

Development of Design Guidance for K-12 Schools from 30% to 50% Energy Savings

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Development of Design Guidance for K-12 Schools from 30% to 50% Energy Savings¹

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ABSTRACT

This paper describes the development of energy efficiency recommendations for achieving 30% whole-building energy savings in K-12 Schools over levels achieved by following the *ANSI/ASHRAE/IESNA Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings* (1999 and 2004 versions). Exhaustive simulations were run to create packages of energy design solutions available over a wide range of K-12 schools and climates. These design recommendations look at building envelope, fenestration, lighting systems (including electrical lights and daylighting), HVAC systems, building automation and controls, outside air treatment, and service water heating. We document and discuss the energy modeling performed to demonstrate that the recommendations will result in at least 30% energy savings over ASHRAE 90.1-1999 and ASHRAE 90.1-2004. Recommendations are evaluated based on the availability of daylighting for the school and by the type of HVAC system. Compared to the ASHRAE 90.1-1999 baseline, the recommendations result in more than 30% savings in all climate zones for both *daylit* and *nodaylit* elementary, middle, and high schools with a range of HVAC system types. These recommendations have been included in the *Advanced Energy Design Guide for K-12 School Buildings*. Compared to the more stringent ASHRAE 90.1-2004 baseline, the recommendations result in more than 30% savings in all climate zones, for only the *daylit* elementary, middle, and high schools, with a range of HVAC system types. To inform the future development of recommendations for higher level of energy savings, we analyzed a subset of recommendations to understand which energy efficiency technologies would be needed to achieve 50% energy savings.

Introduction

This paper describes the development of energy efficiency recommendations for achieving 30% whole-building energy savings in K-12 schools over levels achieved by following the *ANSI/ASHRAE/IESNA Standard 90.1, Energy Standard for Buildings Except Low-Rise Residential Buildings* (over both the 1999 and 2004 versions of the standard). These recommendations were included in the *Advanced Energy Design Guide for K-12 School Buildings* (AEDG-K-12 2008), a design guidance document intended to provide recommendations for achieving 30% whole-building energy savings in K-12 Schools. The K-12 AEDG was developed in collaboration with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the American Institute of Architects (AIA), the

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Illuminating Engineering Society of North America (IESNA), the U.S. Green Building Council (USGBC), and supported through the U.S. Department of Energy (DOE).

Previous guides in this series include the *Advanced Energy Design Guide for Small Office Buildings* (AEDG-SO 2004), the *Advanced Energy Design Guide for Small Retail Buildings* (AEDG-SR 2006), and the *Advanced Energy Design Guide for Small Warehouses and Self-Storage Buildings* (AEDG-WH 2008). The guides published to date are available as free downloads from ASHRAE at www.ASHRAE.org/aedg

Included in the K-12 AEDG are prescriptive recommendations by climate zone for the design of the building envelope, fenestration, lighting systems (including electrical lights and daylighting), HVAC systems, building automation and controls, outside air treatment, and service water heating. Additional savings recommendations for electrical distribution, plug loads, renewable energy systems, and using the building as a teaching tool are also included, but are not necessary for 30% savings. The K-12 AEDG contains recommendations only. It is not a code or standard.

The K-12 AEDG was developed by a project committee (PC) that represents a diverse group of professionals. The formulation of the prototype, baseline, and low-energy models was an iterative process during the guide development; discussions about the model inputs and the model results were held with the PC. Results from the modeling, combined with input from the PC, led to the development of the final recommendations. The purpose of the recommendations provided in the K-12 AEDG is to help designers design energy-efficient schools. The goal of 30% energy savings over ASHRAE 90.1-1999 was the primary focus of the Guide. The focus was on high performance buildings and the related energy savings, not on installations that have a payback of less than some given number of years.

Our objectives, as discussed in this paper, are to:

- Develop prototypical, baseline and low-energy EnergyPlus K-12 school models.
- Document the EnergyPlus modeling assumptions needed to verify 30% energy savings.
- Demonstrate that the recommendations result in 30% or greater energy savings by climate zone.

Evaluation Approach

The purpose of the building energy simulation analysis presented in this paper is to assess and quantify the energy savings potential of the Guide's final recommendations. The AEDGs contain a set of energy efficiency recommendations for eight climate zones across the country. To provide prescriptive 30% recommendations, a specific quantitative energy savings goal must be measured against a specific version of Standard 90.1. For the K-12 AEDG, this is 90.1-1999, the "turn of the Millennium" standard (ASHRAE 1999). The energy savings of the prescriptive recommendations were also examined relative to ASHRAE 90.1-2004 (ASHRAE 2004). The following steps were used to determine 30% savings:

1. Develop "typical" K-12 school prototype characteristics.
2. Create baseline models for each climate zone from the prototypes that are minimally code compliant for both ASHRAE 90.1-1999 and ASHRAE 90.1-2004.

3. Create the low-energy models based on the recommended energy efficiency technologies in the Guide.
4. Verify 30% energy savings across the various school types, HVAC system types, and daylighting options over the 15 climate zones and sub-zones.

Evaluation Metrics

The 30% energy savings goal of the AEDG series is based on site energy savings between a minimally code compliant school and a low-energy school that uses the recommendations in the Guide. Other metrics, such as energy cost savings, source energy savings, and carbon savings, could be used to determine energy savings. Each metric has advantages and disadvantages from an implementation and a calculation perspective, and each can favor different technologies and fuel types. The K-12 AEDG uses “whole-building” site energy savings to retain consistency from the previous AEDGs. The “whole-building” energy savings indicate the savings when all the loads (regulated and unregulated) are included in the energy savings calculations.

