface area to sense slight changes in room air temperature.

Electrical Contacts

Electrical contacts in the thermostat use the mechanical movement of the bimetal to actuate an electrical circuit to control the heating and/or cooling system. If a thermostat contains one set of contacts - a moving contact attached to the free end of the bimetal and a fixed contact attached to the base or cover of the thermostat - it is either a cooling or a heating thermostat, depending on whether the contact is "made" (closed) on a rise or a drop in room temperature.

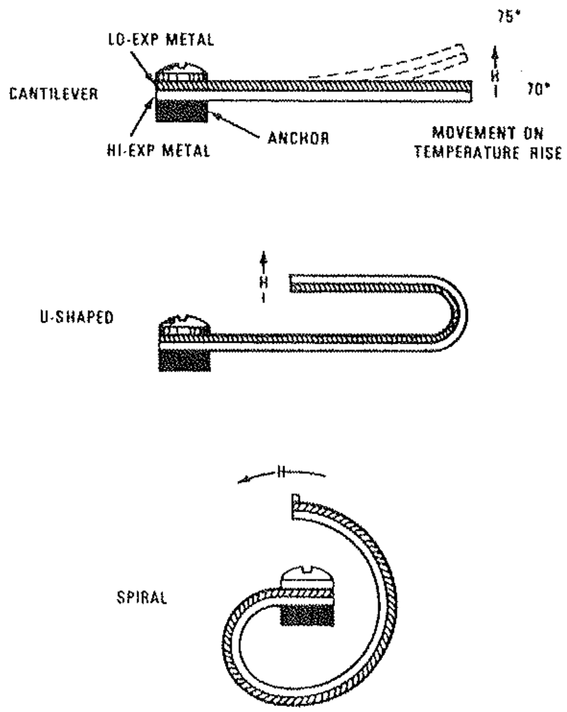


Figure 4-1: SHAPES of common thermostatic bimetals.

In Figure 4-2 A, the movement of the cantilever bimetal, when the room temperature increases, will "make" the connection between the moving and the fixed contacts, thereby closing the control circuit. The "thermostat" would be connected to a cooling system, since the circuit is completed on a rise in room temperature. If the moving contacts were reversed, the moving contact placed on the opposite (bottom) side of the cantilever bimetal, and the fixed contact placed below the bimetal, the electrical circuit would be completed on a drop in room temperature. The "thermostat" would then be connected to a heating system since the circuit would close on a decrease in room temperature. Thermostats may use permanent magnets adjacent to the fixed contact to provide "sharp" make and break action.

Many thermostats use mercury switches (Figure 4-2B) or glass enclosed contacts (Figure 4-2C) to complete the control circuits because these devices protect the electrical contacts from dirt, dust, moisture, and corrosive substances. Using glass-enclosed contacts eliminates the critical "leveling" requirements of the mercury switch and reduces the thermostat's susceptibility to vibration.

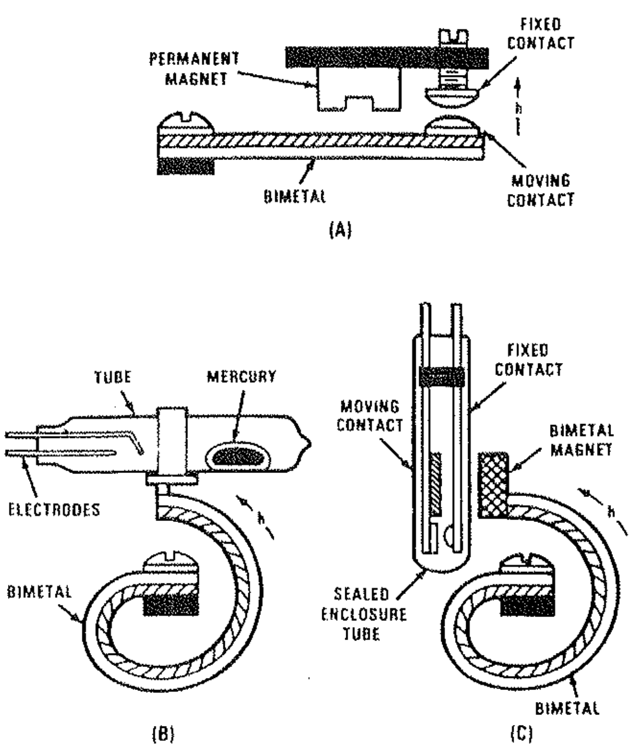


Figure 4-2: Three popular types of thermostatic contacts --- open contacts (A), mercury switch (B), and glass enclosed contact (C). See photos for actual examples.

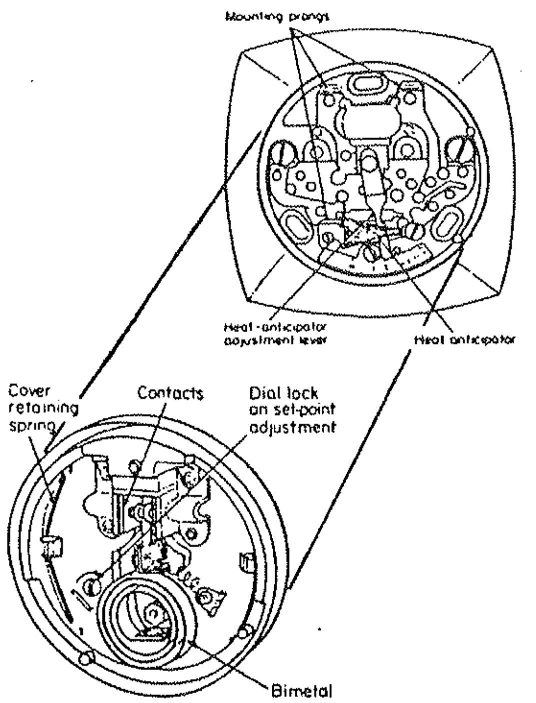
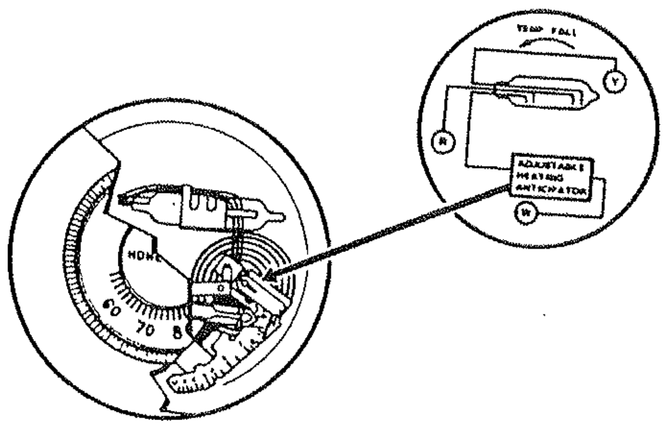


Figure 4-2: Type A, Open contacts thermostat.

Figure 4-2: Type B, Mercury switch (Honeywell Inc.).



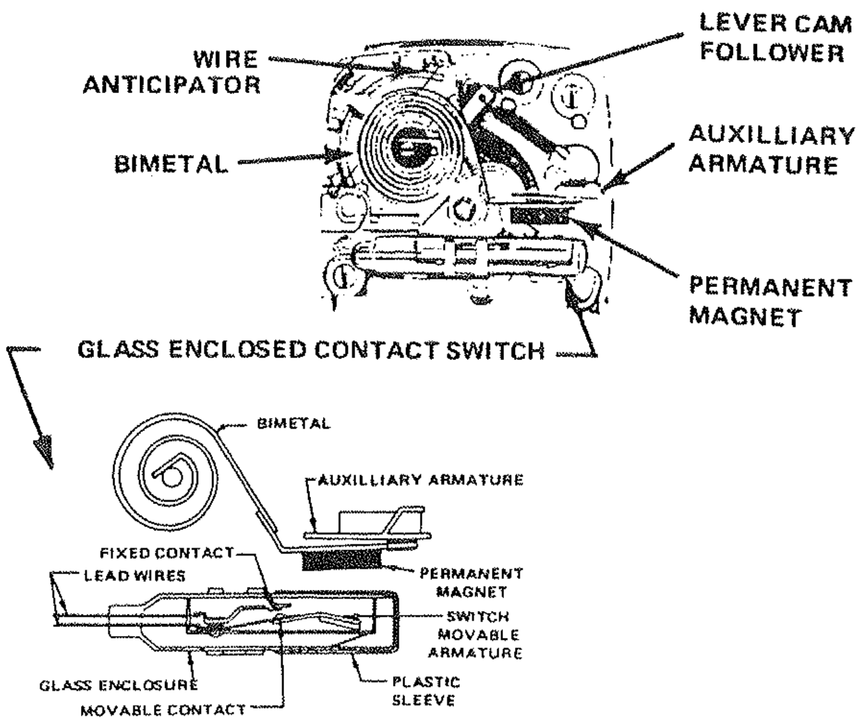


Figure 4-2: Type C. Glass enclosed contacts thermostat.

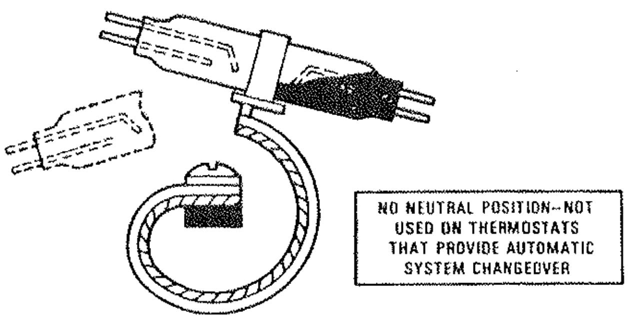


Figure 4-3: **Single pole, double throw mercury tube switch used in some combination heating-cooling thermostats. Mercury is considered a toxic material and through the Thermostat Recycling Corporation (TRC), used mercury thermostats are collected by wholesalers for proper disposal. Visit www.nema.org/trc**

A *combination* thermostat will make a circuit on either a rise or a drop in temperature. Combination thermostats will have two sets of contacts: two single pole, single throw mercury tubes or one single pole, double throw mercury tube to provide control of both the heating and the cooling system (Figure 4-3).

Adjusting Devices

Room thermostats are designed to control room temperatures over a fairly wide range - usually about 50° F to 90° F. Therefore, the room thermostat must have an adjusting mechanism so that the homeowner can set the thermostat to maintain a desired temperature - normal settings are between 72° F and 75° F. The dial setting or "set" temperature of heating thermostats is the temperature at which the thermostat will *make* its control circuit to bring "on" the heating system. The thermostat will normally break the heating circuit when the room air temperature rises 3/4 – IF above the "set" temperature. Therefore, the "set" temperature of the heating thermostat should be the *minimum* temperature of the conditioned space. However, the dial setting or "set" temperature of the cooling thermostat is the temperature at which the thermostat *will break* the control circuit. The cooling thermostat will normally make the cooling circuit when the room air temperature is above the "set" temperature of the cooling thermostat; therefore, the "set" temperature of the cooling thermostat should, again, be the minimum room temperature.

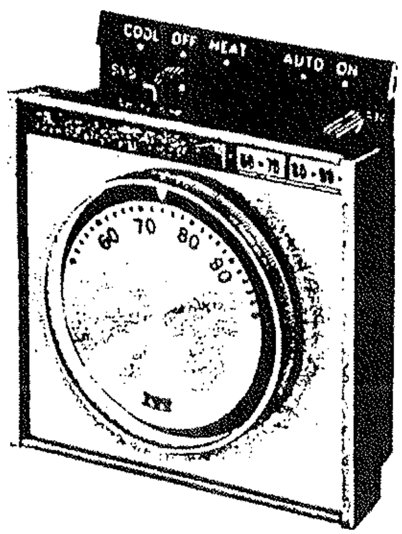


Figure 4-4: Combination thermostat with system and fan switches (ITT General Controls).

