Chapter 12.2

Other forms of energy

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SCOPE

This section is intended to provide engineers, settlement planners and developers with information about energy sources and applications other than grid electricity. The scope of application includes both urban and rural settlements.

Important energy sources and applications in this context include

- energy efficient building design;
- the supply and use of hydrocarbon fuels (paraffin, LPG, coal, wood); and
- solar energy applications (in particular, solar water heating and the use of solar photovoltaic systems for off-grid electricity supply).

Guidelines are provided on the costs, applications, environmental and safety aspects, and relevant planning considerations associated with these energy sources and technologies.

Background information and references are also provided for other renewable energy technologies which are less widely used in South Africa, but which might be considered by planners in specific circumstances: wind turbines for electricity generation, small-scale hydropower, biogas digesters, extraction of landfill gas and solar-thermal electricity generation.

Some of the practices addressed in this section are still under development in South Africa and not yet well standardised. These topics are therefore addressed in a more descriptive and lengthy way. Improved concise guidelines should be possible in future revisions, as the practices become more widely established.

INTRODUCTION

The supply of grid electricity is the foremost energy infrastructure concern for planners, engineers and developers in South African urban settlements.

However, in lower-income urban communities - which include the majority of South Africa's urban population - grid electricity is only one part of energy supply and use. In practice, low-income households continue to use a variety of other energy sources, even when grid electricity is available. It is therefore useful for planners to consider these wider energy needs.

A second reason for considering energy alternatives to grid electricity is that, in dispersed or remote settlements (generally rural), grid electrification can be highly uneconomical. In this situation, decentralised "off-grid" sources of electricity may be preferable. These are nearly always more costly than a normal urban electricity supply, but nonetheless may be cheaper than grid extension and reticulation over long distances with low load densities. Again, electricity is only a part of the energy supply/use equation in such areas, and other fuel use must also be taken into account.

A third reason for examining energy alternatives arises from environmental concerns. Global environmental concerns about reducing pollution and greenhouse gas emissions have led to a greater awareness of the benefits of energy conservation and energy efficiency, as well as to a preference for using renewable energy sources where possible rather than fossil fuels which pollute the environment. Local environmental issues include serious concerns about

- the impact of smoky local indoor/outdoor environments on health;
- fires;
- contamination and poisoning; and
- land degradation caused by pollution from power stations and the over-exploitation of natural vegetation for energy purposes.

PLANNING CONSIDERATIONS

Most of the energy sources and applications treated in this section do not involve the provision of extensive physical infrastructure within settlements. Many of them involve economic and behavioural choices by individual consumers or households. Physical planning issues do arise, but other important consumer-oriented considerations include

- mechanisms to encourage the integration of thermally efficient design in low-cost housing developments;
- suitable distribution channels for commercial fuels, energy-related equipment, and appliances;
- finance and repayment mechanisms;
- social planning, consultation, education and awareness-building; and
- the application of technical, safety and environmental standards.

Relevant planning issues will be noted in each of the sub-sections below. In general, the following broad recommendations could be considered by planners:

- Understand local energy needs, consumption patterns and supply options.
- Recognise that electricity does not address all the energy needs of lower-income communities, and make provision for the optimal use of other energy sources.
- Ensure consumers are able to make well-informed choices about their energy options, through awareness and education campaigns. Include information about costs, health and safety.
- In physical planning, take account of the orientation and spacing of buildings for good use of passive solar design principles (alongside other factors affecting layout choices, such as security, variety, etc).
- Promote the energy-efficient and cost-saving design of buildings.
- Take account of the environmental impacts of different energy options.

ENERGY CONDITIONS IN SOUTH AFRICA

This section provides a brief overview of household energy consumption patterns in South Africa, the costs and availability of non-electric fuels and renewable energy options, and the distribution of renewable energy resources in South Africa.

Energy consumption patterns in South Africa

Overall, the residential sector accounts for approximately 20% of the energy consumption in SA. The percentage of households with access to grid electricity stood at about 66% in 1997-98 and is steadily increasing. However, in lower-income newly electrified settlements the average levels of electricity consumption per household are quite low - typically 50 to 150 kWh/month in the first few years after electrification (Davis 1995).

There are several reasons for this. Income constraints can make it difficult to afford higher electricity bills, and also difficult to acquire the more expensive energy-intensive electric appliances, such as stoves. Such households may therefore continue using existing cheaper appliances (such as primus stoves), cheaper fuels (such as coal for heating in winter) and non-commercial fuels like fuelwood and dung. Households without any electricity have, of course, to rely on such non-electric fuels and appliances.

"Fuel-switching" is a common phenomenon. It used to be thought that households in Southern Africa and similar developing countries would progressively switch from traditional fuels (e.g. wood) through transitional fuels (e.g. paraffin), then towards the partial use of electricity and finally to almost complete reliance on electricity. This may turn out to be a valid long-term trend, but in the medium term fuel-switching occurs in both directions, depending largely on economic circumstances and changes in prices. Multiple fuel use is likely to continue to be the norm for lower-income households in South Africa, both urban and rural, electrified and non-electrified.

The proportions of different fuels used tends to vary in different parts of the country, reflecting climatic differences (e.g. cold winters in the interior highveld) and local differences in prices (e.g. cheap coal in proximity to coalfields). Figure 12.2.1 illustrates this variation for households in four metropolitan centres.

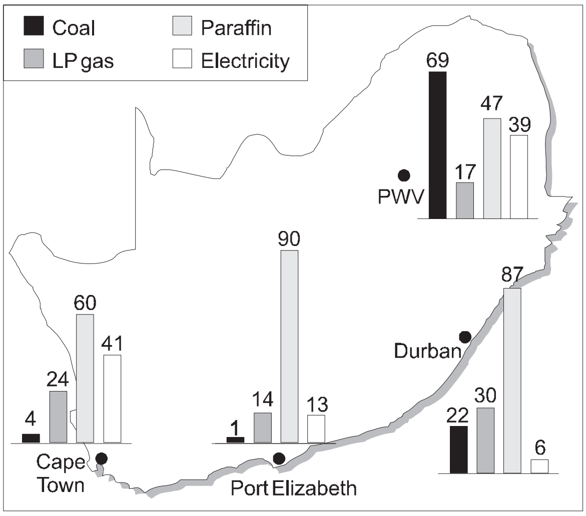

Figure 12.2.1: Percentage of households using different energy carriers, in four metropolitan areas
Note: Percentages total more than 100 %, indicating multiple fuel use by households.
Source: Williams 1993

Rural households make extensive use of wood and other biomass (crop residues, dung, etc) for cooking and heating. However, the use of wood also occurs in urban and peri-urban settlements. When wood can be collected "free" - although often involving considerable labour - it may be the most economically attractive or indeed the only energy option for low-income households. However, wood is also increasingly a commercial fuel, especially in areas of fuelwood scarcity.

Comparative energy costs

It is difficult to give accurate costs for the "useful" energy obtained from different fuel-appliance combinations, because the efficiency of the energy utilisation can vary. Table 12.2.1 provides estimated comparative costs for (a) the energy content and (b)

Table 12.2.1: Comparative consumer costs of different fuels for domestic cooking and heating (1997 prices)

	UNIT COST OF FUEL (UNITS AS SHOWN)		COST OF ENERGY CONTENT (CENTS/kWh)		ASSUMED EFFICIENCY OF UTILISATION	COST OF USEFUL ENERGY (CENTS/kWh)	
	GAUTENG	CAPE TOWN	GAUTENG	CAPE TOWN		GAUTENG	CAPE TOWN
COOKING							
Grid electricity	20 c/kWh	25 c/kWh	20	25	65%	31	38
Coal	26 c/kg	55 c/kg	4	8	15%	25	53
Paraffin	220 c/litre	168 c/litre	21	16	35%	61	47
LP gas	395 c/kg	321 c/kg	29	24	45%	64	52
Wood (commercial)	21 c/kg	45 c/kg	4	9	15%	28	60
COMBINED COOKING AND SPACE-HEAING							
Grid electricity	20 c/kWh	25 c/kWh	20	25	95%	21	26
Coal	26 c/kg	55 c/kg	4	8	45%	8	18
WATER HEATING							
Grid electricity	20 c/kWh	25 c/kWh	20	25	70%	29	36
LP gas	395 c/kg	321 c/kg	29	24	90%	32	26

Sources: Prices from Graham (1997). Efficiencies adapted from Fecher (1998), Gentles (1993), Lawrence et al (1993), Thorne 1995. Fuel prices can be higher from small traders and in rural areas.

the useful energy derived from different fuels, assuming the efficiencies shown, and based on typical 1997 prices for Gauteng and Cape Town.

Thermal energy services (cooking, heating, cooling) consume the largest amounts of household energy and are therefore a major concern for household choices about which fuels and appliances to use. As mentioned, the cost of the appliances themselves can be a deciding factor as well.

In general, poorer households spend a larger proportion of their income on energy services than more affluent households. They may also use less efficient appliances and pay more for the fuels they use, for example, by buying fuels like paraffin in small quantities. The use of candles for lighting is widespread in non-electrified households, but also in low-income electrified households. Households without an electricity supply often spend a large portion (e.g. one-third) of their overall energy budgets on dry-cell batteries for radios, etc (Hofmeyr 1994).

For lighting and media appliances (radio, TV, etc) small solar photovoltaic systems can provide a cost-effective alternative to paraffin lamps, candles and dry-cell or rechargeable batteries. The capital cost is higher, but life-cycle costs are lower for equivalent services. Table 12.2.2 gives examples of comparative lighting costs (using 1992 relative prices) for equivalent lighting levels.

Table 12.2.2: Comparative energy costs for 1 000 lumen-hours of lighting

Candles	R2,50
Paraffin lamp (wick)	R0,40
Pressurised paraffin lamp	R0,10
LP gas	R0,20
Solar home system	R0,05
Grid electricity	R0,002

Source: Cowan et al (1992)

For more detailed comparisons of fuel and appliance costs, variations in different parts of the country, life-cycle costs of fuel-appliance combinations and comparative costs of off-grid electricity options, see Energy & Development Group (1997), Graham (1997) and Cowan et al (1992).

THE DISTRIBUTION OF RENEWABLE ENERGY RESOURCES IN SOUTH AFRICA

Solar energy resources

Solar energy is generally abundant in South Africa, with a daily average of between 4 500 Wh (Durban) and 6 400 Wh (Upington) per square metre per day. These are values for solar irradiation measured on a horizontal surface (see Figure 12.2.2). For purposes of collecting solar energy, the solar collector is usually tilted to receive more energy throughout the year. Table 12.2.3 includes solar irradiation values for tilted surfaces. For many solar energy applications, a fixed-tilt angle is chosen which maximises the solar irradiation received during the "worst" solar month of the year, as shown in Table 12.2.3.

Solar radiation data for approximately 100 weather stations, and detailed data for the ten major South African measuring sites shown in Table 12.2.3, can be obtained in Eberhard (1990) and Cowan et al (1992); the latter source also includes software for calculating solar irradiation on north-facing tilted surfaces at different times of year, hour by hour.

For some purposes (e.g. in building design) it is useful to know the solar irradiation on vertical surfaces. Examples are provided in Table 12.2.4. Monthly values for all major weather stations are obtainable in Cowan et al (1992) and Eberhard (1990).

Table 12.2.4: Solar irradiation on vertical north-facing surfaces

MONTHLY MEAN IRRADIATION, IN Wh PER SQUARE METRE PER DAY		
Location	Maximum month	Minimum month
Bloemfontein	6 115 (Jul)	2 045 (Dec)
Cape Town	4 929 (Apr)	2 387 (Dec)
Durban	4 972 (Jun)	1 837 (Dec)
Pretoria	5 696 (Jun)	1 697 (Dec)

Source: Cowan et al (1992)

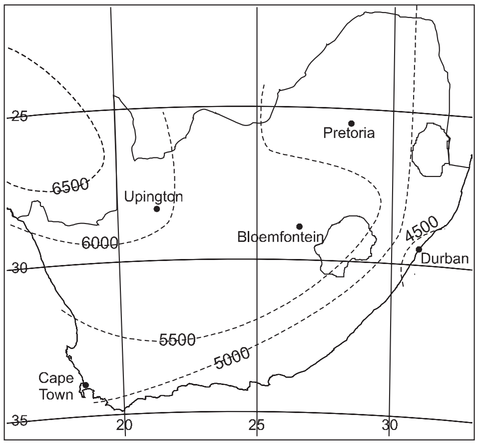

Figure 12.2.2: Annual mean solar irradiation on a horizontal surface (in Wh per square metre per day)

Source: Eberhard (1990)

Table 12.2.3: Solar irradiation values, from long-term measurements

LOCATION	MONTHLY MEAN SOLAR IRRADIATION, IN WH PER SQUARE METRE PER DAY				
	ON A HORIZONTAL SURFACE		ON A TILTED SURFACE (SEE NOTE)		TILT ANGLE (DEGREES)
	BEST MONTH	WORST MONTH	BEST MONTH	WORST MONTH	
Alexander Bay	8 364	3 555	6 732	6 164	45
Bloemfontein	8 096	3 747	7 031	6 318	35
Cape Town	7 956	2 390	6 275	4 702	60
Durban	5 740	3 033	5 488	4 759	35
Grootfontein	8 238	3 403	6 917	6 278	45
Nelspruit	6 045	3 919	5 765	5 108	20
Port Elizabeth	7 216	2 655	5 856	5 260	50
Pretoria	6 908	3 908	6 668	5 652	30
Roodeplaat	6 963	3 884	6 552	5 896	30
Upington	8 390	3 824	7 370	6 466	40

Source: Cowan et al (1992)
Note: A fixed north-facing tilt, in degrees from horizontal, which maximises solar irradiation for the worst month of the year.

Wind energy resources

Wind-speed measurements for South Africa are available from a large number of measuring stations across the country. However, the majority are agricultural stations and these wind measurements (usually at a height of 2 m and often in sheltered locations) are not always useful for judging wind-energy resources. Wind speeds can vary greatly over short distances in complex terrain. Wind-energy potential is highly sensitive to wind speeds, since doubling the wind speed increases the available power by a factor of eight. Average wind speeds of 6 ms^{-1} or more are favourable for electricity generation from wind, and wind speeds below 4,5 ms^{-1} are usually not viable, except for water pumping. Figure 12.2.3 provides an indication of wind-energy potential in different parts of South Africa. However, accurate site-specific wind assessments are essential to establish the viability of wind generation in a particular location. The most comprehensive source of analysed wind data, including frequency distributions and monthly variations, is Diab (1995).

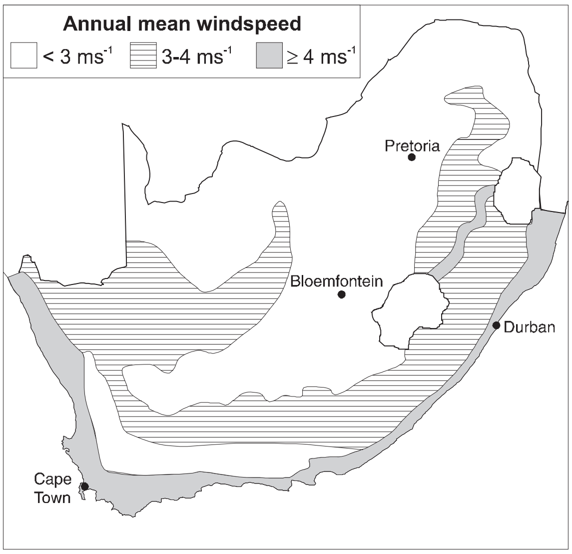

Figure 12.2.3: Annual mean wind speeds (normalised to 10 m height above ground, in ms^{-1})
Source: Adapted from Diab (1995)

Diab (1995) presents wind distribution statistics for 79 stations with hourly wind data. Of these, the following have wind data for at least two years, measured at a height greater than 2 m, and show annual mean wind speeds greater than 4 ms^{-1} (normalised to 10 m above ground level):

> 4,0 to 4,5 ms^{-1}	Alexander Bay, Beaufort West, Cape Town Airport, East London, Hermanus, Port Elizabeth, Stilbaai, Struisbaai, Vrede
> 4,5 to 5,0 ms^{-1}	Berg River, Wingfield
> 5,0 to 5,5 ms^{-1}	Gordons Bay
> 5,5 to 6,0 ms^{-1}	Buffeljagsbaai,Danger Point Die Gruis, Gansbaai
> 6,0 to 6,5 m^{s-1}	—
> 6,5 to 7,0 ms^{-1}	Waenhuiskrans

Other measurements of promising wind speeds, which either come from shorter periods of data or come from stations which were excluded from Diab’s wind distribution statistics (and may not be fully reliable), are:

> 6,0 to 6,5 ms^{-1}	Bird Island, Klippepunt, Saldanha, Thyspunt
> 6,5 to 7,0 ms^{-1}	Cape Infanta, Hluhluwe
> 7,0 to 7,5 ms-1	Cape Recife, Hangklip
> 7,5 to 8,0 ms^{-1}	Seal Island

Hydropower resources

Hydro-power resources in South Africa are even more site-specific than wind. In general, the eastern slopes of the country from the Drakensberg down to the coast are more likely to offer the combination of sufficient water flow and gradient usually needed for viable small-scale hydro-electric installations (see later section on Small Hydropower).

