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TOWARDS NET ZERO ENERGY SCHOOLS - A CASE STUDY APPROACH

Ruthwik Pasunuru
Hamed Hakim

Civil Engineering
365 Weil Hall
University of Florida
Gainesville, FL 32611, USA

Arati Sakhalkar

Mechanical and Aerospace Engineering
231 MAE-A Building
University of Florida
Gainesville, FL 32611, USA

Charles J. Kibert
Ravi Srinivasan

Powell Center for Construction and Environment
University of Florida
Gainesville, FL 32611, USA

ABSTRACT

Net zero energy is a topic that is trending in the construction industry. A part of the net zero movement garnering the most attention is K-12 public school construction. Alachua County's Meadowbrook Elementary School (K-5) is a high performance school which can achieve net zero energy status with some proven and effective practices. In this paper, we discuss and compare the current baseline energy usage of the school since its completion and target opportunities to reduce energy usage. Recommendations based on the ASHRAE Advanced Energy Design Guide (50% Energy Savings) with the help of energy modelling and simulation would close the gap needed to make Florida schools energy self-sufficient. Further renewable energy production will be added by taking advantage of the Florida climate zone. The suggestions reviewed and applied in this paper will establish guidelines for prospective net zero energy schools in general and the Florida based schools in particular.

1 INTRODUCTION

The net zero movement is gaining momentum rapidly as the economic recession moved out of the way. According to the 2007 Energy Independence and Security Act (EISA) all new construction in the United States should be net zero energy by the year 2030. "By bringing more energy efficient technologies to American homes and businesses, we won't just significantly reduce our energy demand, we'll put more money back in the pockets of hardworking Americans" (Obama, 2009). The increasing number of net zero energy schools can reflect the growing demand for super-efficient educational facilities. New Buildings Institute in their current report (NBI, 2014) predicts that there are at least 35 to 50 net zero energy or net zero ready schools in the U.S. and the number is expected to grow in the near future. Schools consume 17% of the total non-residential energy in United States. Several government and non-profit organizations like the U.S. Green Building Council (USGBC), National Renewable energy Laboratory (NREL), Florida Solar Research Center (FSEC), and Department of Energy (DOE) are playing a key role in catalyzing the net zero schools movement across the country. Importing huge amounts of foreign energy sources and plummeting energy prices are some significant factors which contributed to this movement.

A major target of energy efficient schools is to save on high utility expenses. According to the U.S. Department of Energy (DOE), nationally K-12 schools spend over $6 billion each year on the energy. DOE indicates that at least 25% reduction in energy consumption can be achieved through smart energy management. In almost all of the schools, utility costs are the second highest expenditure after employee salaries thus taking high toll on the schools exchequer. In case of energy consumption, upon analyzing 330 elementary and 126 high schools throughout U.S., the average Energy Use Intensity (EUI) is 68 for elementary schools and 80 KBtu/sf-yr for the other one (DOE 2013). This magnitude of energy usage reflects the opportunity to reduce the consumption and increase the efficiency. Therefore, schools should try to reduce the operating costs by adopting energy efficient design strategies and restricting the EUI to less than half of the national average . Thereafter, implementing renewable energy technologies such as photovoltaic (PV) panels, solar thermal systems, and wind turbines can offset the energy usage and lead to a valuable net-zero facility.

Table 1: Net Zero Energy School Projects. (Source: Hutton 2011, Doo Consulting 2013)

Projects	**Climate Zone**	**EUI(KBtu/sf-yr)**
Prairie Hill Learning Center – Earth House	5	12.6
Watkinson School	5	13.8
Marin County Day School	3	24.7
Putney School Field House	5	11
Hayes Freedom High School	4	23.3
Green Valley Ranch	5	25
Richardsville Elementary	4	17.5
Lady Bird Johnson Middle School	3	22.8
Samuel Bright house Elementary	4	29.5
Sangre de Cristo PK-12	7	22.1
P.S. 62 Richmond	5	30
Colonel Smith Middle School	3	15
Evie Garrett Dennis Pre-K - 12 School	5	26
Hood River Middle School	4	27
Locust Trace AgriScience Farm	4	16.2
Average		21.1

