JOURNAL OF ENERGY R & D IN SOUTHERN AFRICA

Vol. 2
No. 3
August 1991

Journal of Energy R & D in Southern Africa

Vol. 2 No. 3 August 1991

Contents

A quarterly publication

Supported by the National Energy Council

Editor:
B H A Winter

Production Editor:
Y Blomkamp

Production Assistant:
Mrs M J Reichardt

ISSN 1016-1686

It is the policy of the Journal to publish original research covering the technical, economic, political and techno-social aspects of energy in Southern Africa. Only previously unpublished work will be accepted. However, conference papers delivered but not published elsewhere are also welcomed. Short comments, not exceeding 500 words, on articles published in the Journal are also invited. Announcements of relevant publications, reviews, conferences, seminars and meetings will be included.

Those wishing to submit contributions for publication should refer to the guidelines set out in *Information for Authors* printed on the inside back cover of the Journal. All contributions are refereed by experts drawn from the Editorial Advisory Panel before publication.

The Editor does not accept responsibility for viewpoints or opinions expressed, nor the correctness of facts or figures.

Subscriptions:

Individuals (Southern Africa)
R60/year or R25/single copy

Individuals (Elsewhere)
US$60/year or US$25/single copy

Corporate (Southern Africa)
R120/year or R30/single copy

Corporate (Elsewhere)
US$120/year or US$30/single copy

This includes postage and packing in Southern Africa. Overseas airmail will be an additional US$35/year or US$10/single copy.

Enquiries may be directed to:
The Production Editor, Journal of Energy R & D in Southern Africa, Energy Research Institute, University of Cape Town, P O Box 33, Plumstead 7800, South Africa.

Tel.: (021) 705 0120

Fax.: (021) 705 6266

THE ENERGY SITUATION IN SOUTH AFRICA

*G P N VENTER

South Africa can be described as a country in transition from a developing to a developed economy. Whether this transition will be progressive rather than retrogressive will in large measure depend on how well its resources are husbanded. From an energy perspective the greatest challenge is to make affordable and appropriate energy available to all of the people of South Africa.

Coal as a finite, non-renewable resource is already providing more than 80% of the country's energy needs. As a source of electricity generation, coal will continue to dominate well into the next century, but nuclear power and natural gas, if discovered in sufficient quantities, should play a more significant role in the future. The provision of energy in remote areas and to developing communities is also a major area of concern to the authorities in South Africa, and it is especially here that renewable energy applications have a particular role to play.

These issues are discussed in the context of bilateral collaboration between South Africa and the Republic of China.

The original version of this paper was presented at the ROC-RSA Energy Conference held in Taipei, Taiwan, 11-12 March 1991.

INTRODUCTION

In July 1981, Mr Borre, Assistant Secretary for International Affairs of the US Department of Energy remarked that "As we face the 1980's, the enduring lesson of the 1970's must be that the Free World's economic well-being over the coming decade must be shielded from the continuing turmoils and tensions in and around the Middle East's oil producing areas. Even today, in the midst of this temporary episode of market softness, it is worth remembering that key elements in the oil supply side from the Middle East remain fragile and exposed to external and internal risks of severe dimensions."(1)

With the war in the Persian Gulf still fresh in mind, it does not take much to be reminded of the nervousness in the market as reflected in the uncertainty in the price of oil — North Sea Brent ranging from a high of over US$40 by mid-October 1990 to a low of around US$17 a barrel by the end of February 1991(2). Significantly, the oil price actually dropped by more than US$10 a barrel the moment hostilities broke out on January 16, 1991. It was explained later as being due to a worst-case scenario already accounted for in the pre-war price rise.

It is indeed a fact that in recent times no single event or issue, political, social or otherwise, has more profoundly shaken the world order than the end of the era of "cheap" oil after 1973. And this includes the demise of traditional Communism in Europe and the reunification of Germany in 1990. In an absolute sense, the important fact is that 20th century civilization requires an abundance of appropriate, useful, affordable energy for its sustained development. Any country that lacks such an energy base will fall behind those who have it, especially in terms of quality of life reckoned in knowledge, health, wealth, and general well-being. This is illustrated simply by comparing industrial energy use with the use of traditional fuels, as reflected in Table 1(3). This is what the energy issue is all about, and the rest of this paper will focus on the relative state of energy in the RSA economy.

Table 1: Trends in population and energy use per person(3)

	1890	1910	1930	1950	1970	1990
World population (10^9)	1,49	1,70	2,02	2,51	3,62	5,32
Traditional energy per person (kW)	0,35	0,30	0,28	0,27	0,27	0,28
Industrial energy per person (kW)	0,32	0,64	0,65	1,03	2,04	2,30
Total world energy (10^9 kW)	1,00	1,60	2,28	3,26	8,36	13,73
Cumulative industrial energy use (× 10^9 Watt-years)	10	26	54	97	196	393

Industrial energy forms are mainly coal, oil and natural gas, with smaller contributions from hydropower and nuclear energy. Traditional fuels are wood, crop wastes and dung.

WEALTH, TECHNOLOGY AND ENERGY

It is increasingly being realized that South Africa is not a First World country. In fact, the RSA can be described as being in transition from a developing to a developed economy. Whether this transition will be progressive rather than retrogressive will in large measure depend on how well its resources are husbanded. However, in the context of Southern Africa, South Africa is indeed a regional power, as can be seen from Table 2(4). Southern Africa is defined roughly as a line running west to east encompassing all the countries to the south, starting with Angola, Zambia, Malawi, and Mozambique.

This view of South Africa is confirmed even in a total African context, if one uses the electricity industry as a barometer of economic growth and of wealth. South Africa, with about 7% of Africa's population and 4% of the land area, generates 60% of Africa's electricity. It is also true that more than 60% of the population of South Africa currently do not have direct access to electricity.

---

*Group Executive: Electrical Energy, Energy Efficiency and Decision Support, National Energy Council, Private Bag X03, Lynnwood Ridge 0040, South Africa

Table 2: Selected statistics for Southern Africa(4)

(a) = 1986	1988 Population (millions)	GDP/Capita (1989: US$)	Foreign Debt (US$ millions)	Index of 1988 food production (1980 = 100)	1988 per capita energy consumption (kg oil equivalent)
Angola	9,5	600	—	88	203(a)
Botswana	1,2	1 310	500	75	415
Lesotho	1,7	245	281	83	—
Madagascar	10,9	195	3 602	97	39
Malawi	8,0	170	1 349	87	42
Mauritius	1,1	1 280	861	103	402
Mozambique	14,9	100	4 406	84	86
Namibia	—	—	—	—	—
South Africa(5)	34,0	2 611	20 597	84	2 950
Swaziland	0,8	750	293	104	292(a)
Zambia	7,6	240	6 498	97	376
Zimbabwe	9,3	540	2 659	91	527

If it is accepted that technology can be defined as "the purposeful and systematic use of scientific knowledge to improve Man's lot"(6), then the way in which both the demand and the supply side of the energy equation in a country is addressed is directly related to that country's ability to usefully employ the latest energy technology available internationally. What is important, and also frightening, is that without technology (and implicitly therefore the ability to employ it) there is no way that wealth can be created and, sadly, no aid programme can be successful — a fact seemingly not appreciated by most of the organizations and countries providing aid to the poor and underdeveloped Third World.

It is well known that South Africa has ample reserves of coal and uranium but limited hydro-energy potential, although the Southern African region has considerable hydro-energy potential. The exploitation of the latter is very much dependent on political stability and a programme of sustained economic growth in the region.

COAL

South Africa's recoverable bituminous or hard coal reserves are currently estimated at 55 000 million tons, or 10% of the estimated world total(7) (Fig. 1). More than 50% of these reserves are situated in the eastern Transvaal Highveld. These reserves are the fourth largest in the world after the USA, USSR and mainland China.

As was stated earlier, the energy crises in the 1970's highlighted the dependence of the world economies on oil, and coal was re-discovered as a major energy resource. South Africa penetrated a volatile international coal market by concentrating on two main issues, namely, cost and reliability of supply. Within a short period of time the RSA emerged as a major exporter of steam coal and currently ranks third in the world behind the United States and Australia. The growth of South African coal sales, both locally and internationally, is depicted in Figure 2 for the period 1950 to 1989(8). The Figure shows that for 1989 sales totalled 175 million tons, of which some 47 million tons of coal were exported. Today, the value of domestic coal sales amounts to about 50% of all local mineral sales, and coal exports have become the second most important earner of foreign exchange after gold — earning about US$1 300 million annually.

The largest domestic consumers of coal in 1989 were ESKOM at 67 million tons and the Sasol synfuels plants at 33 million tons(9). Considerable quantities of discards are generated during mining and beneficiation, and serious attention is currently being given to the possible utilization of these coal discards for gasification and other applications. It is important to note that most of the tonnage used for electricity generation and synthetic fuels production is lower grade run-of-mine coal (less

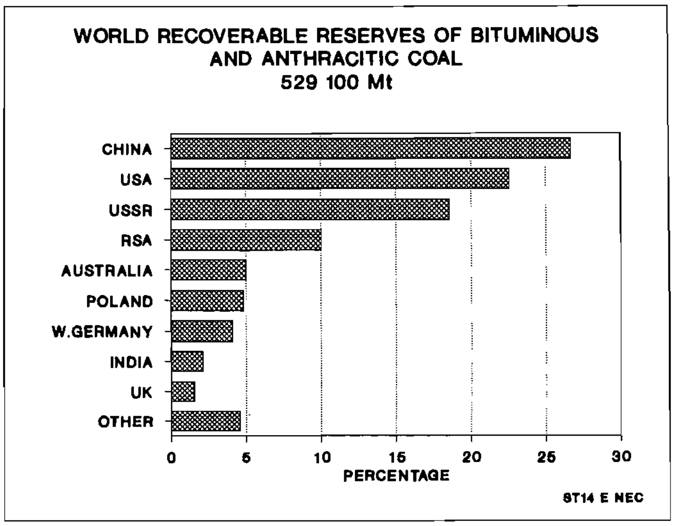


Figure 1: World reserves of hard coal, 1988(7)

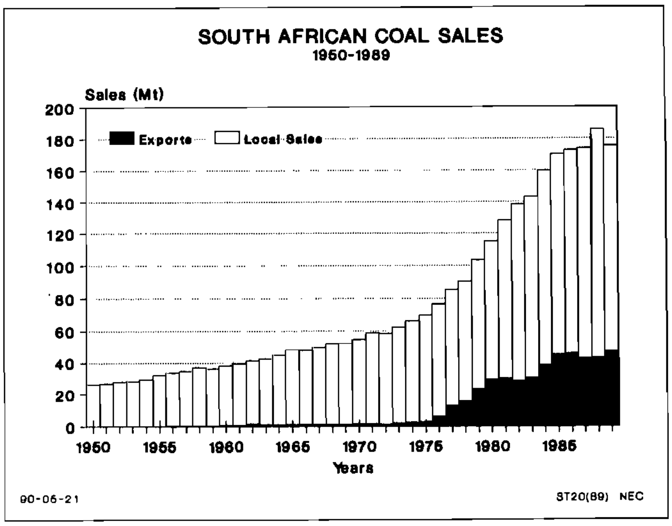


Figure 2: South African coal sales, 1950-1989(8)

than 22,7 MJ/kg), whereas the exported coal, at approximately 28 MJ/kg, is a washed, better quality coal.

The fact is that coal is a finite, non-renewable resource which is already providing more than 80% of the country's energy needs. There are as yet no economically viable alternatives on the horizon which will substantially decrease South Africa's reliance on coal. There is therefore a responsibility towards future generations to extend the coal reserves in the only other feasible way, and that is by improving the efficiency of exploitation and utilization. The challenge is an immense one in view of the large quantities of coal discards which are generated, given the current market requirements (Figure 3).

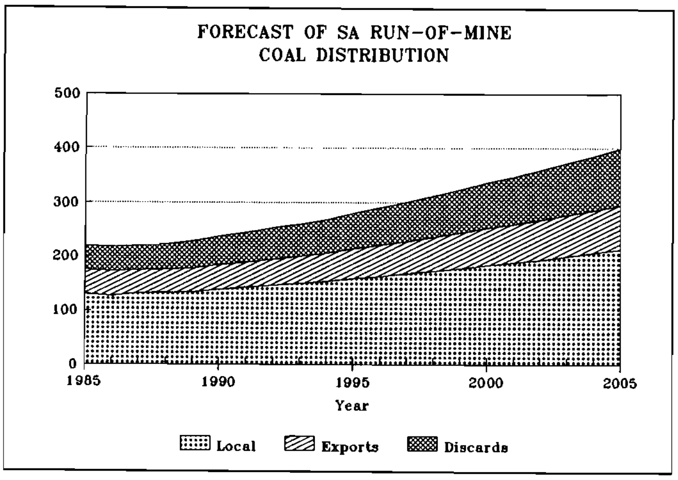


Figure 3: Forecast of South African run-of-mine coal distribution

In 1986 the domestic coal market was totally deregulated, i.e. in terms of distribution, stock-piling and pricing. In order to ensure optimal and orderly development, as well as satisfying the long-term local demand, coal exports were regulated from 1973 until mid-1991. Control was based on a government-imposed ceiling of 80 million tons per year for 30 years, which was introduced in 1982. Export quotas for the 80 million tons per year were allocated to some 22 companies, but additional permits were granted on an *ad hoc* basis as an incentive for better utilization of reserves and to provide an opportunity for new entrepreneurs to enter the market. Coal exports were totally deregulated as a result of an investigation by the National Energy Council and the Coal Advisory Committee into the rationale behind export control and the achievements of the export industry over especially the last few years. As a consequence the market mechanism will henceforth determine export opportunities and priorities.

Apart from its contribution to industry, secondary products and infrastructural development, the South African coal industry is also a major provider of employment. It employs approximately 90 000 people, of which almost 90% are unskilled and semi-skilled workers. These workers in turn support about 470 000 dependents. Almost 70% of the unskilled and semi-skilled work-force is drawn from the national states and eight neighbouring states in Southern Africa, which means that thousands of families beyond its borders also benefit from the wealth created by the RSA coal-mining industry.

ELECTRICITY

Since the mid-1960's the country's installed electricity generating capacity increased from around 5 000 MW to just over 40 000 MW(8), of which the national utility ESKOM's share was more than 35 000 MW in 1990(10). Currently electricity represents about 27% of total net energy demand in South Africa. The sectoral consumption of electricity will differ somewhat from that, in especially the USA and Europe, in view of the differing climatic conditions and the fact that South Africa has an intensive mining industry. The sectoral consumption of electricity is shown in Figure 4.