ENERGY-EFFICIENT BUILDING DESIGN

Energy-efficient building design can help to reduce:

- excessive consumption of electricity or other fuels to maintain comfortable working, leisure or sleeping spaces;
- indoor/outdoor pollution; and
- health risks from a polluted or thermally uncomfortable environment.

This section discusses principles of building design, layout and user behaviour which can save energy, reduce costs and contribute to improved living environments. The focus is on information of interest to planners, designers, builders and building owners/occupants in residential areas.

Benefits of energy-efficient buildings

The energy consumption and expenditure required to maintain a comfortable (or in some cases simply bearable) indoor environment can be very significant, across all classes of housing and commercial building types. The potential for energy savings through improved energy-conscious building design can be as much as 70% in some cases. The "passive design" or "solar passive design" of buildings refers to construction/design techniques which

- make better use of natural energy flows (e.g. solar heating in the day, cooling at night);
- use building elements to insulate, capture, store or otherwise control energy flows; and
- reduce the need for "active" energy consumption/management.

Such techniques can be low-cost, long-lasting and offer the following potential benefits:

- lower energy bills for owners/occupants (especially in winter, when the energy bills of poorer households can rise significantly);
- reduced total electricity consumption - winter consumption levels are about 1 600 GWh/month higher than summer (Eskom, 1996);
- reduced electricity peak demand, associated with "cold snaps" (with resultant economic benefits both for electricity generation and the peak national/local distribution capacity required);
- less pollution (and lower health costs); and
- generally, a more pleasant and healthy environment in the home or workplace.

A particular South African health problem is respiratory disease caused by use of coal and wood for indoor cooking and space-heating (Terblanche et al 1993; Van Horen et al 1996). This could be partially alleviated by thermally efficient building design in low-income communities reliant on these fuels for heating.

Both the national electrification programme and the national housing programme present important drivers for improved thermal efficiency in housing:

- As the number of electrified houses increases, electric space-heating has an increasing impact on electricity consumption and winter peak demand (which will lead to more peaked and expensive generation, transmission and distribution).
- The national housing programme represents a unique opportunity to include low-cost thermal improvements which will reduce energy consumption for space-heating; if this opportunity is missed, it could result in long-term cost increases for residents, service providers and society at large (Simmonds 1997).

Guidelines for energy-conscious design

For specific climate zones and building types, it is possible to state relatively concise guidelines. However, the field is complex, and as Holm (1996) warns, over-simplification can lead to inappropriate application.

The approach adopted here is to discuss the principal elements of energy-conscious building design, and to give some indication of possible strategies. For more detailed information, Holm and Viljoen (1996) and Holm (1996) are useful resources. There are also numerous international texts in this field.

The Directorate: Settlement Policy of the Department of Housing (in association with other government departments) is in the process of drafting a set of guidelines for "environmentally sound low-cost housing".

Principal elements in managing indoor environments

Occupational comfort is related to temperature, air flow, lighting, humidity, the level of activity and clothing. The last two parameters are primarily under the control of occupants, and thus not discussed here. The other parameters are often actively managed in large commercial buildings, and to a lesser or greater extent in other buildings such as houses.

Energy-efficient or "passive" building design aims to reduce the active use of energy, and to achieve moderate variations around comfortable mean temperature (and other) conditions, using more economical means.

Figure 12.2.4 illustrates a cross-section through two rooms in a house, to show the main energy flows and parameters that influence the indoor environment.

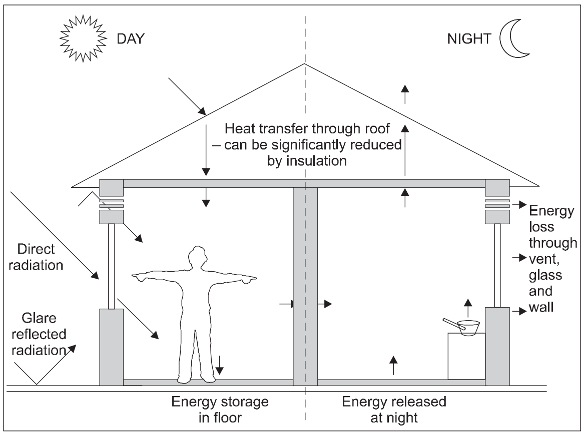

Figure 12.2.4: Principal energy flows in a home

Important elements of the energy flow diagram are:

- *energy source elements* - the sun shining through windows or heating external surfaces, human activity, appliances, heaters etc. in the home;
- *elements that remove energy from a home* - cooler air either flowing through a house or cooling external walls and roof, dark sky acting as a radiation sink at night, an air conditioner; and
- *energy stores within a home* - walls, floors, bodies of water within the home which can either absorb heat energy (helping to keep space temperatures lower) or give energy out (helping to warm a space).

Heat transfer is always from regions of higher temperature to regions of lower temperature. Three heat-transfer mechanisms are important:

- *conduction* through solid structures such as walls and roofing materials, which is highly dependent on the composition and thickness of the material (e.g. the conductivity of steel is a thousand times the conductivity of insulators like glass-fibre quilt);
- *convective* heat transfer, strongly related to air movement (which is enhanced by ventilation, or reduced through the use of multiple barriers or sealed cavities, as in a cavity wall); and
- *radiation*, proportional to the fourth power of the absolute temperature (Kelvin), and thus highly significant at elevated temperatures. Absorption of radiant energy also depends on the reflectivity of surfaces (highly polished surfaces and those painted with light colour paints are able to reflect most solar radiation while dark, rougher surfaces may absorb 95% or more).

Most heat transfer processes (e.g. from the air inside a room, through the wall to the outside) involve all three mechanisms. Tables listing heat transfer and thermal properties of common building materials are readily available (Wentzel et al 1981; Everett 1970; Burberry 1983; Quick II 1998).

Each of the principal building elements is discussed below, with attention given to opportunities for improvement.

Roof

Fifty to seventy percent of the heat loss from a home in winter can be through an uninsulated roof (Simmonds 1997). Furthermore an uninsulated roof will allow excessive heat gain during the day in summer. The addition of a ceiling can reduce space-heating energy bills by more than half and, even for homes with ceilings, the proper use of ceiling insulation can be a further cost-effective intervention in most climatic regions of South Africa (Temm International 1997; Van Wyk and Mathews 1996).

The following points need to be considered:

- Ceiling and insulation materials should be chosen with due consideration of other aspects of the building. There is little sense in adding thick, high-quality insulation to the ceiling of a draughty, thin-walled home. Cardboard or other low-cost insulators will achieve most of the benefits, at a fraction of the cost.
- Where buildings are otherwise thermally efficient, proper installation of thicker insulation with greater resistance to heat transfer is to be preferred.
- A gap of at least a few centimetres should be allowed between the top of the ceiling and the roof, as this will increase the insulation of the entire structure significantly, and allow ventilation.
- Materials of high reflectance and low emissivity (e.g. reflective aluminium-foil products) can also act as useful insulators, where radiation causes significant heat loss or unwanted gain (as in roof spaces).
- Where high thermal gradients occur across relatively thin insulation (e.g. cardboard ceilings) it is important to place a vapour barrier on the warm side of the insulation, to prevent condensation as warm, moist air comes into contact with cold exterior surfaces. Plastic sheeting or reflective aluminium foil is effective, if properly applied and sealed.
- Light colours tend to reflect more light. Heat gain from a roof is difficult to control in summer, so it is sensible to paint roofs a light colour.

Windows

Windows can be significant sources of both heat gain and loss in a home. Thermal performance will depend on size, orientation, shading, air tightness, material used for glazing, the use or absence of moveable insulation such as shutters or curtains, and on whether or not double glazing is used. Heat loss is primarily the result of convection, conduction and longwave radiation, all of which are significantly reduced by glass. Thus, provided the sun is shining, a window can cause heat gain even on a cold day.

- Windows that face east or west are more difficult to shade in summer (with greater potential for overheating). They should thus be kept relatively small, unless the user regulates the shading using moveable shades or other means discussed below.

- South-facing windows will tend to lose more energy than they gain; they are useful if the intention is to cool a space in summer, but will make it cold during winter. They can also be useful to collect diffuse light for work spaces.

CSIR (1997) provides an excellent paper-based method for calculating shadow angles at different orientations and times of the year, and provides helpful hints for controlling sunlight entry into buildings.

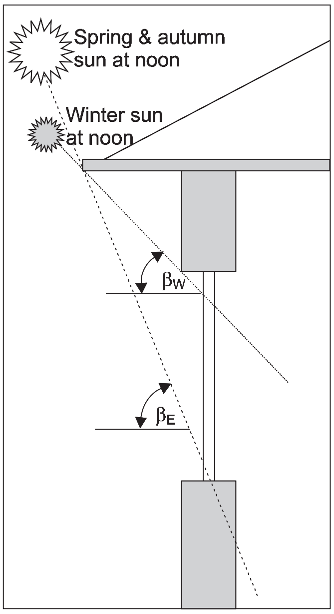

Figure 12.2.5: Shadow angles for north-facing windows
Note: These angles are for maximising winter gain ($\beta_W \geq 66.25^\circ$ - latitude), but avoiding overheating in summer ($\beta_E \leq 90^\circ$ - latitude). Eaves for orientations east or west of north will have to be longer, and it is difficult to avoid excessive solar gain.

Building occupants should manage windows, either opening or closing them to allow ventilation, or drawing curtains at night or in cold weather to minimise heat loss. To retain heat, curtains should be heavy, and/or windows should have close-fitting shutters. On the other hand, interior drapes will tend to absorb heat energy and release much of it into the building. Heat gain can most effectively be reduced using external shutters, louvres or highly reflective interior blinds. More expensive control measures, which are worthwhile in extreme climatic conditions, include double-glazing, adhesive films (which can be retrofitted) and low-emissivity glass.

Walls

Conductivity/insulation: Exterior walls should generally have good thermal insulation properties, to help keep heat out in summer and in during winter. Standard brick or block walls have reasonable thermal properties, especially if a cavity construction is used. Thin (single) brick, fibreboard and especially corrugated iron external walls are inefficient and cold in winter (or hot in summer) and should be insulated (but avoid using dangerously flammable materials).

Even low-cost insulation can reduce winter heat loss in corrugated iron dwellings by 50% (Weggelaar and Mathews 1998). If applied to 700 000 such dwellings in Gauteng, these authors estimate potential energy savings valued at R275-R450 million per year.

Thermal mass High thermal mass (the specific heat capacity x mass of an element) can have a moderating effect on the temperature inside a building. High thermal mass walls exposed to the sun or warm air during the day will warm up slowly (without overheating) and then re-radiate heat into the house overnight, helping to keep the home warm. This is particularly relevant in climates where day-night temperature variations are high (e.g. the highveld and interior regions of the country).

As with windows, north-facing massive uninsulated walls under eaves can be shaded in summer, but exposed to the sun in winter, providing a naturally moderated energy input to the home.

Wall colour: Light colours help to reflect heat. This can reduce overheating of thin, poorly insulated walls exposed to the summer sun.

The Trombe wall is a well-known specialised passive design technology which can be effectively used to warm a house in winter. An external glass pane shields the wall from wind, and significantly reduces convective and long-wave radiation losses, while allowing short-wave radiation from the sun to enter and warm the wall. These walls can also be used to enhance ventilation and facilitate cooling during hot weather, by placing vents that open to the outside near the top of the wall, and fitting temporary insulation on the inner surface. Air heated by the sun rises in the gap between wall and glass and leaves the house, drawing fresh, cooler air into the dwelling.

Other elements with high thermal mass

Floors, massive roof structures (earth or concrete) and specially designed elements such as water-filled structures all have high thermal capacity, and can be used to moderate indoor temperatures. In summer, a house can be fully opened at night, to lose as much heat as possible to the dark sky, and then closed during the day in an effort to keep the heat out and derive the benefit of the pre-cooled walls and floors.

On the other hand, if a building or room is used only for short periods, it may be appropriate to carpet the floors and use insulated walls of a low thermal mass, so that air-conditioning or heating will quickly get the room to the desired temperature without undue energy transfer to walls or floor.

In well-designed buildings, attention should be given to the balance of floor area, effective (exposed) thermal mass and north-facing window area. If window areas are too great for the house's thermal mass, then overheating can occur - even during winter days - and the house will cool down too rapidly at night. Windows that are too small will provide insufficient heat gain. Basic design guidelines are not given here, as appropriate ratios can vary significantly, depending on the thermal properties of different construction materials. Suffice it to say that optimum north-facing window areas are of the order of 10% or more of building floor area (Holm et al nd).

Ventilation

Adequate ventilation is essential to avoid overheating in summer, to avoid damp interiors and, perhaps most importantly, to remove pollutants released by indoor fires and coal stoves, where these are used. It is, however, important that such ventilation be controlled, and to a certain extent directed.

In hot weather, good cross-ventilation can be facilitated by windows or vents on both the leeward and the windward side of buildings. Exit windows should be high, to avoid warmer (lighter) air being trapped above them. Ceiling fans, and especially smaller fans directed as required, can significantly enhance user comfort in hot weather, at a much lower cost than air-conditioning.

Many South African households, however, are over-ventilated in winter, with poorly fitted doors, windows and ceilings. Again, potential savings are significant - in the order of 25% in some simulations performed by Van Wyk and Mathews (1996) on shack-type dwellings. "Weatherisation" - using caulking, weather strips, or even old cloths and cardboard - is a useful strategy.

Where smoky stoves or braziers are used, a direct chimney is better than extensive general ventilation to remove asphyxiating smoke and carbon monoxide. Space-heating efficiency is improved if there is also a specific air-supply vent for the stove/fire - otherwise the combustion draws cold air into the building.

Lighting

Daylight is cheap, provides good colour definition, and tends to have positive effects on people (compared to artificial lighting). Windows and skylights are well known, and work well. Where glare or direct sunlight is not welcome, diffusers or external shading devices can be advantageous. The success of shading devices is strongly dependent on orientation (see above). Excessive summer-heat gain from skylights can be a problem, as external shading is difficult to arrange. More specialised technologies such as solar tubes, and white or translucent reflectors/diffusers placed inside north-facing vertical glazed openings are sometimes useful and should be more widely used.

Humidity

The most important heat loss mechanism for humans is through the evaporation of sweat from the skin. If humidity levels are high, this evaporation is severely impaired, leading to discomfort at high ambient temperatures. Very low humidity leads to excessive dryness and is also undesirable. Reduced humidity levels are difficult to achieve using low-cost passive design features. Mechanical air-conditioning systems are generally used. However, in hot dry climates, air flow over ponds or through screens of wet porous material can be a highly effective method to increase humidity and cool the air.

The external environment

The texture and composition of surface material used around a building can have an important impact:

- Deciduous trees and vines on the sunny sides of a building will naturally adjust to the seasons, providing needed shade in summer, and allowing sunshine to reach the walls and windows in winter.

- Evergreen shrubs and bushes around the south-western to south-eastern borders can help to shelter houses from high winds (e.g. Western Cape) and provide a measure of insulation from cold winter skies in the highveld or interior.

- Low shrubs could be a disadvantage in humid, mild to hot climates, such as in coastal KwaZulu-Natal, where they will tend to obstruct the welcome movement of air. Trees with a high canopy are more desirable.

- Paving, especially on a northern or western aspect will reflect heat against walls and windows, and can add to heat build-up. If the paving is shaded by deciduous plants on a pergola in summer, however, the potential for enhanced heating can be turned to advantage in winter. Grassed areas will tend to be cooler.

