Educational buildings and their potential to become net- zero energy buildings

Aydin Tabrizi[1], Paola Sanguinetti[1]

[1]University of Kansas, Lawrence, KS

ABSTRACT: A Net Zero Energy Building (NZEB) generates at least as much renewable energy on-site as it consumes in a given year. This study compares three real world educational buildings to become NZEB. Each case study consists of: (1) an energy model; (2) CFD model and (3) a cost model. Three performance criteria are considered: net zero energy (NZE), occupant comfort level and cost-benefit analysis. Energy consumption and generation are quantified using zonal models. Computational fluid dynamics (CFD) modeling is used to deal with problems associated with the thermal environment and the performance of building façade regarding the natural ventilation and building energy use. Scenarios are explored to identify the optimal NZEB with consideration of indoor comfort level and cost.

The results present options to achieve NZEB in educational buildings based on the location, climate and size of the structures. The nature of educational buildings and variability in the operation schedule provide opportunities to reduce the operation cost and to generate energy onsite while saving energy without deteriorating the comfort level of occupants in each case.

KEYWORDS: Educational Buildings; Net-Zero Energy Building; Life Cycle Costing; Computer Fluid Dynamics; Double Skin Façade

INTRODUCTION

In the United States, Commercial buildings account for one-fifth of U.S. energy consumption, with office space, retail space, and educational facilities representing the main part of commercial sector energy consumption. Educational buildings consume 614 trillion Btu of combined site electricity, natural gas, fuel oil, and district steam or hot water and they rank as the third highest category of energy consumers of all the commercial building types accounting for 12% of all energy used in commercial buildings.

Various programs to improve the energy and environmental quality of educational buildings have been applied. The Bright schools program is a California energy commission program, which offers specific services to help people to renovate or build new energy efficient school buildings. The green school project is a program developed from the Alliance to save energy, which aims at improving the energy and environmental efficiency of existing school buildings. Energy smart schools is a program of the Department of Energy and its Rebuild America program which mainly aims at offering school training workshops, publications, recognition, direct technical assistance and financing options, in order to improve educational buildings energy efficiency. In order to reduce the energy consumption of the commercial building sector with specific emphasis on educational buildings, the Department of Energy (DOE) has established the Commercial Building Initiative (CBI), a goal to create technologies and design approaches that lead to marketable NZEB by 2025. This goal calls for the increased production of clean renewable fuels and increased efficiency of products, buildings, and vehicles.

Significant policy action towards the promotion of energy-efficiency and on site renewable energy has been developed all around the world with different levels of intensity and structure. Actions such as the development of thermal regulations for buildings or the promotion of passive solar architecture are gaining momentum in current practices. Recently, the Net-Zero Energy Building (NZEB) concept started to appear in the literature as the optimum option for a very energy-efficient educational building . For a NZEB educational facility, a zero energy balance is required on an annual basis. The NZEB must have local systems that produce and export energy carriers into the grids, and make tradeoffs in its operation schedule, to achieve the annual balance.

1.0 EVALUATION OF THREE LEED-RATED EDUCATIONAL BUILDINGS

This paper explores how LEED-rated educational facilities could be retrofitted and their operational modified to achieve the NZEB standard. Three cases studies were selected because of the climatic location, structural type, LEED certification rating and functional similarities to evaluate the potential of NZEB concept. Table 1 presents the information related to three educational buildings.

Table 1: Description for two LEED- rated education buildings.

	Building 1:	**Building 2:**	**Building 3:**
	Center for Design Research (CDR)	The Forum	Richard Klarcheck Information Commons
			
Climatic Zone	Humid Continental	Humid Continental	Humid Continental
Built Year	2011	2014	2007
Area (m^2/ ft^2)	182/1961	242/2600	6410/69000
Building Type	Educational	Educational	Educational
Construction Type	As-Built	As-Designed	As-Built
Sustainability Level	LEED Platinum	LEED Platinum	LEED Silver
Energy Consumption Control	High Efficiency Glazing; Green Wall; Green Roof; HVAC Control	Double Skin Façade; Green Wall; HVAC Control	Double Skin Façade; Green Roof; HVAC Control
Energy Generation	PV Panels; Wind Turbine	PV Panels	N/A
Number of PV Panels	20	60	N/A

The first educational building, the Center for Design Research (CDR), is an existing research facility 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, electric vehicle charging stations, and a green roof. High efficiency windows were 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 auditorium addition. The building incorporates both passive and active sustainable systems with intention to achieve LEED Platinum certification. A living wall with vegetation is used to purify the air in the auditorium space; a water harvesting system is to route precipitation to a cistern; and 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.

The third educational building is a library annex building. The Information Commons (IC) is LEED silver certified and employs a number of technologies that provide Loyola University with a computer center, classrooms and meeting spaces. The building features include a double skin façade allowing passive management of heat flow and natural ventilation throughout the year. Spanning within this façade is a mechanically operable blind that adjusts daylight levels and heat transmittance from the sun. Radiant concrete slab ceilings provide thermal mass to cool in the summer and heat in the winter. A green roof works to absorb rainwater and relieve some of the runoff into Lake Michigan.

