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Cogeneration Workshop for Energy Management Courses by Means of Spreadsheets*

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A spreadsheet-based workshop has been introduced for teaching energy management. Students have to carry out an energy and economic analysis of the cogeneration facilities. In this paper, the spreadsheet and the different phases of the feasibility analysis are described. Students have to consider different issues, such as the analysis of the energy demand and the choice of prime mover, as well as the operating conditions, and the choice of fuel prices. The workshop has been used in two courses dealing with energy management at both bachelor and master level. The main contribution of this approach is related to the use of spreadsheets to solve complex optimization problems, which were not easy to handle in classroom exercises before the introduction of the workshop. The students' feedback was obtained by means of questionnaires. The evaluation of the students' performance shows that the approach is adequate for them to learn about complex decision-making problems.

Keywords: engineering education; active learning; spreadsheets; energy management; cogeneration

INTRODUCTION

ENERGY is undoubtedly currently a major concern in the world. The shortage of resources in the scenario of steadily growing world demand [1] has become both an economic and political issue, not to mention the environmental implications of energy use [2]. In this sense, rational usage has proved to be an important way of improving the energy balance both on a global scale (i.e. national energy balances) and also on a local scale (i.e. industry and domestic energy balances). This is why technologies based on Cogeneration or Combined Heat and Power (CHP) have seen a strong growth in the last decades. In short, they are based on the simultaneous production of both mechanical and thermal energy from a mechanical system in which some kind of combustion process takes place. They encompass a range of technologies, but usually include an electricity generator and a heat recovery system [3]. The former is driven by a prime mover, which is usually an internal combustion engine, a gas turbine or a steam turbine. The excess of produced electricity is sold to electricity companies, resulting in an economic benefit for the plant owner. The heat recovery system makes it possible to obtain thermal energy that can be used for heating or cooling supplies for industrial processes or air-conditioning.

The growth of these technologies in Europe has turned into an important factor for energy, economic and environmental balances, so that both European and National regulations have been established for the promotion of cogeneration based systems [4]. In particular, in Spain, Cogeneration experienced a fast growth in the last decade of the 20th century, as the installed power due to a CHP of 2000 MW in 1995 rose to 5000 MW in 2001 [5]. Nowadays it represents around 6250 MW of the total installed power, and should reach 9215 MW by 2012 [6]. Such facilities are mainly employed in industry applications, although their use has been extended to domestic and commercial applications.

Owing to the evident relevance of this topic, the Industrial Engineering degree at the Universidad Politécnica de Valencia includes courses for those students who are interested in energy management. The courses review the technological, legal and economic implications of cogeneration. In this particular area, energy and economic balances are closely coupled. In addition, European higher education is engaged in a transformation that is driven by the Sorbonne and subsequent declarations and communiqués [7]. This process changes the focus of the educational system from teaching to learning. In this sense, students have to be able to solve problems on their own, and they have to learn the available methodologies. In the field of engineering, such abilities are probably as valuable as the technical knowledge that students are currently learning with the present educational system.

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The authors have prepared the activity presented here with the aim of improving the contents of the energy management and cogeneration courses. The objective of the students' work is to make a feasibility analysis of a cogeneration facility using the spreadsheet that is explained below. This feasibility study includes the analysis of a given energy (electricity and heat) consumer, a proposal for a cogeneration system, energy and economic balances and finally a financial analysis [8]. In the past, this topic was taught in a lecture with some simple exercises solved on the blackboard. This had two major problems: the participation of the students is low and the simplicity of the approach does not allow for an in-depth analysis. It is important that the students learn about the double implications of, for example, modifying the operational conditions of the engine, or the electricity production schedule. Daily decisions in the engineering work are based on detailed balances that cannot be understood with simple classroom exercises. Even though the main concepts can be conveyed by means of conventional teaching methods, the students need to learn about the complex optimization of these systems.

