International Journal of
Science and Engineering Investigations vol. 5, issue 48, January 2016
ISSN: 2251-8843

Technical and Economic Feasibility of Constructing a Zero-Energy Building: An Iranian Case Study

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Abstract- In this research, technical and economical studying of creating a zero-energy building is explored. The building under study is a sports complex located in Zanjan climate, to conserve electricity and gas some actions were taken that have been studied in this building such as: setting the temperature for the summer and winter, setting and servicing burners, installation of air curtains, replacement of ballast induction with electronic one, installing awning windows, and installation of intelligent control room at a cost of about 1,588 dollars, and also items such as: installation of solar water heater, installation of electro-Volta cells and installation of wind turbines at a cost of about 118,480 dollars which are checked by RETScreen. All the mentioned costs were approximately 120,068 dollars, and with this amount of investment 21037 m^3/year saving in gas consumption and 155,005 kwh/year savings in power consumption will be brought about.

Keywords*- zero-energy building, renewable energy, energy consumption optimization, RETScreen software*

I. INTRODUCTION

Nowadays, by reduction in the amount of fossil fuel reserves and the increasing trend of energy prices and more importantly pollution caused by the extraction and use of fossil fuels, and likewise the use of modern technology, zero-energy building is a suitable option for moving forward in reducing energy consumption and eliminating the costs and consequences of environmental problems [1]. For the construction of these buildings, on one hand building's energy consumption should be reduced as much as possible and then by producing energy from renewable sources of energy, the least amount of energy required by building is produced [2]. According to the statistics published, in zero-energy buildings, energy consumption is much lower than typical similar buildings, and this amount in the United States is 75%, in the UK 77%, and Ireland is 85% [3]. With increasing energy costs in 1970 and 1980 in most parts of the world, building engineers and designers thought of building a house with very low energy consumption. By growing governmental attention to this issue in the United States, according to the law adopted in 2007 to support the creation of buildings with net zero energy consumption, half of the commercial buildings until 2040 and all commercial buildings in the United States until 2050 should be zero energy [4]. In Europe, in 2010, it was decided that from 2018, in public and government buildings the issue of approaching zero energy consumption should be discussed, and from 2020 onwards be applied for all new buildings. [5]. In Iran in 1991 with the adoption of section 19 in the field of energy saving, its application became mandatory for public buildings since 2005. Running this topic increases construction cost up to 5%, but reduces the heating and cooling system capacity by 40%.

In literature, articles published in 70s and 80s are among the first attempts to embrace the path of zero-energy buildings (ZEB).

Numerous articles are offered in the field provided [6-11]. Hernandez and Kenny [12] suggested that building energy balance is not just related to the energy used in the operation stage, but the energy used in the building construction should also be considered. In an article [14] Laustsen and [13] Mertz and et al. energy balance reflects the state of energy flow between the buildings and energy installations. Torcellini and colleagues [15] were among the first people who significantly worked in the field of renewable energy. Marszal and colleagues [16] presented a graphical model of renewable energy supply options. Many models of energy audits have been performed by the RETScreen Software of which the efforts of Khatami and colleagues [17] in Iran, Amir Mahmoud and colleagues in Pakistan [18], Abdul Rahman et al in Saudi Arabia [19], Swart et al. South Africa [20], Neamt and colleagues in different places of earth [21], Goshwe et al [22] in Nijeria and also Albadi and colleagues [23] in Oman can be noted.

II. SPECIFICATION OF THE CASE STUDY

A. Geographic location under study

In this part, a sports complex building in Zanjan province located in northwest of Iran will be explored in terms of energy consumption and ways to reduce energy consumption and achieve zero net energy construction. First, the climate condition of the area under study is introduced. The city of Zanjan is located in the center of Zanjan province. The area of this city is 81 kilometers which is located at 48 degrees longitude and 36 degrees latitude, and altitude of 1663 meters above sea level. The temperature cooling outside the city is -6.7 degrees and the temperature of the heating is 24.3 degrees. Solar energy as a source of thermal energy production is used by solar collector and the electric energy by the electro-Volta cells which are available in most parts of the country, especially in western and southeastern areas.

