CENTRE FOR RENEWABLE ENERGY SOURCES

ENERGY AUDIT GUIDE

PART C: BEST PRACTICE - CASE STUDIES GUIDES

COMMUNITY INITIATIVE

ADAPT

European Committee
Directorate General for Employment and Social Affairs
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The present edition constitutes part of a series of three Technical Guides published by the Centre for Renewable Energy Sources (CRES) regarding the Energy Audit procedure in buildings and in industry. The aim of these publications is to comprise a useful and practical tool for Engineers and other scientists that are going to be occupied in the field of Energy Auditing.

The Guides were published by CRES in the frame of project 124/375 of the ADAPT Community Initiative entitled: "Specialisation of Engineers and other Scientists in Energy Audit Actions". The project was co-financed, according to the European Social Fund (ESF) decree, from the Directorate General for Employment and Social Affairs of the European Commission and has been carried out under the supervision of the Division for Community Initiatives of the Hellenic Ministry for Labour and Social Affairs.

The Training Department of CRES was responsible for the implementation of the project, with the scientific support of the Energy Policy & Programming and Supervision & Execution of Energy Programming Departments of CRES. Dr. Ch. Malamatenios, who is the Head of CRES Training Dept, coordinated the project that was realised during the 1998-2000 period.

The transnational partnership was completed by the French organisation ARMINES - Centre d' Energetique, whose colleagues contributed in many ways to the proper dispatch of the project, thus retaining its European dimension, as well as to the preparation of a part of these Guides. More specifically for this Guide, Case Studies No 1 and 2 were provided by CRES, while Case Study No 3 was provided by ARMINES - Centre d' Energetique.

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CASE STUDY 3: ELECTRICAL ENERGY SAVINGS IN AN OFFICE BUILDING

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1. INTRODUCTION

In recent years there is quite an interest in the areas of Rational Use of Energy and Energy Saving. The well-known reasons are the increasing percentage of energy costs in the final cost of a product, increased global market competition and increased environmental problems. The systematic planning and application of energy saving- efficiency measures has proved savings in the order of 5 to 25%, according to the methodology and the type of saving actions. Additionally, energy savings lead to reduced polluting emissions, an effect that became very important during last years. It has been calculated that the combustion of one ton of oil-fuel frees three tons of CO_2 to the atmosphere, having an adverse role on the greenhouse effect.

As a consequence, energy saving measures are the only actions that support the conservation of the environment, while at the same time they are increasing company competitiveness. Energy efficiency is not solely the result of technological measures and thereby capital investments. The main factors/elements in any energy saving plans are the following: <u>Sound structure</u>, <u>energy consciousness</u> and, finally, the <u>application of modern technology</u>.

CRES, together with the Greek Ministries of Development and that of the Environment, Land-planning and Public-service Works, are considering that a reduction in energy consumption in Greece is a matter of urgency and, on these grounds, have set up the Energy-Bus programme, with the following aims:

1. In-site visits to all Greek industrial and tertiary sectors, in order to perform energy audits and suggest energy saving actions.
2. Sensitisation of public opinion in the rational use of energy concept.
3. Improving Greek company's competitiveness.
4. Environmental protection.
5. Reduction of fuel imports.

The Energy-Bus visit to the specific agro-food industry's establishments aimed at the primitive depiction of the enterprise's status, from the energy consumption point of view. For this purpose, the existing processes were recorded, energy balances were transacted, measurements were taken and, finally, the collected data were elaborated. Moreover, a discussion with the industry's managerial staff was held, in order for possible energy efficiency interventions to be assigned.

The current report presents the specific quantities, in both a quantitative and qualitative form, that have been investigated during the visit of the Energy Bus. The established cooperation between this specific agro-food industry and CRES continued and after the energy audit that was performed, in the form of exchanging information on this report results, as well as in other energy efficiency related issues, between CRES expertise staff and the industry's managers. Moreover, it has to be mentioned that, CRES experts performed a second energy audit in the industry's facilities, about three years after this one, in order for the results of some energy efficiency measures taken by the industry to be certified.

2. OPPORTUNITIES FOR SAVINGS IN THE THERMAL ENERGY SYSTEM

2.1. Combustion efficiency

In the specific agro-food industry two steam boilers exist, from which the one is used to cover the thermal loads, while the second one acts as back-up equipment. The gas analyser was used on the burner of the operating boiler to measure the combustion efficiency, as well as the Carbon Monoxide (CO) and smoke quantities in the exhaust gases. The results of these measurements are tabulated at the following table.

Table 1. Gas analyser results from the boiler/burner system

Measured quantity	Burner No 1 Readings	Burner No 2 Readings
Combustion efficiency	84.2%	84.8%
Coefficient ë (Air excess)	2.43	2.35
Percentage of Ï$_2$	12.3%	12.0%
Percentage of CÏ$_2$	6.5%	6.8%
Concentration of CO	21 ppm	99 ppm
Concentration of NOx	78 ppm	77 ppm
Exhaust gas temperature	290ºC	292ºC
Concentration of SO_2	645 ppm	724 ppm
Smoke (Bacharach scale)	2	3
Combustion heat losses	15.8%	15.2%

Combustion efficiency represents the percentage of fuel energy that is used as useful thermal energy. Overall efficiency is the percentage of fuel used in the boiler that is used in steam production or water heating. Part of the fuel energy remains unused due to: a) hot exhaust gases rejection to the environment, b) incomplete combustion, c) heating of excess air quantities, d) losses from the boiler walls.

Combustion efficiency is affected by all combustion parameters (exhaust gases temperature, air excess, concentration of CO, smoke, NO_x, SO_2), which are presented in the above table and their effect on the combustion efficiency are thoroughly described in Appendix 1, and constitutes the most important indicator certifying sound burner operation. Thus, combustion efficiency should be very close to 100.

In the above table 1, where the results of all measurements are presented, the following are observed:

⇒ Combustion efficiency was quite high in both measurements that were performed.

⇒ Excess air is quite high in both measurements, resulting in pointless heating of air. As it was mentioned before, excess air is quite an important parameter for the proper operation of the burner, which should be carefully controlled.

⇒ Oxygen quantity is high, due to high excess air.
⇒ CO concentration is low in the first measurement but quite increased in the second one.
⇒ Smoke concentration is rather low and this is due to the high excess air and not due to sound combustion efficiency, since the latter is not justified by the other combustion parameters.
⇒ Exhaust gas temperature is normal and within sound operation limits (above dew point), in order to prevent condensation of exhaust gas vapours.

2.2. Thermographs interpretation

In the attached thermographs (see Appendix 2 entitled: "THERMOGRAPHS"), various insulated and non-insulated pipes, as well as boiler surfaces with insulation problems are presented. The temperatures (in ºC) shown on the thermographs correspond to the real temperatures of the marked surfaces.

In the following example, a heat loss calculation is performed, using the data derived from thermograph No 5, where a 5 meter part of an un-insulated pipe, having a temperature of 89.7ºC and 60 mm external diameter, has been measured. Heat losses are equivalent to 165 kg of crude oil per year for this particular example, during a period of one operational shift (2,000 hours per year).

The first thermographs are taken from the main and auxiliary boilers' walls, showing problematic areas with a temperature variation. Although variations between hot and cold regions are not large, still the thermographs define the areas where insulation is poor, either due to degradation or bad fitting.

The shell of the boiler in operation can be seen in thermographs 1, 2 and 3. There, some insulation discontinuity can be spotted, mainly on the insulation joints. When the boiler will be opened for periodic maintenance or for flute cleaning, it is important to pay attention to the insulation fittings and to fill in any substantial gaps.

In thermograph 4 some insulated tubes above the header are presented, where insulation problems are obvious, mainly due to the degradation of the existing insulation. Thermograph 5 corresponds to a part of an insulated and non-insulated tubing and thermograph 6 presents the temperature distribution on the condensation collector.

In thermograph 7, insulated pipe-work with non-insulated vanes, installed at the sesame unit, is pictured. Insulating these vanes can attain an important part of energy savings. As it was seen in the new "halvah" unit, all vanes are insulated. In thermographs 8 and 9, steam-piping sections with insulation problems are presented. These are situated at the sesame unit.

2.3. Rationalization in the use of thermal energy – proposed interventions

Boiler efficiency: Two steam boilers exist in the plant. The efficiency of these two steam boilers was measured and is shown in the above-mentioned Table 1. It is suggested to install an automatic system for supervising/controlling the process of combustion.

Heat recovery from the exhaust gases: The high exhaust gases temperature (300ºC) can be used for heat recovery, as it is much higher than the H_2SO_4 dew point (160ºC). The energy that could be recovered in this way can be used for the following:

- to pre-heat combustion air;
- to pre-heat boiler water;
- to heat water for sanitary and other uses.

It is suggested to install an Economizer at the gas exhaust which will pre-heat boiler water. The installed cost of the economizer, with all the associated components, is estimated to be about 14,000,000 GRD, while the expected annual fuel savings will be in the order of 5%.

Steam collectors: The main steam collectors are situated in the boiler room and are well insulated, with the exception of their spatial fittings. The secondary steam-distributing collectors are located inside the building (with high room temperatures). As for their insulation, the picture is similar to that of the steam collectors.

Piping network: The steam distribution network is insulated with glass -fibre wool, having a thickness of 4-5 cm, according to the pipe diameter, while the insulation is enclosed in sheet metal. This insulation is quite satisfactory for the particular steam temperature, the space dedicated to the distribution network (internal spaces with high temperatures) and the pipe diameters.

The dismantling cost for the existing insulation, with it's sheet metal cover, and its reinforcement with an additional insulation layer, would not be of an economical sound, having in mind that a large part of the existing network will soon be inoperative.

Special fittings: Steam-traps and various other fittings of the network are in good condition, with minimal leaks. There are about 200 non-insulated fittings, with gaskets that can be insulated.

Blow-down: At the two steam boilers of the plant there is a small continuous blow-down, in the order of 10%, and the main blow-down, which is performed once per shift, by opening the discharge valve for about 30 seconds. For the large boiler, which will stay in operation, according to the plant's management refurbishment plans, manual blow-down is 0.5 m^3 per discharge, while the daily total discharge is 8 m^3.

The energy provided by the continuous blow-down is partly utilized/recovered with the use of a heat exchanger that has been installed in the boiler room, while the energy from the manual blow-down (small quantity) is rejected. Of course, all the above operations are labour intensive and, as a consequence, not entirely reliable regarding their outcomes. Blow-down is either performed too late or too soon, with all relevant consequences.

For the solution of the above problems, it is proposed to install an automatic blow-down system. The savings on annual fuel consumption, that are possible when the above proposals will be materialized, are in the order of 4%, that is: 2,800,000 kg x 4% = 112,000 kg.

Automation of the boilers' operation: Boilers function under the supervision of stokers and according to the way described above. As a consequence, they do not always operate under their optimal efficiency.

For the remaining large boiler, it is suggested to install a combustion automatic monitoring and optimisation system, for the boiler's safe and economical operation. This will also reduce the workload of the stoker, who will just supervise the boiler's operation, at least for its major part. Furthermore, it is necessary to replace the existing burner with another one, of modern technology, in order to be equipped with the above automatic system.

3. OPPORTUNITIES FOR ELECTRIC ENERGY SAVINGS

3.1. Management of electric energy and electric loads

The main electricity consumers all over the plant are presented in the following table. The priority of the proposed checks and interventions are based, initially, on these electricity consumption patterns.

Table 2. Electric energy consumption per consumer

ELECTRICAL ENERGY CONSUMPTION	
SITE	**kWh**
Laboratories	59,000
Boiler room	78,000
Compressors	1,596,000
Cooling plant	192,000
Air-compressors	882,000
Production line	2,835,000
Building A'	742,000
Machine shop	340,000
Transportation	460,000
Cooling -Refrigeration	540,000
Packaging	320,000
Pump rooms	450,000
Storage tanks	344,000
TOTAL	**8,838,000**

3.2. Measuring electric energy consumption

The electrical energy (power) analyser was connected to the sesame unit substation, for a two hours period, in order to measure the total electric energy consumption from all sesame production machines and to find out all possible load fluctuations during the measuring period. The load (in kW) which is absorbed by air-compressors and the other machinery that are connected on the main electricity panel, during the 88 minutes measurement, as well as the cosö variations, which are proportional to the load's ones, are presented on the diagram below.

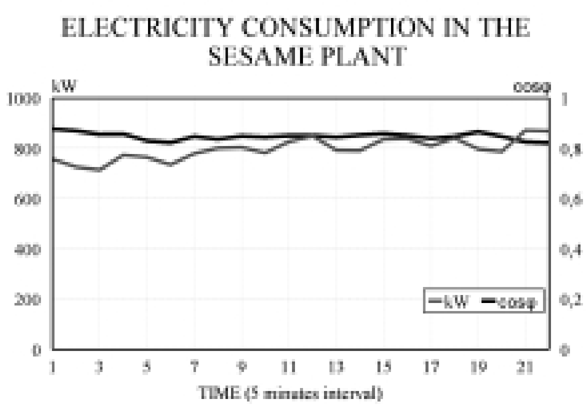


Figure 1. Electricity consumption and Power Factor variation of the agro-food industry

By analysing the results of the measurements the following can be concluded:

- It is observed that peak periods coincide with the national electricity grid's peak periods, where a high load charge also exists.
- Electrical load management is in general satisfactory.
- Observed peaks are most probably due to the simultaneous launching of the two air-compressors.
- Base loads are maintained, even in Sundays, at levels higher than the necessary ones.
- Load demand follows satisfactory, in general, the production sequence of the factory.

By analysing the P.P.C.'s bill, the following are concluded:

- The bill is in the B1.B category, in which the basic cost parameters are the energy consumed, the monthly peak and the power coefficient (cosö).
- The reactive load for the particular month was equal to 0, thus the power coefficient was: cosö=1.
- Compression of the peak load will result in reduced costs of the electricity bill.