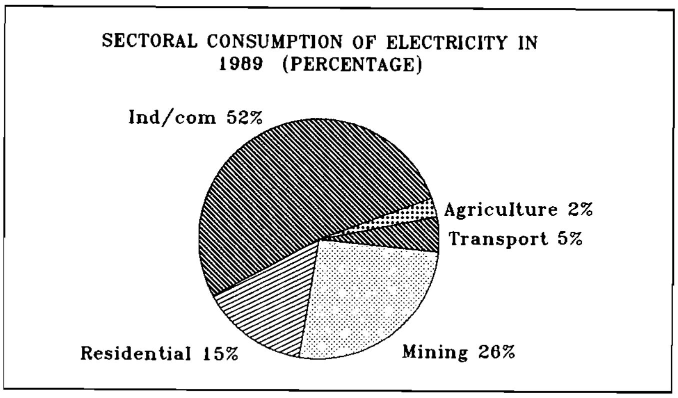


Figure 4: Sectoral consumption of electricity in South Africa

Estimates of electricity demand in the past have, for more reasons than one, been optimistic, with the anticipated growth in demand not materializing as has been expected. Taking into account reserve requirements, ESKOM presently has excess capacity of more than 4 300 MW(10). The present excess capacity is expected to be absorbed by about the year 2000, requiring new generating plant nine years from now. Because of the long lead times, decisions on new plant will need to be taken much sooner, within the next few years. Coal as a source of electricity generation will continue to dominate well into the next century, but nuclear power and natural gas, if discovered in sufficient quantities, will no doubt play a more significant role in future.

It has been pointed out earlier that a developing country, and for that matter South Africa, requires an abundance of appropriate, useful, affordable energy for its sustained development. To achieve this, a sensible strategy is to ensure that the country develops and implements a 'least-cost reasonable-security energy strategy', which can be expressed as the minimization of the Energy Cost Ratio, where

$$\text{Energy Cost Ratio} = \frac{\text{National Energy Cost}}{\text{Gross Domestic Product}}$$

$$= \text{Cost per unit of energy} \times \text{energy consumption/GDP}$$

$$= 12\% \text{ of GDP at present}^{(11)}$$

This ratio can also be termed the inverse energy productivity factor. It indicates that an important objective is to maximize the economic production of one cost unit of energy consumed. In future the energy cost will have to include social costs, such as environmental pollution, utilization of scarce resources, safety and hygiene costs, that have not as yet been quantified. Not only is this true for energy consumption in general, but also for each individual carrier specifically, such as for electricity. The energy-use and cost per carrier is shown diagrammatically in Figure 5, while the variation of the energy ratio with time is shown in Figure 6.

The current strategy for electricity is a free-market approach, as is the case with other energy carriers. It has been pointed out that nobody wants to conserve energy, but everyone wants to save money(12). However, in virtually any socio-political or socio-economic scenario, South Africa must reduce energy costs or increase economic output, but preferably both, to move up the developmental spectrum. Thus there is a real need to educate the consumer on the benefits of the efficient use of energy — and it is not always obvious nor to the individual's direct short-term advantage. This is one of the challenges facing the energy community in South Africa.

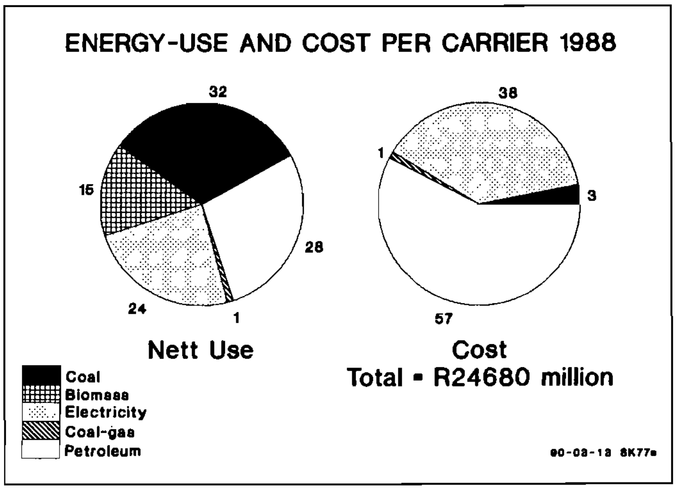


Figure 5: Energy-use and cost per carrier for 1988

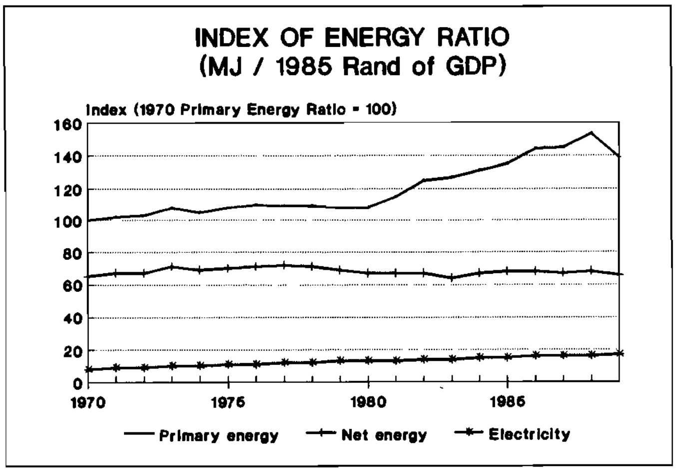


Figure 6: Energy ratio: 1960-1990

NUCLEAR ENERGY

South Africa possesses 432 000 tons or 15% of the Western world's uranium resources in the category less than US$130/kg, which is the second largest after Australia(13). Production of uranium in 1989 was 3 500 tons, of which approximately 90% was available for export. The Atomic Energy Corporation of South Africa, using a locally developed uranium enrichment process, now produces enriched fuel elements for the Koeberg nuclear power station. The estimated requirement of uranium for enrichment for Koeberg is 200 tons to 220 tons per year. Nearly all (i.e. 98%) of the uranium production is recovered as a by-product of gold mining. In 1987 South Africa was ranked as the third largest producer of uranium, after Canada and the USA.

Unless a significant price increase materializes for uranium (currently of the order of US$20/kg), the current production should not have a major impact on the reserves. Also, it should be borne in mind that should future technological advances prove thorium viable as a nuclear fuel, South Africa could contribute 130 000 tons of ThO_2 from known deposits to the international inventory(14).

The single most important constraint in the future availability of uranium resources in South Africa for the manufacture of nuclear fuels is to what extent and at what rate the RSA gold production declines in future. A forecast, based on information available during the mid-eighties reflecting an optimistic view at the time, indicates a sharp drop in gold production at approximately 2005 to virtually zero by 2035. The important point made by Neethling et al.(14) is that as much clarity as possible should be obtained on the impact of a decline in the RSA's gold production before embarking on a large-scale nuclear programme — should this be founded solely on indigenous uranium resources. Advances made in nuclear technology, like the large-scale introduction of breeder reactors, could of course change the picture.

LIQUID FUELS

Due to the fact that South Africa is still officially on the crude oil embargo list of the United Nations, information on the sources of supply, local production, inventories and demand for liquid fuels is classified. Although understandable, this situation bedevils the development of a sensible energy debate and rigorous energy-economic analyses. However, an analysis of the sectoral distribution of liquid fuels indicates that the transportation sector dominates, as can be expected. In the transportation sector cars use petrol (or gasoline) almost exclusively and are also the dominant users of petrol, while for diesel it is the heavy commercial vehicles and agriculture (Figure 7).

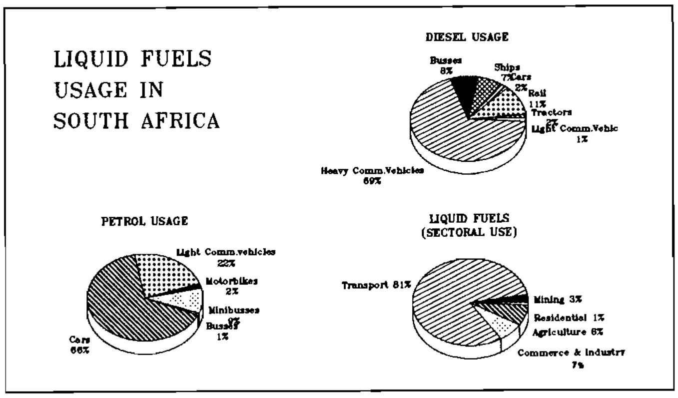


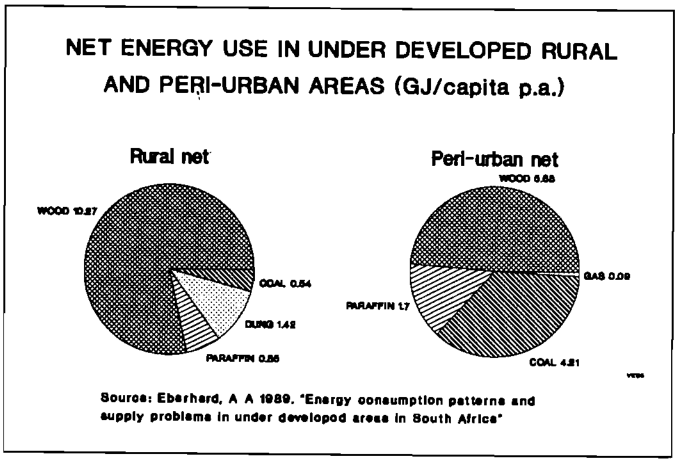
Figure 7: Distribution of liquid fuels usage in South Africa

Broadly speaking, it can be stated that the basic feedstocks for South Africa's liquid fuels requirements consist of crude oil, coal and natural gas. Crude oil is imported. The Sasol "oil-from-coal" process is well known and makes a significant contribution to local demand. Other indigenous energy reserves are offshore natural gas and condensate, and several small offshore oil fields discovered by the government-financed Southern Oil Exploration Corporation (SOEKOR). The small fields could be exploited in future, depending on the oil price and the economic and technical possibility of utilizing floating production platforms. The sizeable natural gas finds off the South African coast form the basis of the Mossgas project where gas is converted into synthetic liquid fuels via the Fischer Tropsch/Sasol Synthol process.

Further synthetic liquid fuels projects (i.e. after Mossgas) will be considered in the light of the economics of such projects, and naturally this will depend on the future price of oil in Rand terms. What is likely in the more immediate future is an expansion in the capacity of the crude oil industry as a result of the rapid growth in the demand for liquid fuel. The discovery of several offshore crude oil deposits by SOEKOR could result in the exploitation of these reserves, if the economics of such ventures prove to be favourable.

RENEWABLE ENERGY

Last but not least is the potential for renewable energy applications in South Africa, particularly solar energy. The provision of energy in remote areas and to developing communities is a major area of concern to the authorities in South Africa, and their net energy use is depicted in Figure 8, to indicate what the issue really is all about — the replacement of wood and coal by other energy carriers(15).


NET ENERGY USE IN UNDER DEVELOPED RURAL AND PERI-URBAN AREAS (GJ/capita p.a.)

Source: Eberhard, A A 1989. 'Energy consumption patterns and supply problems in under developed areas in South Africa'

Figure 8: Net energy use in rural and peri-urban areas(15)

Clearly, the greatest challenge is to make affordable and appropriate energy available to all the people of South Africa. Being a large country, the distribution of energy, whether in the form of network electricity or liquid fuel or coal is a major cost consideration. The use of alternative energy, such as photovoltaic electricity generation, is an attractive option, especially in remote areas far from the national grid. The government has recently decided to give consideration to large-scale alternative energy demonstration programmes to assess the potential of such schemes and to promote consumer acceptance and confidence therein.

THE ENVIRONMENT

Finally, the need to generate and use energy with minimum pollution of the environment is becoming a major concern. Specifically, the focus is shifting to clean energy technologies. It is indeed a challenge and an opportunity for technological innovation. What has changed, however, are the dimensions of this interface. Growth of the population and new technologies have dramatically increased the demand for natural resources and have led to a growing awareness of the need for wise resource management. In fact, in today's modern society, the process of sustainable resource management has become an essential mechanism for ensuring survival and maintaining living standards(16). Without an abundance of appropriate, useful, affordable energy it hardly seems possible or likely that this goal can be achieved. This, then, is the real challenge facing society, and international, cross-cultural collaboration has shown itself to be one of the most potent mechanisms to address this issue, provided that it is driven by mutual trust and respect and common or overlapping spheres of interest.

REFERENCES

(1) BORRE P (1981). Middle East stability: A key to future world energy policy. *In*: Proceedings of the XIIIth AIESEC Annual Economic Congress: ENERGY, A factor in economic development, July.
(2) (a) *The Wall Street Journal* (1991), Friday, January 18.
(b) *Business Day* (1991), Thursday, February 28.
(3) HOLDREN J P (1990). Energy in Transition. *Scientific American*, Vol. 263 (3), September.
(4) (a) WORLD BANK (1990). World Development Report 1990.
(b) WORLD BANK (1989). Sub-Saharan Africa: From Crisis to Sustainable Growth. November.
(5) SOUTH AFRICAN RESERVE BANK (1990). *Quarterly Bulletin*, No. 176, June.
(6) TWISS B (1986). Managing Technological Innovation. 3rd ed. Longman.
(7) BREDELL J H (1987). South African coal resources explained and analysed. RSA Geological Survey, Report 1987-0154.
(8) NATIONAL ENERGY COUNCIL (1990). South African Energy Statistics: 1950-1989, No. 1. National Energy Council.
(9) SCOTT R H (1990). Energy in South Africa: An Overview. *In*: Seminar on Energy and Energy Related Developments in South Africa, Royal Overseas League, London, June 4.
(10) ESKOM (1990). Annual Report.
(11) BASSON J A (1991). The State of Energy Conservation and the Efficient Production and Use of Energy in South Africa. Presented at the ROC-RSA Energy Conference, Taipei, Republic of China, March.
(12) LEWIS C W A, BASSON J A and SNOW A P (1990). Efficient Utilisation of Electricity. Presented at the NEC/ESKOM Seminar on Issues affecting Future Electricity Strategies for South Africa, Pretoria, 25-26 April.
(13) NEETHLING D C, BREDELL J H and BASSON J A (1990). Future Energy Strategies for Southern Africa — The Role of Nuclear Energy. Presented at the Symposium on Nuclear Technology in Southern Africa, ESKOM, Megawatt Park, Institution of Nuclear Engineers, South African Branch, 20-21 June.
(14) BRYNARD H J *et al.* (1990). Uranium Resources, Production and Demand in South Africa. Presented at the Symposium on Nuclear Technology in Southern Africa, ESKOM, Megawatt Park, Institution of Nuclear Engineers, South African Branch, 20-21 June.
(15) EBERHARD A A (1989). Energy consumption patterns and supply problems in underdeveloped rural areas in South Africa. Presented at the Alternative Energy Conference, 2-3 February.
(16) Energy and the Environment: Memorandum to the President's Council to contribute to the development of a policy on a National Management System for the Environment (1990). National Energy Council, March.

