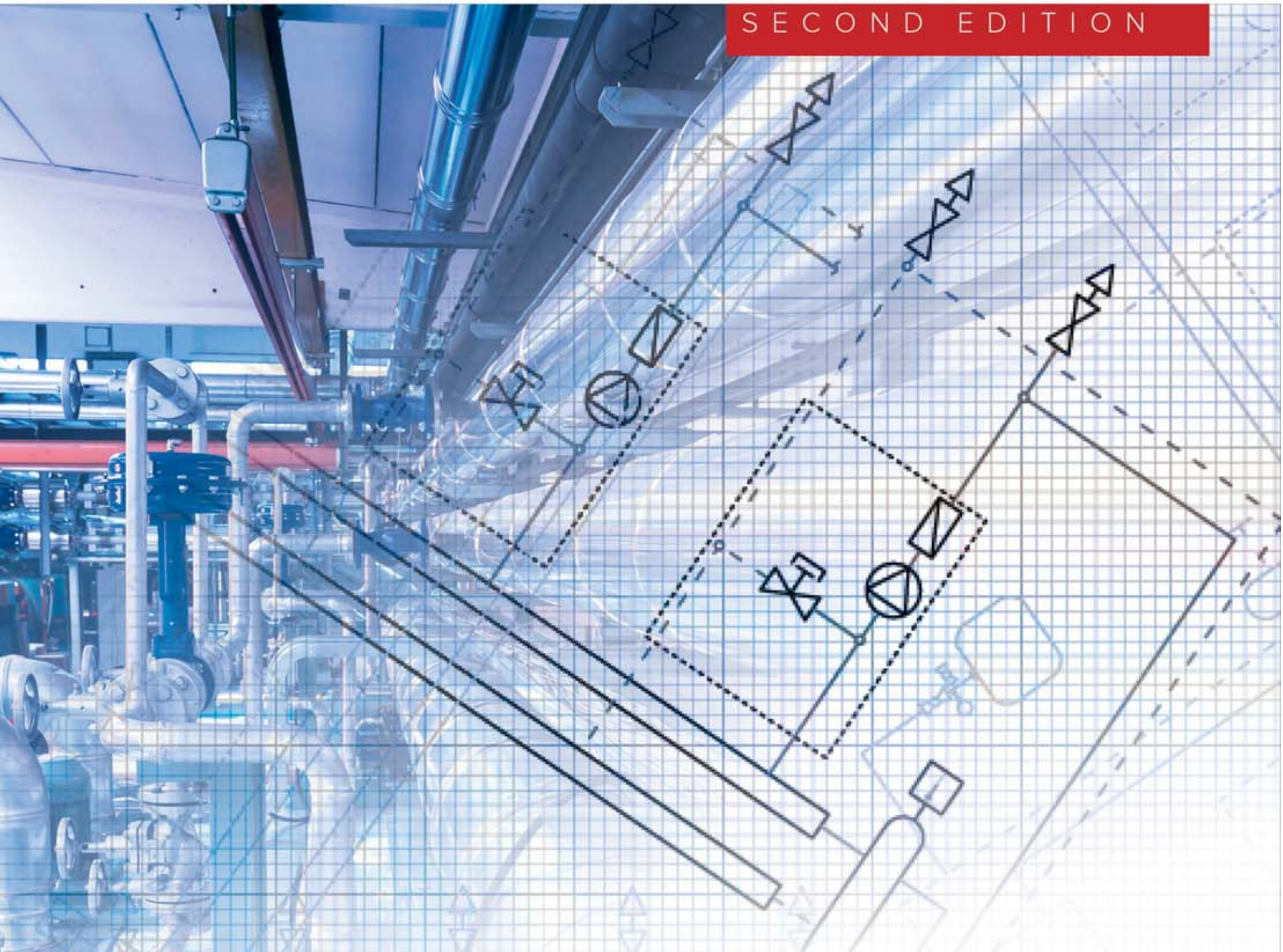
# HVAC DESIGN SOURCEBOOK

SECOND EDITION



W. Larsen Angel, P.E, LEED AP

Mc Graw Hill

# HVAC Design Sourcebook

## About the Author

**W. Larsen Angel,** P.E., LEED AP, is a principal in the MEP consulting engineering firm Green Building Energy Engineers. He has worked in the MEP consulting engineering industry for more than 30 years. Mr. Angel has contributed to the development of design standards and continues to find new ways to streamline the HVAC system design process.