The approach presented in this paper makes use of a spreadsheet to assist the students in the learning process for these complex problems. This type of software is being employed increasingly often for teaching activities [9], even though it was not originally developed for such purposes. The popularity of using spreadsheets in engineering education is primarily due to the suitability of its many features, such as cell structure, mathematics, graphics and programming capabilities in many engineering problems. Compared with commercial purpose-built software, spreadsheets present the solutions in a clear way, allowing the student to track the different internal calculations very intuitively. This makes modifications very accessible for the user, even for beginners. The continuous improvements in these spreadsheet features, together with the low cost, availability and ease of use of the spreadsheets will further enhance their value in engineering education, as demonstrated by the increasing number of publications in this field. A review can be found in [10].

The tool presented here is very similar to the type of software that is usually employed by cogeneration managers, and thus the philosophy is quite close to that of real engineering practice. In addition, it provides students with quick access to the results of a particular situation, which allows them to go deeper into the implications of the decisions that have to be made during the operation of a cogeneration plant.

The paper is divided into five sections. After the introduction, a description of the spreadsheet structure is presented. This is closely linked to the methodology required for this type of problems, which is described in the subsequent section. Finally, a discussion on the learning results is presented, where an analysis for the two courses in which the workshop is carried out. The paper finishes with some concluding remarks.

SPREADSHEET DESCRIPTION

The process of solving this type of problem is made up of different steps, which will be explained in detail in the next section. This has been translated on to the spreadsheet structure using fourteen sheets, making it possible to sequence the problem in different phases. Moreover, in several sheets the same data structure has been used, which enables an easy understanding of the spreadsheet (e.g. Fig. 1). This structure is based on tables that show twelve series of data, corresponding to the average of a parameter (electricity or heat demand, electricity or heat produced by the prime mover, etc.) expressed in power (i.e. energy per unit time) through the day. In order to present this data, a table arrangement is used, where months of the year are in columns and hours of the day in rows.

Energy demand

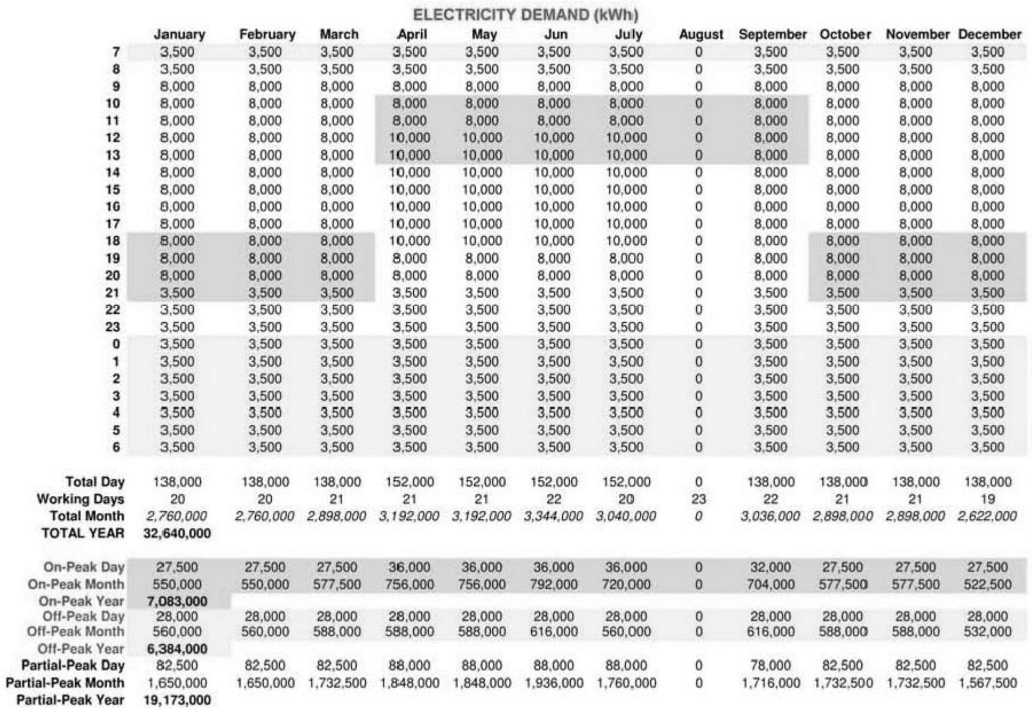
The first two sheets contain the electricity and heat demand. Figure 1 shows the electricity demand sheet. The available information about electricity or heat demand is fed into the analysis using this type of table, which shows the energy demand along each hour of twelve typical days corresponding to each of the twelve months in the year. Each table cell represents the energy demand of one hour. In this way, variations in demand throughout the day and the throughout the year can be accounted for. From this table, and adding the cells properly, the total daily, monthly and yearly energy demand is obtained.

