Achieving 50% Energy Savings in New Schools

A Summary of Recommendations Toward Zero Energy Building

This fact sheet summarizes recommendations for designing elementary, middle, and high school buildings that will result in 50% less energy use than conventional new schools built to minimum code requirements. The recommendations are drawn from the *Advanced Energy Design Guide for K-12 School Buildings*, an ASHRAE publication that provides comprehensive recommendations for designing low-energy-use school buildings (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 schools 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 K-12 schools.

The Opportunity

The mission of K-12 school buildings is to facilitate the education of young people. The energy-saving measures in this fact sheet will enhance the delivery of educational services by improving the learning environment, and will help achieve energy-savings goals that are financially feasible, operationally workable, and otherwise readily achievable.

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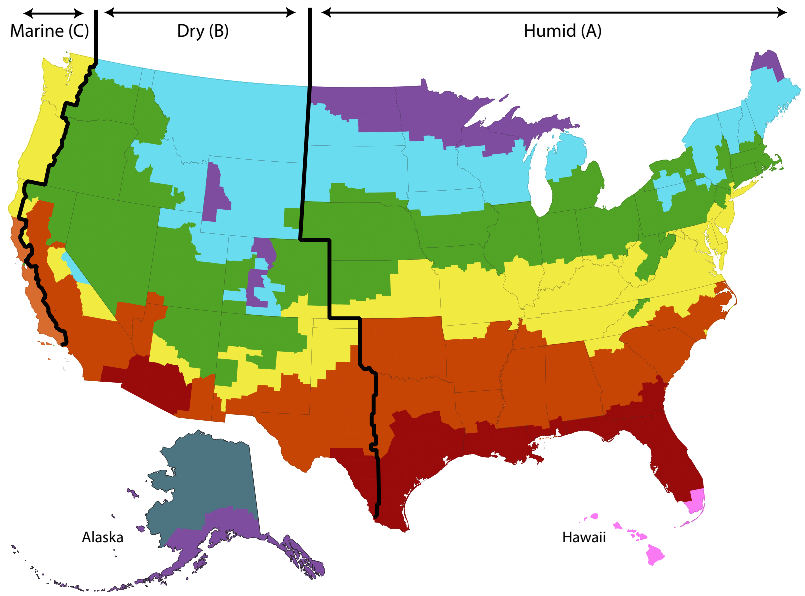
Climate-Appropriate Recommendations

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 learning 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
Roof								
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-38.0	R-38.0	R-38.0	R-49.0	R-49.0	R-49.0	R-60.0	R-60.0
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/ft²)	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-19.5 c.i.	R-19.5 c.i.	R-19.5 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	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.
Below grade walls	Standard 90.1*	Standard 90.1*	R-7.5 c.i. Std 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.
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-19.0	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*	Standard 90.1*	Standard 90.1*	R-10 for 24 in.	R-20 for 24 in.	R-20 for 24 in.
Heated	R-7.5 for 12 in.	R-10 for 24 in.	R-15 for 24 in.	R-20 for 24 in.	R-20 for 24 in.	R-20 for 48 in.	R-25 for 48 in.	R-20 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 ft²	Yes	Yes	Yes	Yes	Yes
Vertical Fenestration								
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-0.64	U-0.60	U-0.44	U-0.44	U-0.42	U-0.34	U-0.34
Fenestration-to-floor -area ratio (FFR)	E or W orientation = 5% maximum N or S orientation = 7% maximum							
Solar heat gain coefficient (SHGC):								
E or W orientation	0.25	0.25	0.25	0.40	0.42	0.42	0.45	0.45
N orientation	0.62	0.62	0.62	0.62	0.62	0.62	0.62	0.62
S orientation	0.25	0.50	0.75	0.75	0.75	0.75	0.75	0.75
Exterior sun control	S orientation only =PF-0.5							

