Feasibility of Converting an Existing Recreational Facility into a Net-Zero Energy Building: KFUPM Beach Case Study

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In general, the implementation of energy efficient measures, EEM's can bring down the energy consumption of residential or non-residential buildings by about 30%. The Net-zero Energy Building, NZEBconcept is usually applied to newly designed buildings. However, the number of already constructed buildings will always outnumber the newly planned buildings. Therefore, this study focuses on techno-economic feasibility of converting an existing recreational facility, King Fahd University of Petroleum & Minerals. KFUPM beach to NZE facility. Its location Al-Khobar, the Eastern Province of Saudi Arabia, considered as one of the most arid and dry climates in the world. This harsh weather imposes another challenge in minimizing Heating, Ventilation and Air-Conditioning load. The objective of the present study is to conduct feasibility study in two phases. In the first phase, measures will be identified to minimize the energy utilization, mainly in terms of the thermal load. In the second phase, a hybrid microgrid solar photovoltaics (PV's)/wind energy system will be designed and optimized to meet the demand. The study focusses economic feasibility of the hybrid microgrid renewable system design based on cost of energy, net present cost, payback period, reduction in carbon footprint, and initial and operational costs.

Keywords: *Net-zero energy building (NZEB), Solar Energy, Photovoltaics (PV), Wind Turbine, Hybrid Energy*

1. INTRODUCTION

In October 2021, Saudi Arabia announced its ambition to reach net zero carbon emissions by 2060 [1]. This pledge was taken at the 26th UN Climate Change Conference (COP26) in Glasgow in October 2021 [2]. Saudi Arabia is world's major oil exporter and its energy demand is met by burning fossil fuels. The government's initial goal is to generate at least 9.5 gigawatts of renewable energy from solar and wind re–source [3]. Due to rapid industrialization and population growth in Saudi Arabia, the energy demand is expected to increase three-fold by 2030 [4]. Almost 50% energy is utilized by non-residential sector and this requirement expected to increase 6-8% annually [5]. This problem can be addressed by implementing energy efficient measures, EEM's specially for already constructed buildings, dwellings, and facilities and also by meeting power requirements by renewable energy sources. The concept of Net-zero energy building, NZEB is usually applied to newly designed buildings. However, the number of already constructed buildings will always outnumber the newly planned buildings. Therefore, this study focuses on techno-economic feasibility of converting a recreational facility, King Fahd University of Petroleum & Minerals, KFUPM beach to NZE facility. The beach is located in Al-Khobar, the Eastern Province of Saudi Arabia, considered as one of the most arid and dry climates in the world. This harsh weather imposes another challenge in minimizing the Heating, Ventilation and Air-Conditioning, HVAC load. In general, the implementation of Energy Efficient Mea–sures, EEM's can bring down the energy consumption of a building or facility by about 30% [6]. The analysis will also include a hybrid microgrid renewable energy system design using solar photovoltaics, PV's and wind turbines to meet the optimized load demand.

The main focus of this study is the economic fea–sibility of the hybrid microgrid renewable energy sys–tem design to be assessed based on project indicators like cost of energy, COE, net present cost, NPC, pay–back period, reduction in carbon footprint and initial and operational costs.

To the best of authors' understanding, this kind of a study which involves both the implementation of EEM's and design of microgrid hybrid renewable energy to fully meet the minimized load requirement of an existing facility is the first of its kind in the region. Also, since KFUPM is one of the leading educational institutes in the region, this project will create an ideal awareness about the importance of NZEB to achieve long term sustainability goals of the kingdom. This proposed NZEB model can be applied to other recre–ational facilities in similar climatic conditions.

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The overall objective of this study is to conduct the feasibility study for converting the KFUPM Beach to NZEB's in two phases. In the first phase, measures will be identified to minimize the energy utilization, mainly in terms of the thermal load. In the second phase, a hybrid microgrid solar photovoltaics (PV's)/wind energy system will be designed to meet the demand of the facility. The specific objectives are:

1. Identification of energy efficient measures, EEM's to minimize the energy demand.
2. Assessment of solar and wind resources for both the locations.
3. Designing a hybrid microgrid renewable energy system using solar photovoltaics, PV's and wind turbines.
4. Conducting a thorough techno-economic analysis to determine payback period, levelized cost of energy (COE), net present cost (NPC), and subsequent reduction in greenhouse gas (GHG) emissions.

Some of the recent studies related to the design of net zero energy facility are reviewed and summarized in Table 1. The advantages and the drawbacks of each study aresystematically discussed.