THE INAPPROPRIATENESS OF "APPROPRIATE ENERGY TECHNOLOGIES" FOR DEVELOPING AREAS

*A A EBERHARD

The notion of appropriate technology has been a governing paradigm in aid-funded energy projects in developing countries over the past 15 years, but very little progress has been made in meeting the energy needs of these areas. The underlying principles and basic constraints of "appropriate energy technology" approaches are examined and the necessity for large-scale State-backed programmes in electrification and afforestation is argued.

An earlier version of this paper was presented at the World Energy Council's Regional Energy Forum for East and Southern African Countries in Harare, 12-14 November 1990.

KEYWORDS: appropriate technology; energy; developing areas

INTRODUCTION

The past decade and a half has seen a multitude of projects aimed at developing and disseminating small energy technologies appropriate to the conditions and needs of Third World households. Many of these projects have been guided by the philosophy or principles of "appropriate technology" and nearly all have been funded and supported by aid agencies from the industrialised countries. Energy has been a priority issue, given public concern following the shock oil price hikes of the 1970's, the growing awareness of devastating deforestation, and the apparent potential for small independent renewable energy systems in developing countries.

Energy, however, is no longer a priority issue for many aid agencies, and as it gives way to popular environmental concerns it seems appropriate that the experience of the past decade and a half be reviewed. What impact have the plethora of small energy development programmes had on the energy problems of Third World countries, and Southern Africa in particular? Do these projects still have a place in energy strategies for the 1990's? Are the Chingwa mud stoves, the ceramic Mbaulas, stone Paolas, Stoven brick stoves, Mabotle or Tstso metal cookers, Vakomana or Gocha saw-dust stoves, the Maikapei retained-heat cookers, solar cookers, Motswedi windmills, Bushpump, Blair, Thebe or Indian Mark II handpumps, Mexican stills or Chinese digesters making any difference at all to the energy supply in the region?

An attempt is made to answer these questions by reviewing a number of energy projects undertaken in Southern Africa. But first, an examination of the notion of "appropriate technology" is made which has underpinned so many of these projects and which, for more than a decade, has informed the funding policies of many aid agencies, especially the smaller non-governmental organisations (NGOs).

ORIGINS

While there have been a small number of international aid-supported projects in the African subcontinent (excluding South Africa), which have involved substantial investment in large-scale energy infrastructure such as electricity grids and upgrading oil refineries, the great majority of projects have involved small energy technology designs aimed at meeting the energy needs of rural households and also, more recently, households in informal urban settlements. Common to many of these projects is the notion that the technology designs should be small scale, low cost, capital-saving and labour-intensive, use local materials and local skills, and, as far as possible, be based on renewable energy resources. These are of course the key principles of "appropriate technology", espoused in a wide and often inchoate literature, but epitomised perhaps best by the writings of E F Schumacher(9), the founder of the Intermediate Technology Group. There have probably been as many critics as there have been adherents of what became almost a movement, but there has been a dearth of intelligent and critical analysis** and the philosophy of "appropriate technology" has retained its dominance in development programmes.

FIRE, EARTH AND SUN

The efforts devoted to the key rural energy problem of fuelwood scarcity and deforestation perhaps best encapsulate this focus on small "appropriate" energy technologies. Millions of dollars of aid have gone into the local development of a host of ingenious fuel-efficient wood and charcoal-burning stoves, biogas digesters and solar cookers.

Solar cookers

Solar cookers are small-scale energy technologies which require very little capital investment, can be made by relatively unskilled labour, are relatively cheap and,

---

*Head, Energy for Development Research Centre, Energy Research Institute, University of Cape Town, Private Bag, Rondebosch 7700, South Africa

**F Stewart (1977), R Kaplinsky (1990) and the critic R S Eckhaus (1987) are amongst the few exceptions best of all, use a renewable and abundant energy source — the sun. In short, solar cookers are an "appropriate technology" and they even work quite well, cooking most foods within a relatively short period over midday when the sun shines. There have been a number of solar cooker development and dissemination programmes in the region, many of them in Lesotho where fuelwood has all but disappeared. However, in spite of substantial funding support, dedicated and skilled project initiators, and a well-developed understanding of the technology, none of these projects has manufactured or sold solar cookers in large numbers, and few of those which have been produced continue to be used regularly.

Take for example the USAID Renewable Energy Technology Project in Lesotho which involved the expenditure of millions of dollars between 1981 and 1984 and included the objective of developing and disseminating solar ovens. Some 50 ovens were manufactured at the CIDA-funded Thaba Tseka Rural Technology Unit workshop. A careful dissemination programme was planned for a remote mountain village with a Peace Corps volunteer living in the village for a number of months explaining the use of the ovens. By the time he left, most ovens appeared to be used, at least intermittently. Follow-up visits, however, revealed a sharp fall-off in usage and a year later, none were being used for cooking, although some were found to be handy storage boxes(3). Further enthusiastic individuals in Lesotho, and throughout the region, have promoted solar cookers, but with no reported success.

Fuel-efficient stoves

The reported potential for fuel-efficient stoves to halt and reverse deforestation has reached almost mythical proportions, and although they have been manufactured and disseminated with markedly greater success than solar cookers (e.g. the improved Jiko in Kenya and the Tsotso in Zimbabwe), there is little documented evidence that improved wood and charcoal burning stoves have either saved overall consumption of fuelwood or reduced woodland denudation in the region(1). In fact, it is generally accepted now that fuelwood gathering is a far less important cause of deforestation than other factors such as land clearing for agriculture or overgrazing(6). It has also been recognised that rural households adapt to fuelwood scarcities and have evolved themselves a range of very simple fuelwood conservation strategies.

Biogas

Biogas digesters have been even less successful in providing an alternative sustainable energy supply for rural households in the regions and in spite of multi-year projects at CARMATEC in Tanzania, Silveira House in Zimbabwe, RIIC in Botswana and the FAO/UNESCO/Chinese Government programmes in Lesotho, the number of operating plants can be counted in tens rather than hundreds or the hundreds of thousands which the Indian and Chinese experience promised. Of 22 biogas digesters visited in Lesotho in 1988, only 6 were operative(8). In July 1988, there was a total of 13 biogas plants operating in Botswana(13).

COMMON CONSTRAINTS

So far just three energy technologies have been examined very briefly (and superficially). A not dissimilar, and perhaps even more dispiriting, picture emerges from other small-scale energy technologies such as solar-stills, locally developed windmills, ram pumps, waste briquetting, agricultural traction, solar dryers, and hot boxes. The author of this paper has argued that what underlies many of these designs are common notions of "appropriate technology". To what extent do these notions of small-scale, capital-saving use of local materials and skills together with renewable energy resources, constrain the potential for these technologies to contribute significantly to energy supply in underdeveloped areas?

There is little doubt that the projects and technologies described above are marginal to current energy use in the region. This is not merely a reflection of the relatively small allocation of resources to these activities or of the complex and intractable problems associated with the introduction of new technologies in conservative rural environments. The marginality of these technologies is also the result of the way in which "appropriateness" has been defined. "Small-scale" inevitably has meant a focus on individual, disparate, localised initiatives rather than large-scale State-backed programmes aimed at maximum impact. "Capital-saving" and "use of local materials and skills" have invariably been interpreted as informal sector, labour-intensive, unskilled production, while capital investment in efficient (and often more cost effective) manufacturing processes has been neglected.

The result is poor quality, intermittent production, marginalised from the main manufacturing sector and marketing channels, inefficient organisation and economic non-viability once the technical and managerial skills of the aid-funded "expert" have departed. The production and dissemination of "appropriate technologies" are seldom conceived of as mainstream economic activities, and there is little analysis of how these new products might compete in the market.

The almost exclusive focus on renewable energy resources has also served to marginalise these programmes and very little attention is given to the major issues of concern to the majority of households in developing countries such as gaining access to the electricity grid or the availability and affordability of commercial fuels including paraffin, LPG, charcoal and fuelwood.

The author would argue then that traditional conceptions of what constitutes an "appropriate technology" have constrained initiatives exploring alternative energy supply options for developing areas. Ultimately, the commonly understood objective of these programmes is to promote development by meeting the basic energy needs of all in the region. The provision of adequate and affordable energy, though, may best be accomplished by new and innovative electrification technology, by sensible paraffin and LPG pricing policies, or by massive afforestation schemes. Many of these technologies use sophisticated manufacturing processes; many may not use local materials; some may be small-scale (like photovoltaics), but others, such as grid-electricity based on hydro-electric schemes, will be large-scale in terms of investment and scope. Clearly, if the notion of "appropriate technology" is to retain any usefulness, it will need substantial redefinition.

THE RELEVANCE OF NOT SO SMALL ENERGY TECHNOLOGIES AND STRATEGIES

In the author's view, the energy supply problems in underdeveloped areas centre around two critical and immediate issues.

Afforestation

In many areas demand for fuelwood is exceeding supply with devastating social, economic and environmental consequences. Women, and increasingly other members of the household, are involved in time-consuming and burdensome fuelwood collection trips, at ever increasing distances from the home. Wood, and sometimes charcoal, has to be transported into areas of greatest scarcity and households have to pay for what was once a "free" resource. Perhaps of greatest concern is the environmental impact of woodland denudation and irreversible loss of topsoil.

The most "appropriate" energy supply strategy for the majority of households in the region is arguably a massive investment in afforestation. There is ample experience over the past 15 years from, for example, Malawi, the Zimbabwe World Bank project, the Lesotho woodlots programme and many smaller initiatives which have explored community and agro-forestry approaches, to know which techniques work and which do not. Afforestation needs to be linked to a broader rural development strategy. Households can seldom be persuaded to plant trees for fuelwood alone. But trees can be integrated into cropping systems and by simply increasing the number of multi-purpose trees, pressure on natural woodland is diminished and fuelwood needs tend to be met. What is essential is for these lessons to be built into sustainable, long-term State-backed and funded programmes. A large-scale afforestation initiative will inevitably also rely on extensive NGO involvement in the implementing of programmes.

Electrification

The second major problem is that the standard, most convenient and affordable domestic supply option, electricity, has still not been made available to many townships and most peri-urban areas. With increasing population and rates of urbanisation, the problem of adequate household energy supply is shifting to those areas which experience major social and economic costs as a result of dependence on costly and inconvenient fossil fuels and batteries.

Electricity is the preferred supply option for households in developed urban areas, yet the majority of the population living in and around urban centres still do not have access to electricity. However, there is still widespread questioning of the appropriateness and affordability of electricity for poorer households. How does the cost of electricity compare with the transitional fuels such as paraffin, LPG and coal?

Figure 1 presents useful energy costs for these fuels at different selling prices. The comparative energy costs are calculated from the respective energy content (or calorific value) of the fuels and the efficiency with which they are used. For example, the efficiency of a wood fire may be only 10%, while a paraffin stove will be of the order of 50% and a gas cooker about 75%. Useful energy costs take calorific values and conversion efficiencies into account and represent the actual cost of energy to the user.

Useful energy from wood and paraffin is the most expensive. Based on standard or recommended prices from suppliers, electricity is generally cheaper than gas, paraffin and wood, but in most cases is more expensive than coal, although the latter situation is often reversed as there are large mark-ups in the distribution of coal in small quantities to townships.

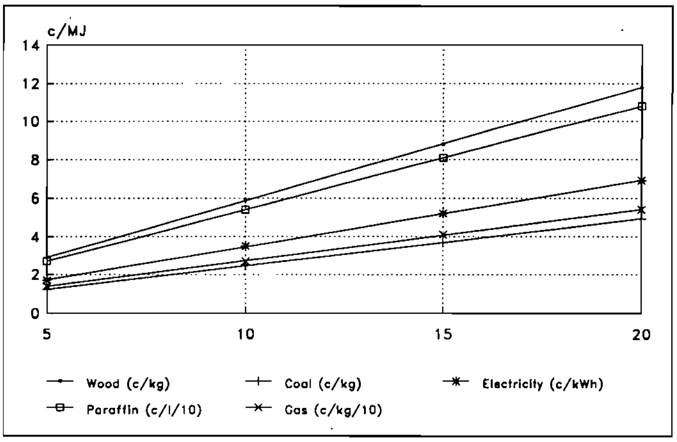


Figure 1: Useful energy costs of different fuels at varying prices

These data clearly dispel the popular myth that most poor households cannot afford electricity: the truth is that those who use primarily wood and paraffin can no longer afford not to use electricity or coal.

The benefits of grid electrification are not automatic, however, and electrification schemes in the region have revealed a number of problems, including low initial consumption, problems with budgeting and metering, the persistent use of transitional fuels and the unaffordability of electrical appliances. However, there have been innovative advances in "appropriate" electrification technologies which can significantly reduce the cost of schemes: for example, single-wire earth-return (SWER), aerial bundle cables, pole-mounted transformers, prepayment meters and prewired harnesses or readyboards which reduce the costs of house wiring. Work is also being done on other problems, particularly on resolving the financial and institutional blockages to an accelerated electrification programme(12).

In rural areas connection to the national grid is not always the cheapest electricity option. Experience in the region has shown that for small remote applications, photovoltaics can be more cost effective. There has been a quiet revolution over the past five years in the telecommunications industry, for example, which now relies heavily on photovoltaics. They are also beginning to be used for institutional energy requirements in rural areas, e.g. vaccine refrigeration and lighting in clinics, educational television in schools, and water pumping for irrigation(10).

Photovoltaics do not fit traditional criteria of "appropriate technology", but they are beginning to provide an appropriate solution to electricity needs in remote areas.

CONCLUSION

This paper does not pretend to present a comprehensive overview of those technologies which have the potential to provide adequate and affordable energy to all households in Southern Africa. It seeks rather to highlight some of the difficulties experienced in small energy technology designs and the way in which many projects in the region have been constrained by inherited notions of "appropriate technology". The consequence has been perhaps to ignore the technological developments in other fields such as the electricity supply industry where innovative low-cost technologies are making grid-electrification more affordable.

International experience over the past decade and a half has indicated that large-scale State-initiated electrification and afforestation programmes can make significant and measurable improvements in household energy supply(2,5). These are perhaps the two priority energy supply technologies for developing countries. In a post-apartheid era and the possible constitution of a Southern African economic community, the potential exists for large-scale regional energy schemes.

Does this mean that there is no room for small energy technologies? Clearly not. It has been shown above that small independent photovoltaic systems have specific economically viable applications. It is also apparent that the intractable problems of underdevelopment in rural areas will require a careful, incremental approach with the introduction of new technologies which can be assimilated by conservative and poor rural households. Energy supply for small water pumping systems, for example, is a great need. The work of development agencies and NGOs in promoting small energy technologies will remain a vital, albeit not central, component of an energy supply strategy to meet basic energy needs in the region. Ultimately though, State-backed large-scale energy initiatives are required to address the basic energy needs of the majority of South Africans.

