Technical Feasibility Study for Zero Energy K-12 Schools

Shanti D. Pless, National Renewable Energy Laboratory
Paul A. Torcellini, National Renewable Energy Laboratory
Eric Bonnema, National Renewable Energy Laboratory
David Goldwasser, National Renewable Energy Laboratory

ABSTRACT

Last year DOE published a common definition for zero energy buildings (ZEB) with the intent of moving the market in a common direction. As a building type, K-12 schools are ideal candidates to lead a market shift from buildings that consume energy to buildings that can produce as much renewable energy as they consume. The space types, owner procurement models, and the educational and community involvement make K-12 schools potential leaders in the energy efficiency markets.

A simulation-based technical feasibility study was completed to show the types of technologies required to achieve ZEB status with this building type. These technologies are prioritized across the building's subsystem such that design teams can readily integrate the ideas. Energy use intensity (EUI) targets were established for U.S. climate zones such that K-12 schools can be zero-ready or can procure solar panels or other renewable energy production sources to meet the zero energy building definition. Results showed that it is possible for K-12 schools to achieve zero energy when the EUI is between 20 and 26 kBtu/ft^2/yr. Temperate climates required a smaller percentage of solar panel coverage than very hot or very cold climates. The paper provides a foundation for technically achieving zero energy schools with a vision of transforming the school construction market to mainstream zero energy buildings within typical construction budgets.

Background

About 40% of U.S. energy consumption is attributed to residential and commercial buildings (U.S. EIAa). Of this, electricity accounts for 61% of energy consumption in commercial buildings (U.S. EIAb). Making zero energy buildings (ZEBs) mainstream is an important milestone in reducing the overall energy use in commercial buildings. To reduce the ambiguity of the term ZEB, the U.S. Department of Energy (DOE) developed a formal definition of zero energy buildings with the help of numerous stakeholders (DOE 2015). This study focuses on the feasibility of ZEB designation for K-12 schools.

The DOE, as part of its ongoing strategy to advance energy efficiency in the new construction market, has developed an ambitious plan to accelerate the market adoption of ZEBs. This multi-faceted ZEB initiative is designed to engage and move the market toward what may seem like an impossible task—from buildings that consume energy to those that are energy neutral or produce energy. An assessment of the potential for achieving ZEBs across the entire building stock was completed in 2006 and showed that low-rise buildings had more opportunity to achieve zero energy status (Griffith 2006). In some building types, such as hospitals, it was very difficult to achieve the goal, while others, such as warehouses, could easily achieve ZEB status. As the zero energy concept becomes better understood in the marketplace, there is a need to publish case studies and provide technical design and operations evidence that ZEBs are possible within typical construction budgets, and then accelerate these resources to be applied in new construction across the K-12 sector.

A key early step of scaling this ZEB initiative is a technical feasibility study that evaluates the possible technology combinations in the different climates needed to achieve the DOE definition of zero energy buildings. This technical feasibility study provides documentation and research results supporting a possible set of strategies to achieve source zero energy K-12 school buildings as defined by the DOE (DOE 2015a). Under this definition, a ZEB is an energy-efficient building in which, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.

This feasibility study provides the technical support to understand if K-12 schools can become ZEBs within their own footprint using on-site renewable generation as specified by the DOE definition. The results can serve as a foundation for those involved in designing, constructing, and renovating schools to make a substantial difference in energy consumption and assume a leadership role in transforming buildings to net producers, rather than consumers, of energy. The goal is to show that zero energy schools are technically achievable using market-available construction techniques. As a feasibility study, no design guidance (such as HVAC system sizing, and construction details) is provided, but rather pathways and directions are given that could lead to widespread deployment of zero energy schools. Since ZEB's require the balance of energy consumption and energy supply, we have focused on establishing EUI targets for K-12 schools with roof-mounted photovoltaic (PV) panels (the typical current energy supply option). The analysis for determining the amount of energy available is not complex, but achieving the low energy requirements involves assessing many options and is complex to analyze.

