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Using Simulation-based Energy Consumption of NIU Engineering Building to Provide Cost-Saving Solutions

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Abstract

In the current global situation where almost all countries need energy to perform their activities, providing energy is a vital demand for modern society. Furthermore, lack of fossil energy draws attention to the utilization of renewable energy, specifically solar energy. Because no specific published record of considering renewable energy solutions applied to the buildings of Northern Illinois University (NIU) have been found already, in this paper, solar energy as an energy solution for Northern Illinois University (NIU) Engineering Building (EB) has been considered. In this case, building envelope model and HVAC system model have been developed in eQUEST software to perform simulation-based energy consumption of EB. This simulation presents annual energy consumption of boiler, chiller plant, and daylighting in EB. Moreover, economic analysis of using solar energy for lighting has been performed to identify the feasibility and savings associated with solar energy which can potentially reduce costs with a reasonable payback time.

Keywords: Renewable energy; building envelope; HVAC system model; eQUEST software; solar energy.

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1. Introduction

With speeding modernization and urbanization, energy consumption of large scale commercial buildings has steadily and rapidly increased around the world. However, most facility management departments neglect huge energy consumption of the buildings. Heating and air conditioning as two important components alone account for 65% of the total building energy consumption in 2003 and are still increasing [1], which not only consumes valuable fossil fuel resources, but also emits a huge amount of CO2 and other pollutants into the atmosphere [2]. Therefore, many countries have conducted various researches related to energy efficiency in buildings to achieve low-carbon energy-saving objectives while decreasing overall energy usage. Several researchers have concentrated on examining building energy consumption conditions [3-21]. Ke and his colleagues [3] analyzed building energy consumption parameters and found that lighting power density has the most significant impact on the building's overall energy consumption. Zhu [4] applied computer-based simulation by using eQUEST software to recognize the effect of different energy-saving measures on building energy consumption. Yu and his colleagues [5] utilized eQUEST software and considered the impact of different parameters including, building envelope shielding, window/wall ratio, external wall thermal emission, external wall thermal insulation, and glass type on air conditioner energy consumption in residential buildings in hot summer and cold winter zone in China. This research resulted in the fact that improvements in envelope shielding and external wall insulation may decrease energy consumption of air conditioners effectively. Florides [6] used TRYSNS software to perform energy consumption analysis of the modern residential buildings of Cyprus and realized that roof insulation measures were remarkably effective in decreasing cooling and heating loads. Yin and his colleagues [7] considered two commercial buildings in Shanghai and used eQUEST to present how double low-E windows with a solar film coating could lead to energy savings effectively. They figured out that internal and external solar film coatings reduced cooling loads by 2.2% and 27.5%, respectively. Kim and his colleagues [8] analyzed an energy efficient building design through data mining approach in eQUEST software and found that HVAC had the most significant effect on building energy consumption and building orientation had the least effect on energy consumption with an efficient energy annual saving of 1507 USD and 11– 17 USD, respectively. By using eQUEST, Sozer [9] focused on improving energy efficiency through the design of a building envelope and he found that window type, shielding, and insulation can reduce heating and cooling energy consumption by 40%. In this paper, eQUEST simulation software has been used in order to perform simulation-based energy consumption. It's interesting to note that there are different types of alternative energy solutions and technologies including geothermal energy [22], wind energy [23], solar energy [24], LED [25], smart grid [26], passive heating and cooling [27], and combined heat and power [28] to utilize. However, we considered solar energy as a suitable alternative energy solution in EB due to its feasibility, performance, easy operation, and reasonable gross costs.

2. Simulation project

2.1. Description of building

This study considered NIU Engineering Building where staff and students work Monday to Friday, it has a peek demand of energy consumption from 8:00 am to 6 pm during a day and it is open 24 hours a day and 7 days a week. Energy consuming equipment are powered on and off according to the workday. The building has 2 floors above ground and 1 floor below and has a floor area of 91,476 ft^2 and includes 29 laboratories.

2.2. Parameter settings in eQUEST software

2.2.1. Building envelope

The building envelope model has been considered as the initial step in eQUEST software. In order to develop it, the software parameter settings in regard to building envelope included floor to floor height, floor to ceiling height, building area, building dimensions, roof concrete thickness, wall concrete thickness, roof exterior finish, wall exterior finish, exterior insulation, interior insulation, and floor interior finish. Moreover, the software parameter settings in regard to doors and windows included height and width of doors, window glass category, glass type, frame type and width, and windows dimension. Full details are shown in table 1 and a 3D model of the building is shown in figure 1.

