Residential Energy

COST SAVINGS AND COMFORT FOR EXISTING BUILDINGS

John Krigger ■ Chris Dorsi

5th Edition
Includes CD

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Cost Savings and Comfort for Existing Buildings

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John Krigger and Chris Dorsi

324 Fuller Avenue • Helena, Montana 59601 • www.srmi.biz
Printed in the U.S. by Thomson-Shore, Inc.
Version RE090109

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Published by Saturn Resource Management, Inc.
324 Fuller Avenue, Helena MT 59601

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www.HomeownersHandbook.biz

For ordering information or special discounts for bulk purchases, please contact Saturn Resource Management, 324 Fuller Ave, Ste C2, Helena, MT 59601, (406) 443-3433.

Design by John Krigger, Chris Dorsi, and Darrel Tenter
Administrative support by Jody Crane
Cover artwork by Bob Starkey
Other artwork and photos by Bob Starkey, John Krigger, Marty Lord, and Steve Hogan
This edition was compiled by Darrel Tenter using Adobe FrameMaker®. The text is set in Minion Pro and Myriad Pro.

Publisher's Cataloging-in-Publication
(Provided by Quality Books, Inc.)

Krigger, John.
Residential energy : cost savings and comfort for existing buildings / John Krigger and Chris Dorsi ; illustrations, Bob Starkey ... [et al.] ; editors, Mary Coster and Margaret Regan. -- 5th ed.
p. cm.
Includes bibliographical references and index.
ISBN-13: 978-1-880120-09-5
ISBN-10: 1-880120-09-7

1. Dwellings--Energy conservation--United States.
I. Dorsi, Chris. II. Title.

TJ163.5.D86K75 2009 696
QBI09-200040

ACKNOWLEDGEMENTS

This publication relies on the ongoing work of many people. We are indebted to those who have contributed their knowledge and insight over the years to the constantly evolving field of building science, and we hope that this book can help all of us better understand how buildings operate.

We offer thanks to the DOE Weatherization Assistance Program, the DOE Existing Building Efficiency Research Program, and Pacific Gas and Electric Company for the original financing and conceptual guidance for this book.

We recognize the periodicals *Energy Design Update* and *Home Energy* for chronicling the residential energy conservation field so competently, and the Affordable Comfort Conference (ACI) for providing a forum for the building science community.

We thank the scientists, engineers, and support staff from these organizations for performing valuable original research, and for producing important information resources:

E-Source
Ecotope Inc.
Florida Solar Energy Center
Lawrence Berkeley Laboratory
National Renewable Energy Laboratory
Oak Ridge National Laboratory
PG&E Energy Training Center – Stockton
Pacific Northwest Laboratories

Thanks to these individuals who provided assistance through personal conversations, seminars, and publications:

Bob Davis, Seattle WA
R.W. Davis, Athens OH
Jim Fitzgerald, Minneapolis MN
Skip Hayden, Ottawa Canada
Joe Lstiburek, Chestnut Hill MA
Gary Nelson, Minneapolis MN
Dale Pickard, Bozeman MT
John Siegenthaler, Utica NY
John Tooley, Raliegh NC

Thanks to these individuals for suggestions, contributions, and technical review of this book:

Rana Belshe, Fairchild WI
Tony Gill, Augusta ME
Adam Gifford, Newport ME
Bruce Harley, Stamford VT
Bill Hill, Muncie IN
Bill Holloway, Stockton CA
Rick Karg, Topsham ME
Tim Lenahan, Columbus OH
Bruce Manclark, Goldendale, WA
Gary Mazade, Victor MT
Joe Miuccio, Liverpool NY
Charlie Richardson, Boulder CO
Russ Rudy, Kansas City, MO
Kendall Shannon, Leawood, KS
Ken Tohinaka, Burlington VT
Bill Van der Meer, Williamsport PA
Doug Walter, Manhattan KS
Larry Weingarten, Monterey CA

Thanks to these loyal customers, whose support makes the fifth edition of this book possible:

Bevilacqua-Knight, Inc.
Conservation Services Group
Kansas Building Science Institute
Lane Community College
New York State Energy Research & Development Authority and OCM BOCES
Hudson Valley Community College
PG&E Energy Training Center – Stockton
Residential Energy Services Network
Southface Energy Institute
Vermont Energy Investment Corporation
Wisconsin Energy Conservation Corporation

Thanks to these certification organizations for their support, guidance, and collaboration:

Residential Energy Services Network (RESNET)
Building Performance Institute (BPI)

Preface

We release this fifth edition of *Residential Energy* at a time of great transition in the field of energy efficiency. Since we first produced this book, we have updated each subsequent edition with the best new practices for the design, construction, and operation of energy-efficient homes. But as this edition goes to print, another important shift has taken place: energy conservation has again become mainstream, and for several good reasons.

Chief among these is the real threat of global climate change. Since our consumption of fossil fuels is the most likely culprit, we can no longer view energy waste in our buildings as a simple personal choice. In the U.S. and Canada, for example, the energy consumption of our buildings accounts for at least 40 percent of our total energy use, with about half of that attributed to residential structures. Every year, the energy consumed by each of those typical homes is responsible for the release of at least 20,000 pounds of carbon dioxide, a potent greenhouse gas that contributes to climate change. By utilizing the tried-and-true conservation solutions presented in this book, we can substantially lighten our impact on the planet.

Of equal importance for each of us is the increasing cost of all types of energy. It was only a few years ago that we expected energy-efficiency improvements to produce savings of 10 to 30 percent in the typical home. Today we've set our goals much more optimistically, and we now envision, design, and build homes with the goal of reducing their consumption by 70 to 90 percent compared to homes built a generation ago. No longer do we accept the incremental approach of installing a few energy-saving gadgets. We have now expanded our focus to include the deep energy reductions that are the hallmark of today's best energy-efficiency projects.

Everyone who owns a home is also vulnerable to today's unstable financial markets. Fortunately, each dollar we spend on efficiency upgrades adds to the value of our dwellings. The most immediate impact is in reduced utility consumption, with the annual return on conservation improvements ranging from 10 to 50 percent annually. Efficient homes are also worth more at the time of resale – it is increasingly hard to sell out-of-date homes whose owners are burdened with high utility costs. And money spent on conservation improvements tends to stay within local communities. The best economic development program for your town may be to spend your money on energy efficiency projects.

We hope this book provides useful guidance as you strive to improve the buildings you work with. We thank you for your commitment to improving our housing stock. Your efforts are important to all of us.

– Chris Dorsi, May 2009

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This chapter provides a general overview of residential energy use. It presents history, statistics, policy, energy-bill analysis, customer education, and energy-efficiency ratings.

Energy – Past and Present

Cultures around the world have used energy conservation principles and passive solar technologies for centuries. For instance, some Native American communities maximized winter heating by orienting their dwellings and villages to the south. Middle East natives used wind chimneys, whitewashed walls and roofs, and window shading for cooling.

Before the industrial revolution, residential heat was provide by wood fires. Artificial light was provided by candles and oil or gas lamps.

A little over 100 years ago, things began to change rapidly. In the early 1880s, Thomas Edison invented the incandescent light and built the world's first power station. By 1908, 8% of American homes had electricity. By 1925, 53% of homes were connected to the country's expanding electrical grid. By the 1930s, natural gas began to compete with wood and coal as a heating fuel. Today, natural gas provides over 50% of the energy used in residential buildings.

Over the past 50 years, Americans have embraced air conditioning, replacing earlier attempts at low-energy cooling. Evaporative coolers appeared in the 1920s and window air conditioners in the 1940s. Central air conditioning followed in the 1950s. Today, around 70% of existing homes and 80% of new homes have air conditioners. Televisions, stereos, computers, swimming pools, spas, and all types of electric gadgets make American homes the most energy consumptive in the world.

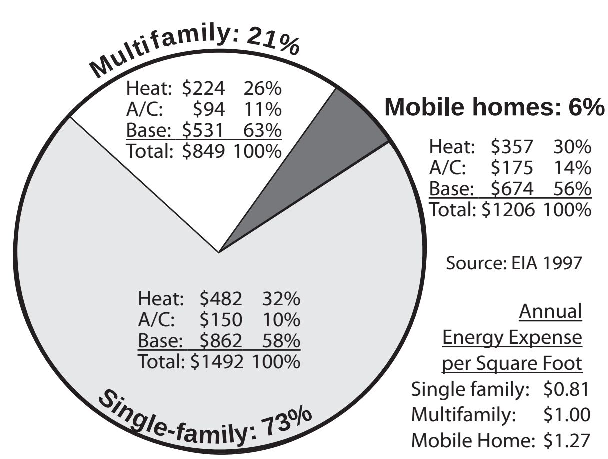
The Energy Picture Today

The United States represents about 5% of the world's population. Yet it consumes 25% of the world's energy supplies. Energy is a principal commodity of our society, amounting to about 9% of the U.S. Gross National Product (GNP).

The benefits we receive from this consumption are counterbalanced by environmental damage. With the exception of some renewable resources, energy consumption inevitably produces harmful by-products such as carbon dioxide, acid rain, and radioactive waste. Carbon dioxide is the most important cause of global warming, which is now an international problem and urgent priority.

Most scientists now agree that our unbridled energy use is warming the atmosphere through a process called the greenhouse effect. Gases, like carbon dioxide, that contribute to the greenhouse effect are called greenhouse gases. Recent climate changes, increasing forest fires, record high temperatures, and other weather events, confirm that the earth is indeed warming. Unfortunately, U.S. greenhouse gas production increased by 16% between 1990 and 2000.

Home Types and Average Energy Costs



This chart summarizes EIA data for 105 million U.S. households.

Annual Average Household Energy Cost by Region (1997)

	Northeast		Midwest		South		West	
	$/yr	%	$/yr	%	$/yr	%	$/yr	%
Space heating	$689	39%	$575	39%	$329	23%	$253	22%
Space cooling	$78	4%	$85	6%	$211	15%	$134	12%
Water heating	$244	14%	$188	13%	$213	15%	$177	15%
Appliances & other	$752	43%	$645	42%	$662	47%	$590	51%
Total cost	**$1763**	**100%**	**$1492**	**100%**	**$1415**	**100%**	**$1155**	**100%**

Energy Information Administration: *A Look at Residential Energy Consumption in 1997.*

Energy consumption also produces undesirable economic side effects. The U.S. imported 55% of the oil it used in 2001, making oil our largest import. Importing oil creates about 25% ($15 billion) of our annual balance-of-trade deficit of over $60 billion per year. Our foreign oil dependence dominates our foreign policy and has precipitated expensive military intervention. Energy conservation can help reduce this reliance on fossil fuels.

Carbon Emissions for Typical U.S. Households

Type of energy	Typical use	Typical CO_2 emission
Natural gas	920 therms	11,000 lbs.
Fuel oil	660 gallons	14,500 lbs.
Electricity	10,800 kWh	16,300 lbs

From Energy Information Administration *A Look at Residential Consumption*.

Energy Sources Compared

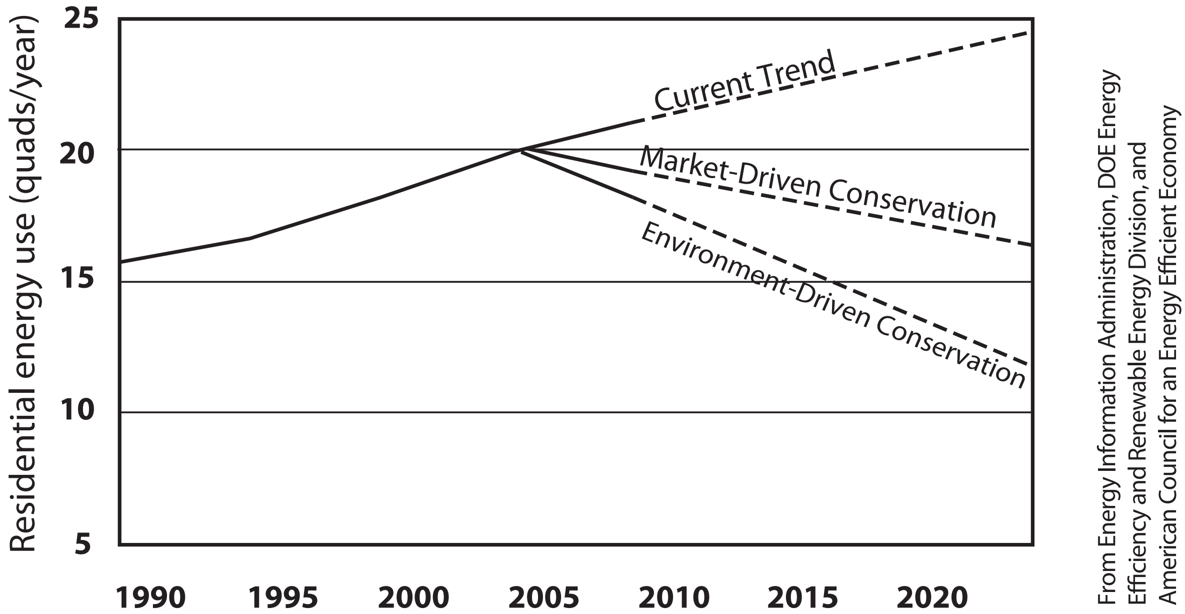
Fossil energy is solar energy stored in ancient plant and animal remains. Fossil fuels, such as coal, oil, and natural gas, are very convenient to use and account for over 95% of energy used in homes. Supplies of fossil energy are limited and nonrenewable. Fossil fuels produce carbon dioxide — the main cause of global warming — and other air pollutants, which are a major worldwide cause of respiratory disease, environmental sensitivities, and neurological disorders.

Nuclear electricity harnesses energy released by the splitting of atoms and releases no carbon dioxide. At one time, experts predicted that nuclear electricity would become the world's cleanest and cheapest energy source — a prediction that has not yet materialized. Nuclear electricity is expensive, requiring large government subsidies. The nuclear industry's radioactive waste disposal process is a grave environmental, economic, socioeconomic, and political problem.

Renewable energy is the same as solar energy, and includes wind power, direct solar energy, and biomass energy. As fossil-fuel supplies dwindle, renewable energy is becoming more widely used. The advantages of renewable energy are safety, environmental quality, and sustainability.

Energy efficiency and energy conservation must bridge the gap between the present fossil-fuel era and the future renewable-energy era. If high standards of residential comfort and convenience are to endure, energy efficiency and energy conservation must precede and support the implementation of renewable energy systems.

Past, Present, and Future Energy Consumption



Each citizen helps make the decision about which energy path we will follow in the future. International standards favor returning to 1990 annual energy consumption levels, though environmental-driven conservation.efforts could result in even lower energy consumption.

Understanding Home Energy Usage

Most of the energy statistics presented here come from the Department of Energy's Energy Information Administration (EIA). EIA reports energy consumption in dollars, millions of BTUs (MMBTU), or quads. A quad is one quadrillion British thermal units of energy—the equivalent of 40 million tons of coal or 182 million barrels of fuel oil.

The EIA recognizes three distinct housing types: single-family, multifamily, and mobile homes among the approximately 105 million American households. Householders in the U.S. spent about $150 billion for 20 quads of energy in 2000. By 2007, consumption rose to 22 quads, a 10% increase. Of this total energy in quads, 65% is electricity, 26% is natural gas, 7% is oil and propane, and the remaining 2% is renewable energy.

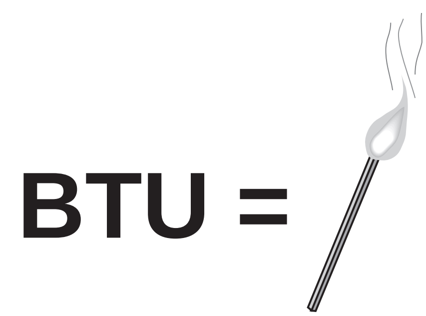
See "Calculating Energy Intensity" on page 24, for more information on energy intensity and energy indexes. See "Analyzing Annual Energy Costs" on page 271.

It's easy to get confused by percentages and pie charts unless you understand the relationship between electricity and natural gas — the leading energy sources. If you look at energy consumption, space heating consumes around half of the primary energy used in an average home. However, space heating is only about one-third of the $1400 average annual household energy cost, because natural gas, the main home-heating fuel, is less expensive than electricity.

This chapter discusses the physical principles essential for understanding energy flows in residential buildings. Building energy efficiency can't be applied like a recipe or building code because too many variables are involved. Energy specialists need energy principles to understand unusual problems and to cut through the confusion of competing energy-saving claims. Understand the principles underlying comfort, heat flow, and electricity use, and you'll make good decisions about which energy-conserving measures to apply.

Buildings use energy for temperature control, lighting, hot water, appliances, and entertainment. Energy use can be excessive because of heat leakage through building shells, inefficient heating and cooling systems, or lack of awareness of efficient operating principles. Waste can be associated with lights, appliances, and other energy-using household devices because of obsolete design or careless operation.