Scope of the Feasibility Study

This study applies to elementary, middle, and high school buildings. Its primary focus is new construction, but these findings may be applicable to facilities undergoing major renovation, addition, remodeling, and modernization (including changes to one or more systems in existing buildings). The schools considered typically included some or all of the following space types:

- Administrative and office
- Classrooms, hallways, and restrooms
- Gymnasiums with locker rooms and showers
- Assembly spaces with either flat or tiered seating
- Food preparation spaces
- Libraries or media centers.

Specialty spaces such as ice rinks, indoor pools, laboratories requiring large quantities of outside air (e.g., woodworking and auto shops), or other unique spaces that generate extraordinary heat or require large amounts of ventilation were not considered in this study. Some larger high schools and vocational schools contain these types of spaces. Schools with these specialized uses can be zero; however, additional analysis would be needed for these non-mainstream buildings. In general, these schools would require additional renewable energy generation, such as PV panels on parking structures or awnings.

Furthermore, this study only looks at the energy consumption of K-12 schools and the ability for on-site renewable resources to meet the energy loads. It does not address other sustainability or design issues such as acoustics, productivity, indoor air quality, water efficiency, landscaping, and transportation except as they relate to energy use. K-12 schools evaluated in this analysis do meet ASHRAE Standards 55-2013 (ASHRAE 2013a) and ASHRAE 62.1-2007 (ASHRAE 2007) for thermal comfort and outside air requirements as part of the energy modeling parameters. In addition, the models meet or exceed ASHRAE Standard 90.1-2013 (ASHRAE 2013b) for energy efficiency in commercial buildings. As a result, this feasibility study contains pathways for zero energy schools but is not a recommendations guide for particular pieces of equipment, nor is it intended to be used as a code or standard.

Evaluation Approach

This section describes the analysis methods used, including the development of the energy simulation models and the methods for determining whether the DOE ZEB definition has been met. The purpose of the building energy simulation analysis was to determine the set of energy efficiency strategies needed to achieve an energy consumption figure that matches the solar energy resource available within the building footprint. The set of energy efficiency strategies we considered covers all eight U.S. climate zones (Briggs, Lucas, and Taylor 2003) and their corresponding subzones (resulting in 15 total climate locations). We used the following steps to determine whether the goal of zero energy was met or exceeded:

- Developed “market available” K-12 school prototype characteristics. (In some cases multiple models were developed with different technologies.)
- Developed best-in-class energy efficiency strategies that have been implemented in ZEB K-12 schools
- Used energy modeling iteratively to create building characteristics that can achieve zero energy. These parameters must also meet the minimum requirements of ASHRAE 90.1-2013 (ASHRAE 2013b) and be consistent within the climate zone and across climate zones.
- Verified zero energy was achieved across the eight U.S. climate zones and corresponding subzones.

Energy is measured based on a specific, defined boundary. Whole-building performance is expressed by the amount of purchased energy that crosses the building site boundary. When on-site solar generation is added, the energy generation offsets the building energy consumption measured at the site boundary. To decouple this, energy consumption is separated from renewable energy production. The DOE definition for a ZEB uses source energy as a metric. This takes the energy flows at the site boundary and applies a site-to-source conversion to approximate the inefficiencies of delivering the energy from the point of extraction to the site. This feasibility study uses the conversion factors in the definition document (DOE 2015a), which are from Standard 105 Table J2-A (ASHRAE 2014).

Modeling Methods

EnergyPlus version 8.4 (DOE 2015b) was used as the energy modeling engine and paired with OpenStudio (Guglielmetti, Macumber, and Long 2011) as the platform to manage input files, simulations, and results. EnergyPlus was selected because it is a tool that accounts for the complicated interactions among climate, internal gains, building form and materials, HVAC systems, and renewable energy systems. EnergyPlus also is a heavily tested program with formal BESTEST validation efforts repeated for every release (Judkoff and Neymark 1995). OpenStudio's core functionality is the user's ability to include high-level parameters of the building (such as building area, internal gains per zone, HVAC system configuration) to generate a fully parameterized EnergyPlus input file. Such files are generated rapidly and can be easily changed to accommodate the evolution of the model. Furthermore, processes were developed to facilitate future applications that support the design and construction of ZEBs, particularly zero energy schools.