In the case of electricity demand, it is necessary to take into account the rate schedule with different hourly zones depending on the contract with the electric supplier. Normally one, two or three time zones will be considered. For the case in Fig. 1, three time zones are considered by using different colours: on-peak, partial-peak and off-peak. In order to calculate the total electricity bill, it is necessary to split the amount of energy between the different rate zones.

A similar sheet exists for the heat demand but here no time zones are distinguished. Thus, electricity and heat demand sheets make up the input of the problem. Filling them out properly makes it possible to define the characteristics of the different applications that can be studied.

Cogeneration system

The next step in the solution process is to define the cogeneration system to be used; this uses two spreadsheets. The first one is used to set up the nominal characteristics of the cogeneration system,



ELECTRICITY DEMAND (kWh)

	January	February	March	April	May	Jun	July	August	September	October	November	December
7	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
8	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
9	8,000	8,000	8,000	8,000	8,000	8,000	8,000	0	8,000	8,000	8,000	8,000
10	8,000	8,000	8,000	8,000	8,000	8,000	8,000	0	8,000	8,000	8,000	8,000
11	8,000	8,000	8,000	8,000	8,000	8,000	8,000	0	8,000	8,000	8,000	8,000
12	8,000	8,000	8,000	10,000	10,000	10,000	10,000	0	8,000	8,000	8,000	8,000
13	8,000	8,000	8,000	10,000	10,000	10,000	10,000	0	8,000	8,000	8,000	8,000
14	8,000	8,000	8,000	10,000	10,000	10,000	10,000	0	8,000	8,000	8,000	8,000
15	8,000	8,000	8,000	10,000	10,000	10,000	10,000	0	8,000	8,000	8,000	8,000
16	8,000	8,000	8,000	10,000	10,000	10,000	10,000	0	8,000	8,000	8,000	8,000
17	8,000	8,000	8,000	10,000	10,000	10,000	10,000	0	8,000	8,000	8,000	8,000
18	8,000	8,000	8,000	10,000	10,000	10,000	10,000	0	8,000	8,000	8,000	8,000
19	8,000	8,000	8,000	8,000	8,000	8,000	8,000	0	8,000	8,000	8,000	8,000
20	8,000	8,000	8,000	8,000	8,000	8,000	8,000	0	8,000	8,000	8,000	8,000
21	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
22	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
23	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
0	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
1	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
2	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
3	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
4	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
5	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
6	3,500	3,500	3,500	3,500	3,500	3,500	3,500	0	3,500	3,500	3,500	3,500
Total Day	138,000	138,000	138,000	152,000	152,000	152,000	152,000	0	138,000	138,000	138,000	138,000
Working Days	20	20	21	21	21	22	20	23	22	21	21	19
Total Month	*2,760,000*	*2,760,000*	*2,898,000*	*3,192,000*	*3,192,000*	*3,344,000*	*3,040,000*	*0*	*3,036,000*	*2,898,000*	*2,898,000*	*2,622,000*
TOTAL YEAR	**32,640,000**											
On-Peak Day	27,500	27,500	27,500	36,000	36,000	36,000	36,000	0	32,000	27,500	27,500	27,500
On-Peak Month	550,000	550,000	577,500	756,000	756,000	792,000	720,000	0	704,000	577,500	577,500	522,500
On-Peak Year	**7,083,000**											
Off-Peak Day	28,000	28,000	28,000	28,000	28,000	28,000	28,000	0	28,000	28,000	28,000	28,000
Off-Peak Month	560,000	560,000	588,000	588,000	588,000	616,000	560,000	0	616,000	588,000	588,000	532,000
Off-Peak Year	**6,384,000**											
Partial-Peak Day	82,500	82,500	82,500	88,000	88,000	88,000	88,000	0	78,000	82,500	82,500	82,500
Partial-Peak Month	1,650,000	1,650,000	1,732,500	1,848,000	1,848,000	1,936,000	1,760,000	0	1,716,000	1,732,500	1,732,500	1,567,500
Partial-Peak Year	**19,173,000**											