Table 1: Building envelope, doors, and windows input data

Parameter	Input data
Floor to floor height	16 ft.
Floor to ceiling height	14 ft.
Building area	Shell 1-9800 ft^2, shell 2-19800 ft^2, shell 3-24800 ft^2, and shell 4-37,076 ft^2.
Exterior insulation	3 in. polyurethane (R-18).
Roof concrete thickness	Metal frame 24 in.
Wall concrete thickness	Below grade walls: 6 in. thickness and floor construction: 4 in. concrete thickness.
Roof exterior finish	Concrete and metal frame.
Wall exterior finish	Concrete and metal frame.
Floor interior finish	No carpet.
Door height and width	Height 6.8 ft. and width 2.5 ft.
Windows dimension	Window height 5.22, sill height 3.00 ft.
Window glass category, glass type, frame type and width	Double clear/tint, single clear/tint, metal frame.

2.2.2. HVAC system model

The average temperature of DeKalb County is 9.10 °C, which is lower than the Illinois average temperature of 10.76°C and is much lower than the national average temperature of 12.47°C, and the monthly radiation levels are between 197.6 MJ/m^2 and 557.4 MJ/m^2. It's worth mentioning that other parameter settings are also shown in table 2.

Table 2: HVAC system parameters

System type	Public areas - variable air volume; process, laboratory, clean room - high pressure constant volume air, class 10,000 class 1,000 and class 100 clean levels
Thermostat cooling set point and heating set point	Public areas - heating 70 degree Fahrenheit; cooling - 76 degree Fahrenheit; process, laboratory, clean room - 68 degree Fahrenheit, 40% humidity.
Supply fan type	Centrifugal backward inclined blade, fan motors retrofitted with variable speed drives.
Return fan type	Centrifugal backward inclined blade, fan motors retrofitted with variable speed drives; many exhaust fans serve the clean room area.
Chilled water system pump configuration	Primary chiller flow / secondary building flow.
Chiller type	Carrier single stage electric centrifugal about ~ 0.65 kW per ton.

2.2.3. Other energy consumption parameters

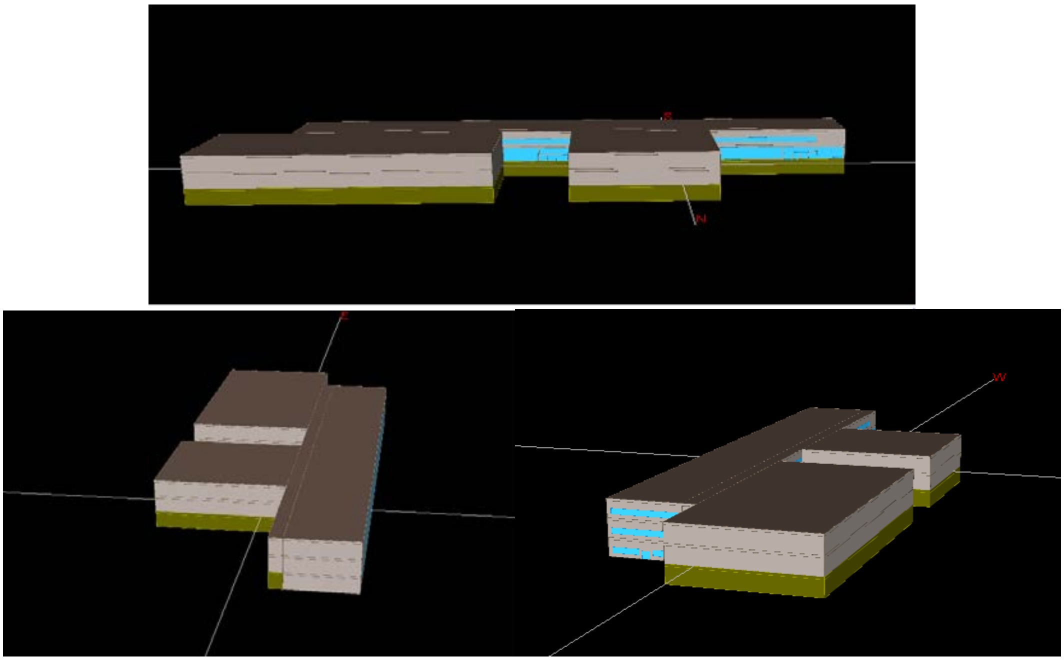


Figure 1: three-dimensional geometry of the Engineering Building

In addition to the building envelope and the HVAC system, occupancy, lighting power density, and equipment power are also parameters that affect a building's energy consumption and therefore must be set in the software.