Table 1. Literature review

Ref.	Methodology used	Advantages	Shortcomings
[6]	The Mechanical Engineering Technology building at the college of technological studies was targeted to convert to NZEB by adopting the following methodology: Determination of the building data like total floor area, orientation of the building with the glass doors and windows on each side, the occupant density profile, heat transfer coefficient of wall and roof, HVAC system with the number and type of chillers used. The application of EEM's in the building is simulated by EnergyPlus program. Three PV module types were studied using Transient simulation (TRNSYS) program to cater the minimized energy requirement of the building. The parameters used for the assessment of the project weregreenhouse gasesreduction, Simple and Energy payback periods, LCOE, Solar thermal fraction and system efficiency	An efficient use of HVAC system mostly related to the design and usage schedule of chillers and lighting system was proposed. It was simulated that with these changes, almost 27% (660 MWh) less energy will be consumed, equivalent to around 550 tons of CO_2 emissions. Three different PV modules were studies and the best case scenario is found to have a LCOE of \$0.09/kWh and a payback period of less than 12 years.	A hybrid microgrid renewable energy system is not proposed. Only solar PV was explored to cater to the energy demands of the building. In some scenarios, the monthly net-zero was not achieved. The battery storage is not discussed. In case of power failure, a battery backup is usually recommended. The initial investment in application of EEM's is not discussed.
[11]	A 2-storey hospital building is targeted to convert to NZEB by adopting the following methodology: The thermal load and the peak load of the hospital building is determined. The external and the internal load is estimated based on ASHRAE standards for hospitals. The heat transfer for the glass and wall materials is determined. Solar resources for the region is determined and HOMER pro software is used to develop a model consisting of solar PV and battery storage. For the assessment of the project NPC, operating cost, and payback period is analyzed. Sensitivity analysis is also performed.	The COE decreased from 0.14 to0.12 USD/kWh The proposed system is 10% more profitable than the grid only system. The proposed system has a payback period of 2.53 years.	This proposed hybrid RE design is found to meet only 75% of the hospital demand throughout the year. The remaining electricity demand is met from the national grid. So, it is not 100% renewable system.
[10]	Out of five tourist cities/facilities in Egypt, one optimum city was selected to establish an environmentally-friendly facility. The system design consists of the solar PV/wind/ diesel/battery and wind/diesel/battery systems. The study methodology included: Identification of the optimum tourist city based on COE and NPC, and GHG emissions. Determination of the load profile with peak load for the most optimum facility. Determination of the solar and wind resource of the region. The evaluation of four various hybrid energy system design consisting of solar photovoltaics(PV)/wind/ diesel/battery	As many as five tourist cities were evaluated for four various hybrid designs consisting of the solar photovoltaics(PV)/wind/ diesel/battery. For each hybrid design, the most optimum city was selected based on COE, NPC, and the GHG emissions.	EEM's for any of the facilities were not discussed. The system design also consisted of a diesel generator, hence, it is not 100% renewable design.

The highly sophisticated and materialistic human life styles have resulted in 30% increased energy con–sumption [7,8]. An inefficient energy consuming buil–ding was converted into a net-zero energy building (NZEB), [6], through effective andefficient cost and energy measures and integrating with PV systems. The study showed an annual energy saving of 1,480 MWh, reduction of 1,021 tons of CO_2 emissions, and simple payback period of 3 years. A hypothetical building was considered to conduct a relative study of a hybrid micro-grid NZEBs for temperate and tropical envi–ronments, considering one-year meteorological data [4]. The study reported payback periods of 1.84 and 2.66 years for Thailand and Pakistan with respective reduc–tion in unit cost of energy of 31% and 27%. The designed systems were around 9% and 7% more cost-effective compared to the existing grid system in Thai–land and Pakistan [9]. To establish an environmentally and economically optimal tourist village among five Egyptian cities such as Qena, Luxor, Giza, Alexandria, and Aswan. [10,11] found that Alexandria to be most viable location for hybrid photovoltaics/wind/diesel/ battery and wind/diesel/battery systems, while Aswan the next best performer for photovoltaic/diesel/battery hybrid system. The proposed optimum hybrid power system, for a village in Alexandria, consisted of 1,600 kW of PV panels (58.09%), 1,000 kW of wind turbines (41.34%), 200 kW of diesel generator (0.57%), 1,000 kW converter, and 589 Ah capacity of batteries. Diabt et al. [10] reported a levelized COE of 0.17 $/kWh with NPC of $15,383,360.

