INTERNATIONAL SEMINAR ON ENERGY EFFICIENCY AND CONSERVATION

Lomé, Togo
March 30-April 8, 1983

(English Version)

Co-sponsored by
ECONOMIC COMMUNITY OF WEST AFRICAN STATES (ECOWAS)
Commission of Transport, Telecommunications and Energy
and
UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT (USAID)
Office of Energy

Hosted by
THE GOVERNMENT OF TOGO
Ministry of Public Works, Mines, and Energy

Organized by
THE ENERGY MANAGEMENT TRAINING PROGRAM FOR
DEVELOPING COUNTRIES (EMTP)
A joint project of
BROOKHAVEN NATIONAL LABORATORY
and
THE INSTITUTE FOR ENERGY RESEARCH
State University of New York/Stony Brook

INTERNATIONAL SEMINAR ON ENERGY EFFICIENCY AND CONSERVATION

Lomé, Togo
March 30--April 8, 1983

(English Version)

Co-sponsored by
ECONOMIC COMMUNITY OF WEST AFRICAN STATES (ECOWAS)
Commission of Transport, Telecommunications and Energy
and
UNITED STATES AGENCY FOR INTERNATIONAL DEVELOPMENT (USAID)
Office of Energy

Hosted by
THE GOVERNMENT OF TOGO
Ministry of Public Works, Mines, and Energy

Organized by
THE ENERGY MANAGEMENT TRAINING PROGRAM FOR
DEVELOPING COUNTRIES (EMTP)
A joint project of
BROOKHAVEN NATIONAL LABORATORY
and
THE INSTITUTE FOR ENERGY RESEARCH
State University of New York/Stony Brook

DISCLAIMER

This Report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency, contractor or subcontractor thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency, contractor or subcontractor thereof.

INTERNATIONAL SEMINAR ON ENERGY EFFICIENCY AND CONSERVATION

CONTENTS

Transportation/Energy Analysis: Principles and Practice
- T. Owen Carroll
  The Institute for Energy Research
  State University of New York at Stony Brook

The Potential for Energy Efficiency in Developing Countries: Case Studies in Senegal and Morocco
- Claude Garrigues

The Importance of Energy Efficiency in the Developing Countries
- David J. Jhirad
  International Energy Program
  Brookhaven National Laboratory

The Potential of Building Electricity Systems for Load Reduction and Load Levelling
- Richard W. Leigh
  Department of Energy and Environment
  Brookhaven National Laboratory

Cost-Based Rates and Other Conservation Options for Electric Utilities
- Richard W. Leigh

Preventive Maintenance in the Electric Power Sector
- Paul H. Shoun
  Power Operations Planning Staff
  Tennessee Valley Authority

Industrial Energy Management
- Barry G. Tunnah
  E/DI Europe, Ltd.

TRANSPORTATION/ENERGY ANALYSIS

- PRINCIPLES AND PRACTICE -

FOR

WEST AFRICA WORKSHOP ON ENERGY CONSERVATION

APRIL, 1983

T.O. Carroll
Institute for Energy Research
State University of New York
Stony Brook, New York 11794

TABLE OF CONTENTS

TRANSPORTATION

1. Introducton

2. Characteristics of Transportation in the Developing Countries

3. Vehicles and Modes of Transportation

   Passenger Movement

   Freight Movement

4. Energy Use for Transportation

5. Potential Energy Savings in Transport

MODULE A2. TRANSPORTATION ENERGY CASE STUDY

1. Introduction

2. Transportation Energy Audit

3. Analysis of Projected Energy Demand and Conservation Potential

   1. Passenger Travel

   2. Freight Transport

   3. Economic Evaluation

4. A Final Comment

TRANSPORTATION

1. INTRODUCTION

Almost without exception, energy earmarked for transportation equals or exceeds energy consumed by any other sector of the economy of developing countries. Moreover, transportation equipment almost invariably utilizes higher priced fuels, such as lighter distillates--gasoline or diesel. Thus, both the high level of demand from the transportation sector and the types of fuel demanded aggravate the balance of payments problem for the oil-importing developing country.

The energy requirements for transportation increase rapidly with economic development.[1] In fact, demand for both passenger and freight transportation tends to increase in greater proportion to that of the overall economic growth.

Attempts have been made in many developing countries to control this expansion of energy use in transportation. Some countries use import barriers and/or higher gasoline prices to constrain demand for travel. Others have, through combinations of import tariff and pricing, encouraged a shift to more

enery-efficient diesel or, as in Brazil, alcohol. Odd-even driving day practices are in effect in Lagos and Caracas. Such individual policy measures do limit energy utilization in the transportation sector somewhat. However, it is imperative that the extensive set of linkages between the physical and economic characteristics of a nation and its transport infrastructure be understood before effective overall strategies can be formulated.

2. CHARACTERISTICS OF TRANSPORTATION IN THE DEVELOPING COUNTRIES

Though per capita vehicle ownership in the developing world remains much less than that of the developed countries, the density of vehicles (vehicles per km of paved road) is comparable all over the globe (see Table 1).[2] Motorized transport in the LDCs serves predominantly urban areas. Thus while typically only 20% of the population in a developing country resides in or around a city (the corresponding figure for developed countries is 60-80%), the overall magnitude of the problems accruing from urban motor congestion are similar in both the developed and developing worlds. For proof, one need only observe the congestion that plagues such cities as Tokyo, Nairobi, Mexico City, and New York City .

Table 1. Characteristics of Transportation

		1960	1975	%
Developing Countries	Cars	3,106,000	13,614,000	338
	Truck	2,373,000	5,750,000	142
	Total Fleet	5,479,000	19,364,000	254
	km of paved roads	166,852	457,586	174
	veh/km of paved road	32.8	42.3	
	vehs/1000 inhabitants		12.8	
Developed Countries (Europe, Japan, USA)	Total Fleet	107,825,000	268,842,000	150
	km of paved roads	2,077,390	6,042,970	190
	veh/km of paved road	51.9	44.5	
	vehs/1000 inhabitants		349.5	

Source: International Road Federation (IRF).

Meanwhile, car registrations have outgrown road building in the developing world by a factor of one-half during the past 10-15 years.[3] Consequently, it would seem likely that the problems associated with the movement of larger numbers of vehicles over limited roadways are likely to become even more severe in the future. Low developing country per capita income presently restrains automobile ownership (see, for example, Figure 1), but by the same token, a hike in incomes would bring the automobile within the grasp of greater numbers of people. Indeed, the data in Table 2 show the growth rates for auto registrations in selected cities are nearly double that of population growth.

Freight transportation (ton-mi per GNP) appears closely tied to economic structure. Bolivia, for example, with its lead exports and petroleum industry shows a transport intensity of 6.8 ton-mi per GNP, while Israel, an agricultural nation, registers 0.5 ton-mi per GNP.[4] Additionally, freight intensity seems to increase only slowly with time. In Korea, for example, freight travel demand increased from 1.2 in 1960 to only 1.6 in 1974. Regardless, even with constant intensity, freight traffic grows in proportion to GNP, exacerbating

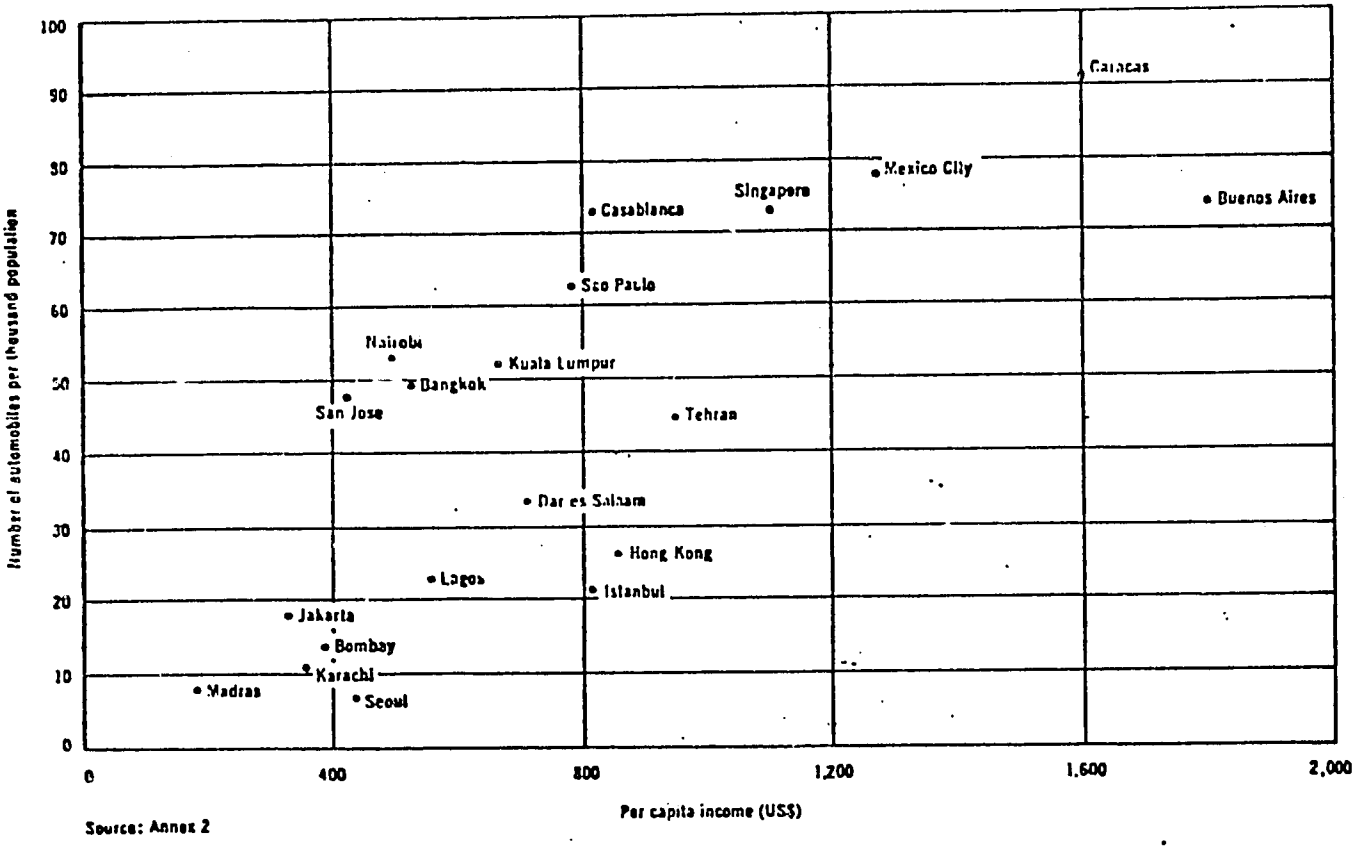


Figure 1. Automobile Numbers and Income Levels

Table 2. Growth of Population and Automobiles in Selected Cities Annual Rate of Growth 1960-70

City	Population %	Automobiles %	City	Population %	Automobiles %
Abidjan	11.0	12.7	Istanbul	6.0	12.2
Seoul[1]	8.5	22.0	Mexico City[3]	5.8	10.5
Lagos[2]	7.9	15.5	Bombay	3.7	8.2
Kuala Lumpur	6.5	11.3	Singapore[4]	2.6	6.7
Bangkok	6.2	12.0	Buenos Aires[5]	2.4	12.1

Note: The data for this sector are generally weak and not closely comparable.

(1) Figures for 1961-70

(2) Figures for 1964-69

Source: Annex 2.

[3] Figures for 1960-71

[4] Figures for 1966-71

[5] Figures for 1960-69

further the problems of congestion, particularly in urban areas.

4. VEHICLES AND MODES OF TRANSPORTATION

The energy intensity of alternative modes of travel widely varies. Because of its obvious influence on energy consumption at the national level, we will now examine some of the characteristics of the spectrum of vehicles available to meet passenger and freight travel demand in the LDCs.

Passenger Movement

The transport/energy efficiency (passenger-km output per kilojoule input) for modes of passenger transport is shown in Table 3.[7] The parameters will vary somewhat for different countries because individual vehicle characteristics differ, and vehicle performance is dependant upon the setting of each country. The commuter rail or metro is, of course, the most transport/energy efficient mode. However, it is also the most capital-intensive of passenger transport systems and the least flexible in adapting to the changing patterns of land use and industrial activity that accompany development. The

Table 3. Transport/Energy Efficiency

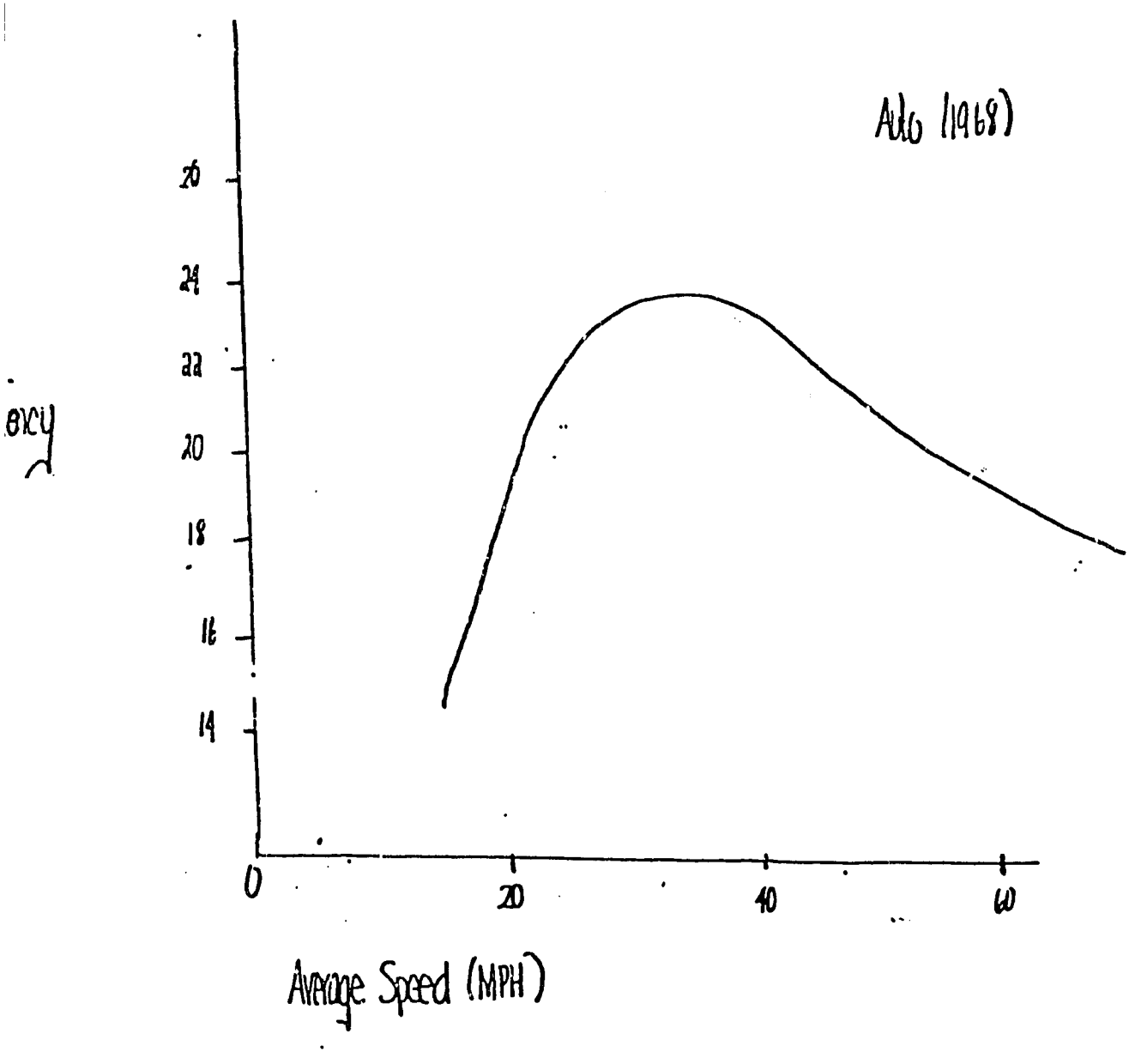
Energy Efficiency		Time-Energy Efficiency		
Mode	Pass-Mi/Gal	Mode	Mi/Hr	(Pass-Mi/Hr) (Miles/Gallon)
Commuter Train	120	Jumbo Jet	400	11200
Motorcycle	110	Jet	400	8000
Volkswagen	58	Corp Jet	300	4500
Bus (Urban)	40	Commuter Train	30	3600
Auto (General)	35	Motorcycle	30	3300
Taxi	32	Volkswagen	30	1740
Jumbo Jet	28	Auto (General)	30	1050
Jet	20	Train (Intercity)	50	850
Train (Intercity)	17	Helicopter	60	480
Liner	15	Taxi	15	480
Corp Jet	15	Bus (Urban)	10	400
Auto (Urban)	10	Auto (Urban)	20	200
Helicopter	8	Liner	10	150
Yacht	6	Yacht	15	50

Source: T.O. Carroll and E. Udell "Solar Energy, Land Use, and Urban Form" in R. Burchell and D. Listokin Energy and Land Use, (Rutgers University Press, New Jersey, 1982).

automobile, on the other hand, is by far the most common means of transport in most countries, providing almost unlimited ability for point-to-point travel.

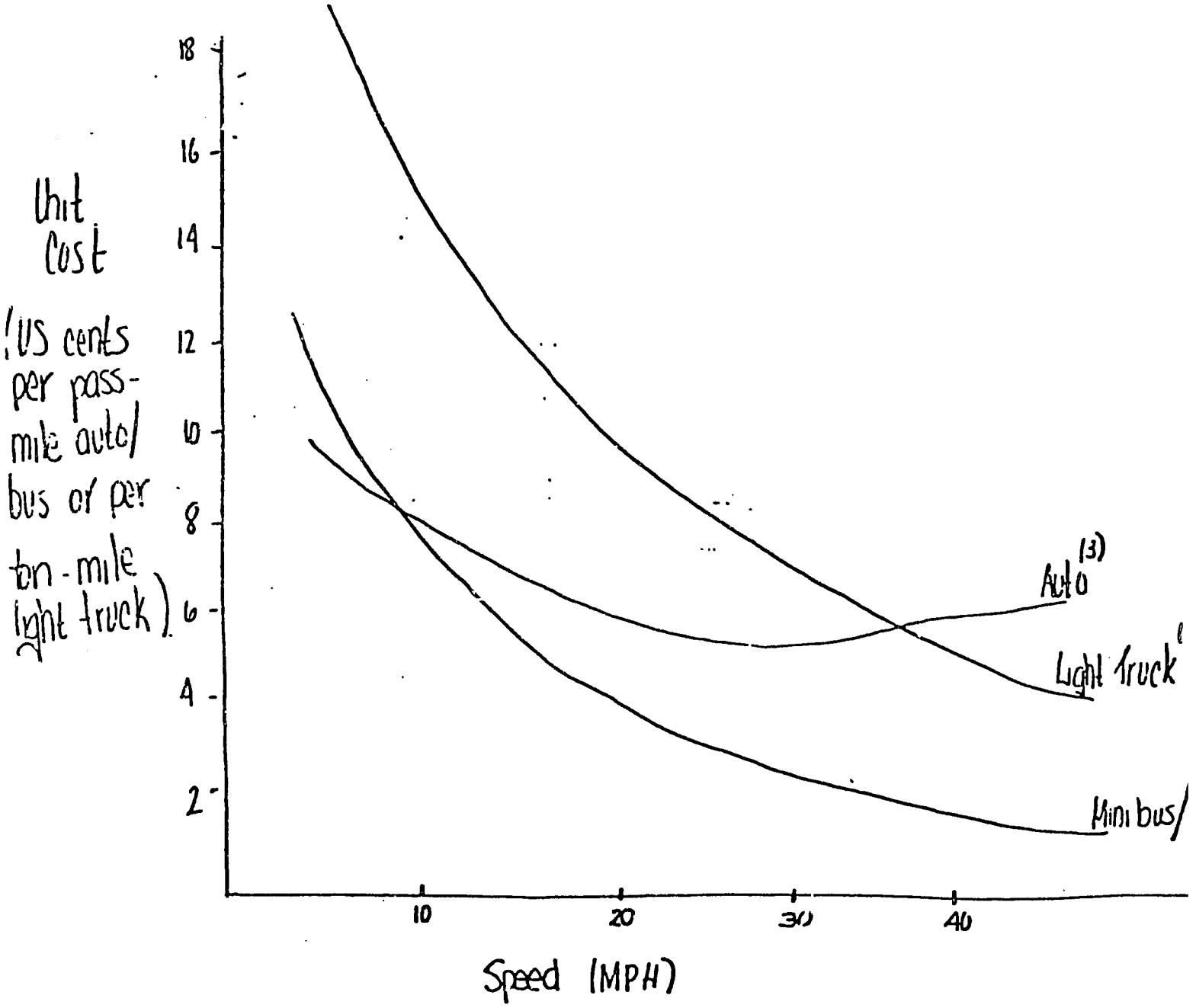
Fuel consumption is a function of average speed. For example, the U.S. auto fleet is designed to maximize efficiency in the 30-50 mile per hour range, as shown in Figure 2.[8] Above this speed, air drag and rolling resistance lower fuel economy. At average speeds near 10 miles per hour, which are common in urban areas, the stop-and-go movement of traffic degrades fuel economy. More alarming, is the relationship between average speed and unit cost of vehicle operation at lower average speeds. In Figure 3, the cost of mini-bus or bus service is generally well below that of automobile travel.[9] However, at average speeds common in the inner districts of urban centers, the operating costs of bus service can exceed the cost of auto operation. Thus, in addition to being a less flexible and less convenient form of travel, buses, at lower average speeds, lose their comparative cost advantage over the automobile as well.

Average speed of travel is an important element of modal choice.[10] We often find people driving their cars in urban areas despite the obvious energy inefficiency of doing so. The



Source R.B Sawhill, et al. "Vehicle Characteristics of Fuel and Travel time on Urban Arterials and Freeways" Forty-Ninth Annual Meeting, (United States Transportation Research Board)

Figure 2, Automobile Efficiency vs. Average Speed



(1) Assumes 5 ton gross weight.
(2) Assumes 22 passenger/40 passenger minibus/bus, respectively at 70 percent cap
(3) Assumes average occupancy of 2

Source: Adopted from Wilbur Smith and Associates "Singapore Mass Tran Study" (1974).

Figure 3. Operating Costs Vs. Average Speed

energy ranking of modes of travel in Table 3 would seem to suggest trains and buses are greatly preferred to automobiles when, in actuality, this is a highly inaccurate portrayal of current use. If estimated vehicle speeds are factored in, we obtain a measure of rapidity of travel (pass-km/hour) and energy efficiency (km per liter) for each mode of transit that correlates closely with present usage.[11] Our "time-energy efficiency" now ranks modes according to distance traveled, number of people moved, rate of travel, and fuel economy. The resulting similarity between real and formulated rankings emphasizes the implicit economic value of time and its importance in transportation planning.

Freight Movement

The comparative transport/energy efficiency of freight transport modes is shown in Table 4.[12] The range of values here is great because, more so than passenger modes, the types and performance of freight vehicles are dependent upon such local conditions as terrain, traffic conditions, materials shipped, and average loads. Although the relative advantage of rail and water transport over truck and air transport is clear, taking advantage of these more energy efficient modes requires

Table 4. Freight Energy Efficiency

	Ton-miles/million Btu	Energy Cost/Total Cost
Pipeline	540 - 6000	.7 - .8
Water	620 - 2000	n.a.
Rail	620 - 3300	.08 - .12
Truck	150 - 900	.1 - .2
Air	15 130	.3 - .4

that large volumes be carried. However, aside from the movement of selected mineral or energy resources, the production, distribution, and use of goods in developing countries involves transporting small loads over large areas. Given these conditions, it is not surprising that road transport is the most rapidly growing component of freight movement in developing countries.

Road freight exhibits scale economies, as shown in Figure 4. Most significant is the fact that, for the same vehicle weight, diesel engines are 30 percent more efficient than gasoline engines.[13] However, since, as seen in Table 4, energy cost as a percentage of total cost of freight movement is not large, higher prices for petroleum fuel have not had substantial impact on this transport sector.

5. ENERGY USE FOR TRANSPORTATION

There are two approaches to the analysis of energy demand in the transportation sector. The first is based on using "elasticity" of demand; the second involves evaluating specific "policy planning" interventions. Each has insights to offer, and we will compare and suggest how these should be used in conjunction with a national energy assessment.

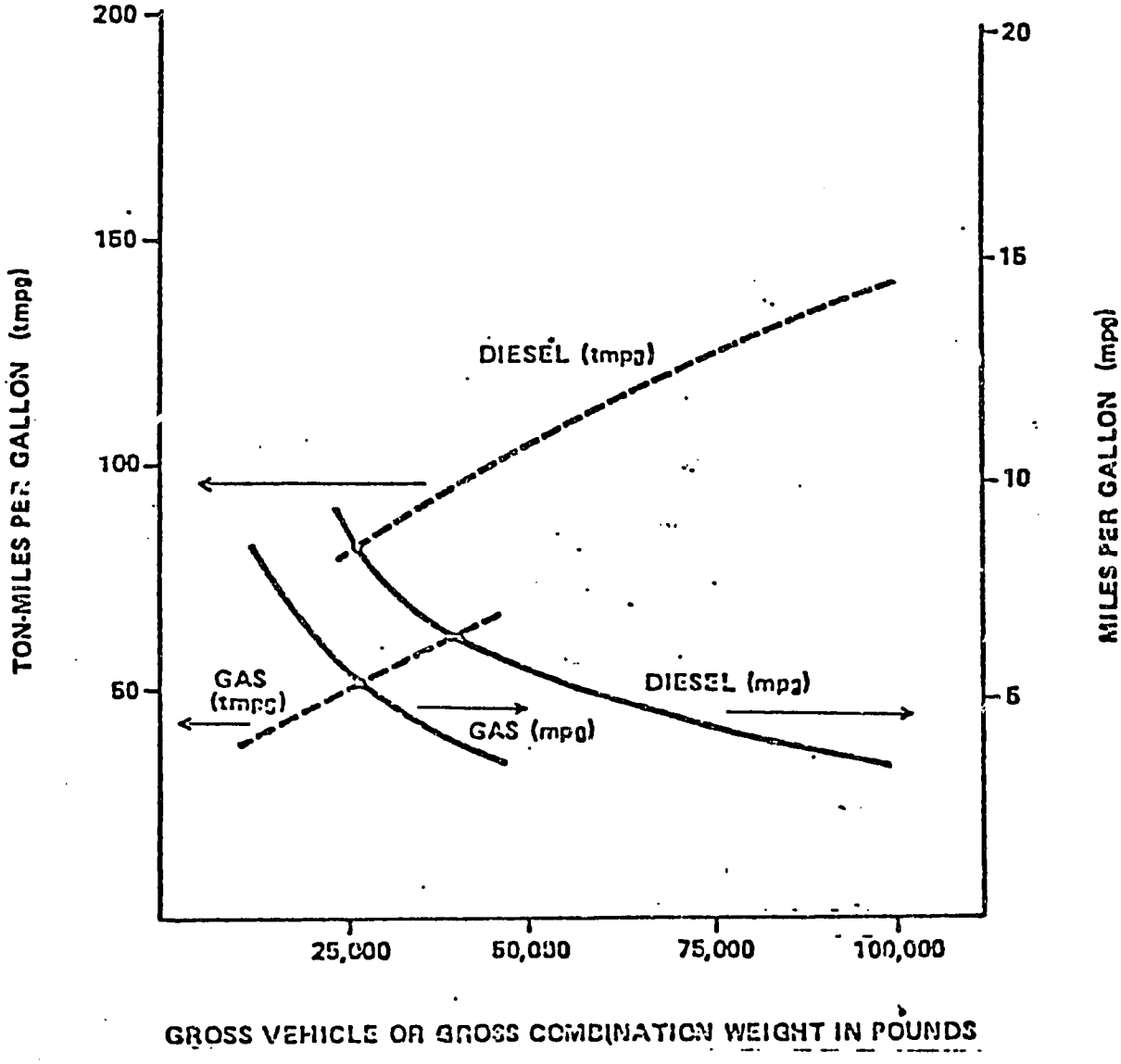


Figure 4. Fuel Efficiency Vs. Gross Vehicle Weight

Source: U.S. Department of Transportation et al., Interagency Study of Post-1980 Goals for Commercial Motor Vehicles, Executive Summary, Washington, D.S., July 1976, p. 6

The "elasticity" approach is a relatively simple concept. It is based on an explicit analytical relationship between fuel consumption E (in liters) on the one hand and, gasoline price, per capita national income, and perhaps other parameters on the other. Their relationship is written in the form:

$$E = k\ P^{a} Y^{b} \qquad (1)$$

where k is a constant, P is the price of gasoline, and Y is per capita income.

The elasticity approach possesses a certain elegance of simplicity but falters when applied to actual situations in developing countries. The concept, of course, is based upon a statistical analysis of the past. The strong assumption must be made, therefore, that future behavioral patterns will mirror those of previous years. But, in developing countries, conditions which determine travel behavior can change rapidly, and the fragile infrastructure is much less absorbent. For example, sharp increases in the price of gasoline have prompted the exceedingly swift introduction of diesel passenger vehicles

(diesel fuel is heavily subsidized because of its use in agriculture) in many LDCs. As a result, extrapolating future transportation behavior on the basis of past actions is a very unexact business.

The "policy/planning" approach relies upon separate estimates for travel demand (measured in passenger-kilometers or tonne-kilometers) and for the energy efficiency of particular transport vehicles (measured in passenger-km or tonne-km per liter). In this sense, the policy planning approach enjoys an advantage over the elasticity approach, in that it is based on data generally available to developing countries. Fuel consumption is expressed as:

$$E = \sum_m \frac{D_m}{e_m} \qquad (2)$$

Where Dm is travel demand for mode "m" (passenger-km or tonne-km) and e_m is the fuel specific transport/energy efficiency (passenger-km or tonne-km per liter) of that mode. Because there is, in this approach, a separation of travel demand and vehicle energy intensity, consideration can

be given to a range of policy options appropriate to the situation found in many developing countries. The case study later in this paper will provide such examples.

It should be emphasized that, for the purposes of government decision-making, it is often the relative impact of alternative policies rather than their exact results which is crucial. Thus, while overall estimates of pass-km or tonne-km moved, may be less than precise, the impact of various policies on fuel consumption can be weighed against each other with some confidence.

6. POTENTIAL ENERGY SAVINGS IN TRANSPORT

A World Bank estimate of potential energy savings in transport is found in Table 6.[14] While only small savings could be obtained through curtailment or travel reduction, technical and regulatory measures could reduce automobile and truck fuel consumption by 20-30 percent. Automobile fuel efficiency, which is expected to continue to rise over the next decade, could be capitalized on by developing countries through high import tariffs, hiking the price of gasoline, or the

Table 6. Developing Countries: Potential Fuel Savings in Transport Sector, 1980's

(Savings as percentage of sector's energy consumption)

	Share of Sectoral Consumption	Savings From				
		Vehicle Efficiency	Regulatory Measures	Better Use	Demand Reduction	Cumulative
Trucks	35 - 45	6	2	10	5	23
Buses	8 - 12	2	(.)	5	(.)	7
Private cars	25 - 35	20	2	2	5	29
Shipping	5 - 10	2	5	5	(.)	12
Air	5 - 10	20	5	5	(.)	30
Rail	2 - 5	1	(.)	5	(.)	6

(.) Less than half the unit shown.

Source: World Bank staff estimates.

imposition of graduated annual registration fees which discriminate against automobiles with large displacement engines. In Korea, for example, a strong government program combining a steep increase in gasoline prices, higher import taxes on cars and spare parts, and regulations raising the cost of locally produced cars and trucks reduced energy consumption by 45% between 1973 and 1975.

The technical efficiency of trucks is not expected to keep pace with that of automobiles. However, there are large, though potentially difficult to realize, savings to be gained from changes in trucking operations. More efficient scheduling of pickup and delivery, increased back-hauling, and the use of more fully-loaded large trucks in place of frequent small loads would conserve fuel, but also require coordinated action from fleet operators and indivudual owner-drivers, as well as shippers. Unfortunately, while Table 6 indicates 10 percent fuel savings to be gained, there are as yet no documented examples of such results.

Shifting passenger travel from automobile to bus can, in many cases, provide travel at 3-4 times the fuel efficiency per passenger-kilometer. However, the provision of alternative transportation services requires care. Bus routes must be

chosen close to desired origins and destinations, and, as noted above, must not critically add to travel time. The same may be said for any shift of truck traffic to rail. The Brazilian revitalization of rail service, which included roll-on/roll-off equipment, has not met with great success. But in India, improved railroads now carry 90 percent of freight traffic.

Other travel modes are also responsive to conservation measures. Jet aircraft engines have been redesigned in recent years. Even ships have changed operating speeds, and sometimes fuel mix, to achieve energy savings. But, since the consumption shares of such modes are usually small when measured against overall national energy use for transportation, the corresponding savings gained are generally not significant.

MODULE A2. TRANSPORTATION ENERGY CASE STUDY

1. INTRODUCTION

This case study, from the Dominican Republic, illustrates the principles and practices involved in developing country transportation energy analysis. Approximately one-tenth of this Caribbean nation's 10 million inhabitants live in the Santo Domingo metropolitan area, and the congestion resulting from the automobile, publico (taxi), and autobus traffic is as thick as any other urban center in the world. Rapidly increasing oil imports and their effect on the national balance of payments lie at the heart of the energy problem in the Dominican Republic. In 1980, Dominican oil imports amounted to more than 500 million U.S.$ in foreign exchange, or more than 40 percent of foreign exchange earnings. An estimated 30 percent of the 1,000 KBOE of oil is consumed by passenger and freight transportation.

A steep increase in diesel (gasoil) fuel demand is expected as a result of continued substitution of diesel-powered for gasoline-fueled vehicles (particularly in inter-urban transport services), and because of the expanding

diesel truck fleet. Additionally, diesel minibuses are being introduced into the mass transportaton fleet, until now dominated by "publicos" (taxis) (as seen in Figure 2.) Registrations of large diesel trucks used in distribution have increased steadily as demand for agricultural and manufactured goods has risen.

2. TRANSPORTATION ENERGY AUDIT

The Transportation Energy Audit for the Dominican Republic is shown in Table 2. National energy consumption estimates require the specific parameters shown for passenger and freight traffic. In each case, we determine a) the number of vehicles and, where significant, the breakdown into gasoline and diesel-powered vehicles; b) fuel efficiency expressed in kilometers per liter; and c) each travel mode's annual fuel consumption rate. It should be noted that information needed for the transportation energy audit is rarely found in one agency or source, may indeed be entirely unavailable, and/or sometimes appears in a form difficult to incorporate into the audit. Naturally, the best field conditions are where transportation studies have recently been undertaken.

Table 2

Transportation Energy Audit (1980)

Metropolitan Santo Domingo

Passenger	#Vehicles[1]	Cap/Occup.[7]	Distance Traveled	Fuel Eff.	Fuel Consumption[4]
private	42000	5/1.3	17000 km/veh-yr[a]	35 km/gal[5]	20 million gal/yr[11]
publico (taxi)	7600[2]	5/3	60000 " " " [b]	30 " " [b]	5000 gal/dy for 380 vehicles daily
minibus	0[3]	22/13	60000 " " "	20 " " [12]	Ind. est. 14 gal/ve
autobus	450	30/18	60000 " " " [c]	12 " "	5000 gal/dy for 300 vehichles daily.[6]

Nationwide Freight	#Vehicles[1]	Cap/Loading	Dist.Traveled	Fuel Eff.	Fuel Consumption
camionetas (small trucks)	26600	n.a./1.5 tonne	24000 km/veh-yr[9]	30 km/gal[9]	n.a.
large trucks	15500	10 tonne/2 tonne	35000 " " " [8]	15 " " [8]	n.a.

Notes to Table 2

Data Sources

1. Obras Publicas (Public Works Department)
2. Only half the publico fleet is permitted to operate each day.
3. Minibuses are just now being introduced into the public transport fleet.
4. ONATRATE. (Office of Road Transport)
5. The private auto fuel efficiency was given by auto dealers.
6. SIDCHODISNA (Union of Chauffeurs of the National District).
7. The occupancy rates were estimated by a variety of observers.
8. FENATRADO (National Transport Federation). Data on fuel efficiency of trucks was also obtained from "Tables for Estimating Vehicle Operating Costs on Rural Roads in Developing Countries", Transport and Road Research Laboratory, Crowtherne, Bershire UK, (1976).
9. The fuel efficiency of small trucks was given by dealers. The fleet mix is about 85 percent gasoline-powered and 15 percent diesel-powered vehicles. Data is not sufficient to assign different fuel efficiency to each engine type.
10. Annual tonnage carried was taken from Oficina Natonal de Estadisticos (National Statistical Office). Obras Publicas provided fleet mix by gross weight. From these sources, we compute weighted-average truck capacity and fleet average tonnage carried.
11. The private vehicle fleet has 96 percent gasoline engines. However, diesel-powered autos are increasing rapidly because diesel fuel price is low (heavily subsidized).
12. This is the fuel efficiency of a new diesel Datsun 22-passenger minibus.

Computation Notes

a. The annual distance traveled by private vehicles was determined from vehicles, efficiency, and consumption; that is, col(3) = (4) x (5)/(1).

b. The fuel efficiency of publicos was assumed to be 30 km/gal. Publicos are restricted to driving every other day, and we allow twenty percent downtime for maintenance. With these assumptions, the computation is the same as in note a.

c. We assume 300 driving days annually. The computation is the same as in note a.

In the Dominican Republic, the numbers of autobuses, average occupancy, and fuel consumption are obtained from the agencies noted, but not the distance traveled. In principle, a set of three parameters in the transportation energy audit can be used to calculate the fourth (that is, using the columns in Table 2, (1) x (3)/(4) = (5)). This was done as shown in footnote C. Similarly, some judgement was necessary concerning the fuel consumption of publicos to complete the energy audit in Table 2.

3. ANALYSIS OF PROJECTED ENERGY DEMAND AND CONSERVATION POLICY

In this section, we will analyze energy consumption trends in the transportation sector. Later, we will look at examples of conservation opportunites and their impact.

3.1 Passenger Travel

Base year (1980) demand for passenger travel in the Dominican Republic is shown in Table 3. These figures are simply the product of occupancy, distance traveled, and number of vehicles from the transportation energy audit. The

TABLE 3

Mass Transport Analysis: Minibus/Auto Impact Bans

Passenger	Passenger-km Travel Demand (million pass-km)				Fuel Efficiency[2] (pass-km/boe)	Annual Fuel Consumption (thous boe)		
	Base 1980[1]	Projected 1990	Minibus	Plus Import Ban		Projected 1990	Minibus	Plus Import Ban
Private	940	1940	1940	1300	2100	920	920	620
Publico (taxi)	590	910	640	960	4100	220	150	230
Minibus	—	—	270	590	10500	—	30	60
Autobus	340	490	490	490	9100	50	50	50
	1870	3340	3340	3340		1190	1150	960

Notes

1. From Table 2, cols. (1)x(2)x(3). Only half of publico fleet is permitted to operate each day. Two thirds of autobus fleet operates each day.

2. The product of occupancy rate and fuel efficiency from Table 2 (cols. (2)x(4) scaled to boe).

3/

breakdown of demand into private auto, publicos, and autobus, is typical of most developing countries. At present, private autos are the least energy efficent mode of transport and consume 80 percent of passenger transportation fuels while carrying only 50 percent of passenger-km travelled.

Energy demand projections in Table 3 are based upon auto and public transit forecasts and assume constant vehicle efficiencies to the year 1990. We note that travel demand (pass-km) has increased at an annual rate of 7.5 percent over the past five years. Obras Publicas reports a 4.3 percent annual rise in ridership or public travel demand. For the sake of simplicity, assume fuel efficiency of each transportation mode remains unchanged between now and 1990.

In an effort to cope with increasing travel demand, the Dominican government has decided to replace 30 percent of publicos with minibuses. The diesel-powered Datsuns carry 22 passengers and have a fuel efficiency rate of 19 km/gal, or 10,500 passenger-km/boe at an average 60 percent load factor. In Table 3, we show the fuel consumption of these minibuses which now carry 30 percent of public travel demand.

Interestingly, the total fuel requirement for passenger travel has been reduced from 1190 thousand boe to 1150 thousand boe, a rather small net change.

Other conservation measures would do more. For example, a substantial hike in the duty assessed imported vehicles[2], or an outright ban[3], could dramatically reduce travel by private automobile. If implemented in the mid-80's, and given the 4 percent annual increase in automobile registrations, a policy of this nature would result in a full 1/3 reduction in travel by private auto and an overall energy savings in the transportation sector approaching 20 percent.

While restricting automobile imports appears quite effective in reducing the overall demand for oil, a deeper look reveals something more; namely, that merely counting barrels of oil equivalent is insufficient if the true impact of a conservation measure is to be evaluated. In our Dominican example, while we would initially note that a net reduction in fuel consumption of 190 thousand boe would occur, what may be more significant is that gasoline demand (automobile) will decrease by 250 thousand boe, while demand for diesel (mini-bus) will increase by 60 thousand boe. Since the Dominican Republic operates a refinery, these shifts in demand

may be inconsistant with the refining petroleum product mix. Thus, the real economic value of the energy savings accrued by restricting automobiles would not be known until this factor was weighed.

3.3 Economic Evaluation

An economic assessment of the impact of conservation measures must look at more than just energy savings. For, while foreign exchange dollars for oil imports may be saved, aiding a country's balance of payments situtation, regulatory measures may also lead to additional monetary costs. As we have in the Domincan study, a policy to restrict automobile imports makes sense only when coupled with an expansion in the minibus fleet sufficient to carry a large chunk of the additional passenger ridership. In this case, 2900 more minibuses would need to be added to the fleet at a capital cost of $40 million.

Although subsidizing transit fares helps in the recovery of operating costs, capital investments - such as the cost of 2900 minibuses - are paid back through achieved fuel savings associated with government policy as shown in Table 5. In this simple example, the rate of return on Dominican policy limiting

Table 5

Economic Analysis

Minibus/plus Automobile Import Restrictions

Capital Cost	2900 vehicle @ $13500/veh.[1]	= 40. million[2]
Fuel Savings	230 thous. boe @ $34/bbl[3]	= 7.8 million
	Rate of return (10 yr.)	= 15 percent

---

1 Mid '82 foreign exchange cost (excluding import duties, taxes, etc.) of Datsun 22-passenger diesel minibus.

2 An additional foreign exchange savings of $190 million over the ten-year period could be credited for the 29000 automobiles not purchased because of government policy measures.

3 Platts' Oilgram: Price f.o.b. Rotterdam, October 1, 1982

auto transport and expanding public transport is 15 percent annually. Additionally, although it has not been included, the foreign exchange not spent on imported automobiles would represent a further contribution toward improved balance of payments.

In this case study, the economic evaluation is oversimplified. In practice, one would look more closely at the public transport operation costs and fare structure to obtain a detailed picture of expenditures and income. The change in petroleum product mix away from gasoline and toward larger fractions of diesel fuel could have a significant impact upon the economics of domestic refining. Finally, petroleum fuel prices are regulated by government, subsidized for some groups and taxed for others, in an effort to achieve social goals. A more complete economic evaluation would include a look at the distributional effects of energy conservation measures.

4. A FINAL COMMENT

The analysis of conservation measures provides quantitative results and qualitative information with which decisionmakers may judge the merits of alternative actions. In

the Dominican Republic, the energy savings and their economic value associated with reduced levels of automobiles are significant. But, despite the attractiveness of these energy savings, higher vehicle import duties, import quotas and/or fuel prices may be difficult to achieve within the social and political climate prevailing in the country. Gasoline price increases in Egypt, for example, were met by street riots. In short, while analysis identifies desirable options, the decisionmaker must also be astute in judging which of the alternatives considered can be successfully implemented.

REFERENCES

TRANSPORTATION

1. N. Clark, J. Lee, and K. Ogden, "The Use of Energy for Personal Mobility," Transportation Research 8, 399 (Pergarman Press, 1974).

2. "Urban Transport - Sector Policy Paper," The World Bank, (Washington, D.C.), May, 1975.

3. B. Chatelin, "Patterns of Transportation and Energy," Energy Management Training Program Monogram, SUNY, Stony Brook (1979).

4. W. Owens "Energy Use in Transportation," Energy Management Training Program, SUNY, Stony Brook (1979).

5. T.O. Carroll, et al. "A Systems View of Energy and Land Use," IEEE Trans. on Systems, Man, and Cybernetics SMC-7 (4), 256, April, 1977..

6. L. Unikel, "El Desarello Urbano de Mexico," El Colegiode, Mexico (1976).

7. S.S. Remmer and L. Icerman, Energy O.I (Addban-Wesley Publ. Co., Reading, Ma., 1974).

8. R. Sawhill, J. Matteson, and J. Hall, "Vehicle Characteristics of Fuel and Travel Time on Urban Arterials and Freeways," Committee on Vehicle Characteristics, 49th Annual Meeting, U.S. Transportation Research Board.

9. "Singapore Mass Transit Study," Wilbur Smith and Assoc. (1914).

10. W. Brog, "Subjective Perception of Car Costs," Transportation Research Record No. 858, Committee on Passenger and Freight Transportation Characteristics, U.S. Transportation Research Board.

11. T.O. Caroll and E. Udell, "Solar Energy, Land Use, and Urban Form," in R.Burchell and D. Listokin, Energy and Land Use (Rutgers University Press, New Jersey, 1982).

12. Op. cit. ref. 7

13. "Interagency Study of Post-1980 Goals for Commercial Vehicles," U.S. Department of Transportation, (July 1976).

14. Transportation Department, The World Bank (1979).

REFERENCES

TRANSPORTATION/ENERGY CASE STUDY

1. Most of the data for this case study was taken from the report, "Energy Strategies for the Dominican Republic," of the Comision Nacional de Politica Energetica, Dominican Pepublic (Sept. '80).

2. The present import duty is 35 percent, whereas, in Colombia, the duty is 350 percent.

3. Such bans are in existence in a number of countries.

4. See Transportation Section, Figure 4

SEMINAR OF ENERGY EFFICIENCY AND CONSERVATION

LOME, TOGO - March 30 - April 8, 1983

Claude Garrigues

Reasons for considering energy-efficiency as an important element of West African Energy Strategy (summary)

energy conservation is an important element as such: this is a major conclusion wich could be drawn from two surveys made by the World Bank covering MOROCCO and SENEGAL.

MOROCCO: 13% of energy consumed by the Industrial Sector, say 100 000 tep, could be saved by an USm$ 80 investment : its overall pay-back period would be 1.7 years and the yearly saving, USm $ 50.

SENEGAL : the present consumption is 750 000 tons of oil (excluding fuelwood). According to the survey 10% of the consumption could be saved by an investment with a pay-back period of less than three years. This percentage could be increased up to 40% by considering energy conservation measures connected with extension and modernization investiments.

it does not mean privation or income reduction : a five speed car gives more miles per gallon, reduces costs, is less noisy and lasts longer; a building heated at 29°C does not mean more confort, it means more expenses, uneasiness and respiratory problems etc.etc...

it means jobs: carrying out energy audits, implementing energy conservation measures, manufacturing equipments, require jobs and procure salaries.

the only bad effect is on the Gross National Product :energy conservation reduces the G.N.P.! in the same way as car accidents increase it!

40

BUT, evaluating the potential for energy conservation is relatively easy : coming down to the implementation is not so simple

the decision making process very peculiar : it has nothing to do with the chain of decision leading to the opening of a cement or a textile plant : a large part of the potential can be achieved with very little investiment and sometime with no investiment at all : this means, there is no incentives for a salesman, to go to the factory, meet the decision makers, provide him with information, and try to convince him.

Consequently the decision maker is left alone and very often he does not realize the potential he is sleeping on : this is the duty of the Goverment to evaluate this potential and do something to wake him up.

We will deal of this point later on.

Results of industrial and electric utility case studies carried out in selected West African and other developing countries.

THE POTENTIAL FOR ENERGY CONSERVATION IN THE MOROCCAN INDUSTRY

To carry out this evaluation we visited 9 plants, obtained energy data on 15 other plants : we calculated the specific consumptions of those 24 plants, compared them with their european conterparts and evaluated the potential; this potential was then extrapolated to the whole moroccan industrial sector:as said yesterday we assumed, 100 000 tep, say US m$ 50, could be saved by investing USm$ 80 in retrofitting equipments (programmation, regulation, leak-plugging, insulation and heat-recovering)

Further financial savings could also be achieved by shifting from oil products to imported coal or eventually to local natural gas.

Results of industrial and electric utilities case studies carried out in West African and other countries .

THE POTENTIAL FOR ENERGY CONSERVATION IN THE SENEGALESE INDUSTRY.

This assignement was quite similar to MOROCCO's, with a difference: the Senegalese Industrial Sector is not as developped as MOROCCO's : this gave us sufficient time to have a look on other aspects of the senegalese economy say utilities companies, building and transport activities.

We visited 10 plants and -when this was possible- we calculated the specific consumptions, compared them with their european counterpart and evaluated the potential for energy conservation.

On the basis of data collected by another consultant we calculated also the specific consumption of three utilities companies and similarly evaluated their potential.

Then we extrapolated these potentials to the whole industrial and utility sectors. The results of these calculations was that the potential for energy conservation is 36 000tep -say 8% of the consumption- if we restrict to retrofitting measures or 154 000 tep -30% of the consumption - if we consider longer pay-back periods investiment -say modernization or extension investiment-

Results of analysis and case studies in the transportation and buildings sectors of West African and other developing countries.

PRELIMINARY EVALUATION OF THE POTENTIAL FOR ENERGY CONSERVATION IN THE TRANSPORTATION AND BUILDINGS SECTORS IN SENEGAL.

Our purpose was not to carry out a thorough and extensive survey but to ascertain if it was worth doing a special effort on these sectors : Sometime we were in a position to calculate the savings involved by our recommendations, sometime we could not. However, though incomplete was our approach, we are convinced that in SENEGAL there in an ample matter for energy conservation in those sectors.

Our main recommendations were as follows :

- making walk and bicycle riding more pleasant and less hazardous than at present.
- favouring collective transports by :
  - giving more possibilities to the DAKAR public transport company
  - making easier the traffic conditions for collective bus

potential saving : 8000tep/US$2 900 000

- training drivers of the DAKAR public transport company to save gaz oil

potential saving : 600tep/US$ 220 000 : cost of training = US$ 38000

- setting up commuter trains between DAKAR and RUFISQUE

potential saving : 4300tep/US$1 500 000

- setting up a non-stop working day

potential saving 4000tep/US$£ 1 400 000

- giving to the national railway company the possibilities to recapture its normal share of the transport market

potential saving : 9 000tep/US$3 200 000

- promoting central air-conditionning units instead of individual ones

potential saving : 19 000tep/US$6 800 000

- promoting buildings technics and urbanism adapted to local needs and not following the european patterns of the late sixties.
- promoting a solar water heater adapted to local conditions and not following the european patterns.

potential saving : 2 700 tep/US$1 000 000

- discouraging the use of plaster as it is more fuel intensive than cement
- economizing on superfluous cement
- promoting stabilized earth
- promoting natural and passive air conditionning systems, the use of insulating material against sunheat, double roofing, double wall, suppression of openings on east and west sides, utilization of plants in a patio or as a roof and wall covering,
- promoting air-humidification instead of air conditionning in dry and hot environments
- promoting tree planting in urban areas

It is difficult to ascertain the potential for energy conservation contained in those measures : it is certainly considerable and in any case larger than 50 000tep; so we think, it is worth conducting a comprehensive survey to put figures on it and evaluate the cost efficiency of each item of this long list of recommandations and the possible impact on SENEGAL or any other country.

Analysing Energy-Efficiency in the industrial Sector 1

METHODS OF CONDUCTING ENERGY AUDITS.

To conduct energy audits we follow the following procedure:

a - Evaluation of the overall potential for energy conservation
b - Thorough examination of the plant or building
c - Setting up a list of measures leading to energy savings
d - Selection of measures
e - Setting up the definitive list of measures
f - Implementation of recommandations
g - Setting indicators to monitor plant or building performances.

a - Evaluation of the overall potential

We collect data on energy consumption, production, manpower, covered surface etc. ; then we visit the place to understand the process and identify obvious opportunities for saving : this requires usually between one and three hours.

Then we draw up energy balances and calculate specific consumptions, some ratios and, by comparing those figures with similar plants or buildings, we make an assumption of the potential for savings.
One or two days are necessary to evaluate the potential.

b - Thorough examination of the plant or building

We visit again the installation for a more complete examination : each place of the installation where energy is transformed is submitted to a systematic search and for each of them we collect as much information as is available.
This job requires usually one full day.

c - Setting up a list of measures leading to energy savings

Each functions of each systems where energy is transformed is confronted with the following check-list which recapitulates the technics for energy conservation:

- modifying the relationships with the environment
- tarification (paying energy the minimum price)
- programmation (providing energy when it is required)
- regulation (providing just the quantity of energy required)
- leak-plugging (avoiding the use of energy without making it work)
- insulation
- energy recovering
- shifting to other fuels
- shifting to another product
- shifting to another process

when an opportunity for energy saving is discovered, we evaluate it in terms of quantity, price and investment .
This is the longest part of the audit : between 10 and 20 days.

d - Selection of the measures

This usually very long list is submitted to the plant manager for approbation.Some of the measures are retained, some are not, as not feasible.
A two hours meeting is necessary to sort out the final list.

e - Drawing up the definitive list of measures

The retained measures are classed according to their cost-efficiency; their interactions will be taken into consideration: this leads to a definitive list and a final objective of energy savings.
This phase requires two or three days.

f - Implementation of recommandations

We assist the industrialist or the building owner in his negociations with the contractors or utility companies; usually a two hours meeting is sufficient.

g - Setting up indicators to monitor plant or building performances

We usually recommand to the industrialist or building owner to calculate every month or every year a handful of ratios or specific consumptions to evaluate the overall performances of his plant or building.

Conclusion

This procedure is rather complex but this is the only way not to by pass opportunities to conserve energy : of course, a "walk through audit" is more expeditive but it misses a lot of wastage.

More over, after gaining experience, screening cost-efficient and not cost-efficient measures becomes easier and this reduces a lot the cumbersome task of evaluating savings and investment attached to each measure.

But one has to go along this systematic procedure if he doesn't want to miss important opportunities for energy savings.

Economic analysis of energy efficiency Measures 2

GOVERNMENT INCENTIVES

As said before, Government cannot count on private initiatives to promote Energy conservation: they should count on themselves. The list of incentives they can propose is as follow :

- set up a price for energy in accordance with its future expected cost
- promote the idea of energy conservation (press,radio,T.V.)
- start a decentralised and adapted promotion compaign from the countries top authorities down to the bottom.
- set up an organization in charge of Energy Conservation
- collecting energy data in all sectors
- launch a five year Energy Conservation Plan
- set up a system of financial incentives (but this is not an essential item)

Analysing Energy-Efficiency in the Industriel Sector 2

Case studies of industrial energy conservation in West African Countries

A - PHOSPHATE AIR DRYER

Following our method, we will try to have a first idea of the dryer efficiency, without proceeding to the complete calculation.

To do that, we will compare the quantity of fuel oil burned with the quantity of water removed from the phosphates rocks.