As part of the case studies, data of the building's real energy consumption and the amount of energy generation by the PV renewable systems were collected and measured at first. Then modeling, simulation and output aggregation were conducted to quantify the energy consumption by the building facilities. After that the developed scenarios were evaluated to test parametric variations of renewable systems and building operation schedules. Lastly, the scenarios were evaluated to test the performance and efficiency level of the façade. In the meantime, the results were analyzed to give recommendations about the optimization of buildings performance and consideration of new factors for building performance enhancement or as the modification to the renewable systems.

Building performance was quantified using data measurements collected for the renewable energy sources on site. A base case model was generated to compare to the real building data. The buildings were simulated in the BIM software and the energy consumption of the buildings were quantified taking into account the energy produced by renewable systems. The building models were exported into energy modeling tool to analyze the building's energy performance.

The energy consumed in operation and the energy generated by the renewables was calculated for each case study as the base case. A set of alternative scenarios were developed and analyzed a part of a retrofit plan. Figure 1 shows the research procedure and the approach to analyze the facilities, evaluate scenarios, and facilitate the decision-making process toward the most optimum retrofit plan.

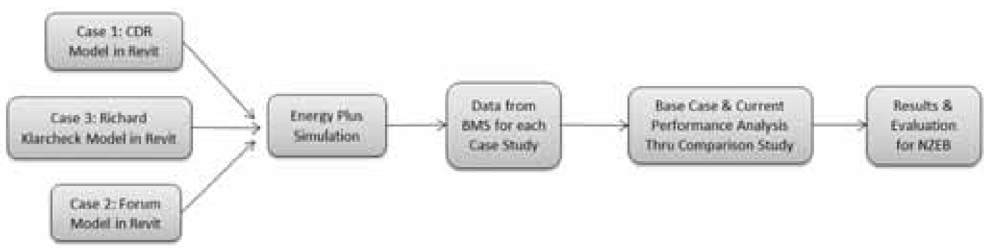
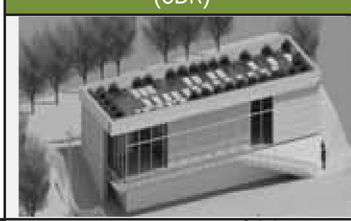
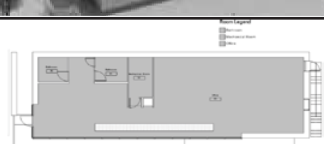
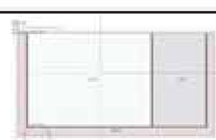


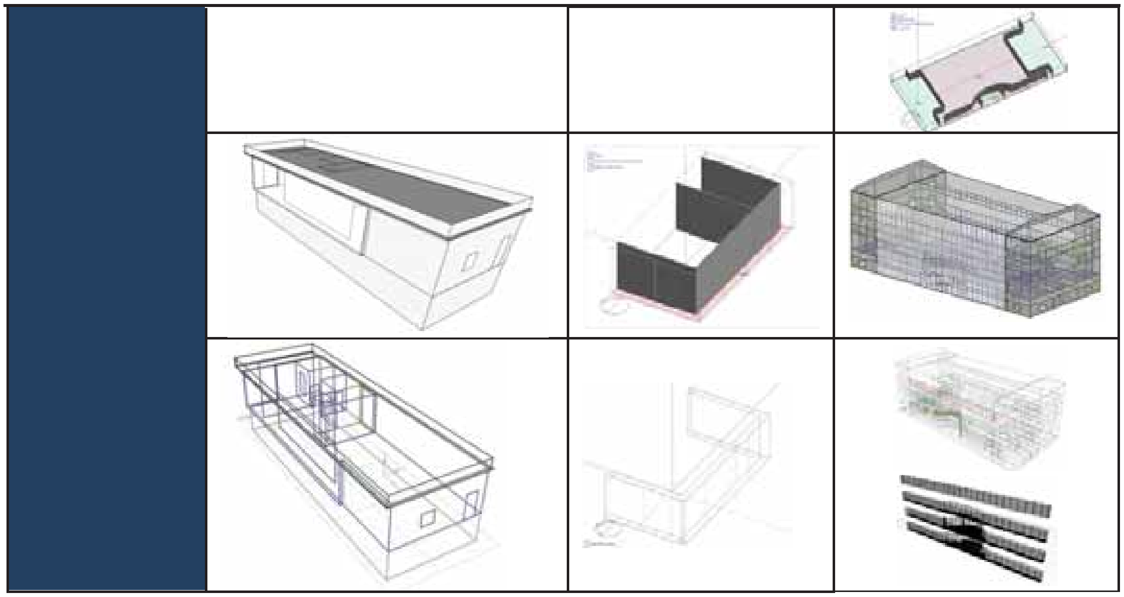
Figure 1: Energy data procedure.

2.0 ENERGY QUANTIFICATION

Each building was modeled is simulated in Revit Architecture, a Building Information Modeling tool. The analytical volumes were verified and each model was exported as a gbXML file into Green Building Studio™ and Ecotect™ (Table 2). These tools were used to specify operational schedules and weather data, to be exported as an Input Data File (IDF) into EnergyPlus, the U.S. Department of Energy tools for comprehensive simulation of the building envelope, fenestration, HVAC systems, daylighting and renewable energy components. The EnergyPlus IDF editor was used to verify the geometry and explore scenarios to achieve a balance between the predicted energy consumption and energy generation.

Table 2: BIM model for energy simulation and occupant comfort analysis.

