Achieving 50% Energy Savings in Office Buildings

A Summary of Recommendations Toward a Zero Energy Building

This fact sheet summarizes recommendations for designing new office buildings that result in 50% less energy use than conventional designs meeting minimum code requirements. The recommendations are drawn from the *Advanced Energy Design Guide for Small to Medium Office Buildings*, an ASHRAE publication that provides comprehensive recommendations for designing low-energy-use office buildings with gross floor areas up to 100,000 ft^2 (see sidebar at lower right).

Designed as a stand-alone document, this fact sheet provides key principles and a set of prescriptive design recommendations appropriate for smaller office buildings with insufficient budgets to fully implement best practices for integrated design and optimized performance. The recommendations have undergone a thorough analysis and review process through ASHRAE, and have been deemed an easily replicable combination of measures to achieve 50% savings in the greatest number of office buildings.

The Opportunity

Energy efficiency offers an excellent opportunity to enhance an office building's working environment, by improving the quality of lighting, reducing background noise levels, providing proper ventilation, and better control of temperature and humidity ranges. These improvements can increase worker productivity,

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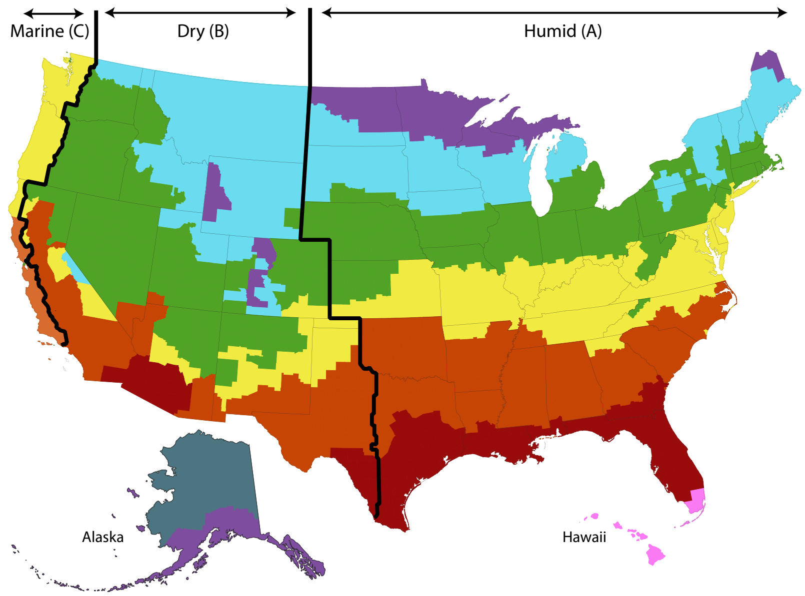
Climate-Appropriate Recommendations

Users of this fact sheet should determine the recommendations for their design and construction projects by first locating the correct climate zone. The U.S. Department of Energy has identified eight climate zones for the United States as shown in the map below.



Climate Zone Descriptions

- 1 Very Hot - Humid (1A), Dry (1B)
- 2 Hot - Humid (2A), Dry (2B)
- 3 Warm - Humid (3A), Dry (3B), Warm - Marine (3C)
- 4 Mixed - Humid (4A), Dry (4B), Mixed - Marine (4C)
- 5 Cool - Humid (5A), Dry (5B), Marine (5C)
- 6 Cold - Humid (6A), Dry (6B)
- 7 Very Cold
- 8 Subarctic

What is an AEDG?

The Advanced Energy Design Guides (AEDGs) are a series of guide books that provide comprehensive, user-friendly, how-to recommendations for high-performance buildings that can be designed and built within typical construction budgets. There are four AEDGs targeting 50% energy savings, and six that target 30% energy savings. Each guide was developed under the leadership of a Steering Committee that included ASHRAE, The American Institute of Architects (AIA), Illuminating Engineering Society of North America (IES), U.S. Green Building Council (USGBC), and the U.S. Department of Energy which also provided financial support. Additional technical support for the AEDGs was provided by the National Renewable Energy Laboratory (NREL) and Pacific Northwest National Laboratory (PNNL). Many of the AEDGs are accompanied by a Technical Support Document that includes more details of the energy and cost trade-offs that led to the recommendations in the AEDGs. Further information and links to access the AEDGs and TSDs can be found at the AEDG website (*http://energy.gov/eere/buildings/advanced-energy-design-guides*).

