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Cutting operating costs in buildings

Conservation – a new and efficient source of energy

"Energy is becoming increasingly expensive. Conservation can offset the increase in energy cost and can therefore be considered a new and fairly inexpensive source of energy." So says J.A. Basson, Head of the Energy in Buildings Division of the NBRI, in the following article, which looks at the ways in which energy savings in both new and existing buildings can be achieved.

ENERGY CONSERVATION in buildings is becoming more important as the cost of energy increases and as man becomes more aware that fossil energy resources are finite. It can truthfully be said that large amounts of energy can be saved in almost any building without materially reducing the function of the building or the comfort of the occupants.

Not much actual progress has been made in South Africa in energy conservation in buildings. Few people here have knowledge of the techniques of analysis and/or experience of the results. The experience in the United States of America is that an energy cost saving of up to 20 per cent is quite feasible and that savings of up to 50 per cent may be possible. The process of energy conservation in buildings is really one of reducing waste.

Energy used in buildings accounts for approximately 25 per cent of all energy used in South Africa and electricity is the major source of this energy. Before electrical energy can be saved, it is essential that the electricity rate structure be understood.

Price of electricity

The price of electricity is fixed by the local authority, and varies according to factors such as locality, type of consumer and size of connection. A study of the prevailing rate must be made to determine where conservation efforts should be directed.

Table 1 indicates the mean annual percentage increase in the price of electricity[1] and coal since 1970. The rates of increase for electricity were calculated from the average income to ESCOM from sales of electricity and thus average out both area price differences and small and large consumer rates.

Electricity charges for large buildings usually have two components viz. the peak power requirement and the total amount of energy consumed.

TABLE 1: Annual rate of increase in cost of coal and electricity[1]

	Compound annual rate of increase (%)		
Period	Electricity	Coal	Inflation
1970 - 1979	13,4	15,9	9,1
1974 - 1979	23,3	22,3	11,6
1976 - 1979	23,1	14,9	11,6

TABLE 2: Energy consumption figures for a typical large air conditioned office building (gross floor area 1 140 m³)

	Installed capacity		Energy consumed per annum	
Sub-system	kWA	%	kWh	%
Lighting	210	9	676 000	23
Fans	255	11	626 000	21
Pumps	100	5	333 000	11
Heating, dieseline	1 200	52	576 000	19
Cooling	533	23	772 000	26
TOTAL	2 308	100	2 983 000	100

Peak electrical kVA consumed – 97 Wm^{-2} gross floor area
Energy consumed per annum – 262 kWh m^{-2} gross floor area.

(a) *The peak power requirement.* This is often described as the maximum demand charge. The peak power requirement determines the capacity required from the electrical utility, and therefore also the amount of capital to be invested in generation and distribution facilities. In large energy intensive buildings the maximum demand cost is becoming a large and extremely important component and can be responsible for as much as 60 per cent of the electricity account (see Table 3). The maximum demand is a function of the design of the building and the systems installed. Large cost savings can be achieved by reducing or controlling the peak demand.

TABLE 3: Annual energy cost figures for the air conditioned office building described in Table 2.

Component	Cost (1980)	% of total
Electricity: unit charge	R35 800	14
Electricity: maximum demand charge	R56 200	22
Dieseline	R22 100	9
TOTAL ENERGY	R114 100	45
Operating and maintenance cost, mechanical/electrical systems	R56 050	22
Insurance, taxes, cleaning, etc.	R87 000	33
TOTAL OPERATING COST	R257 150	100
Energy cost per m² gross floor area	R10	—

(b) *Energy consumption.* The energy consumed is the product of the power required and the time for which it is required and is expressed in kilowatt hours. This unit charge, as it is called, is thus related to the way in which the building or the building system is used.

The interaction of these two parameters can best be seen by referring to Fig. 1, in which the equivalent cost of electricity for a typical large consumer in Pretoria is given. The load factor indicated on this graph is the ratio of the mean demand to the peak demand. The following tariffs were used in drawing up Fig. 1 (1981 figures):

Maximum monthly demand charge	R4,28 $kVA^{-1}month^{-1}$
Unit charge	1,16c kWh^{-1}

The equivalent cost of electricity is therefore high when the load factor is low, i.e. when the peak demand is much higher than the mean demand.

