Zero Energy Schools – Beyond Platinum

By Paul C. Hutton

One of the fastest growing trends in school design is Net Zero Energy Schools. There are now at least a dozen or more schools completed or in construction that have achieved, or have committed to, this incredible level of energy efficiency.

Sangre de Cristo PK-12
Photo courtesy of Hutton Architecture Studio

Introduction

One of the fastest growing trends in school design is Net Zero Energy Schools. There are now at least a dozen or more schools completed or in construction that have achieved, or have committed to, this incredible level of energy efficiency. In this article we'll examine this trend and take a brief look at some of the exemplary projects that attempt it.

Definitions of Net Zero Energy Building

There is no universally accepted definition for Net Zero Energy Building. Fortunately several credible organizations have developed definitions. Several of the most common variations are quoted below. ASHRAE's definition has the virtue of being succinct and to the point, but there is some value in NREL's more elaborated version. It makes the point that a Net Zero Energy Building should not be a building with typical energy use and a large compliment of renewable energy added on. It clearly advocates for achieving energy efficiency first and renewable energy second. This attitude closely mirrors the approach we adopt within our own practice and that is promoted in this article.

- **American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE):** "A building which, on an annual basis, uses no more energy than is provided by the building's on-site renewable energy sources."
- **National Renewable Energy Laboratory (NREL):** "A residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies."
- **Department of Energy:** "A building that produces and exports at least as much emissions-free renewable energy as it imports and uses from emission-producing energy sources annually."

NREL Zero Energy Building (ZEB) Hierarchy

NREL has developed a further set of definitions in order to evaluate different gradations of compliance with Net Zero Energy goals. They are as follows:

- **ZEB A:** renewable energy sourced within building footprint
- **ZEB B:** renewable energy sourced on-site
- **ZEB C:** renewable energy generated on-site from off-site resources
- **ZEB D:** renewable energy generated off-site

In general, schools pursuing Net Zero Energy will fall into either Category A or B. Which category generally depends on where renewable energy technology is installed, on the roof or on the ground. A few schools, including at least one of our examples, is Category D as it uses off site wind generated by the local utility. And although there is no example included in this article, a school that uses woody biomass could conceivably pursue Category C.

Other Relevant Terminology

There are other terms related to Net Zero Energy Building, but they have subtle differences. A few of them are less stringent than our Net Zero Energy (Grid Neutral, for example), while a few are even more stringent (Zero Carbon, for example). In order to avoid confusion, a few of those will be described here.

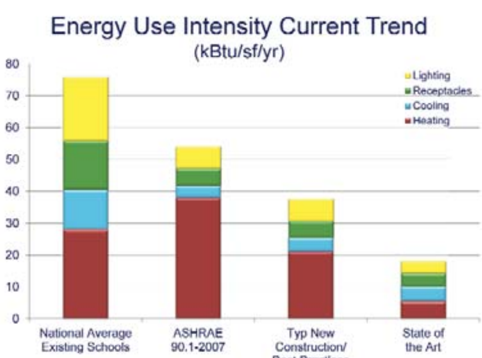
- **Net Zero Site Energy:** A site Zero Energy Building produces at least as much energy as it uses in a year, when accounted for at the site.
- **Net Zero Energy Cost:** In a Cost Zero Energy Building, the amount of money the utility pays the building owner for the energy the building exports to the grid is equal to the amount the owner pays to the utility for the energy services and energy used over the course of the year.

- **Net Zero Energy Emissions:** A building that produces at least as much emissions-free renewable energy as it uses from emissions-producing energy sources.
- **Grid Neutral Site:** A site that produces at least as much electricity as it uses in a year. Building may still use fossil fuel on site.
- **Zero Carbon:** Zero Carbon Buildings produce no net carbon emissions from all energy use over the course of a year. Such a building derives all of its energy from renewable or carbon-free sources.

For the purposes of this article, we will generally adhere to the NREL definition and refer exclusively to Site Energy Use Intensity (EUI) as our energy use metric.

School Energy Use Trend

The average existing school building in the U.S. has an EUI of 76 kBTU/SF/YR, and an average age of 42 years. Current building and energy codes limit new school building EUI to approximately 55. Typical new school construction in the state of Colorado, where there are funding incentives for better performance, averages approximately 38, and integrating all available best practices may result in an EUI of approximately 18. These numbers would vary, of course, depending on climate, occupancy patterns, and other variables.