	Building 1: Center for Design Research (CDR)	Building 2: The Forum	Building 3: Richard Klarcheck Information Commons
			
BIM Model, Zoning/Space Analysis			



2.1 Quantification of the base case

For each educational building, a base case model is generated. The monthly cost of energy is calculated including the savings produced by photovoltaic (PV) panels installed on the roof. The quantification of each base case takes into account the installation cost of PV systems on the rooftop, with variations based on building features.

2.1.1 CDR base case

The CDR base case model is calibrated using energy data measurements collected for two years . The facility operation schedule was obtained in consultation with the facility manager and used as an input for energy analysis and cost evaluation. The facility is occupied during the week and weekends and consumes energy 24 hours every day for lighting, plug loads and HVAC control. Table 4 shows the monthly energy cost for this building. The cost of energy use in this building averages USD 893/month, USD 10,712/year or ¢ 46/ft^2.

The CDR roof surface measures 23.12 meter X 7.88 meter (75.86 ft. X 25.85 ft.) and PV types (250 W_p) are currently installed. The PV panel size is 165.1 X 101.6 cm (65 X 40 inches) and 20 PV panels occupy 17% of the roof surface. The cost for installation of each PV panel is estimated to be USD 498.69 and the overall installation for 20 panels is USD 9,974.

2.1.2 Forum base case

For the Forum base case model, it was assumed that the building is in operation during the weekdays and weekends. The energy consumption due to operation of a double skin façade is analysed . The cost of energy use in this building each month is USD 1462.27, for one year USD 17547.24 and ¢ 56/ft^2. The Forum monthly energy use is equal to 9208 kWh and based on Westar Energy definition, this building can be categorized under small general service building type.

The cost analysis for the installation of the PV panels to generate energy is according to the national renewable energy laboratory (NREL) , where the median installed price of PV systems is USD 5.30/W for residential and small commercial systems smaller than 10 kilowatts (kW) in size and USD 4.60/W for commercial systems of 100 kW in size. For systems larger than 10,000 kW generally the price ranges from USD 2.50/W to USD 4.00/W and this variability in pricing is due to the price difference across the states and various types of PV applications and system configurations. This building measures 242 m^2 (2600 ft^2) and half of roof area is covered with PV panels based on building design. Therefore, considering the mean of USD 3/W for PV installation at this building, will result the total cost of USD 3659.

2.1.3 RKIC base case

Data from building management system shows that the building is in operation during the weekdays 24 hours except Fridays until 10 PM. For the weekends the building is in operation from 8 AM to 9 PM on

Saturdays and from 10 AM onward for Sundays (Table 3). IT is important to note that the facility's 300 computers never go into sleep status. The facility's energy consumption was evaluated with the consideration of double skin façade influence for the summer and winter seasons. Two ventilation types were considered based on the building zoning and accumulated data from the building management system to estimate the energy consumption with the consideration of DSF: a) mixed ventilation (natural + mechanical) for lobby space and mechanical ventilation for the sides. The mixed ventilation uses the DSF cavity zone as a buffer to treat the air and ventilation load between the interior and exterior of the building. The building annual energy use is 1,362,772 kWh and based on Integrys Energy Group , this building can be categorized under high load factor electric rate building type. The cost of energy use is USD 21,401 each month and for one year is USD 256,812 and ₵ 31/ft^2.

Table 3: RKIC base case operation schedule.

	OCCUPANCY	OPERATION SCHEDULE HOURS				TEMPERATURE SET POINT (°F)	TEMPERATURE SET BACK (°F)	VENTILATION MODE
		Weekdays	Friday	Saturday	Sunday			
LOBBY/LIBRARY	Full Use (All Year)	00:00 AM-11:00 PM	00:00 AM-10:00 PM	08:00 AM-09:00 PM	10:00 AM-00:00 AM	Heating: 68° Cooling: 72°	Heating: 55° Cooling: 76°	VAV + outside air reset + mixed mode
OFFICE/CLASSROOM	Full Use (All Year)	08:00 AM-05:00 PM	08:00 AM-05:00 PM	Off	Off	Heating: 68° Cooling: 72°	Heating: 55° Cooling: 76°	VAV + outside air reset

2.2 Comparison of energy costs

The cost of energy consumption is comprised of different factors including: 1) customer charge, 2) energy charge, 3) demand charge, 4) fuel charge, 5) property tax surcharge, 6) transmission delivery charge, 7) environment cost recovery rider, 8) energy efficiency rider, 9) franchise fees, and 10) sales tax. In order to calculate the energy consumption cost in each building, the energy monthly cost for commercial and educational facilities were extracted from Westar Energy website for the state of Kansas based on sales tax for state and locally and from Integrys Energy Group for the state of Illinois. According to the US EIA, the cost of electricity for the commercial building at the state of Kansas is ₵ 10.5 per kWh and ₵ 8.88 per kWh for the state of Illinois. Table 4 compares the monthly for each base case.

Table 4: Base case monthly energy cost for CDR, the Forum and RKIC.