3.3. Optimisation of electrical energy loads and peaks - proposed interventions

a. The analysis of Sundays' basic loads leads to the conclusion that it is possible to reduce base loads only by 20 kW. This would lead to annual energy savings in the order of:

20 kW x 24 h/Sunday x 50 Sundays/year = 24,000 kWh

Total annual savings in electricity bills are valued at <u>400,000 GRD</u>.

b. During a typical working day, there exist a potential to reduce peak load (from air-compressors, re-scheduling of secondary loads, etc.) by about <u>200 kW</u>, aiming at lowering load costs. For the implementation of the above interventions it is necessary to use <u>Peak Electric Load Supervision Mechanisms</u>.

The benefit from implementing the above interventions, i.e. the reduction in load costs will reach a total of 300,000 GRD for peaking months and 150,000 GRD for the other months. Annual total savings in electricity bills will be in the order of <u>3,000,000 GRD</u>.

c. <u>Improvement of the Power Coefficient (cos ö)</u>

This has been taken care, with the necessary compensation capacitance devices existing and working well, thus constantly providing cosö=1.

d. <u>Compressed air</u>

Peaks of the electrical load time-charts are mainly due to the simultaneous launching of the two air-compressors, rated at 220 kW in total. In addition, a large percentage of the energy consumption is also due to the simultaneous operation of these compressors.

In order to rationalize the energy use in the production of compressed air process, the following interventions can be performed:

a) Adjustment of the pressure level, at any time, to the minimal required, since energy consumption increases exponentially with exit pressure increase.
b) Frequent cleaning of air filters. Blocked filters induce penalties in air-compressors efficiency.
c) Continuous check for leakage points.
d) Rational use of compressed air.
e) The use of compressed air blowers to clean machinery (hoses are about 9 mm in diameter) should be avoided.
f) Exploitation of the rejected heat with the use of a water-to-water exchanger (boiler).

APPENDIX 1
GAS ANALYSER'S PARAMETERS OUTLINE

Combustion Efficiency (efficiency ratio)

Combustion efficiency represents the percentage of fuel energy that is used as useful thermal energy. Overall efficiency is the percentage of fuel used in the boiler that is used in steam production or water heating. Part of the fuel energy remains unused due to:
a) hot exhaust gases rejection to the environment,
b) incomplete combustion,
c) heating of excess air quantities,
d) losses from the boiler walls.

Combustion efficiency is affected by all combustion parameters and is the most important indicator certifying sound burner operation. Thus, combustion efficiency should be close to the 100 value.

Exhaust gases temperature

The exhaust gases temperature, usually measured in degrees Celsius (^oC), should not be very high, as this heat is wasted to the environment. Thermal losses through exhaust gases are the largest and most important ones from the total system losses. On the other hand, exhaust losses, can be easily adjusted and controlled, in most cases, simply by adjusting the burners' air/ fuel ratio. Still, the exhaust gas temperature should be higher than the dew temperature, thus avoiding exhaust gas condensation, but not too high, to avoid thermal losses.

Dew condensation is responsible for corrosion, as the SO_3 in exhaust gases forms H_2SO_4. The SO_3 is produced from the sulfur combustion to form SO_2, which in turn, with the presence of excess air, oxidizes to form SO_3. For example, if it is assumed that crude oil contains 4% sulfur (which is the highest allowable sulfur containment in crude oil No 3500 for Greece), then the dew-condensation exhaust gas temperature is 1630^{o}C. On the other hand, the lowest permissible temperature of metal surfaces in contact with exhaust gases is 1200^{o}C.

Extremely high exhaust gas temperatures are mainly due to burner operating conditions, which in turn are due to:
- Low or high excess air
- Depositions on tubing, either from the water or the combustion side
- Boiler operation at higher than normal load
- Wrong burner adjustment or use of an unsuitable burner for the fuel and boiler type used.

Lambda coefficient (excess air)

It is the ratio of the air quantity supplied to the burner, to that quantity necessary for a stoichiometric combustion. Stoichiometric combustion takes place when all carbon, hydrogen and sulfur contained in a fuel burn to form carbon dioxide, water and sulfur dioxide, using the minimum quantity of oxygen. For a typical crude oil type, the quantity of oxygen needed for stoichiometric combustion is about 3.2 kg of oxygen per kg of fuel. Because air contains 21% of oxygen by volume (or 23% by oxygen weight), the theoretically required quantity is 13.8 kg of air per kg of fuel.

The total oxygen quantity burns during the combustion process, while the nitrogen that is flowing towards the chimney, has been previously heated, thus wasting heat to the environment. On the other hand, for perfect combustion, it is necessary to have complete mixing of the fuel with the air, so as to obtain contact between every fuel and oxygen molecule. Nevertheless, such a complete mixing between fuel and air is impossible.

For this reason, it is necessary to provide a larger quantity of oxygen from the one required for stoichiometric combustion. Otherwise the combustion will be incomplete, resulting in a production of carbon monoxide or even non-combusted fuel in the form of smoke. It is said that there is 20% excess air, or the lambda coefficient is 1.20, when the oxygen quantity is 20% larger than the one required for sroichiometric combustion.

Excess oxygen does not take any part in combustion, but it is flowing as a heated exhaust gas through the chimney. The excess air quantity plays an important role in the boiler efficiency. When there is small excess in air, combustion is incomplete, fuel is wasted and the chimney fumigates, while large excess in air, flows through the chimney as excessive thermal loss. In both cases, boiler efficiency is reduced.

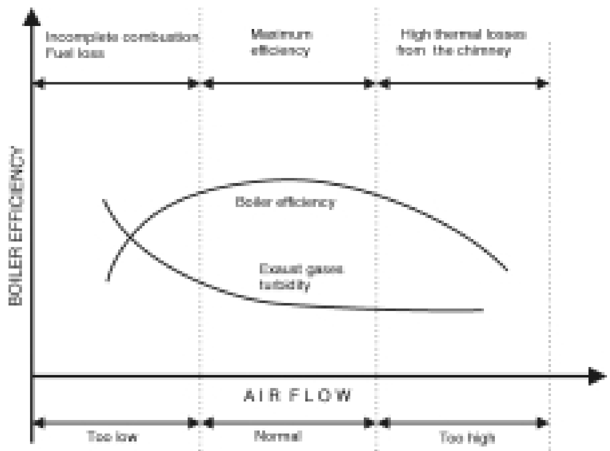


Chart 1. Relation between air supply, boiler efficiency and exhaust gas fogginess

Incomplete combustion due to inadequate air supply is easily perceptible because of the smoke in the chimney. Additionally, an air quantity smaller than the one required for normal combustion (with normal meaning the quantity of air required for complete combustion), entails operational difficulties. This is the main reason that many boilers operate with large air excess, giving clean exhaust gases and operating stability, but with the penalty of bigger losses and hence, lower boiler efficiency.

Excess air calculation

If it is assumed that fuel is comprised only by carbon and combustion uses only pure oxygen (not air), then the combustion products (exhaust gases) will be pure carbon dioxide. If the theoretical quantity of air is used for combustion, the oxygen percentage in the air will be substituted by carbon dioxide, meaning that exhaust gases will contain 21% by volume carbon dioxide and 79% by volume nitrogen (having in mind that during combustion, one volume of oxygen gives one volume of CO_2). If, on the other hand, some excess air is used, exhaust gases will be less dense and thus their CO_2 content will be less than 21%.

The larger the excess air, the smaller the exhaust gases CO_2 content and the larger their O_2 content will be. What happens with pure carbon combustion is true for any fuel. For every fuel type containing a specific proportion of carbon to hydrogen, there is an upper limit in the CO_2 content of exhaust gases, which corresponds to combustion using only the theoretically required quantity of air, which is with no excess air. In this case, there is no oxygen in the exhaust gases. For crude oil, the maximum content of CO_2 is:

$$CO_{2max} = 15.6\% \text{ per volume in dry exhaust gases}$$

Excess air can be calculated using the following formula:

$$\text{Excess air \%} = \left[\frac{CO_{2max}}{CO_2} - 1\right] \times 100$$

where: CO_{2max} = the highest possible content of dry exhaust gases in CO_2 (the one corresponding to zero excess air),

CO_2 = the content of dry exhaust gases in CO_2 under real operating conditions.

For crude oil (where the maximum content of CO_2 in dry exhaust gases is 15.6%), if CO_2 is measured to be 12%, then excess air is calculated as:

$$\left[\frac{15.6}{12} - 1\right] \times 100 = 30$$

In general, the rule is to maximize the CO_2 content in exhaust gases, so that the most economical excess air quantity is used together with the highest boiler efficiency. An effective method to adjust the excess air quantity in a boiler is to start with increasing a small excess air quantity as long as the CO_2 content of the exhaust gases is increasing as well. When the CO_2 content of the exhaust gases starts decreasing, then we have passed the optimum point of excess air quantity.

To obtain the optimum boiler efficiency, exhaust gases must be free of carbon monoxide, while at the same time, their oxygen content must be low and CO_2 high. In this way combustion is using the lowest possible excess air quantity.

Carbon monoxide

This is the quantity of CO found in exhaust gases as a result of incomplete combustion. Its presence is measured in ppm (parts per million), under standard conditions (temperature of 0ºC and pressure of 1atm), and should be minimal. The following are true for the exhaust gas contents:

- When exhaust gases contain CO or smoke without oxygen, it is an indication of incomplete combustion due to small air excess.
- When exhaust gases contain CO or smoke with oxygen, this is due to the two following reasons:
  1. normal air inflow in the combustion chamber without proper fuel-air mixing, or
  2. low air inflow in the combustion chamber, together with secondary inflow due to leakages.

Smog

It represents the exhaust gases content in non-combusted fuel and it is measured in units under the Bacharach scale. Its value should be on the scale very near 0, otherwise what stands for the increased CO content is also true in this case.

Nitrogen oxide quantity

It represents the exhaust gas content in NO, measured in ppm, under standard conditions. Its value depends on the excess air and exhaust gas temperature.

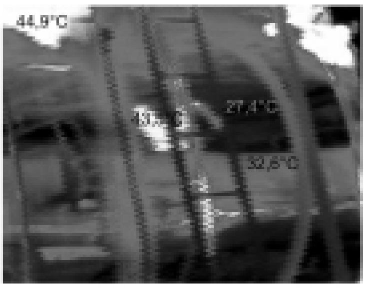
Sulfur dioxide quantity

It represents the exhaust gas content in SO_2, measured in ppm. Its value depends mainly on the sulfur content of the fuel and should be as low as possible.

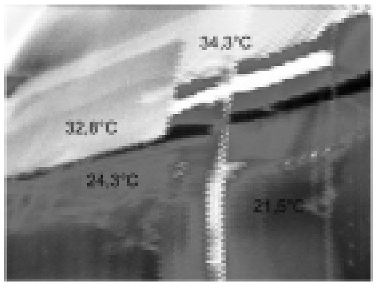
Combustion thermal losses

It is the percentage of fuel thermal energy that is not utilized. It's value results from an expression of the form: {100 - thermal combustion efficiency}, and should be near 0.

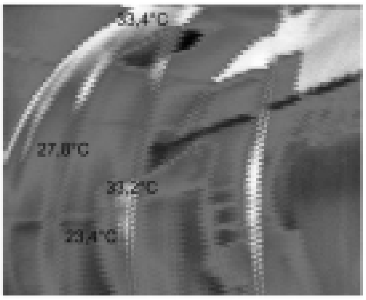
APPENDIX 2
THERMOGRAPHS



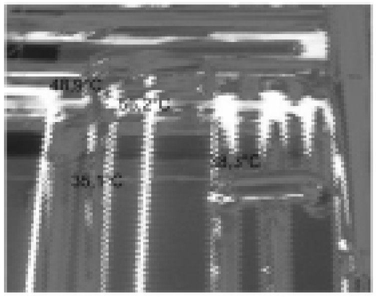
THERMOGRAPH 1: BOILER'S WALL



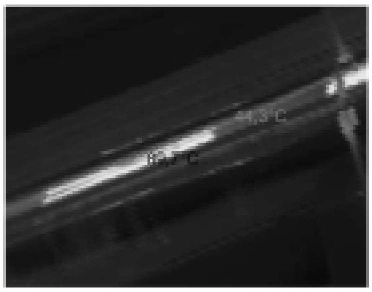
THERMOGRAPH 2: BOILER'S WALL



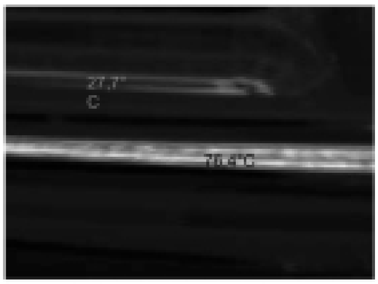
THERMOGRAPH 3: BOILER'S WALL



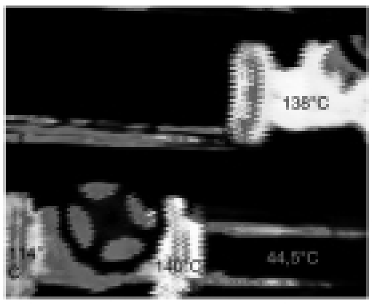
THERMOGRAPH 4: COLLECTOR IN BOILER ROOM



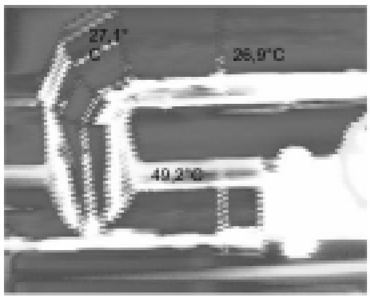
THERMOGRAPH 5: STEAM PIPE



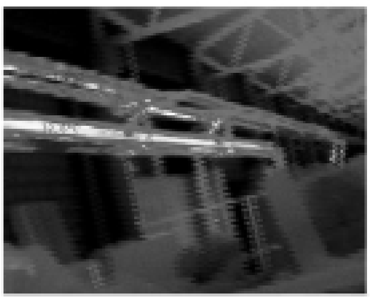
THERMOGRAPH 6: STEAM PIPES



THERMOGRAPH 7: PIPES AND VALVES



THERMOGRAPH 8: STEAM PIPES



THERMOGRAPH 9: STEAM PIPES

CASE STUDY 2: ENERGY AUDIT IN A HOTEL IN GREECE (ISLAND OF CRETE)

1. CURRENT SITUATION

1.1. General remarks

The visit of CRES "Energy Bus" to the present hotel, for the conduction of the energy survey (audit) presented below, was realized after a relevant assignment from the consultancy office ENVIROPLAN S.A. to CRES. The aim of this visit was to delineate the situation of the hotel's buildings from the energy point of view, in order to identify the current status of the hotel's energy consumption and its energy losses, both for the thermal and the electric loads. The aim of the present report is to show in brief the qualitative and quantitative values examined during the energy audit, as well as to propose some identified ways to save energy in various hotel's systems.