Graphic 1

Why Schools are good candidates for Zero Energy

Schools are good candidates for Net Zero Energy because they already use less energy than most commercial building types. Schools use only 33% the energy of hospitals per square foot and 51% the energy of office buildings per square foot. Collectively, schools use only 17% of total non-residential building energy. Schools use less energy than other building types due a combination of factors:

- Less use during the summer
- Extensive vacation periods when building systems are in unoccupied mode
- Shorter period of use in the typical day
- Minimal process loads

In addition to having less energy use intensity, schools have another advantage in the race towards Net Zero Energy. They are typically more receptive to the application of renewable energy because they have larger sites (except in a few denser urban conditions), they have large roof areas relative to their gross floor area, and they are owned by entities with a long term investment horizon.

Relationship of Net Zero Energy Schools to LEED

Three LEED credits deal with the energy use of a building. One LEED credit focuses on improving energy performance over ASHRAE 90.1, giving more points for each percentage threshold over the baseline model, based on cost, up to a reduction of 48%. A Zero Energy School would try to surpass this goal and minimize energy use so that the balance of energy needs can be supplied with renewable technologies. Another LEED credit focuses on on-site renewable power to offset building costs, awarding points for each percentage threshold in renewable energy cost savings, up to a 13% reduction. A Zero Energy School in the ZEB A or B category may have a 100% reduction in energy costs. The final LEED energy credit is for purchasing off-site renewable energy in order to offset building energy use. Only a ZEB D category would be able to earn this credit – since a ZEB A or B would have no energy use to offset.

Studies regarding the energy efficiency of LEED rated buildings are unfortunately a bit inconclusive, and there is some debate about their real world energy performance. A Net Zero Energy School would not necessarily be LEED rated, but its energy performance would exceed the threshold needed even for Platinum.

The LEED system has no mechanism by which to recognize Net Zero Energy performance, but the National Renewable Energy Laboratory maintains a database on all verified Zero Energy building in the U.S. Based on the current trend, it is entirely possible there will be more Net Zero Schools than LEED Platinum schools in a year or two.

Relationship of Net Zero Energy Schools to the 2030 Challenge

As an advocate of the 2030 Challenge, adopted by the American Institute of Architects and hundreds of other municipalities and organizations, I am glad to witness the Net Zero Energy Schools trend. The ultimate goal of the 2030 Challenge is, of course, Net Zero Energy for all buildings of every type, new and existing. But it allows that to occur as late as the year 2030. And even in 2030, the challenge allows up to 20% of a building's energy use to be offset by off-site renewables, a ZEB D condition which many Net Zero Schools have already surpassed by supplying all their energy needs on-site.

The design and construction of Net Zero Energy Schools now is fortunate, for they allow designers to test strategies and technologies for application to a wider range of building types. Because some building types are inherently more energy intensive and others are inherently less energy intensive, achieving the 2030 Challenge may result in an average condition of Net Zero Energy. In this condition, a few buildings may be "allowed" to exceed Net Zero Energy use, while other building types may be "required" to produce more energy than they consume. Schools may very well fall into the category of Energy Producers in the 2030 future.

Fundamental Design Strategies to achieve Zero Energy

In order for a school building to achieve Zero Energy, without over-reliance on renewable energy, it must get all the basics of sustainable design right. The checklist we use consists of the following elements. Every one of these design components has the capability of reducing building energy use by 10% or more. Conversely, if the design team ignores any one of these, it may have to overcompensate with excessive design or cost on one or more of the others. Each of the main points is followed by a brief explanation.

- **Orientation/Massing:** While not every new building can be optimally oriented, we have found that it is almost always possible to orient the main axis of the building within 15 degrees of east-west. Doing so results in energy savings by reducing heat load on the building in the summer, and by facilitating daylight harvesting. Whenever possible we seek to obtain a reasonable ratio of surface area to volume, without denying daylight access to learning spaces. We also seek to utilize two and even three story construction in lieu of single floor designs. Combining optimum orientation and massing can easily yield 15% energy savings.

- **Envelope:** Current Building codes require continuous insulation, which is a significant improvement over previous codes without that provision. Our goal for exterior walls is an effective R-value of 25. We also routinely exceed building code required roof insulation, using R-30 minimum instead of R-20. With both wall and roof insulation, it is still important to understand there is a definite point of diminishing returns, beyond which increasing insulation may be a poor investment compared to other possible energy conserving measures. Providing a well designed, constructed, and insulated envelope can yield energy savings of 15% over minimal code compliant construction.

