Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2017
(ICMERE2017) 18 – 20 December, 2017, Chittagong, Bangladesh

ICMERE2017-PI-311

PERFORMANCE ANALYSIS AND INVESTIGATION FOR THE DEVELOPMENT OF ENERGY EFFICIENT BUILDING

F. Rashid[1], M. E. Hoque[2], K.I. Peash[3], F. Faisal[4]

[1-4]Department of Mechanical Engineering, Rajshahi University of Engineering & Technology, Bangladesh

Email: frrashed10@gmail.com*, emdadulhoque@gmail.com, peash.khairul@gmail.com, fahimfaisal37@gmail.com.

Abstract- *Recent research shows that about 20%–30% of building energy consumption can be saved through optimized operation and management without changing the building structure and the hardware configuration of the energy supply system. More energy consumption can be saved by changing those. Therefore, there is a huge potential for building energy savings through efficient operation. The way of improving building energy efficiency in operation is to coordinate and optimize the operation of various energy sources and loads. In this paper, the scheduling problem of building energy supplies is considered with the practical background of a low energy building. The objective function is to minimize the overall cost of electricity and natural gas for a building operation over a time horizon while satisfying the energy balance and complicated operating constraints of individual energy supply equipment and devices. The testing results show that significant energy cost savings can be achieved through integrated scheduling and control of various building energy supply sources. It is very important to fully utilize solar energy and optimize the operation of electrical storage.*

Keywords: Energy efficient building, Renewable energy, Energy economics.

1. INTRODUCTION

In recent years, in order to reduce energy consumption and improve energy efficiency significant efforts have been made. The idea of energy efficiency in buildings is related to the energy supply needed to achieve desirable environmental conditions that reduce energy consumption. Buildings are the largest energy-consumer. For approximately 40% of total world annual energy consumption, in the form of lighting, heating, cooling and air conditioning are consumed by the buildings. Again space heating consumptions and supply hot water account for more than 80% of total energy consumption in the buildings [1]. One of the best methods to reduce energy cost in buildings is to design based on heating and cooling [2]. In order to design energy-efficient building, construction parameters and design variables must be optimized [3]. Consequently, it is necessary to identify the design variables that are directly related to heat transfer processes [4]. The existing design phase of a building is the best time to integrate sustainable strategies. When the integrated mechanisms are put into action at the very beginning of the construction phase, this will reduce implementation costs as compared to when they are installed in subsequent stages of construction [5]. Again, energy-efficient building design methods are an added value that benefits the user. If a building design based on energy-saving criteria then these energy saving criteria of building reduces economic costs throughout the useful life of the building because of its lower energy consumption, and also compensates for the greater initial cost of investment. Since there are also a small amount of CO_2 emissions into the atmosphere throughout the building's life cycle, this will benefit society as well.

The variables that are associated to energy efficient building shape and which influence heating and cooling requirements are the following: (i) shape factor; (ii) compactness index; (iii) climate; and (iv) the influence of shape on the life cycle of the building. . For maintaining the building at a comfortable temperature the characteristics of the building envelope are crucial variables that should be taken into account because they are relevant to the energy requirements.

Based on energy saving technologies results, it has been found that in the industrial sectors and in building design, a sizeable amount of electric energy, emissions and utility bill can be saved using energy saving technologies [6] [7]. Payback periods for different energy savings measures have been identified and found to be economically viable in most cases. In recent years, worldwide different countries have implemented energy policies to achieve low power dissipating equipment of which improving the efficiency of energy consumption while reducing overall energy consumption is a crucial point. Moreover, from the foreign energy saving industrial building to support the development of energy service companies the energy performance project model allows energy consumers to pay for the cost of energy-saving projects through the energy efficiency created by the project [8]. Before practical implementation a simulation can be done for determining the output of the power consumption. In this purpose an energy simulating software named eQUEST is used

2. ENERGY CONSUMPTION

For different purposes in industrial facilities and in buildings, energy is a basic need all around the world. Countries with faster economic growth require huge amount of energy. Energy is thus a vital factor for economic employment and competitiveness. However, global population and energy needs are increased day by day. This concern must be introduced by the community to overcome any shortage of energy resources in recent future. World marketed energy consumption is projected to increase by 33% from 2010 to 2030. Total world energy use rose from 82,919 ZW in 1980 to 116,614 ZW in 2000 and then is expected to reach 198,654 ZW in 2030 [9] [10].