Room thermostats are precision calibrated at the factory so that they actually control the room temperature at the point selected on the "dial" face. If recalibration in the field is necessary, be sure to follow the manufacturer's instructions.

Control Switches

A simple gravity heating system could be "controlled" by the homeowner by simply adjusting the temperature control point. During the summer months, homeowners usually turn their gravity heating systems "off" by setting the control point at the lowest dial reading. However, modern forced air heating and/or cooling systems, especially those using a combination thermostat, provide the homeowner with a number of system options which are controlled by switches located on the thermostat.

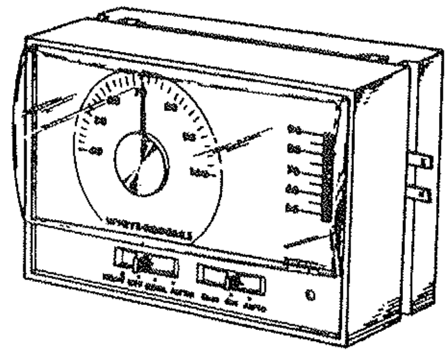


Figure 4-5: Thermostat with several deluxe features separate temperature dials for heating and cooling, plus system and fan switches (White Rodgers Controls).

Figure 4-4 is a typical combination thermostat. While the temperature control point is established by rotating the dial to the desired room temperature, the homeowner selects the system operation desired by manually setting the "System" (SYS) switch to COOL, OFF, or HEAT. The blower operation is controlled by the FAN switch which is a simple two-position switch. When the switch is placed in the AUTO position, the blower operation will be controlled by the thermostat and the blower will operate during the system "on" cycles. If the FAN switch is moved to the "ON" position the blower will operate continuously.

Figure 4-5, a somewhat more sophisticated thermostat, contains two dials for establishing temperature control points (one for heating and one for cooling), a FAN switch and a SYSTEM switch that may be set to AUTO for automatic system changeover from heating to cooling. The HEAT, OFF and COOL position, on the SYSTEM switch provides a manual changeover capability.

Thermostat Enclosure

The base and the protective cover, which usually contains a thermometer, are basic components of the thermostat. The size and shape of these components are determined by the size of the internal components and the tastes of the designer. The thermostat must also be designed to provide for free passage of room air around the bimetal.

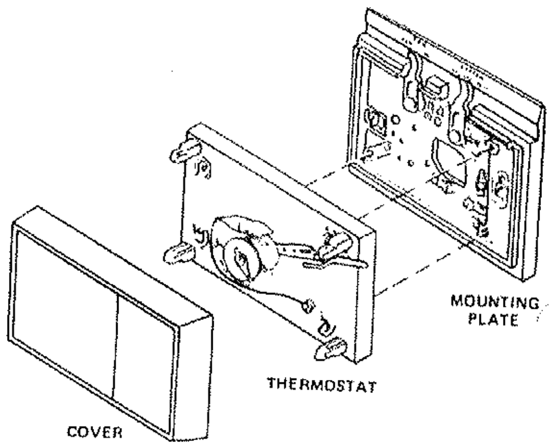
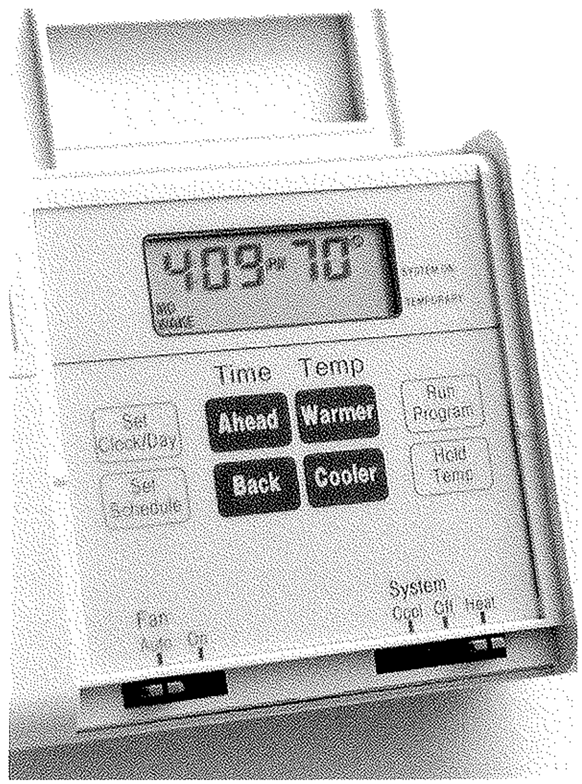


Figure 4-5: Thermostats often involve three major areas: 1) temperature, mode of operation and time readout, 2) touch pad keys to adjust device and 3) sub-base with system and fan switches (White Rodgers).



Newer type electronic thermostats can be programmable or nonprogrammable. Theses thermostats often use thermistors or other integrated circuit sensors to sense temperature changes. Thermistors operation is based on the fact that the electrical resistance of a ceramic semiconductor changes as its temperature changes. Generally, these thermostats have an LED display for enhanced readability.

Programmable electronic thermostats can be programmed to set back the temperature at predetermined times and days. This allows for additional energy savings by automatically reducing the demand for heating or cooling, for example at night or during the day when no one may be home. These can also provide additional information such as filter change reminder, auxiliary heat, static pressure measurement and system run time data.
Many of these thermostats provide for adjusting burner on-time and fan operation.

Self-Check, Lesson 4 Quiz

You should have read all the material in Lesson 4 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 Functional requirements of a thermostat's components dictate the size and shape of the base, cover, and thermometer.

2. T F A "system" switch may provide for either manual or automatic changeover to heating or cooling.

3. T F The size of the surface area of the bimetal is of little importance.

4. T F The "set" temperature should be the desired minimum room temperature.

5. T F If the moving contact reaches the fixed contact when the temperature increases by a predetermined amount, the circuit would be connected to a cooling source.

6. T F A permanent magnet may be located adjacent to the fixed contact to provide sharp "make" and "break" characteristics.

7. T F A combination thermostat can employ either two SPST mercury tubes or one SPDT mercury tube.

8. T F There are no economical advantages to enclosing contacts in glass.

9. T F The most common type of temperature sensing element is the thermostatic bimetal.

10. T F The U-shaped form of thermostatic bimetal is really shaped like a W.

11. T F Three forms of thermostatic bimetals are commonly used.

In the following multiple choice questions, choose the phrase that most correctly completes the statement and circle the corresponding letter in front of the phrase.

12. Control switches are in greater demand because of the increased use of:

a. heating thermostats. b. cooling thermostats.
c. combination thermostats d. none of the above.

13. A switch to control cooling, heating, or turning a system "on" and "off" is a:

a. system switch. b. fan switch.
c. mercury switch. d. bimetal.

14. Adjusting devices in ordinary thermostats allow for a temperature range of approximately:

a. 40 – 50°. b. 45 - 95°.
c. 50 - 90°. d. 60 - 85°.

15. A combination thermostat will make a circuit on a:

a. temperature rise. b. temperature drop.
c. either of the above. d. neither of the above.

16. A SPST mercury tube attached to the bimetal allows for an electrical circuit to be made on a:

a. rise in temperature. b. drop in temperature.
c. either of the above. d. neither of the above.

17. An electrical contact that is attached to a moving end of the bimetal is called:

a. mercury. b. fixed contact.
c. moving contact. d. none of the above.

18. A sealed contact switch used on a spiral element results in bimetal movement which causes the circuit to:

a. be completed inside the tube. b. short out.
c. burn out the motor winding. d. none of the above.

19. The thermostatic bimetal is made up of two or more layers of metallic alloys have different coefficients of:

a. contraction. b. expansion.
c. compression. d. heat absorption.

20. Thermostatic bimetals all have the basic property of being able to change curvature:

a. automatically. b. with the aid of a surge of electricity.
c. with temperature changes. d. in an electrical circuit.

21. The "make" temperature of a heating thermostat should be the minimum temperature of:

a. the entire house. b. the conditioned space.
c. an average of outdoor and indoor temperature. d. the outside air.

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

22. Two switches usually found on a modern thermostat are:

a. ______________________ b. ______________________.

23. The main parts of a thermostat are:

a. ______________________

b. ______________________

c. ______________________

d. ______________________

e. ______________________

f. ______________________

g. ______________________

24. Hermetically sealed contacts are safe from ______________, ______________ and/or ______________.

25. Electrical contacts use the movement of the bimetal caused by changes in ______________ to provide an electrical circuit.

26. The electric circuit completes on a drop in room temperature when the ______________contact is on the bottom side of the bimetal and the ______________ contact is below it.

27. Room thermostats measure a change in ______________ temperature.

Check Your Answers!

Now compare your answers with those given in the answer key at the back of this book. The answer key a1lso 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 5 Overview

Armed with an overview of the room thermostat - its basic parts and operations, it is now time to consider some of the refinements and peculiarities brought about by practical operating factors. Lesson 5, *Thermostat Heat and Cold Anticipation,* deals with the problem of increasing thermostat sensitivity (response) as a consequence of inertia in the heating and cooling system and thermal lag in the thermostat's bimetal itself.

Thus, a thermostat must be made to anticipate change as well as react to change. In this lesson, you'll learn how the introduction of artificial heat by means of a small electric resistor greatly improves a thermostat's response.

After completing the lesson, you should be able to:

1. Know that thermostat sensitivity is affected by system lag and operating differential.
2. Understand how artificial heat allows the thermostat to lead changes in room temperature.
3. Know the various types of heat anticipators and the advantages and disadvantages of each.
4. Understand how "cold" anticipation differs markedly from "hot" anticipation.

Now read Lesson 5 which begins on the next page.

Lesson 5: Thermostat Heat & Cold Anticipation

The sensitivity of room thermostats is affected by both *system lag* and *operating differential.* System lag is the amount of time required for the heating or cooling system to produce a temperature change that is felt at the thermostat. The operating differential of a thermostat is the change in room air temperature necessary to open or close the thermostat contacts.

Heat Anticipation

Heat anticipators are used in low voltage thermostats to reduce the effects of system lag and operating differential. If the thermostatic bimetal is exposed to a small amount of "artificial" heat, the sensitivity of the thermostat will increase because the bimetal "reactions" to changes in room air temperature will *lead* actual changes in room temperature.

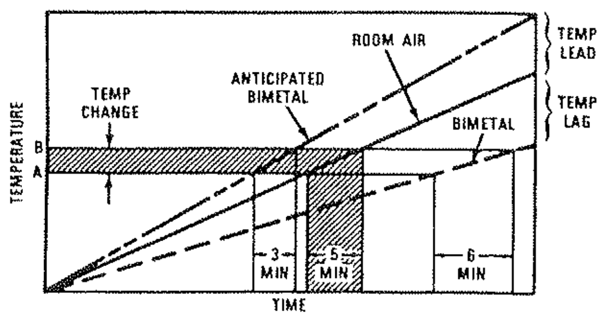


Figure 5-1: Graph shows that anticipated bimetal temperature is always higher than room air and responds faster to temperature change than unheated bimetal.