A wind-solar PV hybrid system was assessed in this study by Homeida et al. [12] in order to power a 100 kta green hydrogen plant in Yanbu, Saudi Arabia. The results indicated that 100% solar PV offered the lowest cost of hydrogen (~$1.65/kg) and electricity (~$26.5/MWh) under net metering. Although the hybrid system has a lot of economic potential, the analysis's generalizability is limited because it makes assumptions about fixed tariffs, grid backup, and low electrolyzer efficiency. In order to characterize wind regimes, Shah–zada et al [13] fitted Weibull distributions to ten years' worth of wind data collected at nine coastal locations along Saudi Arabia's Red Sea coast. The authors estimated the number of Electric Vehicle, EV charging ports that could be dependably powered by standalone wind plus battery systems by evaluating the capacity factors of 36 distinct turbine models of rated capacities (1.5–4 MW). Authors discovered that many places, particularly in the southwest, exhibit poor viability for wind-based charging infrastructure, while only a limited number of sites (such as Neom and Yanbu) had mar–ginal wind potential. The study's conclusions heavily rely on the sites selected, the turbine models, and the assumptions made about load profiles. It is primarily technical and does not include economic analysis.

Bosko et al. [14] used a vortex lattice/free-wake approach to model wake interactions in order to develop a genetic algorithm-based method for optimizing wind farm layouts. According to the results, overall energy output was greatly increased by optimizing turbine po–sitions outside of fixed grid patterns. Although efficient, the approach was computationally demanding and igno–red long-term operational or wider economic consi–derations. The techno-economic performance of glazed versus unglazed flat-plate solar collectors for industrial solar water heating of 24,000 L/day in Abha, Saudi Arabia, was assessed by Rehman et al. [15]. In com–parison to unglazed collectors, it was reported that glazed collectors produced substantially higher heat output and solar fractions (approximately 150% more), as well as greater fuel and cost savings. Glazed types were preferred by economic metrics (Internal Rate of Return, IRR, payback periods), although IRR is sens–itive to inflation and declines with system size. Geog–raphic specificity, the assumption of constant cost/tariff parameters, and the exclusion of long-term degradation effects were the study's limitations.

The entire development cycle for contemporary wind turbine rotor blades was reviewed in [16], including conceptual design, material selection, structural analysis, manufacturing, and validation/testing. In order to lower costs, increase dependability, and spur innovation, the study identified best practices for coordinating these phases. Its main conclusions included that improved blade performance results from early integ–ration of aerodynamic and structural design and that standardized testing methods facilitate comparison and scaling. Lack of reliable fatigue and long-term field data, as well as challenges associated with extrapolating lab results to full-size blades, were some of the limi–tations mentioned.

The design of rotor blades using composite lami–nates, their manufacturing, and experimental verifi–cation through static and dynamic tests (stiffness, na–tural frequencies, vibration modes) were described in paper [17]. It identified that the manufactured composite blades fulfilled the desired mechanical performance standards. However, the study did not thoroughly exa–mined scaling to larger blade sizes and had limitations in evaluating long-term durability (e.g., fatigue, envi–ronmental aging).

Using actual wind data from Turaif, Saudi Arabia, Mohandes et al. [18] examined the effects of grid size (i.e., layout resolution) on wind farm optimization using a genetic algorithm. They discovered that while exe–cution time does not significantly correlate with grid size, larger grid sizes (e.g., 19×19) produce higher con–version efficiencies (≈ 0.992) than smaller ones (10×10 gives ~0.813). One drawback considered was the fixed wind direction and the number of turbines, which limits their applicability to more intricate, real-world designs.

The design, fabrication, and verification testing pha–ses of a wind turbine rotor blade composed of laminated composite materials were presented by Rasuo and Veg [19]. Dynamic tests measured the natural frequencies, vibration modes, damping ratio, and fatigue behavior; while static tests evaluated the torsional and flexural stiffness as well as elastic-axis position. The authors de–monstrated that, under the tested loads, the composite blade satisfies the necessary mechanical and dynamic performance requirements. Not all in-field variability may be captured by fatigue/damage scenarios, as envi–ronmental durability testing is relatively limited.

A hybrid microgrid Net Zero Energy Building, incorporating PV panels and inverters was proposed for a two-story hospital structure located in Taxila, Pakistan

[11]. The modelling and optimization analysis of the proposed system suggested payback period of 2.53 years with COE of 0.12 $/kWh. Abdulkarim [20] simu–lated the sustainable green/clean energy utilization in the mosque buildings using ANSYS software in Sulai–maniyah city, Iraq. The study employed pipes grid around the foundations of the mosque filled with hot water used as a heater to minimize the electricity con–sumption. Elshurafa et al. [21] performed techno-eco–nomic analysis of a 124 kW installed capacity PV system on the roof top of a mosque in Riyadh, Saudi Arabia, considering net metering mechanism. The study found that at a capital cost of 1.18 $/W, the net metering reduced the annual energy bill by almost 50% with a capacity factor of 18.2%.