The following climate zone recommendation table represents one way, but not the only way, for reaching the 50% energy savings target. The specific energy-saving recommendations will enable contractors, consulting engineers, architects, and designers to achieve advanced levels of energy savings without detailed energy modeling or analyses. Each column addresses a single climate zone, and includes a set of common items arranged by building subsystem. For some subsystems, recommendations depend on the construction type. Each value represents either an upper or lower limit, depending on the context. More specific recommendations for maintaining a quality work environment can be found in ASHRAE Standard 55, ASHRAE Standard 62.1, and the IES Lighting Handbook, as well as the full AEDG.

Climate Dependent Recommendations: Envelope

Item and Component	Recommendations by Climate Zone							
	1	2	3	4	5	6	7	8
Roofs								
Insulation entirely above deck	R-20.0 c.i.	R-25.0 c.i.	R-25.0 c.i.	R-30.0 c.i.	R-30.0 c.i.	R-30.0 c.i.	R-35.0 c.i.	R-35.0 c.i.
Attic and other	R-38	R-38.0	R-38.0	R-49.0	R-49.0	R-49.0	R-60.0	R-60.0
Metal building	R-10.0 + R-19.0 FC	R-10.0 + R-19.0 FC	R-10.0 + R-19.0 FC	R-19.0 + R-11.0 Ls	R-19.0 + R-11.0 Ls	R-25.0 + R-11.0 Ls	R-30.0 + R-11.0 Ls	R-25.0 + R-11.0 + R-11.0 Ls
Solar reflectance index (SRI)	78	78	78	Standard 90.1*	Standard 90.1*	Standard 90.1*	Standard 90.1*	Standard 90.1*
Walls								
Mass (HC > 7 Btu/ft^2)	R-5.7 c.i.	R-7.6 c.i.	R-11.4 c.i.	R-13.3 c.i.	R-13.3 c.i.	R-19.0 c.i.	R-19.0 c.i.	R-19.0 c.i.
Steel framed	R-13.0 + R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 R-7.5 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-15.6 c.i.	R-13.0 + R-18.8 c.i.	R-13.0 + R-18.8 c.i.	R-13.0 + R-18.8 c.i.
Wood framed and other	R-13.0	R-13.0 + R-3.8 c.i.	R-13.0 + R-3.8 c.i.	R-13.0 + R-7.5 c.i.	R-13.0 + R-10.0 c.i.	R-13.0 + R-12.5 c.i.	R-13.0 + R-15.0 c.i.	R-13.0 + R-18.8 c.i.
Metal building	R-0.0 + R-9.8 c.i.	R-0.0 + R-9.8 c.i.	R-0.0 + R-13.0 c.i.	R-0.0 + R-15.8 c.i.	R-0.0 + R-19.0 c.i.	R-0.0 + R-19.0 c.i.	R-0.0 + R-22.1 c.i.	R-0.0 + R-25.0 c.i.
Below grade walls	Standard 90.1*	Standard 90.1*	R-7.5 c.i. (Standard 90.1* in CZ 3A)	R-7.5 c.i.	R-7.5 c.i.	R-10.0 c.i.	R-15.0 c.i.	R-15.0 c.i.
Continuous air barrier	Entire building envelope							
Floors								
Mass	R-4.2 c.i.	R-10.4 c.i.	R-12.5 c.i.	R-14.6 c.i.	R-14.6 c.i.	R-16.7 c.i.	R-20.9 c.i.	R-23.0 c.i.
Steel/wood framed	R-19.0	R-30.0	R-30.0	R-38.0	R-38.0	R-38.0	R-49.0	R-60.0
Slabs								
Unheated	Standard 90.1*	Standard 90.1*	Standard 90.1*	R-15.0 for 24 in.	R-15.0 for 24 in.	R-20.0 for 24 in.	R-20.0 for 24 in.	R-20.0 for 48 in.
Heated	R-7.5 for 12 in.	R-10.0 for 24 in.	R-15.0 for 24 in.	R-20.0 for 24 in.	R-20.0 for 24 in.	R-20.0 for 48 in.	R-25.0 for 48 in.	R-20.0 full slab
Doors								
Swinging	U-0.70	U-0.70	U-0.70	U-0.50	U-0.50	U-0.50	U-0.50	U-0.50
Nonswinging	U-1.45	U-0.50	U-0.50	U-0.50	U-0.50	U-0.50	U-0.50	U-0.50
Vestibules								
At building entrance	Standard 90.1*	Standard 90.1*	Yes if > 10,000 ft^2	Yes	Yes	Yes	Yes	Yes
Vertical Fenestration								
Window to wall ratio	20% to 40%							
Window orientation	Area of W and E windows each less than area of S windows (N in southern hemisphere)							
Exterior sun control (S,E, and W only)	PF-0.5	PF-0.5	PF-0.5	PF-0.5	PF-0.5	ASHRAE 90.1*	ASHRAE 90.1*	ASHRAE 90.1*
Thermal transmittance								
Nonmetal framing	U-0.56	U-0.45	U-0.41	U-0.38	U-0.35	U-0.35	U-0.33	U-0.25
Metal framing	U-0.65	U-0.65	U-0.60	U-0.39	U-0.39	U-0.39	U-0.34	U-0.34
Solar Heat Gain Coefficient - SHGC (Nonmetal framing/ Metal framing)	0.25/0.25	0.25/0.25	0.25/0.25	0.26/0.38	0.26/0.38	0.35/0.38	0.40/0.40	0.40/0.40