- Pergolas and verandas can provide an important buffer zone around a building, especially with potted plants (their high thermal mass and active transpiration tend to cool the environment).

Site and building orientation

Buildings with a longer axis should preferably be orientated within 15°of an east-west line. This will tend to allow more windows, other openings such as doors, and increased wall area on the northern side to gain maximum benefit from the winter sun, while avoiding overheating in summer (see comments above regarding shade angles). Designers should locate living spaces on this northern side. Westerly orientations, in particular, should be avoided in hotter regions, as a baking afternoon sun can be very difficult to keep out. Northerly orientation can also facilitate the installation of solar water heaters (depending on roof design).

However, the effect of orientation is marginal for small, square structures that have small window areas. It should be stressed that other factors - such as access, security, variety, privacy/conviviality, slope and prevailing wind - should play a role in site layout and planning. Careful planning can still harness the benefits of passive solar design for a range of building orientations.

Solar access

Options for passive solar design can be severely restricted by adjacent buildings, especially on the northern side of a property. Site planners and designers should take careful cognisance of existing buildings, and future building possibilities, from the point of view of the current project as well as the needs of future developers on the southern side. In some countries solar rights are legislated, with shading of sites by adjacent buildings between 9 am and 3 pm prohibited (Holm and Viljoen 1996). Shared walls on the eastern and western sides can be an advantage, as they provide excellent insulation.

Site layout and development planning should be carried out with the above concerns regarding shading borne in mind. Road and stand plans should maximise the northern aspects, and avoid dense packing on south-facing slopes (where shading by adjacent buildings will be more severe).

Different climatic conditions

Most of the suggestions discussed above can be used to good effect to reduce the cost of energy services and enhance the built environment in all parts of South Africa. However, cost-effectiveness and appropriateness of different interventions is highly dependent on climate. The interior of the country generally has colder night-time and winter temperatures, and in some parts higher daytime summer temperatures. Thus insulation, winter solar gain and thermal mass are important. The Western Cape coastal regions tend to have a more temperate climate, and savings from passive design investments will not be as significant. In hot, humid areas such as coastal KwaZulu-Natal, summer ventilation and avoidance of heat gain (shaded walls, reflective insulation in roofs) are more important. Holm (1996) provides a detailed description of 13 climatic zones in Southern Africa, and provides design guidelines for each.

Economics and implementation

Changes to standard designs that bear relatively little cost - such as orientation of buildings towards the north, proper placement of windows for ventilation and summer shading - should be implemented wherever possible. Poor airtightness is frequently a result of poor quality control in construction, and can be improved by better training and quality control. Post-construction weatherisation can also be done low cost.

Cost-benefit estimates for more expensive options (installation of ceilings, insulation, etc) should consider three perspectives, namely those of:

- the householder;
- society at large; and
- the energy utility (especially the electricity-supply authorities).

Sometimes, the savings accruing to building owners may be insufficient to justify extra expense but, if the potential savings to the electricity-supply agency or society at large are also considered, a stronger motivation for an intervention can be made.

In general, ceilings and ceiling insulation will be cost-effective for all three parties in most parts of the country. The addition of low-cost insulation to single-skin corrugated-iron structures can also yield positive net benefits to householders. However, especially in coastal regions where ambient temperatures tend to be more stable, it may not be worthwhile from the householder's perspective to invest in ceiling insulation, or even a ceiling.

Estimates of the energy savings that can result from specific changes in design in specific climate zones can be derived from simulations or manual calculations - for example the CR method (Wentzel et al 1981). Computer programs are useful, some of which have been validated in South Africa (e.g. QUICK II 1998). Internationally developed and marketed programs such as DOE-2E, BLAST, and TRNSYS are also useful, provided that appropriate weather data are used. Such software can be sourced through enquiries addressed to the USA National Renewable Energy Laboratory, or similar institutions.

The viability of different interventions is also affected by the unit energy cost of the fuel being saved. Households using lower-cost heating fuels such as coal or wood will realise smaller financial savings than those using electricity. On the other hand, their health benefits may be greater.

Depending on a household's ability to set aside money for longer-term benefits (the effective "household discount rate" which balances capital investment against current demands on income), fuel savings from improved building design may not pay back the cost of the investment sufficiently quickly to be attractive. Poor people, in particular, can generally ill-afford capital expenditure, even if payback times are short.

Nevertheless, from the perspective of an electricity-supply utility (seeking to reduce peak demand), or the perspective of local or international society at large (seeking to reduce the impact of excessive energy consumption for space heating on health and the environment), it may be worthwhile to support such investments. This support can be in the form of

- direct subsidies;
- incentives offered for residential demand-side energy management; and
- careful structuring of finance packages (especially for new homes) to encourage people to choose better building designs which will save them money in the longer term.

A particular opportunity to support such investments, which is becoming more readily available, is access to international sources of finance, motivated by global environmental concerns.

Frequently, the pressure on housing developers is to deliver the maximum number of units possible, with minimum capital cost. In the absence of prescriptive legislation in South Africa to enforce construction methods that are more thermally efficient, this tends to result in householders and energy utilities being left with the long-term burden of high energy costs, and uncomfortable living environments. The development of social compacts between prospective homeowners, NGOs, planners and developers (and possibly with international funders) is an important element of building community-wide strategies to rationalise longer-term energy consumption.

HYDROCARBON FUELS

Paraffin

Paraffin is a liquid hydrocarbon fuel, which is produced by refining crude oil. It is very widely used in South Africa as a household fuel in non-electrified or recently electrified settlements.

Paraffin has a calorific value of 37,5 MJ/litre or 46 MJ/kg.

Utilisation and availability

Paraffin is mainly used in domestic applications for

- space heating;
- cooking;
- water heating;
- lighting; and
- refrigeration (less common).

Unlike liquified petroleum gas (LPG), paraffin is not suited to piped reticulation in buildings and is consequently not used in institutions or commercial enterprises.

Approximately 850 million litres of paraffin are used annually in South Africa (DME 1996).

Paraffin is widely available from small traders, garages and supermarkets in quantities determined by the customer's container size. The standard form of distribution is in 220 litre drums or 20-25 litre tins.

Appliances

A wide range of paraffin appliances is available. These may be pressurised (as in the case of a Primus stove or hurricane lamp) or non-pressurised, as in the case of a wick lamp. Pressurised appliances are more efficient and provide higher levels of output than non-pressurised units. Paraffin appliances tend to be portable and operate from a dedicated (or integral) fuel tank, which requires periodic refilling from a storage container.

Typical appliances include

- stoves - usually single-pot stoves;
- heaters - wick or pressurised;
- lamps - wick or pressurised hurricane-type; and
- fridges and freezers - usually wick-type units.

Appliances are widely available from general dealers, supermarkets and hardware stores.

Comparative costs

The retail price of paraffin is highly variable, due to the diversity in the distribution chain. Consequently, the retail price ranges from R2,50/litre upwards (October 1997 prices).

Hazards

The hazards associated with the use of paraffin include household fires, burns, asphyxiation and, most significantly, poisoning. Paraffin is poisonous in both liquid form and as a vapour. Up to 10 % of children in lower-income households suffer accidental poisoning (PASASA 1997). Children in the age group 1-4 years are most at risk.

Asphyxiation may occur as a result of the inhalation of poisonous paraffin fumes or due to the production of carbon dioxide and monoxide in confined or sealed rooms.

Safety measures

The high social costs of healthcare for paraffin-related injuries or poisoning have resulted in a concerted effort to provide practical measures and greater public awareness of safety in the use of paraffin.

The basic concerns include

- safe packaging and storage - dedicated containers with labels, safety caps, and a locked and ventilated storage area;

- safe utilisation - care of and correct use of appliances, safe handling by using a funnel, avoiding and cleaning spills, adequate ventilation of rooms; and

- health and safety awareness - information pamphlets, poison treatment cards, poison information centres.

The Paraffin Safety Association of South Africa, PASASA (tel: 0800 22 44 22) has developed a child-proof paraffin safety cap for commonly used containers. In addition, PASASA has developed paraffin safety labels for containers, safety posters and training packs for free distribution.

Planning considerations

As in the case of LPG (see below), the planning considerations for paraffin relate to the distribution of paraffin through a network of depots (or wholesalers) and small traders, and to general household fire and safety concerns.

Liquid petroleum gas (LPG)

Liquified petroleum gas (LPG) is a mixture of butane and propane gas stored under pressure, usually in steel cylinders. It is heavier than air, non-toxic and odourless. A smelling agent is added to aid users to detect leaks.

LPG is convenient as it has a high calorific value (energy content per kg) and is hence very portable, provides instantaneous heat, and is easy to ignite and clean-burning.

It is the most environmentally friendly of the commonly used fossil fuels because it is usually efficiently used and has low levels of harmful combustion products.

LPG has a calorific value of 49,7 MJ/kg or 13,8 kWh/kg, which is equivalent to 13,8 units of electricity.

Utilisation and availability

Approximately 280 million kilograms of LPG are consumed annually in South Africa (DME 1996).

Typical uses include

- space heating;
- cooking;
- water heating;
- refrigeration;
- lighting;
- workshop uses: brazing, soldering, welding; and
- school/technical laboratories

for use in

- domestic households;
- restaurants;
- hospitals;
- schools;
- small businesses; and
- recreation/leisure.

Appliances

LPG appliances include most of the commonly used electrical appliances other than electronic and/or motorised equipment. These include

- stoves/ovens;
- grills/braais;
- heaters (portable and fixed);
- instantaneous water heaters;
- lamps (portable and fixed);
- irons;
- refrigeration;
- welding plant; and
- bunsen burners.

The most commonly used LPG appliances are cooking, space heating and lighting appliances.

Appliances are designed to operate at an unregulated high pressure, such as in the CADAC (or similar) type of camping appliances, or at a lower pressure controlled by a regulator mounted on - or adjacent to - the gas storage cylinder. High-pressure and low-pressure appliances are not interchangeable.

Most households use gas appliances which operate off a small dedicated gas cylinder, rather than off a reticulated system of gas piping and fixed storage cylinders. Commonly used cylinder sizes are No 3 to No 10, and 9 kg cylinders (see Table 12.2.5).

Gas appliances must comply with SABS 1539:1991.

Comparative costs

The 1998 retail cost of LPG was R4,20 per kg (i.e. a unit energy cost of 8 c/MJ or 30 c/kWh).

The comparative effective costs per energy service are presented in Table 12.2.1.

Hazards

Typical hazards with LPG include:

- burns - common;
- explosions - quite uncommon; and
- asphyxiation due to displacement of air (by unburnt LPG in basements or on tanked floors or, more often, by carbon monoxide build-up in closed rooms).

Installation practices

LPG storage cylinders are supplied in a range of standard sizes in two categories: camping/hobby-type and household/industrial type.

The larger (9-48 kg) cylinders are designed to operate at 7 bar and are tested to 30 bar.

SABS 087:1975, Part 1, Code of practice for consumer LPG cylinder installation, is applicable to the storage of cylinders and gas piping in all cases when more than one cylinder, or a cylinder greater than 19 kg, is used on household premises.

In practice, it is recommended to use two cylinders, a duty and a standby cylinder, to ensure continuous service when the duty cylinder runs empty. It is also more convenient for households to manage two No 10 cylinders (4,5 kg) rather than one 9 kg cylinder.

Fixed gas installations must be installed by a registered gas installer (accredited installers can be checked with the LP Gas Association - refer to contact details below).

Guidelines for installation

The most important installation consideration is

Table 12.2.5: Standardised sizes of gas cylinders

CAMPING/ HOBBY HIGH PRESSURE APPLIANCES	HOUSEHOLD/INDUSTRIAL LOW-PRESSURE APPLIANCES	ENERGY CONTENT MJ	DIMENSIONS	
			DIAM. mm	HEIGHT mm
100 g		5		
200 g		10		
No 3		70		
No 7		160		
No 10		230		
	9 kg	450	305	406
	19 kg	950	305	762
	48 kg	2 400	381	1 143

the provision of good ventilation, preferably natural ventilation, in the storage area and the appliance area. Two airbricks or 150 x 150 mm weather louvres at ground level and high up on an exterior wall are recommended.

Storage of cylinders: outdoors, in a lockable and protected area, in an upright position.

Pipework: 10 mm Class 2 copper with brass compression fittings.

Regulators should comply with SABS 1237:1990.

Safety measures

The LP Gas Association (tel 011 886 9702 or 021 531 5785, PO Box 456, Pinegowrie, 2123) has developed a range of safety-information material and provides training courses for gas suppliers.

The basic safety issues include:

- Safe storage - safe handling and storage of cylinders.
- Safe utilisation - care of and correct use of appliances.
- Health and safety awareness - information pamphlets and training courses for suppliers.

Planning considerations

LPG distribution is provided via depots, which supply small traders or dealers such as general dealers or hardware stores.

Small traders typically supply approximately 2 000 kg/month which corresponds to settlements of between 500-1 000 households or 2 000-10 000 people, depending on the average monthly consumption and household sizes.

An average coverage per small trader could be 3 000 people.

An LPG depot is capable of distributing cylinders to 10-15 small traders.

Coal

Household use of coal

Coal (bituminous or ordinary coal) is one of the lowest-cost fuels available to households for space heating, and ranks on a par with most other fuels when used for cooking and water-heating (see Table 12.2.1). As a result it is widely used in Gauteng, parts of KwaZulu-Natal and in rural and urban settlements close to coal mining districts (refer to Figure 12.2.1). About one million households use coal in these areas (5 to 6 million people). Coal use is less common in other areas, partly because of higher prices due to transportation costs.

Typical appliances include

- cast iron "coal stoves" with closed combustion chambers exiting to a chimney (such as the Dover stove); and
- open and closed braziers, with the Mbaula being a common example; these do not have a chimney and are normally ignited outside, before being brought into the home.

Environmental and health issues

The coal generally used by householders is of relatively low quality (C or D grade), as this is significantly cheaper than higher grade coals. It has an energy content greater than 21 MJ/kg, an ash content of 15% to 50%, and releases noxious volatiles on combustion. The sulphur content is relatively low (1-2%). When burnt relatively inefficiently (as in a stove or Mbaula), the dangerous pollutants include particulates and noxious gases such as sulphur dioxide. Aside from general concerns regarding unpleasant smog and grime on buildings, the indoor and outdoor pollution levels in communities that use coal are high enough to markedly increase the risks of respiratory tract illnesses, with the use of coal in the home increasing risk by a factor of nine in one study (Van Horen et al 1996). If homes are under-ventilated, there is also a risk of asphyxiation from carbon monoxide poisoning. The direct health risks attached to household coal combustion thus have high personal and societal costs.

Efforts to reduce pollution

Strategies to reduce indoor and outdoor pollution from residential coal consumption include

- encouraging the substitution of coal use by other fuels which are cleaner, but require different appliances (LPG, paraffin, electricity);
- the provision of other fuels which can replace coal in existing coal-burning appliances (low-smoke coal, wood, briquettes);
- legislation to reduce allowable smoke emissions and/or prohibit coal use;
- improvement of stove combustion efficiency;
- education on the need to ignite Mbaulas outside the home, only bringing them inside

once smoke production has reduced;

- education regarding proper lighting methods (starting a fire on top of a pile of coal rather than underneath can reduce the amount of smoke produced);

- education regarding proper ventilation;

- substitution of open braziers and Mbaulas by stoves with chimneys (to remove smoke from indoor environment); and

- improving the thermal performance of houses to reduce the requirement for space heating (refer to the energy-efficient building design section above).

Although many of the interventions listed above fall primarily within the responsibility of coal users themselves, the effects of pollution affect society as a whole, and it is therefore important for planners, local authorities and national agencies to be directly involved. Some of the above strategies are discussed briefly below.

Substitution of coal with different "clean" fuels (e.g. electricity, gas). Both electrification and the provision of gas have the potential to reduce coal combustion in homes, reducing local pollution effects to a minimum. Experience to date, however, indicates that coal stoves continue to be used even after settlement electrification (Van Horen et al 1996). Costs to the householder remain an important barrier to fuel substitution. Coal can be the cheapest fuel for thermal applications (especially space heating - Table 12.2.1). Furthermore, replacement of the multi-purpose coal stove can require the purchase of three appliances: a stove, a water heater and one or more space heaters. Strategies to increase the rate of transition to electricity include

- the subsidisation of new-appliance costs (or improving access to credit for appliance purchase); and

- the subsidisation of electricity tariffs for low-income households (currently being mooted by the National Electricity Regulator).