* 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**	
	Visible transmittance (VT)	See Table 5-5 in the AEDG for appropriate VT value
	Interior/exterior sun control (S orientation only)	S orientation = no glare during school hours
	Classrooms, resource rooms, cafeteria, gym, and multipurpose rooms	Daylight 100% of floor area for 2/3 of school hours
	Administration areas	Daylight perimeter floor area (15 ft) for 2/3 of school hours
	Interior Finishes	
	Interior surface average reflectance for daylighted rooms	Ceilings = 80% Wall surfaces = 70%
	Interior Lighting	
	Lighting power density (LPD)	Whole buildings = 0.7 W/ft^2 Gyms, multipurpose rooms = 1.0 W/ft^2 Classrooms, art rooms, kitchens, libraries, media centers = 0.8 W/ft^2 Cafeterias, lobbies = 0.7 W/ft^2 Office = 0.6 W/ft^2 Auditorium, restroom = 0.5 W/ft^2 Corridors, mechanical rooms =0.4 W/ft^2
	Light source lamp efficacy (mean LPW)	T8 & T5 > 2 ft = 92 T8 & T5 ≤ 2 ft = 85 All other > 50
	T8 ballasts	• Non-dimming = NEMA premium instant start • Dimming = NEMA premium program start
	T5/T5HO ballasts	Electronic program start
	CFL and HID ballasts	Electronic
	Dimming controls daylight harvesting	Dim all fixtures in daylight zones
	Lighting controls	Manual ON, auto/timed OFF in all non-critical areas (vacancy sensor)
	Exterior Lighting	
	Façade and landscape lighting	LPD = 0.075 W/ft^2 in LZ-3 & LZ-4 LPD = 0.05 W/ft^2 in LZ-2 Controls = auto OFF between 12am and 6am
	Parking lots and drives	LPD = 0.1 W/ft^2 in LZ-3 & LZ-4 LPD = 0.06 W/ft^2 in LZ-2 Controls = auto reduce to 25% (12am to 6am)
	Walkways, plazas, and special feature areas	LPD = 0.16 W/ft^2 in LZ-3 & LZ-4 LPD = 0.14 W/ft^2 in LZ-2 Controls = auto reduce to 25% (12am to 6am)
	All other exterior lighting	LPD = Comply with Standard 90.1* Controls = auto reduce to 25% (12am to 6am)
Plug Loads	**Equipment Choices**	
	Laptop computers	Minimum 2/3 of total computers
	ENERGY STAR equipment	All computers, equipment, and appliances
	Vending machines	De-lamp and specify minimum efficiency consistent with Energy Star

	Item	Recommendation
Plug Loads	**Controls/ Programs**	
	Computer power controls	Network control with power saving modes and control OFF during unoccupied hours
	Power outlet control	• Controllable power outlets with auto OFF during unoccupied hours for classrooms, office, library/media spaces • All plug-in equipment not requiring continuous operation to use controllable outlets
	Policies	Implement at least one: • District/school policy on allowed equipment • School energy teams
Kitchen	**Kitchen Equipment**	
	Cooking equipment	ENERGY STAR or California rebate-qualified equipment
	Walk-in refrigeration equipment	6 in. insulation on low-temp walk-in equipment, Insulated floor, LED lighting, floating-head pressure controls, liquid pressure amplifier, subcooled liquid refrigerant, evaporative condenser
	Exhaust hoods	Side panels, larger overhangs, rear seal at appliances, proximity hoods, VAV demand-based exhaust
Service Water Heating	Gas water heating (condensing)	95% efficiency
	Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99 − 0.0012 × Volume
	Point-of-use heater selection	0.81 EF of 81% Et
	Electric heat pump water heater efficiency	COP 3.0 (interior heat source)
	Solar hot water heating	30% solar hot-water fraction when LCC effective
	Pipe insulation thickness (d < 1.5 in./d ≥ 1.5 in.)	1 in./1.5 in.
HVAC	**Ground-Source Heat Pump (GSHP) System with DOAS (See AEDG for other HVAC types)**	
	GSHP cooling efficiency	17.1 EER
	GSHP heating efficiency	3.6 COP
	GSHP compressor capacity control	Two stage or variable speed
	Water circulation pumps	VFD and NEMA Premium Efficiency
	Cooling tower/fluid cooler	VFD on fans
	Boiler efficiency	90% Ec
	Maximum fan power	0.4 W/cfm
	Exhaust air energy recovery in DOAS	A (humid) zones = 60% enthalpy reduction B (dry) zones = 60% dry-bulb temperature reduction
	DOAS ventilation control	DCV with VFD
	Ducts and Dampers	
	Outdoor air damper	Motorized damper
	Duct deal class	Seal Class A
	Insulation level	R-6