	Building 1: CDR	Building 2: Forum	Building 3: Richard Klarcheck IC
Energy Charge (Westar Energy & Integrys Energy Electric Companies)			
Customer Charge	20	20	250
Energy Charge (USD ($) 0.013085 per kWh for all kWh)	74.59	74.59	17831.87
	78.14	345.85	
Energy Charge ($)	152.73	420.44	17832
Demand Charge	339.75	339.75	11,616.89
($ 11.61680 per kW for primary service)	175.95	175.95	
Fuel Charge	65.71	201.07	29757.49
Transmission Charge	40.76	124.71	3580
Environmental Cost Recovery Rider	9.12	27.89	732.10
Energy Efficiency Rider	1.62	4.95	733.17
Property Tax Surcharge	3.33	10.18	1507.23
Sub Total ($)	808.96	1324.95	19589.23

Franchise Fee	24.27	39.75	587.68
Sub Total ($)	833.23	1364.7	19589.23
Sales Tax	51.24	83.93	1224.33
	8.33	13.65	587.68
Total Sales Tax	59.58	97.58	1812.00
Total Bill Monthly ($)	892.8	1462.27	21401.23
Average Bill Monthly ($/ft^2)	0.46	0.56	0.31

3.0 Cost-benefit analysis & risk considerations for NZEB decision-making

For each educational building, two scenarios were evaluated to achieve NZEB by implementing energy improvement strategies. The scenarios involve the opportunity to extend the number of PV panels in buildings 1 and 2 and addition of PV panels in building 3 where PV panels do not exist in this facility base case design (Table 5). In conjunction with this modification, changes to operation schedules for each building's lighting, HVAC, and equipment use (plug loads) were evaluated in each case (Table 6). The flexibility in the buildings operation schedule is investigated especially during summer when classes are not in session and lower occupancy rates can be used in the calculation based on the available life safety codes upon the type of occupancy .

Due to these building operation modifications, the CDR performs during normal office hours (8:00 AM- 5:00 PM) annually except weekends; however, the Forum performs during normal office hours (8:00 AM- 5:00 PM) during the winter semester from Monday to Friday while classes are in session. During the summer semester, there are no activities other than weekly seminars for staff and group discussion once a week.

At RKIC, the main computer lab (core zone) is in operation during normal office hours (8:00 AM- 5:00 PM), however during the final exams at the month of December and May, the facility is in operation from 8:00 AM to midnight. On the weekends the facility is occupied from 10:00 AM to 3:00 PM during the semester session and it is mostly in low occupancy during the summer. For both cases the rooms on facility corner are in use for 8:00 AM to 5:00 PM for summer and winter semesters and are not occupied during the summer holidays. In the case of weekends, the rooms are not occupied for both summer and winter semester (Table 6). The impact of these strategies and the opportunity to reduce costs due to energy consumption are examined in the following sections and shown in Table 7.

Table 5: Base case and alternative scenarios for pv panels addition.

	Building 1: CDR			Building 2: Forum			Building 3: RKIC		
Area distribution of PV panels	Base Case	Scenario 1	Scenario 2	Base Case	Scenario 1	Scenario 2	Base Case	Scenario 1	Scenario 2
Roof	17%	34%	17%	41%	83%	100%	0%	61%	100%
South façade	0%	0%	17%	0%	0%	0%	0%	0%	0%

Table 6: Alternative scenarios for operation schedule change during summer and winter.

	Building 1: CDR		Building 2: Forum		Building 3: RKIC						
					Core Zone (Lobby)				Side Zone (Office)		
	Winter Semester	Summer Semester	Winter Semester	Summer Semester	Winter Semester	Summer Semester	Dec & May	Weekends	Winter Semester	Summer Semester	Weekends
Occupancy (People)	90-120 People or 0.05-0.07/ft2		173 People or 0.07/ft2	26 People or 0.01/ft2	690 People or 0.02/ft2				178 People or 0.02/ft2		0
Operation Schedule Hours	8:00 AM 5:00 PM		8:00 AM 5:00 PM	9:00 AM 3:00 PM	8:00 AM 5:00 PM	8:00 AM 5:00 PM	8:00 AM 12:00 AM	10:00 AM 3:00 PM	8:00 AM 5:00 PM	8:00 AM 5:00 PM	No Occupancy
Days per Week	5		5	1	7				5		0
Temperature Set Point (°F)	Cooling: 72° Heating: 68°		68°	Original: 72° Modified:78°	68°	72°	Cooling: 72° Heating: 68°	Cooling: 76° Heating: 64°	68°	72°	Off
Ventilation Mode	VAV + outside air reset + mixed mode+ open blind		VAV + outside air reset + mixed mode+ close blind		VAV with HR + outside air reset + mixed mode			Natural Ventilation	VAV with HR + outside air reset		Natural Ventilation

3.1 CDR improvement scenarios results

The energy generated by the PV panels account for 4097 kWh/yr and the consumed energy by the building is 36111 kWh/yr. The PV panels energy generation will reduce the building energy use to 32014 kWh/yr which will reduce the base cost to USD 9497.6/yr with a net savings (NS) of USD 1215/yr. The simple payback period (SPBP) is the initial cost of the item divided by the annual cost savings. The SPBP for building base case is 8 years and 2 months and ROI of 12.2%. The amount of energy production does not categorize this building under NZEB definition and alternative scenarios are required to analyze for this criteria.

By modifying the CDR operation schedules the energy consumption is reduced from 36,111 kWh/yr to 29,166 kWh/yr or 19%. The average monthly cost of energy is reduced from USD 892.80/month to USD 839.63/month and for one year it will cost USD 10075.56.