Benefits of creating net zero energy schools are numerous. As most renewable technologies are purchased locally, they noticeably contribute to the local economy and thereby creating employment in the neighborhood. Furthermore, schools are significantly spending on utility costs, hence applying efficient operation and maintenance plan will reduce those expenses drastically. This high amount saved can be spent on other purposes like recruiting new teachers and required supplies like books, computers, and other materials. In addition to the saving purposes, the educational role of the school buildings and an appropriate healthy environment for student can further promote the benefits of these schools. Education under healthy conditions keeps mind active and improves the performance of the students in the tests. Many studies suggest that students having proper learning environment enhance their academic skills and score higher on tests compared to others. On the financial aspect, the net zero schools perform very well and profitable in the long run. On contrast to general perception, the initial investment cost of an energy efficient school is almost on par with the conventional school building. But the savings on operations and maintenance are quite impressive. Life cycle cost of the buildings suggests very fast payback periods and more return on investment.

2 TOWARDS A NET ZERO ENERGY SCHOOL IN FLORIDA

2.1 Meadowbrook Elementary School

Meadowbrook Elementary School is a public school located in Gainesville, FL with latitude of 29° 41' 17.48" and longitude of -82° 27' 38.74". This school is one of the 39 public elementary schools in Alachua County and began operation in Fall 2012. The school serves 600 students from preschool to 5th grade and has an overall student-to-teacher ratio of 17:1. The school with the area of 101,476 sf has a flexible design and is adaptable to be expanded to serve 200 students for future needs. The building creates an educational community-based facility that covers wide areas of administration, a dining / multi-purpose space for community events, a media center, and classrooms.

Meadowbrook has the site area of around 20 acres and was built through proper civil, architectural design, and preconstruction planning. The main part of the school includes a 2-story, concrete tilt wall building with bar joists and a mixture of standing seam metal roof and modified bituminous roofing systems. The tilt-up structure provides a fast approach mechanism with a reasonable cost and offers a durable system that is uniform and thus energy efficient. The MEP systems feature two 150 ton chillers outfitted with bi-polar ionization modules that allow for less outside air leading to higher efficiencies. The school demonstrates its commitment to sustainability by designating green strategies that brought highest level (4 Globes) of the Green Globes Certification.

The building is oriented toward East-West axis to guarantee the highest quality of daylight and the least amount of heat gain through use of proper passive design. The roof is constructed of high reflectance, high albedo materials. Tilt-up concrete wall with several internal and external layers of other material coupled with insulation comprise the building envelope and resist the warm and humid dominant local climate. The thermal resistance for the roof was specified as R-20 and as R-12 for the walls. The building benefits from double-pane low-e windows that are properly shaded with outside horizontal sunshade. In case of HVAC systems, the incorporated chilled water equipment is highly efficient and the building conforms to the thermal comfort requirements of ASHRAE 55. The building automation system is designed to control temperature and humidity levels to prevent fungus, mold, or bacteria growth. Meadowbrook Elementary School is taking the advantage of innovative building materials with low embodied energy and less harmful impact. Locally manufactured materials were used in concrete, sheetrock, and masonry. The lighting system used in Meadowbrook School was designed to be compliant with the IESNA lighting Handbook and local lighting control is available in all spaces. The indoor air quality is very important in all educational facilities. The design aims to provide fresh air to each classroom and control humidity, and carbon dioxide levels. Furthermore, using low-emission and non-toxic paints, sealers, coatings, and adhesives in construction phase has provided a healthy environment for students and teachers.

Proper orientation of the building coupled with adequate amount of glazing ensure that daylight can penetrate the building spaces. Most of the classrooms are located along the southern part to maximize the amount of achievable light stream. The white reflective interior walls help to distribute the sunlight inside the larger spaces. A large north-facing entrance provides adequate daylight for dining area. In addition to natural lighting, the school benefits from energy-efficient electric lighting strategies.