# HVAC Design Sourcebook

W. Larsen Angel, P.E., LEED AP

**Second Edition**

New York Chicago San Francisco
Athens London Madrid
Mexico City Milan New Delhi
Singapore Sydney Toronto

ISBN: 978-1-26-045725-4
MHID: 1-26-045725-7

The material in this eBook also appears in the print version of this title: ISBN: 978-1-26-045724-7, MHID: 1-26-045724-9.

eBook conversion by codeMantra
Version 1.0

**To Lisa, my dear wife, who is my one and only true love.**
**Thank you for the insights and help you provided for this book,**
**and for life in general. You are truly my inspiration.**

**"… with God all things are possible."—Matthew 19:26**

# Contents

*This page intentionally left blank*

# Preface

Are you searching for a practical handbook that will assist you in the process of designing heating, ventilating, and air-conditioning (HVAC) systems for commercial buildings? The *HVAC Design Sourcebook* is the tool you need to quickly become a valuable member of your design team.

The typical approach to training junior employees in the process of designing HVAC systems is to have them try to learn the skills they need to work as effective members of a design team from the senior HVAC engineers they are working under. Unfortunately, the knowledge the senior engineers are expected to impart has taken them years to develop and, without a practical training resource, the process of teaching junior HVAC system designers the essentials of HVAC system design becomes time-consuming, ineffective, and costly.

The *HVAC Design Sourcebook* fills the void in the industry for a practical resource to assist in the process of training junior HVAC system designers in the basics of HVAC system design. Essential design concepts are clearly explained and illustrated with photographs of actual HVAC systems installations and graphical conventions used in the preparation of construction drawings. Codes and standards are referenced frequently to emphasize the need for HVAC systems to be designed in accordance with the requirements of the regulating authorities. Other topics such as the overall design process, HVAC systems and equipment, piping and ductwork distribution systems, noise and vibration control, and automatic temperature controls are presented in a manner that can be understood and applied by the junior HVAC system designer. The ultimate goal of preparing complete, well-coordinated HVAC system construction drawings is consistently in view throughout the book.

New for this second edition of the *HVAC Design Sourcebook* is a discussion of variable refrigerant flow (VRF) systems, strategies to control indoor air relative humidity, essential sustainable design practices, central plant optimization, construction administration, and the commissioning process. Finally, the concepts presented in the *HVAC Design Sourcebook* are applied to an example HVAC system design project.

The *HVAC Design Sourcebook* is the essential resource for individuals who are considering or pursuing a career in the field of HVAC system design.

For further online materials relating to this book, please go to www.mhprofessional.com/HVACdesign

*W. Larsen Angel, P.E., LEED AP*

*This page intentionally left blank*

# Acknowledgments

Thanks to my two sons, Larsen Jr. and Christian, for their encouragement. Special thanks to Larsen Jr. for his help with this book.

*This page intentionally left blank*

# HVAC Design Sourcebook

# CHAPTER 1

# What Is HVAC?

The term *HVAC* stands for heating, ventilating, and air-conditioning. It describes the field that is concerned with heating, ventilating, and air-conditioning the indoor environment in order to meet the comfort, health, and safety needs of building occupants and the environmental needs of indoor equipment or processes. Although HVAC systems are required for airplanes, ships, automobiles, and other special applications, this book will focus on HVAC systems for commercial buildings.

Heating and ventilating systems for buildings have been in existence for centuries. Fireplaces and windows, the earliest forms of indoor heating and ventilating, remained the primary means of heating and ventilating buildings into the late nineteenth century. It was in the nineteenth century that engineers began to use steam heating systems, which consisted of coal-fired boilers, pipes, and radiators, to heat buildings. Steam heating systems are still widely used today, although natural gas and fuel oil have replaced coal as the primary fuel source.