Fig. 1. Electricity demand sheet. Energy values correspond to the case of optimization of a hypothetical public building.

which are related to the prime mover: electrical and heat power, power to heat ratio, electrical and thermal efficiency, investment and operational cost, fuel consumption, etc. In order to make it easier for the students to define the system, four alternatives are predefined with different prime movers: gas turbine, steam turbine, diesel engine and natural gas engine. The students only have to select one of these, by clicking on a macro button. It is also possible to increase the number of units to be used in order to achieve a higher power.

In the second sheet, the operation mode that defines the load profile of the engine is set up. Different macros are assigned to the corresponding buttons, and they make it possible for the student to select the engine load by using different criteria:

- electricity-match mode, where the generated electricity at any instant is equal to the electrical demand;
- heat-match mode, where the useful thermal output at any instant is equal to the thermal demand;
- full load, where the engine operates at full load at any instant.

By means of the macros the engine load for each hour and each month is obtained, in the same way as for energy demand (Fig. 1).

Energy calculations

Once the demand is known and the cogeneration system has been defined, all the necessary input data are defined, and calculations can proceed. Six sheets are used to present the hourly energy balances, using the same general structure already described, corresponding to the following parameters.

- Regarding electricity, the auto-generated, imported and exported electricity are calculated. Auto-generated electricity is calculated by using the prime mover nominal power and load profile. The imported electricity is the necessary electricity to be purchased from the local grid to fulfil the electricity demand. It is obtained by subtracting the auto-generated electricity from the electricity demanded. Finally, the exported electricity is the excess of generated electricity that can be sold. It is calculated by subtracting the demand from the electricity generated.
- Regarding thermal energy, the thermal output, the generation with an auxiliary system and the excess of heat are considered. The thermal output of the prime mover is calculated by using the heat power and the load profile. Similarly to electricity, this thermal energy can be higher or lower than the demand. Thus, the thermal energy generated with an auxiliary system is calculated in the event that one requires more heat, as well as the excess of heat released to the atmosphere, in the opposite case. A boiler is assumed to be an auxiliary system.

Annual energy balance

From the calculations in the previous worksheets, the energy balance is calculated for both the conventional and the cogeneration situations. Results are presented in an additional worksheet. For the conventional case, electrical demand is imported from the local grid and the thermal demand is assumed to be covered by burning fuel in a boiler. For the cogeneration situation, an annual balance is calculated from the information in the previous worksheets. The fuel energy consumption is calculated by means of the efficiency of the particular system, either prime mover or boiler. This parameter will be larger in cogeneration than in the conventional case, since electricity is auto-generated.

The key point of cogeneration is the decrease of primary fuel consumption for the global energy system, compared with a conventional situation. This is an important aspect that must be highlighted to the students. Owing to these advantages, there are promotional policies in many countries for motivating cogeneration projects. They consist of incentives such as investment grants or advantageous export electrical tariffs. In order to access these incentives, cogeneration systems usually have to fulfil some requirements regarding efficiency. Fulfilling these requirements will be included in this sheet according to the country's legislation. In Spain the students learn about the so-called 'Equivalent Electrical Efficiency' [11], which can be defined as:

$$\eta_{EEE} = \frac{W_e}{H_{fC} - \frac{Q_u}{0.9}} \tag{1}$$

where H_{fC} is the annual fuel consumption of the cogeneration system for producing the electrical energy W_e and the useful heat energy Q_u.This parameter must be higher than a minimum defined in the legislation for each type of cogeneration facility in order to be allowed to connect to the grid.