Measurement of Heat Energy



A kitchen match contains about one BTU of heat energy. One hundred thousand BTUs equals one therm of heat energy.

What is Energy?

Energy is a measurable quantity of heat, work, or light. *Potential energy* is stored energy, like a cord of wood. *Kinetic energy* is transitional energy, like a flame.

More than 99% of the energy we use comes from the sun. The only other significant source is nuclear material in the earth. Plants build their tissues with sunlight, and the composition of all fossil fuels is ancient plant and animal tissue. We burn fossil fuels to produce heat and work energy.

We measure energy many ways: therms of natural gas, kilowatt-hours of electricity, barrels of oil, gallons of propane, and pounds of steam are all common measurements of energy. Although energy measurement takes many forms, all types of energy are equivalent.

The energy from last summer's sunshine is chemically locked in the produce we buy at the grocery store. That chemical energy in food is burned in our bodies to provide the kinetic energy and heat required to keep the human machine functioning. Solar energy from the age of the dinosaurs, stored for eons as chemical energy in deposits of coal and oil, provides energy for our modern world.

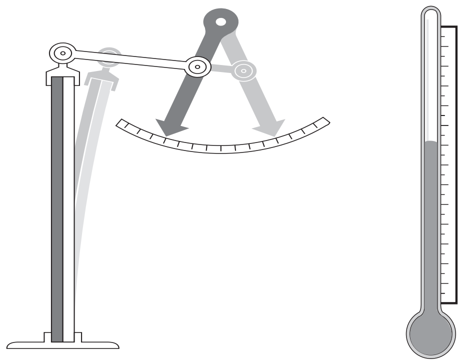
Laws of Thermodynamics

Two laws of the science of thermodynamics govern the behavior of heat in our universe. These laws were first described in the nineteenth century and helped to spawn the industrial revolution. Remember that no device, system, or idea can violate these laws. Attempts have been made but no exceptions have ever been demonstrated.

The first law of thermodynamics says that energy is neither created nor destroyed. Energy merely moves from place to place and changes form. The potential energy of gasoline becomes the automobile's movement, the engine's heat, and tires' friction on the road.

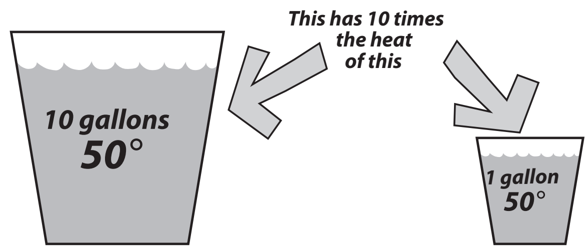
The second law of thermodynamics says that heat moves from high temperature regions to low temperature regions — never the reverse (without additional energy from an external source).

Measuring Temperature



Temperature is measured by the movement of a bimetal element or by the expansion of the liquid metal mercury.

Quantities: Heat and Material



If two different amounts of the same material have the same temperature, the heat content in each is directly related to the mass of the material.

Temperature and Heat

Temperature is a measure of how fast the molecules in a substance are moving or vibrating. Temperature is the average kinetic energy or motion of molecules. Molecules in a solid are stationary, but they vibrate faster and faster as heat is added, raising the temperature.

Heat flows because of a difference in temperature between two places. Heat is measured in *British thermal units (BTU)*, which is the amount of heat required to raise a pound of water's temperature 1°F. A BTU is approximately the amount of heat released by burning one wooden kitchen match.The number of BTUs of heat that a pound of any material absorbs or releases for each degree of temperature change is called its *specific heat*. It is measured in BTUs per pound per degree Fahrenheit (BTU/lb./°F). Water has a specific heat of 1 BTU/lb./°F. It takes only 0.2 BTU to raise a pound of aluminum 1°F, so aluminum has a specific heat of 0.2 BTU/lb./°F. If we add one BTU to a pound of aluminum, it will get 5°F warmer.

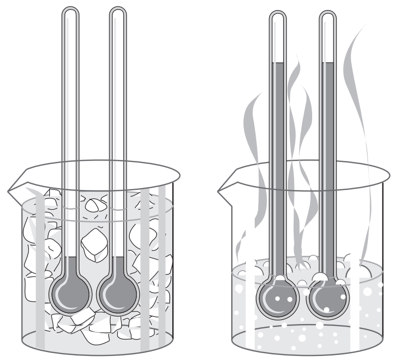
The temperature of a given weight of material tells us how much energy that material contains, which is called *enthalpy*.

Sensible and Latent Heat

The relationship between water's temperature and its heat content is predictable — add a BTU to a pound of water, and by definition, it gets one Fahrenheit degree warmer. Add 150 BTUs to a pound of 50°F water, and its temperature increases 150°F to the temperature of 200°F. This *sensible* relationship ends at 212°F — water's boiling point. With continued heating, the pound of water remains at 212°F, while it absorbs 970 BTUs during its complete evaporation into steam — six times the heat it absorbed going from 50°F to 212°F.

This unexpected or hidden heat, which is released or absorbed as a substance changes form, is called *latent heat*. Our pound of liquid water vaporized when we added 970 BTUs, which is called the *latent heat of evaporation* for water. If we could catch all the steam and recondense it, the 970 BTUs would be released again. This is the principle of steam heating.

Boiling and Freezing Points



The boiling point and freezing point of water are important to calibrating thermometers because these two states are easy to recognize and duplicate. Freezing point: 32°F or 0°C; boiling point: 212°F or 100°C.

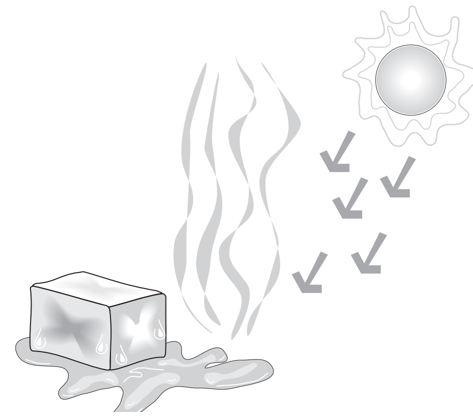
Our pound of water would go through a similar metamorphosis if we were to cool it: the water would lose 1°F for every BTU removed until reaching its freezing point, 32°F. We would then have to remove 144 BTUs — water's *latent heat of fusion* — to turn the pound of water into a block of ice. Conversely, it would take 144 BTUs of heat to melt the pound of ice again.

Steam-heating systems, air conditioners, and refrigerators use latent heat to carry energy from one place to another. In steam heating systems, water is vaporized at a boiler and condensed back to a liquid in radiators. In an air conditioner, a special fluid called a refrigerant vaporizes at the evaporator, absorbing heat from inside the home in the process. The hot gas is then piped outdoors to a condenser, where it *condenses* back to a liquid, releasing its latent heat into the outdoor air.

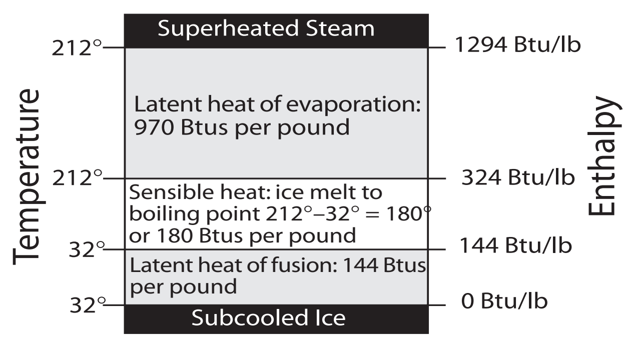
Heat and Work

The American system of measurement has many ways of describing energy — the BTU for heat and the foot-pound for work being two of the most common. If you lift a one-pound weight one foot off the floor, you have done one *foot-pound* of work.

Latent Heat



Latent heat is the heat absorbed or released when a material changes phase between a solid and a liquid or between a liquid and a gas.



At the phase changes, temperature remains constant while enthalpy changes dramatically. Although often considered zero BTUs/lb. enthalpy, ice still has some energy content.

To prove that heat and work are equivalent, a British physicist, James Joule, used mechanical energy (or work) to stir water. He found that for every 778 foot-pounds of work he performed stirring one pound of water, the pound of water absorbed 1 BTU. Joule determined this by measuring temperature change of stirred water in an insulated tank. Now we know that 778 foot-pounds is equivalent to 1 BTU. This was an essential piece of knowledge for the industrial revolution.

The *joule,* an international energy unit, describes both work and heat. A million BTUs (MMBTU) approximately equals a gigajoule (billion joules).

Chapter 2 Energy and the Building Shell

This chapter explains building construction, building-shell heat flows, building inspection and diagnosis, and calculations of heat loss and gain. The chapter's goals are to link physics with building construction in order to give you a better understanding of energy flows through the building shell.

An ideal building maximizes heat retention during the winter and minimizes heat gains during the summer to reduce heating and cooling needs. The best way to achieve energy efficiency in a new building is by energy-efficient design, planning, and construction. In existing buildings, technicians perform modifications — called weatherization — to reduce heat loss and heat gain.

Making decisions about a building's weatherization is the job of an energy auditor. Auditors take measurements, estimate costs, develop energy-savings projections, and perform physical inspections of buildings to decide which retrofits to recommend.

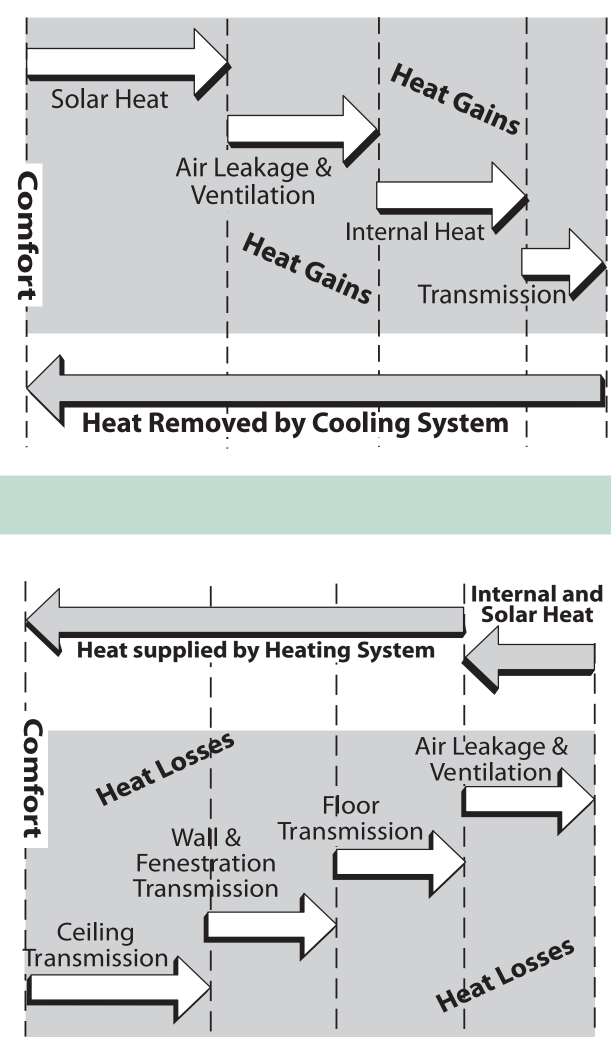
See "An Energy Audit's Purpose" on page 19.

For large residential buildings, the auditors may be architects and engineers. For homes, a trained energy auditor (who may even perform part of the weatherization work) makes decisions about weatherization projects.

Heat loss and gain through the building shell are the largest energy demands on residential buildings. To maintain comfort, heating and cooling systems supply or remove heat at a rate roughly equaling heat's flow rate through the building shell.

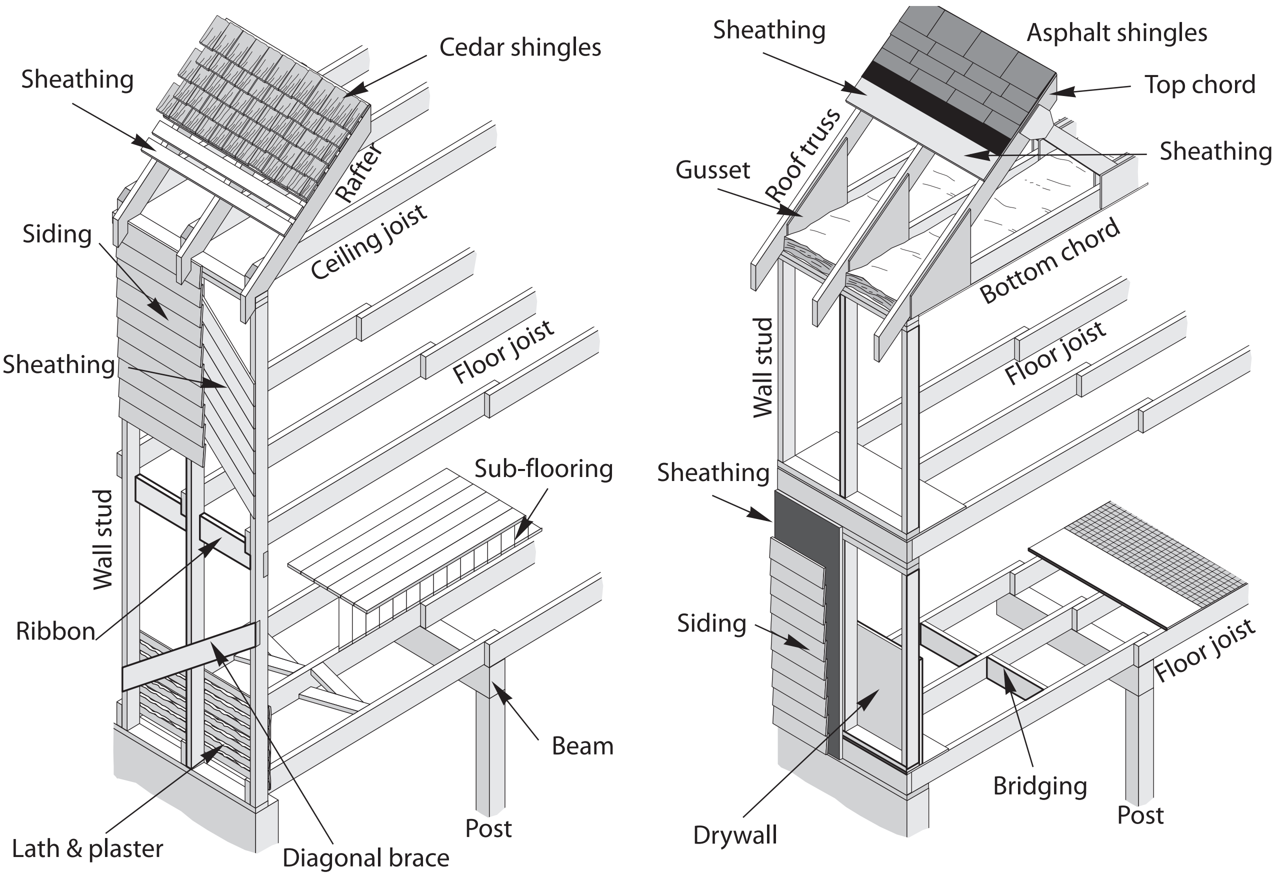
The amount of heating energy needed by the home over a heating season is the sum of heat transmission losses through the floor, exterior walls, and ceiling, added to the air leakage, minus solar radiation gain and internal heat production. Cooling energy needs are determined by solar radiation, internal heat, air leakage, and heat transmission. Total heating energy and total cooling energy also include the inefficiencies of the heating and cooling systems.

Maintaining Home Comfort



Heat is lost in winter and gained in summer through the building shell. Heating and cooling systems create comfort by adding or subtracting heat.

Balloon Framing | **Platform Framing**



Balloon framing is characteristic of some older homes. The wall cavities of balloon-framed houses are often open to both the basement and the attic. Modern homes on the other hand feature pre-built roof trusses, platform framing, and 4' x 8'- sheets of plywood or OSB sheathing material for walls, floors and ceilings.

Energy-efficient buildings have a *thermal boundary,* which is a line or plane defined by insulation and an air barrier. The air barrier is any interior or exterior sheeting material that resists airflow through it. An effective air barrier is nearly airtight. In hot climates, energy-efficient buildings block solar radiation with exterior shade (from trees), reflective exterior surfaces, and window shading.

Building Construction

Buildings have construction flaws that waste energy, reduce comfort, and encourage building deterioration. Knowledge about construction characteristics can help you locate and correct these flaws.

Building materials have different thermal conductivities. Metals such as aluminum and steel conduct heat rapidly, while insulating materials such as mineral fiber and plastic foam conduct heat slowly. The thermal conductance of wood, masonry, and plastic are between these extremes.

The simplest buildings are just large six-sided rectangular boxes. The building's shell is comprised of its foundation, bottom floor, exterior walls, and roof assembly. These components generally have at least two layers with a cavity between. For example, a wall has interior sheeting and exterior siding; the roof assembly has a ceiling inside and a roof outside.