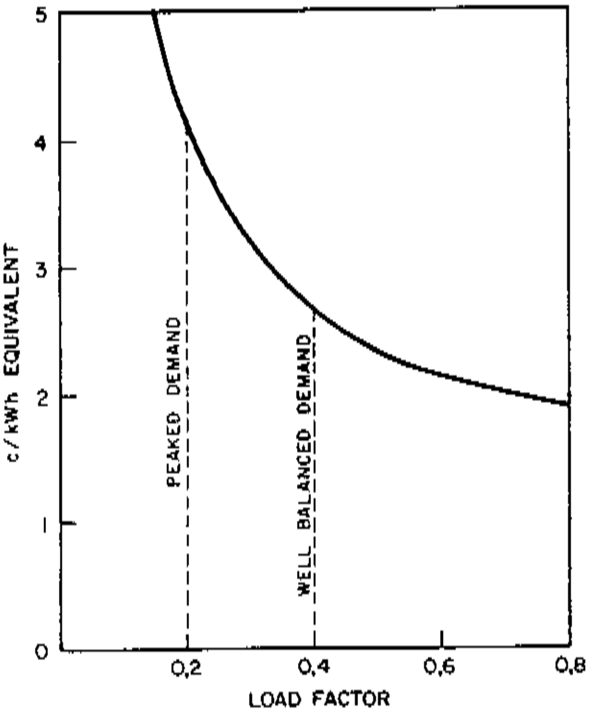

Fig. 1: Equivalent cost of high tension electricity Pretoria, February 1981.

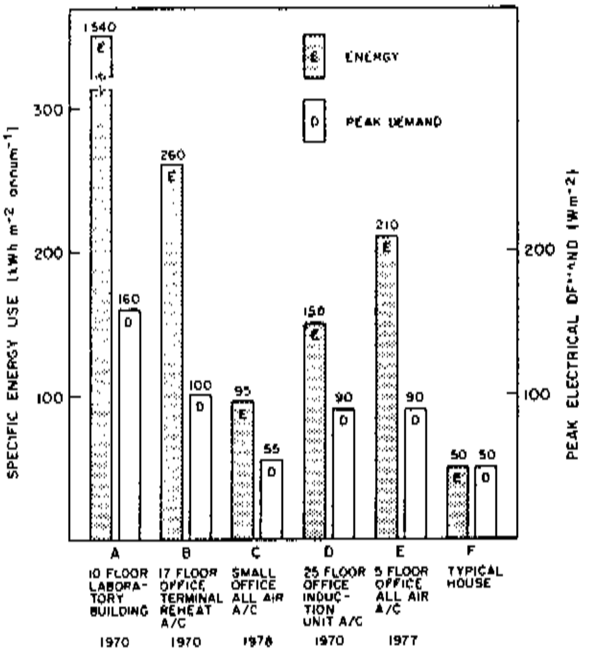

Fig. 2: Specific energy consumption and peak electrical demand for a number of buildings.

Energy used in buildings

A data base for the consumption of energy in buildings in South Africa is not yet available, but the NBRI is making a survey to produce some data on this subject. Preliminary data as taken from this survey is reproduced in Fig. 2.

Because of the importance of both the energy consumed and the peak electrical demand, both of these parameters have been expressed in specific terms as a function of the gross floor area of the building. It can be seen that the specific energy consumption and peak demand figures vary widely. As far as is known, no extensive energy conservation programme has been instituted in any of these buildings. Buildings A to E are all provided with air conditioning systems. It is only in building A where this system is operated for 24 hours per day and 7 days per week and where the humidity is controlled.