The K-12 AEDG was written to help owners and designers of elementary, middle, and high schools achieve energy savings of at least 30% compared to the minimum requirements of ANSI/ASHRAE/IESNA Standard 90.1-1999, which is consistent with other AEDGs in the series. It is also the most recent code for which DOE had issued a formal determination of energy savings at the time the first AEDG was written.

Climate Zones

The AEDGs contain a unique set of energy efficiency recommendations for a range of climate zones. The four AEDGs developed to date have standardized climate zones that the International Energy Conservation Code and ASHRAE have adopted for residential and commercial applications (Briggs et al. 2003). It includes eight zones covering the entire United States (see Figure 1). Climate zones are categorized by heating degree days and cooling degree days, and range from the very hot zone 1 to the very cold zone 8. Some are divided into sub-zones based on humidity levels. Humid sub-zones are A zones, dry sub-zones are B zones, and marine sub-zones are C zones. Figure 1 also shows the cities that were used in the modeling analysis to represent the 15 climate zones (and sub-zones).

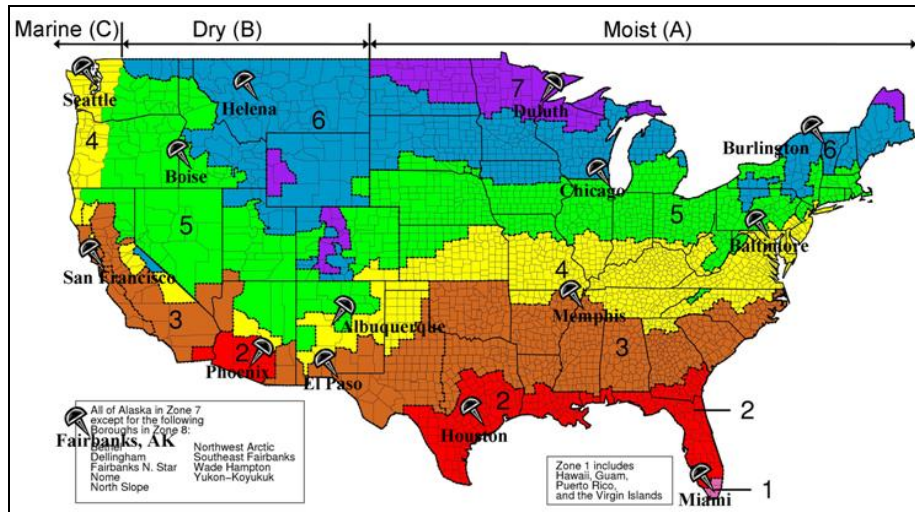
Prototype Model Development and Assumptions

For school characteristics that are not specified by ASHRAE 90.1-1999, ASHRAE 90.1-2004, or ASHRAE 62.1-2001 (ASHRAE 2001), but are needed to develop code compliant baseline and low-energy models, we attempted to document “typical” K-12 practices, characteristics, and features. Typical school characteristics helped to inform our development of realistic models for the 30% AEDG analysis. Data sets evaluated include:

- The 2003 Commercial Building Energy Consumption Survey (CBECS) (EIA 2005).
- The School Planning and Management (SPM 2007) and American School and University (ASU 2006) annual construction survey and report.

- Additional data sets from the PC, including plug load surveys, actual floor plates, and space programming requirements.

Figure 1. DOE Climate Zones and Representative Cities



From the survey of “typical” school characteristics, we developed prototype elementary, middle, and high school models (see Table 1).

Table 1. K-12 AEDG Prototype Characteristics and Data Sources

School Characteristic	K-12 AEDG Prototype	Source
Size	73,930 ft ² elementary, 116,080 ft ² middle, 210,810 ft ² high	ASU, SPM, CBECS 2003, AEDG PC
Number of floors	1 for elementary, 1 for middle, 2 for high schools	CBECS 2003
Constructions	Mass walls, insulation entirely above deck	CBECS 2003, AEDG PC
Floor plan	North- and south-facing classrooms similar to example floor plans	AEDG PC
Window area	35% fenestration to gross wall area	CBECS 2003, AEDG PC
Occupancy	Fully occupied during school hours, partially occupied year round and into the evening	CBECS 2003, AEDG PC
Peak plug loads	1.1 W/ft ² for elementary, 1.0 W/ft ² for middle and high	AEDG PC
Percent conditioned	Fully heated and cooled	CBECS 2003
HVAC system types	Baseline: PSZ Low-energy: PSZ, PVAV, and VAV	2003 CBECS AEDG PC

Space Type Sizes and Layout

The space types and layouts of the prototype models were developed based on the average sizes of elementary, middle, and high schools, the “typical” space types included in elementary, middle, and high schools (SPM 2007), the North Carolina Schools standard area profiles (North Carolina 2007), and the sample floor plans provided by the PC. In general, 30 ft × 32 ft double loaded classrooms, 10 ft wide corridors in the elementary schools and 15 ft wide corridors and lockers in the middle and high schools were used to construct the prototype classroom wings. Classrooms at the end of a wing are modeled as individual thermal zones, and classrooms with similar configurations are modeled as a lumped thermal zone. Classrooms that are expected to have significantly different use or internal gain schedules, such as the computer classrooms or extended use/community use classrooms, are modeled as separate zones. The classrooms were configured in “wings” that face north and south. A main corridor and lobby separate the classroom wings from the support spaces on the east side of the prototype model configurations. Table 2 shows the space types and sizes included in each prototype.