* 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*

High-performance school buildings provide more comfortable learning spaces and improve student productivity and attendance. An environment that includes appropriate lighting, sound, temperature, humidity, and air quality can help students learn better[1]. In many cases, improving these attributes can also reduce energy use and significantly lower operational and life-cycle costs. Many schools spend more money on energy each year than on school supplies, even before considering maintenance costs.

By using energy efficiently and lowering a school's energy bills, millions of dollars each year can be redirected toward improving facilities, increasing teachers' salaries, or providing educational resources.

The Approach

Traditional wisdom has society believing that energy-efficient buildings must cost more to build than traditional structures; however, thoughtfully designed, energy-efficient schools can cost less. Building a new school to achieve at least 50% energy savings is within the reach of any committed school district, but it does take thought, determination, and a strong goal-setting process.

The design and construction of a high-performance school 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.

Project Delivery

An interactive team approach is recommended for all phases of a project's management. All parties work together through all phases of design and construction to maximize project efficiency and to yield coordinated, constructible, and cost-effective results. For smaller projects using the prescriptive approach described in this fact sheet, the project team may not include all disciplines. The efficiency and quality of the design and construction are obtained through the following team interactions and processes:

- Define energy design and performance goals and expectations, and identify the project team and stakeholders.
- Establish early involvement of all design professionals and construction team members. Include operations and maintenance staff as part of the owner's team.
- Establish open communication, with early input on project strategies from all parties. Conduct Owner's Project Requirements workshops and a project kickoff meeting to discuss goals and facilitate mutual cooperation.
- Develop an integrated commissioning strategy.
- Use the building as a teaching tool.
- Train building users and operations staff.
- Submeter end use energy consumption.

[1] U.S. Department of Energy. 2013. *Advanced Energy Retrofit Guide for K-12 schools*. pp 13–14.

Case Study: Kinard Core Knowledge Middle School

Poudre School District, located in Fort Collins, Colorado, includes 50 schools serving 24,000 students and is the ninth-largest school district in Colorado. The 113,000-ft^2 Kinard Core Knowledge Middle School is the most energy-efficient school in the Poudre School District—it was qualified as "Designed to Earn the ENERGY STAR" before it completed construction. The building's annual energy use is 25 kBtu/ft^2·yr, which outperforms ANSI/ASHRAE/IES Standard 90.1-2004 requirements by 50% and saves $40,000/yr in energy costs compared to the most recently constructed middle school in the Poudre School District.

Kinard Core Knowledge Middle School Building Exterior. *Source: Time Frame Images courtesy of RB+B Architects published in AEDG*

Two Harbors High School.
Source: John Gregor, Coldsnap Photography published in AEDG

Case Study: Two Harbors High School

The 190,000-ft^2 Two Harbors High School, located near Duluth, Minnesota, was built to replace a 1935 vintage building. The project offered the opportunity to design and construct an energy-efficient facility with low maintenance, low operating costs, and multiuse spaces available for use by the school and the community.

Completed in 2005, the school has received a number of awards, including a Council of Educational Facility Planners International Design Concept award (2005), an ASHRAE technology award (2009), and the Minnesota Governors' Partnership Award (2008).