The building shell's seams at edges, corners, and around openings are the obvious thermal weak points, containing heat-conductive structural members and leaky joints between building materials.

Penetrations through insulation and air barriers occur where mechanical and electrical components pass through the building shell. These are often major flaws in the building shell.

Protrusions and indentations to the building's shell increase seams and create areas where the insulation and air barrier aren't continuous. Protrusions include bay windows, dormers, and porches. Indentations include recessed entrances, porches, and windows. These building-shell irregularities allow air leakage between indoors and outdoors and convection within building cavities.

Structural Design

Building structures are classified as planer or skeletal design, depending on whether they are supported by columns and beams or by panels. Many buildings combine these two structural styles.

Planer construction is usually simpler (such as masonry or framed walls) with familiar interior and exterior surfaces. Wood-frame structures have many joints between their different components, making airtightness an important design and construction issue. Insulation is installed between the framing and sometimes attached over the framing to reduce conduction through these structural components. Masonry structures, when they are insulated, have surface-applied insulation.

See "Home Types and Average Energy Costs" on page 13.

Skeletal construction often contains deeper floor and ceiling cavities and more vertical shafts than planer construction. The steel columns and beams of a skeletal steel framework are hidden behind non-structural walls and suspended ceilings. Less-conductive building components called thermal breaks are used to separate metal, concrete, and glass from each other. A thermal break prevents direct linkage between indoors and outdoors through these very conductive materials.

Foundations support the building's weight with masonry walls, piers, or slabs. They transfer this weight to the ground and also tie the building to the ground for seismic and wind resistance. Masonry materials are preferred for foundations because they resist rot and corrosion.

Foundations should sit on and be surrounded by dry ground. However, in real life, they frequently encounter ground moisture or runoff from surrounding roofs or adjacent land. Moisture problems should be considered when planning weatherization projects.

Single-family Home Construction

Many wood-frame homes, built before 1940, used *balloon-frame construction*, which features wall studs that may be two stories high. These tall studs usually have no top or bottom plates. Floor joists and ceiling joists are attached to the studs and supported by ribbons. The stud cavities are often open to both the basement and attic.

Modern wood-frame homes are generally of *platform-frame construction*. Each floor, framed with structural lumber and sheathed with plywood or particle board, serves as a platform for framing the exterior walls. The top plate of the first floor's exterior wall becomes the platform for framing the second floor and walls.

Some homes may have elements of both styles of framing. For example, newer balloon-framed homes may have a bottom plate that sits on the

Chapter 3 Air Leakage

Air leakage in buildings represents from 5% to 40% of the space-conditioning costs. Controlling air leakage is one of the most important functions of weatherization, and often the most difficult.

An air barrier is a building component designed to stop air leakage. The air barrier combined with the insulation defines the thermal boundary.

The main goals of air leakage control are to:

- Save energy.
- Increase comfort.
- Protect insulation's thermal integrity.
- Reduce direct cooling or heating of people and building components by outdoor air.
- Avoid moisture migration into building cavities.

Air sealing may provide these additional benefits:

- Reduce vermin's access to indoors.
- Reduce flow of air pollution from external sources.
- Reduce rainwater leakage.
- Enhance fire safety.

Traditional thought was that existing buildings were relatively airtight, except for seams where building materials joined, especially around windows and doors. In the past, engineers tried to estimate air leakage based on the length and width of cracks between building materials. Estimating crack size was not accurate because it neglected major air leaks in hidden locations.

From 1975 to 1985, scientists and technicians developed and implemented instruments to assess air leakage, including blower doors, infrared scanners, and tracer-gas analysis. With these developments, we now know that the building's hidden air leaks are usually more important than seams between building materials. As a result, technicians have found new ways of finding and sealing these hidden air leakage pathways.

Air Leakage Through Construction Materials

	$CFM_{50}/100\ ft^2$
5/8" oriented-strand board	0.09
1/2" drywall	0.26
4-mil air barrier paper	0.26
1/8" hardboard	0.37
1" EPS (dense)	1.5
(materials below not considered air barriers)	
15# perforated asphalt felt	5.3
Standard concrete block	7.9
1" EPS (light)	170
5/8" tongue & groove boards	300
6" fiberglass batt	490
3" vermiculite	930
1.5" spray-on cellulose	1160

These values represent the approximate air leakage through each square foot of material during a 50-pascal blower-door test.

Based on: "Air Permeance of Building Materials" research report by Canada Mortgage Housing Corporation. Units converted from all-metric by the author.

In the 1990s Canadian building scientists measured the air permeability of various building materials and joints. The durability of air barriers in very high winds has also been measured.

Most homes are ventilated by natural air leakage, and this fact informs decisions about whether to seal air leaks and how airtight to make a home. Scientists, engineers, and technicians continue to debate whether air leakage is an acceptable strategy to ventilate homes.

Some recent state building codes now require strong and effective air barriers and mechanical ventilation systems. Canadian builders, architects, and engineers have understood the need for air and vapor barriers for years because of their cold climate and the moisture problems that result from ineffective air and vapor barriers.

This chapter discusses the principles of air leakage, diagnosis of air leaks, construction flaws that allow air leakage, and methods and materials for sealing air leaks.

Air-Sealing Principles

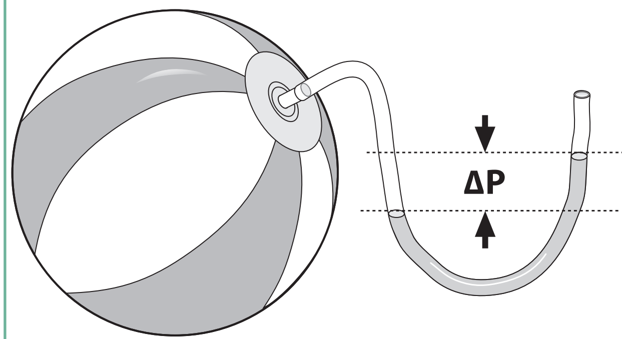
Air leakage from one zone to another requires a hole between the zones and pressure to push air through that hole. The airflow rate through a hole or group of holes depends on two factors: the cross-sectional area of the holes and the difference in pressure (ΔP). Air leaking in is often called infiltration and air leaking out is called exfiltration.

Natural airflows are usually small and variable — too difficult to measure. A blower door's pressure and airflow, however, are steady and measurable. Measuring pressure and airflow with a blower door allows you to estimate the size of holes.

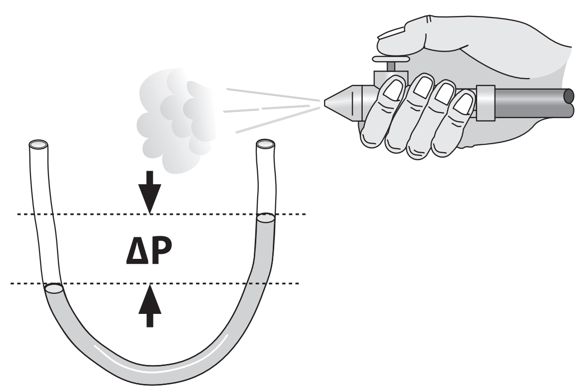
Direct air leakage occurs at windows, doors, and other concentrations of seams, where air leaks directly through the shell. Indirect air leakage enters the building shell in one location, flows through building cavities, and emerges at a different location.

Many indirect air leaks are found in intermediate zones like attics and crawl spaces. One seldom-recognized air-leakage source is airflow through building materials themselves. Concrete block, brick, perforated felt, and most insulation materials have relatively high air permeability and aren't considered air barriers.

Manometer Readings



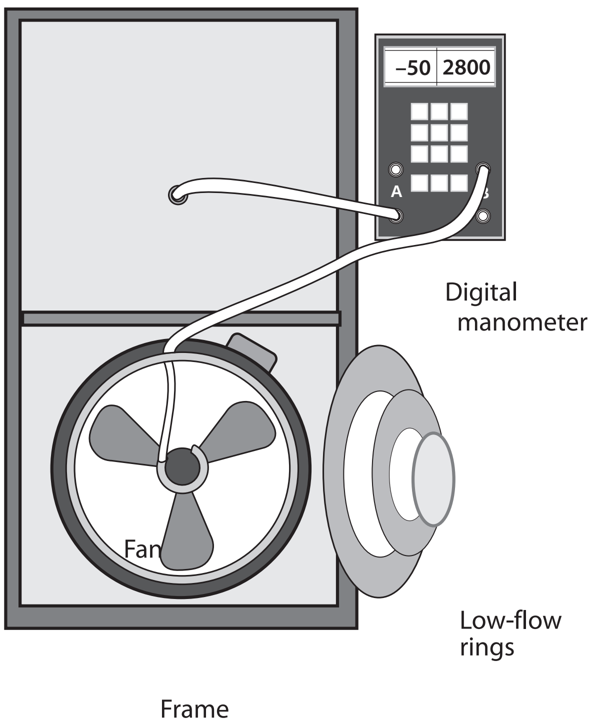
The pressure inside an inflated beach ball is greater than the pressure of the atmosphere. This pressure difference (ΔP) can be measured with a manometer showing how many inches the water level differs in its height. This is the origin of the measurement: inches of water column (IWC).



Air blown across the opening of a liquid manometer creates a vacuum in the tube and a measurable difference in the height of the water level. This ΔP depends on the air velocity and is used to calculate airflow in CFM.

Pressures driving natural air leakage come from wind, exhaust fans, furnace blowers, chimneys, and the stack effect. The stack effect (also called chimney effect) is caused by density differences between warm and cool air masses.

Blower Door



Blower doors create a measurable house pressure and airflow in order to evaluate a building's air leakage.

Chimneys and exhaust fans (including clothes dryers) remove air from the home, creating a slight vacuum, often called depressurization. The wind, furnace blower, and stack effect tend to pressurize some areas of the home and depressurize others.

Beyond air leakage, air can also move around inside building cavities, increasing the rate of heat transmission. Air convects inside building cavities, carrying heat from one surface to another. Air can wash over the insulation's surface, convecting heat away. Or air can convect through an insulation material, reducing its thermal resistance.

Ideally, an effective air barrier surrounds the home on all sides, adjacent to its insulation. An effective air barrier prevents most air leakage and convection. However, many if not most American homes have flawed air barriers that can be significantly improved by diagnosis and air sealing.

Air Pressure and Flow

Air pressure, airflow, and the size of air leaks are directly related to each other. A pressure difference on opposite sides of a hole causes an increase in airflow through the hole. Bigger holes pass more air at the same pressure than smaller ones.

Pressure and airflow can be measured by instruments called manometers. Manometers come in three common types: a transparent tube filled with water; a round gauge with a needle indicating the pressure or flow amount; or a digital manometer, giving a digital readout of pressure.

The air inside an inflated beach ball is denser than the atmosphere outside. Measure this pressure difference by attaching a manometer to the beach ball's valve. The lighter atmosphere presses on one side of the liquid, and the denser beach ball air presses on the other. The distance that the beach ball's denser air moves the water column off level — measured in inches — is a unit of air pressure.

The small air pressure differences caused by wind, blower doors, furnace fans, and chimneys are measured in inches of water column (abbreviated IWC) in the American measurement system. The more common metric unit for small air pressures is the pascal — 249 pascals equal 1.0 IWC.

When talking about pressure differences between two areas, we say that the zone having denser air is pressurized, or is the high-pressure area. The zone with less dense air is depressurized, is under vacuum, or is the low-pressure area.

Another type of manometer is a round gauge with an arc-shaped scale for measuring either pressure (in pascals) or airflow cubic feet per minute (CFM). This gauge has a high pressure tap and a low pressure tap. If the gauge is physically located in the low pressure area — as with typical blower-door testing — its low pressure tap is open to that area (indoors), and a hose is used to expose its high pressure tap to the high pressure area (outdoors).

Heat transmission is the average home's leading cause of winter heat loss. Most single-family homes lose three to six times as much heat through transmission as through air leakage. Insulation slows heat transmission through the building's floor, walls, and ceiling or roof.

Insulation performs the following thermal functions:

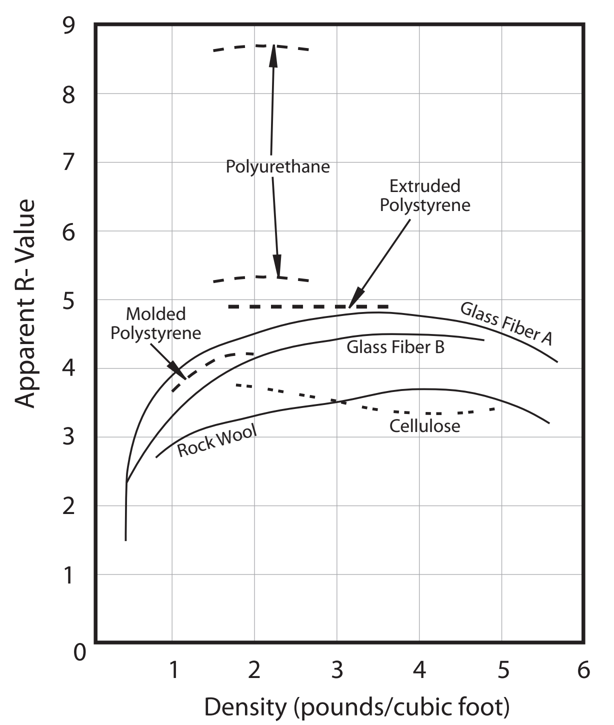
- Conserves energy by slowing heat transmission.
- Enhances comfort by reducing temperature variations within the conditioned space.
- Reduces the size of heating and cooling equipment needed by a building in direct proportion to R-value.
- Prevents wintertime condensation by preventing low interior surface temperatures.

Insulation may also offer the following benefits:

- Adds structural strength.
- Reduces noise and vibration.
- Impedes air leakage and water vapor transmission.
- Improves the building's fire resistance.

This chapter tells how insulation works, describes insulation types, and discusses other important issues relating to insulation.

Density of Insulation Versus R-Value



Insulation's density affects its R-value, depending on the material.

Insulation Characteristics

Insulation is installed in building cavities, attached to a building's structural frame, or attached to the building shell's exterior surfaces.

Insulation slows heat transmission in two important ways:

1. By forcing the heat to conduct through air or some other gas. Gases are generally poor heat conductors.
2. By reducing heat radiation and air convection within cavities where insulation is installed.

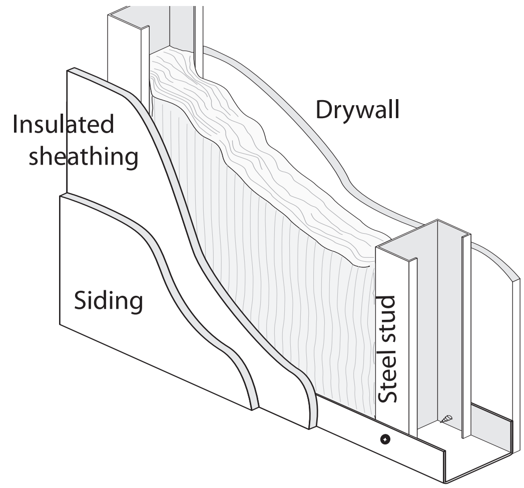
Insulating materials are not as continuous or dense as other building material which are heat conductors — they harbor millions of tiny air pockets within their fibers or bubbles (in plastic foam insulation). Heat transmission proceeds slowly through insulation, having to cross this myriad of slow-conducting air pockets.

Whole-Wall R-Values from Full-Scale Tests

Wall Type	W-W R
Standard 2-by-4	9.7
2-by-6 perfect installation	12.8
2-by-6 poor installation	11.0
Steel frame wall C-stud	5.6
Steel stud wall w/EPS sheathing	10.5
Structural 6-inch EPS-insulated panel	21.6
Stucco-covered straw bale	16–28
Lightweight concrete block	10–30
Insulating concrete form	26–44

These values are calculated using data from full-scale wall thermal-resistance tests performed at Oak Ridge National Laboratory. W-W R or whole-wall R-value measures R-value of the entire wall section, including framing material. The first four examples here are stud walls insulated with fiberglass batts.

Steel-Stud Walls



The relatively low R-value of steel-stud walls can be improved by insulated sheathing as shown here. Whole-wall R-value varies widely depending on the installation quality of the fiberglass insulation but can be less than R-5 for a 3.5-inch steel stud wall without insulated sheathing.

Insulation Thermal Performance factors

Insulation's ability to retard heat flow is measured by its R-value. "R" stands for thermal resistance. The R-value in any building assembly, created by a combination of insulation and other building materials, is affected by the following factors:

- Thermal bridging or thermal shorts in the assembly.
- Type and density of the insulation.
- Air leakage and convection from voids, gaps, or low insulation density.
- Water's presence within the assembly.
- Mass of the insulated assembly.