B. Building under study

The mentioned Sports Complex is located in northwestern Iran. Building plan is a regular polygon. In this complex there is a niche with the height of 15 meters and total foundation of 1798 square meters and consists of a 2-storey building and a sports hall, buildings use is office and sports and there is a maximum of 150 people. The façade of the building is a combination of stone and aluminum and exterior walls thickness is 35cm. Its heating system is provided by the central engine room, there is an air conditioner for ball sports hall, and 19 coil fans are used for office buildings, and cooling is provided by one absorption chiller to provide cooling capacity of 50 tons. The total amount of electricity used in the building according to calculation from electrical equipment was considered as 136502 kWh/year, and gas consumption according to the energy consumption of buildings and equipment was considered as 58601 m^3/year. With regards to the area of infrastructure of building, the ratio of annual electrical energy is 47 kWh per square meter for electricity and 31 m^3 per square meter for gas consumption, if this amount is converted to energy unit that is kilowatt-hours (with conversion ratio of 9.5 kWh for a cubic meter of natural gas) is equal to 295 kWh per square meter for natural gas consumption of the building. The outer shell of the building has respected the requirements of section 19 of the National Building Regulations about energy saving, and external walls have thermal insulation and its windows are double-glazed made of UPVC, which will prevent the loss of a lot of values of energy. One of the most important parameters in determining energy consumption is determining the heat transfer coefficient of outer shell of the building. To determine this factor, at first one should examine the various components of the outer shell and the heat transfer coefficients of each segment. According to the information, the area of the roof will be achieved as 1528 m^3 the area of the exterior walls as 1916 m^2, area of windows as 113 m^2, area of doors as 12m^2 and the floor area of the sports complex as 1516 m^2.In this building, electricity is used for lighting and power equipment, and natural gas is used to provide cooling, heating and hot water. Sum of energy consumption in various sectors, and equipment in the building calculated and given in Table I.

III. COMPUTATIONAL SOFTWARE

Clean Energy Project Analysis Software, RETScreen Software, is the leading software in making decisions related to clean energy. The software significantly reduces the cost needed to implement the project and sets up business in clean energy as well as costs (financial and time) associated with identifying and assessing potential energy projects. All project models are included in this software, and have traditional and non-traditional sources of clean energy resources and their common technologies.

TABLE I. POWER EQUIPMENT OF THE BUILDING

Lighting equipment			row
watt	number	kind	1
1600	40	Fluorescent	2
5200	260	Fluorescent	3
750	30	Fluorescent	4
845	65	Fluorescent	5
14000	35	Helium vapor	6
80	4	LED	7
Electrical equipment			
1060	2	Water chiller	8
1340	2	refrigerator	9
400	1	computer	10
660	1	printer	11
1550	1	Floor scrubber passion	12
9000	5	Hand dryer	13
1060	5	Bodybuilding set	14
Mechanical room equipment			
30000	4	3-phase pump motor	15
2400	2	1-phase gearbox motor	16
12000	4	3-phase pump motor	17
3000	2	3-phase pump motor	18
4500	6	3-phase pump motor	19
11000	2	3-phase pump motor	20
1100	2	1-phase pump motor	21
740	2	1-phase pump motor	22
6400	1	Absorption chiller	23
740	2	Boiler burner	24
2869	19	Fan coil	25

An example of project model includes items such as making energy efficient (from large industrial facilities to individual houses), heating and cooling systems (e.g. bio-mass, heating pumps and solar heating, air / water), electricity (including renewable energy such as solar, wind, wave, hydro, geothermal, etc. and common technologies such as gas and steam turbines, and periodic engines) and the combination of heat and electricity. Weather databases are entirely mixed in this analytical instrument. (4700 weather stations on land, as well as NASA satellite data covering the entire planet are available). The maps of the world's energy resources are also placed in this instrument. [24]

IV. THE PROPOSED SOLUTIONS

The following solutions and energy savings for each solution separately and also their final cost in terms of domestic and international rates in building a sports complex have been studied:

A. Architecture Solutions

Installation of shade for windows is so effective.

B. Saving opportunities associated with building installations

1) Installation of solar water heater
2) Setting the temperature inside the space for the summer
3) Setting the temperature inside the space for the winter
4) Adjustment and servicing burners
5) Installing air curtains
6) Installing smart powerhouse control system

C. Saving opportunities associated with building and lighting equipment

1) Replacement of ballast induction with electronic one
2) Installation of photovoltaic cells
3) Installation of wind turbines

V. RESULTS AND DISCUSSION

Energy audit of buildings includes a wide range of check pass of facilities to detailed analysis and dynamic simulation of the building with all its components, and in simple terms includes a series of measures and activities that ultimately results in reduction of energy consumption. What is presented in this paper is the energy audit in a detailed method. In this way, the control of standards and specifications of a building is done through operational method, it is also tried to use the tools and building energy consumption simulation software with the help of Carrier Software and analysis of renewable energy by RETScreen software so that the mentioned sport building is evaluated in achieving a net zero energy buildings.