Other parameters that quantify the benefits of cogeneration in terms of primary energy are the 'Fuel Energy Savings' (*FES*) and 'Fuel Energy Savings Ratio' (*FESR*):

$$FES = H_{fS} - H_{fC} \tag{2}$$

$$FESR = \frac{H_{fS} - H_{fC}}{H_{fS}} \tag{3}$$

where H_{fC} is, again, the annual fuel consumption of the cogeneration system and H_{fS} is the annual fuel consumption if the separate production of electricity and heat were considered:

$$H_{fS} = \frac{W_e}{\eta_{W,r}} + \frac{Q_u}{\eta_{Q,r}} \tag{4}$$

where W_e and Q_u are the electricity and useful heat produced by the cogeneration system, and $\eta_{W,r}$, $\eta_{Q,r}$ are reference efficiencies for the separate production of electricity and heat. The FESR is included in the EU directive for cogeneration [4] as a parameter for determining efficiency. More information about different efficiency indicators can be found in [12].

Annual cost calculation

The next two sheets are devoted to the economic balance. In the first sheet the annual fuel and electricity bill is calculated. It is quite a complex sheet and is where the fuel and electricity costs for the conventional and cogeneration situation are calculated.

Fuel costs are easily evaluated with the fuel rate and fuel consumption. They are calculated for the initial situation, as well as for the cogeneration case. In the latter, both the prime mover and the auxiliary heating system have to be accounted for. On the other hand, the electricity costs are far more complex. Apart from the three basic components (a fixed term proportional to the power supplied, a second one related to the total energy consumed and a third related to the reactive energy) different tariffs depending on rate schedule, exporting and importing, etc. have to be accounted for. The annual costs calculated on this sheet are: the imported electricity cost for both the conventional and cogeneration cases, and the exported electricity income from cogeneration.

In order to sum up all the economic data, another sheet is used where the annual fuel and electric costs are collected, as well as the operational and maintenance costs of the cogeneration system (in the conventional case these costs will be zero).

Economic viability

Finally, in the last sheet, the economic analysis is complemented by the calculations related to the viability of the investment in the cogeneration for the case under study. Two economic indexes, the Net Present Value (NPV) and the Internal Rate of Return (IRR), have been chosen in order to do this analysis. This sheet is arranged in tabular form, where each column represents a year in the project lifetime, and all the necessary parameters for achieving the results are calculated in different rows.

The Net Present Value measures the accumulated excess or deficit of cash flow if the economic values are referred to the year in which the project starts. A project with a positive NPV will be viable. This parameter is calculated according to the following equation:

$$NPV = \sum_{t=0}^{N} \frac{F_t}{(1+d)t}, \tag{5}$$

where, d is the market interest rate, and F_t is the net cash flow in year t. Initial cash flow F_0 will be equal to the investment cost. In the subsequent years ($t > 0$) this cash flow is given by Equation (6).

$$F_t = f_t - T_t \tag{6}$$

where:

T_t = income tax, evaluated from the annual profit and a tax rate established by the government; and

f_t = annual operation profit, which is calculated from Equation (7).

$$f_t = \left(C_e + I_e + C_h - C_f - C_{om}\right)_t \tag{7}$$

where:

C_e = savings in the imported electricity compared with the conventional situation
I_e = income from selling excess electricity;
C_h = savings in heat production compared with the conventional situation;
C_f = fuel costs for the cogeneration system;
C_{om} = operation and maintenance costs of the cogeneration system.

Throughout the project's lifetime, the worksheet takes into account the influence of the annual inflation rate and some taxes on the economical benefit, in order to make the calculations of the annual profit more realistic.