Similar strategies can be used to promote gas use.

Substitution of coal with low-smoke coal or other similar solid fuels. A number of "low-smoke coal" fuels have been developed. These offer the potential of easier substitution in the market place: householders would not have to purchase new appliances or change their cooking and space-heating social/behavioural practices. These fuels can also be marketed through existing coal dealer networks, reducing disruptive effects on employment, etc.

However, low-smoke coals are more expensive than ordinary coal, with production costs three or more times the pithead price of bituminous (ordinary) coal. Even if one assumes savings in distribution costs for locally produced fuels, low-smoke fuels retail prices are from 1,7 to 10 times the retail price of coal (on a per-unit energy basis). Since they have relatively few advantages to the customer (apart from low smoke emission), it is clear that some form of market intervention would be necessary to achieve more widespread use. For a discussion of fuel types and market intervention options see Van Horen et al (1995).

Three products have recently been tested in a large-scale experiment:

- Two brands of devolatilised discard coal (produced by heating discard coal under controlled conditions).

- Compressed paper with a binder. User and merchant reaction was mixed. The devolatilised coal fuels, in particular, were difficult to light, initially blocked grates because they had too high a percentage of fines, and did not have good heat retention. The paper-based fuel was much easier to use, although it also did not have good heat-retention properties. There are thus a number of problems still to be overcome, before it will be possible to actively market a product that can compete directly with coal (Asamoah et al 1998).

Legislation of smoke-control zones

Part III of the Atmospheric Pollution Prevention Act (No 45 of 1965) makes provision for smoke control zones in which the sale or combustion of coal for domestic use can be controlled. Enforcement is usually through an education process, with warnings or "abatement" notices being served prior to prosecution for an offence in terms of the Act. Although effective in wealthier communities, where alternatives to coal are affordable, the Act cannot be expected to be observed in poorer communities where there is little economic alternative to coal. It is thus necessary to develop and implement other viable strategies before considering enforcing the observance of a legislated smoke-control zone.

Education and awareness

National or regional strategies can be effective only in as much as they are taken on board by communities and individuals. It is therefore important to engage in debate and education programmes, and generally raise awareness around coal pollution and abatement strategies.

Biomass

Biomass is extensively used for cooking in South Africa, with an estimated 16 million people relying predominantly on wood for space heating and cooking needs (Van Horen et al 1996). People tend to use open or sheltered fires, usually with a few stones or bricks to support pots or a grid. Varieties of "improved wood stoves" are available, but have not been extensively used or marketed in South Africa. Mean annual per capita consumption of biomass varies depending on the availability of wood, and the degree of substitution with other fuels such as paraffin, gas or even electricity. Typical values are from 350-700 kg per capita per year. Wood is usually collected at low or zero direct financial cost to the household. However, collection times are long (often three or more hours per trip), with multiple trips required per week. Commercialisation of the fuelwood market in rural areas is increasing. Prices are of the order of 20c to 50c per kg (1997-98), depending on availability and quantities purchased.

Concerns regarding fuelwood use

Wood is in many ways an attractive fuel for residential energy supply, as it is low cost (see Table 12.2.1), popular, familiar to people, and the resource is generally well distributed. If harvested on a sustainable basis the net greenhouse gas emissions are zero, and the resource is renewable. However, there are health and broader environmental concerns which should be addressed.

Health related concerns include the following:

- Burning wood brings increased risk of respiratory tract infection and eye diseases as a result of exposure to smoke in poorly ventilated houses. Studies have recorded exposures to total suspended particles from two to eight times recognised international standards (Van Horen et al 1996).
- Even if ventilation is provided, cooks may be so close to the fire that smoke exposure is still high.
- In denser settlements, outdoor air pollution from woodsmoke may also be a problem.
- The risk of burns, especially to children around open fires, is increased.
- Spinal injury and other personal-safety risks are associated with wood-collection trips.

Supply sustainability concerns include the decreasing availability of wood fuel as a result of

- unsustainable harvesting pressure and practices (environmental denudation); and
- competing land use claims for agriculture and housing development.

Biomass strategies

Key strategies for improvement of health and safety in the household environment include the following:

- Substitution of fuelwood with cleaner fuels (electricity, gas, paraffin). However, where wood remains significantly cheaper than alternative fuels, such strategies are expected to have limited impact.
- Greater use of improved stoves with chimneys. Such stoves should remove all smoke from the immediate cooking environment and also have good combustion efficiency to reduce total emissions. "Cooking efficiency", which is related to combustion efficiency, heat transfer efficiency, and the ability to control the rate of combustion are also important. A key difficulty is the establishment of a sustainable market that can deliver products of adequate standard.

Concerns regarding sustainability of supply can be partly addressed by reducing consumption. However, what is more important is the achievement of an integrated development and resource utilisation framework which takes into account land-use priorities, institutional and private ownership constraints, and biomass energy requirements. Measures directly related to biomass supply include the following:

- Redistribution of wood from areas of surplus to areas of need, preferably using commercially sustainable mechanisms. Sources of potential surplus include commercial farms, commercial forests, water-catchment areas infested with alien vegetation, and farm and game management areas suffering from bush encroachment.
- Encouragement of sustainable harvesting practices. These are often already practised by communities and include collection of dead wood only, cutting of selected branches to allow coppicing to occur, and careful selection of trees to be felled on the basis of size, position and species. Where coppicing does occur it is often useful to prune new shoots selectively to achieve more rapid re-growth of the remaining shoots.
- Development of tree planting and management strategies can enhance the supply

of wood for fuel and other purposes (construction, fencing, carving, etc). Options include woodlots, agroforestry and social forestry.

Woodlots require the establishment and management of small- to medium-sized plantations to produce fuel and other forest products. They have met with mixed success, as management and ownership structures are difficult to establish and maintain in the long term. However, where suitable local authority management structures are in place, they can be effective.

Agroforestry involves the planting of trees in association with crops. This can have benefits for crop production (shade, windbreaks, nitrogen enrichment).

Social forestry is a broad term, referring to community-based resource management involving the planting and management of trees in woodlots, as part of agroforestry, as part of land-reclamation processes, or in greening projects. Greening projects are perhaps most important in terms of settlement development and planning, as they can result in more pleasing and comfortable living spaces and greater access to fruit, wood and other products, depending on species and planting practice (Gandar 1994).

The Directorate of Forestry (Department of Water Affairs & Forestry) is the national entity responsible for overseeing many of the above strategies.

Town gas

Town gas, also called “producer gas”, is the term used to describe reticulated gas, which is supplied in older parts of South African cities, such as Woodstock and Observatory in Cape Town, Melville in Johannesburg and parts of Durban and Port Elizabeth.

The gas is usually produced from coal, using a coal gasifier, or as a by-product of the chemical industry. Its calorific value varies, depending on the source, method of manufacture and supply pressure, ranging from 13,3 to 34,0 MJ/m^3.

The gas is reticulated in pipes (or gas mains) in the streets and supplied onto each erf via a gas meter, as for water or electricity.

Town gas is currently not considered for any new settlements, although this may change if the Pande natural gas reserves in Mozambique are developed and marketed in Mpumalanga and Gauteng.

Appliances

Built-in appliances such as instantaneous water heaters, cooking stoves and “gas fires” (space heaters) are commonly supplied by town gas.

In general, town-gas appliances operate at a lower pressure than bottled LPG appliances. Consequently, although most gas appliances can operate off either type of supply, they would require modifications to the jets or burners to adapt to the difference in pressure.

Safety

The safety considerations for LPG appliances apply equally to town gas appliances. However, the protection and marking of underground gas pipes also requires attention, to avoid accidental damage and leaks.

Planning considerations

No planning for town gas is required until town gas becomes an available option for new settlements.

SOLAR ENERGY APPLICATIONS IN SOUTH AFRICA

Provision of energy to sites and buildings usually requires the development of infrastructure to deliver the energy carrier (electricity, town gas, LPG, paraffin, etc) to properties. Solar energy is, however, generally available to householders. The following sections discuss the methods and mechanisms to facilitate the use of freely available solar energy for services such as water heating and electricity provision.

The Solar Energy Society of Southern Africa (SESSA) may be contacted for information at PO Box 152, La Montagne 0184, tel (012) 804 3435, fax (012) 804 5691.

Solar photovoltaic electricity supply

Photovoltaic (PV) modules are semiconductor devices that convert the radiant energy of the sun into a direct current (DC) electrical source. These can be coupled with energy storage devices such as batteries and power management equipment, to form an integrated system capable of delivering electricity for wide range of application. Simple systems usually have DC outputs to DC appliances such as lights, television, radio or hi-fi. Larger systems often incorporate a DC-AC inverter to power AC loads. PV systems are modular, have low enviromental impact, are quiet and have a long life (15 year warranties on the PV modules are common). Unit costs of energy are relatively high (R3,60 to R5,00 per kWh, in 1997 rands). However, PV systems can be installed at the point of need, thus significantly reducing the capital expenditure required for grid extension and even local distribution.

Typical applications of PV systems

Typical applications are listed below, with some indication of the number of installations in South Africa as at September 1998.[1]

- power for telecommunications (between 60 000 and 100 000 systems, or more than 2 MW_p installed);
- rural health-centre service provision (communications, vaccine refrigeration, lighting), with more than 180 such systems installed;
- school lighting and educational equipment power supply (more than 1 200 systems installed);
- domestic lighting, media and other high-quality energy supply needs:
  - individual household systems, often called Solar Home Systems (SHS), with an estimated 50 000 to 60 000 systems installed
  - battery-charging systems (shared by a number of users), a few pilot projects in operation
  - mini-grid reticulation systems (very little SA experience to date);
- water pumping (thousands of systems have been installed - see solar water pumping section below); and
- galvanic protection of structures against corrosion.

Potentially important applications of PV systems which have not yet been implemented on a significant scale in South Africa include

- street lighting in unelectrified communities or along roads not served by nearby sub-stations;
- grid-connected distributed generation systems - for example to provide reinforcement for daytime peak loads at the end of a long line which has insufficient capacity, or for back-up power; and
- building-integrated systems in which the PV modules also serve as facade or roof covering (these offer considerable potential in the future, as the dual purpose renders the products more economically viable).

The use of large PV power plants to generate electricity for the grid is not yet cost-effective.

Hybrid energy supply systems

Sometimes the reliability and cost-effectiveness of a renewable energy system can be improved by connecting two or more energy sources to the system, creating a hybrid energy system. A diesel generator in combination with PV modules will increase the ability of the system to cope with an uneven load demand profile or periods of adverse

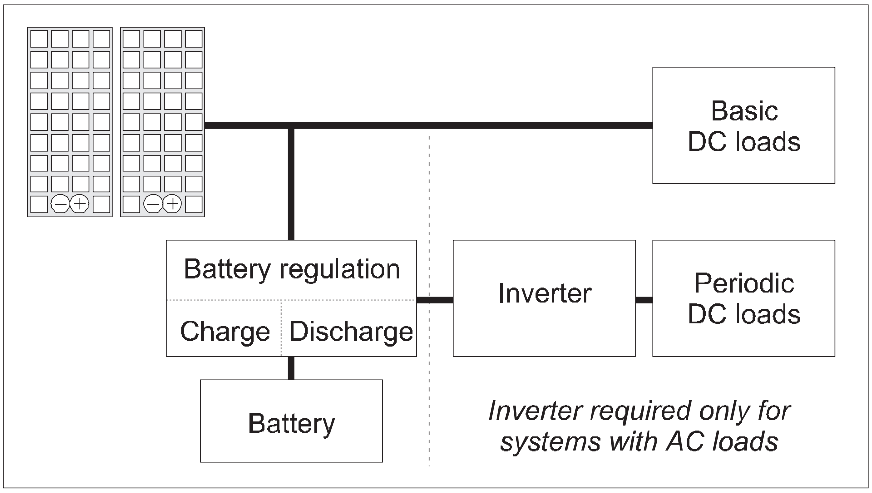

Figure 12.2.6: Principal components of a stand-alone photovoltaic system

1 The power of PV modules and system is rated in peak watts, or W_p, corresponding to the instantaneous output under standard irradiation conditions, similar to clear sun at midday.

weather conditions. Wind turbines can also complement PV systems effectively, especially in regions where periods of cloudy weather tend to be accompanied by windy weather. Hybrid systems are by nature more complex, and are thus usually justified only for larger systems (5 kWh per day and above). Design guidelines and general reference material on hybrid potential in South Africa may be found in Seeling-Hochmuth (1998). An application receiving considerable attention at present is that of remote-settlement household electrification using mini-grid reticulation systems powered by hybrid energy systems.

Costs

The modular nature of PV systems tends to make their costs per unit of energy available (kWh/day) relatively independent of system size. Most other energy systems show significant economies of scale, with diesel systems tending to be more economical where the daily power demand is greater than 2 kWh/day. PV thus tends to be most economical for smaller-scale applications. Figure 12.2.7 shows generic life-cycle cost estimates (including battery replacement, but excluding a technician's travelling time), while Table 12.2.6 indicates the range of capital costs for some common applications (including the cost of system-specific appliances).

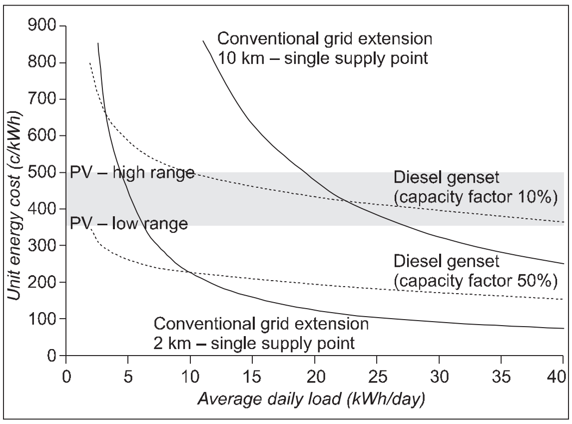

Figure 12.2.7: Comparative unit energy costs for single installations (1997 rands)

Selection of the most appropriate technology

Independent isolated applications

Capital and running costs are among the most important factors in deciding whether PV, hybrid systems, diesel, extension of the grid or other technologies are most suitable for a particular application. Costs of energy supply technologies can often be estimated reasonably accurately, and discounted life-cycle cost analyses provide an important tool to aid investment decisions. Figure 12.2.7 gives the approximate unit energy costs for PV, diesel and grid for individual applications (e.g. provision of power to a remote household or

Table 12.2.6: Typical PV applications and associated capital costs

SYSTEM DESCRIPTION	SYSTEM SIZE (PEAK WATTS PV ARRAY POWER) AND APPROXIMATE DESIGN LOAD (WH/DAY)	CAPITAL COST (INCLUDING INSTALLATION)
Solar home system (medium): 3 DC lights, socket for B&W TV.	50 W_p 110 - 150 Wh/day	R2 500 to R4 000 depending on supplier and quantity (1997)
School system (as installed during 1996 Eskom programme): Lighting for a few classrooms, inverter to provide power for audio-visual equipment, etc.	500 W_p 1 100 - 1 500 Wh/day 900 W_p 2 000 - 2 600 Wh/day	R55 000 R61 000 (Borchers and Hofmeyr 1997)
Health Centre: Lighting, vaccine refrigeration (high availability required), examination lighting, communications; staff quarters lighting and entertainment.	450 W_p 900 - 1 200 Wh/day 600 W_p 1 200 - 1 600 Wh/day	R62 000 R76 000 (Borchers and Hofmeyr 1997)

health centre). From this figure it is clear that PV systems tend to be the most cost-effective for relatively small loads, remote from the grid. Additional factors which may increase the desirability of PV systems - even for higher load applications - include

- concerns regarding maintenance costs, reliability and security of fuel supply of diesel systems (particularly for systems where high reliability is important, such as telecommunications); and
- a requirement for low noise and/or pollution levels (particularly in environmentally sensitive areas, such as nature reserves or tourist areas).

When comparing costs of systems, it is important to consider the load devices that will be used. As will be discussed in more detail below, it is frequently worthwhile to use different appliances (and a broader range of energy carriers) than would be the case if grid electricity were available.