Table 2. Total Space Sizes Included in the AEDG Prototypes

Space Type	Elementary School		Middle School		High School	
	Total Size (ft ²)	% of total	Total Size (ft ²)	% of total	Total Size (ft ²)	% of total
Classrooms (all types except computer classrooms)	35,443	47.9%	47,161	40.6%	64,108	30.4%
Offices	4,745	6.4%	8,586	7.4%	11,449	5.4%
Multipurpose room/gym	3,841	5.2%	12,008	10.3%	34,690	16.5%
Computer classrooms	1,743	2.4%	2,227	1.9%	10,265	4.9%
Kitchen	1,808	2.4%	2,324	2.0%	2,324	1.1%
Cafeteria	3,389	4.6%	5,229	4.5%	6,714	3.2%
Media center	4,293	5.8%	5,810	5.0%	9,038	4.3%
Corridors/lobby	13,913	18.8%	25,351	21.8%	49,711	23.6%
Mechanical/restrooms	4,756	6.4%	7,381	6.4%	11,879	5.6%
Auditorium	0	0.0%	0	0.0%	10,631	5.0%
Total	73,932		116,079		210,810	

Baseline Model Development and Assumptions

The baseline models for the elementary, middle, and high schools were developed by applying the criteria in ASHRAE 90.1 and ASHRAE 62 to the prototype characteristics. We used the criteria in ASHRAE 90.1-1999 and ASHRAE 62-2001 as the baselines to calculate energy savings for the K-12 AEDG recommendations. For the baselines needed to verify 30% savings over ASHRAE 90.1-2004, we updated the K-12 AEDG baselines to be minimally code compliant with ASHRAE 90.1-2004.

Form and Floor Plate

The prototype characteristics as documented in the previous section, combined with modeling assumptions, were used to generate the baseline models form and floor plate. The baseline fenestration to gross wall area and skylight area in the gym were determined based on the expected window and skylight area needed to provide full daylighting to the classrooms and gym. The fenestration was equally applied over all of the exterior walls. Per ASHRAE 90.1, Appendix G modeling rules, the baseline fenestration and skylight area should be the same as the low-energy model. No overhangs were included. No plenums were modeled.

Envelope

The PC assumed, based on experience of those in the K-12 school construction industry, that schools are typically constructed with mass exterior walls, built-up roofs, and slab-on-grade floors. These envelope constructions represent common construction practices for K-12 schools. There is some regional variation in construction techniques, but the PC felt that mass walls and built-up roofs were the most common due to their durability. This assumption is confirmed by the CBECS analysis of construction types. The baseline school envelope characteristics were developed to meet the prescriptive design option requirements in accordance with ASHRAE 90.1-1999, Section 5.3. For the ASHRAE 90.1-2004 baselines, we used the prescriptive building envelope option in Section 5.5 of the standard.

The baseline schools are modeled with mass wall constructions. The layers consisted of stucco, concrete block, rigid insulation, and gypsum board. The U-values of the insulation varied based on the respective standard and were adjusted to account for the standard film coefficients. R-values for most of the layers were derived from Appendix A of ASHRAE 90.1-1999. Insulation R-values for continuous insulations were selected to meet the insulation minimum R-values required in Appendix B (Building Envelope Requirements) of ASHRAE 90.1-1999, as defined by climate range. Similar wall insulation values were modeled in the ASHRAE 90.1-2004 baselines, as the mass wall requirements did not change significantly from ASHRAE 90.1-1999 to ASHRAE 90.1-2004.

Built-up, rigid insulation above a structural metal deck roof was used in the baseline models. The layers consisted of the roof membrane, roof insulations, and metal decking. The U-values varied based on the respective standard and were adjusted to account for the standard film coefficients. Added insulation is continuous and uninterrupted by framing. Roof insulation R-values were also set to match the minimum roof insulation requirements in Appendix B (Building Envelope Requirements) in ASHRAE 90.1-1999, by climate. Similar roof insulation values were modeled in the ASHRAE 90.1-2004 baselines, as the insulation above deck roof requirements did not change significantly from ASHRAE 90.1-1999 to ASHRAE 90.1-2004.

The baseline buildings were modeled with slab-on-grade floors. The layers consist of carpet pad over 8 in. of heavyweight concrete. For this analysis, the average monthly temperatures were used as the input for the ground temperatures under the floor slab in the EnergyPlus input files.

Fenestration systems in the baseline schools were modeled as single banded windows with one band per floor per façade, at 35% fenestration to gross wall area. Windows are collected into a single object and frames are neglected to reduce complexity in the EnergyPlus

models and make the simulations run faster. The window performance is modeled as for the entire glazed area. U-factor and solar heat gain coefficient (SHGC) values were treated as whole assembly. Window U-factor and SHGC were set to match the fenestration performance criteria outlined in Appendix B of ASHRAE 90.1-1999, by climate zone. If the SHGC had no recommendation in ASHRAE 90.1 (1999 or 2004), the SHGC was set to the previous table's value of SHGC. Similar window U-factors and SHGCs were modeled in the ASHRAE 90.1-2004 baselines, as the window requirements did not change significantly from ASHRAE 90.1-1999 to ASHRAE 90.1-2004. The multipliers from the visible light transmittance (VLT) tables in ASHRAE 90.1-2004 Appendix C, Table C3.5 (ASHRAE 2004) were used to calculate baseline VLT values for the windows.

The K-12 AEDG recommends daylighting in the gyms. One of the gym daylighting options includes skylights with an area of 4% of the floor area. The baseline models also include the skylights, but without daylighting controls, as recommended in Appendix G of ASHRAE 90.1-2004. The skylights are 4 ft × 4 ft (1.22 m × 1.22 m) and spaced equally throughout the gym and multipurpose spaces. Window U-factor and SHGCs are set to match the fenestration performance criteria outlined in Appendix B of ASHRAE 90.1-1999, by climate zone.