Developing "Market Available" K-12 School Facility Prototypes

Unlike percent-savings energy analysis, ZEBs do not need a reference point to a fictitious code-compliant building as a mechanism for generating savings numbers. ZEBs rely on absolute numbers and balancing the absolute energy consumption with energy generated by renewables on site. Although the comparison with existing buildings or current codes is not included in the analysis, the absolute targets provide a focused direction for minimizing the energy impact of buildings such that they have a zero energy footprint.

A "market available" prototype is an energy model that is a representative example of a K-12 school facility. The primary and secondary school DOE Commercial Prototype Building Models (DOE 2014) were used as the "typical" prototype for space layouts and space types. Because of different space types and configurations, different models were used to represent these buildings. Many areas of the United States also have middle schools, which typically fall between primary and secondary schools in terms of space types. For determining the feasibility of zero energy schools, middle schools do not need to be modeled separately. The high-level characteristics for the two prototype buildings are shown in Table 1.

DOE prototype building models (DOE 2014), derived from Deru et al. 2011 and Pless, Torcellini, and Long 2007, were used as a starting point to help define building characteristics that were not regulated by code. The prototypical buildings were then modified to comply with the *50% Advanced Energy Design Guide for K-12 Schools* (ASHRAE 2012) and the related technical support document (Bonnema et al. 2013). These models were compared against Standard 90.1-2013 (ASHRAE 2013b) to ensure that building parameters at least met the current code requirements. Next, space layouts were modified to represent current practice based on input from a technical advisory team assisting with the project. This team consisted of 12 members from the industry with backgrounds in zero energy buildings and areas such as energy modeling, mechanical electrical plumbing (MEP), and construction administration. The team provided insights into current construction practices and industry changes since the *50% Advanced Energy Design Guide for K-12 Schools* was developed. One of the major variations was reducing the building footprint by increasing the number of stories to reflect trends observed by the technical advisory team. These changes made achieving ZEBs more challenging because as the footprint decreased, the amount of space available for renewable energy generation also decreased.

Table 1. Feasibility study prototype characteristics

Building Characteristic	Feasibility Study Prototype	
Building type	Primary school	Secondary school
Size (ft^2)	82,500	227,700
Number of floors	2	3
Number of students	650	1,200
Space types	Art classroom, cafeteria, classroom, corridor, multipurpose room, kitchen, lobby, mechanical room, media center, office, restrooms	Art classroom, auditorium, cafeteria, classroom, corridor, gyms, kitchen, library, lobby, mechanical room, office, restrooms
Wall construction	Steel-framed	Steel-framed
Roof construction	Insulation entirely above deck	Insulation entirely above deck
Window area	35% window to gross wall area	35% window to gross wall area
Percent conditioned	Fully heated and cooled	Fully heated and cooled
HVAC system types	Zone-level ground source heat pump (GSHP) in classroom wings and common areas; packaged single zone GSHPs in gym, kitchen, cafeteria; dedicated outside air system with CO_2 based flow for ventilation air.	Zone-level ground source heat pump (GSHP) in classroom wings and common areas; packaged single zone GSHPs in gyms, kitchen, cafeteria, auditorium; dedicated outside air system with CO_2 based flow for ventilation air.

Creating Low-Energy Models Based on the Prototypical Buildings

This study is a best-in-class look at energy efficiency for schools. The technologies and strategies were based on previous work for 50% energy reduction in schools (ASHRAE 2012) as well as current case studies of very low-energy and ZEB schools (NBI, 2016). Efficiencies and equipment parameters reflect currently available approaches and technologies, including the following:

- Classroom orientation for a long east-west axis
- Enhanced building opaque envelope insulation, window glazing, and overhangs
- Enhanced air barrier, targeting a tested infiltration rate of 0.25 CFM/ft^2 at 75 Pascal (Pa)
- Reduced lighting power density based on LED technology, targeting a 0.5 W/ft^2 whole-building lighting power density (LPD)
- Use of vacancy sensors to minimize lighting during non-occupied periods
- Enhanced controls for common areas and exterior lighting based on LED lighting
- Daylighting in perimeter zones of classrooms, resource rooms, cafeterias, gyms, and multipurpose rooms
- Exterior lighting power density reductions

- Plug load reductions and improved controls for shedding loads during unoccupied periods
- High-performance commercial kitchen equipment and ventilation
- Demand-controlled ventilation and energy recovery ventilators using dedicated outside air systems with climate zone specific heat and energy recovery devices from exhaust air
- High-efficiency heating, ventilating, and air-conditioning equipment including system configurations based on ground coupled heat pump loops
- Variable speed ground loop pumping, with 19.7 EER cooling/3.7 COP heating (variable speed heat pumps)
- High-efficiency service water heating equipment and distribution systems.