Figure 5-1 is a graph comparing room air temperature with bimetal and anticipated bimetal temperatures. The temperature of the anticipated bimetal is always higher than the room air temperature. Furthermore, the anticipated bimetal will sense a change in room air temperature before the change actually occurs. For example, if the room air temperature increases from point A to point B in five minutes, the anticipated bimetal will feel this change in only three minutes, while the unanticipated bimetal will not feel the change in air temperature until six minutes have passed.

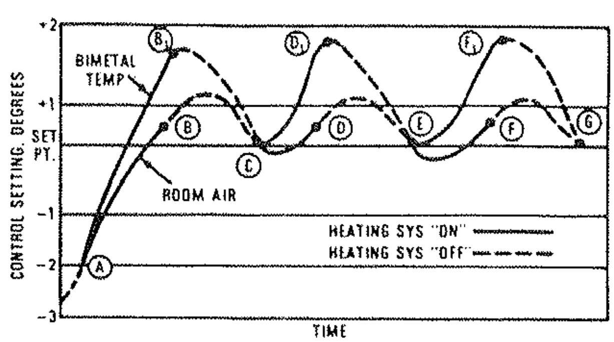


Figure 5-2: plot of temperature vs. time shows how room air temperature variations peaks and valleys) are minimized using heat anticipation.

The effect of heat anticipation on room air temperature control is shown in Figure 5-2. At point A, the heating system is on and the room air temperature is increasing. The temperature of the anticipated bimetal is also increasing, but at a faster rate. At point B, the thermostat contacts open and the bimetal immediately starts to cool because the "anticipator" is now deenergized. At point B, however, the room air temperature continues to increase slightly as the residual heat in the furnace is distributed to the rooms by the blower. At point C, the temperature of the bimetal has decreased to the control setting and the thermostat contacts close, energizing the "anticipator" and starting the furnace burner. Due to the artificial heat of the "anticipator," the bimetal temperature immediately starts to increase. However, the room air temperature continues to fall until the temperature in the furnace reaches the "cut-in" setting on the fan control. The cycles continue and repeat from points D through G.

The use of heat anticipation to reduce the effects of system lag and operating differential has become almost universal. However, there are several types of heat anticipators used in room thermostats.

Types of Heat Anticipators

Fixed Anticipators

A fixed anticipator is a small resistor which will generate a specific amount of heat when current flows through it. Thermostats are furnished with a "standard" anticipator unless a "non-standard" unit is specified (Figure 5-3). The heat output of the fixed anticipator is equal to the square of the current times the resistance of the heater ($W = I^2R$). Since the fixed anticipator is wired in series with the other loads in the circuit such as relays and gas valves, the current flow through the anticipator will be determined by the amperage draw of these loads.

If the anticipator must be replaced or changed, follow the manufacturer's instructions. To change a fixed anticipator, remove the screw holding the anticipator to the base of the thermostat, change the anticipator, and carefully replace the screw so that the anticipator is neither cracked nor distorted in the process. *The wattage of the heat anticipator will determine the cycle rate of the system. The higher the wattage, the faster the system will cycle.*

Adjustable Anticipators

An adjustable heat anticipator is actually a variable resistor. The heat output of an adjustable anticipator is changed by varying the position of the slider on the resistor (Figure 5-4). The manufacturer's recommendations regarding the correct positioning of the slider should be followed.

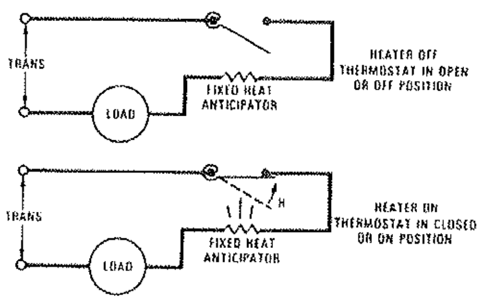


Figure 5-3: Fixed heat anticipator is a small resistor placed in series with the thermostat contacts.

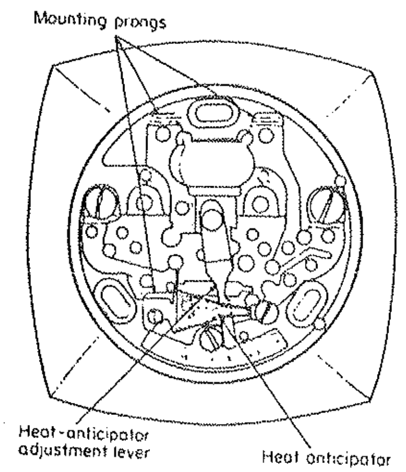
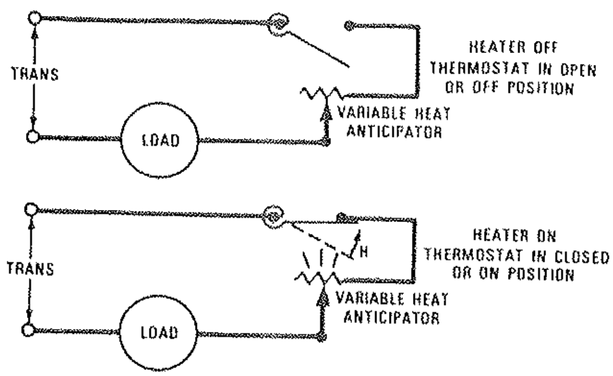


Figure 5-4: Variable heat anticipator is often a wound wire resistor with a moveable contact slider (SHOWN AT LEFT) to increase or decrease resistance in circuit (Penn Controls).



Voltage Anticipators

A voltage anticipator (Figure 5-5) is a fixed anticipator which is wired in parallel with the thermostat control circuit. Since each load in a parallel circuit will draw its rated current, the heat output of the voltage anticipator is completely independent of the load current flow in the heating control circuits. Therefore, one selected value of a voltage anticipator can be used with all heating circuits. Voltage anticipators are factory selected, and since they are not affected by current now through the control system, they should not require adjustments.

Since the voltage across each load in a parallel circuit equals the supply voltage, the heat output of the voltage anticipator is affected by voltage variations in the supply circuit. Voltage anticipators also require additional wiring between the transformer and the thermostat.

Cycle Anticipators

A cycle anticipator is a fixed anticipator which is fastened to the bimetal (Figure 5-6). Cycle anticipators are normally found on thermostats designed for millivolt control systems. Only fractional voltages are available for heating the anticipator; therefore, using a cycle anticipator which applies heat directly to the bimetal by conduction, rather than a fixed anticipator which depends on convection and radiation for heat transfer to the bimetal, provides desired sensitivity in millivolt thermostats.

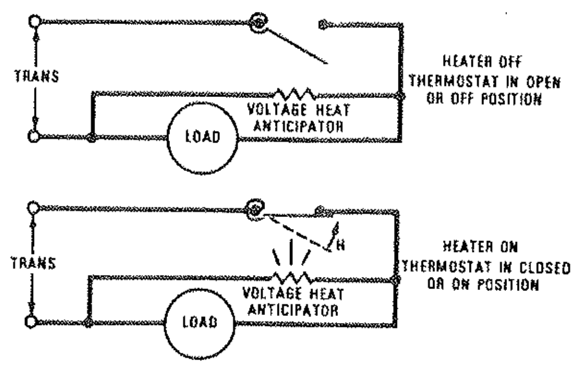


Figure 5-5: Voltage anticipator is a fixed anticipator placed in parallel with thermostat circuit.

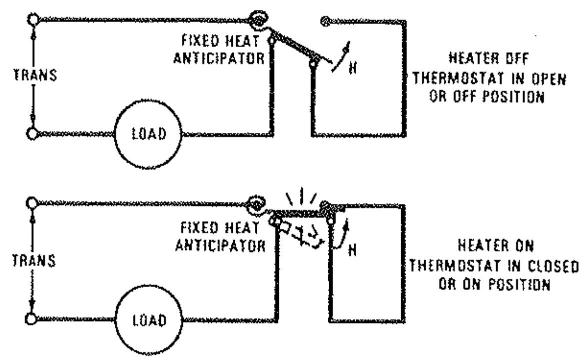


Figure 5-6: Cycle anticipators is used in millivolt circuits and is fastened directly to bimetal.

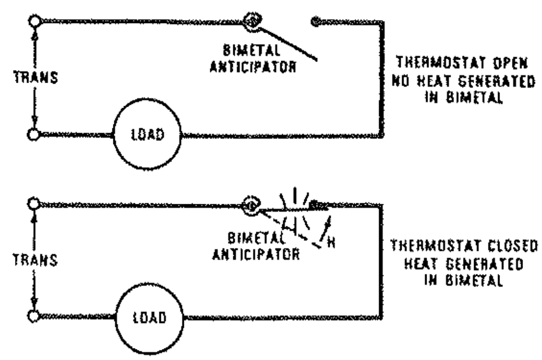


Figure 5-7: Bimetal anticipators are used in some line voltage thermostats.

Bimetal Anticipation

The thermostatic bimetal itself (if carefully selected) can be used to provide heat anticipation. (Figure 5-7). However, bimetal anticipators are *generally* found on line voltage, heating-only thermostats. A thermostat with a bimetal anticipator can handle 13 amps at 115 volts for heating, but only 1 or 2 amps for cooling, because the heat generated by 13 amps of current flowing through a bimetal anticipator is so great that the air temperature would have to decrease as much as 20° F before the bimetal would warp and break the electrical contacts. Therefore, a cooling thermostat with a bimetal anticipator set at 76 °F would not break its contacts until the room air reached 56°F - the thermostat would have a 20 deg operating differential.

Cold Anticipation

In heating thermostats, the heat anticipator is generating heat only when the heating system is "on." Heat anticipation causes the bimetal to break its contacts before the room air temperature has increased enough to cause the thermostat to turn off the system.

In cooling thermostats, the cold anticipator is energized only when the cooling system is "off." The bimetal will make the contacts, closing the control circuits and turning the system on before the room air temperature has increased to the "dial" setting, since the bimetal temperature is *leading* room air temperature. When a thermostat with cold anticipation (Figure 5-8) is "off," the cooling control circuit is open and room air temperature is rising. The cold anticipator, which is wired in parallel with the thermostat's contacts, has a very high resistance (4,000 to 10,000 ohms). Therefore, current flow through the anticipator in a low voltage system is small, less than 10 milliamperes. However, current does flow through the anticipator, since the resistance of the open circuit is infinite and electricity always follows the path of least resistance.

The small current flow through the anticipator is not high enough to energize the relays, solenoid valves or contactors normally found in cooling system circuits. The wattage output of a cold anticipator is not affected by the current draw of the primary circuit. It is determined by the "open circuit voltage" of the primary circuit. Cold anticipators are factory-selected and should not be changed in the field.

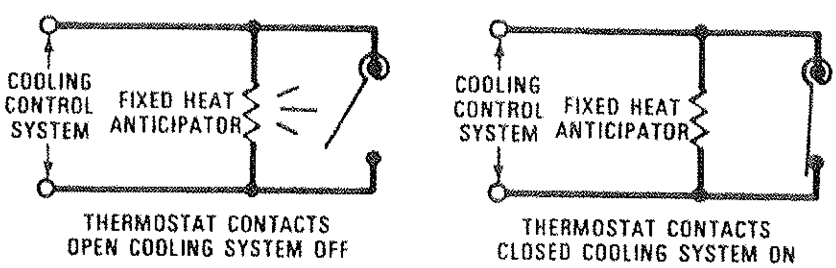


Figure 5-8: Cooling anticipation is "on" when system is "off" -- opposite the heating sequence.