Q = tons of fuel oil
Pci = Calorific value of fuel oil (thermies/ton of fuel oil)
We = Water content of wet rocks (tons of water/ton of dry rocks)
Ws = Water content of dry rocks (tons of water/ton of dry rocks)
M = tonnage of rocks

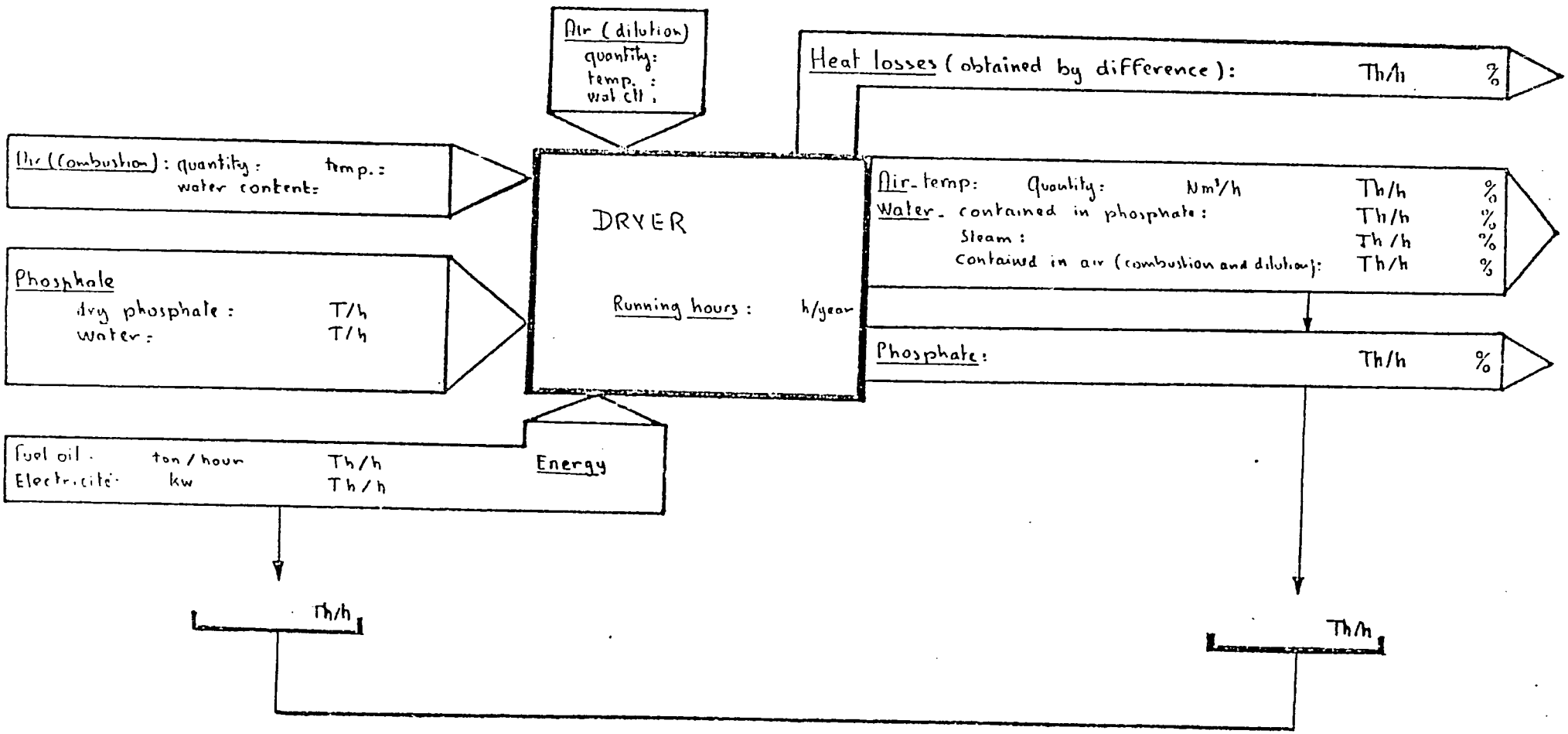
$$R = \frac{\text{Quantity of heat required to turn water into steam}}{\text{fuel oil heat content}}$$

$$R = \frac{(We - Ws) \times M \times 600}{Pci \times 0}$$

if $R > 0,9$: data are wrong
if $0.9 > R > 0.8$: another part of the plant desserves more attention
if $R < 0.8$: there is an opportunity for energy savings

If $R<0.8$, it is worth trying to find out where are the opportunities for energy savings : we will establish the energy balance sheet as indicated in the attached table. And on the basic of these figures, find out energy conservation technics which can be applied to the diyer.

MATERIALS FLOWS AND HEAT BALANCES



Analysing Energy Efficiency in the Industrial Sector

Case studies of industrial energy conservation in West African Countries.

B. CEMENT PLANT

Energy conservation in a cement plant is a very specialized job. So our purpose will be more to identify where problems are, more than to try to solve them.

Our first task will be to appreciate the overall performance of the whole plant by calculating two ratios :

- quantity of thermies / tons of klinker
- quantity of electricity / con of cement

and ton of cement / tonoof klinker (taking into consideration that some tonnage of klinker are shipped before being grinded into cement) Those ratios will be compared with the corresponding ratios of comparable cement plant.
This comparison will establish the order of magnitude of the problem.

The next step will be to compare the specific consumption of each sector of the plant in terms of Kwh/ton or liter of gas-oil/ton of production; we will examine the following sections:

- Quarry
- primary crushing
- formulation
- drying
- secondary crushing
- homogeneization=
- storage 1
- kiln (s)
- storage 2
- grinding

ratios will be compared with those obtained in similar plants. Differences will be noted and explanation will be obtained from the management.

The last step will be a visit of the plant to locate the last possibilities of saving (warming up of the heavy fuel oil, electric generators, lighting etc.)

Analysing Energy-Efficiency in transportation

POTENTIAL FOR ENERGY CONSERVATION IN TRANSPORT IN DAKAR AREA

Basic data were obtained from a survey made by SONED and SCET International for the Ministère de l'Equipement released in May 1981.

It reviews the urban transport means used in DAKAR. Their characteristics are given in the attached table.

This table indicates :

- private cars are very energy intensive, require a lot of space and consequently a lot of investment : 33 000 cars consume 41% of the fuel used in DAKAR area, require 86% of the space available and secure only 33% of the movements.
- contrariwise the 264 SOTRAC buses consume 20% of the fuel, require only 2% of the space but secure 37% of the movements; their efficiency in terms of Km x movement / consumption is 3.3 time higher than cars.
- shifting 1% of the movements from cars to SOTRAC buses means a yearly saving of 1600tep/year or USm$0.6.

This indicates that Goverment should promote SOTRAC buses and discourage the use of private cars.

A lot has been already done: SOTRAC runs 400 buses and the average rate of occupency has been reduced from 29% down to 27%, and we assume that collective transportation means have increase their share of the market from 56% in 1980 to 65% in 1981.

This procures a saving of 15 000tep or US m$5.6

Is that a maximum ? we do not think so : in TUNIS the rate is 68% and we assume that a rate of 70% could be attained in DAKAR.

This means a saving of 8000tep or USm$3.0

SOTRAC

Coming to SOTRAC itself, the average consumption is 39l/100km for the buses equiped with a M.A.N. Diesel engine and 45l/100km for the buses equiped with a FULGAR Diesel Engine.

Of course SOTRAC is going to shift to MAN Diesel Engine, which means the final figure will attain 39l/100km.

MAIN CHARACTERISTICS OF TRANSPORTATION MEANS IN DAKAR AREA

(average day)

Transportation means	Consumption (l/100km)	Movements (Nb)	%	Vehicles (Nb)	Ground Occupation	Total ground occupation (1)	%	Energy efficiency (2)	Comments
Collective private buses	20	180,000	19	500	1,8	900	2	30	(1): Number of vehicles x ground occup.
Authorized taxis	15	75,000	8	1,600	1	1,600	4	11	(2) = Number of movements (3) / Fuel consumption (l/day)
Private cars	10	315,000	33	33,000	1	33,000	86	21	(3) = Number of movements x average distance
Motor bikes	4	30,000	3	8,000	0,3	2,400	6	25	
buses	41,5	350,000	37	264	2.5	660	2	70	
		950,000	100			38,560	100		

This compares quite favorably with the consumption figure achieved with the PARIS REGIE AUTONOME DES TRANSPORTS PARISIENS (R.A.T.P.) = 391/100km :it is even better as the average rate of occupancy is lower in PARIS than in DAKAR (22% against 39%)

Does it mean that there is no scope for further saving ? there is at least two areas where a productive effort could be made:

- training the bus drivers to save fuel: a minimum of 5% could be easily saved (US$ 221 000/600tep) : training would last 4 months and cost US$ 38 000)

- Improving the traffic conditions for collective transportation means : if RATPachieved 391/100km in 1981, the corresponding figure in 1975 was 371/100km; this 5% increase is due to worsening traffic conditions: we can expect for SOTRAC another 5% improvement if collective and SOTRAC buses are allowed to drive more freely without being continously stopped by traffic jams or unlawful parking; saving (US$ 221 000/600tep)

THE IMPORTANCE OF ENERGY EFFICIENCY IN THE DEVELOPING COUNTRIES

David J. Jhirad

International Energy Program
Brookhaven National Laboratory
Upton, NY 11973

Presented at the

West Africa Seminar on Energy Efficiency and Conservation
Lome, Togo
March 30 - April 8, 1983

56

DISCLAIMER

This Report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency, contractor or subcontractor thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency, contractor or subcontractor thereof.

TABLE OF CONTENTS

1 Introduction..... 1
References..... 4

2 Energy Efficiency in Development Countries: Technical and Economic Potential..... 5
2.1 Energy Consumption Patterns..... 5
2.2 Relevance of Experience in Industrialized Countries..... 7
2.3 Financial and Economic Analysis of Energy-Efficiency Investments..... 8
References..... 13

3 Technologies for Waste Energy Utilization in the Industrial Sector..... 15
References..... 19

4 Observations from a Case Study of Brazil..... 21
4.1 The Energy Situation in Brazil..... 21
4.2 Economically Attractive Technologies in Brazil: Some Selected Examples..... 25
4.2.1 Heat Pumps: Commercial and Industrial Applications.... 25
4.2.2 Air Chilling--Water Heating Heat Pumps for Commercial and Residential Applications..... 27
4.2.3 Industrial Applications of Heat Pumps Which Use Low Temperature Waste Heat as the Heat Source..... 30
4.2.4 Heat Pump Application Potential..... 32
4.2.5 Summary..... 35
4.2.6 Heat Recuperators..... 35
4.3 Financial Analysis of Heat Pump Technology..... 36
References..... 39

58

1 INTRODUCTION

Many developing nations have been seriously affected by the rise in energy prices of the 1970s, and planners from these nations are seeking methods and technologies to reduce energy costs associated with economic output, while simultaneously maintaining economic growth and improving their balance of payments.

Several developing nations have therefore embarked on energy strategies that involve increasing their indigenous supply of conventional fuels, expanding the use of large-scale hydroelectric and nuclear systems, improving the efficiency of oil utilization in industry and transportation, and developing renewable energy technologies. More attention is now being paid to a balanced approach that combines investments in energy supply with investments in energy saving.

However, experience gained by the World Bank over the last few years has shown that few developing countries have given a high enough priority to energy-efficiency and demand management strategies, in spite of the fact that investments in energy-efficiency are very attractive compared with investments in new supply, often yielding significant energy savings in a relatively short time.[1]

The unpopularity of the phrase "energy conservation" is probably due to the fact that energy conservation has traditionally been equated with austerity or curtailment, rather than with a modern economic and engineering concept which stresses improved efficiency of energy conversion devices and processes. In this paper, the terms "energy-efficiency" and "energy conservation" are used interchangeably in order to emphasize the view that improved energy utilization can be desirable from an economic as well as an engineering perspective.

The paper presents some results from ongoing work at the Brookhaven National Laboratory on the economics and potential for energy-efficiency and substitution in the developing countries.[2,3] By and large, the emphasis in this paper is on energy conservation in the industrial sector. A detailed financial analysis of one particular technology, industrial heat pumps, is presented for one developing country, Brazil, to illustrate the effect of government financial incentives on the attractiveness of investments in energy efficiency.

Studies in the industrialized countries have revealed conclusively that, from an economic and technological viewpoint, there are substantial opportunities for using energy more efficiently in all sectors of the national economy. One representative study has indicated that an average of 25% of energy use in the U.S. manufacturing sector could be saved through measures whose capital and life-style costs are les than those needed to generate equivalent amounts of new energy supply.[4] Particular industries will differ considerably in their potential for energy-efficiency measures, and also in the mix of energy savings that can be achieved in coal, gas, and electricity.

A straightforward yet powerful technological idea appears therefore to be an essential ingredient in all short- and long-term energy options: that

the aggressive development and implementation of energy efficiency technologies is an essential element of any financially and economically responsible energy plan. Research and experience in industrialized countries has suggested that energy efficiency technologies could play a vital role in improving industrial productivity and sustaining economic growth in the 1980s and 1990s, and would be less costly and more environmentally benign than a national energy strategy oriented exclusively to supply. In addition, the relatively short installation times of energy efficiency measures allow rapid and cost-effective responses to unanticipated changes in energy needs.

Many important lessons have been learned, both in the developed and in the developing countries, about the effect of pricing and non-pricing policy tools on energy demand, and there appears to be a significant potential for the transfer of these learning experiences to countries in the early phases of their energy-efficiency strategies.

Even though many energy-efficient technologies are cost competitive with new sources of energy supply, there are still significant barriers that impede the flow of capital in developing countries into these technologies. These barriers include:

- The limited availability of capital for investment in energy-efficient technologies and systems.

- A government pricing policy where the average price of energy charged to private manufacturers is considerably below the escalating replacement cost of new supply.

- The fact that many manufacturers require a higher rate of return on energy-efficiency investments relative to competing investments which are critical to maintaining or expanding their market share of particular products.

- The existence of laws and regulations restricting or preventing the generation of by product electricity by manufacturers.

Government policy incentives to remove barriers and to encourage energy conservation investments should be based on appropriate criteria for public and private decision making, as well on careful micro and macro cost-benefit calculations.

Examples of such incentives could include:

- Low-interest loans for purchase of energy-efficient equipment, and reduced import duties on such equipment.

- Changes in pricing policy, such as decreasing or removing fuel subsidies for industrial users.

- Changes in tax policy, such as added taxes on fuels for low-efficiency users or tax credits for installing more efficient equipment.

- Mandatory energy productivity targets and performance standards for boilers and other equipment.

- Permission to generate on-site electricity, receive standby power, and sell excess power to the grid at reasonable prices.

Government policies should be designed to improve industrial energy efficiency and to encourage private decision makers to invest in nationally beneficial energy conservation projects. These policies must be carefully integrated with a comprehensive national program to increase industrial productivity and to meet important national objectives such as equity, improved balance of payments, increased employment and economic growth.

REFERENCES

1. Harold Wackman, "Energy Efficiency in the Developing Countries," a paper for presentation at the United Nations ACC Technical Group Meeting on Energy Conservation, New York, December 13-15, 1982.

2. David J. Jhirad and William Rutter, "Renewable Energy in Brazil: Opportunities, Barriers, and Remedies," Brookhaven National Laboratory, BNL 51527. March 1982.

3. G. Anandalingam and David Jhirad, "Analytic Tools for Techno-economic Assessments of Industrial Energy Efficiency in Developing Countries," Brookhaven National Laboratory, Informal Report, August 1982.

4. G. N. Hatsopoulos, E. P. Cyftopoulos, R. W. Sant, and T. F. Widmer, "Capital Investment to Save Energy," Harvard Business Review, March-April 1978.

2 ENERGY EFFICIENCY IN DEVELOPING COUNTRIES: TECHNICAL AND ECONOMIC POTENTIAL

2.1 ENERGY CONSUMPTION PATTERNS

The use of commercial energy in the most energy-intensive industries in developing countries has been extensively reviewed elsewhere,[1,2] so that what follows is only a brief summary of commercial energy consumption patterns in developing countries.

The relative magnitude of energy consumption in the different sectors of the economy depends greatly on economic structures, technological development, and various fuel mixes. In addition, the relative amount of energy consumption in each end-use sector is strongly dependent on whether one is considering only commercial energy or all forms of energy, including "traditional" fuels such as firewood and cattle dung. If traditional fuels are excluded, the industrial, power, and transport sectors account for the largest segment of energy consumption. The industrial sector may consume from 25% to over 70% of the commercial energy in developing countries. In India, for example, industry accounts for over 75% of commercial fuel consumption.

Typically, the largest 5 or 6 industries in developing countries represent over 70% of total industrial energy use. The major energy consumers are cement, iron and steel, aluminum, chemicals including fertilizers, pulp and paper, and mining.

There are different ways of measuring the energy intensity of a national economy, or of buildings, industries, transportation, and power systems. A widely used but crude yardstick is the amount of energy consumed (in tons of oil equivalent) per unit of gross domestic product (GDP).

A better indicator of the way in which energy is used is the ratio of energy use (measured in megajoules or kilocalories) to activity level in a particular sector (tons of output in industry or agriculture, passenger-mile or ton, kilometer in transport, square feet or square meter in residential and commercial buildings). Table 2.1 displays the specific energy consumption per metric ton of product for a number of developed and developing countries, and Table 2.2 focuses specifically on the energy intensity of steel and cement production in various countries.

According to this measure of energy intensity, there is great scope for improved energy-efficiency in the energy-intensive industries of the developing countries, brought about through low-cost, good housekeeping measures, and by means of capital-intensive investments in new and existing plants, such as the introduction of continuous casting in the steel industry and the dry process of cement manufacture. Conservative estimates of the savings that could be achieved by modifying existing plants are presented in Table 2.3.

Table 2.1
Specific Energy Consumption Per Metric Ton of Product
(10^4 kcal)

	Pulp & Paper	Cement		Aluminum	Fertilizer
		Dry	Wet		
United States	970	136	170	947	1132
Sweden	756	140		1648	--
United Kingdom	--	89	160	2107	1223
Germany	--	74-90	120-140	1492	--
Egypt	--	162		2120	1625
India	--	170		--	1700
Bangladesh	1566	170		--	--
Kenya	1285	134		--	--

Source: J. Jankowski, Jr. Resources for the Future, Discussion Paper D-73A.

Table 2.2
Energy Intensity Comparisons in Selected Countries -- 1979-81
(kilograms of coal equivalent per ton of output)

	Crude Steel	Cement Clinker
Japan	650	125
U.S.	890	215
Brazil	920	150
India	1400	215
China	1260	206

64

Table 2.3
Developing Countries: Possible Savings in the Major Energy-Intensive Industries, 1980s

	LDC Percentage of World Production, 1978	Energy Consumption per Metric Ton of Output[a]	Potential Savings With Existing Plant (1978) Production Levels)	
			Percent	000 bdoe[b]
Aluminum (from Alumina)	8.2	28-36	5-10	5-12
Copper (Smelted & & Refined)	22.3	3-8	5-10	1-4
Steel (Crude	8.1	4-6	5-10	35-90
Cement (Clinker)	27.4	0.5-1.0 (fuel)	15-25	60-170
		0.2-0.3 (electricity)	5-10	7-15
Ammonia	15.1	6-8	5-15	10-40
Petroleum Refining				
Distillation	11.6	0.4	10-20	35-70
Cracking	6.9	0.7	10-20	7-15
Pulp and Paper	11.8	4-8	20-25	35-95

[a]Expressed in barrels of oil equivalent, assuming that 1 kWh of electricity input requires 2,670 kcal (10,600 Btu) of heat. This conversion factor varies widely depending on the type of primary energy, transmission losses, etc.
[b]Thousand barrels a day of oil equivalent.
Source: "Energy in the Developing Countries," World Bank, 1980.

2.2 RELEVANCE OF EXPERIENCE IN INDUSTRIALIZED COUNTRIES

The US Industrial Energy Efficiency Program found that during 1976, 1977, and 1978, the ten most energy-intensive industries improved their energy efficiency by 8 percent, 11 percent, and 14 percent respectively in comparison with 1972 levels (measured as energy consumption per unit of output). These energy efficiency savings were achieved largely through short-term measures whose capital investment requirement was modest, with pay-back periods of few weeks of months. Those improvements have also been made in other industrialized countries. For example, energy consumption per ton of steel produced in Germany and Japan has declined by about 7% and 14% respectively between 1945 and 1979, and energy consumption per ton of cement has declined by about 5% and 10% in Germany and Japan over the same period.

Actions that have proved successful in promoting energy-efficiency in the industrialized countries include:

- Providing financial assistance for investments in energy-efficient technology in small-, medium-, and large-scale industry possibly in the form of loans from development banks at concessional interest rates. Government incentives to manufac-

ture or import energy conservation equipment should also be adopted. These could include tax credits, import policies, and licensing arrangements.

- Promoting changes in regulatory policy to induce the manufacture and installation of energy-efficient equipment, such as household applieances, automobiles, and cogeneration systems.

- Establishing a legislative framework to encourage energy-efficient activities by industrial and commercial enterprises.

- Introducing technical assistance and training programs in energy audits for industry, buildings, the electric power sector, and transportation. Detailed energy audits should be performed in all key energy-intensive industries, where energy costs range between 20 and 50 percent of total production costs.

- Promoting rational pricing policies for industrial users.

2.3 FINANCIAL AND ECONOMIC ANALYSIS OF ENERGY-EFFICIENCY INVESTMENTS

This section reviews briefly the analysis and planning tools used in the financial and economic analysis of energy conservation investments in developing countries. (See reference 1.3 for a detailed discussion.)*

Governments in developing countries have to take into account the impact of policy incentives on investment by specific firms, the effect of investment on industrial energy use, and the impact of changed industrial energy use on economic growth, balance of payments, employment and inflation.

One method of analyzing the economics of energy conservation investment from a national perspective is to use "shadow prices."** Shadow prices try to capture the marginal opportunity costs of factors of production in the context of national objectives. For instance, in most developing countries, the availability of foreign capital goods is a constraint on economic growth and anything that reduces the availability of foreign exchange would therefore reduce economic growth. Since growth is an important objective, the shadow price of oil should be greater than the world market price of oil, and economic analyses conducted by the government would have to use shadow prices to compare alternative investment options. In contrast, industrial decision makers use financial - internal rate of return - criteria to estimate the attractiveness of an investment.

A number of technical, economic and financial factors combine to determine the financial feasibility and economic attractiveness of investment in energy efficient technologies. As one may expect, there is often a substantial difference between what is attractive to private businesses and what is good from the nations perspective.

---

*Available as a supplementary paper at the West African Seminar.
**UNIDO, Guide to Practical Project Appraisal, U.S., New York, 1978.

66

Businesses make investment decisions by comparing the cost of an investment project, the expected returns (yearly cash flow), and the price of capital. The price of capital can be taken as either the rate of interest at which the firm obtains loans or the rate of return that investors expect on the equity for the project. The degree of risk associated with the project would affect the price of capital; high risk ventures have a high price of capital.

Widely used methods in the engineering literature for evaluating the engineering-economics of energy conservation investments (e.g., Gyftopolous, Widmer,[2.1]) are the internal rate of return (IRR) and the gross payback period (GPB). Another widely used method in the economics literature is the net present value (NPV) of a stream of costs and benefits of an investment project. In fact IRR, GPB and NPV are all related to each other. Most private sector investors use Gross Payback period and the Internal Rate of Return as the criteria while national economic planners, who have a longer term perspective, tend to use the net present value approach.

When the investment is analyzed from the point-of-view of the government, social benefits and costs should be taken into account. In this case the benefits are measured in terms of fuel saved at shadow prices, where a premium is added to the price of the fuel. The costs to the government from instituting policy incentives are estimated by computing the difference in cost of the energy conservation investment with and without the appropriate incentives.

Other factors that a government planner would take into account would be indirect benefits and costs. These would include the impact of energy conservation investments on aggregate consumption, employment, balance of payments, economic growth and the impact on the poorest section of the population. Methods for doing this are discussed in detail elsewhere.[2-4]

The priority attached by the government to any incentive scheme should depend on the results of a social cost-benefit analysis. The government should take into account the criteria used by private firms for specific investment decisions and design incentive schemes that would lead to private sector investment in industrial energy conservation while providing net positive social benefit.

When assessing the costs and benefits of energy conservation from a national perspective, it is essential to have some data on the costs of saving and supplying equivalent amounts and forms of energy. The data presented here are for the industrial sector only, and are derived from studies carried out in the U.S. and Canada. Similar data should be obtained for the developing countries, and should be assembled for the other energy-consuming sectors of the economy -- transportation, electric utilities, and residential and commercial buildings.

In general, capital costs for energy savings (up to a certain point) are substantially lower than those for equivalent new energy supplies. Several studies have shown[1,5,6] that cost effective efficiency improvements represent an energy saving of about 25 percent for all manufacturing in the U.S.

and Canada. In one study, a total of 39 energy-saving conservation projects in five industries were selected and evaluated as the basis for determining the economics of industrial energy conservation. The projects were classified according to four categories of conservation measures. The categories and industries are as follows:

Categories

A Insulation and general housekeeping
B Waste heat recovery
C Instrumentation and controls
D Process change

Industries

1. Food and Beverage, predominantly Meat and Poultry Products
2. Pulp and Paper Mills
3. Iron and Steel Mills
4. Industrial Minerals, predominantly Cement Manufacturers
5. Chemicals, predominantly Industrial Chemicals

Full implementation of these projects was found to yield a saving of 16 percent of the energy demand in the five industries.

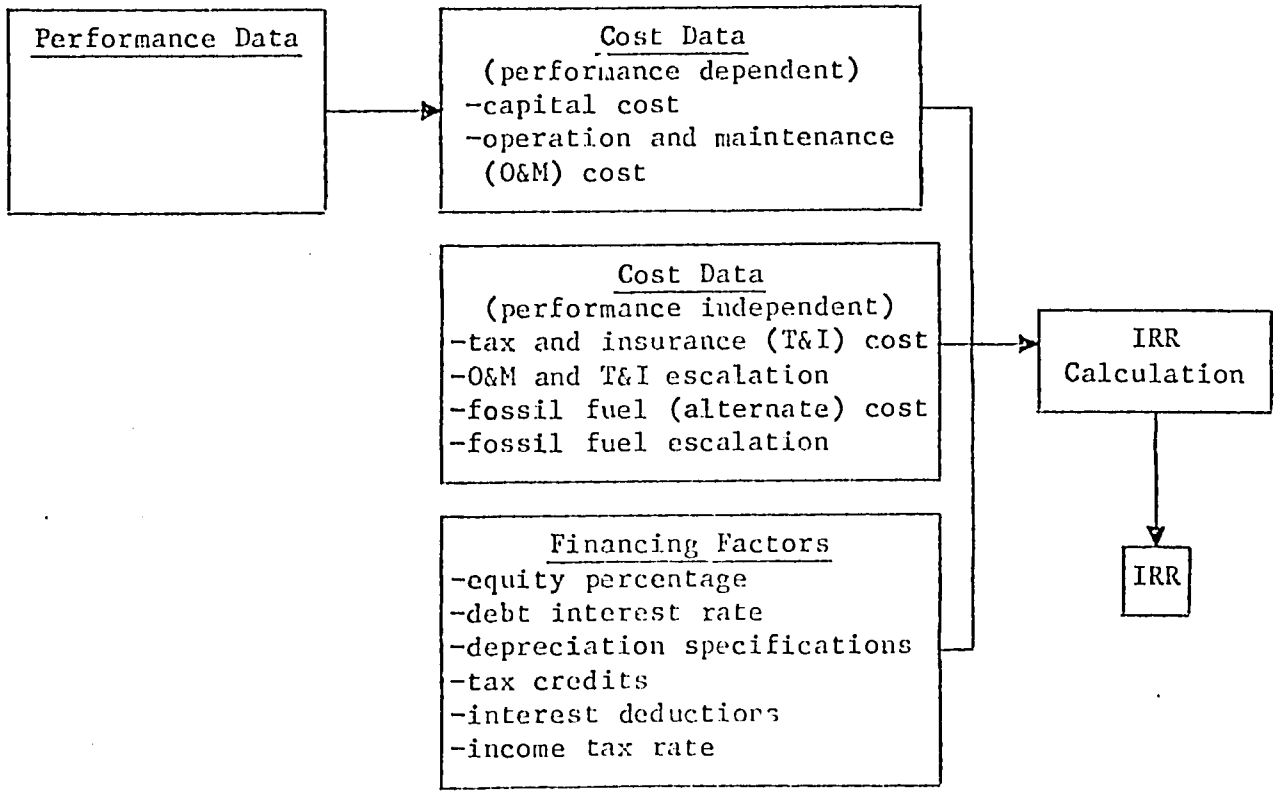


Figure 2.1. Determination of Internal Rate of Return for an Energy Efficiency investment.

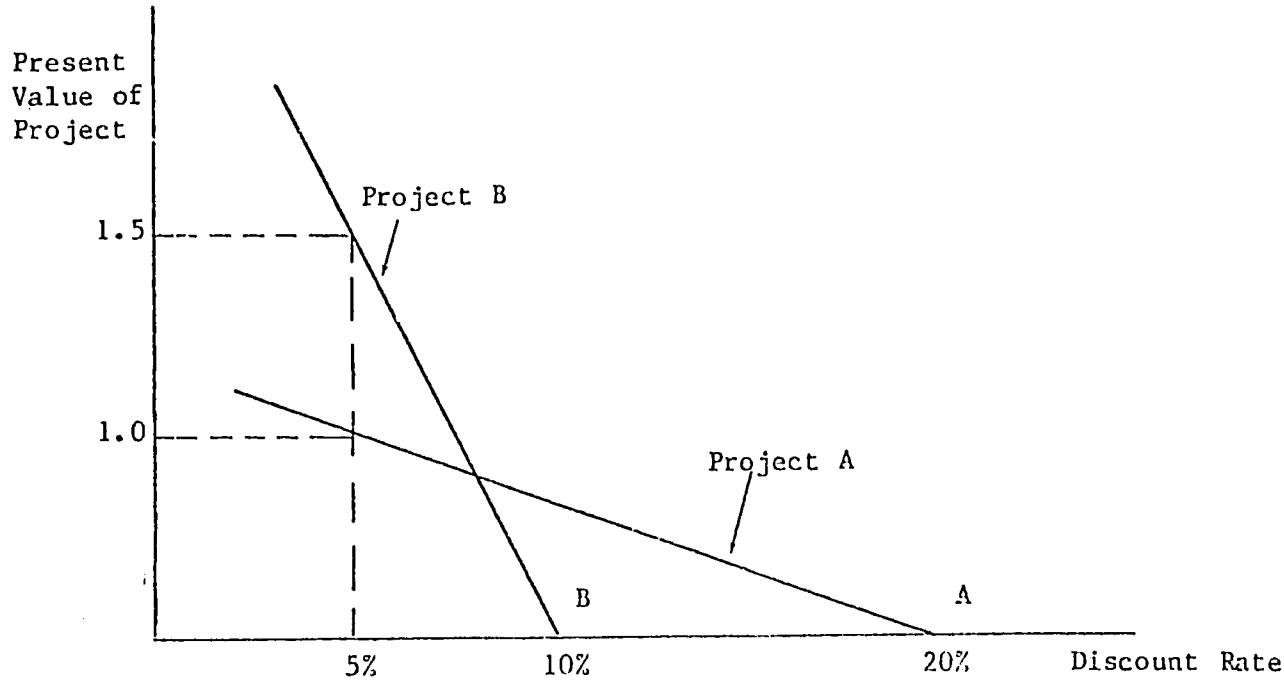


Figure 2.2. Conflict between Present Value and Internal Rate of Return in ranking projects.

Costs of individual projects ranged from two cents to $3.57 per million Btu saved. The average price of energy saved for all 39 projects, weighted by the annual energy savings for each project, was $1.58 per million Btu, equivalent to $9.16 per barrel of oil equivalent. It should also be noted that the Canadian Industry Energy Conservation Task Force considered that up to 23 percent reductions in energy intensity were possible over a 5-year time period. This is consistent with studies performed in the United States.[5]

The marginal and average cost curves for the 39 selected industrial energy conservation projects are shown in Figure 2.3.

In examining Figure 2.3, the following points should be borne in mind.

- the costs of energy supply projects are representative of the expected Canadian experience over the time frame 1980-2010. It is clear that, for many developing countries, some oil and gas fields can provide incremental energy at supply prices competitive with energy-saving measures. However, some options such as oil shale or coal liquefaction would generate energy at a higher cost than the projects described here.

- The Canadian study compared "Btu's supplied" and did not take into account the end-use efficiencies with which the different energy forms were utilized. The study also did not attempt to differentiate between the energy types -- electricity, natural gas, heavy fuel oil, etc. saved by each conservation project.

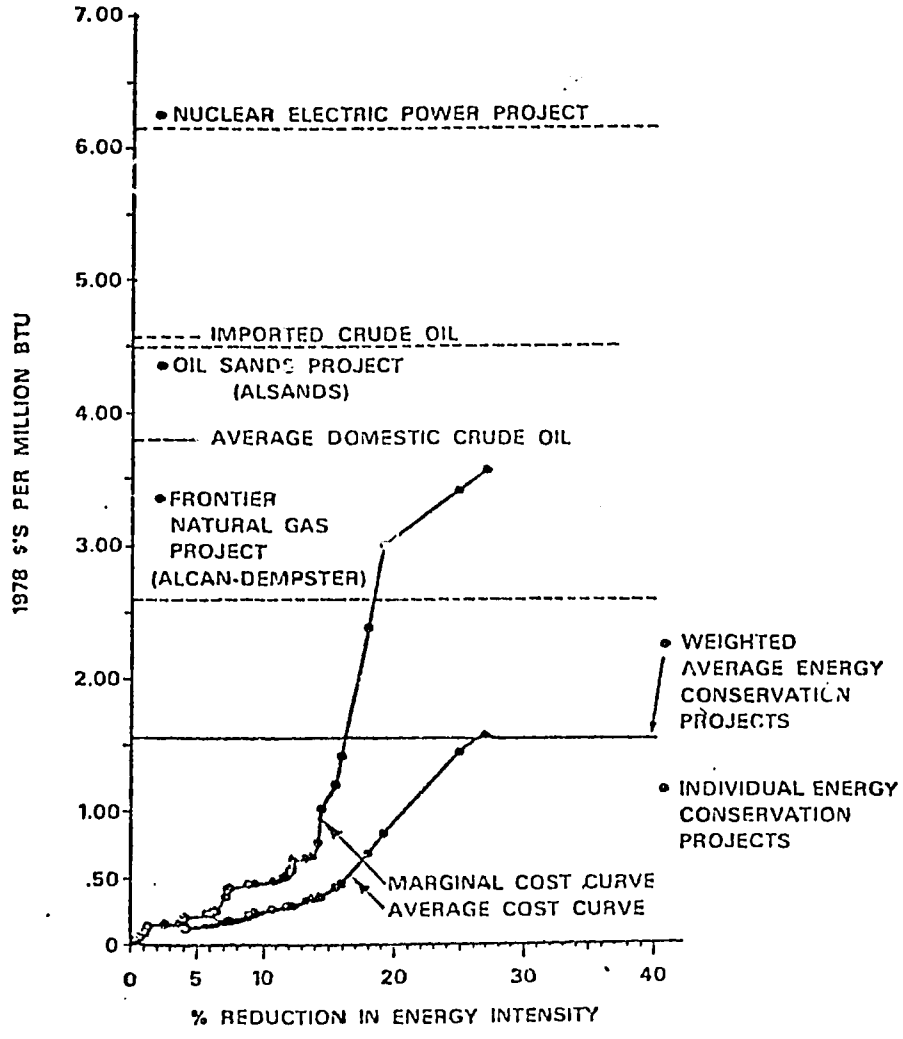


Figure 2.3

- The quantification of comparative benefits of energy conservation and energy supply projects is obviously very complex and was not attempted in the Canadian study.

Industrial energy conservation projects show a wide range of costs and energy savings, depending on the type of project, the relevant industry, and local energy prices, but one can reasonably expect an average, cost-effective energy savings potential of 25 percent or more in the industrial sector of developing countries. Detailed engineering and economic studies will, of course, be necessary to quantify the costs and benefits of industrial energy conservation projects compared with developing new sources of supply. Such comparisons will have to include questions such as the timing of new investments, relative implementation rates, employment, training, and foreign exchange aspects, and environmental and health effects.

10

REFERENCES

1. E. P. Cyftopolous and T. F. Widmer, "Benefit-Cost of Energy Conservation," in Thermodynamics: Second Law Analysis, American Chemical Society, 1980.

2. United Nations Industrial Development Organization, Guidelines for Project Evaluation, United Nations, New York, 1972.

3. United Nations Industrial Development Organization, Guide to Practical Project Appraisal, United Nations, New York, 1978.

4. I.M.D. Little and J. A. Mirrlees, Project Appraisal and Planning for Developing Countries, Heinemann Educational Books, London, 1974.

5. G. N. Hatsopoulos, E. P. Cyftopolous, R. W. Sant, and T. F. Widmer, "Capital Investment to Save Energy," Harvard Business Review, Vol. 56, No. 2, March-April 1978.

6. Report by Acres Consulting Services Limited, "A Study of the Potential for Energy Conservation in Canadian Industry," Conservation and Renewable energy Branch, Energy, Mines and Resources Canada, December 1979.

3 TECHNOLOGIES FOR WASTE ENERGY UTILIZATION IN THE INDUSTRIAL SECTOR

There currently exists a fairly broad sepctrum of cost-effective and proven energy-saving technologies that have found application in all energy-using sectors of the economy. In this section, we list only those technologies that are relevant to the industrial sector. Excellent recent reviews of such technologies may be found in references 1 and 2.

The function of energy-saving technologies is to address the major sources of energy inefficiency in manufacturing which are

- Combustion of high-grade fuel to produce low temperature process heat.
- Loss of high-grade waste heat to the environment.
- Use of particular manufacturing processes.

The first two sources of energy inefficiency are common to many industries and processes, and can be reduced with technologies that are widely applicable. These inefficiencies are found in dryers, ovens, furnaces, and fuel-fired kilns, and can be reduced through recovery and recycling of waste heat. Good housekeeping measures such as insulation of pipes address mainly the second source of energy inefficiency.

The conventional method of raising process steam in fuel-fired boilers is very inefficient because the product is low temperature steam (300 to 350°F, 50 to 150 psi) while the combustion of the fuel generates high-temperature heat. To realize significant savings, one must make better use of the high temperature heat created by fuel combustion, and cogeneration, or the sequential generation of steam and electricity can accomplish this.

Processes for the manufacture of metals, ceramics, glass, and cement require high temperature heat, typically in excess of 2000°F. Losses are due to poor insulation, high-quality energy escaping in the form of exhaust gases, or materials leaving the furnace. Technologies to reduce these losses include better insulation, recycling of exhaust gases to reheat air, heat recovery from material leaving the furnace to preheat material entering, employing exhaust heat for steam raising or process heat or cogenerating electricity from exhaust heat.

In order of increasing capital investment, technical measures may be classified as follows.

- **Good Housekeeping Measures:** The improvement of the operating efficiency of existing processes or equipment. These measures require little or no capital investment.

- **Equipment Replacement:** Relatively simple modifications to plant or equipment requiring minor capital investment, such as improving insulation of pipes and tanks and installing additional instrumentation for better process control.

72

- **Major Retrofits and New Technology:** Substantial replacement or modification of plant requiring major capital investment. These measures include energy-efficient technologies and systems such as waste-heat recuperators, heat pumps, and cogeneration, as well as major process modifications.

Technologies and measures for improving industrial and commercial energy efficiency fall into the following categories:

- Waste heat recovery
- Improved thermal processing
- Cogeneration
- AC induction electric motors/controllers
- Fuel substitution
- Improved energy management in industrial and commercial buildings
- Energy saving advanced manufacturing processes and materials substitution.

Major features of systems in the first four categories are summarized in Tables 3.1, 3.2, 3.3, and 3.4.

Table 3.1
Waste Heat Recovery

Technology	Applications	Status
Advanced-design low-temp. heat exchangers	Heat recovery from previously non-exploitable sources	Commercial, payback of less than two years
Waste heat recovery heat pumps	Service hot water or hot process fluids from low temperature reject-heat sources such as refrigeration, air conditioning, equipment cooling, process liquids, treated sewage	Commercial, payback is 6 months to two years
Mid-temperature metallic heat recuperators and heat pipes	Recover boiler flue-gas energy up to 1000°F for heating boiler feed water, combustion air, or other loads	Commercial, payback is typically less than three years
Ceramic matrix or ceramic tube heat recuperators	High temperature heat recovery from melting furnaces, calciners, smelters, reduction and heat treat furnaces	Nearly commercial. Demonstration projects at variour locations in the U.S.

Table 3.2
Improved Thermal Processing

Technology	Applications	Status
Computer-based combustion control systems for boiler or furnace control & process controllers	Suitable for use with large industrial boilers, furnaces or cogenerators to maximize efficiency and minimize pollution	Commercial, economics variable with installation. Inexpensive process controllers reduce waste energy in practically every industrial process
High performance furnace/boiler insulation	Reduce heat loss, equipment downtime	Commercial. Short paybacks
Improved atmosphere generators, induction heating eqpt. burners, furnaces	Reduce energy consumption in conventional high temperature processing equipment	Commercial. Fuel savings vary with type of equipment

Table 3.3
AC Induction Electric Motors/Controllers

Technology	Applications	Status
Conventional motor design with larger cores & windings, & improved electrical insulation	Reduces internal resistance of of motor. Replacement for any heavy-duty application	Commercial, gives longer service life and lower optional costs than other conventional motors
Power factor controller, for motor load matching, speed control	Suitable for intermittent or low capacity factor electric motor applications	Commercial, savings of 25%-50% on motor energy costs
Advanced 3-phase motor coil configuration	For intermittent or low-capacity factor motor applications	Commercially available as new motor or rewind service for existing AC motor. 66%-75% savings, 4 month to 3 year payback
Solid state triac replacement of mechanical start-winding switch	For improvement of single-phase induction motors	Commercial. Enhanced reliability, reduced electrical noise

Table 3.4
Cogeneration

Technology	Applications	Status
Steam turbine, gas turbine, or diesel engine topping cycles. Waste heat recovery from electric generator prime mover.*	Suitable for industrial or large commercial applications with combined heat and electrical load. Choice of system depends on ratio of electricity to heat load	Commerically available, economics variable; depends on fuel cost, financing, grid or stand-alone. Many successful installations exist
Organic or steam Rankine bottoming turbine generators*	Waste heat streams are used to drive electric generators	Commercialization is just beginning

*Combined cycle systems, namely those which use a combination of topping and bottoming cycle strategies, have also been demonstrated commercially successful.

75

REFERENCES

1. Elias P. Gyftopolous and Thomas F. Widmer, "Cost-Effective Waste Energy Utilization," Annual Review of Energy, 1982. Vol. 7, pp. 293-327, Palo Alto, CA 94306.

2. M. H. Chiogioji, Industrial Energy Conservation, New York: Marcel Dekker, p. 603, 1979.

76

4 OBSERVATIONS FROM A CASE STUDY OF BRAZIL

4.1 THE ENERGY SITUATION IN BRAZIL

Like other oil-importing developing nations, Brazil has been seriously affected by the rise in oil prices of the 1970s. It now depends on industrialized countries for capital and technology to support its program of economic development and on OPEC for petroleum to fuel its modern industrial sector.

Faced with these problems, Brazil has embarked on an ambitious plan to diversify its energy sector, reduce its dependence on imported petroleum fuels, and increase exports. Brazil's energy strategy contains the following elements:

- increased production of ethanol from biomass sources, mainly sugarcane and some cassava;
- increased domestic production of oil, gas, and coal;
- continued expansion of large-scale hydroelectric systems and nuclear systems;
- increased efficiency of energy consumption, particularly oil use in industry and transportation;
- increased use of renewable energy sources such as solar thermal and electric systems, wind power, biogas, and small-scale hydroelectric power.

These measures are being adopted by many other developing nations. The World Bank has estimated that the capital investment required for these programs in oil-importing developing countries over the next ten years, will total over 600 billion dollars. The average annual rate of $60 billion is higher by a factor of five than the corresponding rate of investment during the period 1966 to 1975.

As the largest oil importer in the developing world, and as the world's tenth nation in economic output, Brazil is likely to have unique needs for petroleum-substitution technology in its industrial and transportation sector. It is now apparent that Brazil's successful economic growth program of the postwar period contained a major flaw. The basic energy to run Brazil's vigorous and expanding industrial sector was oil, much of which was imported. Cheap imported petroleum and abundant domestic hydropower were taken for granted by Brazilian energy planners. In 1979, Brazil imported nearly 85% of its petroleum,* and these imports accounted for 42% of the total energy consumption of the country. In 1980, Brazil's bill for imported petroleum was $10 billion, about half the total value of its imports or exports. Figure 4.1 shows the evolution of Brazil's oil import bill.

Brazilian energy planners are currently seeking ways to use energy more efficiently, particularly in the industrial sector, while maintaining economic growth rates that have traditionally been much higher then those of the advanced industrialized nations. An important way out of this dilemma is offered by the potential use of methods and technologies that improve energy

Table 4.1
Petroleum Consumption in Brazil, 1979

Petroleum consumption	=	41% of total energy
Total petroleum consumption	=	1,079,000 barrels/day
Imported petroleum	=	914,000 barrels/day
Fuel oil	=	33% of total petroleum
Diesel oil	=	28% of total petroleum
Gasoline	=	20% of total petroleum
Other	=	19% of total petroleum

efficiency and utilize indigenous renewable resources. The federal government in Brazil has strongly encouraged such measures. For example, the Brazilian Energy Model, which is the central planning document issued by the Ministry of Mines and Energy in Brasilia, calls for a saving of 85,000 bbl/day of fuel oil in the industrial sector by 1985.

Brazil's industrial expansion has occurred mainly in the most energy-intensive sectors. In 1979, the cement and steel industries consumed 15 and 17% respectively of the total fuel oil used in Brazil, far surpassing their nearest competitors: petroleum refining (11%), petrochemicals (9%), and ceramics (9%). Tables 4.1 and 4.2 show the consumption of petroleum products in 1979 and the percentage of fuel oil used by different sectors of Brazilian industry.

Brazil is expected to rank among the top ten steel producers in the world in the 1980s. By the end of the 1970s it has already become the

Table 4.2
Fuel Oil Utilized by Brazilian Industry

Sector	Percentage of total fuel oil used
Steel	17
Cement	15
Petroleum refining	11
Ceramics	9
Petrochemicals	9
Food and beverages	8
Pulp and paper	6
Electric power	6
Textiles	4

*The latest (1981) figures show that the share of domestic oil production in Brazil's total oil consumption has risen to 23%, from 14% two years ago. The total amount of oil produced is now 230,110 bbl/day, compared with 203,100 in 1980 and 168,692 in 1979.

4 OBSERVATIONS FROM A CASE STUDY OF BRAZIL

4.1 THE ENERGY SITUATION IN BRAZIL

Like other oil-importing developing nations, Brazil has been seriously affected by the rise in oil prices of the 1970s. It now depends on industrialized countries for capital and technology to support its program of economic development and on OPEC for petroleum to fuel its modern industrial sector.

Faced with these problems, Brazil has embarked on an ambitious plan to diversify its energy sector, reduce its dependence on imported petroleum fuels, and increase exports. Brazil's energy strategy contains the following elements:

- increased production of ethanol from biomass sources, mainly sugarcane and some cassava;
- increased domestic production of oil, gas, and coal;
- continued expansion of large-scale hydroelectric systems and nuclear systems;
- increased efficiency of energy consumption, particularly oil use in industry and transportation;
- increased use of renewable energy sources such as solar thermal and electric systems, wind power, biogas, and small-scale hydroelectric power.

These measures are being adopted by many other developing nations. The World Bank has estimated that the capital investment required for these programs in oil-importing developing countries over the next ten years, will total over 600 billion dollars. The average annual rate of $60 billion is higher by a factor of five than the corresponding rate of investment during the period 1966 to 1975.

As the largest oil importer in the developing world, and as the world's tenth nation in economic output, Brazil is likely to have unique needs for petroleum-substitution technology in its industrial and transportation sector. It is now apparent that Brazil's successful economic growth program of the postwar period contained a major flaw. The basic energy to run Brazil's vigorous and expanding industrial sector was oil, much of which was imported. Cheap imported petroleum and abundant domestic hydropower were taken for granted by Brazilian energy planners. In 1979, Brazil imported nearly 85% of its petroleum,* and these imports accounted for 42% of the total energy consumption of the country. In 1980, Brazil's bill for imported petroleum was $10 billion, about half the total value of its imports or exports. Figure 4.1 shows the evolution of Brazil's oil import bill.

Brazilian energy planners are currently seeking ways to use energy more efficiently, particularly in the industrial sector, while maintaining economic growth rates that have traditionally been much higher then those of the advanced industrialized nations. An important way out of this dilemma is offered by the potential use of methods and technologies that improve energy

Table 4.1
Petroleum Consumption in Brazil, 1979

Petroleum consumption	=	41% of total energy
Total petroleum consumption	=	1,079,000 barrels/day
Imported petroleum	=	914,000 barrels/day
Fuel oil	=	33% of total petroleum
Diesel oil	=	28% of total petroleum
Gasoline	=	20% of total petroleum
Other	=	19% of total petroleum

efficiency and utilize indigenous renewable resources. The federal government in Brazil has strongly encouraged such measures. For example, the Brazilian Energy Model, which is the central planning document issued by the Ministry of Mines and Energy in Brasilia, calls for a saving of 85,000 bbl/day of fuel oil in the industrial sector by 1985.

Brazil's industrial expansion has occurred mainly in the most energy-intensive sectors. In 1979, the cement and steel industries consumed 15 and 17% respectively of the total fuel oil used in Brazil, far surpassing their nearest competitors: petroleum refining (11%), petrochemicals (9%), and ceramics (9%). Tables 4.1 and 4.2 show the consumption of petroleum products in 1979 and the percentage of fuel oil used by different sectors of Brazilian industry.

Brazil is expected to rank among the top ten steel producers in the world in the 1980s. By the end of the 1970s it has already become the

Table 4.2
Fuel Oil Utilized by Brazilian Industry

Sector	Percentage of total fuel oil used
Steel	17
Cement	15
Petroleum refining	11
Ceramics	9
Petrochemicals	9
Food and beverages	8
Pulp and paper	6
Electric power	6
Textiles	4

*The latest (1981) figures show that the share of domestic oil production in Brazil's total oil consumption has risen to 23%, from 14% two years ago. The total amount of oil produced is now 230,110 bbl/day, compared with 203,100 in 1980 and 168,692 in 1979.

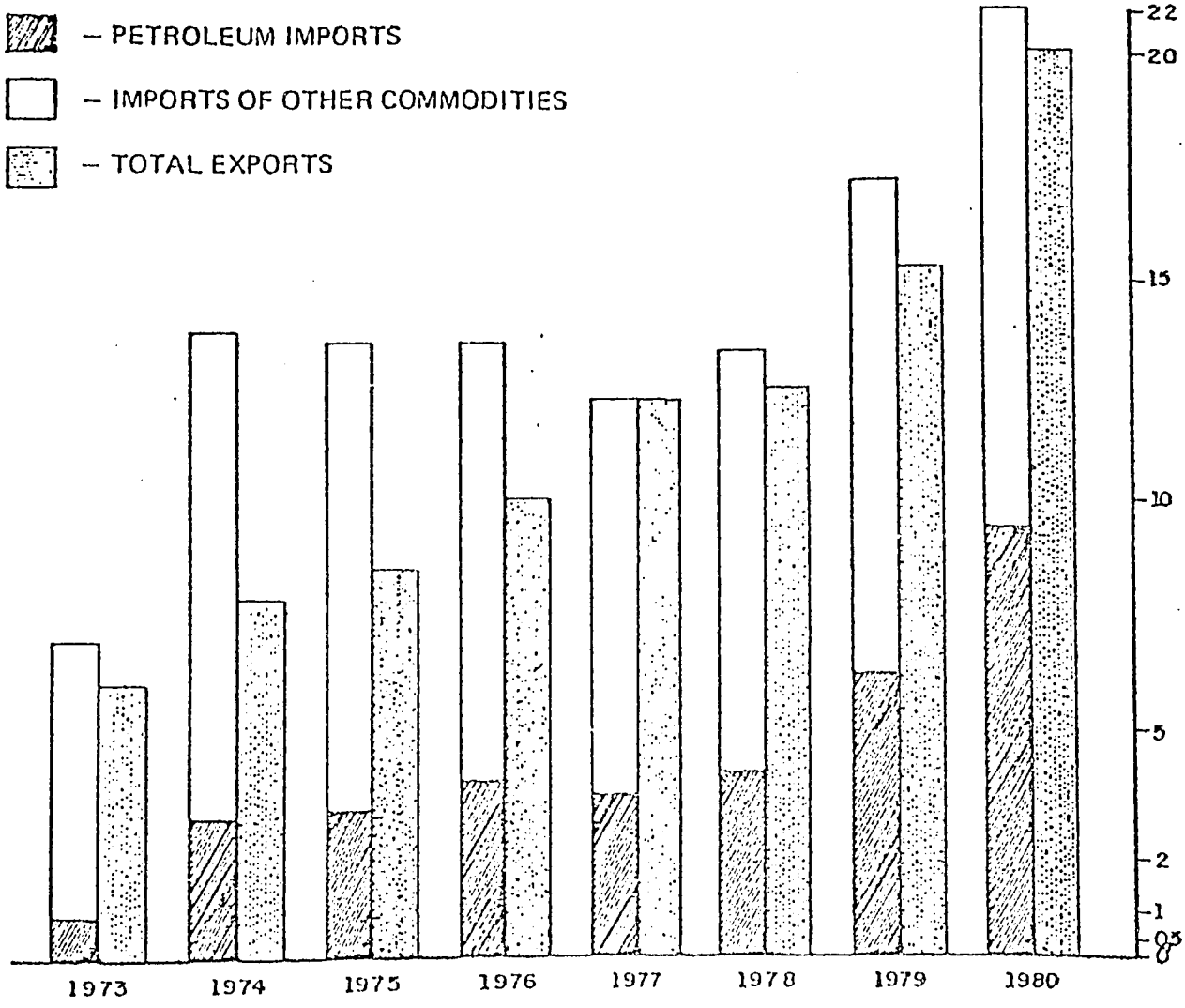


Figure 4.1 Brazil imports and exports, current prices (10^6 U.S. $).

world's tenth largest producer of petrochemicals, with major expansion plans on the drawing boards. By 1980, Brazil's oil-refining capacity was sufficient to produce its total domestic requirements for petroleum derivatives. Brazil is also rapidly expanding its production of nonferrous metals, including the smelting and refining of aluminum.

Table 4.3 provides forecasts of primary energy consumption by type in Brazil. An important feature of these data is that, while total primary consumption is projected to increase by 42% over the period 1980 to 1985, petroleum consumption is expected to drop by 15% in absolute terms. This is a substantial reversal of the trend during the 1970s, when petroleum consumption more than doubled to maintain a fairly constant 40% of the primary energy market. Energy sources expected to displace petroleum include

Table 4.3
Primary Energy Consumption and Goals, Brazil (From [1,2])

Primary energy source	1979 boe/d*	1979 Percent	1985 boe/d*	1985 Percent
1. Non renewable	1,100,000	45.4	1,217,000	34.7
Fossil				
Imported petroleum	836,000	34.5	420,000	12.0
Domestic petroleum**	149,000	6.2	420,000	12.0
Natural gas	10,000	0.4	25,000	0.7
Coal	105,000	4.3	304,000	8.7
Oil shale	--	--	25,000	0.7
Nuclear	--	--	23,000	0.6
2. Renewable	1,320,000	54.6	2,293,000	65.3
Biomass				
Alcohol	39,000	1.6	145,000	4.1
Bagasse	113,000	4.7	198,000	5.7
Firewood	421,000	17.4	394,000	11.2
Charcoal	61,000	2.6	187,000	5.3
Hydro Electric	686,000	28.3	1,354,000	38.6
New sources (solar, wind, etc.)	--	--	15,000	0.4
3. Primary energy consumption	2,420,000	100.0	3,510,000	100.0
4. Energy conservation	--		200,000	
5. Total (3 + 4)	2,420,000		3,710,000	

*boe/d - Barrel of oil equivalent per day.
**The figures for petroleum and alcohol do not include the amounts to be used as industrial feedstocks.

alcohol, bagasse, and charcoal. By 1985, alcohol is expected to supply about 4.1% of Brazil's primary energy, and bagasse and charcoal are each expected to provide about 5%; coal production is projected to nearly triple; and direct solar, biogas, wind, refuse, methanol from wood, and minihydro are projected to grow substantially.

By far the most significant primary energy source in Brazil's future is hydroelectricity. Expansion of electric generating capacity figures heavily in Brazil's plans for future reduction in dependence on imported oil. Use of hydropower is expected to double over the next five years, providing almost 40% of Brazil's energy by 1985. Hydropower will continue to be the dominant source of Brazil's electric energy, growing from about 85% of installed capacity in 1979 to about 90% in 1985.

Between 1969 and 1979, the portion of national primary energy consumption supplied by imports rose from about 26% to almost 40%. By 1985, however, Brazilian energy planners expect petroleum imports to drop to 50% of present levels. Imports are projected to provide only about 12% of primary national consumption in that year.

While gasoline and fuel oil needs are expected to decline significantly by 1985, diesel oil consumption is projected to grow by about 20%. Finally, it is significant that the planned contribution from conservation in 1985 exceeds that of the alcohol program, and is about 20% of projected total petroleum consumption in that year.

Electricity consumption by sector is shown in Table 4.4. (SP = Sao Paulo, PR = Parana, SC = Santa Catarina, RGS = Rio Grande do Sul.) Electricity generated from on-site power sources, mostly within large industries, amounts to < 5% of total generation in Brazil.

The transportation sector is the largest user of petroleum, consuming virtually all the gasoline and 80% of the diesel fuel. The next largest user is the industrial sector, which consumes over 90% of the fuel oil. Table 4.5 presents the percentage breakdown by end-use sector.