3.1.1 Scenario 1

The generated energy by PV panels will increase from 4097 kWh/yr to 8333 or 51%. However, doubling the number of PV panels will increase the cost from USD 9,974 to USD 19,948. The PV panel's energy generation will reduce the building energy use to 20833 kWh/yr or 42% and according to new operation cost of USD 10075.56/yr and reduced cost to USD 7196.8/yr, the building energy cost will reduce USD 2878.7/yr. The initial SPBP of 8 years and 2 months (base case) will reduce to 6 years and 10 months with ROI increase from 12.2% to 14.4%.

3.1.2 Scenario 2

The generated energy by PV panels will increase from 4097 kWh/yr to 9722 kWh/yr or 58% and the PV panel's energy generation will reduce the building energy use to 19444 kWh/yr or 46%. According to new operation cost of 10075.56 $/yr and reduced cost to 6717 $/yr, the building energy cost will reduce USD 3358.6/yr. The initial SPBP of 8 years and 2 months will reduce to 5 years and 10 months with ROI increase from 12.2% to 16.8% and the numbers obtained in both scenarios justify the investment to achieve NZEB (Table 7).

3.2 Forum improvement scenarios results

The energy generated by the PV panels account for 21366 kWh/yr and the consumed energy by the building is 110496 kWh/yr. The PV panels energy generation will reduce the building energy use to 89130 kWh/yr and accordingly, it will reduce the energy cost of the building (NS) USD 3393/yr. Building base case SPBP will be 2 years and 3 months with ROI of 92.8% and the amount of energy production does not categorize this project under NZEB definition.

The application of passive strategies in case study 2 such as DSF to provide natural ventilation and modification of building operation schedule and temperature set point change will reduce the building energy consumption from 110496 kWh/yr to 53191.44 kWh/yr or 4432.62 kWh/month or 52%. This modification will reduce the building energy cost from USD 1462.27/month to USD 1023.56/month or USD 12,282.72/yr instead of USD 17547.24/yr.

3.2.1 Scenario 1

The generated energy by PV panels will increase from 21366 kWh/yr to 42732 kWh/yr or 50%. The associated increase of cost will be USD 7317 instead of USD 3659 initial cost of PV panels' installation where the PV panel's energy generation will reduce the building energy use to 10,459 kWh/yr or 91%. According to new operation cost of USD 12,282.72/yr and reduced cost to USD 2415/yr, the building energy cost will reduce USD 9,868/yr. The initial (base case) SPBP of 2 years and 3 months will reduce to 10 months with ROI increase from 92.8% to 134.9%.

3.2.2 Scenario 2

The generated energy by PV panels will increase from 21366 kWh/yr to 51246 kWh/yr or 58% and the associated increase of cost will be USD 10233 instead of USD 3659 initial cost. The PV panel's energy generation will reduce the building energy use to 1,954 kWh/yr or 98% which defines the building almost as near NZEB. According to new operation cost of USD 12,282.72/yr and reduced cost to USD 451/yr, the building energy cost will reduce USD 11,832/yr and the initial SPBP of 2 years and 3 months will reduce to 11 months with ROI increase from 92.8% to 115.6% (Table 7).

3.3 RKIC improvement scenarios results

The building annual energy use is 1,362,772 kWh or 113,564 kWh/month. The modification of building operation schedule, temperature set point and consideration of natural ventilation influence with the mixed mode ventilation of DSF will reduce the energy use to 789,700 kWh per year or 65,808 kWh/month. This change will reduce the building energy cost almost 50% from USD 21,401/month to 12,516/month or USD 150,192 per year (₵ 18/ft^2) instead of USD 256,812 per year (₵ 31/ft^2).

3.3.1 Scenario 1

The installation of PV panels will generate 223,416.5 kWh/yr of energy and with consideration of USD 4.60/W for commercial systems of 100 kW in size , it will cost USD 563,132. The energy offset by the PV panels will reduce the building energy use from 789,700 kWh/yr to 566,283.5 kWh/yr and associated cost will reduce from USD 150,192/yr to USD 108,636/yr. The difference in the added cost of USD 563.132 of PV panels' addition and reduction of USD 106,620 due to the building schedule modification will cause USD 456,512 extra cost. However, the USD 41,556 saving due to the PV panels energy generation plus USD 106,620 (USD 148,176) saving each year, will cause the PV panels cost to be paid off in 3 years and 6 months (simple payback period of 3.5 years).

3.3.2 Scenario 2

The installation of PV panels will generate 365,821.25 kWh/yr of energy and with consideration of USD 4.60/W for commercial systems of 100 kW in size , it will cost USD 922,070. The energy offset by the PV panels will reduce the building energy use from 789,700 kWh/yr to 423,878.75 kWh/yr and associated cost will reduce from USD 150,192/yr to USD 82,140/yr. The difference in the added cost of USD 922,070 of PV panels' addition and reduction of USD 106,620 due to the building schedule modification will cause USD 815,450 extra cost. However, the USD 68,052 saving due to the PV panels energy generation plus USD 106,620 (USD 174672) saving each year, will cause the PV panels cost to be paid off in 5 years (simple payback period of 5 years) (Table 7).

