IMPACT OF ENERGY CONSUMPTION & GENERATION VARIATION ON THE FULFILLMENT OF NET-ZERO ENERGY EDUCATIONAL BUILDINGS

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ABSTRACT

The Net-Zero Energy (NZE) building standard requires a balance between the building’s energy consumption and generation. Any fluctuation in the energy generation by renewable technologies can greatly impact this balance and the overall energy performance of a NZE building. In this study, the feasibility of achieving NZE standard is evaluated for two LEED-rated educational buildings. Energy improvements strategies are investigated by making parametric variations to each building’s base case simulation model. The case study examines each building’s energy generation through the use of photovoltaic panels. The degradation rate is used to explore the risk that this source of renewable energy could behave non-efficiently under certain conditions. The factors affecting building energy consumption such as the operation schedule and the temperature set point are also studied. The results show alternative scenarios to improve building performance and achieve the NZE building standard.

Keywords: Operation Schedule, PV Modules; Degradation; Educational Building; NZEB

INTRODUCTION

In the United States, the commercial building sector accounts for one-fifth of U.S. energy consumption, which includes office space, retail space, and educational facilities (EIA 2009). In this sector, educational buildings rank as the third highest category of energy consumers. Educational buildings consume 614 trillion Btu of combined site electricity, natural gas, fuel oil, and district steam or hot water (Pless and Torcellini 2005). In order to optimize the energy performance of educational buildings, the US Department of Energy (DOE) has established a goal to reduce energy consumption and increase the production of clean renewable energies (Independence).

Energy-efficient educational buildings are expected to have lower energy consumption; however, they often may not perform as expected due to changes in the building operation or temperature set-points during the periods of inactivity. In the case of energy generation, sources of renewable energy such as solar energy are being considered to improve building performance. For photovoltaic (PV) modules to be a commercially viable source of energy, the reliability over the warranted lifetime needs to be examined. Degradation begins after installation and continues until the system is decommissioned (Jordan and Kurtz 2013). A wide variety of degradation rates have been reported in the literature with respect to age, manufacturer, and geographic location (Hottel and Woertz 1942). The study by the National Renewable Energy Laboratory (NREL) on 2000 solar panels shows that the performance of a PV module will decrease over time and the degradation rate is typically higher in the first year upon initial exposure to light and then stabilizes. PV modules may have a long-term power output degradation rate of between 0.3% and 1% per annum where the median degradation rate for PV solar panel modules is 0.5%/year and the average is 0.8%/year.

In this study, the feasibility of achieving NZE standard is evaluated for two LEED-rated educational buildings. Energy improvements strategies are investigated by making parametric variations to each building’s base case simulation model. The degradation rate is used to explore the risk that this source of renewable energy could behave non-efficiently under certain conditions. The factors affecting building energy consumption such as the operation schedule and the temperature set point are also studied. Optimization scenarios are identified to maximize each building energy performance with potential of achieving NZE.

CASE STUDY: LEED-RATED EDUCATIONAL BUILDINGS

Table 1 presents the information related to two educational buildings at the University of Kansas. The first educational building, the Center for Design Research (CDR), is an existing building with LEED platinum certification and with several sustainable systems, including features such as rainwater collection and reuse, a living wall, real-time display of energy usage, a wind turbine, solar collectors (PV panels), and a green roof. High efficiency windows are used to eliminate glare effects and reduce solar heat gain during the summer months and heat loss during the winter months. The second educational building, the Forum, is a building addition, which incorporates both passive and active sustainable systems with intention to achieve LEED Platinum certification. PV panels on the roof are to generate energy on site. A double skin façade (DSF) system mediates the heat transfer between the exterior and interior of the building depending on the time of the year. Vertical louvers control the amount of light and solar gain entering the space.

Energy consumption base case

For each educational building, a simulation model is created for the base case using Design Builder and Energy Plus. The monthly energy use is calculated considering the current building operation schedule and temperature set points (Table 2).