The hotel, which begun operation in 1991 and was expanded in 1995, is a three star rated hotel having a capacity of 140 rooms, with 280 beds. It operates for almost 8 months, from the middle of March to the end of October, and is located 2 kilometres away from Rethymnon city in Crete. It consists of the main building and four smaller independent units. Located at the floor of the main building are the reception, cafeteria, restaurant and the kitchen. At the basement of the building the recreation and conference rooms, as well as the electromechanical installations are located. The rest of the two floors have 30 rooms.

The other four buildings are two-floor blocks having 49, 11, 41, and 9 rooms (totalling 110 rooms), respectively. The total constructed surface is 3,821 m², which is divided in: 2,572 m^2 (67%) for rooms, 908 m^2 (24%) for utility spaces - corridors, restaurants, reception rooms -,150 m^2 (4%) for electromechanical installations - kitchen, boiler rooms -, and the rest 191 m^2 (5%) for other spaces (see fig.1).

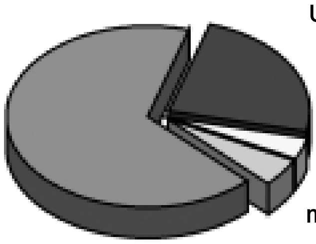


Figure 1. Surface distribution per use

Hotel's electricity supply is accomplished by the PPC (Public Power Corporation) network at medium voltage. Installed power is 468 kVA, while the agreed with PPC power is 400 kW. The maximum power demand during the peak period (August 1997) reached about 160 kW. Maximum demand peaks occur during the early morning or early afternoon hours. Total electricity consumption averages 300,000 kWh per year. Electricity is used partly by the kitchen equipment, by refrigerators-freezers, pumps-circulators, air-conditioning and laundry, as well as for lighting.

The building's roof is constructed with reinforced concrete, without having the required thermal insulation. Rooms have aluminium frame windows and wooden entrance doors. Most of them have poor weather proofness and many openings, due to ageing and exposure to sea salinity. On the building's roof a central solar system has been installed. The system's capacity is lower than the one required, resulting in the necessity of a back-up boiler that runs extensively, even during clear weather days. Furthermore, liquid gas is used for the operation of the kitchen equipment.

1.2. Electro-mechanical equipment

The daily electricity consumption per hotel sector is shown in the following table 1. Electricity driven engines and equipment have been registered and their running times have been calculated, over a typical hotel's operating day, following a relative interview with each sector's manager.

Table 1. Daily electricity consumption per sector

SECTOR	Consumption (kWh/day)
AIR-CONDITIONING	1128
LAUNDRIES	612
KITCHEN	361
PUMPS	143
RESTAURANT	76
SNACK BAR, Cookery	71
MINI MARKET	12
OTHER EQUIPMENT	52

As it can be noticed, the sectors having the highest consumption are the air-conditioning (46%) and the laundries (25%).

1.3. Lighting

The bulb types used all over the hotel and their space distribution is shown in the following tables.

Table 2. Lamp types used and running time in hours

Lamp type	Number of Lamps	Running time/day	Installed Power (kW)
Incandescent	790	5	31.0
Fluorescent	210	5	7.6
Low consumption	250	16	5.0
Low consumption (9 Watt)	300	3	2.7
Halogen	6	11	1.8

Table 3. Lamps distribution per space and type

Installation area	Type of Lamps	Running time/day	Installed Power (kW)
Corridors	Low consumption	12	2.0
Rooms	Incandescent + Fluorescent	3	28.0
Reception	Low cons./ Incandescent	10	3.5
Recreation halls	Incandescent + Fluorescent	10	2.5
Restaurants	Low consumption	5	0.5
Kitchens	Fluorescent	8	1.5
Offices & Store houses	Fluorescent	5	2.2
Laundries	Incandescent	8	0.8
Surroundings	Halogen, Incandescent	11	5.4

In figure 2, the electricity consumption distribution per use (corridors, rooms, etc.) is presented for lighting. It is noticed that the consumption of lighting in corridors, reception rooms and the surrounding is high enough, mainly due to the long running time. In rooms, where incandescent lamps are mainly used, the daily consumption is 82 kWh, since the daily running time in hours is low enough (3 to 4 hours/day).

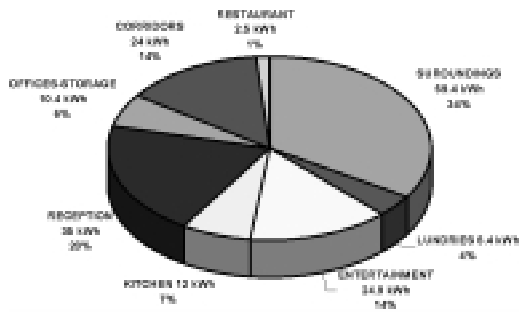


Figure 2. Electricity consumption distribution for lighting

1.4. Heating, Cooling, Domestic Hot Water (DHW)

A water-cooled central air-conditioning unit supplies the building's air-conditioning with a capacity of 84 kW. Cooling is accomplished in the various spaces through fan coils, having a total capacity of 7000 BTU/h. Besides that, a boiler is used for hot water production and another one for the central space heating of the building. The first boiler has a nominal capacity of 160,000 kcal/h and operates about 8 hours per day, covering the DHW demands of both the main building and the other ones, since the central solar collector system has no sufficient efficiency and the collectors' surface area is small. DHW temperature is set at 60ºC.

The second boiler, which has a nominal capacity of 410,000 kcal/h, covers the central building, as well as the rest units' heating demands, in the beginning and at the end of the hotel's working period. Boilers and burners Nº1 and Nº2 were purchased by the same manufacturing firm and have the following features:

Table 4. Specifications of Boilers-Burners Í ï1 & 2

	BOILER Í ï 1		BOILER Í ï 2	
Year of installation:	1990		1990	
Capacity:	160,000 Kcal		410,000 Kcal	
Working pressure:	5 atm		5 atm	
Working temperature:	Up to 110 ^{0}C		Up to 110 ^{0}C	
Boilers' room temperature:	25 ^{0}C		25 ^{0}C	
Boilers' room relative humidity:	58%		58%	
	BURNER Í ï 1		**BURNER Í ï 2**	
Year of installation:	1990		1990	
Fuel flow:	**Min**	**Max**	**Min**	**Max**
	11 kg/h	21 kg/h	13 kg/h	55 kg/h

1.5. Energy and fuel consumption

The fuel used for space heating and partially for domestic hot water production is fuel oil. Liquid gas is used for the basic kitchen equipment, while electricity is used for the building's lighting, the rest of the kitchen's equipment, the laundries-dryers, for air-conditioning, motor driving and other services. The main source for domestic hot water is the central solar system. The following diagrams are showing the diachronic variation of the monthly electricity, fuel oil and liquid gas consumption. In figure 3, existing differences in consumption from year to year are noticed, which must be due to variable booking levels. On the other hand, in figures 4 and 5, where the monthly fuel oil and liquid gas consumption are shown respectively, a rising tendency is noticed.

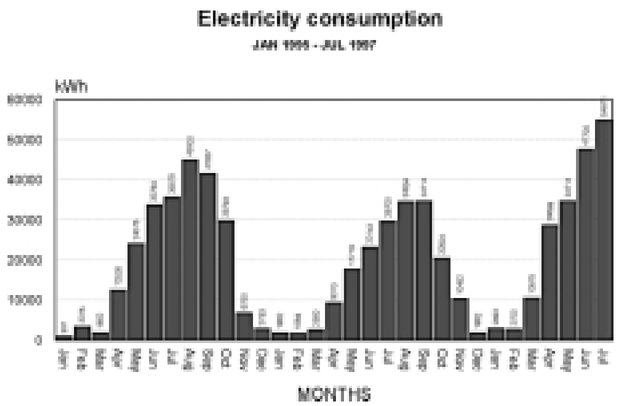


Figure 3. Electricity consumption for years 1995 to 1997

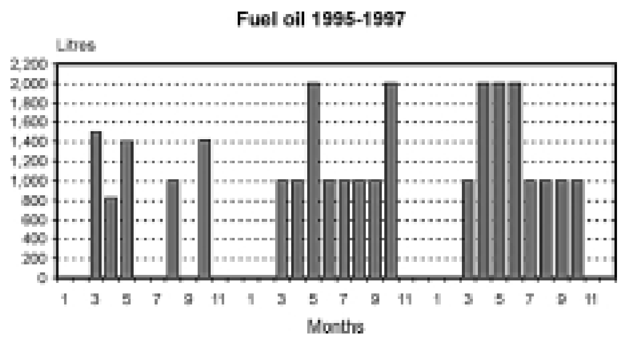


Figure 4. Fuel oil consumption for years 1995 to 1997

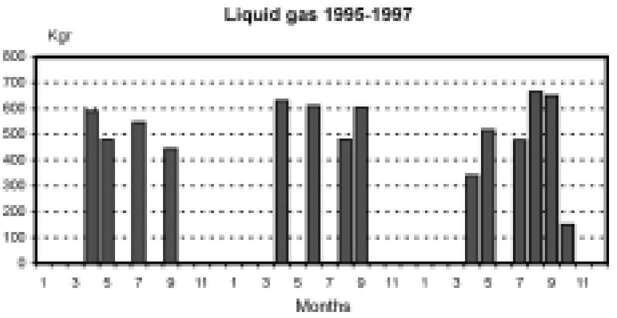


Figure 5. Liquid gas consumption for years 1995 to 1997

In the following diagrams the variation of the power factor (cosö), the Maximum Registered Demand (MRD) and the Agreed Maximum Demand (AMD) for the years 1995 to 1997 are shown. The power factor affects the power cost. The power paid to PPC is not the MRD but the AMD, which for the invoice type (Â2.Ã) of this specific hotel is 965 GRD/kW. The AMD is the product of MRD and a coefficient that depends on the cosö, which is:

- smaller than unity (<1), if cosö is larger than 0.85 (AMD = RMD x 0.85/cosö), and there is a power discount according to the value of cosö,
- greater than unity (>1) if cosö is smaller than 0.80 (AMD = RMD x 0.80/cosö), and there is a power surcharge according to the value of cosö,
- equal to unity (=1), if cosö is between 0.80 and 0.85. In this case the AMD is equal to RMD (AMD=RMD).

Regarding figure 6, it is evident that during last years (1996 and 1997) the power factor was low, resulting in a rise on the charged power by the PPC. It is noticed that, in many months, cosö is lower than 0.80, resulting in a power fine, as is shown in figure 7.

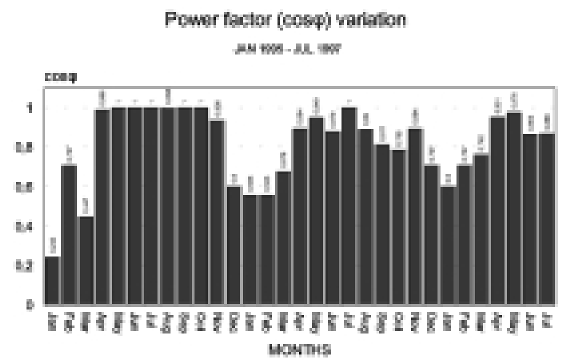


Figure 6. Power factor cosö variation for years 1995-1997

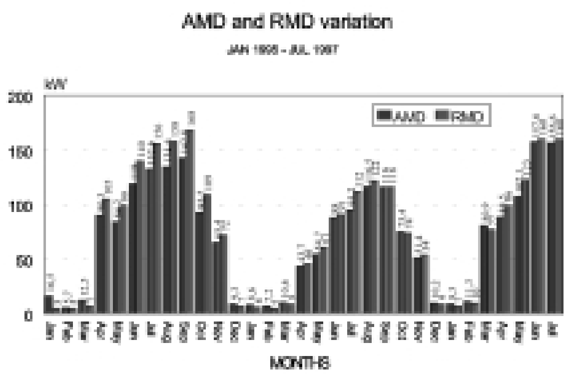


Figure 7. AMD and RMD variation for years 1995-1997

In figure 8, the variation of the power factor and the recorded maximum demand (RMD) are shown. It is noticed that when the RMD is high then cosö is usually low, resulting in a considerable power fine. By installing power factor correction capacitors, the power factor will be improved and there will be a discount in the Registered Maximum Demand.

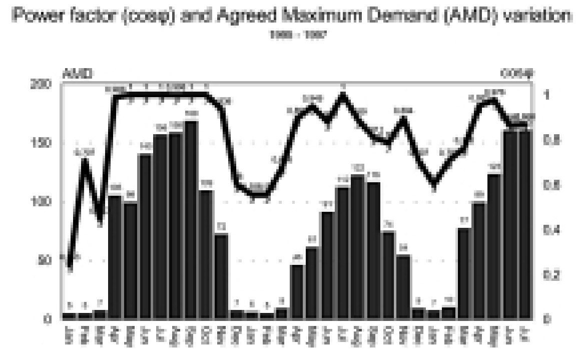


Figure 8. Agreed Maximum Demand and cosö variation for years 1995-1997

In figure 9 the electricity consumption is presented, in relation to the hotel's bookings. It can be noticed that during 1996, when the hotel's booking was relatively low, electricity consumption was very low as well.

