

ENERGY CONSUMPTION AND SAVINGS MODEL FOR COGENERATION IN COMMERCIAL BUILDINGS

Emmanuel C. Nsofor
Southern Illinois University

ABSTRACT

Environmental problems, electricity deregulation, and anxiety over energy security are contributing to growing attention being paid to cogeneration. This study is on the analysis of cogeneration as a conservation strategy for improving energy efficiency in commercial buildings. An energy conservation model for cogeneration that includes applying a simplified method and energy data for a commercial establishment was developed. The methodology calculates the current consumption and future operating costs, savings and simple payback for an upgrade system. It was determined that using this strategy would result in significant energy savings with an appreciable payback for the investments made.

INTRODUCTION

In addition to more efficient utilization of energy, cogeneration supplies on-site energy, using power-generating units located very close to the customer's industrial or commercial facility. A number of commercial and industrial power plants operate with processes that involve great quantities of thermal energy exhausted to the atmosphere. Many of the plants were designed when fuel was cheap and readily available; not much effort was made towards conserving energy. Waste liquids and gases discharged from these plants sometimes have temperatures that are up to 1000°C (1832°F). This constitutes substantial energy losses and justifies efforts to recover these losses. Heat recovery conserves energy resources and reduces fuel consumption and operating costs. If heat recovery is adequately harnessed, it also lowers particulate emissions.

Cogeneration commonly involves the production of electrical energy and useful thermal energy from a single primary fuel source. The heat rejected from one power production process becomes useful thermal energy for a subsequent conversion process. This simultaneous production of the two forms of energy results in better economic use of fuel compared to producing them separately. Energy conservation resulting from cogeneration helps to maximize fuel efficiency, improve energy efficiency in power plants and has the potential to reduce environmental pollution. Apart from some additional cost for the cogeneration, equipment output is greatly enhanced using the same quantity of input to the power plant. Because waste heat in conventional power plants is the result of intrinsic thermodynamic process of power generation, any effort that utilizes this waste thermal energy will improve fuel efficiency and contribute to the reduction of environmental pollution. Cogeneration does not require additional combustion and does not generate additional carbon dioxide. Cogeneration can be combined with existing energy supply systems. Also, the plants can be located close to where the energy is required, thus eliminating the costs and losses associated with transmission when electricity is bought via the grid from utility companies.

Considerable studies have been done on cogeneration as a way of contributing to efficient use of energy. Amundsen [1] reported that cogeneration, although century-old, has gained a new life in the United States because of its inherent efficiency, favorable regulations, and rising costs of centrally generated electricity. The study reported that cogeneration capacity in the United States will more than double by the year 2005 and that related equipment and services will experience a booming market. Smith [2] performed cogeneration studies on a small turbine-generator and reported on the economic analysis, type of system, and physical installation. The greatest emphasis on cogeneration today is on industrial plants using large quantities of thermal energy as process steam. Economy on the use of fuel is enhanced by the low capital costs of cogeneration systems. Clark [3] reported that the cost of most cogeneration systems is at least 50% less than current costs for large coal-fired or nuclear central generating stations.

Birur and Lee [4] described an analysis of cogeneration energy systems using a computer-aided engineering technique, which consisted of an input data processor program used to evaluate the performance of cogeneration systems. The study indicated that the program contained a data base on boilers, data for four types of engines, as well as electric and

steam load profiles. Voorspools and D'haeseleer [5] discussed the dynamic interaction between cogeneration systems and the central power system, as well as the dynamic response of the cogeneration units themselves. Turner and Petursson [6] reported on reducing facility-operating costs through on-site generation of electricity and provided an overview of on-site electricity as a cost reduction measure for large facilities. The technological options available, as well as advantages and disadvantages, were discussed in the report. A case study, with step-by-step approach to arriving at the economics of installing a cogeneration plant was described. Options for heat-generating equipment were investigated and sensitivity analyses for determining the factors that influence the financial performance of each of the options were described.