A. Detailed review of the proposed Architecture solutions

1) *Installation of shade for windows*

The architecture of a building plays an important role in its energy consumption. In the building of sports complex, the construction has a condition regarding the external wall insulation and light walls re of UPVC double glazed type. Regarding all these, the only architectural solution that can be examined is the role of shade for walls through which the light passes. The cost of installing tents in the sports complex building is 300 $ and 537 m^3 savings happens in fuel per year, cooling load of the building is reduced and this is because the ratio of window area to the total area of the walls that pass light is less than 6%, and thus its contribution in increasing or decreasing the load of the building is small.

B. Detailed review of the proposed mechanical solutions

1) *The use of solar water heater*

Using solar energy as a renewable source of energy has an important role in reducing energy consumption. Solar water heater in the building of the sports complex was modeled and designed using RETScreen software. At first, the hot water need of the building is calculated by standard of ASHREA handbook. According to the mentioned handbook standards, the total use of bathrooms is 80 G.P.H, use of toilets is 56 G.P.H, use the dishwashing sink is 20 G.P.H, and the total use of showers of sports complex is 1350 G.P.H. According to the amounts listed above, use of water heater is 1506 G.P.H and the actual amount of use of hot water is 602.4 G.P.H. With respect to supply coefficient of source as 1, volume of source of hot water is calculated as 2846 Lit. Therefore, two hot water coils with a capacity of 3,000 liters are used. The thermal load required for hot water usage is calculated as 126461 kcal / h and the level of coil of hot water source is calculated as 85 ft^2. Based on the values obtained and volume of 3000 liters for supplying source of hot water, it was tried to design hot water solar heaters. Solar radiation intensity for the area is studied. Installation of collectors with an angle of 36 degrees, which is equal to the latitude of the study area, has been better regarding solar energy throughout the year better and more energy per unit area, will be attracted to the collector. In Table II details of the solar water heaters powered by software RETScreen, such as the collectors, water heaters and heat capacity are provided. As is clear from Table II, the area of collectors of the sports complex is 24 square meters and thermal capacity is 14.7 kW, and taking into account the price per square meter of collector is $ 270, its total price will be equal to 6480 dollars.

In Table III the balance of the different parts of the solar water heater can be seen. In the summery part, solar fraction refers to solar energy contribution in production of hot water, i.e. 53 percent of the energy required for hot water supply of building is provided by solar energy. And the energy absorbed by collectors is 15.8 MWh. The cost of implementation of solar water heater with the specifications mentioned is about 6480 dollars, the reduction of fuel consumption in heating is 5571m^3, and fuel savings is 9.5% and a return period of investment of solar water heater is 12.4 years.

In this section, economic performance of solar water heaters will be exploited and a detailed report of costs incurred and income earned from several parameters are analyzed. In Fig. 1, the return of investment and retained earnings during the lifetime of solar water heaters is presented.

Two words Simple payback and Equity payback refer to capital return time in years where Simple payback method, just the price of fuel savings per year is considered, but in the case of Equity payback in addition to the price of fuel saving parameters other income-generating parameters are also considered and the received loan parameters are also involved in the equation, with these interpretations the latter method i.e. Equity payback method seems more logical to calculate the return on investment.

TABLE II. DATA OF SOLAR POWER HEATER

Solar water heater		
Type	Glazed	
Manufacturer	Alternate Energy Technologies	
Model	Morning Star MSC-21E	
Gross area per solar collector	m^2	2
Aperture area per solar collector	m^2	1.75
Fr (tau alpha) coefficient	-	0.66
Fr UL coefficient	$(W/m^2)/°C$	6.37
Temperature coefficient for Fr UL	$(W/m^2)/°C^2$	0
Number of collectors	-	12
Solar collector area	m^2	23.99
Capacity	kW	14.68
Miscellaneous losses	%	2

TABLE III. BALANCE OF SOLAR WATER HEATER SYSTEM

Balance of system & miscellaneous		
Storage	Yes	
Storage capacity / solar collector area	L/m^2	100
Storage capacity	L	2097.6
Heat exchanger		Yes
Heat exchanger efficiency	%	80
Miscellaneous losses	%	4
Pump power / solar collector area	W/m^2	8
Electricity rate	$/kWh	0.08
Summary		
Electricity - pump	MWh	0.4
Heating delivered	MWh	15.8
Solar fraction	%	52

As is clear from Fig.1, return on investment in Equity payback method is seven years and in Simple payback method is 12.4 years.