Another typical index of economic performance is the Internal Rate of Return. It is defined as the interest rate that will result in zero NPV at the end of the project's lifetime, see Equation (8). A project is feasible if the IRR is greater than the interest rate that could be obtained in an alternative investment (i.e. the market interest rate). This parameter is calculated numerically by means of a built-in function:

$$NPV = \sum_{t=0}^{N} \frac{F_t}{(1 + IRR)^t} = 0 \tag{8}$$

TEACHING APPROACH: WORKSHOP AND CASE STUDIES

First cogeneration concepts are explained in a short lecture. The lecture finishes by describing the spreadsheet. The students then start the workshop activity, following a detailed guide; their work will later be evaluated by the teacher. The guide drives the students through the main concepts by offering basic instructions. The solution process is divided into six stages, which are the usual ones for this type of problems: current situation analysis, proposal of different solutions, energy balance analysis, economic analysis, best alternative choice and, finally, sensitivity analysis. Figure 2 shows a flowchart of the solution process. Each of the steps will be explained in detail in the following sections.

Current situation analysis

The first step is to evaluate the initial situation. Although different cases may be studied (e.g. a manufacturing industry, a public building or a residential property), the following parameters are needed to quantify the description of the energy demand:

- maximum and minimum electrical and thermal power consumption, as well as the time of day and the month when they occur;
- daily electrical and thermal 24-hour evolutions are also asked for with the maximum electricity consumption;
- another important issue is the monthly consumption throughout the year;
- finally, the students have to determine the approximate operating range of the heat-to-electricity ratio of the current application demands.

Generation of solutions

After the analysis of the current situation, students are encouraged to choose up to three cogeneration systems depending on the prime mover. Moreover, three operational modes are studied with the different movers: electricity-match mode, heat-match mode and engine full load operation. Therefore, the complete set of solutions is composed of nine alternatives, which have to be analysed in detail later.

Energy balance analysis

The nine possible solutions are evaluated in terms of electricity and heat balances. Depending on the energy demands, on the engine characteristics and on the operation mode, there are different scenarios concerning the production and consumption of electric and heat power. Figure 3 illustrates these situations. For each plot, the demand is described by means of a point in the thermal energy–electricity plane, whereas a prime mover (in these examples, an engine) is represented by a straight line, which corresponds to the possible operational conditions of the engine in terms of thermal energy and electricity. The final point on the straight line (highest electricity and thermal energy) corresponds to the engine's full-load conditions.

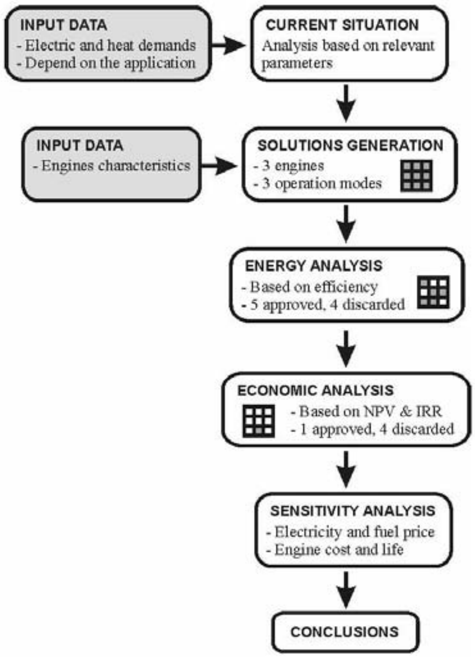


Fig. 2. Flowchart of the solution process.

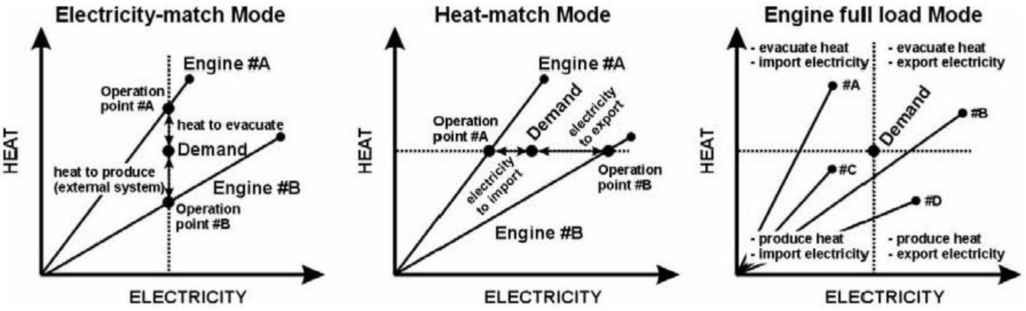


Fig. 3. Plots describing the relationship between energy demand and the different operation modes of the cogeneration prime mover.

