DOMESTIC UTILISATION OF ELECTRICAL GRID ENERGY IN SOUTH AFRICA

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PREFACE

I am most grateful to Prof Lane for his guidance and for the encouraging support which he has always given me while working on this project.

A special word of thanks must go to the municipalities in the Western Cape who have given me valuable data about their domestic consumers.

I am very grateful to Mr Brian Lee for proof reading this document. His comments are very much appreciated.

My thanks to my wife Elizabeth and my children, for their kind patience and help while I was working on this project.

ABSTRACT

The domestic sector is one of the largest users of nett energy in the RSA (24%, excluding energy used for transport), but it accounts for only 14% of the electrical energy used in the RSA.

There is a very strong correlation between the time of the peak of the load for the domestic sector and the time of the peak of the national load. The domestic load is the largest contributor to the peak of the national load. This makes the domestic load more important than is generally realised.

Only limited research has been done about the ways in which domestic energy is used in South Africa. Developed countries, such as the United States of America, are continuously engaged in end-use load research, so they have vast data banks available on domestic end-uses of electricity. Data on domestic end-use of electricity are urgently needed especially for South Africa with its very fast growing newly urbanised sector. Since most energy sources are not replenishable, ways and means must be found to promote the wise and effective use of all forms of energy. Effective use of energy can only be promoted if the ways in which electricity is used are known.

In this dissertation the electrical energy requirements of the South African domestic sector are analyzed for the present situation and for the next few decades. A model is developed to represent the electrical load. The model has subsections representing the components of the national domestic

electrical load, concentrating on electrical energy for domestic water heating, with responses to factors such as:

- population growth,
- urbanisation,
- electrification,
- energy efficiency of appliances,
- consumer awareness of energy conservation.

The model is to be used for scenario planning of the electrical grid.

The results of this study will assist to ensure effective planning of the electrical grid of South Africa into the next century.

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1 INTRODUCTION

1.1 Motivation

The domestic sector is one of the largest users of nett energy in the RSA (24%, excluding energy used for transport), but it accounts for only 14% of the electrical energy generated in the RSA. In developed countries 24% to 38% of the electrical energy generated is used in the domestic sector. (Youliang, 1988:215)

The main reason for the low percentage use of domestic electrical energy in South Africa is that less than half of the South African population have electricity in their homes. It was reported that the South African domestic electrical energy consumption in South Africa was 55 PJ (13%) in 1984, while the total nett domestic energy consumption was 429 PJ (Basson, 1987:295). Another source which has the domestic consumption of coal somewhat lower, states that the domestic electrical energy consumed in 1988 was 69 PJ (20%) while the total nett domestic energy consumption was 346 PJ (van Niekerk, 1990:1).

The urban developed sector uses mainly electrical energy, but the developing and underdeveloped sector of the community uses mainly firewood. Firewood constituted 51% (219 PJ) of the total domestic energy during 1984 (Basson, 1987:295).

It is important to note that there is a very strong correlation between the time of the peak of the electrical energy demand of the domestic sector and the time of the peak of the national load. A simple calculation based on a typical domestic load shape and the national load shows that an increase in the domestic load, which will increase the national energy consumption by 5%, will increase the national maximum demand by as much as 7,5%. The total number of small energy consumers (e.g. space heaters and stoves) can very easily add up to

Table 1 Total Nett Energy demand by the domestic sector according to energy source.

Energy Source	YEAR					
	1988		2000		2020	
	PJ	%	PJ	%	PJ	%
Electricity	69	20	106	26	218	35
Coal	43	12	45	11	56	9
Oil	25	7	51	12	89	15
Gas	1	1	1	1	2	1
Non-commercial	208	60	209	50	240	40
TOTAL	346	100	412	100	605	100

become peak energy consumers. This implies that domestic energy consumption has a greater impact on national energy demand than is generally realized.

As the South African community develops during the next few years, the electrical energy used in the domestic sector is expected to increase more than three fold by the year 2020, as indicated in Table 1 (van Niekerk, 1990:2). The time it takes for the South African developing population to develop cannot be predicted accurately, but that the South African developing community will develop is not doubted. A thorough knowledge of the use of electrical energy by the developed sector of the community is invaluable in determining the future use of electricity when most of the South African population has developed.

Only limited research has been done about the ways in which domestic energy is used in South Africa. Since most energy sources are non-replenishable, ways and means must be found to promote the wise and effective use of all forms of energy. Much work has been done in this regard in developed countries such as the United States of America, but knowledge in this field is urgently needed specifically for South Africa, which has a very fast growing newly urbanised sector.

In this dissertation the electrical energy requirements of the South African domestic sector is analyzed for the present situation and for the next few decades. Special reference is made to the electrical energy needed to provide hot water. Models are developed to represent the electrical load. The results of this study will assist to ensure effective planning of the electrical grid of South Africa into the next century.

1.2 Objectives

This study aims at developing a model with subsections representing the components of the national domestic electrical load, concentrating on electrical energy for domestic water heating, with responses to factors such as:

* population growth,
* urbanisation,
* electrification,
* energy efficiency of appliances,
* consumer awareness of energy conservation.

The model is to be used for scenario planning of the electrical grid.

The objective of this study is to concentrate on the use of hot water in the household, while investigating the use of electricity for other domestic purposes in less detail. Some studies have been conducted in this field, but a model representing when and for what hot water is used, calibrated for South African conditions by using actual measurements, is not available.

Studies which have been conducted include the following:

* An analysis of time and volume distributions for hot water consumption using data acquired from seven New Zealand households. This study gives a useful analysis of the frequency and size of hot water use. From this information reliable estimates of energy losses in hot water pipes can be determined. (Carrington *et al.*, 1985:65-75)

* A physical model of a hot water system was built at the Department of Mechanical Engineering of the University of Canterbury, New Zealand, to determine possible savings by using solar panels and waste water heat exchangers. The system was microprocessor controlled and has given very useful information on pipe and other losses in a hot water system (Parker & Tucker, 1991:8-18).

* EPRI (Electric Power Research Institute) in the United States has developed a computer model of a number of water heaters. The model represents the physical characteristics of the hot water cylinders such as insulation thickness, type of insulation material and tank size. The model is developed by EPRI for use by their members. A personal telephonic conversation in July 1992 with Dr Carl Hiller from EPRI has revealed some of the details of the model. The model is designed specifically for the conditions in the USA and is used by their utilities to predict energy savings due to proposed energy conservation measures.

* A comprehensive domestic end-use study has been conducted in New South Wales to provide an insight into and an understanding of the nature of demand for electricity by the domestic sector. The information is to be used for estimating demand profiles and to develop forecasting models (Bartels *et al.*, 1988).

Major end-uses analyzed in this study are water heating, space heating, clothes drying, cooking, dishwashing, freezing, automatic defrosting of the fridge and pumping of swimming pool water. Water heating, for example, constituted 13 % of the total domestic load (Bartels *et al.*, 1988:18), which is much lower than in South Africa.

* An estimate of the hot water usage in South Africa was made by J.L. Coetzee in a report for the National Energy Council. The estimate is based on the hot water consumption in a few municipalities. The study was conducted to estimate the effect of introducing heat pumps for domestic water heating (Coetzee, 1989:34).

* The United States Department of Energy has published a useful load research manual. This manual helps utilities to comply with United States legislation which requires them to report their findings as prescribed under the Public Utility Regulatory Policies Act of 1978 (Argonne National Laboratory, 1980).

1.3 The use of electricity in westernised homes

The domestic use of electricity differs greatly from country to country. Factors which influence the use of electricity include:

- type, design and construction of dwelling,
- culture of the user,
- climate,
- size of family,
- appliance ownership,
- availability and cost of other energy sources,
- income,
- knowledge of the user.

The above factors (Schipper *et al.*, 1985) apply in different magnitude to different end-uses of electricity. It is thus important that each end-use be investigated separately. The use of electricity can be divided into the following categories:

- water heating,
- lighting,
- food preparation,
- refrigeration,
- space heating/cooling,
- laundry appliances,
- life quality appliances,
- swimming pool water circulation and cleaning.

For the purpose of the above categories, life quality appliances can be defined as appliances which are not included in any of the other categories and which help to improve the quality of life, such as appliances used for entertainment and hobbies.

The RSA has a mixture of first-world and third-world dwellings. The use of energy in both the well-established, westernised, first-world homes and in newly-urbanised homes of the metropolitan areas is investigated. The use of energy in the newly urbanising community is reported on by Uken and Sinclair (1990:1-69).

1.4 Electricity usage by function

Domestic energy has not been considered a large component of South African energy requirements, and the major drives to conserve energy in western nations since the oil crisis in the seventies have not been promoted in South Africa with the same determination as they have been in western nations. Some data about the domestic end-uses of electricity in South Africa are given as background information.

According to an unpublished report (NBRI, 1982), the breakdown of the average use of electricity at 10 870 kWh per annum per home was observed in 7 middle class homes in Pretoria as far back as 1976, as shown in Table 2.

Table 2 Average electricity usage in SA homes.

Function	%
Water Heating	41
Cooking	14
Refrigeration	12
Lighting	8
Dishwasher	7
Plugs	7
Space Heating	5
Kettle	3
Washing Machine	3
	100

Although the values shown in Table 2 do not reflect the use of electricity by appliances such as TV sets, swimming-pool pumps, air conditioning units or tumble driers, they do at least suggest that the main uses of domestic electricity are for water heating, cooking and the popular freezer/refrigerator combination.

Another study, of which the results are listed in Table 3, was undertaken in 1979. It shows the wide variety in the electricity usage per month of different households with similar numbers of occupants. (Nieuwmeyer, 1980).

The 1988 statistical yearbook of ESKOM (1988:19) states that the domestic electricity consumption in the RSA is 14,7 % of the total electricity consumption (Eskom 1988:47), and that 129 493 million kWh were sold during 1988. So the domestic consumption of electrical energy for 1988 was 19 000 million kWh. Coetzee (1989:33) reports that the following is being used for water heating:

get
new
data

- in winter: 23 million kWh/day
- in summer: 19 million kWh/day, when feed water temperature is 10°C higher.

Table 3 Typical use of electricity in South African homes

HOUSE	A	B	C	
FUNCTION	kWh/m	kWh/m	kWh/m	%
Water heater	312	272	193	18
Stove	50	88	52	5
Refrigerator		30	37	3
Freezer			100	9
Kitchen			227	21
Lighting	152	215	202	19
Swimming Pool			255	25
Total			1066	100

When calculated in annual terms the electrical energy for water heating amounts to 7 759 million kWh/year which is 41% of the annual domestic consumption, assuming that the energy for hot water reported by Coetzee was for 1988.

This seems a little high, especially if it is compared with electricity usage in IEA countries as listed in Table 4 (IEA 1989:34), but direct comparisons with developed countries with different climatic conditions and different ethnic groups cannot always be made.
Considering a family of 4, Table 4 gives the following averages:

for lighting : 852 kWh/a,
water heating : 1 552 kWk/a,
refrigeration : 1 520 kWh/a.

These values differ considerably from the values which are available for South African conditions.

Table 4: Residential electricity end-use

FUNCTION	kWh per capita per annum						
	Germany	Italy	Japan	Sweden	UK	USA	Average
Space heating*	372	21	157	1 695	321	415	497
Water heating*	304	281	150	748	328	519	388
Cooking*	139	21	-	244	225	218	169
Lighting	111	113	231	293	128	405	213
Refrigeration	298	129	327	533	280	716	380
Other appliances	361	145	272	620	316	779	415
TOTAL excluding space heating	1 213	689	980	2 438	1 277	2 637	313

FUNCTION	Domestic electricity use as a percentage excluding space heating						
	Germany	Italy	Japan	Sweden	UK	USA	Average
Water heating	25	41	15	31	26	20	26
Cooking	11	3	-	10	10	8	9
Lighting	9	16	24	12	10	15	14
Refrigeration	25	19	33	22	22	27	25
Other appliances	30	21	28	25	25	30	26
TOTAL excluding space heating	100	100	100	100	100	100	100

* Gas is also utilized for these purposes in many countries.

1.5 Conclusions

There are reasons for the differences between South African domestic electricity consumption patterns and those in developed countries, such as the use of gas for water heating in other countries and differing climatic conditions, but it appears that reliable data are required for South African conditions if meaningful comparisons are to be made.

As reliable data become available, it may also become clear that there is much scope for more efficient use of electricity in South Africa.

Any effort to reduce domestic electricity consumption should concentrate on usages which account for a large portion of the electrical energy and/or on those in which a large reduction of consumption is possible so as to lead to a considerable decrease in cost.

According to the International Energy Agency the residential sector accounted for about 32% of electricity used in IEA countries. From 1982 to 1987 its consumption increased by 3,4% per annum, almost double the rate of increase in total primary energy requirements. (IEA, 1989:31).

It is clear from the above observations in IEA countries, which are all developed countries, that the percentage of electricity used by the domestic sector in developed countries is much larger than the corresponding percentage in South Africa. It can be expected that this percentage will also increase in South Africa as the country develops.

2 THE MATHEMATICAL MODEL OF THE ELECTRICAL LOAD

2.1 Factors influencing the magnitude of the domestic electrical load

Factors which influence the total electrical domestic load for South Africa are:

- * the size of the South African population;
- * the availability of electricity in the home;
- * the ownership of electrical appliances;
- * the power rating of the appliance;
- * the attitude of the consumer (e.g. economy values, conservation values).

All the factors mentioned above are reasonably obvious, but the ownership of appliances may need some explanation.

Various studies have shown that the consumption of electricity by the consumers of the developing community in newly electrified areas is heavily influenced by the ownership of appliances (Heron *et al.*, 1990:8).

The future increase in domestic load will be largely the result of increased urbanisation and population growth in the developing community.

The developed community in South Africa is not likely to grow very much over the next few decades, and is also not likely to use more energy per household, as is indicated by the fact that many other developed countries have experienced a reduction in domestic energy usage because of concern about the adverse influence of the use of fossil fuels on the environment.

It has been predicted that the township load will constitute as much as 10 % of the evening winter peak in 2010, whereas this only constituted 3,6 % during 1989. (Lane & Delport, 1991:3.1)

In the developing community, a strong positive correlation exists between the ownership of appliances and the use of electricity (Heron *et al.*, 1990:9). The basic appliances which are bought by members of the developing community as they start using electricity replace other appliances which use non-electric energy sources. Examples of such appliances are the hot plate, kettle and bar heaters. But for the more developed community there is sometimes a negative correlation, because when new appliances are bought they do not replace other fuel sources, but do some of the tasks already done by electric appliances. However, in many cases they do so more efficiently. These appliances are specifically designed for the purpose, so they can be designed to be more energy efficient. Examples of such appliances are the electric cooker pot and the microwave oven.

It follows that a model predicting future electrical energy demands for South Africa, based on appliance ownership, is likely to be more accurate for the developing community than for the developed community. However, such a model can also be used with success for the developed community.

It is evident that a model predicting the future electrical energy demands should be based on the ownership of appliances, as the developing community of South Africa are likely to be responsible for the greatest future increases of the national domestic load.

A model will be developed which will make provision for different types of consumers and different types of appliances.

2.2 The electrical domestic load of one household

The probable domestic energy consumption of a appliances per time unit, per customer (household) h of consumption category c in the region g at time t can be represented as:

$$L_{gcht} = \sum_{j=1}^{a} e_{gc} o_{gcj} u_{gcjt} P_j \quad . \quad 1$$

where:

e_{gc} = percentage of customers (households) in region g, category c who have grid electricity in their homes;

o_{gcj} = percentage of customers (households) in region g, category c, with grid electricity in their homes who own appliance j;

u_{gcjt} = usage of appliance j by a customer (household) in region g, category c at time t, (this factor also allows for the reduction in the use of other appliances, because the owner now has this appliance; u could even be negative);

P_j = power rating of appliance j;

g = the geographical region where customer (household) h is situated;

c = category, a factor indicating the living standard of customer (household) h;

j = appliance;

h = customer (household).

The total domestic consumption due to appliance j in region g, for all r categories, over a period of n time intervals will be:

$$L_{jg} = \sum_{c=1}^{r} \frac{N_{gc}}{S_{gc}} \int_{t=0}^{n} L_{gcjht}\,dt \quad \cdot\cdot \quad 2$$

where:

N_{gc} = number of people of category c in region g;

S_{gc} = number of people per household for category c in region g.

The national load for a particular appliance can also be calculated as follows:

The probable electrical load for appliance j as used by household h is:

$$L_{gcjht} = e_{gc}\ o_{cgj}\ u_{gcjt}\ P_j \quad . \ 3$$

The national load due to appliance j over n periods of time, category c for all r household groups and geographical region g for all t geographical regions is:

$$L_j = \sum_{g=1}^{t} \sum_{c=1}^{r} \frac{N_{gc}}{S_{gc}} \int_{t=0}^{n} L_{gcjht}\,dt \quad \cdot \quad 4$$

2.3 Geographical Regions

For the purpose of the model, the country must be divided into geographical regions. The division will be influenced by the availability of data and the statistical justification for the division.

It has been found that data about appliance ownership are available according to National Press Union areas. For this reason it seems appropriate to refer in this study to geographical regions as defined by the National Press Union.

The NPU divides the country up into 8 regions:

A. Witwatersrand
B. Northern Transvaal
C. Orange Free State
D. Natal
E. Eastern Cape
F. Northern Cape
G. Western Cape
H. Transkei.

(SAARF, 1991:17)

These regions are a combination of magisterial districts as used by the Central Statistical Services.

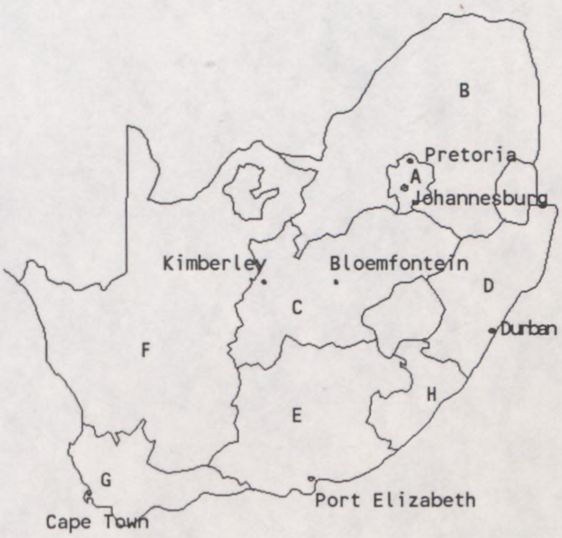


Figure 1
Map of National Press Union Areas

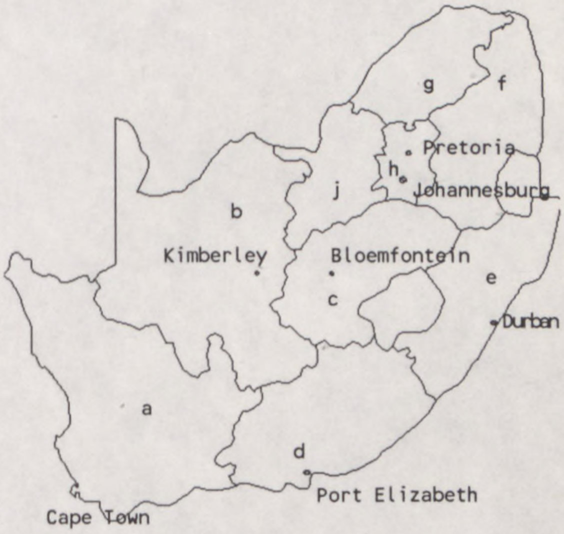


Figure 2
Map of Development Regions

The National Press Union areas differ slightly from the Development regions as used by the Central Statistical Services.

The difference is mainly that the Western Cape region of the National Press Union division is much smaller in area, and the Northern Cape region is correspondingly larger; and the Transvaal region of the NPU is divided into Western Transvaal, Northern Transvaal and Eastern Transvaal.

2.4 Categories

In each area there are various categories of people with certain standards of living who live in specific sections of the areas.

In metropolitan and urban areas the categories are:

* upper class urban;
* medium class urban;
* newly urbanised, who have formal dwellings;
* newly urbanised, but living in informal dwellings;

in villages, those having:

* a high standard of living;
* a medium standard of living;
* a low standard of living;
* informal dwellings;

in rural areas, those having:

* a high standard of living;
* a medium standard of living;
* a low standard of living.

2.5 Application of the model

To apply the model, one needs a vast amount of data. The manpower needed to collect this data, to analyze it and to structure it in the required form, is considerable, and is beyond the scope of this study. The usefulness of this model has been demonstrated in this study by determining the electrical energy required for hot water consumption, both for 1990 and for the year 2000.

3 POPULATION TRENDS

3.1 Population growth: developing world and developed world

It has taken from 1850 to 1925, 75 years, to increase the world population by 1 000 million from 1 000 million to 2 000 million, from 1925 to 1975, 50 years, to add another 2 000 million, and it has only taken from 1975 to 1986, 11 years, to increase the world population by 1 000 million from 4 000 million to 5 000 million.

Presently 277 children are born worldwide every minute, of which about 245 are born in less developed countries.

It is estimated that the annual percentage population growth during the period 1990 to 2000 will be 0,46% for the developed world, and 2,03% for the less developed world, while the average annual percentage population growth for the world is expected to be 1,7% (United Nations, 1991: *World population prospects 1990* as referred to by Spies, 1991b:3.86).

Table 5 The increase in world population to the year 2020

Period	Number of years	Population in millions
1850-1925	75	2 000
1925-1960	35	3 000
1960-1975	15	4 000
1975-1986	11	5 000
1986-1997	11	6 000
1997-2008	11	7 000
2008-2020	12	8 000

Table 6 gives comparative increases in world population for the period from 1950 to 2025 (Spies 1991b:3.84). It can be seen from Table 6 that while the expected growth rate for the developed regions of the world for the period from 1950 to 2025 ranges from 0,93 % to 0,46 %, the growth rate for the developing regions is expected to range from 2,24 % to 1,44 %.

Table 6: Comparative increases in the world population from 1950, with forecasts up to 2025 (United Nations, 1991: *World population prospects 1990* as referred to by Spies, 1991b:3.86).

	Million persons 1950	Million persons 1990	Growth %/year 1950-90	Million persons 2000	Growth %/year '90-2000	Million persons 2025	Growth %/year 2000-25
World	2 517	5 292	1,88	6 261	1,70	8 504	1,23
Developed	833	1 207	0,93	1 264	0,46	1 345	0,28
Less Developed	1 684	4086	2,24	4 997	2,03	7 150	1,44
Latin America	166	448	2,51	538	1,85	757	1,38
North America	166	276	1,28	295	0,67	332	0,47
Eastern Europe	89	113	0,60	117	0,35	123	0,20
Northern Europe	72	84	0,39	86	0,24	88	0,09
Southern Europe	109	144	0,70	148	0,27	148	0,00
Western Europe	123	157	0,61	159	0,13	156	-0,08
China	555	1 139	1,81	1 299	1,32	1 513	0,61
India	358	853	2,19	1 042	2,02	1 442	1,31
Rest of Asia	464	1 121	2,23	1 372	2,04	1 957	^[1,43
Oceania	13	26	1,75	30	1,44	38	0,95
USSR	180	289	1,19	308	0,64	352	0,54
Southern Africa	46	130	2,63	171	2,78	312	2,43
Rest of Africa	176	512	2,71	696	3,12	1 285	2,48

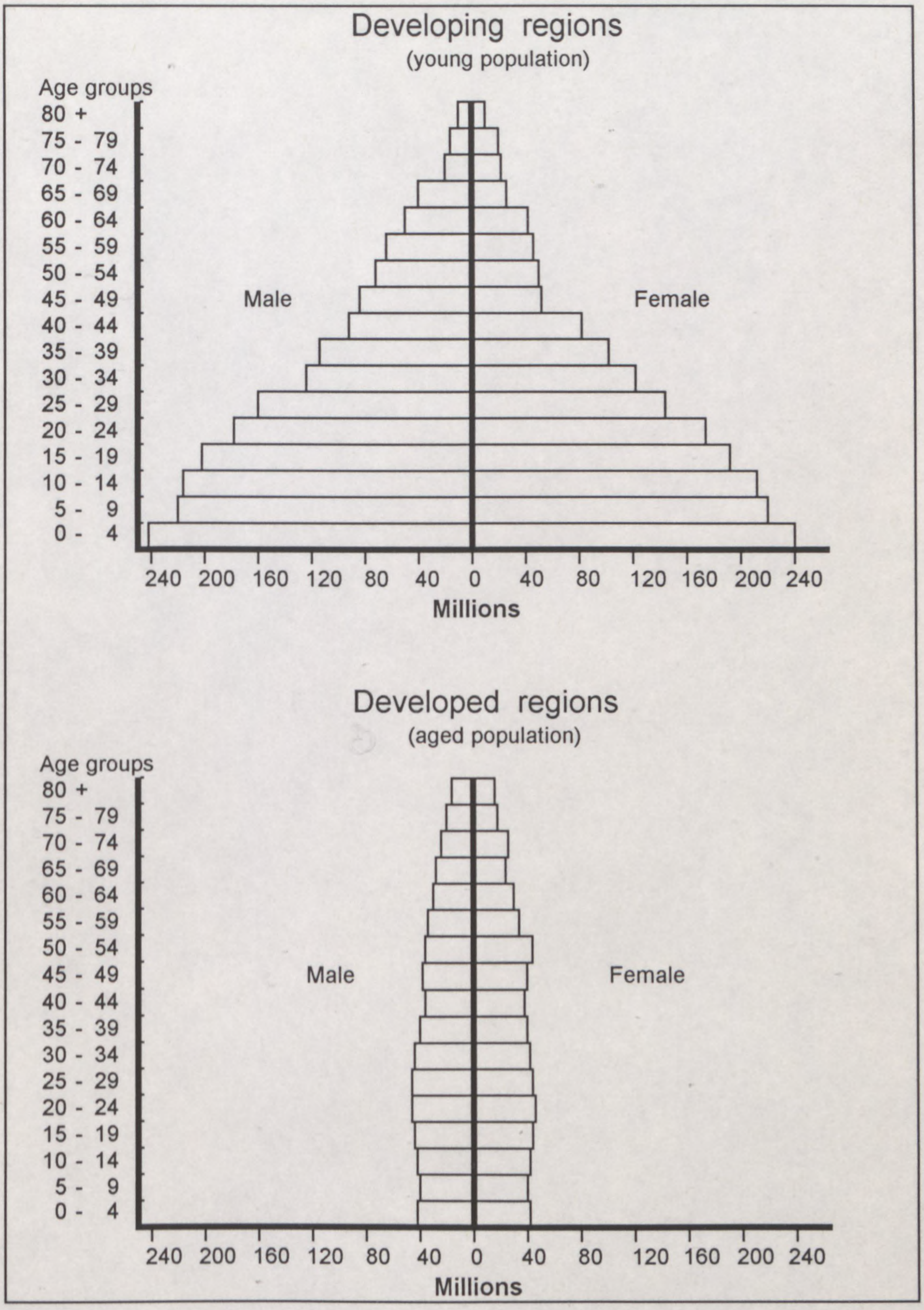
Groupings in the table represent the following countries and regions:

Latin America: Caribbean, Central and South America
North America: US, Bermuda, Canada, Greenland, St Pierre and Miquelon

Eastern Europe: Bulgaria, Czechoslovakia, German DR, Hungary, Poland and Rumania
Northern Europe: Channel Islands, Faeroe Islands, Finland, Iceland, Ireland, United Kingdom, Isle of Man, Denmark, Norway and Sweden
Southern Europe: Andorra, Albania, Gibraltar, Greece, Holy Sea, Italy, Malta, Portugal, San Marino, Spain and Yugoslavia
Western Europe: Austria, France, West Germany, the Benelux countries, Monaco and Switzerland

Rest of Asia: The rest of Asia including Arab countries and Israel

Southern Africa: South Africa (1910 boundaries), BLS countries, Namibia, Mozambique, Zimbabwe, Zambia, Malawi, Angola and Zaire



Developing regions
(young population)

Developed regions
(aged population)

Figure 3 Population age pyramid of developing and developed regions of the world -1984 (United Nations: 1982 : *Estimates and projections as assessed in 1980.* as referred to by Spies, 1991b:3.91)

Africa is expected to experience the highest population growth rates in the world during the coming decades, ranging from 3 % to 2,48 % per annum during the period from 1990 to 2025.