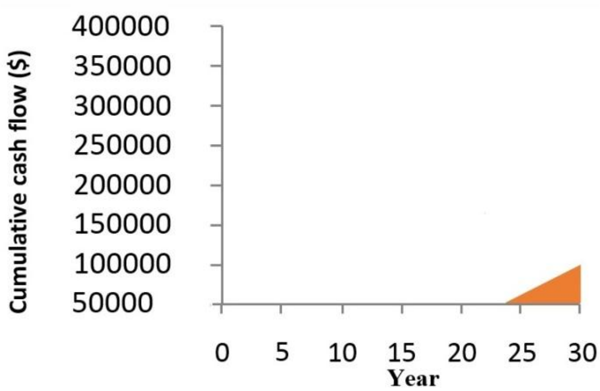

Figure 1. Return of investment and during the lifetime of solar power heater

In Table IV the used parameters in the economic analysis of solar water heaters have been provided. As you can see, the amount of the loan is $ 4536, which is equal to 70% of the total investment required, and only $ 1,944 is invested by the owner of the building and annually around 645.8 dollars must be paid for repayment of the loan.

TABLE IV. FINANCIAL PARAMETERS

Financial parameters		
General		
Fuel cost escalation rate	%	20
Project life	yr	30
Finance		
Debt ratio	%	70
Debt	$	4536
Equity	$	1944
Debt interest rate	%	7
Debt term	yrs.	10
Debt payments	$/yrs.	645.8

In Table V, the initial cost to run solar water heaters system, as well as annual income and fees received annually are observed. As is clear, annual payment is about 854.6 dollars and the amount of annual income and financial savings of the project is $ 732.1. Note that a significant amount of the annual payment is for loan and after years and full repayment of the loan the project will be highly profitable.

TABLE V. PROJECT COSTS AND SAVINGS/INCOME SUMMARY

Project costs and savings/income summary			
Initial costs			
Heating system	100%	$	6480
Balance of system & misc.	0%	$	0
Total initial costs	100%	$	6480
Annual costs and debt payments			
O&M		$	0
Fuel cost - proposed case		$	207.6
Debt payments - 10 yrs.		$	645.8
Total annual costs		$	853.8
Annual savings and income			
Fuel cost - base case		$	398.5
GHG reduction income - 30 yrs.		$	5.94
CE production income - 30 yrs.		$	327.7
Total annual savings and income		$	732.12

2) *Setting the temperature inside the space for the summer*

In Sports Complex in Mashhad by setting the inside temperature for different seasons (given the fact that the heating and cooling system is fan coil and has the feature of self-regulation without any charge) some energy loss can be prevented.

3) *Setting the temperature inside the space for the winter*

Like the previous part, even in winter by adjusting the fan coil temperature and avoiding opening windows energy consumption can be prevented and environmental emissions can be stopped.

4) *Adjustment and servicing burners*

Optimized burning of fuel in the burners can reduce fuel consumption, thus, by timely servicing of burners, their efficiency can be kept at an optimal level, this work is done by the analysis of combustion gases to determine whether efficiency torch is desirable or not, because the high efficiency of the burner causes reduction of fuel consumption.

5) *Installation of air curtains*

By installing air curtains at the entrance of the building, air infiltration be reduced which is a factor for thermal and cooling load and also the entry of contaminated air into the building and also insects can be prevented.

6) *Installing smart powerhouse control system*

Now, to set the temperature of the water used for heating buildings and use in the building in the powerhouse normal thermostats are used, which can be set by the operator to the desired room temperature, and based on the set point they try to turn off and on the burners. The benefits of intelligent engine control systems are:

1) Low cost and short payback period due to significant savings in fuel consumption
2) Reduction of wearing out of engine parts and increase of efficiency and safety of components of mechanical installations
3) Providing the conditions for rest of the residents, according to the ambient temperature outside the building
4) Ability to set the software system in terms of use type of building
5) Reducing of fuel consumption and costs to 40% in nonresidential buildings (administrative and commercial) and to 15% of residential buildings.