- **Daylighting:** Because electric lighting can consume as much as 20% of total site energy use, it is important to do everything possible to minimize that. The best place to start is by substituting free daylight for costly electric light during the day. As the school schedule coincides well with daylight hours (more so than office building or hospital schedules), it is easily accomplished. We routinely plan to reduce electric lighting energy use by at least half through daylight harvesting.

- **HVAC and controls:** The combination of space heating, ventilation, and air conditioning consume more energy than any other single component in a school building. Design and integration of these systems is therefore critical to improved energy performance. Air delivery through displacement ventilation has the potential to reduce energy use slightly while greatly improving both indoor air quality and acoustics. Geo-exchange systems have become quite popular and in fact are used in all but two of the example projects here. They can reduce site energy use substantially. Energy recovery, natural ventilation, and radiant heating are HVAC strategies rapidly growing in popularity and all have the potential to reduce energy use. The most important issues in HVAC design are to integrate the system selection with basic building design and to align the systems with owner expectations and maintenance capabilities.

- **Electrical lighting and controls:** The first step to reduce energy use related to electric lighting is to minimize lighting power density (LPD) while still maintaining comfortable interior lighting. This is done through careful fixture selection and placement. If this is achieved, energy use is limited even without sophisticated controls or occupant acceptance. Automated controls that turn off electric lights such as occupancy/vacancy sensors, timed sweeps, and dimming in response to daylighting all can be used to reduce the time during which electric lights are turned on, further reducing energy use for lighting.

Hayes Freedom High School
Photo credit: Lincoln Barbour

- **Occupant Behavior and Plug Loads:** School designers and administrators are well aware of the challenges posed by occupant behavior. Nowhere is this more evident than in the effort to control potentially excessive and wasteful plug loads. A recent study by one of our client school districts revealed one refrigerator per every three classrooms. These appliances had been brought in by staff after the building was competed and were never factored into our energy models. Another example of wasteful plug loads is the inclusion of incandescent lamps for "mood lighting." And finally, neglecting to turn off computers and monitors can substantially increase energy use in a building.

- **Renewable energy:** Renewable energy sources on a school building or site are necessary in order to achieve Net Zero Energy, but the selection should be made in consideration of other building systems, local climate, and financial constraints such as rebate availability. Installing PV panels in very cloudy climates, or wind turbines in poor wind energy areas, is simply not good decision making and in the end will only harm the movement toward Net Zero Energy Schools. One other form of renewable energy popular in sunny climates is pre-heated ventilation air. This strategy utilizes wall mounted panels on the east and south to deliver pre-heated air to the HVAC system, or exhaust it directly in the cooling season.

Search for Examples of Net Zero Schools

When I began the research for this investigation more than a year ago, I had begun to hear about Zero Energy Schools, and conducted a Google search. The results of that search, as well as connections through various architectural colleagues, form the basis for the schools used as examples in this article. I am sure that I have overlooked other worthy examples, and I know for a certainty that there are design teams with conscientious clients across the United States, who are now developing a whole new group of Zero Energy Schools. It is not my intention to imply the projects included in this article are the best examples of Net Zero Energy Schools, but they serve admirably to illustrate the variety and scope of this trend.

Example Projects

The projects selected for illustration in this article fall into two broad categories. First are those that have actually achieved, or will soon achieve, Net Zero Energy through installation of renewable energy technology. Second are those that have been designed according to basic energy efficiency principles and have had renewable energy technology designed and sized, but are still awaiting funding for those renewable sources. There is actually a third category populated by only one project. That is the Greensburg, Kansas, project, Kiowa County K-12 School, which utilizes off-site renewable energy from the local utility (ZEB D). The projects, listed in chronological order, include the following:

Prairie Hill Learning Center
Location: Roca, Nebraska
Architect: The Architectural Partnership
Energy Consultant: M.E. Group / Dixon Power

Putney School Field House
Location: Putney, Vermont
Architect: Maclay Architects
Energy Consultant: Kohler and Lewis

Marin Country Day School – Learning Resources Center
Location: Corte Madera, California
Architect: EHDD Architecture
Energy Consultant: Stantec Consulting

Hayes Freedom High School
Location: Camas, Washington
Architect: Mahlum Architects
Energy Consultant: Interface

Evie Garrett Dennis PK-12 School
Location: Denver, Colorado
Architect: DLR Group
Energy Consultant: M.E. Group

Centennial PK-12 School
Location: Centennial, Colorado
Architect: SlaterPaull
Energy Consultant: M.E. Group

Richardsville Elementary School
Location: Bowling Green, Kentucky
Architect: Sherman Carter Barnhart
Energy Consultant: CMTA Inc.