In the Middle Ages, people made the connection between "bad air" in overcrowded or smoky rooms and disease. In the eighteenth and nineteenth centuries, scientists and physicians began to study the sources of indoor air contaminants and the effects these contaminants had on human health. As a result, in 1895 the American Society of Heating and Ventilating Engineers (ASHVE) adopted a minimum ventilation rate of 30 cubic feet per minute (cfm) of outdoor air per occupant as a ventilation standard for public buildings. It was understood at the time that this ventilation rate was sufficient to dilute the indoor air contaminants to a level that was acceptable for human occupancy. Outdoor air ventilation rates that are required to produce acceptable indoor air quality for various occupancies continue to be studied by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the successor of ASHVE. *ANSI/ASHRAE Standard 62.1-2019—Ventilation for Acceptable Indoor Air Quality* is devoted to the subject of indoor air quality. The guidelines of this standard have largely been incorporated into the various mechanical codes applied to building construction, such as the *International Mechanical Code* (IMC), published by the International Code Council, Inc. (ICC).

Mechanical cooling (air-conditioning) systems are a relatively recent development. The first central building air-conditioning system, designed for the Missouri State Building, was demonstrated to the public during the 1904 World's Fair held in St. Louis. Since that time, a great deal of research has been performed and a wide variety of air-conditioning equipment has been developed to meet the diverse air-conditioning needs of modern buildings.

In addition to heating, ventilating, and air-conditioning the indoor environment to meet the comfort and health needs of the building occupants, modern HVAC systems are frequently required to protect the safety of the occupants or, in industrial applications, to provide a clean environment for the processes performed within the building. For example, smoke control systems may be required to minimize the spread of smoke within a building during a fire. Also, HVAC systems may be required to maintain air pressure relationships between adjacent spaces where hazardous materials are handled or infectious patients are being treated and to signal the building operator or activate emergency ventilation systems if these pressure relationships are not maintained. HVAC systems may also be required to provide a high level of air filtration in order to maintain a clean indoor environment for such processes as semiconductor fabrication.

With the understanding of what HVAC systems are and what they are expected to accomplish, it is the role of the HVAC system designer to design HVAC systems to meet project needs. In order to do this, the HVAC system designer must first understand the project requirements. The designer must then use this information, along with a knowledge of the potential HVAC system options, to design the HVAC systems (in accordance with the applicable codes) that are appropriate for the project. Factors governing the HVAC system selection and the ultimate HVAC system design include:

- HVAC system types that are available to meet the project needs
- Building owner's preferences or standards
- Building owner's budget
- Installed cost, operating cost, and maintenance cost of the potential HVAC system options
- Space limitations, both indoors and outdoors, and coordination with other building elements such as the architectural, structural, and electrical systems

After all factors have been considered and the final HVAC system configuration has been developed, the HVAC system designer must present the HVAC system design in a clear and concise way through the use of construction documents. Construction documents are the drawings and specifications for a project that are used by the installing contractor to construct the HVAC systems. The construction documents are also used by the building maintenance personnel as a resource in the ongoing operations and maintenance of the HVAC systems.

In this book, we will discuss the HVAC system design process from concept to completion of the construction documents (Chap. 2); piping, valves, and specialties, which are an integral part of HVAC systems (Chap. 3); the central plant, which is where fuel sources are converted to heating and cooling energy (Chap. 4); air systems, which circulate air within the building (Chap. 5); piping and ductwork distribution systems, which are used to distribute the heating and cooling energy from the central plant to the air systems and terminal equipment and eventually to the spaces within the building (Chap. 6); terminal equipment, which is often used in the distribution of the heating and cooling energy to the spaces within the building (Chap. 7); variable refrigerant flow systems, in which multiple, direct expansion indoor fan-coil units are connected to a single, outdoor heat pump or energy recovery unit (Chap. 8); humidity control, which is crucial for cooling operation in warm, humid climates (Chap. 9); noise and vibration control, which is a critical component of a successful HVAC system design (Chap. 10);

automatic temperature controls, without which HVAC systems cannot function properly (Chap. 11); sustainability, which is the process of designing HVAC systems with the goal of conserving natural resources and improving the overall indoor environment (Chap. 12); preparation of construction drawings, including some important drafting and computer-aided design concepts (Chap. 13); an example design project, including example construction drawings (Chap. 14); central plant optimization, which is employed to reduce energy use and cost (Chap. 15); construction administration, which is the process of ensuring that the HVAC systems construction corresponds to the HVAC systems design (Chap. 16); and the commissioning process, which is the process of ensuring that the HVAC systems function in the manner in which they were intended (Chap. 17).