* Recommendation is compliant with the more stringent of either the most recent version of ANSI/ASHRAE/IES Standard 90.1 or the local code requirements

Recommendations for All Climate Zones (CZs)

	Item	Recommendation
Daylighting/Lighting	**Daylighting**	
	Light to solar-gain ratio	Minimum VT/SHGC = 1.10
	Vertical fenestration EA target	CZ 1-4: 0.08 CZ 5-8: 0.12
	Interior Finishes	
	Interior surface average reflectance	Ceilings = 80% Wall surfaces = 70% Open office partitions = 50%
	Open office partitions parallel to window walls	Total partition height = 36 in. maximum - or - Partition above desk height = min 50% translucent
	Interior Lighting	
	Lighting power density (LPD)	0.75 W/ft^2
	24 hour lighting LPD	0.075 W/ft^2
	Light source lamp efficacy (mean LPW)	• T8 & T5 > 2 ft = 92, • T8 & T5 ≤ 2 ft = 85, • All other > 50
	Ballasts	• 4 ft T8 lamp nondimming applications = NEMA Premium instant start • 4 ft T8 lamp dimming applications = NEMA Premier program start • Fluorescent and HID sources = electronic
	Controls for daylight harvesting in open offices - locate on N and S sides of bldg	Dim all general fluorescent lights within primary and secondary daylight zones of open offices.
	Automatic controls	• Auto ON to 50% or manual ON with auto OFF = private offices, conference and meeting rooms, lounge and break rooms, copy rooms, storage rooms. • Auto ON occupancy sensors or manual ON with auto OFF vacancy sensors = restrooms, electrical/mechanical rooms, open and private office task lighting • Time switch control = all other spaces
	Exterior Lighting	
	Façade and landscape lighting	• LPD = 0.075 W/ft^2 in LZ3 & LZ4, 0.05 W/ft^2 in LZ2 • Controls = auto OFF between 12am and 6am
	Parking lots and drives	• LPD = 0.1 W/ft^2 in LZ3 & LZ4, 0.06 W/ft^2 in LZ2 • Controls = auto reduce to 25% (12am to 6am)
	Walkways, plazas, and special feature areas	• LPD = 0.16 W/ft^2 LZ3 & LZ4, 0.14 W/ft^2 in LZ • Controls = auto reduce to 25% (12am to 6am)