When the bimetal temperature has increased to the control point - cold anticipation causes the bimetal temperature to *lead* room air temperature - the contacts close and the cooling system is energized. When the contacts close, the cold anticipator is shunted out of the thermostat's circuit, since the resistance of the closed contacts is less than the resistance of the anticipator.

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 A small amount of artificial heat introduced to the room thermostat has no effect on the bimetal.

2. T F The heat anticipator reduces the effect of system and thermal lag.

3. T F There is no significant difference in the operation of heat anticipation and cold anticipation.

4. T F When the contacts close in a heating thermostat, the heat anticipator is energized and the heating system starts.

5. T F Cycle heat anticipators are fixed anticipators which are fastened directly to the bimetal.

6. T F Cycle heat anticipators have yet to become standard equipment on thermostats used in residential installations.

7. T F Current flow through a fixed anticipator can be determined by measuring the amperage draw of the various loads in the control circuit.

8. T F It is better to use a bimetal anticipator on a cooling thermostat than on a heating thermostat.

9. T F There is little similarity between the operation of a fixed anticipator and a variable heat anticipator.

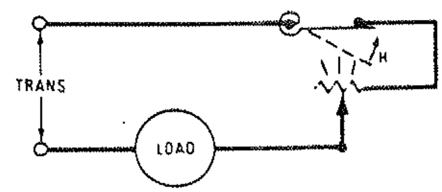
10. T F Voltage type heat anticipators are also fixed anticipators.

11. T F The cold anticipator is in parallel with the thermostat contacts.

12. T F The current flow through the cold anticipator is great enough to energize relays in the cooling system control circuit.

In the following multiple choice questions, choose the phrase that most correctly completes the statement and circle the corresponding letter in front of the phrase.

13. The figure to the right illustrates a:



a. cycle anticipator.
b. voltage type heat anticipator.
c. fixed anticipator.
d. variable heat anticipator.

14. The heat output of a voltage anticipator is independent of the:

a. bimetal. b. load current flow.
c. heating circuit. d. cycle anticipator.

15. When current flows through a fixed anticipator, a fixed value resistor will generate a specific amount of:

a. heat. b. electricity.
c. cold air. d. none of the above.

16. In heating thermostats, the heat anticipator generates heat only when the system is:

a. on. b. off.
c. operating for long periods of time. d. operating for short periods of time.

17. The effect of the cycle anticipator on the thermostat is that sensitivity:

a. increases. b. decreases.
c. does not change. d. fluctuates.

18. In a cycle anticipator, heat is applied directly to the bimetal by:

a. convention. b. radiation.
c. conduction. d. evaporation.

19. A bimetal anticipator cannot be used on a cooling thermostat because:

a. current flow generates too much beat. b. Underwriters Laboratories will not allow it.
c. of the danger of fire. d. the thermostat case might break.

20. Because the cold anticipator has a very high resistance, current flow through the heater in a low voltage control system would be:

a. very small.
b. very large.
c. blow a fuse.
d. remain constant.

21. The operating differential of a thermostat is the change in room air temperature necessary to:

a. open the thermostat contacts.
b. close the thermostat contacts.
c. open or close the thermostat contacts.
d. none of the above.

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

22. The adjustable heat anticipator utilizes ________________ rather than ________________ resistors, thus allowing for different heat anticipation values.

23. Voltage anticipators are wired in ______________ rather than in _______________ to the thermostat heating control circuit.

24. Anticipation is a feature which was developed to help reduce ______________ _______ and ____________________ _____________________.

25. The cold anticipator anticipates a rise in room air temperature by causing the bimetal to close its contacts __________________ the room air temperature reaches the thermostat's dial setting.

26. The change in room air temperature necessary to open or close the thermostat contacts is the _______________________ _______________________.

27. System lag is the amount of time required for the heating or cooling system to produce a ________________ ___________________ that is felt at the thermostat.

28. Five types of anticipators used in thermostats are:

a. ________________________

b. ________________________

c. ________________________

d. ________________________

e. ________________________

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 6 Overview

In the lesson just completed, you learned how heat anticipation improved the sensitivity of a room thermostat. Now the bad news. In Lesson 6, you are going to learn how heat anticipation contributes to or increases a thermostat's droop characteristic. Droop causes a thermostat set at 75° F on a mild day to control at 69°F on a cold day, yet there's plenty of reserve Btu available at the furnace or boiler. This is one of two basic reasons why many people must set their thermostat higher on a cold day to stay warm. (The other reason: increased body heat loss by radiation to colder windows and exterior walls.)

This interesting and generally unknown phenomenon is fully explained, so at the completion of the lesson, you should be able to:

1. Define droop and explain its effect on the heating system.

2. Discuss all the factors that contribute to droop and how to minimize the amount of droop.

3. Describe the merits of outdoor compensation.

Now read Lesson 6 which begins on the next page.

Lesson 6: Thermostat Droop

When a thermostat's contacts are closed for an extended period of time, the thermostat will tend to control room air temperature at a point which is lower than the temperature set on the "dial." This shift in the operating control is known as ***droop***.

Droop is primarily caused by the artificial heating of the bimetal by the heat anticipator. However, the heat generated by the current flow through the thermostat's contacts, heat storage in the thermostat itself, and heat in the wall area to which the thermostat is attached are three additional sources of artificial heat which contribute to a thermostat's droop.

Droop will vary directly with the operating time of the heating system. Figure 6-1 is a chart which represents actual test data for determining a thermostat's droop characteristics.

Sizing the Heat Anticipator

It is possible to minimize droop by adjusting the system cycle rate. The time for one "on" period and one "off" period, or the system cycle rate, is determined by a combination of factors:

1. *The system capacity*. The heating system should be selected to match the structure's heat loss at design conditions. There can be "too much" as well as "too little" capacity.

2. *The system lag*. There is a mass of metal, primarily in the furnace itself, which must be heated to the fan controls "cut-in" or the integrated circuit board activation point before heat is supplied to the rooms. On the other hand, when the thermostat contacts open and the burner shuts down, this same mass of metal must be cooled to the fan control's "cutout" or the integrated circuit board deactivate point before the blower stops supplying the rooms with heated air. System lag is also affected by the *rate of air recirculation* or number of air changes, which is determined by the cubic feet of air per minute delivered to the conditioned space by the blower and the size of the structure.

3. *The amount of heat anticipation*. If an anticipator with a high heat output is used, the system will cycle rapidly, "on" times will be short, and room air temperature variations will not be large. If an anticipator with a low heat output is used, cycles will be infrequent and "on" times will be relatively long.

Generally speaking, rapid cycling is preferred if the controlled equipment will not be damaged. However, rapid cycling may damage compressors, heat pumps, oil burners and stokers. Heating systems using these components may require slower cycle rates even though this will result in greater room air temperature variations. If a slower cycle rate is used to protect equipment, the anticipator used in the system should not be "oversized" to the point that it will cause excessive droop when the system is operating at design conditions. Droop, or thermal offset, should not exceed 4° F to meet NEMA standards for room thermostats.

Outdoor Compensation

Droop becomes a problem only when the heating system operates for long "on" periods. Since long "on" periods occur only when outside temperatures are low, it may be desirable to control the heat output of the anticipator so that it varies with outside temperatures. The amount of artificial heat supplied by the anticipator could be reduced as outside air temperature decreases to hold droop to a minimum. However, whether or not this would be desirable depends, in part, on the heat distribution system used in the structure.

Wall heaters, space heaters and furnace duct systems may supply heat to the room from an *inside* wall. However, the outside walls are usually the "cold" walls. Since body heat loss by radiation does not depend on room air temperature, it is possible to be uncomfortably cool in a 70° F room when the outside air temperature is low. The body will radiate heat to the cold walls even though the room air temperature is at the control point.

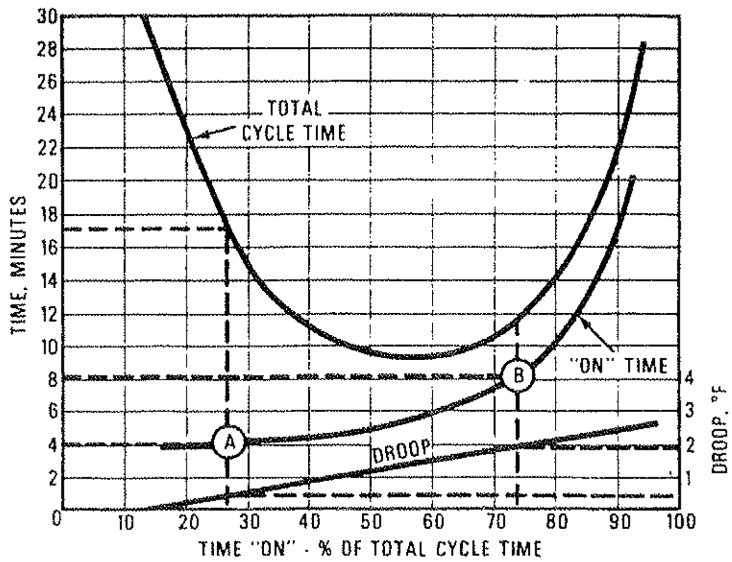


Figure 6-1: Test of a thermostat's droop characteristics can be reported graphically as above. Value of droop is read on lower right hand vertical scale. Note droop increases from 0° F at 15 percent "on" time up to about 2.5 at 95 percent "on" time. Table 1 below compares performance for conditions at points A and B on graph.

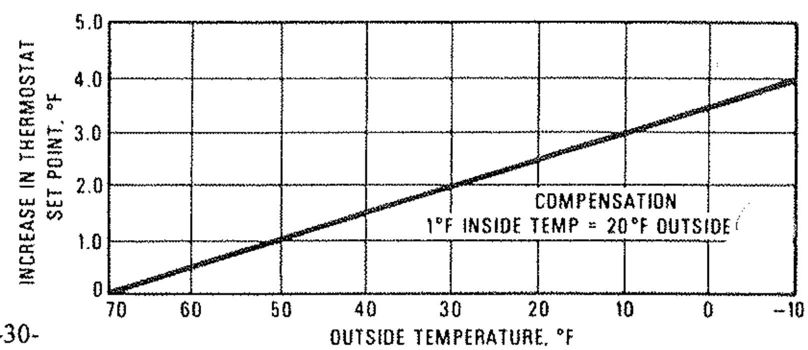
TABLE 6-1: Thermostat operating data for conditions A & B in Figure 6-1.

Analysis	Point A	Point B
Total Cycle Time	17.5 Min	12.0 Min
"On" Time	4.5 Min	8.2 Min
% "On" Time	25.7%	73.3%
"Off" Time	13.0 Min	3.8 Min
Droop	0.4° F	1.9° F

With these "cold wall" systems, it may be necessary to compensate for the cold outside walls by increasing the room air temperature. This can be done by manually changing the thermostat control point or by varying the heat output of the anticipator.
A thermistor is commonly used to raise the temperature control point of the thermostat so that it will actually control room air temperature at a level which is above the control point set on the thermostat. A thermistor is an electrical device that will increase its resistance to the flow of current as its temperature decreases. (Lesson 12 deals with this in more detail.) A thermistor, which should be mounted on an outside wall of the home, (where it will sense outside air temperature), can be wired to a thermostat heater which supplies artificial heat for anticipation through a separate circuit. When the thermistor senses colder air, its resistance will increase, thereby decreasing the current flow through the thermostat's heat anticipator.

Thermistors can be selected to increase the control point of the room thermostat above the set point by almost any desired amount. Figure 6-2 is a graph showing a typical operation of a thermistor compensating circuit - the temperature control point is increased 1° F for each 20° F drop in the outside air temperature.