The architectural design of the building ensures abundant daylighting. High clerestory windows provide daylighting for interior spaces. The lighting systems are integrated with the building management system and use occupancy schedules, daylighting sensors, and occupancy sensors to minimize electricity use for lighting. Demand controlled thermal displacement ventilation in the classrooms and a CO_2 override for high occupancy situations helps reduce energy transport loads and heating energy. Outdoor air is also preconditioned with energy recovery ventilators. High-efficiency hydronic heating and chilled water systems are used to meet the space conditioning loads while taking up minimal space.

Key Tactics for Schools

The following recommendations are examples of key design tactics for achieving high-performance K-12 schools cost effectively:

- Use double glazing with non-selective low-e coating in areas that are integral to your daylighting strategy to maximizing visible light transmission. High visible transmittance daylighting glass maximizes daylight transmission and minimizes daylighting aperture cost.
- Use the minimum amount of glass in the daylighting strategy needed to achieve the lighting level objectives during peak cooling times. Because glass costs more than opaque envelope materials and results in higher heating and cooling energy use, the benefits of reduced electric lighting are outweighed by the costs as window area increases.
- Minimize east- and west-facing window areas. Where they are necessary, select tinted glazing to help reduce peak cooling loads and, in turn, reduce installed cooling equipment.
- Paint interior walls light colors, select highly reflective ceiling materials, and select floor finishes that are not extremely dark.
- Select Energy Star computers, vending machines, televisions, appliances, and kitchen equipment whenever possible. Very high plug load efficiency can be achieved with minimal additional cost.
- Use multiple lamp fluorescent fixtures or LED fixtures that can be switched and/or dimmed to provide multiple light levels in daylighted gymnasiums.
- Analyze seasonal and hourly loads carefully to determine full-load conditions for HVAC systems, making sure to accurately account for the benefits of daylighting in terms of cooling load reduction.

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

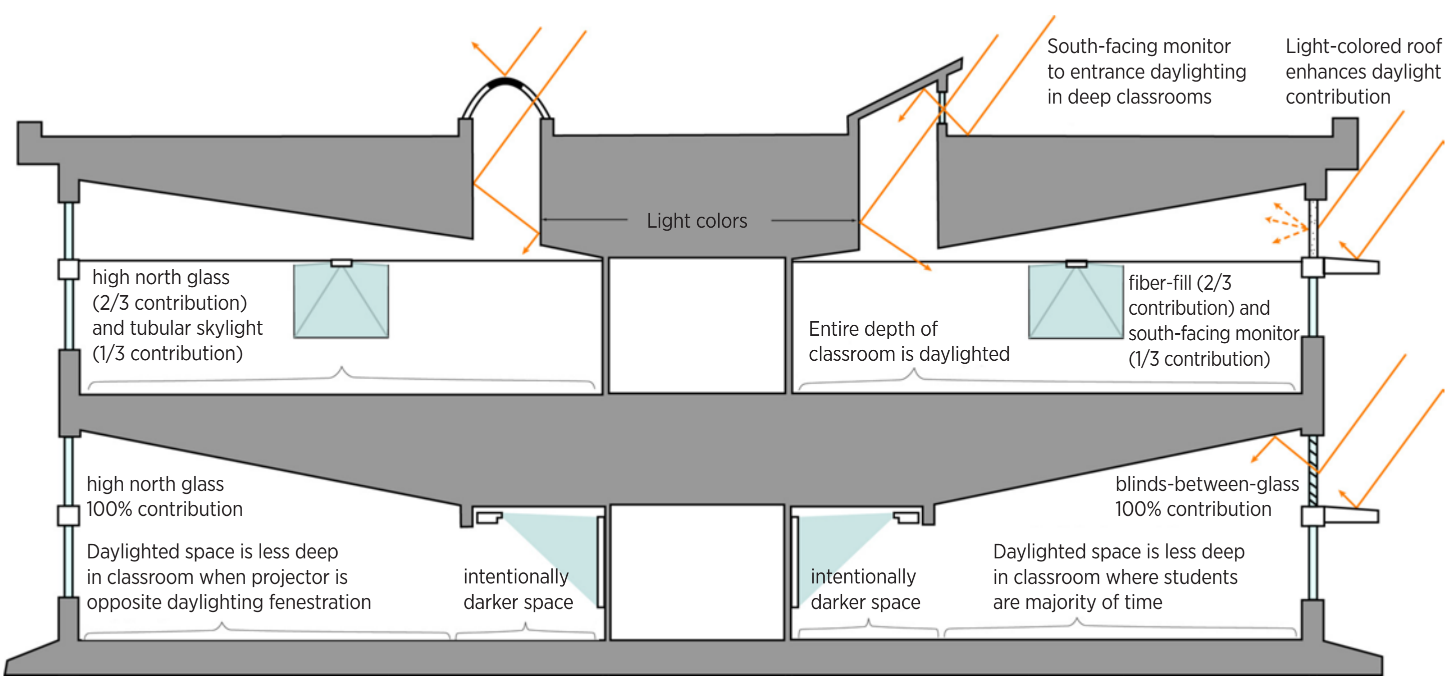
Gloria Marshall Elementary School Exterior. *Source: SHW Group published in AEDG*