Table 7: Cost-Benefit Analysis for NZEB Decision-Making

	Building 1: CDR			Building 2: Forum			Building 3: RKIC		
	Base Case	Scenario 1	Scenario 2	Base Case	Scenario 1	Scenario 2	Base Case	Scenario 1	Scenario 2
Energy Consumption (kWh/yr)	36111	29166	29166	110496	53191.44	53191.44	1,362,772	789700	789700
Energy Generation (kWh/yr)	4097	8333	9722	21366	42732	51246	0	223416.5	365,821.25
Cost ($/month)	892.8	839.63	839.63	1462.27	1023.56	1023.56	21401	12516	12516
Total cost ($)	9974	19948	19948	3659	7317	10233	256812	150192	82140
Building Energy Use (kWh/yr)	20833	9444	9444	10459	1954	1954	1,362,772	566283.5	423878.75
Simple Pay Back Period (SPBP)	8 years and 2 months	6 years and 10 months	5 years and 10 months	2 years and 3 months	10 months	11 months	N/A	3 years and 6 months	5 years

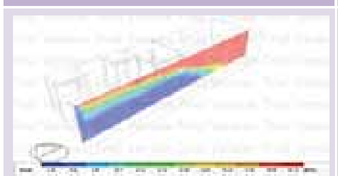
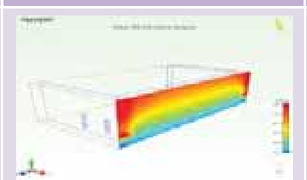
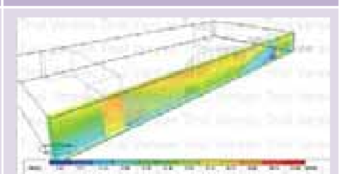
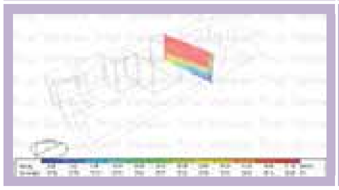
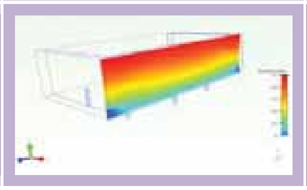
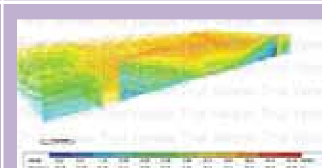
4.0 GLAZED FAÇADE & DSF THERMAL ANALYSIS VIA COMPUTER FLUID DYNAMICS

Application of new types of facade is necessary for more environmental friendly and energy efficient building design. However, there is a limited research of double skin façade and solely glazed covered façade concept performance at humid continental cities such as Lawrence, KS and Chicago, IL due to the focus of DSF Studies to the colder and more temperate climates of central Europe. In addition, available papers mostly describe DSF concept for energy efficiency through principles without any comprehensive experimental results .

4.1 Stack pressure (Thermal Buoyancy) in naturally ventilated façades

Buoyancy-driven ventilation is prevalent in many naturally ventilated buildings, with air flow caused by pressure differences across the building envelope. With this type of ventilation the pressure differences are due to air density differences, which in turn are due to temperature differences . It is the magnitude of these temperature and resulting pressure differences, as well as the building-opening characteristics that determine the magnitude of the buoyancy airflow. In stack-driven ventilation, height is increased and therefore the pressure difference between an inlet and outlet is increased. Above or below the neutral pressure level (NPL), airflow and direction can be determined; it is always from the higher-pressure region to the area of lower pressure. In other words, a temperature difference between the inlet and outlet can enhance the effects of buoyancy-driven ventilation. When the inside air temperature is greater than the outside air temperature, air enters through openings in the lower part of the building and escapes through openings at a higher level. Calculation of stack pressure is based on the temperature difference between the two air masses and the vertical spacing between the openings . When natural ventilation is used in a buoyancy-driven case, the airflow is not assisted by forced air from wind or mechanical systems .

Table 8: Natural ventilation heat transfer through the façade.

Building 1:	Building 2:	Building 3:
Center for Design Research (CDR)	The Forum	Richard Klarcheck Information Commons
		
		

4.2 Three case studies CFD analysis

The natural ventilation performance in DSF zone of case studies 2 and 3 and external glazing layer in thermal heat transfer through the building façade are presented in Table 8. Buoyancy driven flows predicted using space temperature calculated with 1000 iterations between airflow and thermal calculations. Through analysis, it was discovered that thermal buoyancy in the cavity was great enough resulting in warmed return air extracted from the space from the top of façade due to the Ventury effect . In all three cases, the stack air temperature increased towards the top of the façade in a fairly linear progression. Therefore, the findings show the efficiency of DSF in reducing the energy use by mechanical systems at DSF zone and necessity of façade reinforcement in the case of single layer glazing for thermal control of the indoor environment.

5.0 DISCUSSION

Three LEED-rated educational buildings feasibility to meet the NZEB energy efficiency were evaluated in this study. The costs of alternative energy improvements strategies are compared to a base case to determine if future operational savings justify the higher initial investments of additional PV panels to each building. The influence of natural ventilation and reduction in building energy use with consideration of new types of façade such as single layered glazed façade and double skin façade were evaluated through computer fluid dynamics.