	Item	Recommendation
Plug Loads	**Equipment Choices**	
	Laptop computers	Minimum 2/3 of total computers
	ENERGY STAR equipment	For all computers, equipment, and appliances
	Controls	
	Computer power control	Network control with power savings modes fully and control OFF during unoccupied hours
	Occupancy sensors	Desk plug strip occupancy sensors
	Timer switches	Water coolers and coffee makers control OFF during unoccupied hours
	Vending machine control	Yes
SWH	Gas water heater efficiency	Condensing water heaters = 90% efficiency
	Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99–0.0012 x volume (see Table 5-7 in the AEDG)
	Point-of-use heater selection	0.81 EF or 81% Et
	Electric heat pump water heater efficiency	COP 3.0 (interior heat source)
	Pipe insulation thickness (d<1½ in./ d≥1½ in.)	1 in. / 1 ½ in.
HVAC	**VAV DX with Gas Furnace or Hydronic Heating (See AEDG for other HVAC types)**	
	DX efficiency	See Table 5-9 in the AEDG for efficiency
	Low temperature air supply and SAT reset	• CZ 1–4: 50°F to 58°F • CZ 5–8: 50°F to 61°F
	Perimeter convector heat source	• CZ 1–4: Electric • CZ 5–8: Hot water
	Gas Furnace with DX units	Standard 90.1*
	Condensing boiler efficiency	CZ 1–4: Standard 90.1* CZ 5–8: 90%
	Economizer	• CZ 1: Standard 90.1* • CZ 2A, 3A, 4A: ≥54,000 Btu/h, differential enthalpy control • CZ 2B, 3B, 3C, 4B, 4C, 5, 6, 7, and 8: ≥54,000 Btu/h, differential dry-bulb control
	Energy recovery	Yes, see Table 5-11 in the AEDG for effectiveness
	Indirect evaporative cooling	• Recommended in CZ 2B, 3B, 4B, 5B only
	Demand control and ventilation reset	Yes
	ESP	2.0 in. w.c.
	Ducts and Dampers	
	OA damper	Motorized damper
	Friction rate	0.08 in./100 ft.
	Sealing	Seal Class B
	Location	Interior Only
	Insulation level	R-6.0

* Recommendation is compliant with the more stringent of either the most recent version of ANSI/ASHRAE/IES Standard 90.1 or the local code requirements

Opportunity *from page 1*

increase staff retention, elevate corporate brand awareness, and help to justify significant rental and sales price premiums[1,2]. Daylighting can improve worker performance by using natural light to produce a high-quality, glare-free visual environment. Quality lighting systems include a combination of daylighting and energy-efficient electric lighting systems, which complement each other by reducing visual strain and providing better lighting quality.

Advanced energy-efficient heating and cooling systems can produce quieter, more comfortable, and more productive spaces. Because workers are by far the largest expense for most office buildings, accounting for 92% of the life-cycle cost, worker productivity and staff turnover have a tremendous effect on overall costs. In addition, by using energy efficiently and lowering an office's energy bills, hundreds of thousands of dollars can be redirected each year into upgrading facilities, increasing office workers' salaries, and investing in the latest technologies in office appliances and equipment.

[1] RMI. 1994. "Greening the Building and the Bottom Line." Boulder, CO: Rocky Mountain Institute.

[2] CoStar. 2008. "Does Green Pay Off?" *Journal of Real Estate Portfolio Management* 14 (4).

The Approach

Traditional wisdom has society believing that energy-efficient buildings must cost more to build than traditional structures; however, thoughtfully designed, high-performance office buildings can cost less. Achieving 50% energy savings is within the reach of any committed building owner, but it does take thought, determination, and strong goal-setting. The design and construction of a high-performance office building requires an integrated approach in which factors such as comfort, indoor air quality, and acoustics remain priorities and are not adversely affected by energy reduction efforts. These factors were important considerations in the development of the recommendations table presented here.

Owner requirements should consider the nature of project team contracts; a basic understanding of climate, site requirements, drivers for building orientation, and massing; and project budget and cost assumptions of the building owner, a designated construction manager, or both. The project team should also set a goal to allow for ongoing maintenance and replacement of critical systems to ensure the enduring performance of the overall office building design.

Exterior of the CMTA Headquarters. *Source: High Performing Buildings published in AEDG.*

Case Study: CMTA Office Building

CMTA Properties designed and built a new 20,000-ft^2 office building in Louisville, Kentucky, in 2008. The goal was to showcase a green, energy-efficient building design that could provide a living demonstration of these technologies for clients and would be the first step toward a zero energy building. The exterior walls are constructed of insulated concrete forms, a structural wall system that provides an excellent thermal barrier and reduces air infiltration. The full thermal envelope, which includes roof insulation and high-performance glass, exceeds ANSI/ASHRAE/IES Standard 90.1-2004 by 20%.

The lighting system is designed to 0.65 W/ft^2, exceeding the energy code by 40%. Daylight control systems further reduce electric lighting energy use in the work areas. The space conditioning system includes high-efficiency, geothermal water source heat pump units and a demand controlled ventilation system modulates the outdoor air coming into the building in response to space conditions. An Ethernet-based digital electric metering system is used to measure the energy consumed by the heating, ventilation, and air conditioning (HVAC), lighting, and plug loads.