Envelope

Based on the input from the technical advisory team, it was assumed that these facilities are typically constructed with steel-framed exterior walls, built-up roofs, and slab-on-grade floors. Built-up, rigid insulation above a structural metal deck roof was used in the ZEB models. The layers consisted of the roof membrane, roof insulation, and metal decking. The R-values varied based on the applicable climate zone. Added insulation was continuous and uninterrupted by framing. The exterior wall and roof R-values are shown in Table 2.

Table 2. Exterior Wall and Roof Constructions

Climate Zone	Roof Insulation R-Value, Nominal (h·ft²·°F/Btu)	Wall Insulation R-Value, Nominal (h·ft²·°F/Btu)
1	R-20.0 c.i.	R-13.0 + R-7.5 c.i.[a]
2	R-25.0 c.i.	R-13.0 + R-7.5 c.i.
3	R-25.0 c.i.	R-13.0 + R-7.5 c.i.
4	R-30.0 c.i.	R-13.0 + R-7.5 c.i.
5	R-30.0 c.i.	R-13.0 + R-15.6 c.i.
6	R-30.0 c.i.	R-13.0 + R-18.8 c.i.
7	R-35.0 c.i.	R-13.0 + R-18.8 c.i.
8	R-35.0 c.i.	R-13.0 + R-18.8 c.i.

[a]continuous insulation

Fenestration

Building fenestration includes all envelope penetrations used for ingress and egress or lighting such as windows, doors, and skylights. This feasibility study specifies window properties as window systems and not as window frame and glass separately. Thus, window frames were not explicitly modeled and only one window was modeled per exterior surface. This reduced the complexity and increased the speed of the simulations. Most of the building (except the restrooms, gym, and auditorium [secondary school only]) had an overall fraction of fenestration to gross wall area of 35%; individual fenestration objects were distributed evenly on applicable exterior surfaces. The U-factors and solar heat gain coefficients (SHGCs) applied to the fenestration objects were whole-assembly values and included framing effects. The U-values, SHGCs, and visible light transmittance (VLT) of the windows that were used in both the primary and secondary school zero energy models are shown in Table 3.

Table 3. Window Constructions

Climate Zone	U-Factor (Btu/h·ft²·°F)	SHGC	VLT
1 (A,B)	1.22	0.25	0.280
2 (A,B)	1.22	0.25	0.280
3 (A,B)	0.57	0.25	0.280
3 (C)	1.22	0.25	0.280
4 (A,B,C)	0.57	0.26	0.290
5 (A,B)	0.57	0.26	0.290
6 (A,B)	0.57	0.35	0.390
7	0.57	0.40	0.440
8	0.46	0.40	0.440

Infiltration

Infiltration rates were calculated using an infiltration rate factor and total exterior wall areas for each zone. The calculated infiltration rate factor was assumed to be constant throughout the year. This is a good assumption for annual energy performance, but caution should be used in evaluating hour-by-hour loads with this method. To determine the infiltration rate factor, the building was assumed to be constructed such that at a pressure differential of 75 Pa, the infiltration rate was equivalent to 0.25 CFM/ft² of external wall area. Because a large amount of outside air was brought into the building by the HVAC system, the calculated zone infiltration rates were modified via an infiltration schedule that was set to 0.5 during HVAC system operation. In other words, the total infiltration was cut by half during occupied hours.