4.2 ECONOMICALLY ATTRACTIVE TECHNOLOGIES IN BRAZIL: SOME SELECTED EXAMPLES

4.2.1 Heat Pumps: Commercial and Industrial Applications

Air chilling--water heating heat pumps and industrialized waste heat heat pumps appear to be appropriate technologies for use in Brazil. Both utilize available, domestically produced hydroelectric energy to directly displace imported oil. In the case of air chilling--water heating heat pumps, simultaneous production of air conditioning and hot water is ideally suited to the local climatic conditions. In the case of industrial waste heat heat pumps, the technology is well matched to Brazil's very important textile, pulp and paper, and food processing industries. The economic performance of both types of heat pumps appears to be superior to that of resistance heating, fossil fuels, and solar, based on current electricity prices in the U.S., and this is likely to hold true also for Brazil.

The physical and engineering principles underlying vapor compression heat pump technology have been understood for decades (Heap,[10] p. 3) and are the subject of a large body of technical literature. For this reason, as well as reasons given below, further discussion of heat pumps will be limited to two basic applications:

- Residential or commercial sized heat pumps that simultaneously provide water heating and space cooling;
- Industrial sized heat pumps that utilize low temperature waste heat as the heat source.

Air-to-air heat pumps used for space heating will not be discussed because, in Brazil, space heating is not a significant application, and the applications of primary interest are industrial and commercial. Solar-assisted heat pumps are also not considered for residential and commercial applications, but this appears to be a fruitful area for further investigation.

83

Table 4.4
Electricity Consumption by Sector, 1979 (GWh)[3,8]

	Industrial	Residential	Commercial	Rural	Other*	Total
SP	25,928	8,341	4,381	581	4,114	43,345
	60%	19%	10%	1%	10%	100%
PR	2,475	945	700	139	578	4,837
	58%	20%	14%	3%	12%	100%
SC	1,904	496	343	178	216	3,137
	61%	16%	11%	5%	7%	100%
RGS	2,471	1,238	792	234	537	5,272
	47%	24%	15%	4%	10%	100%
Southern states	32,778	11,020	6,216	1,132	5,445	56,591
	58%	19%	11%	2%	10%	100%
Brazil	63,776	21,131	12,603	1,520	10,824	109,854
	58%	19%	12%	1%	10%	100%

*Includes public lighting, government, water, and sewage.

Table 4.5
Petroleum Products Consumption by Sector, 1979[9]

State	Product	Industry	Transport.	Commercial	Household	Rural	Others
SP	LPG	9.8%	--	4.1%	85.9%	<0.1%	0.2%
	Gasoline	2.0%	93.8%	2.8%	--	0.2%	1.2%
	Diesel oil	19.5%	68.0%	8.3%	--	2.3%	1.9%
	Fuel oil	91.0%	0.5%	6.8%	--	1.4%	0.3%
PR	LPG	2.6%	--	5.6%	91.5%	--	0.3%
	Gasoline	0.9%	94.5%	2.5%	--	0.3%	1.8%
	Diesel oil	8.3%	76.3%	5.9%	--	2.5%	7.0%
	Fuel oil	91.6%	1.4%	3.4%	--	2.9%	0.7%
SC	LPG	13.7%	--	5.5%	80.4%	--	0.4%
	Gasoline	1.3%	96.2%	1.4%	--	0.2%	0.9%
	Diesel oil	11.5%	81.3%	3.2%	--	0.8%	3.2%
	Fuel oil	91.5%	0.5%	3.1%	--	1.2%	3.7%
RGS	LPG	3.7%	--	6.5%	86.6%	--	3.2%
	Gasoline	0.7%	95.6%	2.1%	--	0.3%	1.3%
	Diesel oil	5.4%	76.7%	3.7%	--	6.9%	7.3%
	Fuel oil	85.7%	0.1%	6.4%	--	1.0%	6.8%
Brazil	LPG	6.8%	<0.1%	3.7%	88.8%	--	0.6%
	Gasoline	1.5%	94.2%	2.5%	--	0.3%	1.5%
	Diesel oil	14.4%	71.3%	7.1%	--	2.9%	4.3%
	Fuel oil	92.3%	0.5%	4.8%	--	1.5%	0.9%

The following sections present some interesting examples of applications for air chilling--water heating pumps and for industrial sized heat pumps using waste heat recovery as the thermal source. The list of uses is by no means comprehensive; it simply serves to illustrate the variety of elegant ways in which heat pumps can be applied to the efficient utilization of Brazil's hydroelectric resources.

4.2.2 Air Chilling—Water Heating Heat Pumps for Commercial and Residential Applications

Figure 4.2 schematically illustrates the basic operating principles of an air chilling--water heating heat pump. The electrically driven compressor forces refrigerant through a condensing heat exchanger that transfers the latent heat to the hot water supply. This condensor may be remotely located as shown, or immersed in the storage tank. The hot water is stored for use on demand. The refrigerant is then expanded through a capillary tube, where it is cooled by its change of state from liquid to gas. The cold refrigerant is used to cool the ventilation system via a fan forcing ventilating air over the heat exchange evaporator. The heat provided to the water system can be used either directly or in a preheat mode, depending on the hot water use and required temperature. The chilled air can be used for cooling and dehumidification, either as a stand-alone system or in conjunction with a conventional air conditioning system.

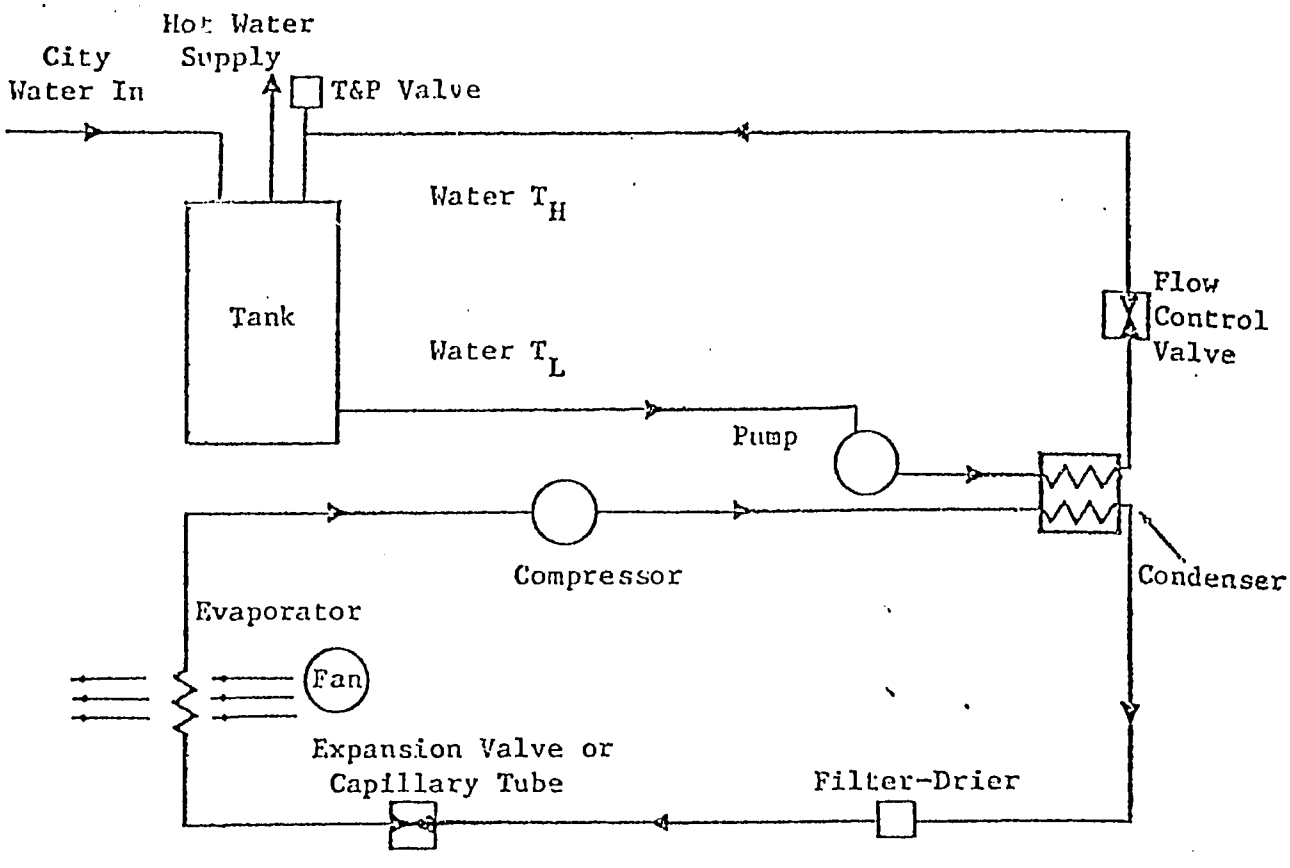


Figure 4.2 An air chilling--water heating heat pump: basic principles (from E-Tech, Inc., Atlanta, GA).

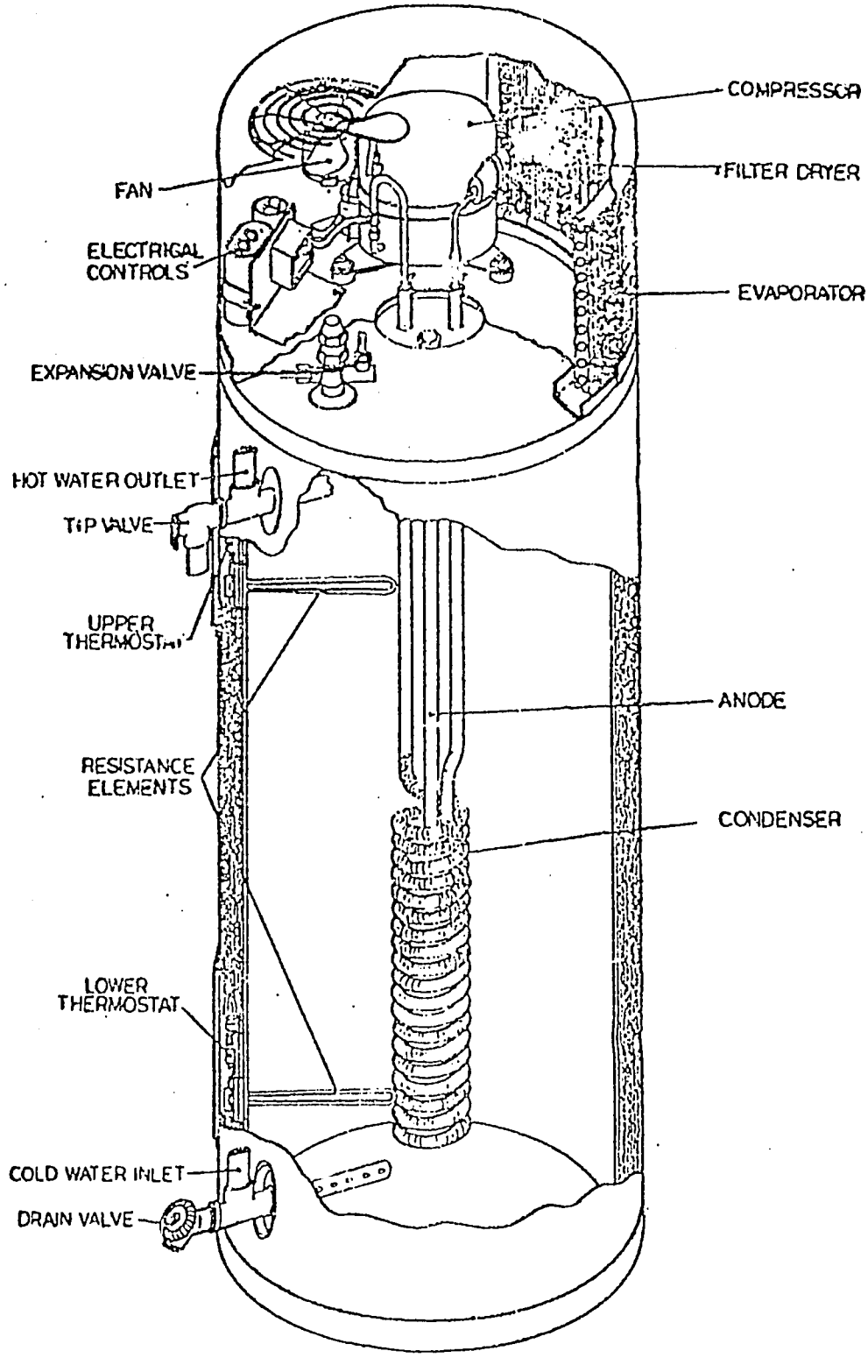


Figure 4.3. The Temcor unit (from TVA[11]).

46

The performance of air chilling--water heating heat pumps is optimal in warm climates, where applications combining air conditioning and water heating are in demand. The climate of Southern Brazil appears suitable for such pumps since the average daily winter temperature in the southern coastal region is no lower than 13° to 16°C, and since building cooling loads become larger further north. Air cooling--water heating heat pumps can be expected to have good economics in commercial buildings such as hospitals, hotels, offices, schools, restaurants, and apartment houses, and to find a market in private homes for use in smaller air conditioning and domestic hot water systems.

Testing and evaluation of air chilling--water heating heat pumps have demonstrated their good performance under the climatic and power cost conditions in the U.S., particularly in the sunbelt region. In a TVA field test program,[11] two systems, the Temcor immersed condensor type and the remote condensor Efficiency II, demonstrated annual power savings of 46 and 57% respectively compared with resistance water heating, with the air conditioning benefits not taken into account. The Temcor unit, manufactured by Energy Utilization Systems in Pittsburgh, now costs $1000 to 1200 installed (Figure 4.3). The Efficiency II, is manufactured by E-Tech in Atlanta (Figure 4.4). The units tested were primarily for residential applications and sized accordingly, but there is no reason why similar or better results could not be obtained with higher capacity designs. Other U.S. manufacturers include Fedders Corp. of Edison, NJ, whose retrofit unit is similar to the E-Tech design, and Mor-Flo Industries of Cleveland, OH.

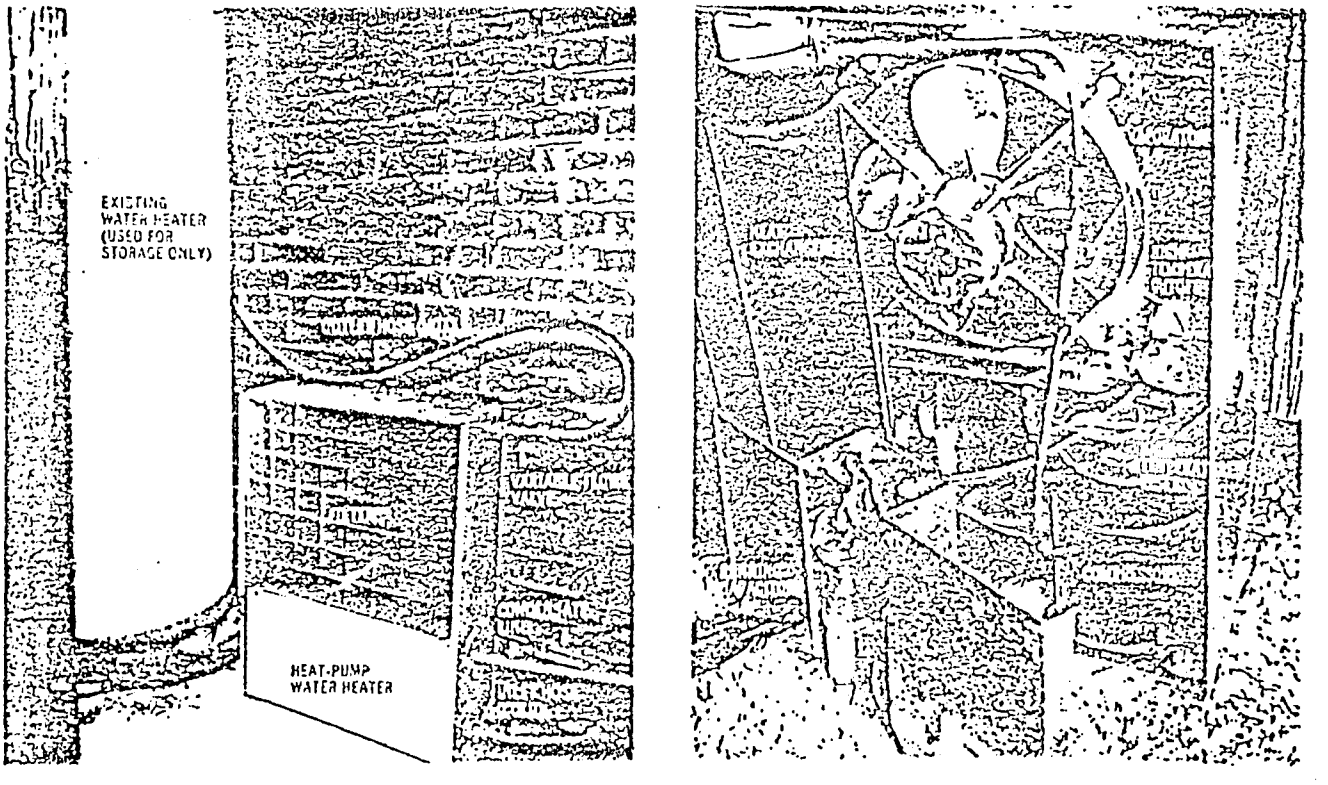


Figure 4.4 The Efficiency II heat pump (from Popular Science, April 1980).

87

The air conditioning benefits of air chilling--water heating heat pumps are easy to estimate. Basically, the heat provided to the water supply is the sum of the heat supplied by the electrically powered compression of the refrigerant plus the heat extracted from the ambient air: the latter is the air conditioning benefit of the unit. For example, if an air chilling--water heating heat pump has a heating coefficient of performance (COP) of 3.0, this means that two units of heat are extracted from the surrounding air for every one unit of electrical energy supplied; thus, three units of water heating and two units of air conditioning are delivered for every unit of electric power supplied. During the heating season, of course, a penalty for the heat withdrawn from room air is paid, by increased use of the building's heat system, but this consideration should not be significant in Brazil's year-round moderate climate.

In summary, a consideration must be given to Brazil's ample supply of electric power, a brief heating season, the proven performance and reliability of air chilling--water heating heat pumps, an established need for simultaneous airconditioning and water heating, and a government policy aimed at reducing fuel oil consumption while expanding the economy and improving the population's standard of living. The combination of these factors suggests that the air chilling--water heating heat pump is a system with much potential in Brazil's energy future.

4.2.3 Industrial Applications of Heat Pumps Which Use Low Temperature Waste Heat as the Heat Source

Although the use of heat pumps with solar collectors as the heat source has been shown to be a viable technique for enhancing the performance of solar systems,[12] this section will be limited to heat pumps which use low temperature industrial reject heat as the source to supply process heat at a higher temperature.

Exploitable waste heat streams exist in nearly every major form of industry, and heat pumps that use industrial waste heat as the source can be used in a variety of ways. One specific example, the McQuay-Perfex "Templifier" (developed originally by Westinghouse) installed at the Wolverine Division of UOP's Decatur, AL, plant, uses the heat contained in 38°C equipment cooling water to provide 71° to 88°C water to the distribution manifold at a COP of 3.45. This installation was inspected by U.S. and Brazilian energy teams in 1981, and additional details of its technical and economic performance are discussed below.

The installation inspected was a 600-hp, 5.4-MBtu/hr (1.58-MW_{th}) Westinghouse Templifier heat pump used to produce 160° to 190°F (71° to 88°C) water from low temperature waste heat. Table 4.6 gives performance specifications of the Templifier and compares its economic characteristics with those of gas-fired boilers, and Figure 4.5 schematically shows the operating strategy used.

Heat pumps have excellent market potential in Brazil for several reasons:

- Direct displacement of oil and gas with hydroelectricity.
- Excellent return on investment.

Table 4.6
Operating and Economic Characteristics of the
Templifier Industrial Heat Pump (from Wolverine Division of UOP, Decatur, AL)

Operating characteristics, Templifier specifications:

Maximum conditions: 5.43 million Btu/hr (1.58 MW) heating 1170 lpm of hot water to 71° - 88°C when supplied with 5680 lpm of source water at 43°C and 460 kW of electric power. Coefficient of performance = 3.45.
Minimum operating conditions: 24°C input water at 5680 lpm; 60° - 77°C output water at 1420 lpm. Coefficient of performance = 3.09.

Economic characteristics compared with those of boilers:

Templifier	Gas-fired boiler
Electricity cost: 2¢/kWh	Gas/propane cost: \$3.25/Mcf (\$0.11/m^3)
Installation cost: \$225,000	Installation cost: 0
Coefficient of performance: 3.45	Efficiency: 65%
System capacity: 5.43 million Btu/hr	System capacity: 5.43 million Btu/hr
Maintenance: \$6000	Maintenance: \$3000

Payback: 1.34 yr

ROI: 79.71%

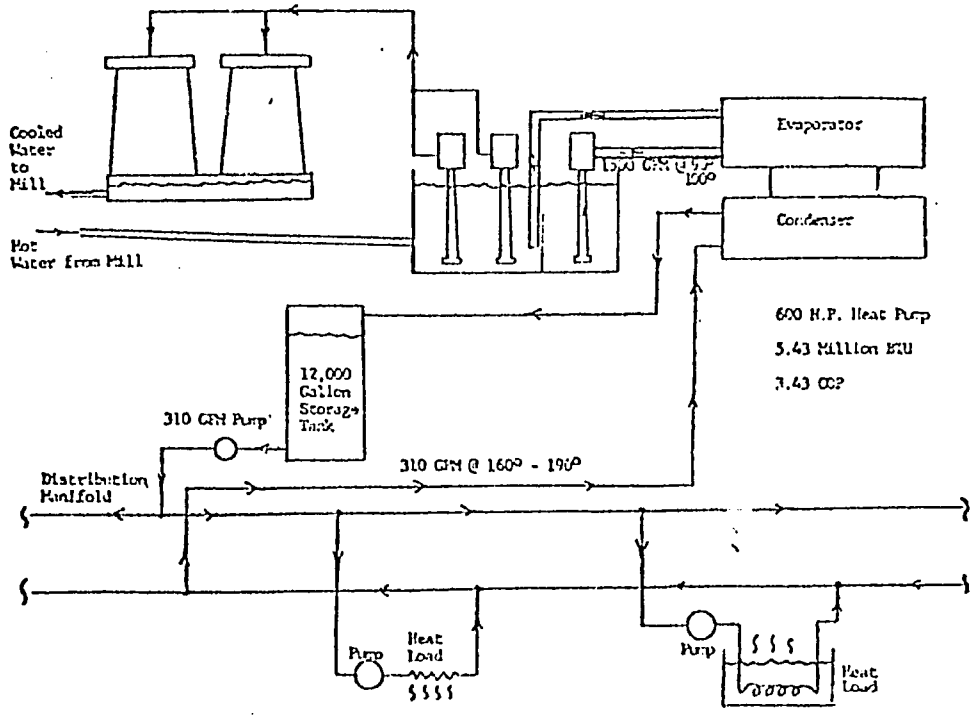


Figure 4.5. Operating strategy of Westinghouse Templifier heat pump (from Wolverine Division of UOP, Decatur, AL).

49

- Textile and food processing industries in Brazil consume over 10% of the fuel oil, and have temperature requirements well matched to the use of industrial heat pumps.
- Existing and potential Brazilian manufacturing capability for this technology. Brazil currently has a well developed air conditioning and refrigeration industry.
- Better utilization of the existing excess electricity generating capacity to meet a highly peaked evening lighting load.

Generally speaking, industrial heat pumps are applicable to industries that require a series of cooling and low temperature heating processes in close proximity. For example, an energy audit and analysis of a Detroit meat packing plant showed that the proposed installation of two 386-kW heat pumps, designed to use 32°C refrigeration reject heat, could provide 75% of the plant's heating requirement for 1.9×10^6 liter/day of 60°C process water. For an estimated capital expenditure of $150,000 to 200,000, a payback of slightly more than one year was calculated.[13]

4.2.4 Heat Pump Application Potential

The calculation of potential markets for new technologies is at best extremely imprecise. This is due in part to the large number of statistical and behavioral assumptions required; therefore, quantitative market potential estimates for air chilling--water heating heat pumps and industrial waste heat heat pumps are limited to maximum market saturation calculations. Factors taken into account include industrial or residential energy consumption profiles, historical petroleum use, technical characteristics of the equipment, and Brazil's well-known emphasis on reducing petroleum consumption. Factors such as capital availability, consumer acceptance, and projected growth rates are not included.

Air Chilling--Water Heating Heat Pumps. Total LPG consumption for the four southern states of Brazil amounted to about 1400×10^3 toe for 1979 and nearly all the LPG was used in the residential sector, mostly to heat water.

In order to calculate how much installed heat pump capacity this would have represented, a capacity factor range of 0.33 to 0.50 is assumed. Thus, assuming that

- all residential/commercial water heating is provided by LPG,
- 80% of all LPG is consumed to heat water in residential/commercial situations, and
- LPG is burned at 70% typical efficiency,

the maximum potential market for air chilling--water heating heat pumps in the four southern states in 1979 was 2310 to 3150 MW thermal output capacity, or 7.88×10^{12} to 11.78×10^{12} Btu/hr.

Industrial Heat Pumps. The approach taken to estimating the potential market for industrial waste heat heat pumps starts with the total Brazilian fuel oil consumption, which in 1979 was 17.6×10^6 toe, of which 85% was industrial, with 5% used to generate electricity (Table 4.7). Since industrial waste heat heat pumps are basically designed to deliver energy at 100°C and less, the market analysis was limited to applications within this

90

Table 4.7
Percent of Total Fuel Oil Consumption in Brazil, by Industry (from [21] p.81)

Industry[a]	Main application	% Total fuel oil consumptio
Cement[b]	High temp. heat	15
Ceramics	High temp. heat	9
Electric power	Thermoelectric gen.	6
Petrol. ref.	Steam	11
	Electric power	
Steel[c]	Steam	17
	Heat	
	Electric power	
Pulp & paper[d]	Steam	6
	Electric power	
Food processing	Steam	8
	Low to mid temp. heat	
Textiles	Steam	4
Petrochemicals	Steam	9
Total		85

[a]To encourage energy saving, the Brazilian Government provides 90% of the investment in energy-efficiency measures as a loan at 5% interest payable in 5 years with 1 year grace period.
[b]By December 1981, 39% of oil used in the cement industry had been replaced by substitute fuels.
[c]By December 1981, a 24% savings in energy use was achieved.
[d]14% energy savings had been achieved by December 1981.

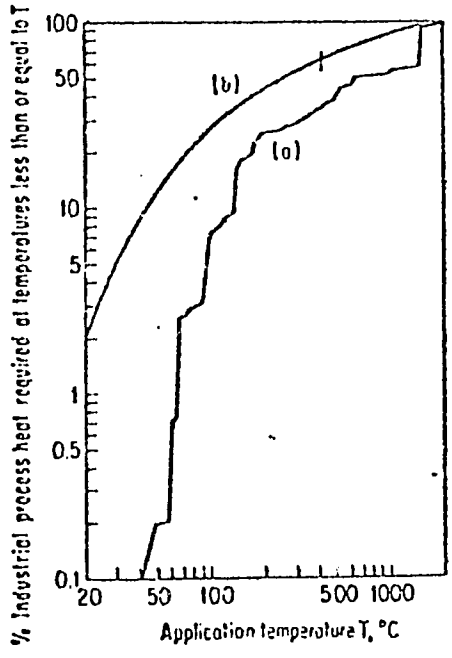


Figure 4.6 Cumulative process heat requirements as a function of process temperature: (a) all heat supplied at required process temperature, (b) heat supplied as preheat from 16°C up to T°C (from ERDA[14,15]).

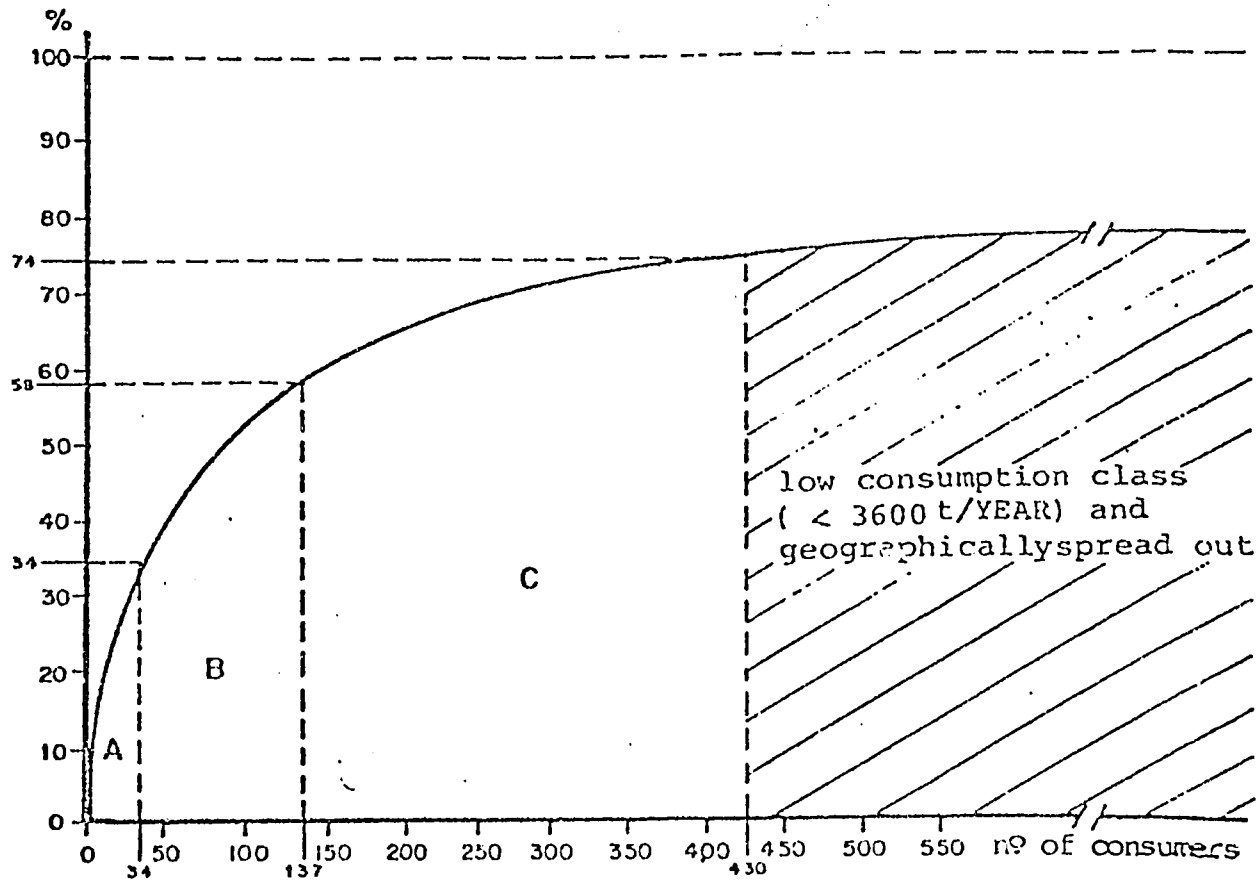


Figure 4.7 Concentration of fuel oil consumption by company (from MME,[2] p. 83). Consumption classes: A, >68,000 t/yr; B, 18,000 to 68,000 t/yr; C, 3,600 to 18,000 t/yr.

temperature regime. Figure 4.6, which characterizes the industrial heat temperature requirement profile for the U.S. industrial mix, shows that 20% of all process heat, including preheat energy for higher temperature processes, falls within this limit.

Another constraint on the maximum size of the potential market is the distribution of total Brazilian fuel oil consumption as a function of the size of the consuming unit because industrial waste heat heat pumps are less likely to be installed in small industrial facilities than in large ones. Figure 4.7 shows that 58% of fuel oil is used at facilities with consumption rates of 18,000 toe/yr or more and the balance at those with lower rates. If it is assumed that only those with rates >18,000 toe/yr could install industrial waste heat heat pumps, the calculation for the maximum potential fuel oil displacement that could have been achieved by industrial waste heat heat pumps for all of Brazil in 1979 is as follows:

17.6×10^6 toe/yr total fuel oil consumption
x 0.80 industrial thermal use
x 0.20 heat and preheat fraction <100°C, U.S.
x 0.58 suitable-size fraction of companies
= 1.63×10^6 toe/yr.

To calculate the approximate installed maximum thermal output capacity this represents, an annual utilization of 4000 hr is assumed. Thus, for 1979, industrial waste heat heat pumps could have accounted for

92

$$1.63\times10^{6}\ \frac{\text{toe}}{\text{yr}} \times 0.7\ (\text{eff.}) \times 0.0205\ \frac{\text{boe/d}}{\text{toe/yr}} \times 5.9\times10^{6}\ \frac{\text{Btu}}{\text{boe}} \times \frac{1\ \text{day}}{24\ \text{hr}} \times 2.9\times10^{-4}\ \frac{\text{kW}}{\text{Btu/hr}}$$

$$\times \frac{8760}{4000}\ (\text{utilization} = 3.65\ \text{GW} = 3650\ \text{1-MW units.}$$

4.2.5 Summary

Two specific types of heat pumps appear to offer outstanding prospects for use under Brazilian conditions. Factors favoring heat pump utilization include a national policy of reducing fuel oil consumption, ample hydroelectric generating capacity, a moderate climate, an industrial energy use profile in which about half of all thermal energy is low to mid temperature, a residential/commercial energy use pattern dominated by electricity, the desire to make efficient use of generating and transmission capacity, and the capability to produce vapor compression equipment.

Residential/commercial heat pumps which provide simultaneous air conditioning and water heating could capture a large share of both energy markets and at the same time provide very efficient utilization of electricity generating capacity. Furthermore, the excellent economics of these devices compared with other renewable energy technologies should provide rapid consumer acceptance in such applications as domestic hot water/air conditioning, and in hospitals, restaurants, and a variety of small commercial establishments.

Industrial heat pumps that utilize reject heat streams to provide low temperature process heat and preheat appear to be well suited to Brazil's energy needs. Such pumps provide excellent return on investment and their use is technically feasible in industries such as food processing, textiles, alcohol production, pulp and paper, refining, and petrochemicals. Furthermore, on the basis of Brazil's energy profile, such devices, powered by renewable indigenous hydroelectricity, could displace a maximum of about 9% of total fuel oil consumption, with perhaps 4.5% as a realistic goal.

4.2.6 Heat Recuperators

Basically, a heat recuperator is an air-to-air heat exchanger fitted to the exhaust of a combustion process. Generally, combustion air is preheated by passing through the recuperator, to save fuel (see Figure 4.8).

At Wolverine in Decatur, AL, recuperators have been fitted to annealing furnaces. By preheating combustion air to about 900°F (482°C), a 22% savings in natural gas consumption is realized. Installed cost is $12,000 for each furnace. With gas priced at $3.25/mcf ($0.11/m^3), this results in a simple payback of a little more than one year.

This recuperator was inspected by U.S. and Brazilian energy groups in 1981, and it was determined that recuperators have excellent market potential in Brazil for a variety of reasons: the technology is simple and well under-

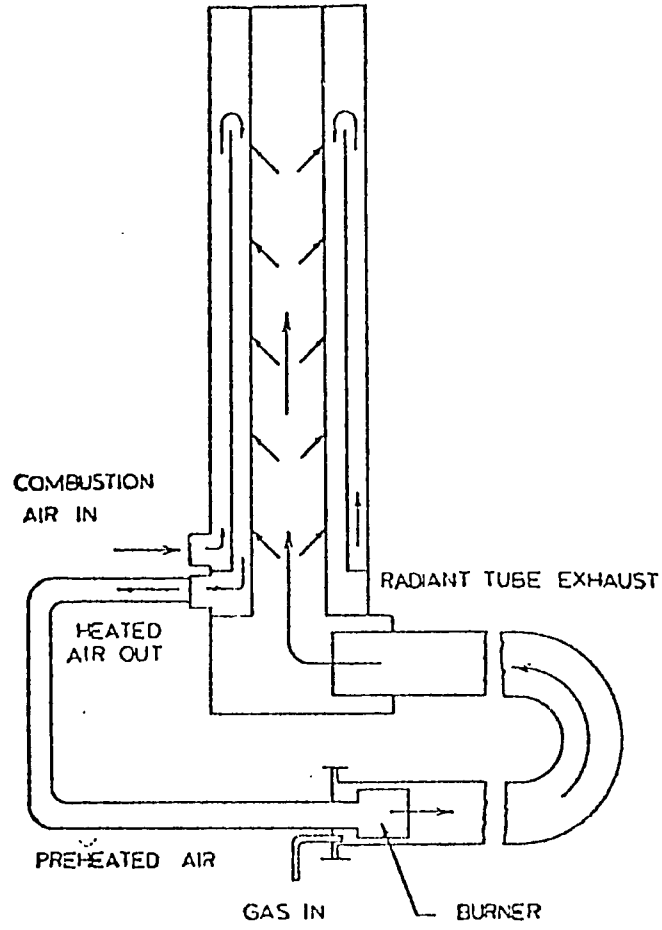


Figure 4.8 Heat recuperator (from Wolverine Division of UOP, Decatur, AL).

stood, it directly displaces significant quantities of oil, and it can be readily manufactured and installed by Brazilian concerns.

4.3 FINANCIAL ANALYSIS OF HEAT PUMP TECHNOLOGY

A detailed financial analysis of industrial heat pump technology has been performed for Brazil. For this technology, the financial criteria computed are the internal rate of return (IRR), the levelized cost of energy, and the payback period. The IRR is particularly important, since it is the criterion used by many international financial institutions for project evaluation. Figures 4.9 and 4.10 show the internal rate of return for industrial heat pumps and solar industrial process heat as a function of capital cost for two oil prices ($34 and 45 per bbl) and various debt interest rates. With inflation in Brazil running close to 100%, the Brazilian government has encouraged investment in alcohol and coal production by indexing loan payments at only a 55% rate of increase. This government subsidy is equivalent to a negative interest rate on loans, and it vastly improves the internal rate of return on a solar investment. Figure 4.11 demonstrates the effect that investment tax credits have on the internal rate of return, and therefore the economic viability, of renewable energy projects. Changes in financial policy variables such as tax credits and debt interest rates can thus play a powerful and decisive role in creating a favorable investment climate for indigenous renewable energy systems, and the national economy can be expected to benefit from the savings in imported oil.

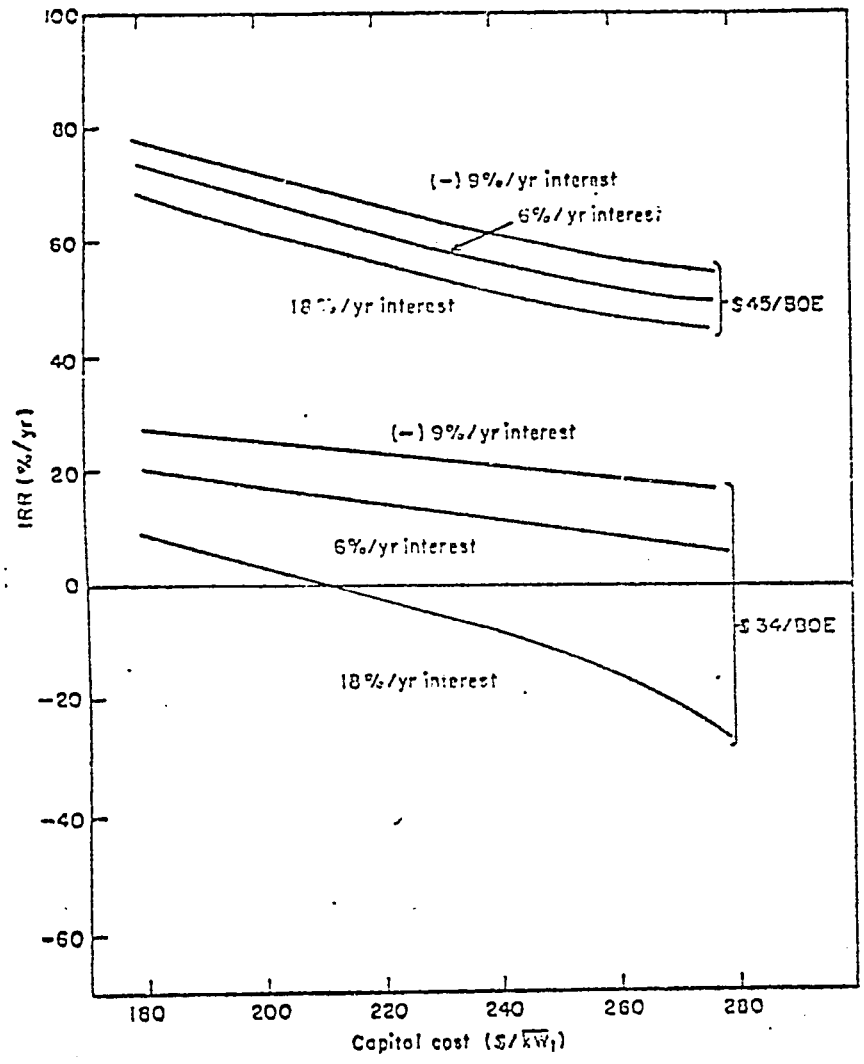


Figure 4.9 Industrial heat pump IRR vs capital cost.

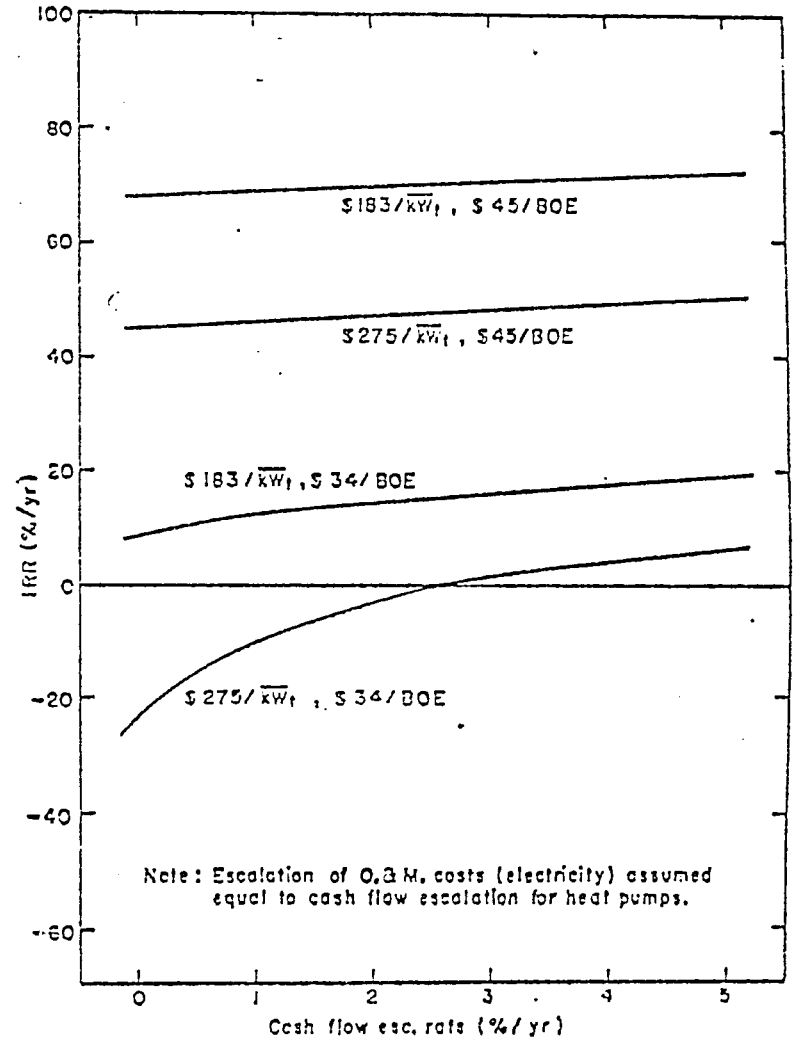


Figure 4.10 Industrial heat pump IRR vs cash flow escalation rate.

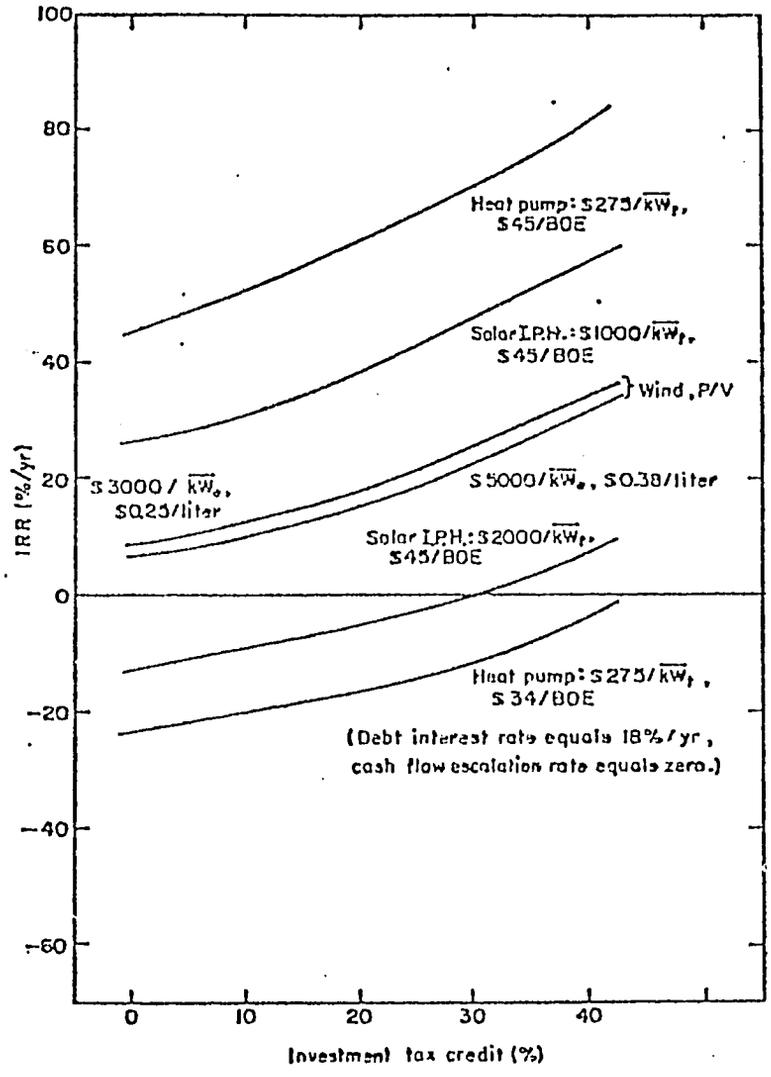


Figure 4.11 IRR vs investment tax credit.

REFERENCES

1. National Energy Balance, Federal Republic of Brazil, Ministry of Mines and Energy, July 1980.

2. Brazilian Energy Model, Version II, Revised and Actualized, Federal Republic of Brazil, Ministry of Mines and Energy, May 1981.

3. Annual Reports 1979-CESP, Light, CPFL, Statistic Anuary-1980, Fundacao Instituto de Geografia e Estatistica.

4. Anuario Estatistico, Brazil Fundacao Instituto Brasileiro de Geographic e Estastistica, 1979.

5. Brazilian Energy Statistics 1979, Ann. Bull. Brazilian Nat. Committee of World Energy Conf., 1979.

6. Comissao Estadual de Energia: Plano de Substituicao de Derivados de Petroleo no Rio Grande do Sul, Secretaria de Energia, Minas e Comunicaoes, p. 13., Porto Alegre, Rio Grande do Sul, 1980.

7. Conselho Estadual de Energia: Parana em Face No Problema Energetico, Companhia Paranaense de Energia (COPEL), Curitiba Parana, October 1980.

8. Comissao Estadual de Energia: PROENERGIA, Programa Catarinense de Energia, Caplan p. 25; State of Santa Catarina, Gabinete de Planejamento e Coordenacao Geral, Florianorois, Brazil.

9. Statistic Anuary, 1980, Conselho Nacional do Petroleo.

10. R. D. Heap, Heat Pumps, Halsted Div., Wiley, New York, 1979.

11. Heat Pump Water Heater Field Test Data, Interim Report, Div. of Energy Conservation and Rates, Load Management Branch, TVA, Summer 1980.

12. A. Weinstein and G. Van Zuiden, Reducing solar costs with the solar-assisted-Templifier, in Proc. Ann. Meet. Int. Solar Energy Soc., Atlanta, May 1979, Vol. I.

13. J. Forwalter, Waste heat recovery from refrigeration. Food Processing (Dec. 1979).

14. Analysis of the Economic Potential of Solar Thermal Energy to Provide Industrial Heat, Vols. 1-3, COO-2829, Intertechnology Corp., Warranton, VA, Feb. 1977.

15. Survey of the Applications of Solar Thermal Energy Systems to Industrial Process Heat, Vols. 1-3, TID-27348-1, Battelle Columbus Labs., for US ERDA, Jan. 1977.

97

THE POTENTIAL OF BUILDING ELECTRICITY SYSTEMS FOR LOAD REDUCTION AND LOAD LEVELLING

Richard W. Leigh
Department of Energy and Environment
Brookhaven National Laboratory

INTRODUCTION

In a previous discussion I analyzed the cost of production of electricity as seen by the utility as a function of time of day or time of year. I stressed that there were many activities which could be undertaken at the building level to reduce the load, shave the peak load preferentially or even transfer load from on peak to off peak, and that these steps could reduce the utility load, or the rate of growth of that load, at a cost substantially below the cost to the utility of electricity from new generation capacity. I then went on to discuss two broad classes of utility actions which could realize these potential benefits: effective rate structures such as peak load and time of day metering, on the one hand, and actions which could be taken unilaterally by the utility, such as a utility sponsored conservation effort in the customer's building, on the other. Here I return to examine a sample list of energy conservation options and to demonstrate both that there are many economically adavantageous steps that can be taken to reduce electricity costs (if an adequate rate structure is in effect) and that in many cases the analysis can be done in an extremely simple manner.

This last point is important. Although computers and advanced mathematical techniques are valuable in energy planning

98

on a national or utility level, most of the calculations needed to analyse energy conservation devices and techniques can be done by hand on a single sheet of paper (with the help of a calculator). I will demonstrate some of the more useful techniques below, and understanding these techniques is more important than remembering the particular examples, since any conservation idea must be analyzed for the particular application in question, using local weather data, the correct building characteristics and electric rates for the utility in question.

In the analysis of conservation options the perennial problem of financial analysis arises regularly: how is one to compare a one-time capital outlay for a conservation device with the ongoing savings which will accrue from its installation? One way is to use a detailed financial model, and in the course of this workshop some which are quite sophisticated will be discussed. These are quite appropriate to large projects where hundreds of thousands of dollars are at stake or where two projects may be tight competitors for the same scarce capital. For small projects, especially for initial screening, and for cases where the benefits are clearly overwhelming, a much simpler technique will suffice: we assume that we have taken out a five year loan to cover the total capital outlay at an interest rate that is five percent above the inflation rate. This results (1) in annual payments (including interest and repayment of principal) that amount to 23% of the capital outlay when measured in constant (non-inflating) currency of the year of purchase. We add another two percent to cover insurance and the minimal operations and maintenance expenses associated with most of the

devices to be discussed, and conclude that for these analyses, the annual cost of a capital item amounts to 25% of the capital outlay. Thus to derive annual costs we will multiply the capital outlay by a "capital recovery factor" of 0.25; if we know how much energy a device is saving each year, then the cost of saved energy is given by:

Cost of saved energy = (0.25)x(capital outlay)/(annual energy saved).

Note that this gives the cost of saved energy during the first five years of the life of the device; thereafter the savings are virtually free until the end of the technical life of the device. The cost of saved energy may be compared with the cost of purchasing the energy if the device were not installed. Note also that if you don't like the interest rate or the time period of the loan it is easy to apply the same method using your own numbers (1).

We will now apply these techniques to two of the principal consumers of electricity in the ECOWAS countries, air conditioning and lighting, and to one potential alternative source of electricity, cogeneration.

AIR CONDITIONING

In the urban areas of ECOWAS countries, air conditioning is one of the largest consumers of electricity; it is also one of the most troublesome, since the power required depends on weather conditions and so will rise and fall with the sun for an entire city at the same time, putting a severe strain on the electric utility. Thus there are two ways in which conservation

techniques can lower the cooling load and hence the electrical load: overall reduction of the annual energy consumed, which is good, and targeted reduction of the peak load, which is better. We will discuss techniques which produce each of these results.

Before we tackle specific techniques, however, a general discussion of airconditioning loads will prove useful. The heat being removed from the interior of a building to maintain a given comfort level arises from four distinct sources. First, there is solar energy which penetrates directly into the building through windows, skylights or open doors. Second, there is heat which is conducted through the walls because the sun and warm air hold the outside of the wall at a higher temperature than the inside, which is in contact with the conditioned air. Third, air which leaks into the building ("infiltrates") through cracks, open doors and windows and intentional ventilation is warmer than the inside air and must be cooled. Fourth, this same air in humid climates is laden with water which must be partially removed to assure comfort, and the condensation of this water vapor requires energy in addition to that being used to cool the air down.

Each of these mechanisms produces significant cooling loads, but they do so at different times. The solar energy will of course depend on clouds, but has an underlying regularity: on clear days it will peak up in the morning for light coming in through east facing windows, in the afternoon for west facing windows and around noon for apertures in a roof. In equatorial regions, relatively little solar energy will come directly in through south or north facing windows, especially if the roof has

101

any overhang. The sun's maximum intensity is about one kilowatt per square meter (kW/m2) on a surface which is perpendicular to the sun's rays; Thus somewhat less than one kilowatt will enter a building through a one square meter west facing window late in the afternoon. If the ground around the building has a light colored surface, such as sand, reflected light can have up to 20% of the intensity of sunlight and can contribute significant amounts of energy to the cooling load; we will ignore this refinement here.

The impact of heat being conducted in through the walls will depend on both the outdoor temperature and the solar heating of the exterior walls and must be calculated on a case by case basis. Heavy masonry or adobe buildings are an important special case; for them the peak load will be considerably delayed and attenuated by their thermal mass. The load due to cooling infiltrating air once it is in the building will peak with the outdoor temperature. The electric load due to dehumidification, however, will be much more constant, since the amount of water in the air does not change greatly during the course of a day. It should be clear that lowering these different cooling loads will have decidedly different effects on the electrical load and the utility. We will consider several possibilities in turn.

Leak Stoppage

At the risk of being obvious, it is a terrible waste to air condition a space which has large amounts of outside air blowing through it. Especially for small window mounted units, a few minutes of care stopping up the leaks around the window sash, particularly those resulting from the window being locked in a

half-open position, will pay for themselves in a few weeks in energy savings. A good government policy direction would be to require the inclusion of strips of foam rubber or a similar leak-stopping material in every air conditioner package. We will not attempt to quantify the possible savings here, since the effort involved can range from one minute to one hour and different people value their time very differently. The load reduction will occur both on the temperature peak for the day and more uniformly in humid climates as the dehumidification load drops. Similar savings can be realized in large central installations by ensuring that self-closing doors actually shut, that windows are not left open and that the mixing system is adjusted to admit the minimum amount of fresh air needed for adequate ventilation.

A similar situation occurs with insulation. Many older buildings having little or no insulation in the ceiling are now airconditioned, and the resultant waste of electricity is large. Foamed plastics can be applied directly to the roof from the outside, and 15 centimeters will provide excellent insulation and weatherproofing at minimal cost. In planning central air conditioning systems for new buildings, careful analysis will show that insulation levels substantially in excess of standard practice will pay for themselves in capital costs alone since the lower peak thermal load will allow a lower capacity air conditioning system to be installed at a commensurate monetary saving; subsequent savings will also result from lower energy consumption. Again, due to the wide range of needs and costs, we will not attempt to quantify these options here.

Reflective Surfaces for Windows

Thin films of plastic are available which can be mounted on the exterior surfaces of glass windows and which will reflect 50 to 90% (depending on the type purchased) of the incident solar energy back away from the building. This will result in a substantial saving in the electricity used for air conditioning, but films with a transmittance so low that people will be led to turn on lights should not be used, since the low efficiency of the lights will lead to a larger air conditioning load than was present initially. The plastic comes with an adhesive attached and need only be cut to the size of the panes of glass and (carefully) applied. The installed cost is $10-20 per square meter(CFA 3500-7000 per square meter). The peak solar input through west (or East) facing windows will be 0.6-0.8 kW/m2 after accounting for haze, the sun's angle and dispersion resulting from the long path of the light through the atmosphere. Thus a plastic film which transmits 25% of the incident radiation will reflect 0.45-0.6 kW/m2 and thus lower the peak thermal load by that amount.