2.2 Methodology

To begin with, operating energy data of the Meadowbrook Elementary School has been obtained and calibrated based on the simulated energy model of the school. Simulation of the model is carried out using Trane trace 700 software. Then the calibrated energy model is compared with ASHRAE 90.1-2007 and ASHRAE Advanced Energy Design Guide for K-12 Schools to analyze the performance of the building. The major components which have a significant impact on the energy consumption of the building have been targeted. Further a proposed model was developed with energy efficient strategies implemented in existing net zero energy schools and from design guides. Finally, strategies regarding installation of

Figure 1: Meadowbrook Elementary School.

renewable energy technologies to off-set the consumed energy and thereby achieving a net zero energy school are discussed.

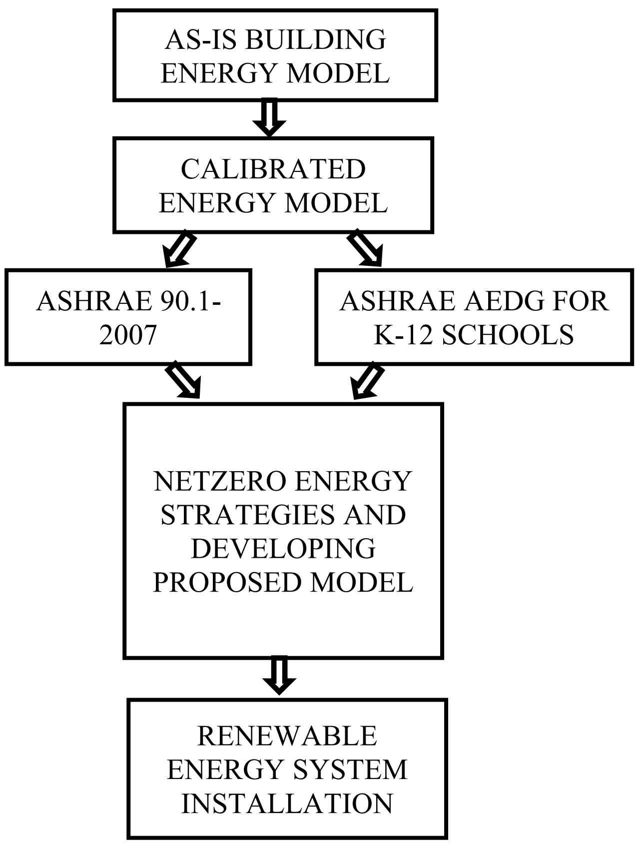

Figure 2. Methodology.

2.2.1 Calibrated Existing Model

First and crucial step in Energy Modelling is to calibrate simulated data to actual energy usage of the building. Energy modelling of the school is carried out using Trane Trace 700 software. Trace 700 is a design and analysis tool that can be used to model buildings and to compare energy consumption and operating costs of different alternatives. The actual building drawings comprising Mechanical, Electrical and Architectural Plans were used as a source of data to model envelope, lighting and HVAC systems. The simulation is carried out to determine the energy consumption of various end use categories. As shown in the figure 3, auxiliary loads which include supply fans, pumps and stand-alone base utilizes consume 34% of the total energy. This is followed by plug loads at 27%, cooling at 19%, lighting at 15% and heating at 22%. The building EUI as determined by the simulation was 27.68 KBtu/sf-yr (292.04 MJ/m2-year). When compared to conventional school buildings, i.e. 68 KBtu/sf-yr or 717.43 MJ/m2-year (DOE 2013) this value is much less. This supports the fact that Meadowbrook elementary school is highly energy efficient.

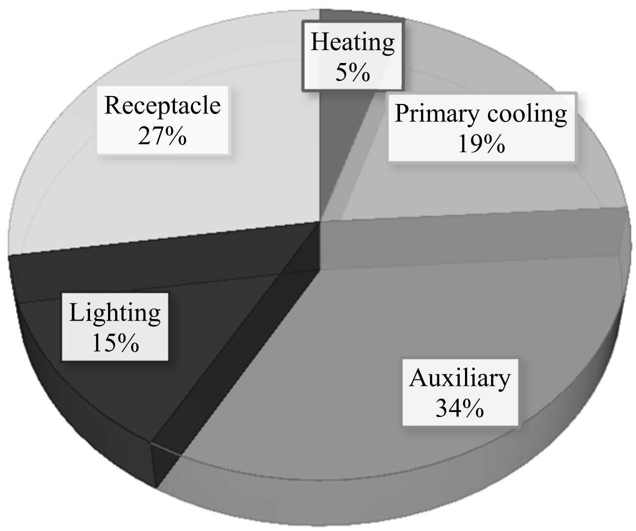

Figure 3: Energy end-use breakdown in the actual (existing) model.