*This page intentionally left blank*

# CHAPTER 2

# The Design Process

## HVAC Load Calculations

HVAC load calculations are the foundation upon which the HVAC system design is built. Therefore, it is imperative that the HVAC system designer accurately calculate the peak heating and cooling loads for the project in order to properly design the HVAC systems. The most accurate method for calculating the HVAC loads of a commercial building is the heat balance method. This method is described in detail in Chap. 18 of the 2017 *ASHRAE Handbook—Fundamentals*. The HVAC system designer must have a good understanding of this method in order to understand how a building's construction materials, geometry, orientation, and internal functions affect the HVAC loads within the different areas of the building.

Because the process of calculating HVAC loads is quite involved, commercially available HVAC load calculation software is used almost exclusively for commercial projects. This section provides an overview of the major considerations associated with HVAC load calculations for commercial buildings. The details of how building information is entered into the HVAC load calculation program will vary from one program to another. The HVAC system designer should consult the software user's manual for detailed instructions on how to set up the load calculations.

Buildings are affected by heating and cooling loads both external to and internal to the building. External loads include heat gains or losses from exterior walls (above and below grade), windows, roofs, skylights, doors, floors, partitions (walls, floors, and/or ceilings internal to a building that separate conditioned spaces from unconditioned spaces), and outdoor air leakage (referred to as infiltration). External loads vary with outdoor air temperature and relative humidity, the intensity and position of the sun, external shading, wind speed, and the temperature of the ground. External loads are also dependent upon the geographical location of the building. Internal loads include heat gains from people, lighting, and equipment. These loads also vary and depend upon the occupancy of the various spaces within the building and equipment usage.

In most situations, the goal of proper HVAC system design is to maintain a constant indoor air temperature year-round, regardless of the outdoor conditions or internal functions. In some cases, it is desirable to also maintain a constant indoor air relative humidity which adds complexity to the design due to the requirement to control an additional variable. Humidity control is discussed in Chap. 7.

In order to maintain a constant indoor air temperature, the HVAC systems serving a building must be sized to offset the heat that is lost from the various spaces within the building (when the heat losses exceed the heat gains) and offset the heat that is added to the various spaces within the building (when the heat gains exceed the heat losses).

## Terms

Before we continue with the discussion of HVAC load calculations for commercial buildings, it is necessary to define some terms:

- Space: The smallest area defined in the HVAC load calculation usually consists of a single room.
- Zone: Typically a collection of spaces, all of which have similar HVAC loading characteristics. HVAC loading characteristics are defined as the manner in which the HVAC loads vary within a space. For example, three offices located on the south side of a building would normally have similar HVAC loading characteristics because the spaces have a similar use and the heat gains and losses through the exterior building components would vary similarly for all of the spaces. Therefore, these spaces would commonly be grouped into one HVAC zone. The space temperature of these three offices would be controlled by a single thermostat[1] located in one of the offices. However, single-space zones in a building are common where temperature control of that one space is critical. An example would be a conference room. It would not be desirable for the space temperature in a conference room to be controlled by a thermostat located in a nearby office. If that office was unoccupied, the thermostat would call for minimum cooling. However, if the conference room was fully occupied at the same time, it would require maximum cooling. In this case, the thermostat would not adequately satisfy the cooling requirement of the conference room because the conference room has different HVAC loading characteristics than the office. Another example of a single-space zone would be an office located in the corner of a building. Because this office would have two exterior walls with exposures that are at right angles to each other, its HVAC loading characteristics would be different from any other space on that floor.
- Terminal Equipment: The equipment that delivers the heating or cooling energy to the HVAC zones in response to the zone thermostats. An example of terminal equipment for a commercial building is a variable air volume (VAV) terminal unit. Multiple VAV terminal units are normally served by a single VAV air system (see air system description below). Each VAV terminal unit receives conditioned supply air from the air system, modulates the supply airflow, and may add heat to the supply airflow in response to the zone thermostat controlling the VAV terminal unit. Another example of terminal equipment for a commercial building is a finned-tube radiator that is sometimes used to provide radiant heat for zones having external loads.
- Air System: The HVAC equipment that conditions the air supplied to the HVAC zones. An air system also returns air from the HVAC zones and provides outdoor air ventilation when required. An air system may serve multiple zones (as in the case of the VAV terminal units described above) or it may serve only one zone. In the case of the single-zone air system, the zone thermostat controls the heating and cooling capacity of the air system, and there is no terminal equipment. An example of a single-zone air system that most people are familiar with is the fan-coil unit that provides heating and cooling for a home in response to the zone thermostat.