Since a given building has an airconditioner installed in it of a given capacity, this will not affect the power demand of one building directly, but if such films are installed on a large number of buildings throughout a utility service area, the total power requirements will be lowered since each unit will come on less often, leading fewer units to be on at one time. If the average coefficient of performance (COP) of the air conditioners is 2.5, the power demand on the utility will be lowered by the above thermal loads divided by 2.5, or 0.18-0.24 kW/m2. If the

utility load peaks in the late afternoon, it will find its peak load reduced by up to that amount, depending on the shape of the residual peak load and the degree of coincidence of the avoided power demand and the residual peak load. If the utility's peak is lowered significantly, it will actually need less generation capacity, or will be in a position to build additional capacity more slowly. The cost of deferring generation capacity in this way is the cost of the film per square meter divided by the avoided power demand per meter, or 40-110 $/kW (2) (15,000-39,000 CFA/kW), which compares quite favorably with the cost of new peaking capacity. Therefore, if the utility load peaks in the late afternoon, it is less expensive to the utility (and to all its customers) to install such plastic films on the west windows of airconditioned buildings at the utility's expense than it is to build the additional capacity that would otherwise be required. Since the operators of the building would enjoy substantially lower electric bills, a scheme to split the savings between the building and the utility might be most advantageous to both in the long run.

Even if the utility peak occurs early in the afternoon, so that no peak load reduction results from installation of such films, the daily energy load in kilowatt hours (kWh) will be substantially reduced, and here the same results will apply to east windows and the reflection of morning sun. A west (or east) facing window will admit 900-1300 kilowatt hours per square meter per year (kWh/m2-yr) of thermal energy; our reflective film cuts this by 75%, and dividing by our COP of 2.5 we find a saving of

270-390 kWh/m2-yr of electricity. Annualizing the capital cost of the film ($10-20/m2, above) with our 0.25 capital recovery factor (above), we find that it costs 2.5-5 $/m2-yr to have the film in place, and dividing this by the energy savings per meter, we find a cost of saved energy of 0.006-0.018 $/kWh (2.2-6.5 CFA/kWh), well below the cost of generation. If rate structures and education cannot interest customers in this kind of saving (and this may occur simply because the amount of money per customer is small) it is in the interest of all of the customers to have the utility install such reflective films for free, or for some nominal price which will split the savings between the utility and the customers receiving the installation.

Cool Storage

Except in the most humid and cloudy of climates, cooling loads are substantially greater during the day than they are at night. Partly as a result of this, electric utilities are hardest pressed to meet loads during the day; at night, especially late at night, they can turn off all but their most efficient equipment and consequently, can charge less for electrical energy. Cool storage provides a way for a building to to provide a cooled environment during the day while consuming only less expensive nighttime ("off-peak") electrical energy. If the building has a cooling system based on chilled water (the only case we will consider here) the method is extremely simple: A large, insulated tank for water is added, and (if needed) the capacity of the chillers is increased. The chillers are then run all night, cooling the tank of water down to perhaps 4-5 ^{o}C. Nighttime cooling loads must be met at the same time, of course.

During the day, the chillers are turned off and the building cooled by circulation of the stored cool water. The system will function much more efficiently if the tank is designed to function in a stratified mode with heavier chilled water entering and exiting at the bottom and lighter, warm water entering and exiting at the top; mixing will be suppressed by the difference in density between warm and cool water. Enhanced reliability could be an added benefit of this system in an area troubled by unreliable power if the building management also invested in sufficient backup generation capacity to keep the circulation pumps and fans operating, but we will not pursue this option further here.

These systems are somewhat large: if the average daytime load is 10-100 kW thermal (4-40 kW electric) and we assume a 10 ^{o}C temperature change in the water and that we must store water sufficient to cool the building for ten hours, we need 8600-860,000 liters of water, which would occupy a space with linear dimensions of 2 - 10 meters. Such systems are, however, quite cost effective. Tankage costs 0.60-0.30 $/liter (200-100 CFA/liter) in this size range, with unit cost decreasing with increasing size. Annualized, the cost is thus 0.15-0.075 $/liter-yr (50-25 CFA/liter-yr). With a ten degree temperature drop, we can store 10000 calories per liter per day, or (for daily cycling and a COP of 2.5) 4.23 kWh/liter-yr. Dividing, we get the unit cost of storing electricity as coolness to be 0.035-.018 $/kWh (12-6 CFA/kWh) electric, much less than the normal difference between he costs of on peak and off peak power.

107

A new cool storage system currently under development at Brookhaven National Laboratory promises to offer more attractive economics in a smaller space by making use of the high specific heat of fusion of ice, eight times the heat storage capacity of the sensible heat stored in a ten degree temperature change. Inside an insulated, lightweight tank, small plastic bags containing pure water are immersed in a mixture of water and anti-freeze which will act as a heat exchange medium. Thus large amounts of thermal energy can be pumped in and out of the tank by the anti-freeze solution while being stored in the heat of fusion of the pure water.

No matter what storage system is used, if additional cooling capacity is needed to cool it in the few hours available late at night, additional costs will of course be incurred. It is unlikely that additional capacity will be needed, however, since cooling systems are normally sized to meet a generous peak load, so that they normally operate at a low load factor. Addition of the storage capability will ennable the chillers to operate at higher load factors as needed to cool the storage medium.

Although cool storage does offer sufficient returns to the utility to justify installation by the utility, there is little reason to follow that route, as long as appropriate time of day electric rates can be set up. Since the system requires a certain amount of attention to operations (to make sure it has not slipped into charging itself during the day, for example), it is appropriate that those best suited to operate it (the building management) have a financial stake in efficient operation. This

is assured if they are the purchasers. Conversely, none of the reasons for utility ownership outlined in the previous talk obtain; the project is big enough to merit careful assessment by the prospective purchaser, the savings will be large and clearly delineated and the technology will not intimidate the purchaser. Consequently, cool storage will stand as an example of an electricity conservation investment most appropriately evaluated and purchased by the traditional decision maker, the building management.

HIGH EFFICIENCY LIGHTING

Although the prevalence of fluorescent bulbs in many parts of West Africa indicate strong awareness of the importance of high efficiency lighting, the value of efforts in this area to utilities is worth emphasizing. A 100 Watt incandescent light bulb produces about 1700 lumens of light (an ill-defined efficiency of about 3%). A standard fluorescent light will have an output of some 60 lumens/Watt, and so will need only 30 W to produce the same output. In addition, the fluorescent will typically have a lifetime of 10,000 hours, compared to the 1000 hour life of the incandescent bulb. Thus the initial cost of the fluorescent light, $20-30, may be reduced by the cost of ten incandescent bulbs, say $10, to leave an increased capital cost for fluorescent lighting of $10-20 for 1700 lumens. But over the 10,000 hour life of the bulb it will save (100-30)x10000 W-hrs or 700 kWh, at a cost of 0.015-0.030 $/kWh (5-10 CFA/kWh). Since this is far below the cost of generating a kilowatt hour, it is advantageous to install such bulbs everywhere, and in fact this is happening. In new installations where the load is dominated

by lighting requirements, for example in rural electrification projects, the installation of one 44 W fluorescent bulb in place of one 100 W incandescent represents a saving of 66 W of power capacity that the utility need not install at a cost of $10-20. This corresponds to a cost of avoided capacity of 150-300 $/kW, comparable to the cost of peaking capacity but substantially less than the cost of new baseload power. In short, fluorescent lighting will be paid for completely by the capacity savings it allows the utility, with all energy savings constituting a bonus. In new rural electrification projects, if there is any danger that the new customers would choose incandescent lighting on the basis of low first cost, the utility will find it advantageous to simply give them fluorescent lights gratis to avoid the expense of expanding capacity to supply inefficient lighting systems. Comparable considerations apply to metal arc lighting (sodium or mercury lamps) for lighting outdoor or large indoor areas where the large minimum size inherent in these devices at present is not a problem.

COGENERATION

The standard methods of producing electricity from sources of thermal energy involve the currently unavoidable loss of 60-70% of the energy content of the fuel as waste heat. Furthermore, industrial processes based on thermal inputs often use only a small fraction of the energy available due to temperature requirements; again the bulk of the energy content of the fuel may be rejected as waste. Cogeneration is a technology which attempts to overcome this waste by generating electricity

at the site at which the thermal energy is being produced and consumed, thus assuring that a much larger fraction of the energy content of the fuel is put to good use.

The subject is far too broad to cover in the time available at this workshop. I will only attempt to catagorize cogeneration systems, delineate some requirements for economic feasibility and give ar example of a rough economic analysis suitable for establishing the desireability of further study. For projects of this magnitude, there is no alternative to detailed engineering and economic analyses for each individual project.

Cogeneration systems normally are used in applications where oil or gas is currently being burned, and they continue to burn the same fuel, albeit at higher efficiency. Systems powered by solar energy, garbage burning or coal have been demonstrated in the U.S., but only garbage burning systems have been found economic, and West Africa is probably not yet blessed with enough garbage to make them practical. It should also be noted that the range of possible system sizes is enormous, ranging from a few kilowatts to a few hundred megawatts, and may incorporate a wide variety of prime movers.

Cogeneration systems may be divided into two sorts: "topping cycles" and "bottoming cycles". Topping cycles work like ordinary electric power plants; the fuel is burned and the highest temperature energy is used to produce electricity, either by expansion of the exhaust gases in a combustion turbine or diesel engine or by producing very high pressure steam for use in a steam turbine. The exhaust gases and waste steam from this process, at temperatures ranging from 100-450 ^{o}C, are then

directed to the thermal demands. These could include absorption air conditioners, cleaning, food, lumber or paper processing or even refinery needs in the 350-450 ^{o}C regime. A bottoming cycle is appropriate where very high temperature heat is needed (brick, cement or primary metals for example) so that the energy exhausted by that process is still at a temperature that is high enough to drive a steam turbine and produce useful quantities of electricity.

For bottoming cycle systems, the efficiency both before and after the introduction of cogeneration is extremely process-dependent. For topping cycles, if the process to which the reject heat is directed can use the thermal energy at temperatures of 150 ^{o}C or below, it is generally possible to extract 30% of the energy of the fuel as electricity and 50% as thermal energy. If the process demands energy at a higher temperature, the efficiency of electricity generation will be compromised by thermodynamic limitations, but thermal efficiency may be higher. To account for the greater value of electricity, it is customary in the U.S. to measure the efficency of a cogeneration system as

$$\text{Efficiency} = (E + TP/2)/FC$$

where E is the electricity produced, TP is the thermal energy produced and usefully consumed and FC is the energy content of the fuel consumed.

Due to the expense of moving thermal energy (in insulated hot water pipes, for example), the cogeneration system is almost always installed at or near the point of consumption of thermal

112

energy. Also, the ratio of electricity production to thermal energy production is rigidly fixed for some technologies (diesels and backpressure turbines) and only moderately variable for others (extraction turbines). Since our goal is effective utilization of both electricity and thermal energy, careful sizing of the system is necessary. If the thermal loads are large relative to the electrical loads, supplying all the thermal energy through cogeneration is only feasible if the electricity not consumed locally can be sold to the utilty. If the thermal loads are irregular, thermal storage may be needed. If the electrical loads are large, it may be prudent to size the cogeneration system to the smaller thermal loads and purchase the residual electric power requirements from the utility. It should be clear that a good working relationship with the utility is important.

As an example of a fairly large cogeneration system, consider the configuration shown in Fig. 1a, designed around a combustion turbine, a steam turbine operating off of reject heat from the combustion turbine, and an absorption air conditioning system functioning on the heat rejected by both turbines. The fluids, fluid temperatures and steady state power ratings are shown at various points in the system. The alternative, a centrifugal chiller-based system using electic power purchasd from the utility, is shown in Fig. 1b for comparison.

The efficiency of electric generation is 33%, and the cogeneration efficiency, as defined above, is

Efficiency = (17 + 5.4 + 34/2)/68 = 0.58 = 58%.

To evaluate the economics of operation in the first year, we

first define the necessary economic parameters and give some exemplary values:

KxP = Total Capital (=$22.4 million @ $1000/kW)
R = Levelizing Factor (=0.20 here, to account for longer life, separate accounting of operations and maintenance; was 0.25 in earlier examples).
M = Maintenance Costs (=$0.005/kWh)
E = Electricity Produced per year (=22.4MWx8760 hours=200 million kWh)
FC= Fuel Consumed per Year = EP/Efficiency = 3xEP
CF= Cost of Fuel (=$4.60 or $2.30/GJ, $0.0165 or $0.0082/kWh =5.8 or 2.9 CFA/kWh; derived from $28/barrel for oil or one half that for gas.)
EC= Electricity Consumed in Alternative Electric Air Conditioner(=9.3 MWx8760 hours=81 million kWh per year)
VE= Value per kWh of electricity sold to utility.
CE= Cost per kWh of electricity purchased from utility.

We will ignore electric consumption by the facility other than that used for air conditioning in the conventional system, assuming that power for lights and internal use is purchased from the utility in both cases. In the case of the cogeneration, then, all electric power produced is sold to the utility. This is one form of accounting used in cogeneration systems; it is called "arbitrage". Whether it is advantageous or whether the cogenerator would choose to meet his or her own needs for electricity and sell only the excess to the utility, buying only such power as could not be provided internally ("net buy/sell") will depend on VE and CE and on knowledge of the cogenerator's demand for power. This option is one of many which we must leave out now but which must be addressed in the evaluation of actual proposals for cogeneration systems.

The total benefits, B, of operating the cogeneration system will be the income from the sale of electricity minus the costs of operating the system plus the savings accrueing from not

114

operating the conventional system. We assume the capital costs of the absorption and electric air conditioners roughly balance each other, and find

$$B = ExVE - KxPxR - 3xExCF - ExM + ECxCE$$

$$= Ex(VE - 3xCF - M) + ECx(CE/VE)xVE - KxPxR.$$

Figure 2 shows B as a function of the value of electricity, VE, for the two parametric fuel costs listed above, and for CE/VE=0.8, 1.0 and 1.2. It should be clear from Fig. 2 that the value of the cogeneration system depends quite strongly on VE, what the utility will pay for electricity, on CE, the cost of purchased electricity, and on the price of fuel. Regions where natural gas is now being flared are prime candidates for these technologies, and the lower fuel price was chosen to indicate the favorable economics that inexpensive fuel would make possible.

Cogeneration can be an economic and socially attractive conservation measure, but as the above discussion should indicate, it is complex to evaluate. In addition to the factors discussed above, a variety of points must be considered. Among these are:

- Load factors (we have assumed the machines run 100% of the time; in fact, they will not.)
- Variations in thermal load; the need for load following operation, thermal storage or other controls.
- Financing methods
- Establishing the value of electricity to the utility; should average or marginal costs be used?
- Environmental impacts: Many cogeneration technologies produce more pollutants than do standard electric generation technologies.

Discussion of many of these questions can be found in the

115

bibliographic references.

FOOTNOTES

1) The capital recovery factor is given by

$$CRF = P/C = I/[1-1/(1+I)^{**}N]+D$$

where C is the total capital required, P is the payment per year (or other uniform period), D is the insurance and operations and maintenance cost per year, I is the interest per year, N is the number of years and "**" indicates exponentiation, raising (1+I) to the power N. For our example, I = 0.05, N = 5 and D = 0.02.

2) In computing a range of values such as 40-110 $/kW, I will always present the widest range possible for a given set of inputs. For this example, the low end, 40 $/kW, is the quotient of 10 $/m2 (the smaller price) and 0.24 kW/m2 (the larger power), while the upper end of the range is the quotient of the larger price and the smaller power.

116

```
                 |----------------|
                 |                |
 68 MW (fuel)    | Combustion     |  17 MW (Electric)
-------->--------|                |------------>---------|
                 |    Turbine     |                      |
                 |                |                      |
                 |---|------------|                      | 22.4MW
                     |(Exhaust)                          |->-----
                     |T = 540                            |
                     |                |-----------|      |
                 |---------|          |Steam      |      |
                 | Heat    |----------| Turbine   |---->---|
                 |Exchanger|-->--|    |           | 5.4 MW
                 |---------| 7 MW|    |--|--------| (Electric)
                     |            |       |27MW
        (Exhaust)    |            |---->--|    |-----------|
          T = 112    |             Steam |    |Absorption | 28 MW
                     |                   |-->-| Air       |---->----
                                             |Conditioner|Cooling
                                             |-----------|
```

(a) Cogeneration System

```
|-----------|                    |------------|
|Electric   | 9.3 MW Electric    |Electric    | 28 MW
| Utility   |-------->----------|   Air      |---->----
|-----------|                    | Conditioner|Cooling
                                 |------------|
```

(b) Conventional System

Figure 1
Comparison of Cogeneration and Conventional Utility Systems for Large Air Conditioning Loads.

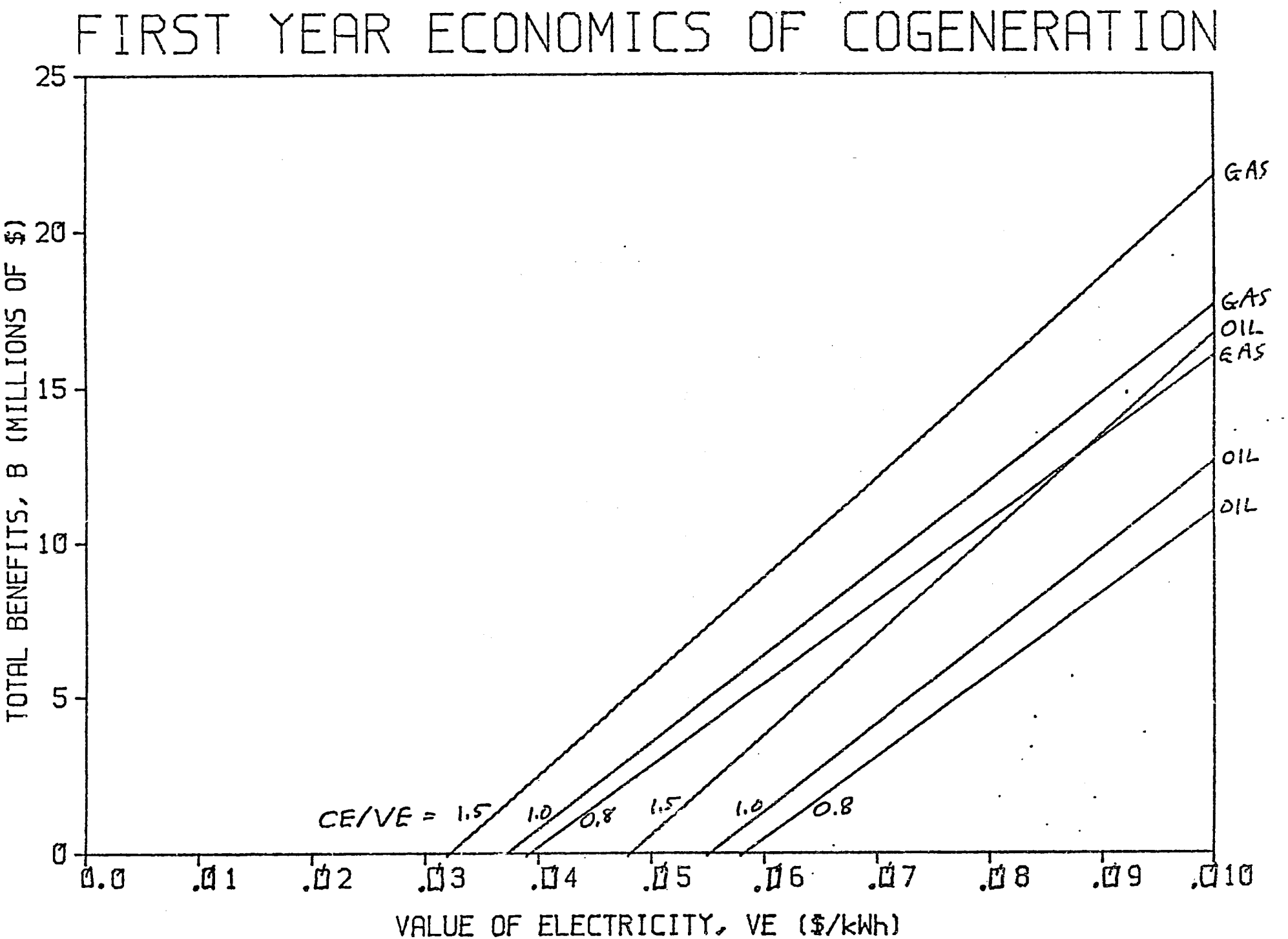

FIRST YEAR ECONOMICS OF COGENERATION
TOTAL BENEFITS, B (MILLIONS OF $)
25
20
15
10
5
0
0.0
.01
.02
.03
.04
.05
.06
.07
.08
.09
.10
VALUE OF ELECTRICITY, VE ($/kWh)
CE/VE = 1.5
1.0
0.8
1.5
1.0
0.8
GAS
GAS
OIL
GAS
OIL
OIL

FIGURE 2

COST-BASED RATES AND OTHER CONSERVATION OPTIONS FOR ELECTRIC UTILITIES

Richard W. Leigh
Department of Energy and Environment
Brookhaven National Laboratory

INTRODUCTION

Rapidly rising demand and severe financial constraints on construction are placing many electric utilities in developing countries in severe binds. In this series of lectures we will examine several conservation alternatives and see, first, that under certain ideal circumstances, the growth in electrical demand can be curtailed for less than the cost of additional electricity. Since conservation choices are normally made by consumers, however, while new generating capacity is supplied by the utility, the options are often not explored in a logical way. We explore several such impediments to rational selection of the best mix of conservation and utility expansion options and develop two approaches which will help to overcome them.

To quantify the discussion, we first develop several aspects of the costs of operating an electric utility. We then turn to the loads served by the utility, first characterizing them by sector and structure, and delineating the impediments to conservation in each case. We will incorporate in this discussion a point which will be established in succeeding lectures, that load growth can easily be curtailed at a cost of $0.08/kWh (28 CFA/kWh) or less, or moved off-peak at a cost of $0.04/kWh (14 CFA/kWh) or less. In the last two sections of this lecture, we will discuss the options available to the utility for promoting

119

these cost-effective conservation measures, better rate design and direct intervention to promote conservation.

THE COSTS OF OPERATING AN ELECTRIC UTILITY

The primary job of an electric utility is to provide electric power to meet a load, the sum of hundreds of thousands of individual loads, which varies in response to people's habits, the earth's turning, weather and a variety of other regular and stochastic processes. The load is typically lowest late at night, rising throughout the morning to reach a peak at midday or in the afternoon and declining again through the evening, although a broad shoulder due to lighting requirements will often hold it steady as the day fades. On weekends many industrial and commercial enterprises are shut and the peak demand will be substantially lower than during the week. If the load is dominated by air conditioning, it will be characterized by strong peaks and be highly weather dependent; if by a continuous industrial process, the entire load will be stable and uniform.

The load can be partially characterized by three parameters: the total annual electric energy consumed, TE, the annual maximum peak load, PM, and the dimensionless ratio of those, the load factor LF, where:

$$LF = TE/(PMxH)$$

with H=8760 hours per year. Thus a uniform load has a load factor of 1.00, and the "peakier" the load, the smaller LF is.

The electric power is supplied by a variety of types of generating equipment, which we will group into two loose catagories: "baseload" equipment, which has higher capital costs

120

but which burns less expensive fuel more efficiently, and "peaking" equipment, which is relatively inexpensive, but which tends to burn expensive fuels less efficiently. Nuclear power plants or coal fired steam turbines are examples of baseload capacity, while combustion turbines burning oil or gas would be typical peaking facilities. For simplicity, we will consider only one representative of each type, a coal plant and a combustion turbine; in actuality, the number of systems and choices is quite large. Various parameters characterizing these two types of plants are shown in Table 1.

TABLE 1
CHARACTERISTICS OF GENERATING EQUIPMENT

NAME	SYMBOL	TYPICAL VALUES BASELOAD	PEAKING	UNITS
Peak Power Output	P	>100,000	<100,000	kW
Annual Energy	E	> 7x10^8	<1.8x10^8	kWh/yr
Load Factor	LF	0.80	0.20	
Conversion Efficiency	Y	0.33	0.25	
Unit Capital Cost	K	1200	200	$/kW
		420,000	70,000	CFA/kW
Unit Fuel Cost	CF	2.60	4.60	$/GJ
(Coal and Oil, respectively)		910	1610	CFA/GJ
Unit Maintenance Cost	M	0.005	0.005	$/kWh
		1.75	1.75	CFA/kWh
Levelizing Factor (Capital Recovery)	R	0.28	0.28	1/yr
Energy Conversion Factor	GK	0.0036	0.0036	GJ/kWh

The conversion efficiency, Y, is the ratio of electricity produced per year (E) to the total chemical energy content of the fuel consumed. The unit fuel costs are given in dollars or CFA per GJ (billion joules, "gigajoules"), and the conversion factor

121

GK is used below to convert $/GJ to $/kWh. For a plant or group of plants, as for the entire utility load, E = PxHxLF. When we need to differentiate, BL will indicate baseload equipment and PK will indicate peaking equipment. Thus E(BL) is the total electrical energy produced by baseload equipment and P(PK) is the peak power available from peaking equipment.

The capital recovery (levelizing) factor converts a one time capital charge into a stream of annual payments over a period of perhaps thirty years, assuming that the utility took out a loan to cover the capital outlay and is paying it back over the life of the equipment. The value of 0.28 is typical of U.S. utilities currently and includes interest, repayment of capital, insurance and the repayment of loans taken out during construction. It will be discussed further in a later lecture; for now it is sufficient simply to remember that if an item costs K $/kW in capital, it will cost RxK $/kW-yr to own and energy will have a unit cost of RxK/(HxLF) $/kWh.

With this established, we can write down the total annual cost of operation of a unit, including capital, fuel and maintenance, as:

$$CT(E) = RxKxP + (CFxGK/Y + M)xE,$$

where we have explicitly included the dependence of total cost on annual energy E. Then the average unit cost of electricity from this unit is

$$CA = CT(E)/E = RxKxP/E + CFxGK/Y + M$$
$$= RxK/(HxLF) + CFxGK/Y + M.$$

Clearly, as the load factor on a device goes down, the unit cost of electricity from that device goes up. Substituting values

from Table 1 we find

$$CA(BL) = \$(0.048 + 0.028 + 0.005)/kWh = \$0.081/kWh,$$
$$= (16.8 + 9.8 + 1.8)\ CFA/kWh = 28.4\ CFA/kWh,$$

$$CA(PK) = \$(0.032 + 0.066 + 0.005)/kWh = \$0.103/kWh,$$
$$= (11.2 + 23.1 + 1.8)\ CFA/kWh = 363.1\ CFA/kWh,$$

so the average cost of baseload power is some 20% less than that of peaking power.

So far we have answered the question "What is the average cost of electric power from a given unit", but that is not the only question it is important to ask. Suppose the unit is installed and operating at less than full power. We may then ask what it will cost to produce an added amount of energy E1, and this will indicate the cost to the utility of having a load added under these circumstances or the savings accruing if the load E1 is turned off. The quantity we seek here is the "unit marginal operating cost", and in terms of the annual cost defined above it is

$$MOC(E1) = (\ C(E+E1) - C(E)\ )/E1$$
$$= CFxGK/Y + M$$
$$= \$0.033/kWh = 11.6\ CFA/kWh \quad \text{(baseload)}$$

and

$$= \$0.071/kWh = 24.9\ CFA/kWh \quad \text{(on peak)}.$$

Note that no capital costs were incurred. For a system with excess or adequate capacity, additional power produced on peak costs over twice as much as power produced by baseload equipment.

It is also reasonable to enquire as to the cost of meeting a load for which capacity does not currently exist. This quantity is called the total marginal cost of the load in question. Because capacity must be installed in some relation to the peak

power demand of the new load, while other expenses will be incurred in proportion to the total energy involved, this quantity is more complex and cannot be adequately defined in the time available for this discussion. Its determination rests on interpreting the total difference in capital and operating costs between two least-cost ("optimized") utility systems, one serving the currently anticipated load and one serving that plus the additional load for which the cost is sought (see the paper by R.Bright and myself in the Bibliography). These results are obtained by using large computer programs which simulate the operation and growth of the utility over a substantial period of time, perhaps thirty years ("WASP" or "PROMOD"). Even without such efforts, however, there are several factors indicating that the total marginal cost of new load will be as high or higher than the average cost of baseload energy, CA(BL).

First, the cost will involve a large capital component, and with interest rates high and likely to stay high, the levelizing factor for capital recovery on new equipment will not fall significantly in the near future. Second, most utilities have built too many oil plants (considered peaking plants these days) due to the low price of oil when the planning was being carried out. Anything they build today must almost certainly be a baseload plant, and the capital requirements for baseload plants have been rising inexorably and in excess of inflation. The cost of nuclear plants is at this point prohibitive, and at least in the developed countries, pollution control requirements are driving up the price of coal plants as well. Finally, even coal prices have been tracking rising oil prices, although these seem

124

at last to be levelling off and even falling a bit for the time being.

Thus the cost of electrical energy from new generation facilities seems to be at least $0.08/kWh (28 CFA/kWh), the cost of new capacity is several hundred dollars per kilowatt and on-peak loads cost at least $0.04/kWh (14 CFA/kWh) more than off peak loads. We therefore turn to the loads served by the utility to see what can be done to lower consumpton and to slow its growth.

UTILITY LOADS

The loads served by the utility can be broken into two useful sectors, the industrial sector on one hand and the residential and commercial sectors on the other. Industrial loads tend to be uniform (have high load factors), especially in industries which work three shifts, and to be large, with a single customer often having a peak demand in the megawatt range. Residential and commercial loads tend to be dominated by air conditioning and lighting, and thus to have strong peaks and low load factors, with very small average demands late at night.

The differing character of these loads offer different possibilities for conservation. There are several major reasons for inefficient use of electricity by the consumer (who may be the resident of a home, the manager of a small business or the plant manager of a large building or factory):

(1) The potential total annual savings are not worth the additional investment needed to bring about efficient use of electricity;

(2) The rates the consumer is paying are conveying misleading information about the cost of electricity;

(3) The potential total annual savings are well worth the investment required to bring them about, but are not worth the time required on the part of the consumer to analyze the situation and realize this;

(4) The total annual cost of the electricity is too small to merit the attention of the consumer;

(5) The consumer does not understand the situation even if (3) is not the case, and therefore takes no action to lower or to shift consumption.

Many other reasons could doubtless be enumerated, but these will give us sufficient material for discussion here. With respect to problem (1), we will see in the succeeding lectures that there are in fact a great many ways in which electricity use can be curtailed or shifted to off-peak at costs substantially below those derived in the last section for energy from new capacity. Thus we will see that problem (1) is not a problem in so many cases that we should turn our attention to issues (2) through (5).

Problem (2) arises when the tariffs are structured so that, for example, a customer with a very peaked load, responsible for the purchase of a substantial amount of largely unused capacity, pays only an energy-related charge, or when the rates do not differentiate between on-peak and off-peak demand for a customer who is in a position to shift the load in time cost-effectively. Since the cost of more sophisticated metering is often viewed as an obstacle to adequate rate structures, the problem is somewhat

126

more likely to arise with small users. The next section, rate structures, will discuss problem (2) in detail.

Problems (3) and (5) represent cases where direct action by the utility may be advantageous, since the limited resources of individual residential consumers make inefficiencies based on inadequate analysis more likely. We will see in the last section of this lecture that the benefits are sometimes sufficiently large to permit these actions to be taken without coercion and to structure them so as to be to the benefit of all concerned parties. Problems (3) and (4) can occur in industrial settings, where managers do not take all cost-effective measures, but rather pay attention to a few projects with the largest cash flows or the largest political implications. Here the virtues of direct utility action are less clear, since the management of an industrial plant ought to be able to pay sufficient attention to energy issues, given the large size of typical industrial loads. In industrial settings, a combination of rate design, educaton and argument should probably be tried before the utility itself gets involved in end use conservaton technology.

UTILITY RATE STRUCTURE

The primary function of utility tariffs is, of course, to recover the annual operating expenses of the utility so that it can pay the fuel bills and payroll and finance new construction. The tariffs have a second function, however, which is almost as important, and that is to convey to the consumers information about the cost of supplying electricity to meet precisely the type of load they are imposing on the utility.

127

If the utility and its customers were all one economic entity, it would be straightforward to compare the costs of high efficiency lighting or of some form of storage for peak shaving to those of expanding the generating capacity of the utility and to make a rational decision about which way to proceed. The fact that consumers and utility are different, however, complicates this process. The utility decides what to build on the basis of past and projected loads (and other factors, such as availability of funds or environmental constraints) while the consumers decide whether to conserve or not on the basis of the costs they perceive in the utility's rate structure. To the extent the rate structure distorts the costs actually incurred by the utility (and all rate structures do, to some extent) the ability of the customers to make decisions that are optimal from the perspective of the utility and the customers taken as a whole will be impaired.

The process of constructing rates which do transmit the true costs adequately to the ultimate consumers is a complex one which cannot be treated here in detail (see the books of Kahn, Bonbright and Caywood in the bibliography). We will simply review the principles of the process, delineate several common rate structures and discuss their advantages and disadvantages in a general way.

The first step is the definition of a variety of "classes" of customers, usually on the basis of size. Such a breakdown might group customers into residential, commercial, small industrial and large industrial users respectively, for example. For each such class one or more of the rate structures to be

described below is offered, but before proceeding to that discussion, I would like to emphasize the importance of allocating costs between classes in proportion to the costs of providing services to that class. If, for example, the industrial sector is overcharged for electricity while the residential sector is undercharged (perhaps as a result of political pressure), residential consumers will have insufficient incentive to conserve, thus forcing the utility to operate in an uneconomic manner, and they will pay for this electricity anyway when they purchase the output of the industry. Conversely, if the residential sector is overcharged to subsidize the industrial sector (perhaps as a result of political pressure), industries will have insufficient incentive to economize and the resulting diseconomy in the operation of the utility will ultimately cost all parties more. The mechanics of equitable allocation of costs between classes is a complex and not entirely closed question which is dealt with in the above-mentioned texts; the importance of doing it as well as possible if cost-effective levels of conservation are to be achieved cannot be over-emphasized.

As an aside, this does not mean that subsidies must be ruled out, only that they must be made explicit. It may be that the ony way to promote rural electrification, which many view as an important part of the development process, is to offer rural villages a modest amount of electricity for free or for a small and symbolic rate. The advisability of such subsidies must be determined on a case specific basis; my point is only that if they are deemed advisable, the subsidy should be a visible item

129

in the budget of some appropriate agency, not a hidden tax on other consumers, no matter how attractive the option may appear politically.

Within each class, various rate structures may be offered. The simplest, no longer in use in developed countries except for the particularly well defined case of street lighting, is simply to establish a monthly charge based on the number of lightbulbs or outlets a customer has. This eliminates the cost of metering, but constitutes such a strong incentive for theft of power (by installing but not reporting other appliances) that it has fallen into almost total disuse. Note that this is a perfect example of a system which fails to give the consumer any information concerning the cost of the power being consumed.

A similar system has proven very uneconomic in large apartment buildings in the U.S. Here the consumption of the entire building is metered and paid for at wholesale rates, but the individual apartments are not metered; rather the monthly bill for the entire building is simply divided among apartments, so that users of small amounts of power help to pay for the consumption of large users. This situation actually constitutes an incentive to consume more power, and in the recent conversion of a New York City building to individual apartment "submetering", electricity consumption dropped 15-20% as individuals became directly responsible for their own consumption.

It is not surprising, then, that it has become common for individual residential consumers to pay rates based on the use of a simple integrating energy consumption meter. The tariff

incorporates a fixed monthly "customer charge" which pays for the capacity required to meet that customer's demand, the accounting costs associated with that customer and (sometimes) the first few units of energy consumed. To this is added an energy charge proportional to the customer's energy consumption that month. At one point in the U.S., "declining block" rates were popular, wherin lower and lower energy charges were assessed as the customer's monthly consumption increased; today it is widely accepted that if anything, larger amounts of electricity correspond to increased costs and these schemes are being phased out in favor of rates based on a constant energy charge.

Time of day rates which reflect to the customer the different costs of on-peak and off-peak energy are available to residential consumers in the U.S. and Europe, but their primary application is in electric space heating, an area of little interest in West Africa. Only if substantial residential demand for electrically produced hot water or central air conditioning (see the discussion of cool storage below) develops will time-of-day metering and rates become worthwhile for the residential sector. In the southwest U.S., electric loads dominated by air conditioning were lowered by seven to sixteen per cent after the introduction of time of day rates (1); this was due solely to changed habits, rather than the introduction of storage technologies or other technical improvements.

In the commercial and industrial sectors, however, the availability of time of day metering and cost based rates for on peak and off peak power could lead to the widespread

implementation of various end-use technologies which would slow the growth of peak loads in the short run and produce a more uniform load, which could be more economically served, in the long run. One example of such a technology, cool storage for off-peak airconditioning, will be discussed in detail in a later lecture; other possibilities include late night pumping of irrigation water (also attractive because of significant reductions in evaporation losses) and the re-scheduling of electrically intensive processes in industry or food processing.

The preceeding discussion was implicitly confined to consideration of time-of-day metering of energy consumption alone; at modest increase in the complexity of the metering equipment, the maximum power demanded during the billing period (or during some subset of the billing period such as on-peak or off-peak hours) can be measured and a "demand charge" assessed in addition to the energy charge. Such rate structures, to date usually without a time-of-day componant, are common in the industrial sectors of developed countries, and are already in use in some developing countries. Of course, compared to rates based only on measurement of energy, either the customer charge or the energy charge or both is reduced, so that for some "typical customer" there is no change in the monthly bill. But now the manager of a large building can examine the bill and determine that in fact a large part of the cost of electricity is arising from the fact that, for example, the air conditioners, refrigeration and water pumping unit all go on at once and create a very large demand for power. In fact the installation of a switch preventing the air conditioning from going on when the

132

pumps are running would cost a minuscule amount compared to the potential savings, and with a tariff incorporating demand charges (and an explanation of how they work) the building manager has a strong incentive to take action. The utility will benefit immediately both because they can run inefficient peaking units less often and because the lowered peak load will increase system reliability. (This was a particularly simple example; microcomputer based "load management systems" which keep track of many different systems at once and establish priorities for operation are available for factories or large buildings.)

An important factor to consider in defining rate structures is the cost of metering. Meters range in price from $50-100 (CFA 17500-35,000) for a device measuring only energy to ten times that for a sophisticated digital meter capable of measuring reactive as well as resistive power and energy in each of several time-of-day catagories. The only sure thing is that the advance of digital electronics will bring the cost of sophisticated metering down, probably very quickly over the next few years. Currently, however, separate demand metering is probably not a worthwhile effort in the residential sector, due to the combination of its added cost, the added cost of collecting the data, the small size of residential bills and the likelihood that homeowners would not have the expertise or inclination to perform the type of load management described above. As a rule of thumb, however, both demand metering and time-of-day metering will prove worthwhile in a broad spectrum of commercial and industrial applicatons.

137

DIRECT UTILITY INTERVENTION FOR END USE CONSERVATION

In an earlier sectoin of this lecture, five potential reasons for insufficient implementation of end use conservation of electric energy were presented. The preceeding discussion of rate structures was structured around the second reason and focussed on ways of getting sufficient information to the consumer to permit him or her to make decisions that would be reasonable from the perspective of both the utility and its other customers. The last three reasons for insufficient end-use conservation assumed that the consumer has sufficient information about the consequences of decisions but for other reasons - the small relative or absolute size of the potential savings and lack of information or education - still will not take action. Several approaches are possible. In the case of problem five (inadequate education), for example, obvious approaches such as poster campaigns or the inclusion of conservation awareness and education material in the utility bill can produce significant benefits if done thoughtfully, with both the interests and background of the customer kept carefully in mind.

Problems (3) and (4), however, represent an issue of substance, since life is short and one cannot reasonably ask consumers to spend unjustifiable amounts of time on what is to them a small problem; the only reason the utility can justify the time to analyse many conservation issues is because it can do so for many consumers at once. There are, however, many examples of small conservation initiatives which are (to the utility) well worth pursuing; we will examine in detail the value of reflecting plastic films which reduce air conditioning peak and energy loads

significantly when installed on east and west facing windows. For cases like this there is an approach which has met with substantial success in parts of the U.S., which is essentially for the utility to undertake and/or subsidize (in whole or in part) certain electricity conservation measures in the customer's premises even though these measures will lower the customer's electric bill sufficiently to have caused the customer to undertake the measures spontaneously in a more perfect world. The key point is that the rate structure and potential savings to the utility must be such that the savings to the utility exceed the decrease in the customer's bill by an amount sufficient to pay for the subsidy and leave a margin of advantage for the utility to share with its other customers.

How is this possible? The most well known case occurred in the Northwest U.S., where several conditions which are neither common nor unique obtained: 1) the average cost for electricity produced by the utility, which was also the price paid by residential consumers, was quite low due to the presence in the generation system of a great deal of inexpensive hydropower; 2) the total marginal cost of electricity from new generation capacity was quite high, perhaps twice the average cost, since no more hydropower was available and new nuclear or coal fired plants had to be built; 3) the load, which was largely space heating in poorly insulated houses, could be curtailed (by adding insulation) at a price per kilowatt hour saved that was substantially less than the total marginal cost of new energy but roughly equal to the lower average price per kilowatt hour seen

135

by the customers.

Thus there was little incentive for individual customers to insulate the buildings themselves - the savings would be small and slow in coming and they had other things on their minds. But when the utility installed the insulation it (and all the customers, not just those getting the insulation) saved the cost of building expensive new capacity that would have been required to met normal load growth at the (smaller) cost of providing free insulation to the least insulated homes in the utility's service area.

I will not provide the detailed economics of this particular example since they cannot possibly apply to West African situations. Consider, however, the case of reducing air conditioning loads by the application of reflecting films to west facing windows. In a later lecture, we will see that this can, under certain circumstances, reduce the peak power demand on the utility at a cost of 40-110 $/kW, substantially below the capital cost of new peaking capacity. (For the peak load reduction to actually occur, the peak must be largely due to air conditioning, and must actually be reduced by the conservation effort, not simply postponed an hour or so with a slight reduction in magnitude.) Since most developing country utilities are in demand-limited situations, anything that cuts peak loads and allows the postponement of capacity additions can lessen the financial pressure on the utility considerably.

If a careful case study shows that peak reduction will occur, the utility should give serious thought to distributing such reflective films to customers for free, including

instructions and projections of the savings that will accrue to the customer if the installation is carried out (getting the customer to provide the labor will ensure that the cost is at the low end of the range, near 40$/kW). Even in situations where the customers probably lack the necessary technical expertise, the utility may find it worthwhile to carry out the whole job themselves; in other cases, it may be possible for the utility and the customers to share both the costs and the benefits of the conservation retrofit.

Other technical innovations offering small individual savings and large utility impacts may be analysed in a comparable manner. The point I hope to have made clearly is that careful analysis of conservation options includes analysis from the perspective of all the players in the arena: individual customers, the utility and its management, and the group of all customers taken together, who ultimately pay the bills for the utility which supplies them with power.

NOTES

1) D.P.Lifson and A.K.Miedema, "A Comparative Analysis of Time of Use Electricity Rate Effects", Energy-The International Journal, Vol 6, p. 403, May 1981.

BIBLIOGRAPHY

Richard W. Leigh
Department of Energy and Environment
Brookhaven National Laboratory

I Cost Based Rates and Other Conservation Options for Electric Utilities

1) Constatantine W. Bary, "Operational Economics of Electric Utilities", Columbia University Press, New York, 1965.

2) J.C.Bonbright, "Principles of Electric Utility Rates", Columbia University Press, New York, 1969.

3) R.E.Caywood, "Electric Utility Rate Economics", McGraw-Hill, New York, 1972

4) Alfred Kahn, "The Economics of Regulation: Principles and Institutions. Vols. 1&2, Economic Principles", James Wiley and Sons, New York, 1970.

5) The Solar Energy Research Institute (SERI), "A New Prosperity: Building a Sustainable Energy Future", Henry Kelly and Karl Gawell, study directors, Brick House Publishing, Andover Massachusetts, 1981, Chapter 4: Electric Utilities.

6) R.Bright and R.Leigh, "Photovoltaics and Electric Utilities", Brookhaven National Laboratory, Upton NY, 11973, 1981 and to be published.

II The Potential of Building Energy Systems for Load Reduction and Load Levelling

7) SERI, op. cit., Chapter 1, Buildings.

8) Solar Products Specifications Guide, SolarVision Inc, Church Hill, Harrisville NH 03405, U.S.A. (This annual publication is a compendium of manufacturer's specifications for a wide range of solar and conservation equipment.)

9) Energy Users News,Fairchild Publications, 7 East 12th St, New York NY 10003. (A weekly newspaper for energy managers and professionals, contains very up-to-date information on conservation technologies for large facilities.)

10) George Polimeros, "Energy Cogeneration Handbook", Industrrial Press, Inc., 200 Madison Ave, New York NY 10157.

11) "Cogeneration", Pequot Publishing Co., 654 Hillside Road, Fairfield CT 06430. (A bimonthly trade magazine)

"PREVENTIVE MAINTENANCE IN THE ELECTRIC POWER SECTOR"

Presented by
Paul H. Shoun, Chief, Operations Planning Staff
Tennessee Valley Authority
USA

to the Seminar on
"Energy Efficiency and Conservation"
Deux Feurier Hotel - Lome, Togo-Africa
March 30-April 8, 1983

Seminar Cosponsored by:	The Commission on Transport, Telecommunications and Energy of the Economic Community of West African States (ECOWAS) and the Office of Energy of the United States Agency of International Development (USAID)
Hosted by:	The Togolese Ministry of Public Works, Mines, and Energy
Organized by:	The Energy Management Training Program (EMTP), a joint project of Brookhaven National Laboratory and the Institute for Energy Research of the State University of New York (Stony Brook)

139

PREVENTIVE MAINTENANCE IN THE ELECTRIC POWER SECTOR

Executive Summary

For the past five years I have been a member of a five-man team critiquing electric power disturbances in the U.S. and Canada. I am presently chairman of the Disturbance Analysis Subcommittee (formerly known as Reliability Issues Task Force) which serves under the Operating Committee of the North American Electric Reliability Council (NERC). In September 1981 we published our second report analyzing major power outages which occurred during the period January 1, 1979-December 31, 1980. (See attachment 1.) Since then we have been updating the disturbance analysis data for the continental grid on an annual basis.

In those 1979 disturbances, lack of adequate maintenance or poor maintenance practices was the second most prominent cause of system outages in those cases studied. We suspect that poor maintenance practices represent an increasing exposure to additional system malfunctions and outages. Fortunately, for the North American power grid maintenance performance has improved considerably since 1979 when this subject was emphasized. However, in future years as utilities find themselves hard-pressed for operating funds, the temptation is to cut maintenance. When a utility's cash flow is short the first place many budget people turn to is the maintenance account. This happens because preventive maintenance is something that can be temporarily delayed. Also, it happens because few people in administrative management really understand the value of maintenance. Further, there is always a considerable time lag before the consequences begin to show.

It was the San Francisco longshoreman, Philosopher Eric Hoffer, who a few years ago best emphasized the value of maintenance. In an interview with Eric Severeid, of CBS, Mr. Hoffer was asked how he had so accurately predicted the recovery of Germany and Japan following World War II. Mr. Hoffer replied, "that was easy, I was familiar with their capacity for maintenance. I had studied their maintenance records. Show me a country or a company that has a good maintenance capability and I will show you a country or a company that will succeed."

A good preventive maintenance program is the key to a safe and reliable operating utility. A good maintenance program will also contribute signficantly to energy efficiency and conservation. Such a program must fit into the whole concept of building and operating a power system. In order to be successful, a preventive maintenance program should have at least five major ingredients: Good planning and design, good construction and installation, good inspection and test, good operational checks and scheduled maintenance, and good documentation and recordkeeping. In TVA we have our best engineers, technicians, and craftsmen assigned to the operating and maintenance (O&M) forces. It could be said that a power system plan designed without emphasis on O&M is no design at all. Certainly O&M needs should be paramount in planning and designing any power system component. Assuming that a good system plan is developed and that good detailed engineering follows, it is then essential that the facility be constructed accordingly. If the quality of workmanship or installation is not adequate, it is imperative that a system of inspection and test be

devised to detect those flaws and discrepancies. A good field inspection and test organization can make up for a lot of mistakes and, if necessary, can redesign and reinstall to make the various components work together in a system configuration like it was conceived to work.

Once installed, properly tested, and certified for service, it is essential that a schedule of routine tests, inspections, and operational checks be implemented. Proper maintenance must be performed to keep the equipment in good operating condition. Experience is the best teacher when trying to determine the optimum interval for operational test and routine maintenance to assure system component reliability.

Last and equally important is the necessity for good documentation and recordkeeping. The larger the organization the more essential and more valuable data recordkeeping really is. Component failure and system outage data should be communicated so that system planners and designers can have constant feedback on equipment performance, component failure, etc., so that systems can be planned better and designed better.

There is no substitute for a good preventive maintenance program and this subject deserves the highest order of priority on the part of every electric utility. It is the least expensive and most cost effective effort a utility can have.

PREVENTIVE MAINTENANCE IN THE ELECTRIC POWER SECTOR

An effective preventive maintenance program is a form of operational quality assurance (QA) program and as such is one of the key elements of safe and reliable utility operations of any kind. A comprehensive program is rooted in good design and construction practices which recognize that all types of equipment require some types of maintenance. After equipment has been installed, tested, and certified for service, the program includes a schedule of routine inspections, tests, and operational checks to detect incipient failure conditions which would prevent proper operation. The program includes good documentation of the inspection and test procedures to be followed by maintenance personnel, results of the work performed, and the dates when work was performed and is next scheduled. Lastly, the program includes feedback of information on actual equipment performance to system planners and designers so that future facilities can be made more safe, reliable, and economical. Good documentation and recordkeeping of equipment performance, inspection, and maintenance performed are essential.

One of the few phases of any utility's operations that is not directly impacted by legislative or judicial actions, intervention by environmental and "public interest" groups, or even by its own customers, is that of its preventive maintenance programs. For all practical purposes, it is master of its own destiny in this phase of its operation. It can maintain that degree of maintenance which it believes necessary for safe and reliable operation of its system. That degree may, however, be influenced significantly by the utility's short-term financial position.

If you are considering development of a preventive maintenance program for the first time, here are some of the fundamentals you might like to consider:

Preventive Maintenance (PM)--PM in the literature is variously written about as a simple procedure and a complex, sophisticated maintenance program. The reason is quite simple--PM can be either. The intensity of the program should be dictated by reliability, availability, and life-cycle cost considerations. To help you address PM within your requirements, let us cover the fundamentals of PM briefly. Whether you are involved with a power system, an individual plant, or any other institution or enterprise, the same basic principles apply.

<u>What is PM</u>?--PM is the planned, systematic repair or replacement of selected components to achieve the established goals and objectives of the program.

<u>Is PM necessary or justifiable in your activity</u>?--To answer this question, one must do a thorough review of several facets of the maintenance and operations requirements of the equipment or system in question.

1. What <u>exactly</u> is the ultimate objective of the plant, system, or component in question?

   It is obvious that the dependability of an emergency generator for a hospital is more critical than the same equipment that is on a construction site. The former can be life supporting--the latter a matter of economic concern. Not all distinctions are as clear. Therefore, the analysis should strive to identify the precise end

function for the plant, system, or equipment under study. Remember, 99-percent reliability can cost 5 to 10 times as much as 80-percent reliability.

2. What exactly is the expected consequence of an untimely failure?

   The answer to this question is perhaps the key to determining the intensity of PM. If every critical component has an in-line spare, PM is not as important as on a single critical component. The economic consequences of failure may far outweigh the costs of preventing failure.

3. When failure occurs, what is the "allowable" turnaround time to resume operation?

   The "allowable" turnaround time dictates the requirements of redundant design, spare inventory, and PM cycle.

If need is established, how is the program developed?

I. Once the need for a program is established the research of specific data for each major component can begin. The ultimate list of data for each component will be the product of numerous revisions, but it should include the following.

   A. Nomenclature--Describe the equipment by its critical "pedigree," e.g., motor, G.E., T.E.F.C., 350 Hp, 3 phase, 480 V, model number, serial number, etc.

   B. Service and environmental data, e.g., pulverizer motor, fine dust and ambient temperature of 150°F, 2 shift, five-day operation, etc.

   C. Location--Physical and system, e.g., pulverizer A-4, elevation 481, NW. corner, etc.

   D. Critical operating and maintenance data--This data can be a few lines of information for the mechanic or a copy of a several-page technical procedure.

   To begin a PM program, few things can beat an index card system. Many well-defined systems have failed because of automation before maturity.

II. Once the equipment is adequately identified, the next step is the accumulation of failure and repair history for each component to be included in the program. These records will be valuable in determining initial inspection/repair cycles and to help the craftsman in diagnosis of equipment malfunctions.

   The next piece of data needed is manufacturer's recommended service cycle. If this information is not available onsite, contact the vendor. These recommended cycles serve as an excellent starting point, but later equipment performance and operating experience are the best teachers.

III. Determine the inspection/repair/replacement cycle. The resultant plan must address the following constraints:

A. Maximum operation between inspections
B. Warranty considerations (if any)
C. Mean time to failure from analysis of equipment history and vendor material

IV. Levelize the requirements into a workable schedule.

It is amazing the number of quarterly, monthly, semi-annual, and weekly inspections that are scheduled for the first week of July!

One approach to leveling a schedule is to add the total annual hours of craftsmen's time required for each job. Add all the total jobs together and divide by 12. Then manually distribute index cards into 12 "piles" until the schedule is about equal. Then a special crew can be assigned PM work after the schedule is leveled on an annual basis.

Installing the Program--While the mechanics of designing the PM program are straightforward, selling the program to management and labor may not be. Management may require an engineering analysis to show how a return on the initial expenditure can be returned. There will be questions of why maintenance costs go up initially. Answering these and other valid management concerns will require you to do a thorough job of analyzing past performance, estimating costs (both direct and consequential), and making predictions as to future performance.

Selling the maintenance department will require finesse, perseverance, and human relations skills. After all, "they" have been doing things for a long time without a PM program so why start one now?

Nurturing the Program--Good PM systems are not self perpetuating! They will die and wither from inattention. The successful PM program is dynamic, constantly improving from feedback. If it does not receive sufficient attention, it will not survive more than a few months.

Examples of TVA Maintenance Programs Included in Attachment

TVA, like most good electric power operations, places a lot of emphasis on preventive maintenance in its diversified programs. Since there are so many different maintenance programs it would be impossible to discuss any one of them in any depth in a short seminar presentation. Therefore, for your follow-up study, I am including attachment 2 (Tennessee Valley Authority's Maintenance Program - Our Successes, Failures, and Future Plans) as an example of what one of our major maintenance programs in power operations is all about. We have included with the attachment some of the maintenance and test schedule intervals but because of space requirements have not included the dozens of reporting forms used to document maintenance needs and findings.

Certainly in these days of high fuel cost and harsh economic times we need to get more utilization out of existing facilities, therefore, preventive maintenance offers one of the best tools to achieve this objective.

PHS:VTH
3-2-83

INDUSTRIAL ENERGY MANAGEMENT

Background Material Prepared for a
Seminar on Energy Efficiency and Conservation

Lome, Togo

April, 1983

Barry G. Tunnah

Prepared with funding from the Office of Energy
U. S. Agency for International Development
under Contract No. IQC/PDC 1406-I-00-2175-00

Energy/Development International
100 North Country Road
Setauket, N.Y. 11733
U.S.A.

E/DI Europe, Ltd.
8 Cavendish Place
London W1M 9DJ
England, U.K.

145

TABLE OF CONTENTS

SESSION ONE	-	INTRODUCTION
SESSION THREE	-	ROLE OF ENERGY EFFICIENCY Case study: The Tunisian project Visits to industrial plants in Togo
SESSION FIVE	-	ENERGY CONSERVATION PERSPECTIVES Training programmes
SESSION SEVEN	-	ANALYZING ENERGY EFFICIENCY IN THE INDUSTRIAL SECTOR Energy audits, conservation measures Use of microcomputers for energy management work
SESSION NINE	-	FIELD TRIP Planned visit to Phosphate complex
SESSION THIRTEEN	-	ECONOMIC ANALYSIS OF ENERGY EFFICIENCY MEASURES Use of microcomputer for DCF calculations

APPENDICES

SESSION ONE: INTRODUCTION

1. INTRODUCTION

In many developing countries, industry represents the most important consumer of imported petroleum products and of electricity. Industry may also consume significant quantities of non-commercial fuels, such as wood and charcoal. The potential benefits of improving the efficiency of use of energy by industry can therefore be very important in developing countries. The rational use of energy will often provide an opportunity to reduce energy imports, to save scarce foreign currency, and thus to accelerate the development process overall.

There is a common misconception that, because developing countries consume relatively little energy compared with the industrialised countries, this energy must continue to be used for essential development purposes, satisfying basic human needs, raising the standard of living of rural populations and initiating industrialisation programmes. In fact, the mere existence of a low level of consumption provides no guarantee of a high efficiency of energy use. Significant energy wastage can, and frequently does, occur in developing countries. All uses of energy, whether viewed as "essential" for basic human needs or not, warrant close examination.