Kolanowski [7] studied a method for selecting cogeneration systems. The method used the monthly consumption and amount spent on gas and electricity, building thermal mass and the operating hours to size the cogeneration system. Analysis of the cogeneration system's annual electrical and gas savings was provided. Le Goff and Hornut [8] proposed methods for coupling a cogeneration system with a refrigerator operating partly by compression using electricity at off-peak hours and partly by absorption using waste heat. The system used a binary mixture of ammonia plus sodium thiocyanate with reservoirs for storing the separated components.

In this study, a modified BIN method that calculates the energy consumption and energy savings with payback was developed. The method was used to analyze the cogeneration operations and replacement savings for generating electric power in a commercial facility in lieu of purchasing electricity from the utility company during peak period. The Department of Defense (DOD) bin weather data collected over several years for the city in which the facility is located was used. Energy-use data for the facility was obtained from the utility bills of the company.

METHODOLOGY

The commercial facility consists of three buildings with a gross area of 31,227 square meters (336,000 square feet). One of the buildings, which is oriented North-South, has nine levels, and a total approximate air-conditioned floor area of 12,825 square meters (138,000 square feet). The

second building is oriented Northwest-Southeast. This building has eight levels, and a total approximate air conditioned floor area of 10,967 square meters (118,000 square feet). The third is a six-story building that has an approximate orientation of Northeast-Southwest with total air-conditioned floor area of approximately 7,435 square meters (80,000 square feet). The facility is located in Seattle, Washington, a city that has an elevation of 137 meters (449 feet), latitude of 47.45°N and a longitude of 122.20°W.

The commercial businesses in the buildings include engineering, consulting, software development and use, marketing, accounting, and other ventures. The building spaces are used for purposes such as offices, conference rooms, cafeteria, copy/print rooms, etc. The occupancy period was taken as between 8.00 a.m. – 5.00 p.m. during the normal week and the buildings were considered to be unoccupied during the weekends and holidays. The main building loads are from occupants, office equipment (printers, computers, fax machines, copiers, etc.); lighting; fans for air distribution; and solar gain. Miscellaneous appliances include fans, heaters, coffee machines, microwave ovens, kitchen equipment, etc.

The method used in this study calculates the energy demand and consumption, as well as potential energy savings, with simple payback calculations to determine whether cogeneration will be a worthwhile investment. The computations include: (a) calculation of existing demand and consumption (on and off-peak), (b) finding the peak consumption, (c) calculation of heat recovery, and (d) calculating the power production and savings obtained by using cogeneration. Some of these calculations involve the conversion of the raw data (available from BIN data, measurements, energy audit, etc.) to quantifiable numbers like kW, and kWh, etc. to give information for determining the system's performance. Energy consumption information was obtained from the utility bills of the company. Other information like the total electrical loads and mechanical loads in the building were obtained from a site survey and from the design drawings of the facility.

The relevant equations and procedures are incorporated in the flowcharts and nomenclature. The total system efficiency for the cogeneration system is defined by the following equation:

$$\eta_{\text{cogeneration}} = \frac{PO + TE}{FE} \quad (1)$$

The useful thermal energy (heat) output from fuel consumed can be obtained from the thermal efficiency of the boiler, which is

$$\eta_{thermal} = \frac{\text{Thermal Energy Output}}{\text{Energy Input}} \quad (2)$$

For the generation of electricity only, the efficiency is defined as

$$\eta_{electric} = \frac{\text{Electric Power Output}}{\text{Energy Input}} \quad (3)$$

The fuel savings (FS) compares the fuel used by the recommended cogeneration system to that used by the existing system, where electric power and thermal energy are produced separately. This is given by the equation

$$FS = 1 - \frac{FE}{\frac{PO}{\eta_{electric}} + \frac{TE}{\eta_{thermal}}} \quad (4)$$

Because the calculations could be done and plotted on spreadsheets, MS Excel was used in this study. Flowchart 1 shows the information on the existing system. The cogeneration system selected for the establishment consisted of two engines that generate the electricity needed for the facility, so that there will not be the need to purchase energy from the utility company during peak-demand period because the unit cost of on-peak electricity is very expensive compared with off-peak electricity. Flowchart 2 shows the information for the cogeneration system with the two engines and flowchart 3 shows the procedure for calculating the cost savings. The relevant subscripts for the terms in the flowcharts were applied, as appropriate, in the calculations.