  Air can be conditioned in an air system by heating, cooling, humidifying (adding moisture), or dehumidifying (removing moisture). The components of an air system that are relevant to HVAC load calculations are the supply fan and return fan (if applicable), which circulate the air through the heating and/or cooling coils in the unit; the heating and/or cooling coils, which transfer the necessary heating and/or cooling energy that is required by the zones to the airstream; and the outdoor air ventilation, which is usually introduced at a mixing point upstream of the heating and cooling coils. The combination of return air and outdoor air is called mixed air.

Other components of an air system that are relevant to HVAC load calculations but are not as widely used include a humidifier, which is used to add moisture to the supply air; a reheat coil, which is used to reheat the supply air after it has been cooled (often used as a means to maintain the indoor air relative humidity of the zones at a maximum level); and an energy recovery coil, wheel, or plate heat exchanger, which is used to exchange energy from an exhaust airstream to the outdoor air airstream.

- Central Plant: Buildings require heating and cooling energy to offset the heat gains and heat losses and to condition the outdoor air ventilation for the building. The central plant refers to the equipment that generates the heating and cooling energy utilized by the building. This equipment can be either centralized or decentralized. In a centralized system the central plant equipment is remote from the air systems and terminal equipment. An example of a centralized system would be a central heating and cooling plant for a building where the plant is remote from the air systems and contains boilers that provide heating water or steam to the air system heating coils and chillers that provide chilled water to the air system cooling coils. Heating and cooling energy may also be supplied by the central plant to various types of heating and/or cooling terminal equipment in the building.

  In a decentralized system, the central plant equipment is an integral part of each air system. An example of a decentralized system would be multiple rooftop units serving a building where each rooftop unit contains a gas-fired furnace that provides heating energy to the airstream through a heat exchanger and a complete refrigeration system that provides cooling energy to the airstream through a cooling coil. This type of unit is referred to as a self-contained unit because all of the necessary heating and cooling equipment is contained within one complete package. In this example of a decentralized system, each air system (rooftop unit) contains the central heating and cooling plant equipment.

## Geographical Location

Now that the terms for calculating HVAC loads have been defined, we will discuss the process of setting up the HVAC load calculations, assuming the calculation will be performed with commercially available HVAC load calculation software. The first step in the process is to define the inputs to the program, starting with the building's geographical location. Once the location has been selected, the program will utilize that area's database of annual weather data (contained within the program) to simulate the outdoor conditions, which include air temperature and relative humidity, wind speed and direction, intensity and position of the sun, and ground temperature. The database contains weather data for 365 typical (not actual) 24-hour days, totaling 8,760 hours of weather data for that location.

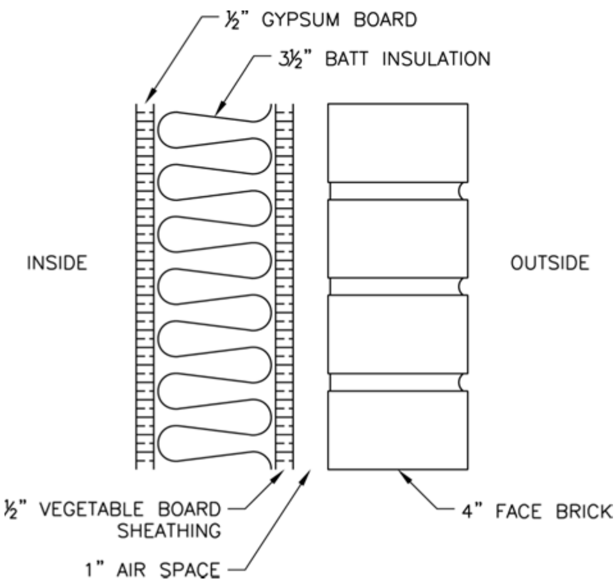
## Building Materials

### *Opaque Materials*

All materials conduct heat to some degree. The conductance, or U-Value, of a material, expressed in terms of British thermal units per hour per square foot per Fahrenheit degree (Btu/h·ft$^2$·°F), is a measure of how well the material conducts heat. The higher the U-Value, the better the material conducts heat and vice versa. For HVAC load calculations, the U-Value for each type of wall, roof, and partition needs to be calculated. This is done by examining the wall, roof, and partition sections in the architectural drawings for the building. The properties of common construction materials are listed in Chap. 26 of the 2017 *ASHRAE Handbook—Fundamentals* and are also included in the building materials database of some HVAC load calculation programs.