The gross per capita national product is on average more than thirteen times higher in the more developed regions than in the less developed regions. Current trends in population growth and economic growth suggest that this discrepancy could worsen towards the turn of the century.

3.2 Age distribution

The age distribution of the developed world differs greatly from that of the developing world. Figure 3 shows this difference very effectively for the world of about 1984.

One very important effect of the relatively young age of the developing world is that modernisation can take place very quickly: young people are able to and want to change or modernise, whereas older people find it very difficult to change. In the developing community of South Africa about 2,5% of the population reaches the age of maturity each year. This means that by 2010 50% of the developing community will be people who have reached maturity since 1990; these will include people who have just left school and want to live a life with a higher standard of living than their parents. These are the sort of people who will not tolerate a house without electricity. Most of them will probably not be classed as 'developing' any more but rather as 'developed'.

3.3 The international experience of the demographic transition

The broader demographic realities of South Africa approximate those typical of developing societies. South Africa shares many of the characteristics of demographic trends in South America, or South East Asia. In order to contextualise the South African demographic realities properly, it is necessary to reflect on international experience, particularly in the developing world.

In virtually all developing countries the structure of population changes during a period of time (see Figure 4) follows a similar pattern. Demographers call these changes 'the demographic transition'. During this transition, economic development initially affects the death rate and only later the birth rate (see Figure 4).

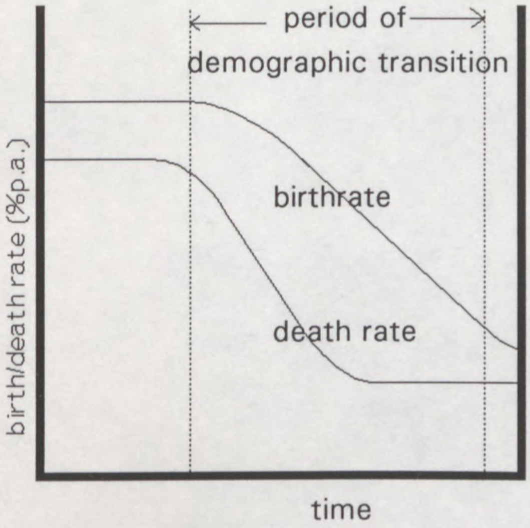


Figure 4: Demographic transition (UF, 1990:5)

Modernisation and economic development lengthen life expectancy (most significantly through reducing the infant mortality rate) without immediately reducing the average number of children born to families. It is only after several decades of experiencing economic development and particularly urban life, that people reduce their family sizes.

The consequence of this lag is that overall population growth in developing countries tends to be rapid until after birth rates decline to a level approaching the death rate. This is the situation which now characterises the advanced industrialised societies of North America and Western Europe, some of which are now experiencing a slightly declining population, despite rapid population growth earlier this century.

3.4 Relationship between population and economic growth

The generalised relationship between population and economic growth rates is such that, initially, population increases faster than wealth. While the Gross Domestic Product (GDP) may be increasing in absolute terms, the GDP in terms of the number among whom it has to be divided will often be declining. The reason is that although modernisation expands the capacity of the economy to produce goods, it also helps to decrease the death rate and hence accelerates population growth.

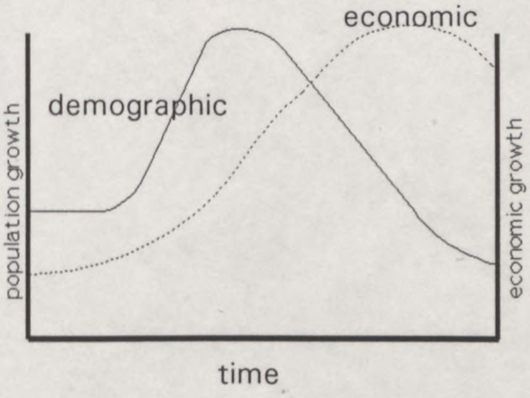


Figure 5: Population and economic growth (UF, 1990:5)

In time the modernising effects of socioeconomic change and urbanisation tend to reduce the birth rate to the point where the overall population growth rate declines. Figure 5 illustrates the relationship between population and economic growth. If the population growth rate is well on the downward trend, and the economic growth rate has increased sufficiently, then a mature relationship has been reached and the GDP per capita will begin to increase.

Unfortunately South Africa's economic growth rate has not matched its rate of population increase during the past decade. In this respect South Africa, like many other African countries, is finding that economic growth is losing the apparent race between economic growth and population growth. The extent of divergence is not as great as is the case elsewhere in Africa, but the trend is nevertheless worrying. (UF 1990:6)

3.5 Population growth in South Africa compared with other countries

South Africa is not likely to reach the situation where the birth rate matches the death rate within the next few decades. In South Africa birth rates have consistently far exceeded death rates for several decades. Figure 6 traces out the actual course of the levels of natural increase. On this cycle the position of four South African ethnic groups are indicated.

It can be seen that the black population has passed the explosive stage, but has not progressed very far on the downward phase of the cycle. In 1985 the crude birth rate (CBR) was 38 per 1 000 per year and the crude death rate (CDR) was 9 per 1 000 per year, with a concomitant rate of natural increase (RNI) of 29 per 1 000 per year which represents a population growth of 2,9 % per year.

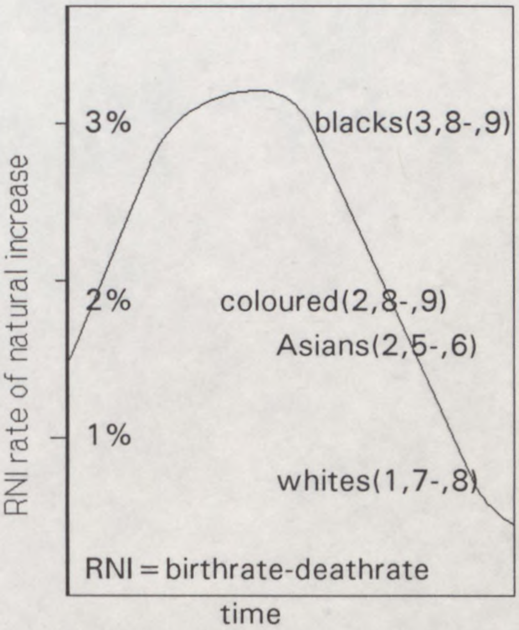


Figure 6: The Demographic Cycle (Sadie, 1988:3)

The population growth for the Coloured, Asian and White population groups in 1985 was 1,7 1,9 and 0,9 % respectively. (Sadie, 1988:3). For the South African population as a whole the population growth was 2,5 % per year (UF 1990:6). This compares closely with countries such as Brazil (2,8%) or Bangladesh (2,9%). Mexico (3,4%) has a very high population growth which strains the economy, while China (1,2%) and India (1,9%) are examples of countries with relatively low population increase, although reservations have been expressed as to the methods that have been employed to achieve such low rates.

The values of estimated future population growth given in Figure 7 to Figure 10 should be compared with the expected population growth for the developed and developing sector of the South African population. The population growth for South Africa for the period 1990 to 2020 is estimated to range between 0,6 and 0,21 % per year for the developed sector and between 2,8 and 2,1 % per year for the developing sector (Spies 1991a:3.103). In numbers this means that there will be an increase in the developed section of the SA population of around 30 000 per year, while the increase in the developing sector of the SA population will be around 1 000 000 per year, or 30 times the increase in the developed sector.

It is clear that the population growth in South Africa during the next few decades will predominantly be in the developing sector.

3.6 The accuracy of South African demographic data

To draw valid conclusions from demographic data, comprehensive and accurate data are required. Accurate data about migration, registration and census enumerations are available for the white group but not enough is known about the expansion of the coloured and Asian populations, and even less about the black population group. One would be inclined to expect that data compiled recently would be more accurate than those published decades ago, but in some instances a deterioration has set in since 1970. (Sadie 1988:1)

In the present political climate it may not be advisable to categorise the South African population into four ethnic groups: whites, Asian, coloured and blacks, but it does make demographic sense because these ethnic groups tend to be homogeneous rather than to overlap, and because the studies thus far made of them are liable to different degrees of statistical error.

While persons are legally obliged to fill in census forms and register births, deaths and immigration, they do not necessarily do so, sometimes because it would be to their detriment to make their presence known. For this reason it is very difficult to obtain accurate population statistics.

There was severe underestimation in both the 1980 and 1985 censuses. Central Statistical Services adjusted the 1980 raw counts before publication, but in 1985 they reported the raw counts directly. Their calculation of corrected estimates is not always accepted as being correct, especially when there are no usable vital statistics as a check for the black people.

A comparison of the data of subsequent censuses indicates that the published data for the Asian, Coloured and black community do not pass the test of the demographic identity by satisfying the equation:

$$N_{t+n} = N_t + B + M - D$$

where:

N_{t+n} = Number in year t+n,
N_t = Number in year t,
B = Births during n years,
M = Nett migration during n years,

and
D = Deaths during n years.

It is impossible to estimate future population figures accurately because available data about present and past population figures are unreliable.

Methods which are used to adjust census results in order to compensate for errors and undercounting include:

- Comparing a current census with previous censuses;
- Comparing census data with data in the population register;
- Comparing census data with the number and ages of school children;
- Sample surveys specifically undertaken to check census data.

These apply to the total population. Suggested methods for adjusting smaller geographical areas include:

- Checking census data by using information obtained from administrative sources such as the number of school children in a particular age group;
- Sample regional surveys.

3.7 Population estimates of the South African population

It is understood that it is very difficult to establish accurate estimates of the present size and future trends of the South African population, but various independent studies have been undertaken which have yielded remarkably similar results. Table 7 lists some of these results for the total South African population:

Table 7: Forecasts of the total population of South Africa (including TBVC), 1985-2020

YEAR	Population in 000's				
	Grobbelaar	Urban Foundation	Sadie	Mostert & van Tonder Low variant	UN Median Variant
1985	33 180	33 172	32 702	34 644	32 392
1990	37 377	37 533	37 533	39 506	36 754
1995	42 044	42 316	42 344	45 014	41 623
2000	47 174	47 592	47 592	51 173	46 918
2005	52 677	53 283	52 771	58 032	52 490
2010	58 503	59 734	-	64 381	58 525
2015	64 621	-	-	70 647	64 553
2020	70 765	-	-	79 996	70 662

Sources: Grobbelaar, 1990; Mostert & van Tonder, 1987;
UF, 1990; Sadie, 1988; Spies, 1991b

While most forecasts are of the same order of magnitude, those by Mostert and van Tonder (1987) deviate sharply from any other present or past forecasts of the South African population. All three of the forecasts of Mostert and van Tonder with respect to the black population (low, medium and high variants) turned out to be considerably higher than the others. The reasons for this discrepancy are firstly, that their estimate of the 1985 black population is considerably higher, and secondly, that they assume that the age specific fertility rates among black females in the 15-24 age group will remain constant to the year 2005 while that for the 30-34 age group will decline only marginally during the period 1985 - 2005.

Table 8: Population forecast by population group (UF 1990:14)

Population distribution forecasts by population groups					
000's					
	White	Col	Asians	Blacks	Total
1985	4,854	2,958	899	24,462	33,172
1990	5,052	3,244	978	28,259	37,533
1995	5,249	3,527	1,025	32,515	42,316
2000	5,428	3,783	1,122	37,260	47,592
2005	5,590	4,006	1,178	42,509	53,283
2010	5,757	4,243	1,236	48,498	59,734

Other forecasters expect that age specific fertility rates among black females will decline gradually over time due to the influences of modernity, such as increasingly higher levels of education, urbanisation and the transition from subsistence agriculture to formal and informal commercial and industrial economic activities among blacks in general.

The medium and high variants of the forecast by Mostert & van Tonder must however be considered if the underdeveloped section of the South African population does not develop. Development of the underdeveloped sector depends on economic growth in South Africa, and there are many factors which influence economic growth, such as social stability, education and an awareness of the need for technological development among all South Africans.

Table 9 Population figures for high population growth

The South African Population								Population Increase			
		000's									
	White	Col	Asians	Blacks	Total						
1985	4,854	2,958	899	24,462	33,172		White	Col	Asians	Blacks	Total
1990	5,052	3,244	978	28,259	37,533	1985-'90	0.80%	1.87%	1.71%	2.93%	2.50%
1995	5,249	3,527	1,053	32,515	42,343	1990-'95	0.77%	1.68%	1.48%	2.85%	2.44%
2000	5,428	3,783	1,122	37,260	47,592	'95-2000	0.67%	1.41%	1.28%	2.76%	2.36%
2005	5,590	4,006	1,178	42,528	53,302	2000-'05	0.59%	1.15%	0.98%	2.68%	2.29%
2010	5,738	4,195	1,224	48,347	59,504	2005-'10	0.52%	0.93%	0.76%	2.60%	2.23%
2015	5,868	4,336	1,256	54,744	66,205	2010-'15	0.45%	0.66%	0.51%	2.52%	2.16%
2020	5,980	4,454	1,281	61,741	73,456	2015-'20	0.38%	0.54%	0.40%	2.43%	2.10%
2025	6,071	4,546	1,299	69,355	81,271	2022-'25	0.30%	0.41%	0.29%	2.35%	2.04%
2030	6,141	4,617	1,313	77,597	89,667	2025-'30	0.23%	0.31%	0.21%	2.27%	1.99%

3.8 Population estimates for South Africa by population group

The previous section clearly illustrates that a reasonable estimate of population numbers for the next few decades can be found. Considering the estimates accepted by prominent demographers as listed in Table 7, the following forecasts of the South African population by population group are given and can be used for the model of the consumption of domestic grid electricity.

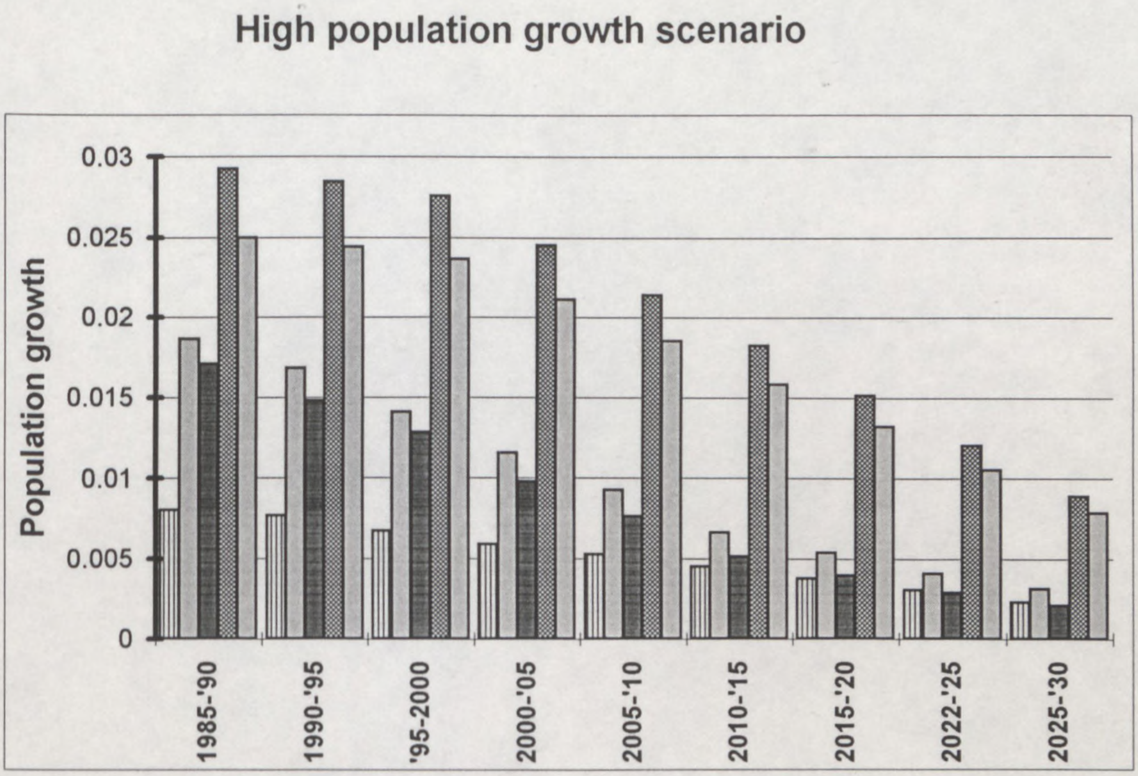


Figure 7 Population growth for high population growth scenario

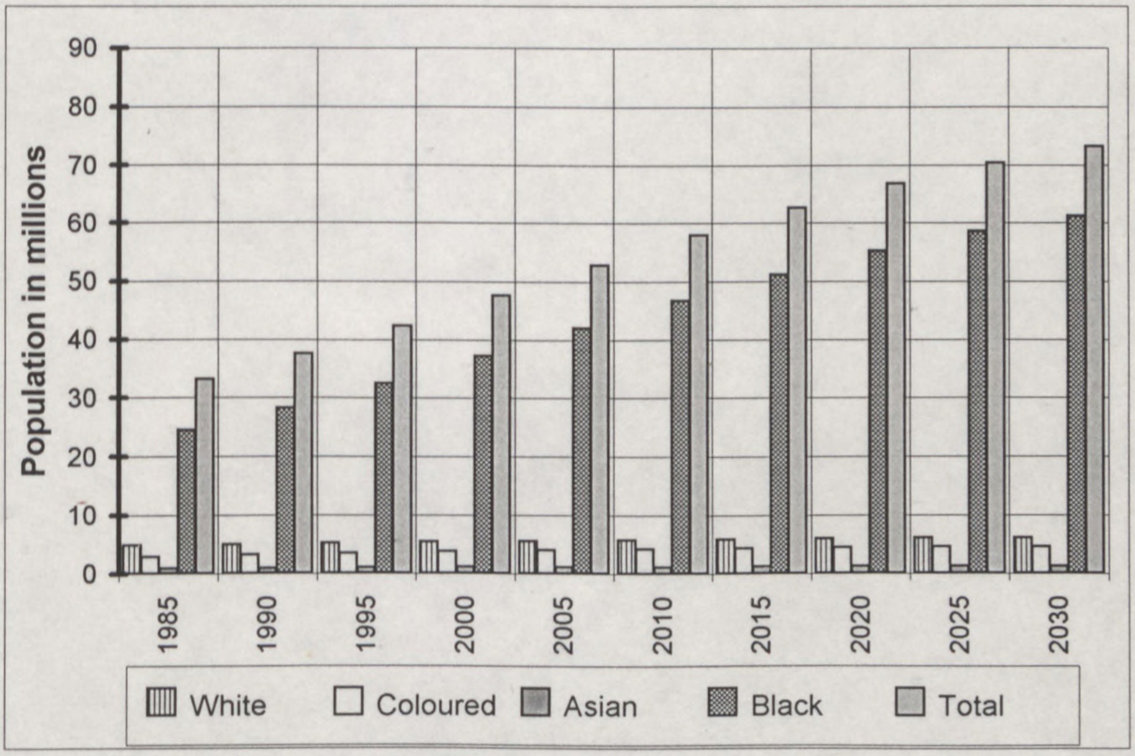


Figure 8 Population forecast for high population growth scenario

Table 10 Population figures for medium population growth

The South African Population							Population Increase				
		000's									
	White	Col	Asians	Blacks	Total						
1985	4,854	2,958	899	24,462	33,172		White	Col	Asians	Blacks	Total
1990	5,052	3,244	978	28,259	37,533	1985-'90	0.80%	1.87%	1.71%	2.93%	2.50%
1995	5,249	3,527	1,053	32,515	42,343	1990-'95	0.77%	1.68%	1.48%	2.85%	2.44%
2000	5,428	3,783	1,122	37,260	47,592	'95-2000	0.67%	1.41%	1.28%	2.76%	2.36%
2005	5,590	4,006	1,178	42,362	53,136	2000-'05	0.59%	1.15%	0.98%	2.60%	2.23%
2010	5,738	4,195	1,224	47,785	58,942	2005-'10	0.52%	0.93%	0.76%	2.44%	2.10%
2015	5,868	4,336	1,256	53,477	64,938	2010-'15	0.45%	0.66%	0.51%	2.28%	1.96%
2020	5,980	4,454	1,281	59,376	71,091	2015-'20	0.38%	0.54%	0.40%	2.11%	1.83%
2025	6,071	4,546	1,299	65,405	77,321	2022-'25	0.30%	0.41%	0.29%	1.95%	1.69%
2030	6,141	4,617	1,313	71,476	83,546	2025-'30	0.23%	0.31%	0.21%	1.79%	1.56%

In Table 9 to Table 11 further estimates of population figures are given up to the year 2030. These tables make provision for a low, medium and high estimate of population growth. The difference is mainly in rate of population growth of the black population group, because, as has been pointed out, the population growth of the black population group exceeds that of the other population groups by far.

Medium population growth scenario

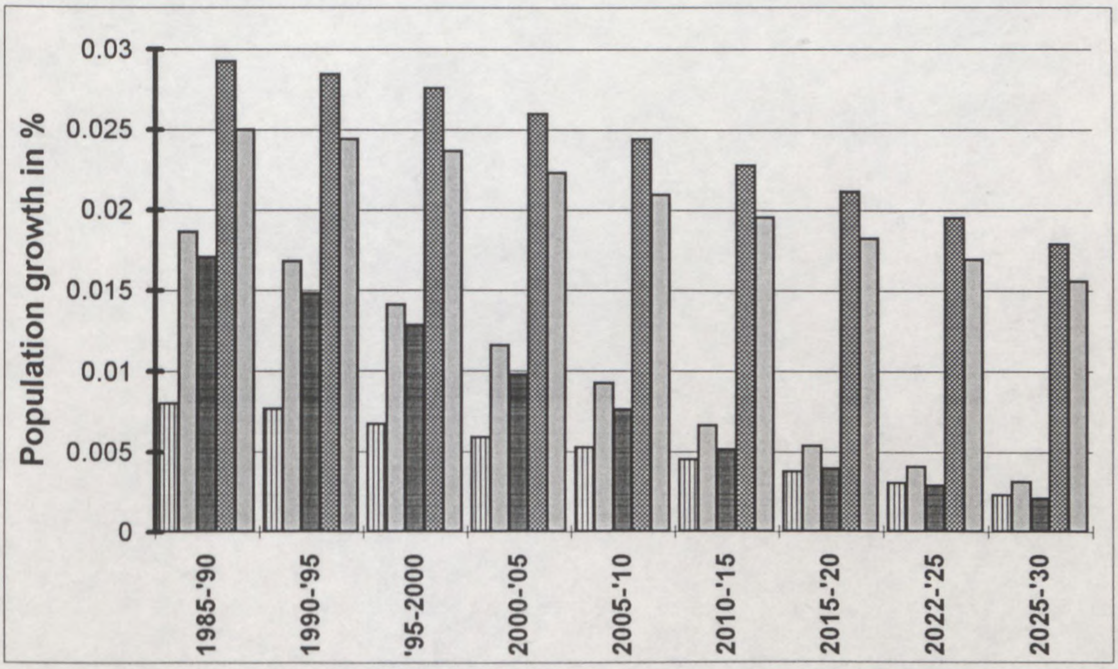


Figure 9 Population growth for medium population growth scenario

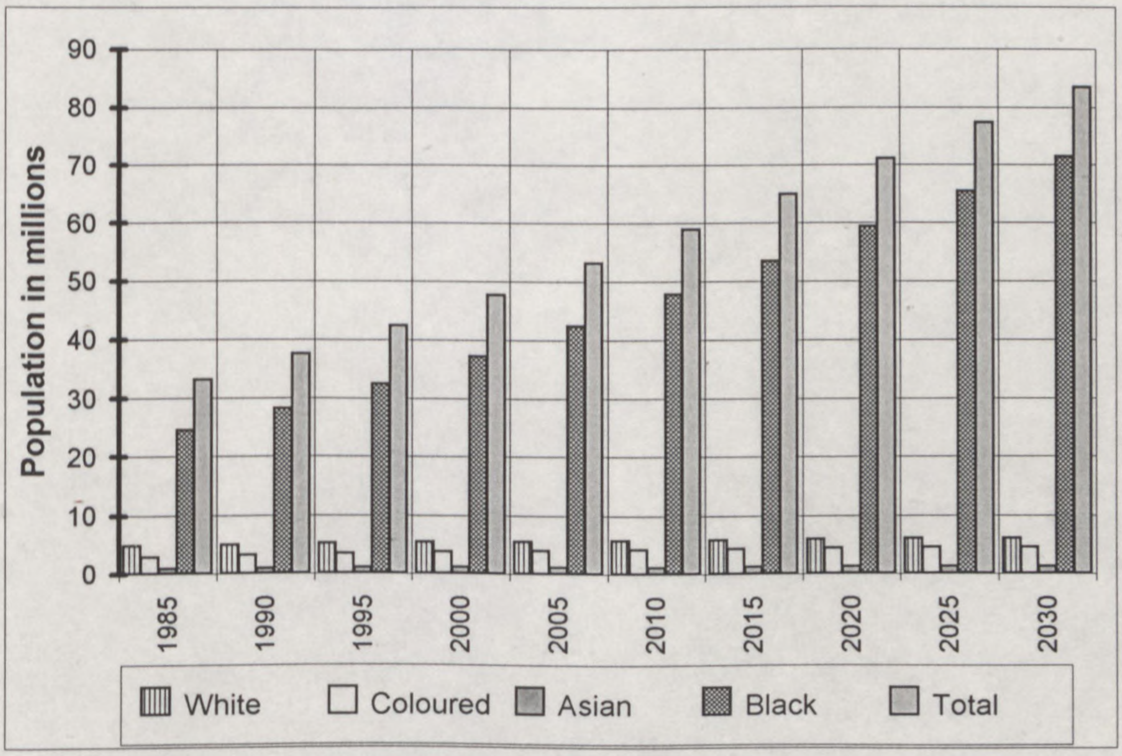


Figure 10 Population forecast for medium population growth scenario

Table 11 Population figures for low population growth

The South African Population								Population Increase			
		000's									
	White	Col	Asians	Blacks	Total						
1985	4,854	2,958	899	24,462	33,172		White	Col	Asians	Blacks	Total
1990	5,052	3,244	978	28,259	37,533	1985-'90	0.80%	1.87%	1.71%	2.93%	2.50%
1995	5,249	3,527	1,053	32,515	42,343	1990-'95	0.77%	1.68%	1.48%	2.85%	2.44%
2000	5,428	3,783	1,122	37,260	47,592	'95-2000	0.67%	1.41%	1.28%	2.76%	2.36%
2005	5,590	4,006	1,178	42,054	52,828	2000-'05	0.59%	1.15%	0.98%	2.45%	2.11%
2010	5,738	4,195	1,224	46,746	57,903	2005-'10	0.52%	0.93%	0.76%	2.14%	1.85%
2015	5,868	4,336	1,256	51,174	62,634	2010-'15	0.45%	0.66%	0.51%	1.83%	1.58%
2020	5,980	4,454	1,281	55,169	66,883	2015-'20	0.38%	0.54%	0.40%	1.51%	1.32%
2025	6,071	4,546	1,299	58,568	70,484	2022-'25	0.30%	0.41%	0.29%	1.20%	1.05%
2030	6,141	4,617	1,313	61,224	73,295	2025-'30	0.23%	0.31%	0.21%	0.89%	0.79%

If modernisation in the underdeveloped sector does take place at a relatively fast rate, the population figures of the estimate in Table 11 can be expected. This will happen if South Africa experiences sustained economic growth, and the underdeveloped community becomes economically active enough for their standard of living to improve.