Kiowa County K-12 School
Location: Greensburg, Kansas
Architect: BNIM Architects, ATS&R Architects
Energy Consultant: BGR Consulting Engineers, NREL

Sangre de Cristo PK-12 School
Location: Mosca, Colorado
Architect: klipp, Hutton Architecture Studio
Energy Consultant: ME Group

Lady Bird Johnson Middle School
Location: Irving, Texas
Architect: Corgan Associates, Inc.
Energy Consultant: Image Engineering Group, Ltd.

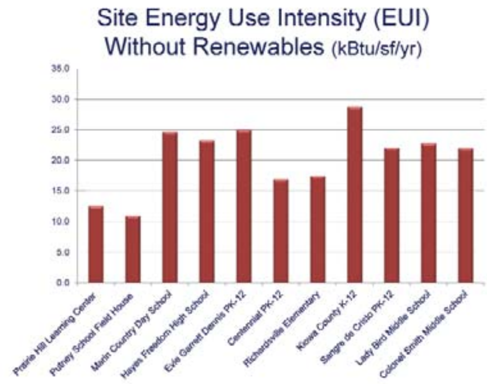
Colonel Smith Middle School
Location: Fort Huachuca, Arizona
Architect: Emc2 Group Architects Planners, PC
Energy Consultant: CSMS Design Team

Area of Example Schools

The size of school buildings attempting to achieve Net Zero Energy has steadily increased in the last few years. The blue line in Graphic 3 illustrates the total area in gross square feet of each school, plotted in chronological order. Initially, only very small school buildings attempted Net Zero Energy, but now there are full size elementary and middle schools pursuing the goal.

Energy Use Intensity of Example Schools

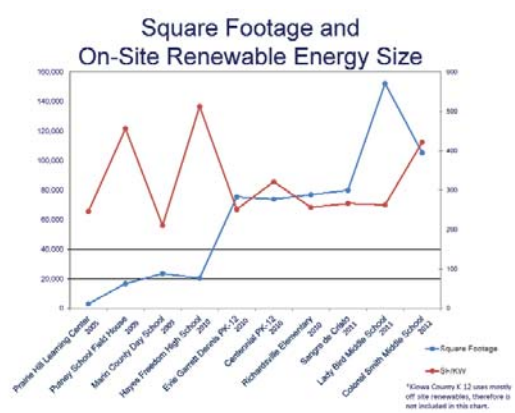
The example schools all have Site Energy Use Intensity well below national averages and code maximums. Graphic 2 illustrates all the example schools EUI, still plotted in chronological order. The energy data for this chart excludes renewable energy. This is done in order to gauge the inherent energy efficiency of each building design, and eliminate the results being skewed by different building owner's ability, or inability, to fund renewable energy technology.



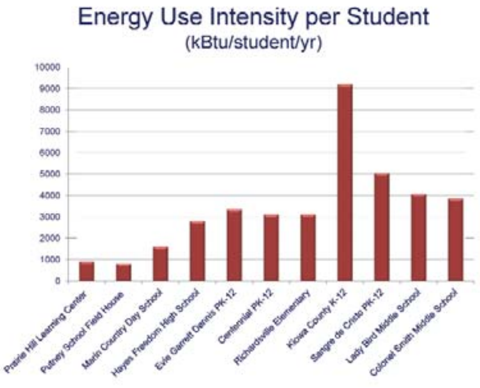
Graphic 2

Building Area Relative to On-Site Renewable Energy

Graphic 3 looks at Energy Use Intensity in a different manner altogether. It focuses on how much on-site renewable energy is required to maintain the building. Renewable energy sources, whether wind or photovoltaic, have a rated capacity. Using the rated capacity, the chart displays how many square feet are supported by each kW of renewable. More square feet supported per kW implies higher building efficiency.