The plot on the left in Fig. 3 represents the electricity-match mode operation of two engines, i.e. the operation condition of each engine is chosen in such a way that it produces the exact amount of electricity demanded. It is observed that the heat production exceeds the demand in case #A, so it will be necessary to evacuate heat power. However, an auxiliary system, e.g. a boiler, should provide heat power in case #B, since the engine is incapable of providing the quantity demanded. For the heat-match mode (central plot in Fig. 3) the operational condition of each engine is chosen so that it produces the exact amount of thermal energy demanded. Similar situations as for the electricity-match mode may appear in terms of importing or exporting electricity power, as the plot suggests.

Finally, if the engine is operated at full load (right plot in Fig. 3), up to four situations may occur, depending on the engine nominal power.

Students have to provide summary results of the imported or exported electricity, evacuated or auxiliary heat, and fuel consumption each over a year by using the appropriate spreadsheet. The Equivalent Electrical Efficiency (Equation (1)) is also an important parameter, since it will determine whether the excess of electrical power can be exported, and therefore sold, to the electricity grid. Results are presented in a table for the three engine options. Alternatives that do not accomplish a minimum value of EEE will be discarded. Students will have to choose the five best alternatives to continue with the economic analysis and justify their decision.

Economic analysis

The evaluation of the feasibility of a project is sometimes neglected by students, whose thinking is mainly focused on technical issues. In this part of the workshop they are encouraged to make an economic analysis of five alternatives by obtaining the corresponding NPV and IRR with the aid of the spreadsheet. These results will also be collected in a table to be filled out in the student's guide.

Students might discover that alternatives that achieve better performance in terms of energy efficiency are discarded when checking the results of the economic analysis. Therefore, discussions may arise in order to take into account environmental issues. In the end, students have to choose a solution, considering the different advantages/disadvantages.

Sensitivity analysis

After deciding on a final solution, students have to evaluate the impact that the adopted hypotheses have on the economic analysis of this solution. Owing to electricity and fuel price fluctuations and project uncertainties, such as engine maintenance costs and useful life, a sensitivity analysis is performed with these critical parameters.

Taking advantage of the cross-reference formulae inserted in the spreadsheet, the study is performed automatically by changing the corresponding cells. Therefore, students only have to concentrate on the analysis of the results.

DISCUSSION

The described spreadsheet is used in two different courses within the Industrial Engineering Degree of the Universidad Politécnica de Valencia. In the first course, entitled 'Energy Management' (bachelor degree), the objective is to present the student with a feasibility analysis of any facility in which energy fluxes have to be evaluated in depth. Whether this facility is a cogeneration one or not is not important. In the second course, entitled 'Cogeneration' (master degree), the feasibility analysis is not the most important issue, since it has already been studied in previous modules. Instead, the main objective here is to present the student with a close-to-reality problem of decision-making when installing a cogeneration facility.

Energy management course

In the Energy Management course the workshop is completed as described above. The students work in groups of twos or threes and are continually supervised by a teacher. This practical work takes 3 or 4 hours, depending on the students' abilities. Apart from other skill-based objectives, mainly related to the use of this type of software, the learning-oriented objectives in the use of the spreadsheet are as follows.

- The student should be able to define the steps that have to be followed for the development of a feasibility study of a cogeneration project.
- The student should be able to analyse the technical problem from the perspective of both energy and economics. In this sense, the student has to learn to employ the energy efficiency parameters, as well as the indicators for economic feasibility.
- The student should be able to apply the methodology to other types of feasibility problems in the area of energy engineering.