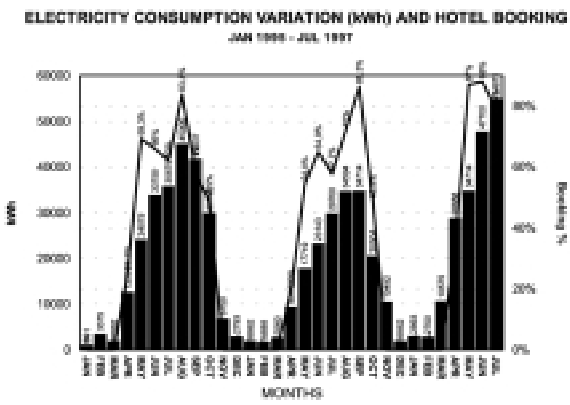


Figure 9. Electricity consumption in relation to hotel's bookings

1.6. Annual energy consumption and distribution

The annual hotel's consumption of electricity, liquid gas and fuel oil are shown in figure 10. For comparison purposes, fuel oil and liquid gas energy outputs have been converted to kWh, according to their heating values (1 kgr of oil corresponds to 11.92 kWh and 1 kgr of liquid gas to 12.73 kWh).

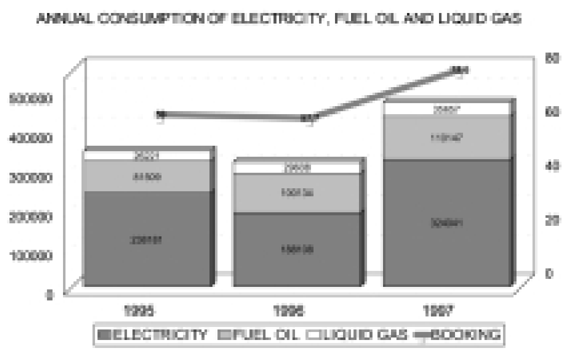


Figure 10. Total fuel and electricity consumption for years 1995-1997

It can be noticed that, the total annual liquid gas and fuel oil consumption is increasing for the period 1995-1997, despite the fact that the hotel's booking load is fluctuating. The annual total electricity consumption is fluctuating in accordance to the booking fluctuations and was expected to be very high during 1997. In figure 11, which shows the percentage contribution of thermal and electrical loads in the hotel's total annual energy consumption, it is noticed that the thermal loads contribute 31% of the total consumption, while the electrical loads (lighting, laundries– dryers, air-conditioning and other services) contribute the 69% of it.

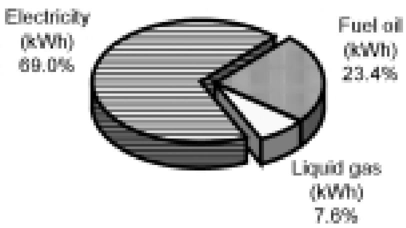


Figure 11. Annual total energy consumption distribution

Presented in figure 12 is the annual electricity consumption distribution of the lighting, electromechanical equipment, air-conditioning, etc. As it can be noticed, the highest percentage of the electricity consumption is due to air-conditioning (41.6%), while the laundries follow with 24.7%. Lighting contributes the 14.3% of the energy consumed, i.e. a low percentage compared to the hotels' average.

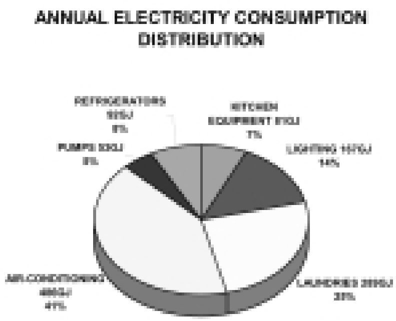


Figure 12. Annual electricity consumption distribution

In figure 13, the annual fuel oil distribution for the production of DHW is shown. It is noticed that, besides the existing solar collectors system, the greatest percentage of fuel oil is used for preparing the necessary DHW quantities. The solar system does not fully satisfy the needs of the hotel and should be better maintained (collectors & piping cleaning, broken glass cover replacement, check for leaks, etc.), while the collector area should be increased (more than the existing 140 m^2), to provide higher solar fractions.

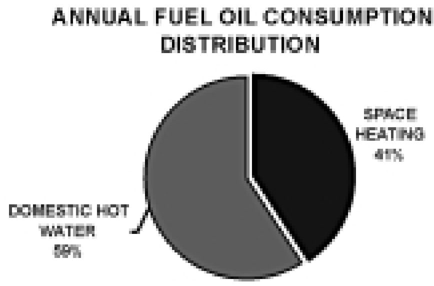


Figure 13. Annual fuel oil consumption distribution

1.7. Energy balance

In the following figure 14, the energy flow to the hotel for each type of energy (electrical, thermal) in Giga-Joule is presented. Regarding the total energy consumption, it is noticed that its most important part is related to the air-conditioning, followed by the laundries and, finally, by the domestic hot water production.

1.8. Energy consumption indicators

In the hotel under examination, the total floor area to beds ratio is 13.6 m^2/bed. The <u>electricity consumption</u> per square meter and bed for 1997 was:

84.8 kWh/m^2/year *or 1,157 kWh/bed/year*

Moreover, the <u>thermal energy consumption</u> (using fuel oil and liquid gas, converted to kWh) per square meter, for the same year was:

38.2 kWh/m^2/ year or *520.7 kWh/bed/year*

Finally, the <u>total energy consumption</u> of the hotel (electrical and thermal) for the year 1997 was:

123 kWh/m^2/year *or 1,678 kWh/bed/year*

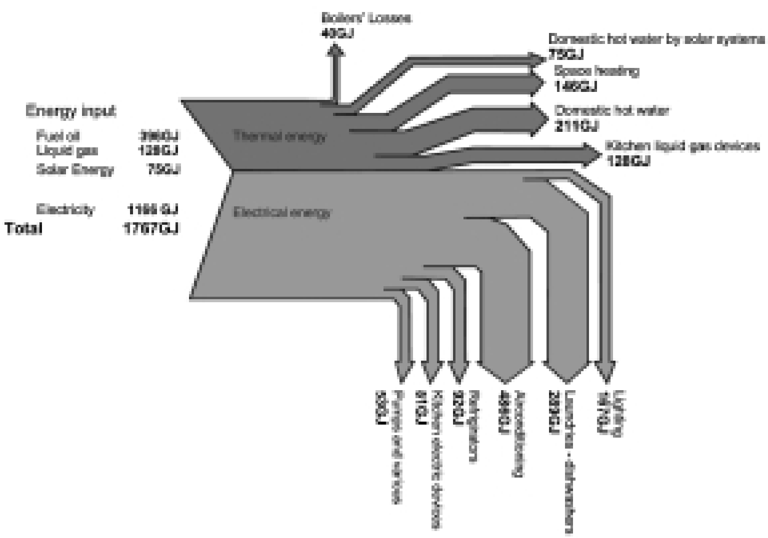


Figure 14. Energy flow diagram for the hotel

2. MEASUREMENTS

2.1. Combustion efficiency and exhaust gas measurements

The combustion efficiency measurement from the exhaust gas analysis is accomplished with the use of a gas analyser. The combustion parameters that were measured during this specific audit are illustrated in Annex A, quoted at the end of the previous case study, in order for their importance to be determined and for the understanding of the gas analysis results.

2.1.1. Measurements outputs

Using the gas analyser, the combustion efficiency of the hotel's burners-boilers was measured, as was the case with the rest of the combustion parameters. Measurement took place at 25/09/1997 (at 13:45), where the outdoors temperature was 23ºC and the relative humidity was 48%. The measurements' results are shown in the following table.

Table 5. Gas analysis results

MEASURED PARAMETER	1st measu-rement	2nd measu-rement
Burner - Boiler Nº 1		
COMBUSTION EFFICIENCY	88.0%	86.9%
ë COEFFICIENT (Excess Air)	1.38	1.39
PERCENTAGE OF O_2	5.7%	5.8%
PERCENTAGE OF CO_2	11.1%	11.1%
QUANTITY OF CO	15 ppm	6 ppm
QUANTITY OF NO_x	39 ppm	40 ppm
EXHAUST GASES TEMPERATURE	252°C	276°C
QUANTITY OF SO_2	2 ppm	1 ppm
SMOKE (Bacharach Scale)	2	2
COMBUSTION HEAT LOSSES	12%	13.1%
Burner - Boiler Nº 2		
COMBUSTION EFFICIENCY	93%	92.9%
ë COEFFICIENT (Excess Air)	1.19	1.18
PERCENTAGE OF O_2	3.3%	3.3%
PERCENTAGE OF CO_2	12.9%	12.9%
QUANTITY OF CO	0 ppm	0 ppm
QUANTITY OF NO_x	52 ppm	54 ppm
EXHAUST GASES TEMPERATURE	182°C	186°C
QUANTITY OF SO_2	1 ppm	4 ppm
SMOKE (Bacharach Scale)	1	1
COMBUSTION HEAT LOSSES	7.0%	7.1%

2.1.2. Remarks

From the above table 5, where the results of the measurements taken for the two burners-boilers are reported, one can notice the following:

- Combustion efficiency is very good for both boilers, while for the second one is close to its perfect value (93%).
- Air excess is within allowable limits for good operation in both boilers (ë=1.39 and 1.19, respectively). Good combustion efficiency is also due to the correct excess air quantity, showing a small deviation for the first boiler.
- Carbon dioxide quantity is also very low for both boilers and between the limits of proper and good operation (CO_2 percentage of 11.1% and 12.9%, respectively), which means that the combustion quality is quite normal.
- The quantity of CO is minimum for the first boiler, while it is zero in the second one, which means that a perfect air-fuel mixing takes place.
- Smoke is very low in the first boiler (2 degrees of Bacharach scale) and minimum in the second one (1 degree of the Bacharach scale).
- Exhaust gases temperature for the boiler Nº1 (276ºC) is slightly above the allowable limits, resulting in heat losses towards the environment. This could be reduced with the better adjustment of the excess air and, in addition, with pipe descaling.

In this case, it is proposed to reduce the excess air of the boiler Nº1, by calibrating the burner to work with the proper air/fuel ratio, that is: ë= 1.2. The result of this adjustment will be a reduction on the exhaust gases temperature and, furthermore, an improvement in the combustion efficiency. Besides that, boilers' piping cleaning should be done in a regular base, both from the water and the exhaust gases sides. Finally, although boiler Nº2 functions properly, it is necessary to be maintained as described above.

2.2. Electrical parameters' measurements

2.2.1. Use of the power analyser

Electrical parameters' measurements have been accomplished using the power analyser. This instrument was connected to the main electricity supply panel for a 24-hour period, in order to register the electrical power demand variations during a whole day. Therefore, instant readings for voltage, current, apparent reactive and active power, cosö, energy per phase and for all phases were registered. These values were read every 5 minutes and stored in the memory pack of the electric energy analyser.

Measurement data were analysed and the power demand, as well as the power factor (cosö), variations were graphically presented, for the measurement period. In parallel, the electricity consumption (in kWh) for all hotel's equipment and for the specific time period was graphically presented, as well as the reactive power per phase and for all three phases.

2.2.2. Electricity consumption measurement for the whole hotel

In the following figure 15, the power consumed by all of the hotel's equipment (in kW) and the current variation (in Amps) are shown. It can be noticed that there are sharp variations in electrical power demand. More specifically, the highest power demand occurs during early morning hours, mainly due to the kitchen devices and the laundry's operation, as well as due to other hotel's services. Nighttime hour power demand is significantly reduced.

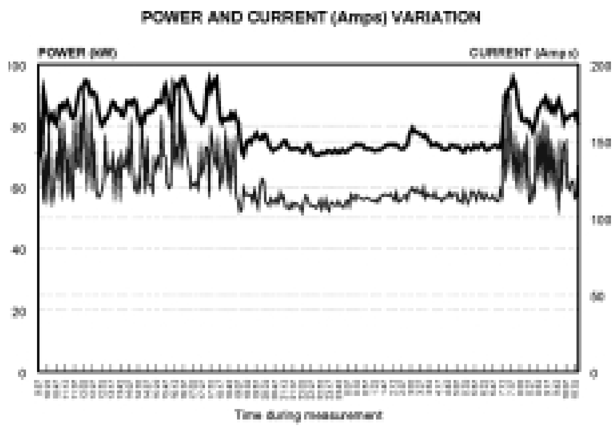


Figure 15. Hotel's power demand variation

In figure 16, the electricity consumption of the entire hotel's loads, air-conditioners excluded, is shown. Power consumption was 1,977 kWh for a time period of 24.5 hours.

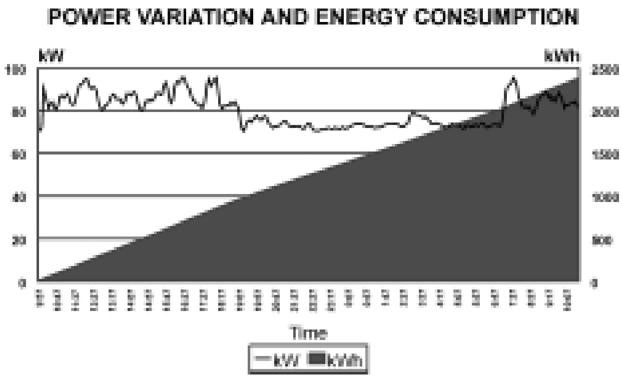


Figure 16. Power distribution and energy consumption in the hotel

3. PROPOSED ENERGY EFFICIENCY INTERVENSIONS

3.1. Intervention 1

It has been determined by the energy audit that, the power factor varies at very low values (0.6 to 0.8), resulting in high charges on the PPC invoices. It is proposed to install proper devices (capacitors) for the correction of the hotel's power factor, in order to achieve an improved cosö (cosö ≈ 1). The payback period for these compensation systems is relatively short.