For this first educational building (CDR), energy data is collected for two years. This data provided detailed information for the building's operation schedule, which served as input for the energy analysis (Tabrizi and Sanguinetti 2013). This facility is occupied during the week and weekends during the academic calendar (September through May) and summer semester (June through August). The building's daily energy consumption included lighting, plug loads and HVAC control with no adjustments in the temperature set- points.

For the second educational building (Forum), the base case energy model is created according to predicted building use. Table 2 shows the assumptions for the building operation schedule during the weekdays and weekends, for the academic calendar and summer semesters. The simulation model used mixed ventilation, mechanical and natural ventilation, through a double skin façade (Tabrizi and Sanguinetti 2014).

Energy generation base case

For the two educational buildings, this study is limited to the calculation of energy generated by the PV panels. Table 3 shows the parameters for base case including the percent surface area, and the assumptions for the initial efficiency and rate of degradation.

ANALYSIS OF ENERGY MODIFICATION SCENARIOS

The study explores one aspect of energy underperformance that could be improved by adjusting the energy demand during periods of inactivity in educational buildings. The strategy to reduce energy consumption is to make adjustments in the space temperature set points: 20°C (68°F) during the heating season, and 22°C (72°F) during the cooling season, when the building is within the acceptable range of 80% building occupancy (ASHRAE Standard 55).

Due to the nature of the two selected educational buildings, there is a possibility for both to have extended operation hours during the academic calendar and shorter operation hours during the summer months.

Table 1: Description for two LEED- Rated Education buildings

	Educational Building 1: Center for Design Research	Educational Building 2: The Forum
		
Climatic Zone	Humid Continental	Humid Continental
Built Year	2011	2014
Area (ft^2/m^2)	1961/182	2600/242
Building Type	Educational	Educational
Construction Type	As-Built	As-Designed
Sustainability Level	LEED Platinum	LEED Platinum
Energy Consumption Control	High Efficiency Glazing; Green Wall; Green Roof; HVAC Control	Double Skin Façade; Green Wall; HVAC Control
Energy Generation Strategies	PV Panels; Wind Turbine	PV Panels
PV Panels Installed Power (kWp)	5	15

For each building case, two alternative scenarios are used to explore a) the modification of temperature set points in conjunction with changes in occupancy to reduce consumption with, and b) the addition of PV panels on the building surface increase to increase energy generation. Both buildings have lower occupancy in the summer months which provides an opportunity for the modification of the temperature set-point. For the energy generation modification, the addition of PV panels are kept in line with the acceptable limit allowing for 10%-15% clear space for maintenance and operation control (Pless and Torcellini 2005). In the first building, 17% of the roof surface is dedicated to PV panels and the modification scenario will increase the PV panels to 51%. In the second building, the roof surface has 41% of PV panels installed. The modification scenario will 1) increase the PV panels to 83% with on the roof surface, with enough space for maintenance, and 2) integrate PV panels on the building's south façade to cover 100% of the surface.

Figure 1 shows the analysis approach for this case study. To evaluate the potential of achieving the NZE standard, a sensitivity analysis is conducted to examine the parameters affecting energy consumption and generation measures. The base-case model is compared to a variable range (Min, Max) in each scenario (Table 3, Table 4).

Equation 1 shows the linear regression-based analysis utilized for the calculation of the building energy use (Tian 2013).

$$E_{total}(n_1, n_2, \dots, n_x) = \sum_{i=0}^{n} B_i n_i \qquad (1)$$

Where
E_{total} = Total building energy consumption;
N_i = Value of each design variable;
B_i =Regression coefficient for each design variable;
n= Number of significant design variables