2.2.2 Comparison of EUI of Calibrated Model with AEDG and ASHRAE 90.1-2007

Four major components of a building whose properties have significant impact on energy consumption are targeted. The components include building envelope, Lighting, HVAC system and plug loads. Applying energy efficient strategies for the above mentioned components, based on various design guides, three additional models were developed to compare the performance of the building (refer to Table 3). They are as follows:

1) ASHRAE 90.1- 2007
2) ASHRAE AEDG 50% Savings
3) Proposed Model

Net Zero strategies for Envelope, HVAC system, plug loads and lighting were explained in detail. All the recommendations considered for developing the above models are mentioned. The values recommended in the design guides were used for models 1 and 2 whereas the proposed model was developed by considering the state of art and the best practices implemented in existing net zero energy schools in US. The existing highly efficient systems such as bipolar ventilation is retained in the proposed model as it is considered best possible option compared to others.

To offset the reduced energy consumption, potential areas where PV panels can be installed is analyzed by taking advantage of Florida climate zone. As some roof area is already covered with Solar panels, remaining requirement of energy to make the School Net Zero is evaluated. Also advantages of having a flat roof when compared to pitched roof were also discussed.

3 MODELLING AND ANALYSIS

3.1 Calibrated Existing Model

For this project monthly calibration method was adopted by comparing metered energy usage to simulated energy usage. Several calibration standards and measurements are used to check the authenticity of the simulated data by comparing it with metered energy usage. As operating schedules are major assumptions in any energy model, for our study energy data from September to May is considered as summer energy consumption of the school is inconsistent. Considering the age of the School, i.e. 42 years, it was assumed that summer energy data would not be a representative sample of the measured usage. In this process, coefficient of variance of the root mean squared error is calculated and if it falls in the tolerance range accepted by following methods then the simulation model is ready to use.

Following are some of the widely used techniques:

- ASHRAE Guidelines 14-2002: Measure of energy and demand savings (ASHRAE Standards Committee 2002)
- Measurement and verification (M&V) Guidelines for Federal Energy Projects, Federal Energy Management Program (FEMP 2008)
- International Performance Measurement and Verification Protocol (IPMVP 2002)

As measure of calibration, all the standards use Coefficient of Variance (CV) derived from Root Mean Square Error (RMSE). They are calculated based on equations 1 and 2.

$$RMSE_{MONTH} = \left[\frac{(M_{Month} - S_{Month})]^2}{N_{Month}}\right]^{\frac{1}{2}} \quad (1)$$

$$CV(RMSE_{MONTH})\% = \frac{RMSE_{MONTH}}{A_{MONTH}} \times 100 \quad (2)$$

where:
M_{Month}, is Actual Energy Consumption of each month
N_{Month}, is Simulated Energy Consumption of each month
A_{Month}, is the Average monthly energy consumption