Yumul and Domingo [22]studied the feasibility of retrofits to the existing university gymnasium to make a nearly zero-energy building. In the research, the emp–hasis was placed on reducing the consumption of energy by applying fundamental techniques of energy effici–ency and satisfying the rest of the demand by solar pho–tovoltaic power generation. The approach of the re–search included the assessment of energy, load calcu–lation, size determination of the PV system, and an economic analysis performed by introducing the techni–ques of payback value and economic savings. Though the analysis proved the feasibility of being close to a net-zero energy building, the approach was restricted to a single form of renewable energy system, failing to take into account the combination of hybrid solar and other forms of renewable energy systems, along with the effects of adverse climatic conditions. Furthermore, the techniques of reducing the thermal loads and HVAC optimization have not been properly investigated.

Sidney et al [23] examined the technical and econo–mic viability of transforming an existing university building into an NZEB. The work was centered on the analysis of present building energy use, the adoption of energy efficiency techniques, and the use of on-site renewable energy technologies, especially solar photo–voltaic systems. The analysis was based on building simulation, demand-supply alignment, and economic viability using net present cost, payback period, amon–gst other parameters. It can be seen that, despite con–firming that a building can achieve NZEB performance, the scope of the study was limited to a moderately climatic area and based on the use of single renewable technologies alone, thus identifying an area of research to develop the study on NZEB in extreme climatic conditions involving hybrid systems for renewables.

A research gap in the application and validation of a practical NZEB solution approach for existing uni–versity buildings was also identified in the Ascione et al. (2018) study[24], which evaluated the gap between the existing energy performance of university buildings and the almost zero energy building (nZEB) standards. Ins–tead, the need for analyzing the current performance level of university buildings in use and the scope for improvement in energy efficiency was fulfilled by the Ascione et al. (2018) study. Similarly, in the Ascione et al. (2018) research, the analysis of the gap between the existing performance level of university buildings in use and the almost zero energy building standards was accomplished.

This study examines the techno-economic feasibility of retrofitting the KFUPM Beach recreational facility in Saudi Arabia into a net-zero energy facility under hot arid climatic conditions. Unlike most existing studies that focus on new buildings or single renewable sources, this work integrates energy efficiency measures with a hybrid solar PV–wind microgrid to fully meet the re–duced demand of an existing facility. Economic perfor–mance is evaluated using cost of energy, net present cost, payback period, and emission reduction metrics. The study addresses the lack of comprehensive NZEB retrofit analyses for existing recreational facilities in extreme climates.

This study offers a practical methodology for retro–fitting existing recreational and institutional facilities into net-zero energy facilities by integrating energy efficiency measures with a hybrid solar PV–wind mic–rogrid. The proposed approach can support university campus energy planning and decision-making by provi–ding clear techno-economic indicators such as cost of energy, net present cost, and payback period. The findings are particularly applicable to facilities opera–ting in hot arid climates, where cooling loads dominate energy consumption, and the proposed NZEB model can be adapted to similar facilities seeking to reduce grid dependence and carbon emissions.

2. STUDY SITE DESCRIPTION

2.1 Study Siteand Load Profile

Geographic coordinates of the site are 26°6'7"N 50°6'40"E, with an approximate area of 805,608 square meters. Situated in Al-Khobar, Eastern Province, Saudi Arabia, this beach is a prominent location within the region.The average annual energy consumption of the beach for the years 2020, 2021 and 2022, was 833,019, 838,035 and 913,410 kWh. The average monthly consumption for the last three years was 69,418, 69,836 and 76,118 kWh. The peak load of 95,345 kWh was observed in the month of October during three years. October falls in Autumn (mid-September to Mid-December) is similar to spring when daytime temperatures remain between 25 -30 °C with cooler evenings. During Saudi Arabia's winter days, the climate offers balmy temperatures during the day and cooler nights, creating an ideal environment for activities such as camping, rock climbing, or exploring verdant highlands. Consequently, these recreational facilities experience increased usage during this season.

The proposed model aims to produce 2,500 kWh daily, featuring a peak load of 352 kW and a load factor of 0.3. The beach location of KFUPM is illustrated in Figure 1, while Figure 2 presents the average synthetic daily load profile. Additionally, Figure 3 showcases the average monthly load profile, with July identified as the peak load month.

This project targets to convert the KFUPM beach to NZE facility. The methodology includes determination of the thermal load at the beach with details about the type of lighting of the individual chalets and streets, the heat load of the shower facilities and cafeteria etc. The solar and wind resource at the location will be assessed to design a hybrid microgrid renewable energy system by using HOMER Pro software.