It is therefore important that developing countries be encouraged to examine industrial energy consumption at the plant level, to identify actions needed and to establish priorities for the training of manpower and the investment of capital. The emphasis should be on immediate action to improve energy efficiency in the factories, including basic training for local engineers in the principles and practice of energy conservation.

Properly carried out, energy management programmes will result in reductions in the level of energy consumption in particular processes or factories, but note that lowering overall national energy use is not necessarily the objective. Rather, energy management seeks to make each unit of energy input produce more in terms of the output of useful work, thereby freeing incremental energy supplies for purposes related to economic expansion and development.

2. POTENTIAL BENEFITS OF CONSERVATION

To get some idea of the levels of improvement in energy efficiency which are possible, the progress in the U.S.A. serves as an example. Energy efficiency improvement targets were developed for energy intensive industries for the period from base year 1972 to January 1980, and these ranged from 9 to 24%. The targets were estimated for each industry to include both technically and economically feasible conservation measures. The equivalent target for the ten industries as a whole, calculated as a weighted average of the individual targets, was about 14 percent. By the end of 1979, the improvement actually achieved by the largest consumers in the energy-intensive industries was 15.4%, with some industries already reporting much greater improvement than their 1980 target:

Industry	1980 Target %	Progress reported by end 1979 %	Difference
Chemicals	14	22	+8
Primary metals	9	8	-1
Petroleum refining	12	15	+3
Stone, clay, glass	16	13	-3
Paper	20	17	-3
Food processing	12	15	+3
Fabricated metals	24	22	-2
Transportation equipment	16	23	+7
Machinery	15	25	+10
Textiles	22	18	-4

Over the same period, growth in output rose about 17%, but energy efficiency improvements were sufficient to "offset" this increase to such an extent that the absolute level of energy consumption by the companies reporting in the ten major industries was actually lower in 1979 than 1972. In absolute terms, the savings represent a saving of over 1 million barrels of oil per day, valued at over $9 billion dollars per year for the reporting corporations.

These energy efficiency improvements have been attained primarily through the application of no or low cost conservation measures. These actions range from the initiation of energy management awareness programmes to relatively low cost

improvements, such as the use of insulation in process equipment and the installation of improved fuel use controls on boilers and other energy-intensive process equipment.

In the United Kingdom, some industries have set their own voluntary targets, and many data are available on individual company successes. For example, over the ten years from 1971 through 1980, Imperial Chemical Industries (ICI) has reduced energy use per unit of output 35%, 10% having been achieved since 1978. Pilkingtons, the glass manufacturers, improved energy efficiency by 20% between 1974 and 1980.

The U.K. has been perhaps the most successful country in encouraging the appointment of energy managers in factories. Over the last seven years, the government has vigorously promoted the energy manager concept and there are now over eight thousand energy managers divided into over seventy regional groups with a national coordinating committee.

As a final example of the national potential for improved energy efficiency, we may examine briefly the results obtained from a recent study in Tunisia(1); the study will be discussed in detail later. Among the findings of the study, a widespread lack of careful energy accounting and a resultant lack of awareness of the possibilities for energy saving were apparent. There was rarely any focus for energy data, energy conservation and energy management. It was clear that much improvement in energy efficiency can be achieved with little or no investment. The potantial for improvement obviously varies from plant to plant, but typical improvements of 15 to 20% should be achieved within two years through a combination of better management and moderate capital investment.

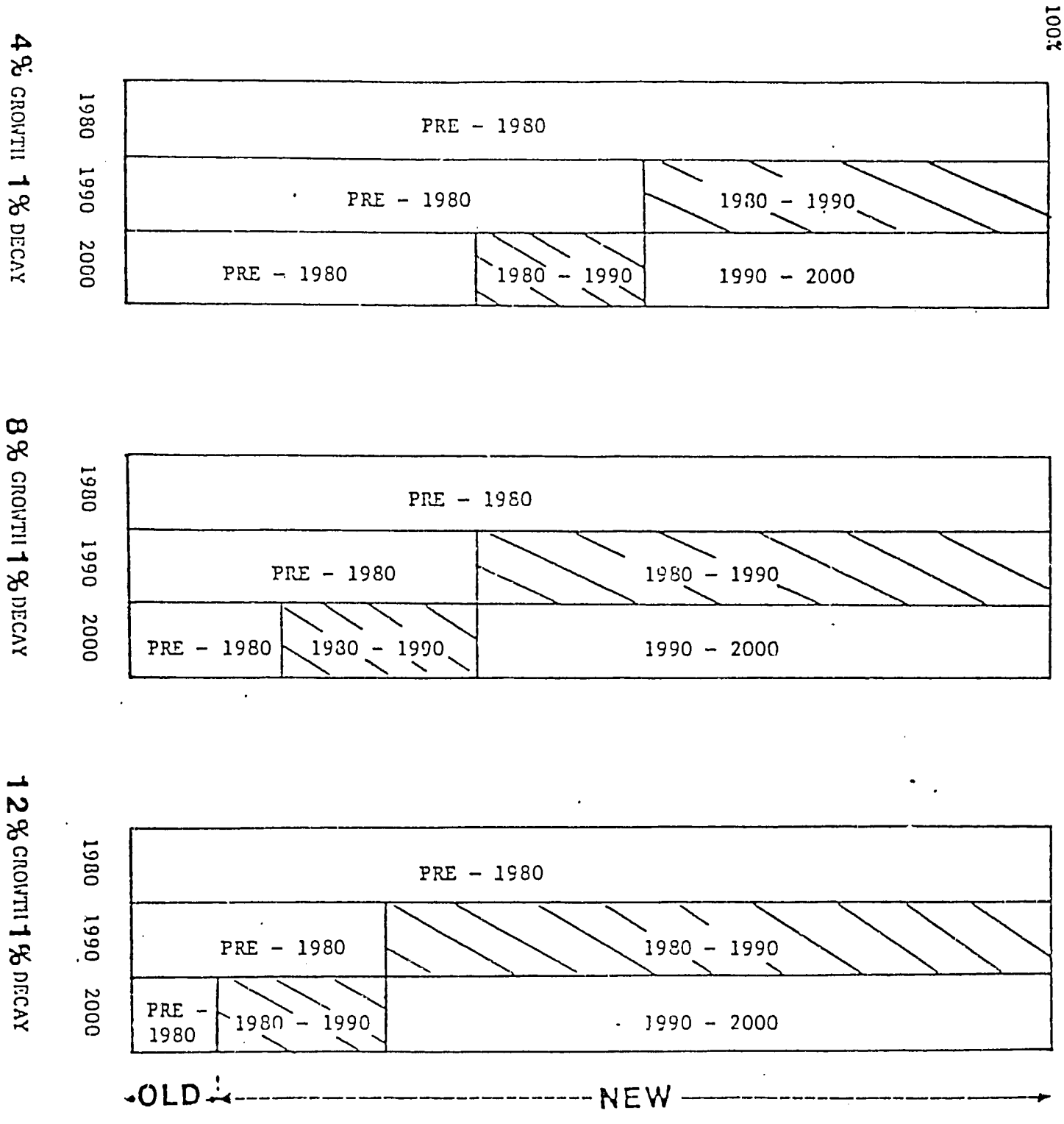
We should also note that, for most countries, the impact of new plant commissioning can be very significant. There is a need for attention to be paid in developing countries to the energy efficiency of new plant designs, which can often contribute much greater savings to the economy than savings achievable in the existing plants. This is evident, when we examine the contribution to industrial sector output of new plants over the next 20 years, as illustrated in Exhibit A.

---

(1) Industrial Energy Study for Tunisia; Final Report, September 1982, by E/DI Europe Ltd. for USAID and the Ministry of National Economy, Tunis.

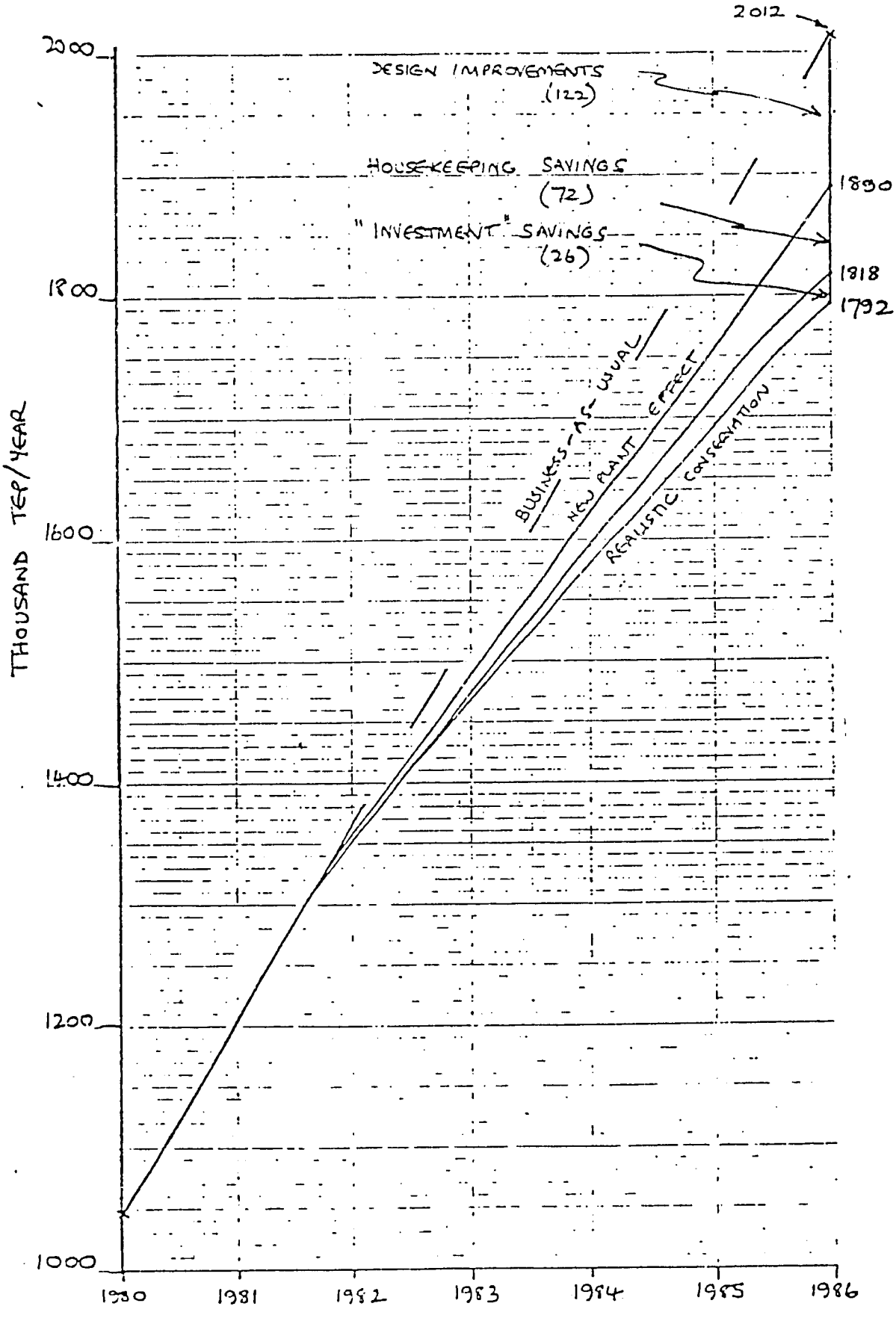
EXHIBIT A

AGE DISTRIBUTION OF PLANTS



The potential for savings in Tunisia is illustrated in Exhibit B. The cumulative savings from 1982 through 1986 from energy management efforts in existing plants alone is valued at about 50 million dollars at world market prices. The resources for promoting better energy management, in terms of manpower and equipment, which can be justified by the 50 million dollars are clearly substantial, but without a major effort to focus attention and action on energy problems, the undoubted potential for conservation will not be realised. In our experience, this situation is typical for many developing countries.

EXHIBIT B : PROJECTED DEMANDS



3. OVERVIEW OF THE SEMINAR

The Seminar will concentrate on the role of energy management in the industrial sector, and will also consider the possibilities in other sectors, such as buildings, transportation,and the electric utility sector.

Session Two will introduce the problem areas relating to energy demand in West Africa, and will review the demands for electricity, oil and non-traditional fuels, especially with respect to imports of energy. A panel discussion will follow the formal presentations.

Session Three will present the results of prior work in the field of industrial energy management in a number of developing countries to illustrate, through actual studies, the potential benefits of effective energy management. Session Four will continue with case studies in the transport, buildings and electric utility sectors.

Session Five is a review of the barriers and incentives connected with energy conservation, and will include discussion of such issues as energy tarification, regulatory aspects, technical information, training programmes. capital requirements for investments, etc.

Session Six will cover the role of the donor agencies in supporting energy conservation projects, and a panel discussion will follow the formal presentations.

Having introduced the topic of energy conservation thoroughly, and having reviewed some of the policy-related factors which can effect conservation programmes, Session Seven will go into the details of industrial plant energy audits, and will illustrate the procedures used to establish energy use patterns and to identify energy conservation opportunities. Examples of the use of micro-computers for energy management work, both for data base storage and handling and for engineering calculations, will be given. Session Eight will continue this theme.

In order to reinforce the audit techniques and procedures covered in the previous sessions, Session Nine will consist of a field visit to the phosphate processing complex of OTP. The seminar participants will be divided into several groups and

will conduct practical audit work, such as collecting operating data on the plant itself, and measuring combustion efficiency and heat losses with portable instruments. A review of the field work will be conducted on the following morning.

Session Ten is to be devoted to a detailed technical discussion of the potential for energy efficiency in the electric utility sector, while Sessions Eleven and Twelve will deal with the detailed technical aspects of energy management in the buildings and transport sectors respectively. A field trip to demonstrate energy conservation in the buildings sector is being planned for Session Thirteen.

Session Fourteen will cover the economic analysis of energy efficiency measures at the micro level, including the use of microcomputers for calculations of the return on capital investments, and will also discuss the economics of conservation from a national perspective, thus linking the development of energy policies with economic analyses at the plant level.

The final session, Session Fifteen, will include discussion of the findings and recommendations of participants, and will be used to establish the consensus of opinions for follow-up action.

1. CASE STUDY: INDUSTRIAL ENERGY PROJECT, TUNISIA

The findings and conclusions presented here for Tunisia are used to illustrate the typical situation in developing countries, and are intended to show how energy efficiency may be improved through a properly structured study. The remarks are, in our experience, broadly applicable to many countries and are not unique to Tunisia.

1.1 Project Objectives

This project was carried out to assist the Government of Tunisia to improve their energy planning capability and to stimulate improved energy efficiency in the industrial sector. The basic objectives were:

(1) To improve the collection of industrial energy data, starting with the collection of basic data at the individual plant level, in order to provide accurate and timely data on which to base regulatory and investment policies and programs.

(2) To analyse data taken from selected plant audits with a view to identifying energy conservation opportunities.

(3) To train Tunisian personnel, in particular at the plant level, to perform practical plant energy audits and to implement in-plant energy efficiency improvements.

1.2 Industrial Conservation Training Courses

Two cycles of training courses were conducted for a total of 21 engineers from industrial plants, the state electricity and gas utility and the national oil company. The course consisted of lectures on industrial energy conservation principles and techniques, and a series of one day visits was made to industrial plants to reinforce the classroom lectures with practical demonstrations of the principles involved and of the use of portable diagnostic instruments. The Table of Contents of the Course Manual is shown in Exhibit C.

Exhibit C

ENERGY AUDIT TRAINING COURSE MANUAL

TABLE OF CONTENTS

PART I		Page
1	INTPODUCTION TO THIS PROJECT	1.1
2	ENERGY CONSUMPTION IN TUNISIA	2.3
3	BASIC PRINCIPLES OF ENERGY CONSERVATION	3.3
4	PLANT AUDITS	4.3
	A. Initial visits; objectives; data collection (forms); checklists; instruments; reports to be produced.	4.3
	B. Main audit visits; objectives; procedures to be used (audit questions, data forms and checklists); report to be produced.	4.5
PART II		
5	BASIC INFORMATION	5.2
	Alternative fuels and their characteristics; units; conversion factors and heating values.	5.2
6	ENERGY AUDITS	6.4
	A. The purpose of energy audits	6.4
	B. The scope of an energy audit	6.5
	C. The benefits of energy audits	6.8
	D. Instrumentation	6.9

		Page
7	BASIC UNIT OPERATIONS	7.1
	A. Combustion	7.3
	B. Heat transfer	7.19
	C. Evaporation	7.28
	D. Drying	7.35
	E. Distillation	7.39
	F. Boilers and steam systems	7.42
	G. Electrical demand	7.58
	H. Cogeneration	7.71
	I. Compression	7.77
8	PROCESS ANALYSIS	8.2
9	LIGHTING	9.2
10	SPACE CONDITIONING BUILDINGS	10.2
11	CHECKLISTS OF CONSERVATION MEASURES GENERALLY APPLICABLE	11.2
12	SPECIFIC INDUSTRY MEASURES AND TARGET SETTING	12.2
13	TYPICAL COMPANY CONSERVATION PROGRAMMES	13.2
14	ECONOMIC ASPECTS OF ENERGY CONSERVATION	14.2

157

1.3 Audit Work

An integral part of the training effort was the conduct of audits in selected plants by the Tunisian engineers themselves. The participants were divided into small groups of 4 or 5 engineers and these groups carried out specific tasks in the plants, such as performing heat and material balances around kilns, furnaces and boilers. At all times, the training of the engineers was given an equal priority to the identification of energy conservation opportunities. Full reports of the audit work were prepared and the findings discussed with representatives of the plants. In all plants, it was possible to develop recommendations for immediate action to improve energy efficiency.

1.4 General Findings of the Audit Work

Several comments may be made regarding energy management in general, as observed in the broad range of industrial facilities visited. With some notable exceptions, the general standard of energy consumption monitoring and energy management was poor; closer control of operations could lead to significant energy savings in the short term. In general:

(1) There is a widespread lack of careful energy accounting, and a resultant lack of awareness of the possibilities for energy saving

(2) Where data are assembled regularly, reports are often incorrect, inconsistent and incomplete; there is a need for rigorous checking of all data

(3) Important energy-related data are often missing and no attempt is made to relate energy consumption to production, a fundamental pre-requisite for improving efficiency

(4) There is a need for top management to demonstrate a firm commitment to energy efficiency

(5) Energy and production data are often quoted in diverse units and confusion between such units as litres and kilogrammes, cubic metres and tonnes, etc., can often occur. In some cases, data records are kept without quoting units, which can lead to further

confusion. It is recommended that complete energy reports be prepared regularly with all energy consumptions converted to a common unit for comparison purposes (e.g. kilocalories, TEP, etc.)

(6) On occasions we observed a surprising degree of confusion about the grade of fuel oil used and its calorific value. Quality control of fuel purchases appears non-existent, and control of the quantity of fuel delivered often leaves much to be desired.

(7) When asked about equipment performance or efficiency, plant personnel often quoted design data and were unable to quantify with any certainty the current situation.

(8) Accurate measurement is essential to establish the priorities for energy efficiency improvement but the standard of instrumentation for measuring important flows and temperatures is generally poor.

(9) A questioning attitude by the plant engineers is generally absent and an analytical approach to energy data is lacking.

(10) A regular, comprehensive and reliable monthly report on energy consumption should always be prepared in a format which will allow comparisons to be made on energy efficiency from one month to the next.

(11) A significantly improved standard of maintenance and housekeeping is necessary in many of the plants to improve the operating performance and to contribute to improved energy efficiency. Safe and clean working conditions are essential for efficient plant operation.

(12) There appears to be a general lack of qualified engineering personnel to identify and implement energy efficiency measures.

(13) There is a general lack of information on basic calculations and standard engineering data.

(14) Above all, there is a widespread lack of focus for energy data, energy conservation and energy management. There is a need for a clear definition of responsibilities for energy matters and it is recommended that an energy manager be considered for all the plants.

It is most important to appreciate that the findings listed here for Tunisia are quite typical of our observations in a number of developing countries, and indeed are often found to apply to developed countries too. The findings are by no means applicable only to Tunisia: the situation is frequently worse in many countries.

1.5 Specific Findings for the Plants

Specific findings and recommendations were discussed fully in a series of comprehensive reports of audits carried out at the selected plants. The potential for improved energy efficiency obviously varies from plant to plant, but typical improvements of 15 to 20% should be achieved on average within two years through a combination of better management and moderate capital investment.

In some of the plants, a great deal of improvement could be made with little or no investment. For example, high excess air rates were frequently found on boilers, furnaces and kilns. In most cases, we believe that simple adjustments could save as much as 10% of the fuel. In many plants, a poor standard of instrumentation contributes to poor energy efficiency.

The reports prepared for each of the seven plants include specific recommendations for improving operating efficiencies, such as improved instrumentation, additional insulation of hot lines and tanks, better control of fuel to air ratios, and the installation of waste heat recovery systems (see Exhibit D).

1.6 Energy Data Collection

To assemble comprehensive data on industrial sector energy consumption, it was decided to collect data on the supply side from the distributors of oil products, gas and electricity, and on the demand side from a total of 60 industrial consumers. Data on energy consumption and industrial production available from the national statistics institute (INS) were also examined. Examples of the data collected from plants are given in Exhibit E.

Exhibit D : Summary & Results - Tunisia

	HOUSEKEEPING	MINOR INVESTMENTS	MAJOR INVESTMENTS
STEEL	o Improve site cleanliness, safety o Initiate proper record-keeping o Appoint energy manager o Improve instrument and burner maintenance o Control combustion at boiler and furnaces	o Install automatic control on air/fuel for ladle heating (PBP < 2 years)	o Install stack gas recuperators on reheat furnaces (savings 12.5% PBP 2 years)
SUGAR	o Initiate monthly reports on energy consumption o Improve operation of fuel oil storage and handling system (e.g. better temperature control)	o Recover heat from boiler blowdown (PBP < 2 years) o Improve condensate recovery (PBP < 2 years) o Modify steam system to supply LP steam to deaerator	(none identified)
CEMENT (WET)	o Improve site cleanliness and maintenance o Initiate proper monthly energy monitoring (improve data reliability) and improve energy management o Reduce water content in slurry (20% savings) o Repair combustion control instruments	o Replace electric heating of fuel oil by steam heating (PBP 1 year)	(Plant is old and quarry reserves are limited; technology is outdated)
CEMENT (DRY)	o Improved format for monthly report o No focus for energy management	o Improve clinker cooler operation (PBP not established)	(Plant is new, with best modern technology)
BRICKS	o Initiate proper record keeping o No focus for energy management (appoint energy manager) o Reschedule plant operations (40-50% savings) o Remove one of two air fans o Reduce losses/breakage	o Recycle hot exhaust kiln gases to dryers (12% savings, PBP < 2 years) o Trials of supplementary ceramic fibre insulation (savings 4%, PBP 1 year)	(New plant, but lacks adequate instrumentation)
PHOSPHATES	o Reduce material losses o Improve maintenance and scheduling o Initiate proper record keeping o Study rail transport and potential losses o Improve control of fuel oil storage and handling	o Reduce water in filter cake entering dryer o Modify control system to control on direct measurement of phosphate exit temperature	(None identified)
PAPER	o Initiate proper record keeping o Improve maintenance o Eliminate steam leaks	o New burners for black liquor boiler o Insulation on steam lines, hot fuel oil lines, etc. o Improve condensate recovery	o Eliminate static letdown of steam at power plant; install new turbogenerator
BRICKS	o Improve cleanliness, maintenance o Reduce breakages o Initiate proper record keeping o Eliminate flue gas leakages o Improve boiler combustion control	o Modify wiring system to allow selective shutdown of motors, drivers o Modify kiln gas recycle to dryers to increase heat recovery	(None identified)

PLANT DATA

SUBSECTORS/PLANTS	PLANT NUMBER	OUTPUT DATA: YEAR	OUTPUT DATA: QUANTITY	OUTPUT DATA: PRIMARY PRODUCT	ENERGY CONSUMPTION DATA (TEP): ELEC.	NAT.GAS	GASOIL	FOD	F.O.LEGER	F.O. LOURD	OTHER	TOTAL ENERGY	SPECIFIC CONSUMPTION TEP/T
MATERIALS OF CONSTRUCTION													
Cement													
•	B	1980	436618 T	clinker	13450	-	-	-	-	74133	-	87583	0.201
•	A	1980	721350 T	clinker	23254	-	1139	-	-	66554	-	90947	0.126
•	G	1980	482500 T	clinker	22516	39892	689	-	-	-	-	63097	0.131
•	51	1981	769624 T	clinker	30316	-	780	-	-	68276	9	99391	0.129
			2,410,092 T		89,536	39,892	2,608	0	0	208,963	9	341,008	0.141
Bricks													
•	C	1980	97147 T	bricks	2312	-	204	-	-	6172	-	8688	0.089
•	07	1980	178223 T	bricks	3686	-	904	-	-	12353	-	16943	0.095
•	09	1980	155540 T	bricks	2272	-	579	-	-	5728	-	8579	0.055
•	F	1980	89302 T	bricks	1200	5346	534	-	-	-	-	7080	0.079
•	23	1981	55360 T	bricks	641	-	307	-	-	3131	-	4079	0.074
•	24	1981	55000 T	bricks	860	-	271	-	-	2609	-	3740	0.068
•	14	1981	n.a.	bricks	2391	-	-	-	2777	4576	1767	11511	n.a.
•	37	1980	39985 T	bricks	642	-	17	-	-	1571	-	2230	0.056
•	48	1981	30000 T	bricks	570	-	123	-	-	1761	-	2454	0.082
			700,557 T		14,574	5,346	2,939	0	2,777	37,901	1,767	65,304	0.077
•	35	1981	4500 T	ref.bricks	344	-	51	-	-	789	-	1184	0.263
Glass													
•	15	1980	17656 T	glass containers	1956	171	386	-	-	4520	1166	8199	0.464
Others													
•	03	1981	64500 T	lime	341	-	26	-	-	-	3082	3449	0.053
•	26	1980	56000 T	lime	345	-	37	-	-	-	2975	3357	0.060
•	25	1981	835000 M^2	tiles	771	-	122	300	-	4061	-	5854	(0.007 TEP/M^2)
•	34	1980	3600 T	porcelain	334	-	30	1714	-	-	-	2078	0.577
•	06	1980	131462 T	reinforced concrete prod.	826	-	148	28	-	1741	-	2743	0.021
•	22	1981	8209 T	plaster	169	-	90	-	-	210	-	469	0.057
•	28	1980	22100 T	asbestos tiles and pipes	956	-	-	385	-	-	-	1341	0.061
•	29	1981	28000 T	asbestos cement pipes	1015	-	47	-	613	-	-	1675	0.060
TOTAL SUBSECTOR ENERGY USE					111,167	45,409	6,484	3,027	3,390	258,185	8,999	436,661	

Exhibit E

SUBSECTORS/PLANTS	PLANT NUMBER	OUTPUT DATA YEAR	QUANTITY	PRIMARY PRODUCT	ENERGY CONSUMPTION DATA (TEP) ELEC.	NAT.GAS	GASOIL	F.O.D.	F.O.LEGER	F.O.LOURD	OTHER	TOTAL ENERGY	SPECIFIC CONSUMPTION TEP/T
CHEMICALS													
•	01	1980	70148 T	SSP & blended fertilisers	423	-	89	-	-	-	3	515	0.007
•	H	1980	317416 T	TSP	2159	-	-	-	-	22030	-	24189	0.076
•	38	1980	-	TSP, sulphuric, phosphoric acid & Fert.	2319	12063	158	133	-	-	-	14673	-
•	33	1981	418074 T	TSP	72	-	225	-	-	17130	-	17427	0.042
•	39	1981	514974 T	DAP	2547	12580	154	-	-	-	-	15281	0.030
•	40	1980	62611 T	MAP	571	707	-	-	-	-	-	1278	0.020
•	32	1980	59965 T	mix.fertil.	935	-	129	-	-	1966	-	3030	0.051
			1,524,033	mix.fert. and related prod.	9,026	25,350	755	133	-	41,126	3	76,393	0.135
•	41	1980	19730 T	alum.fluoride	1958	3072	63	-	-	-	-	5093	0.258
•	36	1981	-	indus.gases (oxygen, acetylene, CO_2)	1696	-	-	-	-	-	957	2653	-
TOTAL SUBSECTOR					12,680	28,422	818	133	-	41,126	960	64,139	
MECHANICAL, METALLURGICAL, ELECTRICAL													
Basic Steel													
•	D	1980	177937 T	steel billets (for rolling, etc.)	30933	-	414	4025	-	21629	76480	133481	0.750
Others													
•	31	1980	2847 T	elec.cables	534	-	8	100	-	-	1	643	0.226
•	19	1980	120000 units	gas bottles	216	-	-	-	-	-	64	280	(2.3 TEP/1000 bottles)
•	05	1980	19200 T	lead	1306	-	-	421	1580	-	5021	8328	0.434
•	04	1980	70338 units	household appliances	924	-	39	318	-	868	12	2161	(0.031 TEP/unit)
•	13	1980	8777 units	assembly of cars, trucks & buses	536	-	-	547	-	-	-	1083	(0.159 TEP/unit)
•	02	1980	2300 T	castings	192	-	28	154	-	-	322	696	0.290
•	42	1980	4787 T	iron & steel mouldings	1504	-	-	354	-	-	582	2440	0.510
•	44	1980	-	household fittings & ironmongery	1270	-	-	95	290	-	9	1664	-
TOTAL SUBSECTOR					37,415	-	489	6,014	1,870	22,497	82,491	150,776	

EXHIBIT E continued

SUBSECTOR/PLANTS	PLANT NUMBER	OUTPUT DATA YEAR	QUANTITY	PRIMARY PRODUCT	ENERGY CONSUMPTION DATA (TEP) ELEC.	NAT.GAS	GASOIL	FOO	F.O.LEGER	F.O.LOURD	OTHER	TOTAL ENERGY	SPECIFIC CONSUMPTION TEP/T
MINING													
•	J	1980	4328667 T	enriched phos. rock	40703	-	7852	1250	-	92150	-	141955	0.033
TEXTILES													
•	11	1980	13.6x10^{6}m	finish.textil.	106	-	-	191	-	5672	36	6005	(0.442 TEP/1000 metres)
•	12	1980	16.1x10^{6}m	denim textiles	2550	-	-	32	-	2490	193	5265	(0.327 "
•	43	1980	-	cloth&thread	2365	-	-	-	11	591	-	2967	-
TOTAL SUBSECTOR					5,021	-	-	223	11	8,753	229	14,237	
PAPER													
•	I	1980	23808 T	paper	15546	-	127	259	-	27301	-	43233	1.816
FOOD PROCESSING													
Dairy Products													
•	10	1980	41x10^{6}L	proces.milk, yoghurt	1657	-	316	13	-	1550	5	3541	(86 TEP/10^6 litres)
•	17	1980	56x10^{6}L	processed milk, cheese,yoghurt	1328	-	267	47	-	974	8	2624	(47 TEP/10^6 litres)
					2,985	-	583	60	-	2,524	13	6,165	(35 TEP/10^6 litres)
Baking,Biscuits													
•	20	1981	2210 T	biscuits	228	29	-	-	-	-	-	257	0.116
•	30	1980	3200 T (flour)	bread&cakes	24	-	51	101	-	-	-	176	(0.055 TEP/t flour)
					252	29	51	101	-	-	-	433	-
Sugar													
•	E	1980	60615 T	sugar	209	-	-	26	20	16296	509	17060	0.281
Drinks													
•	45	1980	-	beer,soft drinks, ice	1444	-	295	53	-	1758	43	3593	-
•	46	1981	1.8x10^{6}L	alcohol	59	-	28	19	-	827	4	937	
					1,503	-	323	72	-	2,585	47	4,530	
Others													
•	21	1981	539 T	chocolate	163	-	-	147	-	-	-	310	0.575
•	27	1981	3704 T	tomato concent.	141	-	-	-	-	657	-	798	0.215
•	47	1980	-	preserved fruits & tomatoes	147	-	171	-	-	999	-	1317	-
•	49	1980	73988 T	flour&semolina	1543	-	56	19	-	-	-	1618	0.022
•	50	1981	9291 T	couscous	492	-	-	-	21	978	-	1491	0.160
TOTAL SUBSECTOR					7,435	29	1,184	425	41	24,039	569	33,722	

EXHIBIT E continued

UBSECTOR/PLANTS	PLANT NUMBER	OUTPUT DATA			ENERGY CONSUMPTION DATA (TEP)								SPECIFIC CONSUMPTION
		YEAR	QUANTITY	PRIMARY PRODUCT	ELEC.	NAT.GAS	GASOIL	FOD	F.O.LEGER	F.O.LOURD	OTHER	TOTAL	TEP/T
MISCELLANEOUS													
•	08	1980	8200 T	misc. house-hold articles	1519	-	66	-	-	-	10	1595	0.195
•	16	1980	160000 units	tyres	802	-	-	-	24	1667	5	2498	(15.6 TEP/1000 units)
					2,321	-	66	-	24	1,667	15	4,093	

EXHIBIT E continued

1.7 Energy Use by the Industrial Sector

An examination of the data from plants and distributors shows that the sample of 60 plants represents a coverage of over 80% of the energy consumed in the industrial sector. For the fuels used by large factories, coverage was considerably higher: for heavy fuel oil, the sample represented 95% and for natural gas 98% of industrial sector use of the respective fuels, and somewhat less for electricity. (see Exhibits F and G).

An estimate of the energy consumed in the industrial sector was made for 1980, with the following result:

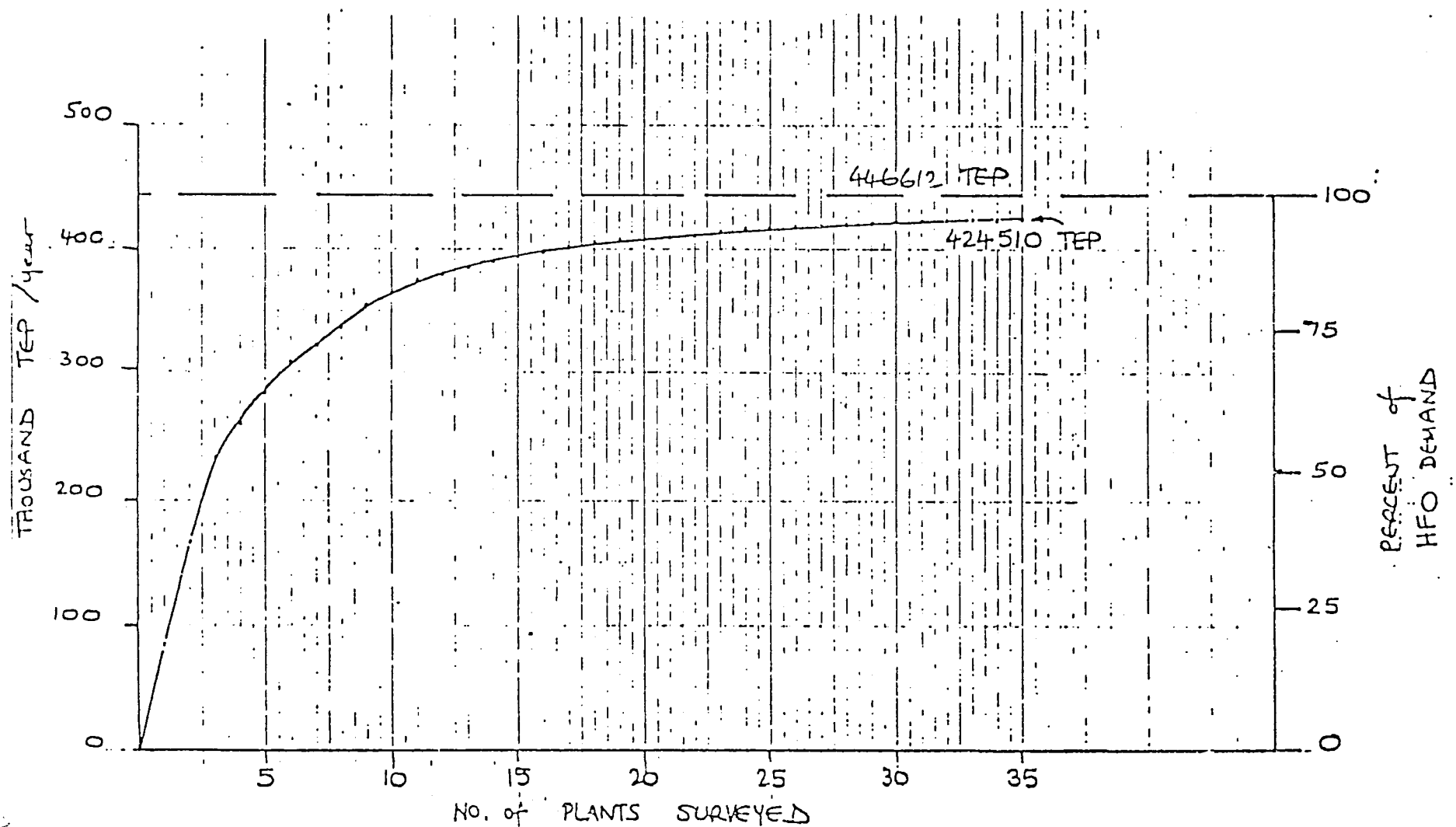
	10^3 TEP	%
Materials of construction	417.1	39.8
Chemicals	96.4	9.2
Mechanical, metallurgical, electrical	166.1	15.8
Mining	178.9	17.1
Textiles	42.9	4.1
Paper	44.7	4.3
Food Processing	89.3	8.5
Miscellaneous	12.1	1.2
	1047.5	100.0

It was also estimated that industry represents at least one third of the national consumption of commercial fuels, and between 25 and 30 percent of the total national energy demand.

Although the plant survey covered the 60 largest plants, the energy patterns derived from this project are believed to represent the sector as a whole. In any case, it may be concluded that policy initiatives and plant-level work aimed at relatively few large energy consumers could have a significant impact on the national energy situation. Policies and programmes for improving the efficiency of the major energy consuming plants should receive a high priority.

The percentage of selling price represented by the cost of energy was calculated for major products (see Exhibit H). Other types of data analysis were carried out; for example Exhibit I shows a table of energy consumption and output per employee, which can be used as a guide for national planning purposes.

Exhibit F : HEAVY FUEL OIL CONSUMPTION – CUMULATIVE.



BT 10.9.82

Exhibit G : Cumulative Electricity Consumption.

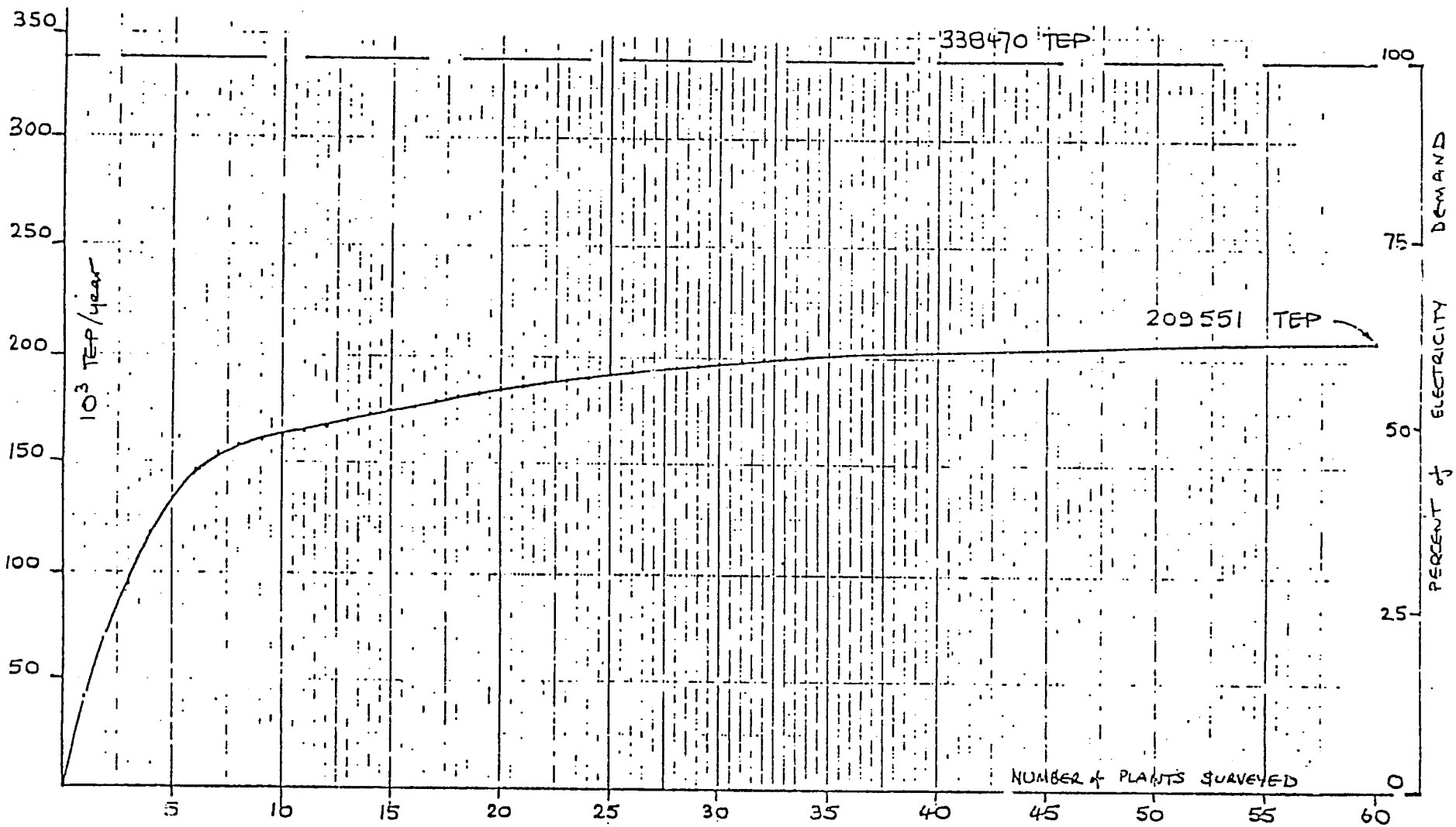


EXHIBIT H

ENERGY COSTS IN RELATION TO PRODUCT PRICES

Products	Energy cost/selling price (%)
Steel (reinforcing bars)	35
Lime	31
Plaster	28
Cement	24-25
Bricks	24
Glass bottles	18
Paper	17
Enriched phosphate rock	12
Sugar	8
Couscous	7
TSP	5
Milk	3
Bread	3
Tomato concentrate	3
DAP	2
Household appliances	2
Textiles	2
Flour	1
Camionette	0.3

Source: E/DI Europe Ltd., based on data from Tunisia (1980,1981)

Exhibit I

ENERGY CONSUMPTION AND OUTPUT PER EMPLOYEE

	EMPLOYEES	ENERGY CONSUMPTION TEP/EMPLOYEE	OUTPUT PER YEAR, TONNES/ EMPLOYEE
I MATERIALS OF CONSTRUCTION			
Cement			
•	650	135	672
•	650	140	1110
•	540	117	894
•	511	194	1506
	2351	145	1025
Bricks			
•	220	39	442
•	500	34	356
•	250	34	622
•	250	28	357
•	145	28	382
•	173	22	382
•	700	16	N/A
•	96	23	417
•	150	16	200
	2484	26	393
•	105	11	43
Glass			
•	508	36	35
Others			
•	150	23	430
•	130	26	431
•	278	21	-
•	283	7	13
•	1130	2	116
•	96	5	86
•	310	4	71
•	150	11	190
II CHEMICALS			
•	230*	2	305
•	570	42	557
•	600	24	-
•	490	36	853
•	110	28	545
•	555	28	928
•	75	17	835
•	141	36	140
•	170	16	-

*Includes seasonal workers

170

Exhibit I (continued)

	EMPLOYEES	ENERGY CONSUMPTION TEP/EMPLOYEE	OUTPUT PER YEAR TONNES/ EMPLOYEE
III MECHANICAL, METALLURGICAL, ELECTRICAL			
Steel			
•	2400	56	74
Others			
•	174	4	16
•	420	1	-
•	530	16	36
•	1000	2	-
•	1600	1	-
•	404	2	6
•	580	4	8
•	900	2	-
IV MINING			
•	13500	11	321
V TEXTILES			
•	700	9	-
•	970	5	-
•	950	3	-
	2620	5	
VI PAPER			
•	1700	25	14
FOOD PROCESSING			
Dairy			
•	327	11	-
•	435	6	-
Baking, biscuits			
•	128	2	17
•	48	4	-
Sugar			
•	435 (1)	39	139
Drinks			
•	970	4	-
•	56	17	-
Others			
•	64	5	8
•	108	7	34
•	300	4	-
•	220	7	336
•	69	22	135
VIII MISCELLANEOUS			
•	330	8	-
•	270	6	30

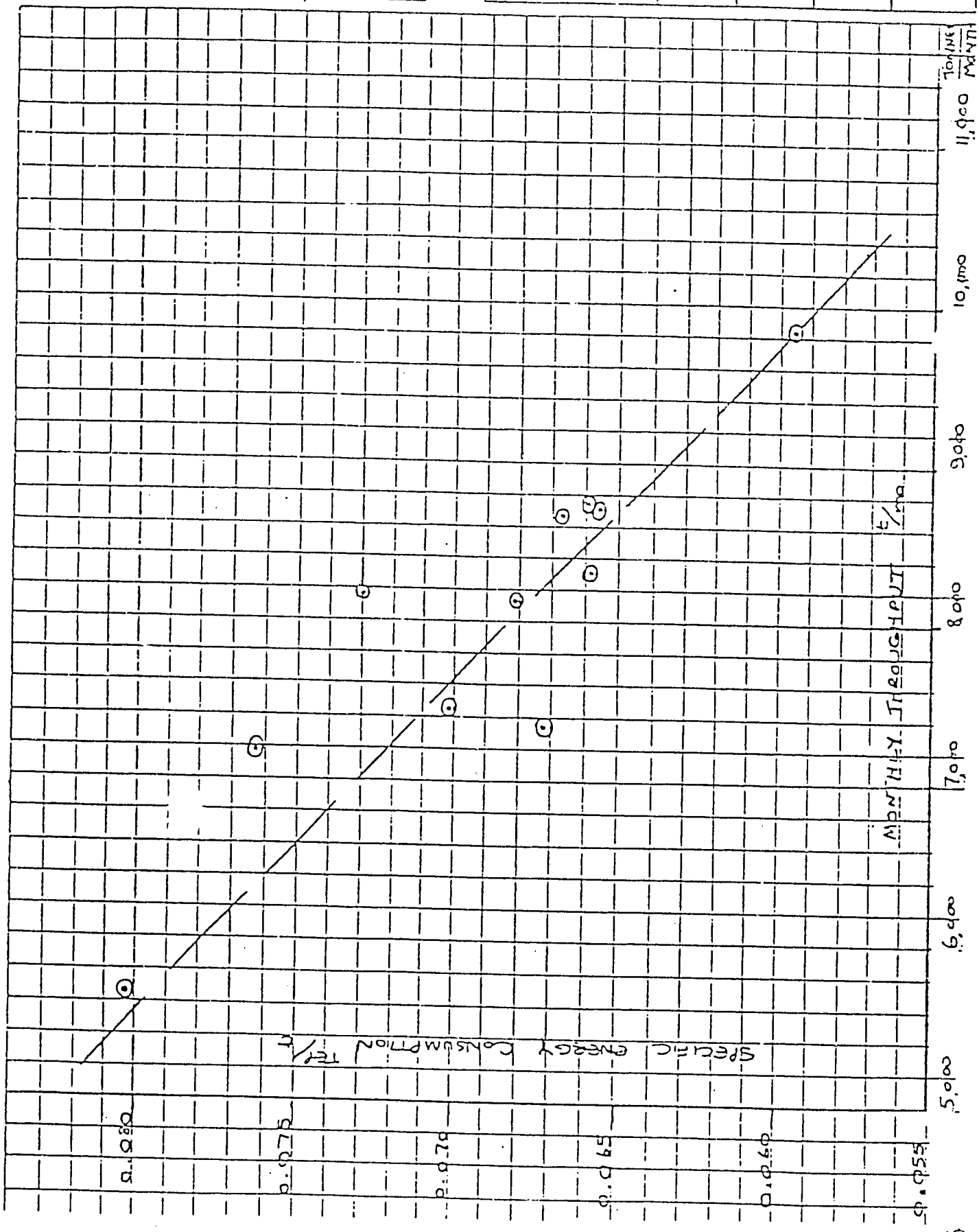
(1) Includes seasonal

EXHIBIT J

LOCATION: BRICKWORKS

SUBJECT: ENERGY CONSUMPTION / THROUGHPUT

REVISIONS	0	1	2	3	4
DATE	30.7.81				
BY	BT				
REVIEW					
CHECK					
APPR					



172

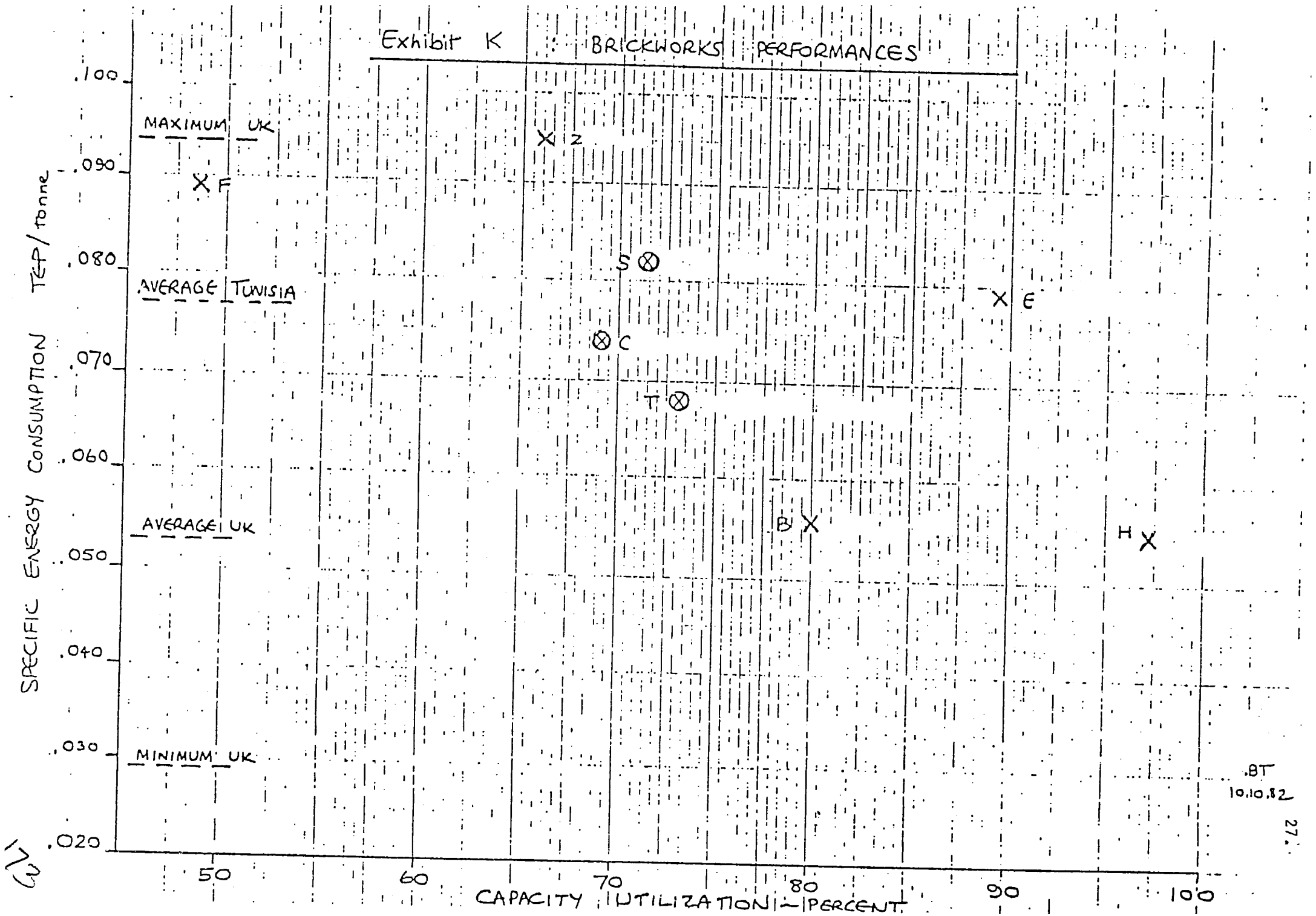


Exhibit K
BRICKWORKS PERFORMANCES
SPECIFIC ENERGY CONSUMPTION TEP/tonne
.100
.090
.080
.070
.060
.050
.040
.030
.020
MAXIMUM UK
AVERAGE TUNISIA
AVERAGE UK
MINIMUM UK
F
Z
S
C
T
E
B
H
50
60
70
80
90
100
CAPACITY UTILIZATION - PERCENT
BT
10.10.82
27.

1.8 Projected Energy Demands

An estimate of industrial energy consumption was made for 1986 using subsector growth rates taken from reports on the National Plan. Assuming no change in energy use patterns and in the current energy efficiencies, the total industrial sector demand may be expected to increase to over 2 million TEP by 1986 from the level of about 1 million TEP in 1980.

An examination of fuel substitution possibilities was made and an estimate of the potential for natural gas was made. With a very vigorous gas conversion programme, it was estimated that industry could be using almost 900,000 TEP per year by 1986/87.

1.9 Potential for Energy Conservation

The prospects for energy conservation obviously vary from plant to plant. For the seven plants audited during this project, comprehensive reports were prepared which included specific recommendations for improving plant operating efficiency, and these recommendations were discussed extensively with plant managements.

At a "macro level",examination of the energy data was conducted for each industrial subsector. An example of the analysis for the brick industry is shown in Exhibits J and K, indicating the adverse impact of low capacity utilisation which appears to be quite important. From the results of the audits and the visits to the other plants in the survey and of a review of specific energy consumption data, estimates of the conservation potential were made for each subsector. Through a programme of "vigorous conservation", it was estimated that industry demand could be cut by about 13% compared with the "business-as-usual" estimation by 1986/87. By "vigorous conservation", we mean a major programme of housekeeping and energy management improvements throughout the industrial sector, and investment in all conservation measures showing reasonable payback periods (say 3 years or better). For new plants, we imply a thorough examination of design parameters and the incorporation at the design stage of cost effective energy-saving measures to a greater extent than typically included in conventional plant designs.

The "vigorous conservation" case presents a very difficult challenge for industry and may take longer than 1986/87 to be fully realised. We therefore suggested a more realistic scenario for quantifying the probable impact of conservation by 1986. Briefly, this requires that serious efforts be made in the largest of the existing plants to improve energy management (in all 60 plants covered by the current survey, for example) and assumes that these efforts achieve 70% of the full potential by 1986. We also suggest that 50% of cost-effective capital investments are actually effected in existing plants by 1986, and that new plants are commissioned with energy efficiencies 15% better than current subsector averages.

The benefits obtainable under this scenario were estimated to reach about 220,000 TEP per year by 1986 over the "business-as-usual" case:

	10^3 TEP
Housekeeping contribution in existing plants	72
Contribution from investments in existing plants	26
Contribution from improved efficiency of new plants	122
	220

The contribution from improvements in new plant efficiency are clearly important and most of these savings will probably be obtained with relatively minor efforts by Tunisian industry. This is because technical improvements to plants will occur through the normal competitive pressures of the market place. A more active involvement of plant engineers seeking higher levels of efficiency could probably contribute even more significant savings.

For the "realistic" scenario, the cumulative savings from 1982 through 1986 -- excluding the contribution from new plant improvements -- amount to about 50 million dollars at world market prices. About one-third represents the contribution of capital investments of around 24 million dollars over a four year period to the end of 1986 (see Exhibit B).

The resources for promoting conservation in terms of manpower and equipment which can be justified by the 50 million dollars are clearly substantial. The potential also supports our strong recommendation that energy managers be appointed at the

plant level, as full-time staff for all large plants and part-time at others. Without a major effort to focus attention on energy problems, an effort in which energy managers have a key responsibility, the undoubted potential for conservation will not be realised.

1.10 Recommendations for Data Collection

Comprehensive data are essential for energy planning at the national level. To provide timely and accurate energy data which are not currently available, it was recommended that a regular annual report be obtained from major energy consumers, and that reports be obtained from the distributors of petroleum fuels, electricity and gas on their sales of energy products to the industrial sector.