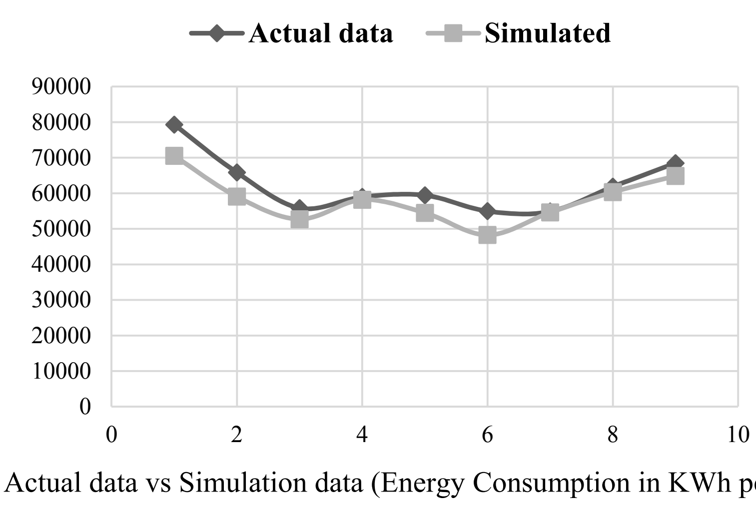

Figure 4: Actual data vs Simulation data (Energy Consumption in KWh per month) .

Table 2: Calibrating Meadowbrook energy consumption 2012-2013.

Energy Consumption in KWh			
Month	**Actual data (M)**	**Simulated data (S)**	**(M-S)²**
Sep	79281	70507	76983076
Oct	65840	59045	46172025
Nov	55840	52701	9853321
Dec	58960	58152	652864
Jan	59440	54483	24571849
Feb	54960	48257	44930209
Mar	54880	54610	72900
Apr	61840	60324	2298256
May	68480	64866	13060996
Total	693313	656737	13060996
$RMSE_{Month}$	4928.325116		
CV ($RMSE_{Month}$)	**8%**		

The ranges of tolerance for monthly data calibration of CV (RMSE) are ±5%, ±10% and ±15% for IPMVP, FEMP and `ASHRAE respectively. From the table 2 we can understand that CV ($RMSE_{Month}$) satisfies the tolerance range and the simulation data to be used in calibration is reliable (refer to table 2 and figure 4). Now this model is considered as Baseline model for carrying out further simulations and comparing the results with various design guides. Finally, an efficient model has been proposed with all the best practices and high performance products.

3.2 Comparison of EUI of Calibrated model with AEDG and ASHRAE 90.1-2007

Table 3: Comparison.

	Existing Situation	**1**	**2**	**3**
Component	**As-is Model**	**ASHRAE 90.1, 2007**	**ASHRAE AEDG 50%Savings**	**Proposed Model**
ENVELOPE				
Roof	U-0.0468 Steel Sheet 6" Insulation	U-0.048 6in. R-20 insulation	U-0.039 R-25 continuous insulation (c.i)	R-40 with poly iso-cynurate insulation
Wall	U-0.0693 Tilt up Concrete Panel 2.5in. R-12 insulation	U-0.124 3.5in. R-13 Steel framed wall	U- 0.064 R-13.0 + R-7.5 c.i.	R-28 Spray foam insulation. Insulated Concrete Form walls
Glazing	U-0.85 & SC-0.37	U-0.75 & SC-0.287	U-0.64, SHGC-0.46, SC-0.53	Low-E, Triple pane U-0.25, SC-0.32

LIGHTING	LPD (W/sf) Classroom-0.5 Restroom-1.36 Corridor-1.46 Office-1.01 Storage-0.8 Cafeteria- 1 Kitchen-1.2	LPD (W/sf) Classroom-1.4 Restroom, Kitchen, Cafeteria, conference-0.9 Corridor-0.5 Office-1.1 Storage-0.8 Library-1.2	LPD (W/sf) Classrooms, art rooms, kitchens, media rooms-0.8 Cafeteria, Lobby-0.7 Offices-0.60 Rest rooms-0.5 Corridors & Mechanical rooms-0.4	Usage of LED is recommended to reduce energy consumption due to high efficacy and life of lamps
PLUG LOADS	1.4 W/sf	1.4 W/sf	1.4 W/sf	0.7 W/sf
HVAC				
Ventilation	Bipolar Ventilation 5cfm/person	ASHRAE 62.1-2004/2007 10 cfm/person	Bipolar Ventilation 5cfm/person	Bipolar Ventilation 5cfm/person
Chillers	2 A/C Chillers 1.21 KW/ton 0.662 IPLV	No, Rooftop units	10 EER, 12.75 IPLV	11.6 EER, 19.8 IPLV with VFD and NEMA motors