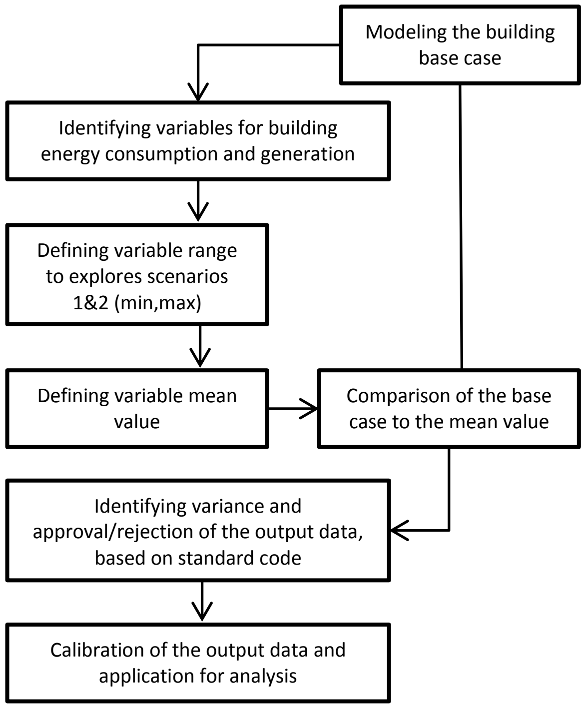

Figure 1: Analysis approach for the case study

Three variables (n_1, n_2, n_3) are considered, n_1 and n_2 are two energy consumption variables, and n_3 is an energy generation variable. n_1 stands for building occupied time or operation schedule, n_2 for temperature set-point change, and n_3 s for PV panels' surface area and degradation variation. In the calculations, n_1 and n_2 are compared to n_3 to identify the correlation between these variables to achieve Net Zero Energy balance in year 1 of as well as subsequent operation years (Figure *1*).

Table 2: Base case building use information

Energy Consumption Variables		**Educational Building 1: CDR**	**Educational Building 2: Forum**
Operation Schedule Hours	Weekdays	05:00 AM- 00:00 AM	07:00 AM- 07:00 PM
	Saturday	08:00 AM- 00:00 AM	08:00 AM- 05:00 PM
	Sunday	08:00 AM- 00:00 AM	09:00 AM- 03:00 PM
	Summer	10:00 AM-19:00 PM	09:00 AM- 04:00 PM
Temperature Set Point (°C)		Heating: 20° Cooling: 22°	Heating: 20° Cooling: 22°

Table 3: Base Case PV Panel installation

Area distribution of PV panels	**Educational Building 1: CDR**	**Educational Building 2: Forum**
Roof	17%	41%
South façade	0%	0%
Initial Efficiency	10%	10%
Rate of Degradation %	0	0

IMPACT OF PV PANEL DEGRADATION ON ENERGY GENERATION

PV panels are vulnerable to degradation due to internal factors such as their age, failure in wiring and adhesion failure, or external (on-site) factors such as deposition of dust, bird- droppings, water-stains (salts), snow, temperature/moisture and others which can significantly degrade their efficiency over time (Johansson and Burnham 1993, King, Quintana et al. 2000, Asl-Soleimani, Farhangi et al. 2001, Tian, Wang et al. 2007). A study by the National Renewable Energy Laboratory (NREL) on 2000 solar panels made it clear that the performance of a PV module will decrease over time and the degradation rate is typically higher in the first year upon initial exposure to light and then stabilizes. Other factors affecting the degree of degradation include the quality of materials used in manufacture, the manufacturing process, the quality of assembly and packaging of the cells into the module, as well as maintenance levels employed at the site. PV modules may have a long-term power output degradation rate of between 0.3% and 1% per annum where the median degradation rate for PV solar panel modules is 0.5%/year and the average is 0.8%/year. Therefore, the risk of degradation over time indicates an uncertain state that could lead to a performance loss.

The financeable life for a solar PV system is usually considered to be the manufacturer's guarantee period, which is often 20–25 years (Jordan, Smith et al. 2010). Additionally, Monte Carlo simulation conducted by NREL, showed a typical maximum manufacturer warranties are 80% power production after 25 years of field use. In order to analyse the associated risk with PV panels indicated in two case studies and to evaluate their efficiency in the 80% warranty range by the manufacturer, the probability analysis should be calculated with the degradation range of 0.8 ± 05 and 0.8 ± 0.2 for the first year and 25 years of PV installation according to Equation 2.