<u>Settlement electrification - when to extend the grid or use off-grid technology</u>

Where technology selection may affect an entire community, the decision is more complex. The South African electricity-supply industry is currently engaged in a large, heavily subsidised programme to extend grid access to millions of households. The rapid pace of development, and the changeable nature of planning structures, means that there is little long-term certainty regarding the future reach of the grid. Furthermore, even remote communities usually have high expectations of gaining access to the grid in the near future. As a result there is considerable reluctance on the part of communities and many institutions to invest in PV, as subsidised grid access is a far more preferable power supply option, if it can be obtained. The arrival of grid to a settlement will significantly reduce the value of any prior investment in PV or other off-grid technology. Every effort should therefore be made to determine the probability of grid electrification. Grid-planning uncertainty remains one of the most important barriers to wider-scale use of PV technology for rural electrification.

From a financial (and economic) point of view, the principal factors affecting technology choice for community electrification are listed in Table 12.2.7 However, electrification planning decisions are fraught with political, economic and social ramifications. It is thus essential that decision-makers consult appropriately, both with authorities and proposed target communities.

PV system design:

The principal components of a typical stand-alone PV system are the PV array (comprising one or more PV modules), charge controller and a lead-acid battery (see Figure 12.2.6). In some cases an inverter will be used to deliver AC power. Larger systems may incorporate a maximum power-point tracker. Both the wiring used and the specific appliances used are crucial to successful operation of a PV system. It is therefore advisable to consider the entire system from module to load appliances when conceiving and implementing a PV system application. The following aspects are important considerations for PV system design. For more detailed information on technical design elements refer to Cowan et al (1992) or Hankins (1995).

Polycrystalline, monocrystalline and amorphous (thin film) modules are available. While the latter have lower costs, they tend to suffer gradual degradation of output power over time, and should thus be used with caution in situations where long life is important.

Physical tracking of the sun can lead to gains of 25 to 35% in PV array output. However, the added complexity and reduced reliability means that this is usually not economical.

Given the high capital cost of PV systems, it is important to specify load accurately, and to avoid overdesign of capacity.

Appliance efficiency is more important for PV systems than for grid or diesel systems, due to the high marginal costs of energy.

An energy-service approach should be adopted in preference to an electricity-service approach. This requires consideration of the most appropriate energy source for each appliance/service required. For most applications involving heating PV will not be the most appropriate, as gas or other clean fuels provide a convenient and cheaper service. Refrigeration is also cheaper using gas, provided that supply availability can be assured.

The cost increases significantly if the system is required to store enough energy in the battery to deliver the full load, even under prolonged adverse weather conditions. Prioritisation of loads can be considered. Very high availability levels (requiring over-sizing) are normally only specified where essential (e.g. for vaccine refrigeration or telecommunications).

Careful matching of PV array size, storage capacity and load for local solar radiation conditions is important to reduce overall costs. Paper-based methods and a computer program (POWACOST)

Table 12.2.7: Criteria for grid versus off-grid electrification

SETTLEMENT CHARACTERISTIC VIABILITY	EFFECT ON GRID ELECTRIFICATION VIABILITY	EFFECT ON OFF-GRID ELECTRIFICATION VIABILITY
Proximity to existing or planned grid infrastructure of suitable capacity and voltage rating.	Grid extension costs are of the order of R20 000 to R55 000 per km for low and medium voltage extensions (1998).	Off-grid technology costs are little affected by distance from the grid and comparative viability thus increases with distance.
Settlement size (number of households).	Costs of grid extension per household reduce for large settlements.	Costs per household relatively independent of settlement size.
Proximity of households to each other (hh/km^2).	Costs increase for more scattered communities.	SHS costs independent of settlement layout but mini-grid systems costs are affected in the same way as grid costs.
Proximity of settlement to other similar settlements.	Clusters of settlements may be able to share bulk-electricity supply costs.	Will have little effect on off-grid electrification viability.
Expected load, especially for businesses, institutions and water supply.	Higher load can improve the viability of extending the grid.	Large loads may be most cost-effectively served by hybrid or diesel systems.
Presence or otherwise of exceptional renewable energy resources.	Scarcity of biomass may result in greater demand for electricity (for cooking and space heating).	Exceptional local wind, micro-hydro or biomass resources can offer lower cost options for mini-grid hybrid systems.
Existence in settlements of community services such as schools, health centre, community centre, police, water pumps, etc.	The economic and social benefits of electrification can be significantly enhanced.	Off-grid options can still contribute to social and economic benefits for such services, but not to quite the same extent as for grid.

are included in Cowan et al (1992).

The charge controller (or regulator) is the heart of a PV system. It is very important to match its control characteristics to those required by the particular type of battery used.

Battery technology selection is important, as incorrect matching of battery to charge controller and system load profile can lead to high battery-replacement costs. For larger systems, the use of specialist deep-cycle batteries is advised. Cowan et al (1992) provide a detailed description of battery technologies and implications for PV systems. IEC 61427-1 is a draft standard for secondary cells and batteries for PV systems.

Current flows in DC systems tend to be quite high (a 100 W load will draw 8,3 A at 12 V). Voltage drop in cables should be kept below 8%.

Both DC and AC output systems can be used. Selection of appropriate voltage will depend on the requirements of available appliances and load duty profiles. For simple systems DC is usually satisfactory. DC refrigerators are also usually more efficient. For larger systems, some appliances require AC (audio-visual equipment, workshop tools). However, the choice of DC or AC lighting on large systems is not simple. Careful analysis of the cost, efficiency and reliability implications of different options is required.

Installation of PV systems with a system voltage less than 50 V currently does not fall under the SABS 0142:1993 code of practice on the wiring of premises. However, there are indications that this will become a requirement. Cowan (1996) provides a detailed code of practice for installations.

Important applications of PV in rural settlements

Four major programmes using PV technology to deliver services in rural settlements have been initiated in South Africa. Considerable technical expertise has been built up, and although national standards are not yet available, potential users are encouraged to contact the organisations below to obtain information on standards and specifications:

- Health centre electrification: principally through the Independent Development Trust (Cape Town), with technical support primarily through the Energy & Development Group (Noordhoek).

- School electrification: Eskom (Megawatt Park and Non-Grid Electrification), with international and government support through the Department of Minerals and Energy.

- Solar Home System projects: a variety of role-players including government, Eskom and the private sector. Detailed specifications are being drafted by Eskom NRS (NRS 052, draft 1998).

- Rural telecommunications service delivery: primarily managed by Telkom.

Maintenance and user training

PV systems are generally regarded as being low-maintenance items. However, the remote location of most installations means that scheduled or unscheduled maintenance costs can be very high. Unfortunately, experience in rural community household-electrification programmes (in South Africa and internationally), and in many institutional settings such as schools and water-supply projects, indicates that provision for maintenance (financial, institutional, training, user education) is frequently insufficient. Three areas are critical:

<u>Cost of components</u>

Battery replacements, in particular, represent an ongoing cost, particularly in low-cost household applications, where average lifetimes are about 3,5 years. Lights also have a finite life (1 000 to 10 000 hours) and will need to be replaced.

<u>Availability of technical resources</u>

Although most small systems are not complex, the average user will not be able to carry out all the maintenance. Given the high cost of travelling and specialised staff, it is important to establish and support local technicians, equipped to service the systems in a given area.

<u>End-user/customer training</u>

PV systems serving loads that are under user control (households, schools, clinics, etc) need to be properly operated to obtain maximum benefit, and to reduce the probability of premature battery failure. It is thus important to provide informative user education, and to ensure that systems are equipped with indicators to inform the user regarding battery status.

Quality assurance and specifications

Although the PV industry has been active in South Africa for close on twenty years, the market size has been inadequate to develop recognised quality-assurance standards, training certification, and standard specifications for PV systems and components (other than the modules). As a result, it is sometimes difficult for the purchaser to ensure that components used are efficient and of good quality, and to ensure that design and installation are properly carried out. Changes are, however, taking place rapidly, both within the country and internationally. Standard specifications for particular system configurations and for specific balance of system components are being developed. A number of codes of practice for installation have also been developed, and may be incorporated into national standards documents. Although there has been some development of training courses, certified PV training courses are not yet well established. The following documents (or the latest drafts) are useful:

- Code of practice for installing low-voltage PV power systems (draft). Prepared for Department of Minerals & Energy, Pretoria, by the Energy and Development Research Centre (1996).

- Code of Practice: Southern African Solar Module Suppliers Association (1994).

- NRS 052:1998 (draft), Technical specification for PV systems for use in individual homes.

Finance and dissemination models

PV systems require large capital investments up front (as does grid electrification). However, the dispersed location of customers and the autonomy of installations mean that they are not normally considered part of utility business. As a result, consumers do not gain access to the low-interest - and often subsidised - long-term finance so essential to grid development, or to the project management and consumer support programmes that are crucial to normal grid-electrification project development and long-term operation.

For institutional clients such as schools, health centres and water authorities, access to finance for capital expenditure and project management can usually be resolved. Longer-term maintenance is often more difficult, as discussed above.

For households, the problems are far more intractable. Finance services geared to remote rural areas are expensive to administer, particularly for the small- to medium-scale loans required for PV systems. Incomes are often uncertain and security may be a problem. Customers require assurance that systems will work for extended periods, and there are also concerns regarding the sustained provision of maintenance services. Despite these barriers, numerous householders (numbered in the tens of thousands) have already purchased PV systems. Various strategies have been proposed or tested to enhance dissemination potential.

Hire purchase or loan schemes involve the establishment of specialised credit facilities that can be used either by individuals or, in some cases, by groups or co-operatives, to purchase PV systems. In parallel with the credit facility, NGOs, government, industry or perhaps the grid utility provide project-management services to facilitate bulk purchasing, customer education, local technician training, and efficient installation of PV systems within a community. A variation of this system is to establish a local service point near the targeted communities. This owner/franchisee/agent can then act as a liaison for loan applications, system supply and technical support. Although customers will need to make provision in the long term for ongoing maintenance costs, purchase costs are for a finite period (typically three or four years) and, once the system is paid off, monthly costs will be significantly reduced.

An alternative is to maintain more of a *utility* approach to PV electrification. In this case financial, technical and administrative infrastructure is established in a region to enable long-term leasing of PV systems by customers for a monthly fee. Essentially, the customer pays for an energy service, not a product. The approach is potentially more attractive to customers, as the risks involved are far lower, and monthly payments should be lower than for a loan-based system. Maintenance will remain the responsibility of the service provider (except for lights and possibly house wiring). Should the grid arrive at some future date, customers can simply stop their lease and return the systems to the service provider, with relatively little loss of investment.

An important technical development which makes both "service-based" and loan-based dissemination strategies simpler to administer, is the introduction of pre-payment meter technology to PV systems. This allows the user to have greater control over monthly expenditure, and provides a reasonably efficient way to eliminate bad debts. The addition of active security chips to controller, array and battery makes it possible to reduce the potential for tampering and theft.

Solar water pumping

Solar water-pumping systems use the sun's energy to produce electricity which, in turn, drives a submersible or line-shaft pump.

Solar water pumping is increasingly attractive as a replacement for hand pumps, wind pumps and diesel pumps. Between 10 000 and 20 000 systems are already in operation internationally, roughly 3 000 of which have been installed in southern Africa. Some solar pumps have been in operation for more than 10 years in South Africa.

Comparison of different pumping options

Grid electricity pumps

These are the cheapest option if grid electricity is available at the water source. However, extensions of MV powerlines typically cost from R40 000 to R60 000 per km and consequently non-grid options are often cheaper if grid supply is not available.

Diesel water pumps

This option is widely used for off-grid applications. Although the initial costs are low there are significant disadvantages to diesel systems. These include very high operating costs, high levels of maintenance and supervision, noise and dirt, and a dependence on a reliable fuel supply.

Solar water pumps

This option is applicable for off-grid applications and is more widely used now that farmers and authorities are becoming more familiar with the benefits of minimal maintenance, low operating costs and quiet and reliable operation. Disadvantages include the high initial costs (two or three times the costs of diesel) and the risk of theft of solar panels.

Wind pumps

This option has been widely used on farms and in rural areas. Approximately 300 000 wind pumps have been supplied in South Africa. Disadvantages include the relatively high levels of maintenance required and the unreliability of the wind.

Hand pumps

This option is suitable for very small water demands (<50 people). It is not suited to reticulated water-supply schemes.

Table 12.2.8 shows the comparative characteristics of these different pumping options.

When is solar pumping appropriate?

Solar pumping is appropriate in any application where grid electricity is unlikely to be available for five years (or more) and the average pumping requirement is less than 2 000 m^4/day - that is, volumetric demand (m^3/day) multiplied by the total head (m).The criterion of 2 000 m^4/day is illustrated in Figure 12.2.8.

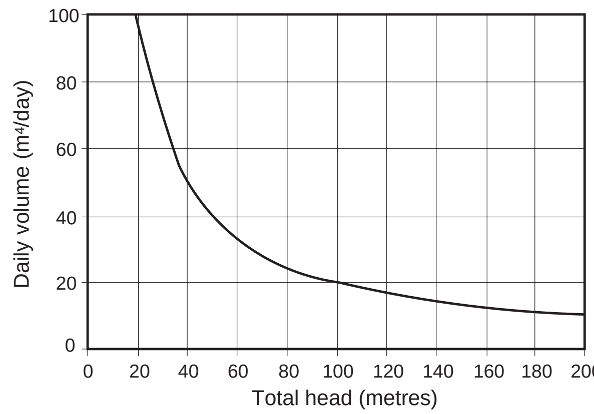

Figure 12.2.8: Volume and head relationship for the pumping criterion of 2 000 m^4 per day

Table 12.2.8: Comparative characteristics of different community water pumping options

	NO OF PEOPLE	INITIAL COST	O&M COSTS	OPERATOR INPUT	RISK OF THEFT
Grid	Any	Depends on access	Very low	None	Low
Diesel	>1500*	Low	High	High	Medium
Solar	<1500*	High	Low	Minimal	Can be high
Wind	<200	Medium	Low	Minimal	Low
Hand	<50	Low	Very low	Minimal	Low

* Assumes a 50 m total head.
Source: Borchers (1998)

Table 12.2.9: Typical initial costs and associated operating costs for different pumping systems (in 1997 rands)

NUMBER OF PEOPLE		100	500	2 000	6 000
PUMPING REQUIREMENT		125 m^4/DAY	625 m^4/DAY	2500 m^4/DAY	7500 m^4/DAY
Grid	Initial cost	7 500	8 500	11 500	16 500
	Annual cost	500	1 000	2 300	5 400
Diesel	Initial cost	36 000	39 500	46 800	63 000
	Annual cost	9 000	16 000	2 300	34 000
Solar	Initial cost	14 000	43 300	240 000	-
	Annual cost	100	200	350	-
Wind	Initial cost	15 500	-	-	-
	Annual cost	2 000	-	-	-
Hand	Initial cost	8 500	-	-	-
	Annual cost	nil	-	-	-

Source: Borchers (1998)

Costs

Typical comparative initial costs and operating costs for the different pumping options are shown in Table 12.2.9.

Principles of operation

Solar (photovoltaic) panels convert solar light energy directly into direct current (DC) electricity, which is conditioned in a controller, to an electrical output suitable for a DC or AC pump motor. Water is generally pumped into a storage reservoir and reticulated to households or community standpipes. Figure 12.2.9 Illustrates the principles of operation.

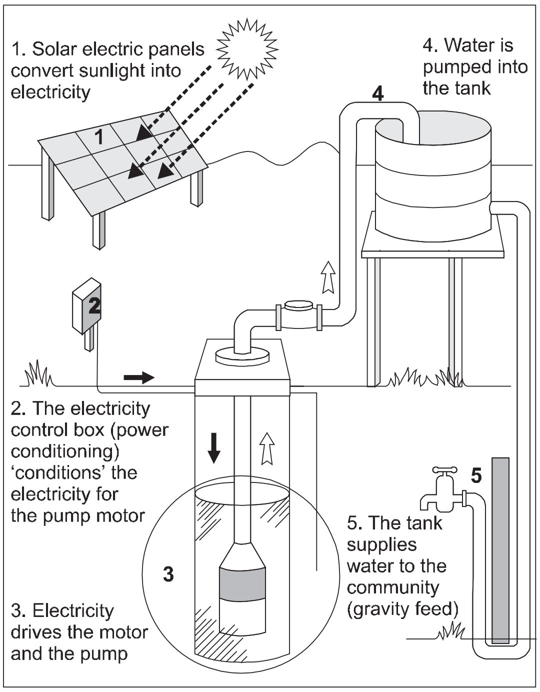

Figure 12.2.9: Operating principles of solar water-pumping systems

Description of typical solar pumping systems

There are five typical configurations of solar water-pumping systems. They are

- surface-mounted centrifugal or diaphragm suction pumps;
- floating pumps;
- submersible diaphragm or piston pumps;
- line-shaft-driven positive displacement pumps; and
- submersible multi-stage centrifugal pumps.