3.3 NZE Strategies for Meadowbrook Elementary School and Proposed Model

3.3.1 Envelope

Highly insulated envelope would have lower heat gains and thereby reduces cooling loads of the building. For the Florida climate zone, insulated cool roof with high Solar Reflective Index (SRI) is recommended to avoid heat absorption. Using R-40 with poly iso-cynurate for roof insulation will yield better results as it already being used in some of the other net zero schools. Likewise, using Insulated Concrete Forms (ICF) and R-28 Spray foam insulation for walls is recommended. For window glazing, triple pane low-E windows should be preferred which has less U-value and Shading co-efficient (SC). It should also be noted that after some level of insulation, envelope may yield diminishing results. For example, having windows with high shading co-efficient would reduce the daylighting of the building. Therefore, perfect balance between building envelope and daylighting should be maintained.

3.3.2 HVAC

Meadowbrook has two Air-cooled chillers which supply chilled water to seven AHUs located in different parts of building. The efficiency of two chillers is 1.21kW/ton which is less in comparison to chillers available in market. This can be improved by using high efficiency chillers with variable frequency drives (VFD) controls having high efficiencies of about 1kW/ton. The school also uses a Bipolar Ionization system in order to purify air, remove mold, dust, odors and reduce gaseous contaminants like VOCs. The system is very efficient and has reduced the OA requirements to 5cfm/person. Other strategies such as energy recovery systems, demand control ventilation and dedicated outdoor air systems can also be implemented in order to make the school consistent with the net zero energy goal.

3.3.3 Lighting

Lighting is one of the major factors contributing the energy consumption of Meadowbrook. Currently, the school uses a variety of fluorescent and high-intensity discharge (HID) lamps for internal lighting. Existing lighting power densities (LPD) of various rooms such as classrooms, conference halls, cafeteria, corridors, and storage rooms have been replaced with recommended LPD's from design guides. However, energy savings can be observed in this area by retrofitting these lights with high efficient LED lamps having high lumens to watts ratio. Also, the amount of heat generated by LED lamps is much less than the existing ones which would further reduce the cooling loads. The lifespan of the LED lamps is much higher as compared to fluorescent lamps and thus requires less number of replacements. Further savings in the lighting energy use can be obtained by implementing efficient daylighting strategies and controls. Additional 20% savings can be realized by installing tubular daylighting devices such as solar tubes.

3.3.4 Plug Loads

Reducing plug loads in schools has been highly challenging for design engineers. Based on the study conveyed by Srinivasan et al. (2013), the plug load densities for classroom with computers can be determined depending upon the classroom area and the number of computers used. As plug loads constitute for 27% of the total energy consumption in the actual model, plug load density was reduced based on the above study. Actual model of the school estimated the value to be 1.4 W/sf which is very high. Benchmark model plug load densities were used, as existing approaches such as NREL, ASHRAE 90.1-1989, and COMNET either under or over-estimate the value for plug load density. Assuming 4 computers for each classroom, plug load density of 0.7 W/sf is considered for computer-equipped classrooms.

Also using ENERGY STAR equipment will mitigate the energy consumption of the building drastically. Apart from those systems which require continuous energy like refrigerators and security cameras, other equipment such as printers, coffee machines should be turned off when not in use. A normal school which has 180 working days with 8.00am to 3.00pm schedule is unoccupied for 75% of the year. Regulating these loads will save significant amount of energy.

3.4 Renewables

3.4.1 Scope of PV Panels to Offset the Energy Consumption

The gap between the proposed target EUI and the net zero energy goal is eliminated by installing photovoltaic panels on the roof of the building. Meadowbrook currently has 183 kW PV array system consisting of 609 Hanwha panels with a capacity of 300W per panel. Based on the results obtained from NREL PV Watts calculator, our target EUI of the proposed model requires 500 kW PV modules to completely offset energy consumption.

3.4.2 Potential Roof Area for PV Array Installation

From the total roof area, six potential areas suitable for PV array installation were chosen based on their orientation which have maximum exposure to Sun. Considering about 85% of the available area as some space is required for creating pathways to walk, maintenance and to avoid shading of panels, potential area for PV array installation is 28,050 sf (Table 4, Figure 5).

