ZEROBUILD JOURNAL

Vaka Analizi

Vatandaş ve ark. 02:02 (2024) 139-150

Mevcut Binaların Enerji Performansının Artırılarak Net Sıfır veya Neredeyse Sıfır Enerji Bina Dönüşümü Hedefine Yönelik Vaka Çalışması

Sedat Vatandaş[1] Sercan İşcan[2] İlhan Seven[1] Emre Ünalan[2]

[1]Enerman Danışmanlık Gayr. Ith. Ihr. Ltd. Şti., Barış 120 Sk. No:3 Kat.1 Nilüfer, Bursa
[2]Boğaziçi Üniversitesi Yapı İşleri Daire Başkanlığı, Kuzey Kampüs, Sarıyer, İstanbul
Sorumlu Yazar: sedat.vatandas@enerman.com.tr

Öne Çıkanlar

- Binalarda enerji verimliliği önlemleri çalışıldı
- Uygun elektrik kullanımı yöntemi seçilerek emisyon azaltıldı
- Pratik Bir Enerji verimliliği finansal analiz yöntemi önerildi.

Geliş Tarihi: 19.06.2024 Kabul Tarihi: 22.07.2024 Doi: 10.5281/zenodo.13117697

Amaç:
Bu çalışmada, yaklaşık 20.000 m² kullanım alanına sahip, 225 TEP(ton eşdeğer petrol) enerji kullanımı olan bir öğretim binasının mevcut enerji kullanımı detaylı bir şekilde incelenmiş ve bu analiz sonucunda verimlilik önerileri sıralanmıştır. Enerji verimli bina uygulamalarının ötesinde Neredeyse Sıfır Enerji Bina (nSEB) ve Net Sıfır Enerji Bina (NSEB) uygulamaları için yapılabilecek çalışmalar emisyon, maliyet gibi parametreler üzerinden analiz edilmiştir.

Metot:
Enerji verimli bina, nSEB ve NSEB uygulamaları olacak şekilde üç senaryo hazırlanmıştır. Her bir senaryo için tespit edilmiş projelerin yatırım maliyeti, enerji kazancı, geri dönüş süresi, emisyon kazançları hesaplanarak tablolar halinde sunulmuştur. Her senaryonun yatırım maliyeti, yıllık kazancı, geri dönüş süresi, emisyon azaltımı ve ton emisyon azaltımı başına yatırım maliyetleri hesaplanarak kıyaslanmıştır.

Sonuç:
Kıyaslama neticesinde mevcut binalarda enerji verimli bina çalışmalarının ötesinde nSEB uygulamaları için 2 kat, NSEB uygulamaları için ise 3 kat daha fazla ilk yatırım maliyeti oluştuğu görülmüştür. Enerji verimli bina, nSEB ve NSEB uygulamaları ile sırasıyla %35, %69 ve %100 verimlilik sağlandığı görülmüştür. Ton emisyon azaltım maliyetleri kıyaslandığında en yüksek maliyetin NSEB bina uygulaması için olduğu en düşük maliyetin ise nSEB bina uygulamaları için olduğu hesaplanmıştır. Yenilenebilir enerji uygulamaları neticesinde nSEB ve NSEB uygulamalarının geri dönüş süresinin enerji verimli bina uygulamalarına göre daha kısa olduğu belirlenmiştir.

Anahtar Kelimeler: Enerji Etüdü, Bina Enerji Etüdü, Enerji verimli bina, nSEB ve NSEB uygulamaları

ZEROBUILD JOURNAL

Case Study

Vatandas et al. 02:02 (2024) 139-150

Case Study on Improving the Energy Performance of Existing Buildings Towards Net Zero or Nearly Zero Energy Building Transition

Sedat Vatandaş[1] Sercan İşcan[2] İlhan Seven[1] Emre Ünalan[2]

[1]Enerman Danışmanlık Gayr. Ith. Ihr. Ltd. Şti., Barış 120 Sk. No:3 Kat.1 Nilüfer, Bursa
[2]Boğaziçi Üniversitesi Yapı İşleri Daire Başkanlığı, Kuzey Kampüs, Sarıyer, İstanbul
Sorumlu Yazar: sedat.vatandas@enerman.com.tr

Highlights:

- Energy Efficiency Measures in Buildings was Studied
- Emissions were reduced by choosing the appropriate electricity consumption method
- A practical energy efficiency financial analysis method was proposed.