3. ENERGY MANAGEMENT

The strategy of meeting energy demand when and where it is needed is called energy management. This can be achieved by optimizing and adjusting energy using systems and techniques so as to reduce energy requirements per unit of output while reducing total costs of producing the output from these systems or holding constant [11] [12]. As the price of energy is rising, the energy management began to be considered one of the main functions of industrial management in the 1970s and reports about the approaching exhaustion of world energy resources [11]. Nowadays, the role of energy management has greatly expanded in industrial sector. Top management of the company participates in planning various energy management projects on a regular basis. The details of energy conservation activities and various achievements by the company regarding energy conservation projects are summarized in the annual reports of the many companies. To be effective, energy management programs should include four main sections [11] [13]: (1) Engineering analysis and investments proposals based on feasibility studies; (2) Energy audit and accounting; (3) Analysis of historical data; (4) Personnel training and information.

4. METHODOLOGY

eQUEST is a simulation software which is used to analyze the effect of various energy-saving measures on industrial building and equipment. The Quick Energy Simulation Tool eQUEST allows us with limited simulation experience to develop three dimensional simulation models of a particular building design. These simulations incorporate building location, orientation, wall/roof construction, window properties, as well as HVAC systems, day-lighting and various control strategies, along with the ability to evaluate design options for any single or combination of energy conservation measures [14]. In this work mainly power consumption of buildings equipment is calculated and shown that without different modification the power or energy consumption is higher compared to the power consumption with different types of equipment modification. This power saving is shown with eQUEST software. Finally the payback calculation is shown to recover the cost of the modified equipment. The objective is to determine the power consumption of GSSL at existing condition and then at improved condition which reduces the power consumption. At first, determine the power consumption of GSSL at existing condition GSSL Company has a rectangular building of area 55,760 sq. ft. which length and width is 410ft and 136ft respectively. The power consumption calculation is carried out for the ground and floor only. The fan type of HVAC system was forward curved centrifugal inlet vanes. The CHW loop flow was constant and the motor efficiency was high. The chiller type was electric centrifugal open and compressor was at constant speed. The set point of chiller water control system was fixed and the operation was in demand. There was no daylight control system in the industry. But for an efficient design of building daylight, shape of the building, orientation of building, building envelope, shading of building and different passive system must need to be considered.

4.1 Influence of Shape on the Energy Optimization of Buildings:

Solar energy receives a building as well as total energy consumption of a building depend on the shape of that building [15]. For cooling up to 25% the radiation hitting a building can increase energy requirements [16]. Accordingly, building shape not only determines the total area of a building that receive solar radiation, but also the surface exposed to the outside, and thus to energy losses. When a building is designed, the ratio between its outer surface and the total constructed volume should be as small as possible, tending toward the ideal case of a hemisphere [17]. However, due to this design and construction issues, this shape is not attainable in most work. For this reason, many researchers have started to study the performance of parallelepiped-shaped buildings and to vary the shape factor in order to find the best model. In other cases, they prefer by defining a hexagonal or octagonal foundation plan, a curved or oval foundation plan or one without any specific geometric shape until obtaining the optimal dimensions for the specific geometric context.

4.2 Influence of Orientation on the Energy Optimization of Buildings:

Among different parameters that intercede in the passive solar design of buildings, orientation is the most important and the one that has been most frequently considered. The level of solar radiation received on the building depends on the azimuth angle in the wall, and thus, on the orientation angle of building [18]. Other parameters of passive design, such as shading or the performance of the solar envelope also influence by the orientation of the facade of buildings. Benefits derived from optimal building orientation are the following:

(a) Building orientation is a low-cost measure that is applicable in the initial stages of work design.
(b) Building orientation reduces the energy demand.
(c) Building orientation reduces the use of more sophisticated passive systems.
(d) Building orientation increases the performance of other complex passive techniques.
(e) Building orientation increases the quantity of daylight, reduces the energy demand for artificial light, and contributes less to the internal heating load of the building.
However, orientation can also be considered with a view to optimizing other parameters such as building shape, total solar radiation received, the annual energy demand and ground plan surface.