The current PV array installed on the roof has a low efficiency of about 14% and occupies approximately 18,000 sf. Thus, roughly 10,000 sf of south facing area is available for installing additional panels. The energy consumption of the school can be completely offset by installing an additional 317 kW array. Lesser number of panels will be required if higher efficiency modules are used. PV modules available today are about 20% efficient. Thus, using such high efficiency panels and adopting energy efficient strategies as suggested earlier, Meadowbrook has an opportunity to achieve a net zero energy status within the building footprint itself. However, if the available roof area is insufficient, a Solar carport can be created for the parking lot and could be used as PV system support. The solar carport will also provide shade, which not only protects the vehicles from the harsh effects of the sun but minimizes radiant heat transfer, which will require more of the car's energy to cool down.

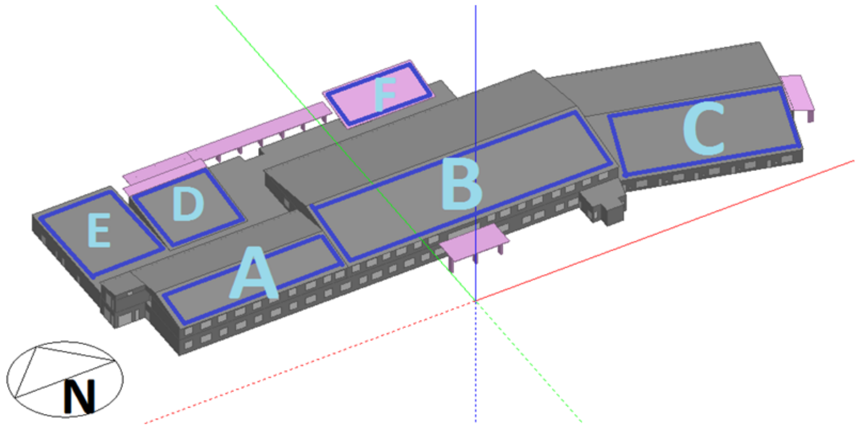

Figure 5: Model showing potential areas suitable for PV array installation (Ratio of panel to total area: 85%, PV Panel Area = (85%)(33000)= 28050 SF).

Table 4: Potential PV array installation area.

Zone	A	B	C	D	E	F	**Total (SF)**
Area (SF)	4400	11700	7000	3100	4500	2300	33000

Having flat roof has more benefits when compared to existing pitched roof. More PV panels can be installed on a flat roof. For Meadowbrook, considering flat roof would increase the available area for PV array installation by 60%. If a flat roof is assumed 53,000 sf of roof area is available, that provides 20,000 sf more space than the current roof area.

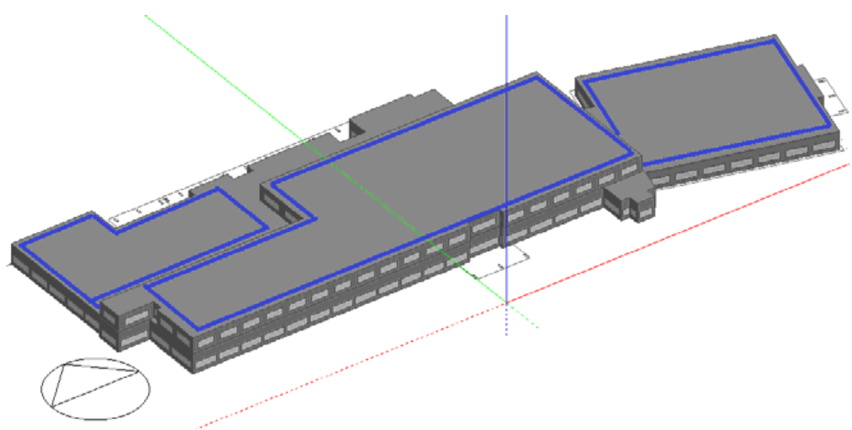

Figure 6: Model showing increased roof areas suitable for PV array installation.