Total Community Options Corporate Headquarters Main Entry. *Source: Oz Architecture published in AEDG*

Case Study: Total Community Options Corporate Headquarters

Total Community Options' new 45,000-ft^2 corporate headquarters in Denver was completed in September 2010 and centralized several departments and business units that were spread across multiple locations throughout the city. Savings from long-term operating efficiencies of the building allowed the nonprofit organization to spend more funds on programs and services. The design team found solutions where abundant natural light and views were allowed. The building saves 70% in energy costs compared to a typical office building.

Project Delivery

The following multidisciplinary recommendations will enable building owners to identify a series of items for which the project team must achieve a direction and agreement.

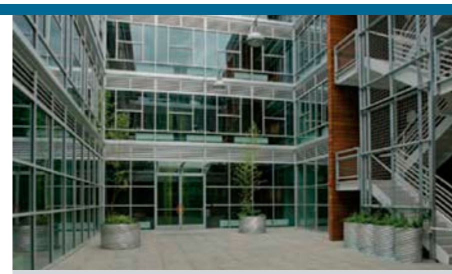
- Define energy design and performance goals and expectations, and identify the project team and stakeholders.
- Address building configuration and floor area minimization issues.
- Define safety and comfort criteria.
- Develop an integrated commissioning strategy.
- Train building users and operations staff.
- Submeter end use energy consumption.

Key Tactics for Office Buildings

The following recommendations are examples of key design tactics for achieving high-performance office buildings cost effectively:

- Understand schedules for occupancy, building use, and utility rates.
- Paint interior walls light colors, select highly reflective ceiling materials, and select floor finishes that are not extremely dark.
- Consider how the building will be zoned for heating, ventilation, air conditioning, and lighting.
- Minimize lighting and plug loads using energy efficient products and controls.
- Ensure that safety factors and diversity factors are appropriate in order to avoid equipment oversizing.
- Select Energy Star office and break room equipment whenever possible. Very high plug load efficiency can be achieved with minimal additional cost.
- Apply automatic controls so occupants can focus on their day-to-day activities.

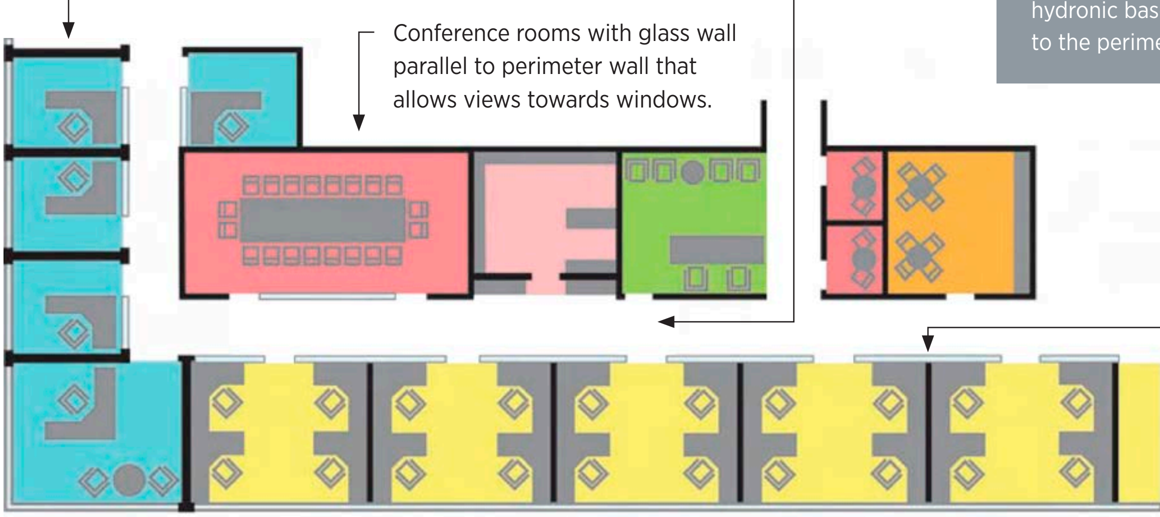
For more detailed guidance, please download the full AEDG from ASHRAE via DOE's AEDG website: *energy.gov/eere/buildings/advanced-energy-design-guides*.