4.3 Influence of the Building Envelope in the Energy Demand:

For a building, building envelope means foundation, roof, walls, doors and windows of that building. Depending upon the design number of walls, doors, roof and windows vary from building to building. The total energy consumption of a building depends mainly on the building envelope such as foundation, roof, walls, doors, and windows and the operation period of the heating system. These are the two main factors that have the greatest impact on total energy consumption of a building [19]. Building envelope determines interior climate conditions and thus the additional energy demand for heating and cooling required for a building. Actions on the elements of the building envelope can have a positive impact on certain energy requirements and have a negative effect on others. As a result, it is necessary to evaluate the performance of the building as a whole.

4.4 Influence of Glazing on the Energy Optimization of Buildings:

In building interiors window glazing is one of the weakest thermal control points. In a standard family residence, 10–20% of all heat loss occurs through the windows [20]. In glazing design, it is necessary to consider performance in terms of thermal comfort, heat transfer, light transmission, and appearance. In summer window glazing that reduces the entry of solar radiation is most effective and decreases the cooling demand. In contrast, this type of glazing increases the need for heating because it hinders the use of solar energy for passive heating in winter. The development of glazing that decreases the quantity of solar radiation should not affect the possibility of seeing through windows, especially in office buildings when a large amount of natural light is required. A decrease in natural daylight causes a corresponding increase in artificial light. This signifies an increase in indoor temperature and as well as higher energy costs. Furthermore, when temperatures are high, design solutions that improve the amount of daylight entering windows are often associated with a potential risk of inside overheating and an increase in the cooling demand in hot seasons.

4.5 Influence of Shading on Buildings:

The amount of solar radiation received by a building depends on the shading of building elements. This strategy gives positive results when actions are performed on the building facade cavities. Because building shading element are the elements that transmit the highest level of radiation to the inside of the building.

4.5 Influence of Passive Systems:

In ancient times passive techniques of temperature control and inside humidity were first employed. Due to the widespread use of electrical energy, passive technique methods gradually became obsolete. However, in developed countries with hot climates there is currently a growing interest in these low-cost systems for the passive cooling of buildings [21]. Depending on the natural convective movement caused by the different densities of cold and hot air these mechanisms are based on. However, to enhance system performance the term passive does not exclude the use of a fan or pump. Even passive systems highlight the use of natural heating or cooling sources, some type of power is necessary to initially start operation. Since the passive heat transfer system is low cost and simple, the ratio of power consumption to the total consumption of the installation is relatively low. The type of passive system chosen influence different factors of energy efficient building design.

5. RESULTS

At first the simulation was done in eQUEST for an existing building in this work. From the simulation result, it is clear that the total power consumption of that existing building for a year is 1084800 kWh. Then some modification of the existing building was done and simulates in eQUEST and finds the total power consumption of that building. Finally compare the power consumption of the existing building and the modified building, if the power consumption of the modified building is less than the existing building then the design of the building is efficient. In this work, in this way energy efficient building was designed and eQUEST is the main design tool here.
For improving the building design in this work, first of all, it requires to replace forward curved centrifugal inlet vanes by variable speed drive in fan type of HVAC control system. The CHW loop flow must be variable and the motor efficiency has to be standard. The chiller has to be screw type and compressor will be at variable speed. The set point of chiller water control system has to be in load reset and the operation must be in schedule. The daylight should also be controlled. Usually the system can be improved by using the daylight, because daylight is a major source of renewable energy. If daylight can be used properly, then the electric power consumption can be reduced.
From simulation we found that, the power consumption of existing condition is = 1084800 kWh, the power consumption of improved condition is = 900510 kWh, the power saved per year is = 184290 kWh, the price of 1 kWh is = 6 BDT [22], so the savings per year is = 1105740 BDT. From the Fig 1 and Fig 2, the power consumption of existing and modified building system is shown below for different month in the year 2017.