Building air infiltration is addressed indirectly in the Standard through the requirements in building envelope sealing, fenestration and door air leakage, etc. ASHRAE 90.1 does not specify the air infiltration rate. For this analysis, the infiltration rate was assumed to be a peak of 0.5 air changes per hour (ACH). The infiltration schedule was also incorporated into the modeling by assuming 0.25 ACH of infiltration when the HVAC system is enabled and the building is pressurized and 0.5 ACH of infiltration when it is disabled at night and on weekends. The ACH assumption was based on Chan's (2006) work on determining typical infiltration in commercial buildings. Chan's results show an ACH range from 0.1 to 1.0 for a typical range of temperature and wind conditions, with a medium near 0.5 ACH.

Internal Loads

Internal loads include heat generated from occupants, lights, and appliances (plug loads such as computers, printers, and small beverage machines). For the occupancy loads, the load intensity refers to the maximum occupancy at the peak time of a typical day. Lighting and plug loads are represented by peak power density in watts per square foot. The equipment load intensities for the classrooms are assumed based on the results of the plug load audits performed by members of the PC. Elementary schools have a higher plug load than middle and high schools due to the amount of equipment elementary school teachers bring in from home and plug in their classrooms, such as fish tanks, refrigerators, and microwaves.

The equipment loads include all loads not associated with HVAC, service water heating, and lighting. In addition to all loads that are plugged in, equipment loads include items such as elevators, distribution transformer losses, cooking appliances, and kitchen walk-in refrigerators.

The occupancy loads are based on typical occupant density for schools. The baseline interior lighting power density (LPD) for each specific area is derived using the space-by-space method described in ASHRAE Standard 90.1-1999. The baseline ASHRAE 90.1-1999 and ASHRAE 90.1-2004 LPDs, peak occupancy, and peak plug loads are shown in Table 3. Plug load schedules, occupancy schedules, and lighting schedules were developed by modifying the standard educational building schedule sets available in ASHRAE 90.1-1989 (ASHRAE 1989),

based on input from each PC member and from the typical operating characteristics from CBECS.

Table 3. Elementary, Middle, and High School Baseline Internal Loads by Space Type

Space Type	ASHRAE 90.1-1999 LPD (W/ft ²)	ASHRAE 90.1-2004 LPD (W/ft ²)	Peak Equipment Load (W/ft ²)	Maximum Occupants (#/1000 ft ²)
Classrooms (Elementary)	1.6	1.4	1.4	25
Classrooms (Middle and High)	1.6	1.4	0.9	25
Offices	1.5	1.1	1.0	5
Multipurpose room (Elementary)	1.9	1.4	0.5	30
Gym (Middle and High)	1.9	1.4	0.5	100
Auxiliary gym (High)	1.9	1.4	0.5	30
Computer classrooms	1.6	1.4	1.9	30
Kitchen	2.2	1.2	1.9	15
Cafeteria	1.4	0.9	1.0	100
Media center	1.8	1.2	1.4	25
Lobby	1.8	1.3	0.4	10
Corridors	0.7	0.5	0.4	1
Restrooms	1.0	0.9	0.4	10
Mechanical	1.3	1.5	0.9	1
Auditorium (High)	1.6	1.4	0.5	100
Elementary weighted average	1.53	1.25	1.10	20
Middle weighted average	1.52	1.22	0.82	27
High weighted average	1.57	1.25	0.74	30

HVAC Systems and Components

The scope of this Guide covers all sizes of K-12 schools that use multiple HVAC system types. To meet the minimum energy efficiency requirements of ASHRAE 90.1-1999 and ASHRAE 90.1-2004 for the baseline models, the PC agreed to use packaged single-zone (PSZ) unitary heating and cooling equipment. The types of HVAC systems in K-12 schools are highly variable. The PC felt that package rooftops were an acceptable baseline system based on industry experience and on the CBECS analysis, which showed that package rooftop units are common. The code minimum EER of these system types are also the highest as compared to larger PSZs, PVAV, and VAV with air-cooled chiller systems. This ensured the best case baseline cooling efficiency, and ensured the low-energy recommendations would result in at least 30% savings. To model this baseline system type, we modeled each thermal zone with an autosized package single-zone (PSZ) system with a constant volume fan, direct expansion (DX) cooling, and gas-fired furnace. To apply ASHRAE 90.1-1999 and ASHRAE 90.1-2004, we

assumed the baseline rooftop units would be on individual classroom rooftops in the range of 5 tons and 2,000 cfm (0.94 m³/s). For larger spaces, multiple 5-ton units would be used. A 1.2 sizing factor was applied to all autosized heating and cooling capacities and air flow rates.

Ventilation rates by space type were determined based on ASHRAE 62-2001 (ASHRAE 2001). Demand-controlled ventilation is required by ASHRAE 90.1-1999 in densely occupied spaces such as auditoriums and cafeterias. The ASHRAE 90.1-2004 baselines used these same outdoor air (OA) rates. To model demand-controlled ventilation in these spaces, we modified the OA rates to match the baseline occupancy schedules.