Exposed outside walls are blanketed with a "curtain" of warm air by perimeter heating systems which supply heat to the room from the outside walls (radiators, fin-tube baseboard heaters, convectors and ducted perimeter distribution systems). In these systems, it is often not as necessary to raise the thermostat's control point above the set point as outside temperature drops. In fact, several tests and experience with perimeter systems have shown that it is sometimes desirable to lower the inside temperature control point as outside temperatures decrease. Since droop does lower the operating control point when the heating system is "on" for long periods of time, some droop might be considered desirable under these conditions.



-30-

Figure 6-2: Compensation for droop is often made automatically with additional controllers by increasing the thermostat's set point 1° F for each 20° F decrease in outdoor temperature.

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 Room temperature can drop even with an adequate heating system, because of thermostat droop.

2. T F There would be less droop in a thermostat with no heat anticipator.

3. T F The mass or "size" of the thermostat can affect its droop characteristic.

4. T F Systems that supply heat directly at cold exterior surfaces help nullify the effects of the cold wall.

5. T F If room air temperature is at the "set" point, it is impossible for a person to be uncomfortable.

6. T F Thermostat location has no effect on droop.

7. T F One degree F of droop is considered serious.

8. T F Droop occurs gradually as heating loads increase.

9. T F Two air changes per minute means the equivalent of all the air in a room being replaced every 30 seconds.

10. T F The heating effect of the heat anticipator on the bimetal causes droop.

11. T F Heat generated by current flow through the contacts has no effect on thermal offset.

12. T F An anticipator with a high beat output gives short and frequent cycles.

13. T F A heat pump can easily withstand rapid cycling.

14. T F Serious droop problems are confined primarily to heating systems.

15. T F Over sizing the heating plant to give the homeowner plenty of reserve capacity is a good idea.

In the following multiple choice questions, choose the phrase that most correctly completes the statement and circle the corresponding letter in front of the phrase.

16. A shift in the operating control point which causes the thermostat to control at a temperature different from that set by the temperature adjusting device is known as:

a. cold anticipation.
b. droop.
c. heat anticipation.
d. outdoor compensation.

17. Heat storage capacity of the thermostat affects droop:

a. on cooling only.
b. on heating only.
c. not at all.
d. to some extent.

18. An anticipator with a high heat output will cycle a heating system:

a. very slowly.
b. once.
c. rapidly.
d. not at all.

19. The maximum droop limit by NEMA standards is:

a. 1° F.
b. 2° F.
c. 3° F.
d. 4° F.

20. A slower cycle rate may result in greater variation of:

a. room air temperature.
b. outdoor temperature.
c. thermostat components.
d. heat anticipator selection.

21. Droop occurs when a system is:

a. oversized.
b. undersized.
c. operating long "off" periods.
d. operating for long "on" periods.

22. As the temperature outdoors drops, the heating system operates:

a. less efficiently.
b. for shorter periods of time.
c. for longer periods of time.
d. erratically.

23. A mass of metal which stores up heat or cold after the heating system has stopped can affect:

a. system capacity.
b. system lag.
c. the rate of air circulation.
d. the cycle rate.

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

24. A/an ____________________ is often used in a compensating control to ________________ the set point on the indoor thermostat as the outdoor temperature gets colder.

25. A heating system circulating 1,200 cfm of air through a house will have ________________ system lag than the same system circulating 600 cfm of air.

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 7 Overview

The basic single switch (stage) thermostat or even the basic combination heating-cooling thermostat is not adequate to meet designers' demands for special control arrangement for more sophisticated applications. As a result, single unit thermostat enclosures with multiple switches have been developed. Chief among these is the popular two-stage thermostat. Lesson 7, therefore, explains specifically how the two-stage thermostat operates and the reasons for its development. The lesson also discusses some other special feature thermostats or "optional accessories" that are available.

Since this is the last lesson dealing specifically and solely with the thermostat, the lesson ends by offering guidelines on the proper installation of a room thermostat.

After studying the lesson, you should be able to:

1. Explain the operation of two-stage thermostats in both separate and combination heatcool versions.
2. Recognize the advantage of a time-controlled thermostat in many installations.
3. Understand the six guidelines for correctly installing a room thermostat.

Now read Lesson 7 which begins on the next page.

Lesson 7: Two-Stage Thermostats

One of the most common variations of the simple low voltage thermostat is the so-called twostage thermostat. Both cooling and heating operations can utilize the multi-switch feature provided.

Two-Stage Thermostats

Two Stage Cooling Thermostats

When cooling loads in a structure vary by significant amounts, the cooling system may be designed so that two separate systems serve the same conditioned space. The operation of these systems can be controlled by two-stage thermostats.

Common two-stage cooling thermostats consist of two switches mounted on a single bimetal. Both switches will open at the "set" temperature; however, the switches are placed on the bimetal so that there is a 2° F differential between them. The first stage switch will close when room air temperature reaches 2° F above the "set" temperature and turn on the first-stage of the system. If the room air temperature continues to climb after the first stage system is operating and reaches 4° F above the "set" temperature, the second-stage contacts will close and the second-stage system will begin to deliver conditioned air to the rooms.

Two Stage Heating Thermostats

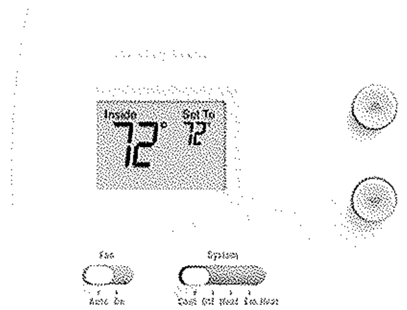
Two-stage thermostats using a single bimetal are also used for heating applications. In general, single-stage heating and two-stage cooling thermostats have been required for most conventional systems. However, two-stage heating and single-stage cooling thermostats have been required for air source heat pumps.

Heat pumps are normally sized to meet cooling load requirements. When outside temperature conditions are low, the air source heat pump alone may not be able to meet the heating requirements, and additional heating is provided by using auxiliary or supplemental electric resistance heaters.

The second-stage switch (contacts) on the heat pump thermostat is used to control the operation of the auxiliary or supplemental strip heaters. In addition, the second-stage heating switch in the room thermostat is normally wired in series with an outside air thermostat. Therefore, the room thermostat cannot bring in the auxiliary or supplemental strip heaters unless 1) inside conditions bring on the second-stage contacts; and 2) the outside air thermostat contacts are closed. If several banks of strip heaters are used, each bank will normally be provided with a separate adjustable outside air thermostat - the first bank's thermostat may be set to close when the outside air temperature drops to 40° F, the second bank's at 35° F, then 30° F etc.

Two-Stage Combination Thermostats

Combination two-stage thermostats using two bimetals are used in two-stage heating and cooling systems. Heat pumps using two compressor systems are being used in areas when the heating load exceeds the cooling load because the two-compressor system can be sized to meet beating requirements and still not be oversized for the cooling requirements.



Typical two-stage heating, single-stage cooling thermostat often used to control ordinary heat pump systems. (Honeywell Inc.)

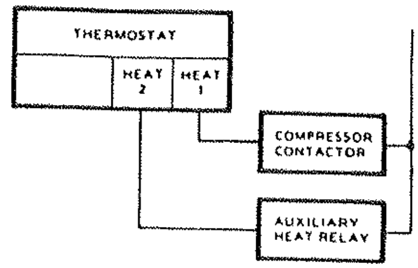


Figure 7-1 is a schematic diagram of a typical two-stage heating and cooling thermostat. Each cooling mercury switch controls one cooling system. The second-stage cooling system is not used unless load conditions within the structure require additional cooling. The leads between the "C" and "X" terminals of this thermostat could be changed to equalize wear on the compressors during the cooling season. The first-stage heating switch will bring in both compressors. The second-stage heating switch will bring in supplemental electrical strip heaters. However, in areas where strip heaters are not required to supplement the heat supplied by the compressor, each of the heating switches would be arranged to control one of the compressors.

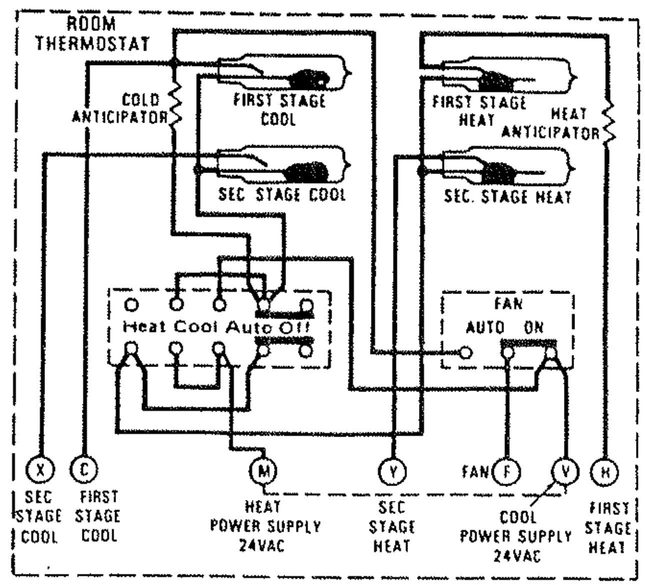


Figure 7-1. Schematic wiring diagram of a two-stage heating, two-stage cooling thermostat. This control is used when a two-compressor or two speed system is installed.

There is a mechanical interlock (4° F minimum) between the heating and cooling switches in order to prevent an "override" or "overlap." An override occurs if the heating system raises room temperature significantly so that the cooling system would "kick in." An overlap exists if both the heating and the cooling operation could occur at the same time.

Time Controlled Room Thermostats

Time-controlled room thermostats (Figure 7-2) will automatically lower the night temperature for comfortable sleeping winter or summer. Lowering the night temperature during extremely hot weather also stores cooling capacity in the house during the hours when the air-cooled condensers operate at maximum efficiency and economy. The lower nighttime temperature will then ease the demands on the system during the following day.

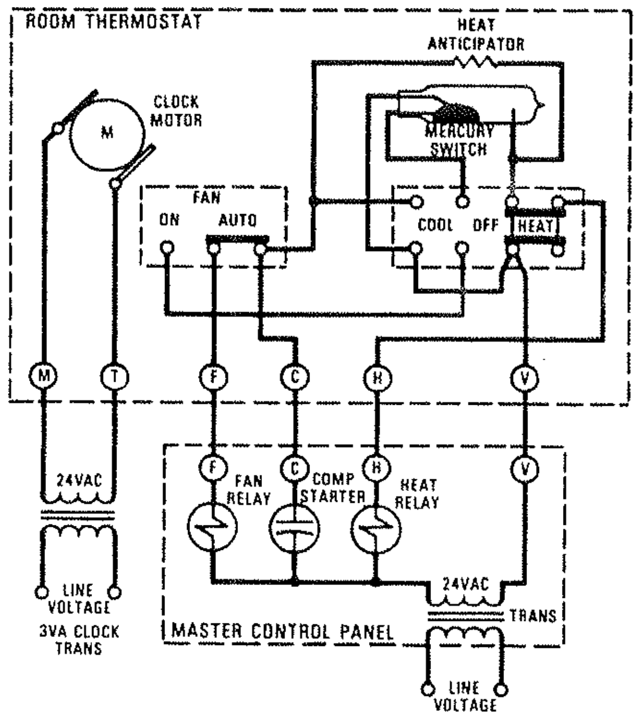
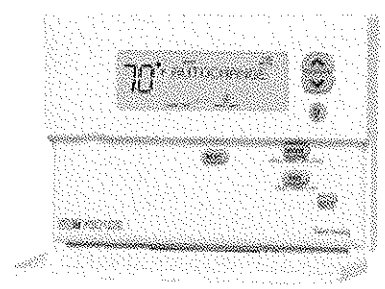


Figure 7-2. This "two-stage" thermostat maintains two different cooling temperature levels --- one for daytime, one for nighttime operation.