RESULTS

By applying this method to the commercial facility, a new two-engine system was selected so that power can be produced to satisfy substantial demand. This resulted in only a limited amount of power to be bought from the utility company. This occurred when the utility company power is most expensive. It should be noted that the unit cost of



Your up-to-the-minute reference on all aspects of indoor air quality management, including important new material on building security and toxic mold...

MANAGING INDOOR AIR QUALITY



THIRD EDITION

By Shirley J. Hansen, Ph.D., and H.E. Burroughs, C.I.A.Q.P.

This practical desk reference is structured to serve as a guide and information resource – both on treating existing indoor air problems effectively – and on preventing costly IAQ problems from occurring in the first place. Finding solutions to indoor air quality problems is often a complex, multifaceted, multidisciplinary endeavor. A single discipline approach from the environmental engineer, the industrial hygienist, or the medical doctor, unfortunately tends to narrow both the control and the treatments options. This book cuts across these professions without being limited by the specificity and bias of any one discipline, to offer those concerned with the total facility a broader, more comprehensive approach to managing indoor air quality and mitigating indoor air quality problems. The third edition has undergone extensive updates and editing in response to the rapid pace of changes and advances in the IAQ industry – most notably the new chapter on building security and the increased emphasis on mold-related issues.

ISBN: 0-88173-440-3

ORDER CODE: 0536

6 x 9, 356 pp., Illus.
Hardcover, \$92.00

CONTENTS

- 1 - Indoor Air Quality: An Overview – Were Are We?
- 2 - Indoor Air Quality in Retrospect: How Did We Get Here?
- 3 - Classifying Indoor Air Problems: What Kind & How Big a Problem Do We Have?
- 4 - Investigating Indoor Air Quality Problems: How to find Out What Went Wrong
- 5 - Controlling Indoor Air Problems: How to Keep the Building Working Well
- 6 - The Thermal Environment: An Internal Habitat
- 7 - HVAC: The Heart of the System
- 8 - Filtration: Understanding an Underutilized Asset
- 9 - Building Security & Safety: Readyng Your Building for "Extraordinary" Environmental Stress
- 10 - Operations & Maintenance: An Ounce of Prevention
- 11 - Management Procedures: The Soft Side of IAQ Success
- 12 - What "They" Say: from Whence Does My Help Cometh?
- Appendix A – Glossary of Acronyms & Abbreviations
- Appendix B – Glossary of Terms
- Appendix C – Selected Resources & References
- Appendix D – Investigation Forms
- Appendix E – Guidance Checklist for Design Documentation
- Index

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Managing Indoor Air Quality, Third Edition	0536	\$92.00	

② Indicate shipping address: **CODE: Journal 2004**

Applicable Discount

*Georgia Residents
add 6% Sales Tax*

NAME (Please print) _____ BUSINESS PHONE _____

Shipping Fees

9.00

SIGNATURE (Required to process order) _____

TOTAL

COMPANY _____

MEMBER DISCOUNTS

A 15% discount is allowed to AEE members.

AEE Member (Member No. _____)

STREET ADDRESS ONLY (No P.O. Box) _____

CITY, STATE, ZIP _____

Send your order to:

AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org

③ Select method of payment:

CHECK ENCLOSED

CHARGE TO MY CREDIT CARD

VISA

MASTERCARD

AMERICAN EXPRESS

Make check payable
in U.S. funds to:
AEE ENERGY BOOKS

TO ORDER BY PHONE

Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX

Complete and Fax to:
(770) 381-9865

CARD NO. _____

Expiration date _____ Signature _____

INTERNATIONAL ORDERS

Must be prepaid in U.S. dollars and must include an additional charge of \$10.00 per book plus 15% for shipping and handling by surface mail.

Here's your complete
guide to making crucial
"repair or replace" decisions
for your facility...