Figure 1. The KFUPM Beach

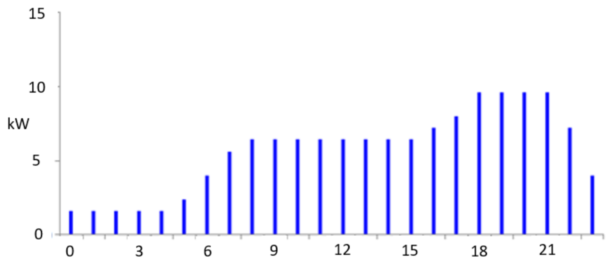

Figure 2: The average daily load profile

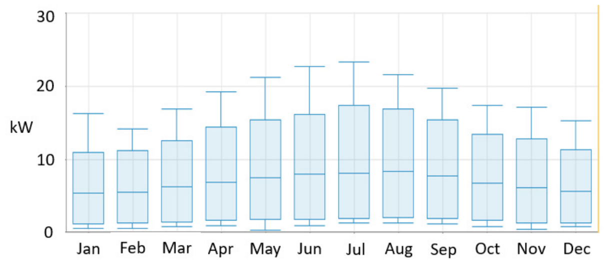

Figure 3. The average monthly load profile

2.2 Research Methodology

The methodology of the study is shown in Figure 4. Firstly, the street and chalet lighting is assessed and found to be optimum. The air conditioning in the mosque, cafeteria and other places is assessed. There is an abundant open area near the sea and also towards the parking and may be a good option for PV panels and wind turbines installation. The analysis excludes shading from adjacent buildings. HOMER software input data consists of monthly meandaily solar global horizontal radiation(GHI, measured in kWh/m²/day), obtained from a dataset spanning approximately 22 years. The wind resource is found to be favourable near the seaside. The feasibility of converting the recre–ational facility to a net-zero facility is then evaluated. A PV-wind system with a converter and battery storage is suggested. Equation (1) is utilized to determine PV array output, P_{pv}.

$$P_{WTFG} = \left(\frac{\rho}{\rho_0}\right) \cdot P_{WTG,STP} \tag{1}$$

where:

Y_{PV} = Rated capacity of the PV array [kW]

f_{PV} = PV derating factor [%]

$\bar{G}_T$ = Solar radiation [kW/m^2]

$G_{T,STC}$ = Incident radiation at standard test conditions [1 kW/m^2]

α_P = Temperature coefficient of power [%/°C]

T_C = PV cell temperature [°C]

$T_{c,STC}$ = PV cell temperature at standard conditions [25°C]

To deal with the difference between the real- and ideal operating conditions in which PV panelsarerated, the derating factor, f_{PV} is introduced. The derating factor take care of soiling effect, cable losses, shading, snow cover, and aging. In present case, derating factor is taken as 88% [25]. The total Net Present Cost (NPC) is calculated (Eq. 2) by summing the discounted cash flow for each year throughout the project's duration.

$$C_{NPC} = \frac{C_{ann.tot}}{CRF_{\left(i,R_{proj}\right)}} \tag{2}$$

In equation 2, $C_{ann.tot}$ denotes the total annualized cost, with "i" representing discount rate and "R_{proj}" indicating project lifetime. The capital recovery factor, estimates the total capital cost of a system into an equivalent annualized cost over the project lifetime, accounting for the interest rate, denoted by CRF(i,R_{proj}), is determined by Eq. (3).

$$CRF\left(i,N\right) = \frac{i\left(1+i\right)^N}{i\left(1+i\right)^N - 1} \tag{3}$$

The Cost of Electricity (COE) is calculated by dividing the annualized cost of electricity generation by total electrical load, with 'N' indicating the number of years. Equation (4) is used to compute COE, where E_{prim} and E_{def} represent the yearly primary and deferrable load, respectively, and $E_{grid.sales}$ denotes annual energy sold to grid.

$$COE = \frac{c_{ann.tot}}{E_{prim} + E_{def} + E_{grid,sales}} \tag{4}$$

The Simple Payback Period (SPP) is the duration to recover its initial cost. Internal Rate of Return (IRR) measures the profitability of an investment. SPP and IRR are determined as follows:

SPP = Investment Cost /Annual average Cash flow (5)

$$IRR = \left(\frac{Future\,Value}{Net\ Present\ Cost} \right)^{(1/N)} - 1 \quad (6)$$