Received: 19.06.2024 Accepted: 22.07.2024 Doi: 10.5281/zenodo.13117697

Abstract

The European Union introduced the concepts of Nearly Zero Energy Building (nZEB) and Net Zero Energy Building (NZEB) in 2010, leading to a shift in energy efficiency efforts in buildings, especially in response to increasing energy consumption. In this study, the current energy usage of an educational building with an approximate usable area of 20,000 m² and an energy consumption of 225 TOE (tons of oil equivalent) was thoroughly examined. Based on this analysis, efficiency recommendations were made. Beyond energy-efficient building applications, potential studies for Nearly Zero Energy Building (nZEB) and Net Zero Energy Building (NZEB) applications were analyzed in terms of emissions and costs.

The benchmarking results showed that the initial investment cost for nZEB applications in existing buildings is twice as much, and for NZEB applications, three times as much, compared to energy-efficient building works. It was observed that energy-efficient building, nZEB, and NZEB applications provide efficiency rates of 35%, 69%, and 100%, respectively. When comparing the costs of emission reduction per ton, the highest cost was calculated for NZEB applications at 107,274 TL, while the lowest cost was for nZEB applications at 96,252 TL.

Keywords: Energy Audit, Building Energy Audit, Energy efficient building, nZEB and ZEB applications

1. Introduction

With the growing population and advancing technology, energy usage has been rapidly increasing in buildings, as in all other areas. Notably, the proportion of energy consumption in buildings within the total energy use has shown significant growth over the years. Since 2015, emissions from buildings have been increasing by an average of 1% annually [1].

The emissions are the unconscious or uncalculated use of fossil fuels to meet energy needs. 40% of the world's total energy consumption comes from buildings [2]. In 2022, the energy consumption in the building sector increased by approximately 1%.

Within the framework of sustainable development goals, energy efficiency in buildings holds a significant place in aligning with the Paris Climate Agreement and the goal of becoming carbon-neutral. The European Green Deal, signed in 2019, aims to make the European Union (EU) climate-neutral by 2050. It reports that a plan will be presented to increase the EU's greenhouse gas emission reduction target for 2030 to at least 50% and 55% compared to 1990 levels [3]. In this context, the necessity for the efficient use of energy in buildings highlights the need for energy-efficient buildings, (nZEB), and (ZEB).

With the enactment of the Energy Efficiency Law in 2007, Türkiye entered a new phase, committing to becoming carbon neutral by 2053. Alongside this, efforts are underway to increase the average energy performance of public institutions by 30% by 2030, compared to the 2016-2017-2018 averages [4]. The energy efficiency of existing buildings and the construction of nZEB and NZEB are being supported through various incentive mechanisms. As in other developing countries, Türkiye is experiencing increased building demand due to a growing population and a decreasing average household size. According to building usage permit statistics in Türkiye, an average of 106,000 new buildings are constructed annually. There is significant potential in the rapidly growing and transforming building stock for the efficient use of energy and the widespread adoption of on-site energy production [5].

Below are definitions of new concepts currently being discussed worldwide in the context of low energy, passive energy production, and energy efficiency:

Energy Efficient Building: An energy-efficient building uses less energy compared to a conventional building while providing greater comfort to its occupants. These buildings typically save energy through a combination of energy-efficient building components, high-efficiency HVAC (Heating, ventilation and air Conditioning) systems, and renewable energy sources [6].

Nearly Zero Energy Building (nZEB): A nearly zero energy building is characterized by very high energy performance, consuming minimal energy from external sources. Energy consumption should be close to zero or at a minimum, and any energy needed should be met through renewable energy produced on-site or nearby [7].

Net Zero Energy Building (NZEB): A net Zero Energy Building (NZEB) is an energy-efficient building where, on an annual basis, the total energy consumed is equal to or less than the renewable energy produced on-site [8].

2. Material and Method

The study measured the current energy performance of an academic building called the Square (Education) Building, located on the North Campus of Bogaziçi University. Projects aimed at achieving energy efficient building, nZEB, and NZEB standards were identified and compared. Since there are no submeters to determine the energy consumption of individual buildings, and all buildings on campus use electrical energy under single subscription.

This methodology involved calculating electricity and natural gas consumption by using Equation (1) and Equation (2) with coefficients determined based on buildings respective consumption purposes. In Table 1, the electrical energy consumption breakdown calculated by the following equation is presented;

$$C_E(\%) = \frac{(A \cdot EC) \cdot 100}{\sum(A.EC)} \tag{1}$$

Where CE is the electricity consumption of the building (%), A is the total area (m2), and EC is the coefficient of electricity consumption. The electricity consumption coefficients were introduced based on a scoring system is given in Table 2.