HANDBOOK OF FACILITY ASSESSMENT

By James Piper

This practical guide is designed for facility and maintenance managers who are facing "repair or replace" decisions for their buildings. Filled with useful information and resources to aid in the decision process, this hands-on reference will show you how to accurately rate the condition of existing equipment and components, effectively assess your options, and avoid making costly mistakes. Detailed step-by-step instructions are provided, along with forms listing specific criteria identified for rating each building component.

ISBN: 0-88173-321-0

ORDER CODE: 0469

6 x 9, 452 pp., Illus.
Hardcover, \$135.00



— CONTENTS —

- 1 - The Facility Assessment Process
- 2 - General Forms
- 3 - The Building Site
- 4 - The Building Envelope
- 5 - The Building Interior
- 6 - Mechanical Systems
- 7 - Plumbing Systems
- 8 - Electrical Systems
- 9 - Transportation Systems
- 10 - Outdoor Recreational Facilities
- Index

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Handbook of Facility Assessment	0469	\$135.00	

② Indicate shipping address: **CODE: Journal 2004**

NAME (Please print) _____ BUSINESS PHONE _____

SIGNATURE (Required to process order) _____

COMPANY _____

STREET ADDRESS ONLY (No P.O. Box) _____

CITY, STATE, ZIP _____

③ Select method of payment:

- CHECK ENCLOSED
- CHARGE TO MY CREDIT CARD
 - VISA MASTERCARD AMERICAN EXPRESS

Make check payable
in U.S. funds to:
AEE ENERGY BOOKS

CARD NO. _____

Expiration date _____ Signature _____

Applicable Discount
*Georgia Residents
add 6% Sales Tax*

Shipping Fees **9.00**

TOTAL **_____**

MEMBER DISCOUNTS

A 15% discount is allowed to AEE members.
 AEE Member (Member No. _____)

Send your order to:

AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS

Must be prepaid in U.S. dollars and must include an additional charge of \$10.00 per book plus 15% for shipping and handling by surface mail.

on-peak electricity is about three times the unit cost of off-peak electricity. The generators selected were natural-gas-driven caterpillar models each of which has a net power output of 732 kW at full load. The total installed cost was calculated to be \$1,756,800. With the annual savings (after maintenance and gas costs), the payback period was calculated to be 8.75 years. Table 1 gives a summary of annual present and projected future energy demand and consumption for the facility. Figure 1 gives a summary of the present energy costs for the facility. Table 2 and Figure 2 show the results of analysis for demand, consumption and costs, with the selection of the two engine system to satisfy the present and projected future demand requirements for the facility.

Table 1. Summary of Annual Energy Demand for the Facility

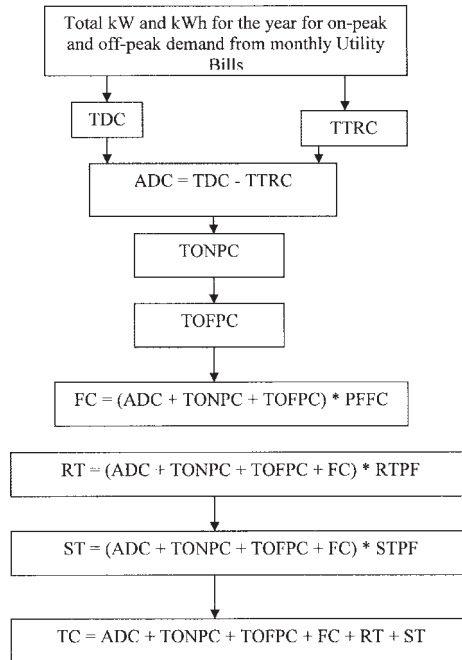
<i>Month</i>	<i>Present</i>	<i>Projected</i>			
	<i>kW</i>	<i>Future</i>	<i>Present</i>	<i>Projected</i>	<i>Future</i>
	<i>Demand</i>	<i>Demand</i>	<i>kWh</i>	<i>kW</i>	<i>kWh</i>
				<i>Addition</i>	
Jan.	1,182	1,374	452,955	93,332	546,287
Feb.	1,193	1,385	573,283	82,087	655,370
Mar.	1,172	1,364	504,882	83,779	588,661
Apr.	1,207	1,321	486,829	50,805	537,634
May	1,367	1,512	453,498	53,050	506,548
June	1,597	1,773	453,882	61,316	515,198
July	1,684	1,877	545,232	57,233	602,465
Aug.	1,506	1,685	400,520	67,880	468,400
Sept.	1,609	1,752	541,474	55,845	597,319
Oct.	1,370	1,485	461,389	55,557	516,946
Nov.	1,120	1,311	491,254	72,640	563,894
Dec.	1,173	1,365	515,878	90,618	606,496
Total			5,881,076	824,142	6,705,218