Typical energy consumption figures and costs for a large South African office building provided with an energy inefficient all-air reheat air conditioning system are given in Tables 2 and 3. Many systems of this type are used in South Africa, especially in commercial buildings and hospitals. The auxiliary components, such as fans and pumps, account for a large proportion of the energy used, whereas the maximum demand is to a great extent determined by the heating and cooling equipment. The overdesign of equipment, as is often the case, leads to lower operating efficiencies. An example is the heating system which accounts for more than half the installed capacity but consumes only a fifth of the total energy.

Energy use in buildings is determined by the use of the buildings and therefore by the systems installed

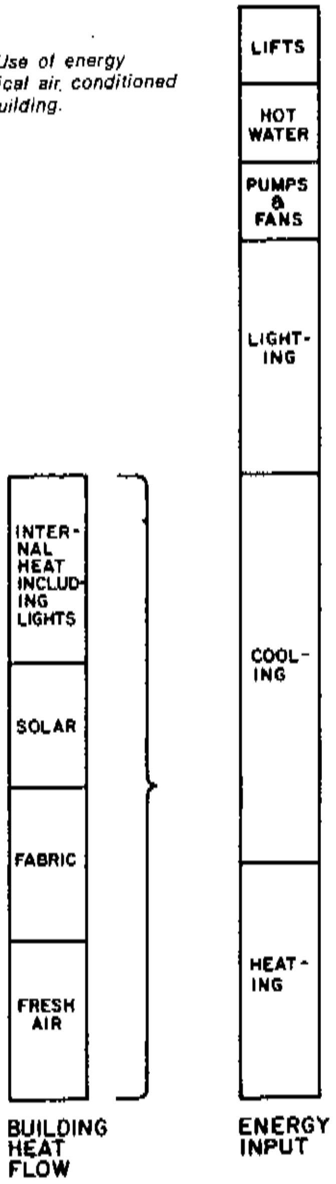

Fig. 3: Use of energy in a typical air conditioned office building.

in the building. Table 4 lists the different uses of energy in a variety of buildings more or less in order of importance.

The analysis of energy use in air conditioned office buildings is especially complex as it is determined by the building fabric, the use of the building, the systems inside the building and the prevailing climate, including the effect of solar radiation, as indicated in Fig. 3. The building heat flow given by the left hand bar in this figure, requires an energy input as indicated in the right hand bar, to remove or add heat as the case may be. Energy inputs are also required for other systems such as lighting, fans, pumps, etc.

Energy conservation in buildings

Energy analysis for existing buildings is easier than for new buildings. The energy consumption of an existing building does not have to be calculated: it is known. The operating schedules for energy consuming equipment and systems do not have to be anticipated or predicted; they exist in reality.

The first step in identifying energy conservation options is to conduct an energy audit[2,3] to determine how the energy is being used. An energy audit can be defined as developing an understanding[4] of the specific energy usage patterns of a given facility. The energy audit progresses from an analysis of consumption over a fairly long operating period, such as a year, to successively shorter periods, viz. monthly, weekly, daily and hourly.

The energy analysis and conservation process moves through consecutive stages of analysis of energy use data, scheduling energy using equipment, optimisation, capital improvement, evaluation, implementation and monitoring of performance, as indicated in Fig. 4.