The use of this spreadsheet has been successful. The students may feel overwhelmed after hearing the description of the spreadsheet, because of the massive amount of information that they have to consider. However, since they only have to choose some parameters, which are then automated with macros, at the end of the day, they are able to understand the key parameters that lead to a cogeneration system being profitable both from the energy and the economical points of view. They learn a methodology of analysis that can be applied to any system in which energy and economic flows have to be optimized. This methodology is applied later in the course to a case study of a system for power generation (cogeneration, solar cell, wind mill . . .). The evaluation of this case study shows that the students have understood the main concepts presented in the spreadsheet workshop. They learn to use the main parameters that quantify the energy and economic efficiency of a system, and they also learn to analyse and explain the results of the system optimization.

At the end of the practical work the students are invited to fill in a feedback form. This form includes general issues such as teacher's abilities and the tools that the students have available to them to carry out the work. The results of this feedback form show that the students consider that the workshop is well integrated within the Energy management course, and they really appreciate the practical approach of the workshop. They also think that this work could be useful in their future careers as engineers. Finally, they marked their overall satisfaction with a 4.5 over 5.

Cogeneration course

In the Cogeneration course, the practical work is presented in different ways according to the maturity of the students. First, the work is not presented as a classroom exercise, it is rather a mini-project that the students have to carry out on their own. Secondly, each group of two or three students is asked to carry out a feasibility analysis of a cogeneration system for a real situation of a particular industrial or residential sector (ceramic, paper, chemical, hospital, university . . .). They have to do a bibliographic search for the values of electricity and heat demands, as well as their time structure. This issue is very revealing for the student, since searching for reliable data is one of the major challenges in a feasibility analysis. Once they have found the necessary input data for the problem, the students have to customize the tables corresponding to their energy demand fluctuations. They have to choose the engine according not only to the energy demand but also for the engine's technical features. Instead of using generic engine data, they must look at the catalogues of the manufacturing companies.

After collecting and introducing the input data, the students start the optimization process and they have to select the engine power and number of units, their operation mode and the best price for fuel and electricity. The objective is to achieve at least the minimum energy efficiency required by law, as well as to maximize profit. For this, the students are encouraged to use the advanced functions of the spreadsheet program, such as a solver tool that finds optima for functions under given constraints. The most advanced users are also encouraged to program or modify some macros in Visual Basic language to take account of the variation of thermal and electric efficiency with engine load. At the end of the work the students have to submit a written report with a description of the procedure.

The students on the Cogeneration course show a considerable interest in carrying out this kind of activity. It must be underlined that the students do not need to complete the project to pass the course, but completion can increase a student's mark. They may be faced with two negative issues, the difficulty in finding reliable data to perform the analysis and a certain feeling of frustration when a cogeneration system cannot reach energy or economic profitability. These two situations are similar to those of an engineer working in this field, and therefore can be considered as additional training for students. On the positive side, the students feel satisfied because they are able to manage a complete feasibility analysis.

The evaluation of students learning has been carried out by analysing the reports that have been submitted for correction. Results show that students are able to handle the worksheet properly; most of them can even modify the file if necessary to accommodate it to their particular problem. The evaluation of the reports has also shown that the spreadsheet is a very useful tool, as the students can focus on the analysis of technical results, rather than on the operational steps to get these results. This improves their analysis capability. They can compare very different situations, and identify the governing factors behind the optimization of cogeneration in terms of energy and money.

From the point of view of the learning process, it may be stated that several educational objectives have been reached. From a cognitive point of view, the students learn about different cogeneration engines, current energy prices, national legislation on cogeneration systems, etc. From the point of view of skills, they learn to implement the different parts of the feasibility analysis in the spreadsheet, as well as to look for the required information on energy demands and engines features. Finally, from a point of view of attitudes, they become conscious of the limitation of energy resources, and of the importance of optimum energy management, as one of the major objectives of the engineer work.

CONCLUDING REMARKS

A spreadsheet-based practical workshop has been proposed in this paper. This work consists of the completion of the feasibility analysis of a cogeneration facility from the point of view of energy efficiency and financial profit. The spreadsheet is arranged according to the different phases of the analysis. Factors such as the evolution of electricity and heat demands, the choice of engine type and operating conditions, and electricity and fuel prices can be analysed. The spreadsheet-based practical work has been adapted to two different courses on Energy Management and Cogeneration. The results have been successful on both courses.

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