In Table VI, information about energy savings for the summer temperature regulation, temperature regulation for the winter, setting up and servicing burners, installation of air curtains and installing smart powerhouse control system are provided.

TABLE VI. ANALYSIS OF SUMMER AND WINTER TEMPERATURE, BURNER, AIR CURTAIN AND SMART POWERHOUSE CONTROL SYSTEM REGULATION

Saving percent		Cost to run project ($)	method
heating	cooling		
-	1.5	-	summer temperature regulation
6	-	-	winter temperature regulation
-	-	600	air curtain
1.4	-	-	setting up and servicing burners
10.5	6.1	400	smart powerhouse control system

C. Saving opportunities associated with building and lighting equipment

1) *Electronic ballasts*

Electronic ballasts for the duration of about 1 second transmit sufficient and standard flow through the lamp filaments. This pre-heating causes the lamp filaments to sufficiently heated and lamps with lower voltage get started. The number of fluorescent lamp which can be replaced by ballasts is 395 and their total capacity is 8395 watts. The cost of implementing this is $ 288, reduction of power consumption in a year is 11405 kWh, the amount of savings in electricity consumption is 8.4% and a payback period is estimated as 0.5 years.

2) *Using electro-Volta cells*

Electricity generated by solar cells has been calculated at an angle of 36 degrees from horizon. In this system a single-axis solar radiation following the absorption of solar radiation is used to enhance absorb radiation. As is clear from the above table, the amount of electricity injected into the national power grid by cells is 9 MW. The installed cells were of polycrystalline cells with an efficiency of 10.4% made by BP Solar manufacturing company. Full view of solar cells can be seen in Table VII.

As is clear from Table VII, the selected capacity for photovoltaic cells of Mashhad sports complex is 60 kW, which occupies an area of over 577 square meters. The cost of implementing solar cell with 60 kW capacities for the building of the sports complex is $ 108,000, reduced power consumption in a year is 124.6 MWh, the amount of savings in power consumption is estimated as 91.3% and the return on investment is 4.5 years.

TABLE VII. PROPERTIES OF PHOTOVOLTAIC AND INVERTOR SYSTEM OF SPORT COMPLEX

Photovoltaic		
Type	poly-Si	
Power capacity	kW	60
Manufacturer	BP SOLAR	
Model	Poly-si-ac power wall	
Efficiency	%	10.4
Nominal operating cell temperature	°C	45
Temperature coefficient	% / °C	0.4
Solar collector area	m²	577
Miscellaneous losses	%	2
Inverter		
Efficiency	%	90
Capacity	kW	60
Summary		
Capacity factor	%	25.4
Electricity delivered to load	MWh	124.613
Electricity exported to grid	MWh	8.96

In this section the financial performance of the installation and operation of solar cells in building f of the sports complex will be discussed.

As is clear from Fig. 2, return on investment period in equity payback method is 4.5 years and by Simple payback it is 10 years.

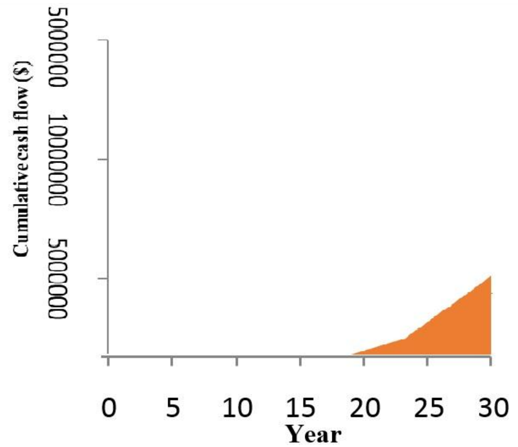

Figure 2. Return of investment and retained earnings during the lifetime of photovoltaic cells

D. Wind energy

Another option to supply energy from renewable sources is wind power, which is partially available in the study area. Average annual wind blowing in Mashhad at the height of 10 meters is 5.6 ^{m}/s, while for the wind turbine to be able to operate at its maximum, according to Fig. 3 which is the output power curve based on wind speed, for a typical turbine model 12 ^{m}/s blow is required.