REFERENCES

(1) DICKSON B J and BALDWIN S A (1990). The development of low-cost fuel-efficient wood burning stoves appropriate for underdeveloped areas of South Africa. Energy Research Institute, Report No. GEN 136.
(2) DINGLEY C (1988). A review of electrification programmes in six countries. University of Cape Town.
(3) EBERHARD A A (1984). Dissemination of solar ovens in Lesotho: problems and lessons. *In*: Solar World Congress/ Ed. by S V Szokolay. Pergamon Press, pp. 2754-2758.
(4) ECKHAUS R S (1987). Appropriate technology: the movement has only a few clothes on. *Issues in Science and Technology*, Winter, pp. 62-71.
(5) FOLEY G (1984). Farm and community forestry. Earthscan Technical Report No. 3, International Institute for Environment and Development.
(6) FOLEY G, MOSS P and TIMBERLAKE L (1984). Stoves and trees. Earthscan.
(7) KAPLINSKY R (1990). The economics of small. IT Press.
(8) LAW S M and EBERHARD A A (1990). Directory of rural energy programmes in Southern Africa. Energy Research Institute, Report No. GEN 143.
(9) SCHUMACHER E F (1975). Small is beautiful. Harper Collins.
(10) SINCLAIR D (1989). A review of international and local developments in photovoltaic technology and economics in developing areas. Unpublished MSc dissertation, University of Cape Town.
(11) STEWART F (1977). Technology and underdevelopment. Macmillan Press.
(12) THERON P, EBERHARD A A and DINGLEY C (1991). Electricity provision in urban areas of South Africa: Towards a new policy framework. Urban Forum.
(13) WOTO T (1988). Biogas technology in Botswana: A sociological evaluation. RIIC.

ECONOMICS OF LOADING PIT-HEAD POWER STATIONS

*R K DUTKIEWICZ

The merit order method of loading power stations onto an electrical grid system is based on loading power stations or individual units on the basis of the next lowest marginal cost of production. When this system is applied to a generating system with pit-head power stations, coal mines are often used below their optimum capacity except for the initial years of operation. This results in a large capital expenditure on under-utilized colliery capacity. If pit-head power stations were designed for a lower tonnage over their entire life, substantial savings in capital cost would be obtained, at the expense of additional coal consumption. The economic viability of such a planning philosophy would depend on the relative capital and operating costs of the colliery.

This paper determines the relative costs of operating a pit-head power station on the basis of the traditional decreasing merit order basis, and on an alternative basis which allocates the load factor for a station which it maintains for the whole life of the station. The calculations are based on a number of simplifying assumptions and are therefore not strictly representative of the real world where factors other than pure cost influence the power plant loading programme.

However, the results of the analysis show that alternative methods of power plant loading may be more economic than the traditional merit order system under certain conditions.

KEYWORDS: power stations; economics

INTRODUCTION

The traditional method for assigning power stations is based on the so-called "merit order" system whereby plant is switched onto the system in an order based on the fuel cost associated with the production of the next unit of electricity. Thus at any time the next power plant to be connected to the grid is that which has the lowest marginal cost. In countries where extensive use of transport of coal is used, the cheapest coal will be utilized first and will be sent to that power station which is the most efficient. In such a system there is no loading relationship between a colliery and a power station. Collieries are loaded in order of increasing coal cost, whilst power stations are loaded in order of decreasing efficiency.

This philosophy has been carried over to systems with a pit-head economy where power stations are loaded in ascending order of marginal cost. Here the marginal cost includes the cost components of the mine as well as the effect of efficiency of the power station. The mine cost used in such an analysis depends on the system of ownership of the colliery. If the colliery is owned by the electrical utility, then the coal cost is the short-run marginal cost of the coal mine. If the colliery is owned separately, then the coal cost is the total cost of the coal.

With this system of pit-head power station operation it has become traditional that new stations are loaded preferentially and that older, less efficient stations become intermediary, and finally peaking, stations.

This traditional system of merit order operation has resulted in a planning philosophy for power station systems which allows the colliery to be utilized at full output for only a few years after the construction of the power station; thereafter the output decreases with time. This means that an asset which is capable of a given output is intentionally under-utilized during most of its life.

This thinking is the result of an acceptance of the merit order system, which is a logical method of operating power stations in a coal-transport system, and its implementation into a pit-head system. Moreover, this thinking is reinforced by the generally divided ownership of the mine on the one hand, and the power station on the other.

However, if the power station/colliery is considered as a single economic system, then the minimization of cost under joint ownership, or at least joint planning, may well lead to a different method of operating the power stations.

The typical load factors of some ESKOM power stations and their related collieries, both expressed as a function of the power station out-put, are given in Table 1[(2)].

Table 1: Load factors achieved by certain power stations and the collieries derived from the design tonnage

Power Station	Load Factor % Station	Load Factor % Colliery
Hendrina	67,3	67,8
Arnot	65,9	72,5
Kriel	63,1	67,9
Matla	65,1	71,7
Duvha	69,4	73,1
Tutuka	59,8	69,6
Lethabo	62,5	71,9

It appears therefore that the design tonnage of the collieries is consistently higher than that required by the power station. The minimum cost would be reached when the load factor of the colliery was exactly equal to the requirement of the power station.

This is of course a simplification since the analysis should include the cost of increasing maintenance of a power station with age, as well as the injections of capital required to maintain the design output of the colliery.

---

*Director, Energy Research Institute, University of Cape Town, P O Box 33, Plumstead 7800, South Africa

COST OF OPERATING A PIT-HEAD UTILITY

The cost of operating a pit-head utility is made up of the cost of a power station and of the coal mine. Each component can be considered as made up of a fixed capital cost, which is a function of the size of the asset, and an operating cost which will be simplified in this consideration to be a function of the units generated in the case of the power station, and the amount of coal mined in the case of the mine. It will also be assumed that the cost of transporting coal is so high that the minimum total cost is achieved with pit-head operation.

If P is the annual capital cost of the power station per kilowatt of installed capacity, and the annual capital cost of the coal mine is Q per ton/year of potential output, then the annual capital cost component of the combination of power station and colliery Z_1 is given by:

$$Z_1 = MP + QT_1$$

where M is the power station capacity in kilowatts and T_1 is the yearly tonnage of the colliery. The design tonnage T_1 is related to the maximum capacity of the power station.

Thus if the power station is designed to operate as a base load station, then the colliery capacity will be of a size to satisfy this maximum demand. As the load factor of the power station decreases, so the tonnage from the colliery decreases even though the design throughput is still possible.

In terms of the station demand for coal, the tonnage T is given by the equation:

$$T = 8760LM / nk \quad \text{...} \quad (1)$$

where k is the calorific value of the coal expressed here as kWh/ton, n is the power station overall efficiency expressed as a fraction, L is the power station load factor as a fraction, and the quantity 8760 is the number of hours in a year.

In general, the load factor on the station will decrease with time and thus T is a decreasing quantity with time even though the quantity T_1, which is the original design capacity of the colliery, is still available. The design colliery tonnage T_1 is given by the equation:

$$T_1 = 8760L_1 = M / nk$$

where L_1 is the original design load factor for the power station. The efficiency of the power station could also be considered as a variable with time, but since it is affected mainly by the design operating conditions, and any reduction in efficiency due to age can usually be restored by adequate maintenance, the efficiency will be considered constant with time but will vary from station to station.

The operating cost of the power station is given by the product of the number of units produced and the unit cost of operation. This operating cost includes maintenance, water, chemicals for water treatment, etc., but does not include coal since this is considered separately as a colliery cost. If the unit cost of operation is b, then the operating cost of the power station is given by:

$$\text{power station operating cost} = bLM8760$$

Similarly, the operating cost for the colliery is given by the following equation where c is the operating cost in recovering a ton of coal:

$$\text{colliery operating cost} = cT$$

The total operating cost Z_2 of generating electricity is then:

$$Z_2 = 8760bLM + cT$$

Using the values for Z_1 (capital cost) and Z_2 (variable cost) and the relation for T for the operating component and T_1 for the capital component, then the total cost Z is given by the sum of Z_1 and Z_2 thus:

$$Z = (MP + 8760QL_1M / nk + 8760bLM + 8760cLM / nk) \quad \text{..} \quad (2)$$

In general, the total cost of operating a number of stations Q over a number of years n will be given by the general equation:

$$Z = \sum_{i=1}^{Q} \sum_{j=1}^{N} \{M_iP_i + 8760Q_iL_{i,1}M_i / n_ik + 8760b_iL_{i,j}M_i + 8760c_iL_{i,j}M_i / n_ik\} \quad \text{........................} \quad (3)$$

The quantity $[\Sigma \Sigma M_i P_i]$ is a function of the overall system demand and is unaffected by the method by which power stations are loaded. Therefore it may be considered a constant in the above equation. In the above equation the quantity b_i, which is the cost of routine maintenance and excludes fuel cost, is usually negligible compared with the other terms and may be eliminated. More correctly, since it is not expected that the b_i will vary significantly from station to station, whilst the term $[\Sigma \Sigma L_{i,j} M_i]$ is a function of the total system demand and is unaffected by the method of loading stations, the complete quantity may be considered a constant term which can be included with the $[\Sigma \Sigma M_iP_i]$ constant term. If this combined constant term is termed A, then the above equation converts to:

$$Z = A + B \sum_{i=1}^{p} \sum_{j=1}^{N} Q_iL_{i,1} / n_i + D \sum_{i=1}^{p} \sum_{j=1}^{N} c_iL_{i,j}M_i / n_i \quad \text{........} \quad (4)$$

where A, B, and D are constants.

This analysis assumes that the load factor on a power station is originally large, i.e. L_1, and then decreases year by year, whilst newer stations, because of their higher efficiency, are placed above it in the merit order. That this happens is illustrated in Figure 1 which shows that for an actual pit-head power utility the load factor is proportional to efficiency.

The efficiencies in this Figure vary from 15,6% for a 50-year-old station with steam pressure of 2,5 MPa to 36,3% for a recently commissioned station with steam pressure of 16,1 MPa(1).

ILLUSTRATIVE EXAMPLE — MERIT ORDER LOADING

Equation (4) can be solved for a minimum total cost by integrating and setting to zero. In order to carry out the integration, the form of the function $L_{i,j}$ has to be known.

The result of the calculation is strongly influenced by the form of the load duration curve. Typically the load duration curve has a minimum point of around 50% and has a curvilinear form. The example that will be used here assumes that there is a triangular load duration curve for ease of calculation. It is not assumed that the results will be realistic of any given situation since the costing procedure and relationships are much more complicated than has been assumed in this paper.

Assume therefore that for this very simplified case the load factor diagram is a triangular one where the maximum demand decreases linearly with time. Assume furthermore that a new power station of capacity M is introduced every year and that in the first case a new station is introduced as a "base load" station at the bottom of the diagram displacing all the existing stations upwards. This is illustrated in Figure 2.

Since all the stations are the same size, it is reasonable to assume that the values such as c, P, b, etc. as defined above are the same for each station as is, of course, the value M. It is however assumed that the efficiency increases with every subsequent station because of improved technology. It is further assumed that the efficiency increases by 0,4% per annum from a base of 20% in base year 1.

With the assumption of a linear increase in the maximum load demand and a triangular load factor diagram, it can be shown that the load factor L for the i'th power station in year j is given by the expression:

$$L_{i,j} = i^2 / 2j - (i-1)^2 / 2j$$
$$= (2i - 1) / 2j \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

with the boundary condition that $L_{i,j} = 0$ for $j > i$.

Carrying out this integration over a 25-year period gives the results:

$$\Sigma\,\Sigma\,(L_{i,1} / n_i) = 92{,}1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

and

$$\Sigma\,\Sigma\,(L_{i,j} / n_i) = 663{,}2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

The load factor of a typical power station in the above example is shown in Figure 3. The original load factor is high compared with actual power station conditions because no allowance has been made for planned and unscheduled outages.

ILLUSTRATIVE EXAMPLE — CONSTANT LOAD FACTOR

Consider now the alternative situation where the power stations are designed right from the beginning to be intermediary or peaking power stations. Under these conditions the colliery would be built *ab initio* with a reduced capacity, compared with the original concept outlined above, and would maintain the full output for the full lifetime of the power station/colliery complex. This is illustrated in Figure 4.

If the concept of a triangular load diagram is maintained, then by definition all the power stations will have a load factor of 50%. If the station efficiency is again changed linearly from 20%, then the following results are obtained from the integration:

$$\Sigma\,\Sigma\,(L_{i,1} / n_i) = 50{,}3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

and

$$\Sigma\,\Sigma\,(L_{i,j} / n_i) = 696{,}7 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

For ease of comparison these values are tabulated below.

SYSTEM	$\Sigma\Sigma\,(L_{i,1} / n_i)$	$\Sigma\Sigma\,(L_{i,j} / n_i)$
Merit order	92,1	663,2
Constant load factor	50,3	696,7

The second column represents the total capacity of collieries constructed during the 25-year period, whilst the third column represents the total coal consumed during the 25-year period considered.

It is evident that there is a 45% reduction in colliery capacity, and thus capital cost, in favour of the system with a constant load factor. This is achieved at the expense of an increase in coal consumption since the older stations are more heavily utilised compared with the traditional merit order system. The increase in coal use is 5%.

If these values are substituted into equation (4) and a break-even situation is postulated for the two systems, then:

$$(92{,}1\ Q + 663{,}2\ c) = (50{,}3\ Q + 696{,}7\ c)$$

Therefore: $\quad Q / c = 33{,}5/41{,}8 = 0{,}8$

Therefore if the ratio Q/c is greater than 0,8, then the system of keeping the load factor fixed over the life of the station is cheaper than the traditional method of merit order rating. In the utility referred to previously the ratio of Q over c is approximately 2,5. Whilst this may not necessarily be true for developed countries with high labour costs, it is representative of developing countries. It thus appears that for a typical coal price structure the case can be made that the traditional method of merit order rating is more expensive than the system of designing the power station/colliery complex for a given load factor and then maintaining that load factor fixed over the life of the station.

DISCUSSION

The illustrative study used above is very much a simplified one. However, many of the assumptions made would be in favour of the economics of the traditional merit order system. The most serious error is in assuming that all power stations and collieries cost the same. In a pit-head economy it is likely that the cheapest coal mines would be developed first and that subsequent mining would be at greater depths, with narrower seams, etc. Therefore under the traditional merit order system more expensive coal would be used to replace cheaper and older coal.