Natural gas consumption is calculated by Equation (2);

$$C_N(\%) = \frac{(A \cdot NC) \cdot 100}{\sum(A.NC)} \tag{2}$$

Here CN is the natural gas consumption of the building (%) A is the total area, and NC is the natural gas consumption coefficient. The natural gas consumption coefficient is determined based on the scoring system presented in Table 3. The natural gas consumption coefficients are introduced in Table 4.

Energy consumption data has been compiled on a monthly basis following energy audits conducted in buildings. Based on the results of these audits, projects have been identified to enhance energy efficiency. All savings are calculated and compared with the building reference energy consumption shown in Table 5. Initially, projects were prioritized to reduce the building's energy demand as per the base scenario. Projects identified in the base scenario aimed at reducing the structural energy consumption of the building are listed (Appendix 1). The primary project involved an insulation study due to the lack of insulation in the building envelope.

This study was conducted in accordance with TS 825 standards, and post-insulation energy consumption of the building was assessed.

Table 1. Electricity Consumption Breakdown

	Building Name	Area (M^2)	Electricity Cons. Coef.	Energy Consumption	Natural Gas Consumption %
		A	E_C	$A \times E_C$	
01	Library	7,946.52	1	7,946.52	%8.89
02	Education Building	18,281.09	3	54,843.28	%61.36
03	Lab	2805.74	2	5,611.47	%6.28
04	Library Add. Building	3,578.65	1	3,578.65	%4.00
05	New Classroom	8,701.65	2	17,403.29	%19.47
	Total Area:	**86,960**			

Table 2. Electricity Consumption Coefficients

Coefficient	Coefficient Explanation
1	Library where circulation is high and the number of equipment consuming electricity is low with respect to unit area.
2	Buildings with intensive use, such as classrooms and laboratories, where there is no circulation.
3	Educational buildings where there are both classrooms and academic staff rooms and the number of equipment is higher than the others

Table 3. Natural Gas Consumption Breakdown

	Building Name	Area (m^2)	Natural Gas Cons. Coef.	Energy Consumption	Natural Gas Consumption %
		A	N_C	$A \times N_C$	
01	4. Dormitory	6,373.23	2	12,746.45	%12.09
02	Education Building	18,281.09	1	18,281.09	%17.34
03	3. Dormitory	5,536.71	2	11,073.43	%10.51
04	2. Dormitory	3,496.47	1	3,496.47	%6.63
05	New Classroom	8,701.65	1	8,701.65	%8.25
	TOTAL AREA:	**86,960**			

Table 4. Natural Gas Consumption Coefficients

0	Security offices that do not use natural gas, etc.
1	Daily used buildings such as classrooms and libraries
2	Buildings used day and night, such as lodgings and dormitories.

Table 5. Building Reference Energy Consumption

	Electricity (TOE)	Natural Gas (TOE)	Total (TOE)	Primary Energy (TOE)
Reference Energy	130.94	113.75	244.69	352.85

Additionally, recommendations have been developed to reduce energy demand using thermostatic valves. Other projects aimed at decreasing energy demand include completing insulation deficiencies in heat transmission lines.

Since electricity is used directly, the plan focuses on reducing demand through technological changes rather than structural alterations. The most crucial project in this regard is the conversion of lighting to LED (light-emitting diode). This initiative includes assessing lighting levels and recommending the conversion of fixtures to LED for improved energy efficiency.

In the study, energy efficiency practices were aimed at reducing the building's energy demand through structural projects. As a result of these efforts, the building's energy class increased from E to C, indicating that the 2030 target of 30% energy efficiency will be achieved.

The building's energy supply for heating with boiler rooms and transitioning from split air conditioners to centralized cooling has been evaluated for nZEB or NZEB applications. Additionally, electricity generation through photovoltaic system installations has been assessed.

Appendix 2 and Appendix 3 lists the projected projects for nZEB and NZEB in addition to existing energy efficiency measures. Scenario outcomes have been studied based on these projected projects. Energy classes of the buildings regarding scenarios are shown in Figure 1.

3. Results and Discussion

For the evaluation of an existing building's energy efficiency towards nZEB and NZEB standards, various projects have been developed:

A common project across all scenarios was the insulation project, which aims to reduce energy demand. This highlights the necessity of initially reducing energy demand through structural changes to achieve energy efficiency. These measures not only decrease energy consumption but also enhance comfort levels, leading to long-term cost savings.