3.2. Intervention 2

The energy audit showed that there is a large number of incandescent lamps. In each of the hotel's 140 rooms there are 5 lamps on average, of 40 Watts each, whose mean operational time is 3 hours/day. Furthermore, in the surroundings of the hotel, there are 100 lamps (40 Watts each) operating for 12 hours/day. It is proposed to replace these lamps with low consumption ones, having a nominal power of 7 or 11 Watts (equivalent to an incandescent lamp of 40 Watts).

This means that the energy consumption for lighting in these spaces will be significantly reduced. More specifically:
Total room lamps: 680 +
Total surroundings lamps: 100 ⇒ Total number of lamps:780
Capital cost of low consumption lamps:
780 x 2,000 GRD = 1,560,000 GRD.

Annual electricity consumption by incandescent lamps:
680 lampsx40 Wattsx 3 hoursx30 daysx7 months=17,136 kWh
100 lampsx40 Wattsx12 hoursx30 daysx7 months=10,080 kWh
Total = 27,216 kWh, and at a price of 21 GRD/kWh:
Annual cost = 571,536 GRD.

Using the low consumption lamps:
680 lamps x 7 Watts x 3 hours x 30 days x 7 months = 3,000 kWh
100 lamps x 11 Watts x 12 hours x 30 days x 7 months = 2,772 kWh
Total = 5,772 kWh, and at a price of 21 GRD/kWh:
Annual cost = 121,212 GRD.

Thus, the *annual energy savings* will be: *21,444 kWh/year* or *450,324 GRD/year* and the *payback period*: 1,560,000 GRD/ 450,324 GRD/year = *3.5 years*.

Furthermore, as it was found out, the lighting contributes up to 14% of the total electricity consumed. Rational use of lighting may induce important energy savings. It is very important that the artificial lighting must be used only when it is absolutely necessary. The greatest waste of energy (in corridors, rooms, utility-auxiliary spaces, toilets) is done when lamps remain on, by negligence, during clear sunny days.

3.3. Intervention 3

Important energy savings could be achieved when insulating the hotel buildings' roofs. From the thermographic examination of the buildings, it is evident that there is a lack of thermal insulation on their roofs, resulting in considerable energy losses during the space cooling or heating processes. It is proposed to insulate these roofs for increased efficiency. Generally, it has been calculated that with the proper roof insulation, using an insulating thickness of 5 cm, the resulting energy savings will be 7 litres of oil/m^2/year.

3.4. Intervention 4

The majority of the hotel's windows were examined with the thermographic camera and found to have bad weather-proofness, resulting in heavy energy losses. An important problem was found in the windows of the main building's rooms (38 rooms) located at the Northeast side. Due to their light construction and their exposure to sea salinity, they exhibit increased leaks, which increase the heating and cooling losses by about 15%. It is proposed to replace the aluminium frames and the window-glasses with new type, double-glazed windows.

3.5. Intervention 5

The central air-conditioning unit operates for at least 12 hours/ day during the summer period and the energy losses due to open windows are significant. It is proposed to install control systems for the automatic interruption of air-condition's operation in each room. By installing them, heating or cooling losses because of open windows in the rooms will be avoided.

3.6. Intervention 6

The hotel uses the water network of the city of Rethymnon for its water supply. The water is particularly hard, resulting in significant salt scaling at the heat exchanger coils of the boilers used for domestic hot water production and space heating. The salt scaling in coils reduces the heat energy absorption ability of the circulating water, which in turn reduces the efficiency of the boiler, resulting in fuel over-consumption. It is proposed to install water softeners in order to avoid the salt scaling in the coils and to increase the boilers' efficiencies.

3.7. Intervention 7

The measurements' results for the boilers proved that the combustion efficiency is quite normal, resulting in efficient utilization of the fuel oil's thermal content. Boilers' efficiency is over 85%. The regular maintenance of boilers and their burners (internal cleaning, proper adjustment, nozzle check, etc.) will keep the efficiency in levels above 85%, resulting in further energy savings, due to the reduction of heat losses and to the more effective use of the oil's heating energy.

CASE STUDY 3: ELECTRICAL ENERGY SAVINGS IN AN OFFICE BUILDING

1. BACKGROUND AND OBJECTIVE OF THE STUDY

In 1998, the facility management company MULTISERVICE settled a profit-sharing contract with a newly renovated office building. It was stipulated in this contract that MULTISERVICE had the complete responsibility for the functioning of the building. Its tasks are multi-service:

- technical and financial management
- environmental engineering
- electrical engineering, plumbing, lifts and fire protection
- building management system, tele-surveillance and building maintenance.

The company carried out an energy audit of the building to determine:

- the existence of potential savings in electric energy linked with rate optimisation and technical work investments
- the possibility of developing a rate optimisation internally (done by the facility management contractor).

The aims of the entire energy audit procedure that has been carried-out were to:

1. calculate a few ratios and compare them with the values of the literature,
2. check if the chiller installed in the building is well sized, according to the thermal loads covered by the different cooling equipment,
3. find potential savings related to the electricity bill, especially concerning:
   - the subscribed power;
   - the electricity rate selection;
   - the suppression of the consumption in reactive energy;
   - potential savings on electrical energy consumption, especially night running appliances: cooling systems, ventilation, etc.
4. compare different economic scenarios of retrofit.

This specific case study first presents the building with its characteristics before a diagnosis was performed. All information is provided to help the reader find possible savings, while some additional information is provided in order to guide the reader in calculations. Then building retrofits with their economic evaluation are exposed.

2. BUILDING FEATURES

2.1. Presentation of the building

The building is an "office building" in Paris area, housed between two other buildings. When the building was diagnosed, its population was of 350 people, although it was originally designed to host 614 people. Its overall area is 10,000 m^2, including 7,740 m^2 offices with corridors and two levels in the basement. The building comprises 10 floors structured as below:

<u>Floor -2</u>: Car-park, technical rooms

<u>Floor -1</u>: Gymnasium, medical and social rooms, paper storage room, building management systems

<u>Floor 1</u>: Entrance hall, mail office, meeting rooms, working offices

<u>Floors 2 to 9</u>: Offices, meeting rooms, technical rooms for each floor

<u>Rooftop</u>: Technical rooms

A plan of a typical office floor is presented in Appendix 1. The distribution of areas as regards their surface is presented below:

2.2. Heating production

Two exchangers steam/water of 1,200 kW connected to the Paris district network produce hot water. The network is dry saturated steam at a pressure of 3 bars. Building annual consumption is 1,860 tons of steam. It is both distributed to a circuit of static radiators and to the coils of central station air handling

Levels	Office area & corridors (m^2)	Staircases (m^2)	Lifts (m^2)	Hall (m^2)	Car-park (m^2)	Technical rooms (m^2)
Roof	×	×	×	×	×	100
L9	270	50	16	×	×	×
L8	450	50	16	×	×	×
L7	780	50	20	×	×	×
L6	780	50	20	×	×	×
L5	780	50	20	×	×	×
L4	780	50	20	×	×	×
L3	780	50	20	×	×	×
L2	780	50	20	×	×	×
L1	1360	50	20	100	280	×
L-1	1010	20	19	×	130	×
L-2	×	20	15	×	1400	360
TOTAL	**7770**	**490**	**206**	**100**	**1810**	**460**

units. The total power for both circuits is 1,022 kW. Only offices and corridors are heated.

2.3. Cooling production

The cooling production is realised by two chillers with two air-cooled capacitors installed on the roof of the building. The primary chiller is sized for cooling needs of the whole building. The compressor always runs with 4 cylinders of one of the three compressors overnight. The complete characteristics of this chiller are detailed in the following Table 1:

Table 1. Technical characteristics of chiller Nº 1

Brand name	COOLING
Type	Cooling-1
Cooling capacity	262.3 kW
Absorbed power	88.5 kW
EER	2.96
Power stage (number of used cylinders/total number)	22-33-56-67-89-100
Minimal cubic capacity	22%
Refrigerant	R-22
Evaporator data	
Fluid	Cold water
Inlet water temperature	12°C
Outlet water temperature	6°C
Water flow	10.4 lit/s (40 m^3/h)
Loss of head	1.59 mH_2O
Condenser data	
Inlet air temperature	30°C
Number of fans	6
Air flow	29.8 l/s
Compressor data	
Number of compressors	3
Total number of cylinders	18
Type	Semi-hermetic
Electrical consumption data	
Maximal absorbed power	130 kW
Intensity at full load	130 kW
Consumption of control circuit	0.8 kW

<u>For Chiller Nº2</u>:

Brand name:	COOLING
Type:	Cooling-2 (1 compressor)
Cooling capacity:	54 kW (refrigerant R22)
Coefficient of performance at full load:	3.86
Temperature cold water:	6/12ºC
Flow of cold water:	10 m^3/h
Power regulation:	50/100 %
Absorbed power 2 fans:	2.8 kW
Absorbed power regulation:	0.2 kW

The second chiller is used as an emergency system of the computer room that, before the building was renovated, used to serve. Each unit has its own control, more specifically:

- an electronic regulation with chips (control of the temperature of evaporator outlet, power, compressor, fan regulation and diagnosis) for the Cooling-1 unit, and
- a regulation with thermostat located in the return circuit for the Cooling-2 unit.

2.4. Ventilation-air conditioning

Base conditions in the Paris area (zone H1) are the following:

Base conditions	Outdoor temperature (°C)	Humidity (%)
Summer	**30**	**40**
Winter	**-5**	**90**

Rooms	*Temperature*		*Humidity*
	Winter	*Summer*	
Floor offices	**20°C**	**U**	**U**
Meeting rooms	**20°C**	**24°C**	**U**
Basement offices	**20°C**	**25°C**	**U**
Offset room	**20°C**	**25°C**	**50% ± 10%**
Sports-hall	**20°C**	**25°C**	**U**
Utility room	**20°C**	**22°C**	**U**
Computer room	**20°C**	**20°C**	**50% ± 10%**
Cafeteria	**20°C**	**25°C**	**U**
Archives	**16°C**	**U**	**U**
Sports-hall toilets	**22°C**	**U**	**U**
Office toilets	**U**	**U**	**U**
Paper storage	**20°C**	**20°C**	**50% ± 10%**
Basement computer room	**20°C**	**24°C**	**U**
Test room	**20°C**	**24°C**	**U**

U: uncontrolled

Comfort temperatures and humilities were set as above in the different areas of the building.

The building has 6 central station air-handling units (AHU) for air conditioning purposes, installed in the following areas:

- <u>Offices</u>, with a flow of 18,420 m^3/h. This air unit has only a heater unit but no cooling battery. Only the offices of the first and last (floor 9) floors are cooled by 16 and 19 fan coil units, respectively.
  Blowing temperature: 20ºC (minimal: 18ºC).
- <u>Meeting rooms</u>, with a flow of 10,000 m^3/h (with heater and water cooling batteries).
  Blowing temperature: 16ºC.
- <u>Offset room</u>, with a flow of 3,000 m^3/h (with heater and water cooling batteries).
  Blowing temperatures: 25ºC, for -5ºC outdoor in winter,
  16ºC, for 30ºC outdoor in summer.
- <u>Sports-hall</u>, with a flow of 3,000 m^3/h (with heater and water cooling batteries).
  Blowing temperatures: 25ºC, for -5ºC outdoor in winter,
  16ºC, for 30ºC outdoor in summer.
- <u>Utility room</u>, with a flow of 2,570 m^3/h (with only a water cooling battery).
  Blowing temperature: 16ºC.
- <u>Cafeteria</u>, with a flow of 2,200 m^3/h (with heater and water cooling batteries).
  Blowing temperature: 16 ºC.

These flows are calculated to comply with the legislation of air change rate (30 m^3/h per person) and summer heat loads. Air conditioning units are sized according to the maximum power of office areas including corridors. The central station air-handling unit is oversized, since it is designed for 614 people and not 350 people.

The building has several fan coil units and vertical packaged systems (blowing temperature: 16ºC):

- One vertical packaged system and two fan coil units (air circulation flow: 1,550 m^3/h) for the computer room and two fan coil units in the test room (air circulation flow: 440 m^3/h).
- One vertical packaged unit in the storage paper room (air circulation flow: 1,500 m^3/h).
- Eight fan coil units 4 tubes in the mail and social rooms as well (air circulation flow: 440 m^3/h).

2.5. Domestic hot water

Domestic hot water (DHW), for sanitary purposes, is produced in 15 electrical tanks of a total capacity of 850 litres.

2.6. Generating unit

A combustion engine drives the generating unit. It is designed to be used as an emergency unit of the safety devices in case of failure of the electrical supply. Pre-quoted devices are smoke extraction fans and car-park air extraction of a power of 74 kVA. The power of the installed generating group is 65 kVA. The group is not enable to subscribe an EJP electricity rate since the present subscribed power is 220 kW.

2.7. Controllers

A building management system monitors all the alarms, the hourly programming, temperature set points, fire systems, lifts, doors opening and badges. The person in charge for the maintenance is able to modify all the values of the local equipment using an appropriate software package (340 display points in total).

Control concerns:

a) Central station air handling units. These are programmed to be stopped between 7 pm (9.30 pm for the meeting room) and 7 am. The packaged AC unit of the computer room and the paper storage room, as well as the central station air-handling unit of the utility room, work permanently.

b) Heating production. From 7 pm to 7 am, the departure temperature of the circuit coming from the heating network is decreased by 5ºC.

c) Cooling production. As mentioned above, each cooling unit has its own regulation. Nevertheless, a remote control of the chillers is not possible, neither the automatic permutation of the units. It is not possible to monitor cooling production from the building management system.

2.8. Electricity metering

Since 1995, EDF proposes a contract called “Diapason” to help customers to subscribe the right power and chose the adequate rate, as well as to limit the over- costs of reactive energy. To do so, different formulas are offered:

- a free annual balance sheet, established from the maximal powers reached between two meter readings;
- an in-depth balance sheet, based on the power called every ten minutes throughout the past year. Yearly and monthly load curves are also provided. EDF averts the customer in case of significant power over-passing;
- a detailed monthly balance sheet based on the power called every ten minutes throughout the past month. Monthly and weekly load curves are also provided.