Three of these are illustrated in Figure 12.2.10.

Life-cycle costs of different pump types

Typical unit water-pumping costs (1998) for different solar pump options based on 15-year life-cycle costs are shown in Table 12.2.10.

Table 12.2.10: Typical pumping costs for solar pumps, based on15-year life-cycle costs

PUMP TYPE	TYPICAL PUMPING CAPACITY	UNIT COST FOR WATER
Submersible diaphragm / piston pumps	0 - 400 m4	>1,2 c/m4
Surface-mounted line shaft pumps	0 - 1 200 m4	1,5 - 5 c/m4
Submersible multi-stage pumps	0 - 4 500 m4	> 20 c/m4

Source: Borchers (1998)

Planning and installation considerations

The planning and installation considerations for solar water pumps are generally similar to other water-pumping systems, except that special care needs to be taken to minimise the risk of theft of the PV modules.

The risk of theft of the modules may be reduced through community participation and ownership, and the location of solar pumps out of sight of opportunistic thieves (i.e not near main roads).

Solar water heating

Water heating accounts for up to 40% of household energy consumption. Solar water heating (SWH) systems can provide water at temperatures of up to 85˚C on sunny days, independently of other energy sources, for a wide range of uses in urban and rural areas. SWH systems generally have some form of auxiliary (or backup) heating for periods of overcast weather and for short-term peak demands which exceed the average daily output of solar-heated water.

SWH systems are an attractive alternative to more conventional water-heating systems because they have fewer negative effects on the environment and can be more cost-effective within comparatively short payback periods - as little as 3-5 years (depending on the exact application).

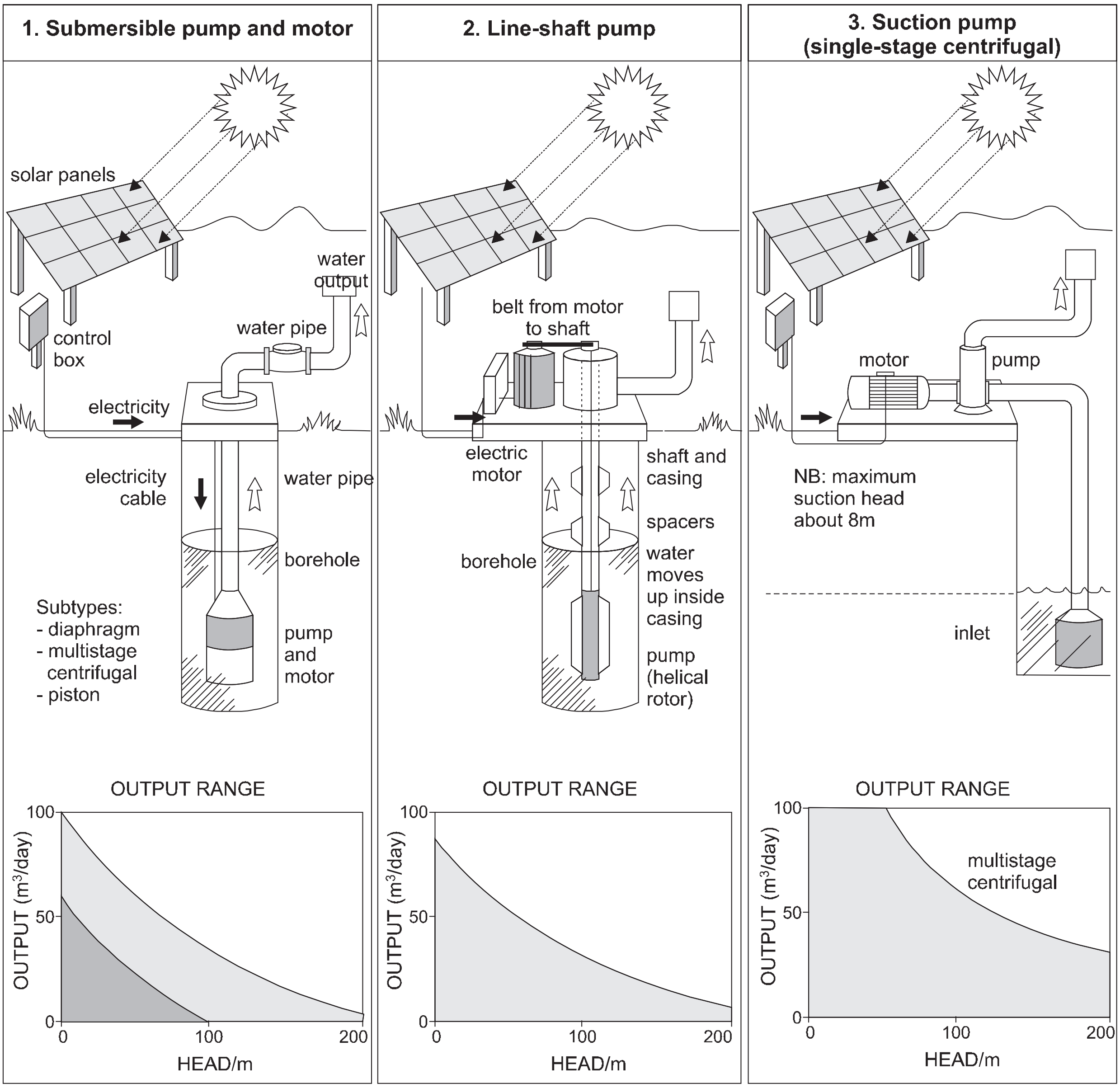

Figure 12.2.10: Three typical configurations for solar water-pumping systems

Typical applications include

- domestic water heating;
- hot water for public bath houses;
- underfloor heating;
- old age homes;
- swimming pools;
- horticulture / aquaculture;
- small businesses: laundries; hairdressers; undertakers; caterers/restaurants;
- hospitals;
- clinics; and
- school hostels.

Advantages

- the ability to provide 40-100% of hot water needs;
- the use of renewable energy (avoidance of environmental costs of electricity generation and transmission);
- the reliability of the energy source;
- the fact that it is financially cheaper (after a period of between 3-5 years); and
- the reduction of uncertainty of monthly cash flows.

Disadvantages

- the high initial cost (twice as much as a conventional electrical "geyser");
- the need for some form of backup heating for overcast weather; and
- the lack of confidence in quality assurance.

This section focuses on domestic and institutional (i.e. hostels, public bath houses, hospitals and clinics') hot-water systems.

Current use of SWH systems in SA

SWH systems have been available commercially for many years. The supply and installation of SWH systems experienced a significant peak in the mid-1970s as a result of the energy crisis and subsequent focus on alternatives to fossil-fuel-based energy systems.

SWH systems are relatively simple devices which are well suited to local manufacture. Consequently, SWH systems offer opportunities for job creation, in addition to electricity and energy savings. However, the relative ease of production requires careful consideration of quality assurance measures, to prevent poor performance and premature failure.

Current estimates suggest that, by 1994, over 70 000 domestic SWH systems had been installed in South Africa (Energy and Development Group 1997a). See Table 12.2.11.

When is SWH appropriate?

SWH systems produce hot water whenever the sun shines, regardless of whether the hot water is used. SWH systems are therefore most suited to applications which require consistent quantities of hot water on a daily basis throughout the year. Solar water heating is generally not suited to applications which require variable and unpredictable hot water demands.

In the case of households, SWH should immediately be considered if grid electricity is not available (i.e. for use in conjunction with non-grid electricity systems such as PV, wind or diesel units).

In cases where grid electricity is available, SWH systems may become cost-effective in 18 months to a few years (depending on the circumstances) for new houses and new institutional applications.

Although SWH systems operate well anywhere in South Africa, they are more appropriate in the sunny inland regions of the country.

Comparative costs

The comparative (1998) costs of SWH, electrical storage heating systems and instantaneous water heating for a typical family of four to five persons are presented in Table 12.2.12 in terms of overall life-cycle costs over 10 years.

The cumulative costs and payback characteristics are shown in Figure 12.2.11.

Table 12.2.11: Estimated solar water-heater capacity installed in South Africa

APPLICATION	INSTALLED COLLECTOR AREA (m^2)	COMMENTS
Domestic	220 000	Approx 70 000 systems
Commercial and industrial	34 000	e.g. Milnerton Girls' School
Agriculture/horticulture	2 600	
Swimming pools	227 000	Approx 8 000 systems
Public bathhouses	-	e.g. Durban Metro, Langa

Source: Borchers (1998).

Table 12.2.12: Comparative water-heating costs

	SWH SYSTEM	ELECTRICAL GEYSER	ELECTRICAL INSTANTANEOUS HEATER
Initial cost	R3 750	R2 000	R2 400
Annual operating cost	R375	R950	R750
Life-cycle costs	R5 800	R7 100	R6 600

Note: The life-cycle costs are highly sensitive to the particular application and should be established for each specific case. The key sensitivities are initial cost, real discount rate, operating lifetime, and utilisation of the solar heated water (or solar fraction).

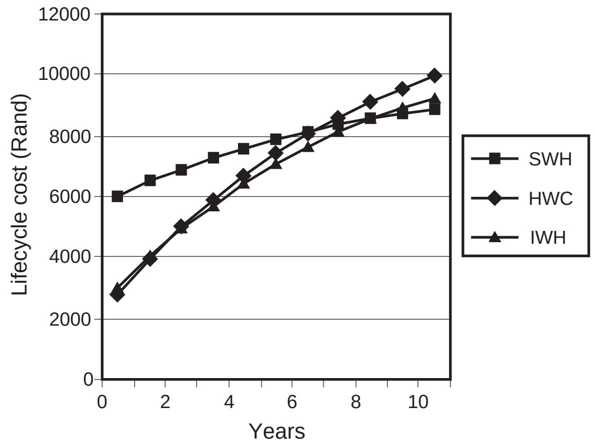

Figure 12.2.11: Cumulative costs and payback characteristics of SWH, electrical storage heaters and instantaneous water heaters

Typical considerations in planning for SWH systems

Water supply

Reticulated water supply, for a continuous/ pressurised supply, or standpipe in the yard, for a batch-heating type of supply.

Water pressure

Generally best at <200 kPa to reduce water consumption, minimise the mixing of hot and cold water in the storage tank, and reduce stress and wear and tear on the valves and connections.

Water quality implications

Generally, water which is safe for potable use is safe for use in SWH systems. Corrosion of SWH systems may be a problem with untreated (farm) water, but is generally avoided through appropriate choice of materials, such as copper and plastics.

System durability and expected lifetimes

SWH systems generally last as long as - or longer than - standard electrical storage heaters. Unless abnormal hail or freezing damages the SWH systems, the storage tank is likely to fail first.

Criteria for selecting SWH for water heating

Access to grid electricity

If the need for hot water cannot be met with grid electricity, SWH systems (with LPG or wood-fired auxiliary backup heating) are highly recommended. If grid electricity is available, the comparative costs and benefits of electrical and solar water heating need to be assessed in detail.

Hot water draw-off patterns

The water consumption patterns of the users (volume, time of draws, consistency of draw-off patterns) can influence the utilisation of solar heated water. For example, use of hot water in the afternoon and early evening is ideal (high levels of solar utilisation) while early morning consumption is less satisfactory due to overnight heat loss and the need for auxiliary backup (non-solar) heating.

Solar access

The effectiveness of SWH systems is dependent on solar access, that is, geographical location, orientation of the collectors (facing north in the range 15˚E - 45˚W) and angle of tilt of the collectors (ideally latitude +10˚), and shading by adjacent buildings or trees. Clearly, if the collectors are not oriented correctly or if they are shaded, they will need to be oversized to compensate, thereby increasing the cost.

Freezing conditions

SWH systems are very exposed and vulnerable to freezing if they are not specifically designed for such areas (e.g. indirect heating systems). In general, all inland parts of South Africa (except the Lowveld in Mpumalanga and the Northern Province) are freezing areas. The immediate coastal zones are generally non-freezing areas.

System types

The two essential basic components of all SWH systems are the solar collector (or absorber) and the solar water-storage tank (with safety valves). Other optional components, depending on the system type, are insulated interconnecting pipework, a circulating pump, non-return valves, auxiliary backup heating systems, support structures, and instrumentation.

SWH systems may use direct heating or indirect heating systems depending on the type (see below) and the need for protection of the solar collector and interconnecting pipework against damage due to freezing. In direct-heating systems the hot water is heated directly in the solar collector, whereas in indirectly heated systems it is heated in the storage tank, using an anti-freeze primary heating fluid and a heat exchanger.

Domestic SWH systems are generally supplied in four types:

Direct batch heater

A small (10-50 litre) directly heated, portable SWH system which is filled and drawn off by hand and manually placed in the sun.

Application: Suitable for households which do not have piped water (i.e. non-pressurised) and which may not be able to afford bigger or more complex systems.

Auxiliary backup heating: None.
Typical cost: R100-R800 (1998).
Typical output: 30-120 litres/day at 55˚C for multiple draw-offs.
Suitable for freezing and non-freezing areas.

Integral SWH system

Figure 12.2.12 - a small (100-litre, typically) directly heated SWH system in which the solar water-storage tank is painted black and enclosed in a glazed and insulated casing to act as the solar collector. Integral systems are usually roof-mounted and can be pressurised. Integral SWH systems are not suitable for early morning water draw-offs, due to high overnight heat loss.

Auxiliary backup heating: Integral systems generally do not have backup heating, although electrical backup is possible.

Application: Suitable for households which have piped water but which may not be able to afford more sophisticated systems.
Typical cost: R1 200-R1 800 (1998).
Typical output: 100-150 litres/day at 55°C for multiple draw-offs.
Suitable for freezing and non-freezing areas.

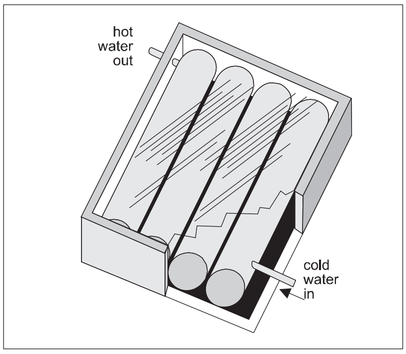

Figure 12.2.12: Integral solar water-heating system

Close-coupled SWH system

Figure 12.2.13 - a small to large (100 litre/1,6 m^2 - 300 litre/4,2 m^2) direct or indirect heating, roof-mounted SWH system in which the horizontal solar storage tank and solar collector are mounted adjacent to one another as a packaged, close-coupled unit. It may be pressurised <400 kPa and equipped with an optional single electrical backup heating element (1,5-3 kW) mounted halfway up the tank height.

Application: retrofit to existing houses or install in new houses which have flat or low-pitched roofs and will not allow a tank to be mounted in the roof space.

Typical cost: R4 000-R10 000 (1998).
Typical output: 150-400 litres/day at 55°C for multiple draw-offs.
Suitable for freezing areas (indirect heating) or non-freezing areas (direct heating).

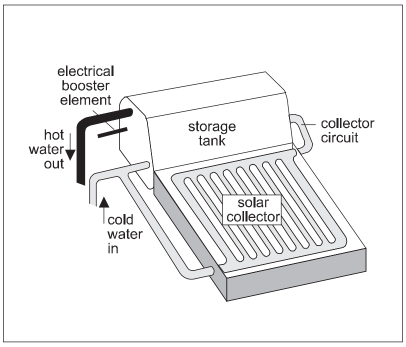

Figure 12.2.13: A close-coupled solar water-heating system

Split collector/storage system

Thermosiphon or pumped - Figure 12.2.14 - the most elegant and sophisticated of SWH system configurations, in which the solar storage tank is mounted in the roof space and the solar collector is mounted externally on the roof. These are usually larger systems (200 litre/2,8 m^2 - 300 litre/4,2 m^2) and pressurised <400 kPa. The heating fluid may circulate automatically by thermosiphon if the storage tank is physically higher than the top of the solar collector, otherwise it will require the additional complexity of a circulation pump. Electrical backup with single or dual (bottom and halfway up) elements (1,5-3 kW) forms part of the system.