The initial energy use in three building differs significantly and it can be related to the structure, building area, building operation schedule and glazing type/area in each case. All cases justify the initial investment in the case of PV panels increase and reduction of buildings energy use by through building operation schedule modification. In building 1 (CDR), the SPBP reduces significantly from 8 years-2 months to 6 years-10 months and 5 years-10 months in each scenario respectively. Similarly in building 2 (Forum), the SPBP reduces from 2 years-3 months to 10 months and 11 months respectively. In building 3 (RKIC), the facility with sole high energy consumption, generates energy through installation of PV panels with SPBP of 3.5 years and 5 years respectively (Figure 2). The application of scenario 2 (17% roof-17% south façade) in building 1 reduce the SPBP significantly in comparison to scenario 1 in the same building and it can be discussed as an interoperability between energy reduction factors and cost benefits (Figure 3). However, in the 2nd and 3rd building, the increase of PV panel's number and modification of building energy use in scenario 2 influences the SPBP negatively in comparison to scenario 1. This can be discussed as the importance of correlation between cost benefits and energy savings where despite the reduction in energy amount, the SPBP increases. The application of scenario 2 in 2nd and 3rd buildings presents the lack of interoperability between environmental issues and economic aspect and demonstrates the importance of further research to create the link between economic and environmental aspects to establish the basis of sustainability concept for NZEB.

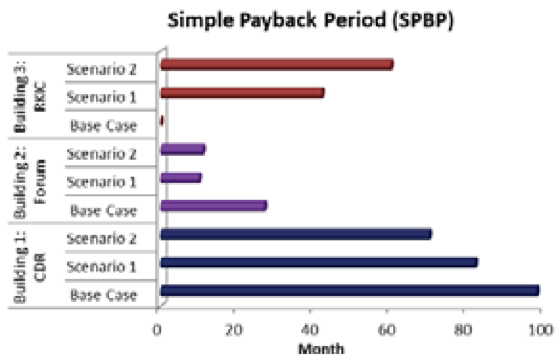


Figure 2: SPBP fluctuation in each case.

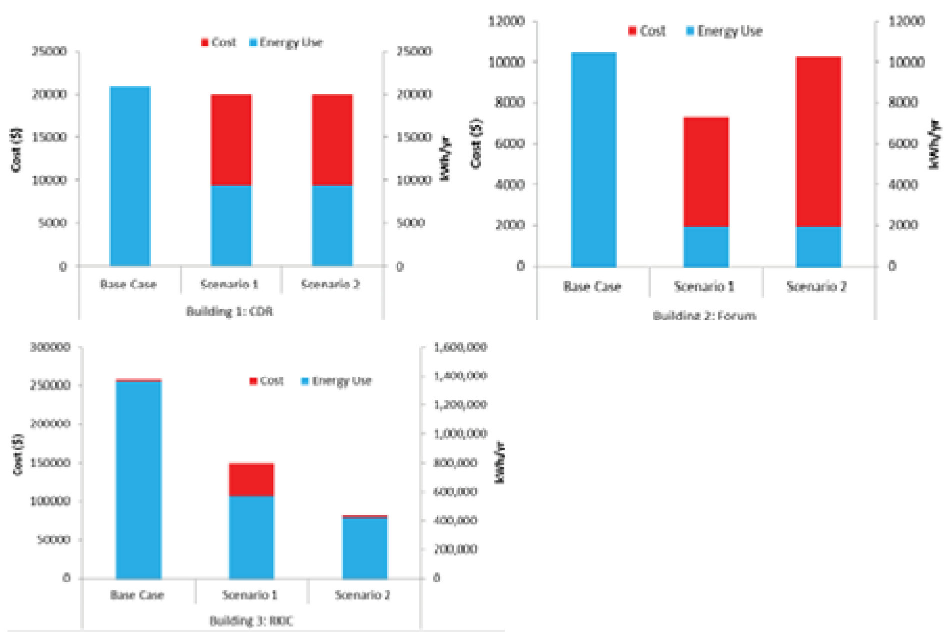


Figure 3: Energy use versus cost in each case.

The results obtained in this study, clarify the benefits of PV panels installation in order to generate energy and compensate for building energy use. However, the cost benefit analysis of PV panels contradicts the results obtained from energy analysis where the SPBP increases after installation of further PV panels in the 2nd and 3rd buildings. This observation highlights the importance of cost-benefit analysis for renewable energy systems such as PV panels to evaluate their adequacy in each project both environmentally and economically and clarifies the requirement of further research. Therefore, it is required to evaluate the optimum percentage of PV panels in every project to compensate for energy consumption while considering the life cycle cost of project and it is recommended to reduce the energy use in the building by modifying the building energy use first before consideration of PV panels installation or addition onsite.

The CFD analysis in 2nd and 3rd building presents the expected performance of double skin façade for the purpose of natural ventilation. In both cases, the cold air inlet from façade bottom entrance warms up by the occupant use and existing equipment and the hot air leaves the façade cavity zone at the upper level. However, the further research regarding the size of perforation at bottom and top of DSF cavity zone and the required area to compensate for mechanical ventilation through DSF natural ventilation effect is required in future research. In case 1, the CFD analysis presents the thermal heat circulation around the single layer glazed wall and indoor environment. As expected, the glazing surface creates a cold spot zone on the building exterior in comparison to indoor heated environment. The research on the glazing insulation and the design of shading devices to fulfill occupant comfort level around the glazing surface require future research.

6.0 CONCLUSION

In this paper, the operational performance of three LEED-rated educational buildings was evaluated using the Cost-benefit analysis and CFD simulation to evaluate and compare strategies to achieve Net Zero Energy Building (NZEB). The application of PV panels was evaluated in relation to building cost, energy performance and simple energy payback period (SPBP). The results in each case study are promising and present the possibility of achieving NZEB in educational buildings considering the location, climate and size of the structures. In the meantime, the nature of buildings and flexibility in the operation schedule during each semester (winter, summer) provides the opportunity to reduce the operation cost and to generate energy onsite while saving energy without deteriorating the comfort level of occupants in each case.