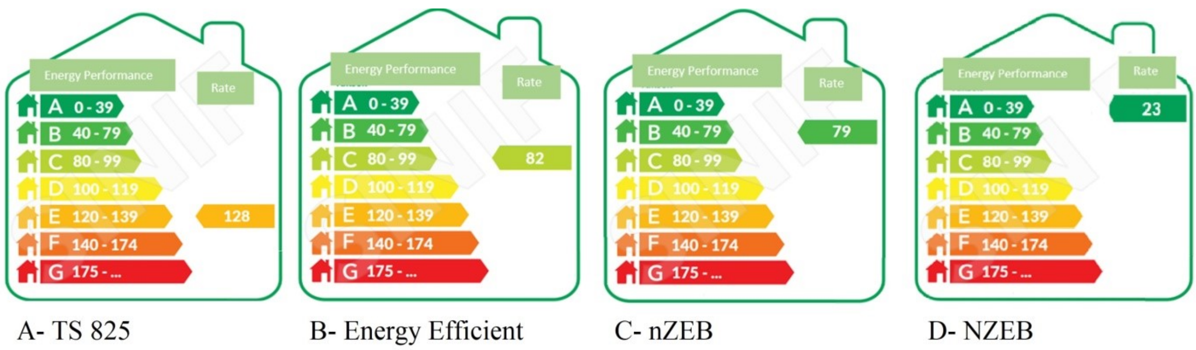

Figure 1. Energy Performance Target of Buildings

Table 6. nZEB and NZEB Measures

nZEB	**NZEB**
Boiler Replacement - Natural Gas Hot Water Boiler	Central Heating and Cooling System - VRF
Central Cooling System - VRF	800 kW PV System
500 kW PV System	

Basic structural projects and fast-gain projects have been developed for energy-efficient buildings. Unlike the energy-efficient building scenario, projects that have been studied for nZEB and NZEB are shown in Table 6. In the nZEB's scenario, boiler replacement with condensing boilers has been implemented to enhance energy efficiency. Considering the abundance of split air conditioners in the building, an evaluation for a Variable Refrigerant Flow (VRF) system for cooling has been conducted. Additionally, a solar power plant was installed to benefit from renewable sources. These steps aim to optimize energy usage both in natural gas and electricity consumption, while increasing renewable energy generation to ensure electricity is consumed where possible.

Another common project for all three scenarios is replacing lighting systems with LED fixtures. Lighting contributes the highest amount of electricity usage in a building, generally consuming from 20% to 50% of the total electricity. The efficient and effective use of lighting can offer major energy and cost savings [9]. Other projects were determined based on cost, savings, and decarbonization considerations. For the nZEB scenario, projects focused on reducing natural gas usage, while for the NZEB scenario, projects focused on electrification and installing higher capacity solar power systems.

In the nZEB application, electricity savings are calculated at 73.6%, and natural gas savings at 70.9%. Overall primary energy savings are determined to be 69%.

For the NZEB application, the building's heating system is entirely electrified with the implementation of VRF systems throughout. This eliminates the need for natural gas and facilitates full electrification, complemented by increasing the installed capacity of the solar energy plant to meet all electricity demands. Thus, the solar energy plant is expected to cover 100.7% of the electricity usage, effectively eliminating natural gas usage.

The outcomes of these projects have been evaluated, and summarized results are provided in Table 7.

As the building's energy savings increase, it is observed that the investment cost also increases, while the cost per ton of emission reduction also rises. Additionally, with the increase in investment cost, the simple payback period decreases.

The fact that buildings were not initially designed as NZEBs during their construction phase results in significant cost increases when retrofitting for efficiency measures. Therefore, it can be said that the design phase is the most important step of a ZEB project. Everything starts at the design desk and affects all dimensions from the first moment until the first invoice is received in the operation phase. A lot of responsibility falls on the leader of the design team (usually an architect with experience in ZEB) [10].

Table 7. Savings, Payback Period, and Emission Reduction

	Investment Cost (Euro)	Annual Savings (Euro)	PBP* (y)	Primary Energy Savings (%)	Emission Reduction (ton-CO_2)	Investment per Emission Reduction (Ton/Euro)
Energy Efficient Building	683,512.15	45,709.42	14.95	35%	243,34	2,808
nZEB	1,512,015.59	156,20470	9.68	69%	565,52	2674
NZEB	2,005.923,72	215,181.24	9.32	100%	673,17	2980

* **PBP:** Payback Period

4. Conclusion

In this case study, an energy assessment of an educational building was conducted to carry out energy enhancement projects. Projects necessary for the building to become an energy-efficient building, nZEB, and NZEB were studied in three scenarios.