CONCLUSION

This study provided a method for calculating and selecting an optimum cogeneration system to meet the energy savings need of a facility thus enhancing efficient use of energy while minimizing the impact on the environment. The method uses bin data, utility bills, data collected from the buildings and manufacturer's data among other informa-

tion to calculate the energy consumption and replacement savings with simple payback for in-house electricity generation. The method was applied to a commercial facility, and it resulted in the selection of a new two-engine system such that a limited amount of power will be bought from the utility company during peak demand when the utility company power is most expensive. The generators selected are natural-gas-driven caterpillar models, each of which has a net power output of 732 kW at full load. The annual savings (after maintenance and gas costs) was also calculated, and the payback period was less than nine years. This looks reasonable because the average lifespan of these generators is much more than ten years. The calculations can be done and charted using spreadsheets and user-friendliness can be added with graphical user interface.

Flowchart 1. Current System



ACKNOWLEDGMENT

The author is grateful to Veeraraghavan Vijayaraghavan for data collection and some analysis.

NOMENCLATURE

ADC	Actual demand cost
DC	Demand cost
ES	Estimated savings
FC	Facility charges
FE	Energy input to the cogeneration system from fuel consumed

Flowchart 2. Modified System with Cogeneration System and Two Engines

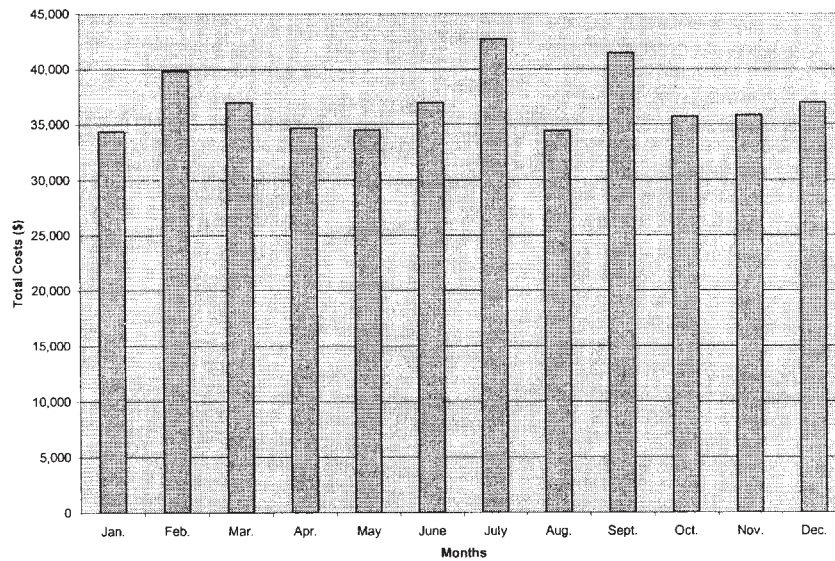
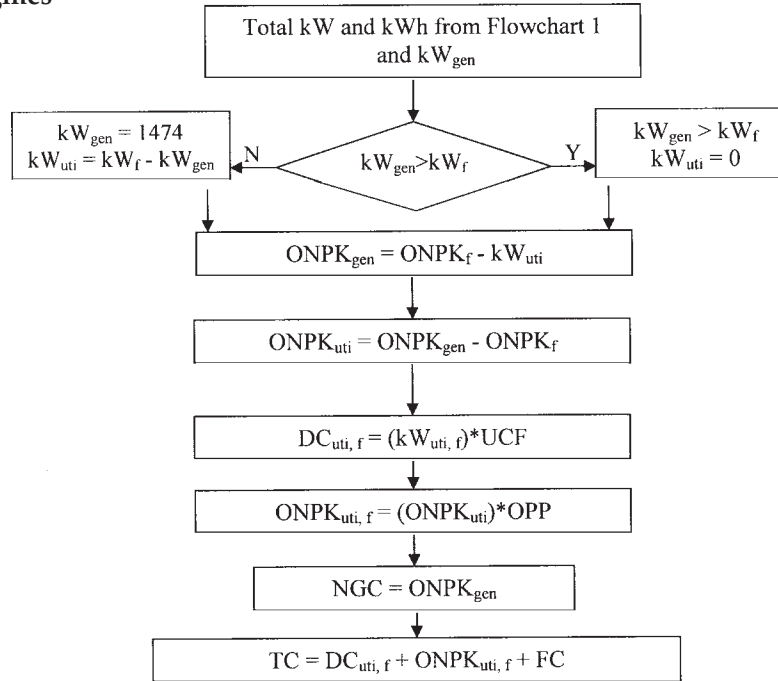