If modernisation does not take place, then the population growth will be as given in Table 9. The economic conditions in South Africa will deteriorate even more and the underdeveloped community of South Africa will continue to live in poverty. The country will not be able to sustain its large population numbers.

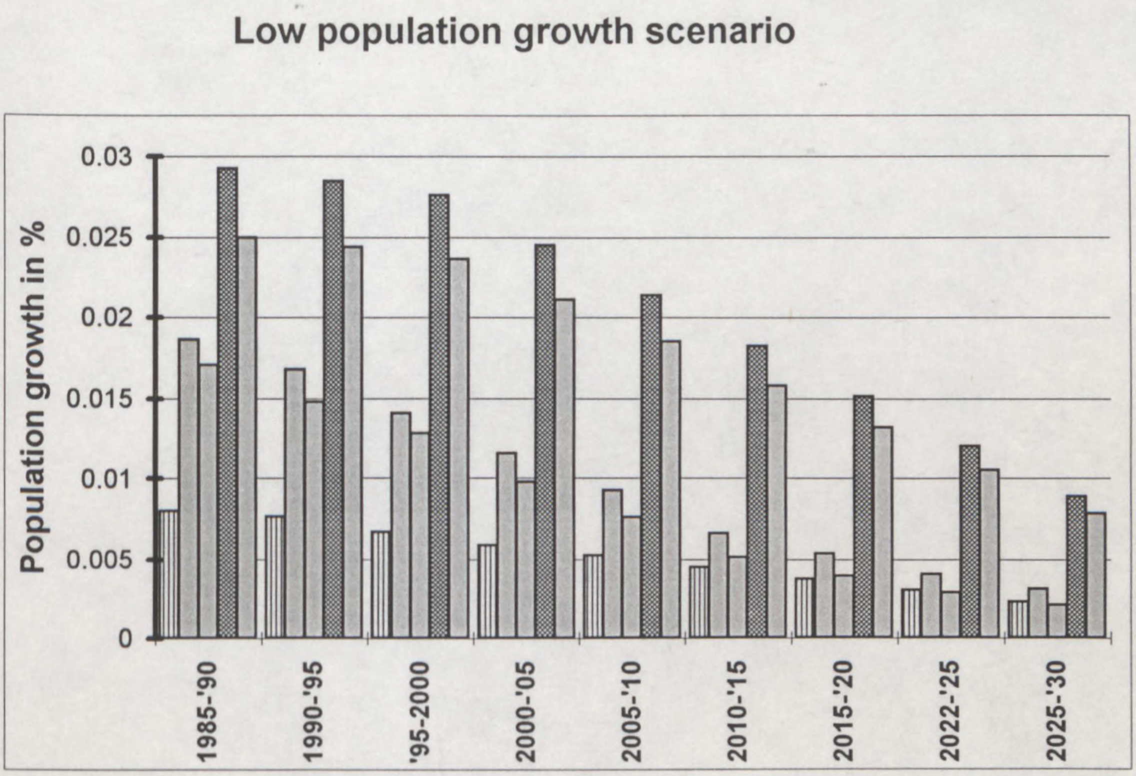


Figure 11 Population growth for low population growth scenario

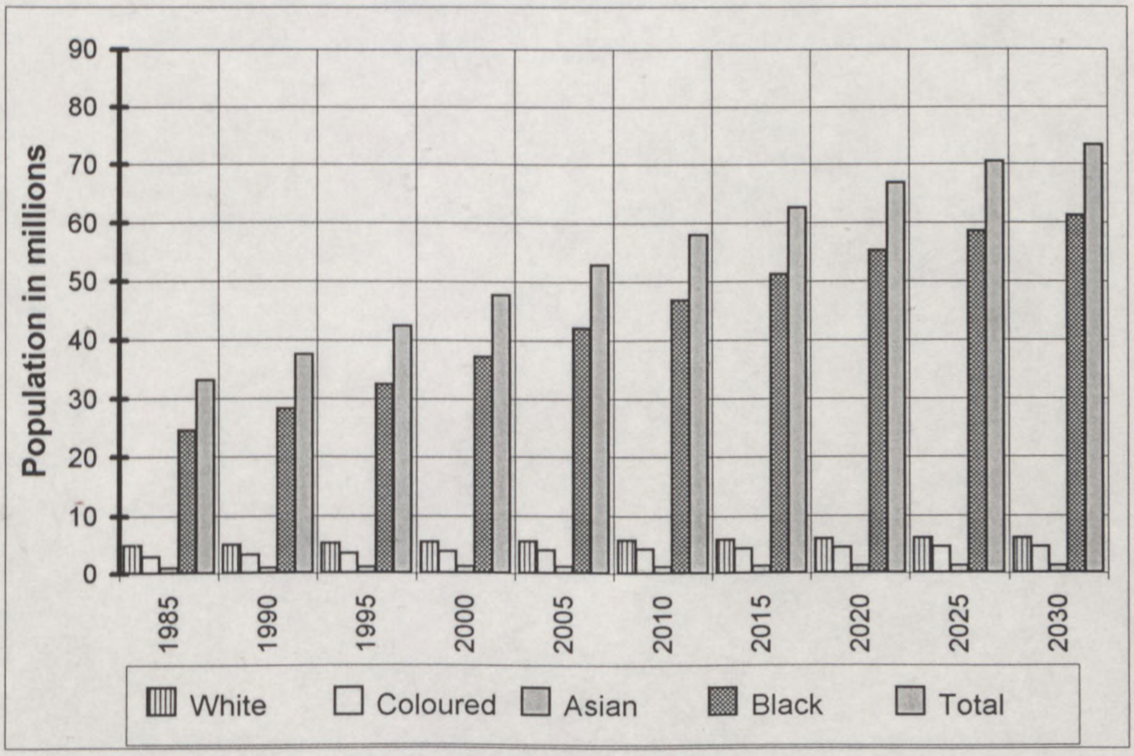


Figure 12 Population forecast for low population growth scenario

4 URBANISATION

4.1 Introduction

The urbanised community is much more likely to have electrified homes than their rural counterparts, and they consume more electricity, so it is important to know how many people live in urban areas in order to determine domestic electricity consumption.

Approximately two thirds of the annual population growth in the Third World occurs in urban areas. Approximately 50 % of current urban growth in developing countries consists of millions of peasants and villagers leaving bleak prospects in rural areas in the hope of finding work in urban centres. These people are often poorly trained and ill equipped for industrial occupations. Some of the fastest growth in urban concentrations is to be expected in African countries.

Table 12 indicates how urbanisation is a phenomenon of the present world, and it can be seen from Table 13 (compiled from data by Spies, 1991b:3.121) that it is especially a phenomenon of Africa.

Table 12 Percentage of the world population living in urban areas (United Nations, 1989: *The Prospects of World Urbanization 1988* as referred to by Spies, 1991b:3.124)

Year	World population millions	Percentage in urban areas
1950	2 500	29 %
1980	4 400	41 %
2025	8 200	61 %

Table 13 Comparative indicators of urbanisation

Year	World	Developed Regions	Less Dev. Regions	Africa	South Africa
Urban dwellers as percentage of total population					
1950	29	54	17	15	42
1980	40	70	30	28	53
2000	47	75	40	41	71
2020	58	78	54	55	80
The average rate of growth (in percent) of urban population					
1950	3,2	2,4	4,4	4,6	4,5
1980	2,4	1,0	3,6	5,2	2,8
2000	2,6	0,7	3,4	4,5	3,6
2020	2,0	0,3	2,6	3,0	2,4

Vast shanty towns and settlements will continue to be a predominant characteristic of Third World urban growth over the next decade. This process is most apparent in and around major urban concentrations in Africa such as Lagos, Nairobi, Addis Ababa, Lusaka and most recently Maputu and Harare. As a result, millions of children are growing up under very poor urban conditions, which could have a lasting effect on future generations.

To counteract the problems caused by too rapid urbanisation, a proactive management approach is urgently needed that will give planners scope to use the opportunities that are becoming available to improve social conditions.

For example, family planning should be facilitated and encouraged, and an active search for employment in innovative small business ventures should be promoted among new arrivals.

South Africa's urban population (including TBVC states) is expected to increase from roughly 15 million in 1980 to approximately 33 million by the year 2000, to approximately 45 million by the year 2010 and to approximately 55 million by 2020 (Spies, 1991:3.120).

Approximately a million people are expected to be added to urban concentrations in South Africa every year for the next few decades. The need for appropriate housing, social services, education and employment will be great. Current efforts by the South African Government (see the White Paper on Urbanisation) and the Urban Foundation, to investigate and propagate innovative solutions to the challenges of urbanisation, are aimed at solving one of South Africa's most serious developing dilemmas.

4.2 Present state of urbanisation in South Africa

Urbanisation is the focus of much research in South Africa by bodies such as the Urban Foundation, the Human Sciences Research Council and the Development Bank of South Africa. The Government is also fully aware of the significance of urbanisation and a report on urbanisation was completed for the President's Council in 1985. Government policy on urbanisation is spelled out in a white paper which was released in 1986. Since 1986 this white paper has had far-reaching socio-economic implications, with the need for:

* a comprehensive and coordinated urbanisation strategy;

* land and housing;

* standards for housing and health in developing communities;

* the provision of infrastructure and the deregulation of the small business sector.

When studying the economic development of countries such as Taiwan, Mexico and Thailand, and the action taken by these countries to bring electricity to the poor (de Beer, 1992:4), it becomes clear that electrification is a very important stimulus for modernisation and social upliftment, which Eskom with their commendably positive policy of electrification is endeavouring to assist.

There is a marked difference between the present degree of urbanisation of the different population groups. There is a very high degree of urbanisation of the white and Asian population groups, but only about 55 % of the black population group is urbanised.

Table 14 Urbanisation in South Africa for different population groups

Sources: 1) Spies, 1991:126
2) Lucas, 1990

Population group	Degree of urbanisation in percent 1980 (2)	1985 (1)	1990 (2)
Whites	89	90	89
Coloured	77	78	78
Asians	88	93	90
Blacks	33	42	56
Total	53	56	63

It is clear from Table 14 that the black population group is presently experiencing a rapid rate of urbanisation, and that the other population groups are virtually completely urbanised. The rapid rate of urbanisation will cause a large demand for electrification in the next few decades, for it is the newly urbanised population who will demand electrification as they move into a new environment with expectations of increased economic activity and an improvement in their standard of living.

There also appear to be considerable differences in the level of urbanisation of the black population groups in the various development regions, as can be seen in Table 15.

Table 15 Urbanisation of the black population group in different development regions (Lucas, 1990)

Development region	Degree of urbanisation in percent
South Western Cape	90
Witwatersrand	84
Eastern Cape	67
Eastern Transvaal	24
Northern Transvaal	7

4.3 Development and modernisation

While it is clear that future energy demand in urban areas is fundamentally a function of urban growth and modernisation and while the energy transition process is well described in terms of its order of energy carriers, it is uncertain how quickly South Africans will move through the transition process (Doppegieter, 1991:60).

At the moment there are great expectations of better living conditions amongst the underdeveloped community in South Africa. The Government is also aware of these expectations and wants to do all in its power to meet these expectations as far as possible. The expectations of the poor of the poor population are especially focused on education (a determinant of the ability to compete for lucrative employment in the market place) and housing (a determinant of physical living standards).

Given the political strength of the highly mobilised urban black population in metropolitan areas, policy making in post apartheid South Africa will probably focus strongly on urban needs. The pace and dimensions of the urbanisation process will also ensure that this process takes central stage in the coming decades, irrespective of the Government in power. Crucial issues will include the provision of housing and related urban infrastructure, particularly roads, water and sewerage, but also including electrification.

According to Market Research Africa (MRA) (Figure 13), urban black household needs or likes changed between 1985 and 1989. Electricity, which was rated fifth in 1985, became the second priority in 1989. The higher priority accorded this issue perhaps partly reflects the fact that black urban communities now generally regard electricity as something which is realistically within reach, which may formerly not have been the case.

Surveys undertaken by Eskom in townships where electrification is considered, also point to the high priority accorded to electricity by the developing community. They also perceive electricity to improve their standard of living by providing cleanliness, deceasing the burden of housework, and creating an atmosphere for children to study.

Extracts are appended from surveys undertaken by Eskom in Qumeni, Edenvale, Willowfontein, Imbali, Ashdown and Peacetown to determine the perceptions which the developing community has towards electricity.

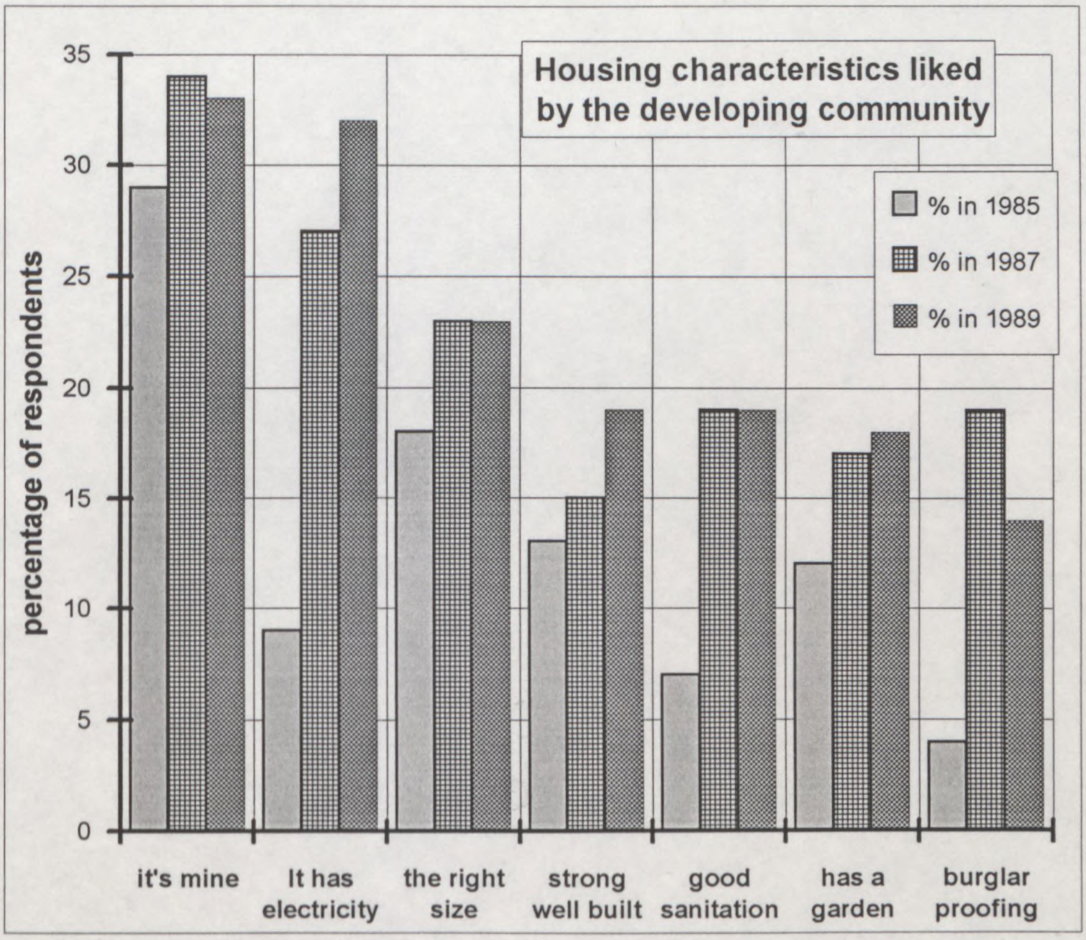


Figure 13 Housing characteristiccs liked by the developing community (MRA, 1989:35)

*** Qumeni**

Basic needs to the household in order of priority:

Need:	Priority ranking
Electricity	32 %
Piped water	31 %
Bigger houses	18 %
Telephone	9 %
Fencing	9 %
Flush Toilet	1 %

(Eskom, 1989:23)

Advantages of having electricity in the home:

Electricity is versatile	52 %
Convenience, decrease of housework burden	30 %
Cleanliness	20 %

(Eskom, 1989:Ap13-14)

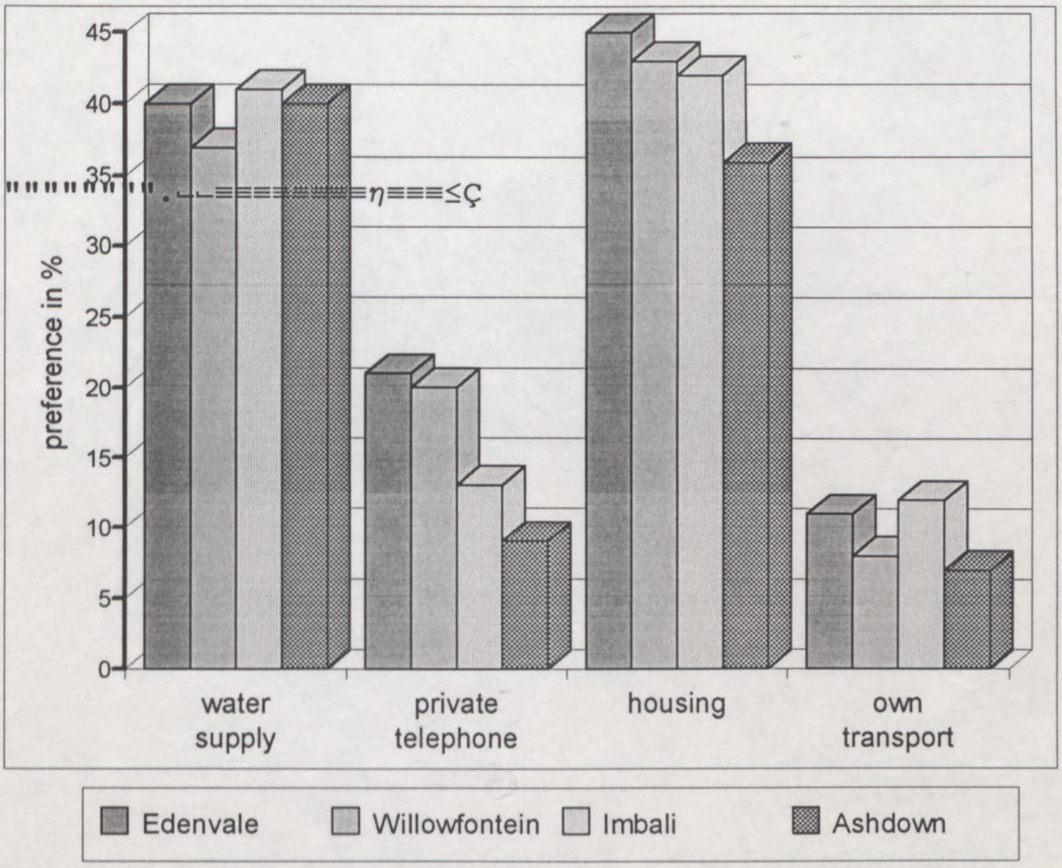


Figure 14: Preferrences of the household rather than electricity (DRA, 1990:47)

* **Edendale, Willowfontein, Imbali and Ashdown:**

Figure 14 indicates that more than half the respondents in the townships listed would prefer to spend money on obtaining electricity in the home than on any of the alternatives which were presented.

* **Peacetown:**

A good proportion of the population (9 %) wanted electricity to enable them to open a small business. It has been found in other townships also that electricity has been a stimulus to small businesses, since it leads to economic growth and modernisation.

Children do much of the household tasks in the underdeveloped community (Ross, 1991:4.12). This is one of the reasons why they do not receive formal education. Electrification brings with it time savings for most household tasks ranging from 23 to 54 % (Heron *et al.*, 1990:2.5). This is of great value to the housewife and also to the children who then have more time for education; it is thus extremely important for the modernisation process.

It is clear that modernisation of the newly urbanised South African community is essential for socio-economic development. An increase in living standards is expected by the developing community who see electricity as a giant step towards modernisation. They want it in their homes. Unquestionably there will be tremendous pressure exerted during the next few decades by the developing community to obtain electricity.

4.4 Forecasts of urbanisation in South Africa

To see the South African urbanisation process in perspective one must take note of the following: (UF, 275:12)

- Whilst some South African cities have grown at relatively rapid rates, and some continue to do so, these rates are not out of keeping with international experience in both developing and in some developed countries. Moreover, these rates of growth change over time and very high rates are not sustained indefinitely.
- The South African urbanisation experience has much in common with that of the developing countries.
- Urbanisation appears to be the product of population growth, but its medium term effect is to reduce population growth.
- In international terms, South African cities are neither especially large, nor are they expected to reach population numbers that rival the world's largest cities in the future. Nevertheless, in geographical terms, South African cities are scattered in form, and low in population density, and they will reach population sizes comparable to the largest cities in the developing world.

Comparing the degree of urbanisation in the white and Asian population groups as given in Table 14 (89 % and 90 %)with the degree of urbanisation in the developed world as given in Table 13 (approximately 73 %) makes it clear that not much more urbanisation will take place in the white and Asian population groups during the next few decades. Not much urbanisation can be expected in the coloured population group either (presently approximately 78 % urbanised). More urbanisation will, however, take place in the black population group.

Table 16 Forecast of black urbanisation (UF, 1990:21)

POPULATION	1990		2000		2010	
DISTRIBUTION	%	M	%	M	%	M
SA Metropolitan	24	6,7	27	10,2	30	14,3
Homeland Metropolitan	15	4,3	18	6,6	19	9,3
SA Urban	7	1,9	7	2,5	7	3,3
Homeland Urban	4	1,1	5	1,7	5	2,4
Homeland Dense Settlement	8	2,2	8	3,0	8	3,9
Total Urban	57	16,2	65	24,0	69	33,2
Total Rural	43	12,1	34	12,4	32	15.3

Table 16 presents a forecast of the expected rate of urbanisation for the next two decades. During this period the urban population is likely to double and there will be a large need for housing. As the standard of living of the newly urbanised improves, electricity will have to be provided.

The rural population will not increase significantly during the next few decades. Some of the rural population will move to urban areas, but this will only cause the black urban population to increase from 57 to 69 %. The largest increase in urban population will be because of natural growth. Those who do move from rural to urban areas will most probably be young people, looking for employment, so the urban population is likely to get younger.

The following characteristics of urban population growth have been identified by the Urban Foundation: (UF, 1990:22,35&37)

- * The main areas of emigration have been the white rural areas. This is likely to change with the homeland rural areas becoming major areas of emigration.

* The main areas of immigration have been the metropolitan areas, most particularly the 'homeland part' of the metropolitan areas. In the future SA metropolitan areas are likely to be the main areas of immigration.

* South Africa's metropolitan areas are expected to experience the most rapid growth, with the PWV reaching about 16 million, Durban about 6 million and Cape Town about 4 million by 2010.

* Most metropolitan growth has come and will come in the form of increases to the black population of the metropolitan areas. Much of this growth has been and will probably continue to be expressed in the form of spontaneous, unplanned, informal settlements.