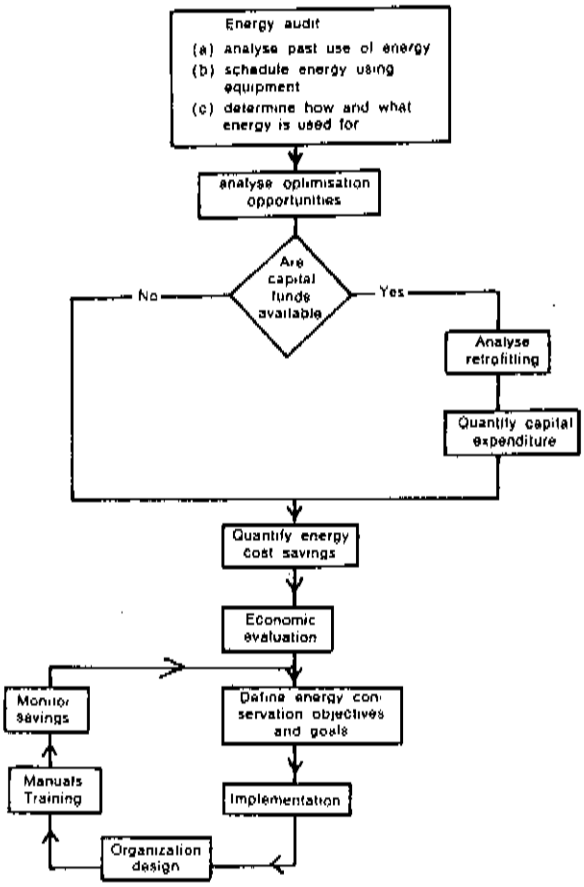

Fig. 4: Flow diagram of building energy conservation programme.

TABLE 4: Use of energy in specific buildings (in approximate order of importance).

Houses	Flats	Shops	Offices	Hospitals	Hotels
Hot water	Hot water	Lighting	Lighting	Hot water	Hot water
Kitchen	Kitchen	Cooling	Pumps & Fans	Heating	Cooking
Space heating	Lighting	Pumps & Fans	Cooling	Cooking	Cooling
Lighting	Space heating	Heating	Heating	Hospital functions	Laundry
Other	Lifts	Refrigeration	Lifts	Laundry	Pumps & Fans
		Other	Other	Cooling	Heating
				Refrigeration	Refrigeration
				Lighting	Other

History

Energy invoices for the building are analysed, preferably over the previous five years to see if the figures reveal any trend on an annual or monthly cycle. Comparative cost indices are important parameters of the building and can be used to compare energy use and cost with other buildings (See Fig. 2).

Energy using equipment

A schedule of all the energy using equipment must be drawn up together with the power actually consumed by each item during the operating period. As indicated in Table 2, seemingly major items of equipment become fairly low energy users while others that seem unimportant, turn out to be high energy users. The schedule need not be too complex and it is more important to make it all inclusive than accurate. Before this activity is considered complete, flow diagrams should be developed for all energy consuming fluid systems and a reasonable understanding of building use schedules should have been gained.

The equipment schedule, together with information on the use of energy is used to determine what energy is being used for, the peak demand patterns and the efficiency of usage. The use of energy and the peak demand pattern should be indicated on a graph to simplify the determination and analysis of trends.

Optimisation

Initially energy conservation starts with optimisation of the equipment as installed. The same process as tuning a car is followed in order to tune the systems in the building to match the actual requirements.

It must be taken into account that the designer of the building and its systems did not know much about the way the building would be used. Design techniques and equipment have probably improved since then.

The following typical conservation options can be assessed for suitability. They normally require little or no expenditure of capital and are often referred to as a "no cost-low cost" process.

(i) Reduce running periods, i.e. the system or component may be switched off when not required.

(ii) Install simple peak load control, to reduce peak demand.

(iii) Adjust thermostats so that air temperatures are raised in summer and lowered in winter. Thermostats with a wide temperature differential may be used.

(iv) Reduce the volume of fresh air processed during hot and cold periods.

(v) Use fresh air for cooling in all-air systems during periods of moderate weather. This so-called 'economiser cycle' should be incorporated into the automatic control system.

(vi) Investigate whether humidity control is really necessary for the particular application or whether the dehumidification part of the cycle can perhaps be disconnected.

(vii) Ensure that simultaneous cooling and heating cannot take place unless dehumidification by overcooling is essential.

(viii) Tune the system properly. Many systems are overdesigned by as much as 40 per cent and fine tuning will ensure that they operate at a higher load factor, are more efficient and reduce peak demand.

One approach of tuning the system is to set a number of room thermostats to their limit when peak conditions are experienced and measuring the temperatures achieved in the spaces. The capacity of the system must now be reduced by reducing and re-balancing the circulating air and water flow rate and reducing the heating or cooling capacity of the system. For instance consider an all-air system that is over capacity in which the circulating air volume can be reduced by 20 per cent. The energy cost for the fan motor is reduced by approximately 48 per cent when it is expressed in terms of the Pretoria high tension electricity tariff as indicated in Table 5.