Secondly, it has been assumed that the cost of the power station remains fixed irrespective of the system used to determine loading. In fact, a power station designed for a lower load factor would have a lower cost because of the lower capacity required from some of the auxiliary equipment, i.e. such items as make up water systems, water-treatment plant, ash disposal, etc.

Lastly, in the economic analysis a yearly construction programme of power stations is assumed. In fact power stations are introduced as larger blocks in advance of load growth. This results in plant being under-utilised until the demand is achieved. Thus there is a further cost penalty for plant with large capital expenditure. The analysis as outlined above therefore again favours the traditional merit order system.

On the other hand, there is one simplifying assumption that is made for ease of calculation and, whilst adequate in an illustrative example, would require a more detailed investigation in a real system. This refers to the assumption that a colliery capital cost is a linear function of its annual output. Colliery costs are in fact a series of step functions of output due to the flexibility of many of the components of the mine. Thus a conveyor belt system can be upgraded over a range of throughput at minimal costs, but further increases would require a larger system. In open cast mines one drag-line would be used at any output up to the maximum capacity of the drag-line, after which another drag-line would be required, leading to a step jump in expenditure.

It is likely therefore that compared with the illustrative example a real system would show a higher cost saving by the adoption of a fixed load factor system. In a real system where the load factor will be changing with a changing industrial and domestic demand mix it is understandable that different power stations would be operating at different load factors, but each one would be operating at its designed load factor in order to maximize asset usage.

CONCLUSION

An analysis of the economics of operating power stations in a pit-head economy shows that it may be preferable to load the power stations by some method other than the traditional merit order where a power station starts its life with a high load factor which decreases as newer and more efficient stations come onto the grid. It can be shown that a system of designing a power station for a given load factor and then maintaining this load factor over its entire life may be beneficial. The economic benefit arises due to the smaller collieries which are constructed leading to a lower capital cost. This lower economic cost is achieved at the expense of an increase in coal usage due to the larger use of older and therefore less efficient stations.

The illustrative example, which assumes a triangular load duration curve and a linear annual growth rate, has shown that the increase in coal consumption is 5%, with efficiency increasing by 0,4% per annum from a base of 20%. If the base efficiency was higher or the increase in efficiency was at a lower rate, then the increase in coal consumption would be less than the 5% quoted.

Whether there is an overall benefit depends on the relative values of the capital cost of the colliery per annual ton of output and of the operating cost of the colliery per ton mined. In the illustrative example the break-even ratio of capital cost over operating cost is 0,8. If the actual ratio is greater than 0,8, the constant load factor system is preferred; a ratio lower than 0,8 would mean that the traditional merit order system is preferred.

Since the constant load factor method leads to a lower capital cost, it may be preferred in situations where the limitations on power system development are the shortage of capital, whilst operating costs, being paid out of revenue, are more easily obtained. This is likely to be the situation in developing countries where electricity is required for economic development, but capital can be obtained only from the results of such economic growth. In order to achieve the maximum economic growth with minimum capital expenditure, a constant load factor approach to power system planning may be beneficial.

The cost calculations made in this paper are very much simplified ones and that in the real situation there are a large number of parameters that have not been discussed in this paper.

ACKNOWLEDGEMENTS

I would like to acknowledge the helpful comments on the draft of this paper made by various people and especially by Mr P J Rubbers of ESKOM.

REFERENCES

(1) ESKOM (1984). Annual report.
(2) RUBBERS P J (1991). Personal communication.

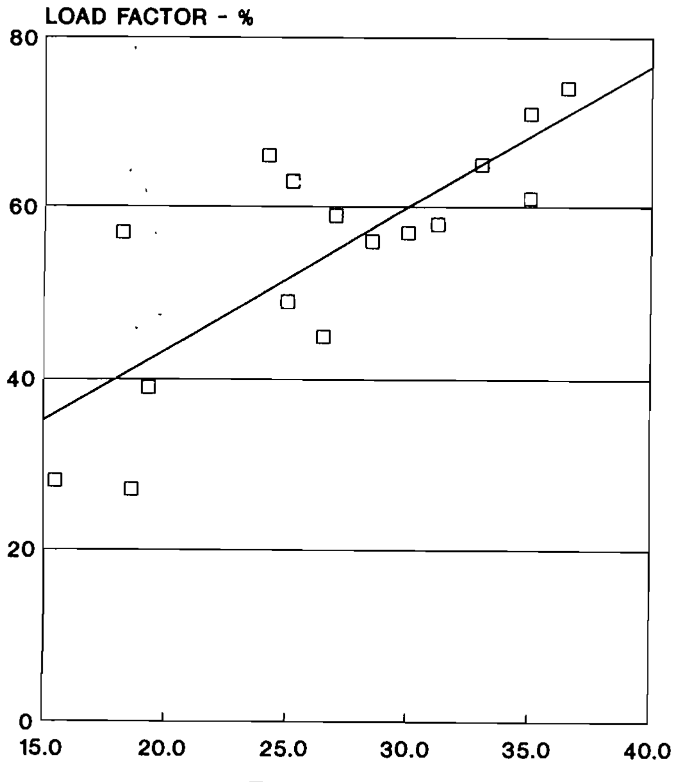


Figure 1: Relationship between power station efficiency and load factor in an electrical utility

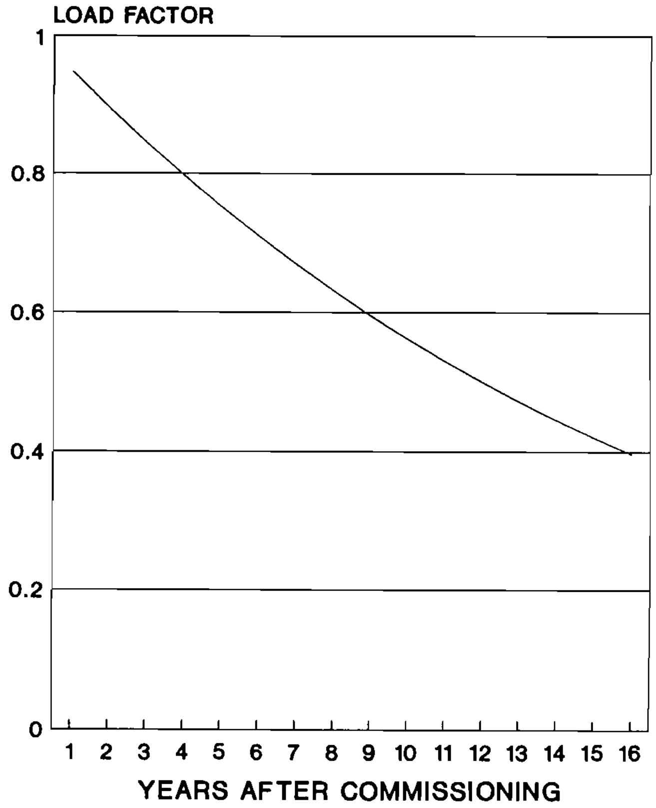


Figure 3: Typical load factor variation for a power station subject to merit order loading (illustrative example)

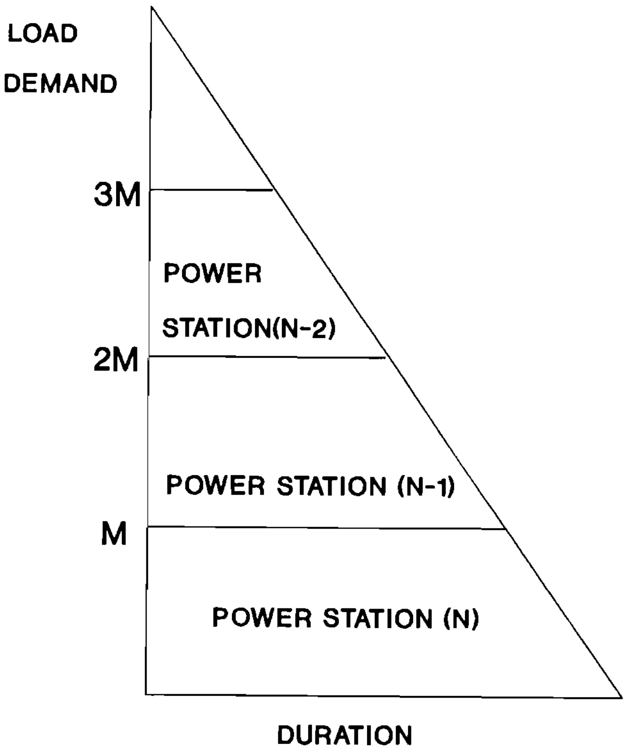


Figure 2: Triangular load demand diagram for a number of power stations in the n'th year of operation of the system

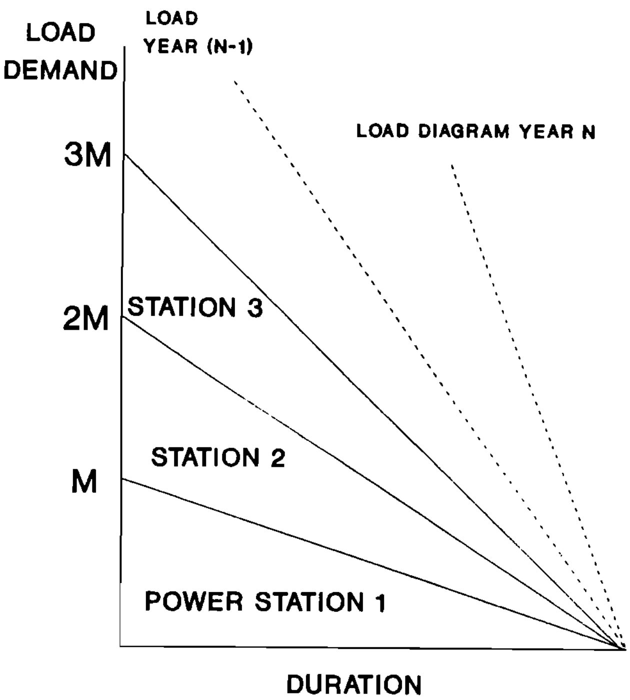


Figure 4: Triangular load demand diagram for power stations each with a constant load factor

SOLAR TESTING REVISITED: THE CASE FOR STANDARDS AND TESTING FACILITIES FOR SWH AND PV IN SOUTH AFRICA

*G J MORRIS

Despite the appeal and promising early prospects of solar technologies in the 1970's, the degree of practical implementation of SWH and PV systems in South Africa is disappointingly limited. In part this can be ascribed to the lack of effective and accessible national solar standards and testing facilities. General dissatisfaction has been expressed regarding the existing SABS standard and test facilities for SWH systems. The long duration and arbitrary nature of the thermal performance tests undermined the intentions of providing a consistent and meaningful standard. Furthermore, no local standards or testing facilities exist for the emerging PV industry. This paper presents the essential findings and recommendations of a research project which reviewed existing local and international solar standards and testing facilities with a view to making recommendations for local implementation of standards and testing facilities to meet current and future needs in South Africa. The recommendations have found general support and are currently being implemented.

KEYWORDS: solar testing; solar standards; solar water heaters; photovoltaics

INTRODUCTION

Solar thermal energy conversion in the form of solar water heating (SWH), and direct conversion of solar into electrical energy by means of photovoltaics (PV), are immensely appealing options for supplying some basic energy needs in South Africa. The limited degree of practical implementation of these technologies in the region is therefore disappointing. Significant aggravating factors in the chequered development of the solar industry have been the inconsistent and inadequate local standards and testing and R&D facilities at its disposal. The old National Building Research Institute (NBRI) conducted pioneering R&D on SWH systems in the mid-1950's(1) and supported the industry and SABS until the early 1980's(2). This support mirrored the world-wide focus on renewable energy R&D in the wake of the oil price crises of the 1970's. Similarly, the founding of the Solar Energy Society of South Africa (SESSA) in 1975 reflected the growth of the local solar industry. In response to industry and consumer interest the SABS published a South African standard for SWH's in 1980(3).

Despite the latent potential of the solar technologies, the current status of SWH standards and testing is at a particularly low ebb. The NBRI (now Division of Building Technology) has discontinued any further R&D support and the SWH industry and consumers have expressed dissatisfaction with the implementation of the existing standard (SABS 1307-1980) and the present procedure for thermal performance testing. Arbitrary supplementary test facilities are located at a few universities, but in general these are dated and do not allow for co-ordinated and structured research or testing. Furthermore, no standards or independent testing facilities exist for the emergent PV industry. There are compelling imperatives to establish confidence in PV as a viable technology for diverse applications requiring electricity in non-electrified areas(4).

Based on the perception that solar technologies increasingly have a role to play in meeting the basic energy needs of South Africans, and in recognition of the expressed desire for meaningful national standards and testing facilities, the Energy for Development Research Centre (EDRC) prepared a solar testing research proposal in 1989. This initiative was supported by the National Energy Council (NEC) and provided for a phased project over three years. The objectives of the first phase were:

(i) to assess the existing local solar standards and testing facilities,
(ii) to conduct a literature review of internationally accepted standards and test procedures for SWH and PV,
(iii) to review existing test facilities abroad, and
(iv) to investigate the feasibility of a national solar testing facility in South Africa.

This initial phase of the EDRC/NEC research project(5) was structured as a desk-based review of standards, test procedures and the research literature which was further informed by visits and discussions with industry, regulatory authorities and research facilities both in South Africa and abroad.

This paper presents the essential findings of the first phase of the project by addressing the question of standards and testing in general before discussing the specific findings with regard to SWH and PV respectively.

BACKGROUND TO STANDARDS AND TESTING

Standards in engineering could be grouped into (i) national standards (including standard specifications, standard codes of practice and standard methods) as prepared by the SABS, (ii) project specifications prepared by consultants or project managers for engineering design and project management, and (iii) codes of ethics prepared and enforced by industry associations to maintain the image of the industry through good business practice and quality service.

---

*Principal Research Officer, Energy for Development Centre, Energy Research Institute, University of Cape Town, Private Bag, Rondebosch 7700, South Africa

Standards are supported by testing methods or procedures for evaluating compliance with the standard. Solar certification tests typically include (i) qualification tests to assess construction, design, durability and safety, and (ii) thermal or electrical performance tests. In addition, they may include (iii) an assessment of installation procedures, documentation and user manuals, and (iv) procedures for inspecting and testing systems *in situ*.

The purposes of performance testing can be further categorized into (i) arbitrary performance tests under specified test conditions, (ii) tests which can be used to predict performance under non-test conditions, and (iii) diagnostic and R&D tests. Type (i) tests are extremely limited in their value since the results give no measure of in-service performance under a range of different conditions. Although more complex, type (ii) tests can be more representative of expectable in-service performance and can facilitate more equitable comparisons of the performance between different systems. Type (iii) tests would tend to be focused more on product development than certification efforts.