Two types of wall R-values are referenced in this book: clear-wall R and whole-wall R. Clear-wall R is the average R of the cavity between framing members. Whole-wall R is the average R-value of the wall including framing materials.

See "Materials/Building Assembly R-Values" on page 272.

Thermal bridging — Thermal bridging is rapid heat transfer through thermally conductive building materials like wood, steel, and aluminum. Strategies for reducing thermal bridging include minimizing framing materials and applying insulated sheathing as a thermal break.

Steel framing is a challenge to build and insulate adequately, especially in cold climates. Without insulated sheathing, the steel studs can cause condensation in cavities and wetting of surrounding building materials, in addition to a low whole-wall R-value.

See "Approximate R-Values of Wall Assemblies from Guarded Hot Box Testing" on page 274.

Insulation type and density — Some common insulating materials have an ideal density, where the R-value per inch is at its maximum. Compressing fiberglass and mineral wool to a specific density increases R-values per inch; after that optimal density, compressing the insulation decreases R-value per inch. For instance, mineral wool has a maximum R-value of R-3.6 per inch at about 4 pounds per cubic foot (lb/ft^3). At lower densities, mineral wool's R-value per inch is less (R-2.7 at 1 lb/ft^3), and at greater densities is also less (R-3.2 at 6 lb/ft^3).

Fiberglass reaches its highest R-value per inch of about R-4.2 at about 3.2 lb/ft^3. Cellulose has a maximum R-value per inch of about R-3.9 at between 1 and 2 lb/ft^3.

Convection and air leakage — Air convection within insulated building cavities increases heat transmission. Air convects heat off one surface and transports the heat to the adjacent surface — between drywall and the facing of batt insulation, for example. Convecting air can also find its way through channels around the insulation's edge gaps — between batts and framing lumber, for example. Edge gaps of only 4% of the insulated surface area can produce up to a 30% loss in effective R-value for R-19 ceiling insulation.

If air from inside or outside the building leaks into an insulated cavity, the effectiveness of the insulation is further reduced. This reduction typically varies from 15–50%. Air can even flow through fibrous insulating materials such as loosely installed fiberglass. Insulation's installed density is an important issue, especially in cold climates.

Wind also affects insulation performance. Wind convects heat away from the surfaces of a building. If voids and edge gaps exist, wind can push outdoor air through building cavities around the insulation or push air through insulation. These effects increase heat transmission.

Moisture condensation — Absorbed water decreases the R-value of insulation. Water fills the insulation's air spaces, and conducts heat far better than air. Water and ice also can damage insulation. Wet insulation can help corrode metals and supply water to insects and microorganisms that rot organic building materials.

Insulation R-Values per Inch

Insulation Type	R/inch
Fiberglass batts, blown, board	2.6–4.2
Cellulose blown	3.2–3.6
Mineral wool batts, blown, board	2.6–4.4
Vermiculite or perlite	2.1–2.4
Expanded polystyrene (white)	3.6–4.4
Extruded polystyrene (blue/pink)	5.0
Polyisocyanurate board	5.6–7.6

R-values vary by insulation type, density, and the quality of installation.

Air leakage is the most potent moisture-carrying mechanism affecting condensation in building cavities. Vapor diffusion is water vapor traveling through permeable materials like drywall and masonry. Low-R building materials combined with water-absorbent building materials create the largest potential moisture problems.

Thermal mass effect — The mass of building components, particularly walls, affects the heat flow through them. Especially in sunny climates with large temperature swings, massive building assemblies absorb energy surpluses from both the indoors and outdoors, slowing heat transmission. This thermal-mass factor varies, depending on the calculated R-value of the massive wall. The higher the massive wall's R-value, the greater the mass factor. The mass factor varies from around 1 to 2.6, according to tests performed at Oak Ridge National Laboratory on full-scale massive walls. The mass factor is multiplied by the calculated R-value to estimate a higher R-value that accounts for the thermal mass effect. Walls insulated on the exterior perform better than walls insulated on the interior. Walls insulated on the exterior have mass factors as high as 2.6, while walls insulated on the interior have mass factors only as high as 1.5. The mass factors vary according to calculated R-value and climate. Of the six cities simulated in the testing, Phoenix benefited most from mass

Windows are a significant source of transmission heat loss in cold climates and a significant source of solar heat gain in temperate or hot climates. Windows exist to provide natural light, ventilation, and a view to the outdoors. These functions make windows a formidable energy problem. The difficulty is limiting heat loss and gain while preserving natural light and view.

Most window energy conservation measures are expensive too; retrofit or replacement window costs commonly range from $5 to $50 per square foot of window area. Window replacements or retrofits for energy efficiency must be designed to significantly reduce thermal transmittance, reduce solar transmittance, or reduce both. Air leakage reduction is usually a secondary benefit producing only small energy savings, unless the window has large visible air leaks.

Doors generally have a thermal transmittance higher than walls, but lower than windows. Their surface area is small and replacement cost is high, so door replacement is not usually considered a cost-effective energy conservation measure. However, doors can be a significant air leakage problem due to faulty operation or poor air seals.

This chapter outlines the most important energy characteristics of windows and doors (also referred to as fenestration) and defines the challenging terminology associated with window ratings.

For a discussion of comfort and windows, see "Fenestration" on page 59.

Window Characteristics

Windows are composed of the following parts:

- Glass Assembly — One or more glass panes with spacers and gaskets, if needed.
- Sash — Frames the glass assembly. Sashes are either movable for ventilation, or fixed.
- Frame — Surrounds the sash and is the window part attached to the building.
- Rough Opening — Structural framing around the window to which the window frame is attached.

Energy Characteristics of Typical Window Glass Options

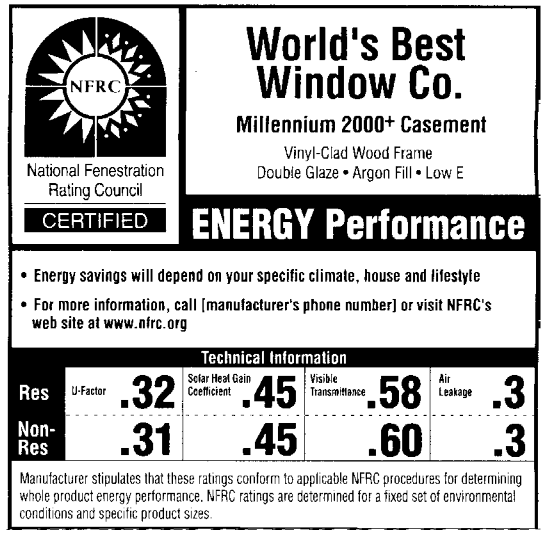
Glazing Assembly	U-factor	R-value	SHGC	VT
Single glass	1.1	0.9	0.87	0.90
Standard insulated glass	0.50	2.0	0.76	0.81
High-SHGC, low-e insulated glass	0.30	3.3	0.74	0.76
Medium-SHGC, low-e insulated glass	0.26	3.8	0.58	0.78
Low-SHGC, low-e insulated glass	0.29	3.4	0.35	0.65
Triple glazed 2 low-e insulated coatings	0.12	8.3	0.50	0.65

Understanding state-of-the-art window features is difficult because heat flow through windows is complicated and the terminology is unnecessarily complex. Conduction, convection, and radiation are all important window heat-flow mechanisms. The high conductivity of glass is tolerated because of its other useful and unusual qualities, including the fact that glass absorbs most infrared radiation while transmitting most solar radiation.

Thermal transmittance (U-factor) and solar heat gain are the most important energy considerations for windows. Air leakage as well as the window's optical characteristics, frame material, and type of glass assembly also enter into window selection.

Radiation, convection, and infiltration from windows reduce indoor comfort. Radiation is more complex with windows than with other building components.

NFRC Window Label



The NFRC label rates U-factor, SHGC, visible transmittance, and air leakage. Manufacturers associated with NFRC must submit their products for testing.

Window Research, Testing, and Rating

Four organizations serve as gate keepers for information about window thermal and structural characteristics. Their roles are briefly explained here to facilitate further information gathering.

National Fenestration Rating Council (NFRC): A public/private collaborative agency created to establish standardized window testing and rating. The Council simulates window performance with computers, then verifies that simulation with laboratory testing. NFRC labels are applied to windows made by member manufacturers listing thermal transmittance (U-factor), solar transmittance, visible transmittance, and air leakage. Condensation resistance is also being listed on some window models.

American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE): A professional society providing the theoretical framework for calculating heat flows through windows. ASHRAE's Handbook of the Fundamentals is the most common technical reference about window heat flows.

Lawrence Berkeley Laboratory (LBL): North America's most authoritative and prolific window research facility. LBL excels at computer simulation of window heat flows. LBL researches and develops new window technologies and distributes information about windows.

American Society for Testing and Materials (ASTM): Develops testing methodology for all types of building systems. Testing methods are specified by building codes and rating organizations like the NFRC. Windows are tested under ASTM standards for air leakage, water leakage, and structural strength.

Thermal Transmittance (U-factor)

The window industry describes and rates its products by U-factor or thermal transmittance. The U-factor includes heat transfer by conduction, convection, and radiation through the window assembly.

The U-factor is the reciprocal or inverse of R-value (U=1/R). U-factor is measured in units of BTUs per square foot per hour per degree Fahrenheit. As U-factor decreases, heat flow decreases. Lower U-factors are more energy-conserving than higher U-factors.

The U-factors of windows are rated using an area-weighted average of different sections of the window that have distinctly different U-factors: the frame, the edge of the glass area (a 2.5-inch band), and the central area of the glass.

Solar and Optical Characteristics

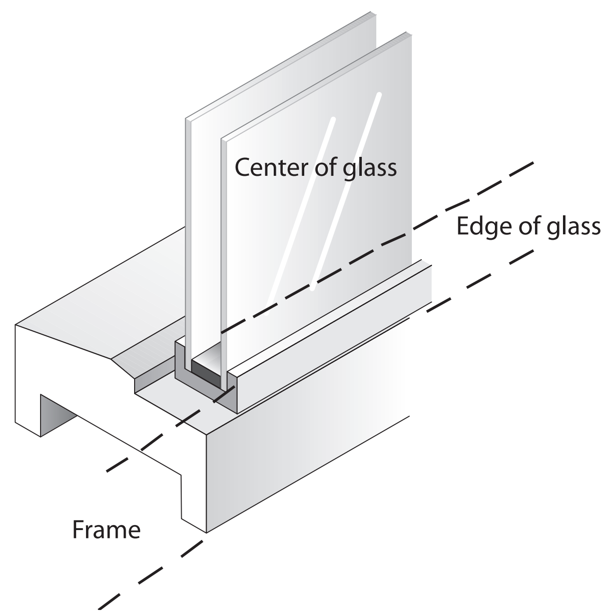
Solar heat gain shares importance with thermal transmittance as a primary window energy characteristic. Solar heat gain through windows can account for up to 40% of the total heat removed by an air conditioner. There are three common factors used to measure solar heat gain, and you are likely to encounter any of them. Each of these factors is a ratio and has no unit of measurement. Therefore, each factor may be expressed as a decimal number between 0 and 1.0 or as a percentage.

Solar Heat Gain Coefficient (SHGC): The ratio of solar heat passing through the glass to solar heat falling on the glass at a 90° angle. Includes radiant heat transmitted, and also the solar heat absorbed and reradiated indoors. Single pane glass has a SHGC of 0.87.

Shading Coefficient (SC): Compares the solar transmittance of a glass assembly — with its interior and exterior shading devices — to that of single-pane glass, which has a shading coefficient of one. The shading coefficient is always less than one and approximately 1.15 times greater than the SHGC of the glass assembly being considered.

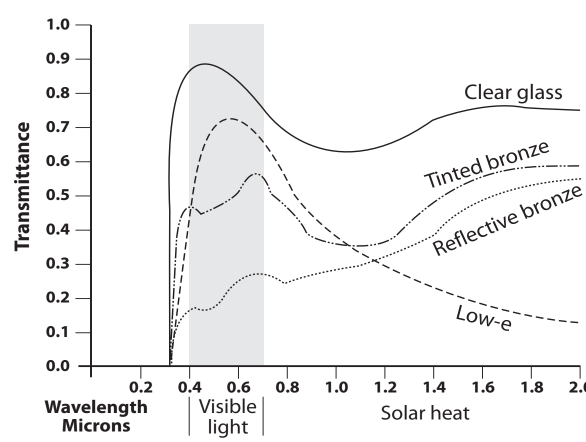
Generally, buildings in hot, sunny climates should employ window glass with SHGC of less than 0.50. South-facing windows used for passive solar heating need a SHGC of 0.70 or more.

U-Factor of Insulated Glass



The U-factor of an insulated glass window is an area-weighted average of the window's center of glass, edge of glass, and window frame.

Transmittance Spectrum for Glass Types



Transmittance of radiant energy varies widely with the type of glass used in a window.

A building's correctly sized heating system is designed to provide heat at roughly the same rate as heat is being lost during worst-case outdoor temperatures. *Output* is the heater's heat-production rate. The *heating load* is the building's heat loss rate. A heater's output should be larger than the building's heating load, except in the very severest weather conditions, so the heater cycles on and off to satisfy the load for most of the heating season.

The word *heater*, as used here, means a furnace, boiler, or space heater, and *heating system* means the heater and its distribution system. A *circulator* is a blower or pump for moving the heating fluid — air, water, or steam.

There are two types of heaters: room heaters and central heaters. Room heaters deliver all their heat into one area — generally a single room. Central heaters convert fossil fuel or electricity to heat in a central location and employ ducts or pipes to distribute the heat.

Typical Annual Heating Energy Use

Region & Fuel	Single Family	Multi-family	Mobile Home
Northern U.S.			
Electric (kWh)	*9k–14k	4k–9k	6k–8k
Gas (MMBTU)	80–115	60–70	60–70
Oil (MMBTU)	80–115	55–65	55–65
Southern U.S.			
Electric (kWh)	*4k–6k	2k–4k	1K–5k
Gas (MMBTU)	35–80	20–35	25–40
Oil (MMBTU)	45–90	20–60	20–60

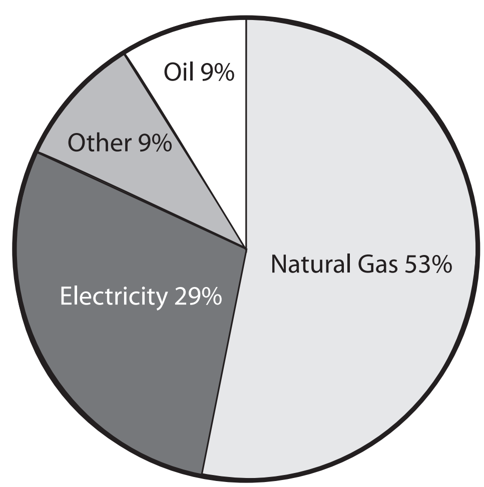
* k=1000. From Lawrence Berkeley Laboratory and Energy Information Administration. (1997)

Combustion fuels like gas, oil, and wood convert their potential energy to heat at *delivered efficiency* ranging from 35% to 95%. Delivered efficiency is the heating system's useful heat output divided by the energy input into the heating system. Efficiency is an important concept with combustion heating and there are several types of efficiency discussed in this chapter. The formula for determining any type of efficiency is the following:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}}$$

Electric resistance heat is considered 100% efficient, except for distribution losses. Heat pumps are a special type of electric heat that move heat from outdoors to indoors during the heating season and from indoors to outdoors during the cooling season. Heat pumps are generally more than 100% efficient because they can move more than a kilowatt-hour of heat for each kilowatt-hour of electricity they use. However, generating electricity from coal or oil wastes about 70% of the fuel's potential energy. Therefore, electricity is an expensive way to heat.

Residential Heating Fuel Types



Natural gas is North America's most popular heating fuel, followed by electricity.

Combustion Heating Basics

This section introduces the principles and components of gas, propane, and oil heaters. Gas and propane heaters are almost identical and are referred to here as gas heaters. Oil heaters are significantly different from gas and propane units.

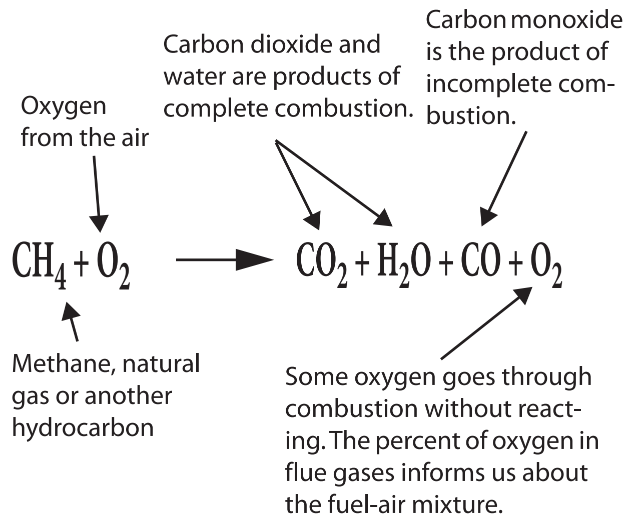
In gas and oil heaters, burners mix and burn fuel in combustion chambers. The *heat exchanger*, surrounding the combustion chamber, transfers heat from the flame and combustion gases to the heating fluid — air, water, or steam. Combustion gases leave the combustion chamber through the heat exchanger's flue(s), which connects to a chimney. A *flue* is a passageway for venting combustion gases: a flue may be a space between the heat exchanger's sections or a tube within the heat exchanger. Chimneys are made of metal, masonry, or other noncombustible material. The chimney's inner passageway is often also called a flue.