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	6.7	7.0	9.1	9.8	17.4	25.6	26.8	32.1	26.9	21.6	14.6	7.2	204.9
Heat Reject.	0.3	0.3	0.4	0.5	1.1	2.4	2.6	3.2	2.7	1.8	0.9	0.3	16.4
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	6.2	6.6	7.7	6.7	7.5	7.7	7.1	8.4	7.4	7.8	6.5	6.2	85.9
Pumps & Aux.	2.6	2.9	3.5	3.7	5.9	6.9	6.7	7.8	6.6	6.2	4.9	2.9	60.6
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	33.6	31.2	36.4	33.1	35.5	35.0	33.6	36.4	33.1	34.6	33.1	33.6	409.4
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	24.7	23.4	28.2	24.6	27.0	27.0	24.7	28.2	24.6	25.9	24.6	24.7	307.6
Total	74.2	71.3	85.2	78.5	94.5	104.6	101.7	116.0	101.4	97.8	84.7	74.9	1,084.8

Fig 1: Energy consumption for existing building

Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Tot
Space Cool	2.50	2.09	3.25	3.57	6.39	14.32	16.28	20.04	17.31	11.38	6.00	2.77	105
Heat Reject.	0.16	0.13	0.25	0.28	0.76	2.02	2.27	2.76	2.35	1.44	0.62	0.16	13
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	
Vent. Fans	3.75	4.07	4.63	3.99	4.40	4.67	4.34	5.24	4.87	5.18	4.15	3.82	53
Pumps & Aux.	4.75	4.49	5.48	4.81	5.43	5.85	5.52	6.44	5.51	5.44	4.95	4.77	63
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	
Misc. Equip.	33.65	31.24	36.37	33.15	35.47	34.97	33.65	36.37	33.15	34.56	33.15	33.65	409
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	
Area Lights	20.78	19.47	23.30	20.34	22.26	22.22	20.30	23.20	20.40	21.49	20.80	20.95	255
Total	65.58	61.48	73.29	66.14	74.71	84.04	82.36	94.06	83.58	79.48	69.68	66.12	900

Fig 2: Energy consumption for modified building

The price of different modified equipment's is shown in table 1 and the existing chiller type is electric centrifugal open and the price of it = 175000 USD = 14371000 BDT (2sets), considering a better chiller condition the selling price of the existing chiller = 75% of 175000 US (10778250 BDT). So in order to design energy efficient building, in the modified building replace the chiller with screw type chiller and the price of it = 164630 USD (2sets) (13519415.6 BDT) . Solar panel cost per sq. ft = 2 USD = 164.24 BDT, Area covered by solar panel = 15028 sq. ft, total cost of solar panel = 30056 USD = 2468198.72 BDT, total cost = 96116 USD = 7893045.92 BDT, So payback period = 7893045.92 / 1105740 = 7.14 years, so the cost will be compensated within 7 years approximately.

So the existing building in this work can be modified to energy efficient building by replacing some equipment. But the initial cost of that equipment is a vital point. After 7 years the implementation cost can be recovered and then the building can easily be run with less amount of energy consumption as before.

For designing a building, in this way eQUEST can be used and in our work, only consider a certain building to calculate the power consumption rate. In eQUEST there are also other parameters which can be changed to design an efficient building. Here in this work only electric consumption is considered but gas consumption of that existing building and the modified building can also be determined.

Table 1: Table for the price of variable speed drive

Name	No. of sets	Cost per set	Total Cost
For FA AHU 1F/01,02,03,04 (Approx. 12 kW)	4	1,935.00	7,740.00
For Chilled Water Pump (Approx. 35 kW)	2	5,375.00	10,750.00
For Condenser Water Pump (Approx. 35 kW)	2	5,375.00	10,750.00
For Cooling Tower (Approx. 11 kW)	2	1,720.00	3,440.00
			Total = 32680 USD
			Total =2683681.6 BDT

6. DISCUSSION

Energy is a growing demand, but the sources of energy are limited. So it requires saving energy or reducing energy consumption in building and in industrial sector. Major part of energy is consumed by the equipment's in industrial sector building. A modification is needed to reduce the energy consumption of those building. In this work before the modification of different equipment's the electric energy consumption is 1084800 kWh. But after the modification of different equipment's the power consumption is 900510 kWh. So the power saved per year is 184290 kWh. Considering the cost of 1kWh is 6 BDT [12], the savings per year is 1105740 BDT. Though there was some implementation cost for the modified equipment but within 7 years payback period the cost can be compensated.