The annual report from industrial companies should be concise and should include energy and production data. To be of use for planning purposes and for monitoring energy consumption in the industrial sector, the data must be collected promptly each year. A specific individual should be nominated by each factory to complete the report, preferably the energy manager. The report should include a simple calculation of specific energy consumption and a comparison with the previous year made to bring energy efficiency to the attention of all concerned.

The assembly of data and its analysis could best be performed in future years with the aid of electronic data processing. A complex computerised system could be counterproductive, and we strongly recommend an interactive microcomputer system be utilised.

1.11 Recommendations for Future Work in Tunisia

The potential for improved energy efficiency in the industrial sector has been shown to be very large indeed by the current project. To realise the potential savings available, the Government of Tunisia needs to create a permanent industrial energy conservation capability including an ability within the private sector to conduct audits and implement recommendations. However, the attainment of significant savings cannot rely solely on a technical approach: the development and implementation of effective government policy must be given its due priority.

We therefore recommend that the government set up a permanent programme:

(1) To encourage and assist industry to use energy more efficiently through improved operating practices and through investment in new equipment.

(2) To support energy policy development by creating and maintaining an industrial energy data base for monitoring consumption and for the analysis of policy options.

The programme relies on positive but limited government intervention. We recommended an "Industrial Energy Efficiency Group" (IEEG) be formed, with two sections:

(1) A Technical Section to be responsible for technical assistance services such as plant surveys, brief audits, development and management of plant-level conservation programmes, equipment specifications, and special studies. This section should act as a catalyst for action by the enterprises themselves rather than a resource which can carry out all the necessary work.

(2) A Policy and Analysis Section responsible for regular data collection and analysis, coordination of training programmes, preparation and dissemination of publicity materials and technical information, and the support necessary for developing national energy policies and legislative initiatives.

We believe it is most important that the two Sections work closely together; each can be highly effective as part of a combined operation. We do not believe either Section working alone would be as effective, and it would be a mistake to proceed with a programme relying on the activities of one or other of the Sections in isolation.

It is essential the IEEG be given authority to act independently and be allocated the necessary resources of manpower and equipment. Strong leadership is essential too, as the work of the group will be a blend of technical work and publi relations, with much of its success relying on the establishment of credibility with industrial enterprises.

2. VISITS TO INDUSTRIAL PLANTS IN TOGO

In preparation for this seminar, a series of plant visits were made in and around Lomé. The visits were used to select a suitable plant for the planned field trip, and to gain a general idea of the present energy situation in the Togolese industrial sector. The plants visited were:

(1) CIMAO clinker manufacture
(2) SNS steelworks
(3) CIMTOGO clinker grinding plant
(4) Brasserie du Benin brewery
(5) SOTOMA brickworks and marble processing plant
(6) OTP phosphate processing complex

Brief summaries of the data collected and our observations are attached.

Plant visited: Les Ciments de l'Afrique de l'Ouest (CIMAO) Date: 16 Dec 1982

Contact: Messrs. Philippe, Lawson

Activities: This plant was commissioned in 1980 and produces cement clinker using local materials. It is jointly owned by the Governments of Togo, Ghana and the Ivory Coast. There are about 500 employees. The plant consists of two Polysius-designed 4-stage suspension preheater kilns, each with a capacity of about 600,000 tonnes per year. Raw materials are obtained from adjacent quarries and held in a covered stockpile close to the kilns. Moisture content averages about 14%, but can range from about 8% in the dry season to 18% in the rainy season. The raw materials are processed in ball mills (one for each kiln) in which heat is recovered from kiln exhaust gases; a supplementary burner for drying is also installed. The 4-stage suspension preheaters and kilns are conventional modern designs, with clinker cooling accomplished in exterior orbital cooler pipes. Clinker is transferred to storage silos prior to transport by rail to CIMTOGO for grinding and blending for the manufacture of cement, or to the port at Lome for direct export. Total investments, including the railway and port facilities, amounted to 67.5 billion CFA francs.

Main energy consuming equipment: This is a modern conventional cement plant. Major energy use is as follows:

(1) Electricity (raw material grinding and kiln rotation)
(2) Heavy fuel oil (kiln firing)

Electricity is purchased from the grid, and fuel oil is received by the railway system.

Observations:

(1) Fuel oil is held in heated storage tanks and is also preheated prior to firing in the kilns. A thermal fluid system is used and a small boiler is always on-line to heat this fluid to about 120°C. The fuel oil tank is held at about 70°C, which appears rather high (50°C would probably be sufficient). The fuel oil tank also appears to be uninsulated.

(2) The thermal fluid boiler has a fully automatic Klöckner pressure jet burner system, but there is no means of measuring the stack temperature or stack gas oxygen content. There is therefore no way of checking combustion efficiency. Of course, the quantity of fuel burned in the thermal fluid boiler is only about 190 kg/h, which is under 2% of the total plant fuel oil consumption.

(3) The fuel oil is preheated from around 70°C to 90°C immediately prior to the main kiln burners (Paillard MY Simplex, pressure jet burners).

(4) The oxygen content of the kiln exit gases is monitored continuously and is normally maintained at a maximum of about 1.5%. One kiln was operating at 0.5% during our visit. The CO content of the gases is also monitored and should be at a very low level if combustion is properly controlled. Readings were very low on our visit.

(5) The standard 4-stage SP system operates effectively, kiln gases entering stage 1 at 1200°C and leaving stage 4 at 300°C.

(6) All electricity is purchased from the grid: no electricity is self-generated. The supply was said to be quite reliable, with few voltage reductions or power cuts.

(7) The kilns are stopped every 3 months or so for refractory brick repair. This seems to be rather frequent and should be checked.

Energy consumption data: Data for a typical month were obtained (October 1982):

Clinker produced	71,367 tonnes
Electricity consumed	5.336 million kwH
Fuel oil consumed	7,033 tonnes (PCI 9850 kcal/kg)

Thus electricity use is equivalent to about 75 kwh per tonne of clinker, and overall fuel use is 970 kcal/kg of clinker. For the kilns only, fuel use is about 915 kcal/kg. These figures are quite reasonable in comparison to international standards, although the fuel figure of 970 kcal/kg is somewhat high (probably due to the relatively high moisture content of the raw materials).

Remarks:

This plant utilises the latest modern cement-making technology and appears to operate well up to international standards. While it is usually possible to make some energy savings in all plants, the potential for energy efficiency improvement is not believed to be very great in this plant. However, it should be noted that the kilns are currently operating at around 70-75% of maximum capacity; for maximum energy efficiency, the plant should be run as close to maximum capacity as possible.

Finally, it should be noted that a monthly report is produced for the plant, and that both electricity and fuel oil consumptions are checked regularly and specific energy consumptions are calculated each month.

Plant visited: Société Nationale de Sidérurgie (SNS) Date: 16 Dec. 1982

Contact: M. Sikpa

Activities: This plant is an integrated steel mill, producing reinforcing steel bars primarily from local scrap. The Swiss-designed plant was commissioned in January 1979, and was built at a cost of about 14 billion CFA francs. It is owned by the Government of Togo. The plant consists of a scrap preparation section, an electric arc furnace for steel making, and a reheat furnace and rolling mills. The annual capacity of the arc furnace is about 20,000 tonnes, and that of the rolling mills is 40,000 tonnes, but production is currently running at under 9,000 tonnes per year. About 30% of production is used in Togo, and up to 70% is exported to Upper Volta, Benin and Niger.

Main energy consuming equipment: The main energy forms consumed are:

(1) Electricity in the arc furnace
(2) Gasoil in the reheat furnace

Electricity is purchased from the grid: the plant is located about 200 metres from a new power plant which has two 30 MW gas turbines in service (and four 10 MW diesel generators being installed). Gasoil is supplied by road tankers.

Observations: Unfortunately the plant was shut down during our visit, but it is possible to make the following comments:

(1) The steel mill may be divided into two main sections, the steel-making section and the rolling mills.

(2) The steel-making section includes feed preparation, where local scrap (and a minor amount of imported scrap) is cut into small pieces prior to loading into the arc furnace. The furnace itself has a capacity of 15 tonnes and can operate up to 5 pours per day in full three-shift operation. The heating cycle for the furnace is about 4 hours. Three electrodes are fitted.

(3) The composition of the steel produced is adjusted by addition of various chemicals and additives. Carbon content may be controlled by oxygen lancing, oxygen being supplied in cylinders.

(4) The arc furnace may be tipped to pour the molten steel into ladles. The ladles themselves are preheated using gasoil burners; the ladle lids were not well insulated. The ladles transfer molten steel to the casting section, where ingots are cast and later stockpiled outside the rolling mill building. Ingots typically weigh 150 kilogrammes.

(5) Prior to rolling,the ingots are reheated in a furnace fired with gasoil. The reheat furnace requires a heating period of about 2 days from a cold start and is supposed to operate continuously. The ingots are heated to about 1200°C in the furnace.

(6) The reheat furnace is a conventional pusher furnace fired by gasoil. It appears that the furnace could be fired on heavy fuel oil but "supplies" were stated to be a problem. This should be investigated, as the heavier fuels are cheaper than gasoil.

(7) The furnace has North American burners, with separate forced draft primary and secondary air ducts. There is no automatic fuel/air ratio control, and no measurement of oxygen/carbon dioxide in the stack gas. The stack gas temperature is not measured. There is therefore no means of checking combustion efficiency.

(8) The furnace insulation appears to be ordinary brick and thus heat loss should be checked when the plant is operating normally.

Energy consumption data: Data were obtained from the plant and from the power station. We noted several discrepancies, including the fact that ingot production was said to be about 3,500 tonnes greater than rebar production, and yet the stack of ingots seen on site was only perhaps 100-200 tonnes. We do not believe the data are reliable, but report these in any case in Exhibit A, together with some calculated ratios, such as electricity consumptions per tonne of product.

It will be seen that the electricity consumption in the arc furnace fluctuates quite broadly, while oxygen consumption is extremely variable, according to the data provided. The electricity and gasoil consumptions for the rolling mills are also extremely variable; better records should be kept as a start to improving energy management.

EXHIBIT A - 1982 DATA FOR SNS

	January	February	March	April	May	June	July	August	Sept.	Totals
STEELMAKING SECTION										
Ingot production (tonnes)	1 640	1 634	1 061	plant down	1 521	1 284	441	1 272	1 320	10 173
Electricity consumed (10^3 kwh)	1 089	1 137	795		1 068	929	318	898	1 016	7 250
Oxygen consumed (10^3 CFA francs)	2 406	4 410	10 572	4 301	3 292	4 111	10 397	6 034	8 409	53 932
Electricity (kwh/t)	664	696	749	-	702	724	721	706	770	713
Oxygen (francs/t)	1 467	2 699	9 964	-	2 164	3 202	23 576	4 744	6 370	5 301
ROLLING SECTION										
Product (tonnes)	487	1 049	1 035	511	602	1 097	714	171	976	6 642
Ingots processed	4 181	9 708	8 956	4 661	5 990	10 416	5 964	2 019	9 516	63 430
Ingots/tonne	8.59	9.25	8.65	9.12	9.95	9.49	8.35	11.81	9.75	9.55
Electricity consumed (10^3 kwh)	362	441	279	234	381	464	277	270	384	3 092 (1)
Electricity (kwh/t)	743	420	270	458	633	423	388	1 578	393	466
Gasoil consumed (metered, lit)	45 440	90 860	83 279	44 781	65 200	92 826	50 024	32 303	95 117	599 830
Gasoil (litres/t)	93.3	86.6	80.5	87.6	108.3	84.6	70.1	188.9	97.5	90.3
Hours operational	102	226	167	136	163	252	98	40	184	1 368
Tonnes/hour	4.77	4.64	6.20	3.76	3.69	4.35	7.29	4.28	5.30	4.86
Good product as % of total tonnage processed	94.2	91.0	92.3	92.0	86.9	91.0	96.0	78.5	88.0	-

Notes

(1) These figures obtained by difference from the total consumption reported by the power plant and the electric arc furnace consumption figures.

Remarks

In general, we would recommend a much greater attention to the collection of reliable energy and production data by plant management. The plant itself did not have electricity consumption data for the rolling mills separately from the arc furnace consumption, for example. We understand that the new management team took over in September, and it is therefore hoped that data (and energy management) will improve. The potential for energy saving cannot be judged at this time; plant tests are recommended as soon as steady operation is achieved. It is particularly important that the reheat furnace be operated at high throughput whenever possible: it is preferable for the ingots to be stockpiled and the furnace to be run at maximum rate for say 1-2 months and then shut down while the stock is rebuilt. In our judgement, this plant uses reasonably modern technology, but does not appear to have been designed for optimum energy efficiency as it lacks good instrumentation in many areas.

Plant visited: CIMTOGO

Date: 17 Dec 1982

Contact: M. Brenner

Activities: This plant is owned 50% by the Togolese government and 50% by private interests, and was originally commissioned in 1971. The plant grinds cement clinker and blends this with gypsum, imported pozzolanic material, sand and other additives to produce a range of finished cements in bags. The plant produces sufficient cement for the entire Togo market, and also exports finished cement. Clinker from CIMAO is loaded into ships through the jetty located adjacent to the CIMTOGO plant.

The plant was originally constructed with one grinding mill to produce 150,000 tonnes/year, operating entirely on imported clinker. Expansions in 1977 and 1980 have resulted in a current grinding capacity of 850,000 tonnes/year. It is intended that all the Togolese portion of the CIMAO plant production will be ground by CIMTOGO (planned to be up to 300 - 350,000 t/y) to satisfy the local markets currently about 220,000 t/y, as well as for exports to Upper Volta and Niger, currently running at about 40,000 t/y.

Main energy consuming equipment: Almost all the energy used in the plant is electricity for grinding mills although some gasoil is used in a rotary dryer for the imported pozzolan. The electrical power factor is greater than 0.85.

Observations:

(1) The plant appears to be well maintained and efficiently operated. Cements are produced to French standard specifications.

(2) Quality problems are sometimes experienced due to density (quality) variations in the CIMAO clinker. This can have some effect on energy use as the energy used for grinding can be adversely affected.

(3) Grindings aids have been tested but have not been found useful.

(4) As the plant is not running at full capacity, grinding is often carried out at night to minimise electricity costs:

23 CFA francs/kwh day rate
19 " " " night rate

(5) The pozzolan drier is a rotary type, with once through air flow (no recycle). A Saake rotary cup burner is installed, rated at 500 kg/hr maximum.

(6) Plant problems are currently related to economics rather than energy. Cement production for 1983 is expected to be about 260,000 t/y, although capacity is 850,000 t/y. CIMAO clinker prices are high, and the local cement price is controlled by the Government.

Energy consumption data: Data on electricity consumption were provided by the plant:

	Consumption (kwh)	Production (tonnes)	Kwh/t
1979	10,534,000	297,615	35.4
1980	10,561,000	303,042	34.8
1981	9,804,000	278,472	35.2
First 9 months, 1982	-	207,974	-

In addition, it appears that about 15 litres of gasoil are consumed per tonne of pozzolan processed in the dryer, that is, about 655 tonnes per year of gasoil:

$$260{,}000 \text{ t/y} \times 20\% \text{ pozzolan} \times \frac{15}{1000} \times 0.84 \text{ SG} = 655 \text{ t/y}$$

A figure of 20% pozzolan content is assumed for the calculation, although it was stated that up to 25% pozzolan can be included in finished cement. The total of 555 tonnes/year seems rather high and should be checked, as control appears to be maintained solely on the product exit moisture content and not on the exit gas relative humidity. There is no combustion efficiency monitoring, but the burner has automatic air/fuel ratio control.

The cost of the electricity represents around 3% of the final cement selling price.

Remarks:

The plant appears well operated and efficient in its use of energy. Potential savings are probably quite limited, therefore.

Plant visited: Brasserie du Benin Date: 20 Dec 1982

Contact: M. Ayayi Ajavon

Activities: This plant is primarily a brewery, although it also produces soft drinks. The plant is jointly owned by private German and Togolese interests, and was initially set up in 1966. It has been expanded on several occasions since then, the latest being in 1981, and currently there are 470 employees. Several types of lager and Guinness are brewed. There are two boilers of 10 t/h steam capacity, although only one is normally in operation at a time. Each boiler operates for about one week. The boilers are fired about 50% of the time on gasoil and 50% on heavy fuel oil. There are five 50 CV ammonia compressors for the main refrigeration system, as well as a number of air compressors, gas liquifiers, pumps, etc.

The process is a conventional brewing process, with fermentation followed by cooking, and then filtration of the product. Roasted malt is imported. Carbon dioxide produced during the brewing is collected, compressed and liquified: it is used primarily for the manufacture of soft drinks. The beer is packed in cans (one line, 25,000 cans/hour) or bottles (one line 12,000, one line 30,000 bottles/hour).

Main energy consuming equipment: Heavy fuel oil and gasoil are used in the boilers, and electricity is used throughout the plant to drive ammonia and air compressors, bottling lines, pumps, lights, etc. Some diesel oil is used occasionally for the emergency electricity generator sets (three 340 KW), although the grid electricity supply is generally very reliable.

Observations:

(1) The boilers are designed for 8 bar steam generation and are fitted with Saake rotary cup burners. Fuel and water are metered, and full instrumentation is fitted, including automatic stack dampers and fuel/air ratio control. Forced draft fans are fitted.

(2) Regular checks of boiler efficiency are carried out by the plant technical staff. We were able to use a portable stack gas analyser and check the boiler efficiency with the plant technician for various

firing rates (1 lowest; maximum setting would be 10):

Firing position	1	1	5.5	5.5	8
Oxygen %	6.1	6.2	5.7	5.8	4.3
Temperature ^{o}C	160	164	210	206	222
Efficiency %	82.8	82.5	80.4	80.6	80.6

These figures are good, and show that the boiler is well adjusted for automatic air/fuel ratio control over a wide firing range. It may be possible to improve combustion conditions by reducing the oxygen content to say 2 or 3%, resulting in an efficiency improvement of about 1 to 2 percentage points.

(3) The boiler, as well as being well instrumented, was properly maintained, clean, and well insulated. Heat loss from the structure is thus properly controlled.

(4) The general level of lighting is good where necessary, and it was noted that lights were turned off at idle workstations. Most lighting is fluorescent.

(5) Maximum condensate recovery is practised.

(6) All utility piping was color-coded and tanks and lines were properly insulated where necessary.

(7) Water evaporated from the cookers (evaporators) amounts to about 18%, and this is vented to atmosphere. There appears little prospect of heat recovery being economically viable.

(8) Water recycle is practised in the bottle washing machines, with the final, used, water rejected to drain.

Energy consumption data: Some energy data were provided, but corresponding production figures were not supplied at the time. The figures for November 1982 were:

Consumptions

Water	127,000 M^3
Electricity	457,000 kwh
Gasoil and fuel oil	205,000 litres

It was stated that the plant runs typically at a production rate of around 500,000 hectolitres/year.

Remarks:

This is a well run factory and we doubt that significant further energy savings can be made. The boiler operation is particularly good, and the regular monitoring of performance and adjustment of firing conditions is a model of good energy management.

Plant visited: SOTOMA

Date: 21 Dec 1982

Contact: Messrs. Akitani and Djato

Activities: This factory produces marble items from roughly quarried blocks, and also manufactures bricks. A section for the production of ceramic tiles is currently shut down due to adverse market conditions. The marble quarries are located about 120 and 200 km from the factory, and the activities at the factory consist of various types of stone cutting and polishing. Electricity is used for the machines.

Of major interest from an energy point of view is the brickworks section. A clay quarry 15 km from Lome and another close to the plant are used for the raw materials. Four batch brick kilns are installed, preceded by a large drying chamber into which kiln exhaust gases can be blown to hasten the drying of the raw bricks, hourdis and tiles. The brick kilns are fired using cotton linters (residues) and some coke and husks from coconut palms. Wood is used only to start the fires. Until a few months ago, the kilns were fired using heavy fuel oil: conversion to cotton residues means that fuel costs have been reduced by about 90%, and a locally-available waste product is being used effectively.

The brickworks, whose capacity is about 60 tonnes/day, uses the conventional brickmaking process. Clay and sand are mixed with water and extruded into the required form. Individual bricks are wire cut and stacked on pallets for drying. After drying, the bricks are fired for about 24 hours.

Main energy consuming equipment: In the brickworks, essentially all the energy consumed is in the form of cotton linters for firing the brick kilns. Minor amounts of electricity are used for materials handling, such as clay and sand mixing.

Observations:

(1) The brick kilns (clamps) are of standard design and are now becoming rather old. The batch firing method is not the most efficient means of brick manufacture available, but is appropriate for small scale brick production and is an effective way of using a locally-available waste product as a fuel.

(2) The consumption of fuel for brickmaking was about 60 litres oil per tonne when fuel oil was used (approximately 6000 kcal/tonne). About 6 tonnes of cotton linter are used per furnace per batch of bricks fired, representing a similar specific energy consumption.

(3) Cotton linter waste is available at a rate of about 18,000 tonnes/year, and the brickworks currently uses about 2,500 tonnes/year at a cost of 5000 CFAF/t to produce 18,000 tonnes of bricks. The original plant design capacity was 27,000 tonnes/year, but the age of the equipment is such that this is no longer possible.

(4) There is no appreciable amount of carbon in the clay used for the bricks in Togo and therefore all energy input comes from the fuel fired in the kilns.

(5) A high brick reject rate is caused by overfiring parts of the brick stacks, but the operation is still economically viable.

(6) The marble handling section is essentially a craft industry using entirely electricity. The potential for savings is negligible. No lights were left on, and machines were switched off when not attended. There may be some potential for improving the cutting techniques by using diamond-tipped saws rather than simple steel cutters.

Energy consumption data: A figure of 21,700 kwh of electricity was quoted for a recent month, and the cotton linter consumption was stated to be around 2,500 tonnes/year.

Remarks:

This plant provides an excellent example of the effective use of locally-available waste materials as a source of energy. The cost of fuel has been reduced to such an extent we do not believe that conventional attempts to economise on fuel use will be economically viable. At the present time, the ready availability of cheap fuel is assured, and conservation efforts are hardly relevant.

Plant visited: Office Togolais des Phosphates (OTP) Processing Complex

Date: 17 Dec 1982

Contact: M. Moukaela

Activities: This plant,which is owned by the government, beneficiates phosphate rock mined about 35 km away from the site, which is placed on the coast for access to water used in the processing. Essentially all the production is exported by ship.

The phosphate rock is mined open cast and is brought to the plant by train: about 25-30 trains per day discharge around 20,000 t/d of rock (63-66 BPL quality) which is processed to raise the phosphate content to 78-80 BPL. About 25 years of reserves remain in the ground. The process consists of slurrying in seawater the rock which arrives in a powdery form direct from the mines, removing very large oversized particles in a vibratory sieve, and then removing large and fine cuts of steriles in two stages of hydrocyclones before drying the required "heart cut" in fuel oil fired rotary driers.

The removal of steriles is carried out in five similar processing lines as follows. The slurry, containing 200 to 300 gm/litre solids in about 2400 M^3/hr seawater, is passed through a sieve to remove all particles greater than about 3mm diameter. A "top cut" of fines under 25 microns is removed in the first stage hydrocyclone. After the removal of heavier particles in the second stage hydrocyclone, the slurry containing 70% solids is passed to centrifuges where a fresh water rinse is applied to remove salts to meet a specification of 500 ppm chlorides (maximum). The consumption of fresh water is about 800 litres per tonne of product, and is pumped from 7 wells. The centrifuge exit water is filtered and some phosphate is recovered to join the main centrifuge outlet stream, which is designed to contain around 16% moisture.

This material is then fed to rotary driers fired by heavy fuel oil. The phosphate is dried to a moisture content of 2% maximum, at which point it is stored and then shipped to customers.

---

* Normally 3 or 4 lines in service, with 1-2 lines undergoing maintenance.

Main energy consuming equipment: The major energy consumption is in the form of heavy fuel oil for the rotary driers. Electricity use is quite low, as no grinding of phosphate rock is required. Electricity is used for slurry pumping, conveyor belts, drier rotation, etc.

Observations:

(1) The general appearance of the site appears well organised and maintained. Most of the time was spent in the drying area, as this is where most of the energy is used.

(2) A brief examination of the drying lines showed that the three oldest driers are poorly insulated. Drier 1 was not operating, but both Driers 2 and 3 were operating with flames passing from the combustion sections into the rotating drying sections.

(3) Driers 1, 2 and 3 have induced draft systems while Driers 4 and 5 have forced draft fan systems.

(4) Some gas temperature readings were taken around the driers. The exit gas temperatures were recorded as shown by the plant instruments, but the outside temperature of the ductwork seemed particularly hot on Driers 2 and 3. The following data were obtained:

	Drier 2	Drier 3	Drier 4	Drier 5
Hot air to rotating dryer section (°C)	920	820	(instruments not working)	570
Exit gas temperature (°C)	77	100	"	67

The inlet temperatures on Driers 2 and 3 appear excessively high and are evidence of poor flame shape and inadequate mixing of the dilution air introduced at the outlet of the combustion section.

(5) Saake rotary cup burners were fitted to the driers. No measurement of exit gas humidity is taken. Control is maintained based on the phosphate product moisture content, determined regularly in the plant laboratory.

(6) Heavy fuel oil is stored in tanks which appear uninsulated and are painted black. These tanks are heated by steam, raised in a nearby boiler (which was not visited, as the boilerplant was closed to visitors at the time).

(7) The yield of phosphate product is fairly steady at about 60% of the inlet phosphate rock, as received from the mines.

(8) The water content of the drier feed and product streams is monitored regularly. Plant records indicated that the feed moisture was generally in the range 17.3 to 18.9%, with one or two low figures around 16.6 and high figures around 19.5 being noted. It is clear that the inlet moisture content is not averaging close to the 16% design figure. Drier outlet moisture contents were in the range 1.8 to 2.0%.

Energy consumption data: Data for a typical month were obtained (November 1982):

Production	203,421	tonnes
Fuel oil consumed	3,173,379	litres
Electricity consumed	1,870,143	kwh
Fuel use	15.6	litres/tonne
Electricity use	11.5	kwh/tonne

Remarks:

Comprehensive plant records are kept and specific energy consumptions are reported regularly. However, no attempts to relate energy use to throughput or to moisture contents appear to be made. The critical factor affecting fuel use is clearly the drier input moisture content. If this could be reduced to 16%, the design figure, substantial savings could be achieved.

We would therefore recommend that a careful study of drier operation be carried out, and test runs performed over a reasonable period of time to collect comprehensive data on all relevant parameters (e.g. air and fuel flow rates, phosphate processing rate, gas and product temperatures, inlet and outlet moisture levels, exit gas humidity, etc.). Detailed heat and material balances should then be calculated, and heat losses in the exit gases and from the structure should

be estimated. The effectiveness of the control system should also be examined. It may prove possible to reduce energy consumption by improving the drier operating procedures.

It is also possible that some processing changes could be economically viable. For example, the final freshwater washing step should be examined: currently this rinse occurs in the final centrifuge bowl immediately prior to entry of the phosphate to the drier. Alternatives should be investigated with the objective of reducing the water content of the drier feed. The economics of an additional water separation stage could also be examined (e.g. additional second-stage centrifuges, series operation of existing centrifuges, additional vacuum filtration equipment, etc.).

The final product specification of 2% moisture also deserves attention. A small relaxation in this figure could have a significant effect on fuel use, as well as resulting in reduced product loss during loading of ships (reduced wind-blown phosphate losses).

Finally, it should be remarked that a thorough investigation of the phosphate processing operations will require adequate time for on-site observations. However, a major study appears justified in view of the large consumption of fuel oil. It may also be worthwhile to examine the potential for fuel substitution (e.g. using wood-based fuel) although it is doubtful if the reconstruction of the plant for alternative fuels will be economically viable, particularly after operation of the existing plant has been optimised.

SESSION FIVE: ENERGY CONSERVATION PERSPECTIVES

1. TRAINING PROGRAMMES

1.1 Introduction

A comprehensive industrial energy management training programme would typically have the following complementary primary objectives:

(1) The training of engineers, managers and government officials in the basic techniques of industrial energy management.

(2) The training of plant level engineers in the performance of practical plant energy audits, in the collection of energy-related data, and in the practical application of the techniques of energy conservation.

(3) The improvement in awareness of engineers, managers and government planners in the potential for improved energy efficiency in the industrial sector, and in their appreciation of its limitations and costs.

(4) The establishment of comprehensive and accurate energy data systems at the plant level, which will contribute to improved energy management within the plants and will provide national energy planners with reliable data on which to base policy decisions.

(5) The performance of detailed energy audits at selected industrial facilities in order to quantify conservation potential and to develop specific action plans to achieve this potential, in addition to providing a training experience for engineers.

In the national context, effective industrial energy management requires the training of significant numbers of local engineers to become familiar with the general concepts of energy analysis and conservation, and with the technologies for improved energy efficiency which are applicable to their particular industry. It must be recognised, however, that formal training is merely the beginning. The ability of local engineers to conduct audits and conservation studies similar to the examples applied in the training programme will depend on their gaining further experience of conditions in industry, and will come with the confidence that exposure to different plants and different problems will develop. A good training programme would provide some assistance in this respect through incorporating an extended "follow-up" assistance effort: any training programme must allow sufficient time for the development of local personnel.

1.2 Personnel to be Trained

In addition to factory "energy managers" and to plant level engineers in general, any national training programme should include personnel from oil, gas, coal and electricity companies, which are often state-owned. In our view, these personnel have a key role to play in disseminating energy conservation principles throughout the industrial sector of the country concerned. While plant engineers have specific responsibilities within their own companies, we feel that utility and fuels company personnel can work independently across a broad range of industries, providing the catalyst for company and plant specific conservation programmes. Where a plant is considering what kind of conservation activities would be started, such personnel could be made available to assist in the initial energy audits and the planning of the conservation programme most appropriate to that plant.

In addition, we suggest that a training programme include a series of brief lectures for plant supervisors and company management to explain the basic principles of industrial energy conservation, the basic techniques of energy audits, and the relevant financial and economic considerations. We also believe that company financial officers should have some appreciation of the role that industrial energy management can play in the operation of the company. It is important that production managers be fully conversant with energy management procedures and it is through these "abbreviated" courses that we would hope to initiate a link from the plant engineers carrying out detailed conservation work to their managements.

1.3 The Structure of the Training Programme

Based on our experiences in several developing countries and in the United Kingdom and the United States, we have developed some guidelines for an industrial energy management training programme. This programme draws extensively upon our work in Tunisia, the People's Republic of China, Kenya, the Sudan and Turkey.

We feel strongly, however, that a training programme should be a continuing exercise, to disseminate energy awareness, the practical techniques of data collection and analysis, and the development of company conservation programmes throughout the industrial sector of a country. For this reason, we consider the programme described here is a good start, but is insufficient to achieve

truly national results in a meaningful way: that is, for there to be built up a local ability to conduct energy audits and energy conservation studies with a view to establishing permanent energy conservation programmes in a large number of companies. For this to occur, a continuing effort is necessary over several years. Indeed, training is a vital activity which should be considered as an ongoing necessity to achieve improved energy efficiency in industry. This training must be supplemented by such activities as demonstrations of new technologies, establishment of incentives for capital investment, and the creation of appropriate tarification policies for energy products.

We would thus recommend that a similar training programme be conducted regularly, with up to about 20 participants each time. The results of the first training programme should be used to modify the subsequent programme (in terms of emphasis in obvious areas of need, for example, specific to the country in question)

Before discussing the details of each element in the programme, it should be pointed out that we have prepared a training programme for engineers irrespective of the industries which the engineer represents. In the experience of E/DI Europe, which covers many industries in many countries, it is our view that the greater part of energy conservation work is common to all industries. The principles of measurement, data organisation and analysis, cost-benefit evaluations and company/national conservation programmes should therefore be taught to all. Assignments within specific industries and technical lectures and visits oriented to specific industries can be given from time to time throughout the programme, of course, but we would prefer to emphasise the common approaches to energy management, rather than the relatively minor differences. Successful energy conservation is rarely a question of technology; it is almost always a question of systematic data collection and analysis, and of properly organised management.

Of course, there may be exceptions to this approach which are necessary due to local conditions, especially where significant progress in industrial energy management may have already been made. For this reason, the "diagnostic" phase is important (see below) for it is through this task that the design of a programme most suited to the needs of a particular country can be made. Any programme must take fully into account the level of energy awareness and standard of energy management already attained, and must address the priorities of the country and of specific industries where appropriate.

1.4 Diagnostics and Planning

In the first month of a training programme, the scope of work must be properly defined. For one country alone, we would suggest a visit by a team of say two experts for one to two weeks in the country should be sufficient, with some preparatory work conducted by correspondence. The resumes of prospective training course participants would be reviewed and recommendations for the final list would be made to the appropriate host government agency. The invitation list for course participants would of course include the introductory "management" seminar.

Within this phase, the timing and logistics for all elements of the programme and the specifics of course content would be decided as far as possible, bearing in mind the desirability of coordinating the training programme with any other energy management efforts currently in progress in the country. Some flexibility in the timing of assignments and plant visits must, of course, be maintained.

This phase will also include discussion of the lectures and course content with host government representatives to define those parts of the training programme which could be given by local personnel, and to agree on the detailed course content appropriate to the level of knowledge and experience of the actual participants. The experience gained by local personnel in giving lectures themselves should prove invaluable for the ongoing training effort which we see as essential in future years.

1.5 Management Seminar

An introductory seminar of about one week should be given for management personnel from utility companies, fuel supply companies, government agencies and industrial plants. This provides the opportunity to review with senior engineers, managers, and financial officers the proposed industrial energy management training programme, emphasising to them the potential benefits of energy conservation throughout the industrial sector. A brief introduction should be given to the techniques of energy auditing and energy management in general; it is hoped that the seminar will develop an improved awareness of the need for conservation, and above all the need for senior management support for the efforts of plant engineers and energy managers.

1.6 Training Seminars

Lectures on industrial energy conservation principles and techniques should be given to plant engineers, energy managers, and other suitable personnel. The topics to be covered in these lectures should include at least the following:

(1) Introduction to the training programme and industrial energy management in general - background, objectives, etc.

(2) A review of energy consumption and the energy situation in the country or region in question.

(3) The detailed structure of the training programme (lectures, plant visits, audit assignments, overseas training etc.), including objectives of each task, procedures, logistics, responsibilities of participants, etc.

(4) Basic principles of energy conservation.

(5) Basic information - alternative fuels and their characteristics, common units of measurement and conversion factors, heating values, etc.

(6) Energy audits - the purpose of audits, the scope of an energy audit, data forms and questionnaires, data analysis, benefits of audits, procedures to be adopted, instruments (portable, fixed).

(7) Basic unit operations - we concentrate on the most important operations (combustion, steam generation) but include discussion of at least the following:

- Combustion
- Heat transfer
- Evaporation
- Drying
- Distillation
- Boilers and steam systems
- Electrical demand management
- Co-generation
- Plant compressed air systems

The lectures include discussion of basic theoretical principles, practical applications, calculation methods (vigorous and "short-cut"). They are

illustrated by a variety of calculation exercises for the participants to carry out themselves, by practical industry case studies, and with films appropriate to the topic under review.

(8) Process analysis - a brief review of the need for analysis of the specific processes used in different industries, with illustrations of international comparisons of specific energy consumptions in a range of industries and the limitations of this approach.

(9) Industrial lighting, and the significant potential for conservation in this area.

(10) Space conditioning of offices and other industrial buildings, including audit forms and parameters affecting energy use.

(11) Check lists of conservation measures generally applicable in the industrial sector, arranged according to the unit operations previously discussed.

(12) Conservation measures for specific industries, and the need for target setting, to be illustrated by actual case studies from developing and developed countries.

(13) Typical company and plant conservation programmes, including case studies and guidelines on how to develop effective programmes.

(14) Economic aspects of energy conservation, including the common calculation procedures employed for payback, rate of return, etc.

In conjunction with the lectures indicated above, a series of one-day visits are normally made to selected plants (say three or four nearby plants). These visits are intended to reinforce the classroom lectures with practical demonstrations of the principles involved, and are used in preparation for the longer visits to be carried out at a later stage of the programme. These visits therefore serve as an introduction for participants to

- the use of audit forms and techniques for obtaining data
- the identification of problem areas in energy use, by data analysis and by inspection of the physical plant
- the handling of portable instruments for the diagnosis of plant performance.

The programme participants are usually divided into two groups for each visit, with participants alternating between these groups for the different visits:

Group 1 concentrates on data collection and the use of audit forms. The duties of this group include obtaining basic data on energy consumption and levels of production, obtaining details of the manufacturing processes in use and major production units/equipment, and inspecting the plant briefly (primarily to gain a general impression of operating practices and efficiency and to relate the data collected to the corresponding physical plant).

Group 2 are assigned to inspect specific sections of the factory, where they observe the location of important measuring points and the availability (or lack) of data on key operating parameters (flows, pressures, temperatures, etc.) The use of portable instruments is demonstrated to this group.

It is important to note that no conclusions are drawn from the data collected in the initial visits.

1.7 Audit Assignments

For the next phase of the training, participants are divided into groups of six or seven in order to undertake "short audits" in selected plants. The objectives of the "short audits" are:

- To train local engineers in energy audit procedures and the techniques of data collection and analysis (including the use of portable instruments)
- To collect the energy consumption data for selected major industrial consumers
- To identify and quantify specific energy conservation opportunities in the plants.

Due to time limitations, the scope of these audit assignments will necessarily be limited. However, they serve as practical experience for the course participants who should then be better able to develop more detailed audits wherever justified in their own companies.

Details of the programmes for the short audits are usually developed during the earlier one-day visits. Each training group will itself be split into two during the audit work, some engineers to concentrate on examination of energy-related records and the completion of comprehensive audit forms, and some to carry out test runs in the plants.

Plant engineers should be placed as far as possible in groups covering their particular industry, with the balance of each group composed of fuels and utility company and government personnel. Each group spends about one week on a plant carrying out a specific assignment related to energy auditing and the identification of conservation measures. The work should include in-plant data collection and time should also be allowed for the group to work with their instructors (two to each group) to make at least a preliminary analysis of the data in the second week. The participants must have the opportunity to play an active role in the writing of the final report.

2. APPROACH TO CONSERVATION PROGRAMMES

Action by national governments to stimulate energy conservation can usually be justified by the significant potential benefits. The types of action which governments can take include sponsoring plant audits and training programmes. Indeed, the training element of the Tunisia project was paramount. International agencies are often prepared to provide grants or loans on preferential terms to enable developing countries to conduct industrial conservation programmes.

Of course, the problem of achieving improved energy efficiency is not solely that of the developing countries. A recent study reported that the potential existed in the U.K. to save 14% of current energy use with projects offering three year paybacks or better. Very few of the companies surveyed in the study had implemented the full variety of technically possible energy saving measures. Three main barriers to conservation were highlighted:

(1) The knowledge barrier. Many of the companies interviewed had not recognised many technically possible and financially attractive opportunities for energy savings. Many had also made little use of the sources of information and advice that are available.

(2) Energy Management. There is clear evidence that the companies with the most sophisticated energy management systems had made the most progress in achieving energy savings. The effect on management attitudes of even the simplest energy monitoring and target setting system was particularly noticeable.

(3) Capital budgeting. The financial appraisal of conservation investments was usually crude, based on short payback periods which ignore some of the special features of energy conservation investment - notably long life, low risk and savings linked to fuel price inflation - which more sophisticated financial analysis would bring into the reckoning.

The report therefore recommended the improvement of the status which managements give to energy conservation; the upgrading of government information and advisory services; boosting publicity on conservation and an examination of selective financial aid to industry, possibly involving longer term bank lending and 'pay a you save' schemes. These findings and recommendations have broad applicability in developed and developing countries.

At the plant level, managements must undertake initial audits to determine how much energy is used in each important processing stage, and should initiate proper energy consumption monitoring. Areas for improving efficiency should be examined and the necessary cost-benefit evaluations performed. Above all, management must take a vigorous interest in energy conservation. Effective energy management within an industrial enterprise requires:

(1) the commitment of all concerned

(2) communication throughout the company

(3) an organisation (or structure) which results in properly defined responsibilities and authorities

(4) the involvement of personnel at various levels in setting goals for improvement

(5) leadership in the work of improving efficiency (such as that provided by an "Energy Manager")

(6) technical and economic expertise, to fully evaluate and exploit conservation opportunities

In conclusion, it is particularly important to stress that energy conservation is not a negative concept. It is essentially the improvement of the efficiency with which energy is used, enabling economic development and the improvement of living standards to be pursued. We must recognise however that changes in attitudes and changes in the established way of doing things are brought about only slowly. Opportunities for saving energy are often not taken up even when a first-class financial case exists. We must conclude that even more must be done to stimulate both interest and action.

1. CONSERVATION AT THE PLANT LEVEL

Before discussing the procedures for energy auditing which are used to identify the opportunities for energy savings, we should understand some of the basic principles which apply to energy conservation work in general:

(1) The manner and extent of all energy use should be examined

(2) An essential element of energy conservation is the systematic measurement of plant energy and material flows

(3) To carry out accurate energy and material flow measurements, it is necessary to use properly calibrated and maintained instruments

(4) The maximum amount of useful work should be obtained at each stage of temperature or pressure reduction

Energy audits in industrial plants are used, as we shall see, to determine energy use patterns and to evaluate the existing efficiency of energy use. Based on these energy audits, it is usually possible to identify energy conservation opportunities in the following categories:

(1) Housekeeping measures: the improvement of efficiency using little or no capital investment, effective in the short term

(2) Minor capital investments: relatively simple modifications to the plant, with savings obtainable in the medium term

(3) Major capital investments: substantial replacement or modification of plant, with savings obtainable in the medium to long term

Some typical conservation measures within these categories are:

Housekeeping

- energy consumption monitoring
- closer control of operations
- improved maintenance
- elimination of leaks
- improved scheduling

Minor capital investments

- improved insulation
- better levels of instrumentation
- condensate recovery
- additional heat exchangers
- higher efficiency lighting
- combustion air preheating
- power factor improvement
- electricity load levelling

Major capital investment

- replacement of boilers
- replacement of obsolescent plant
- conversion to different processes
- rebuilding furnaces with recuperators

As a general rule, measurable improvements in the plants will be the result of the accumulated effort of many small actions, rather than the result of one or two spectacular major capital investments. The contribution of housekeeping is important and it is true that energy efficiency improvements through housekeeping are relatively easily obtained in many plants by better management. Regrettably, it is also true that housekeeping successes are relatively easily lost unless the drive for efficiency is maintained over the long term.

2. INTRODUCTION TO AUDITING

An integral element of a national energy programme is a knowledge of disaggregated industrial energy demand. Effective incentives for efficient energy use cannot be designed without a detailed knowledge of energy consumption patterns within the industrial sector. At the plant level, an effective energy management programme must be related to a numerical target or objective. To define such targets for reducing waste and improving energy efficiency, each plant needs to know exactly what energy it uses: a procedure for defining energy use and for updating records periodically is essential. Such a procedure is provided by an energy audit, which includes:

(1) Monitoring the type and quantity of fuels and electricity consumed

(2) Relating energy consumptions and costs to the output of the plant

(3) Identifying the activities and major processing stages where energy is used

(4) Identifying the opportunities for energy savings

The purpose of an energy audit is thus to provide plants with accurate means of recording energy consumption and costs, to provide plants with the information necessary for identifying real opportunities for energy savings, and to provide comprehensive and accurate data appropriate for national energy planning activities. An energy audit should be viewed as a critical examination of the plant.

There are, of course, many "levels" of energy audits, ranging from simple data surveys to highly detailed examinations of existing data coupled with special plant test runs designed to provide new data. An initial audit for a plant will probably take about 2-3 days on average, depending on the complexity of the plant and the availability (and accuracy) of data on existing operations. This kind of brief audit cannot be very sophisticated, but is most useful in revealing inadequacies in metering and measurement. The aim of the brief initial audit is to obtain data and energy savings quickly; accuracy will be gained in the light of experience.

A more comprehensive plant energy audit usually follows the first brief audit, and can take from several weeks to several months to complete. Detailed studies to establish, and investigate, energy and material balances for specific plant departments or items of process equipment are carried out. The audit report will include a description of energy inputs and product outputs by major department or by major processing function, and will evaluate the efficiency of each step of the manufacturing process. Means of improving these efficiencies will be listed, and at least a preliminary assessment of the cost of the improvements will be made to indicate the expected payback on any capital investment needed. The audit report should conclude with specific recommendations for detailed engineering studies and feasibility analyses, which must then be performed to justify the implementation of those conservation measures that require investments.

In order to carry out this kind of audit work successfully, engineers with wide experience in operating industrial plants are essential. Two basic areas of experience are needed within an audit team:

(1) Experience and familiarity with "plant services", such as steam generation and compressed air systems;

(2) Experience of the "process" side of plant operations, e.g. cement production, chemical processes, etc.

The availability of process expertise is important for the conduct of any detailed audit. Where outside experts are used to carry out the work, it is also important that one or more counterparts from the plant itself work closely with these experts, to assist them in gaining a rapid understanding of the plant operations, and to learn for themselves the techniques used for data collection and analysis.

3. INFORMATION OBTAINED IN AN AUDIT

The information to be collected during the audits will fall into the following categories:

(1) Energy consumption by type of energy, by department, by major items of process equipment, by end-use (e.g. lighting, process heat)

(2) Material balance data (raw materials, intermediate and final products, by-products, etc.)

(3) Energy cost and tariff data

(4) Process flow diagrams

(5) Data on the supply of auxiliary services (e.g. cooling water, compressed air, steam)

(6) Sources of energy supplies (e.g. electricity from the grid or self-generation)

(7) Potential for fuel substitution, process modifications, and the use of cogeneration systems (combined heat and power generation)

(8) Energy management procedures and energy awareness training programmes within the establishment

An example of the data collection questionnaire used in a comprehensive audit is shown in Exhibit L. While questionnaires are an integral part of auditing, they do not in themselves constitute the whole audit. The forms represent a systematic way of collecting certain basic data that experience has shown are relevant in virtually all audits. However, questionnaires must be supported by observations made during inspection of the plant and by measurements taken with fixed or portable instruments on important energy consuming equipment such as boilers and kilns. The audit is not complete until the data collected from these various sources has been analysed and a final report, including recommendations, has been prepared and presented to management.

4. DIAGNOSTIC INSTRUMENTS

The instruments typically used in plant audit work will include portable equipment to supplement existing plant flow, temperature and pressure measurements, and will be used by the audit engineers to assist in the diagnosis of operating performance. Some typical instruments are as follows:

(1) For combustion processes, stack gas analysis equipment to determine oxygen levels, CO, gas temperature etc. Today, these can be electronic instruments giving a continuous readout of key parameters calculating combustion efficiency automatically. A smoke pump is also useful.

EXHIBIT L

EXTENDED ENERGY AUDIT QUESTIONNAIRE

A. Identification

1. Name of company
2. Full postal address
3. Telephone
4. Persons interviewed
5. Their positions/titles
6. Head office
7. Branch of industry in which the factory is classified:

- ☐ Mining
- ☐ Textiles
- ☐ Food Processing
- ☐ Other
- ☐ Construction Materials
- ☐ Mechanical/Electrical
- ☐ Oil Refining
- ☐ Paper
- ☐ Chemicals
- ☐ Electricity Generation

8. Date of factory commissioning
9. Number of employees

B. Processing Activities

10. Provide a flow sheet of the plant indicating major operations.

11. List the different process units (manufacturing stages) including units for the production of utilities (e.g. boiler, electricity generation, oxygen plant, compressed air).

15. List all major products:

Product	Units	Plant Capacity	Actual Production	Corresponding Value of Sales

D. Energy Supplies/Consumption

16. Complete table for all energy supplies consumed; if no use, enter zero.

Energy Type	calorific value	Quantity/year	units	Cost per year	current price	Source
purchased electricity						
natural gas						
coal						
coke						
wood						
charcoal						
LPG						
Distillate* fuel oil						
Residual* fuel oil						
Others (specify)						

* Specify grade/specification of fuel oil.

17. Is electricity generated at the factory? ☐ Yes ☐ No

18. If yes, what type of generator is installed ?

☐ diesel ☐ gas turbine ☐ steam turbine ☐ waste heat boilers

☐ other

19. What self-generating capacity is installed ? _____ KW

20. How much electricity was generated by the plant last year ? _____ KWH

21. Fuels used for self-generation:

Fuel Type		Quantity Consumed	Units

22. Is self-generation capacity to be increased? ☐ Yes ☐ No

(Give details.)

E. Combined Heat and Power Generation (Co-Generation).

23. Is there a co-generation system installed in the plant?

24. If yes, give details of the system

energy source	heat production	steam	electricity production
Uses ?			
Type of equipment			

25. When was the system installed? _____

26. Are there plans to install co-generation systems or to increase the capacity of an existing system?

F. Electricity Consumption

27. What is the total installed capacity of motors and other equipment ? [KW]

28. Specify voltage levels utilised. [ ]

29. Give the latest annual consumptions:

Electricity	KWH Consumed
Purchased:	
Self-generated:	

30. Are there data available on daily and seasonal variations in electricity consumption?

[ ]

31. Is there a daily load curve available? [ ] Yes, copy attached [ ] No

32. What is the average power factor for the plant? [ ]

33. Estimate the breakdown of electricity use by completing the following table:

	Quantity (incl. units)	Percent of total Electricity
Motive power (motors) Heating Lighting Others (specify)		

Note: rough estimates are acceptable if accurate data not available.

G. Boilers

34. How many boilers are installed?

35. Any increase or changes planned?

36. Complete the following table for each boiler:

	Units	Boiler	Boiler	Boiler
Type/model	-			
Steam capacity				
Steam pressure				
Steam temperature				
Fuel type	-			
Fuel consumed				
Steam produced				
Estimated efficiency				

37. What is the source of boiler feed water?

38. What water treatment is used?

39. What is the water quality after treatment?

40. What is the consumption rate of water?

quantity	units

41. What percentage of condensate is re-used?

42. What is the peak demand for steam?

H. Energy Utilisation

43. What process units/departments are the major consumers of energy?

major units	energy used - type, quantity	specific energy consumption	efficiency	alternative fuels *

* with or without modification of the plant

44. How much energy is used in heating/cooling buildings?

45. How much energy is used for mechanical handling and transport within the factory?

46. Are fuel oil tanks heated? ☐ Yes ☐ No

47. If so, how are they heated

48. How is the system controlled?

I. Energy Management

49. Who is responsible for energy management?

Name

Position

Full time/part time

Qualifications, experience

50. Is there an "energy team"? ☐ Yes ☐ No. If so, how many?

51. Is there an "energy committee"? ☐ Yes ☐ No

52. If yes, list the members of the committee and their titles.

Name	Title	Name	Title

F. Electricity Consumption

27. What is the total installed capacity of motors and other equipment ? [ ] KW

28. Specify voltage levels utilised. [ ]

29. Give the latest annual consumptions:

Electricity	KWH Consumed
Purchased:	
Self-generated:	

30. Are there data available on daily and seasonal variations in electricity consumption?

[ ]

31. Is there a daily load curve available? [ ] Yes, copy attached [ ] No

32. What is the average power factor for the plant? [ ]

33. Estimate the breakdown of electricity use by completing the following table:

	Quantity (incl. units)	Percent of total Electricity
Motive power (motors) Heating Lighting Others (specify)		

Note: rough estimates are acceptable if accurate data not available.

53. What are the tasks and responsibilities of the energy committee?

54. How is energy consumption examined and controlled:

- ☐ by senior management only?
- ☐ by each plant within the company?
- ☐ as a routine matter, or from time to time?
  - when was the last complete review performed?

55. What analysis of energy consumption is carried out?

- ☐ According to department (e.g. offices, process plant)
- ☐ By major equipment (eg furnaces, boilers)
- ☐ By end-use (e.g. lighting, process heat, rotation equipment).
- ☐ By major product line.
- ☐ By total monthly consumption.

56. What units of measurement are used?

57. Are the consumptions of different forms of energy converted into a common unit of energy, e.g. kilocalories, BTU, KWH? ☐ Yes - unit ☐ No

58. Does the analysis include study of the relation between energy used and level of production? ☐ Yes ☐ No

59. Describe briefly the records kept of energy consumption.

60. Is current energy consumption compared with energy consumed in previous periods, or with other similar factories? Explain:

61. Are adjustments to energy consumption made for variations in product quality, in the quality or type of raw materials, in climatic conditions, in capacity utilisation, etc.? Explain :

62. Are specific, quantitative objectives set by management:
- ☐ for total energy consumption?
- ☐ for specific energy consumption?
- ☐ for energy savings (e.g. percentage reduction)?
- ☐ for improvements in specified processes or manufacturing stages?

63. What action has been taken to educate personnel in energy conservation procedures?

64. Is there a formal system of preventive maintenance? (Give details.)

J. Energy Conservation Problems and Activities

65. Summarise the major energy problems as viewed by plant management:

66. What constraints to improvement of energy efficiency exist?

67. What studies have been performed in relation to improving energy efficiency?

68. Summarise major energy conservation activities already initiated or planned (specify timing):

69. What is the potential for using non-conventional energy forms or renewable resources (e.g. wood, solar, wind, biomass, biogas)?

(2) For direct temperature measurement, miniature digital thermometers with a selection of probes and leads.

(3) For non-contact temperature measurement, an infra-red pyrometer.

(4) For air and gas flow measurement, a pitot tube and manometer.

(5) For electrical measurements, clip-on voltmeter, ammeter, power consumption meter and power factor meter.

In addition, it is sometimes useful to have a portable relative humidity meter for the analysis of drying processes, as well as a miscellaneous collection of pressure gauges and recorders for temporary installation in the plant during extended audits.

5. BASIC PROCEDURES

The details of procedures to be adopted will vary according to the scope of the proposed audit and to the size and type of facilities. In general, however, the following procedures are common to audit work:

Step 1: Plan the entire project. This includes setting audit objectives; dividing the facility into operating departments (or cost centres, as appropriate); selecting the audit team members; assigning responsibilities.

Step 2: Collect basic energy consumption and production data from the departments/cost centres, using the forms provided in this manual (or similar)

Step 3: Carry out plant test runs to gather additional data on the operating performance of specific equipment, departments or cost centres.

Step 4: Calculate energy balances and efficiencies.

Step 5: Identify improved energy management procedures, and estimate energy savings if appropriate.

Step 6: Identify improved maintenance and operating procedures, estimate energy savings obtainable, and assign responsibilities to specific individuals for implementation of all worthwhile measures.

Step 7: Identify minor cost improvements, estimate cost of implementation, calculate energy-saving potential, and prepare schedules for implementing all attractive capital investments (specify who will do what, and when).

Step 8: Identify major cost improvements, estimate costs, calculate energy saving potential, and prepare detailed schedules of items showing attractive payback.

Step 9: Prepare a report to management summarising the findings and recommendations of the audit, and including all data collected and procedures used in technical appendices. The report may include recommendations for energy efficiency improvement targets, based on the data gathered during the audit work and the analyses performed.

6. EXAMPLES OF ENERGY CONSERVATION MEASURES

6.1 Housekeeping

Turning to the practical side of energy management, it is useful to examine some typical results obtained recently in Tunisia. The first category of improvements is housekeeping:

A. Energy reporting

At El Fouledh steelworks, a great deal of energy and production data are available, but most of the data are never put together in one regular report. By collecting information from several departments, it was possible to reconstruct the energy situation, by department within the works, for 1980. An example of part of the report is given as Exhibit M. It is only by tabulating energy information regularly, and by arranging the report in a format which makes comparisons easy, that a start can be made to investigate energy efficiency at the plant level (and at the departmental level within the plant).

B. Furnace efficiencies

At the phosphate rock beneficiation complex at Metlaoui, several small furnaces are used to heat fuel oil tanks and lines. Measurements were taken with portable stack gas analysers under various firing conditions: some results are shown in Exhibit N. Flue gas losses were calculated at about 25 to 30 percent; excess air rates were around 60%. Better control of the plant should provide an excess air rate of under 20% (and flue gas losses closer to 20%). The calculation of furnace efficiencies is relatively simple, and the principles are shown in Exhibits O and P.