The efficiency of a combustion heater depends on losses to incomplete combustion, chimney losses, losses at the beginning and end of the burner cycle (called off-cycle losses), and losses from the pipes and ducts (called distribution losses). Room heaters have no distribution losses, so they are more efficient than central-heating units.

The Combustion Process

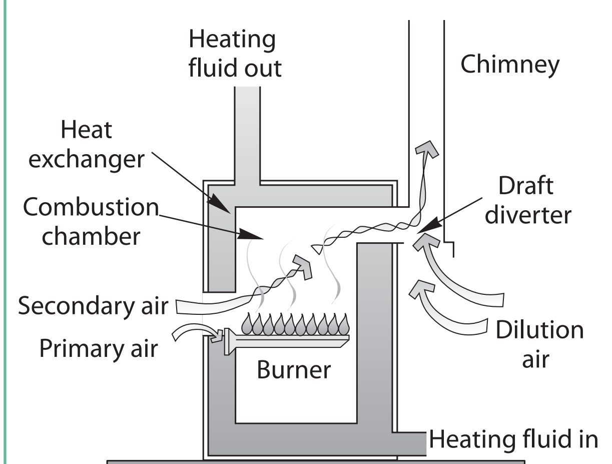
Combustion fuels are primarily hydrocarbons — molecules composed of hydrogen and carbon. Combustion is rapid oxidation; oxygen combines with the carbon and hydrogen, splitting the hydrocarbon molecule. Carbon dioxide (CO_2) and water vapor are the main products of this heat-liberating chemical reaction. Most of the flame's heat radiates to surrounding metal and rides combustion gases convecting against the heat exchanger's surfaces and transferring heat. Some of the flame's heat escapes up the chimney.

Combustion: The Chemical Reaction



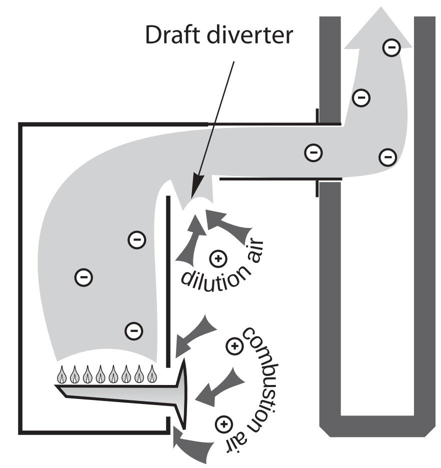
Combustion is a heat-yielding chemical reaction starting with a hydrocarbon and oxygen and producing CO_2 and water as its ideal products.

Open-Combustion, Atmospheric-Draft Heater

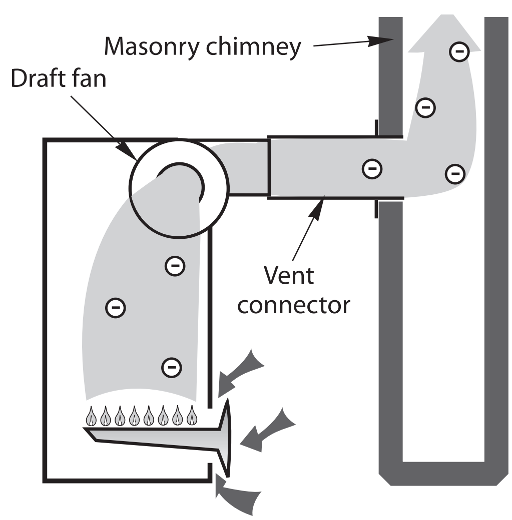


Atmospheric-draft heaters use only the buoyancy of the combustion gases and the flame's heat to exhaust combustion by-products and pull combustion air into the burner.

Atmospheric Versus Fan-Assisted Draft



An atmospheric open-combustion heater uses only the buoyancy of the combustion gases to exhaust these gases and to pull combustion air in.



The fan-assisted appliance creates over-fire draft with a draft fan. Chimney draft is atmospheric.

Air is about 21% oxygen. The other 79% of air is nitrogen, most of which travels through the combustion process unreacted. The combustion gases in the chimney contain unreacted oxygen in addition to the unreacted nitrogen. These unreacted gases absorb heat from combustion and carry the heat up the chimney. Unreacted oxygen is a sign of *excess air*, which is inversely proportional to efficiency.

See "Combustion Heating" on page 38 for more on principles of combustion.

Open versus sealed combustion — The terms open-combustion and sealed-combustion describe whether or not the combustion chamber, heat exchanger, flues, and chimney are open to the surrounding air.

The majority of combustion heaters in homes are open combustion. These heaters draw combustion air from the surrounding room. Older open-combustion heaters also draw indoor air into their chimneys through a dilution device — either a *draft diverter* (gas) or *barometric draft control* (oil). The air that these devices allow into the chimney is called *dilution air.* A draft diverter is an opening between the heat exchanger's flues and the chimney. The draft diverter is designed to moderate excessive updrafts and divert downdrafts that might interfere with the burner or extinguish the pilot. A barometric draft control performs the same function except that it adjusts dilution air to maintain a consistent chimney draft.

Sealed-combustion heaters are safer and often more efficient than open-combustion heaters. Sealed-combustion heaters have no openings from the home into their heat exchangers or chimneys. Instead, a sealed tube, sometimes combined with the chimney, brings combustion air in from the outdoors.

Burners

The burner's job is to mix the fuel and air and burn this mixture. The three common burner types are atmospheric burners, induced-draft burners, and power burners. Atmospheric burners are the most common type of gas burner. Gas pressure propels gas through a gas orifice into a venturi tube where the gas mixes with *primary air* admitted by an air shutter. A pilot light, hot-surface igniter, or sparking electrode ignites the mixture. *Secondary air* in the combustion chamber around the flame provides oxygen for the fuel's nearly complete combustion.

CHAPTER 7 LIGHTING AND APPLIANCES

This chapter discusses lighting and home appliances. Lighting and appliances account for 10% to 50% of residential energy use, depending on climate and the energy efficiency of the home. A home with an efficient shell in a mild climate uses a larger percent of the its energy for lighting and appliances than one with an inefficient shell in a severe climate.

Annual Electrical Energy: Kilowatt-Hours

Appliance	Low Estimate	High Estimate
Lighting	200	2000
Refrigerator	500	2000
Clothes Dryer	300	1500
Clothes Washer*	100	1000
Television	100	600
Well pump	250	750
Hot tub / spa	1000	2500
Computer	50	400

* Includes water heating.

Energy Information Administration, Lawrence Berkeley Laboratory, and utility sources.

See "Analyzing Annual Energy Costs" on page 271 and "Annual Average Household Energy Cost by Region (1997)" on page 14 for more information on percentage of energy used for lighting and appliances.

Lighting

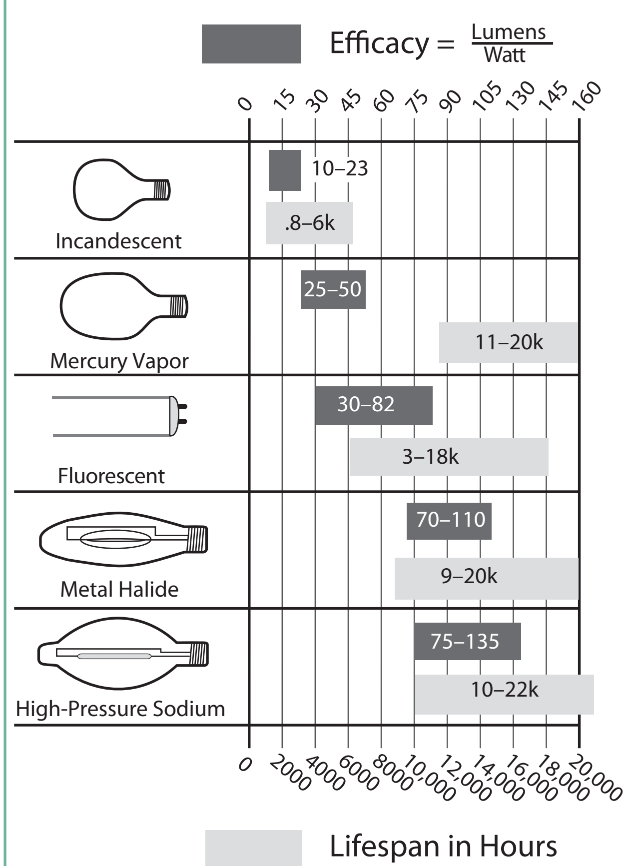
Homes are the setting for various visually-intensive tasks such as sewing, office work, crafts, and cooking. More people are working at home and need lighting suited for their vocation. Lighting also provides outdoor security and night time visibility. Retrofits consist mainly of replacing the existing lamps or fixtures with more efficient models.

To choose the best lighting options, it helps to understand basic lighting principles and terminology.

Efficacy (efficiency)

Lighting efficiency is known as *efficacy* and is measured in lumens per watt.

Efficacy and Lifespan



Efficacy and lamp life vary widely among the common lighting types.

Illumination

A lumen measures light output from a lamp. All lamps are rated in lumens. For example, a 100-watt incandescent lamp produces about 1750 lumens. Dividing a lamp's number of lumens by its watts gives efficacy—a measurement of lighting efficiency.

The distribution of light on a horizontal surface is called its illumination. Illumination is measured in footcandles. A footcandle of illumination is a lumen of light distributed over one square foot of area.

The amount of light required, measured in footcandles, varies according to the difficulty of a visual task. Ideal illumination is the minimum footcandles necessary to comfortably perform a task at the maximum practical rate of speed without eyestrain.

In the past, illumination of 100 footcandles was thought to be minimum for visual tasks in the workplace. Now, the Illuminating Engineering Society says that 30 to 50 footcandles is adequate for most home and office work. Difficult and lengthy visual tasks, like sewing for extended periods of time, requires 200 to 500 footcandles. Where no seeing tasks are performed, the lighting system needs to provide only security, safety, or visual pleasure—from 5 to 20 footcandles.

Lighting Uses

Three categories of lighting by function are ambient lighting, task lighting, and accent lighting.

Ambient lighting provides security and safety, as well as lighting for tasks that occur throughout the lighted space.

Task lighting provides light at the work area. Illumination levels should be high enough for accurate task execution in task areas—not throughout the entire lighted space.

Accent lighting illuminates walls so that their brightness contrasts less with brighter areas, like ceilings and windows. Accent lighting is also used to make the space more visually comfortable.

Lighting Color

Lamps are assigned a color temperature depending on their "coolness" or "warmness." People perceive colors at the blue-green end of the color spectrum as cool and those at the spectrum's red end as warm. Morning light from the north is a more bluish than southwest evening light.

Cool light sources are preferred for visual tasks, since they produce better contrast at the printed page, workbench, or other task. Warm light sources are preferred for living spaces, because they are more flattering to people's skin and clothing.

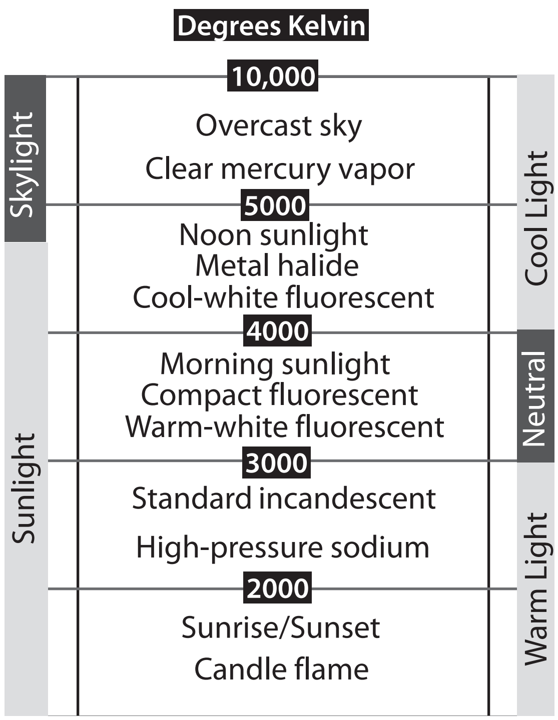
Color Rendering Index

Lighting Type	Color Rendering Index
Incandescent	97–100
Fluorescent (Standard)	52–62
Fluorescent (T-8 & CFL)	81–90
Mercury vapor	22–52
Metal halide	60–90
High-pressure sodium	25–65

Color rendering — The color of light from a lamp and that light's ability to render correct color are separate and independent characteristics.

Artificial light sources vary widely in what is called the color rendering index (CRI). Incandescent lamps are rated at CRI of 100—nearly equal to sunlight—while some high-pressure sodium lamps have a CRI of 22.

Color Temperature



Color temperature compares an artificial light source to sunlight and skylight.

Light's color rendering ability is not related to its color temperature. Blue north skylight, white noon sunlight, and a red sunset all have perfect color rendering (a CRI of 100), because our eyes are designed to read the colors of objects illuminated by sunlight.

Light Quality

Light quality describes how well people in a lighted space can see to do visual tasks, and how visually comfortable they feel in that space. High lighting quality is characterized by fairly uniform brightness and the absence of glare. Light quality is important to energy efficiency because spaces with higher lighting quality need less illumination.

For example, direct intense sunlight streaming through windows of a room with chocolate brown carpets and dark wall paneling will likely give too much contrast in brightness. The eye's pupil will have to constantly adjust its diameter as the eye wanders through the differing brightness of contrasting areas. Making this area visually comfortable would involve a high illumination level and many electric lights.

Now consider a room bathed in soft light. You can hardly tell where the light is coming from because no area of the room appears much brighter than another. The walls, ceiling, floor, and work surfaces are light colored. People can perform tasks faster and with fewer mistakes with this type of high-quality lighting. Lighting this area requires far less electric lighting than the previous example because of its superior lighting quality.

***Glare* —** Eliminating glare is essential for good lighting quality. Glare comes in at least three varieties: direct glare, reflected glare, and veiling reflections.

Direct glare is strong light from a window or bright lamp shining directly into your eyes. Reflected glare is strong light reflected off a shiny surface into your eye. Veiling reflection is glare from a work surface like a printed page or computer screen.

Types of Lighting

There are four basic types of lighting: incandescent, fluorescent, high-intensity discharge, and low-pressure sodium.

Incandescents dominate residential lighting, fluorescents dominate commercial indoor lighting, and high-intensity discharge lighting dominates outdoor lighting. These lighting types vary widely in their construction, efficacy, color characteristics, and lamp life.

***Incandescent* —** Incandescent lamps are the oldest, most common, and most inexpensive lamps. Incandescent light is produced by a white-hot coil of tungsten wire that glows when heated by electrical current. The type of glass enclosure surrounding this tungsten filament determines its light beam's characteristics.

CHAPTER 8 COOLING

This chapter contains a mixture of information about the building shell, landscaping, windows, and mechanical cooling systems. This mixture of topics is necessary to develop an energy-efficient cooling strategy.

How Cooling is Different than Heating

Cooling is the most variable type of energy consumption in American homes. Two similar homes in the same neighborhood could differ by a factor of 50 for cooling costs. For example, an inefficient home with air conditioning could use $500 worth of electricity in a hot month, while a neighbor in a well-designed home–with no mechanical air conditioning–might spend only $10 per month on electricity to operate room fans and evaporative coolers.

The most effective strategies for improving cooling efficiency are different from the strategies to improve heating efficiency. For example:

- ♦ Shade trees and nighttime ventilation will reduce the need for air conditioning, but won't reduce heating consumption.
- ♦ Window glass with a low solar heat gain coefficient (SHGC) will reduce cooling load, but heating efficiency is improved by windows with a low U-factor.
- ♦ Low humidity helps reduce cooling energy consumption, but not heating consumption.

A home's cooling energy consumption depends on its shading, insulation, reflectivity, and the heat-tolerance of its residents. Shading the home, making it as reflective as possible, and using nighttime ventilation can reduce air-conditioning costs or eliminate the need for air conditioning altogether.