TABLE 5: Energy and cost conservation achieved by decreasing the amount of air circulated.

	As installed	After reducing air flow rate by 20%
Circulating air volume (m^3s^{-1})	20	16
Static pressure required (Pa)	750	480
Electrical power required (kW)	25	13
Energy consumed per annum (12 hrs day^{-1}, 5,5 days per week), kWh	85 800	44 600
Maximum demand charge per annum at R4,28 $kVA^{-1}month^{-1}$	R1 284	R668
Energy cost at 1,16c kWh^{-1}	R 995	R517
TOTAL ELECTRICITY COST PER ANNUM	R2 279	R1 185

(ix) Investigate the air and water temperatures in systems controlled indirectly as a function of parameters such as outdoor air temperature, i.e. a check must be made as to the extent to which the existing schedules are correct.

(x) Check the effectiveness of thermal insulation, especially in areas where it is not visible.

(xi) Introduce efficient maintenance procedures.

(xii) Investigate the use of multiple cooling and heating machines, each with its own auxiliary equipment, such as pumps and cooling towers. Separate units and their associated auxiliaries can be shut down as the load decreases to ensure a higher load factor, and therefore higher efficiency.

(xiii) Avoid control of condenser water temperature by means of a bypass valve or throttling air damper. It is better to operate at a lower temperature so as to increase the efficiency of the cooling machine and to cycle the cooling tower fan from a water thermostat with wide control differential.

Capital improvement

At this stage replacement of components or equipment is often required for the introduction of energy efficient equipment and processes. This stage therefore requires the expenditure of capital. The following different possibilities can be investigated:

(i) Load management. The load factor can be increased by
   (a) storing energy to reduce peak loads
   (b) scheduling non-essential loads
   (c) power factor correction.

Automated load management equipment is available on the market. Energy consumption is not reduced when load management is employed. The reduced maximum demand cost in effect indicates that capital is conserved by the supply authority;

(ii) Installation of preferably automatic monitoring and controlling equipment;

(iii) Improving insulation, especially in cases where the economic thickness of insulation was initially based on considerably cheaper sources of energy;

(iv) Heat reclamation where energy at a high temperature level can be reclaimed for use at a lower temperature. For example in many cooling processes energy is withdrawn from a space and could be used for preheating water by employing a heat pump cycle or heat exchanger;

(v) Replacing inefficient systems and equipment with efficient systems and equipment;

(vi) Redesign of buildings and systems in buildings for optimum utilization of energy. The computer is becoming a valuable tool for this purpose, and design and simulation techniques that are now becoming available make detailed calculations possible, even on an hour by hour and day by day basis, to ensure greater accuracy and enable more alternatives to be investigated to achieve an optimal solution.

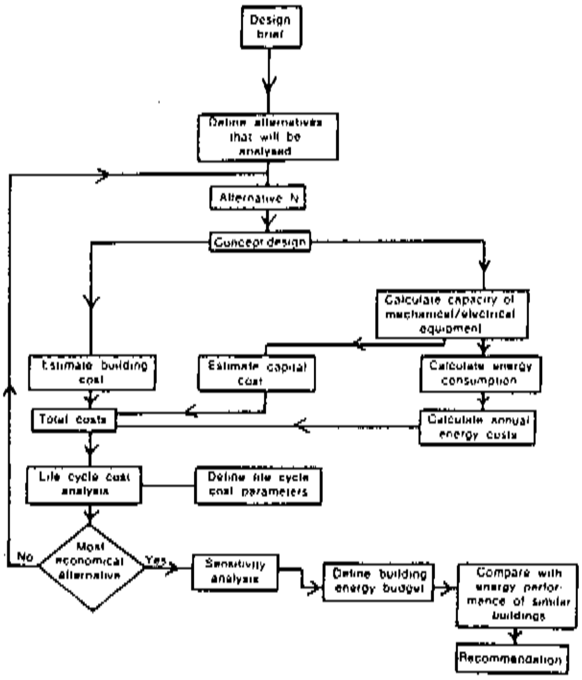

Fig. 5: Flow diagram for design process of large energy intensive buildings.