For the spaces without demand-controlled ventilation, OA was scheduled based on the HVAC system availability schedule. Code allows OA to be controlled with a gravity damper, which opens whenever the fans operate. However, we modeled an OA motorized damper based on HVAC system availability schedules in the baseline models. The motorized damper is closed during unoccupied hours, resulting in no OA when the system night cycles. Using gravity dampers in colder climates that have significant night cycling can result in significant heating, which would inflate the baseline energy use in these climates. Therefore, all the baseline models include motorized OA dampers. The PC also felt that gravity dampers were not a common configuration for OA control. In accordance with ASHRAE 90.1-1999 and ASHRAE 90.1-2004, an economizer is not required if the system is smaller than 65,000 Btu/h in cooling capacity, regardless of climate location. Therefore, the 5-ton rooftops do not include economizers in the baseline models.

The constant volume fan energy use is determined from two primary input parameters: total supply fan static pressure drops and fan/motor efficiency. We have assumed that the package rooftop system contains only a supply fan, and there is no return fan or central exhaust fan in the system. The total supply fan static pressure drops were based on PC members' input on standard HVAC ductwork design for representative duct runs served by the packaged unitary equipment. A total fan static pressure of 2.50 in. water column (w.c.) (625 Pa) was used for the 5-ton unit. The total fan efficiency is a combination of the supply fan, motor, and drive efficiency. To calculate the total fan efficiency, the power delivered to the airflow by the fan is divided by the maximum allowable motor power, which equates to a 33% efficient fan/motor/drive combination. This efficiency was used as the baseline model input for the EnergyPlus package rooftop total fan efficiency.

The code minimum efficiency for cooling equipment is determined based on cooling system type and size. To apply ASHRAE 90.1-1999 and ASHRAE 90.1-2004, we assume the baseline rooftop units would be individual classroom rooftop units in the range of 5 tons and 2,000 cfm. ASHRAE 90.1-1999 and ASHRAE 90.1-2004 require that the energy efficiency of single packaged unitary air conditioners at this level (less than 65,000 Btu/h) should be rated by the seasonal energy efficiency ratio (SEER). Therefore, for the elementary, middle, and high school ASHRAE 90.1-1999 baseline models, the minimum efficiency of 9.7 SEER was used for each rooftop. For the ASHRAE 90.1-2004 baseline models, the minimum efficiency requirements were increased to a 12 SEER for this sized package rooftop unit. The gas-fired furnace efficiency levels were incorporated as 80% efficient gas furnaces in the package rooftops, to match the minimum efficiency requirements for both ASHRAE 90.1-1999 and ASHRAE 90.1-2004.

Service Water Heating

The PC defined the baseline service hot water system for the K-12 schools as a gas-fired storage water heater that meets the minimum Standards requirement for medium-sized water heaters under Standard 90.1-1999. Gas water heaters were chosen for the baseline to be consistent with the use of gas for heating in the baseline prototype schools. The thermal efficiency of the baseline water heaters is 80% for ASHRAE 90.1-1999 and ASHRAE 90.1-2004.

Low-Energy Model Development and Assumptions

The final recommendations included in the Guide were determined based on an iterative process that uses the PC's expertise and results from modeling the recommendations. To quantify the potential energy savings from the final recommended energy efficiency measures in the Guide, we implemented the following energy efficiency technologies to simulate the low-energy building models. The energy efficiency measures included in the 30% saving calculation are:

- Enhanced building envelope, including additional insulation and high-performance window glazing with overhangs
- Reduced LPD and occupancy controls, combined with classroom and gym daylighting
- Higher efficiency HVAC equipment, combined with demand-controlled ventilation, energy recovery ventilator (ERV), economizers, and lower pressure ductwork design and higher efficiency fans
- High-efficiency service water heating

The following guiding principles were used to develop the final recommendation for the K-12 AEDG:

- Provide recommendations that represent responsible, but not necessarily the best, K-12 school design practices. If a recommendation generally represents good design practice, it is recommended for all climate zones, even if the resulting savings exceed 30%.
- Use off-the shelf technologies that are available from multiple sources. The PC did not recommend technologies or techniques that are unique or available from a single manufacturer.
- Provide recommendations that are at least as stringent as those in the forthcoming ASHRAE 90.1-2007, including Addenda AS and AT (ASHRAE 2007). We did not want our recommendations to be less stringent than the most recent version of ASHRAE 90.1.
- Use the recommendations from the previous AEDGs as a starting point for fine tuning the K-12 AEDG recommendations. Develop recommendations to address concerns on usability, operations and maintenance, simplicity, and flexibility.
- Verify 30% energy savings for the recommendations that represent the most typical K-12 school components, or for the components that are the least likely to result in 30% savings.

Lighting and Daylighting Recommendations

The PC considered daylighting to be the most important recommendation in the K-12 AEDG because daylighting has many benefits, both real and perceived, in the K-12 school industry. One measurable benefit is energy savings because electrical lighting is one of the largest energy users in schools. Depending on climate, lighting energy use can be as high as about 35% of the total energy use of a basic energy code-compliant school. Because lighting-related improvements can be inexpensive and offer rapid payback, these are at the top of the list of recommendations for meeting an overall target of 30% energy savings or greater. There are two distinctly different approaches to reducing electrical lighting power: through daylighting or with high-efficiency electrical lighting systems. Either can be used to meet the recommendations in this Guide.

Designing a daylit school. For the daylighting options, recommendations are given for classrooms and gyms/multipurpose rooms. There are three classroom daylighting patterns: a toplit pattern, a sidelit pattern, and a combined toplit and sidelit pattern. For the gym/multipurpose rooms, there are two toplit daylighting patterns: a roof monitor pattern and a skylight pattern. Recommendations for north- and south-facing versions for each pattern are provided in the Guide. East- and west-facing daylighting systems are not recommended. Recommended patterns are also provided by climate zone. The gym daylighting and classroom sidelighting recommendations were included in the low-energy models, as this was considered the daylighting design that would provide the least amount of daylighting.