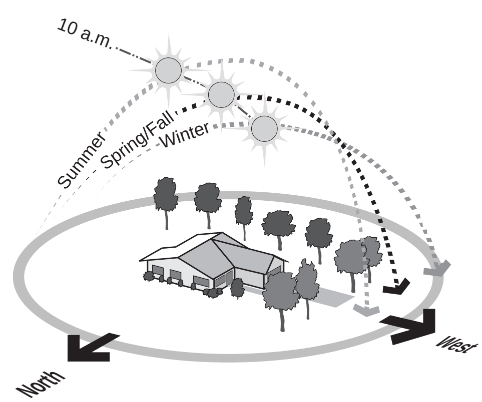
See "Analyzing Annual Energy Costs" on page 271 and "Annual Average Household Energy Cost by Region (1997)" on page 14 for information on cooling energy consumption.

Annual Air-Conditioning Energy Use (kWh/yr)

Region & A/C Type	Single Family	Multi-family	Mobile Home
North	**kWh/yr**	**kWh/yr**	**kWh/yr**
Room	200–500	100–300	300–600
Central	900–1400	400–600	1200–1800
South	**kWh/yr**	**kWh/yr**	**kWh/yr**
Room	1100–1500	300–600	1000–1400
Central	3000–4600	1000–1600	2600–3400

From: Lawrence Berkeley National Laboratory, Energy Information Administration, and utility sources. For U.S, households.

Solar Radiation: Winter and Summer



Summer Comfort Principles

The combination of air temperature, radiant temperature, humidity, and air movement determine comfort. Air temperature and radiant temperature determine the rate that a human body can lose heat by convection and radiation, which are the body's preferred cooling mechanisms. The relative humidity determines the rate that a human body can reject heat by evaporation of sweat, the body's last-resort cooling system.

Air temperature and radiant temperature have a combined effect on human comfort. Air temperature is widely recognized as a comfort determinant, but radiant temperature is equally important. Absorbed summer sunlight raises wall and ceiling temperatures, making these surfaces radiant heaters.

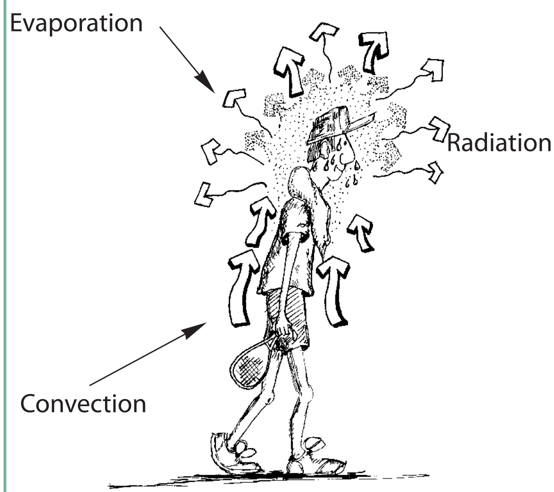
Relative humidity is the percent at which air at any temperature is saturated with water vapor. Air at 100% relative humidity is saturated and can hold no more water vapor. Dew point is the temperature at which condensation begins. At 100% relative humidity the dew point is the same as the air temperature. Below 100% relative humidity, the dew point is less than the air temperature.

Humidity affects the choice of a cooling strategy during hot weather. At low relative humidity and low dew point, evaporative cooling and ventilation are effective cooling methods. Ventilation works well up to about 70% relative humidity (or a dew point in the high 60°s). Most Americans use air conditioning during hot weather—when the dew point is above 68°F or when the relative humidity outdoors is over 70%.

At 70% relative humidity or above, the air feels either hot and sticky, or cold and clammy, and is not comfortable to most people. Air conditioners must remove moisture from indoor air to achieve comfort.

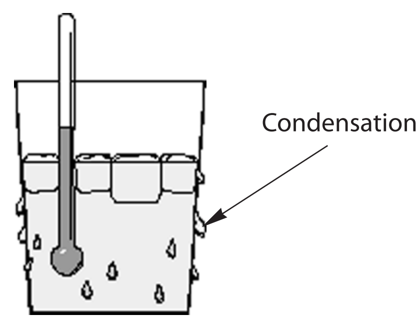
Moving air always makes you feel cooler, because it carries heat away from the skin and increases the evaporation of sweat. Circulating air inside your home is the key element to staying comfortable during hot weather. Rapidly moving air works well by itself, and can be combined with air conditioners, evaporative coolers, and whole-house fans to further improve comfort.

Convection, Radiation, and Evaporation



The human body loses heat steadily by convection, radiation, and evaporation. Summer comfort is often defined as staying cool with a minimum of sweat.

Dew Point

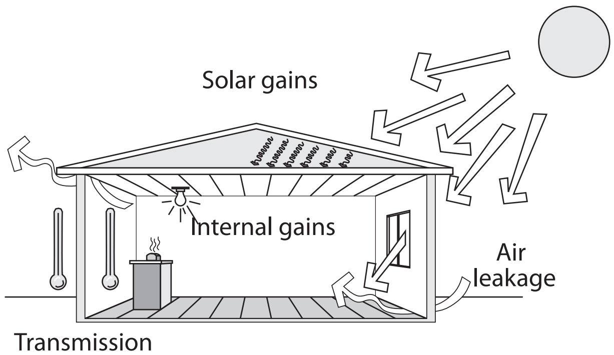


Fill a beverage glass with warm water. Then slowly add ice. When condensation begins to appear, the temperature of the glass has reached the dew point temperature of the air.

Whenever the outdoor air temperature and humidity are comfortable, ventilating with outdoor air will carry heat away from the home and reduce air-conditioning costs.

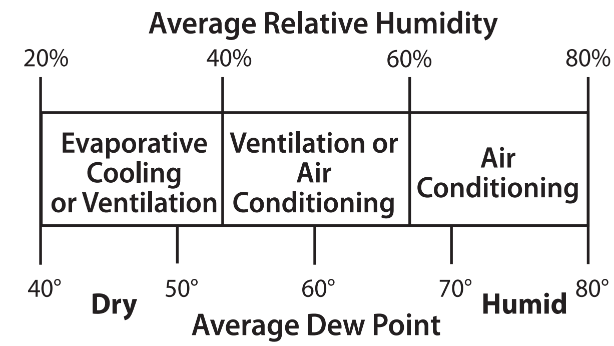
See "Energy, Comfort, Climate" on page 36 for more information on human comfort.

Four Types of Heat Gains



Solar gain is the dominant heat gain. Air leakage and internal gains are about equally important. Transmission heat gains are usually least important.

Humidity's Effect on Cooling Strategies



Dew point and relative humidity are two commonly reported indicators of summer humidity. The higher these values are, the more difficult it becomes to provide acceptable comfort without air conditioning.

Heat Gain

During the cooling season, unwanted indoor heat is called *heat gain*. There are four types of heat gain in the home: solar heat, internal heat, air leakage, and temperature-driven heat transmission.

Solar Gain — In most climates, solar heat is the largest heat gain, contributing about 50% of the heat accumulating indoors. Solar energy falling on the roof and coming through the windows accounts for most of this. Walls are less important as a source of solar heat.

Internal Gains — Internal gains include the waste heat from lighting, refrigeration, water heating, and other appliances, as well as the body heat from people inside the home. Efficient appliances produce less waste heat, and so contribute less to summer overheating. Internal gains usually account for around 20% of the total summer heat gain.

Air Leakage — Air leakage allows hot outdoor air to leak into the home, and cold indoor air to leave. Air sealing helps reduce both summer heat gain and winter heat loss. Air leakage contributes about 20% to summer heat gain.

Heat transmission — Heat transmission through the shell of the home is the least important summer heat gain because the temperature difference between indoors and outdoors is much smaller in summer than in winter. Heat transmission typically represents around 10% of the total cooling load.

Reflectivity

Solar energy falling on the roof and coming through the windows accounts for most of the solar heat accumulating indoors. Walls are less important as a source of solar heat.

Just as insulation levels (R-values) are the most important characteristic for low-energy heating, a well-shaded or reflective home enables low-energy cooling.

The most important places to use shading and reflectivity are on the roof and windows. Energy conservation measures that block the sun before it strikes the roof or windows are the most effective. Trees and other plants that provide shade are the best long-term investment for reducing cooling costs.

See "Temperature and Heat" on page 28 , "Sensible and Latent Heat" on page 28, and "Radiation" on page 33 for principles involved in heat gain.

Chapter 9 Water Heating

This chapter explores types of water-heating systems along with energy-efficiency and maintenance issues relating to water heating.

A *domestic hot-water system* consists of: a heat source, a heat exchanger, a piping system, and plumbing fixtures like showers and sinks. Most domestic hot-water systems also have storage tanks. The heat source is a gas or oil burner, electric heating elements, a heat pump, or a solar collector. Heat exchangers usually consist of metal tanks or pipes.

A vast majority of North Americans use storage water heaters consisting of a tank, insulation, and a heating device which uses gas, oil or electricity. Recent improvements in water heaters include more and better tank insulation and improved combustion systems.

Water-heating Energy Use

The average household uses around 3500 kilowatt-hours of electricity or 230 therms of natural gas to heat water annually. Water heating consumes approximately 15% of the electricity and 25% of the natural gas used in residences. Water heating is the most variable class of energy consumption among families and varies according to water-heater capacity, climate, economic status, work schedule, and age.

Water heaters use energy in three ways: demand, standby, and distribution. *Demand* means energy is used for heating incoming cold water up to the temperature setpoint as hot water in the tank is used. Demand energy depends on water heater efficiency, occupant behavior, and consumption of fixtures like shower, clothes washer, and dishwasher.

Standby energy accounts for heat lost through the storage tank's walls. Standby losses amount to 20% to 60% of the total water-heating energy. Households using less hot water have a higher percent of standby losses.

Distribution losses consist of heat escaping through the pipes and fixtures. Pipes near the water heater lose heat even when water isn't flowing because hot water rises out of the tank, cools off in the nearby pipes, then falls back down into the tank.

Typical Consumption According to Family Size

Number of Residents	Annual kWh	Annual Therms	Gallons Per Day
1	2700	180	25
2	3500	230	40
3	4900	320	50
4	5400	350	65
5	6300	410	75
6	7000	750	85

Author's interpretation of single-family house data from Energy Information Administration, Lawrence Berkeley Laboratory, *Home Energy Magazine*, and others.

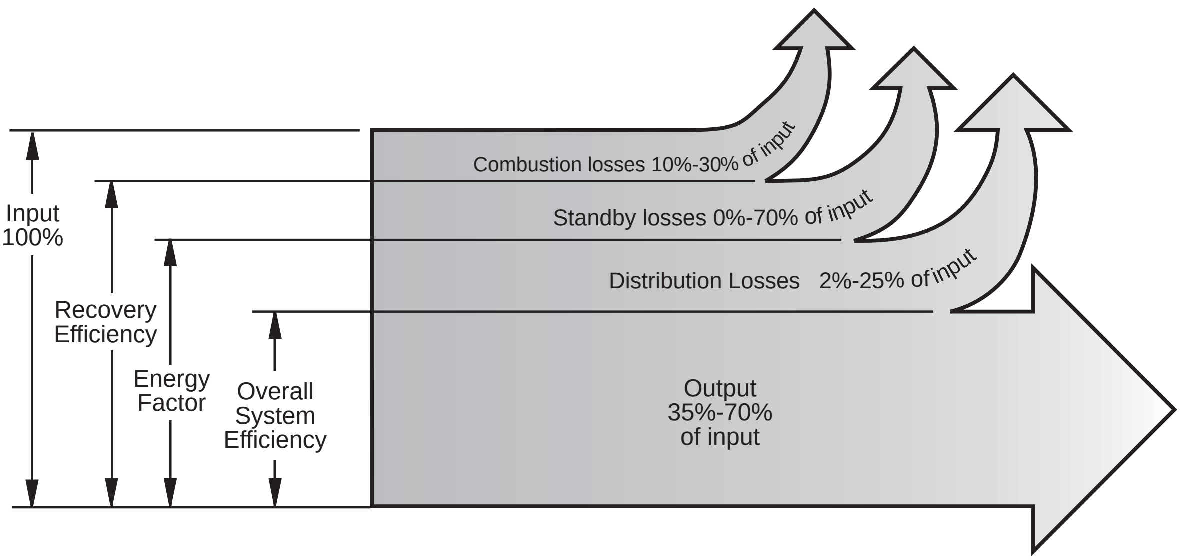
Water-heating Capacity

Americans use 15 to 40 gallons of hot water per day per person. Designing or selecting a water heater involves consideration of the first-hour rating and the storage capacity.

Hourly peak hot-water flow rate in gallons per hour is known as the *first-hour rating* or *recovery capacity*—an important design consideration for water-heating systems. The size of heating equipment, capacity of storage tanks, and design of piping systems is determined by recovery capacity needed by a building.

Water-heating systems are designed for recovery capacities of 3 to 20 gallons per hour per resident. Multifamily buildings—especially large ones—need less recovery capacity per resident or dwell-

Water-Heating Efficiency



The various efficiencies used for rating water-heating systems account for losses in the combustion process, standby losses, and distribution losses.

ing unit because of residents' differing schedules. Suggested recovery capacities for multifamily range from 3 to 10 gallons per hour per resident.

Storage capacity, the amount of water in the storage tank, relates to the number of occupants or number of dwelling units in a building. Storage capacity typically varies from 8 to 20 gallons per person or 30 to 65 gallons per living unit. Most single-family homes have 40-gallon or 50-gallon storage tanks.

Water-heating Efficiency

There are several types of efficiencies used to rate water-heating systems. The *energy factor* is the most common efficiency for single-family water heaters. Energy factor assumes that residents use 64 gallons per day. It accounts for energy losses during the water-heating process, by a pilot light, and through the storage tank. Its numerical value—a decimal between 0.50 and 1.0—describes the fraction of the water heater's energy input that actually remains in the water leaving the storage tank. In 2004, the current required minimum energy factors are 0.59 for gas and oil water heaters and 0.90 for electric water heaters.

Energy Factors: Required and Best Available

New Water Heater	Required	Best Available
Electric	0.90	0.92–0.95
Natural Gas	0.59	0.62–0.65
Oil	0.59	0.62–0.68

Recovery efficiency accounts for just the losses during the water-heating process. A storage water heater's energy factor is less than its recovery efficiency. For demand water heaters without pilot lights, recovery efficiency is the same as their energy factor because they have no storage losses.

Overall system efficiency includes all losses and measures the efficiency of the water heater and its distribution system in providing heated water to points of use.

The American Council for an Energy Efficient Economy lists the most efficient storage water heaters in their annual guide, The *Consumer Guide to Home Energy Savings*. See "Bibliography" on page 304.

Water-heater Design Types

Design of water-heating systems is based on three interrelated factors: *recovery capacity* (gallons per hour), *energy input* (BTUs per hour), and *storage capacity* (gallons). These are determined by occupancy, number of plumbing fixtures, and per capita use.

Fuels for water heating include: fossil fuel, electricity, solar energy, and waste heat recovery. Each of these fuels can be used directly or indirectly. Direct water heating applies the fuel's heat to only one heat exchanger—a tank or pipes containing domestic hot water. Indirect water heating applies heat collected by water or air in a remote area to heat the domestic hot water. This remote heat comes from a boiler, solar collector, or waste heat exchanger. Indirect water heaters employ two or more heat exchangers.

Storage Water Heaters

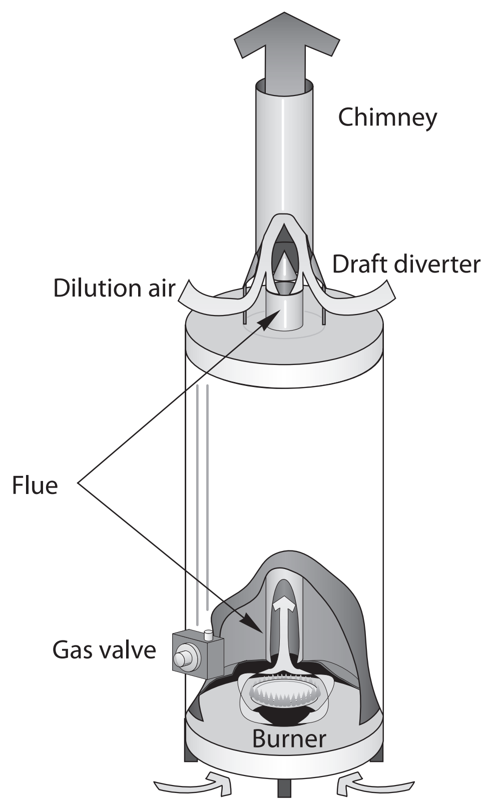
Most single-family homes use direct storage water heaters that combine the heating device, heat exchanger, and storage tank into one unit. Single-family, storage water heaters hold 30 to 80 gallons of water. Their tanks are insulated with fiberglass or plastic foam insulation and covered with outer jackets of painted sheet metal. Hot water exits the top of the tank, and cold water enters through a tube extending to the tank's bottom.

