Fundamentals of Heating Systems

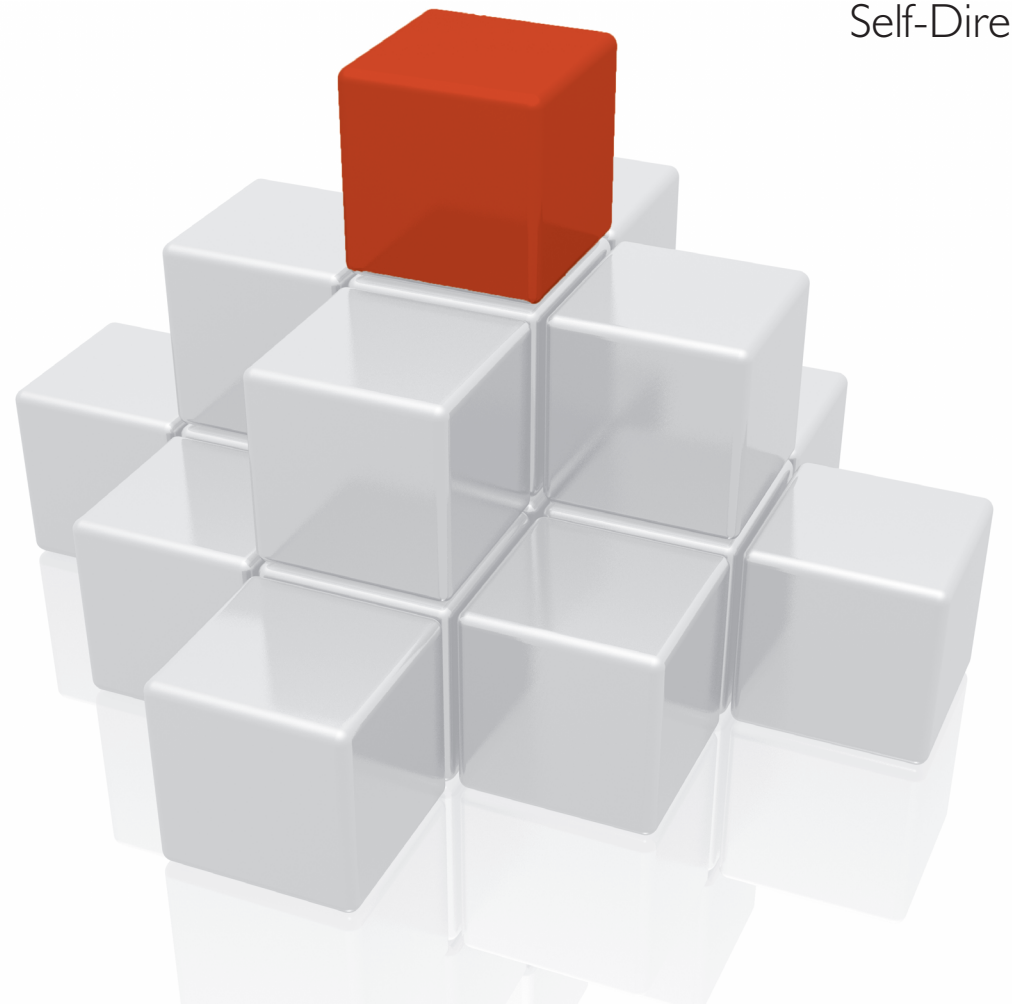
Second Edition

Mark Hegberg

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Fundamentals of Heating System Design

Second Edition

Mark Hegberg

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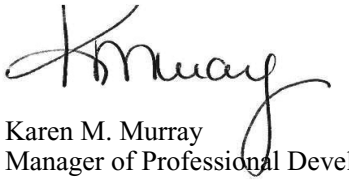
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Fundamentals of Heating System Design

Second Edition

Introduction

Instructions

This chapter is introductory in nature and contains little technical material beyond the introduction of terminology and the units that will be used in this course. You should review the terminology in Appendix A to learn the terms that are used. Also, an extensive list of references is included in Appendix B if you desire more in-depth analysis of this material.

COURSE OVERVIEW

This course begins with an overview of the various options available for heating system design, including the distribution system within the building, the energy conversion plant, and the fuel source. While these three components are discussed separately, often the selection of one of the three will limit the number of options available for the other two components in the system. While some solid fuel heating systems will be discussed, most heating plants in use today use gas (natural or propane), electricity, or oil as the fuel. Large industrial systems (which may use coal or other solid fuels) are discussed insofar as they may be used for space heating. Their application for process heating or high-pressure steam generation is beyond the scope of this course, which addresses primarily residential and commercial building heating systems.