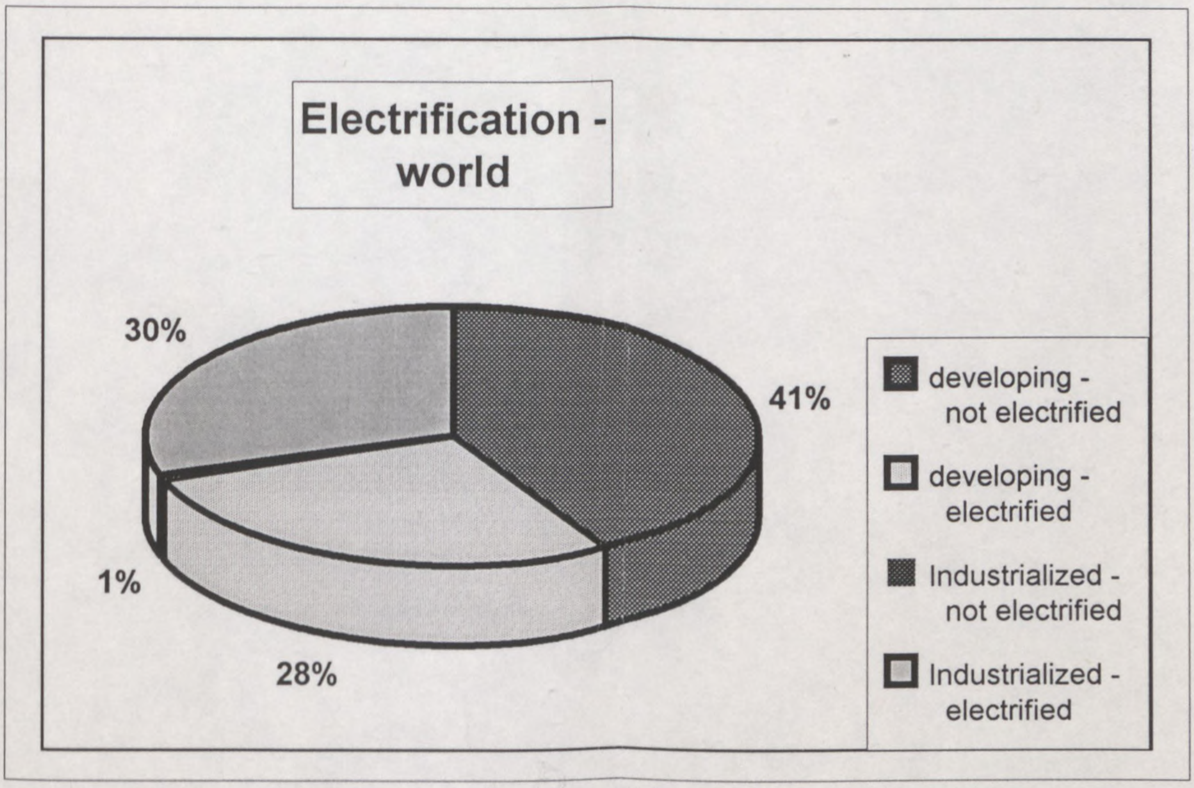
5 ELECTRIFICATION

5.1 Introduction

The population of the world is just over 5 000 million. Of this number some 1 500 million live in industrialised countries, and virtually all have electricity in their homes. Some 3 500 million live in developing countries, mainly in Asia, Latin America, and Africa. An estimated 1 500 million of these have electricity. Overall levels of electrification are thus 60 % globally and 40 % in the developing world. In comparison the level of electrification in the developing sector of the South African population is about 30 %.

Figure 15 compares levels of electrification of South Africa with the level worldwide.

Electrification in the urban centres of the developing world is generally at a relatively high level, averaging about 70 % of households, but in rural areas it is much lower at around 30 %. Levels of electrification in Africa are generally much lower than in developing countries elsewhere. It is estimated that only 5 % of the African rural population have electricity.



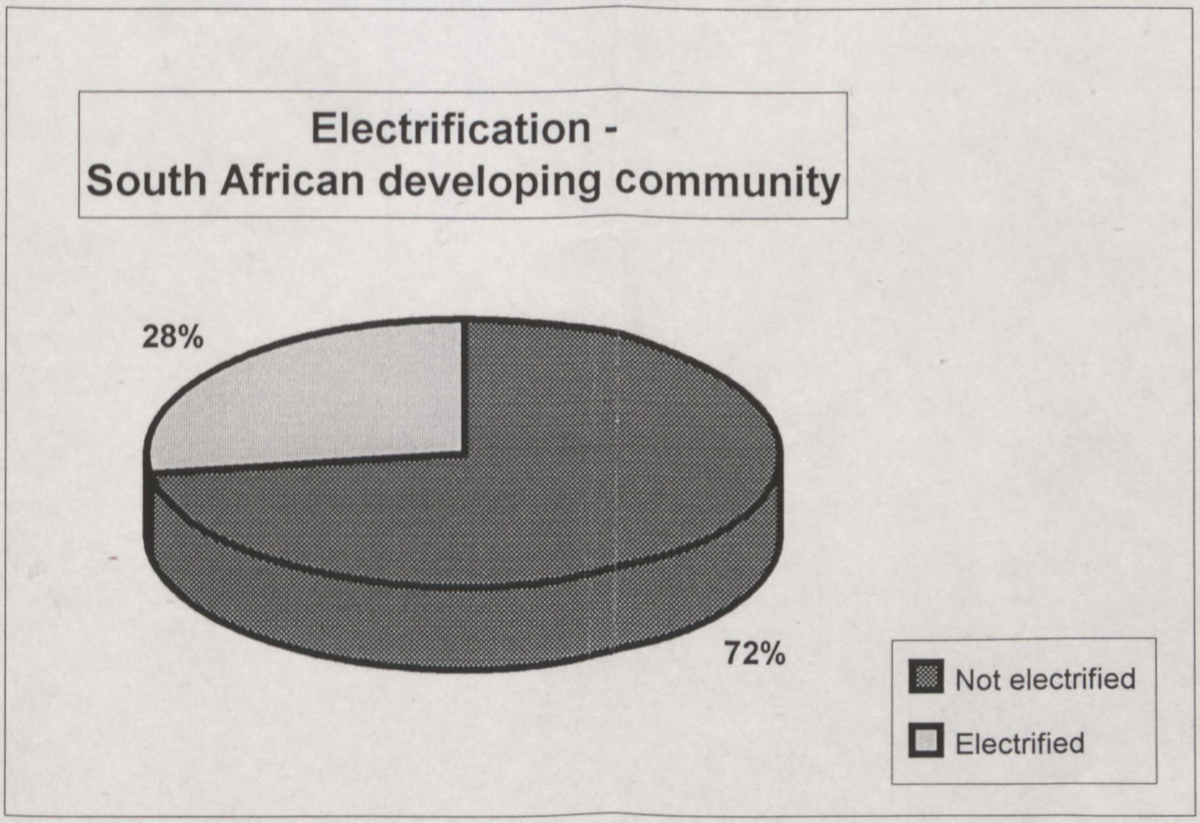


Figure 15 Comparison between electrification in the world and in South Africa

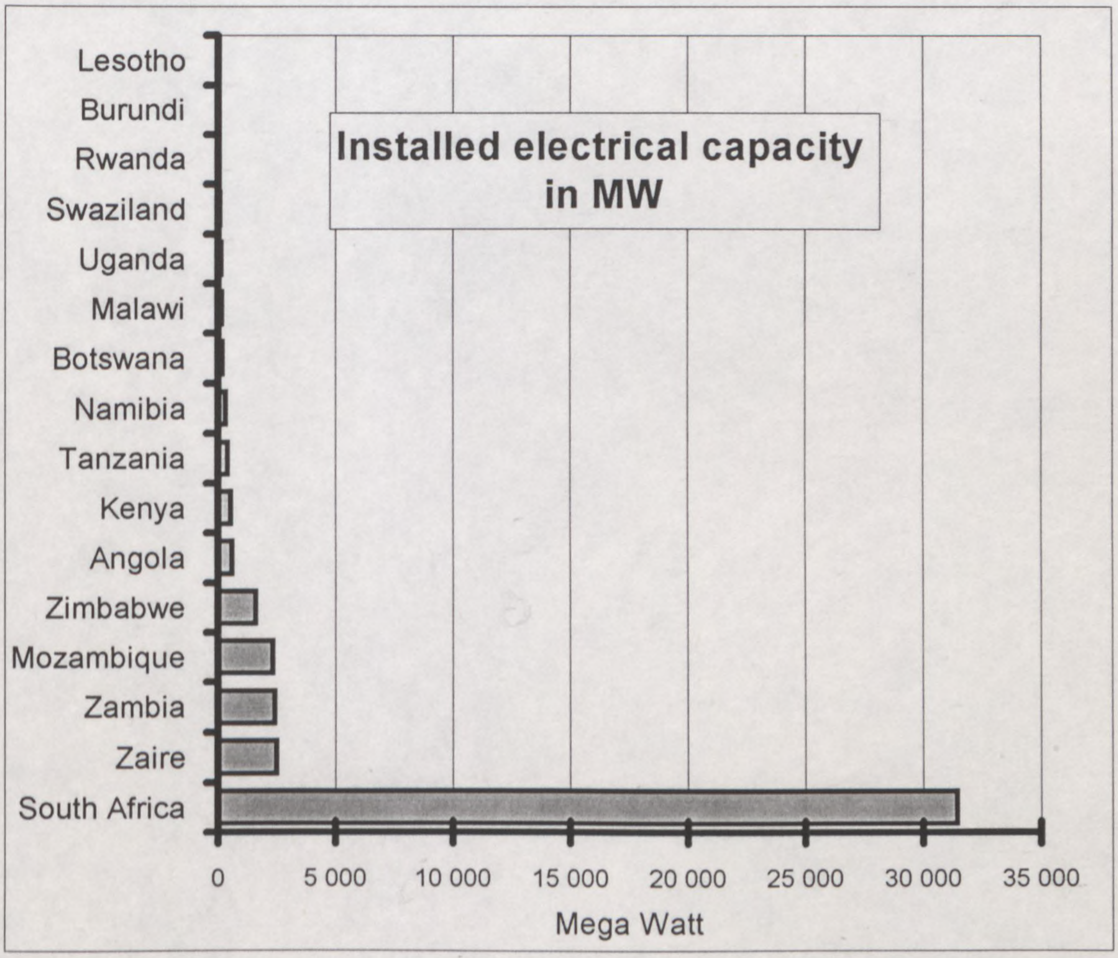


Figure 16 Installed electrical generating plant in 1988: Eastern and Southern African countries
(World Energy Council Commission, 1992:73)

There is no shortage of resources for economic electrical power generation in East and Southern Africa. Zaire, for example, has the capacity to generate 100 000 MW of hydro electric power, but produces barely 2 500 MW (see Figure 16), and only 2% of the population have electricity in their homes (see Figure 17).

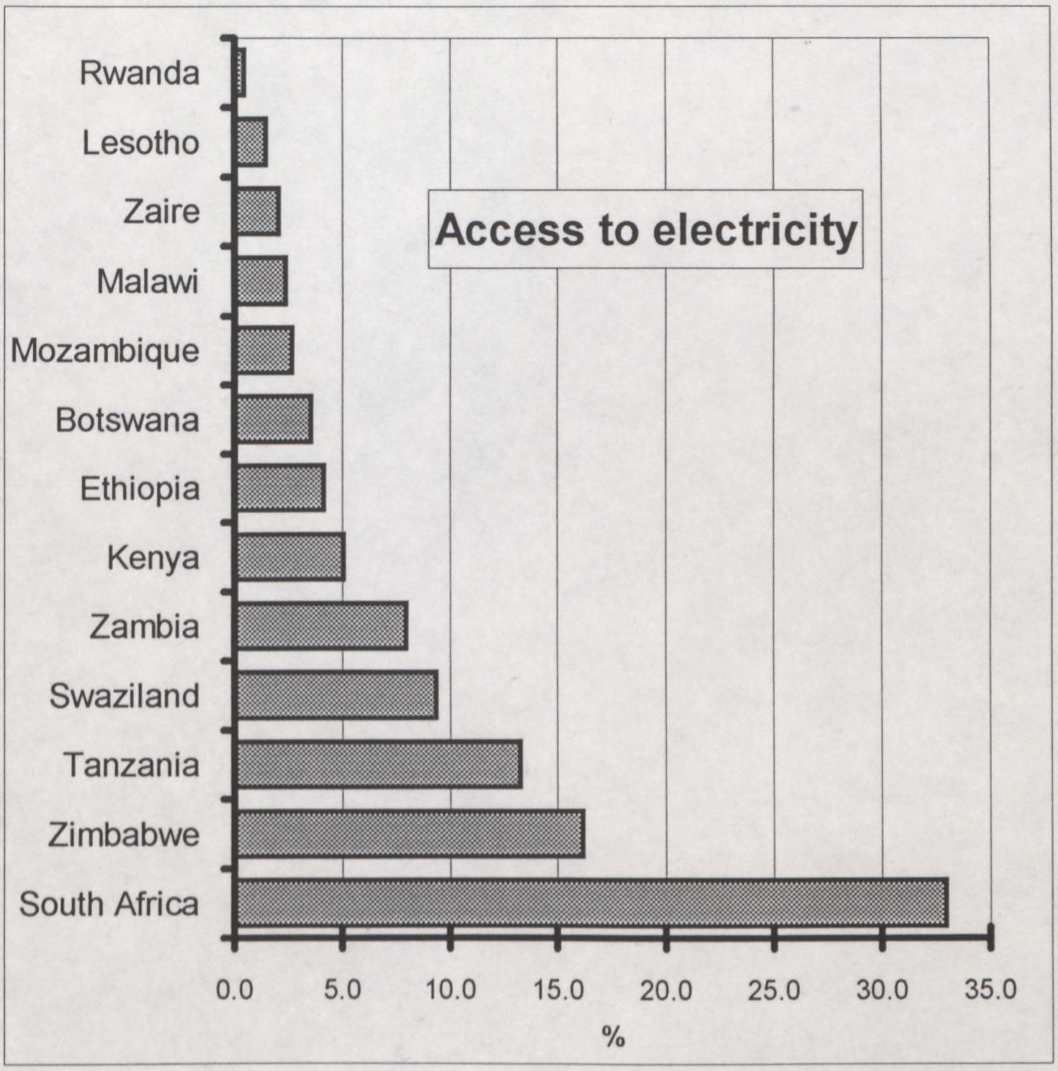


Figure 17 Levels of electrification in Southern and Eastern African countries (World Energy Council Commission, 1992:44)

Despite the fact that South Africa is the African giant in terms of electrical energy (see Figure 16), the level of electrification in certain areas of South Africa is, by world standards, extremely low.

Figure 17 shows percentages of the population in various Southern and Eastern African countries who have access to electricity.

Table 17 compares electrification data in various countries with the conditions in South Africa. All the data is for 1985 except the last row, which is for 1988.

Table 17 Comparative country data (Dingley, 1988:3)

	Brazil	Cost Rica	USA	Hong Kong	Thailand	Greece	RSA
Area (1000's km)	8 512	51	9 373	1	514	132	1 221
Population (millions)	135	2,5	239	5,5	52	10	32
Population Density (/km^2)	16	49	26	5104	101	75	27
Per Capita GNP (US $)	1640	1290	16400	6220	830	3550	2010
Appr.Electr.consumption (kWh p.a. per capita)	1385	1000	10000	3600	387	2400	4890
Appr.level of electrification (% households)	65	85	100	95	75	100	35

Many countries in the developing world are committed to electrification as part of their governments' objective of attaining a certain minimum standard of living for all. It is estimated that the current level of expenditure in the developing world on electrification projects in rural areas alone is about $ 5 000 to $ 6 000 million per year. (Dingley, 1990:5)

When development takes place, the demand for electrical domestic energy is likely to increase dramatically. Table 18 shows that the domestic electricity demand in Brazil increased more than eight fold during the period from 1960 to 1985. Over the same period the penetration levels of certain appliances such as refrigerators have increased from 30 % to 77 %, while the penetration level of TV's has increased drastically from 12 % to 86 %.

Table 18: The use of household energy in Brazil for the period 1960 to 1985. (Jannuzzi, 1989:285)

Year	Domestic energy PJ		
	Electr.	Gas	Wood
1960	14	19	432
1970	30	65	538
1980	83	137	452
1985	117	178	410

5.2 Availability of grid electricity in different sections of the South African community

Appendix A gives a listing of the availability of grid electricity in South African black households by region, living standards, income and metropolitan area for the years 1989, 1990 and 1991 (SAARF, 1991). The same information is available for other population groups, but electrification for the other race groups is nearly 100%, with the exception of the coloured living in rural areas and some of the smaller villages, so the data is not so meaningful for population groups other than blacks. Appendix A is the basis of most of the tables and diagrams in this section.

Table 19 gives an indication of the availability of electricity in various types of homes, while Table 20 gives the total number of homes. This information is also given in graphical form in Figure 18.

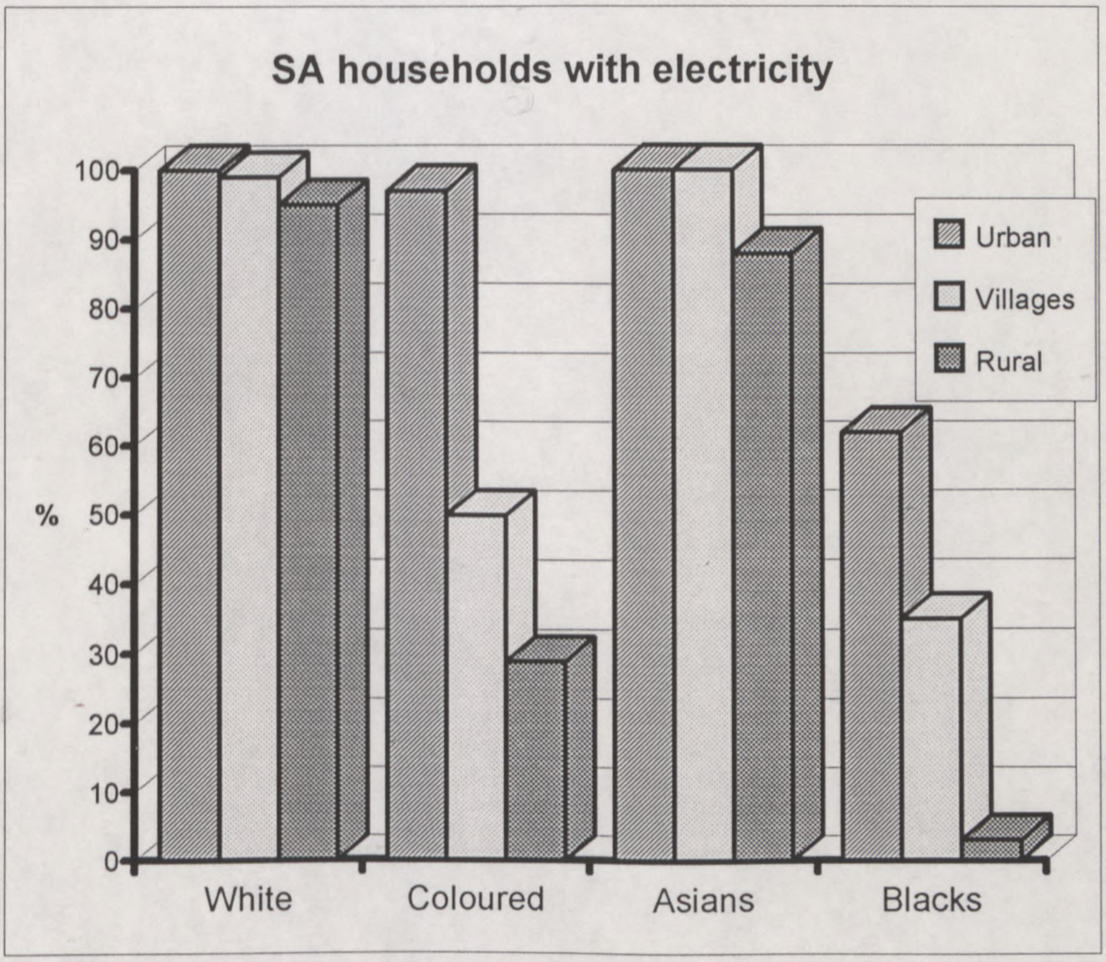


Figure 18 South African households with electricity

Percentage households with electricity (1991)

	Urban	Villages	Rural	Total
White	100	99	95	99
Coloured	97	50	29	73
Asian	100	100	88	99
Black	62	35	3	28
Total		58	10	49

Table 19 Percentage South African households with electricity (SAARF, 1991)

Number of households (thousands) (1991)

	Urban		Village		Rural		Total	
	elec.	tot.	elec.	tot.	elec.	rural	elec.	total
White	1 228	1 230	258	260	146	155	1 634	1 645
Coloured	322	331	53	106	38	131	413	568
Asian	147	147	22	22	10	11	179	181
Black	1 184	1 900	159	455	92	2 703	1 433	5 052
Total	2 881	3 608	492	843	286	3 000	3 660	7 446

Table 20: Number of households with electricity and the total number of households (SAARF, 1991)

Table 19 shows that a large proportion (51%) of South African households do not have electricity in their homes. If a larger proportion of the South African community gets electricity in their homes, and they make good use of the electricity, then it can be expected that the domestic use of electrical energy will increase significantly because of the large numbers involved.

Of the 3,8 million South African households which do not have electricity in their homes, 2,6 million households are black households in rural areas (SAARF, 1991). The large number of families involved is illustrated in Figure 19.

Figure 20 shows the electrification figures for the years 1989 to 1991. There does seem to be a slight improvement in the number of people with electricity, but much more needs to be done.

There is a large variation between different areas in the percentage of people with electricity. Figure 21 shows this difference. The low percentage for the Cape is very noticeable. This low percentage is mainly due to the policy which gave preference to coloured labour and prevented the black population group from settling in the Cape up until 1986.

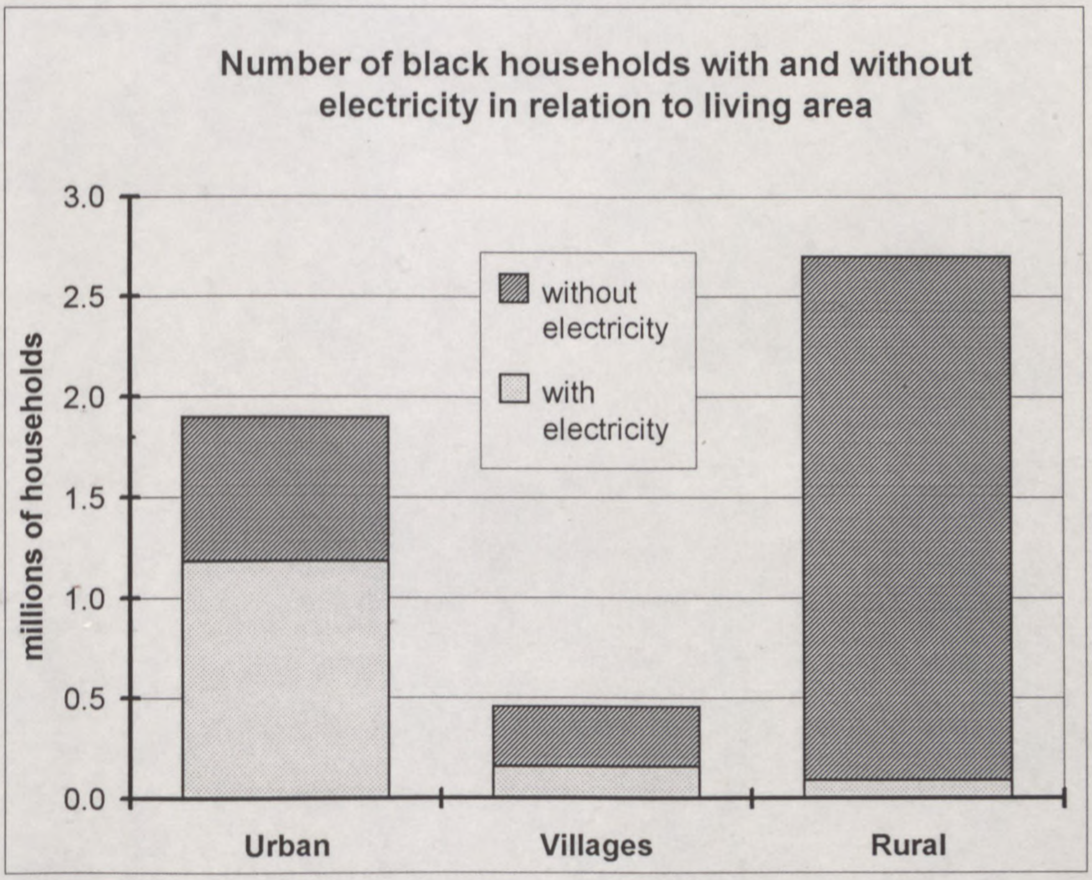


Figure 19 Number of black households with and without electricity in 1991

Figure 22 shows the electrification figures for different income and living standard groups. There is a strong correlation between both income and living standard and the level of electrification. The standard of living was determined by factors such as the possession of appliances, the availability of running water, electricity and telephone, the size of the dwelling and the employment of a domestic servant.

During the next few years it is unlikely that grid electricity will be available to a large proportion of the remote rural areas, but:

- * there will be migration to urban and metropolitan areas, and
- * there are densely populated areas, (dense or closer settlements) which are not classed as urban or metropolitan areas where it would be economically viable to provide grid electricity.