7. CONCLUSIONS

The sustainable design of energy efficient building reduces the energy demand for heating and cooling. The benefits of an energy-efficient industrial building design should be evaluated for the entire life cycle of the building. In this work, a study is carried out for an existing building and then the equipment of that building is modified. The power consumption has been reduced in the modified system. A more energy-efficient industrial building design does not necessarily coincide with more economical or more environmentally friendly designs. For energy efficient industrial building screw type chiller, variable speed compressor need to be used and daylight energy need to use properly with appropriate modification.

8. REFERENCES

[1] Zolfani, S. H., & Saparauskas, J. (2013). "New application of SWARA method in prioritizing sustainability assessment indicators of energy system." Engineering Economics, 24(5), 408-414.

[2] Omer, A. M. (2008). "Renewable building energy systems and passive human comfort solutions." Renewable and sustainable energy reviews, 12(6), 1562-1587.

[3] Feng, Y. (2004). "Thermal design standards for energy efficiency of residential buildings in hot summer/cold winter zones." Energy and Buildings, 36(12), 1309-1312.

[4] Ekici, B. B., & Aksoy, U. T. (2011). "Prediction of building energy needs in early stage of design by using ANFIS." Expert Systems with Applications, 38(5), 5352-5358.

[5] Wang, W., Rivard, H., & Zmeureanu, R. (2006). "Floor shape optimization for green building design." Advanced Engineering Informatics, 20(4), 363-378.

[6] Worrell, E., & Price, L. (2001). "Policy scenarios for energy efficiency improvement in industry." Energy policy, 29(14), 1223-1241.

[7] Ke, M. T., Yeh, C. H., & Jian, J. T. (2013). "Analysis of building energy consumption parameters and energy savings measurement and verification by applying eQUEST software."Energy and Buildings, 61, 100-107.

[8] U.S Energy Information Administration. International Energy Outlook 2009: World Energy and economic Outlook; 2009, Available Online at: http://www.eia.doe.gov/oiaf/ieo.

[9] U.S Energy Information Administration. International Energy Outlook 2009: World Energy and economic Outlook; 2009, Available Online at: http://www.eia.doe.gov/oiaf/ieo.

[10] United Nations Industrial Development Organization (UNIDO). Policies for promoting industrial energy efficiency in developing countries and transition economies; 2008, http://www.greenhouse.gov.au/challenge.

[11] Petrecca, G. (2012). Industrial Energy Management: Principles and Applications: Principles and Applications. Springer Science & Business Media.

[12] Abdelaziz, E. A., Saidur, R., and Mekhilef, S. (2011). A review on energy saving strategies in industrial sector. Renewable and sustainable energy reviews, 15(1), 150-168.

[13] Kannan, R., and Boie, W. (2003). Energy management practices in SME—case study of a bakery in Germany. Energy Conversion and Management, 44(6), 945-959.

[14] https://openei.org/wiki/The Quick Energy Simulation Tool (eQUEST).

[15] Mingfang T. Solar control for buildings. Building and Environment 2002;37:659–64

[16] Elasfouri AS, Maraqa R, Tabbalat R. Shading control by neighbouring buildings: application to buildings in Amman, Jordan. International Journal of Refrigeration 1991; 14:112–6.

[17] Neufert E. Arte de proyectar en Arquitectura. Barcelona: Gustavo Gili, SA Editorial; 1995.

[18] Mingfang T. Solar control for buildings. Building and Environment 2002; 37:659–64.

[19] Manioglu ˘ G, Yilmaz Z. Economic evaluation of the building envelope and operation period of heating system in terms of thermal comfort. Energy and Buildings 2006; 38:266–72.

[20] Roos A, Karlsson B. Optical and thermal characterization of multiple glazed windows with low U-values. Solar Energy 1994; 52:315 25.

[21] Givoni B. Performance and applicability of passive and low-energy cooling systems. Energy and Buildings 1991; 17:177–99.

[22] http://www.bpdb.gov.bd/download/tariff.pdf