$$Power\ (Year_n) = Power\ (Year_1) \cdot (1-R_d)^n \quad (2)$$

Table 3: Building 1- Parameter ranges for building use and PV panel installation

	Academic year			Summer		
	Min	Avg	Max	Min	Avg	Max
Number of use hours per day (hr/day)	7	9	24	3	5	9
Temperature Set Point (°C)	18	19	20	22	23	24
Area distribution of PV Panels (%)	17	34	51	17	34	51

Table 4: Building 2- Parameter ranges for building use and PV panel installation

	Academic year			Summer		
	Min	Avg	Max	Min	Avg	Max
Number of use hours per day (hr/day)	9	10	12	3	6	8
Temperature Set Point (°C)	15	18	20	22	23	26
Area distribution of PV Panels (%)	41	83	100	41	83	100

RESULTS

Table 5 presents the total building energy use and the total energy savings for each educational building. The results compare the base case with two scenarios exploring the variation of parameters for initial energy consumption and estimated energy generation.

Parametric study for base case 1 (CDR building)

For the CDR base case, the energy consumed by the building is 198.4 kWh/m^2/yr. The energy generated by the PV panels accounts for 22.5 kWh/m^2/yr. The PV panels' energy generation will reduce the building energy use to 176.2 kWh/m^2/yr. The modification of the CDR operation schedule and temperature set- point can reduce the energy consumption from 198.4 kWh/m^2/yr to 160.2 kWh/m^2/yr or 19% (

Table 5).

CDR Scenario 1

The generated energy by PV panels will increase from 22.5 kWh/m^2/yr to 45.8 or 51% (Table 6). The PV panel's energy generation will reduce the building energy use to 114.4 kWh/m^2/yr or 42%.

CDR Scenario 2

The generated energy by PV panels will increase from 22.5 kWh/m^2/yr to 53.4 kWh/m^2/yr or 58% and the PV panel's energy generation will reduce the building energy use to 106.8 kWh/m^2/yr or 46%.

Parametric study for base case 2 (Forum building)

For the Forum base case, the energy consumed by the building is 456.6 kWh/m^2/yr. The energy generated by the PV panels accounts for 88.2 kWh/m^2/yr. The PV panels' energy generation will reduce the building energy use to 368.3 kWh/m^2/yr.

The modification of building operation schedule and temperature set point change can reduce the building energy consumption from 456.6 kWh/m^2/yr to 219.8 kWh/m^2/yr or 18.3 kWh/m^2/month or 52% (

Table 5).

Forum Scenario 1

The generated energy by PV panels will increase from 88.2 kWh/m^2/yr to 176.6 kWh/m^2/yr or 50%. The PV panel's energy generation will reduce the building energy use to 43.2 kWh/m^2/yr or 91%.

Forum Scenario 2

The generated energy by PV panels will increase from 88.2 kWh/m^2/yr to 211.8 kWh/m^2/yr or 58% and the PV panel's energy generation will reduce the building energy use to 8.1 kWh/m^2/yr or 98% which defines the building almost as near NZEB.

Both of the educational buildings are mainly occupied during the academic year. The parametric variation of energy consumption and generation is analyzed only for the academic year period considering the average as the most efficient range for buildings performance and occupants comfort level.

For each building case, the energy performance is analyzed using the min and max values in parameter range to evaluate the potential to meet the NZE standard. Table 7 table shows the impact of the variability in the PV panel degradation rate on the Estimated Energy Generation without risk of degradation. Table 8 shows the impact of the variability in the PV panel degradation rate on the Total Building Energy Use.

Table 9 shows the correlation between energy consumption and energy generation for each building's energy balance after 2 and 25 years of operation. The operation schedule and temperature set-point are categorized as energy consumption variables, and PV panels degradation is considered as an energy generation variable. Table 9 presents the implementation of the energy generation variable (n3) into energy consumption variable (n1), in the lowest and highest range for the both buildings total energy use after 2nd and 25th years of operation with consideration of PV panels' degradation rate.