C. Plant scheduling

Data obtained at brickworks in Tunisia illustrate the effect that proper scheduling of operations can have on energy efficiency. Exhibit J is a graph of specific energy consumption against throughput for one works on which monthly data for 1980 have been plotted. The exhibit shows that high throughputs give rise to high energy efficiencies: this is the expected result, because much of the energy used in brickworks is lost through

6. DEPT. LAMINOIRE (Rolling Mills)

		J	F	M	A	M	J	J	A	S	O	N	D	1980
MATERIALS														
L1 (Bar)	T	10344	10262	11597	11824	11883	10782	8063	8515	9692	10068	7794	11569	122315
L2 (F.)	T	4668	4095	4731	4601	1395	3626	3626	4091	4319	4640	2784	4339	46915
Total		15012	14357	16328	16425	13278	14408	11689	12606	14011	14708	10578	15908	169230
ENERGY														
No.1 line														
FO Lourd	T	647	622	697	726	753	675	574	591	578	623	495	649	7628
	TEP	634	610	683	711	738	662	563	579	566	611	485	636	7475
FOD	10^3 L													18
	TEP	-	-	-	-	-	-	-	-	-	-	-	-	15
Electricity	10^3 Kwh	1270	1222	1243	1116	1100	1115	1025	1026	998	1142	969	1224	13450
	TEP	109	105	107	96	95	96	88	88	86	98	83	105	1157
Total TEP		743	715	790	807	833	758	651	667	652	709	568	741	8647
TEP/t prod.	10^{-3}	71.8	69.7	68.1	68.3	70.1	70.3	80.7	78.3	67.3	70.4	72.9	64.1	70.7
No.2 line														
FO Lourd	T	420	368	428	377	139	429	462	498	492	482	302	477	4875
	TEP	412	361	419	369	136	420	453	488	482	473	296	467	4778
FOD	10^3 L													11
	TEP	-	-	-	-	-	-	-	-	-	-	-	-	8
Electricity	10^3 Kwh	887	758	856	698	349	725	726	674	697	786	476	715	8347
	TEP	76	65	74	60	30	62	62	58	60	68	41	61	718
Total TEP		488	426	493	429	166	482	515	546	542	541	337	528	5504
TEP/t prod.	10^{-3}	104.5	104.0	104.2	93.2	119.0	132.9	142.0	133.5	125.5	116.6	121.0	121.7	117.3
General														
Gasoil pompe battit.	10^3 L													105
	TEP	7	8	7	8	7	8	7	8	7	8	7	8	90
Pompe Batt.	Kwh	60	71	50	46	52	50	75	54	77	73	45	34	687
P. laminoirs	Kwh	132	132	132	132	132	132	132	132	132	132	132	132	1584
Total 10^3	Kwh	192	203	182	178	184	182	207	186	209	205	177	166	2271
	TEP	17	17	16	15	16	16	18	16	18	18	15	14	195
Grand total	TEP	1255	1166	1306	1259	1022	1264	1191	1237	1219	1276	927	1291	14436
TEP/t prod.	10^{-3}	83.6	81.2	80.0	76.7	77.0	87.7	101.9	98.1	87.0	86.8	87.6	81.2	85.3

EXHIBIT N

TABLE SHOWING THERMAL FLUID BOILER FLUE GAS CONDITIONS AND TEST DATA

DATE / TIME	HIGH FIRE CONDITIONS							LOW FIRE CONDITIONS						
	% CO_2	% O_2	Smoke No.	Flue gas T°C	Ambient T°C	Firing rate litre/h	Flue gas loss %fuel CV	% CO_2	% O_2	Smoke No.	Flue gas T°C	Ambient T°C	Firing rate litre/h	Flue gas loss %fuel CV
27.11.81 14.45	16+17	0.6	6	480	25	-	25.44	-	-	-	-	-	-	-
16.10	-	-	-	-	-	-	-	10	9	5	358	25	-	25.58
28.11.81 09.10	-	-	-	-	-	-	-	10	9	7	331.5	20	-	23.0
09.40	-	-	-	-	-	-	-	9	9	7	333	21	164	25.98
10.20	-	-	-	-	-	-	-	8.5	9	6	359.5	23	187.5	29.16
10.40	-	-	-	-	-	-	-	9	9	-	357	-	201	27.89
11.10	-	-	-	-	-	-	-	8	9	6	351	23	196	30.3
							Average	9.08	9	5.8	348.3	22.4	-	27.05

227

EXHIBIT O

RELATIONSHIP BETWEEN EXCESS AIR, CO_2, O_2 AND CO IN FLUE GAS

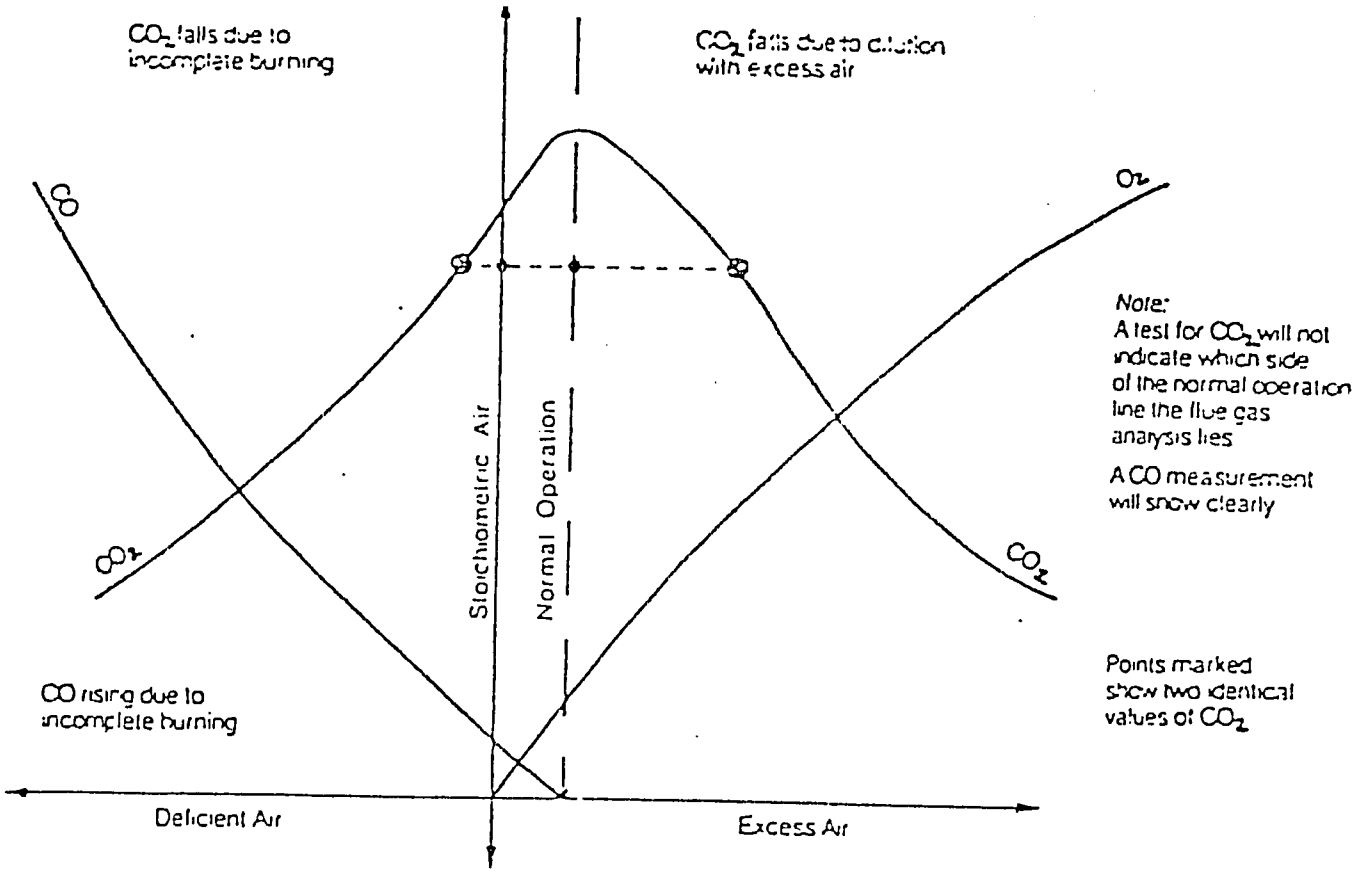
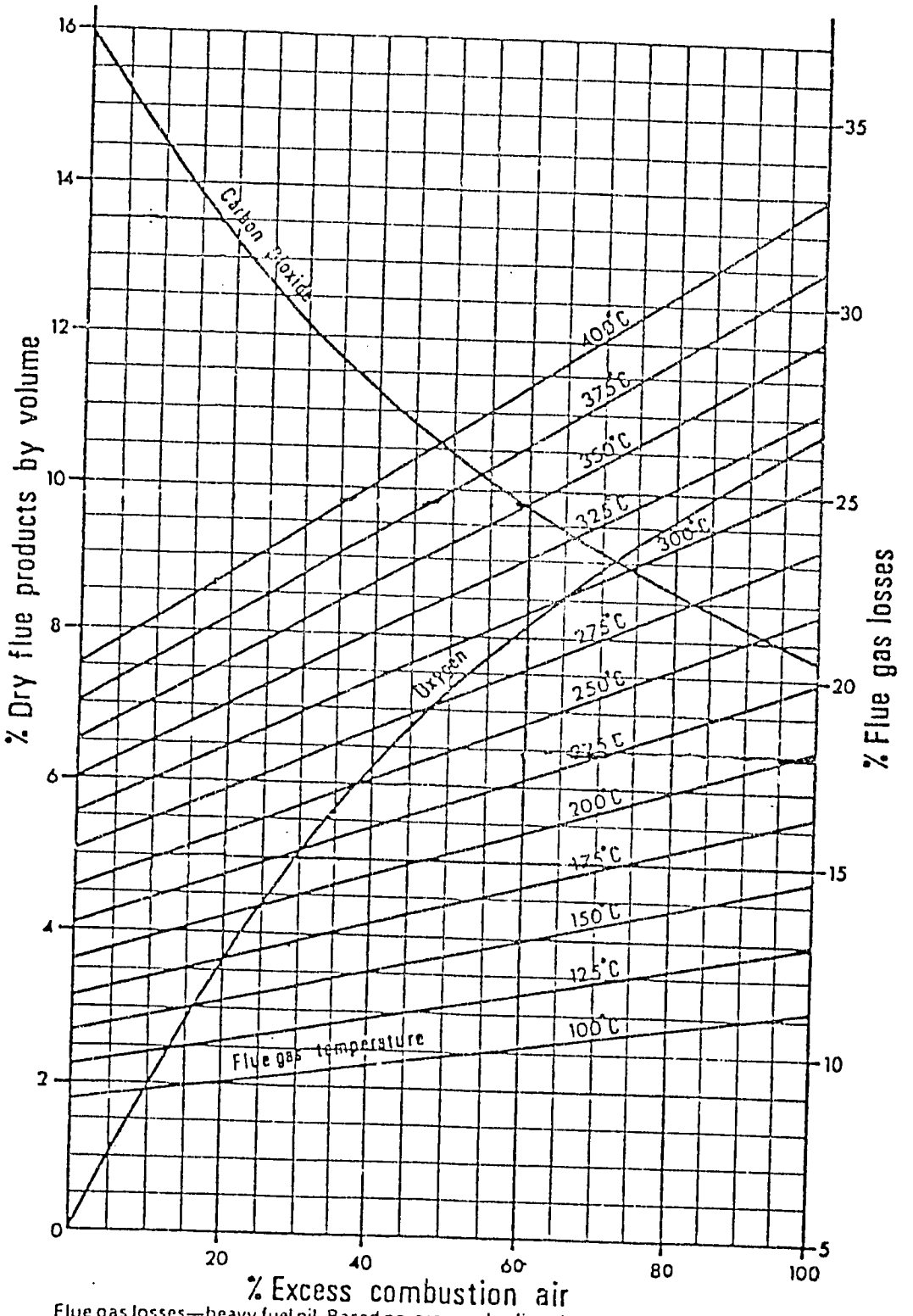


EXHIBIT P

HEAVY FUEL OIL



Flue gas losses—heavy fuel oil. Based on gross calorific value and an ambient temperature of 20°C

the walls of the kilns, irrespective of throughput. Exhibit J therefore suggests that rescheduling of operations to maintain a high utilisation of plant capacity could lead to energy savings of perhaps 25-30%, with no capital investment needed.

Exhibit K shows data for a number of brickworks and a similar situation may be seen for the sector as a whole. Potential energy savings are significant.

D. Steam leaks

An example of the sizeable waste of energy that can be represented by steam leaks was observed at a paper plant. Steam escapes to atmosphere from a safety valve on a tank used for digesting the raw material for pulp manufacture. In the original plant design, the steam was passed through heat exchangers to preheat process water. However, the heat exchangers began to leak and were left out of service, while steam was vented to atmosphere. Using simple measurements, the loss was estimated at 58,000 tonnes of steam per year: assuming only 50% of the energy loss could be recovered for other uses in the factory (perhaps for preheating process water as was designed), the savings would be close to 400,000 dollars per year. These savings clearly justify the repair of the heat exchangers originally installed.

6.2 Minor investments

A typical area for minor capital investments is the improvement of insulation on hot or cold lines and vessels. In the course of audit work in several factories, measurements of the surface temperature of uninsulated hot oil lines were taken and estimates made of the heat losses and the cost of insulation. Exhibit Q is an example of the results of this exercise; the average payback period is about 0.2 years.

Other minor investments identified in the Tunisian project included the installation of fixed stack gas analysers, which would lead to the improved operation of furnaces, boilers and kilns (see also Section 6.1B above).

EXHIBIT Q

TEST RESULTS: TABLE SHOWING EXTENT OF UNLAGGED THERMAL FLUID AND HOT FUEL OIL SERVICES

PLANT AREA CONSIDERED	Approx. pipework length m.	Size of pipe mm.	Surface temp. as measured 0^oC	Heat loss bare pipe kc/mh	Heat loss after insulation kc/mh	Energy saving kc/mh	Annual energy saving $kc/10^6$	Equivalent annual boiler input $kc/10^6$	Annual energy cost saving Dinar	Budget cost for insulation Dinar
Standby oil tank storage compound; Unlagged thermal fluid services	24	38	150	340	34.7	305.3	58.6	83.14	945	140
	30	20	160	231	34.5	196.5	47.16	66.89	760	111
Large oil tank compound; Unlagged thermal fluid and oil services	4	75	65	124	13.2	110.8	3.54	5.03	57	36
	8	38	160	372	37.2	334.8	21.42	30.4	345	47
Preheated fuel oil pipework downstream of rotary kiln pumping and heating unit	24	15	85	77	14	63	12.1	17.15	195	91.2
	24	10	85	55	12.5	42.5	8.16	11.5	131.6	75
								TOTAL	2433.6	500.2

The average payback period is about 0.2 years.

6.3 Major investments

A typical example of an energy conservation measure requiring major capital investment is the recommendation for installation of stack gas recuperators at the steelworks. Two furnaces are used for reheating steel billets, and no attempt is made to recover the energy lost in the furnace stacks. A study showed that recuperation of heat to preheat combustion air could result in an annual saving of over 500 tonnes of heavy fuel oil for each furnace (equivalent to a cost saving of about 110,000 dollars per year). A cost estimate for a recuperator system was made:

		Dollars
(a)	New burner equipment sized for preheated air at 300°C	19,600
(b)	Multi-tube recuperator, with combustion air blow-off facility as over temperature protection - flue gas temperature 750 to 930°C, combustion air 300°C	75,000
(c)	Freight, installation and commissioning of the combustion system, including drawings, pipework and duct modifications	47,000
(d)	Freight, installation, refractory modification, etc., required for recuperator	44,000
	TOTAL ESTIMATED COST PER FURNACE	185,600

The simple payback period for the recuperator system on each furnace is thus under 2 years (based on fuel oil at world market prices).

Another example of a major capital investment was identified at a paper works. Here, steam is raised in two boilers, one operating at 20 atmospheres to provide steam for general process uses, the other at 43 atmospheres to provide steam for the generation of electricity. Due to a limitation in the steam offtake system from the turboalternator, the total amount of steam available at 43 atmospheres cannot be utilised, and up to 40% of the steam is passed through a pressure reducing station to produce 20 atmosphere steam for general process uses. An estimate of the savings obtainable by installing a turboalternator in place of the reducing station was made: about 3.6 million kwh could be generated each year, valued at over 180,000 dollars annually. The cost of a suitable turboalternator set is 120,000 dollars, giving a simple payback period better than 1 year.

7. THE ECONOMICS OF CONSERVATION

The case for investment in energy management and energy conservation measures must be based on sound economic principles. All conservation opportunities should be assessed using the standard techniques such as discounted cash flow (DCF) rate of return, although rapid assessments of profitability may be made (with care) using the simple payback method. As an indication of the attractiveness of typical energy conservation measures, Exhibit R presents some paybacks observed in a study of over 2000 plants. The use of the DCF techniques will be discussed later in connection with microcomputer programmes.

EXHIBIT R

TYPICAL PROFITABILITY OF ENERGY CONSERVATION INVESTMENTS

Generic Measures	Payback period (years)
Improve insulation of buildings	4
Improve control of temperature (thermostats, timeclocks)	0.5
Insulate steam pipes, hot air ducts, hot water pipes, etc.	0.8
Maintain boiler, improve combustion control	1
Replace existing lighting by improved system	2
Clean luminaires, paint walls lighter colour	4
Improve compressed air system, repair leaks, etc.	1
Improve process plant insulation	0.8
Improve process plant control systems	0.8
Return condensate, utilise flash steam	1
Replace boilers	2
Recover waste heat for process heating (incl. recuperators)	1.5
Re-line furnaces, major maintenance of heaters	1.5
Use of waste products as fuel	0.5
Specific Technologies	
Heat recovery from the absorption stage of sulphuric acid plant	1.4
Process heat integration at chemical plant	2
Heat wheel for heat recovery in textile plant	3.2
Heat recovery on a slab reheating furnace	1.5
Replacement of old boiler by coal-fired fluid bed system	4
Rotary air preheater on aluminium melting furnace	2.4
Wet to semi-wet cement plant conversion	5
Self-recuperative burners on forge furnace	3
Recuperative burners on continuous reheat furnace	1.5
Heat recovery by heat pumps in a dairy	2
Coal-fired fluid bed cogeneration system	1.7

Based on studies of over 2200 plants in the U.K. and on technology demonstration projects being monitored by the U.K. Department of Energy.

8. THE USE OF MICROCOMPUTERS FOR INDUSTRIAL ENERGY EFFICIENCY WORK

8.1 Introduction

The use of computers for calculations in industry has, of course, been well developed over a period of many years. The capability of microcomputers has increased to such an extent in the last few years that a large proportion of the tasks traditionally performed on main frame computers can be carried out using small, desk-top microcomputers. In addition, the close interaction of user with microcomputer allows many simple calculations to be performed very rapidly. Indeed, the microcomputer often improves the turnaround time (from submission of input to receipt of output) significantly over that achieved by main frame systems.

The relatively low cost and convenience of the "personal microcomputer" represents a very important advance. The microcomputer can be a highly cost-effective aid to the plant energy manager and the energy planner, both of whom can exploit the computer-user interaction to the full in their daily tasks.

There are of course a large number of possible applications for a microcomputer in industry. These may be divided into several broad categories:

(1) Data management
(2) Engineering calculations
(3) Financial analyses
(4) Special applications

A few examples of each type of application will serve to illustrate the potential for productive utilisation of microcomputers for energy management and energy planning.

8.2 Data Management

Within this category are programmes for standard mathematical calculations including regression analyses and testing of statistical significance, linear programmes, simple curve fitting routines and graphics software. Programmes can be written for specific applications by users, in addition to which there are many ready-made software packages available commercially.

Another type of programme of great utility in all areas of data management is the "electronic spreadsheet", of which Visicalc is probably the most well known. This programme is extremely versatile and is readily usable by engineers after only a few minutes practice. For example, energy planners often have to project energy demands over a period of time for which annual growth rates are specified. The following data are taken from a recent study for the Tunisian industrial sector:

	1980	PCT	PCT GR	1986	PCT
MATCON	417.1	39.82	14.5	939.88	46.72
CHEM	96.4	9.20	10.2	172.65	8.58
MECMET	166.1	15.86	14.3	370.38	18.41
MINING	178.9	17.08	4.9	238.38	11.85
TEXT	42.9	4.10	9.3	73.14	3.64
PAPER	44.7	4.27	10.2	80.06	3.98
FOODPR	89.3	8.53	5	119.67	5.95
OTHER	12.1	1.16	6.3	17.46	0.87
TOTAL	1047.5	100.00		2011.62	100.00

The annual growth rates may be subject to considerable inaccuracy, and the planner may wish to know what the industrial sector demand would become if the construction materials subsector were actually to grow at 10.5% per year ? By setting up a matrix using the Visicalc programme, the user can simply amend the subsector growth rate from 14.5% to 10.5%, and the computer will automatically recalculate the projected demands and other dependent figures within a few seconds. Other key data can be changed by the user, and the sensitivity of the projections to these changes can be observed immediately. Exhibit S shows some typical microcomputer outputs illustrating this particular application of Visicalc.

EXHIBIT S: EXAMPLES OF DEMAND PROJECTIONS BY VISICALC

Growth rate reduced from 14.5 to 10.5%

	1980	PCT	PCT GR	1986	PCT
MATCON	417.1	39.819	10.5	759.30	41.468
CHEM	96.4	9.2029	10.2	172.65	9.4291
MECMET	166.1	15.857	14.3	370.38	20.228
MINING	178.9	17.079	4.9	238.38	13.019
TEXT	42.9	4.0955	9.3	73.144	3.9947
PAPER	44.7	4.2673	10.2	80.057	4.3722
FOODPR	89.3	8.5251	5	119.67	6.5357
OTHER	12.1	1.1551	6.3	17.458	.95343
TOTAL	1047.5	100.		1831.0	100

Basic figure for consumption modified from 417.1 to 505.3 x 10^3 TEP

	1980	PCT	PCT GR	1986	PCT
MATCON	505.3	44.492	10.5	919.86	46.187
CHEM	96.4	8.4882	10.2	172.65	8.6689
MECMET	166.1	14.625	14.3	370.38	18.597
MINING	178.9	15.752	4.9	238.38	11.969
TEXT	42.9	3.7774	9.3	73.144	3.6726
PAPER	44.7	3.9359	10.2	80.057	4.0197
FOODPR	89.3	7.8630	5	119.67	6.0088
OTHER	12.1	1.0654	6.3	17.458	.87656
TOTAL	1135.7	100.		1991.6	100

Another major type of data handling activity is the storage and retrieval of large masses of data. An example of this application to energy management is the collection and analysis of plant-level energy data carried out for the 60 factories in Tunisia. Visits were made to all the plants in turn, and a questionnaire was completed for each by the survey engineers. Data collected included energy consumption figures for each energy form and corresponding production figures. A simplified form was developed for the storage of the most important data using a microcomputer: Exhibit T shows the blank form, and the input data are indicated in Exhibit U.

Many of the items are automatically calculated by the computer. The package used for this work was Versaform, a product of Applied Software Technology. This calculation feature is quite useful, especially for the conversion of the common physical units of consumption into the standard energy unit, "tonnes equivalent petroleum" (TEP). Much time is saved, and the calculation is carried out accurately and correctly for every plant, virtually eliminating the possibility of errors in computing the total plant energy consumption. Several key parameters of energy intensity and energy efficiency are also calculated and displayed on the form. Exhibit V shows the data forms completed for two typical plants, and Exhibit W is a summary listing of all plants included in the file for Tunisia.

With the Versaform software, it is possible to prepare a number of useful reports by searching the data files in different ways. For example, a search for all plants in the "materials of construction" sector may be made (Exhibit X) and a report showing specified key data for all Brickworks within that sector may be produced. This report is shown as Exhibit Y. The options for searching files and data retrieval are virtually unlimited with a sophisticated software package such as Versaform, and the user can begin to create forms, store data and make searches after only a minimum amount of practice on the microcomputer.

Other applications for data files and searching facilities include lists of equipment manufacturers, fuel heating values, insulation and refractory characteristics, process data and specific energy consumptions.

EXHIBIT T: BLANK FORM FOR PLANT DATA

This line:
Name of person interviewed or contacted for information and his telephone number

This line:
Date factory was visited, identity of interviewer, and spare line for entry of special codes by user.

Subsector of manufacturing industry in which the plant is classified.

Major product manufactured

Energy consumed, to be entered in physical units (thousand kilowatt-hours, tonnes, etc.)

```
PLANT ENERGY DATA FORM   YR .. CODE .....

COMPANY ................... SITE .........
CONTACT ................ TEL ............
DATE-VISIT ....... INTVWR ..... XX .....
SUBSEC ......... EMP ..... VALPRO .......
MAJPROD ......... PRODN ....... UN .....

ENERGY CONSUMPTION FIGURES
ENERGY TYPE   CONSUMPTION    EQUIV TEP
ELEC-PURCH(M KWH) .......    E1 ......
NAT-GAS---(M NM3) .......    E2 ......
DOM-FO-(M LITRES) .......    E3 ......
LIGHT-FO-(TONNES) .......    E4 ......
HEAVY-FO-(TONNES) .......    E5 ......
COAL-----(TONNES) .......    E6 ......
                        TOTAL TEP ......

PARAMETERS
SPECIFIC-CONSN ...... TEP/UNIT OUTPUT
ENRGY/EMPLOYEE ...... TEP/EMPLOYEE
ENRGY/VAL-PROD ...... TEP/UNIT CURRENCY
VALUE-PROD/TEP ...... UNIT CURRENCY/TEP
```

Year to which data refer

Identification number for filing/retrieval purposes

Identifies specific factory

Number of employees

Value of production

Units in which production is expressed

Production of main product

Energy consumption expressed as the equivalent tonnes petroleum (1 TEP $= 10^7$ kcal)

Space for various parameters, such as specific energy consumption, energy consumed per unit of production value, etc

EXHIBIT U: TYPICAL INPUT DATA AND CALCULATED VALUES

Input data above line

```
PLANT ENERGY DATA FORM  YR 80 CODE 00007

COMPANY BRIQ.ZARROUK..... SITE KALAA-SGH
CONTACT AMRI,DIR.USINE. TEL (3)31.015...
DATE-VISIT 2/3/82. INTVWR TEAM. XX ...S1
SUBSEC MAT.CONS. EMP 500. VALPRO 3279...
MAJPROD BRICKS... PRODN 178223. UN T....

ENERGY CONSUMPTION FIGURES
ENERGY TYPE    CONSUMPTION   | EQUIV TEP
ELEC-PURCH(M KWH) 11519..    | E1 3686.1
NAT-GAS---(M NM3) 0......    | E2 .....0
DOM-FO-(M LITRES) 1057.2.    | E3 902.95
LIGHT-FO-(TONNES) 0......    | E4 .....0
HEAVY-FO-(TONNES) 12735..    | E5  12353
COAL-----(TONNES) 0......    | E6 .....0
                       TOTAL | TEP  16942
PARAMETERS
SPECIFIC-CONSN 0.0951 TEP/UNIT OUTPUT
ENRGY/EMPLOYEE 33.884 TEP/EMPLOYEE
ENRGY/VAL-PROD 5.1668 TEP/UNIT CURRENCY
VALUE-PROD/TEP 0.1935 UNIT CURRENCY/TEP
```

All these items
calculated automatically
by the computer

EXHIBIT V: TYPICAL PLANT FORMS

PLANT ENERGY DATA FORM YR 81 CODE 00003

COMPANY SA.DOM.FOTINVILLE SITE HAMMAMLIF
CONTACT DE.LABAREYRE... TEL (1)247.431..
DATE-VISIT 24/2/82 INTVWR TEAM. XX ...S1
SUBSEC MAT.CONS. EMP 150. VALPRO 1018...
MAJPROD LIME..... PRODN 64500.. UN T....

ENERGY CONSUMPTION FIGURES

ENERGY TYPE	CONSUMPTION	EQUIV TEP
ELEC-PURCH(M KWH)	1064...	E1 340.48
NAT-GAS---(M NM3)	0.....	E2 0
DOM-FO-(M LITRES)	30.....	E3 25.623
LIGHT-FO-(TONNES)	0.....	E4 0
HEAVY-FO-(TONNES)	0.....	E5 0
COAL-----(TONNES)	4280...	E6 3081.6
	TOTAL	TEP 3447.7

PARAMETERS
SPECIFIC-CONSN 0.0535 TEP/UNIT OUTPUT
ENRGY/EMPLOYEE 22.985 TEP/EMPLOYEE
ENRGY/VAL-PROD 3.3867 TEP/UNIT CURRENCY
VALUE-PROD/TEP 0.2953 UNIT CURRENCY/TEP

PLANT ENERGY DATA FORM YR 80 CODE 00300

COMPANY BRIQ.EL.HAMMA.... SITE EL.HAMMA.
CONTACT MONCEF.JENNI... TEL .....
DATE-VISIT 9/81... INTVWR BT... XX ...S1
SUBSEC MAT.CONS. EMP 250. VALPRO .....
MAJPROD BRICKS... PRODN 89302.. UN T....

ENERGY CONSUMPTION FIGURES

ENERGY TYPE	CONSUMPTION	EQUIV TEP
ELEC-PURCH(M KWH)	3750...	E1 ..1200
NAT-GAS---(M NM3)	5400...	E2 ..5346
DOM-FO-(M LITRES)	624.6..	E3 533.47
LIGHT-FO-(TONNES)	0.....	E4 0
HEAVY-FO-(TONNES)	0.....	E5 0
COAL-----(TONNES)	0.....	E6 0
	TOTAL	TEP 7079.5

PARAMETERS
SPECIFIC-CONSN 0.0793 TEP/UNIT OUTPUT
ENRGY/EMPLOYEE 28.318 TEP/EMPLOYEE
ENRGY/VAL-PROD ..... TEP/UNIT CURRENCY
VALUE-PROD/TEP .....0 UNIT CURRENCY/TEP

EXHIBIT W

1/13/82

CODE	COMPANY	SUBSEC	MAJPROD	PRODN	TOTAL	SPECIF
00001	STEC	CHEMICALS	FERTILIZR	66000	511.87	0.0078
00002	FONDERIES REUNIES	MECMET	CASTINGS	2300	647.10	0.2813
00003	SA DOM POTINVILLE	MAT CONS	LIME	64500	3447.7	0.0535
00004	LE CONFORT	MECMET	APPLIANCE	70338	1555.7	0.0221
00005	SMMT	MECMET	LEAD	19200	8302.1	0.4324
00006	EL ANABIB	MAT CONS	CONCRETE	131462	2743.7	0.0209
00007	BRIQ ZARROUK	MAT CONS	BRICKS	178223	16942	0.0951
00008	COMPT NAT PLASTIQ	MISC	ARTICLES	8200	1595.1	0.1945
00009	BRIQ M'HENNI	MAT CONS	BRICKS	155540	8578.4	0.0552
00010	TUNISIE LAIT	FOOD PROC	MILK	30987	3548.1	0.1145
00011	SITER	TEXTILES	TEXTILES	13600	5968.5	0.4389
00012	SITEX	TEXTILES	TEXTILES	15200	2625.8	0.1728
00013	STIA	MECMET	VEHICLES	8777	1082.6	0.1233
00014	UNION GENERALE	MAT CONS	BRICKS		10272	
00015	SOTUVER	MAT CONS	GLASS	17656	7033.2	0.3983
00016	SONAP	MISC	TYRES	160000	2493.1	0.0156
00017	STIL	FOOD PROC	MILK	56000	2597.1	0.0464
00019	SOC GEN INDUSTRL	MECMET	CYLINDERS	120000.	280.02	0.0023
00020	SOTUBI	FOOD PROC	BISCUITS	2210	228.16	0.1032
00021	SOTUCHOC	FOOD PROC	CHOCOLATE	539	310.11	0.5753
00022	PLATRES TUN MEKN	MAT CONS	TILES	8209	468.70	0.0571
00023	CERAM DE L'OUEST	MAT CONS	BRICKS	55360	4079.1	0.0737
024	CERAM TUNIS IENNE	MAT CONS	BRICKS	55000	3739.6	0.0680
00025	CERAM TUNISIENNE	MAT CONS	TILES	835000	5854.4	0.0070
00026	CIM ARTIF TUNISNE	MAT CONS	LIME	56000	3356.4	0.0599
00027	ALI MAJOUL + CIE	FOOD PROC	TOMATO CN	3704	798.78	0.2157
00028	SICOAC	MAT CONS	PIPES	16100	7964.1	0.4947
00029	CIM AMIANTE TUNSN	MAT CONS	PIPES	28000	1674.8	0.0598
00030	PATISS OUARDA	FOOD PROC	BREAD	3200	125.32	0.0392
00031	S MAT EL CHAKIRA	MECMET	CABLES	2847	634.33	0.2228
00032	GRANUPHOS	CHEMICALS	FERTILIZR	59965	3030.5	0.0505
00033	SIAPE	CHEMICALC	TSP	418074	17428	0.0417
00034	MAN TUN CERAMIQUE	MAT CONS	PORCELAIN	3600	2048.6	0.5691
00035	REFRACTAIRES DE T	MAT CONS	REFRACT	4500	1183.5	0.263
00036	STOA	MECMET	GASES	1830	2642.3	1.4439
00037	SOC LA BRIQUE TUN	MAT CONS	BRICKS	39985	2229.5	0.0558
00038	ICM	CHEMICALS	TSP	49488	14515	0.2933
00039	SAEPA	CHEMICALS	DAP	514974	15281	0.0297
00040	ENGRAIS DE GABES	CHEMICALS	MAP	62611	1277.7	0.0204
00041	ICF	CHEMICALS	AL FLUOR	19730	5093.3	0.2582
00042	SOFOMECA	MECMET	CASTINGS	4787	2426.8	0.5070
00043	SOMOTEX	TEXTILES	THREAD	8595	2966.3	0.3451
00044	ATEL MEC SAHEL	MECMET	IRONMGY		1671.6	
00045	SFBT	FOOD PROC	BEER	295359	3299.1	0.0112
00046	REGIE ALCOOLS	FOOD PROC	ALCOHOL	1800	906.57	0.5037
00047	COOP A J IZIDIHAR	FOOD PROC	PRESERVES		1146.0	
00048	SFAX CERAMIQUE	MAT CONS	BRICKS	30000	2330.8	0.0777
0049	STPA	FOOD PROC	FLOUR	48878	1562.2	0.0320
0050	COUSCOUS DU SUD	FOOD PROC	COUSCOUS	9291	1491.0	0.1605
00051	CIM D'OM KHELIL	MAT CONS	CLINKER	192406	24843	0.1291
01000	CIM ARTIF TUNISNE	MAT CONS	CLINKER	436618	87583	0.2006
02000	BRIQ FOUCHANA	MAT CONS	BRICKS	97147	8689.1	0.0894
03000	BRIQ EL HAMMA	MAT CONS	BRICKS	89302	7079.8	0.0793
04000	CIM BIZERTE	MAT CONS	CLINKER	721350	90946	0.1261

241

EXHIBIT W continued

1/13/82 Page 2

CODE	COMPANY	SUBSEC	MAJPROD	PRODN	TOTAL	SPECIF
05000	CIM GABES	MAT CONS	CLINKER	482500	62408	0.1293
06000	S T SUCRE	FOOD PROC	SUGAR	60615	17061	0.2815
07000	SNCPA	PAPER	PAPER	23808	43106	1.8106
08000	SIAPE	CHEMICALS	TSP	317416	24190	0.0762
09000	C P GAFSA	MINING	PHOS ROCK	4.329	134103	30978
10000	EL FOULEDH	MECMET	STEEL	177937	134549	0.7562
					======	
					826546	
					======	

60 forms read, 60 details scanned,
60 items selected, 60 processed.

EXHIBIT X

1/13/82

CODE	COMPANY	SUBSEC	MAJPROD	PRODN	TOTAL	SPECIF
00003	SA DOM POTINVILLE	MAT CONS	LIME	64500	3447.7	0.0535
00006	EL ANABIB	MAT CONS	CONCRETE	131462	2743.7	0.0209
00007	BRIQ ZARROUK	MAT CONS	BRICKS	178223	16942	0.0951
00009	BRIQ M'HENNI	MAT CONS	BRICKS	155540	8578.4	0.0552
00014	UNION GENERALE	MAT CONS	BRICKS		10272	
00015	SOTUVER	MAT CONS	GLASS	17656	7033.2	0.3983
00022	PLATRES TUN MEKN	MAT CONS	TILES	8209	468.70	0.0571
00023	CERAM DE L'OUEST	MAT CONS	BRICKS	55360	4079.1	0.0737
00024	CERAM TUNIS IENNE	MAT CONS	BRICKS	55000	3739.6	0.0680
00025	CERAM TUNISIENNE	MAT CONS	TILES	835000	5854.4	0.0070
00026	CIM ARTIF TUNISNE	MAT CONS	LIME	56000	3356.4	0.0599
00028	SICOAC	MAT CONS	PIPES	16100	7964.1	0.4947
00029	CIM AMIANTE TUNSN	MAT CONS	PIPES	28000	1674.8	0.0598
034	MAN TUN CERAMIQUE	MAT CONS	PORCELAIN	3600	2048.6	0.5691
00035	REFRACTAIRES DE T	MAT CONS	REFRACT	4500	1183.5	0.263
00037	SOC LA BRIQUE TUN	MAT CONS	BRICKS	39985	2229.5	0.0558
00048	SFAX CERAMIQUE	MAT CONS	BRICKS	30000	2330.8	0.0777
00051	CIM D'OM KHELIL	MAT CONS	CLINKER	192406	24843	0.1291
01000	CIM ARTIF TUNISNE	MAT CONS	CLINKER	436618	87583	0.2006
02000	BRIQ FOUCHANA	MAT CONS	BRICKS	97147	8689.1	0.0894
03000	BRIQ EL HAMMA	MAT CONS	BRICKS	89302	7079.8	0.0793
04000	CIM BIZERTE	MAT CONS	CLINKER	721350	90946	0.1261
05000	CIM GABES	MAT CONS	CLINKER	482500	62408	0.1293
					======	
					365495	
					======	

60 forms read, 60 details scanned,
23 items selected, 23 processed.

EXHIBIT Y

1/13/82

CODE	COMPANY	MAJPROD	PRODN	TOTAL	SPECIF
00007	BRIQ ZARROUK	BRICKS	178223	16942	0.0951
00009	BRIQ M'HENNI	BRICKS	155540	8578.4	0.0552
00014	UNION GENERALE	BRICKS		10272	
00023	CERAM DE L'OUEST	BRICKS	55360	4079.1	0.0737
00024	CERAM TUNIS IENNE	BRICKS	55000	3739.6	0.0680
00037	SOC LA BRIQUE TUN	BRICKS	39985	2229.5	0.0558
00048	SFAX CERAMIQUE	BRICKS	30000	2330.8	0.0777
03000	BRIQ FOUCHANA	BRICKS	97147	8689.1	0.0894
00	BRIQ EL HAMMA	BRICKS	89302	7079.8	0.0793
			=======	======	
			700557	63940	
			=======	======	

60 forms read, 60 details scanned,
9 items selected, 9 processed.

8.3 Engineering Calculations

At the plant level, there are many calculations which are performed regularly by energy managers and engineers. Many of the calculations are not particularly complex, and often can be carried out with electronic calculators in a few minutes. However, the close user interaction provided by personal microcomputers often makes programming for such calculations worthwhile.

Some of the common calculations performed in the course of plant energy audits are:

(i) furnace efficiency based on stack gas analyses and temperatures, taking into account fuel characteristics.

(ii) boiler efficiency, same as above and also including the effect of blowdown and condensate return.

(iii) heat losses from structures, such as boilers, process vessels, cement and brick kilns.

(iv) heat losses from pipes

(v) fuel combustion calculations, to calculate stoichiometric air requirements for different fuels, stack gas volumes and calculated compositions from fuel analyses.

(vi) pump, compressor and turbine calculations, such as work output and efficiency.

(vii) pitot tube calculations, for estimating gas flow rates from instrument readings.

(viii) heat exchanger calculations and sizing of heat recovery systems.

(ix) estimation of steam and compressed air losses from leaks.

(x) heating, ventilation and cooling loads for offices and commercial buildings.

Few software packages are available commercially for these types of engineering calculations, with the possible exception of HVAC programmes based on standard calculational procedures such as ASHRAE methods. Appendix A gives some examples of engineering programmes written specifically for audit work using the Visicalc system.

8.4 Financial Analyses

Much energy management work leads to the identification of conservation opportunities, often requiring capital investment. The evaluation of these investments is necessary, using simple payback techniques or preferably using discounted cash flow methods. A typical DCF rate of return calculation will be discussed in Session Fourteen. Further discussion of rate of return calculations is given in Appendix B.

Other types of financial analyses which could be applied to microcomputers and which are related to energy conservation work include those which provide estimates of the impact of investments on company cash flows and balance sheets. Standard accounting packages can be used for this work.

8.5 Special Applications

There are a variety of special applications for microcomputer programmes which can be used in specific industries. Examples are:

(i) linear programme models for optimising oil refinery and petrochemical plant operations
(ii) fuel blending calculations (e.g. gasoline blending by octane number, fuel oil flending to viscosity and sulphur specifications)
(iii) transportation models for optimising the operation of distribution depots and delivery fleets
(iv) Monte Carlo simulation models (e.g. for estimating the capacity of storage tanks or inventory levels)
(v) electric utility system dispatch models for day-to-day operations, and capacity planning models for optimising new plant construction
(vi) electricity and gas tariff analyses

Many such applications are the subject of commercial software, while there are also many proprietary and company-specific programmes for particular tasks. Increasingly, companies are turning to user-oriented microcomputer systems rather than main frame computers for regular calculations.

Finally, mention should also be made of the special applications of microcomputers as remote terminals linked to energy management control systems or main frame data banks. Microcomputers have been used to monitor and control building heating and lighting systems, for example, in combination with telephone lines and modems.

8.6 Software Needs and Availability

As indicated in the previous section, there are many commercially-available software packages for microcomputers. However, there are relatively few such packages for carrying out energy-related calculations, and it is thus the responsibility of the users either to utilise commercial software such as Visicalc and Versaform for energy calculations or data handling or, where this software is inadequate, to write their own programmes for specific energy-related applications.

In fact, many of the calculations commonly performed by energy engineers are relatively easily programmed for a microcomputer. The standard floppy disk used by most microcomputers can be used to store several programmes or sets of data, making it possible to develop a library of useful programmes on one or two disks which are easily stored and easily transported from one computer location to another.

With respect to the availability of commercial software, the major microcomputer manufacturers provide lists of software developed by them and suitable for their machines, and there are a very large number of specialist software companies throughout the world who write programmes for the main microcomputer systems. The price of software will obviously vary quite considerably, depending on its capabilities, but most commonly-used software is priced in the range from $150 to $500. Visicalc, for example, is typically available at a price at the lower end of this range, while Versaform is priced nearer to top end.

8.7 Aspects of Implementation

There are a number of factors which must be taken into account when considering the implementation of microcomputer systems for energy management work. Software availability has already been mentioned. There is also the question of the hardware itself. Some manufacturers have well-developed dealer networks and can provide good after-sales service and backup, both in terms of repair of defective equipment and in terms of programming support and training.

The minimum hardware requirement for typical energy management work may be summarised as follows:

(1) Microcomputer (say 48 - 64K RAM)
(2) Monitor (a TV set is normally acceptable)
(3) Printer (the dot-matrix type being quite adequate for engineering work)
(4) Disk drive and control card (at least one drive unit, preferably two)

The cost of this hardware can be quite variable from country to country and manufacturer to manufacturer. A very rough guide to the price of a complete package with two disk drives would be $3,500.

Depending on the software systems to be used, various add-on "cards" (printed circuit boards) may be necessary. For example, the Versaform package is written in the Pascal language and therefore a special card, incorporating 16K extra RAM capacity, will usually be needed for a typical microcomputer, permitting it to run Pascal in addition to the Basic language which is usually standard. A Pascal card for the Apple II system will probably cost about $200.

Having purchased the basic hardware and software, the potential user will need to learn how best to operate the microcomputer system. For the optimum use of the microcomputer for energy efficiency work, some training may be desirable for plant engineers. Assuming that the plant engineer has a solid technical background, it may be appropriate for training to be given as follows:

(1) "energy management" training, to teach the principles of energy conservation work, to review the technical basis of common unit operations (e.g. combustion)

(2) an introduction to microcomputers, to encourage familiarity with the capabilities of the particular system and the main features of its operation

(3) training, and practice, in the use of the available software packages

(4) some training in the writing of new programmes (in BASIC and possibly FORTRAN) to cover the gaps which will undoubtedly exist due to limited availability of appropriate software.

Following the initial training, the plant engineer must be encouraged to practice using the microcomputer. There is no substitute for practical experience.

While most medium to large plants, and some small plants, will be able to benefit from the use of a microcomputer for technical work, applications in the area of data base management are less obviously beneficial. In general, data base management will usually prove to be most useful to government agencies for energy planning work, for monitoring the impact of existing energy policies, and for developing new policy initiatives.

Of course, without due consideration to the provision of reliable data and proper thought to the use to which the data will be put, there is little justification for a microcomputer-based system. However, if the right data are available, the closer user interaction achievable with a microcomputer will be found to be extremely valuable for the energy planner and policy maker, and thus the microcomputer system is much superior to the conventional main frame system usually used by a national statistical bureau for many types of work involving the evaluation of options and decision-making.

SESSION NINE: FIELD TRIP

Visit to the OTP Phosphate Processing Complex

A summary of the manufacturing activities carried out at the phosphate processing complex has already been given (Session Three). The purpose of the field trip is to illustrate some of the audit procedures and techniques discussed in Session Seven, and to give seminar participants a first-hand experience of typical audit work in a factory.

The field trip will occupy a whole day. In the morning, all participants will receive a general introduction to the plant and will visit the site to see the major items of processing equipment. After lunch, the participants will be divided into three groups with the following responsibilities:

A: Collect recent data on operations from the plant office, and collect specified data from existing plant instruments (see Exhibit AA).

B: Conduct a check of surface temperatures around one of the rotary drier systems, and thus calculate the heat loss from the drier.

C: Conduct a check of combustion efficiency at the plant boiler.

Group A will spend most of the afternoon on their tasks, while Groups B and C will exchange tasks after about 1 hour.

Exhibit AA

Examples of Data to be Collected

Office

For each of the last 6 months:

Raw material processed (total; by each drier)	tonnes
Quality of input	BPL
Production of phosphate (total; by each drier)	tonnes
Quality of output	BPL
Water content of food to each drier	% wt
Water content of product from each drier	% wt
Water content of product shipped	% wt
Fuel consumed--each type (by each drier, total factory)	tonnes, litres..
Electricity consumed (total)	KWH

Plant

For each drier in operation:

Throughput	tonnes/hour
Water content at inlet	% wt
Water content at outlet	% wt
Fuel consumption	litres/hour
Temperature readings (combustion chamber, drier outlet, etc.)	^{o}C
Fuel oil storage tank temperature	^{o}C
Temperature of fuel oil to burners	^{o}C

SESSION THIRTEEN: ECONOMIC ANALYSIS OF ENERGY EFFICIENCY MEASURES

The Use of a Microcomputer for DCF Calculations

A brief discussion of DCF calculations and the use of a microcomputer to perform them appears in Appendix B.

APPENDIX A EXAMPLES OF ENGINEERING CALCULATIONS

This Appendix gives examples of the use of microcomputer programmes to carry out some engineering calculations commonly applied in energy management work. The calculations are:

(1) Boiler/furnace efficiency
(2) Heat losses from hot structures to atmosphere
(3) Heat losses from pipes
(4) Gas flow measurement by pitot tube

For each programme, a comprehensive discussion of the basis for the calculation method is provided, and examples of typical input and output are shown. The programmes have been applied to the Apple II system, which is quite typical of the many personal microcomputers available at moderate cost to plant engineers.

A.1 BOILER/FURNACE EFFICIENCY CALCULATION ("COMBUSTION EFF")

1. Introduction

This calculation involves estimating the various sources of loss from the boiler or furnace and then calculating the thermal efficiency by difference:

$$\% \text{ thermal efficiency} = 100 - \sum (\text{sources of loss})\ \%$$

Nine different sources of loss have been identified:

(1) Unburnt combustible material in fly ash
(2) Unburnt combustible material in slag or ash withdrawn from the bottom of the combustion zone (in the programme this is referred to as "slag ash")
(3) Sensible heat in fly ash
(4) Sensible heat in slag ash
(5) Sensible heat of dry flue gas
(6) Latent heat of moisture in flue gas
(7) Unburnt combustible carbon monoxide in flue gas
(8) Radiation and convection heat loss from the structure of the boiler or furnace
(9) Sensible heat in blowdown water

Items (1) and (4) are only applicable for solid fuels such as coal and coke; item (9) applies only to boilers.

Apart from the radiation and convection heat loss (item 8), the programme calculates all the individual sources of loss. Item (8) is entered by the user: a programme to calculate such losses follows in this Appendix, but a typical value of 3% can be entered if the actual value is not known.

2. How the Programme is Organised

The programme uses the Visicalc "electronic spreadsheet" system: it is therefore necessary to load Visicalc into the microcomputer prior to loading the "COMBUSTION EFF" diskette.

The worksheet is divided into several "fields" in which the various elements of the programme have been placed. These elements are shown in Exhibit A.1.1, and are:

(1)	Numerical input data	(A1 - E36)
(2)	Identification information	(A37- E48)
(3)	Calculation results	(A50- E82)
(4)	Standard input data	(J1 - R8)
(5)	Typical fuel calorific values	(J20- M47)

The required input data are listed in Exhibit A.1.2. Some items are dependent on the characteristics of the fuel being fired; typical values are shown on the worksheet itself (J1-R8 and J20-M47) and also in Exhibit A.1.4.

3. Calculation Basis

The basic equations used in the calculation procedure are listed in Exhibit A.1.3.

4. Worked Example

Exhibit A.1.4 presents a typical worked example of the combustion efficiency programme applied to a coal-fired boiler.

Note that the Visicalc programme operates by changing the input data. Whenever COMBUSTION EFF is loaded, a set of input and output figures will appear, as these are the data used for the previous calculation. The user must make sure that all the input data are changed to correspond to the new calculation to be performed.

EXHIBIT A.1.1 "COMBUSTION EFF" WORKSHEET

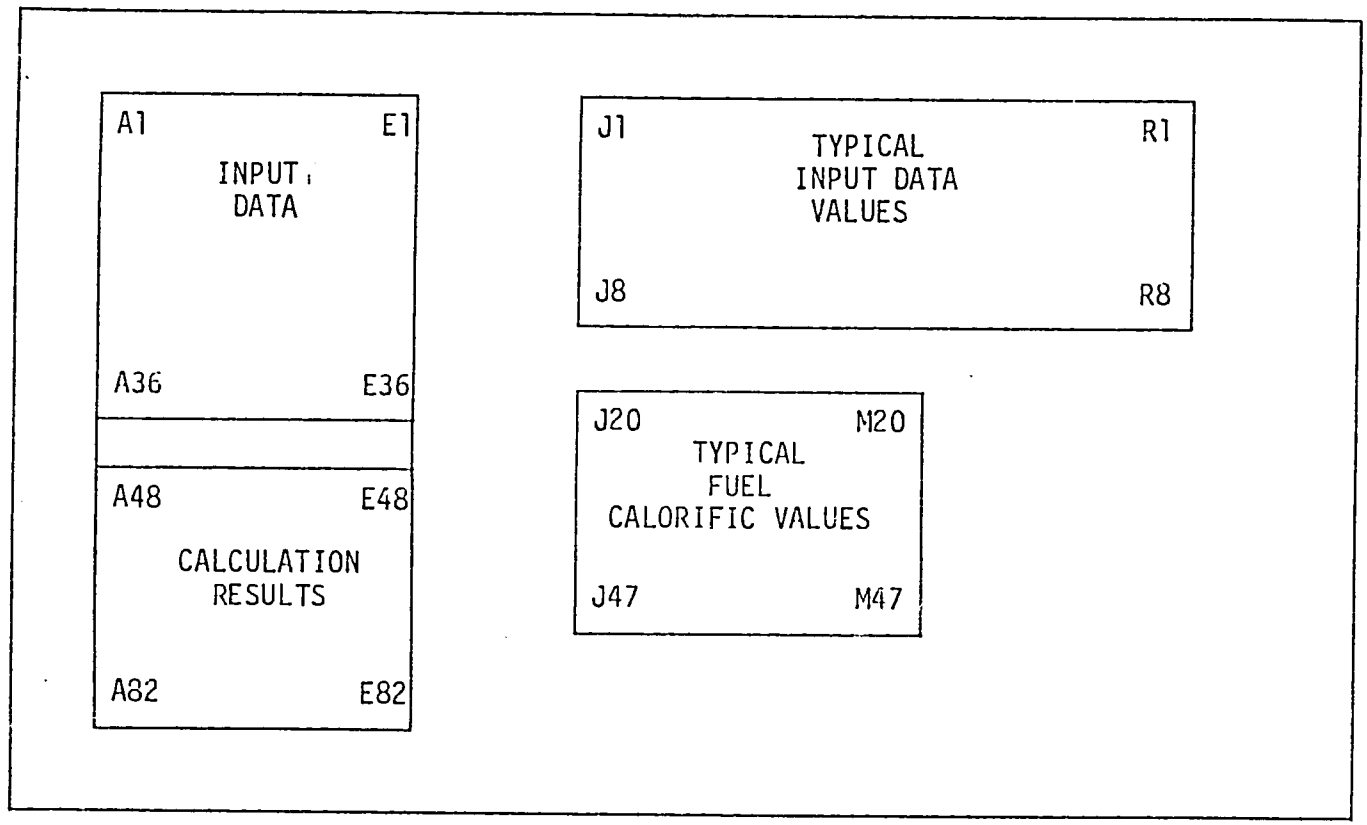


EXHIBIT A.1.2

INPUT DATA

	Symbol	Notes
Weight fraction ash in fuel	A_{fuel}	(1) (2)
Fraction of ash in fuel to fly ash	F_{FA}	(2)
Weight fraction combustibles in slag ash	C_{SA}	(2)
Weight fraction combustibles in fly ash	C_{FA}	(2)
Gross heating value of fuel, kcal/kg	CV_g	(1)
Flue gas temperature, ^oC	T_{FG}	(3)
Ambient temperature, ^oC	T_A	
Slag ash exit temperature, ^oC	T_{SA}	(4)
Oxygen in dry flue gas, vol%	O_2	
Fuel preheat temperature, ^oC	T_{fuel}	(5)
Carbon monoxide in dry flue gas, vol%	CO	
Structure radiation and convection loss, %	L_{RC}	(6)
Blowdown temperature, ^oC	T_{BD}	(7)
Feed water to blowdown, wt%	BD	(8)
Feed water temperature, ^oC	T_{H_2O}	(9)
Maximum theoretical CO_2 in dry flue gas, vol%	CO_{2MAX}	(10)
Water in fuel, wt%	H_2O_{fuel}	(1) (11)
Hydrogen in fuel, wt%	H_{fuel}	(1) (11)
K1 fuel characteristic constant	K_1	(10)
K2 fuel characteristic constant	K_2	(10)

Notes

(1) These data relate to the quality of the fuel "as fired". Note that in the case of coal fuels, "as fired" quality may be significantly different from proximate or ultimate analyses.

(2) Value should be within the range 0.00 to 1.00

(3) Temperature after any economisers or air preheaters

(4) Temperature at which slag and/or ash (other than fly ash) leave the furnace or boiler.

(5) This temperature should be recorded if the fuel is preheated by external means (but not heat recovery from the furnace/boiler). External preheating will be common only for oil fuels. In the case of no preheating or preheating by heat recovery (e.g. self-recuperative gas burners), the ambient temperature can be used for T_{fuel}.

(6) L_{RC} can be the output of the "Heat Losses from Hot Structures" programme. A typical value for a reasonably insulated boiler or furnace operating at full capacity would be around 3% of fuel fired.

(7) Blowdown temperature after any heat recovery.

(8) Percentage of feedwater to blowdown, including any flash steam produced by blowdown.

(9) Feedwater temperature including recycled condensate and makeup, but before preheating in economiser.

(10) These values depend entirely on the characteristics of the fuel used. Select the appropriate value from Exhibit A.1.4 or in the programme itself.

(11) These values depend on the free water in the fuel and the fuel analysis itself. Use actual test data or the typical values shown in Exhibit A.1.4.