Due to the high cost and long payback period of the insulation project, nZEB reduced the cost per emission compared to an energy-efficient building. However, the cost per emission increased for NZEB due to the high cost of the VRF project necessary for electrification. The high cost of the VRF project is attributed to the extensive labor required for changing the heating and cooling systems in the existing building.

In conclusion, integrating various renewable energy applications will support the net zero energy process in buildings, further reducing their energy demands and contributing to environmental sustainability.

Design phase is the most important step of the building for the energy performance. Regarding results NZEB scenario is the shortest amortization period while investment cost is the highest. If the projects were carried out in the design phase, investment could be decreased.

Another key finding is that Türkiye’s target of 30% energy efficiency in public buildings by 2030 is seen as a reasonable and achievable goal within the scope of this study. Achieving Turkey's energy efficiency and renewable energy targets will enhance competitiveness nationally and internationally while ensuring future energy security. Thus, the importance of investments in energy efficiency and renewable energy is paramount, requiring continued encouragement and support for initiatives in this field.

5. References

[1] IEA-Breakthrough Agenda Report 2023-Buildings Report

[2] Harputlugil, T., & de Wilde, P. (2021). The interaction between humans and buildings for energy efficiency: A critical review. Energy Research & Social Science, 71, 101828

[3] Wolf, S., Teitge, J., Mielke, J., Schütze, F., & Jaeger, C. (2021). The European Green Deal—more than climate neutrality. Intereconomics, 56(2), 99-107

[4] Türkiye Presidential Circular No. 2023/15 dated 04/11/2023

[5] Republic of Turkey Ministry of Energy and Natural Resources - Energy Efficiency Strategy and 2nd National Energy Efficiency Action Plan (2024-2030)

[6] Wu, Z., Jin, Y., Huang, L., Zhang, N., Luo, X., Wang, X. "Appraisal of Indoor Environment Quality IEQ in Nearly Zero Energy Building nZEB: A Literature Review," Science and Technology for the Built Environment, vol. 29 (3), pp. 251-267, February 2023

[7] Kurnitski, J., Allard, F., et. al. "How to Define Nearly Net Zero Energy Buildings nZEB," REHVA Journal, May 2011.

[8] ''A Common Definition for Zero Energy Buildings,'' U.S Department of Energy, Sept. 2015

[9] Wan Norsyafizan W. Muhamad; Mohamad Yusof Mat Zain; Norfishah Wahab; Noor Hafizah Abdul Aziz; Rosmalini Abd Kadir '' Energy Efficient Lighting System Design for Building'' International Conference on Intelligent Systems, Modelling and Simulation, January, 2010

[10] ASHRAE (Firm). (2018). Advanced Energy Design Guide for K12 School Buildings: Achieving Zero Energy. ASHRAE.

Appendix 1. Energy Efficiency Measures

No	Energy Efficiency Measure (EEM)	Energy Type	Calculated Annual Energy Savings (kWh)	Calculated Annual Energy Savings (TOE)	Total Energy savings	Calculated Annual Cost Savings (Euro)	Emission Reduction [ton-CO_2]	Estimated Cost (€)	PBP (y)
1	7.463.4 m² of exterior walls in contact with outside air insulated with 8 cm Rock Wool (U Rock Wool = 0.035 W/m²K), 505.5 m² of earth-contact walls insulated with 6 cm XPS (U XPS = 0.030 W/m²K), and 4480 m² of roof insulated with 8 cm Glass Wool (U Glass Wool = 0.035 W/m²K).	Natural Gas	490,022.91	42.14	56.67%	17,902.17	114.67	431,419.74	24.10
2	3.501 lighting systems replaced with LED fixtures, implementation of 75 motion sensors, and 132 lighting kits.	Electricity	193,698.96	16.66	22.40%	21,084.13	86.00	185,553.26	8.80
3	Insulation completion for uninsulated heating system components.	Natural Gas	67,311.00	5.79	7.78%	2,459.10	15.75	40,484.44	16.45
4	Usage of 448 thermostatic valves and 6 frequency-controlled pumps.	Natural Gas	112,171,.35	9.65	12.97%	4,097.99	26.25	26,090.72	6.12
		Electricity	1,525.34	0.13	0.18%	166.03	0.68		
	Total Savings	Natural Gas	669,505.26	57,58	77.42%	24,459.26	156.66	497,958.90	14.95
		Electricity	195,224.30	16.79	22.58%	21,250.16	86.68	185,553.26	
		Total	864,729.56	74.37		45,709.42	243.34	683,512.15	