In order to calculate the U-Value for a wall, roof, or partition type, it is necessary to first sum the resistances of all of the components for each wall, roof, or partition that are shown on the architectural drawings. The resistance of a material is the inverse of the U-Value and is given in terms of hour square foot Fahrenheit degree per British thermal unit (h·ft$^2$·°F/Btu). Most people are familiar with this term because it is used to describe the insulating value of fiberglass batt insulation (e.g., 3½ in. of batt fiberglass insulation has an R-Value of 11, which is typically denoted as R-11). Once the total R-Value of the wall, roof, or partition has been determined, the reciprocal of this total R-Value will be the U-Value.

Figure 2-1 provides an example of how the U-Value is determined for a sample wall that consists of the following components (from inside to outside): gypsum wall board, batt insulation, vegetable board sheathing, air space, and face brick. The U-Value for this wall section is the reciprocal of the R-Value, or 0.066 Btu/h·ft$^2$·°F.




| Component | R-Value |
|---|---|
| 1. Inside surface resistance | 0.69 |
| 2. ½-in. gypsum board | 0.45 |
| 3. 3½-in. fiberglass batt insulation | 11.00 |
| 4. ½-in. vegetable board sheathing | 1.30 |
| 5. 1-in. air space | 0.91 |
| 6. 4-in. face brick | 0.43 |
| 7. Outside surface resistance | 0.33 |
| Total R-Value | 15.11 h·ft$^2$·°F/Btu |

**Figure 2-1** Typical architectural wall section.

In addition to the U-Value of the building envelope[2] materials, the color (light, medium, dark) and the weight (light, medium, heavy) of these materials have to be entered into the HVAC load calculation program because these factors affect the heat absorption and transmittance of these materials. For example, lighter-colored building materials exposed to the sun reflect more of the sun's radiant energy than darker-colored building materials do and, therefore, do not absorb as much of the sun's radiant energy. Second, lighter-weight building materials transmit the energy that they absorb from the sun to the interior of the building more quickly than heavier-weight building materials do. As a result, the peak cooling load of a lightweight building occurs shortly after the outdoor air temperature and intensity of the sun reach their peak; the peak cooling load of a heavyweight building will occur at a longer time interval after the outdoor conditions peak. Lightweight buildings will also cool off more quickly at night in the summer than heavyweight buildings will. In short, heavyweight buildings have more thermal mass than lightweight buildings and, as a result, transmit changes in the outdoor conditions more slowly to the indoor environment.

### *Fenestration*

Fenestrations (windows, skylights, and doors) in a building also have a U-Value associated with them. However, in addition to defining the U-Value for the glazing (glass component only—no frame) contained within the windows, skylights, and doors, the solar heat gain coefficient (SHGC) needs to be determined as well. The SHGC is dimensionless and represents the percentage of the sun's radiant energy that is transferred through the glazing to the space. The SHGC coefficient decreases with added panes of glazing, tinting, and low-e (low-emittance) coatings. For example, SHGCs for various types of glazing are as follows:

| Glazing | SHGC |
|---|---|
| 1/8-in. clear, uncoated, single-pane | 0.86 |
| 1/8-in. clear, uncoated, double-pane | 0.76 |
| 1/8-in. gray, uncoated, double-pane | 0.60 |
| 1/8-in. gray, low-e, double-pane | 0.54 |

It is best to obtain the U-Value and SHGC for the various types of fenestration proposed for a project from the fenestration manufacturers' product data because these values vary considerably from one product to another and from one manufacturer to another. It is also necessary to determine if the window frames are thermally broken from the walls in which they installed, that is, if the frame is insulated from the wall. This can be determined by reviewing the details of the various window types in the architectural drawings for the building.

Buildings will sometimes incorporate elements that provide an external shading of the fenestration components, such as a roof overhang or shading above the top or along the sides of windows. The dimensions and positions relative to the fenestration components of all external shades must be entered into the description of each type of fenestration because they will have a significant impact on the percentage of the sun's radiant energy that is transmitted through the fenestration to the building's spaces. Internal shades such as drapes or venetian blinds may also be used, although it is recommended that they be omitted from the description of the fenestration types because their use will