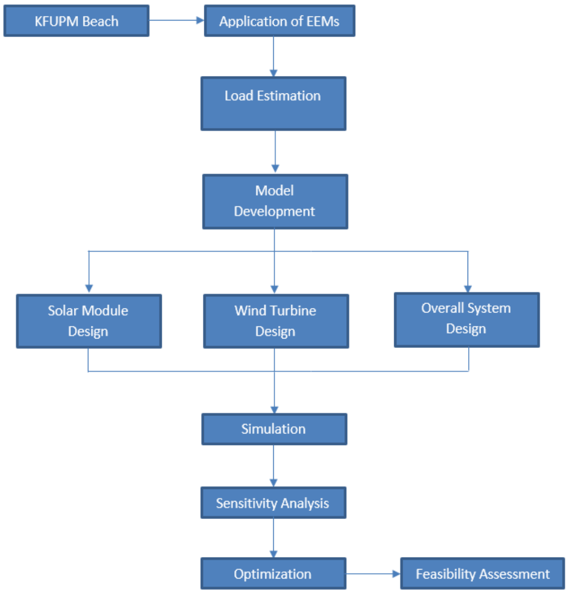

Figure 4: The Methodological framework of the study

Next, we specify the characteristics of the approp–riate PV panel. Information on costs and technical details are summarized in Table 2. The project lifetime discount rate is established at 8%, with an inflation rate of 2%. The optimized grid-connected system is charac–terized by its average energy output (kWh), maximum power capacity (kW), Cost of Electricity (COE, in $/kWh), initial investment, Net Present Cost (NPC, in USD), and System Payback Period (SPP, in years) [26].

Table 2: The system architecture and technical data of the components

S.No	Component	Name	Size	Unit
1.	PV	Generic flat plate PV	921	kW
2.	Storage	Generic 1kWh Lead Acid	5,804	strings
3.	Wind turbine	Generic 3 kW	25	ea.
4.	System converter	System Converter	363	kW

2.3 Solar and Wind Resource Assessment

Figure 5 displays the GHI, with ameanvalue of 5.65 kWh/m²/day and clearness index (CI) in the range of 0.5 to 0.7. The monthly averaged wind speed at 50 m above ground level (AGL)over a 30-year period (1984 – 2013) is presented in Figure 6. The wind shear profile at the location with small shrubs and trees is shown in Figure 7. The maximum and the minimum wind speed values occurred in the months of June and October. The Wei–bull shape and 1-hour autocorrelation factors are found to be 2 and 0.85 while the diurnal pattern strengths and the hourly peak wind speed are0.25 and 15 m/s; res–pectively. Hourly solar irradiance, wind speed, and load profiles were obtained from the HOMER Pro software database, which utilizes long-term meteorological data from publicly available sour–ces such as NASA POWER and typical load profile generation algorithms.

In this study, the HOMER Pro software is utilized to calculate the wind power at each time step, employing three-step methodology. Initially, it discerns the wind speed at the turbine's hub height and calculates the wind power generated at this wind speed under standard air density conditions. Finally, the software adjusts the out–put to account for actual air density. The wind speed at the hub height is extrapolated utilizing the prescribed equation:

$$U_{hub} = U_{anem} \cdot \frac{\ln\left(\frac{z_{hub}}{z_0}\right)}{\ln\left(\frac{z_{anem}}{z_0}\right)} \quad (7)$$

where:
U_{hub} = wind speed at the hub height [m/s]
z_{hub} = hub height [m]
z_{anem} = anemometer height [m]
z_0 = surface roughness length [m]
ln(..) = natural logarithm