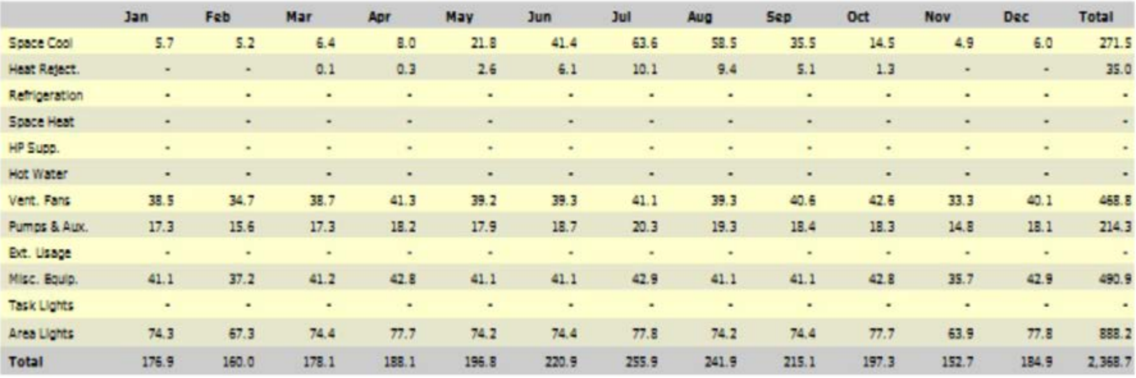
3. Results and discussion

3.1. Running the simulation

All parameters mentioned earlier such as building envelope, HVAC system, occupancy, window glass material, equipment power, and lighting power density were inputted into eQUEST software. The results of baseline model of simulation-based electricity consumption of boilers, chillers, and daylighting are illustrated in figure 2, 3, and 4, respectively.

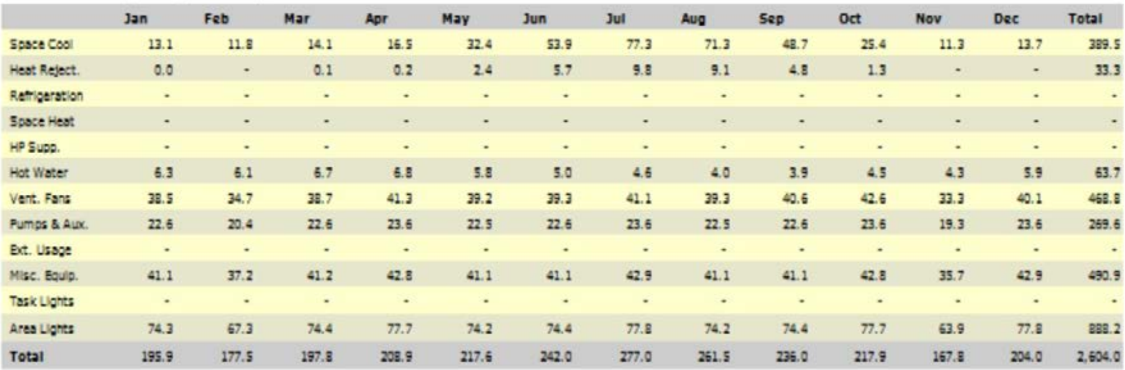
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	13.1	11.8	14.1	16.5	32.4	53.9	77.3	71.3	48.7	25.4	11.3	13.7	389.5
Heat Reject.	0.0	-	0.1	0.2	2.4	5.7	9.8	9.1	4.8	1.3	-	-	33.3
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	38.5	34.7	38.7	41.3	39.2	39.3	41.1	39.3	40.6	42.6	33.3	40.1	468.8
Pumps & Aux.	22.6	20.4	22.6	23.6	22.5	22.6	23.6	22.5	22.6	23.6	19.3	23.6	269.6
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	41.1	37.2	41.2	42.8	41.1	41.1	42.9	41.1	41.1	42.8	35.7	42.9	490.9
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	74.3	67.3	74.4	77.7	74.2	74.4	77.8	74.2	74.4	77.7	63.9	77.8	888.2
Total	189.6	171.4	191.1	202.1	211.8	237.0	272.5	257.6	232.1	213.4	163.5	198.1	2,540.3