Before a heating system can be designed, numerous other factors must be considered. These include the building occupancy, the building envelope, outdoor air ventilation requirements, regional preferences for certain types of systems, and the availability of fuels. These parameters will dictate the size of the system, the type of distribution systems that are appropriate, and the ultimate annual operating cost. The amount of outdoor air that is specified will usually depend on the occupancy of the space and local building codes. Most ventilation codes in the United States are based in some form on ASHRAE Standard 62.1. The most current version is ASHRAE Standard 62.1-2016, *Ventilation for Acceptable Indoor Air Quality*. The 1989 revision of this standard increased the minimum outdoor air requirement from 5 cfm per person to 15 cfm per person. Later versions modified that value significantly. Over the years, a variety of different ventilation rates

have been used, often based on the type of occupancy in the ventilated space. In addition to ASHRAE Standard 62.1, there has also been significant evolutionary change to the model and local building codes and their required outdoor air required ventilation rates and system design requirements. Changes to the quantity of ventilation air has had a significant impact on system design, as it often makes heat recovery systems more economically attractive in heating-dominated climates, while the efficiency of the heating plant has more impact in life-cycle analyses.

A significant portion of this course addresses the many types of heating systems that are used in commercial buildings. The great variety of commercial systems attests to the many applications for which heating systems are needed, and to the fact that these systems are practically always designed by engineers. These are two primary reasons why commercial heating systems are often far more complex than those found in residential applications. Commercial systems will usually be designed to take advantage of certain features in the distribution system or the heating plant to more closely match the requirements of the occupants or the building envelope.

A large class of heating equipment falls in the category of unitary systems. These are systems that are fabricated at the factory and are installed largely intact at the site. Unitary systems encompass practically all types of distribution systems, heating plants, and fuel types, but are usually smaller in size because of practical limitations in transportation and erection. The very large systems will normally be field-erected from many large components according to the engineer's design.

On the basis of sheer numbers, there are many more residential heating systems than commercial, industrial, and all other types combined. While larger commercial buildings will typically have a space cooling system installed, a significant number of houses, particularly in Europe, will only have a heating system. Over 80% of houses in the United States are air conditioned, and so air conditioning must be a primary consideration in the type of distribution system that is selected for the heating system. The vast majority of air-conditioning systems used a forced-air delivery system, making a forced-air heating system a logical choice to keep installed costs reasonable. Solar energy does hold some promise for certain residential applications, although it is quite difficult to justify economically for larger applications. The economics of heating systems—addressing installation and operation and maintenance costs—are covered in Chapter 7, which also addresses life-cycle costs. It is becoming increasingly important for customers to understand the total costs associated with their heating systems, not simply the installed cost at the time of construction or renovation.

The final two chapters in this course address codes, standards, and the commissioning and maintenance of heating systems. Building codes are revised approximately every five years, so this course will simply attempt to make you aware of the sources of these codes and the implications they have on the design of heating systems. When designing heating systems, you should always be not only familiar with the current local codes that apply to that particular job, but

also in compliance with the code. Your systems must follow local code that, in turn, follows either model codes or standards that have been legally adopted. The system must also follow the instructions of local code officials.

Commissioning and maintenance have received more attention in ASHRAE as heating systems have become more complex. Large commercial HVAC systems do not come with an owner's manual for complete operating and maintenance instructions, so it is not always obvious whether these HVAC systems are operating as they were designed. Contacting independent companies that can conduct system performance analysis and/or system balancing is often an important step in turning over the completed project to the new building owner or operator.

TERMINOLOGY

Many of the terms used in this course are listed in Appendix A. An understanding of the HVAC&R terminology is important for a clear understanding of heating system operation. These terms are taken from *Terminology of Heating, Ventilation, Air-Conditioning, & Refrigeration* (ASHRAE 1991).

The engineering units used throughout this course are in either inch-pound (I-P) units, or system international (SI). In the United States the metric-based SI system is occasionally used, but in the HVAC&R industry progress towards complete used of SI is slow. U.S. practitioners will need the ability to work between both sets of units for the foreseeable future. Table 1-1 lists the most common units that are used for the many variables in this text, while Table 1-2 gives factors to convert between the I-P and SI units. In this day and age of smartphones, tablets, personal computers, and other connected devices, there are many freely available apps and web-based resources to convert virtually any unit from I-P to SI and back again.