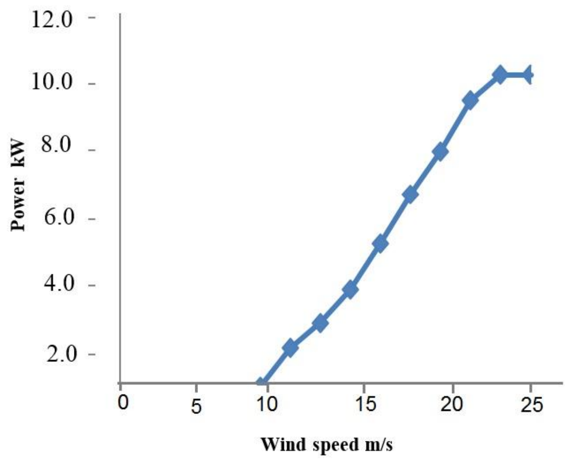

Figure 3. Output power curve of wind turbine based on wind speed

This curve is for turbines with characteristics shown in Table VIII.

TABLE VIII. PROPERTIES OF A WIND TURBINE

Wind Turbine		
Power capacity per turbine	kW	10
Manufacturer	Endurance Wind Power	
Model	S-343 – 18.3m	
Number of turbines	-	1
Power capacity	kW	10
Hub height	m	20
Rotor diameter per turbine	m	7
Swept area per turbine	m²	38
Shape factor	-	2

As it is clear from Table VIII, turbine's nominal capacity is 10 kW and its height is 20 meters and rotor propeller diameter is 7 meters. The cost of wind turbines with the above capacity is $ 4,000, reduced power consumption in a year is 19 Mwh, the amount of savings in power consumption is 13.92% and payback period is estimated as 3 years.

In accordance with Table IX, the net amount of produced and uncorrected energy, and pressure correction coefficients and temperature and also the dissipation coefficient are provided.

TABLE IX. PRODUCTION PARAMETER OF A WIND TURBINE

Unadjusted production energy	MWh	23
Pressure coefficient	-	0.836
Temperature coefficient	-	0.995
Gross energy production	MWh	19
Losses coefficient	-	0.86
Specific yield	kWh/m²	431

In Fig.4, the amount of retained earnings over the life of the project is shown.

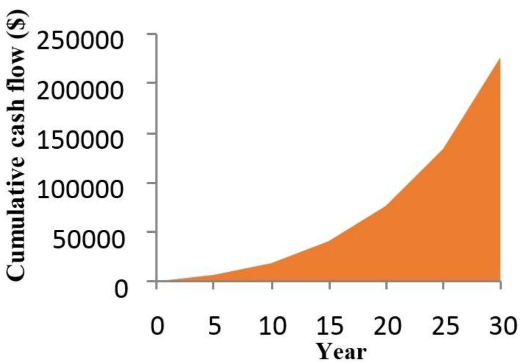

Figure 4. Return of investment and retained earnings during the lifetime of wind turbine

In Table 10, return on investment and other economic parameters that have already been discussed can be observed.

TABLE X. FINANCIAL VIABILITY

Financial viability		
Simple payback	yr.	3.1
Equity payback	yr.	1.2
Net Present Value (NPV)	$	226421.01
Annual life cycle savings	$/yr.	7547.38
Benefit-Cost (B-C) ratio	-	189.68
Debt service coverage	-	3.53

VI. CONCLUSION

In this study, RETScreen software was used for energy audits and review of solutions for energy savings in a region in northeastern Iran. The intended building is a sports complex and the results are summarized as follows:

By installing shades on the windows we can have 0.92 percent reduction in amount of consumption, resulting in 5102 kWh/year savings in gas consumption, by installing of solar water heater 9.5% percent reduction and 52925 kWh/year saving in gas consumption, by setting the inside spaces temperature for the summer and the 1.5% reduction and 8351 kWh/year, savings in gas consumption, by setting the inside spaces temperature for the winter 6 percent reduction and 33402 kWh/year savings in gas consumption, by setting and servicing burners 1.4 percent reduction and 7733kWh/year savings in gas consumption, by installing smart powerhouse control system 16.6% reduction and 92340 kWh/year savings in gas consumption, by installing electronic ballasts instead of induced ballast 8.4 percent reduction and 11405 kWh/year saving in electricity consumption, by installing electro Volta cells 91.3% reduction and 124600 kWh/year saving in electricity consumption, and also by installing wind turbines 13.92 percent reduction and thus 19000 kWh/year in power consumption resulting in savings achieved, and eventually 199852 kWh/year savings for gas consumption, and 155005 kWh/year savings for electricity consumption per year, according to the geography and climate of the area can be achieved, and the total investment return period is 11 years.

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