Using efficient and state-of-the-art products and techniques to design electric lighting. Site constraints or program requirements may preclude daylighting solutions. Therefore, a nondaylit path is provided to meet the recommendations in this Guide. These recommendations include lighting systems that use the most current, energy-efficient lamps, ballasts, and integrated controls. The nondaylit low energy models used the reduced LPDs as recommended in the Guide.

HVAC Recommendations

Recommendations were developed based on the availability of daylighting for the school and by the type of HVAC system. The types of HVAC systems in K-12 schools are highly variable. Therefore, recommendations for multiple HVAC types are provided. To verify savings over this range of design options, we modeled low-energy versions of the elementary, middle, and high schools, each with the daylit option and the nondaylit option. For each daylit and nondaylit option, we modeled three HVAC types. The low-energy HVAC system types included a constant volume package rooftop DX system (PSZ), a package variable air volume (VAV) DX system with a central boiler (PVAV), and a VAV air-cooled chiller and central boiler (VAV). These system types were chosen based on the PC input as to the systems that were the least stringent as well as the most common.

Because conditioning OA for ventilation is such a big contributor to the energy use in a K-12 school building, either exhaust-air energy recovery or demand-controlled ventilation is recommended. The K-12 AEDG provides multiple options beyond code minimum for reducing

OA loads, including scheduled OA control for all zones, carbon dioxide (CO₂) demand-controlled ventilation in all zones, and energy recovery from exhaust air. The PC felt that the use of CO₂ demand-controlled ventilation and ERVs was not a practical technology combination and unneeded for 30% savings. Either demand-controlled ventilation or ERVs can significantly reduce OA loads. However, when one is applied, the energy savings potential for the other is limited. Therefore, for the PSZ, PVAV, and VAV HVAC system types, either CO₂ demand-controlled ventilation or an ERV is recommended. For all HVAC types, recommendations are provided for controlling the OA based on a schedule of the expected occupancy.

To model these recommendations, we modeled the CO₂ demand-controlled ventilation in the low-energy PSZ system and ERVs in the low-energy PVAV and VAV systems. The PC felt that the application of CO₂ demand-control ventilation matched the PSZ configuration better because CO₂ sensors in each zone could control OA for each zone. Likewise, the application of ERVs matched the single OA intake configuration of the PVAV and VAV systems. The HVAC baseline and low-energy modeling inputs are summarized in Table 4.

Table 4. Baseline and Low-Energy HVAC Models Summary

HVAC Input	Baseline PSZ	Low-Energy PSZ	Low-Energy PVAV	Low-Energy VAV
COP of compressor/condenser	3.5 COP ASHRAE 90.1-1999 (SEER 9.7)	4.5 COP (SEER 13)	CZ 1-4: 4.7 COP CZ 5-8: 4.3 COP	CZ 1-4: 2.93 COP CZ 5-8: 2.80 COP
COP of compressor/condenser	4.4 COP ASHRAE 90.1-2004 (SEER 12)	4.5 COP (SEER 13)	CZ 1-4: 4.7 COP CZ 5-8: 4.3 COP	CZ 1-4: 2.93 COP CZ 5-8: 2.80 COP
Heating efficiency	80%	80%	CZ 1-2: 80% CZ 3-8: 85%	CZ 1-2: 80% CZ 3-8: 85%
Fan efficiency	33%	36%	44%	44%
Fan power limitation	1.2 hp/1000 cfm	1 hp/1000 cfm	1.3 hp/1000 cfm	1.3 HP/1000 cfm
Total fan static pressure	2.5 in. w.c.	2.3 in. w.c.	A and B zones: 3.6 in. w.c. C zones: 3.1 in. w.c.	A and B zones: 3.6 in. w.c. C zones: 3.1 in. w.c.
Economizers	None	CZ 1, 2A: None CZ 2B, 3-8: Yes	CZ 1, 2A: none CZ 2B, 3-8: yes	CZ 1, 2A: none CZ 2B, 3-8: yes
ERV	None	None	A zones: 50% total effectiveness B zones: 50% sensible effectiveness C zones: none	A zones: 50% total effectiveness B zones: 50% sensible effectiveness C zones: none
OA control	HVAC operational schedule, CO ₂ demand controlled in cafeteria, gym, auditorium	CO ₂ demand controlled in all zones	Expected occupancy schedule, CO ₂ demand controlled in cafeteria, gym, auditorium	Expected occupancy schedule, CO ₂ demand controlled in cafeteria, gym, auditorium

Evaluation Results

This section documents the energy savings from the recommendations for 30% savings over ASHRAE 90.1-1999 and ASHRAE 90.1-2004. Recommendations are provided based on the availability of daylighting for the school and by the type of HVAC system. To verify savings over this range of design options, we modeled low-energy versions of the elementary, middle, and high schools, each with the daylit option and the nondaylit option. For each daylit and nondaylit option, we modeled three HVAC types. The low-energy HVAC system types included a constant volume package rooftop DX system, a package VAV DX system with a central boiler, and a VAV air-cooled chiller and central boiler. The recommendations in the K-12 AEDG result in more than 30% savings in all climate zones, for each daylit and nondaylit elementary, middle, and high school, with a range of HVAC system types. For 30% savings over ASHRAE 90.1-2004, the recommendations are almost the same as those that are in the K-12 AEDG. The nondaylit option presented in the K-12 AEDG is not available for 30% savings over ASHRAE 90.1-2004, as 30% savings were not possible over all climate zones for the nondaylit recommendations.