MULTISERVICE asked for a free annual balance sheet to analyse EDF load curves. The annual balance sheet, Diapason contract and load curves provided by EDF are presented in Appendix 2.

3. ENERGY AUDIT

The method that was used for analysing the electrical energy consumptions and the potential energy optimisation was as follows:

- Representative ratios were calculated and compared with base data (derived from the literature).
- The plan of low-tension distribution in the building was studied.
- The different meters readings present on the site were recorded.
- The determination of the subscribed power was checked.
- The electricity consumers were listed.
- Rate simulations were carried out.
- Short and middle term solutions of energy savings were proposed.

These stages are developed in the diagnosis presented in this case study. Plan of energy savings identified from the energy audit were:

- the subscribed power,
- the electricity rate selection,
- possible suppressions of the consumption in reactive energy, and
- potential savings on the electrical energy consumption.

3.1. Heating ratio

The steam of the district network is at P=3 bar and is dry saturated steam. The enthalpy given by a water enthalpy diagram is 2,715 kJ/kg, that is 750 kWh/ton. Building annual consumption is 1,860 tons of steam, that is 1,395,000 kWh/year. Heat consumption per m^2 of heated area is 180 kWh/(m^2·year). This figure is a little higher than the one proposed in the relevant standards (165 kWh), but it should be noticed that the building is partially occupied and internal gains lower than this previously calculated by the heat installer.

Annual electricity consumption is 829,620 kWh (see annual balance sheet in Appendix 2). Total energy consumption is 2,224,620 kWh, corresponding to a ratio of 222 kWh/(m^2·year). It is a little lower than the value of 240, which is indicated in the relevant standards.

3.2. Subscribed power

Before the diagnosis, the office building opted for rate A5 option “average uses”. The subscribed powers were as follows:

Periods	Peak (P)	Peak winter hours (HPH)	Off-peak winter hours (HCH)	Peak summer hours (HPE)	Off-peak summer hours (HCE)
Power (kW)	220	240	240	240	240

Hence, the power subscribed for this rate is: 220 + 0.68 x (240-220)= 233.6 kW. The statement provided by EDF (Appendix 2) shows that the system of power reduction along the different periods is not necessary. Indeed, the consumed power of the building does not go beyond 220 kW throughout the year, except in January (225 kW). That is the reason why the rate simulations were performed for a subscribed power of 220 kW.

3.3. Electricity rate selection

Simulations were performed for both the yellow and the green rates with the prices of 1999 (see tables in Appendix 3). Thus, the following results were derived:

Table 2. Green rate A5 (from 250 to 10,000 kW)

Rates	Subscribed power (kW)	Fixed premium (FF)	Consumption (FF)	Overall cost (FF)	Average price of kWh
Average use	220	27 240.00	253 865.82	311 285.82	0.38
short use	220	24 156.00	311 116.64	335 272.64	0.41
long use	220	95 647.20	215 870.90	311 518.10	0.38
very long use	220	155 284.80	179 383.85	334 668.65	0.41

Table 3. Yellow rate (from 36 to 250 kVA)

Rates	Subscribed power (kW)	Fixed premium (FF)	Consumption (FF)	Overall cost (FF)	Average price of kWh
Average use	220	22 862.40	332 601.23	355 463.63	0.43
long use	220	68 323.20	257 858.80	326 182.00	0.40

Note:

In the simulation, the subscribed power considered is 220 kVA. More rigorously, the subscribed power of 220 kW in green rate should have been converted in kVA of the yellow rate according to the formula: $S^2 = P^2 + (0.4xP)^2$, since tan ö equals 0.4. Hence, S= 237 kVA.

As a consequence, the subscribed power with the yellow rate should be higher than the simulated one and the losses compared to the current rate also higher than the simulated ones. Moreover, work costs to modify electricity supply of the building by EDF were appraised at 122,600 FF w/o taxes, only for the room of the low-tension transformer, in case of going to yellow rate. Rate simulations allow confirming that:

- the present green rate A5 option "average uses" can be maintained since it offers the cheapest yearly costs,
- the subscribed power should be decreased to 220 kW, which represents a gain of 3,549.60 F per year.

3.4. Suppression of the consumption in reactive energy

EDF penalises the companies subscribing a green rate when tan ö > 0.4 (cos ö < 0.928) during the peak period and winter periods (November to March included). The electricity sheet sent by EDF for the period of August 1997-July 1998 shows that penalties were applied (see Appendix 2). The billing comprises a charge of 242,125 kVARh of reactive energy for an amount of 19,070 FF, that is 6.6% of the total of the overall energy bill.

Moreover, from the same bill it can be mentioned that, for the time-period of interest it was measured: tan ö =1.06 (cos ö = 0.707). This means that the consumption of reactive energy nearly equals the one of the active energy. This value is well beyond the norm acceptable for a correct installation (tan ö <0.75). Since the power factor is low, which means that the electrical system has a high inductive load, a capacitor can be added in parallel to reduce the reactive power. This capacitor should have the following characteristics:

Then:

$$\tan\phi = \frac{W_r}{W_a} = \frac{223\text{kVAR}}{224\text{kW}} = 0.996$$

with W_a representing the active power and W_r the reactive power, respectively. The reactive power that the capacitor has to compensate is:

$Q_c = W_a(\tan ö - 0.4) = 224x(0.996-0.4) = 224x0.596 = 134$ kVAR

Calculation of the capacitor's theoretical power

Active energy consumption

	peak	peak winter hours	Total
November		49215	49215
December	13287	37477	50764
January	13609	38039	51648
February	11359	31358	42717
March		48542	48542
Total (kWh)	38255	204631	242886

Number of use hours

Peak	177
peak winter hours	909
Total (h)	1086

Active power

Total active consumption (kWh)	242886
Number of use hours (h)	1086
Active power (kW)	224

Reactive energy consumption

	peak+ peak winter hours
November	51128
December	48918
January	48045
February	43580
March	50448
Total (kVARh)	242119

Reactive power

Total active consumption (kWh)	242119
Number of use hours (h)	1086
Active power (kW)	223

This means that the capacitor to be installed must be at the 134 kVAR power range. The chosen material is the following:

Designation	Amount w/o taxes
Activing3 150 kVAR	20,931 FF
Circuit breaker	4,761 FF
Wiring, manpower, works, etc.	9,372 FF
Total F w/o taxes	35,067 FF

3.5. Potential savings on electrical energy consumption

Some solutions to limit electricity bills have been proposed after analysing the annual balance sheet provided by EDF. Energy consumption savings can be defined:

- after checking the adjustment of cooling production to cooling loads.
- after a control visit of the building.

3.5.1. Cooling loads and adjustment of the chiller

Thermal balances on the different premises allow calculating the cooling load of the building. The cooling power required by central station air handling unit is:

$$P = \dot{V} \times \tilde{n} \times (H_o - H_b)$$

with,
- P: Cooling power
- $\dot{V}$: Blown air flow
- $\tilde{n}$: Air density
- H_o: Enthalpy of base outdoor temperature in summer
- H_b: Enthalpy of blown air temperature

In the case of fan coil units and vertical packaged systems,

$$P = \dot{V} \times \tilde{n} \times (H_i - H_b)$$

with
- $\dot{V}$: Circulated air in the room which incorporates fresh air for hygiene (30 m^3/h and per person)
- H_i: Enthalpy of the indoor temperature in summer

The thermal balances are provided in the following Table 4.

Maximum instantaneous cooling needs were assessed to be at 201 kW. Considering 5% line losses and a cooling overpower of 10%, the required power for cooling represents 232 kW. Indeed, the cooling unit installed is 262 kW, which is an over-sizing of 13%. The present cooling production is a little oversized to the daytime needs of the building. The possibility of variable speed for central station air handling units should be considered, since maximal cooling needs are not simultaneously reached in the different parts of the building and the value of 232 kW is probably never reached.

Moreover, the overall flow of the central station air-handling unit of offices was designed for 614 people with 30 m^3/h per person of fresh air, that is 18,420 m^3/h. The present staff of the building is 350 people. The flow could be reduced to 10,500 m^3/h. The adjunction of a two-speed motor in the central station air-handling unit would reduce the flow and the present motor power of 15 kW. Considering equipment running at night, night cooling needs are 36 kW, which is the 14% of the nominal power of the machine.

3.5.2. Potential savings on night running appliances

The plan of action that was drawn-up included:

- the theoretical determination of appliances in operation overnight,

Table 4. Cooling loads balance

Zone	Floor	Number of units installed	Flow (m^3/h)	H_i(kJ/kg)/ T_e(°C)	H_b(kJ/kg)/ T_b(°C)	Overall balance (kW)
Offices	9	19 FCU	11300	25°C	16°C	34
Offices	1	16 FCU	10000	25°C	16°C	30
Mail office	1	5 FCU	3000	25°C	16°C	9
Computer room	1	2 FCU+1 VPS	5250	38 kJ/kg	30 kJ/kg	14
Conference room	-1	4 FCU	2250	24°C	16°C	6
Test room	-1	2 FCU	940	24°C	16°C	2.5
Social rooms	-1	8 FCU	2200	25°C	16°C	6.5
Paper storage	-1	1 VPS	1500	38 kJ/kg	30 kJ/kg	4
					TOTAL: 106 kW	
Zone	**Floor**	**Number of units installed**	**Flow (m^3/h)**	**H_o(kJ/kg)/ T_o(°C)**	**H_b(kJ/kg)/ T_b(°C)**	**Overall balance (kW)**
Utility room		1 CSAHU	10000	30°C	16°C	12
CSAHU meeting rooms		1 CSAHU	2570	30°C	16°C	46
CSAHU sports-halls	-2	1 CSAHU	3000	30°C	16°C	14
CSAHU cafeteria		1 CSAHU	2200	30°C	16°C	10.3
CSAHU offset room		1 CSAHU	3000	57 kJ/kg	30 kJ/kg	13
					TOTAL: 95.3 kW	
Overnight cooling needs: 36 kW					TOTAL POWER: 201.3 kW	

* Symbols: CSAHU: Central Station Air Handling Unit
FCU: Fan-coil unit
VPS: Vertical packaged systems

- the on-site meter reading of technical equipment consuming electricity overnight,
- the comparison with the load curves and the determination of the potential energy savings.

MULTISERVICE did also control visits of the building from 6 to 12 p.m. during one week. Building audit happened at night because the number of running equipment is smaller and so control is simpler. In the following tables, the equipment that was found in operation during the whole night is presented:

Table 5. Equipment theoretically in operation overnight (from 6 p.m. to 8 a.m.)

Designation	Electrical power (kW)
Chillers (compressor+fan)	22
Circulation pump	4
Switch box	2
Fan coil unit	2
Central station air handling unit	1.5
Total	31.5

Table 6. Equipment really in operation overnight (from 6 p.m. to 12 p.m.), September 1998

Designation	Electrical power (kW)
Chillers (compressor+fan)	22
Circulation pump	4
Switch box	2
Fan coil unit	2
Central station air handling unit	1.5
Car-park extractor	3
Car-park lighting (floor -2)	7
Corridor lighting (floor -1)	0.6
Corridor and toilets lighting (floor 1)	0.82
Lighting of office corridor (floor 1)	0.8
Total	43.72

As illustrated in figure 1, the analysis of daily load curves from 22/09/1998 to 02/10/1998 permits to determine that:

- the arithmetical average power is 42.2 kW (subtracting the value of 24/09), which is close to the theoretical power (43.72 kW) calculated for September 1998,
- the low power limit is 36 kW,
- the high power limit is 45 kW.

Despite the short study period, it is obvious that a few savings can be readily achieved:

- The car-park extractor should be stopped from 10 p.m. to 6 a.m. and the whole weekend.
- The car-park lighting should be stopped from 10 p.m. to 6 a.m. and the whole weekend.
- A time switch should be created for all the corridors.

Savings should at least decrease to the low power level calculated from the load curve, that is:

➢ Arithmetical average power: 42.2 kW
➢ Low power limit: 36 kW

Then, the potential savings will be: *Saved power* = 42.2–36=6.2 kW.

For a green rate A5 average uses and a lighting control by the building management system between 10 p.m. and 6 a.m. during the week and the whole weekend:

Periods	***Peak winter hours (HPH)***	***Off peak winter hours (HCH)***	***Peak summer hours (HPE)***	***Off peak summer hours (HCE)***
Duration	693 h (=16*2*52* 5/12)	1213 h (=8*2*52*5/12 +5*52*8*5/12)	970 h (=16*2*52* 7/12)	1699 h (=8*2*52*7/12 +5*52*8*7/12)
Rate	0.49 F/kWh	0.31 F/kWh	0.20 F/kWh	0.13 F/kWh

Thus, the resulting annual savings in electricity consumption will be: 6.2 x (693 x 0.49 + 1,213 x 0.31 + 970 x 0.2 + 1,699 x 0.13)=7,000 FF w/o taxes. Indicated modifications of the management building system may be estimated at 20,000 FF. Electricity meter can possibly be installed for appliances with a power over 4 kW.