Lighting

The lighting power densities (LPDs) used in the ZEB K-12 models are listed in Table 4. Achieving 0.5 W/ft^2 in whole-building LPD typically requires 100% LED designs and careful control design, and is currently being realized in ZEB K-12 examples. Daylight modeling was performed using the EnergyPlus daylighting capabilities. The strategy was to daylight the half of the classroom that was near the view windows, while the other half would be illuminated by the lights. As lower LPDs are achievable, the need for aggressive daylighting design strategies with light shelves, clerestories, or skylights is reduced. The target daylight illuminance was approximately 40 foot-candles and the lighting controls were modeled as continuous dimming from 0%–100%, using a closed-loop control scheme.

For exterior LED lighting, the primary school was modeled with 2,219 W of exterior lighting and the secondary school at18,980 W. In both models, the lights were controlled by an astronomical clock that turned the lights on when the sun set and off when the sun rose. The models also employed an energy-saving feature that reduced lighting to 25% of typical output from midnight to 6 a.m. Note that the secondary schools have significantly more exterior lighting because of the much larger parking lots to accommodate students.

Table 4. Lighting Power Densities by Space Type

Space Type	Feasibility Study LPD (W/ft²)	90.1-2013 LPD (W/ft²)
Auditorium	0.50	0.63
Art room	0.45	1.24
Cafeteria	0.50	0.65
Classroom	0.45	1.24
Corridor	0.40	0.66
Gym/multipurpose room	0.75	1.20
Kitchen	0.45	1.21
Library/media center	0.45	1.06
Lobby	0.50	0.90
Mechanical	0.40	0.42
Office	0.50	0.98
Restroom	0.50	0.98
Whole building	0.50	0.87

Plug and Process Loads

The electric plug and process loads in this feasibility study's energy models represent a space-by-space 40% reduction over a typical school (except for the kitchens). In order to apply the reduction, first a baseline must be set. The baseline for this technical feasibility study was the plug and process loads from the DOE commercial prototype buildings models (DOE 2014), with a few modifications based on the feedback from the technical advisory team. This 40% reduction in plug load density was determined by calculating the plug load density of a typical energy-efficient school and comparing it to a typical school. Moreover, this number is a common plug load reduction target for buildings aiming for zero energy (Fischer et.al. 2006).The calculation for the percent plug load reduction follows:

- *Instructional computer loads*: Assuming 3.8 students per computer (Fox 2005), the primary school with 650 students has about 171 student computers and the secondary school with 1,200 students has approximately 316 computers. Assuming 30-W laptops or mini-desktops and 18-W LED backlit flat panel monitors, the total instructional computer load is 8,208 W for the primary school and 15,168 W for the secondary school.
- *Staff computer loads*: Assuming 20 students per staff member results in 32 (rounded down from 32.5) staff members for the primary school and 60 staff members for the secondary school. For the same 30-W computer and 18-W monitor as the instructional computers, the assumption results in a staff computer load of 1,536 W for the primary school and 2,880 W for the secondary school.
- *Server loads*: An energy-efficient server uses about 48 W per connected computer with a power usage effectiveness of 1.2, resulting in 58 W per computer. For the 171 instructional computers and 32 staff computers in the primary school, this resulted in a server load of 11,774 W. For the 316 student computers and 60 staff computers in the secondary school, this resulted in a server load of 21,808 W 24 hours per day.

- *Staff miscellaneous loads*: It was recognized that the staff would have additional plug-in equipment in the school, so researchers made the following assumptions, which resulted in a total staff miscellaneous load of 34,019 W for the primary school and 63,786 W for the secondary school:
    - Each classroom has an energy-efficient 80-W television and a 40-W multi media player.
    - Two staff members share a 125-W refrigerator and a 1,000-W microwave.
    - Four staff members share a 1,500-W space heater. Note that while an energy efficient building should have excellent comfort, allowances need to be made to ensure that plug load targets are not underestimated.
    - Ten staff members share a 5.6-W per gallon 10-gallon fish tank (56 W).
- *Office loads*: An additional 85 W per staff member was included for items such as task lights, phones, printers, and other office equipment. This resulted in an office load for the primary school of 2,720 W and 5,100 W for the secondary school.
- *Total*: The total plug load for the 73,962 ft² primary school is 58,257 W, or 0.8 W/ft². The total plug load for the 210,892 ft² secondary school is 108,742 W, or 0.5 W/ft².