The whole building energy savings results for the recommendations in the K-12 AEDG are shown in Figure 2 and Figure 3. Energy savings are relative to the ASHRAE 90.1-1999 baseline energy use, and include plug loads in the energy use of the baseline and low-energy models. The analysis shows that the recommendations in the K-12 AEDG succeeded in meeting the goal of 30% or greater energy savings and that this goal can be met for daylit and nondaylit options with a range of HVAC system types. Energy savings are also shown for each elementary, middle, and high school prototype. In general, all the nondaylit models had less energy savings than the daylit equivalent. The daylit models do not have a reduced LPD, but used less lighting energy than the nondaylit models. The nondaylit low-energy PSZ models were just above 30% savings, and the PVAV daylit low-energy models were significantly above 30% energy savings. The PVAV system types performed the best, because of a combination of the higher VAV fan efficiency, higher compressor COP, and higher boiler efficiency. Energy savings by school type did not vary significantly for a given climate zone. Further end use breakdowns are available in Pless et al. (2007).

The energy savings results for the recommendations in the K-12 AEDG, relative to ASHRAE 90.1-2004 are shown in Figure 4. The recommendations in the K-12 AEDG result in 30% or greater energy savings over ASHRAE 90.1-2004 for just the daylit options with a range of HVAC system types. Energy savings are also shown for each elementary, middle, and high school prototype. For many climate zones and school types, energy savings exceeded 30% savings. However, for the most temperate climate zones (such as 4C), combined with the least effective recommendations, energy savings are just above 30%. The project committee felt that if the recommendations in these climate zones are considered good design practices, then they should also be included in the other climate zones. This was the case for recommendations such as air conditioner efficiency, demand controlled ventilation, and energy recovery ventilators. We did allow insulation and lighting power densities recommendations to vary based on climate zone.