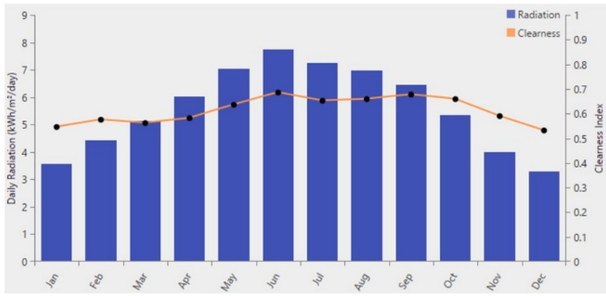

Figure 5. Monthly global horizontal irradiance (GHI) and clearness index data

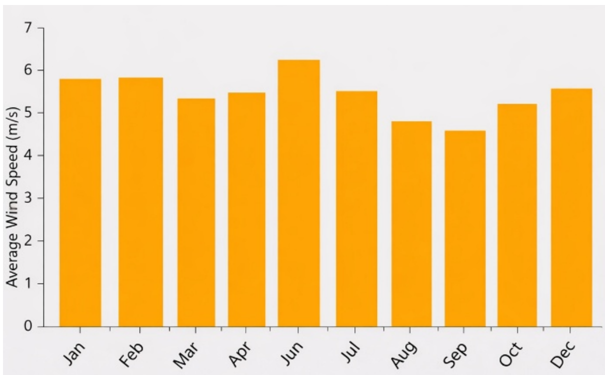

Figure 6. Monthly mean wind speed, m/s

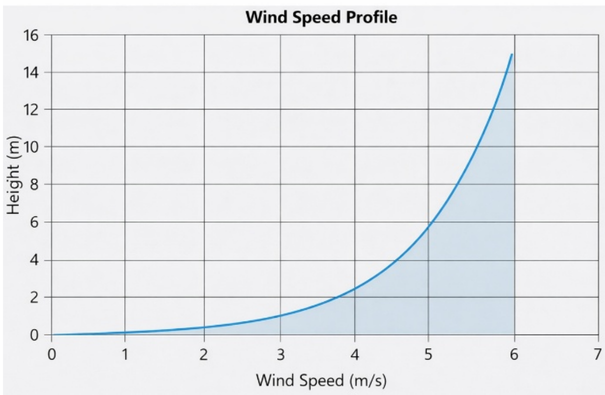

Figure 7. Wind shear profile at the location

The power output is calculated under standard atmospheric conditions with hub height wind speed and turbine's power curve. In the associated diagram, the red dotted line depicts the wind speed at hub height, while the blue dotted line shows the wind power output. If the wind speed falls outside the limits defined by the power curve at the turbine’s hub height, the turbine ceases operation, following the rule that it does not function below the cut-in or above the cut-out wind speeds. Po–wer curves generally reflect turbine performance under standard temperature and pressure (STP) conditions. HOMER modifies the calculated power by applying the air density ratio:

$$P_{WTFG} = \left(\frac{\rho}{\rho_0}\right) \cdot P_{WTG,STP} \tag{8}$$

where:
P_{WTG} = Wind machine power output [kW]
$P_{WTG,STP}$ = Wind machine power output at standard pressure and temperature [kW]
ρ = Air density [kg/m^3]
ρ_0 = Air density at standard conditions (1.225 kg/m^3)

3. RESULTS AND DISCUSSION

In this research, a standalone hybrid system is designed to meet a daily primary load of 2,500 kWh, with a peak demand of about 352 kW. The project lifespan is set as 25 years with discount and inflation rates of 8% and 2%. The proposed hybrid system layout, illustrated in Figure 8, is simulated using HOMER Pro 14. The optimal grid-connected system is chosen based on the lowest COE and NPC, as detailed in Table 3. Ope–rations and maintenance costs for the system converter are negligible, and all component replacement costs are assumed to be identical to the capital cost. A summary of component costs is provided in Figure 9, while Table 4 details the breakdown of the NPC.

The total NPC of the system is around $ 7 million. More than half of this total cost is attributed for the storage system. On grid smart system without storage is found to be more cost effective but it will not be fully renewable. The LCOE for the optimum configuration is 0.594 $/kWh. In the optimum configuration, PV is found to meet 91% of the total load and the remaining is met by the wind turbines. The LCOE values for energy produced from PV and wind are 0.117 and 0.305 $/kWh; respectively.

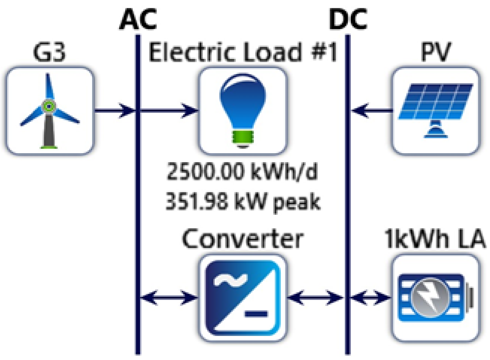

Figure 8. The system configuration

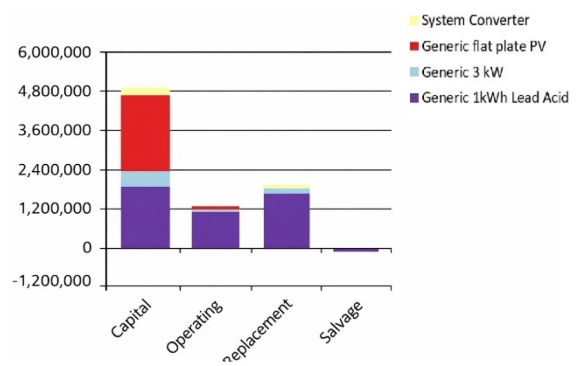

Figure 9. The cost summary

Table 3. The optimization results

Architecture				Cost				PV		Wind Turbine		
PV (kW)	*Wind Turbine, 3 kW*	*1kWh LA*	*Converter (kW)*	*NPC ($)*	*COE ($)*	*Operating cost ($/yr)*	*Initial capital ($)*	*Capital Cost ($)*	*Production (kWh/yr)*	*Capital Cost ($)*	*Production (kWh/yr)*	*O&M Cost ($)*
890.72	25	5,957	4,26.3,206	7,006,608	0.59436	1,867,96.2	4,591,797	2,226,800	1,546,185	450,000	144,035.3	4,500

Table 4. Net Present Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Generic 1kWh Lead Acid	$1.74M	$750,313	$1.56M	-$187,629	$0.00	$3.87M
Generic 3 kW	$450,000	$58,174	$143,463	-$80,851	$0.00	$570,786
Generic PV	$2.30M	$119,016	$0.00	$0.00	$0.00	$2.42M
System Converter	$108,782	$0.00	$46,153	-$8,687	$0.00	$146,248
System	$4.60M	$927,502	$1.75M	$277,166	$0.00	$7.00M

4. CONCLUSIONS

Higher education institutions play an important role in the demonstration of practical pathways toward sustai–nable energy transitions. Beyond economic perfor–mance, this study fills in an integrated engineering fra–mework that will retrofit an existing recreational facility into a net-zero energy facility under hot arid climatic conditions-a context insufficiently explored in the current NZEB literature. The work systematically com–bines demand-side energy efficiency measures, hybrid renewable energy system design, and techno-economic optimization within a unified modeling approach.