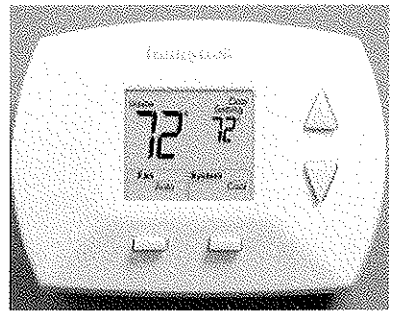
Energy-Conserving Setback Thermostat.

Time-Controlled To Save Energy

The concern over energy waste and reducing utility bills in the face of rising energy costs has fostered great interest in the time-controlled room thermostat. A fully automatic clock thermostat can lower room temperature at night at a pre-selected time, say 10:30 PM. Then, at a second pre-selected time, say 6:00 AM, return room air temperature to a higher, more comfortable level. This shifting of control set points can be accomplished through a timer/cam arrangement (or digital timing) powered by the time segment.

In this basic form, residential customers may save from 5 to 16 percent in heating fuel costs compared to that expended with a fixed temperature setting all day. The exact amount of energy that can be saved varies with the climate and the degree of setback exercised -- 5, 7, 10 degrees, etc.

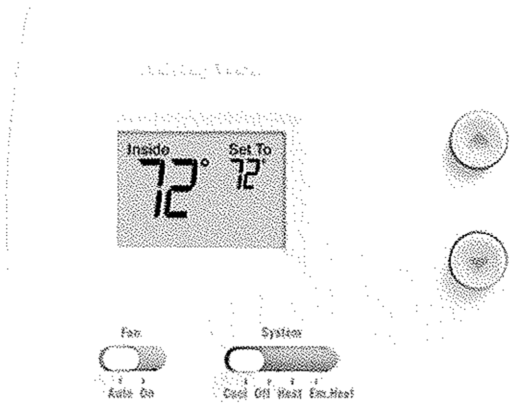
In almost every instance, there is a positive savings in energy despite the need to use "above normal" energy to warm up the house in the morning. One variation to the basic setback arrangement is to provide for two changes in space temperature in a 24-hour period. A working couple may prefer a sequence where the temperature is up to normal at 6:00 AM; turned down at 9:00 AM; and then returned to normal at, say, 3: 00 PM where it remains until 10: 00 PM.



The need to provide additional selections for the user has prompted the development of solid state "programmable" thermostats. These thermostats can provide as many as seven days of desired setback/setup temperature cycles.

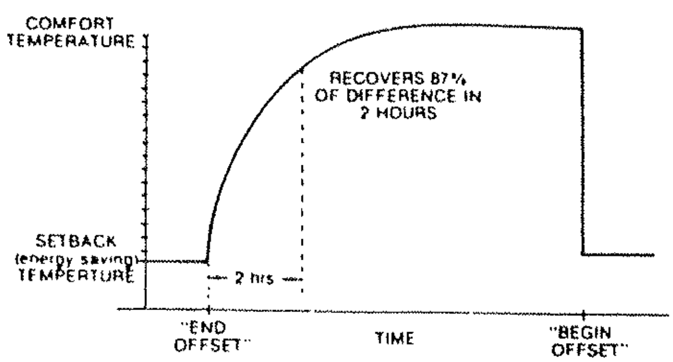
Special Case - The Heat Pump

Tests with heat pumps have shown that in some cases, energy consumption increased with the addition of night setback. This apparent paradox resulted when the outdoor temperature was near the balance point for the system. When the thermostat was reset to the higher daytime temperature setting, the resistance heaters were energized along with the heat pump compressor until the room thermostat setting was satisfied. The saving in energy at night was overshadowed by the increased energy used to recover in the morning.



Heat pump setback thermostat (Honeywell).

Specialized versions of the microprocessor based thermostat permit innovative recovery modes that eliminate the problems associated with night setback for heat pumps.



Instead of instantly changing the room temperature setting back to the normal daytime setting, it is now possible to "program" the thermostat to make the change back to the higher setting gradually over a period of time. In this way, under some conditions, no auxiliary heat is required during the morning recovery phase. In "worse case" situations, auxiliary heaters will not be on as long as under a more conventional setback approach. Fitted with the right thermostat, heat pumps can feature energy-saving night setback.

How to Install Room Thermostats

A room thermostat is a precision instrument and must be installed correctly if it is to maintain the comfort conditions desired. The following considerations are important:

1. Mercury switches must be level - use a spirit level on the thermostat sub-base. Electronic thermostat still must be installed straight and true for aesthetics.

2. Locate the thermostat: (a) in a room which is supplied with conditioned air, (b) where it will be exposed to normal air circulation, (c) approximately 4 ½ - 5 feet above the floor, (d) away from sources of artificial heat or cold such as TV sets, lamps, sunlight, cold air returns, computers, etc.

3. Heat anticipation (if necessary) should be adjusted in accordance with the manufacturer's recommendations.

4. All wires should be firmly connected and splices should be soldered (preferred) or made with tightly connected wire nuts.

5. Use color-coded thermostat cable (#18 if less than 50' or #16 if longer than 50') to reduce the possibility of incorrect wiring.

6. When wiring between the room thermostat and a control panel, wire from function to function with color-coded wire.

Special Switching Functions

Control switches used on modern thermostats (the AUTO, HEAT, COOL, OFF "SYSTEM" switch and the AUTO-ON "FAN" switch) provide complete control of the cooling and heating system at the thermostat. A variety of additional control switches can be provided. For example, many thermostats have control features such as reset circuits so that automatic reset safety controls such as the pressure switches, compressor overloads, etc., can operate as manual reset controls with the reset located at the thermostat.

Conventional thermostats can be used with motorized air dampers (valves in the case of hydronics) to divide a house (or office) into separately controlled zones. Each area would have its own thermostat to regulate the temperature in the selected spaces.

A typical damper motor actuator is a unidirectional motor that rotates 180 degrees to open damper at the call of the thermostat and then another 180 degrees in the same rotational direction to close the damper - again at the call of the thermostat. About 30 seconds is required for the damper motor to open or close the spring to return the valve to a deenergized position.

Actuators can be fitted with end switches that close at the end of a rotational cycle to energize a furnace, compressor, pump or other auxiliary devices.

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 In a two-compressor system, the second unit is not used for cooling unless interior load conditions in the conditioned space require it.

2. T F Two-stage combination heating-cooling thermostats usually use two bimetal sensing elements.

3. T F Two-stage heating and single-stage cooling thermostats are required for heat pumps.

4. T F Strip heaters are used in heat pump systems to provide additional heating capacity in cold weather.

5. T F Cooling capacity is effectively increased using a time-controlled thermostat because cooling effect is stored (absorbed) in the structure during the night.

6. T F A two-stage cooling thermostat usually has but one bimetal sensing element.

7. T F Location of the thermostat is inconsequential as long as it is installed in the largest room of the house.

8. T F There is no such thing as a two-stage heating thermostat.

9. T F Outdoor thermostat are wired in series with the indoor thermostat to stage the energizing of multiple strip heaters.

10. T F A spirit level can be used to check that mercury switch thermostats are level when installed.

11. T F It is a good idea to place a thermostat near a return grille in order to sense the average room air temperature.

12. T F Night setback using a time-controlled thermostat probably saves money.

13. T F A thermostat should be placed at eye level (about 5 ft.) on a wall.

In the following multiple choice questions, choose the phrase that most correctly completes the statement and circle the corresponding letter in front of the phrase.

14. Simultaneous operation of the heating and cooling unit is usually prevented by means of a:

a. manual switch. b. mechanical interlock.
c. damper. d. circuit breaker.

15. As a general rule a thermostat is best located:

a. in the middle of the house. b. in a room most often occupied.
c. in the kitchen. d. close to the furnace.

16. A common mistake in placing a thermostat is to place it:

a. on the same inside wall that serves as a side of the chimney chase.
b. in the occupied zone of the room.
c. where it is exposed to normal air circulation.
d. approximately 3 to 4 ft above the floor.

17. Considering heating operation only, how would you connect a two-compressor heat pump system that does not require auxiliary strip heaters to a two-stage heating, single-stage cooling thermostat?

a. First state heating switch brings on both compressors.
b. First stage heating switch controls one compressor; second stage, the other.
c. Second stage heating switch controls both compressors.
d. Would not use a two-stage thermostat in this case.

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

18. If it is necessary to splice thermostat wires, it is best to use ______________ connections.

19. Conventional thermostats controlling ____________ _____________ _____________ can be used to provide separately controlled zones in a building.

20. A two compressor heat pump system allows a unit to be more closely sized to the _________________ load but not be oversized for the _________________ load.

21. ________________ stage heating-cooling thermostats using two bimetals are required for conventional two-stage cooling and heating systems.

22. An important guideline is that the ________________ ________________ should be properly adjusted to match the low voltage circuit current draw.

23. There is a ________________ degree differential between stages in an ordinary two-stage cooling thermostat.

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 8 Overview

This, the last lesson in Unit 2, deals with the humidistat. Specifically, the lesson covers its construction, operation, and installation.

Essentially, the humidistat is a thermostat that reacts to moisture change rather than temperature change. The humidistat, as such, is a relatively old device. Until recently, however, it was seldom used in residential and light commercial installations. Now, with the introduction and popular use of power humidifiers, the need for more precise winter humidity control has been intensified. For uncontrolled, a modern power humidifier could introduce great quantities of moisture that could prove damaging to building materials.

There's also a second cause for expanded use of the humidistat. The concept of summer cooling with reheat is finding renewed interest, and this control operation requires the use of a humidistat.

For both of these reasons, you'll be encountering more and more humidistats in your service work.

Your principal goals in studying this lesson should be to:

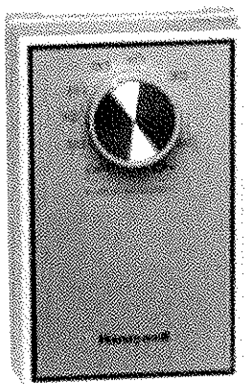
1. Understand the construction details of a typical low voltage, hair element humidistat.
2. Understand the operating sequences and sensitivity limitations of the ordinary humidistat.
3. Explain why a humidistat's set point must be readjusted downward in cold weather.
4. Know the objectives of reheat control.
5. List installation guidelines.

Now read Lesson 8 which begins on the next page.

Lesson 8: The Humidistat

Complete comfort is not considered possible unless the humidity or moisture level in room air is also controlled along with air temperature. Consequently, equipment to add and remove moisture from air is very often included in a total system design.

In winter, indoor humidity is often *less* than desired, so moisture must be added to the air using some type of humidifying apparatus. In summer, an *excess* of moisture indoors usually exists, and dehumidification equipment, probably the ordinary air conditioner, is used.



Wall mounted, low voltage humidistat. User dials in desired indoor relative humidity (Honeywell, Inc.).

While in ordinary small applications, direct control of summer humidity is not regularly attempted, both summer and winter humidity levels can be controlled by means of a single humidistat.

Humidistat Design Details

The ordinary low voltage humidistat is very similar to the low voltage thermostat - it contains both a sensing element and a low voltage electric switch.