Graphic 3



Graphic 4

Student Enrollment Relative to Energy Use

The example schools have widely varying student capacities, or enrollment. The area of building per student (a basic metric used to evaluate building efficiency) varies from a low of 75 SF/student to a high of 320 SF/student. While there are valid reasons for schools to have more or less area per student (see text below), designers and owners have some responsibility to use all resources, financial as well as energy, responsibly. When a school building has many more square feet per student, its energy use per student will rise, even with sustainable design strategies.

Rural Schools and Energy Consumption

We are fortunate to have within our example schools group several in rural locations. These schools range in size from the 3,700 s.f. Prairie Hill Learning Center to the 132,000 s.f. Kiowa County PK-12 School. Rural schools can be every bit as energy efficient as their suburban and urban counterparts. They may even have a Net Zero Energy advantage in that their large sites allow renewable energy technology deployment. In fact, two of our rural schools planned ground mounted photovoltaic installation, something that would be impossible in an urban setting.

Rural schools, however, encounter two trends that may adversely affect energy efficiency. Because they frequently serve a dispersed population of small size, it is more common for them to gather more grade levels in one building. Four of the rural schools in our sample group provide K-12 (or PK-12) under one roof. This type of building configuration is inherently less efficient than single age group schools, such as elementary, middle, or high school.

Rural schools also need to serve as community centers. They must therefore provide facilities that are not available nearby. Such facilities may be gymnasiums with large amounts of seating for assemblies, libraries, meeting spaces, and computer labs.

The combination of multi-age facilities and community amenities results in rural schools often having significantly more area per student than other schools. Whereas the average new school built in the U.S. has 141 s.f. per student, rural schools frequently have up to 200 s.f. per student, and occasionally even more. Graphic 4 illustrates the impact of rural school size on energy use intensity, when measured in kBTU/student/year. The point here is not to criticize rural schools for the almost inevitable use of more energy per student. Rather, it is to illustrate the challenge faced by rural schools and to demonstrate their need for realistic budgets in both construction and operating costs.

Conclusions

Given the geographic, climatic, size, and programmatic variation among the example schools, a wide diversity of approaches to achieving Net Zero Energy would be expected. What is most surprising about this group is the high level of consistency of approach. One strategy is used by all the projects – daylighting. All projects but one use optimized orientation and photovoltaic panels, and all but two projects use a geo-exchange system. This remarkable consistency may be a clue as to how to approach Net Zero Energy Schools in the future, but only time will tell if this trend persists or other energy conserving strategies emerge and dominate.

The Future of Zero Energy Schools

The projects included here as examples suggest there is currently a practical limit to site EUI for school buildings using off the shelf technology and without exorbitant budgets. Depending on climate and other variables, that limit is estimated to lie between 15 and 25 kBTU/SF/YR. The gap between that range and Zero Net Energy must still be closed with renewable energy technology. According to our example projects, the preferred renewable technology is photovoltaic. Wind energy appears only occasionally and usually in wind power areas 3 and better. Occasionally wind turbines are included in areas with less wind potential, but they seem to be used more as learning opportunities than as actual energy production devices.

It may be hoped that progress will continue in photovoltaic panel efficiency and cost effectiveness, as well as wind turbine efficiency. PV efficiencies have doubled over the last 20 years. If renewable energy technology continues to advance, Net Zero Energy Schools will be more affordable than ever. Without that, we will have to hope for continued refinement in other areas such as envelope insulation, HVAC systems, and lighting design. More likely is a combination of all the above, in which we integrate our efforts and incorporate the most appropriate strategies and technologies into a synergistic building that supports the most fundamental mission of our school buildings – to facilitate learning. ■

Paul Hutton, AIA, LEED AP, is the founding Principal of Hutton Architecture Studio, in Denver, Colorado. From its origin more than 20 years ago the firm has been dedicated to creating high performance, daylighted, environments for learning. Paul has conducted research, lectured, and written extensively about daylighting schools for nearly 30 years. He developed and still teaches the daylighting and sustainability course at the University of Colorado at Denver College of Architecture. The firm's Aspen Middle School was Colorado's first completed LEED NC Gold school building. Since early 2009, Hutton Architecture Studio has partnered with the Governors Energy Office to administer the state's High Performance Building Program. Paul lives on a sustainable ranch south of Denver, where he is actively pursuing the goal of living at zero net energy. A special thanks to Pete Jefferson at M.E. Group for help providing data on net zero schools.