The results show that a hybrid solar PV–wind microgrid is able to reliably serve the reduced energy demand at the KFUPM Beach, with solar PV providing the dominant share of energy, and wind supplementing generation on non-peak solar periods. In the analysis, the strong impact of energy storage on system feasibility was explored, showing key trade-offs among renewable penetration, system reliability, and economic perfor–mance. These will be useful engineering insights into the design of the optimum renewable-based microgrids, not merely by minimizing cost.

From a research and development point of view, contribution of this research is that it increases the state of art of NZEB retrofitting by simultaneously addres–sing existing buildings, hybrid renewable systems, and harsh climatic conditions, which is not very commonly done together within the previous studies. The proposed approach can be applied for similar institutional and recreational buildings and help increase independence from fossil fuel-based power generation. From an overall point of view, the contribution of the proposed work is addressing the gap between theoretical models of NZEB and their implementation.

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NOMENCLATURE

E	Energy, kWh
P	Power, kW
C	Cost, USD
COE	Cost of Energy, USD/kWh
NPC	Net Present Cost, USD
CRF	Capital Recovery Factor
i	Discount (interest) rate, %
n	Project lifetime, years
L	Electrical load, kW
E_{PV}	Energy generated by photovoltaic system, kWh
E_{WT}	Energy generated by wind turbine, kWh
G	Global horizontal solar irradiance, kWh/m²/day
v	Wind speed, m/s
GHG	Greenhouse gas emissions, kg CO_2-eq
CAPEX	Capital expenditure, USD
OPEX	Operation and maintenance cost, USD/year

Acronyms and Abbreviations

NZEB	Net-Zero Energy Building
NZE	Net-Zero Energy
KFUPM	King Fahd University of Petroleum & Minerals
EEMs	Energy Efficiency Measures
HVAC	Heating, Ventilation, and Air Conditioning
PV	Photovoltaic
WT	Wind Turbine
COE	Cost of Energy
NPC	Net Present Cost
CRF	Capita Recovery Factor
GHG	Greenhouse Gas
HOMER	Hybrid Optimization Model for Electric Renewables
O&M	Operation and Maintenance
RE	Renewable Energy
kW	Kilowatt
kWh	Kilowatt-hour
USD	United States Dollar

Superscripts

co	convective section
f	furnace section

ИЗВОДЉИВОСТ ПРЕТВАРАЊА ПОСТОЈЕЋЕГ РЕКРЕАТИВНОГ ОБЈЕКТА У ЗГРАДУ СА НУЛТОМ НЕТО ЕНЕРГИЈОМ: СТУДИЈА СЛУЧАЈА ПЛАЖЕ KFUPM

Ш. Рехман, М.А. Басир

Генерално, имплементација енергетски ефикасних мера, ЕЕМ, може смањити потрошњу енергије стамбених или нестамбених зграда за око 30%. Концепт зграде са нултом нето енергијом, NZEB, обично се примењује на новопројектоване зграде. Међутим, број већ изграђених зграда ће увек бити већи од новопланираних зграда. Стога се ова студија фокусира на техно-економску изводљивост претва–рања постојећег рекреативног објекта, Универзитета за нафту и минерале краља Фахда, плажа KFUPM, у објекат NZE. Његова локација је Ал-Хобар, источна провинција Саудијске Арабије, која се сматра једном од најсушнијих и најсушнијих клима на свету. Ово сурово време намеће још један изазов у минимизирању оптерећења грејања, вентилације и климатизације. Циљ ове студије је спровођење студије изводљивости у две фазе. У првој фази, биће идентификоване мере за минимизирање потрошње енергије, углавном у погледу термичког оптерећења. У другој фази, хибридни микромрежни соларни фотонапонски (ФН)/систем енергије ветра биће пројектован и оптимизован како би задовољио потражњу. Студија се фокусира на економску исп–лативост дизајна хибридног микромрежног система обновљивих извора енергије на основу трошкова енергије, нето садашњих трошкова, периода поврата инвестиције, смањења угљеничног отиска и почет–них и оперативних трошкова.