Repeating the same calculation for a typical school with a 150-W computer, a 70-W monitor, a 65-W server with a 1.9 power usage effectiveness (123 W per computer), and 107 W per staff member for office loads results in 107,072 W (1.4 W/ft²) for the primary school and 199,174 W (0.9 W/ft²) for the secondary school. For the food processing loads, the *50% Advanded Energy Design Guide for K-12 Schools* provided best-in-class K-12 school kitchens. Using these numbers for the feasibility study resulted in an overall 40% reduction in plug loads.

Heating, Ventilating, and Air Conditioning

Although many types of HVAC systems could be used in K-12 schools, this study uses a water-to-air ground source heat pump (GSHP) system with a dedicated outside air system (DOAS) for ventilation. Many of the K-12 ZEB case studies reviewed included this system type mainly due to the simplicity of maintenance and operations. Both prototype models were similarly zoned—a central area consisting of common spaces connected the classroom wings. Outside air was controlled to each zone by the occupant schedule to mimic CO_2 controls. The specialty spaces with unusual loads (auditorium [secondary school only], cafeteria, kitchen, gym) were served by packaged single zone GSHP systems that provided both ventilation and space conditioning. The classroom wings and most of the central common spaces were served by zone-level GSHPs. The specialty spaces (auditorium, cafeteria, kitchen, and gym) were served by PSZ heat pump HVAC systems. These systems represent best-in-class efficiency, are connected to the same ground loop as the zone-level heat pumps, and include differential enthalpy-controlled economizers. Economizers were not used in climate zones 1A, 2A, 3A, and 4A as it is not required by Standard 90.1-2013 (ASHRAE 2013b) and the zero energy target could be achieved without them. The PSZ units added energy recovery ventilators (ERVs) in all climate zones with a 75% sensible effectiveness, 69% latent effectiveness, and a 0.5-in. water column pressure drop.

Each zone served by the DOAS (classrooms, corridors, library/media center, lobbies, mechanical rooms, offices, and restrooms) were also modeled with a two-speed GSHP. The primary school had 22 separate heat pumps; the secondary school had 42. The heat pumps represented best-in-class efficiency levels, with a cooling EER of 19.7, a heating COP of 3.7, and 50% efficient constant speed fans that cycled with the load (0.25-in. water column pressure drop). The heat pumps rejected energy to a single loop that was served by a 90% efficient variable speed pump. The boiler on the loop was a 90% efficient natural gas-fired condensing boiler.

In climates where building heating and cooling loads are severely imbalanced, the bore field ground temperature can drift away from its equilibrium point over a period of many years, hindering the ability of the system to operate at its designed efficiency. Many steps can be taken during system design to mitigate long-term temperature drift and/or its impact on the operation of the GSHP system, including upsizing the bore field or coupling a heating or cooling source to the GSHP loop. Given the large number of practical design solutions available, and the successful deployment of GSHP systems in extreme cold climates (Meyer et al. 2011), use of GSHP systems was deemed appropriate for evaluating the ability to achieve zero energy in the school environment.

Service Water Heating

Both the primary school and secondary school models had a 90% efficient natural gas-fired storage tank water heater and the secondary school had a 90% efficient variable speed circulation pump with 13.1 ft of head. The primary school had no circulation pump. The primary school model had water use in the restrooms and kitchen; the restrooms had a peak flow rate of 0.942 gal/min and the kitchen had a peak flow rate of 1.67 gal/min. The secondary school had water use in the restrooms, kitchen, and gym (showers); the restrooms had a peak flow rate of 0.870 gal/min, the kitchen had a peak flow rate of 2.217 gal/min, and the gym (showers) had a peak flow rate of 3.158 gal/min. (See Deru et al. 2011 for more information on how these values were determined.)

Energy Targets Results

Careful goal setting is required to design and construct high-performance buildings. As a best practice, setting an absolute whole-building energy target is critical. One result of the feasibility study is energy targets for energy consumption in K-12 schools such that on-site renewable energy can meet the load. The following approach was used:

1. Started with the primary and secondary school DOE prototype building models (DOE 2014)
2. Updated the models according to the overview strategies in this feasibility study
3. Simulated the zero energy models across a set of 15 climate zones that fully represent the variations in the seven DOE continental U.S. climate zones
4. Ensured that the results of the energy modeling analysis are energy targets that will meet or exceed the goal of zero energy.