Desirable features of a performance test method would typically include practical considerations such as: low cost, duration, ease of implementation, indoor/outdoor testing, climatic conditions required, flexible location, international compatibility, component substitution and legal status. Additional features would be technical considerations such as: accuracy and reliability, instrumentation and control, automation, parallel testing and applicability to a wide range of systems. Finally, features regarding the forms of performance ratings require consideration, such as: time-scale, climatic variation, system boundaries, load demand and energy output or energy savings.

SOLAR WATER HEATING

When considering SWH technologies the distinction between solar collectors and complete systems should be borne in mind. In practice the standards and testing of systems are more valuable than for collectors, which constitute only one of the components of a complete system.

Review of SABS 1307-1980: Standard Specification for collectors for SWH

The existing SABS standard includes (i) prescriptive qualification requirements and qualification test methods and (ii) a thermal performance test procedure with minimum thermal performance requirements. Although the title of the standard implies an emphasis on collectors, the thermal performance test procedure in SABS 1307-1980 is intended for deriving energy ratings for SWH systems. The test results are presented in the form of a "total energy rating" and a "specific energy rating". An associated collector efficiency value is also calculated.

The test procedure is conducted outdoors. It comprises three separate one-day heating tests lasting approximately 8 hours each. The collector or system is mounted on an inclined mount according to the manufacturer's instructions and pre-conditioned by allowing it to stabilize at ambient conditions before being exposed to incident irradiation. The total energy rating is calculated as the energy added to the heated water which is drawn off at the end of each day. The energy ratings are normalised with respect to a total daily insolation of 20 MJ/m^2-day, and an average is taken of values over three separate day tests. The specific energy rating is similar, but calculates the energy gain of the heated water in excess of the energy at a reference temperature of {initial water temperature plus 20 °C}. An average efficiency is calculated as the thermal energy gain of the water drawn off divided by the solar energy incident on the collector during the test.

While the test procedure has advantages in being inexpensive, of short duration, easy to implement and requiring easily satisfied outdoor climatic conditions, it has fundamental problems. Firstly, the accuracy and reliability are variable due to ambient temperature and inlet water temperature effects which are not controlled or accounted for in the calculations. Secondly, the test criteria for rating the system are arbitrarily defined and have no bearing on in-service ratings. Finally, the procedure has unclear system boundaries and is more of a "quasi-system" test despite being titled as a "collector" test procedure. The procedure would in addition not provide a basis for evaluating the effects of fluid flow rates in pumped systems or the effects of integral auxiliary heating.

Further limitations of the procedure relate to the form of the test. These include the fact that (i) the results of the test apply to specified conditions only, (ii) the information content of the results is not meaningful due to the arbitrary definition of the test, (iii) in practice the SABS test has no theoretical or scientific weight in legal disputes, and (iv) the procedure is not compatible with international standards or test approaches.

Review of major international approaches

The three approaches which have influenced significant international SWH standards development are those pursued in the USA, Australia and the European Community. The suite of ISO standards for SWH is essentially derived from these approaches. An intensive German research programme is currently investigating an additional approach, but this is unlikely to be established as a standard in the near future.

United States of America

The US solar standards are prepared and published by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE). The US preference has been for testing SWH components separately, using ASHRAE 93-1986 for outdoor collector tests, to facilitate computer simulation of the performance of systems. The advantages of this approach include (i) accuracy and reliability of tests, (ii) outdoor testing, (iii) component substitutability in configuring SWH systems, and (iv) simulation of system performance. Limitations include the inability to deal with integral or thermosiphon SWH systems which inherently cannot be tested by this approach. In contrast, ASHRAE 95-1981 allows for indoor testing of certain types of complete systems. The limitations of this approach include cost, the requirement for indoor simulated irradiation, the fact that component substitutability is limited, and that the procedure does not allow for extrapolation to long-term in-service performance.

US standards and testing efforts are now inclined towards moving in line with the recommendations of the European Solar Collector and Systems Test Group (CSTG), although there are no concrete indications that this will happen in the near future.

Australia

Australian Standard 2813-1985 specifies a simulator method for testing SWH thermal performance, while AS 2984-1987 provides an outdoor test method. The outdoor test method was developed in recognition that few test sites in Australia would have access to a solar simulator which meets the requirements of AS 2813.

This test method could be described as a "monitoring" method and is based on observing system performance, in normal operating mode under load cycle conditions, over fairly extended periods. In Australian climatic conditions, the testing period typically lasts about six to eight weeks(6). An important feature of the outdoor test method is that it is intended for SWH systems which have auxiliary heaters.

The solar performance tests are complicated in design and potentially time-consuming because all of the following aims are being sought:

- — to evaluate the solar contribution to thermal performance while the auxiliary heating is in operation
- — to average out transient effects by means of sufficiently long test periods with sufficiently similar conditions at the start and end of these test periods
- — to obtain results from several test periods, encompassing a range of climatic/operating conditions, in order to derive parameters which can be used to establish a performance equation for the solar component of the system
- — to be able to use the performance equation to predict the annual solar heating contribution for a range of climatic zones (which must however be similar to the test zone climate) and hence to estimate typical annual energy savings.

To try to achieve these aims, 21 solar tests are required (minimum), with varying controlled load demand. Each test result requires 5 to 15 days' consecutive operation. Some of these test periods could overlap if climatic and operating conditions are suitable. On each day of each test period, nine draw-offs are performed and the energy output, solar input, auxiliary input and other environmental conditions are measured. If the initial 21 test results do not show enough spread in climatic and operating conditions, the tests must be continued further.

The results of this procedure are appealing: it is possible to state how much money the solar component could save, taking into account Australian electricity tariffs, for a specified design load, compared with conventional electric (or gas) heating.

These results, however, could be misleading since arbitrary assumptions are made about draw-off patterns and yearly load profiles in making these predictions. Critics have also questioned whether the tests are reliable: they are not convinced that the same system tested in different laboratories would produce the same results. The results seem however to be accepted by the Australian industry.

The test procedures are not attractive for adoption by other countries. Disadvantages include the following:

- — The procedures are intended for application to SWH systems which have auxiliary heaters.
- — At best, many weeks of controlled and monitored testing are required, and at worst the required tests could take several months per system.

There are further disadvantages, but it is suggested that those noted above are sufficient to disqualify the Australian approach from serious consideration for South African purposes.

Recommendations of the European CSTG

The European Solar Collector and Systems Testing Group has made detailed recommendations about a simplified short-term SWH system test which can be used to predict long-term thermal performance on the basis of a short series of one-day tests(7).

This "black box" approach is suitable for all configurations of SWH systems and appears at present to be the most feasible improvement which could be made to South African SWH performance testing, at acceptable cost.

After extensive research in many countries, the measurements and complexity of the tests have been reduced to a minimum, while allowing extrapolation from test results to obtain an estimate (within approximately 10% accuracy) of annual thermal performance(8). The prediction can be made for different climatic areas.

The test procedures involve a minimum of six one-day system performance tests similar in character to the present SABS one-day tests, but requiring carefully controlled water inlet temperatures and improved instrumentation. The one-day performance tests are conducted independently of one another and can be performed outdoors or indoors. Outdoor testing would be the obvious choice in sunny climates. Figure 1 illustrates the test loop required and Figure 2 indicates the test procedure for each one-day test.

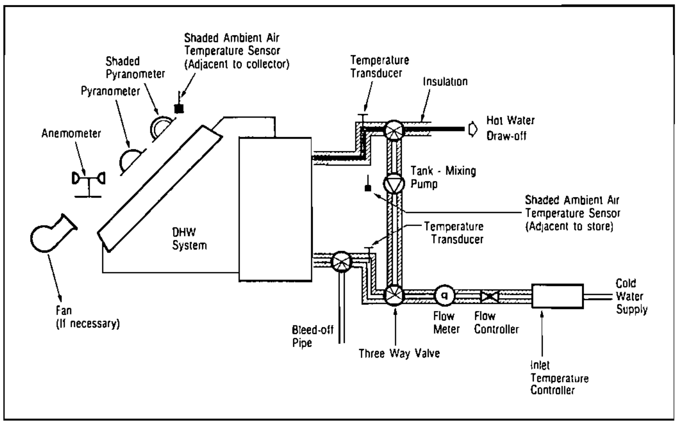


Figure 1: Schematic of test loop for short-term test procedure(7)

The test method provides a system characteristic in the form of Equation (1) which correlates the energy output of the system, **Q**, to the solar energy incident on the system, **H**, and the difference between the daily average ambient temperature, $\mathbf{T}_{a,day}$, and the incoming cold water temperature, $\mathbf{T}_c$.

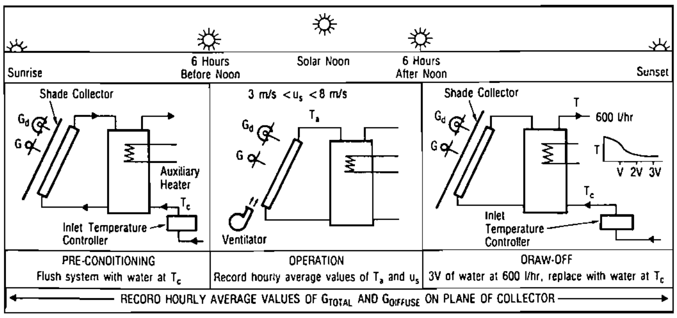


Figure 2: Illustrated summary of short-term testing method(7)

$$Q = \alpha_1 H + \alpha_2(T_{a,day} - T_c) + \alpha_3 \quad (1)$$

On each day of the test the system is preconditioned by flushing and is allowed to operate under carefully monitored conditions which are chosen to cover a reasonable range and combination of typical operating conditions to determine the dependence of the thermal performance on the two primary variables, i.e. daily incident solar radiation, H, and the temperature difference between the average ambient air temperature and the inlet water temperature, $T_{a,day} - T_c$. The recommended test conditions are presented in Table 1.

The test conditions require a wind speed of 3-5 m/s across the system. Three times the volume of the system is drawn off at the end of the twelve-hour test day at a prescribed flow rate. Results are taken from at least four test days with approximately the same values of $(T_{a,day} - T_c)$ and irradiations varying between 8 MJ/m²-day to 25 MJ/m²-day. $T_{a,day}$ is the average surrounding ambient air temperature and T_c is the cold water temperature. In addition, results are required for two different test day conditions where the value of $(T_{a,day} - T_c)$ is at least 10 °C above or below the value of $(T_{a,day} - T_c)$ recorded for the other four test days. The value of $(T_{a,day} - T_c)$ should lie between −5 °C and +20 °C for each test day. Two of the four test days are required with single $3V_s$ draw-offs and irradiations of 20 MJ/m²-day and 10 MJ/m²-day respectively and a fifth optional day is recommended with a noon draw-off of $0,5V_s$ and an end-of-day draw-off of $1,5V_s$ and a corresponding irradiation of 20 MJ/m²-day.

Test day No	Irradiation (MJ/m²· day) approx.	Temp. difference (K)	Draw-off volume	Draw-off time
1	10	$(T_{a,day}-T_c)_1$	3 V_s	solar noon + 6 hours
2	15	$(T_{a,day}-T_c)_1$	3 V_s	solar noon + 6 hours
3	20	$(T_{a,day}-T_c)_1$	3 V_s	solar noon + 6 hours
4	25	$(T_{a,day}-T_c)_1$	3 V_s	solar noon + 6 hours
5	10	$(T_{a,day}-T_c)_2$	3 V_s	solar noon + 6 hours
6	20	$(T_{a,day}-T_c)_2$	3 V_s	solar noon + 6 hours

Table 1: Test conditions for one-day short-term thermal performance tests

Where $(T_{a,day} - T_c)_2 = (T_{a,day} - T_c)_1 \pm 10K$ and both $(T_{a,day} - T_c)_1$ and $(T_{a,day} - T_c)_2$ are between −5K and +20K. $\mathbf{T_c}$ should be approximately 20 °C. The two draw-off temperature profiles for **H** ≈ 10 MJ/m²-day and **H** ≈ 20 MJ/m²-day are recorded for increments of $\mathbf{V_s}/10$.

Two additional tests are required to measure (i) overnight heat loss of the storage vessel, and (ii) the degree of mixing between hot and cold water in the storage vessel during draw-off. These tests do not require outdoor testing.

From the results of the one-day tests, the coefficients derived for the input-output equation are then used to predict day-by-day performance over a typical meteorological year at a given location. This extrapolation procedure also makes use of results from the two additional tests for storage vessel heat loss and mixing characteristics. The extrapolation method is simple and requires the following inputs:

Test results data:

- (i) the coefficients of the characteristic equation, α_1, α_2, and α_3
- (ii) the draw-off temperature profile expressed as a function of volume
- (iii) the draw-off mixing profile expressed as a function of volume
- (iv) the volume of water heated by the auxiliary heater, V_{aux}, for systems with an auxiliary heater (and for which there is no significant mixing between the auxiliary heated water and the solar water)
- (v) the heat loss coefficient of the storage tank, U_s, (W/K).

Climatic data:

- (i) the daily solar irradiation on the plane of the collector (MJ/m²-day)
- (ii) the average ambient temperature for the twelve-hour period around solar noon
- (iii) the average ambient temperature during the night.

System usage data:

- (i) the daily volume of hot water consumption or the minimum useful temperature limit for the hot water consumption
- (ii) the cold water supply temperature for each day.

The method assumes that the system starts with the water at the cold water supply temperature and then proceeds through the following calculated steps:

Step 1 — energy available in the storage tank after the first day
Step 2 — draw-off volume to meet the minimum temperature limit (optional if Step 3 is not already known)
Step 3 — energy drawn-off
Step 4 — energy left in the tank
Step 5 — energy lost overnight

The calculation is repeated for successive days as for day one except that the energy available takes into account the fact that the temperature of the water in the storage tank at the beginning of each day is greater than or equal to the cold water supply temperature due to the carry-over of hot water from the day before. The water in the tank at the start of each successive day is considered to be at a uniform (thoroughly mixed) temperature.

Advantages of this test method include the following:

- — the test method, instrumentation and control requirements are relatively simple
- — the duration of the performance tests is reasonably short
- — all types of domestic SWH systems can be tested, except that there may be problems with testing systems which are operating in conjunction with automatic auxiliary heaters integral to the solar storage tank
- — the method provides a prediction of annual solar output of a system, e.g. in kWh per year, adjustable for climate (but for defined load demand conditions).

Disadvantages of the CSTG/ISO method include:

- — restrictions on draw-off patterns in the test and in long-term performance extrapolations

- — difficulties in testing SWH systems with integral auxiliary heaters which exhibit significant mixing in the storage tank of the solar and auxiliary heated water
- — inflexibility of systems testing with regard to component substitutability
- — climatic conditions required for the test may require manipulation in regions where steady climatic conditions from day to day are commonly experienced. In this case it may be necessary to manipulate total daily irradiation by means of partially shading the collector (this is not covered in the CSTG proposals but has been suggested(6)).