Table 5: Comparative Analysis for NZEB decision-making

	Educational Building 1: CDR			Educational Building 2: Forum		
	Base Case	Scenario 1	Scenario 2	Base Case	Scenario 1	Scenario 2
Initial Energy Consumption (kWh/m^2/yr)	198.4	160.2	160.2	456.6	219.8	219.8
Estimated Energy Generation (kWh/m^2/yr)	22.5	45.8	53.4	88.2	176.6	211.8
Total Building Energy Use (kWh/m^2/yr)	**114.4**	**106.8**	**106.8**	**43.2**	**8.1**	**8.1**
Total Energy Saving (%)	**19**	**51**	**58**	**52**	**91**	**98**

Table 6: Impact of the variability in the PV panel degradation rate (R_d) on the Estimated Energy Generation (kWh/yr)

			Educational Building 1: CDR			Educational Building 2: Forum		
Power year	PV Panel Degradation Rate [R_d] (%/Yr)		Base Case (kWh/yr)	Scenario 1 (kWh/yr)	Scenario 2 (kWh/yr)	Base Case (kWh/yr)	Scenario 1 (kWh/yr)	Scenario 2 (kWh/yr)
2	Min	0.3	4085	8308	9693	21302	42604	51092
	Avg	0.8	4064	8266	9644	21195	42390	50836
	Max	1	4056	8250	9625	21152	42305	50734

Table 7: Impact of the variability in the PV panel degradation rate on the Total Building Energy Use

Academic year Energy Consumption (kWh/m^2/yr)	Educational Building 1: CDR	Educational Building 2: Forum
Min	152.3	136.5
Avg	160.2	219.8
Max	198.4	456.6

Table 8: Estimated PV panels energy generation after 2 and 25 years

Power Year	Academic Year	Educational Building 1: CDR			Educational Building 2: Forum		
		Min	Avg	Max	Min	Avg	Max
2	Estimated Energy Generation (kWh/m^2/yr)	52.9	53	53.2	209.7	210.1	211.1
25		42.1	43.7	50	164.8	173.2	196.4

Table 9: Total Building energy use with integrated variables n_1 & n_2

Power Year	Academic Year	Educational Building 1: CDR			Educational Building 2: Forum		
		Min	Avg	Max	Min	Avg	Max
2	Total Building Energy Use (kWh/m^2/yr)	107.3	107.2	107	10.1	9.7	8.7
25		118.1	116.6	110.7	55.1	46.6	23.3

DISCUSSION

The case study presented here compares two LEED-rated educational building in a similar climate. The building use PV panels improve the building's energy efficiency. The study explores modifications scenarios to compensate for the reduction in energy generation due to the PV panels' degradation over time. The results show an energy reduction of 7%-22% or energy generation of 78%-93% during the 25 years of operation (Table 9). Figure 2 shows that the total building energy use in the lowest and highest range remains in linear relation in comparison to modification scenarios.

A comparison of the results from each building presents an opposite trend in regards to energy generation and total energy savings after 25 years of operation in comparison to the base case. For both buildings, the modification scenarios increase the energy generation. Considering the fact that second building has higher percentage of generation, this could be related to the building construction timeline, higher efficiency materials and the larger available roof space.

The results show that, the first building has an average energy use increase in the 3-9%/m^2 range where the second building has significantly higher use with the 160-360% increase (Table 9). A post-occupancy evaluation will be conducted, as a next step, to analyze the impact of other sustainable strategies on energy demand, including the green roof and green wall in the CDR (building 1), and the double skin façade, natural ventilation, green roof and green wall in the Forum (building 2).

The results indicate that both buildings highest and lowest energy consumption in correlation with average building energy generation, can potentially meet the NZE building standard. To achieve a higher percentage of energy generation and maintain a linear energy balance, more PV panels are required onsite to account for the case of maximum variability, when the required energy generation is higher than average rate.

Although the PV panel efficiency remains in the 80% warranty range after 25 years, a 2% risk associated with the degradation rate of 1%/yr (Max) in both case studies. This result indicates that the real-time occurrence of internal and external degradation factors on PV panels' over time despite having minimal impact (<=1%) on their performance.