The energy targets in this feasibility study are applicable to most K-12 schools with typical programs and use profiles. Table 5 summarizes the demand side site and source energy use intensity targets to meet or exceed zero energy.

Table 5. Energy Use Intensity Targets to Meet or Exceed Zero Energy

Climate Zone	Representative City	Primary School		Secondary School	
		Site Energy (kBtu/ft²·yr)	Source Energy (kBtu/ft²·yr)	Site Energy (kBtu/ft²·yr)	Source Energy (kBtu/ft²·yr)
1A	Miami, FL	25.9	76.4	23.1	68.5
2A	Houston, TX	24.3	71.1	21.7	63.5
2B	Phoenix, AZ	24.7	72.5	21.9	64.3
3A	Memphis, TN	23.8	69.0	21.2	61.6
3B	El Paso, TX	23.4	67.8	20.7	60.2
3C	San Francisco, CA	21.6	61.9	19.0	54.3
4A	Baltimore, MD	23.5	67.6	20.9	60.1
4B	Albuquerque, NM	23.1	66.6	20.4	58.8
4C	Salem, OR	22.4	64.2	19.7	56.4
5A	Chicago, IL	24.3	69.9	21.6	62.2
5B	Boise, ID	23.2	66.7	20.4	58.4
6A	Burlington, VT	24.5	70.1	21.6	61.9
6B	Helena, MT	23.5	66.9	20.5	58.4
7	Duluth, MN	25.9	74.1	22.8	65.1
8	Fairbanks, AL	28.7	82.5	25.0	71.5

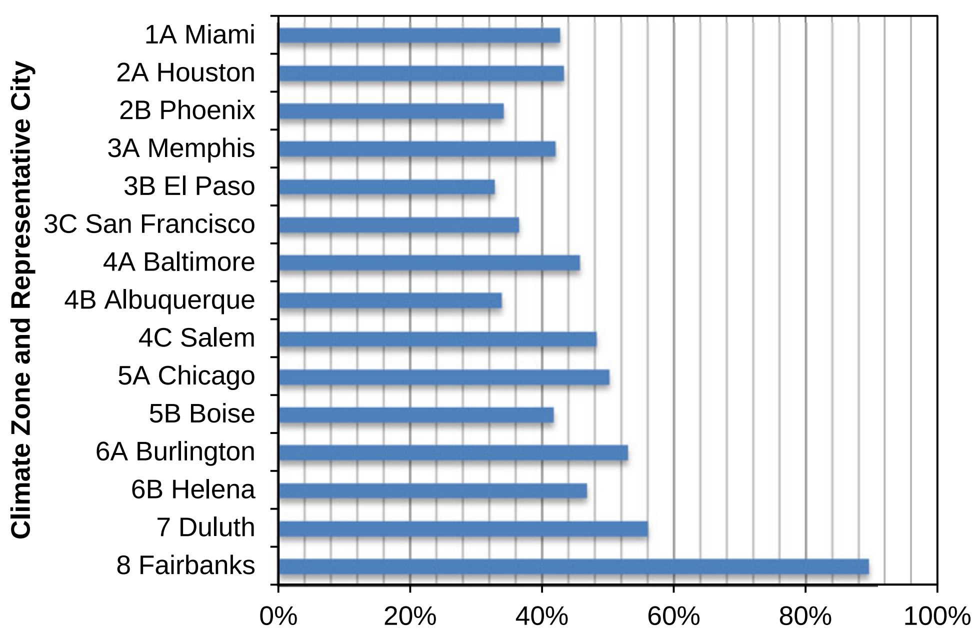

Figure 2. Roof photovoltaic coverage percentage to achieve zero energy—primary school

The energy targets in this study were developed to simplify the process of setting whole-building absolute energy use targets. Although the modeling provides a path to achieve the EUI, many tradeoffs and technologies can be used. These strategies will change as technology improves. Specifying whole-building absolute energy-use targets gives a design team the freedom to reach the performance goal with an approach that best fits the project's overall goals and constraints including those not related to energy performance. It is possible to specify an absolute energy target using the energy target tables in this feasibility study and then focusing analysis efforts on achieving industry best practice energy performance rather than trying to define a reference point against which to measure performance (Leach et al. 2012).