Figure 2. Energy Savings over ASHRAE 90.1-1999 for Non-daylit Schools

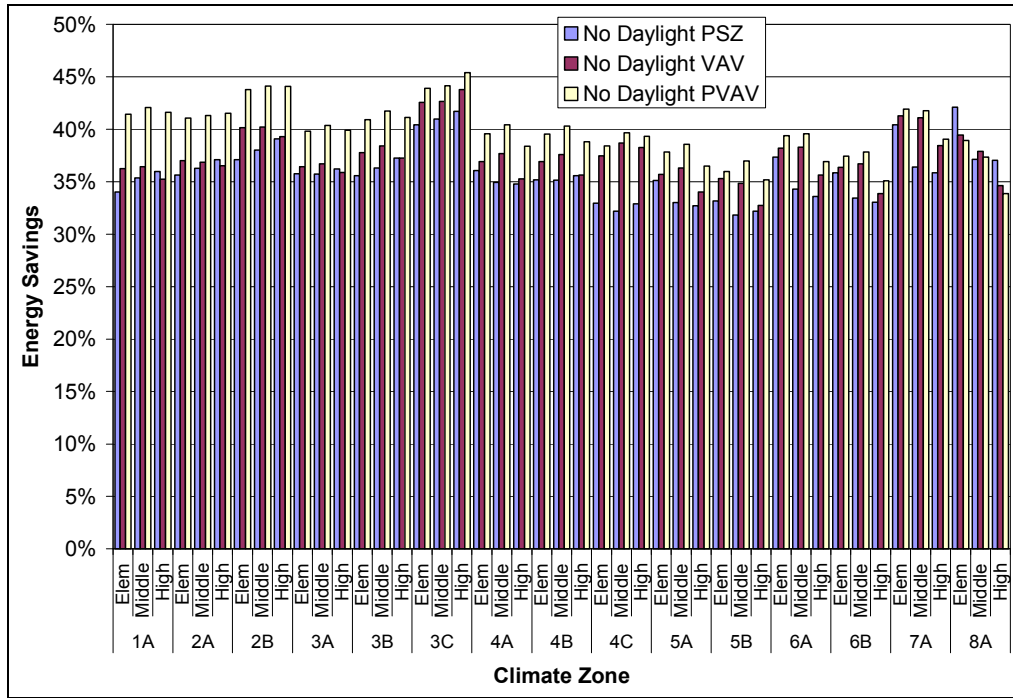


Figure 3. Energy Savings over ASHRAE 90.1-1999 for Daylit Schools

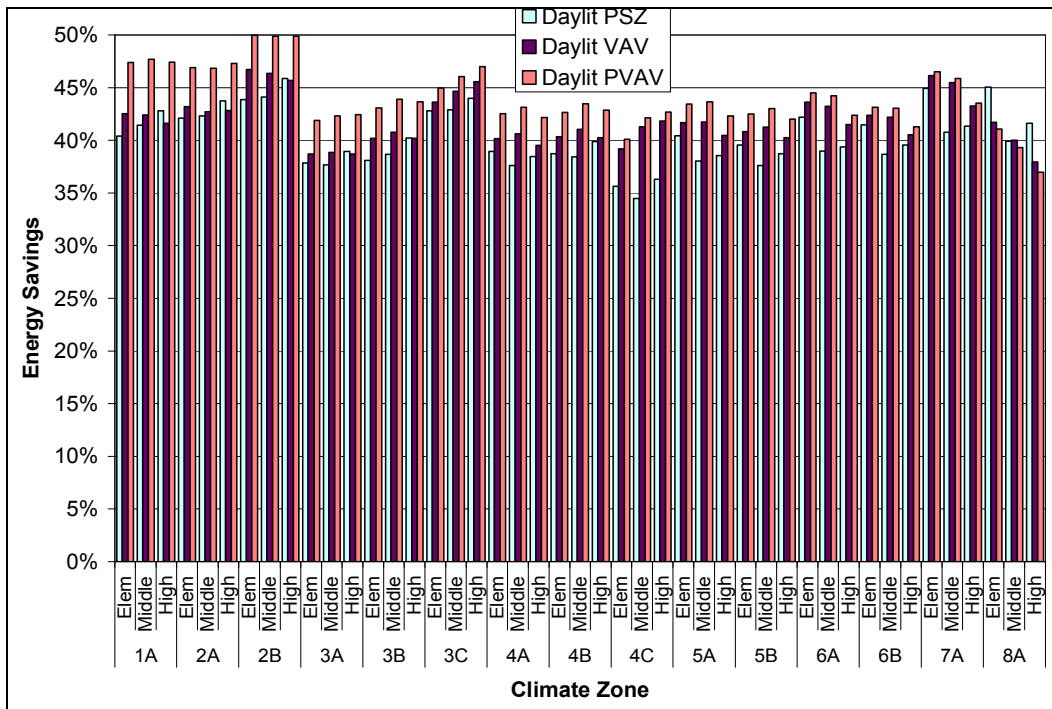
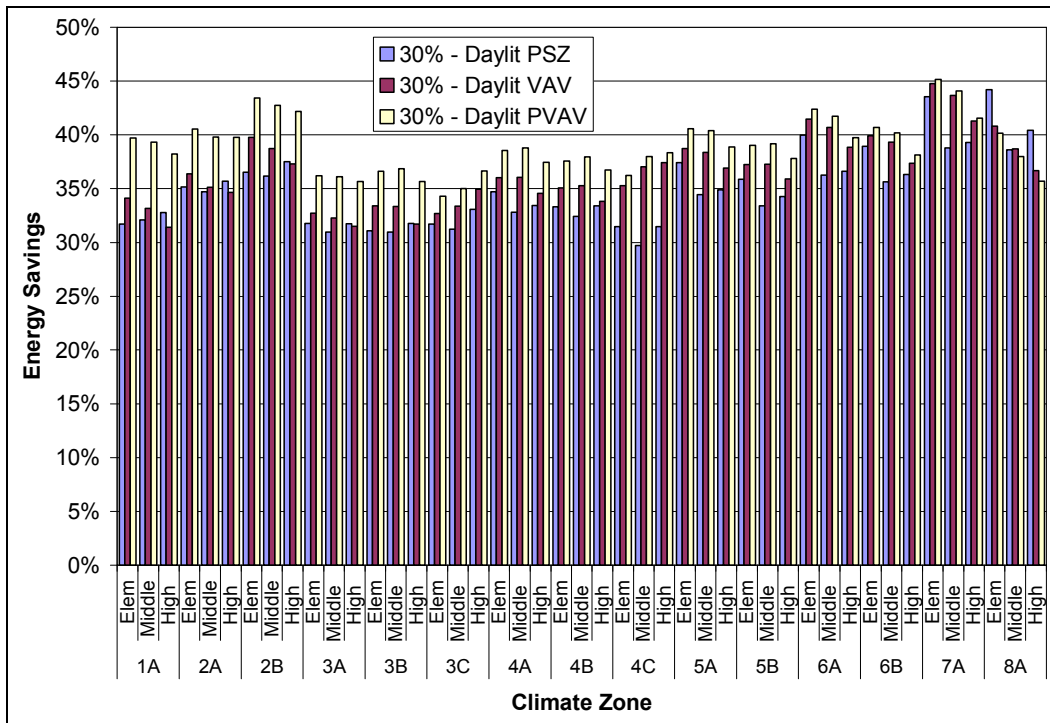


Figure 4. Energy Savings over ASHRAE 90.1-2004 for Daylit Schools



Beyond 30% Energy Savings

To inform the future development of more stringent K-12 AEDGs, we performed a scoping study to understand which energy efficiency technologies would be needed to achieve 50% energy savings. Recommendations included in the 50% scoping analysis include the most stringent of each recommendation in the 30% guide, combined with plug load reductions resulting from high-efficiency distribution transformers and Energy Star® equipment, daylighting in all zones, infiltration reduction, and water-cooled chillers. We modeled these recommendations in a daylit middle school to determine energy savings over ASHRAE 90.1-2004 in each of the 15 climate zones and sub-zones. Based on this initial scoping study, 50% savings should be possible in all climates. For the most temperate climates such as 3C and 4C, energy savings are just above 50%. The study also suggests that 50% savings are possible, but that efficiency measures of unregulated loads, such as plug loads and infiltration, are required. Additional focus on “typical” plug load schedules in K-12 schools and the expected energy savings from ENERGY STAR equipment will be needed to accurately predict the plug load savings. Baseline infiltration inputs will also need to be further researched.

Conclusions

To inform the development of the 30% K-12 Advanced Energy Design Guide, we performed exhaustive simulations to evaluate packages of energy design recommendations available over a wide range of K-12 schools and climates. These design recommendations look at building envelope, fenestration, lighting systems (including electrical lights and daylighting), HVAC systems, building automation and controls, outside air treatment, and service water

heating. Compared to the ASHRAE 90.1-1999 baseline, the recommendations result in more than 30% savings in all climate zones for both *daylit* and *nodaylit* elementary, middle, and high schools with a range of HVAC system types. These recommendations have been included in the *Advanced Energy Design Guide for K-12 School Buildings*. Compared to the more stringent ASHRAE 90.1-2004 baseline, the recommendations result in more than 30% savings in all climate zones, for only the *daylit* elementary, middle, and high schools, with a range of HVAC system types.

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