EXHIBIT A.1.3

PROGRAMME CALCULATION BASIS
(In order of programme execution)

(1) LFA $$= \frac{A_{fuel} \times F_{FA} \times C_{FA} \times 808{,}300}{(1 - C_{FA}) \times CV_G}$$

(2) LSA $$= \frac{A_{fuel} \times (1 - F_{FA}) \times C_{SA} \times 808{,}300}{(1 - C_{SA}) \times CV_G}$$

(3) LFASH $$= \frac{A_{fuel} \times F_{FA} \times (T_{FG} - T_A) \times 21}{(1 - C_{FA}) \times CV_G}$$

(4) LSASH $$= \frac{A_{fuel} \times (1 - F_{FA}) \times (T_{SA} - T_A) \times 21}{(1 - C_{SA}) \times CV_G}$$

(5) CO_2 $$= \left[1 - \frac{O_2}{21} \right] \times CO_{2MAX}$$

(6) LDG $$= \frac{K1 \times (T_{FG} - T_A) \times (1 - 0.01 \; [LFA + LSA])}{CO_2}$$

(7) CV_G^0 $$= CV_G + ([T_{fuel} - T_A] \times 0.47)$$

(8) LH2O $$= \frac{[H_2O_{fuel} + 9H_{fuel}] \; [588 - T_A + 0.50 \; T_{FG}]}{CV_G^0}$$

251

(9) $$LCO = \frac{K2 \times CO\,(1 - 0.01\,[LFA + LSA])}{CO + CO_2}$$

(10) $$SIGMA\ L = LFA + LSA + LFASH + LSASH + LDG + LH2O + LCO + LRC$$

(11) $$LBD = \frac{[T_{BD} - T_{H_2O}] \times BD \times [100 - SIGMAL]}{([T_{BD} - T_{H_2O}] \times BD) + ([100 - BD] \times [660 - T_{H_2O}])}$$

(12) $$E = 100 - [LBD + LFA + LSA + LFASH + LSASH + LDG + LH2O + LCO + LRC]$$

(13) $$XSA = \left[\left(\frac{CO_{2MAX}}{CO_2}\right) - 1\right] \times 100$$

Derived Variables

LFA	energy loss% as combustibles in fly ash
LSA	" " " " slag ash
LFASH	" " sensible heat in fly ash
LSASH	" " " " slag ash
LDG	" " in dry flue gas
CV_G^0	fuel gross heating value + sensible heat in fuel
LH2O	energy loss % as moisture in flue gas
LCO	" " " unburnt CO in flue gas
LBD	" " in blowdown
SIGMAL	sum of various losses, as defined
E	overall thermal efficiency, %
XSA	excess air, %

EXHIBIT A.1.4

A.1

BOILER & FURNACE
EFFICIENCY PROGRAM

ENTER THE INPUT DATA INDICATED: ALL NUMERICAL DATA MUST BE ENTERED IN COLUMN D. TEST DATA ARE ENTERED FIRST, FOLLOWED BY DATA FROM THE TABLE LOCATED IN AREA J1-8 TO R1-8. PLANT IDENTIFICATION AND OTHER INF--ORMATION MAY BE ENTERED AFTER THAT

TEST DATA

WT FRAC ASH IN FUEL	.1
WT FRAC ASH TO FLYASH	.5
WT FRAC COMB IN SLAG ASH	.02
WT FRAC COMB IN FLYASH	.05
FUEL GROSS CV, KCAL/KG	6500
FLUE GAS TEMP, DEGR C	250
AMBIENT TEMP,DEGR C	20
SLAG ASH TEMP, DEGR C	500
VOL % O2 IN FLUE GAS	10
OIL FUEL TEMP, DEGR C	20
VOL % CO IN FLUE GAS	.01
STRUCT HEAT LOSS %	3.2
BLOWDOWN TEMP, DEGR C	205
% BLOWDOWN	4
BFW TEMP,DEGR C	50

TABLE DATA

CO2 MAX	18.5
H2O FUEL	7
H FUEL	5.5
K1	.6
K2	63

NUMERICAL INPUT COMPLETE: ITEMS SUCH AS PLANT NAME ETC MAY NOW BE INPUT:

COMBUSTION EFFICIENCY CALCULATION

PLANT NAME	BIZERTA CEMENT FACTORY
TEST DATE	DEC 12 82
EQUIPMT. NUMBER	F 101
EQUIPMT. TYPE	SHELL BOILER
FUEL	BITUMINOUS COAL
FIRING RATE %	75
DESIGN CAPACITY	500 TONNES/HR

KEY TEST DATA

AMBIENT TEMP, DEG C	20
FLUE GAS TEMP,DEG C	250
FLUE GAS ANALYSIS	
O2	10
CO2 CALC	9.69
CO	.01
FUEL TYPE	
FUEL QUALITY	
H2O	7
H	5.5
ASH	.1
GROSS CV KCAL/KG	6500
% BLOWDOWN	4

LOSSES & EFFICIENCY (% GROSS CV)

COMBUSTIBLES IN FLY ASH	0.33
COMBUSTIBLES IN SLAG ASH	0.13
SENSIBLE HEAT IN FLY ASH	0.04
SENSIBLE HEAT IN SLAG ASH	0.08
DRY FLUE GAS	6.40
MOISTURE IN FLUE GAS	6.02
CO IN FLUE GAS	0.06
STRUCTURE	3.20
SUBTOTAL	16.26
BLOWDOWN LOSSES	0.88
TOTAL LOSSES %	17.14
EFFICIENCY %	82.86
EXCESS AIR %	70.91

E 82

261

EXHIBIT A.1.4 continued

J.1

FUEL TYPE	K1	K2	CO2 MAX	H2O FUEL	H FUEL	
COKE	.69	70	20	2	1.1	COKE
ANTHRACITE	.67	65	20	1	3	ANTHRACITE
BITUMINOUS COAL	.6	63	18.5	7	5.5	BITUMINOUS COAL
COAL TAR	.58	62	17.9	.5	6.2	COAL TAR
PETROL'M FUELS	.53	48	15.7	.1	12.5	PETROL'M FUELS
NATURAL GAS	.34	32	11.7	0	25	NATURAL GAS

R8

J.20

S OME TYPICAL FUEL CALORIFIC VALUES

ALL FIGURES KCAL/KG GROSS-"AS FOUND"

SOLID	BITUM COAL	5400-6550
	ANTHRACITES	6910-7125
	LIGNITE	5510
	PEAT	3800
	WOOD	3780
	COKE	6830
	COKE BREEZE	5555
	PETR. COKE	8333
PETROLEUM FUELS		
	NO 6 F.O.	10100
	NO 4 F.O.	10220
	NO 2 F.O.	10325
	DIST'LATE HTG OIL	10820
	DIESEL	10980
	KEROSENE	11110
	MOTOR GASOLINE	11200
	LIGHT NAPHTHA	113[illegible]0
	LIQ BUTANE	11780
	LIQ PROPANE	11945
GASES	PROPANE-PURE	12037
	ETHANE	12403
	METHANE	13271

M.47

A.2 HEAT LOSSES FROM HOT STRUCTURES TO ATMOSPHERE ("HEATLOSS-STRUCTURES")

1. Introduction

This programme enables the energy loss from the outside surface of kilns, boilers and furnaces to be estimated based on measurements of the temperature of the structure surface. Temperatures may be determined using a contact thermocouple or a non-contact infrared pyrometer, the latter being particularly useful for equipment such as rotating cement and lime kilns.

2. How the Programme is Organised

The Visicalc worksheet is divided into various elements, as shown in Exhibit A.2.1:

(1) Introduction for the user (A1-D37)
(2) Miscellaneous emissivity values (H1-K35)
(3) Convection constants (M1-N6)
(4) Calculation field (A40-X51)
(5) Summary of results (V54-Y61)

The structure may be divided into a number of sections (up to a total of 15), and for each section the following input data are needed:

(1)	Area of the surface, square meters	(A)
(2)	Surface emissivity	(E)
(3)	Convection constant	(C)
(4)	Surface temperature, ^{o}C	(TS)
(5)	Ambient temperature, ^{o}C	(TA)

3. Calculation Basis

The heat loss from a structure consists of two main components, radiation and convection. For each subdivision of the total surface, heat loss by radiation and convection is calculated by the following equations:

Radiation heat loss (Kcal/hour):

$$QSR = 4.90\ EA \left[\left(\frac{TS + 273}{100} \right)^4 - \left(\frac{TA + 273}{100} \right)^4 \right]$$

Convection heat loss (Kcal/hour):

$$QSC = CA\ (TS - TA)^{1.25}$$

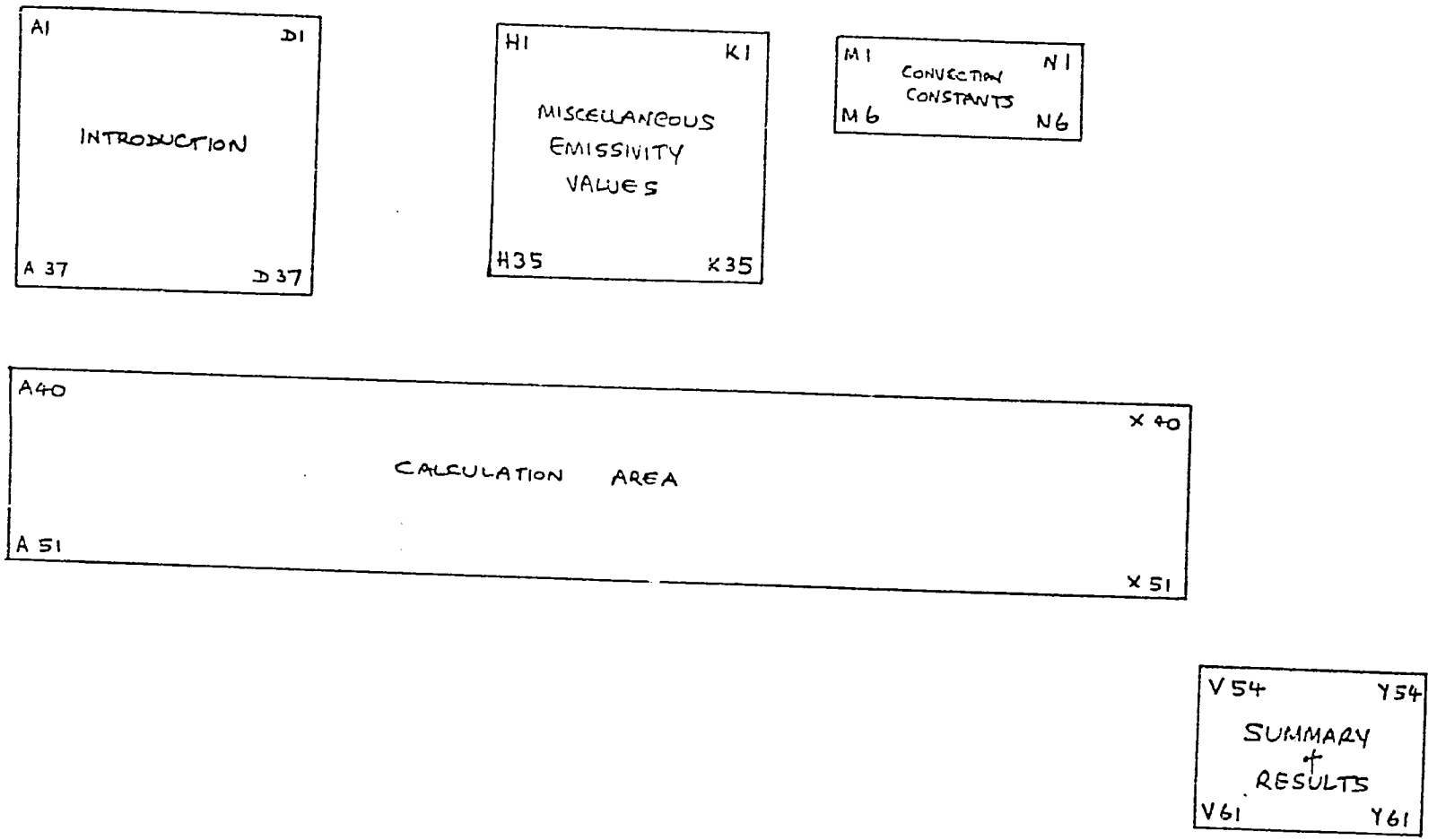
The actual emissivity of a surface may be determined experimentally or typical values may be used (see blocks H1-K35 of the worksheet). A perfect black body radiator has an emissivity value of 1.0.

It should be noted that this programme gives the heat loss for structures in still air conditions and will underestimate the heat loss from structures exposed to windy conditions.

4. Worked Example

Exhibit A.2.2 presents a typical worked example of the heat loss programme. The user must ensure that all input data are changed to correspond to each new calculation, otherwise data will be retained from the previous calculation.

Exhibit A.2.1 : Worksheet for "HEATLOSS-STRUCTURES"



A1 HEAT LOSSES FROM STRUCTURES TO ATMOSPHERE. D1

THE WORKSHEET IS ORGANISED INTO 15 COLUMNS, EACH OF WHICH CORRESPONDS TO A DEFINED AREA OF THE OUTSIDE SURFACE OF THE STRUCTURE. THE USER SHOULD START BY ENTERING THE DATA FOR THE FIRST SECTION, WORKING DOWN THE FIRST COLUMN COMPLETELY BEFORE CONTINUING ON TO THE SECOND COLUMN, AND SO ON TO THE LAST SECTION DEFIN--ED FOR THE STRUCTURE BEING ANALYSED

A MAXIMUM OF 15 COLUMNS MAY BE USED BUT FEWER COLUMNS MAY BE NEEDED IN MANY CASES: THE USER SHOULD COMPLETE THE RELEVANT COLUMNS AND LEAVE THE REMAINING COLUMNS BLANK. WHERE DATA REMAIN FROM A PREVIOUS CALCULATION THE USER MUST REMOVE THIS BY ENTER--ING ZERO IN THE RELEVANT INPUT BLOCKS.

THE CALCULATED HEAT LOSSES FOR EACH SECTION ARE LOCATED AT THE BOTTOM OF THE COLUMNS, AND THE TOTAL HEAT LOSS FOR THE STRUCTURE IS DISPLAYED IN THE LAST COLUMN ON THE RIGHT OF THE WORKSHEET.

FOR YOUR INFORMATION, E VALUES ARE GIVEN IN BLOCKS H1-H35 AND CONVECTION CONSTANTS IN M1-N6. THE WORKSHEET D37

H1 MISCELLANEOUS EMISSIVITY VALUES K1

	E
OIL BASED PAINTS, ALL COLORS EXCEPT ALUMINUM	.94
ALUMINUM PAINT, CLEAN/NEW	.45
" " DIRTY/OLD	.7
ROUGH WHITE MORTAR	.88
ROUGH RED BRICK	.93
ASBESTOS CEMENT	.96
ASBESTOS CLOTH	.9
EARTHENWARE	.92
FIRED CLAY	.91
CONCRETE	.94
LIME MORTAR	.91
WOOD	.9
ROUGH OXIDIZED WROUGHT IRON	.89
" " CAST IRON	.9
POLISHED WROUGHT IRON	.28
ALUMINUM, POLISHED	.15
" OXIDISED	.25

H35 K35

M1 CONVECTION CONSTANT N1

VERTICAL	1.59
HORIZONTAL	2.16
SPHERICAL OR CYLINDRICAL	1.88

M6 N6

EXHIBIT A.2.2

WORKED EXAMPLE: "HEATLOSS-STRUCTURES"

EXHIBIT A.2.2 continued

A40 X40

SECTIONS	....1..	....2..	....3..	....4..		....5..	....6.	....7.		....8..	....9..	...10..		...11..	...12.	...13..		...14..	...15..	TOTAL
INPUT:																				
AREA (A) SQ M	35	35	35	35	SQ M	35	35	35	SQ M	35	35	35	SQ M	35	35	35	SQ M	35	35	525 AREA TOTAL
EMMISSIVITY (E)	.9	.9	.9	.9	E	.9	.9	.9	E	.9	.9	.9	E	.9	.9	.9	E	.9	.9	----
CONVECTION CONSTANT	2.16	2.16	2.16	2.16	CONV C	2.16	2.16	2.16	CONV C	2.16	2.16	2.16	CONV C	2.16	2.16	2.16	CONV C	2.16	2.16	----
SURFACE TEMP(TS) C	350	350	350	350	TS	350	350	350	TS	350	350	350	TS	350	350	350	TS	350	350	----
AMBIENT TEMP(TA) C	20	20	20	20	TA	20	20	20	TA	20	20	20	TA	20	20	20	TA	20	20	----
HEAT LOSSES KCAL/H																				
RADIATION (QSR)	221143.5	221143.5	221143.5	221143.5	QSR	221143.5	221143.5	221143.5	QSR	221143.5	221143.5	221143.5	QSR	221143.5	221143.5	221143.5	QSR	221143.5	221143.5	3317153. QSR KCAL/HRR
CONVECTION (QSC)	106332.1	106332.1	106332.1	106332.1	QSC	106332.1	106332.1	106332.1	QSC	106332.1	106332.1	106332.1	QSC	106332.1	106332.1	106332.1	QSC	106332.1	106332.1	1594981. QSC KCAL/HRR
TOTAL (QSRC)	327475.6	327475.6	327475.6	327475.6	QSRC	327475.6	327475.6	327475.6	QSRC	327475.6	327475.6	327475.6	QSRC	327475.6	327475.6	327475.6	QSRC	327475.6	327475.6	4912134.QSRC KCAL/HRR

A81 X51

Y54

```
HEAT LOSS FROM STRUCTURE------------
SUMMARY OF CALCULATION RESULTS------

TOTAL AREA, SQ M                525
HEAT LOSSES, KCAL PER HOUR
---BY RADIATION            3317153.
---BY CONVECTION           1594981.
---TOTAL                   4912134.
```

Y61

A.3 GAS FLOW RATES BY PITOT TUBE

1. Introduction

Energy audits frequently require the preparation of heat and material balances across important energy consuming items of equipment. For most boilers, kilns, dryers and HVAC systems, it is often necessary to determine air (or flue gas) flow rates into and out of the equipment in order to prepare an acceptable balance. Permanent instrumentation for the measurement of these flows is usually not installed. In situations where the air pressure is sufficiently low to permit an access hole to be inserted in the pipe or duct. a reasonable measurement of flow rate can be made using a portable pitot tube and manometer set. This computer programme provides a quick and simple method for the conversion of plant pitot readings to volume and mass flow rates.

The pitot tube used should be purchased from a reputable manufacturer and should be in accordance with an appropriate national standard (e.g. US or British). A drawing of a typical pitot tube head is shown in Exhibit A.3.1.

The principle of operation of the pitot tube and manometer is illustrated in Exhibit A.3.2. A manometer is used in preference to other pressure measuring devices as it is sensitive to the relatively small pressures involved.

The total pressure of a fluid flowing in a pipe is the sum of two components: the static pressure and the dynamic or velocity pressure. The static pressure is the non-directional potential energy of the fluid, or its "bursting" pressure. The velocity pressure is a measure of the fluid's kinetic energy in a given direction by virtue of its motion. The pitot tube consists of two concentric tubes.The inner tube has a total pressure hole which faces the direction of fluid flow and is subjected to the velocity and static pressures. The outer tube has static pressure holes which are arranged at 90° to the direction of fluid flow. These are subjected only to the static pressure. By connecting the pitot tube to the manometer in such a way that the pressures on the total and static pressure holes are opposed, the manometer will display only the (net) velocity pressure.

The velocity pressure is related to the flow rate of the fluid. In precisely controlled use and by applying various correction factors, fluid flow rates can be determined to an accuracy of ±1% with a pitot tube. In practical energy audits, an accuracy of ±5% is probably realistic when used with care.

The programme described here can be applied to the measurement of air and flue gas, but not steam, flowing in circular cross section pipes.

The standard procedure is to determine the velocity profile along any one pipe diameter and to repeat for a second diameter at right angles to the first. Ten measurements should be taken along each diameter, as shown in Exhibit A3.3. The position of each measurement point is selected so that it represents one of a number of concentric annuli, all having the same cross sectional area. It is assumed that the mean cross sectional velocity is equal to the numerical average of the local velocities measured along the two traverses. The average velocities for the two traverses should be within reasonable agreement.

2. How the Programme is Organised

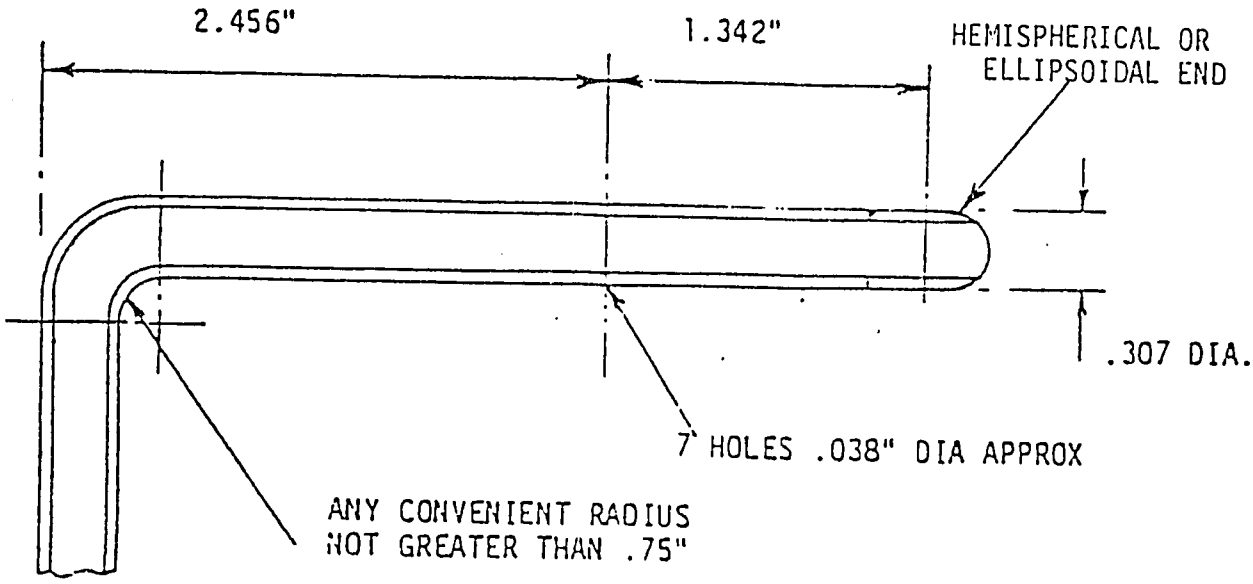
The programme 'PITOT' is written using the Visicalc system. Following loading of the main Visicalc programme, PITOT may be loaded. The worksheet is organised as shown in Exhibit A3.4 and the programme calculation basis is summarised in Exhibit A.3.5.

3. Worked Example

A worked example of the programme is shown as Exhibit A3.6, with the input data clearly indicated on the left hand side.

EXHIBIT A.3.1

DIMENSIONS OF A TYPICAL PITOT TUBE



Pitot tubes such as shown above can for practical purposes be considered to have a basic coefficient (C_0) of unity. However, this should be checked initially by reference to the manufacturers or to a relevant standard design (e.g. BS-1042)

290

Exhibit A 3.2

PRINCIPLE OF OPERATION OF THE PITOT STATIC TUBE

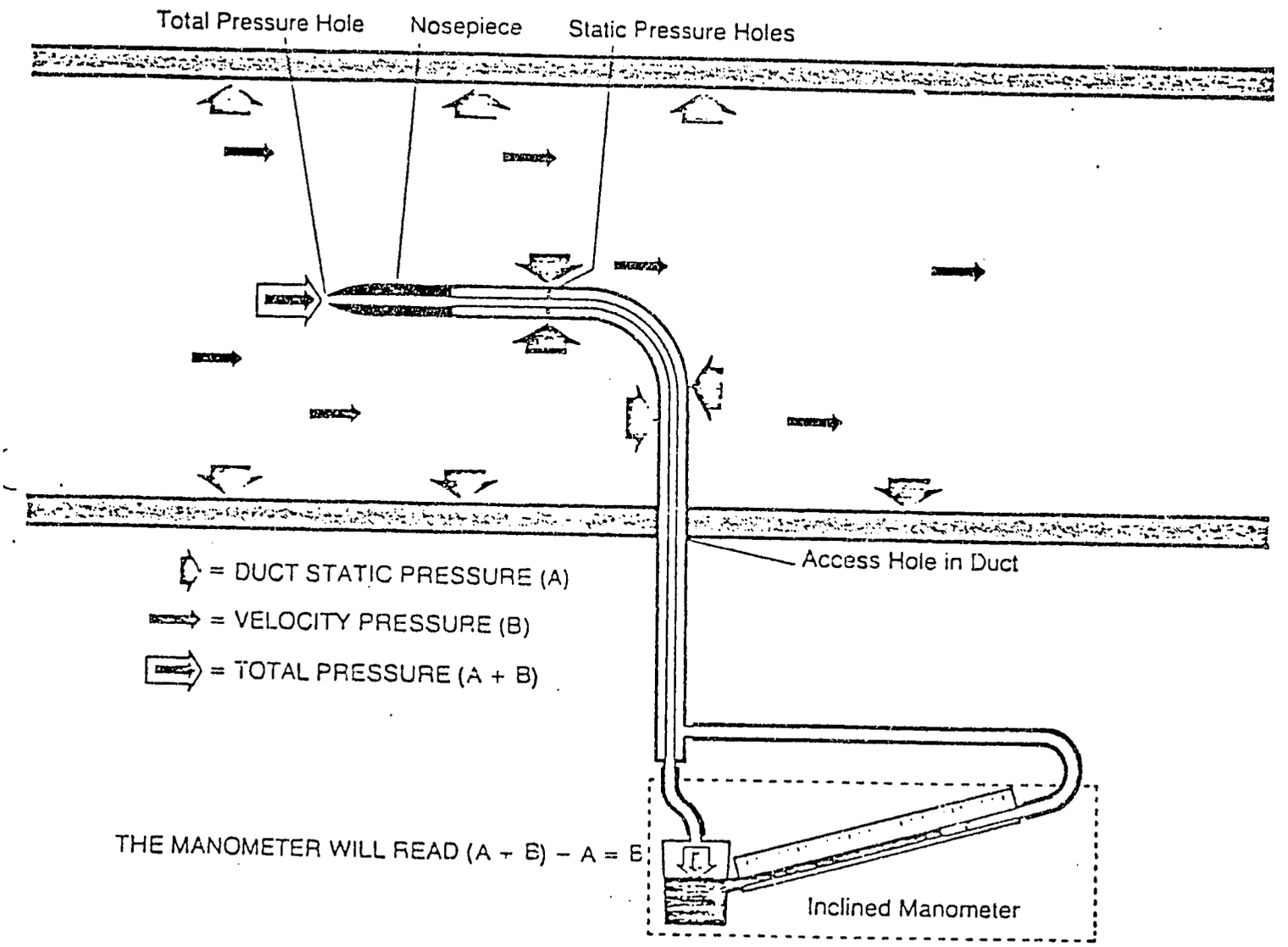


Exhibit A 3.3

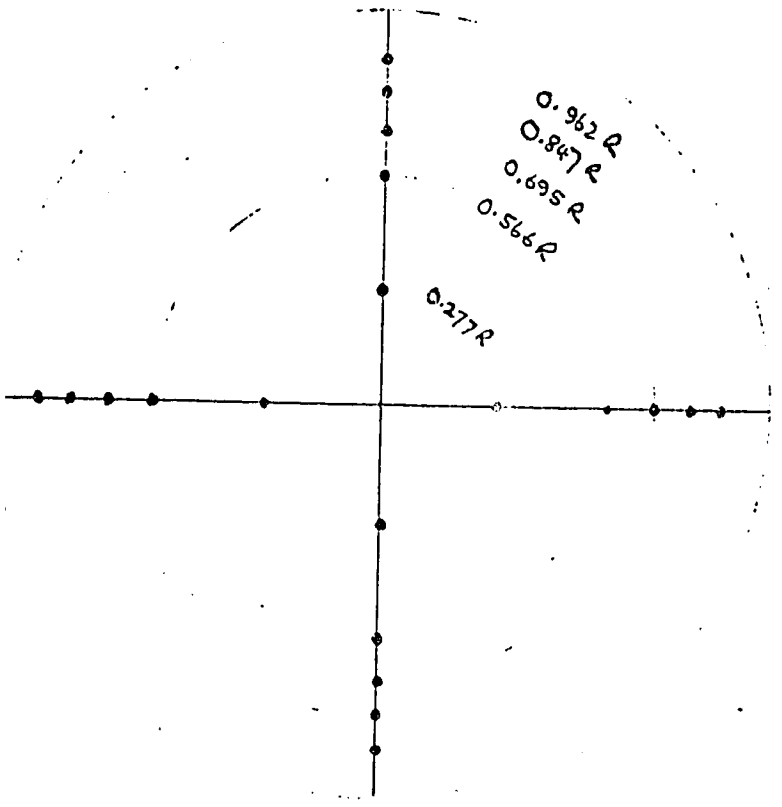


Exhibit A 3.4

Worksheet for 'Pitot'

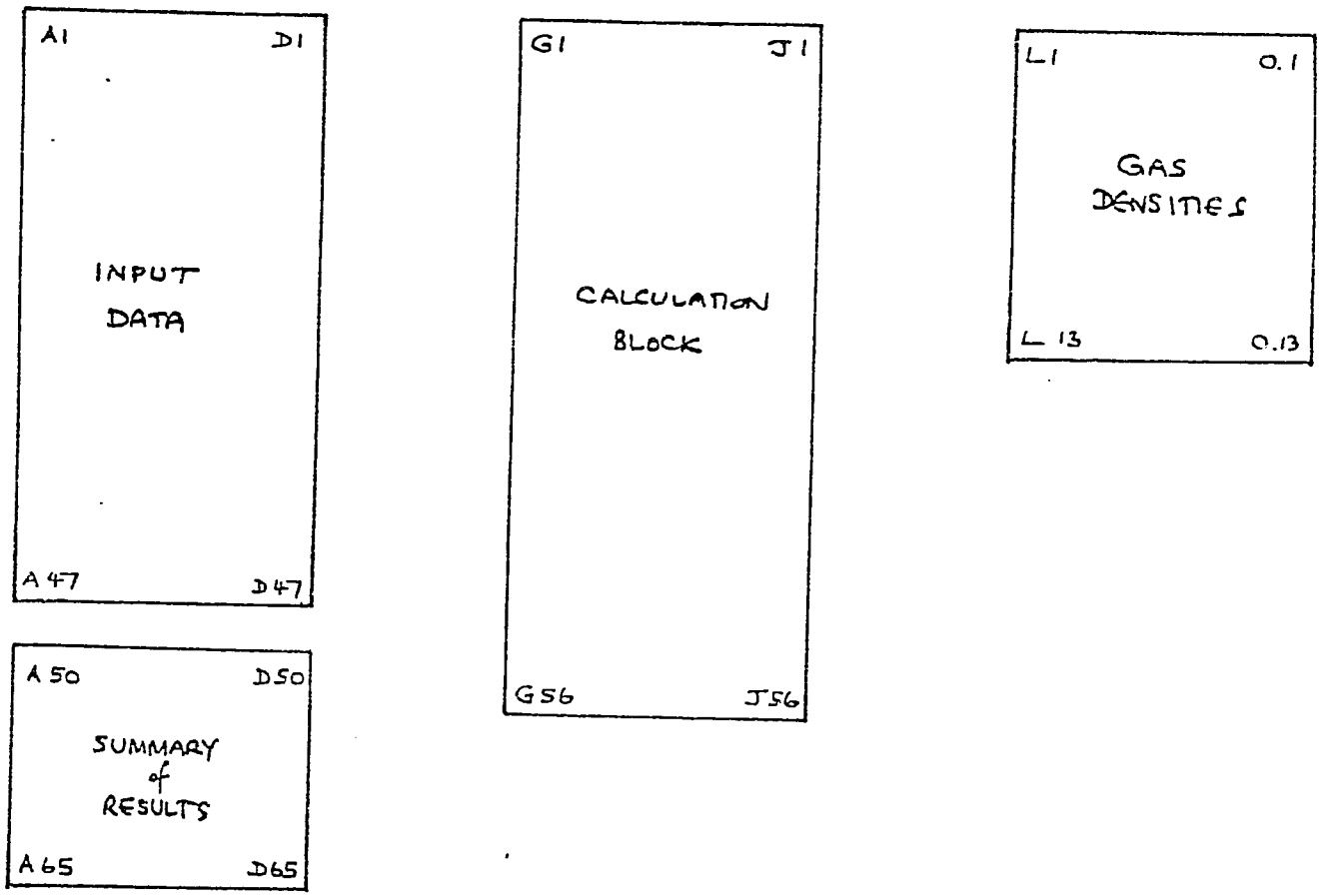


EXHIBIT A 3.5

PROGRAMME CALCULATION BASIS

(1) $$Y = \frac{(10^5 + PS)}{(10^5 + PS + PV)}$$

(2) $$X = 0.085Y$$

(3) $$W = 1.291 \times \sqrt{\frac{(T1 + 273) \times 1.20 \times 10^8}{(1 + X) \times 289 \times PA \times (10^5 + PS) \times D}}$$

(4) $$VHN = W \sqrt{PVHN}$$

where PVHN is one of a total of HN horizontal traverse pitot readings

(5) $$VVN = W \sqrt{PVVN}$$

where PVVN is one of a total of VN vertical traverse pitot readings

(6) $$VHA = \frac{\sum VHN}{HN}$$

(7) $$VVA = \frac{\sum VVN}{VN}$$

(8) $$VAV = \frac{\sum VHN + \sum VVN}{HN + VN}$$

(9) $$Q1 = 188.5 \times R^2 \times VAV$$

(10) $$P1 = 10^5 + PS$$

(11) $$Q2 = \frac{Q1 \times (T2 + 273) \times P1}{(T1 + 273) \times P2}$$

(12) $$M = \frac{Q1 \times 17.34 \times 10^3 \times P1 \times D}{(T1 + 273) \times 10^5}$$

274

Exhibit A 3.5 (continued)

Derived variables

W	intermediate calculation constant depending on gas conditions in pipe
VHN	velocity, m/sec, at point N of horizontal traverse
VVN	velocity, m/sec, at point N of vertical traverse
VHA	mean velocity, m/sec, along horizontal traverse
VVA	mean velocity, m/sec, along vertical traverse
VAV	mean velocity in pipe, m/sec

GAS FLOW RATE ESTIMATION BY PITOT TUBE METHOD

INPUT DATA ARE LISTED BELOW AND THE CALCULATIONS ARE PERFORMED IN THE AREA TO THE RIGHT OF THIS SCREEN.

INPUT DATA FOR TEST NUMBER 25

GAS IN DUCT.....	AIR
ACTUAL GAS TEMP (T1) DEG C	37
* STATIC PRESS (PS) N/M2 G	125000
* VELOCITY PRES (PV) N/M2 G	185000
ATMOSPHERIC PRES (PA) N-BARG	1015
GAS DENSITY (STD) (D) KG/M3	1.2
INTERNAL PIPE RAD (R) METERS	.05

RESULTS TO BE QUOTED FOR

T2--SPECIFY TEMP DEG C	20
P2--SPECIFY PRES N/M2 ABS	100000

PITOT RDGS-HORIZONTAL--NO.?	8
PVHN-1.....	6075
PVHN-2.....	5980
PVHN-3.....	6100
PVHN-4.....	6150
PVHN-5.....	6098
PVHN-6.....	5999
PVHN-7.....	6095
PVHN-8.....	6123
PVHN-9.....	0
PVHN-10.....	0

PITOT RDGS-VERTICAL--NO.?	6
PVVN-1.....	6087
PVVN-2.....	6075
PVVN-3.....	6100
PVVN-4.....	6123
PVVN-5.....	5997
PVVN-6.....	5875
PVVN-7.....	0
PVVN-8.....	0
PVVN-9.....	0
PVVN-10.....	0

RESULTS FOR TEST NUMBER... 25

MEAN VELOCITY IN PIPE AT ACTUAL CONDITIONS--M/SEC	67.34
FLOW RATE AT ACTUAL COND--ITIONS--CUBIC METERS/MIN	102.81
FLOW RATE AT SPECIFIED CONDITIONS-CUBIC METERS/MIN	218.65
AT TEMPERATURE-DEG C	20
AT PRESSURE-N/M2 ABS	100000
MASS FLOW RATE--KG/HOUR	15320

CALCULATION BLOCK

X	.0446463
W	3.72E10
	8.29ME10
	.6698964
	.8448343
VHN-1	67.40732
VHN-2	66.87819
VHN-3	67.54587
VHN-4	67.82214
VHN-5	67.53480
VHN-6	66.98433
VHN-7	67.31819
VHN-8	67.67309
VHN-9	0
VHN-10	0
VVN-1	67.47386
VVN-2	67.40732
VVN-3	67.54587
VVN-4	67.67309
VVN-5	66.97318
VVN-6	66.25845
VVN-7	[illegible]
VVN-8	0
VVN-9	0
VVN-10	0
SUM VHN	539.3639
VHA	67.42049 MEAN VEL--HORIZ
SUM VVN	403.3418
VVA	67.22694 MEAN VEL--VERT
VAV	67.33755 MEAN VEL IN PIPE
Q1	31.73282 FLOW RATE M3/MIN AT ACTUAL CONDITN
P1	225000 ABS PRESSURE AT ACTUAL CONDITIONS NEWTONS/M2 ABS
Q2	67.48343 FLOW M3/MIN AT T2 & P2
M	6792.475 MASS FLOW KG/HOUR

GAS DENSITIES AT 15 C AND 1000 MBARS

	KG/M3
OXYGEN	1.33
NITROGEN	1.17
AIR	1.20
CARBON DIOXIDE	1.83
CARBON MONOXIDE	1.17
HYDROGEN	.084
METHANE	.667
WATER VAPOUR	.75

APPENDIX B CALCULATING THE RATE OF RETURN ON CAPITAL INVESTMENTS

1. Introduction

The economic aspects of energy conservation projects requiring capital investment are at least as important as the technical aspects. When sizing energy conservation equipment such as heat exchangers, the selection of the optimum size is usually determined by economic considerations rather than technical criteria.

Various techniques are available for ranking energy conservation projects according to the amount by which their energy savings exceed their cost of capital. These methods of estimating the rate of return on investments have essentially the same objectives:

(1) to provide a basis for the selection or rejection of projects by ranking them in order of profitability

(2) to ensure that investments are not made in projects which earn less than the cost of capital, which is frequently expressed as a minimum or "cut-off" rate of return.

A simple method of ranking projects is to determine the "payback period", the time taken to repay the invested capital by the net savings from the project. However, the value of savings and costs which occur at different times are not adequately reflected in the determination of payback period, and therefore discounting techniques are now used for evaluating most major investments.

2. Discounted Cash Flow Calculations

In project appraisal work, the objective is to compare and evaluate alternative projects which have different future "net cash flows" at different times. The net cash flow in any given year is the arithmetic sum of cash outflows (e.g. capital expenditures, operating costs, etc.) and cash inflows (energy savings). The problem is to determine the present value of the series of future cash flows which will be generated by the project.

The present value P (i.e. today's value) of an amount of money F_t that will be earned t years in the future is given by:

$$P = \frac{F_t}{(1++)^t}$$

where t is known as the discount rate, analogous to the rate of interest obtained on money invested with a bank. Application of the above formula provides a consistent method of comparing the present values of different amounts of money that will become available at different times.

A pre-requisite for the use of discounting methods is the determination of the cash flow profile of a project. The profile must show all expenditures and all revenues relating to the project for each year of the project's construction, operation and demolition. The cash inflows and outflows are summed to give the net cash flow for each year of the project.

The net present value of the project is defined as the sum of the individual present values of the cash flows that occur in each year of the project:

$$NPV = \frac{F_t}{(1+r)^t}$$

Clearly, for any project, the NPV depends on the value of the discount rate (r) that is used in the calculation. Normally the discount rate adopted represents the cost of capital to the enterprise making the investment.

The significance of net present value is that it represents the residual surplus, in today's values, that the project will earn after repaying the initial capital investment. When projects requiring the same amount of capital are compared, the project with the highest NPV would be preferred as it represents the most efficient use of capital.

The Exhibits illustrate a typical NPV calculation:

(1) Exhibit B.1 is a cash flow profile for a hypothetical project

(2) Exhibit B.2 is a typical NPV calculation using the cash flows from the previous exhibit.

It will be seen that the NPV decreases sharply as the discount rate increases. In other words, the real value of energy savings decreases as the cost of investment capital increases.

EXHIBIT B.1 - CASH FLOW PROFILE

HYPOTHETICAL WASTE HEAT RECOVERY PROJECT

¥ or $ or £	Time (years)											
	0	1	2	3	4	5	6	7	8	9	10	11
Initial capital investment	(60,000)	(20,000)										
Residual scrap value												8,000
Value of energy savings		10,000	15,000	15,000	15,000	15,000	20,000	20,000	20,000	20,000	20,000	
Operating costs:												
labour		(1,000)	(1,000)	(1,000)	(1,000)	(1,000)	(1,000)	(1,000)	(1,000)	(1,000)	(1,000)	
utilities		(1,000)	(1,500)	(1,500)	(1,500)	(1,500)	(2,000)	(2,000)	(2,000)	(2,000)	(2,000)	
maintenance		-	(500)	-	(500)	-	(1,000)	-	(1,000)	-	-	
overheads		(500)	(500)	(500)	(500)	(500)	(500)	(500)	(500)	(500)	(500)	
Net Cash Flow	(60,000)	(12,500)	11,500	12,000	11,500	12,000	15,500	16,500	15,500	16,500	16,500	8,000

Brackets ( ) denote cash outflow

EXHIBIT B.2

ILLUSTRATION OF NET PRESENT VALUE CALCULATION

	0	1	2	3	4	5	6	7	8	9	10	11	Sum of ANNUAL CASH FLOWS
Net Cash Flow (no discounting)	(60,000)	(12,500)	11,500	12,000	11,500	12,000	15,500	16,500	15,500	16,500	16,500	8,000	63,000
5% Discount Rate													
Discount factor	1.000	0.952	0.907	0.864	0.823	0.784	0.746	0.711	0.677	0.645	0.614	0.585	
Present value	(60,000)	(11,900)	10,431	10,368	9,465	9,408	11,563	11,732	10,494	10,643	10,131	4,680	27,015
10% Discount Rate													
Discount factor	1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	
Present value	(60,000)	(11,363)	9,499	9,012	7,865	7,452	6,742	8,465	7,239	6,996	6,369	2,800	3,066

Discount Rate, % per year	Net Present Value ¥ or £ or $
0	63,000
5	27,015
10	3,066

EXHIBIT B.3

RELATIONSHIP BETWEEN NET PRESENT VALUE AND DISCOUNTED CASH FLOW RATE OF RETURN

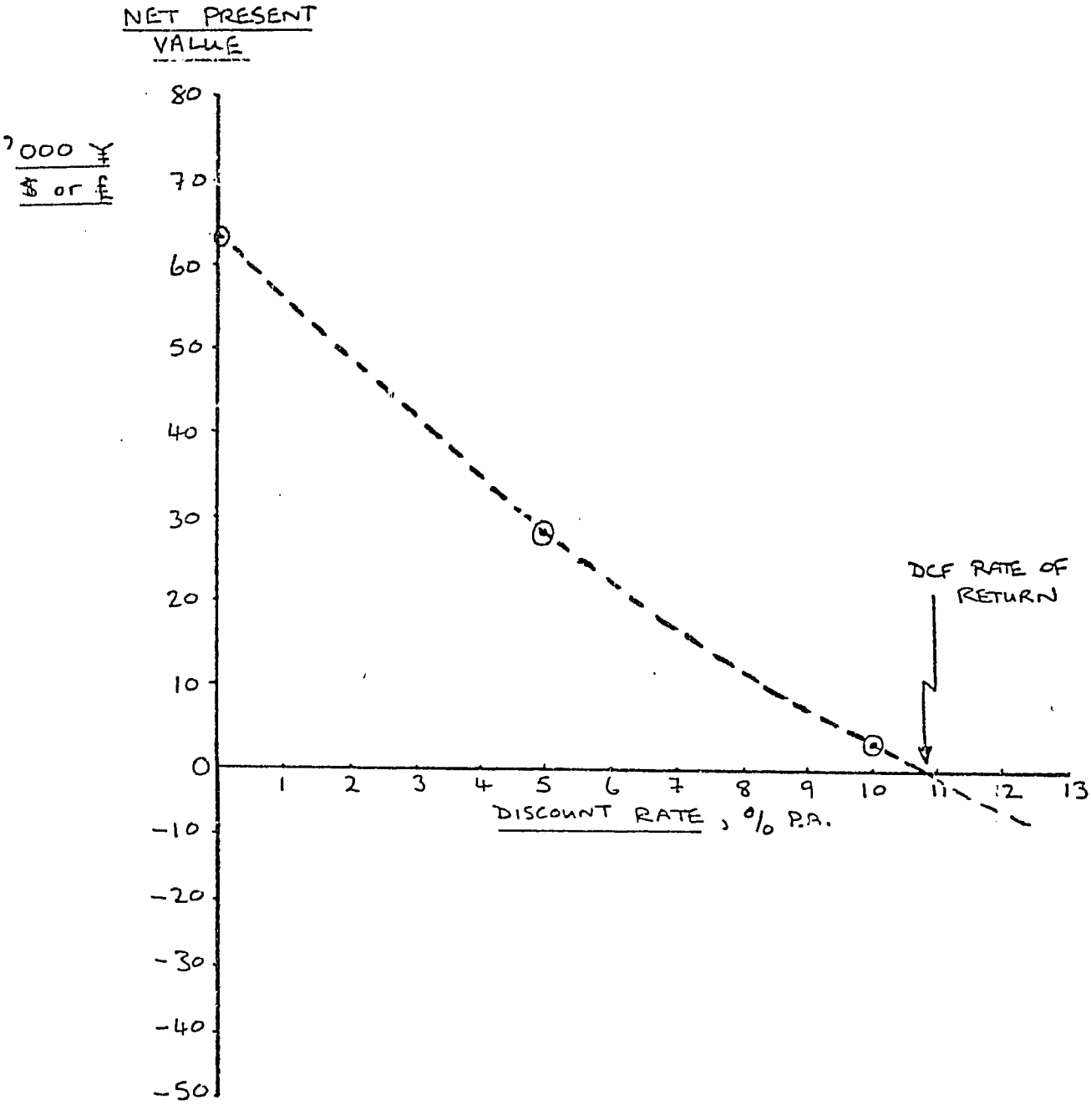


Exhibit B.3 shows in graphical form the relationship for NPV against the discount rate for the same example. It can be seen that the NPV becomes zero at a discount rate of about 11%. This figure is known as the "Discounted Cash Flow Rate of Return" and is defined as the discount rate at which the NPV is zero. The DCF rate of return is normally calculated by iteration or by graphical means.

The significance of the DCF rate of return is that it represents the maximum cost of capital which a project can afford to pay and still break even (including repayment of capital) at the end of the project life. The DCF return provides a quantitative method of ranking projects in order of their efficiency of capital use; the method is particular effective for comparing projects of different size and timing and is probably the method most widely used for the economic analysis of major investments.

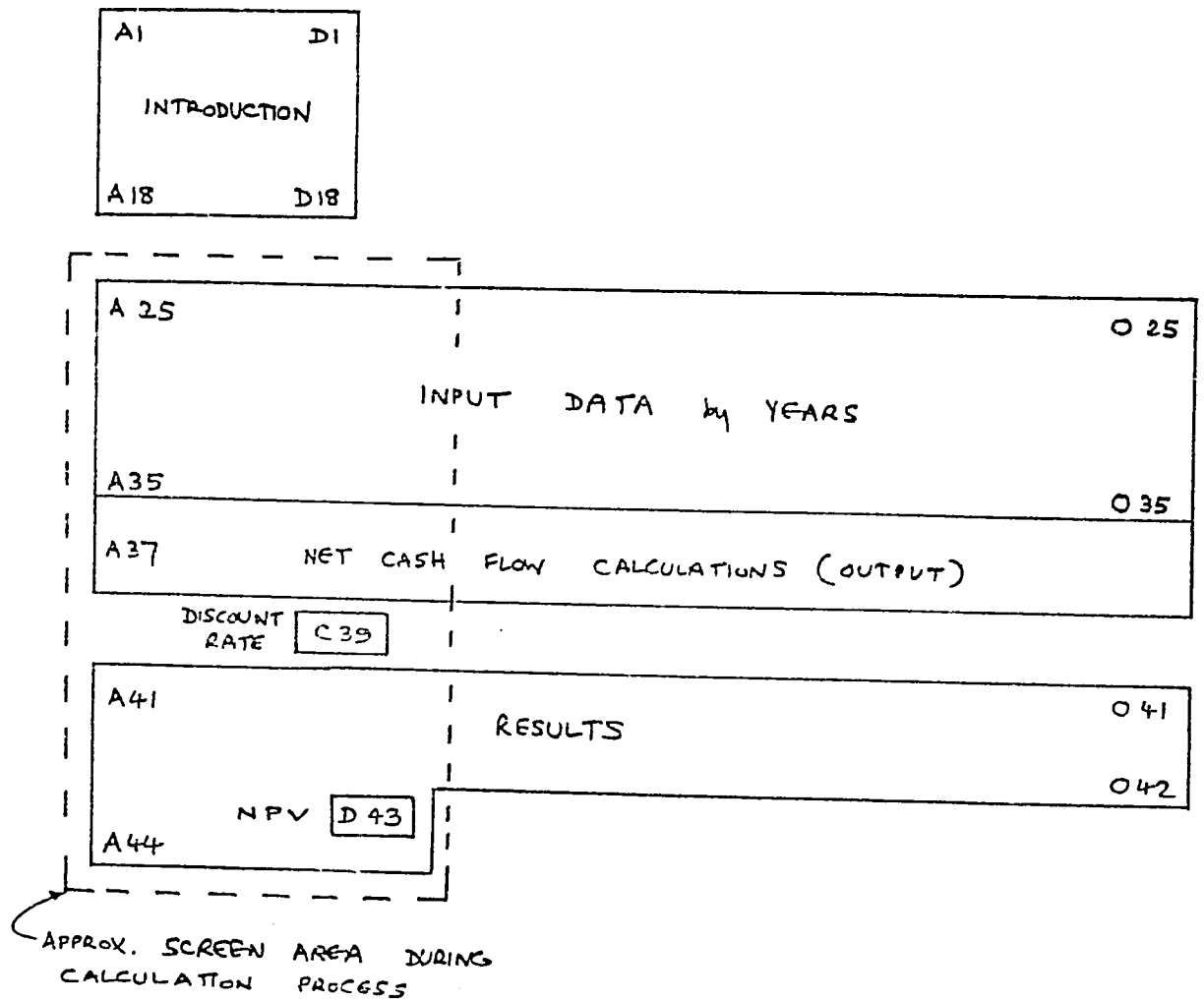
3. Computer Programme

A computer programme "ROI" to calculate the NPV of a series of cash flows has been written in the Visicalc format, the calculation procedure following the method described above. Exhibit B.4 shows the layout of the worksheet.

The user enters the required investment, scrap value, savings and costs data for each year. A total of 11 years are allowed in the programme; normally, the first (year 0) will include the major capital investment, the next ten years (years 1 - 10) will represent the useful life of the project, and year 11 is the year in which the equipment is dismantled and some scrap value obtained. The influence of savings and costs after 10 or 11 years is usually quite minor for most projects, and in practice there is little need for data beyond that period.

It is recommended that the user enters the data for the project in the appropriate columns and then sets the screen into the position indicated in Exhibit B.4, showing the discount rate block C39 and the NPV result simultaneously. Various discount rates can then be entered and the corresponding NPV seen directly. Note that a "forward reference" exists and the user must use the [!] key to obtain the correct NPV after entering each new discount rate value.

Exhibit B.4 : Worksheet for ROI



4. Worked Example

Exhibits B.5 through 7 present the computer worksheet for the example described previously (Exhibit B.1 etc.). Three worksheets are shown to illustrate the effect of changing the discount rate from 5% to 10% and finally to 10.808%, at which point the NPV is close to zero (i.e. the DCF rate of return for this project is 10.808%). Exhibit B.8 shows the three screen presentations that the user will observe for the various discount rates.

A1 RATE OF RETURN CALCULATION D1

THIS PROGRAMME MAY BE USED TO CALCU--LATE THE NET PRESENT VALUE OF A SERIES OF CASH FLOWS RESULTING FROM A CAPITAL INVESTMENT. BY CHANGING THE DISCOUNT FACTOR (INTEREST RATE) THE USER MAY DETERMINE THE DISCOUNT RATE AT WHICH THE NET PRESENT VALUE OF THE INVESTMENT IS ZERO--THAT IS, THE "DISCOUNTED CASH FLOW" RATE OF RETURN.

THE WORKSHEET BEGINS ON LINE 25 AND ALLOWS FOR CALCULATIONS OVER A 12 YEAR PERIOD OVERALL--INVESTMENT BEGINS IN YEAR 0 AND THE LIFE OF THE PROJECT IS ASSUMED TO END IN YEAR 12

A18 D18

EXHIBIT B.5

WORKED EXAMPLE: DISCOUNT RATE 5%

A25

YEAR:	0	1	2	3	4	5	6	7	8
CAPITAL INVESTMENT	60	20							
RESIDUAL SCRAP VALUE									
VALUE OF ENERGY SAVINGS	0	10	15	15	15	15	20	20	20

CONTINUED .....

THE WORKSHEET BEGINS ON LINE 25 AND ALLOWS FOR CALCULATIONS OVER A 12 YEAR PERIOD OVERALL--INVESTMENT BEGINS IN YEAR 0 AND THE LIFE OF THE PROJECT IS ASSUMED TO END IN YEAR 12

D 18

EXHIBIT B.5 continued

WORKED EXAMPLE: DISCOUNT RATE 5%

A 25

O 25

YEAR:	.....0....	....1...	....2...	....3...	....4...	....5...	....6...	....7...	....8...	....9...	...10...	...11..
CAPITAL INVESTMENT	60	20										
RESIDUAL SCRAP VALUE												8
VALUE OF ENERGY SAVINGS	0	10	15	15	15	15	20	20	20	20	20	0
OPERATING COSTS												
LABOR	0	1	1	1	1	1	1	1	1	1	1	0
UTILITIES	0	1	1.5	1.5	1.5	1.5	2	2	2	2	2	0
MAINTENANCE	0	0	.5	0	.5	0	1	0	1	0	0	0
OVERHEADS	0	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5	0
NET CASH FLOW	-60	-12.5	11.5	12	11.5	12	15.5	16.5	15.5	16.5	16.5	8

A35

A37

A39

C 39

DISCOUNT RATE----- 5 PERCENT

A41

O 41

DISCOUNT FACTOR	1	.9523810	.9070295	.8638376	.8227025	.7835262	.7462154	.7106813	.6768394	.6446089	.6139133	.5846793
PRESENT VALUE	-60	-11.9048	10.43084	10.36605	9.461078	9.402314	11.56434	11.72624	10.49101	10.63605	10.12957	4.677434
NET PRESENT VALUE	26.98216											
NPV PER UNIT INVESTMT	.3747522											

O 42

A44

D 44

EXHIBIT B.6 WORKED EXAMPLE: DISCOUNT RATE 10%

YEAR:	.....0....	....1...	....2...	....3...	....4...	....5...	....6...	....7...	....8...	....9...	...10...	...11..
CAPITAL INVESTMENT	60	20										
RESIDUAL SCRAP VALUE												8
VALUE OF ENERGY SAVINGS	0	10	15	15	15	15	20	20	20	20	20	0
OPERATING COSTS												
LABOR	0	1	1	1	1	1	1	1	1	1	1	0
UTILITIES	0	1	1.5	1.5	1.5	1.5	2	2	2	2	2	0
MAINTENANCE	0	0	.5	0	.5	0	1	0	1	0	0	0
OVERHEADS	0	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5	0
NET CASH FLOW	-60	-12.5	11.5	12	11.5	12	13.5	16.5	15.5	16.5	16.5	8

DISCOUNT RATE----- 10 PERCENT

DISCOUNT FACTOR	1	.9090909	.8264463	.7513148	.6830135	.6209213	.5644739	.5131581	.4665074	.4240976	.3855433	.3504939
PRESENT VALUE	-60	-11.3636	9.504132	9.015778	7.854655	7.451056	8.749346	8.467109	7.230864	6.997611	6.361464	2.803951

NET PRESENT VALUE 3.072329

NPV PER UNIT INVESTMT .0426712

EXHIBIT B.7 WORKED EXAMPLE: DISCOUNT RATE 10.808%

YEAR:	.....0....	....1...	....2...	....3...	....4...	....5...	....6...	....7...	....8...	....9...	...10...	...11..
CAPITAL INVESTMENT	60	20										
RESIDUAL SCRAP VALUE												8
VALUE OF ENERGY SAVINGS	0	10	15	15	15	15	20	20	20	20	20	0
OPERATING COSTS												
LABOR	0	1	1	1	1	1	1	1	1	1	1	0
UTILITIES	0	1	1.5	1.5	1.5	1.5	2	2	2	2	2	0
MAINTENANCE	0	0	.5	0	.5	0	1	0	1	0	0	0
OVERHEADS	0	.5	.5	.5	.5	.5	.5	.5	.5	.5	.5	0
NET CASH FLOW	-60	-12.5	11.5	12	11.5	12	15.5	16.5	15.5	16.5	16.5	8

DISCOUNT RATE----- 10.808 PERCENT

DISCOUNT FACTOR	1	.9024619	.8144375	.7349988	.6633085	.5986106	.5402233	.4875309	.4399781	.3970635	.3583347	.3233834
PRESENT VALUE	-60	-11.2808	9.366031	8.819986	7.628047	7.183327	8.373461	8.044261	6.819661	6.551548	5.912522	2.587067
NET PRESENT VALUE	.0051373											
NPV PER UNIT INVESTMT	7.135E-5											