3.5.3. Energy savings in cooling production-use of alternative cooling systems

As was mentioned above, it was found out during the audit that the chiller Cooling-1 was permanently working overnight on one compressor. It is worth studying potential savings when using the emergency chiller Cooling-2 instead. Thus, as far as the absorbed power of Cooling-1 is concerned:

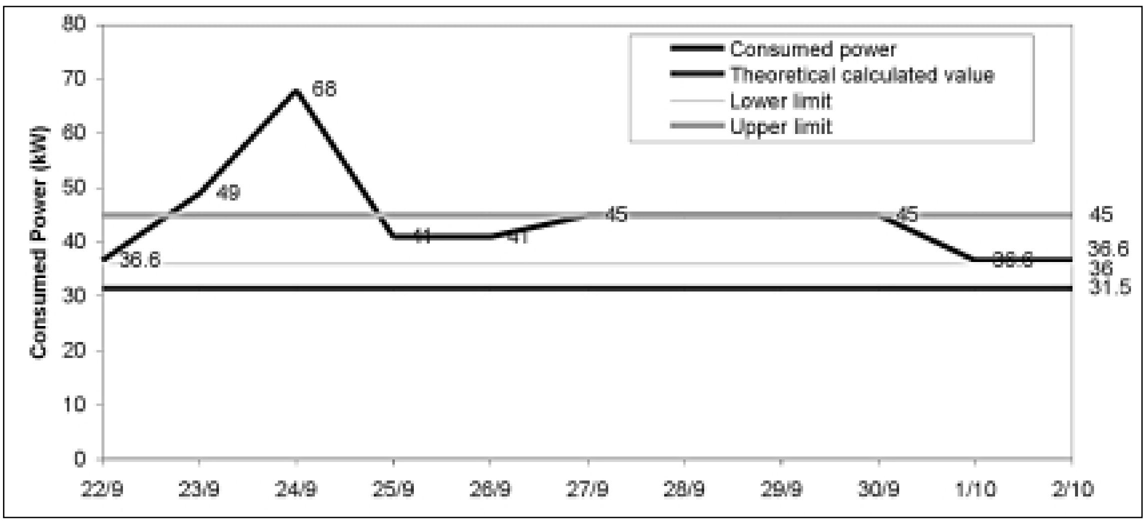


Figure 1. Load curve for "off-peak" hours (10 p.m. – 6 a.m.)

- Compressor 1:
  Flow: 106 m^3/h
  Absorbed power: 22 kW
  Number of cylinders at full load: 6
- Compressor 2:
  Flow: 139 m^3/h
  Absorbed power: 29 kW
  Number of cylinders at full load: 6
- Compressor 3:
  Flow: 106 m^3/h
  Absorbed power: 22 kW
  Number of cylinders at full load: 6

The compression always starts with 4 cylinders of the compressor 1 or 3, that is 22% (=4/18) of the total number of cylinders. The minimal cooling power is:

$$P = \frac{N}{N_{fl}} \times P_{fl}$$

where N is the number of cylinders, N_{fl} the number of cylinders at full load and P_{fl} is the refrigerating capacity at full load.

In this case: $P = \frac{4}{18} \times 262 = 58.2 \text{ kW}$

Moreover, when not having data from the manufacturer for partial load, American norms ARI or the empirical formula of Peitsmann-Nicolaas (approximation by a linear regression) can be used to calculate the absorbed power at partial load. The latter is proposed for reciprocating compressor and R22 refrigerant when condensing and evaporating temperatures are unknown and its expression is as follows:

$$\frac{P_a}{P_{afl}} = 0{,}82 \times (\frac{P}{P_{fl}} - 1) + 1$$

with P_a the absorbed power at partial load, P_{afl} the absorbed power at full load, P the cooling capacity at partial load, and P_{fl} the cooling capacity at full load.

The partial load absorbed power herein is:

$$P_a = 22 \times (0{,}82 \times (\frac{58{,}2}{87{,}3} - 1) + 1) = 15{,}9\text{kW}$$

In addition, the power absorbed by the two fans is:

$$P = 2 \times (\frac{Q \times \ddot{A}P}{\varsigma_{fan}}) = 2 \times (\frac{10.4 \times 0.001 \times 0.63 \times 1.013 \times 10^5}{0.7}) = 2 \times 2.7 = 5.4\,\text{kW}$$

while the consumption of controllers: 0.8 kW (see Table 1). This way, the total absorbed power of Cooling-1 is 22 kW, with a COP at partial load of 2.68.

As regards the absorbed power of the Cooling-2 unit, the following are valid:

Compressor 1:
Flow: 70 m^3/h
Number of cylinders at full load: 1
Refrigerating capacity: 54 kW for water 6/12ºC and air at 30ºC.

Moreover, the coefficient of performance at full load is 3.86, resulting in an absorbed power:

$$P_a = \frac{54}{3.86} = 14\text{kW}$$

The overall absorbed power of the Cooling-2 unit includes:
- One compressor at full load: 14 kW
- Two fans: 2.8 kW
- Regulation: 0.2 kW

Whence, the above procedure results in an absorbed power of 17 kW for the unit Cooling-2 and a COP of 3.17.

In conclusion, if the unit Cooling-2 is going to substitute the Cooling-1 unit during the night operation of the building's equipment, the potential savings regarding power will be: 22–17=5kW. In a next step, the annual cost savings will be: 5 x (693 x 0.49 + 1,213 x 0.31 + 970 x 0.2 + 1,699 x 0.13) = 5,652 FF (w/o taxes). A possible solution is to install an automation system for monitoring:
- the inlet/outlet temperatures of the groups,
- the operation of the pumps,
- the opening/closing of two-way valves, and the
- flow control.

The automaton will be managed from the software of the building management system. The cost of a cooling production automation system is 77,424 FF, analysed as follows:

Cooling production automation system	Quantity	Price (FF) w/o taxes
Computer equipment		21,490
Cold water temperature sensor	4	1,107
Motor valve 230V	2	2,934
2-way butterfly valve	2	
Software	1	17,080
Engineering (function analysis, wiring, test, programming...)		9,413
Electrical works (panel, protection...)		25,400
	TOTAL	***77,424***
BMS – Central unit modification		20,000

3.6. Economic evaluation of electricity bill savings

A Life-Cycle Cost (LCC) method is used to evaluate two alternatives of electricity bill savings. This method is described in detail in par. 5.3.6 of the "Energy Audit Guide-Part A". The two alternatives are the following:

(A) Permute the chillers, purchase a capacitor, change the subscribed power and/or control night lighting.

(B) Do nothing.

The lifetime of the retrofit project is assumed to be 10 years. The discount rate is calculated as below:

$$\theta = \frac{i - \lambda}{1 + \lambda}$$

where è is the composite interest rate, *i* the long term interest rate in France between 1990 and 1995 (= 8.5%) and ë is the annual inflation rate between 1990 and 1995 in France (= 1.9%). Substituting these values in the above relation, it results in a value: è= 6.5%.

The single present value amount can be computed as follows (see Chapter 5 of the "Energy Audit Guide-Part A"):

$$LCC = \sum_{k=0}^{N} CF_k * SPPW(d,k)$$

where: *SPPW (d, k)* = $(1+è)^{-k}$. The calculations for the LCC analysis proceed as follows:

Cost item		Option A	Option B
Initial investment (FF):			
(1) Chiller automation		77424	0
(2) Capacitor		35067	0
(3) Soft time-switch		0	0
(4) Monitor modification		20000	0
TOTAL		**132491**	**0**
Annual operating costs (FF):			
Modification of subscribed power		57420	60970
Suppression of reactive energy		0	19070
Night lighting control		19230	22542
Cooling control		19217	24869
TOTAL		**95867**	**127451**
year	0	132491	0
year	1	222507	119672
year	2	307029	232041
year	3	386392	337551
year	4	460912	436621
year	5	530884	529646
year	6	596584	616992
year	7	658275	699008
year	8	716201	776017
year	9	770592	848327
year	**10**	**821663**	**916224**

Ôherefore, the life cycle cost for option A is the lowest. This analysis can be compared with a simple payback period method, which gives the following results:

INVESTMENT	capacitor	35067	26
	chiller automation	77424	58
	soft timeswitch	0	0
	monitor modification	20000	15
	TOTAL	132491	100%

SAVINGS	modification of subscribed power	3550	10
	suppression of reactive energy	19064	54
	night lighting control	7000	20
	cooling control	5652	16
	TOTAL	35266	100%
	Simple payback period (years)	3.8	

The simple payback period is not very high and is much shorter than the assumed lifetime of the project. Thus, it is recommended for MULTISERVICE, in a first step to change the subscribed power and install a capacitor, and then to invest in a chiller automation system and to proceed with the necessary changes in the building management system.

The chart below (figure 2) shows the effect of the inflation rate and of the interest rate on the choice of investment: it based on the comparison of LCC for both options. It is clear that the interest rate should be high (above 20%) so as option B should be preferred. The limit discount rate is 20%. Indeed, this could be lower if the tax rate was taken into account in the nominal discount rate.

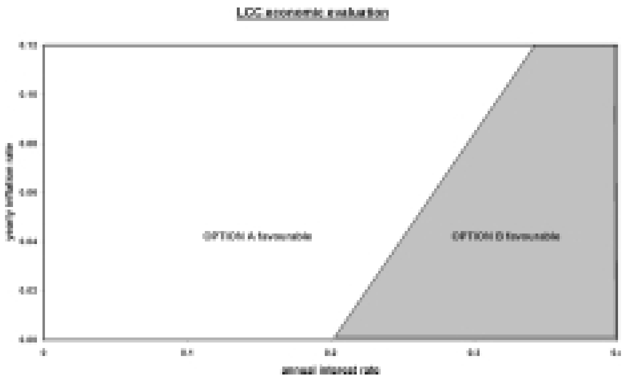
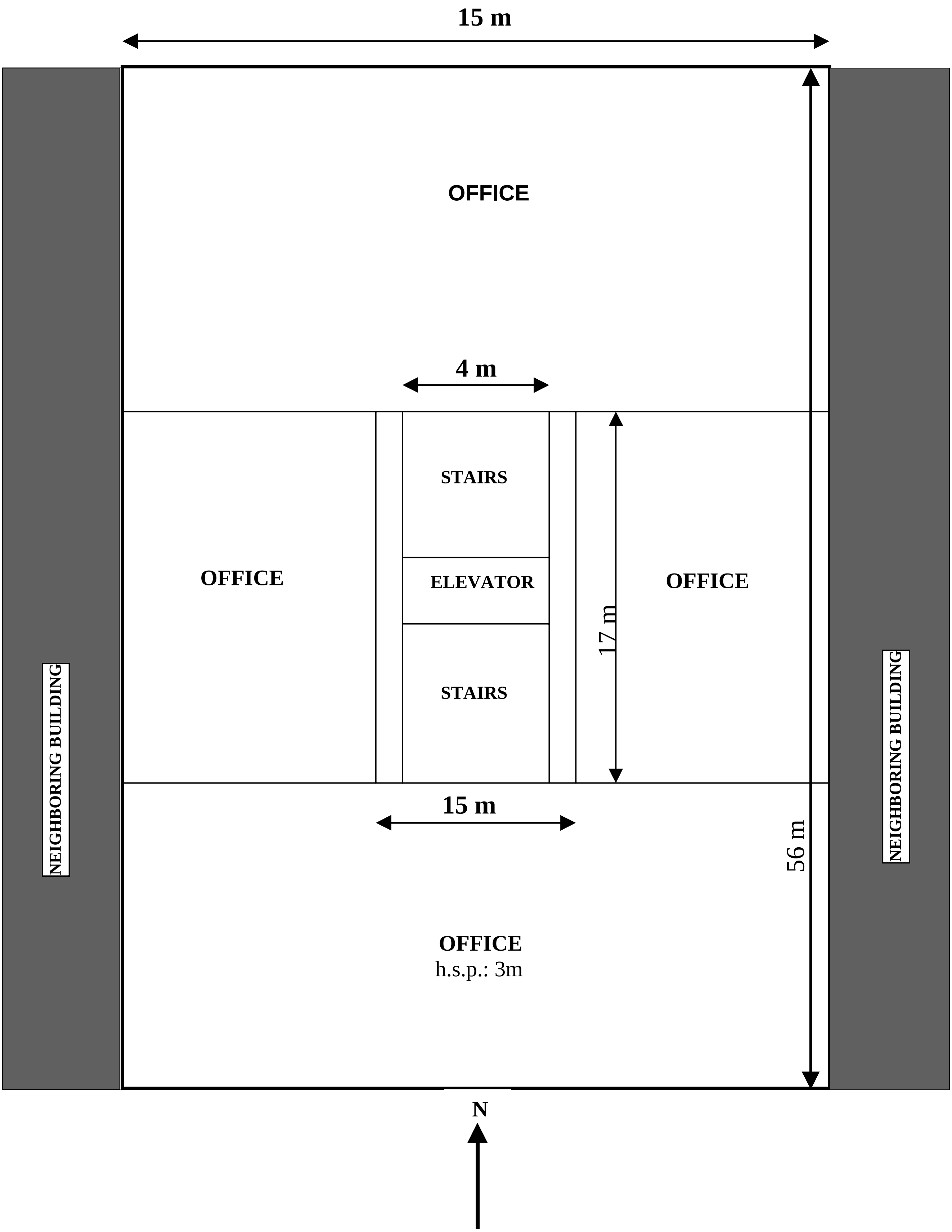


Figure 2. Economic evaluation of investments based on the LCC analysis

APPENDIX 1
TYPICAL PLAN OF A BUILDING'S FLOOR



APPENDIX 2

EDF

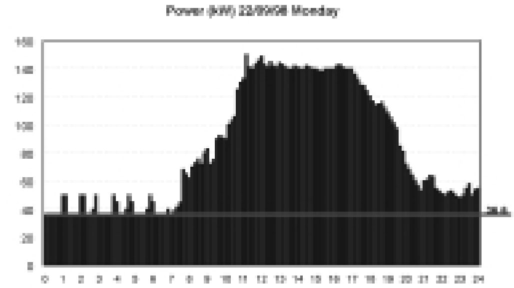
Annual balance sheet
August 1997/July 1998

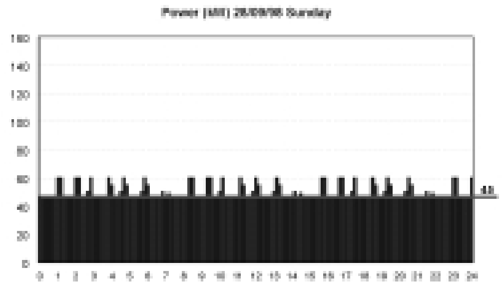
	Peak	Winter peak hours	Winter off-peak hours	Summer peak hours	Summer off-peak hours	Reduced subscribed power
Subscribed power (kW)	220	240	240	240	240	233.6 kW
Maximal reached power (kW)	215	225	123	220	125	Total
Reactive energy consumption (kWh)	38300	204600	103000	333800	150000	829700
Number of use hours	180	900	840	1520	1200	4640