Figure 1. – Present Annual Energy Costs for the Facility

Flowchart 3. Cost Savings

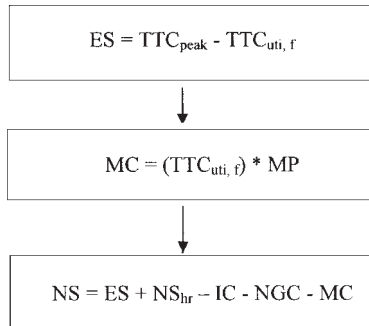


Table 2. Two-Engine Cogeneration System Demand and On-Peak Consumption

Month	Demand (kW)			On-Peak Consumption (kWh)		
	Total	From Engines	From Util. Company.	Total	Generated	Utility Co.
Jan.	1,374	1,374	-	256,555	256,555	-
Feb.	1,385	1,385	-	325,657	325,657	-
Mar.	1,364	1,364	-	298,875	298,875	-
Apr.	1,321	1,321	-	279,785	279,785	-
May	1,512	1,464	48	255,581	247,242	8,339
June	1,773	1,464	309	259,512	204,806	54,706
July	1,877	1,464	413	330,325	237,237	93,088
Aug.	1,685	1,464	221	241,205	204,713	36,492
Sept.	1,752	1,464	288	326,752	262,576	64,176
Oct.	1,485	1,464	21	285,359	281,336	4,023
Nov.	1,311	1,311	-	295,300	295,300	-
Dec.	1,365	1,365	-	287,653	287,653	-
Total			1,229	3,442,558	3,181,734	260,824

- FS Fuel savings
- IC Installed cost
- kW Demand kW (kW)
- kWh Kilowatt hour
- MP Maintenance price/kWh
- MC Maintenance cost
- N No
- NGC Natural gas cost for the year
- NS Net savings for project
- NS_{hr} Net savings from heat recovery