Internal Courtyard of The Terry Thomas. *Source: Chris Meek and Kevin Van Den Wymelenberg published in AEDG.*

Case Study: The Terry Thomas Office Building

The building team for The Terry Thomas, a 40,000-ft^2 commercial office building in Seattle, Washington, used natural ventilation and daylighting as key elements of a building that is 42% more efficient than the requirements of ASHRAE/IESNA Standard 90.1-2004. The building was designed as a "square doughnut" form that enhances the natural ventilation and daylighting and provides communal space for the tenants via the center courtyard. The project used an integrated design process to achieve significant energy efficiency within the initial construction cost budget. The integrated design required that two goals be balanced: remove solar heat and glare that might hinder natural ventilation and provide adequate daylight to interior spaces. Effective external shading was the key to controlling solar gain and thus reducing cooling peak load. The building uses passive cooling and natural ventilation, and radiant hydronic baseboards provide heating to the perimeter.



Daylighting Design Concepts for Office Spaces. *Illustration from AEDG*

Nomenclature

°F	degrees Fahrenheit
AEDG	Advanced Energy Design Guide for Small to Medium Office Buildings
ASHRAE Standard 90.1	ANSI/ASHRAE/IES Standard 90.1-2013: Energy Standard for Buildings Except Low-Rise Residential Buildings
Btu	British thermal unit
c.i.	continuous insulation, as opposed to cavity insulation which has thermal breaks
COP	coefficient of performance, the dimensionless ratio of heating or cooling energy provided to energy consumed, a method to quantify the efficiency of an air conditioner, chiller, or heat pump (the higher the COP the more efficient the unit)
CZ	climate zone as defined in ASHRAE Standard 90.1
d	diameter, ft
DX	direct expansion (air conditioner, chiller, or heat pump), a system where the cooling effect is obtained directly from the expansion of a liquid refrigerant into a vapor
EA	effective aperture, the ratio of glazing area to floor area, weighted by glazing's visible light transmittance (EA = [glazing area * visible light transmittance] / floor area)
EF	energy factor (efficiency metric for water heating systems)
ESP	external static pressure, the static pressure in a fan system that is external to the air handling unit (caused by ductwork, terminal units, etc.)
Et	thermal efficiency (energy factor of a water heater adjusted for standby losses)
FC	filled cavity, a roof system where the space between the purlins (the cavity) is filled with insulation. The first R-value is for insulation over the top of the purlins, the second R-value is for the cavity insulation
ft	feet
gal	gallons
h	hour
HC	heat capacity (Btu/°F), the ratio of the amount of heat energy transferred to an object and the resulting increase in temperature of that object
HID	high-intensity discharge lamps, including metal halide and mercury vapor
HVAC	heating, ventilation, and air conditioning
in.	inches
in. w.c.	inches of water column (a pressure unit equivalent to 249 Pascals)
kW	kilowatts
LPD	lighting power density (installed maximum power in W/ft^2)
LPW	lumens per Watt (efficiency measurement of electric lamps)
Ls	liner system, a type of roof with a metal out layer, a fabric liner inner layer held up with a grid of steel retainer straps, and insulation in the cavity between the inner and outer layers. The first R-value is for insulation between the purlins, the second (or third) R-value is for the insulation over the top of the purlins
LZ	Lighting Zone as defined in Standard 90.1, a categorization of exterior areas from undeveloped rural areas to major metropolitan areas, used to determine allowable outside lighting levels
NEMA	National Electrical Manufacturers Association
PF	projection factor (horizontal projection of overhang divided by its height above the window sill)
R	thermal resistance (h-ft^2-F/Btu)
S, E, W, N	South, East, West, and North
SAT	supply air temperature, the temperature of the air being supplied by a space conditioning unit
SHGC	solar heat gain coefficient (fraction of solar energy transmitted through glazing)
SRI	solar reflectance index, a measure of the roof's ability to reject solar heat, a gauge from 0-100, with 0 being most likely to absorb and store heat (such as a black tar roof) and 100 being the most resistant to solar gains (least likely to get hot) such as a roof painted with white reflective paint, which has both high reflectance and high emittance
T5/T8	typical linear fluorescent lamp designations, denoted by their shape, and their maximum diameter, in eighths of an inch; in this example, we describe (T)ubular-shaped lamps, 5/8" and 1" (8/8") in diameter, respectively
U-Value	thermal transmittance (Btu/h-ft^2-F)
VAV	variable air volume, a fan system in which the fan can change speeds to meet the load
VT	visible transmittance, an optical property that indicates the fraction of visible light transmitted through the window, theoretically varies between 0 and 1 but most values are between 0.30 and 0.70, the higher the VT, the more light is transmitted
W	Watts