Table 1-1 Dimensions and Units Commonly Used in Air-Conditioning Applications

Dimension	I-P Unit	SI Unit
Acceleration	ft/s^2	m/s^2
Area	ft^2	m^2
Density	lb_m/ft^3	kg/m^3
Energy	Btu, $ft \cdot lb_f$	N·m, joule (J)
Force	pound (lb_f)	$(kg \cdot m)/s^2$, newton (N)
Length	foot (ft)	m, metre (m)
Mass	pound mass (lb_m)	kg, kilogram (kg)
Power	Btu/h	J/s, watt (W)
Pressure	psi	N/m^2, pascal (Pa)

Table 1-1 Dimensions and Units Commonly Used in Air-Conditioning Applications *(Continued)*

Dimension	I-P Unit	SI Unit
Specific heat	Btu/lb$_m$·°F	J/(kg·°C) or J/(kg·K)
Time	second (s)	second (s)
Temperature (absolute)	degree Rankine (°R)	kelvin (K)
Temperature	degree Fahrenheit (°F)	degree Celsius (°C)
Thermal conductivity	Btu/h·ft·°F	W/(m·°C) or W/(m·K)
Thermal flux density	Btu/h·ft^2	W/m^2
Velocity	ft/s, ft/min, fpm	m/s
Volume	ft^3	m^3
Volume flow rate	ft^3/s, ft^3 /min, cfm	m^3/s

Table 1-2 Unit Conversion Factors

Dimension	I-P Unit	SI Unit
Length	1 ft = 0.305 m	1 m = 3.281 ft
Area	1 ft^2 = 0.0283 m^2	1 m^2 = 10.76 ft^2
Volume	1 ft^3 = 0.0929 m^3	1 m^3 = 35.32 ft^3
Mass	1 lb$_m$ = 0.435 kg	1 kg = 2.205 lb$_m$
Force	1 lb$_f$ = 4.448 N	1 N = 0.2248 lb$_f$
Energy	1 Btu = 778.2 ft·lb$_f$ = 1.055 kJ	1 kJ = 0.9478 Btu
	1 ft·lb$_f$ = 1.356 J	1 J = 0.7376 ft·lb$_f$
	1 Btu = 2.930 × 10^{-4} kWh	1 kWh = 3.412 × 10^3 Btu
Specific Energy	1 Btu/lb$_m$ = 2.326 kJ/kg	1 kJ/kg = 0.4298 Btu/lb$_m$
Power	1 Btu/h = 0.293 W	1 W = 3.412 Btu/h
	1 hp = 2545 Btu/h = 0.746 kW	1 kW = 1.341 hp
	1 ton = 12,000 Btu/h = 3.516 kW	1 kW = 0.2844 ton refrigeration
Pressure	1 psi = 6.897 × 10^3 Pa	1 Pa = 1.450 × 10^{-4} psi
	1 atm = 14.7 psi = 29.92 in. Hg	1 atm = 101 kPa
Temperature	1°F ΔT = 5/9°C ΔT	1°C ΔT = 9/5°F ΔT
	y°F = (y – 32)(5/9)°C	y°C = [(9/5)y + 32]°F
	°R = °F + 459.68	K = °C + 273.15

Table 1-2 Unit Conversion Factors (Continued)

Dimension	I-P Unit	SI Unit
Velocity	1 ft/min = 5.079×10^{-3} m/s	1 m/s = 1.969×10^{2} ft/min
Mass Density	1 lb_m/ft^3 = 16.02×10^{2} kg/m^3	1 kg/m^3 = 6.243×10^{-2} lb_m/ft^3
Mass Flow Rate	1 lb_m/s = 0.4535 kg/s	1 kg/s = 2.205 lb_m/s
	1 lb_m/h = 1.260×10^{-4} kg/s	1 kg/s = 7.937×10^{3} lb_m/h
Volume Flow Rate	1 cfm = 4.719×10^{-4} m^3/s	1 m^3/s = 2.119×10^{3} cfm
	1 gal/min = 6.309×10^{-5} m^3/s	1 m^3/s = 1.585×10^{4} gal/min
Thermal Conductivity	1 Btu/h·ft·°F = 1.731 W/(m·°C)	1 W/(m·°C) = 0.5778 Btu/(h·ft·°F)
Heat Transfer Coefficient	1 Btu/h·ft^2·°F = 5.679 W/(m^2·°C)	1 W/(m^2·°C) = 0.1761 Btu/(h·ft^2·°F)
Specific Heat	1 Btu/lb_m·°F = 4.186´103 J/(kg·°C)	1 J/(kg·°C) = 2.389×10^{-4} Btu/(lb_m·°F)

REFERENCE MATERIALS

A list of general references is included in Appendix B if you want to go into depth in any of the topics covered in this course. This is only intended as an introductory course to the subject of heating systems. Upon completing this course, you should review some of the references for further study in these areas.