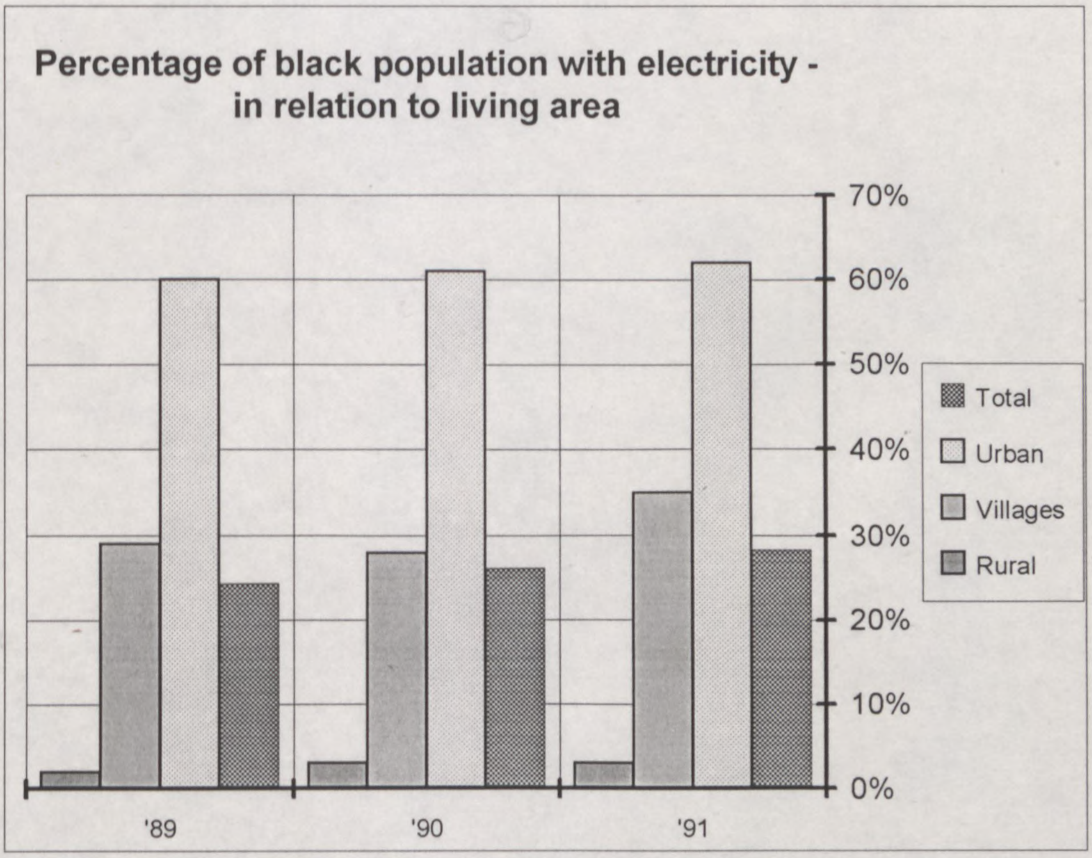
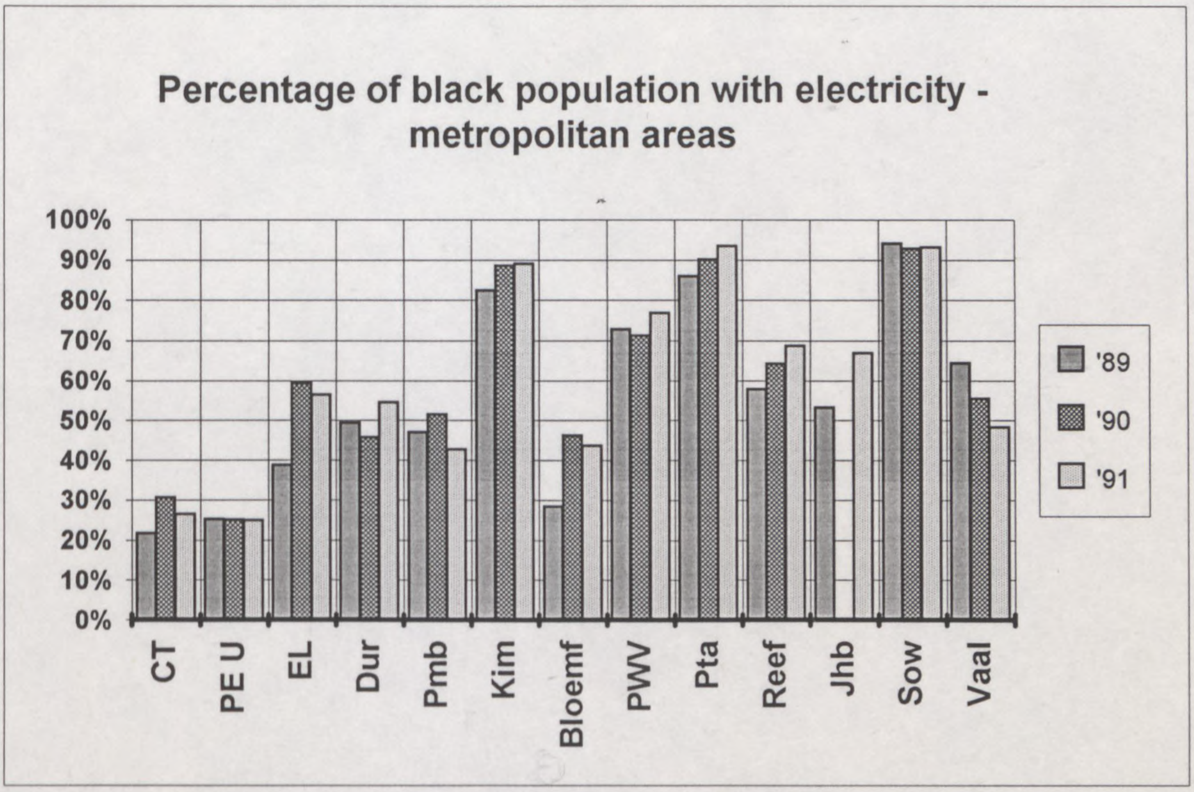


Figure 20 Percentage of the black population with electricity for 1989,1990 and 1991



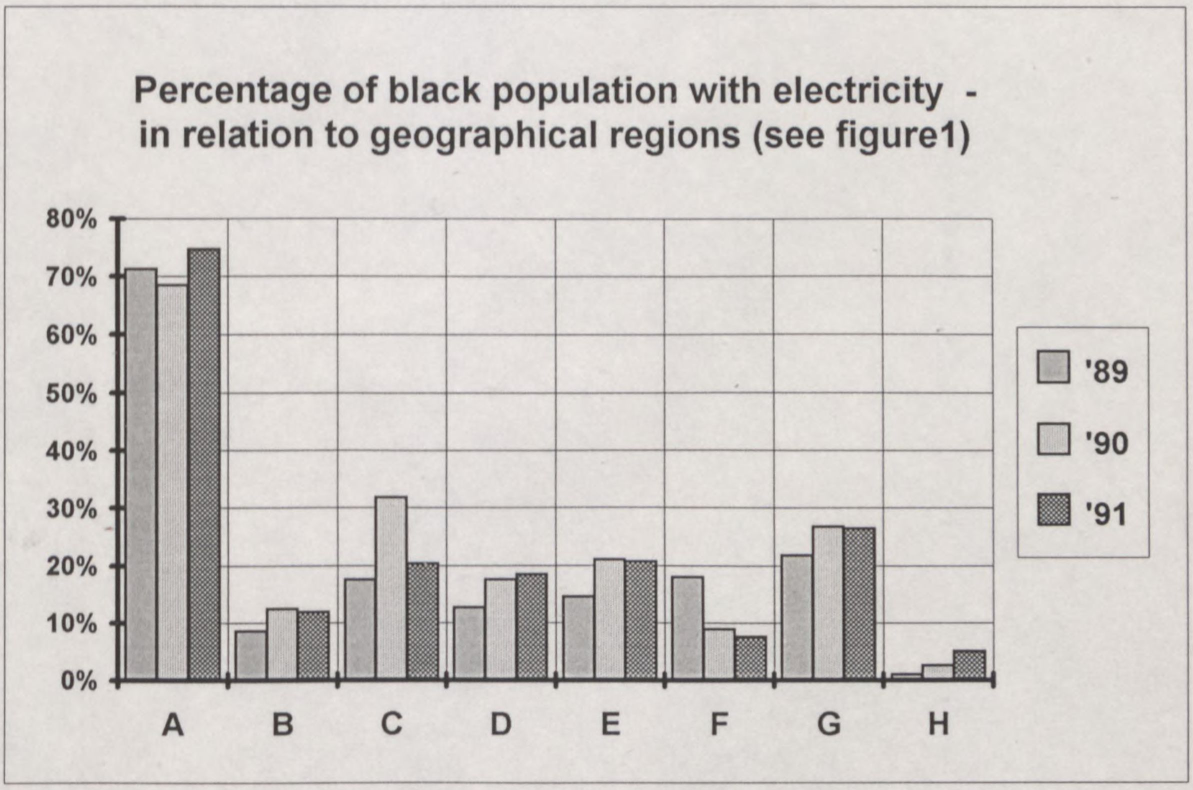
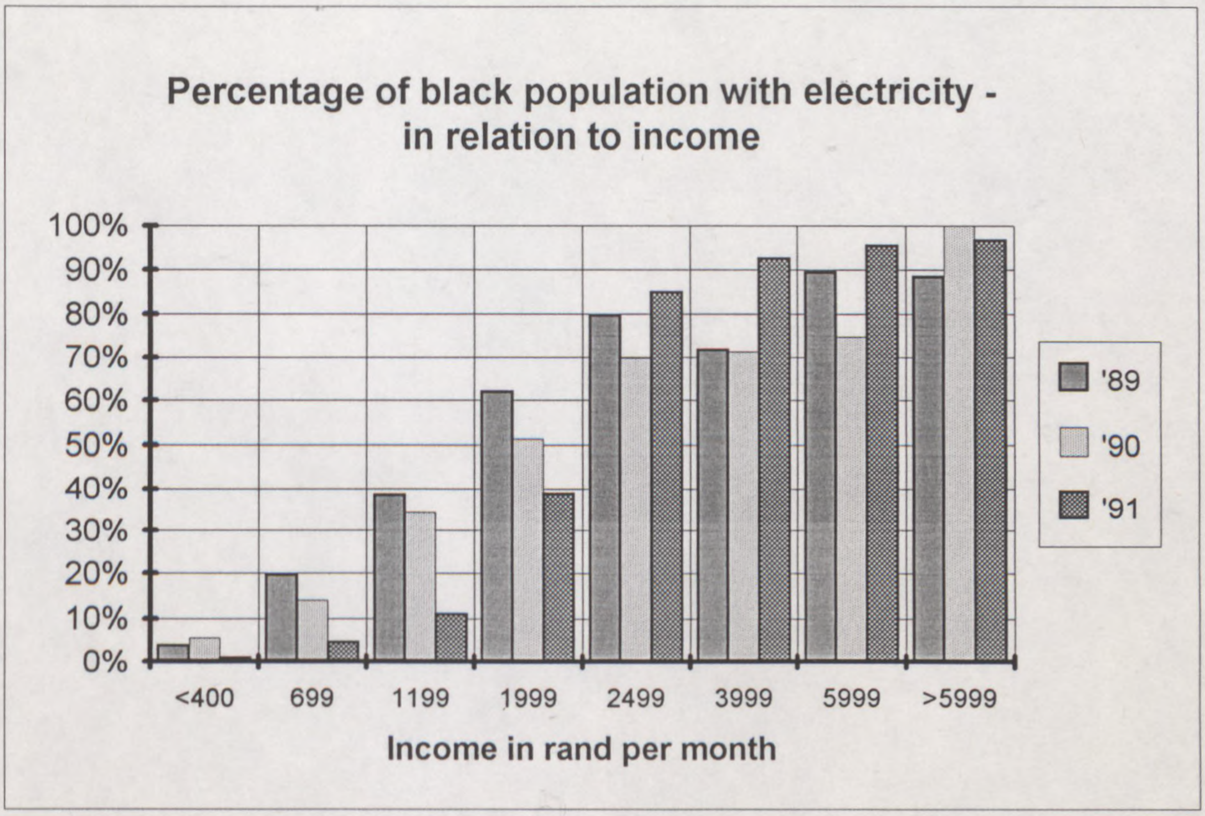


Figure 21 Percentage of black population with electricity in various metropolitan and geographical areas



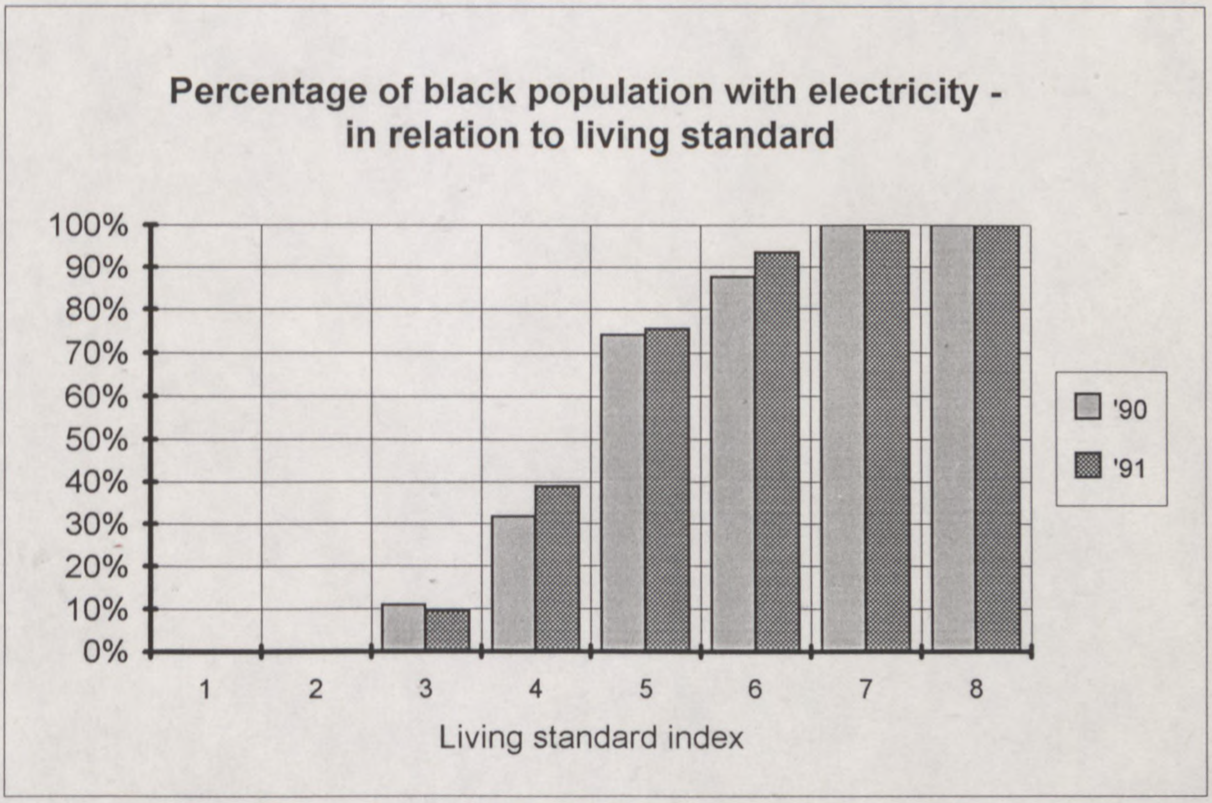


Figure 22 Percentage of black population with electricity in relation to income and living standard

Dense or closer settlements (e.g. settlements in Bophuthatswana near Rustenburg) which occur in rural homelands, are agglomerations of mainly informal dwellings where people do not derive significant income from agriculture. Rather, most commute to work in urban or metropolitan centres which are often 80 km or more away. Such settlements are a relatively recent phenomenon in South Africa.

But it will not be sufficient to electrify densely populated areas only. During the next few years South Africa will have to develop and apply technology which is cost-effective so that rural areas can also be given the advantage of grid electricity.

Some cost-effective measures have already been implemented and tested in South Africa. An example of effective cost reduction occurred when a project to electrify 42 000 km^2 of sparsely populated Kalahari was about to be scrapped due to escalating costs, but innovative construction methods were used to complete the project 8 months ahead of time within the original budget. (Anon., 1992:53)

Cost-effective single phase distribution networks have been used successfully for rural areas in Brazil and Costa Rica. Single phase lines have also been widely used in the USA since the inception of the Rural Electrification Administration's programme in the 1930's. Single phase lines in the USA were designed to be convertible to three phase by the addition of cross arms. (Dingley, 1988:19)

Innovative cost-effective systems could bring about a reduction in house wiring costs by implementing a low voltage system, where the consumer is supplied with electricity at 220 volts, but both conductors are at 110 volt from earth by using a centre tap earth, thus reducing the risk of electrocution and saving the cost of expensive earth leakage equipment. This system is also widely used in Brazil and Costa Rica. (Dingley, 1988:20)

5.3 Electrifying developing communities

Eskom has undertaken a comprehensive survey of electrification possibilities. They have identified nearly 3 million houses which can be electrified during the next five years (De Beer, 1992). Figure 23 gives a graphic representation of this analysis. Eskom has the supply rights to nearly a million of these houses, and plans to electrify them during the next five years. It is hoped that other supply authorities will follow Eskom's example.

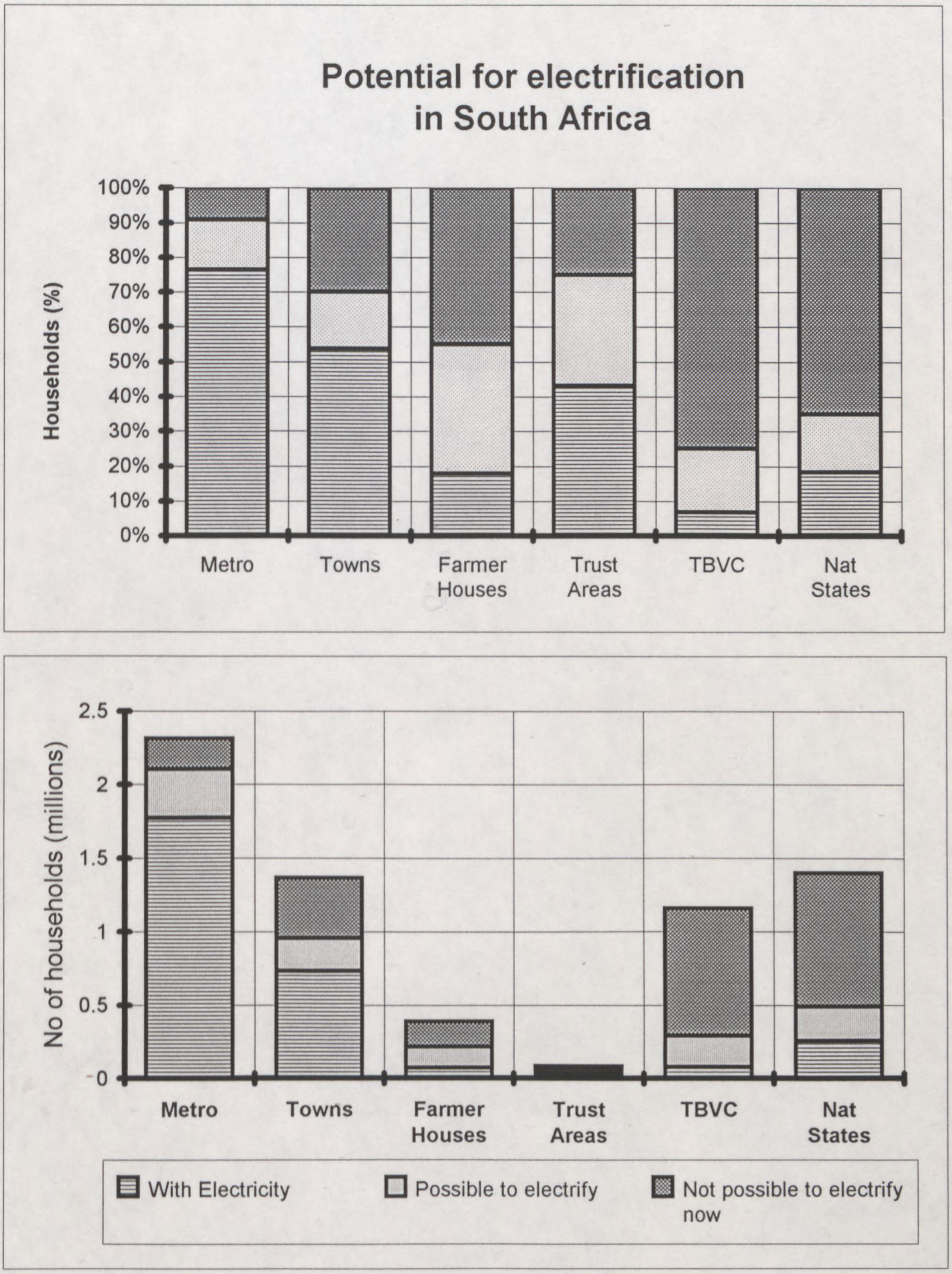


Figure 23 Analysis of the number of houses which can be electrified during the next five years

Electrifying a black area is a substantially different task from electrifying a white area. In a Westernised community electricity is considered as essential, whereas the newly urbanised community in the past may have seen it as a luxury which cannot always be afforded. It may also be a long time before the individual can afford the electrical appliances, so the initial consumption may be low if the supplier does not help the consumer with the acquisition of appliances.

Surveys undertaken some years ago in black urban communities where electricity has been available for quite a number of years have shown that the availability of electricity by no means implies that electricity is to be used as the major source of energy for the household. Figure 20 indicates that even in some areas in the Cape such as Langa and Gugulethu where many people live whose families have been in urban areas for more than a lifetime, only about 50% of the households make use of the available electrical grid system.

More recent surveys show that about 6 700 (81 %) of the 8 300 houses in Gugulethu, and 2 200 (60 %) of the 3 500 houses in Langa have electricity. Many of those which do not, are without electricity because it is not available.

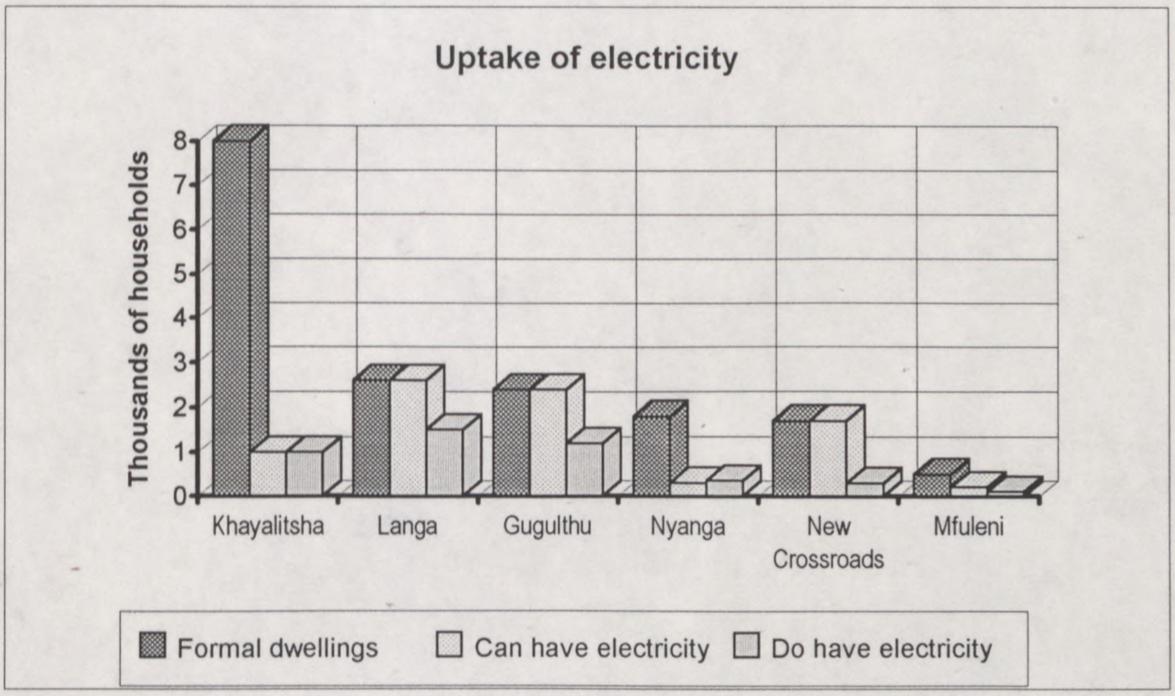


Figure 24 Uptake of electricity by the developing community (Viljoen, 1989:122)

In some isolated areas distribution equipment is faulty, vandalised, or simply lacking. In some cases the supply has been disconnected because of non-payment after individuals have run up impossibly high arrears. (Theron, 1992) It appears that electricity, when available, is used by a much higher percentage than was the case a few years ago.

Table 21
Positive attitudes towards fuels (Viljoen, 1989:112)

Attitude	Elec- tri- fied	Non- elec trf.
Electricity economical	18,8	1,4
Electricity convenient	40,6	2,8
Paraffin economical	18,8	46,6
Paraffin safe	3,1	2,8
Gas economical	0,0	4,7
Gas clean	3,1	15,5
No positive Attitude	9,4	11,4
Non-response	6,2	14,5

Table 21 shows the results of one survey indicating positive attitudes towards electricity compared with other fuels, while Table 22 shows negative attitudes. It can be seen from these tables that some people with electricity in their homes use paraffin because it is perceived to be cheaper. It is remarkable to note that some people are in favour of electricity because they consider it to be economical, whereas others dislike it because they think it is too expensive.

Table 22
Negative attitudes towards fuels (Viljoen, 1989:112)

Attitude	Elec- tri- fied	Non- elec trf.
Electricity expensive	31,2	2,0
Paraffin expensive	0,0	6,7
Gas expensive	0,0	7,8
Paraffin dirty	0,0	12,1
Gas dangerous	3,1	8,1
No negative attitude	50,0	22,9
Non-response	15,6	39,9

The priority of appliances which the developing community possesses irrespective of the energy source is given in Table 23.

Table 24 shows the priority of appliances which are powered by the electrical grid. The difference in priority between appliances irrespective of energy source and those using electrical energy is very noticeable.

Table 23
Possession of appliances by a sample in the developing urban community (Viljoen, 1989:114)

APPLIANCE	% TOTAL HOUSEHOLDS
Stoves	100
Light	100
Iron	74
Heater	57
Radio	52
HiFi/tape recorder	35
TV	33
Fridge	20

It is clear that the developing community is very selective about the appliances for which electrical energy is used. The reason for this may well be that the cost of appliances is a major component of affordability to the household as the household electrifies.

Table 24
Possession of appliances by a sample in the developing urban community
(Viljoen, 1989:114)

APPLIANCE using electrical energy	% TOTAL HOUSEHOLDS
Light	20,7
TV	17,8
Fridge	17,2
Stove	15,0
HiFi	12,2
Heater	6,1

5.4 Reasons for Electrification

The literature lists many reasons for electrification. Those who actively promote electrification use very convincing arguments to prove the need for and advantages of electrification.

Some of the reasons for electrification are:

1. Social upliftment.

* Electrification improves the standard of living. Improved quality of domestic life is seen as an important aspect of electrification by countries which actively promote electrification. Electricity is clean, safe, versatile and convenient.

* Electrification brings improvement to the socially oriented infrastructure, particularly in the health and education sectors.

* Literacy improves with electrification.

* Better services can be provided by small businesses.

2. Reduction of energy cost.

Households with electricity spend less on energy than those without electricity.

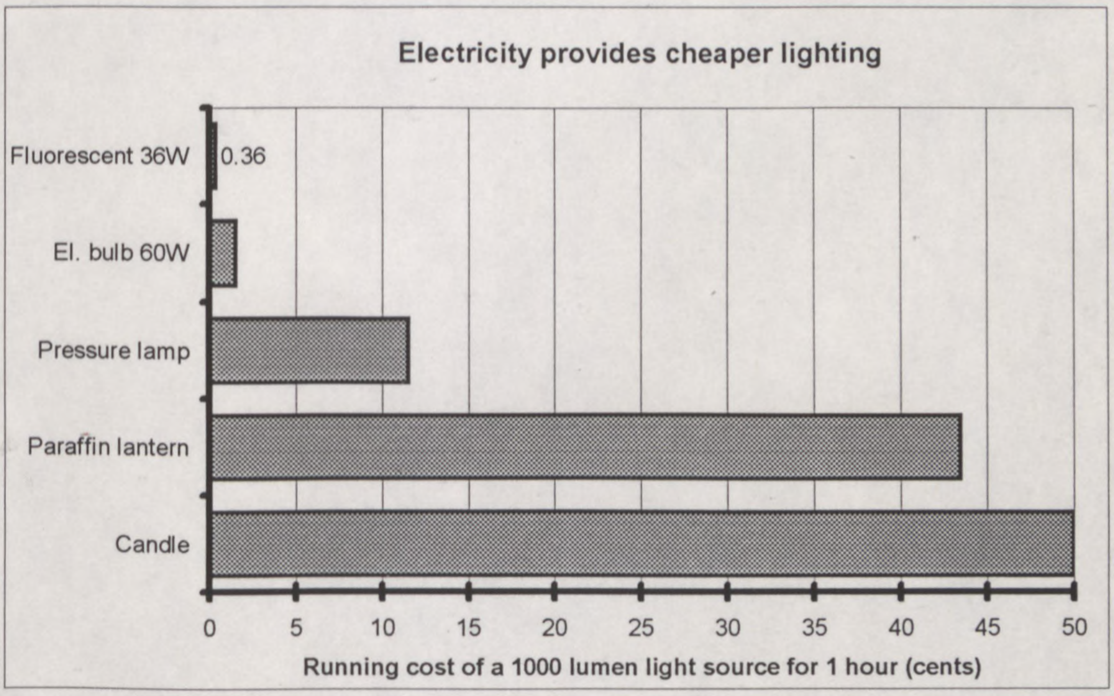


Figure 25 Comparison between the running costs of different light sources

Table 25: Comparative characteristics of various light sources

Light Source	Power	Light	Efficacy	Fuel	Running cost/h	
	W	lm	lm/W	used	c/1000lm	cents
Paraffin based:						
Hurricane lantern	181	69	0,4	14 g/h	43	3
Pressure lamp	1044	1303	1,2	73 g/h	12	15
Candle:		100			50	5
Electrical:						
Tungsten filament	60	660	11	60 W	1,5	1
Fluorescent	40	1944	54	40 W	0,3	0,17

Eberhard (1984:9) reported in 1984 that it cost households without electricity in Lotus River, Grassy Park and Bellville South R 59, R 73 and R 65 respectively per month to provide energy, while households in Gugulethu, Bonteheuwel, Heathfield and Pinelands spent R 25, R 21, R 40 and R 44 per month respectively on electricity. Relatively wealthy Pinelands households spent less than 3 % of household income on domestic energy, while Valhalla Park residents, without electricity, spent 25 % of their income on domestic energy.