Evaluation

At this stage all the energy conservation opportunities have been identified. The cost saving and additional expenditures must be qualified and ranked in order of importance. In most cases the straight payback period of many conservation opportunities will be fairly soon, often less than three years.

If a short payback period of less than five years is used, there is no need to use complex financial techniques[5] such as life cycle costing, as straight payback based on the initial cost saving and expenditure will be sufficiently accurate.

Implementation

At this stage the building's management committee will have to define conservation objectives, the desired payback period or rate of return, and the amount of available capital.

Implementation may to a certain extent inconvenience the occupants of the buildings. The operating and maintenance personnel of the building should be fully involved in the implementation phase. Part of the implementation phase should comprise operating manuals, schedules and training of the operating personnel.

Monitor

Monitoring of the ever evolving energy history is an important part of an energy conservation programme. Monitoring can be used to spot a deviation from the correct course of action as well as the identification of further energy conservation opportunities.

Human factors

The present operating and maintenance department must be made part of the energy conservation programme. Unless care is taken, energy conservation or the lack therof can create the impression that the maintenance department is not doing its job properly.

The maintenance department can be of great value in an energy conservation programme. Nobody knows the building as well as they do. An incentive programme, based on results, should be instituted to ensure their support.

It is essential to use a well-qualified person with the necessary experience to create and plan the energy conservation programme. This person should preferably be independent of the maintenance department to ensure objectivity and freedom to act as an agent of change.

As soon as an energy conservation programme has been decided upon it should be supported publicly by top management, and the required organisational changes should be instituted.

An energy conservation programme, depending on the circumstances and excluding capital investments can cost anything from R1 000 to R100 000. In many cases this cost can be recovered in less than one year.

Energy conservation in new buildings

When new facilities are designed, many of the constraints found in existing buildings do not apply. Computers can be used to calculate the capacity of equipment very accurately and the investigation of different alternatives can be carried out with speed and accuracy. When using programs of this type the parameters can be changed at will, and the program rerun. Programs are available that are capable of simulating the operation of complete systems and calculating the monthly demand and energy requirements. Unfortunately, they are complex, specialised and expensive, but their use is justified in the case of large buildings where money wisely spent in optimising the design of the system can lead to extensive savings later. Fig. 5 indicates the flow process in the design of a new energy efficient large building.

Sophisticated techniques such as those proposed above, are not yet in general use in South Africa. In 1980 the NBRI sent a questionnaire to the designers of large mechanical systems in buildings. Of the 10 designers who responded, only two indicated that they estimated the energy consumption of a building, for which they were designing a system, or that they simulated its operation by computer. Two of the designers indicated that they use very basic design techniques in which the effects of the mass of the building or of hourly variations in climate were not taken into account.

Modern design techniques which can be used to conserve capital and energy in buildings are:

(i) Underdesign by deliberately limiting the capacity of the equipment. It is seldom that all cooling or heating loads will be at a maximum at the same time. When peak conditions are experienced, the temperature is allowed to exceed the design value for a short period.

(ii) The use of building mass to store energy and reduce swings in temperature.

(iii) The use of natural sources of energy, such as the sun and cool night air to warm and cool the structure.

(iv) The storage of energy in order to reduce the peak capacity of the equipment installed.

(v) Sophisticated and often microprocessor-based control equipment.

Conclusion

Energy is becoming increasingly expensive. Conservation can offset the increase in energy cost and can therefore be considered a new and fairly inexpensive source of energy. No general guidelines apply to an energy conservation programme in a building. It is necessary to carry out an energy audit to determine where and how energy is used and to identify energy conservation opportunities. Building owners should ensure that only qualified and experienced people are appointed as energy conservation consultants and should not expect results overnight.

New buildings can be designed to use energy efficiently, but it is necessary for designers to apply techniques of analysis and design that are now available.

It is expected that energy conservation results in buildings in South Africa will initially be slow, until sufficient experience has been gained by the industry and results can be quoted to prove the value of this activity.

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