The sensing element usually consists of electronic circuitry, nylon ribbon, human hair, or at one time even wood that lengthens with a rise in moisture and shrinks with a decrease. Like the expansion of the thermostat's bimetal, this movement is used to open and close an electric switch then can turn equipment on and off.

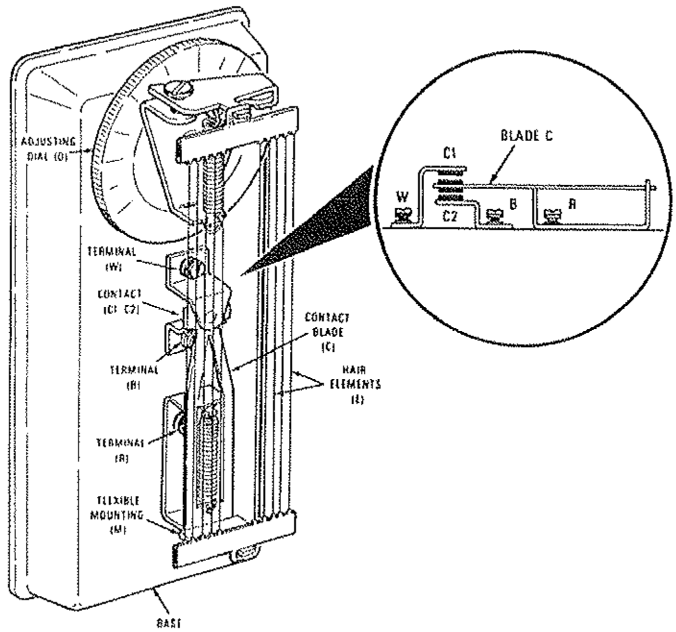


Figure 8-1: Construction details of a three-wire wall-mounted humidistat.

The construction details of an early model wall mounted, human hair element, three-wire, snap acting, permanent-magnet humidistat are illustrated in Figure 8-1. The humidistat mechanism is shown with the outer cover removed.

The device includes human-hair elements E, a contact blade C, and adjusting dial D, a flexible mounting of the contact blade M; contacts C1 and C2, and terminal connections W, B, and R to which wires with white, blue and red-colored insulations, respectively, are attached at the rear of the instrument.

Movement of the adjusting dial D changes the tension of the hair elements. When the relative humidity (RH) of the surrounding air is above that for which the dial is set, the hair elements lengthen and cause blade C to move against contact C1 and make an electric circuit through W and R. When the moisture of the air is below that corresponding to the dial setting, the hair elements shorten in length, and blade contact is made at C2 to complete any circuit through wires B and R. The making of the electric circuit through wires W and R causes the equipment to function to decrease the amount of moisture being held in air; the closing of the circuit through B and R causes air humidification.

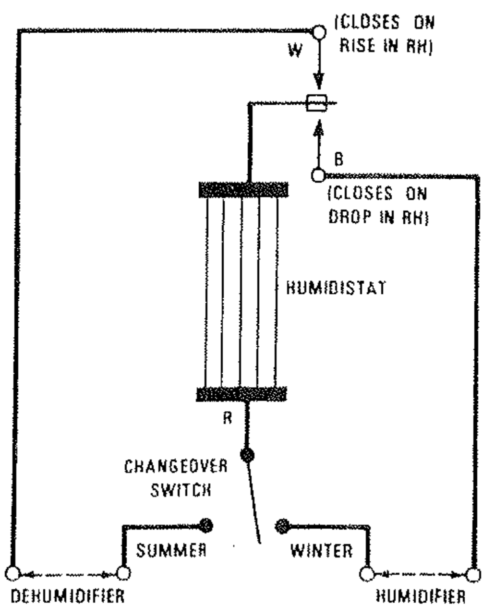


Figure 8-2: Schematic wiring arrangement for yearround control of humidity.

Figure 8-2 shows the basic wiring schematic for a year-round installation. Note that the inclusion of a manual seasonal changeover switch that must be positioned to transfer from winter to summer operation and back again.

Operating Sensitivity

The room humidistat as described here is not as precise a controller as a standard room thermostat. Normally, a change of 5 percent RH is required to actuate the switching action. Therefore, with the dial set at, say, 35 percent RH, room conditions could easily vary from 30 to 40 percent RH. This has been found acceptable for normal comfort applications, since people cannot detect, nor do they react to changes in RH with the same sensitivity as room temperature.

The student should be aware, however, that more precise controls are available for specialized applications, such as computer rooms, libraries, printing plants, etc., where controllers such as wet bulb and dew point thermostats would be used.

Avoiding Condensation

Controlling winter indoor humidity is also complicated by the fact that indoor RH levels must be decreased with decreasing outdoor temperatures to avoid damaging condensation problems in walls, on windows, and in roofs.

For example: on a day near 0° F outdoors, an indoor RH of about 20 percent is recommended. Above 20° F outdoors, however, 35 percent RH is considered safe indoors. Thus, the homeowner must manually readjust the humidistat's set point to a lower value as winter weather becomes more severe. But, like thermostat droop, compensating humidistat controllers are available that can automatically readjust set points up or down.

Summer Reheat

As noted briefly before, the use of a humidistat to control residential and apartment air conditioning equipment is quite possible but not very common. The combination of proper cooling coil design to obtain correct latent heat or moisture removal rate, plus close sizing of cooling units has resulted in acceptable humidity levels under ordinary thermostat control for average conditions in homes and apartments in most areas of the country.

In extremely humid areas, or for unusual occupancy requirements, a humidistat and a thermostat can be teamed (in parallel with each other, and in series with the compressor's contactor relay) to provide improved RH control.

To avoid overcooling on humid but cool days, the air leaving the air conditioning unit must at times be reheated to room temperature, either using electric elements or using a more complex arrangement involving hot refrigerant gas. This, of course, involves the use of additional controllers.

How to Install a Room Humidistat

Guidelines on installing a room humidistat follow closely the rules governing thermostat installation.

1. Mercury switches (if used) must be level --- use a spirit level to check alignment.

2. Locate the humidistat:
    a. In a room that is supplied with conditioned air.
    b. Where it will be exposed to normal air circulation.
    c. Away from extraneous sources of moisture, above a fish tank, in a kitchen, etc.

3. All wires should be firmly connected and splices should be soldered or made with tightly connected clean wire.

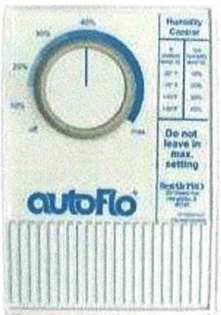
4. Use color coded thermostat cable (# 18 or larger) to reduce the possibility of incorrect wiring.

5. When wiring between the room humidistat and a control panel, wire from function to function with color-coded wire.

Humidistats to control winter humidification equipment can also be installed in the return air duct system as well as in a room location. The device senses the humidity of the return air and turns the humidifier on or off accordingly. Usually these devices are powered by line voltage rather than 24 volts. *(Caution: In this condition, the humidistat is placed before the furnace or air handling filter, so that unfiltered air may change the sensing ability of the controller and may require to be cleaned of dust and dirt from time to time.)*

Some duct-mounted humidistats are fitted with a "sail switch." The sail senses air flow and provides a simple interlock with the humidification equipment so that the humidifier operates only when the system fan is running.

Honeywell S688A-1007 Sail switch.



Duct mounted humidistat (may be converted to wall mount)

Duct-mounted humidistats may also feature double pole switching so that year-round humidification and dehumidification control can be achieved.

Current relays may also be used to activate the humidifier circuit. A special current sensing relay using a sensing loop is used. By running the "common" wire of a 120 volt motor through the sensing loop, the current sensed by the motor being activated closes a set of contacts to activate the humidifier circuit. The humidifier circuit will only be made if the indoor motor is operating.

Currently, with the integrated circuit boards installed in furnaces and air handling equipment today, the humidifier terminal connections to the line voltage are made part of this board. These terminals are then energized whenever the indoor fan motor is activated. 120 volt connection can be made to the humidifier itself or to the primary side of a control transformer for the humidifier control circuit.

Self-Check, Lesson 8 Quiz

You should have read all the material in Lesson 8 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 Comfort involves the control of both temperature and humidity indoors.

2. T F In the wintertime, indoor humidity levels are most often less than desired for good comfort.

3. T F It is necessary to have two separate humidistats for summer and winter operations.

4. T F Human hair lengthens as the moisture level surrounding it decreases.

5. T F In certain applications, a nylon ribbon provides the sensing function.

6. T F Moving the adjusting dial on a humidistat changes the tension on the sensing element.

7. T F A humidistat can be fitted with a seasonal changeover switch.

8. T F A wall-mounted humidistat is just as sensitive as a room thermostat.

9. T F The average person can sense very small changes in humidity levels.

10. T F There's only one way to control or regulate humidity.

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

11. To avoid damaging condensation on a near 0° winter day, the indoor humidity is best set at:

a. 20 percent RH.
b. 35 percent RH.
c. 45 percent RH.
d. over 50 percent RH.

12. The best place to locate a humidistat is:

a. in the kitchen.
b. near the laundry room.
c. in a dark room.
d. away from extraneous sources of moisture.

13. A humidistat is most often used to directly control the operation of:

a. furnace.
b. blower.
c. power humidifier.
d. boiler.

14. In the ordinary air conditioning installation, comfort control is accomplished by means of a:

a. humidistat alone.
b. thermostat alone.
c. combination humidistat and thermostat.
d. rheostat.

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

15. A homeowner must ___________ the set point on his humidistat as the weather gets colder.

16. _______________ permits both ____________ and close ______________ regulation in the summertime.

17. In the reheat system, on cool, humid days, after removing the _________________ from the air, the air is __________________ to room temperature to avoid overcooling of the structure.

18. When wiring, any splices in the low voltage wiring connecting the humidistat should be ______________________.

19. The typical low voltage wire size used to connect a humidistat is number _____________ AWG (American Wire Gauge).

20. Dehumidification means to ___________________ moisture from the air.

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.

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. The student is encouraged to refer back to the lesson for those questions missed and reread the material.

Self-Check Lesson 1

1. T
2. T
3. T
4. T
5. T
6. F
7. F
8. F
9. F
10. T
11. T
12. F
13. T
14. F
15. T
16. F
17. T
18. T
19. F
20. F
21. a
22. c
23. d
24. a
25. c
26. c
27. d
28. c
29. d
30. b
31. a
32. c
33. batteries; generator
34. single phase/polyphase
35. electromagnet
36. series
37. volt
38. series

Self-Check Lesson 2

1. T
2. F
3. T
4. T
5. F
6. T
7. T
8. T
9. F
10. T
11. T
12. F
13. F
14. F
15. F
16. T
17. c
18. a
19. b
20. d
21. c
22. a
23. c
24. a
25. b
26. d
27. inrush
28. 2
29. 20
30. volt amps
31. V x I x PF
32. capacity
33. phasing
34. voltmeter/voltage/transformer

Self-Check Lesson 3

1. F
2. T
3. F
4. T
5. T
6. T
7. T
8. T
9. T
10. F
11. F
12. F
13. a
14. c
15. d
16. a
17. a
18. c
19. loads
20. open/closed/motor/thermostat/anticipation
21. series
22. switch/load/power source.....................................