3. Better and cheaper lighting.

The energy consumed by paraffin lamps and candles is significantly more expensive than the electricity for electric lights. A study in Java showed that a household using electricity for lighting enjoys roughly six times more light than a similar household lighting with paraffin. (Fitzgerald *et al.*, 1990:24). Figure 25 illustrates and Table 25 lists characteristics of various lights. They clearly indicate how superior electricity is when comparing the efficacy and running cost of different light sources.

4. Job Creation.

Electrification will no doubt boost the electrical construction and equipment supply industry. If South Africa wants to connect 7 million households over a period of 20 years, an average of 350 000 per year as estimated by Dingley (1990:17), then the annual cost for the distribution network would be approximately R 700 million, and the cost of wiring and appliances would be another R 700 million per year. This could be translated into the creation of 50 000 jobs in these sectors.

South African electrical supply authorities have a consumer to employee ratio of about 100 to 1, so the additional consumers gained by an electrification program would generate a further 3500 jobs per year in the electrical supply sector. With rationalisation it may be possible to reduce this number by increasing the consumer to employee ratio. In developed countries the employer to consumer ratio is about 250 to 1.

Due to the multiplier effect of electrification many more jobs will be created. Multiplier estimates vary from 1 to 3. The multiplier effect would be significantly affected by the funding strategy. Foreign soft loans would increase the size of the multiplier. Discussions with research staff at Eskom revealed that Eskom is of the opinion that an investment of R 2 000 million by Eskom could produce an economic activity of nearly R 10 000 million. It is estimated that the electrification of one million homes by 1995 would lead to the creation of 268 000 jobs and an increase in the GDP of 6 % (van Gass & du Plessis, 1991).

5. Electrification is complementary to housing and provision of services.

Electrification must be seen to complement other developmental needs such as the provision of housing, water and sewerage services. Funding considerations should be based on an integrated approach.

The provision of adequate housing should be seen as essential for the enhancement of South Africa's productive capacity.

It is interesting to note that the World Bank has compared South Africa's housing policy under apartheid to the command economies of Eastern Europe. The Sunday Star of 18 Aug 1991 reports them as saying, "The housing sector has failed to contribute to broader economic development - and continues to do so." The World Bank acknowledges that housing has major implications for the economy, the fiscal efficiency of cities and the welfare of blacks. The housing crisis (and electrification crisis) needs to be resolved by strong intervention.

Today, however, there are strong pressures in South Africa to improve the housing conditions for blacks, and one can expect a considerable improvement in the housing condition. The people themselves also will be keen to spend money to improve their housing conditions. The report referred to above also says, "Access to electricity is a key to the improvement in housing conditions."

6. Economic progress.

Electrification leads to economic activity in the township concerned. Electricity is needed for bakeries, shops, garages, workshops and a host of other small businesses. Eskom reported that a year after the electrification of Elandskraal the jobs in the township had increased more than three fold due to increased economic activity in the township. Many inhabitants of Peacetown said during a survey undertaken before Peacetown was electrified, that they wanted to start a business after electrification. In another survey undertaken after electrification, 30 % had already started a business and 69 % of them used electricity in their process.

7. The cost of pollution.

Air pollution is damaging to health and it is in particular the most important source of respiratory problems which include asthma and bronchitis as well as ear and nose infections.

Electricity is the cleanest form of power. Opinion surveys amongst blacks have shown over and over again that they consider electricity to be a clean form of energy.

* The major source of pollution is not the power station, but the township using coal for cooking. This is supported by comparing pollution levels of the Eastern Transvaal Highveld with Soweto.

* The highest ambient level of sulphur is found in Soweto, mainly as a result of the fact that open coal fires are still used for cooking.

Although the open coal fire is a traditional cultural habit, the use of coal can also be attributed to the fact that the Soweto electricity supply is unreliable.

* Researchers at Eskom have found that the air at Vereeniging exceeds US health standards 21 % of the time, in Vanderbijlpark 51 % of the time and in Sebokeng 100 % of the time.

* According to Eskom the electrification of all dwellings in the PWV area would reduce the SO_2 and particulate concentrations in the townships by 64 %.

8. Eskom's excess capacity.

Eskom has an excess capacity of 7 000 MW which in Rand value (not book value) is estimated to be worth between R 8 000 and R 10 000 million. There is no return on this capital outlay. The developing community can benefit from this spare capacity which is available.

6 INFLUENCE OF APPLIANCE OWNERSHIP ON ELECTRICITY CONSUMPTION

6.1 Introduction

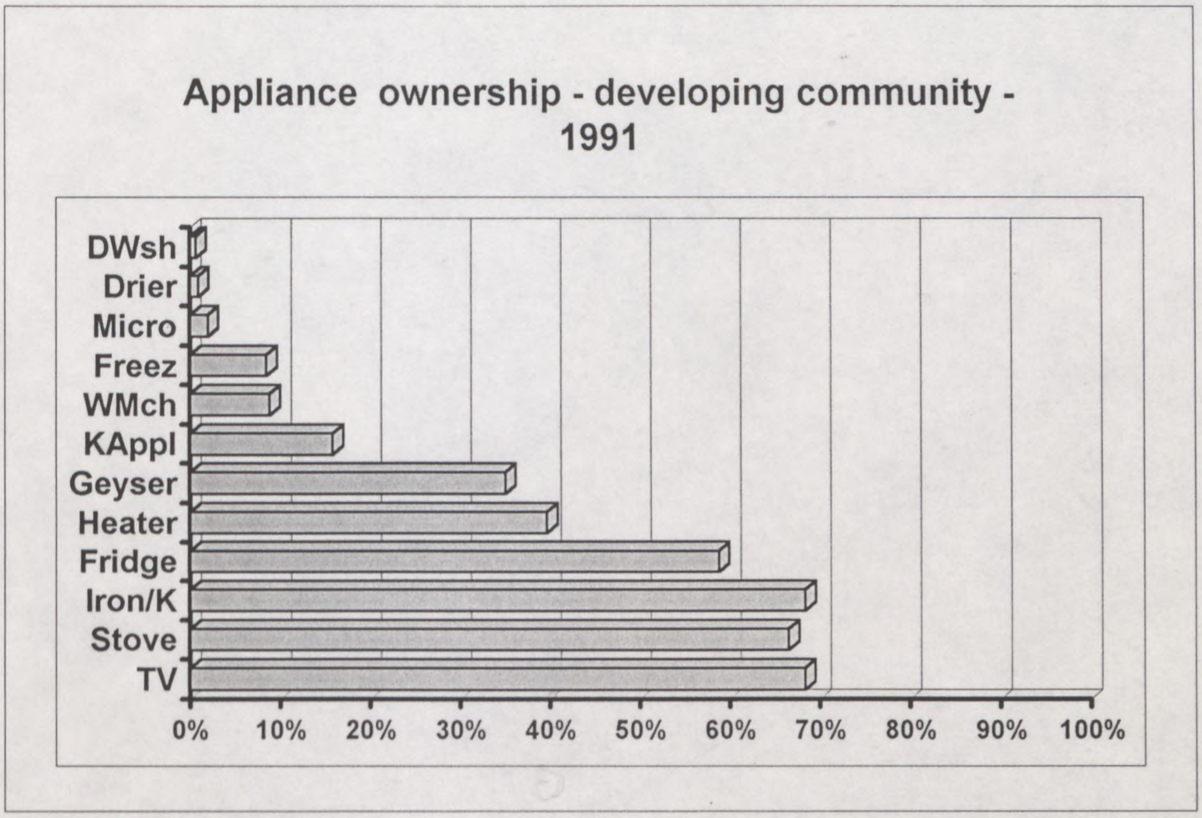
Domestic electrical energy is used exclusively by appliances, so there must be a very close relationship between energy usage and appliance ownership.

Various studies, some of which are referred to below, have shown that there is a very close relationship between appliance ownership and electricity consumption in the low income sector, where the use of electricity is very much limited by the absence of appliances and the consumption can be very low.

At Orange Farm, an informal settlement near Meyerton in the Southern Transvaal for instance, the average monthly consumption is 130 kWh (Berrisford, 1991:4.5). A relationship between average income and average consumption is not available, but there are indications that appliance cost rather than electricity cost is the factor which limits electricity consumption. Simply making electricity available to a community does not imply immediate large scale domestic electricity consumption. This is clear from the Bapong study where a very high connection fee and the cost of appliances limited those who made use of electricity to only 15 % of several hundred homes in the community (Golding, 1991:1).

6.2 Appliance ownership

Information about appliance ownership (excluding the water heater) is available in terms of living standards, regions, metropolitan areas and many other parameters (SAARF, 1991). Appendix B shows this data for one appliance. Appendix F shows the source of the data for the electric water heater. The discussion which follows in this section is based on this data.



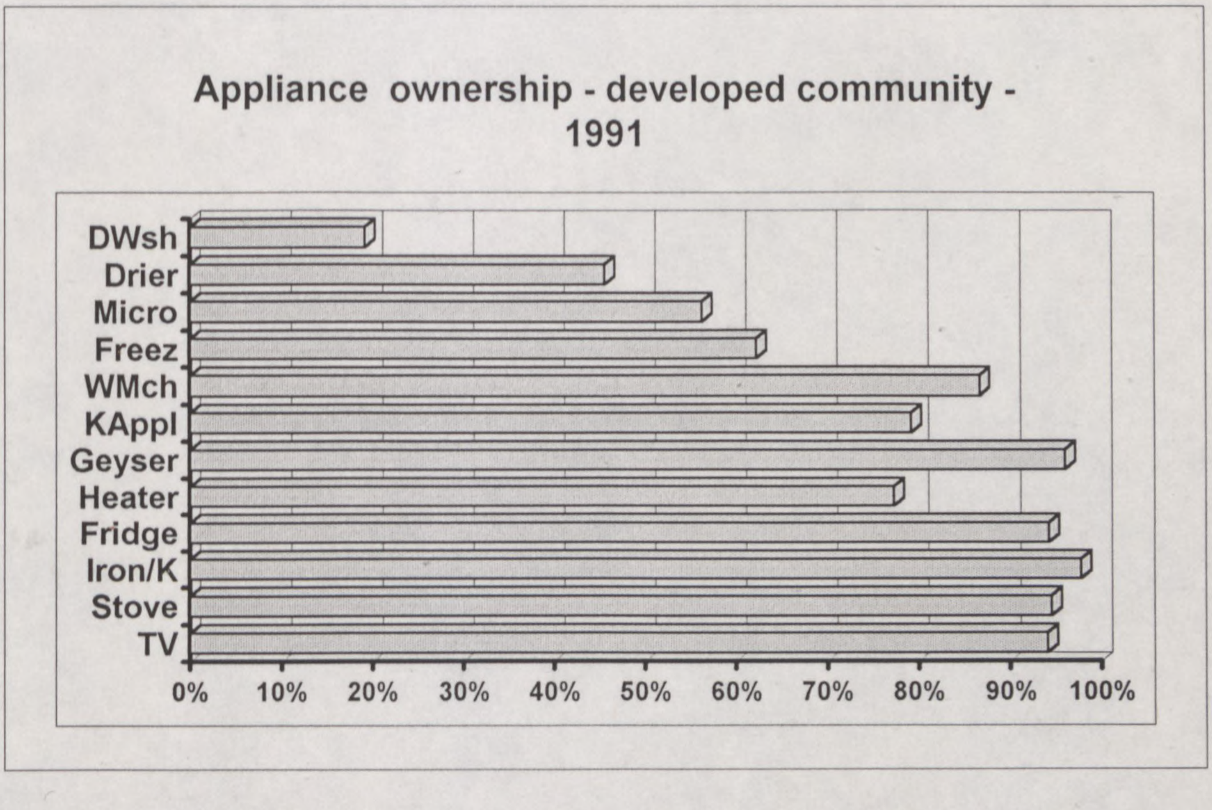


Figure 26 Ownership of electrical appliances as a percentage of households with electricity (SAARF, 1991) (see appendix B for abbreviations)

Figure 26 compares the percentage ownership of appliances in the developing community with that in the westernised community. The ownership of basic appliances, such as stoves/hot plates, kettles and fridges, in the developing community is not significantly different from that in the developed community. There is a marked difference in luxury appliances such as dish washers, microwave ovens and washing machines, but these items do not increase the electricity consumption very much, because their use does not replace non-electrical energy sources.

Considering what has been said in the previous paragraph, it is not surprising that Berrisford (1991:4.2) found that while the average monthly consumption for South Africa is between 700 and 800 kWh per household, the average monthly consumption for the developing sector is only about 30 % less.

There is however a marked difference between the ownership of electric water heaters in developed and developing communities. The ownership in developed communities is nearly three times as much as it is in developing communities. There are many reasons for this, but the primary reason may be the cost of a running hot water system. For the hot water system to be useful, a fitted bathroom is needed. A fitted bathroom may well be the most expensive room in the house. Appendix F shows that 22 % of the developing community own a fitted bath, and 11% own a shower.

It is very noticeable that despite the high cost of appliances, as much as 70 % of households in the developing sector have a television set and that this luxury appliance is the most popular appliance with the developing community. This means that even those who are assumed to be too poor to buy appliances can afford at least some.

The capital cost of an appliance must be converted to a daily or monthly cost to determine the actual cost. For example an appliance costing R 1 000-00 paid over the life-time of the appliance (say 10 years) at 18 % interest will cost only 60 cents per day.

The difficulty which the poor experience is that they usually do not have the capital and they are also not able to obtain loans at reasonable rates of interest. The items bought first are often non-essential items which are thought to improve their life-style, even if only in the short term.

The practice of some supply authorities to make essential appliances available at little or no capital cost when electricity is made available, is very sound. It is in the interest both of the consumer, who otherwise would not be able to finance the purchase of the appliances, and of the supply authority, who will be able to sell his product, electricity, because the consumer has the appliances to use it.

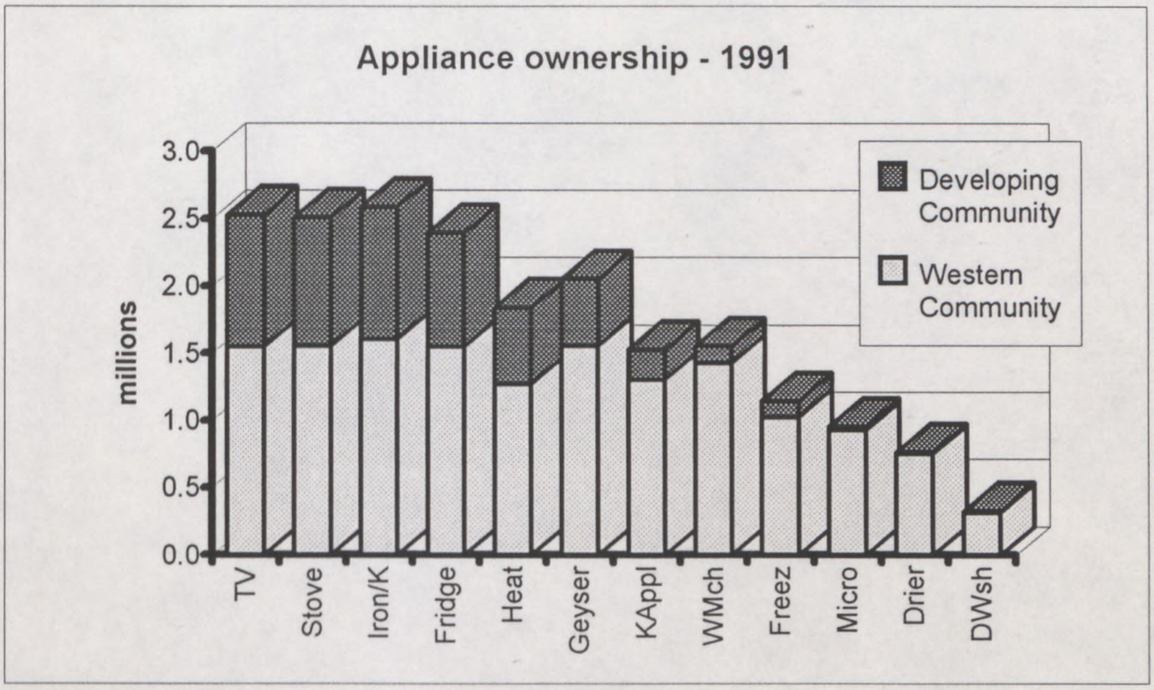


Figure 27 Numbers of appliances owned by various sections of South African communities

Figure 27 compares the number of appliances owned by South Africa's developing community with that of the westernised community. It can be seen that the number of appliances owned by the developing community is much less than the number owned by the westernised community. The main reason for this difference is the low percentage of developing households with electricity in their homes.

Figure 28 shows how the ownership of appliances has changed from 1981 to 1991. Data for 1981 are not available for all the appliances, so not all the appliances are shown for 1981.

The large annual increase of about 10 % per year in the case of the developing community is very noticeable. Increases apply to most appliances. In the case of the luxury appliances such as the microwave oven, tumble drier and the dish washer, the numbers are too small at present to provide a statistically reliable indication of the change that is taking place over the years, but there does seem to be an increase.

The largest increase appears to have taken place in ownership of television sets. This clearly shows the potential of using the television set for educational purposes.

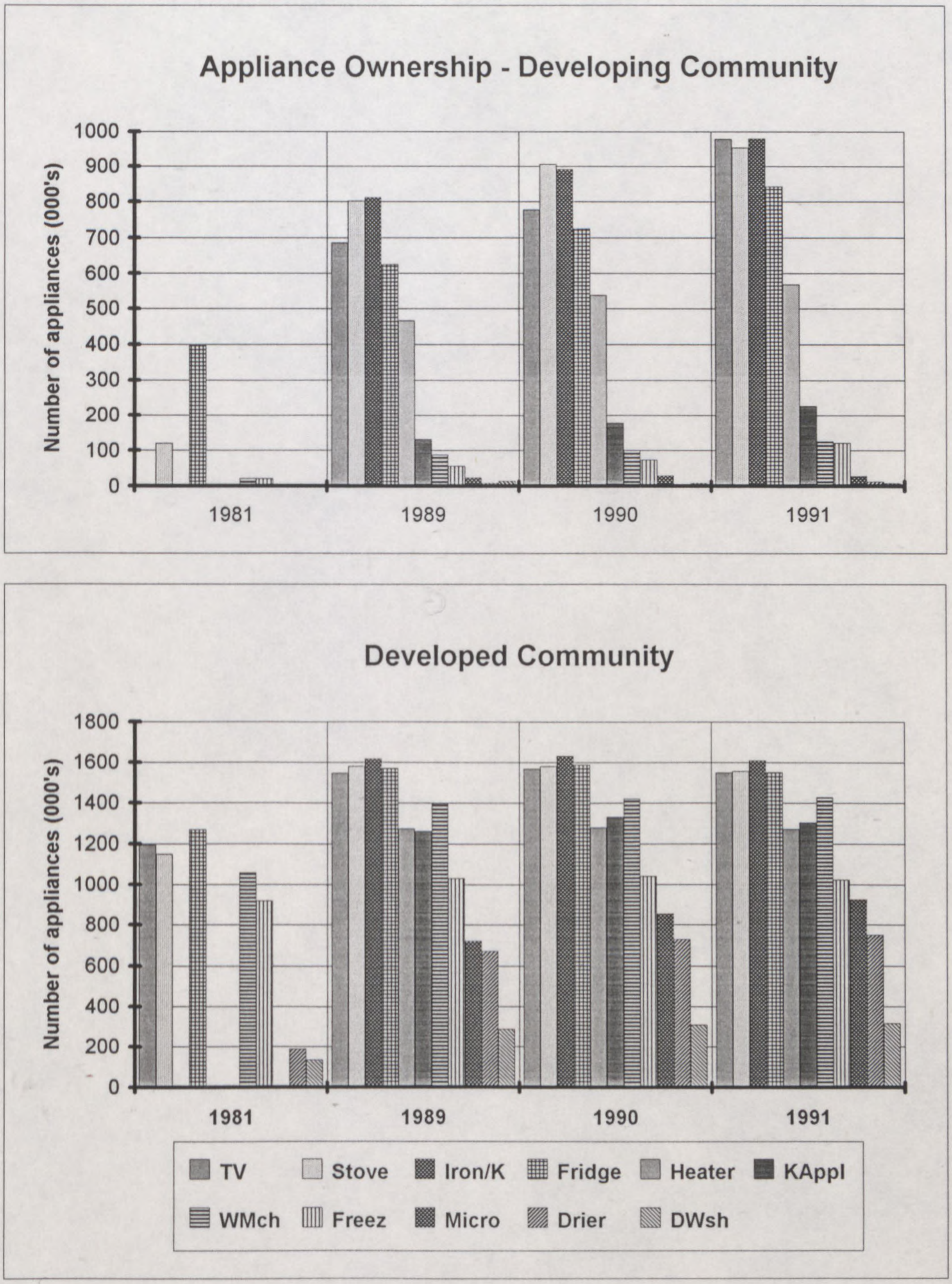


Figure 28 Appliance ownership for the years 1981 to 1991

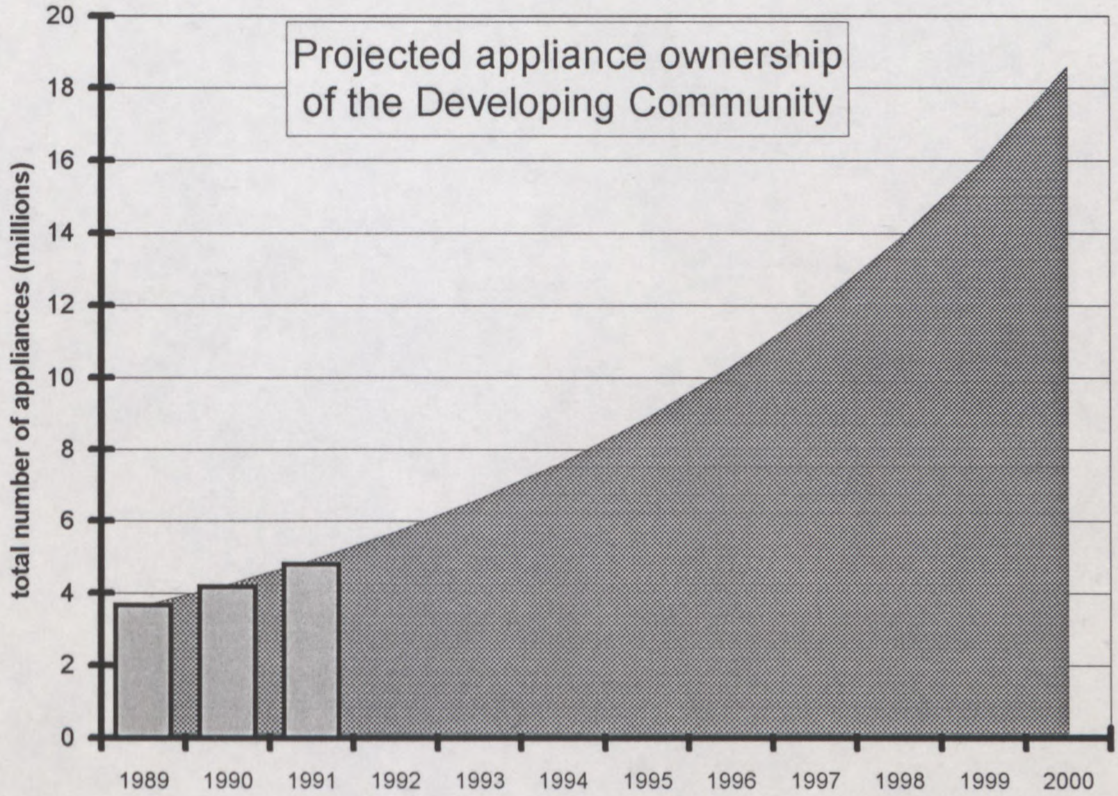


Figure 29 Expected appliance ownership of the developing community for the years up to 2000

In the case of the westernised community there seems to be very little change over the years in ownership of appliances, except in the case of microwave ovens which have increased in number from some 700 000 in 1989 to about 900 000 in 1991.

The trend in the increase of appliance ownership from the year 1989 to 1991 has been extrapolated to the year 2000. Figure 29 shows what the number of appliances is expected to be in the year 2000. The increase depicted in Figure 29 may prove to be an underestimate if the electrification policy of Eskom is successful.

The number of appliances which people can buy depends on their economic ability, which in turn depends on how South Africa develops economically. Economic development will also have a strong positive influence on the number of houses which will be electrified during this decade.