Appendix 2. nZEB Energy Efficiency Measures

No	Energy Efficiency Measure (EEM)	Energy Type	Calculated Annual Energy Savings (kWh)	Calculated Annual Energy Savings (TOE)	Total Energy savings	Calculated Annual Cost Savings (Euro)	Emission Reduction (ton-CO_2)	Estimated Cost (€)	PBP (y)
1	Insulation of exterior walls in contact with outside air with 8 cm Rock Wool, earth-contact walls with 6 cm XPS, and roof with 8 cm Glass Wool	Natural Gas	490,022.91	42.14	23.80%	17,902.17	114.67	431,419.74	24.10
2	3.501 lighting systems replaced with LED fixtures, implementation of 75 motion sensors, and 132 lighting kits.	Electricity	193,698.96	16.66	9.41%	21,084.13	86.00	185,553.26	8.80
3	2 units of floor-standing condensing boilers (799 kW, 80/60 C), external air compensation automation for the heating system and piping.	Natural Gas	268,573.81	23.10	13.05%	9,811.90	44.52	110,074.81	11.22
4	Implementation of VRF (Variable Refrigerant Flow) system with 12 outdoor units and 191 indoor units, replacing 191 split air conditioners.	Electricity	235,768.00	20.28	11.45%	25,663.35	92.4	409,053.63	15.94
5	Installation of a 500 kWp solar power plant.	Electricity	689,665.01	59.31	24.02%	75,070.04	185.26	309,375.00	4.12
6	Insulation completion for uninsulated heating system components.	Natural Gas	67,311.00	5.79	3.27%	2,459.10	15.75	40,484.44	16.45
7	Usage of 448 thermostatic valves and 6 frequency-controlled pumps.	Natural Gas	112,171.35	9.65	5.45%	4,097.99	26.25	26,090.72	6.12
		Electricity	1,525.34	0.13	0.07%	166,03	0.68		
	Total Savings	Natural Gas	938,079.07	80.67	45.57%	34,271.16	201.18	608,033.70	9.68
		Electricity	1,120,657.30	96.38	54.43%	121,983.55	364.34	903,981.89	
		Total	2,058,736.37	177.05		156,254.70	565.52	1,512,015.59	

Appendix 3. NZEB Energy Efficiency Measures

No	Energy Efficiency Measure (EEM)	Energy Type	Calculated Annual Energy Savings (kWh)	Calculated Annual Energy Savings (TOE)	Total Energy savings	Calculated Annual Cost Savings (Euro)	Emission Reduction (ton-CO_2)	Estimated Cost (€)	PBP (y)
1	7,463.4 m² of exterior walls in contact with outside air insulated with 8 cm Rock Wool (U Rock Wool = 0.035 W/m²K), 505.5 m² of earth-contact walls insulated with 6 cm XPS (U XPS = 0.030 W/m²K), and 4480 m² of roof insulated with 8 cm Glass Wool (U Glass Wool = 0.035 W/m²K).	Natural Gas	490,022.91	42.14	17,16%	17,902.17	114.67	431,419.74	24.10
2	3.501 lighting systems replaced with LED fixtures, implementation of 75 motion sensors, and 132 lighting kits.	Electricity	193,698.96	16.66	6,78%	21,084.13	86.00	185,553.26	8.80
3	Implementation of VRF (Variable Refrigerant Flow) system for heating and cooling.	Natural Gas	832,651.51	71.61	29,16%	30,419.54	194.84	893,950.72	15.94
		Electricity	235,768.00	20.28	8,26%	25,663.35	92.4		
4	Installation of a 800 kWp solar power plant.	Electricity	1,103,464.01	94.90	38,64%	120,112.06	185.26	495,000.00	4.12
	Total Savings	Natural Gas	1,322,674.42	113.75	46.32%	48,321.71	309.51	1,323,370.46	9.32
		Electricity	1,532,930.97	131.83	53,68%	166,859.54	363.66	680,553.26	
		Total	2,855,605.39	245.58		215,181.24	673.17	2,005,923.72	