2 Overview of Heating Systems

Study Objectives

Chapter 2 introduces the basic structure of heating systems in their simplest form: the source, plant, and system. This chapter addresses the issue of how selecting one component in the system may limit the options for the other parts of the system. The various options that are in common usage for each component in the heating system will be discussed briefly. Complete this chapter with an appreciation of the many options that are available to heating system designers.

Instructions

Read the material in Chapter 2. Verify the examples presented in the chapter with your own calculations. At the end of the chapter, complete the skill development exercises without referring to the text. Review those sections of the chapter as needed to complete the exercises.

BASIC HEATING SYSTEM COMPONENTS

While there are dozens, and in some cases hundreds, of components that comprise heating systems, they can be categorized into three basic functions:

- Source
- Loads
- Distribution system

Once it has been decided to provide heat at some point in a facilities occupancy for maintaining comfort or just for protecting property, there is an implied load on the facility; the temperature within the space has decreased by heat transfer across the envelope significantly enough to have to replace the lost energy. To get that energy into the space we must convert some stored form of energy to heat (e.g., by burning a log, lighting a kerosene lamp, starting a gas burner) Something must be available as an energy source to release itself as heat when put through some sort of process, this must be done in a manner that

is safe to the occupant and/or the facility and does not make the interior environment less habitable. So, if we think about the simple process of lighting a log, we must have a noncombustible method off holding it while it burns, and we must also make sure that it cannot burn the structural environment around it. When the log burns, besides producing heat, we also use oxygen and create products of combustion that can be harmful. Therefore, we must design a burning process that allows for combustion air to enter the system and products of combustion to be carried away, while at the same time allowing the heat to stay and do useful work conditioning the environment. If only one small space is being serviced, such simple methods of heating may be adequate. However, for larger spaces or several separated areas distance from the heat source, more complicated measures are needed.

Our need for complex heating gave rise to better ways to centrally convert energy into heat and then transport it through a distribution system to a heat exchanger that would transfer the energy to the space where it was required. Today we have stored energy that we can convert to do heating work. We have a distribution system that carries a medium through the source, warming it and transporting it to where it is needed to do the usable work. We also have a load, which is not only the place where the heat is required, but also a method of getting the energy out of the distribution medium into the space that requires heating.

Theoretically, a heating system could operate with only these three components (source, load, and distribution system). Figure 2-1 diagrams that concept for a basic hydronic heating system and illustrates some of the additional elements that come into play for any type of heating system that we may be called on to design or operate. In the recent past (up until about 1930), hot-water heating systems were designed as gravity hot-water heating systems. Heated water, being less dense than unheated water, naturally rose through a piping system, transporting it to a radiator which, when warmed, created natural convective air currents, heating cold air, which would then rise and then fall as it cooled, circulating heat to the required space. Of course as the water was heated and then subsequently cooled, there would also be changes in the contained volume of

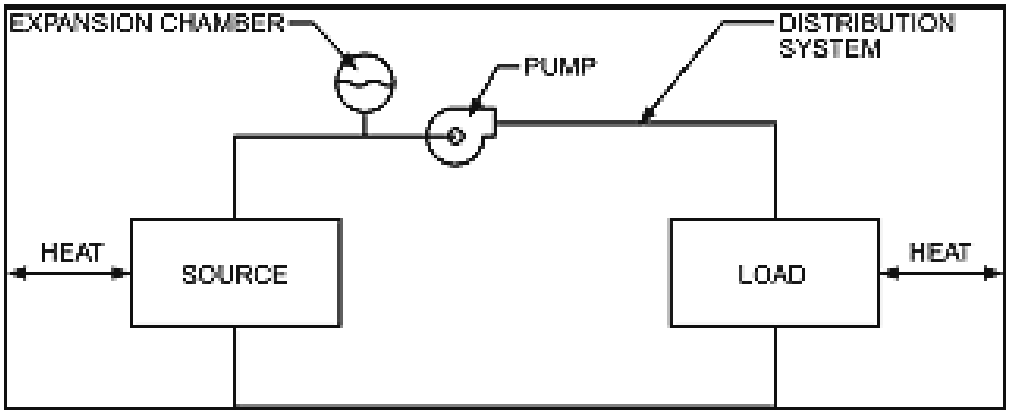


Figure 2-1 Elements of basic heating system.