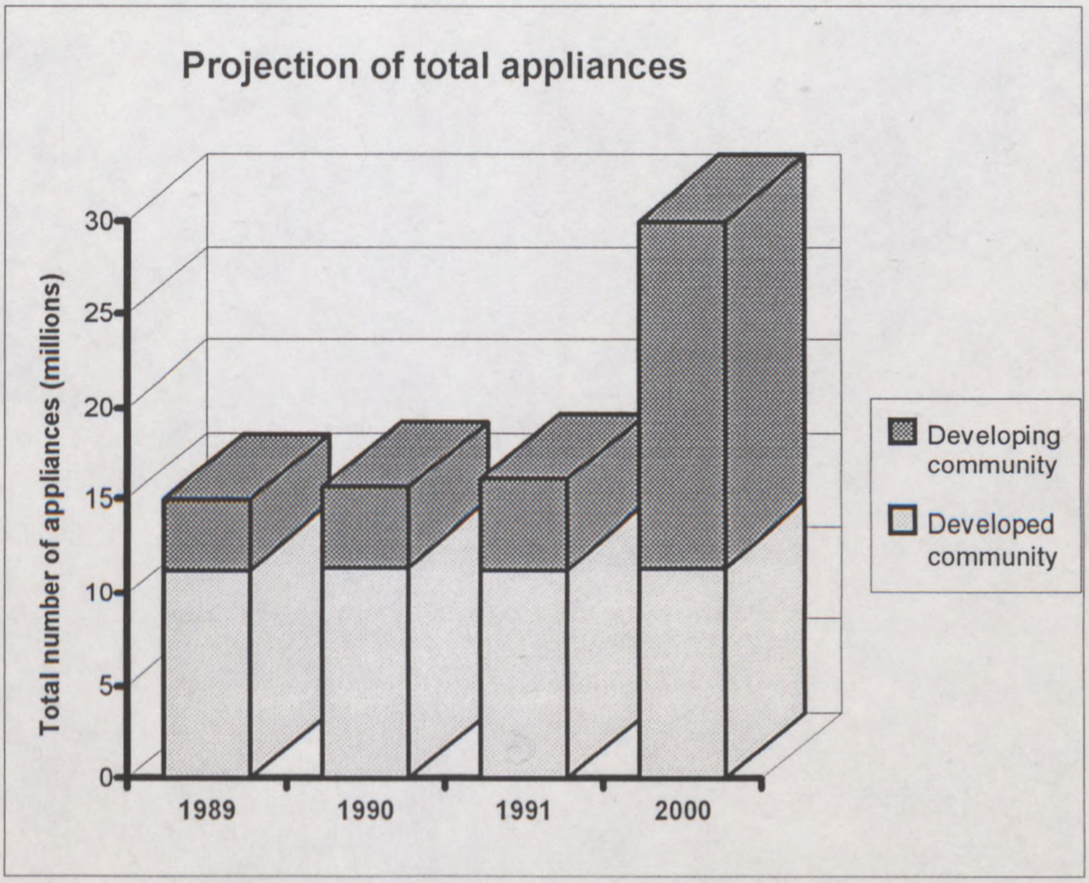


Figure 30 Appliances up to the year 2000: comparison between the developing and developed communities

Figure 30 shows convincingly that if South Africa develops economically during this decade, then the domestic electricity consumption by the year 2000 will be dominated by the developing sector.

The electrical energy consumed does not only depend on the number of appliances, but also on the type of appliance. In the case of the developing community most of the appliances are basic appliances such as stoves and heaters which use electrical energy as a replacement for other forms of energy, while those owned by the westernised community will include many luxury appliances such as microwave ovens, which do not add substantially to household electrical energy consumption. This is another reason why the energy consumed by the developing community by the year 2000 will be more than that consumed by the westernised community.

6.3 Electricity consumption

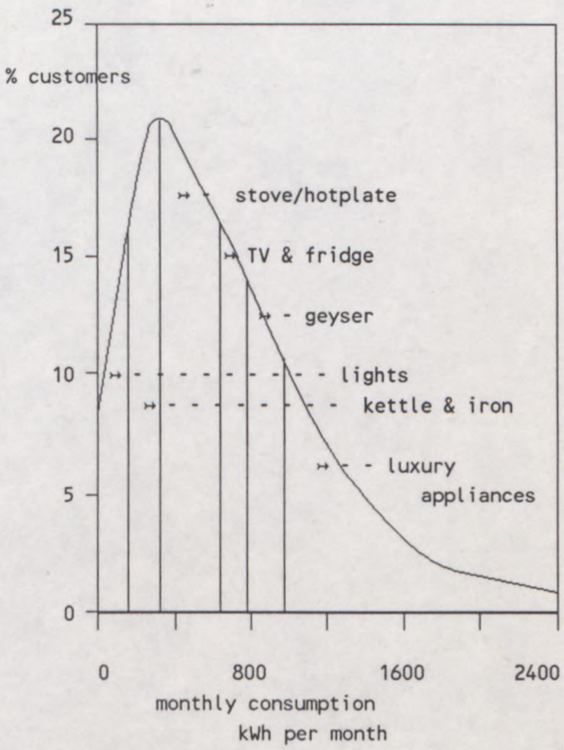


Figure 31 Soweto Electricity Consumption distribution (Berrisford & Bluff, 1991:4.8)

Figure 31 shows the electricity distribution for Soweto in 1990. Various energy consuming appliances are also shown, indicating what the consumption is likely to be for households which own various appliances. Various reports of appliance ownership in developing communities show that the ownership rates of electrical appliances is fairly similar for developing communities: the first usage of electricity is for lights, then come an iron, kettle and some form of entertainment such as a TV and/or hi-fi. After this a major increase in electricity consumption is the result of the hot plate or stove, and lastly electricity is used by a variety of appliances.

It has been found that cooking is not one of the first uses of electricity as the developing community starts using electricity. This tendency is not limited to South Africa. In Mozambique a recent study by the World Bank has shown that the preferred use of electricity for households once connected to the grid follows the pattern of illumination and then refrigeration, with cooking as a lower priority end-use.

In areas with formal dwellings in Maputu, the percentage of the population using electricity for cooking is only 15 % which corresponds closely to the proportion owning electric cooking appliances. The main reason for this low level of electric cooking in Mozambique has been the prohibitive cost of stoves, lack of spare parts for the stoves and the unsuitability of utensils which burn out. Even in Cement City in Maputu, where all households are electrified and incomes are higher, only slightly more than a third of households connected to the grid are actually using electricity as their main cooking fuel, although 70 % own stoves. A study group from the World Bank suggests other reasons for this low level of electrical cooking such as instability of supply and traditional cooking habits (World Bank, 1990:27).

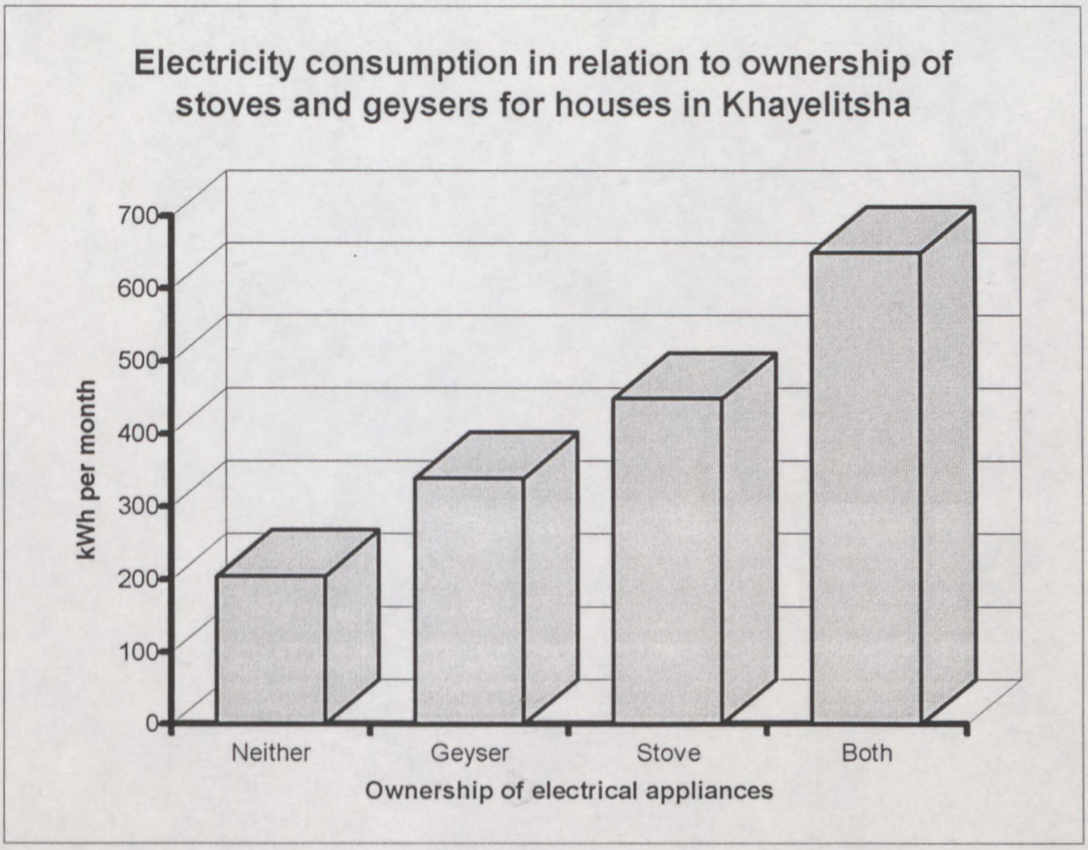


Figure 32 The relationship between the ownership of stoves and hot water cylinders and electricity consumption

An electrical geyser is not as popular in the developing community as might be expected. One of the reasons is the lack of running water in the home. Appendix E gives detail of a survey conducted in developing areas around Cape Town. This survey has shown that hot water is used despite the absence of geysers. A kettle, urn, electrical hot plate, stove or a non-electric stove is used for heating water in the absence of running hot water, but the amount of hot water used is less than half of what would be used if running hot water were available.

The stove and the water heater add considerably to a household's electricity consumption, as is shown in Figure 32 (Theron & Thorne, 1992:7). The close relationship between appliance ownership and energy consumption is indicated in this diagram by the large difference in electricity consumption when comparing consumers who have an electric stove and a geyser with those who do not have these appliances.

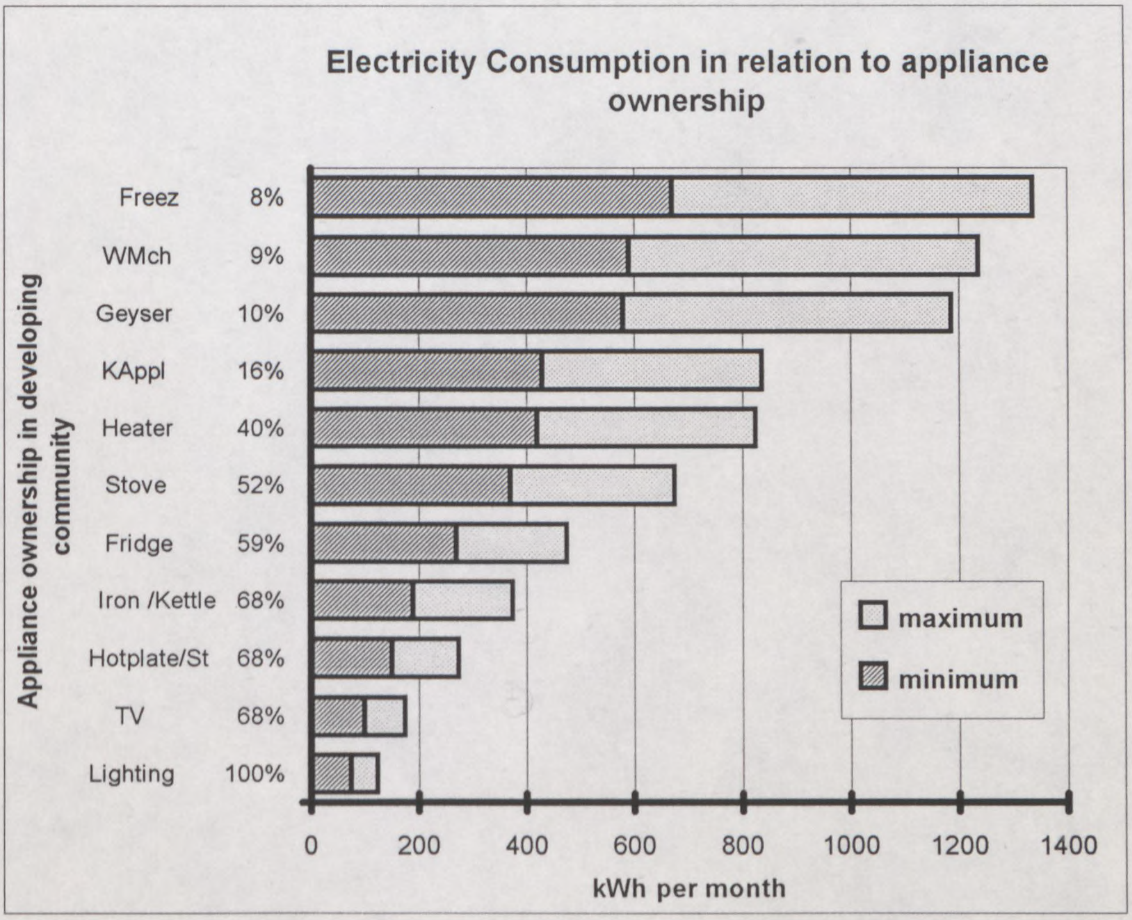


Figure 33 Electricity consumption as a function of appliance ownership

Figure 33 presents results which have been calculated by using values of appliance ownership for the developing community as discussed earlier in this chapter, and also typical monthly consumption figures for each appliance. Possible ranges of energy consumption per month have been calculated for each appliance as used by the developing community. The total monthly energy consumption for a household owning all the appliances up to a particular appliance is shown on the diagram. For example, a household using electricity for lighting, TV, hot plate, iron and kettle is likely to use between 200 and 380 kWh per month.

6.4 Conclusion

Monthly household consumption is dependent on appliance ownership. In the case of the developing community, the relationship is strongly positive, because many of the appliances cause non-electric energy sources to be replaced by electrical energy. However, in the case of the developed community the relationship may even have a negative correlation: for example, when a household acquires a microwave oven, the energy consumption is likely to decrease because cooking can be done more efficiently. The same could be said for a household acquiring a toaster.

Appliance ownership by itself cannot be used to determine energy consumption. Factors which categorize the consumer in terms of his living standard, for example, are also needed. This is the reason for the factors in the proposed model described in chapter 2 which refer to geographical region (g), living standard (c) and utilisation (u).

7. HOT WATER LOAD

7.1 Introduction

The electrical load required to supply domestic hot water is an important load for two reasons:

1. It represents a large portion (30 to 50 %) of the domestic load.
2. It is a load which can easily be controlled by the consumer or the supplier, because the use of the hot water need not coincide with the heating of the hot water.

In what follows a model representing the electrical load due to hot water consumption in South Africa is provided. Readings of the electrical hot water load have been made in various municipalities; based on these readings and on readings found in the literature, an estimate is made of how, when and how much hot water is used. The heat losses are also estimated and the merit of reducing the losses and influencing consumers to use hot water wisely is investigated.

7.2 A model of the hot water load using the normal distribution function

The electrical load is considered to consist of:

1. A morning load - e.g. morning bath, breakfast, washing of dishes;
2. A midday load - e.g. lunch preparation, dish washing;
3. An evening load - e.g. dinner, cooking, washing of dishes, bathing;
4. A steady load to cater for usage outside the above times;
5. Standing loss, the energy required to keep the water hot (this heat loss is dependent on such factors as the thermostat setting, weather, and geographical location);
6. Heat lost due to hot water being left in the water pipe every time hot water is used.

The hot water supplied by the hot water cylinder is not the only hot water which is used. There is the washing machine, for example, where some types heat their own hot water, but other models (for example the top loader and twin tub machines) require a separate supply of hot water.

For the first three loads listed above it is assumed that people using hot water use it randomly, according to a probability distribution function such as the normal distribution curve. The water will be heated after it has been used, the heating up time depending on the amount of water used and the size of the electrical element. The effect of delaying the heating of the water will also be considered.

The following analysis is given to illustrate the mathematical model:

If the hot water is used randomly with a normal distribution, then the hot water usage can be represented by the probability density function for a normal distribution:

$$f(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{t-\mu}{\sigma})^2} \quad . . . \; 5$$

(Mendenhall,1986:141)

and the number of households ***n*** out of a total population of N_{tot} which use hot water at a time ***t*** can be represented by the formula:

$$n(t) = N_{tot} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{t-\mu}{\sigma})^2} \quad . \; 6$$

where σ = standard deviation;
μ = average value.

This can also be written as:

$$n(t) = N_{tot} \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}(\frac{t-t_o}{\sigma})^2} \quad . . \; 7$$

where:

t = time in minutes;
t_o = time at which most people use water;
σ = a measure of the width of the distribution in minutes.

A difference must be made between the amount of water heated by the hot water cylinder, or any other appliance used to heat the water, and the amount of hot water used by the consumer. The difference between these two quantities is due to the heat lost by the hot water before it is used, or because the water is reheated after it has lost some of its heat, prior to being used. In the case of the hot water cylinder the amount of water which is eventually used as hot water is typically only about 60% of the amount of water heated. The heat lost which leads to this difference will be discussed in more detail later.

The amount of water heated can be calculated from measurements of the electrical energy used for water heating by the average household. For this purpose the electricity consumed for hot water and for the total domestic load was measured at about 20 dwellings. The co-operation of a few supply authorities who use the hot water load for load control was obtained to measure their total load and the total hot water load for all the hot water cylinders, which are controlled by the load control apparatus. From these readings it was possible to calculate the electrical hot water load per household reasonably accurately. Some of the readings are listed in Appendix C and D. Average values of the hot water load per household were found to vary between 250 and 500 kWh per month, depending on the season (temperature), the size of the household and the habits and standard of living of the households.

Table 26 converts the electrical energy used for water heating in kWh per month to the amount of water heated per day during winter. Values are also calculated for summer.

Table 26 Average quantity of water heated per person

	Summer	Winter
kWh per month	250	500
No. in household	3.75	3,75
Cold water temp in C	20	15
Hot water temp in C	65	65
HW/day in litres per household	159	261
HW/day in litres per person	42	69

Studies have shown that the amount of hot water used is:

during summer:
50 ℓ per person per day;

during winter:
75 ℓ per person per day.
(Coetzee, J.L. 1989:32)

The average family size, according to the Appliance Media Products Survey, for the family which is most likely to use the hot water cylinder (white, coloured and Asian families):

= 3,75 (SAARF, 1991:21).

According to the above studies the amount of water heated per family per day appears to be:

= 50 x 3.75 = 187 ℓ (summer)

and:

= 75 x 3,75 = 281 ℓ. (winter)

These values do not vary unduly from the values calculated in Table 26.

An assumption about when the water is used is made, based on the readings referred to in Appendix C and D, to calculate the time taken by the water to heat up after using the hot water. The percentage of how much of the water is used in the morning, midday and evening is discussed later, but for the calculations which follow it is assumed that the family uses 50 litres of water at a time.

The heat required (in joules) to heat up m kg water from a temperature of t_{inlet} to $t_{thermostat}$ is:

$$q = m.C_{water}.\Delta t \quad \ldots\ 8$$
$$joules$$

where Δt = $t_{thermostat} - t_{inlet}$

$t_{thermostat}$ = temperature to which water is heated in C;

t_{inlet} = temperature of cold water to be heated in C;

C_{water} = specific heat capacity of water in joules/(kg.C)
= 4,187 J/(kg.C).

The temperature to which the water is heated, $t_{thermostat}$, is not necessarily the thermostat setting, nor the temperature of the water as it leaves the hot water cylinder, because the water may lose heat and cool down before it leaves the hot water cylinder.

The time (in seconds) the element stays on after the hot water is used is:

$$\Delta t_{on} = q/P_e \quad \cdots\cdots\ 9$$

and:

Δt_{on} = $q/(60.P_e)$ minutes

where P_e = power rating of hot water cylinders.

$n(t)$ = number using hot water at time t

$n(t)=N_{tot}f(t)$

where:

$f(t)$ = probability density function

$N_c(t_1)$ = number of heaters which have been switched on by time t_1

= area(A+B):

$$N_c(t_1)=\int_{-\infty}^{t_1} n(t)dt \quad \cdots\cdots \quad 16$$

$N(t_1)$ = number of heaters on at time t_1

= Area(A+B) - Area B

= Area A

$$N(t_1)=$$

$$N_{tot}\left(\int_{-\infty}^{t_1} f(t)dt-\int_{-\infty}^{t_1-\Delta t} f(t)dt\right) \quad . \quad 17$$

$$=N_{tot}\left(erf(t_1)-erf(t_1-\Delta t)\right)$$

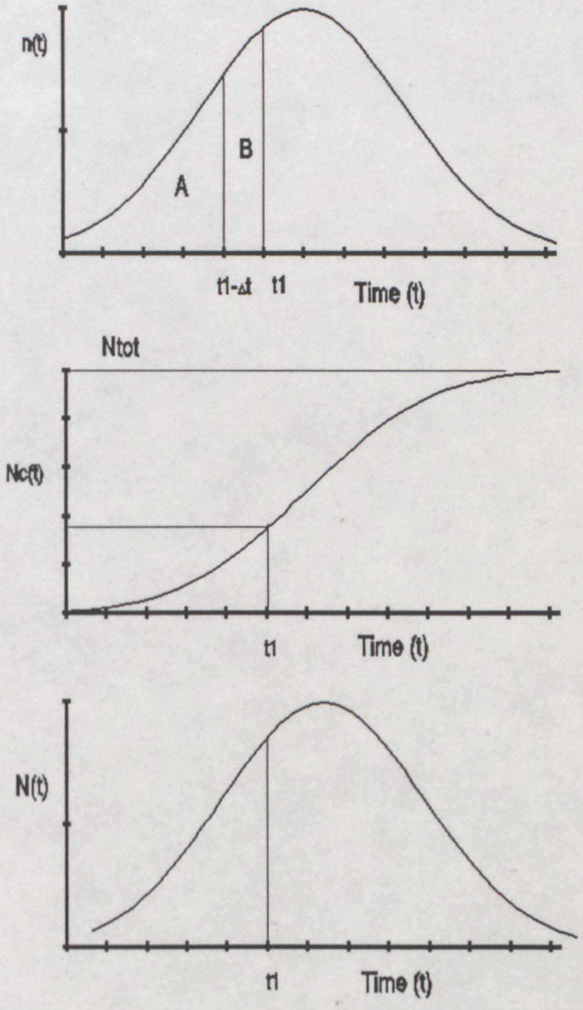


Figure 34 Equations and graphs illustrating the probability density function as applied to water heaters.

Substituting equation 15 into equation 13, the number of hot water cylinders switched on by time t_1, which is also represented by equation 10, becomes:

$$N_c(t_1) = \int_{-\infty}^{t_1} n(t)\ dt$$

$$= N_{tot}\ erf\ (x_1) \qquad . \ . \ . \quad 18$$

$$= N_{tot}\ erf\ (\frac{t_1 - t_o}{\sigma})$$

The number of heaters, ***N*** which are on at any time t_1 is the sum of all the heaters which are turned on between the times $t_1 - \Delta t_{on}$ and t_1 (the heaters which were switched on before $t_1 - \Delta t_{on}$ have already been switched off at time t_1). The number of heaters on at time t_1 can be represented by:

$$N(t_1) =$$

$$N_{tot}\ \frac{1}{\sigma\sqrt{2\pi}} \int_{t_1 - \Delta t_{on}}^{t_1} e^{-\frac{1}{2}(\frac{t-t_o}{\sigma})^2} dt \qquad 19$$

with:

$$x_1 - \Delta x_{on} = (\ \frac{t_1 - \Delta t_{on} - t_0}{\sigma}\ )\ . \qquad 20$$

and substituting $\boldsymbol{x}$ from equation 11 the number of heaters on becomes:

$$N(t_1) =$$

$$N_{tot}\ \frac{1}{\sqrt{2\pi}} \int_{x_1 - \Delta x_{on}}^{x_1} e^{-\frac{1}{2}x^2} dx \quad . \qquad 21$$

or:

$$N(t_1) =$$

$$N_{tot}\ [\frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x_1} e^{-\frac{1}{2}x^2} dx$$

$$. \qquad 22$$

$$-\ \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x_1 - \Delta x_{on}} e^{-\frac{1}{2}x^2} dx\ ]$$

so:

$$N(t_1) = N_{tot}\ [erf((t_1 - t_o)/\sigma)$$

$$-\ erf((t_1 - t_o - \Delta t_{on})/\sigma)] \quad . \qquad 23$$

where from equation 9 the time the cylinders are on in minutes is:

$$\Delta t_{on} = (m_{bath} c_{water} \Delta t_{water})/(60 P_e) \qquad 24$$

and the power consumed by the cylinders that are on is:

$$P_{tot}(t_1) = P_e . N(t_1) \quad . \ . \ . \ . \qquad 25$$

The power per water heater is:

$$P(t_1) = P_e\,[erf((t_1-t_o)/\sigma) - erf((t_1-t_o-\Delta t_{on})/\sigma)] \; . \quad 26$$

The value of erf(x) cannot be less than 0 or greater than 1, so ***$P(t_1)$*** can never be greater than ***P_e***, the power rating of the water heaters.

$N(t_1)$ and ***$P(t_1)$*** both have a maximum value when:

$$t_1 - t_o = \frac{\Delta t_{on}}{2} \quad . \; . \; . \; . \; 27$$

The peak load on the supply due to the hot water cylinders is then given by:

$$P_{peak} = P_e \,.\, N_{tot} \,.\, [erf\,(\frac{\Delta t_{on}}{2\sigma}) - erf\,(-\frac{\Delta t_{on}}{2\sigma})] \qquad 28$$

which can also be written as:

$$P_{peak} = P_e . N_{tot}\,\frac{1}{\sqrt{2\pi}}\,[\int_{-\infty}^{\frac{\Delta t_{on}}{2\sigma}} e^{-\frac{1}{2}x^2}dx - \int_{-\infty}^{\frac{-\Delta t_{on}}{2\sigma}} e^{-\frac{1}{2}x^2}dx\,] \quad . \; 29$$

Separating the integral:

$$P_{peak} = P_e . N_{tot}\,\frac{1}{\sqrt{2\pi}}\,[(\int_{-\infty}^{0} e^{-\frac{1}{2}x^2}dx + \int_{0}^{\frac{\Delta t_{on}}{2\sigma}} e^{-\frac{1}{2}x^2}dx) - (\int_{-\infty}^{0} e^{-\frac{1}{2}x^2}dx + \int_{0}^{\frac{-\Delta t_{on}}{2\sigma}} e^{-\frac{1}{2}x^2}dx\,)] \qquad 30$$

This simplifies to:

$$P_{peak} = P_e.N_{tot}\,\frac{1}{\sqrt{2\pi}}\,[\int_0^{\frac{\Delta t_{on}}{2\sigma}} e^{-\frac{1}{2}x^2}\,dx - \int_0^{\frac{-\Delta t_{on}}{2\sigma}} e^{-\frac{1}{2}x^2}\,dx\,] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 31$$

and:

$$P_{peak} = P_e.N_{tot}.2\frac{1}{\sqrt{2\pi}}\,[\int_0^{\frac{\Delta t_{on}}{2\sigma}} e^{-\frac{1}{2}x^2}\,dx] \qquad 32$$

so:

$$P_{peak} = P_e.N_{tot}.2\frac{1}{\sqrt{2\pi}}[\int_{-\infty}^{\frac{\Delta t_{on}}{2\sigma}} e^{-\frac{1}{2}x^2}\,dx - \int_{-\infty}^{0} e^{-\frac{1}{2}x^2}\,dx \quad . \qquad 33$$

Equation 33 simplifies to:

$$P_{peak} = P_e.N_{tot}.2.[erf(\frac{\Delta t_{on}}{2\sigma}) - 0.5] \qquad 34$$

7.3 Shape of the load curve

The graphs which follow illustrate how the position and the value of the peak vary for different values of the time t_{on} , the power rating of the element $\boldsymbol{P_e}$ and the width of the distribution $\boldsymbol{\sigma}$.