Self-Check Lesson 4

1. T
2. T
3. F
4. T
5. T
6. T
7. T
8. F
9. T
10. F
11. T
12. c
13. a
14. c
15. c
16. c
17. c
18. a
19. b
20. c
21. b
22. fan/system
23. bimetal/electric contacts/thermometer/dial/fan & system switches/anticipator/base and cover
24. dirt/moisture/corrosion
25. air temperature
26. moving/fixed
27. air

Self-Check Lesson 5

1. F
2. T
3. F
4. T
5. T
6. F
7. T
8. F
9. F
10. T
11. T
12. F
13. d
14. b
15. a
16. a
17. a
18. c
19. a
20. a
21. c
22. variable/fixed
23. parallel/series
24. system lag/operating differential
25. before
26. operating differential
27. temperature change
28. fixed/adjustable/voltage/cycle/bimetal

Self-Check Lesson 6

1. T
2. T
3. T
4. T
5. F
6. F
7. F
8. T
9. T
10. T
11. F
12. T
13. F
14. T
15. F
16. b
17. d
18. c
19. d
20. a
21. d
22. c
23. b
24. thermistor/raise
25. less

Self-Check Lesson 7

1. T
2. T
3. T
4. T
5. T
6. T
7. F
8. F
9. T
10. T
11. F
12. T
13. F
14. b
15. b
16. a
17. b
18. soldered
19. motorized air damper
20. heating/cooling
21. two
22. heat anticipator
23. 2

Self-Check Lesson 8

1. T
2. T
3. F
4. F
5. T
6. T
7. T
8. F
9. F
10. F
11. a
12. d
13. c
14. b
15. lower
16. reheat/temperature/humidity
17. moisture/heated
18. soldered
19. 18 most commonly used
20. remove

Appendix B: Glossary

AMBIENT TEMPERATURE: The Temperature surrounding or in the vicinity of a control.

ANTICIPATOR: Small resistance heater placed inside thermostat housing to help thermostat lead or "anticipate" room heating and cooling needs by artificially warming thermostat's sensing elements.

AUTOMATIC PILOT: Refers to the system that provides ignition and safety shutoff for gas burners using a tiny "pilot" flame.

BIMETAL: Sensing element made of two metals with different coefficients of expansion rigidly joined together to cause useful mechanical motion due to heating or cooling of the bimetal.

CdS CELL: Acronym for photo resistance cell made of Cadmium Sulfide. This solid state device changes its electrical resistance when exposed to light. Use: Oil burner safety shutdown.

CHANGEOVER RELAY: Control element is used in heat pump systems to activate refrigerant reversing valve for heating or cooling operation. Not to be confused with reversing relay.

COMBINATION FURNACE CONTROLS: A common controller that combines the functions of the fan switch and high limit safety control into one device.

COMPENSATED CONTROL: The set point of a controller is adjusted up or down as conditions elsewhere change (e.g., set point of room thermostat is raised as outdoor temperature decreases).

CONTACTOR: A magnetic relay of suitable high capacity that can switch large motor-compressor electrical loads.

CONTACTS: The switch side of a relay or contactor.

CONTROL AGENT: The medium regulated by a controlled device. It may be air or gas flow, steam or water, or even electric current.

CONTROLLED DEVICE: A device in a control system that responds to the signals sent by a controller to start and stop or otherwise vary the operation of conditioning equipment (e.g., a gas valve that starts or stops fuel input).

CONTROLLED VARIABLE: The variable condition, temperature, humidity, or pressure that must be held constant.

CONTROLLER: Principal device, say a thermostat, in a control system that measures some variable condition that must be held constant (e.g., room air), and then activates a second device to regulate a medium (e.g., fuel) that affects the variable condition.

CONTROL POINT: The pressure, temperature or humidity actually being maintained as distinguished from the controller's set point which may be higher or lower.

CSR: Acronym for capacitor start, capacitor run indication motor.

DIODE: An electronic device (vacuum tube or solid state) that conducts electricity in only one direction. One use is to convert ac to dc current.

DROOP: The difference between a controller's set point and the actual control point (e.g., room thermostat set at 75° F, but room air stays at 73° F). Also called drift, deviation or offset.

FACTORY WIRING: Control circuit diagrams presented in functional arrangement using symbols and other shorthand notation.

FAN SWITCH: A controller that features a switch and sensing element inserted in a furnace that turns blower on or off at present leaving air temperatures.

FIELD WIRING: Control circuit diagrams presented in a pictorial or "as installed" fashion.

FINAL CONTROL ELEMENT: Last component in control chain. That portion of the controlled device that regulates control agent—valve, damper, etc.

HIGH LIMIT CONTROL: A controller that features normally closed switch and sensing element inserted in a furnace (or boiler) that shuts down burner (or electric heater) regardless of room thermostat demand when circulating air (or water) exceeds present limits.

HUMIDISTAT: A controller designed to sense changes in moisture levels in air. Uses nylon or hair sensor to open and close low voltage switch.

IMPEDANCE RELAY: Prevents compressor startup after a high or low refrigerant pressure shutdown, until a manual reset is performed. Sometimes called a lockout relay.

INHERENT PROTECTOR: A temperature and current sensitive device placed in a hermetic compressor to provide motor overload protection.

LINE VOLTAGE: Full voltage available for use. Usually 110 or 220 volts.

LOW LIMIT CONTROL: A controller that features a switch and sensing element used in heating boilers that also provide domestic use by activating burner regardless of heating thermostat demand.

LOW VOLTATE: Voltage that is 30 volts or less. Usually provided by means of a step-down transformer.

MODULATING CONTROL: Differs from simple on-off or two position control action in that control agent can be regulated from fully on down to fully off in continuous or discreet steps.

MOTOR STARTER: A magnetic contactor that also contains a current overload relay to protect motor.

NEC: Acronym for National Electrical Code published by the National Fire Protection Association.

NEMA: Acronym for National Electrical Manufacturers Association.

OPERATING DIFFERENTIAL: The overall swing (high point minus low point) of a controlled variable that's necessary to activate a controller.

OPERATOR: One of two functional components in a controlled device. The operator converts signal from controller into a useful local action (e.g., motor that converts electric signal into rotating mechanical motion). See also final control element.

PHOTOCELL: A special vacuum tube that generates small electric current when exposed to light.

PILOT GENERATOR: Refers to pilot burner/thermocouple side of automatic gas pilot system, and is usually applied to systems using other than just a single couple.

PF: Acronym for power factor, the correction factor to be applied to the product of volts times amps in ac circuits to account for voltage and current phase differences.

POTENTIAL RELAY: Sometimes called starting or voltage relay. This device cuts out starting circuit in CSR motor driven compressors.

PRIMARY CONTROL: Used most often in reference to an oil burner controller whose functions include starting and stopping burner, ignition, and safety shutdown.

PSC: Acronym for permanent split capacitor motor.

RELAY: An electric switch that permits low voltage controllers to operate equipment powered by high voltages.

REVERSING RELAY: Permits SPDT thermostat to control heating and cooling equipment by forming an interlock that prevents mutual operation.

SAFETY DEVICE: A control that is added to detect a dangerous condition and stop an action or take a new action to remedy problem.

SCR: Acronym for Silicon Controlled Rectifier. It is, in effect, a solid state or electronic switch with no moving parts that can turn current on and off.

SENSING ELEMENT: One of two recognizable components in a controller. Sensing element measures any change in the controlled variable. See also transducer.

SET POINT: The value of the controlled variable (e.g., room air) at which the controller (e.g., thermostat) is set and represents the desired or idealized value to be maintained.

SOLENOID: An electric device for converting electric energy into a mechanical displacement. Usually consists of a magnetic coil and plunger that can move short back and forth distances as the coil is energized or de-energized.

SOLID STATE DEVICE: A group of electronic components that perform jobs similar to vacuum tubes, but unlike tubes they are not electrodes enclosed in glass but rather specifically prepared solid matter.

SWITCHING ACTION: The term pole and throw in combination with the terms single and double are used to describe the action or electric switches. A single-pole switch has functionally one movable "blade" contact. A double=pole switch has two. A single-throw switch can connect to only one circuit or one fixed contact. A double-throw switch can connect a common lead to either of two circuits or two different fixed contacts. These features are usually abbreviated SPST—single-pole, single-throw; SPDT—single-pole, double-throw, etc.

THERMAL DELAY RELAY: Prevents short cycling of compressor by delaying thermostat's call for cooling for several seconds.

THERMISTOR: A solid state sensing device whose electrical resistance varies dramatically with changes in temperature.

THERMOCOUPLE: A means to directly convert heat into small amounts of useful electric current. One end of two dissimilar wires connected together is heated, producing a small voltage across the other ends.

THERMOSTAT: Once a trade name, it has become a standard term for a temperature controller, but particularly in reference to a room air temperature sensing device.

TIMER MOTOR: Electric motor drives a cam that actuates defrost switch at specific time intervals to begin defrosting of outdoor coil when heat pump is on heating cycle.

TRADE NAMES: Because of pioneering development, or merely common usage, some control devices are referred to by their manufacturer's marketing names. The new control technician should not let this become confusing.

TRANSDUCER: Current amplifying solid state device that's equivalent to a triode vacuum tube.

TRANSFORMER: An electrical device that efficiently converts high voltage power to low voltage power (or vice versa).

TWO POSITION CONTROL: A mode of control action that can only turn equipment fully on or fully off.

Wiring Symbols and Abbreviations

Schematic or factory type wiring diagrams are used most often to illustrate electrical component functions. It is essential that the student become thoroughly familiar with the standard symbols and circuit abbreviations used in the heating and air conditioning industry.

Line Voltage Terminals	Function
L1, L2, L3	Incoming power connections
T1, T2, T3	Switched power load connections
(4) (5) (6)	Auxiliary switched load connections

Load Designations	Component
CC	Contactor Coil
CC1, CC2, CC3	Contactor Contacts
FR	Fan Relay Coil
FR1, FR2, FR3	Fan Relay Contacts
SR	Solenoid Relay or Reversing Valve
SR1, SR2	Solenoid Relay Contacts
TD	Time Delay Device
TD1, TD2	Time Delay Contacts

Low Voltage Terminal Designations

Two distinct systems of low voltage terminal designations have been used in the heating and air conditioning industry. One was based on the function of the specific load to which the terminal was connected—"F" for fan circuit, "C" for cooling circuit, etc. The other system was based on a color code. In this system, "G" was used for the fan circuit, "Y" for the cooling circuit, "W" for the heating circuit, and "R" for the power supply. Using color-coded cable—green for the fan circuit, yellow for the cooling circuit, etc.—simplified system hookup and troubleshooting.

The existence of both systems caused some confusion; and for a period of time, a combination terminal marking system was used. In the combination system, terminal designations for a fan circuit were marked "F/G" and terminals for a cooling circuit were marked "C/Y." At the present time, only the color code method is used for low voltage terminal designations.

Low Voltage Code

Color	Function	
R	V	Hot switched leg of 24 volt ac power used on heating only thermostats and heat/cool thermostats with a common power supply
W	H	Heating—single stage
Y	C	Cooling—single stage
G	F	Fan circuit
B	Z	Heating circuit—constant energization through a manual switch
O	D	Cooling circuit—constant energization through a manual switch
RH	M	Isolated power terminal for heating circuit used on heat/cool thermostats with isolated circuits—jumper supplied
RC	V	Isolated power terminal for a cooling circuit used on heat/cool thermostats with isolated circuits—jumper supplied
W1	H1	Heating—first stage of two-stage units
W2	H2	Heating—second stage of two-stage units
Y1	C1	Cooling—first stage of two-stage units
Y2	C2	Cooling—Second stage of two-stage units
X	L	Warning light (dirty filter, electric heat, etc.)