Application: Aesthetic appearance most suitable for new houses with sufficient pitch in the roof to accommodate the storage tank.
Typical cost: R4 500-R12 000.
Typical output: 150-400 litres/day at 55°C for multiple draw-offs.
Suitable for freezing areas (indirect heating) or non-freezing areas (direct heating).

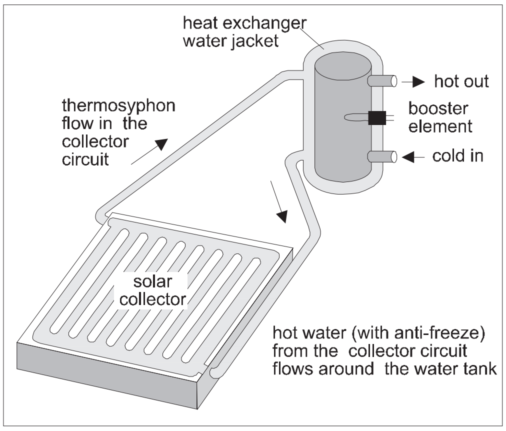

Figure 12.2.14: A split collector/storage solar water-heating system

Large commercial or institutional systems

These are all-purpose designed split collector/ storage-type systems. They are generally forced-circulation systems, although thermosiphon systems are possible if the storage tanks can be located sufficiently high above the collector bank. As in the case of domestic SWH systems, indirect heating is required in freezing areas.

Typical examples of larger systems are those at the Milnerton Girls School (Maclean 1982) and an old age home in Durban (Forbes and Dobson 1982).

Design for upgradability

In cases where the user/client is reluctant to spend the full initial cost of the SWH system, it is recommended that the (electrical) water-heating system be designed so that it can be upgraded for solar heating at a later stage.

Upgradability requires minimal extra expense (a solar-adaptable storage tank), consideration of solar access (for the future collectors), and the location of the storage tank in a position which allows short and inclining collector loop piping.

System sizing

Tables 12.2.13 and 12.2.14 provide guideline information for sizing SWH systems in typical South African conditions.

System design

System design should focus on functionality and reliability. Although thermal efficiency is important, the utilisation of SWH systems is directly dependent on reliable operation over the full design life of the system.

In the case of domestic hot water systems, there are two applicable SABS standards:

- SABS 1307:1992. Specification for domestic solar water heaters (and two associated standard test methods for physical durability testing and thermal performance testing).
- SABS 0106:1985. Draft Code of Practice for the installation of domestic solar water heaters.

Table 12.2.13: Typical hot water requirements for domestic and institutional purposes

HOT WATER SERVICE	HOT WATER SUPPLY TEMPERATURE (DEG C)	WATER TEMPERATURE REQUIRED (DEG C)	VOLUME PER DAY (LITRES/PERSON)
Domestic	55	43	50 - 75
Hospitals	65	43	120
Old age homes	65	43	100
Per shower	55	43	25 - 35
Per bath	55	43	80 - 120

Table 12.2.14: Guidelines for sizing domestic SWH systems

NUMBER OF PEOPLE PER HOUSEHOLD	LITRES OF HOT WATER REQUIRED AT 43°C	SOLAR STORAGE TANK SIZE (LITRES)	COLLECTOR AREA (m^2) DUE NORTH AT LATITUDE +10°
2 - 3	100	100	1,4 - 1,6
4 - 6	200	200	2,8 - 3,2
6 - 8	300	300	3,8 - 4,2

Other solar energy applications in South Africa

Solar water heaters, solar photovoltaic units and the passive solar design of buildings remain the most significant solar energy applications in South Africa at present.

Solar energy can also be used for process heat in industry and agriculture, but this is generally not of relevance to settlement-planning.

In the future it is possible that other means of generating electricity from solar energy will become more widespread. Brief details on solar thermal electricity generation are provided in the section "Other renewable energy sources" below.

Solar cookers

Solar stoves and solar ovens would have great relevance in South Africa if they were popularly adopted on a wide scale. They are mostly considered as a supplementary cooking option in areas of fuel scarcity, in addition to LPG, paraffin, fuelwood and crop residues. In particular, they could benefit households struggling to collect fuelwood, crop residues or dung for their cooking needs, and might help to conserve the environment.

Solar cookers generally use reflectors to concentrate radiant solar energy either directly onto a pot or into a glazed and insulated box (called a "box cooker" or "solar oven"). They are capable of cooking the typical meals of rural and low-income households. A variety of designs are available locally and internationally, including simple solar ovens, reflector-type cookers and heat pipe cookers.

Experience with the promotion of solar cookers in Southern Africa in the 1980s was disappointing. Cooking customs are deeply rooted and slow to change (except in extreme conditions - for example in refugee camps). However, a recent one-year, field testing project (Palmer Development Group 1998) undertaken on behalf of GTZ and the Department of Minerals & Energy has shown high levels of satisfaction (93%) and good utilisation (38% of all meals cooked) of a range of solar cookers.

Typical costs of the cookers in this study ranged from R180 (Sunstove) to R4 600 (SCHW1). The study found clear user preference for certain cooker types, based on utility and cost, and many of the participating households opted to buy a solar cooker.

Solar cookers are safer than fuelstoves or fires, due to the absence of a flame and greater stability.

OTHER RENEWABLE ENERGY SOURCES

This section provides a brief description of other renewable energy sources which are not widely used in South Africa at present (with the exception of wind pumps), but which may be considered in specific circumstances. The topics covered in this section are

- wind power;
- small hydropower;
- biogas and exploitation of landfill gas; and
- solar-thermal electricity generation.

Wind power

Wind power is usually employed either directly (mechanically) for water pumping, or for electricity generation.

Wind pumps

Water-pumping by windmill is a well-established technology that has long been widely used in South Africa, mainly in rural areas but also in small towns. The familiar "American farm windpump" design (with a large number of blades) is well proven, efficient for water pumping, and locally available from a number of manufacturers. More than 300 000 windpumps of this type have been installed in the country (Cowan 1992) although not all would still be in operation. These types of windpump are particularly suited to pumping relatively small quantities of water from deep boreholes, using positive-displacement pump mechanisms (e.g. for livestock watering) and can be used in areas with quite low average wind speeds (e.g. 3 ms^{-1}) but are more likely to be a cost-competitive option if wind-speeds average 4 ms^{-1} or more. Regular basic maintenance is required for trouble-free operation, and partly for this reason there has been a trend in countries such as South Africa and the United States to move towards solar PV pumps for typical ranch and game park applications (in areas without grid electricity).

The use of wind pumps for community water supplies in rural areas has so far not had a very good record in South Africa. The main problems appear to have been unreliable maintenance, lack of community involvement and ownership (Wiseman 1992), and sometimes unreliable supply/storage of water due to variations in wind energy at different times of the year, and from year to year. Any decision to use wind pumps for a community's water supply, and the design of suitable installations, should take account of

- community water needs (quantities, quality, reliability);

- the nature and reliability of the water-supply source;
- the availability of reliable wind-speed data;
- the adequacy of the local wind resource, especially in the calmest months;
- linked to this, the amount of windmill oversizing and water storage required to provide a reliable supply (or else the availability of back-up water supplies);
- water-treatment facilities;
- reliable provisions for routine maintenance and speedy repair; and
- the comparative costs and advantages/ disadvantages of alternative water-pumping options.

A good guide to wind pump sizing, design and economics is Van Meel and Smulders (1989). South African wind pump suppliers have considerable experience and can provide practical recommendations, sizings, costings, etc.

Wind-powered electricity generation

The use of wind energy for electricity generation is one of the fastest-growing developments in the world energy industry at present. Electric wind turbine generators have been used for decades for off-grid electricity (e.g. on farms) but large-scale wind farms feeding power into national grids are more recent. In areas of the world where there are favourable wind resources for electricity generation (greater than 6,5 ms^{-1} mean wind-speeds, preferably higher) and where other sources for electricity generation are expensive or inadequate, grid-connected wind farms are financially viable.

Grid-connected wind generation

Large, efficient and reliable wind turbines involve high-technology design and manufacture. The most cost-efficient machines used to be in the range of a few hundred kilowatts (rated power) but, through technical advances, now generate 1-1,5 MW. In the competitive world market for such wind turbines, there are a number of international market leaders. This leading-edge technology is considered mature and reliable, but still advancing.

Typical costs

Typical international capital costs and electricity generation costs for large-scale wind farms in 1997 were in the region of 4-5 US cents per kWh generated, in locations with very good wind resources.

The costs per kWh are highly dependent on wind speeds, because available wind power is proportional to the cube of the wind velocity. Locations for viable wind farms typically have annual wind speeds in the range 6,5-10 ms^{-1}.

Dependence on wind speeds

The total power of a wind, moving through an area of A m^2 with velocity V ms^{-1}, is given by 0,5 ρAV^3, where ρ is the density of the air in $kg.m^{-3}$ (typically 1,2 $kg.m^{-3}$ at sea-level, 1,0 $kg.m^{-3}$ at 1 500 m altitude). Not all this kinetic energy can be captured by a wind turbine. There is a theoretical maximum which can be captured - about 59% of the total power, known as the Betz maximum; the actual power captured is always less than this. Table 12.2.15 shows the dependence of maximum power on wind velocities.

Table 12.2.15: Maximum wind-power flux (Wm^{-2}) for different wind speeds

WIND SPEED (ms^{-1})	TOTAL WIND POWER (Wm^{-2})	MAXIMUM USABLE WIND POWER (BETZ MAXIMUM, Wm^{-2})
2	4	2
4	35	21
6	119	70
8	282	166
10	550	325
12	950	561
14	1 509	890

Note: For air density 1,1 $kg.m^{-3}$.

Wind turbines can be designed to obtain their peak efficiency at lower or higher wind speeds. However, this does not alter the fact that much less usable power is available from lower-speed winds.

The rated power of a wind turbine is specified for a particular wind speed (often 10 ms^{-1} or more). If a 1 MW machine is rated for a windspeed of 10 ms^{-1} it may deliver only 200 kW at a windspeed of 6 ms^{-1}, or 600 W at 4 ms^{-1}.

This strong dependence on wind speeds illustrates the vital importance of having (a) sufficiently good wind resources, and (b) reliable wind data when assessing and approving the feasibility of wind-generation schemes. A 10% error in estimating the wind resource could lead to a 30% error in estimating the costs of generating electricity.

Energy "storage" through grid connection

Available wind power at a particular site varies from hour to hour, day to day and year to year. Connection to the national grid can provide a "storage" buffer. For example, a wind farm can provide for a local municipality's needs when sufficient wind power is available, and export to the national grid when there is a surplus. When there is a deficit, power from the national grid is imported. South African wind regimes tend to be highly variable, particularly in higher-wind areas affected by cyclic weather patterns.

Financial and regulatory issues include the tariffs at which surplus wind-generated electricity will be purchased by the grid utility, the obligation on the utility to purchase surplus generation (if applicable) and the licensing conditions for the independent power producer (IPP), if applicable. None of these has yet been fully established in South Africa, but policies are on the table to pave the way for fair access to the national transmission network by IPPs.

Applicability of grid-connected wind generation in South Africa

It seems unlikely that the South African national grid, or the Southern African Power Pool, will incorporate significant wind-generation sources in the next ten years. The main reason is that electricity-generation costs from South African coal-fired power stations and from regional hydropower are less than half the best-case costs for wind generation. In the longer term, increases in the cost of coal-fired electricity generation, and pressures to rely increasingly on renewable forms of energy, may encourage more extensive use of wind energy. Pilot wind farms could be justified partly on the grounds of establishing experience for such longer-term developments.

In the short term, such pilot projects would usually require an element of subsidisation or concessionary loan finance in order to be economically sustainable. In specific situations the required subsidy element may be small - for example where:

- a municipality cannot obtain an adequate national-grid supply for less than say 25-30 cents/kWh, and/or is willing to pay a comparable amount for wind-generated electricity;
- existing transmission lines are adequate for maximum imports/exports;
- local wind-speeds average more than 7 ms^{-1} (at the hub-height of the wind turbines); and
- there is sufficient local demand for wind-generated electricity to allow for wind projects large enough to achieve economies of scale, to justify the maintenance infrastructure, etc (e.g. several MW) .

In such a situation, a detailed feasibility assessment for localised wind-farm electricity generation would be warranted. To date, no wind farms have been established in South Africa, although a promising scheme in Darling (Western Cape) is at an advanced feasibility stage.

International interests in promoting environmentally sustainable energy are favourable for obtaining "green" concessionary finance for such wind schemes. In many parts of the world where wind generation is already financially viable without any subsidy, commercial and development banks are widely engaged in wind finance.

Preliminary steps for feasibility assessments

There are two primary questions in any South African feasibility assessment for a potential grid-connected wind generation scheme:

- Are the wind resources in the identified locality sufficiently good for cost-effective wind generation?
- If so, can wind generation be cost-competitive with other electricity-supply options in this locality (taking into account any environmental subsidies for wind generation, if applicable)?

In South African conditions, it is very unlikely that grid-connected wind schemes could deliver electricity for less than the international best costs of 4-5 US cents/kWh. Therefore, if this cost is out of range for consideration, a detailed feasibility assessment is probably not warranted.

Assessing wind resources accurately is expensive and a detailed assessment for wind-farm costing and siting should preferably be undertaken by experts. Before one proceeds to this stage, however, an initial rough assessment of wind energy potential in the proposed locality can be undertaken:

- Check published wind data (e.g. Diab 1995). Is there evidence to suggest promising wind speeds in the region (e.g. an annual mean around 6 ms^{-1} or more)? Is there insufficient evidence to judge? Or is there evidence that annual mean wind speeds are generally too low?

- Check available sources of wind data for the area. How close are the nearest measuring stations? Are the measuring instruments accurate, well maintained and well exposed? Is the data sufficiently long-term to be reliable?

- Consider topography. Are there localities where wind enhancement is expected (e.g. long smooth slopes, "necks", etc)? Is the terrain too complex to make valid use of existing available data? Is turbulence a potential problem (e.g. in mountainous terrain)?

- Consider environmental acceptability (distance from dwellings, visibility impacts) and land-use.

Suitable wind data for initial cost estimates should consist at least of frequency distributions of hourly wind speeds, per month, covering a period of two years or more. These can be multiplied by the "power curves" of suitably sized wind-turbine generators, to estimate the expected electricity generation per year, leading to an initial cost estimate, and a decision whether to proceed to more detailed site-specific wind monitoring. Wind turbine manufacturers/suppliers would normally be pleased to assist.

If available wind data is not adequate for an initial assessment, preliminary site-specific monitoring can be considered, for example by installing a suitably located mast with accurate anemometers at two heights (to measure wind shear) and reliable data-logging. However, given the time implications (at least a year of data collection for preliminary assessment and more than this for detailed assessment) it is advisable to have a strategy for combining these, and expert advice would be useful. The basic techniques for initial assessment are covered well in Lysen (1982).

The broader steps in planning and implementing a wind-energy plant are covered well in the "European best practice guidelines for wind energy development", which is produced by and obtainable from The European Wind Energy Association, e-mail address 10175.1101@compuserve.com.

Off-grid wind generation

Wind power can be used for electricity supply in off-grid areas, either in the form of wind-charger/battery systems or more complex hybrid power systems (where several types of electricity-generating sources are combined - e.g. wind, diesel, solar).

In localities with average annual windspeeds above 4 m/s, even small wind turbines can generate electricity at a lower R/kWh cost than solar PV systems (Cowan et al 1992), but the problem is that the electricity supply from a wind turbine can be very variable in South African climatic conditions. In periods of high wind, much more energy is generated than in periods of low wind. Therefore, if the high-wind periods are interspersed with low-wind periods, a large amount of energy storage is needed to cover the lulls and profit from the peaks in electricity generation, in an optimal way.

In a stand-alone wind/battery system, battery storage/cycling of energy is expensive, adding at least R1-2/kWh to the electricity-generating cost. It is not cost-effective to install sufficient battery capacity to store the full amounts of electricity generated during high-wind periods, and this pushes up the average generating costs of usable energy. As a result, the net costs of off-grid electricity from wind/battery systems are expected to be higher than for PV/battery systems, according to computer modelling for the wind regimes in Cape Town, Port Elizabeth, Alexander Bay and all other major weather data stations in South Africa (Cowan et al 1992).