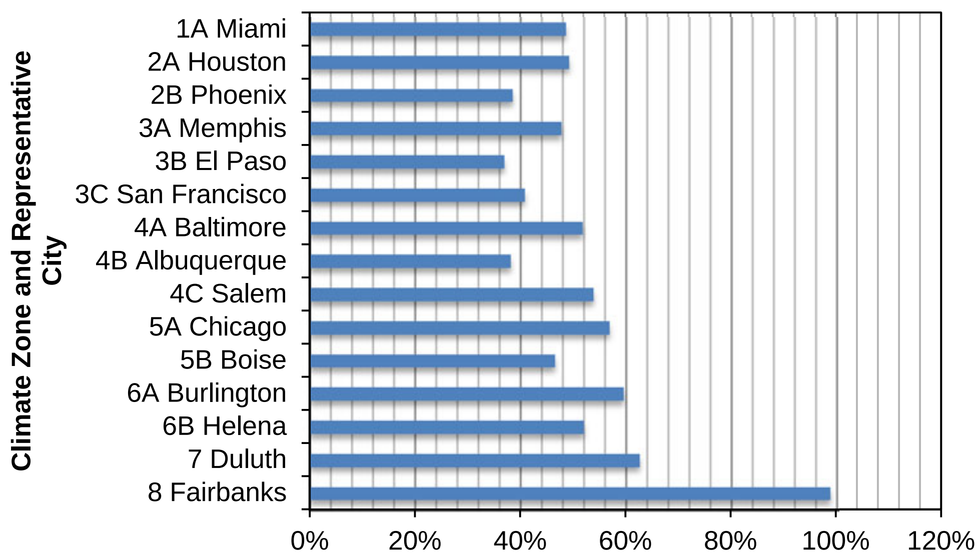

Figure 3. Roof photovoltaic coverage percentage to achieve zero energy—secondary school

Conclusion

Once the EUI targets were estimated, energy consumption was matched with the solar potential for each climate to determine the feasibility of achieving the zero energy goal. The variable was the amount of roof area to be covered by 18% efficient solar PV panels. Based on examining the roof areas of school buildings, approximately 50% of the roof area is available for PV. This is due to ventilation fans, skylights, shading from parapets, rooftop HVAC equipment, plumbing vents, and other obstructions. To maintain consistency in the requirements of ASHRAE 90.1 and the variability of solar across the climate zones, there is fluctuation in the percentages. In other words, energy efficiency was not reduced even if sunnier climates could potentially make buildings less efficient. Efficiency drove the analysis, with PV meeting the load unless the 50% limit was exceeded. If it was exceeded, additional efficiency was uniformly applied across the climate zones. The end result was that temperate climates require a smaller percentage of solar panel coverage than very hot or very cold climates.

The analysis shows target energy use intensities that are independent of the amount of solar installed on the building, but indicates that if solar is placed on these buildings in the amounts specified, the DOE ZEB definition can be met. In climate zones 1 through 6, zero energy can be achieved with less than 50% of the rooftop dedicated to solar panels with costpractical energy-efficiency strategies. In the colder climates (zones 7 and 8), additional space is needed due to larger heating loads as well as diminished solar availability. Figures 2 and 3 show the roof PV coverage percentage required to achieve zero energy in different climate zones.

It is technically possible for new K-12 construction projects to achieve zero energy in all climate zones across the continental United States. The EUI for constructing a zero energy school should be less than 26 kBtu/ft^2/yr for primary schools and less than 22 kBtu/ft^2/yr for secondary schools. Temperate climates require a smaller percentage of solar panel coverage than very hot or very cold climates. Although not ideal, the extremely cold climates (climate zone 8) required that solar panels be installed on site, but outside the building footprint.

Finally, the feasibility study documented models that can be used as a starting point for schools analysis and provide a pathway for a solution for zero energy schools. These starting points, along with the target energy use intensities, can be used by design teams and school boards for moving K-12 schools toward zero-energy.

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