Older storage water heaters, insulated with fiberglass, have a thermal resistance (R-value) of R-3 to R-6, while newer models have R-7 to R-25. The extra cost of the better insulated water heaters will be returned to the buyer in energy savings in a year or less. Improved insulation is the only significant, recent improvement to electric storage water heaters.

A thin layer of glass, mineral, or plastic coats the steel tank's inside for corrosion resistance. A metal rod attached to the top of the tank, called the sacrificial anode, also protects the tank's steel parts from corrosion.

Storage water heaters with better warranties incorporate features like improved tank coatings, auxiliary sacrificial anodes, and curved dip tubes that make flushing more effective at removing sediment.

Standard Gas Water Heater



Combustion air enters the bottom, combusts with gas, then rises through the flue which is surrounded by water. The gases heat the water as they rise through the tank. Dilution air enters through the draft diverter.

"First, do no harm." This statement has been an admonition to many a service provider and is particularly relevant to the field of building energy efficiency. Unless a service provider recognizes existing problems and potential for new ones, calamity will eventually pay a call.

Weatherization work often interacts with a building's pre-existing hazards. When this interaction occurs, we want to remove, or at least mitigate, the hazard, and never aggravate it. The job site presents a series of hazards that workers must recognize and avoid.

Carbon monoxide from combustion appliances, for example, is frequently encountered during weatherization work. Moisture and fire also present major hazards to human health and safety, and are the leading causes of building damage. Energy technicians should take the opportunity to add extra value to their work by reducing the danger of these hazards.

Exposure to toxic substances in the home and at work is probably the greatest long-term health hazard we face. Accidents are the fourth leading cause of death in the United States, and constitute the greatest short-term hazard in our lives.

Home energy conservation modifications can create health and safety hazards if workers and occupants are not aware of the potential problems. Educating workers and occupants about the hazards at home and at the work site reduces the chances of accidents and exposure to toxic substances.

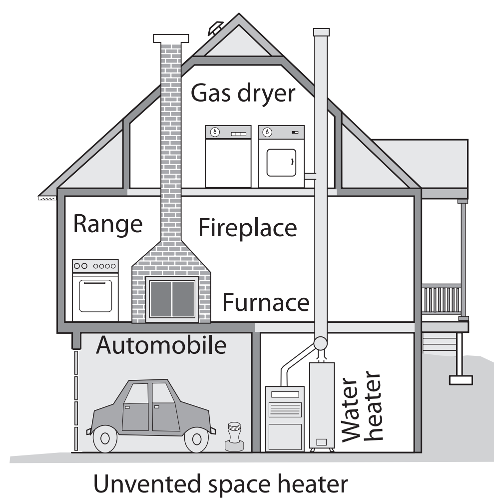
Indoor Pollutants

Air pollution is the most serious long-term health hazard in the indoor environment. By-products from combustion appliances and environmental tobacco smoke are the biggest contributors to indoor air pollution. Both of these sources contain multiple toxins, including carbon monoxide (CO), nitrogen oxides, volatile organic compounds (VOC), and fine dust particles, which are inhaled deeply into the lungs.

Dust also results from construction and other activities. Smaller and lighter dust particles are more dangerous than larger, heavier particles because they remain airborne for longer periods of time, and they settle more deeply in the lungs. The sharpness and chemical activity of dust particles affects the danger they present. A dusty environment also magnifies radon's danger by providing a transport mechanism that carries radon into the lungs.

See "Minimum Ventilation Requirement (MVR)" on page 79 and Appendix A-21 Indoor Air Pollutants for more information on indoor air quality.

Sources of Carbon Monoxide (CO)



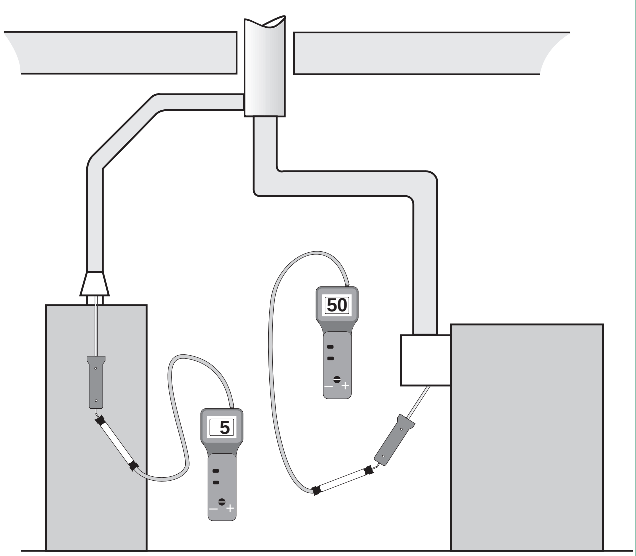
When CO is suspected in health problems, all the potential sources should be considered.

Combustion By-products

The most common sources of combustion by-products in indoor air of residential buildings are unvented combustion space heaters, gas ranges, vented combustion space heaters, central heating systems, and tobacco smoke. Unvented space heaters and gas ranges release all their combustion by-products into the indoor air. Vented space heaters may spill combustion by-products, temporarily or continuously, while they are operating. Continuous spillage from the vent of a combustion appliance is called *backdrafting*. Spillage from wood stoves can be particularly dangerous because wood smoke contains numerous toxins in high concentrations.

The chief causes of backdrafting and spillage in central heating systems and vented space heaters are: blocked chimneys; chimney air leaks; cracked heat exchangers; improperly designed or installed venting; and a depressurized zone near a furnace, water heater, or room heater. Furnace fans, exhaust fans, clothes driers, and chimneys can depressurize this combustion zone. Chimneys that are backdrafting or spilling should be inspected for blockage, leaks, and depressurization.

Electronic CO Testers



Electronic CO testers give a digital readout of CO in parts per million. You should test combustion gases as they leave the heat exchanger before they are diluted.

Technicians should test chimneys to ensure that they have proper draft and little or no carbon monoxide. Chimney testing is especially important as part of air sealing work, which may alter the home's pressure conditions. Draft in atmospheric-draft appliances should be negative 1-to-5 pascals (0.004-to-0.020 inches of water) depending on the outdoor temperature—colder outdoor temperatures should produce higher chimney draft. Measured pressure differences between outdoors and the combustion zone should not exceed 4-to-5 pascals, with exhaust fans and furnace fan running during a worst-case depressurization test. The combustion heater should spill for no longer than 30 seconds under these worst-case test conditions.

See "Combustion Safety and Efficiency" on page 146.

Carbon monoxide (CO) — Carbon monoxide (CO) is released by combustion appliances, automobiles, and cigarettes as a product of incomplete combustion. CO is the largest cause of injury and death from gas poisoning, resulting in more than 500 deaths per year. Many more people are injured by high concentrations of the gas, or sickened by lower concentrations of 5-to-50 parts per million (ppm). The symptoms of low-level CO exposure are similar to the flu, and may go undiagnosed.

CO blocks the oxygen-carrying capacity of the blood's hemoglobin, which carries vital oxygen to the tissues. At low concentrations (5-to-50 ppm), CO reduces nerve reaction time and causes mild drowsiness, nausea, and headaches. Higher concentrations (50-to-3000 ppm), lead to severe headaches, vomiting, and even death, if the high concentration persists. The effects of CO poisoning seem to be largely reversible, except for exposure to very high levels, which can cause brain damage.

The EPA's suggested maximum 8-hour exposure is 9 ppm in room air. Room levels of CO at or above 9 ppm are usually associated with the use of malfunctioning combustion appliances within the living space. These include: unvented combustion space heaters, gas ranges, leaky wood stoves, and backdrafting vented space heaters. Backdrafting furnaces and boilers may also lead to high levels of CO. CO is a common problem in low-income housing, affecting 20% or more of residential buildings in some regions.

The most common CO-testing instruments are electronic sensors with a digital readouts in parts per million (ppm). Unvented combustion appliances should operate with virtually no CO production and vented appliances should produce no more than 100 ppm of CO in the flue gas, measured before the dilution device. CO is normally tested near the flame or at the exhaust port of the heat exchanger. CO is usually caused by one of the following:

- Flame interference from a part of the heating device (a pan over a gas burner on a range top, for example)
- Flame interference from dirt and debris
- Misalignment of the burner
- Inadequate combustion air
- Backdrafting of combustion by-products onto the flame

Environmental tobacco smoke — Tobacco smoke contains more than 3800 chemicals, which include carbon monoxide, ammonia, formaldehyde, and nicotine. According to the EPA, cigarette smoke is responsible for 39% of all exposure to indoor air pollutants.

An estimated 1000 Americans die every day from smoking-related diseases such as lung cancer, emphysema, bronchitis, and heart disease. The EPA estimates that 3,000 nonsmokers die each year from cancer brought about by secondhand smoke. The American Heart Association estimates that 37,000 people die annually in the U.S. from heart disease related to secondhand smoke. Cigarettes are responsible for more deaths than all accidental and environmental causes combined.

Nitrogen oxides, hydrocarbon dust, and volatile organic compounds — Nitrogen oxides are created naturally by the combustion of hydrocarbons in air, which is about 80% nitrogen. Nitrogen dioxide stunts pulmonary development and increases respiratory ailments in children. In healthy adults, nitrogen dioxide causes impaired respiratory function at 2 ppm, and sometimes less.

Wood stoves, unvented kerosene space heaters, and cigarette smoke release fine hydrocarbon dust and volatile organic compounds (VOCs) into the indoor air. The fine particles in smoke can penetrate deeply into the lungs and contribute to a variety of respiratory illnesses.

Other common sources of VOCs are: solvents and cleaners; paints and varnishes; and furniture, carpeting, and draperies. The VOC formaldehyde is particularly prevalent in new homes, because so many new home components—from plywood and sheetrock to cabinets and carpet—contain formaldehyde. Formaldehyde is a respiratory irritant, a sensitizer, and a probable carcinogen. The World Health Organization considers formaldehyde levels of 0.10 ppm the limit for continuous exposure. Symptoms of overexposure to formaldehyde include watery eyes and persistent respiratory distress. Formaldehyde levels of new homes and newly renovated buildings sometimes produce these symptoms.

Radon

Radon is a dangerous indoor air pollutant that comes from the ground through rocky soil. Studies predict 16,000 lung cancer deaths per year caused by radon.

Radon is a radioactive gas, whose decay particles cling to dust and can mutate lung tissue. The concentration of radon varies widely, both regionally and within regions. Energy conservation work probably has little effect on radon concentrations. However, all housing specialists should be aware of radon's danger, radon testing procedures, and radon mitigation strategies.

Appendices

Glossary

Absolute humidity - Air moisture content expressed in grains (or pounds) of water vapor per pound of dry air. Also called: humidity ratio.

Absorptance - The ratio of a solar energy absorbed to incident solar. Also called absorptivity.

Absorption - A solid material's ability to draw in and hold liquid or gas.

Accent lighting - Lighting that illuminates walls, reducing brightness contrast between walls and ceilings or windows.

Ambient lighting - Lighting spread throughout the lighted space for safety, security, and aesthetics.

Air barrier - Any part of the building shell that offers resistance to air leakage. The air barrier is effective if it stops most air leakage. The primary air barrier is the most effective of a series of air barriers.

Air changes per hour at 50 pascals (ACH_{50}) -

The number of times that the complete volume of a home is exchanged for outside air each hour, when a blower door depressurizes the home to 50 pascals.

Air conditioning - Cooling buildings with a refrigeration system. More generally means both heating and cooling.

Air exchange - The total building air exchanged with the outdoors through air leakage and ventilation.

Air handler - A steel cabinet containing a blower with cooling and/or heating coils connected to ducts.

Asbestos - A material made of brittle mineral fibers that damage lungs and other bodily tissues.

Audit - The process of identifying energy conservation opportunities in buildings.

Ampere - A unit of measurement of electrical current flow. A coulomb per second.

Annual fuel utilization efficiency (AFUE) - A laboratory-derived efficiency rating for heating appliances which accounts for chimney losses, jacket losses, and cycling losses.

Annual return - The yearly savings divided by the initial cost needed to achieve the savings, expressed as a percent.

Approach temperature - The temperature difference between the fluid inside a heat exchanger and the fluid outside it.

Aquastat - A heating control that switches the burner or the circulator in a hydronic heating system.

Backdrafting - Continuous spillage of combustion gases from a combustion appliance.

Backdraft damper - A damper, installed near a fan, that allows air to flow in only one direction.

Backer rod - Polyethylene foam rope used as a backer for caulking.

Baffle - A plate or strip designed to retard or redirect the flow of flue gases.

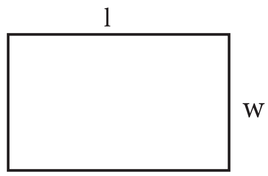
Balance point - The minimum outdoor temperature at which no heating is needed.

Ballast - A coil of wire or electronic device that provides a high starting voltage for a lamp and limits the current from flowing through it.

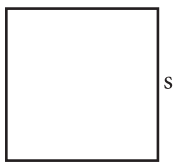
Band joist - See Rim joist.

A-2 Geometry

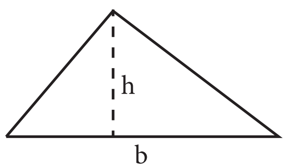
Plane Geometry

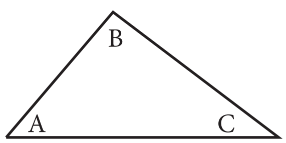


Rectangle
Area: $A = lw$
Perimeter: $P = 2l + 2w$

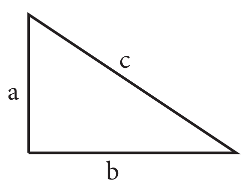


Square
Area: $A = s^2$
Perimeter: $P = 4s$

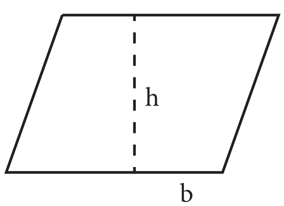




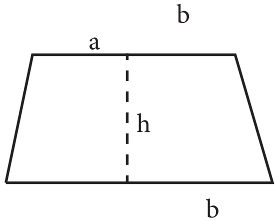
Triangle
Area: $A = \frac{1}{2}bh$
Sum of angles:
$A + B + C = 180°$



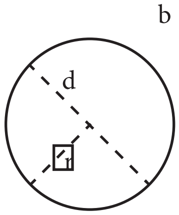
Right Triangle
Pythagorean Theorem:
$a^2 + b^2 = c^2$



Parallelogram
Area: $A = b \bullet h$

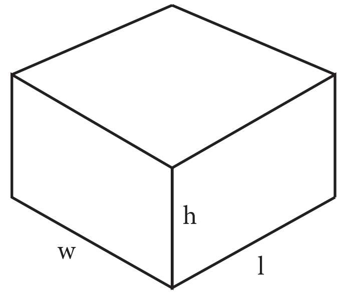


Trapezoid
Area: $A = 1/2h(a + b)$

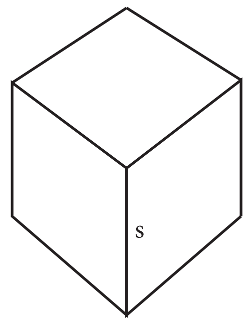


Circle
Area: $A = \pi r^2$
Circumference:
$C = \pi d = 2\pi r$

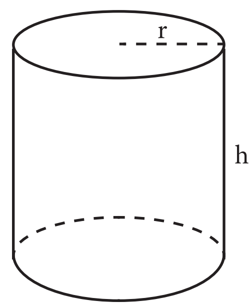
Solid Geometry



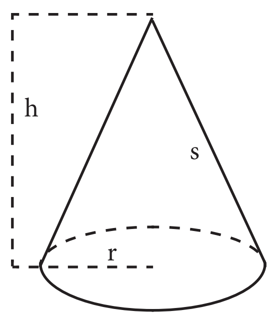
Rectangular Solid
Volume: $V = lwh$



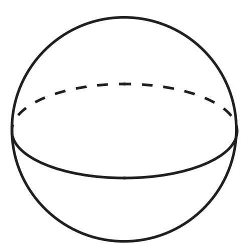
Cube
Volume: $V = s^3$



Right Circular Cylinder
Volume: $V = \pi r^2 h$
Lateral Surface Area:
$L = 2\pi rh$
Total Surface Area:
$S = 2\pi rh + 2\pi r^2$



Right Circular Cone
Volume: $V = \frac{1}{3}\pi r^2 h$
Lateral Surface Area:
$L = \pi rs$
Total Surface Area:
$S = \pi r^2 + \pi rs$



Sphere
Volume: $V = \frac{4}{3}\pi r^3$
Surface Area: $S = 4\pi r^2$

A-24 Energy-Efficiency Organizations

Advanced Energy Corporation (AEC), 909 Capability Drive, Raliegh, NC 27606. 919-857-9000. www.advancedenergy.org. A nonprofit corporation that provides utility companies with information about energy efficiency. Specializes in energy-efficient installation and service of residential heating and cooling systems.