The results show a satisfactory rate for PV panel's energy generation after 25 years of installation and the potential to maintain the NZEB standard considering the probability of maximum associated risk in the degradation rate (Table 10). This outcome points to the importance of further research in other factors such as HVAC systems, building envelope design and local energy systems to evaluate their impact on overall energy use in the fulfillment of NZE standard.

In this study building simulation is used to study energy performance improvements in two educational buildings to meet the net-zero or near zero energy standard. The degradation of PV panels' over time was calculated and the building operation schedule and temperature set-point were modified.

It should be noted that, the degradation of PV panels' is only one of the factors in regards to net-zero energy analysis and building HVAC systems, envelope properties and local energy systems may degrade after 25 years of operation. The evaluation of those factors is out of scope of this paper and it is recommended to consider them in future studies to provide more comprehensive results in the fulfilment of NZE standard.

The current study considers the building energy data in the design phase as the baseline. After calibration of the energy model, alternative scenarios were proposed for performance improvement. In order to identify both buildings real energy performance in the operation phase, a post occupancy evaluation (POE) would be required, followed by another calibration of the energy model to bridge the gap between the energy model and the real building performance.

LIMITATION OF THE STUDY

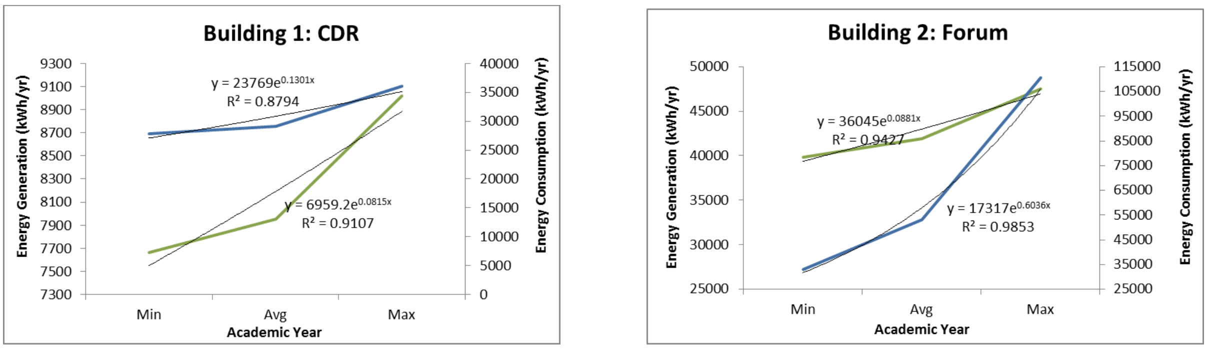

Figure 2: Energy consumption vs. generation (Min, Avg, Max) in buildings 1 & 2

	Educational Building 1: CDR	Educational Building 2: Forum
Power Production % After 25 Years	%80 ≤78% - 93%> 80%	

Table 10: Power Production % after 25 Years

CONCLUSION

The NZEB concept supports the evaluation of sustainable buildings focusing solely on energy performance. In this study, the feasibility of achieving the NZEB standard is evaluated for two LEED-rated educational buildings. Using building simulation, base case models are created. Energy improvements strategies are explored based on each building's operation during the academic year and the summer months. Two factors impacting energy consumption were modified: the temperature set point and the building operation schedule. The study explored how to maximize the application of renewable technologies such as PV panels. The study evaluated the risk in the overall energy performance predictions based the variability of energy generation due to degradation rate of PV panels.

The results indicate that the inefficient building operation causes higher amount of energy use. To fulfil the NZEB standard, a modification in the building operation combined with an investment on renewable technologies is needed to compensate for each building's energy demand. PV panel performance is within the 80% range of the manufacturer warranty for the 25 years after PV panel's installation, irrespective of maximum variability in the building operation and maintenance with higher energy demands. Continuous maintenance of PV panels would be required to avoid the 2% risk under the warranty range.

Finally, the results also show the potential of both buildings to become NZEB with consideration of the variable range in energy consumption and generation. Further study is needed to analyse the life cycle cost of implementing changes to LEED-rated buildings in order to meet the net-zero standard.

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