Figure 2: electricity consumption of boilers



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	5.7	5.2	6.4	8.0	21.8	41.4	63.6	58.5	35.5	14.5	4.9	6.0	271.5
Heat Reject.	-	-	0.1	0.3	2.6	6.1	10.1	9.4	5.1	1.3	-	-	35.0
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	38.5	34.7	38.7	41.3	39.2	39.3	41.1	39.3	40.6	42.6	33.3	40.1	468.8
Pumps & Aux.	17.3	15.6	17.3	18.2	17.9	18.7	20.3	19.3	18.4	18.3	14.8	18.1	214.3
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	41.1	37.2	41.2	42.8	41.1	41.1	42.9	41.1	41.1	42.8	35.7	42.9	490.9
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	74.3	67.3	74.4	77.7	74.2	74.4	77.8	74.2	74.4	77.7	63.9	77.8	888.2
Total	176.9	160.0	178.1	188.1	196.8	220.9	255.9	241.9	215.1	197.3	152.7	184.9	2,368.7

Figure 3: electricity consumption of chillers



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	13.1	11.8	14.1	16.5	32.4	53.9	77.3	71.3	48.7	25.4	11.3	13.7	389.5
Heat Reject.	0.0	-	0.1	0.2	2.4	5.7	9.8	9.1	4.8	1.3	-	-	33.3
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	6.3	6.1	6.7	6.8	5.8	5.0	4.6	4.0	3.9	4.5	4.3	5.9	63.7
Vent. Fans	38.5	34.7	38.7	41.3	39.2	39.3	41.1	39.3	40.6	42.6	33.3	40.1	468.8
Pumps & Aux.	22.6	20.4	22.6	23.6	22.5	22.6	23.6	22.5	22.6	23.6	19.3	23.6	269.6
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	41.1	37.2	41.2	42.8	41.1	41.1	42.9	41.1	41.1	42.8	35.7	42.9	490.9
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	74.3	67.3	74.4	77.7	74.2	74.4	77.8	74.2	74.4	77.7	63.9	77.8	888.2
Total	195.9	177.5	197.8	208.9	217.6	242.0	277.0	261.5	236.0	217.9	167.8	204.0	2,604.0

Figure 4: electricity consumption of daylighting

In order to calculate cost of electricity consumption, specific information has been retrieved from Commonwealth-Edison which is the electricity supplier for city of DeKalb and is listed in table 3.

Table 3: Electricity charge of using Commonwealth-Edison provider (retrieved from [29])

Charge	Cost (USD)
Supply-charge	4.604 cents/kWh
Transmission service charge	0.919 cents /kWh
Total	5.523 cents/kWh

To calculate the net electricity consumption to run lighting in EB (Table 4), electricity consumption of lighting from fig. 4 and electricity charge of using Commonwealth-Edison as electricity provider have been considered.

Table 4: The net electricity consumption to run lightning in EB

Sector	Electricity consumption (MW/h)
Boiler	2,540
Daylighting	2,604
Chiller	2,368
Cost of electricity consumption to run lighting in EB	($ 5.523× 2,604×10^3)/100= $143,818.92/year

3.2. Using solar energy as an alternative solution

It is obvious that solar conversion depends on the various factors such as solar angle, vendor selection, type of solar panel used, and criticality of installation. To perform an accurate estimation of associated costs, Solar-Estimate [30] provided conversion costs based on supplier charges or amount of electricity used per month. It is worth mentioning that Federal Tax Credit information has been gathered from Illinois Department of Commerce and Economic Opportunity (DCEO) [31]. By considering the Engineering Building as a building with flat rooftop and using solar-photovoltaic-panel installation, results of solar conversion are presented in Table 5.

Table 5: Solar conversation values

Factor	Data input / output	
Gross cost		$2, 767,660
DCEO -solar PV rebate: residential	$ 1.50/watt	25% of cost or, -$10,000 maximum
Federal tax credit	(30% of net cost of installation)	-$827,298
Net cost of system after rebates and incentives		$1,930,362
Payback time		14.17 years
Internal rate of return (IRR) on investment:		7.06%

4. Conclusion

This study used eQUEST software to develop building envelop and HVAC system in order to present simulation-based energy consumption of Northern Illinois University (NIU) Engineering Building (EB). Running simulation model represented that electricity consumption of boiler, chiller, and daylighting are 2540, 2604, 2368 kW/h per year, respectively. According to output of simulation model in eQUEST and electricity charge of using Commonwealth-Edison provider, cost of lighting in EB is approximately $143,818.92 per year which is a considerable amount of money. Using solar energy as a suitable alternative energy solution would have $ 2,767,660 as gross cost and payback period is 14.17 years. As a result, utilizing solar panel systems can be a reasonable alternative energy solution that can substantially help the Engineering Building to reduce associated costs.

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