However, studies by show the vulnerability of PV panels to on-site factors such as deposition of dust, bird-droppings, water-stains (salts), and cracked individual cells, causing significant degradation in the efficiency of solar panels. Also, the study by the National Renewable Energy Laboratory (NREL) on 2000 solar panels present the decrease in the performance of PV modules over time with higher degradation rate in the first year upon initial exposure to light. Therefore, the risk of degradation over time indicates an uncertain state with possibility of financial loss and it requires further research in the future for the energy generation potential in the NZE buildings.

In conclusion, LEED-certified buildings are good candidates to become NZEB due to their nature by having larger spaces to accommodate the installation of renewable energies such as PV panels to generate energy and flexibility in their schedule to reduce energy consumption for HVAC, plug loads and lighting use.

Finally, the findings show this building type has great capacity to achieve the NZEB standard because of the variability in the occupancy and operation of the building, and the possibility to maximize the deployment of renewable energy systems.

REFERENCE

Butala, Vincenc, and Peter Novak. "Energy Consumption and Potential Energy Savings in Old School Buildings." *Energy and buildings* 29, no. 3 (1999): 241-46.

Data, Financial. "Integrys Energy Group Inc." (2014).

Dickson, Austin, Blair Garvey, and Michelle Larson. "Green Energy Options for Sustainable Local Economic Development: Policy, Financing and Strategies for Green Energy." *Georgia institute of technology, city and regional planning program, planning local economic development* (2007).

Energy, Westar, and Inc Settlement. "Epa." 2010.

Feldman, D, G Barbose, R Margolis, R Wiser, N Darghouth, and A Goodrich. "Photovoltaic (Pv) Pricing Trends: Historical, Recent, and near-Term Projections." National Renewable Energy Laboratory (NREL), Golden, CO., 2012.

Feldman, David. "Photovoltaic (Pv) Pricing Trends: Historical, Recent, and near-Term Projections." (2014).

Hottel, Hoyt, and B Woertz. "Performance of Flat-Plate Solar-Heat Collectors." *Trans. ASME (Am. Soc. Mech. Eng.);(United States)* 64 (1942).

Hunt, GR, and PP Linden. "The Fluid Mechanics of Natural Ventilation—Displacement Ventilation by Buoyancy-Driven Flows Assisted by Wind." *Building and Environment* 34, no. 6 (1999): 707-20.

Independence, Energy. "Security Act (Eisa). 2007. Energy Independence and Security Act of 2007." *Public Law* (110-40.

Jiang, Jess. "The Price of Electricity in Your State." *Planet Money. http://www. npr. org/blogs/money/2011/10/27/141766341/the-price-of-electricity-in-your-state* (2011).
Jiang, Yi, and Qingyan Chen. "Buoyancy-Driven Single-Sided Natural Ventilation in Buildings with Large Openings." *International Journal of Heat and Mass Transfer* 46, no. 6 (2003): 973-88.
Lin, YJP, and PF Linden. "Buoyancy-Driven Ventilation between Two Chambers." *Journal of Fluid Mechanics* 463 (2002): 293-312.
Milke, James A, and Tony C Caro. "A Survey of Occupant Load Factors in Contemporary Office Buildings." *Journal of Fire Protection Engineering* 8, no. 4 (1996): 169-82.
Olson, Stephen L, and Shana Kellum. "The Impact of Sustainable Buildings on Educational Achievements in K-12 Schools." *Leonardo* 2 (2003).
Pappas, Alexandra, and Zhiqiang Zhai. "Numerical Investigation on Thermal Performance and Correlations of Double Skin Facade with Buoyancy-Driven Airflow." *Energy and buildings* 40, no. 4 (2008): 466-75.
Pless, Shanti, and P Torcellini. "Energy Performance Evaluation of a Low-Energy Academic Building: Preprint." National Renewable Energy Laboratory (NREL), Golden, CO., 2005.
Saelens, Dirk, Jan Carmeliet, and Hugo Hens. "Energy Performance Assessment of Multiple-Skin Facades." *HVAC&R Research* 9, no. 2 (2003): 167-85.
Tabrizi, Aydin, and Paola Sanguinetti. "Case Study: Evaluation of Renewable Energy Strategies Using Building Information Modeling and Energy Simulation." *International Journal of 3-D Information Modeling (IJ3DIM)* 2, no. 4 (2013): 25-37.
Tabrizi, Aydin; , and Paola Sanguinetti. "Nzeb Enhancement for a Leed Platinum Educational Facility ". *Journal of Civil Engineering and Architecture* (2014).
Wagner, Andreas, Thomas Lützkendorf, Karsten Voss, Guido Spars, Anton Maas, and Sebastian Herkel. "Performance Analysis of Commercial Buildings—Results and Experiences from the German Demonstration Program 'Energy Optimized Building (Enob)'." *Energy and Buildings* 68 (2014): 634-38.
Zöllner, A, ERF Winter, and R Viskanta. "Experimental Studies of Combined Heat Transfer in Turbulent Mixed Convection Fluid Flows in Double-Skin-Facades." *International Journal of Heat and Mass Transfer* 45, no. 22 (2002): 4401-08.