There is a different situation, however, if wind generators are used in a "hybrid system" configuration for off-grid power supply. By combining different sources of electricity it is possible to level out the electricity supply. To some extent, the combination of wind and solar PV generators can be complementary (especially in areas where higher winds occur during "bad" weather) but the strongest advantages occur when a controllable electricity source such as a diesel (or other engine) generator forms part of the hybrid system. This can reduce the amount of energy storage required, thus reducing costs, and provide a versatile power system for covering peaky and variable loads.

Such hybrid systems are worth considering

- for medium-load demands (e.g. 5-100 kWh/day, although there is no fixed upper limit - that will depend on the cost-competitiveness of other options, in the local circumstances);

- where the load profile is too irregular to permit the use of diesel generators at consistently high capacity factors (this pushes up the operating and maintenance costs of a simple genset power supply); and

- where skilled maintenance and diesel fuel can be provided on a regular basis.

Before including a wind generator in such a system, reasonably accurate wind-speed data should be to hand. It is likely that a partial contribution from wind generation could be technically economical if mean wind speeds are above 4-4,5 m/s. However, the extra complexity of a hybrid system (including the maintenance tasks, and the more complex system control gear required for optimal performance) should be taken into account. For more detailed information on hybrid-system design and applications, a manual and software design tool is available from the Department of Minerals and Energy in Pretoria (Seeling-Hochmuth 1998).

Applications in South Africa

Stand-alone wind-battery systems have been used in applications such as off-grid coastal holiday homes (usually less than 1 kW), and occasionally in larger applications, such as at remote schools. For larger applications, however, it is more common to combine wind generators with diesel or some other form of power back-up.

Hybrid wind-PV systems are being employed at a small number of rural clinics. Hybrid wind-diesel and wind-diesel-PV systems have been used quite extensively on off-grid commercial farms, for example in the Northern Cape.

There is considerable interest in exploring the potential of such hybrid systems to supply power for local mini-grids, in communities far from the grid. This would provide a higher level of electricity service than individual solar home systems, and may therefore be more attractive to consumers. However, the comparative costs have not yet been fully investigated. The viability is likely to depend on government policy decisions about rural electrification subsidies as well as local conditions (load density, energy resources, capacity for maintenance, etc). Hybrid systems for remote-area power supply have been particularly well developed in Australia, but are not yet common for community electricity supply in South Africa.

Small hydropower

Worldwide, hydropower is the largest application of renewable energy, producing more than 20% of the world's electricity. Within South Africa's borders the potential for large-scale hydropower is limited, due to water shortage, but the broader Southern/Central African region has great potential. It is likely that electricity from hydropower will play an increasingly important role in the Southern African Power Pool. This section, however, is concerned with small-scale applications of hydropower as an alternative to electricity from the national grid. Under suitable conditions, small hydropower plants can supply electricity at a lower cost than other off-grid electricity-supply options such as PV, wind or diesel generators.

Definitions of "small", "mini" and "micro" hydropower vary. Typical definitions (Fraenkel 1996) are

- small-scale hydropower: < 10 MW;
- mini-hydropower: < 500 kW; and
- microhydropower: < 100 kW.

Off-grid hydro plants in South African conditions are most likely to occur in the "micro" range. Eskom, for example, has focused on the development and testing of < 15 kW turbines for off-grid remote applications (Beggs 1996).

Applications in South Africa

Off-grid hydropower plants have been used for farm power and water pumping, for institutional use (e.g. electricity for boarding schools) and, to a limited extent, for local-area grids providing community electricity supply. It is estimated that several hundred micro-hydropower systems have been installed in the country. The main limiting factors are

- the availability of suitable hydrological conditions (see below);
- the ability to match the hydropower supply to local electricity demand; and
- thecomparative costs of grid electricity.

Typical configurations

Micro-hydropower configurations are usually "run of river", that is, they make use of the flow of a river and natural gradients, rather than the head of dams.

Figure 12.2.15 shows typical elements of a micro-hydropower installation. A penstock delivers water at pressure to a turbine. The penstock is often a significant cost element, requiring piping of sufficient strength and diameter to handle the water pressure, flow and shock forces. For this reason, depending on the physical characteristics of the site, it is common to construct a gradually sloping canal (gradient 1:500 to 1:1 000) from the water intake to the penstock forebay, in order to reduce the length and cost of the penstock piping. However, in some site conditions, a canal may be unnecessary or impractical.

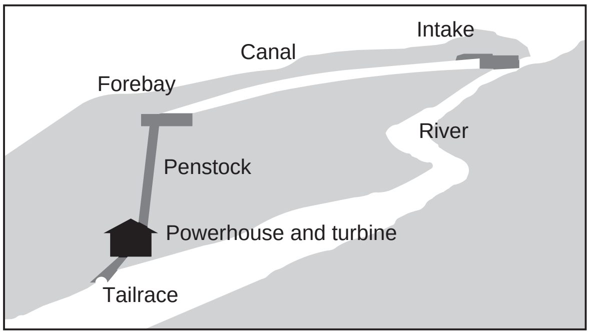

Figure 12.2.15: Schematic of typical micro-hydropower layout

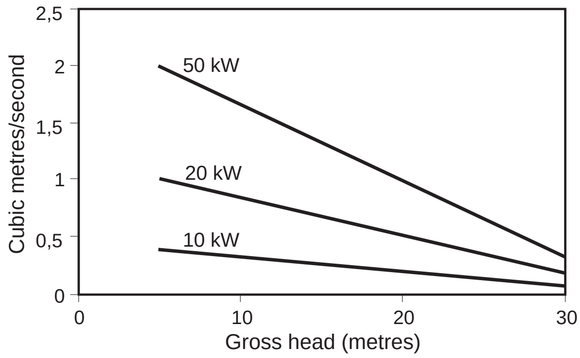

Figure 12.2.16: Approximate net electrical power as a function of flow rates and gross heads

The design of micro-hydropower installations is covered well in many texts (e.g. Harvey 1993; Inversin 1986).

Requirements for cost-effective applications

The cost-effectiveness of off-grid hydropower is highly site-specific. It depends mainly on the hydraulic power available (water flow rate and head), the civil construction required, the size and load profile of electricity demand in the locality, and (where applicable) the cost of distributing the electricity.

Hydraulic power

The gross hydraulic power P_{gross} (kW) available from a vertical head of h_{gross} (m) and volume flow rate Q (m^3s^{-1}), is given by

$$P_{gross} = 9,8 \times Q \times h_{gross}$$

After frictional losses, transmission losses, etc, the net electrical power P_{net} (kW) which can be delivered is usually about 40-60% of the gross hydraulic power (Harvey 1993), leading to the approximation

$$P_{net} \approx 5 \times Q \times h_{gross} \text{ (kW).}$$

Figure 12.2.16 shows approximate net electrical power for a range of flow rates and heads.

Flow rates can be measured by a variety of techniques, including

- installing a notched weir across the river - the water level above the notch indicates flow rate; and
- the "salt gulp" method - where salt water is poured into the river upstream and a conductivity meter is employed downstream to record the rate at which the salt cloud passes (Harvey 1993).

Account must be taken of variations in flow rate, requiring measurements at different times of year. Estimates of year-to-year variations can be made by looking for correlations between such measurements and longer-term records (e.g. records of water flow for gauged rivers in the same/nearby catchment area) or more detailed hydrological assessments.

Civil construction

This can include a weir for intake protection/regulation, the intake itself, a flood spillway, silt basin, canal, forebay tank with silt basin and spillway, penstock (and anchors), powerhouse and tailrace. Costs (and optimum design choices) are affected by labour costs, accessibility and cost of materials.

The proportion of total capital costs attributable to civil works will therefore vary (averaging perhaps 40% in Nepal and Sri Lanka - see Table 12.2.16) and will strongly affect viability.

Electricity demand characteristics

<u>Total demand</u>

Micro-hydropower schemes can show economies of scale. Assuming that sufficient hydraulic power is available throughout the year, the cost-effectiveness is increased for higher load demands. Conversely, if the available hydraulic power is insufficient/unreliable, more expensive back-ups may be required to meet energy needs, raising the overall cost.

<u>Load factor and capacity factor</u>

Hydropower plants have relatively high capital costs and low operating and maintenance costs. Run-of-river hydropower plants do not have significant energy storage, and are therefore most economical when the electricity generated can be fully utilised. If the combined loads are very peaky (e.g. electricity consumption mainly for domestic cooking and

Table 12.2.16: Examples of micro-hydropower capital cost proportions

	NEPAL	SRI LANKA
Penstock	12 %	21 %
Other civil works	19 %	13 %
Electro-mechanical	27 %	48 %
Engineering cost	14 %	12 %
Distribution	28 %	6 %
Total	100 %	100 %

Source: Harvey (1993)

lighting) the load factor will be low (average kW consumed ÷ maximum kW consumed) and the hydropower plant is likely to operate at a low annual capacity factor (kWh/year useful output ÷ maximum kWh/year that could be generated). Oversizing the hydropower plant will also result in low capacity factors. Low capacity factors mean higher unit energy costs, because less benefit is derived from the initial investment. Micro-hydropower viability is therefore improved if

- combined load demand is not too peaky (preferably with peaky loads smoothed out by steadier base loads);
- load demand can adjust to any seasonal variations in hydropower generation capacity; and
- plant capacity factors are high.

Electricity distribution

In cases where hydropower is used for a local grid, supplying many consumers, the electricity distribution costs are likely to be similar to conventional grid distribution. Average electricity costs per consumer, including distribution costs, will be affected by

- distance from the hydropower station and spatial density of consumers; and
- consumption levels and load factor per connection.

Large distances between consumers, with low consumption levels and low load factors, will adversely affect the economics of a hydropowered mini-grid.

In situations where a number of isolated load centres are to be connected (e.g. a number of scattered schools in a district) the use of lower-cost transmission by SWER (single wire earth return) may be indicated. Such a scheme, undertaken by Eskom Non-Grid Electrification, is reported in Dooge (1996).

Typical costs

It is difficult to give general cost guidelines for micro-hydropower electricity supply, because the costs are site-specific. Capital costs for the turbine/generator can be in the region of R3 000/kW (1998 estimate). An indication of the breakdown of the total capital costs (based on figures from Nepal and Sri Lanka) is given in Table 12.2.16.

In 1992, typical South African micro-hydropower unit electricity costs, levelised over a 20-year system life, were estimated as given in Table 12.2.17.

These figures should be inflated by 60-100% to give comparable 1998 estimates. They still show that micro-hydropower can be the cheapest off-grid electricity source, in suitable conditions.

Table 12.2.17: Typical supply costs of micro-hydroelectric power (1992 estimates, excluding reticulation)

HEAD/SLOPE	DAILY DEMAND	CAPACITY FACTORS	
		0,25	0,4
Head 10 m Slope 1:10	5 kWh 25 kWh	74 c/kWh 30 c/kWh	68 c/kWh 23 c/kWh
Head 10 m Slope 1:50	5 kWh 25 kWh	95 c/kWh 39 c/kWh	84 c/kWh 32 c/kWh

Source: Cowan et al (1992)

BIOGAS AND LANDFILLS

Biogas and landfill gas are both potential sources of energy for heating and lighting applications in South Africa. In both cases, methane gas (also known as marsh gas) is produced from a process of digestion of organic waste material. This methane gas can be collected, stored and reticulated for use in households and small businesses. The gas may be used directly in suitably adjusted appliances or indirectly in gensets for electricity generation.

Biogas is highly dependent on a reliable and suitable supply of organic waste (animal manure and plant material) and water. Landfill gas is available only from landfill sites.

Consequently, neither option is generally applicable but there are a number of successful applications which could be replicated. Many municipal sewage works produce biogas as a by-product of the treatment process. This biogas is usually used on site, and not supplied to the surrounding communities. Interestingly, communal household biogas digesters have been widely used in China to handle the digestion of human waste (primarily) and to produce biogas for heating and cooking.

In the case of landfill gas, there are at least two South African applications of note. These include the Grahamstown landfill project, which supplies an adjacent brick kiln, and one of the Johannesburg landfills which provides methane to the chemical industry.

Biogas production

Biogas is produced in a purpose-built biogas digester. The digester comprises an airtight container into which raw waste can be poured, together with water, as a slurry and from which methane gas can be collected under some pressure. There are many configurations of digester, including the underground "Chinese", or fixed-dome digester, and the "Indian" or floating-dome, digester.

The methane is produced by anaerobic digestion of organic matter. The production of methane is highly sensitive to temperature and increases dramatically at higher than ambient air temperatures. The added complexity of auxiliary heating of the digester cannot always be justified by the extra production obtained.

Landfill gas production

Landfill gas is automatically produced in landfills as a result of decomposition of the organic content of municipal refuse collections. This gas is a potential explosion hazard if it is not managed properly and can be utilised productively by creating sealed landfill compartments and extraction wells (similar to boreholes)

Solar-thermal electricity generation

Photovoltaic panels provide a simple, low-maintenance option for generation of electricity from the sun. However, as discussed in the section on solar photovoltaic electricity supply, the per-unit energy costs are relatively high, and there is little size-related reduction in cost as plant size increases. A potentially lower-cost alternative for both small- and large-scale grid-connected plants is to use concentrators to focus sunlight to heat a working fluid, which is then used to drive a conventional thermodynamic power cycle. Thermal-energy storage and/or supplementation with gas-fired burners can be used to deliver power over extended periods. Given the high levels of solar radiation available in parts of South Africa, there has been considerable interest in the possible development of such large-scale grid-connected plants. At present, however, the generation costs would be higher than for South African coal-fired power stations.

Four main technology options are potentially suitable for grid connection. Parabolic dish systems also have the potential to be used in smaller-scale applications (5 kW or larger), either as part of a grid-connected distributed generation system, or for mini-grid or stand-alone applications.

Parabolic trough-based systems

These systems focus sunlight energy onto heater pipes contained within evacuated tubes located along the focal axes of parabolic troughs. Insulated piping connects a field of troughs to a steam generator (with natural gas backup), used to drive a conventional Rankine Cycle turbine-generator. This technology is well established, with a number of plants having been installed. A series of eight plants with a total output of 354 MW has been operating since the late 1980s in California. Demonstrated peak efficiencies of 20% have been achieved.

Power-tower systems

These systems use an array of heliostats (large, individually tracking mirrors) to focus sunlight onto a receiver located at the top of a tower. Here the energy can be used either to generate steam to drive a Rankine Cycle, or to heat air to drive a

Brayton Cycle machine. Several power-tower plants have been established, with the recently commissioned (1996) “Solar Two” project demonstrating integration of molten-salt thermal storage technology.

Dish-Stirling or Dish-Brayton cycle machines

These systems are generally much smaller (of the order of 5-50 kW) per machine. A Stirling or Brayton (gas turbine) machine is mounted at the focal point of a parabolic dish. A large power plant would require a field of such engines to be installed. They are, however, potentially well suited to distributed generation or even stand-alone applications, such as for a mini-grid or for specific higher load applications in rural areas. Dish-Stirling systems currently hold the record for system solar-to-electricity conversion efficiency at 29,4% and can generate AC power directly. The Stirling-engine generator unit also has the potential to be powered by gas or biomass. This allows greater productivity of the capital invested and the potential for night-time or weather-independent power, without relying on expensive battery storage.

Solar chimney

This somewhat unusual approach involves construction of an enormous glass-covered expanse, with the exterior perimeter open and surrounding a tall chimney (perhaps 750 to 1500 m high in current conceptual designs being considered in South Africa). Solar radiation would heat the air trapped under the glass, lowering its density. As a result it would then rise up in the chimney, generating wind speeds in the chimney of the order of 15 ms^{-1}. Wind turbine technology can then be used to generate power. Unlike the technologies described above, solar chimney plants are expected to have low efficiencies (of the order of 1%).

None of the above technologies is currently at a stage where commercial utilisation in South Africa could be justified on financial or economic grounds. However, given the excellent solar resource in parts of the country, the potential reductions in cost that are expected for some of these technologies, and increasing environmental concerns regarding fossil-fuel utilisation, the future prospects for solar thermal power generation may be good. Particular niche markets include regions remote from the grid, or sites where transmission costs result in added cost for conventionally generated power. EPRI & DOE (1997) provide an excellent review of the technical and economic status of solar thermal technologies, from which much of the above material has been drawn.

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