International Standards Organization

The current status (1990/1) of ISO standardization efforts is that ASHRAE has recently assumed the responsibility for the administration of the secretariat of the ISO sub-committee on solar energy systems (ISO/Technical Committee 180 SC 4 Solar Energy Systems — Thermal Performance, Reliability and Durability) in agreement with and on behalf of the American National Standards Institute (ANSI). ISO has prepared final and draft standards for collectors and SWH systems.

The draft ISO standard for solar collector performance test procedures (DP9806-1E) is essentially based on ASHRAE 93. The ISO draft standard for performance testing of unglazed flat plate collectors is similar in format and layout. Solar collector qualification tests are set out in ISO DP9806-2, Solar collectors — Part 2: Qualification test procedures.

There appears to have been vigorous debate around the format and approach to be adopted as the ISO standard thermal test procedure for systems (ISO 9459). Initially the sub-committee agreed to use ASHRAE 95 as the basis for the ISO system test procedure. At a subsequent meeting in 1985 the sub-committee revised the scope of the standard and decided to prepare the draft standard in four parts:

ISO 9459: Part 1 — Performance rating procedure using indoor test methods
ISO 9459: Part 2 — Procedures for system performance characterisation and yearly performance prediction
ISO 9459: Part 3 — Procedures for system component characterisation and the prediction of yearly performance using component performance data
ISO 9459: Part 4 — Test methods to determine durability and reliability.

The rating procedures in ISO DP 9459: Part 1 involve testing for periods of one day under indoor reference conditions (along the lines of the ASHRAE 95 approach). The results allow systems to be compared under identical conditions. The procedures for predicting yearly performance allow the output of the system to be determined for a range of climatic and load conditions.

DP 9459-2 is currently under consideration by the committee and is of primary relevance to SWH testing in South Africa. It represents a compromise between the European Community's CSTG recommended (short-term) approach and the Australian (long-term) approach with a qualification test to determine the degree of mixing of the solar component and auxiliary heated component in the storage tank, and hence whether to use the former or the latter approach.

DP 9459-4 has been circulated for comment and has been approved together with ISO DP 9450: Part 1.

SUMMARY OF SWH FINDINGS

The research has confirmed that: (i) the usefulness of the present South African SWH thermal performance testing procedure is limited; (ii) it lacks a theoretical basis and has poor reliability; (iii) it does not enjoy the confidence of the South African industry; (iv) the existing SABS testing facility is relatively old and the instrumentation could require recalibration and/or replacement; and (v) there is currently no dynamic group of researchers and standards workers to pursue a vigorous SWH research and standards programme in South Africa.

The review of internationally accepted standards and test procedures has confirmed the following:

(i) The three significant approaches for standards and performance testing of SWH systems are:
  - — the component testing simulation approach and indoor testing approach in the US,
  - — the outdoor input/output approach and day-by-day simulation route recommended by the European CSTG, and
  - — the outdoor input/output monitoring and energy savings prediction approach pursued in Australia.

(ii) The ISO draft standard for performance testing of SWH systems is a compromise solution which relies on either the CSTG or the Australian approach, depending on a criterion relating to the degree of mixing of the solar and auxiliary heated volumes of water in the storage tank.

(iii) In general, new initiatives in SWH standards and testing will focus on:
  - — SWH standards that incorporate a suite of qualification and thermal performance test procedures,
  - — *in situ* testing and random, non-intrusive, follow-up testing to pick up poor quality and/or performance due to inept installation or premature in-service degradation,
  - — the establishment of energy ratings for SWH systems which are comparable to other energy appliances and which are realistic and understandable to manufacturers and consumers, and
  - — the establishment of standards for documentation.

Institutional considerations for SWH standards and testing in SA include:
(i) For standards and a national solar testing facility to be effective, they must be motivated from within the solar industry and supported by the NEC.
(ii) An effective initiative would require a long-term commitment by the industry, SABS and NEC.
(iii) Performance and qualification test procedures must be adopted as SABS standards.
(iv) Compatibility with international procedures is preferred.
(v) A national solar testing facility could provide a valuable role of consolidating solar-related testing, research, development, and education.

Specific conclusions relating to SWH are:

(i) There are advantages of implementing a standards test procedure
  - which can provide useful information about long-term performance of SWH systems in different climatic conditions,
  - which is reliable and fair,
  - which can be applied to a wide range of SWH systems, and
  - which is in line with major international test procedures.

(ii) SWH performance testing should be affordable to the local industry and therefore within the present testing capabilities of the SABS at moderate additional expense.

(iii) Based on the research findings and the response of the SABS and industry and subject to qualifications arising out of two areas of research, the CSTG recommendations for short-term performance testing and day-by-day simulation are the most suitable as a standard for implementation in South Africa.

(iv) The upgrading of the existing SABS test facility and employment of a motivated technician under EDRC direction presents the quickest and most effective mechanism for setting in motion the implementation of a revised testing approach in South Africa.

(v) As emphasised by industry representatives, the future of SWH standards and testing will largely depend on (a) the calibre and resourcefulness of the technician/researcher employed for this initial phase of SWH testing, (b) the support and direction of the preliminary research by EDRC, and (c) the co-operation and support of all interested parties.

PHOTOVOLTAICS

In reviewing the international status of standards and testing for photovoltaic systems, the distinct contrasts in the nature and scale of the industry as compared to SWH are highlighted. PV modules are "high technology" products manufactured by a limited number of large corporations in a capital-intensive, highly automated and standardised manner. The product variety is limited and a limited number of makes and types of PV module are available internationally at any time. Currently the performance and quality of complete PV systems rather than PV modules represent the greatest source of uncertainty and concern within the industry in South Africa.

The only effective international testing facility for PV modules is the European Solar Testing Installation (ESTI) at the European Joint Research Centre at Ispra, Italy. ESTI follows test procedures set out in ESTI Specification No. 503 (Version 2.1, May 1990) for crystalline silicon PV modules. Standards and test procedures for thin-film and amorphous PV modules are in the process of being drafted. The Solar Energy Research Institute (SERI) has produced interim qualification test procedures and ESTI is likely to release a specification for thin-film modules in 1991 (ESTI Spec. No. 701). Testing of thin-film devices is intrinsically more awkward than crystalline modules due to (i) their non-linear response to irradiation and cell temperature and (ii) their transient and non-linear time response over both the short-term and longer term.

ESTI Specification No. 503 emphasises module durability and includes the following tests on a sample of eight modules of the type under test: visual inspection, performance at standard test conditions, insulation test, measurement of Normal Operating Cell Temperature (NOCT), performance at NOCT, performance at low irradiance, outdoor exposure, hot spot endurance test, ultra-violet exposure, thermal cycling, humidity freeze test, damp heat, robustness of terminals, twist test, mechanical load, and hail resistance.

Standards testing of PV module performance is not simple. It requires control and measurement of primary determinants (i) total irradiance, (ii) spectral irradiance, and (iii) cell temperature, in addition to secondary factors such as (iv) uniformity of irradiance, (v) temporal stability of the irradiance, and (vi) the directionality of the irradiance.

The measurement and control of spectral irradiance poses particularly difficult problems for PV module testing. It is vital to account for the spectral selectivity of modules' response to irradiance. In practice this is achieved by (i) controlling the test irradiance so that it conforms to a specified standard spectral distribution, (ii) using an intermediate reference device of known spectral response which matches that of the module under test, and then (iii) calibrating the reference device accurately under strict spectrally controlled conditions which may not be suitable for testing the module. Temperature control is relatively easily controlled for indoor pulsed irradiation but less so for outdoor testing.

While full standards testing is important, testing module performance for quality control and under local operating conditions is also important to determine consistent quality and the deviation of the performance from standard test conditions (STC) due to spectral variations and other location-specific operating conditions. Variations in the efficiency from STC specifications of up to 18% and 35% have been reported for crystalline modules and thin-film modules respectively(9).

EDRC research has revealed that the preparation of SABS standard specifications for PV modules is not an immediate priority; the ESTI Specification No. 503 for crystalline modules, and the draft ESTI specification for thin-film modules are applicable and adequate for the purposes of module specifications in South Africa. It would therefore be inappropriate for South Africa to consider the establishment of a full PV module qualification and performance testing infrastructure due to the high cost of test equipment, the limited product variety which is intrinsic to the PV industry, and the fact that excellent international testing facilities are available at ESTI, Ispra.

Nevertheless, general and project-specific engineering specifications for supply and installation projects for PV systems are necessary to establish standards of engineering and project management within the PV industry in South Africa. To this end EDRC has prepared a draft specification for small domestic energy PV systems(10) and is developing specifications for larger systems in collaboration with the PV Industries Association (PVIA) affiliated to SESSA.

To facilitate the implementation of these standards and to improved design, module performance testing for quality control and module testing under local operating conditions are important. These levels of module testing are recognised by the SABS, NEC and industry as valuable services to establish levels of confidence in the actual performance of PV modules in South Africa. Despite general acceptance, these levels of testing of PV modules currently enjoy a lower priority than PV systems testing by industry representatives.

The 1991 EDRC remote area power supply (RAPS) research programme and the ESKOM Engineering Investigations facilities will begin to provide a non-commercial PV system evaluation service to the PV industry and potential users in South Africa and in addition fulfil a long-term monitoring function for PV systems.

CONCLUSIONS

Based on the thorough process of consultation and dialogue with the interested parties involved in SWH, the essential thrust of the EDRC recommendations for SWH standards and testing have been accepted and are being implemented.

The national SWH standard specification, SABS 1307-1980, is being redrafted in two parts, to cover qualification and thermal performance standards for SWH systems, by adopting the short-term testing procedure recommended by the European CSTG (as incorporated in ISO DP 9459-2).

The SABS has made a commitment to upgrade the existing SABS SWH test facility to CSTG/ISO specifications and assigned an engineer to implement the procurement, installation and commissioning of the upgraded SABS facility with technical and theoretical support from EDRC.

The EDRC has undertaken to supervise follow-up investigations by the SABS at this upgraded facility to investigate practical limitations of the CSTG/ISO approach for South African SWH systems.

The essential recommendations for PV testing in South Africa are differentiated into testing considerations for PV systems and PV modules, based on the response to the preliminary findings and proposals presented to the NEC, SABS, ESKOM and industry representatives.

In the case of PV systems the recommendations are for:

(i) the establishing of a non-commercial PV systems testing capability at the EDRC in consultation with ESKOM, as a component of the NEC/EDRC RAPS research programme, and

(ii) the monitoring of energy performance of PV systems based on (a) guidelines on monitoring aims and methods, (b) a review and analysis of past experience, (c) co-operation with ESKOM and other interested parties, (d) identified monitoring sites, and (e) methods and equipment with emphasis on short-term system tests.

In the case of PV modules:

(i) The drafting of SABS standards for PV modules is not necessary; the existing ESTI specifications for crystalline modules and draft specifications for thin-film modules are sufficient; compliance with these should be required in all project specifications for PV systems in South Africa.

(ii) The full testing of novel PV modules to ESTI specifications should be performed at ESTI, Ispra.

(iii) The testing of PV modules for (a) quality control and (b) for performance under local conditions are currently not viewed as priorities; these two important levels of module testing should be re-evaluated periodically.

Finally, although the establishment of a national solar testing facility is not currently justified, the recommendation remains that the costs and benefits of the establishing and independent national testing facility be re-evaluated periodically in terms of the perceived benefits, including (i) serving as a national focus for solar testing and research, (ii) providing theoretical and analytical support to the SABS and the SABS standards programme, (iii) conducting research and development activities in support of the SWH and PV industry, (iv) co-ordinating solar research in South Africa, (v) maintaining representation of South African solar interests in international standards (ISO) and research forums, (vi) rationalising the use of resources, i.e. sharing of instrumentation, personnel, skills and administrative overheads, and (vii) providing or supporting teaching and training programmes for tertiary education at universities and technikons or in-service training for industry.

Overall the project has served to establish the current (1990/1) status of solar standards and testing for SWH and PV in South Africa and abroad. In addition, the research process provided a valuable mechanism to inform the relevant interest groups (SWH and PV industries, CSIR, SABS, NEC and ESKOM) and to stimulate local debate. The conclusions and recommendations provide clear guidelines for the implementation of measures to elevate the existing solar standards and testing infrastructure in South Africa to a level of competence which will enable more meaningful support to the industry and also lay the foundations for the development of more comprehensive standards and testing resources.

ACKNOWLEDGEMENTS

The support of the National Energy Council for this research is hereby acknowledged.

NOMENCLATURE

Q : thermal energy output (MJ)

H : global solar irradiation incident on the plane of the collector (MJ/m^2)

$\mathbf{T}_{a,day}$: daily average ambient air temperature (K)

$\mathbf{T}_c$: inlet water temperature (K)

$\alpha_1, \alpha_2, \alpha_3$: coefficients of characteristic

$\mathbf{V}_s$: volume of storage tank (l)

$\mathbf{V}_{aux}$: volume of water heated by auxiliary heater (l)

$\mathbf{U}_s$: storage tank heat loss coefficient (W/K)

REFERENCES

(1) CHINNERY D N W (1971). Solar water heating in South Africa. NBRI Bulletin 44, CSIR Research Report 248.

(2) MCLEAN D I (1979). Performance testing of solar water heating equipment. NBRI Report No. R/BOU 618, CSIR.

(3) SOUTH AFRICAN BUREAU OF STANDARDS (1980). Standard specification for collectors for solar water heaters. SABS 1307-1980.

(4) EBERHARD A A (1991). Assessing the cost-competitiveness of photovoltaics: experience in South Africa. WEC paper prepared for "Seminar on solar power systems", Alushta, USSR.

(5) MORRIS G J and COWAN W D (1991). Solar testing in South Africa — Phase One. NEC Draft Final Report, Energy for Development Research Centre, University of Cape Town.

(6) MORRISON G (1990). Personal communication.

(7) ARANOVITCH E, GILLIAERT D, GILLETT W B and BATES J E (1989). Recommendations for performance and durability tests of solar collectors and water heating systems. Commission of European Communities.

(8) BOURGES B, RABL A, LEIDE B, CARVALHO M J and COLLARES-PEREIRA M (1989). Solar water heater tests: measurement errors and consequences. Centre d'Energetique, Ecole des Mines de Paris.

(9) BEYER U, DIETRICH B, POTBROCK R and LOFTI A (1990). Solar modules tested at Kobern-Gondorf. *Modern Power Systems,* Vol.10 No.11, November, pp.81-85.

(10) MORRIS G J (1990). Appendix E: General technical specification for small PV systems, design sizing and costing of RAPS. Draft Final Report, Energy for Development Research Centre, University of Cape Town.