Case Study: Gloria Marshall Elementary School

Gloria Marshall Elementary School is a 105,000-ft^2 two-story school that accommodates 800 students. The school created a fun, well-lit, high-comfort, low-energy consumption, high-performance elementary school that emphasizes math and science curriculum by using the building as a teaching tool for sustainability.

Completed in 2010, Gloria Marshall was the first school of its kind in the Houston, Texas, area to use geothermal heating and cooling, sophisticated lighting controls with daylight harvesting, roof-mounted photovoltaic (PV) electricity generation, a wind generator, and rainwater collection for toilet flushing.

Most classrooms are located on the first and second floors of the south exposure to take full benefit of daylight harvesting; the remaining classrooms are located on the second floor of the north exposure. Photosensor controls ramp up dimmable fluorescent fixtures to reach minimum lighting levels in each zone. The heating and cooling system consists of a ground source heat pump system with two-speed compressors to improve efficiency under part-load conditions. Fresh air is introduced into each occupied space by a dedicated outdoor air system, which includes a total energy recovery wheel and variable-frequency drives to vary the outdoor air delivered to each classroom using a central CO_2 testing system.



Sidelighting Enhanced with Toplighted Skylights or Roof Monitors. *Illustration from AEDG*

Nomenclature

°F degrees Fahrenheit

AEDG Advanced Energy Design Guide for K-12 School 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

DCV demand controlled ventilation, a ventilation system in which the flow of outdoor air is varied based on the need for outdoor air in the space

DOAS dedicated outdoor air system, a unit that has the sole job of supplying and conditioning the ventilation air to a space

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)

Ec combustion efficiency for natural gas appliances

EER energy efficiency ratio, the ratio of output cooling energy to input electrical energy, with higher values indicating higher efficiency

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)

FFR fenestration to floor area ratio, a common way to define glazing amounts needed for daylighting

ft feet

gal gallons

GSHP ground source heat pump

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)

K-12 kindergarten through 12th grade

kW kilowatts

LCC life cycle cost, the cost of a particular building component that is to be expected during its lifetime, factors in initial costs, maintenance costs, etc.

LED light emitting diode

LPD lighting power density (installed maximum power in W/ft^2)

LPW lumens per watt (efficiency measurement of electric lamps)

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 roof painted with white reflective paint which has both high reflectance and high emittance

T5/T5HO/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; HO stands for high output

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

VFD variable frequency drive, a solid state power electronics device that can vary the speed of a component (fan, pump, etc.) by modifying the input electrical frequency

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

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

For more information, visit: buildings.energy.gov

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