4 CONCLUSION

The models analyzed in this paper indicate reliable simulation results. However, it should be noted that the results are based on the estimated inputs. Trane Trace 700 energy modelling software is used to analyze four scenarios discussed in this paper, comprising the actual (existing) situation, ASHRAE 90.1-2007, ASHRAE AEDG 50% Savings, and the proposed state-of-the-art model. The existing model was calibrated and complied with FEMP 2008 and ASHRAE Guideline 14-2002. The close distance of the actual to simulated data is an indication of the accuracy of the proposed model during operational months of the building. The available data for the Meadowbrook school energy consumption over summer was not reliable due to the remaining construction activities. Therefore, the results generated by the software were considered for evaluating summer. Financial expenditure to implement energy efficient strategies can be further discussed in future researches. Moreover, further studies should be undertaken to define an optimized balance between the higher upfront costs and obtained EUI, as well as the payback period. "Net Zero" is no more new to construction industry and schools are working as suitable test platforms for implementing technical and financial strategies. We recommend more detailed research on integrating energy and economic policies for schools in Florida which can motivate many other schools to achieve net zero energy status.

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AUTHOR BIOGRAPHIES

RUTHWIK PASUNURU is graduate research assistant at Powell Center for Construction & Environment at the University of Florida. He received his Master of Science in Construction Engineering Management from University of Florida and Bachelor of Technology in Civil Engineering from Jawaharlal Nehru Technological University, India. His research work mainly focus on sustainable construction. His email address is ruthwik.p@ufl.edu.

HAMED HAKIM is a graduate research assistant at Powell Center for Construction & Environment, University of Florida. Since 2012, he has devoted his time to study and conduct researches on green buildings and sustainable built environment. He received his Bachelor of Science in Civil Engineering at Isfahan University of Technology and a Master of Science in Construction Engineering Management at University of Florida. Hamed has over three years working experiences as a project engineer in commercial building projects, as well as part-time internships in the heavy civil construction. . His email address is hamedhakim@ufl.edu.

ARATI SAKHALKAR is a young professional with a passion for the energy and sustainability industry. She received her Bachelor's degree (Distinction Honors) from University of Mumbai, India in 2012. In May 2014, she completed her Master of Science in Mechanical Engineering from University of Florida with a focus on HVAC design, building energy simulation and net-zero energy buildings. With strong fundamentals and constant desire to learn and innovate, she is currently working towards her goal of being a Professional Engineer. Her email address is asakhalkar@ufl.edu.

CHARLES KIBERT is a Professor and Director of the Powell Center for Construction and Environment at the University of Florida. He is co-founder and President of the Cross Creek Initiative, a non-profit industry/university joint venture seeking to implement sustainability principles into construction. He is co-chair of the Curriculum and Accreditation Committee of the U.S. Green Building Council (USGBC) and helped create the first ever student chapter of the USGBC for which he served as faculty advisor. His research interests include sustainable development and construction, deconstruction, net zero energy buildings, carbon foot printing, construction and demolition (C&D) debris recycling, and construction ecology and metabolism . He is the author and co-author of various books, journal publications, and conference proceedings. His email address is ckibert@ufl.edu

RAVI SRINIVASAN is an Assistant Professor of Low/Net Zero Energy Buildings at the Rinker, Sr. School of Construction Management at the University of Florida. He received his Ph.D. and M.S. in Architecture from the University of Pennsylvania and M.S in Engineering from the University of Florida. His current research focuses on the development of Dynamic Sustainability Information Modeling (D-SIM) with integrative three-dimensional building simulation and visualization platform using extensible virtual environments for net zero campuses and cities. He is currently a member of the National Fenestration Research Council (NFRC) ANS Committee, reviewer for reputed journals such as Energy, Applied Energy, Building & Environment, Energy & Buildings and International Journal of Strategic Property Management. He was co-organizer of iiSBE Net Zero Built Environment International Confernece; co-track coordinator at the 45th Winter Simulation Conference. He has chaired sessions in reputed conferences such as Winter Simulation, Building Simulation (IBPSA), and Advanced Building Sciences (IIT-Madras). His email address is sravi@ufl.edu.