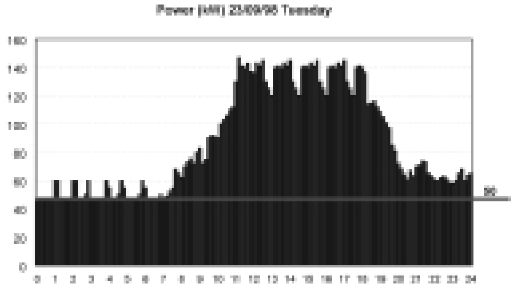
	Reached power (kW)			Active energy consumption (kWh)				Active energy (F) w/o taxes	Reactive energy (P+HP) kVARh	tan PHI	**Reactive energy (F) w/o taxes**	Total bill (F) w/o taxes	Unitary price (centimes/ kWh) w/o taxes
	Peak (P)	**Peak hours (PH))**	Off peak hours (OPH)	Peak (P)	Peak hours (PH)	Off-peak hours (OPH)	Total						
August		**200**	70		11080	6100	17180	2990	12760	1.152		8813	51.3
September		**200**	100		87840	39800	127640	22650	102635	1.168		28681	22.47
October		**220**	125		47745	25130	72875	12750	51680	1.082		18780	25.77
November		**190**	120		49215	24170	73385	37910	51130	1.038	**4140**	47869	65.23
December	215	**220**	115	13290	37480	19960	70730	44350	48920	0.963	**3770**	53939	76.26
January	210	**225**	120	13610	38040	22380	74030	45915	48045	0.93	**3610**	55545	75.03
February	180	**180**	110	11360	31360	17360	60080	37620	43580	1.02	**3490**	46928	78.11
March		**190**	110		48540	19220	67760	35310	50450	1.039	**4060**	45108	66.57
April		**190**	90		41230	18580	59810	10580	44180	1.071		16316	27.28
May		**180**	90		48460	20820	69280	12310	53390	1.101		18041	26.04
June		**210**	95		48330	18630	66960	12000	51950	1.074		17744	26.5
July		**220**	95		49120	20770	69890	12430	51700	1.052		16774	24
				38260	538440	252920	829620	286815	610420		**19070**	374537	45.31

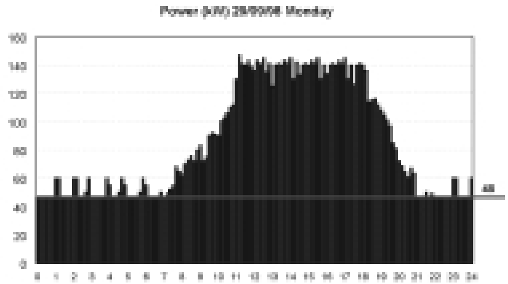
Total billing from August 1997 to July 1998

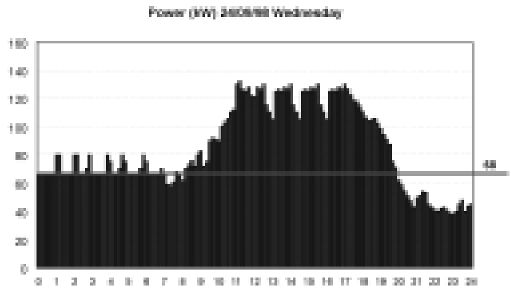
Fixed premium (F) w/o taxes	Over-passing w/o taxes	Active energy (F) w/o taxes	Reactive energy (F) w/o taxes		Miscellaneous costs (F) w/o taxes	Total amount (F) w/o taxes	Added value taxes (F)	Local taxes (F) w/o taxes	total bill (F) taxes included	Unitary price (centimes/ kWh) w/o taxes
60970		286815	19070		4010	374537	77154		451691	45.31

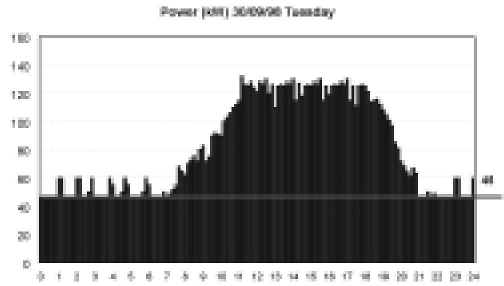


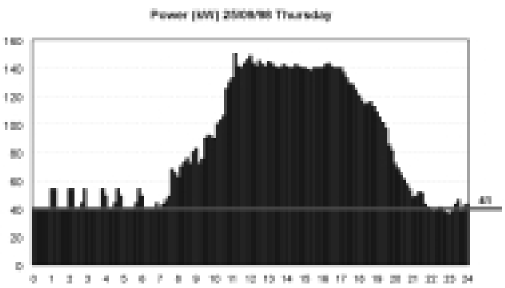


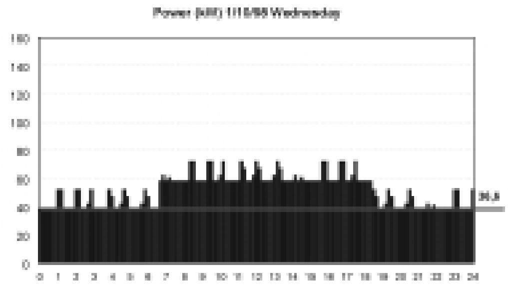


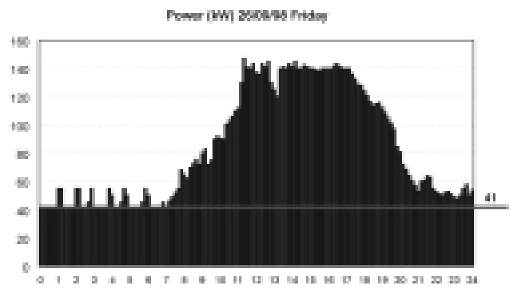


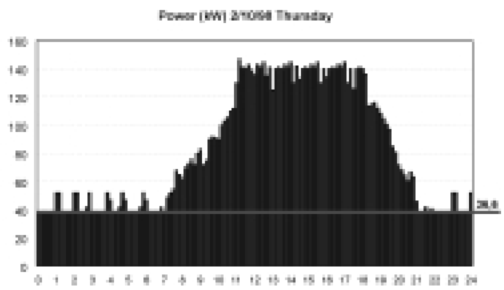


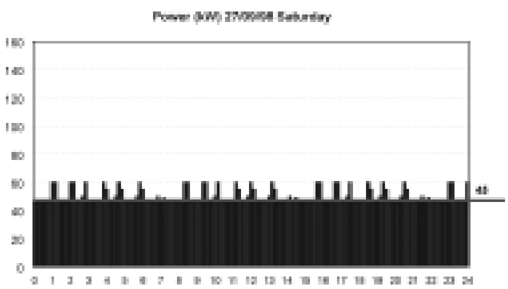












APPENDIX 3

Yellow rate **Base option** **Prices of 01/05/1998**

	Yearly subscription (F/kVA)	Energy price (c/kWh)			
		Winter		Summer	
		Winter peak hours	Winter off-peak hours	Summer peak hours	Summer off-peak hours
Long uses	310.56	54.7	38.19	19.54	15.02
Average uses	103.92	78.01	51.6	20.51	15.8

Winter: from November to March included
Summer: From April to October included
Off-peak hours: 8 hours every day

Green rate **A5 Base option** **Prices of 01/05/1998**

	Yearly subscription (F/kVA)	Energy price (c/kWh)				
		Winter			Summer	
		Peak	Winter peak hours	Winter off-peak hours	Summer peak hours	Summer off-peak hours
Very long uses	705.84	40.59	31.63	24.22	17.49	11.75
Long uses	434.76	67.5	40.63	27.75	18.45	12.44
Average uses	261	95.72	49.28	31.35	19.8	13.39
Short uses	109.8	137.68	63.29	37.69	21.2	14.37

Reactive power: 11.86 c/kVARh

Winter: from November to March included
Summer: From April to October included
Off-peak hours: 8 hours every day and the whole day on Sundays
Peak: 2 hours in the morning and 2 hours in the evening from December to February included.

EDF/GDF SERVICES

OFFICE BUILDING

Rate study from July 1997 to June 1998
Price of 01/05/98
GREEN rate A5
Current situation
Option average uses

RATE PERIODS	SUBSCRIBED POWER	CONSUMPTIONS kWh	UNITARY PRICES	AMOUNTS
PEAK	220	38255	0.96 F	36,617.69 F
WINTER PEAK HOURS	240	204631	0.49 F	100,842.16 F
WINTER OFF-PEAK HOURS	240	103091	0.31 F	32,319.03 F
SUMMER PEAK HOURS	240	325557	0.20 F	64,460.29 F
SUMMER OFF-PEAK HOURS	240	146577	0.13 F	19,626.66 F
TOTAL		818111		253,865.82 F
SUBSCRIPTION	233.6		261.00 F	60,969.60 F
TOTAL W/O TAXES				314,835.42 F
AVERAGE PRICE OF kWh	0.38 F			

Proposition
GREEN rate A5
Option short uses

RATE PERIODS	SUBSCRIBED POWER	CONSUMPTIONS kWh	UNITARY PRICES	AMOUNTS
PEAK	220	38255	1.38 F	52,669.48 F
WINTER PEAK HOURS	220	204631	0.63 F	129,510.96 F
WINTER OFF-PEAK HOURS	220	103091	0.38 F	38,855.00 F
SUMMER PEAK HOURS	220	325557	0.21 F	69,018.08 F
SUMMER OFF-PEAK HOURS	220	146577	0.14 F	21,063.11 F
TOTAL		818111		311,116.64 F
SUBSCRIPTION	220		109.80 F	24,156.00 F
TOTAL W/O TAXES				335,272.64 F
AVERAGE PRICE OF kWh	0.41 F			
LOSSES	-20,437.22 F			

Proposition
GREEN rate A5
Option very long uses

RATE PERIODS	SUBSCRIBED POWER	CONSUMPTIONS kWh	UNITARY PRICES	AMOUNTS
PEAK	220	38255	0.41 F	15,527.70 F
WINTER PEAK HOURS	220	204631	0.32 F	64,724.79 F
WINTER OFF-PEAK HOURS	220	103091	0.24 F	24,968.64 F
SUMMER PEAK HOURS	220	325557	0.17 F	56,939.92 F
SUMMER OFF-PEAK HOURS	220	146577	0.12 F	17,222.80 F
TOTAL		818111		179,383.85 F
SUBSCRIPTION	220		705.84 F	155,284.80 F
TOTAL W/O TAXES				334,668.65 F
AVERAGE PRICE OF kWh	0.41 F			
LOSSES	-19,833.23 F			

Proposition
GREEN rate A5
Option average uses

RATE PERIODS	SUBSCRIBED POWER	CONSUMPTIONS kWh	UNITARY PRICES	AMOUNTS
PEAK	220	38255	0.96 F	36,617.69 F
WINTER PEAK HOURS	220	204631	0.49 F	100,842.16 F
WINTER OFF-PEAK HOURS	220	103091	0.31 F	32,319.03 F
SUMMER PEAK HOURS	220	325557	0.20 F	64,460.29 F
SUMMER OFF-PEAK HOURS	220	146577	0.13 F	19,626.66 F
TOTAL		818111		253,865.82 F
SUBSCRIPTION	220		261.00 F	57,420.00 F
TOTAL W/O TAXES				311,285.82 F
AVERAGE PRICE OF kWh	0.38 F			
GAINS	3,549.60 F			

Proposition
GREEN rate A5
Option long uses

RATE PERIODS	SUBSCRIBED POWER	CONSUMPTIONS kWh	UNITARY PRICES	AMOUNTS
PEAK	220	38255	0.68 F	25,822.13 F
WINTER PEAK HOURS	220	204631	0.41 F	83,141.58 F
WINTER OFF-PEAK HOURS	220	103091	0.28 F	28,607.75 F
SUMMER PEAK HOURS	220	325557	0.18 F	60,065.27 F
SUMMER OFF-PEAK HOURS	220	146577	0.12 F	18,234.18 F
TOTAL		818111		215,870.90 F
SUBSCRIPTION	220		434.76 F	95,647.20 F
TOTAL W/O TAXES				311,518.10 F

AVERAGE PRICE OF kWh	0.38 F
GAINS	3,317.32 F

Proposition
YELLOW rate
Option long uses

RATE PERIODS	SUBSCRIBED POWER	CONSUMPTIONS kWh	UNITARY PRICES	AMOUNTS
PEAK	220	38255	0.55 F	20,925.49 F
WINTER PEAK HOURS	220	204631	0.55 F	111,933.16 F
WINTER OFF-PEAK HOURS	220	103091	0.38 F	39,370.45 F
SUMMER PEAK HOURS	220	325557	0.20 F	63,613.84 F
SUMMER OFF-PEAK HOURS	220	146577	0.15 F	22,015.87 F
TOTAL		818111		257,858.80 F
SUBSCRIPTION	220		310.56 F	68,323.20 F
TOTAL W/O TAXES				326,182.00 F

AVERAGE PRICE OF kWh	0.40 F
LOSSES	-11,346.58 F

Proposition
YELLOW rate
Option average uses

RATE PERIODS	SUBSCRIBED POWER	CONSUMPTIONS kWh	UNITARY PRICES	AMOUNTS
PEAK	220	38255	0.78 F	29,842.73 F
WINTER PEAK HOURS	220	204631	0.78 F	159,632.64 F
WINTER OFF-PEAK HOURS	220	103091	0.52 F	53,194.96 F
SUMMER PEAK HOURS	220	325557	0.21 F	66,771.74 F
SUMMER OFF-PEAK HOURS	220	146577	0.16 F	23,159.17 F
TOTAL		818111		332,601.23 F
SUBSCRIPTION	220		103.92 F	22,862.40 F
TOTAL W/O TAXES				355,463.63 F
AVERAGE PRICE OF kWh	0.43 F			
LOSSES	-40,628.21 F			