DETAILS OF AUTHORS

DUTKIEWICZ R K
Pr Eng, PhD, FIMechE, Hon. F(SA)IMechE, MBIM, MIProdE, FInstE, CEng
Professor of Applied Energy and Director, Energy Research Institute, University of Cape Town, P O Box 33, Plumstead 7800, South Africa
Tel: (021) 705 0120, Fax: (021) 705 6266

Graduated BSc (Eng) and MSc (Eng) at the University of the Witwatersrand. Obtained a PhD at Cambridge University for research work in heat transfer in nuclear reactors.

Design engineer for the Atomic Energy Division for GEC in the United Kingdom. Returned to South Africa to become Head of Research for ESKOM. Promoted to Assistant Chief Engineer and later Manager (System Planning). Joined U.C.T. as Professor in Mechanical Engineering. Started the Energy Research Institute of which he is currently the Director.

EBERHARD A A
BSc (Chem Eng) (Cape Town), BA (SA), PhD (Edinburgh)
Head, Energy for Development Research Centre, Energy Research Institute, University of Cape Town, Private Bag, Rondebosch 7700, South Africa
Tel: (021) 650 2827, Fax: (021) 650 2830

Anton Eberhard joined the Energy Research Institute at the University of Cape Town in 1983, having previously worked as a research and project engineer in industry and as a technical manager of a rural development project. His doctoral thesis, on Technological Change and Rural Development, was completed in 1982 at the University of Edinburgh. Dr Eberhard has initiated and led numerous projects relating to energy problems in underdeveloped areas, and has published a wealth of material on the subject. He currently heads the Energy for Development Research Centre.

MORRIS G J
BSc (Mech Eng) (Cape Town), MSc (Energy Studies) (Cape Town)

Principal Research Officer, Energy for Development Research Centre, Energy Research Institute, Private Bag, Rondebosch 7700, South Africa
Tel: (021) 650 2824, Fax: (021) 650 2830

Glynn Morris graduated from U.C.T. with project interests in solar cookers and photovoltaic (PV) water pumping. He worked at JCI Head Office, for gold mines in the Transvaal and Orange Free State, and later for Du Toit & Van der Vyver, consulting engineers, where he focused on energy recovery in the milling industry and thermal performance of wine cellars. His MSc research investigated the technical and economic performance of diesel and PV energy systems for off-grid power supply. He was appointed at the EDRC in 1989 and is continuing research in remote area power supply (RAPS). He has been living in a solar-powered home for the past four years.

VENTER G P N
BSc (U.P.), MSc (U.P.), PhD (Physics) (U.P.)
Group Executive: Electrical Energy, Energy Efficiency and Decision Support, National Energy Council, Private Bag X03, Lynnwood Ridge 0040, South Africa
Tel: (012) 348 9564/5/6, Telex: 320063 SA, Fax: (012) 348 9676

Gert P N Venter obtained his BSc and MSc degrees in 1965 and 1968 respectively and a Doctorate in Physics in 1971 from the University of Pretoria. In the 1970's he studied at the Goethe University in Frankfurt on an exchange fellowship, at the Von Karman Institute of Fluid Dynamics in Brussels and at the Colorado State University's Civil Engineering Department in the United States.

He joined the CSIR's Air Pollution Research in 1966, and was appointed its head in 1976. In 1981 he was appointed manager of the Foundation for Research Development's National Programme for Energy Research, with parallel responsibility for a while for the National Micro-Electronics Research Programme. Apart from his activities on many advisory bodies for energy-related matters, he serves as Deputy Chairman on the Minister of Health and Welfare's National Air Pollution Advisory Committee, which was instituted in terms of the Air Pollution Prevention Act (No. 45) of 1965.

FORTHCOMING SOUTHERN AFRICAN ENERGY CONFERENCES: 1991 AND 1992

1991

OCTOBER 1991

22-24 INTERNATIONAL SEMINAR AND WORKSHOP ON ENVIRONMENTAL WASTE MANAGEMENT TECHNOLOGY AND EQUIPMENT EXHIBITION
Johannesburg, South Africa
Enquiries: Seminar Co-ordinators, P O Box 93395, Yeoville, South Africa

27-30 CONFERENCE ON CATALYSIS AND CATALYTIC PROCESSING Golden Gate, South Africa
Org.: Catalysis Society of S.A.
Enquiries: Conference Organisers, Department of Chemistry, University of the Witwatersrand, P O Wits, Johannesburg 2050, South Africa

28-29 SOUTHERN AFRICAN INTERNATIONAL CONFERENCE ON ENVIRONMENTAL MANAGEMENT Somerset West, South Africa
Enquiries re. Registration: Mr Jonathon Hanks, SAICEM, c/o Eskom, P O Box 1091, Johannesburg 2000, South Africa
Tel: (011) 800 5528, Fax: (011) 800 4360

NOVEMBER 1991

14-15 AIR POLLUTION AND THE ENVIRONMENT Durban, South Africa
Enquiries: Chairman, Natal Branch, N.A.C.A., 13 Clarendon Drive, Durban North 4051, South Africa
Tel: (031) 838 638 or (011) 728 2418

1992

MARCH 1992

8-11 6TH INTERNATIONAL FERROALLOYS CONGRESS, Cape Town, South Africa
Enquiries: Infacon 6 Congress Secretariat, Mintek, Private Bag X3015, Randburg 2125, South Africa
Tel: (011) 793 3511, Fax: (011) 793 2413

APRIL 1992

27-30 E-I '92 CONFERENCE: ELECTRICITY "BEYOND THE GRID" Halfway House, South Africa
Enquiries: Ms L du Toit, E-I '92 Conference, Private Bag X40175, Cleveland 2022, South Africa
Tel: (011) 626 3440 Ext. 2038, Telex: 4-28850 SA, Fax: (011) 626 3440 Ext. 2368

SEPTEMBER 1992

15-17 TRIBOLOGY '92 Pretoria, South Africa
Enquiries: The Conference Co-ordinator: Mrs Toy Bester, LGI Short Courses, P O Box 30536, Sunnyside 0132, South Africa

---

RECENT ENERGY PUBLICATIONS*

Energy for Development

DIAB R D	Wind energy climatology for the Transvaal (Phase I) and the OFS (Phase II). National Energy Council, July 1991. Ref. No. NE/14/4/1/5
BORCHERS M *et al.*	Energy survey of Namaqualand Townships. National Energy Council, August 1991. Ref. No. NE 14/6/3/ (2)
MORRIS G J *et al.*	Solar testing in South Africa (Phase I). National Energy Council, August 1991. Ref. No. NE 14/3/1/7
MORRIS G J *et al.*	Design, sizing and costing of remote area power supply systems. National Energy Council, August 1991. Ref. No. NE 14/3/1/6
PURCELL C	Battery performance characteristics of stand-alone PV systems. National Energy Council, June 1991. Ref. No. EHE 9
HENDRICKS G J	Solar powered pump. National Energy Council, August 1991. Ref. No. EHE 8
GOSNELL R	Demonstration and evaluation of a PV-powered pump at Sondela, KwaZulu. National Energy Council, August 1991. Ref. No. ETA 3
SMIT J J *et al.*	Ontwikkeling van 'n wisselrigter met 'n hoë-frekwensiekring vir aanwending in hernubare energiestelsels. National Energy Council, July 1991. Ref. No. NE 14/3/1/4
VAN SCHOOR C J	Energy provision to the Lower Orange River Border area. National Energy Council, April 1991. Ref. No. NE 14/6/7

Transport Energy

MYBURGH I S	The suitability of a number of lubricating oils for use in a "diesanol" fuelled engine. National Energy Council, June 1991. Ref. No. EVB 9
MYBURGH I S	Performance evaluation of a Brazilian AE 4.2346 engine. National Energy Council, June 1991. Ref. No. EBB 35

Coal

JACOBS R	Die geologie van Ermelomyne en die invloed daarvan op praktiese mynprobleme. National Energy Council, May 1991. Ref. No. ESA 10
CLARK D	The identification of the most viable smokeless fuel. National Energy Council, May 1991. Ref. No. ESL 2
GREIG G E	A preliminary comparative study of combustion characteristics of gel filled tyres. National Energy Council, May 1991. Ref. No. 7330112028
IPC (PTY) LTD	Coal-bed methane resource development. National Energy Council, July 1991. Ref. No. 733111007
BERGH C E	Die verwantskap tussen die petrografiese eienskappe en die degradasie en maalbaarheidseienskappe van steenkool. National Energy Council, August 1991. Ref. No. ESC 12

Energy Efficiency

ARMSTRONG N N and BOWDEN R S	Comparison of boiler/steam generating sets with alternative electricity generation equipment. National Energy Council, July 1991.	
GREYVENSTEIN G P and COETZEE J L	Die markpotensiaal van hittepompe in Suid-Afrika. National Energy Council, August 1991. Ref. No. EVD 17	R50,00
ANDERSSEN J J and DU TOIT L P	The analysis of the potential for demand-side management by municipalities with Cape Town as case study. National Energy Council, August 1991. Ref. No. EVD 14	R50,00
VAN EEDEN A	Alternative communication approaches to promote effective and efficient energy use in the domestic sector. National Energy Council, August 1991. Ref. No. 179/89	R45,00
GRANVILLE A and FREEMAN M J	Review and analysis of energy use in the metal industries — Part I: Ferroalloys. National Energy Council, August 1991. Ref. No. 7330311010	
UKEN E-A and BEUTE N	The evaluation of the energy and demand efficiency of the major domestic electric equipment. National Energy Council, August 1991. Ref. No. EVD 25	

Integrated Energy Planning

VERMEULEN P J	Evaluation of a long-term model for forecasting energy demand in South Africa with relation to the coupling to current models such as MARKAL. National Energy Council, August 1991. Ref. No. EEV 1
DUTKIEWICZ R K	Energy Profile: Zimbabwe. National Energy Council, July 1991. Ref. No. 7330411001
DUTKIEWICZ R K	Energy Profile: Zambia. National Energy Council, July 1991. Ref. No. 7330411001
HENDRICKS G J	New energy status report: Hydrogen. National Energy Council, May 1991. Ref. No. 7330010003/7330411002
DOPPEGIETER J J *et al.*	Energy Futures 1991. National Energy Council, August 1991. Ref. No. EEV 2

Electricity

HEINICHEN D	Feasibility study into local production of polymeric insulating materials for high voltage equipment. National Energy Council, April 1991. Ref. No. 166/89

* These are Final Reports for NEC-funded projects accepted by the NEC since 1 April 1991. The publications can be ordered from: Mrs W Gilsen, National Energy Council, Private Bag X03, Lynnwood Ridge 0040, South Africa (Tel: (012) 348 9564/5/6). Prices are quoted where known, otherwise they may be obtained from Mrs Gilsen at the National Energy Council.

JOURNAL OF ENERGY R & D IN SOUTHERN AFRICA

INFORMATION FOR AUTHORS

Contributions to the *Journal of Energy R & D in Southern Africa* from those with specialist knowledge in the energy research field are welcomed.

1. All contributions should be submitted in English.
2. Only original work will be accepted and copyright in published papers will be vested in the publisher.
3. The suggested average length for articles and research notes is 4000 to 6000 words, and for book reviews 1200 to 1800 words.
4. The contribution and references should be typed double-spaced with a wide left-hand margin and single-sided using one of the available word processor packages listed at the end. The name and version of the word processor package used must be indicated on the floppy disk. Illustrations, photographs and diagrams should be submitted on separate sheets.
5. Tables should be numbered consecutively in Arabic numberals and given a suitable caption.
6. All graphs, diagrams and other drawings should be referred to as Figures. These should be numbered consecutively in Arabic numerals and placed on separate sheets at the end of the manuscript. Their position should be indicated in the text. All illustrations must have captions, which should be typed on a separate sheet. Graphs, diagrams etc should be printed with a laser printer, using the high quality option. If possible, all graphs should be produced with Harvard Graphics.
7. The format for references should follow that as for footnotes where a number indicates the reference, as shown below:

   Louw (2) states that . . .

   Full references for books and journals must appear at the end of the ariticle in numerical sequence. For references to books, all relevant information should be provided, that is author(s) surname and initial(s), full title (and subtitle, where applicable), publisher, place of publication, date of publication, and page reference. For periodical references, the author(s) surname and initial(s) must be provided, as well as the full title and subtitle (if applicable) of the article and the periodical, volume number, part, date, and page reference. Numbers identifying all references at the end of the contribution should be enclosed in brackets.
8. Standard International (SI) units must be used.
9. All mathematical expressions should be typewritten. Greek letters and other symbols not available on the typewriter should be carefully inserted in ink. A list of symbols marked for the use of the Editor, if not included in the body of the text, should accompany the contribution on a separate page. A nomenclature defining symbols must be included. Numbers identifying mathematical expressions should be enclosed in parentheses. All tables and mathematical expressions should be arranged in such a way that they fit into a single column when set in type. All table columns should have an explanatory heading. Equations that might extend beyond the width of one column should be rephrased to go on two or more lines within column width.
10. Line drawings (not photocopies) and accompanying lettering should be of a sufficient size to allow for reduction if necessary. Photographs of equipment must be glossy prints and should be used sparingly.
11. The body of the contribution should be preceded by an Abstract not exceeding 500 words, which should be a résumé of its essential contents, including the conclusions. Below the Abstract the maximum of four Keywords should be included which reflect the entries the author(s) would like to see in an index. The Keywords may consist of more than one word, but the entire concept should not be more than 30 characters long, including spaces.
12. No contribution or figures will be returned following publication unless requested by the author(s) at the time of its original submission.
13. In a covering letter, the author(s) must state that the contribution has not been published, is not being published or being considered for publication elsewhere, and will not be submitted for publication elsewhere unless rejected by the Editor of the *Journal of Energy R & D in Southern Africa* or withdrawn by the author(s).
14. Authors must supply the following personal information: surname, initials, address, qualifications, occupation and/or employment.
15. Authors whose contributions are accepted for publication will receive a free copy of the issue and 5 copies of their contribution.
16. Neither the Editor nor the Publisher accept responsibility for the opinions or viewpoints expressed, or for the correctness of facts and figures.
17. The Editor reserves the right to make editorial changes to all contributions.
18. All contributions and enquiries should be addressed to: Editor, Journal of Energy R & D in Southern Africa, Energy Research Institute, University of Cape Town, P.O. Box 33, Plumstead 7800, South Africa.

Contributions must be submitted on a 5¼ inch floppy disk and use must be made of one of the following word processor packages:

Multimate
Microsoft Word
PC-Write
PFS: Professional
PFS: Write
Wordperfect
Wordstar
XyWrite

The floppy disk must be adequately packed for postage.