Air Conditioning Contractors of America (ACCA), 2800 Shirlington Rd., Suite 300, Arlington, VA 222. 703-575-4477. www.acca.org. The most active and widely recognized organization representing contractors in the HVAC industry.

Air Conditioning & Refrigeration Institute (ARI), 4100 N. Fairfax Drive, Suite 200, Arlington, VA 22203. 703-524-8800. www.ari.org. Association representing manufacturers of air conditioning, refrigeration, and heating equipment. Provides a variety of services including an information center for dissemination of general information on the industry and the industry's products.

American Council for an Energy-Efficient Economy (ACEEE), 1001 Connecticut Ave. NW, Suite 801, Washington, DC 20036. 202-429-8873. www.aceee.org. ACEEE collaborates with other groups on research into the benefits of energy efficiency, and publishes many reports.

American Gas Association (AGA), 400 N. Capitol St. NW, Washington, DC 20001. 202-824-7000. www.aga.org. The AGA publishes reports on gas efficiency in restaurants, chain stores, cogeneration, gas-fired HVAC, gas-fired heating, cooling, and water heating equipment, and numerous case studies.

American Solar Energy Society, Inc. (ASES), 2400 Central Ave. G-1, Boulder, CO 80301. 303-443-3130. www.ases.org. ASES is a nonprofit educational organization that encourages the use of solar energy technologies. ASES publishes *Solar Today.*

American Home Lighting Institute, PO Box 420288, Dallas, TX 75342-0288. 1-800-605-4448. www.americanlightingassoc.com. Offers information, products, services to general public, educational events and technical assistance to members regarding residential lighting energy conservation.

American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), 1791 Tullie Circle NE, Atlanta, GA 30329. 404-636-8400. www.ashrae.org. Dedicated to the advancement of heating, refrigeration, air conditioning, and ventilation technology and theory. Sponsors research and develops standards documents that help establish acceptable levels of performance for buildings and mechanical equipment. The ASHRAE Handbooks, technical texts on energy fundamentals and systems, and ASHRAE Journal, the Society's monthly magazine, are considered essential sources of information for mechanical engineers. Large publications catalog.

Association of Energy Engineers (AEE), 4025 Pleasantdale Road, Suite 420, Atlanta, GA 30340. 770-447-5083. www.aeecenter.org. Membership organization of engineers, architects, and other professionals with an interest in energy efficiency and energy-related product manufacturers. Promotes scientific and educational interests of professionals engaged in energy management, cogeneration, and overall efficiency improvements.

Building Enclosure Council, c/o National Institute of Building Sciences, 1090 Vermont Ave., Suite 700, Washington, DC 20005. 202-289-7800. www.nibs.org/betechm.html. Assists the building community with building regulations; encourages the acceptance of new products and technology, and provides relevant technical information. Publications include many research reports and conference proceedings.

Building Performance Institute, 10 Hermes Road Suite 200, Malta, NY 12020. 518-899-2727. www.bpi.org. Certifies technicians working in the weatherization and home performance fields. Manages both classroom and field testing of technicians.

Building Science Corporation, 70 Main St., Westford, MA 01886. 978-589-5100. www.buildingscience.com. Consulting and publishing on building science and sustainable building construction. Website has great information on building science.

Building Research Council, University of Illinois At Urbana-Champaign, One East St. Mary's Road, Champaign, IL 61820. 217-333-1801. brc.arch.uiuc.edu/pubprof.htm. Established by the University of Illinois as an agency for research, publication, education, and public service in the area of housing and building. Publishes Council Notes, which are fact sheets about home remodeling, maintenance, and building.

California Energy Commission (CEC), Publications MS-13, 1516 Ninth Street, P.O. Box 944295, Sacramento, CA 94244-2950. 916-654-4287. www.energy.ca.gov. The CEC's publications catalog lists many written information resources on building technology and building energy standards.

Canada Mortgage and Housing Corporation (CMHC), 700 Montreal Road, Ottawa, Ontario, Canada. 613-748-2367. www.cmhc-schl.gc.ca/en/index.cfm. Produces many valuable research reports, booklets, and fact sheets on a wide variety of topics relating to single-family and multifamily buildings.

Electric Power Research Institute (EPRI), P.O. Box 10412, Palo Alto, CA 94303. 415-855-2000. www.epri.com. The electric power industry's research institute. Its publications and research reports are searchable on-line through EPRINET and the EPRI data base on DIALOG. Reports span energy-efficiency, renewable-energy, and waste-management topics related to electric power. Publishes the EPRI Journal, which summarizes EPRI research activities, eight times a year.

Energy Efficiency and Renewable Energy Clearinghouse (EREC). 800-363-3732. www.eere.doe.gov. EREC provides free general and technical information to the public on many topics and technologies pertaining to energy efficiency and renewable energy.

Energy Efficient Building Association (EEBA), 10740 Lyndale Avenue, South, Suite 10W, Bloomington, MN 55420-5615. 952-881-1098. www.eeba.org. Dedicated to the development, dissemination and acceptance of information on the design, construction, and operation of efficient buildings. EEBA offers professional and technical publications and conference proceedings.

Energy Ideas Clearinghouse, 925 Plum St. SE, Townsquare Bldg. #4, PO Box 43165, Olympia, WA 98504. 360-956-2237. www.energyideas.org. A very helpful and comprehensive source for technical information about demand-side management (DSM) in commercial and industrial facilities. Toll free access available from most of the Western U.S.

Florida Solar Energy Center (FSEC), 1679 Clearlake Rd., Cocoa, FL 32922. 321-638-1015. www.fsec.ucf.edu. For anyone building in hot, humid climates, FSEC is a necessary information resource. Publications cover topics such as passive cooling, radiant barriers, moisture control in hot climates, shading techniques, air leakage, air-conditioner performance, and more.

HUD User, P.O. Box 23268, Washington, DC 20006-3268. 800-483-2209. www.huduser.org. HUD User is the information source for research reports and other information generated with HUD funding and through HUD programs. Supplies a great variety and number of reports.

Illuminating Engineering Society of North America (IES), 120 Wall St., 17th floor, New York, NY 10005-4001. 212-248-5000. Technical society dealing with the art, science, or practice of illumination. Provides speakers, referrals, and assistance with technical problems. Conducts area symposia and seminars; workshops and lighting exhibitions; slide presentations. Publications include: IES News and Lighting Design and Application, monthly. Also publishes standards, reports, booklets and guides.

Lawrence Berkeley Laboratory (LBL), Center for Building Technologies, MS90-3111, Berkeley, CA 94720. 510-486-6845. http://eetd.lbl.gov/bt.html. Conducts research in energy analysis, energy-efficient windows, and lighting systems. Pioneered end-use planning and continues to monitor and inventory cost-effectiveness of energy-saving technologies in residential and commercial buildings.

National Association of Home Builders (NAHB), National Research Center (NRC), 1201 15th Street, N.W., Washington, DC 20005. 800-368-5242. www.nahb.com. Sells many books and publications on energy-efficient buildings and all other aspects of the building industry.

National Center for Appropriate Technology (NCAT), P.O. Box 3838, Butte, MT 59702. 406-494-4572. www.ncat.org. NCAT is a good source of information on residential energy efficiency programs operated by utility companies and states.

National Fenestration Rating Council (NFRC), 8484 Georgia Ave., Suite 320, Silver Springs, MD 20910. 301-589-1776. www.nfrc.org. A collaboration between industry, government, and public interest groups working to establish a viable and economical fenestration rating system that will be used by product manufacturers in marketing windows.

National Renewable Energy Laboratory (NREL), 1617 Cole Blvd., Golden, CO 80401-3393. 303-275-3000. www.nrel.gov. The DOE's solar and renewable energy laboratory. Performs many kinds of building energy research. Produces publications on energy efficiency for the DOE.

Oak Ridge National Laboratory (ORNL), Buildings Technology Center, Battelle, UT, P.O. Box 2009, Oak Ridge, TN 37831-8218. www.ornl.gov/sci/btc/index.shtml. Under contract to the U.S. Dept. of Energy, its building research facility performs thermal testing on full size building components. The results of the lab's research are published and available to the public for a nominal price.

Residential Energy Services Network (RESNET). P.O. Box 4561, Oceanside, CA92052. 760-806-3448. www.resnet.us. National organization of energy raters and rating organizations. Mission: To develop a national market for home energy rating systems and energy efficient mortgages.

Southface Energy Institute, 241 Pine St. NE, Atlanta, GA 30308. 404-872-3549. www.southface.org. Nonprofit educational institute focuses on energy-efficient building for the southern states. Website has a good question-and-answer section.

Sustainable Buildings Industry Council, 1331 H Street, N.W., Suite 1000, Washington, DC 20005. 202-628-7400. www.sbicouncil.org. Mission is to advance the design, affordability, energy performance, and environmental soundness of residential, institutional and commercial buildings.

Texas A&M University, Energy Systems Laboratory, College Station, TX 77843-3123. 409-845-1560. www-esl.tamu.edu. Performs research and publishes reports on residential and commercial air conditioning and other topics related to comfort in buildings in hot and humid climates.

U.S. Green Building Council (USGBC), 1800 Massachusetts Ave. NW Suite 300, Washington, DC 20036. 202-828-7422. www.usgbc.org. Administers Leadership in Energy and Environmental Design (LEED), an educational and rating system for green buildings.

Bibliography

2002 Buildings Energy Databook: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Washington, DC. 2002.

ASHRAE Handbook: 1982 Applications: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA. 1982.

ASHRAE Handbook: 1984 Systems: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA. 1984.

ASHRAE Handbook: 1993 Fundamentals: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA. 1993.

Combustion Efficiency: Fact or Fallacy: Davis, Jim. Covington, KY. 1985.

Consumer Guide to Home Energy Savings: Wilson, A, Thorne J. & Morrill, J. American Council for an Energy-Efficient Economy, Washington, DC. 2003.

Cooling Our Communities, A Guidebook On Tree Planting and Light-Colored Surfacing: United States Environmental Protection Agency; Policy, Planning and Evaluation. Lawrence Berkeley Laboratory Report. Washington, DC. 1992.

Cooling With Ventilation: Chandra, Sobrato; Fairey, P.W., III. M.M. Solar Energy Research Institute. Golden, CO. 1986.

Efficient Residential Oil-Heating Systems: Canadian Combustion Research Laboratory. Energy, Mines and Resources, Canada. Ottawa, ON. June, 1983.

Energy Data Sourcebook for the U.S. Residential Sector, Energy Analysis Program, Lawrence Berkeley Laboratory, Berkeley, CA. 1997.

Guide to Oil Heat: Beckett Corporation, Elyria, OH. 1997.

Heating Systems Training Manual: Corporation for Ohio Appalachian Development. Athens, OH. 1991.

HVAC Installation Procedures: Carrier Corporation, Syracuse, NY. 1997.

HVAC Maintenance Procedures: Carrier Corporation, Syracuse, NY. 1997.

HVAC Service Procedures: Carrier Corporation, Syracuse, NY. 1995.

Hydronic Heating: A Practical Overview: Krigger, J. Electric Power Research Institute. Palo Alto, CA. 2000.

Introduction to Indoor Air Quality: Environmental Protection Agency. Washington, DC. 1991.

Landscape Design That Saves Energy: Moffat, Anne Simon; and Schiler, Marc. William Morrow & Company, Inc. New York, NY. 1981.

Landscape Planning For Energy Conservation:

Robinette, G.; and McClennon, C. Van Nostrand Reinhold Company, Inc. New York, NY. 1983.

Landscaping for Energy Conservation: Girgis, Magdy. Florida Solar Energy Center. Cape Canaveral, FL. February, 1985.

Lost Art of Steam Heating, The: Holohan, Dan. Holohan Associates, Bethpage, NY. 1992.

Manual J: Load Calculation for Residential Winter and Summer Air Conditioning: Air Conditioning Contractors of America. Washington, DC. 1986.

MWX90: Minnesota Low Income Weatherization Procedure for the 1990s: Underground Space Center, University of Minnesota. December, 1993.

Modern Hydronic Heating: Siegenthaler, J. Delmar, Albany, NY. 1995.

Moisture Control For Homes. Energy Design Update: Nisson, J.D. Cutter Information Corp. 1989. (report)

Moisture Control Handbook: Principles and Practices for Residential and Small Commercial Buildings: Lstiburek, J., and Carmody, J. Nan Nostrand Reinhold. Oak Ridge, TN. 1993.

No Regrets Remodeling: Home Energy Magazine, Energy Auditor and Retrofitter, Inc. Berkeley, CA. 1997.

Passive Cooling and Human Comfort: Fairey, Phillip W. Florida Solar Energy Center. Cape Canaveral, FL. 1981.

Quiet Indoor Revolution, The: Konzo, S.; and MacDonald, M. Small Homes Council-Building Research Council, University of Illinois, College of Fine and Applied Arts. Champaign, IL. 1992.

Refrigeration and Air Conditioning Technology: Whitman, W, Johnson, W, Tomczyak, J. Delmar, Albany, NY. 2000.

Residential Controls For Heating and Cooling. First Edition: Honeywell, Inc. St. Paul, MN.1985.

Residential Windows: A Guide to New Technologies and Energy Performance: Carmody, J., Selkowitz, S. Heschong, L. WW Norton & Co. New York, NY 1996.

Shading Our Cities: Moll, G.; and Ebenreck, S., eds. Island Press. Washington DC. 1989.

Specification of Energy-Efficient Installation Practices for Residential HVAC Systems: Karg, R. and Krigger, J. Consortium for Energy Efficiency. Boston, MA. 2000.

Water Heater Workbook, The: Weingarten, Larry and Suzanne. Elemental Enterprises, Monterey CA. 1992.

Water Heaters for Superinsulated Homes: Energy Design Update. New York, NY. 1988.

Windows and Energy Efficiency: Energy Design Update. New York, NY. 1986.

Your Home Cooling Energy Guide: Krigger, J. Saturn Resource Management. Helena, MT. 1992.

Your Mobile Home: Energy and Repair Guide For Manufactured Housing: Krigger, J. Saturn Resource Management, Helena, MT. 1998.

Periodicals

Energy Design Update: Aspen Publishers, 1185 Avenue of the Americas, New York, NY 10036. 800-638-8437. www.aspenpublishers.com.

Journal of Light Construction: 186 Allen Brook Lane, Williston, VT. 802-879-3335. www.jlconline.com.

Home Energy: PMB 95, 2124 Kittredge St., Berkeley, CA 94704. 510-524-5405. www.homeenergy.org.

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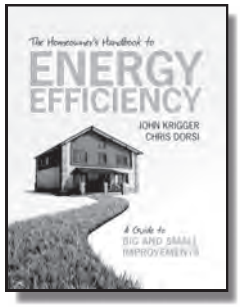
Other Saturn Publications

***Homeowner's Handbook to Energy Efficiency* —** Contains the most important information needed by consumers to save energy in the home. This highly illustrated booklet also provides solid advice for homeowners who plan to design and build a new home. 188 pages.



***Energy Auditor Field Guide* —** Describes the best practices used in assessing the performance of existing homes. It includes step-by-step procedures that identify the most effective energy-saving measures for a home depending on its type and climate.

***Building Shell Field Guide* —** Includes step-by-step procedures for air-sealing and insulating attics, walls, basements, and crawl spaces. Also includes detailed instructions for performing advanced blower-door diagnostics.

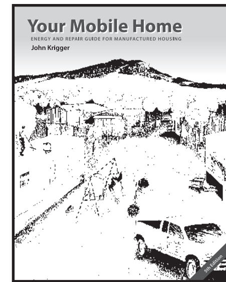
***HVAC Systems Field Guide* —** Contains a wealth of job-tested procedures for improving the safety and efficiency of furnaces, air conditioners, evaporative coolers, and domestic water-heating systems.

***Hydronic Systems Field Guide* —**

Describes the best procedures for evaluating and tuning both steam and hot-water heating systems. It outlines the best ways to optimize the efficiency of all types of hydronic delivery systems.

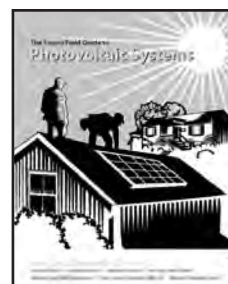
***Your Mobile Home: Energy and Repair Guide for Manufactured Housing* —**

Contains the collective experience of many experts in construction, weatherization, and repair. More than 200 drawings, photos, charts, and graphs. A must have book for mobile home owners. 256 pages.



***Your Home Cooling Energy Guide* —** Explores all the options for shading, ventilation, awnings, sun screens, window films, radiant barriers, insulation, reflective coatings, and shade trees to reduce cooling costs. Includes checklists, tables, a glossary, several informative appendices, and illustrations on almost every page. 80 pages.

***Field Guide to Photovoltaic Systems* —** Provides guidance on preliminary site assessment, prediction of energy output, and financial analyses of residential and light commercial photovoltaic systems. 22 pages.



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