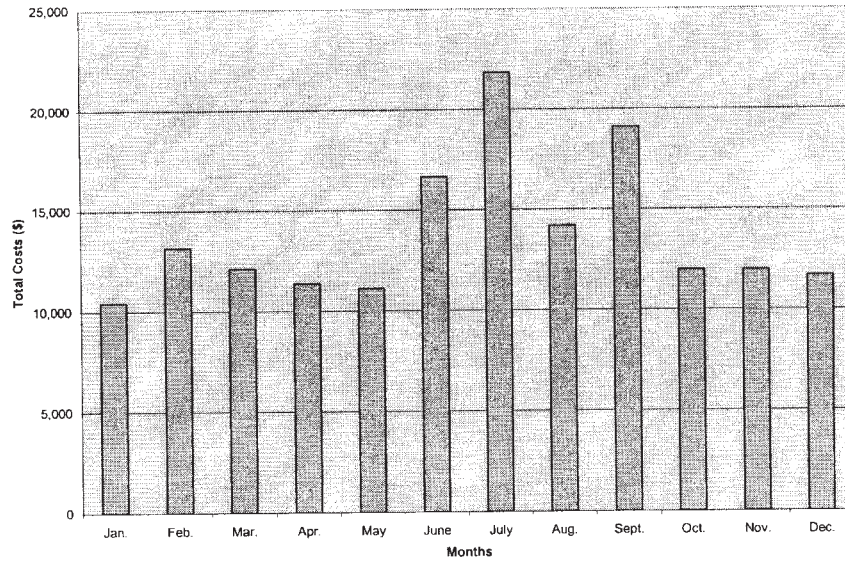


Figure 2. Energy Costs with Two-Engine Cogeneration

OFF	Offpeak price/kWh
ONPK	Onpeak kWh
OPP	Onpeak price/kWh
PFFC	Percentage factor for facility charge
PO	Electric power output from the cogeneration system
RT	Regulatory tax
RTPF	Regulatory tax percentage factor
ST	Sales tax
STPF	Sales tax percentage factor
TC	Total cost
TDC	Total of demand cost for the year
TE	Thermal energy obtained from the cogeneration system
TOFPC	Total offpeak kWh cost for the year
TONPC	Total onpeak kWh cost for the year
TTC _{peak}	Total peak charges to the utility company for the year
TTC _{uti, f}	Total future charges to the utility company for the year
TTRC	Total transformer credit for the year
UCF	Utility charges for the future
Y	Yes
η	Efficiency

SUBSCRIPTS

f	future
gen	generated by the cogeneration system
uti	utility
hr	heat recovery

References

1. Amundsen, R.N., 1990. "Cogeneration Revolution," *Journal of Applied Energy*, Vol. 36, No. 1 - 2, pp 79 - 83.
2. Smith, W, P. Jr., 1986. "Cogeneration: Small Turbine-Generator Case Study," Vol. IA-22, No. 1, pp 121-125.
3. Clark, E.L., 1986. "Cogeneration - Efficient Energy Source," *Annual Review of Energy*, Vol. 11, pp 275-294.
4. Birur, G.C., and Lee, T.Y.R, 1986. "Cogeneration Energy System Analysis Using a Computer-Aided Engineering Technique," *Computers in Engineering, Proceedings of the International Computers in Engineering Conference*, Vol. 3, pp 143 - 149.
5. Voorspools, K.R., and D'haeseleer, W.D., "The Evaluation of Small Cogeneration for Residential Heating," *International Journal of Energy Research*, Vol. 26, No. 13, pp. 1175 - 1190.
6. Turner, W. and Petursson. G., 2001. "Reducing Facility Operating Costs through on-site generation of Electricity," *Energy Engineering*, Vol. 98, No. 5, pp. 77-81.
7. Kolanowski, F.B., 2001. "Sizing the Cogenerator," *Cogeneration and Competitive Power Journal*, Vol. 16 No. 1, pp. 101-107.
8. Le Goff, P., and Hornut, J.M., 1999. "Coupling of an absorption-refrigerator with a cogeneration system," *Chemical Engineering Research and Design, Transactions of the Institute of Chemical Engineers, Part A*, Vol. 77, No. 7, pp. 663-668.

ABOUT THE AUTHOR

Emmanuel C. Nsofor Ph.D. is an assistant professor of Mechanical Engineering at Southern Illinois University, Carbondale, IL. His major research area is energy and thermal analysis. He has experience in design, manufacture, operation and maintenance of a wide range of HVAC equipment and has worked on a Department of Energy (DOE) funded research carrying out experimental investigations and mathematical modeling on the characterization of a thermal energy storage system. He is a member of the American Society of Mechanical Engineers (ASME), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), British Institution of Mechanical Engineers (IMECHE) and is certified as a Chartered Engineer (CEng).