If an instant water heater were used instead of a hot water cylinder, the shape of the load curve will be represented by the shape of the water usage curve.

7.3.1 The influence of the distribution factor

The value of the distribution factor has a large influence on the peak value of the load. Figure 35 shows that the peak value of the hot water consumption with a distribution factor of 30 minutes is about three times as large as what it would be if the distribution factor were 90 minutes.

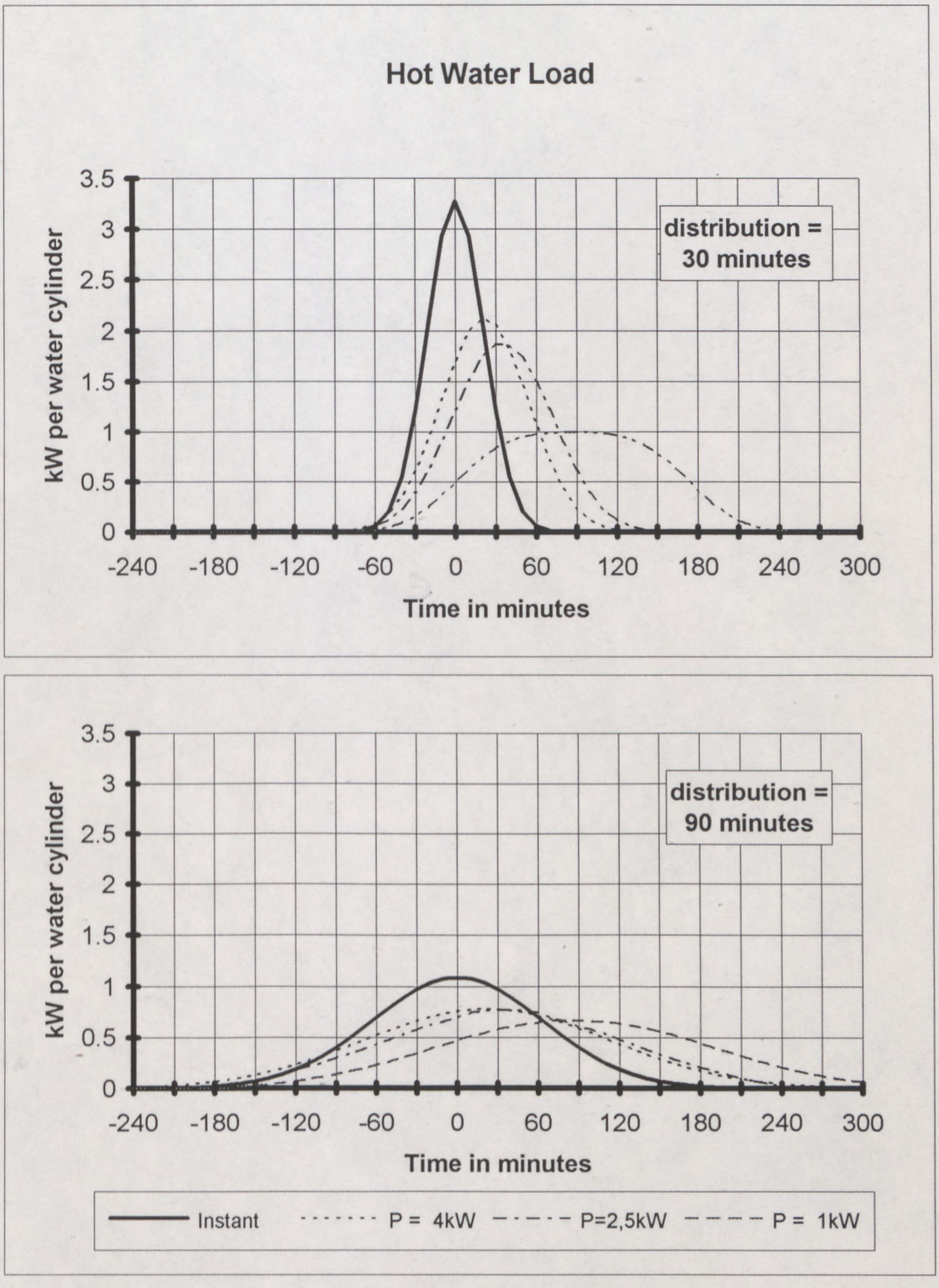


Figure 35 The shape of the load curve for different distribution factors

The ratio of the peak electrical load for a distribution factor of 30 minutes compared with the load for a distribution factor of 90 minutes would also be about 3:1 if instantaneous water heaters were used. It is remarkable, however, that the ratio of the peak electrical load is nearly unity (only approximately 1,2) if the rating of the hot water cylinder element is limited to 1 kW, but it is unlikely that the distribution factor for a large population of hot water consumers will ever be as low as 30 minutes.

During the morning the water consumption of the average electricity consumer is likely to be well dispersed. First of all the time people start their work varies, usually between 7 am and 9 am; then, also, the distance people have to travel to work and thus the time they take to travel to work requires them to leave for work at different times between 6 am and 9 am. It is clear from this reasoning that a distribution factor of 90 minutes value with a peak at 7 am is realistic, and that a lower value than 90 minutes for the distribution factor is unlikely. One has to realize that, if hot water cylinders are used, the peak value of the electrical load will not coincide with the peak value of the hot water consumption: the electrical load will lag behind the hot water consumption by a value of $\Delta t_{on}/2$ as shown in equation 27.

In the evening the distribution factor is likely to be even longer, as children often have a bath before supper, and different members of the family are likely to use hot water up to late in the evening, so, since hot water is used from about 5 pm to 10 pm, a distribution factor of 2 hours seems reasonable, with a peak at 7 pm.

7.3.2 The time of the peak load

The national electrical maximum demand peaks at about 9:00 and 19:00 daily (Eskom, 1990:96), but for Soweto the evening peak is much later at about 21:30 while the morning peak is earlier at about 8:00. It appears that the morning load due to hot water consumption will not coincide with the national peak, so it is not critical as far as the maximum demand is concerned. The evening peak, however, may well coincide with the national peak for the westernised metropolitan consumers, but this does not seem to be so for the urbanising community. Measurements made by Eskom of the supply to Soweto, for example, show that the peak maximum demand in the developing communities occurs much later in the evening (9:00-10:00) and that the evening peak is much larger than the morning peak (nearly 75% more). This has an important advantage because an increase in the electrical load due to the urbanising community using electricity to heat water, does not seem to increase the peak value of the national load by the equivalent amount, but one cannot assume that this will continue to be the case as the communities develop.

Few houses in the developing community have running hot water, so one cannot expect many hot water cylinders in the developing sector, but those households which use electricity for cooking will also use electricity to heat water, and this load is likely to coincide with the peak load for that sector.

7.3.3 The size of the element

Using a smaller element has the following effects concerning energy consumption:

i) Reduction in the peak load.

ii) Delay in the time of the peak load.

iii) Higher value of standing energy loss due to the larger cylinder which is required because of the delay in heating the water.

A reduction in the peak load is only important if the peak value of the electrical load to heat the water coincides with the peak value of the total electrical load. This appears to be important for the evening peak, but it is not important for the morning load. In effect it would be disadvantageous to reduce the peak load by using a smaller element, because the peak due to the hot water load will then move closer to the peak value of the national load which occurs somewhere between 9 and 10 am.

The magnitude by which the peak load reduces due to a smaller element is very dependent on the distribution factor. If the distribution factor is 30 minutes, the peak value reduces to about 33 % if a 1 kW element is used, but if the distribution factor is 90 minutes, the reduction in peak value is about 65 % of what the peak value would be if an instantaneous hot water geyser were used.

7.3.4 The effect of using instant water heaters

The effect of using instant water heaters on the wave shape of the electrical load will be to move the peak value of the electrical load to coincide with the peak value of the water consumption.

7.4 Water usage patterns other than the normal probability density function

A probability distribution $p(x_i)$ of any discrete random variable will satisfy two simple properties:

$0 \leq p(x_i)$

and

$\sum p(x_i) = 1$

Discrete probability distributions are used later in section 7.7.4 to determine the diversity factor of a discrete number of instant water heaters. A probability density function has the following corresponding properties:

$$0 \leq x \leq 1$$

$$\int_{-\infty}^{+\infty} f(x)\ dx = 1 \quad \ldots\ 35$$

The normal probability density function, which has been used up till now, is one of many possible probability density functions. The normal probability density function can be used to represent most hot water consumption patterns, but in some instances other probability density functions are more suitable. One shortcoming of the normal probability density function is that it cannot represent a non-symmetrical function. In some instances the load pattern has been found not to be symmetrical: for example, in some cases the rate at which hot water usage increases before the morning peak is more than the rate at which it decreases after the morning peak, so this cannot be represented accurately by the normal probability density function.

A few probability density functions will be discussed to show their application for the hot water model.

7.4.1 The Gamma probability density function

A function which can be used for non-symmetrical usage of hot water is the Gamma density function.

The equation of the Gamma density function is:

$$f_x(x) = \frac{\lambda^{\alpha}}{\Gamma(\alpha)} x^{\alpha-1} e^{-\lambda x} \quad .\ 36$$

where:

$x > 0, \quad \alpha > 0, \quad \gamma > 0$

and:

$$\Gamma(\alpha) = \int_{0}^{x} x^{\alpha - 1} e^{-x} dx \quad .. \; 37$$

Integration by parts shows that:

$$\Gamma(\alpha) = (\alpha - 1)\Gamma(\alpha - 1) \quad . \; 38$$

Thus to evaluate $\Gamma(\alpha)$ we only need values of $\Gamma(\alpha)$ for $1 \leq \alpha < 2$; tables for this function exist.

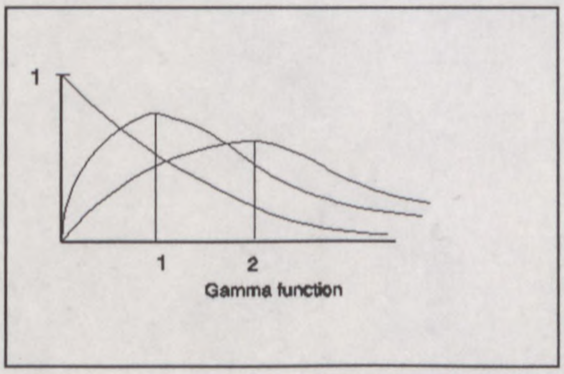


Figure 36 Gamma probability density functions

Figure 36 shows typical Gamma probability density functions $f_x(x)$ for:

$\alpha = 1$, $\gamma = 1$; max value at $x = 0$
$\alpha = 2$, $\gamma = 1$; max value at $x = 1$
$\alpha = 5$, $\gamma = 1$; max value at $x = 2$

7.4.2 The exponential probability density function

The exponential probability density function is a special case of the Gamma probability density function. It is a Gamma probability density function with $\alpha = 1$. This function is also depicted in Figure 36. An example of where this function could be used is in a situation where there is a time when all the users in a group start to use hot water suddenly, such as a group of users who all take part in a sporting event and all use hot water immediately on completion of the event. Such a pattern may also occur at the end of a popular TV program.

It can be seen that for such a load pattern the power per hot water cylinder at the start of such a cycle will be the average rating of the hot water cylinders under consideration. In the case of hot water cylinders this will most probably be in the order of 3 kW per water heater. In the case of a group of people, all using instant water heaters, the instantaneous load at the start of such a cycle will be in the order of 21kW per water heater: this is very large. If it is likely that an exponential probability curve will occur, and instantaneous water heaters are used, then the distribution network must be designed to supply such a large current.

7.4.3 The uniform probability density function.

The uniform probability density function can be defined by the equation:

$$f(x) = \frac{1}{b-a} \quad \ldots\ldots \quad 39$$

This equation is valid for:

$$a \le x \le b$$

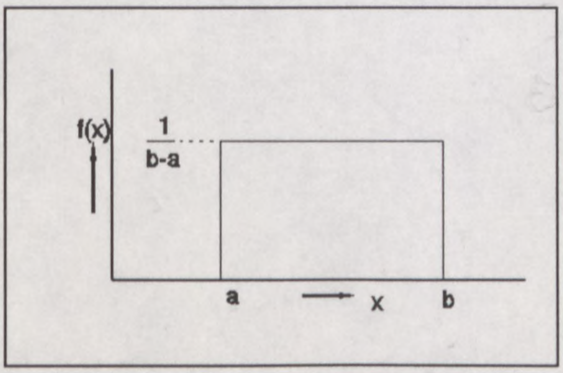


Figure 37 Uniform probability density function

This function is very useful for the situation where the use of hot water stays reasonably constant for a long time. In the sections which follow this probability density pattern is used to study the load pattern if the electrical supply is interrupted for a time. In this case the probability density function is assumed to consist of two uniform distribution functions which follow each other.

7.4.4 The Cauchy probability density function.

The Cauchy probability density function can be represented by the equation:

$$f(x) = \frac{1}{\pi \alpha \left(1 + \left(\frac{x-\beta}{\alpha}\right)^2\right)} \quad 40$$

where:

$$-\infty < x < \infty, \text{ and } \alpha > 0$$

The general shape of this function is similar to the normal probability density function except that it decreases more slowly for large values of x.

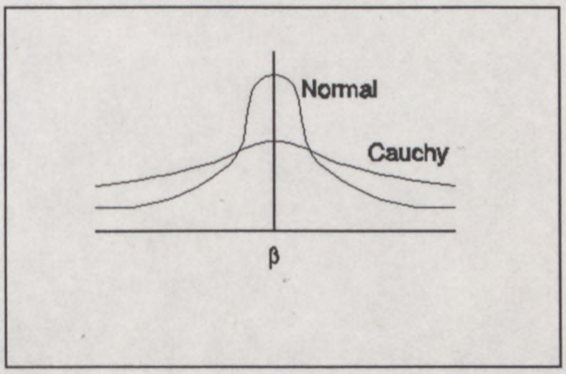


Figure 38 Cauchy probability density function

The function has a unique maximum at

$$x = \beta$$

and it has two points of inflection at

$$x = \beta \pm \alpha/\sqrt{3} .$$

The function is useful for situations where the usage pattern is not uniform enough to use the uniform density function, and the normal density function decreases too fast for large values of x.

7.4.5 The use of different probability density functions

The literature on statistical probability theory discusses many more probability density functions, such as the Weibull function and the Student's t functions, which may be suitable for specific hot water usage patterns, but for most applications the normal density and uniform density functions suffice.

To use any of the above probability density distribution functions for a specific hot water usage pattern, the probability density function is plotted by using the applicable equations or tables which are given in statistical handbooks. The parameters of the chosen function must be adjusted so that the function matches the hot water load pattern as closely as possible; then the function is used as input parameter for the computer model which has been developed. The output from the model will then give the electrical load pattern.

On many occasions the electrical load pattern is known, and the hot water usage pattern needs to be found. Once the hot water usage pattern is known, other parameters such as the element size and the time and duration of disconnection of the electrical supply, can be changed on an empirical basis to determine the influence these parameters have on the electrical load pattern.

To determine the hot water usage pattern from the electrical load pattern it may be necessary to assume some water usage patterns and then to compare the corresponding electrical load patterns with the actual load pattern. The actual hot water load pattern may then be found by iteration.

7.5 Controlling the hot water load

The hot water load is a domestic load which can be controlled with very little inconvenience to the consumer. Many municipalities control the electrical supply to the hot water cylinders of their consumers, as it is for the benefit of the municipality and its customers to decrease the cost of electricity.

Assume that at time t_b up to time t_c the supply is switched off.

Equation 25 represents the electrical load by:

$$P_{tot}(t_1) = P_e \,.\, N(t_1) \,.$$

During the period -∞ to t_b the electrical load will be the same as if there were no disconnection of supply. From equation 23 it can be seen that the number of water heaters which are on will be:

$$N(t_1) = N_{tot}\left[erf\left(\frac{t_1-t_o}{\sigma}\right)-erf\left(\frac{t_1-t_o-t_{on}}{\sigma}\right)\right] \qquad 41$$

so:

$$P_{tot}(t_1) = P_e.N_{tot}\left[erf\left(\frac{t_1-t_o}{\sigma}\right)-erf\left(\frac{t_1-t_o-\Delta t_{on}}{\sigma}\right)\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 42$$

From time t_b to time t_c there will be no electrical hot water load. At time t_c there will be a sudden large load as indicated in Figure 39 as a result of $N_c(t_c)$ hot water cylinders switching on where:

$$N_c(t_c) = N_{tot}\left[erf\left(\frac{t_c-t_o}{\sigma}\right)-erf\left(\frac{t_b-t_o-\Delta t_{on}}{\sigma}\right)\right] \qquad 43$$

so:

$$P_{tot}(t_c) = P_e.N_{tot}\left[erf\left(\frac{t_c-t_o}{\sigma}\right)-erf\left(\frac{t_b-t_o-\Delta t_{on}}{\sigma}\right)\right] \qquad 44$$

The function representing the electrical load after time t_c up to time $t_c + \Delta t_{on}$ is:

$$\begin{aligned} P_{tot}(t_1) &= P_e.N_{tot}\left[erf\left(\frac{t-t_o}{\sigma}\right) - erf\left(\frac{t_1-t_o-(\Delta t_{on}+(t_c-t_b))}{\sigma}\right)\right] \\ &= P_e.N_{tot}\left[erf\left(\frac{t-t_o}{\sigma}\right) - erf\left(\frac{t_1-t_c+t_b-t_o-\Delta t_{on}}{\sigma}\right)\right] \qquad 45 \end{aligned}$$

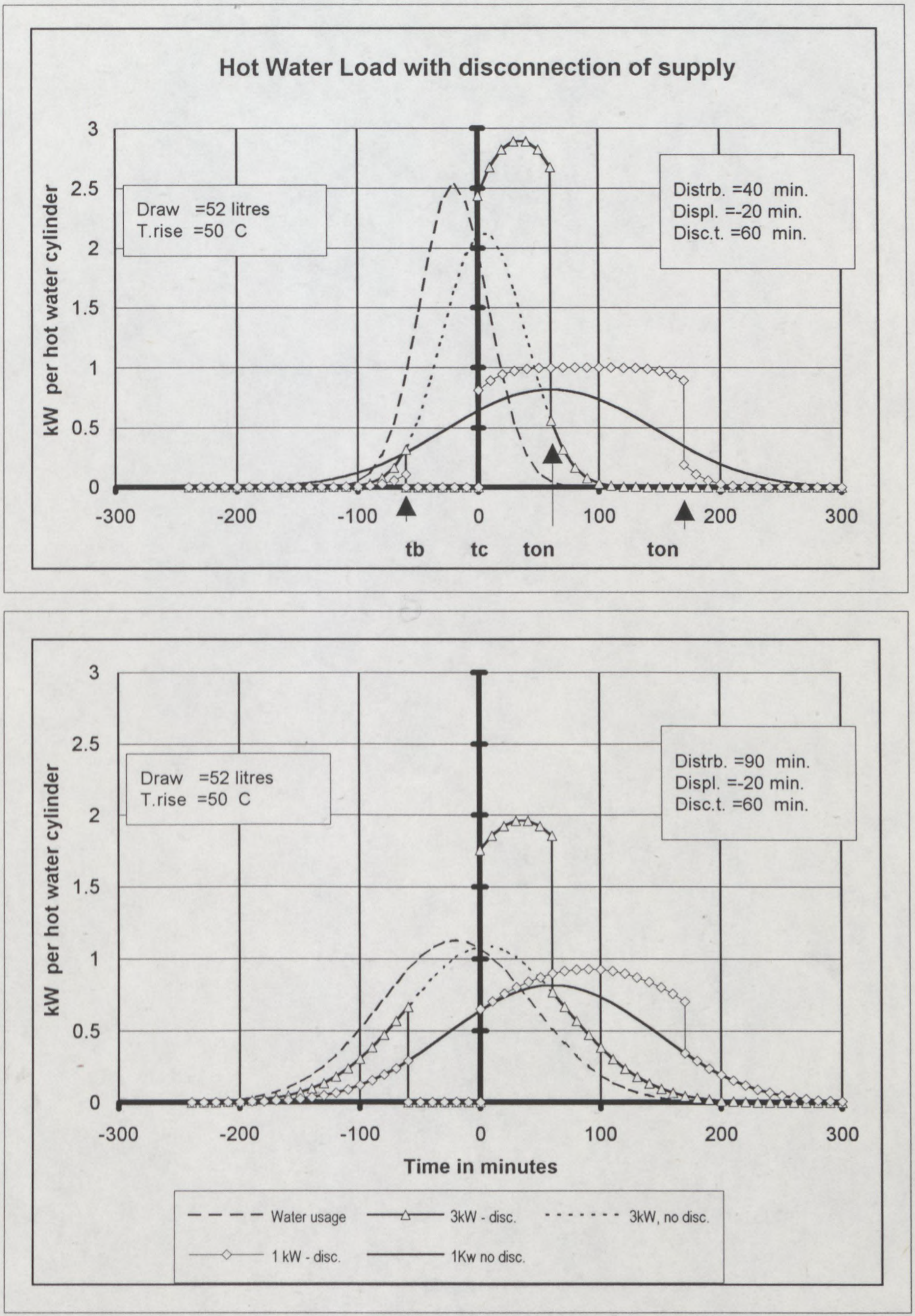


Figure 39 Hot water load with temporary disconnection of supply

After time $t_c + \Delta t_{on}$ the function representing the electrical load will be back to normal. The electrical load can again be represented as:

$$P_{tot}(t_1) = P_e . N_{tot}\ [erf(\frac{t_1 - t_o}{\sigma}) - erf(\frac{t_1 - t_o - \Delta t_{on}}{\sigma})] \tag{46}$$

It can be seen from Figure 39 that the electrical load can be very large shortly after time t_c especially if the electrical elements of the hot water cylinders are large.

A model has been programmed onto a spreadsheet to illustrate the load shapes which can be expected for different conditions. In sections 7.5.1 to 7.5.7 this model is used to determine the electrical load. The abreviations used in the diagrams include:

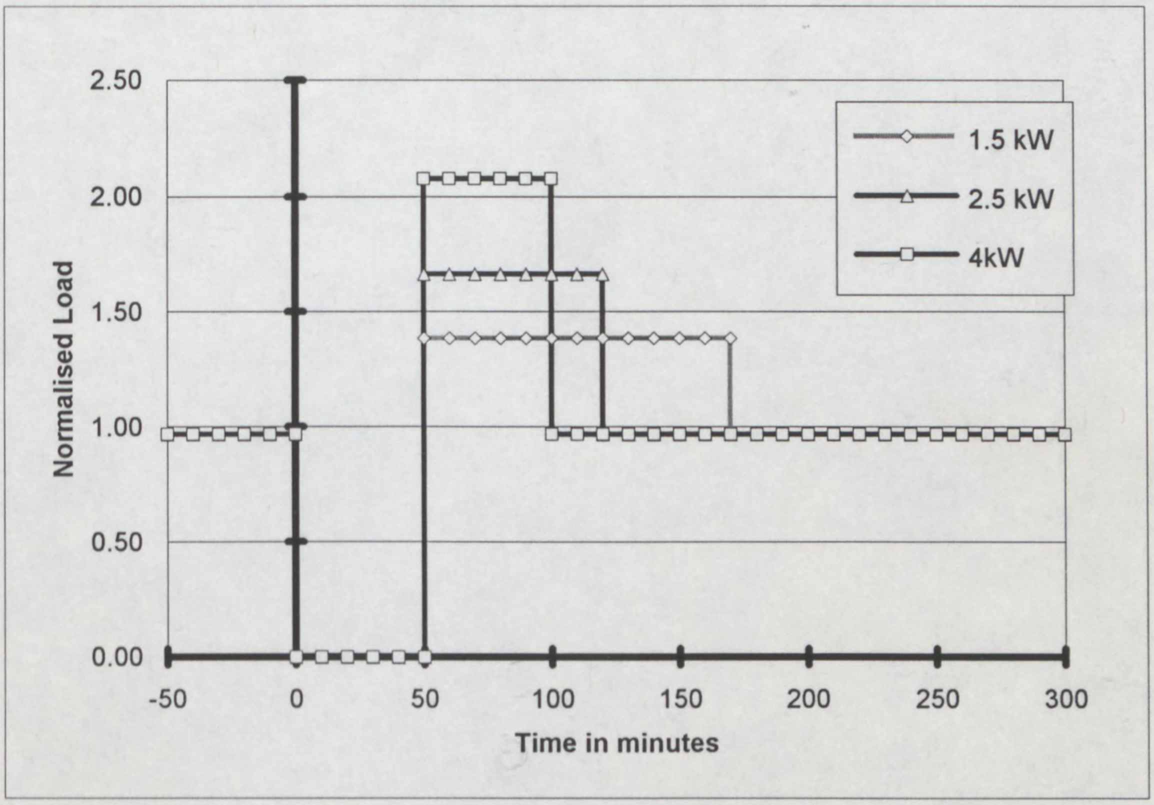
setl.t	Δt_{on}	settling time
disc.t.	t_o	disconnection time
distrb.	t_b	distribution time
Pe	P_e	element size and
T.rise	Δt	temperature rise.

7.5.1 Constant water consumption, varying element size

Consider a constant hot water load where regularly 50ℓ water is drawn per hot water cylinder of which the temperature is raised by 50 C. Then Figure 40a represents the electrical load for different element sizes. In each case the supply is disconnected for 100 minutes, so the amount of water which needs to be heated is the same in each case, but if the elements are large, this heating will be done quickly: for a 4kW element it takes about 45 minutes, whereas if the elements have a rating of 1kW, the settling time is about 180 minutes, but the power consumption will only rise by 60 % against the 240 % in the case of the 4kW elements.

7.5.2 Constant water consumption, varying disconnecting times

Figure 40b indicates the effect of varying the disconnection time for the same water consumption as above and 1,8kW elements. The figure shows that the settling time is not dependent on the disconnection time while the increase in power consumption is directly proportional to the disconnection time.



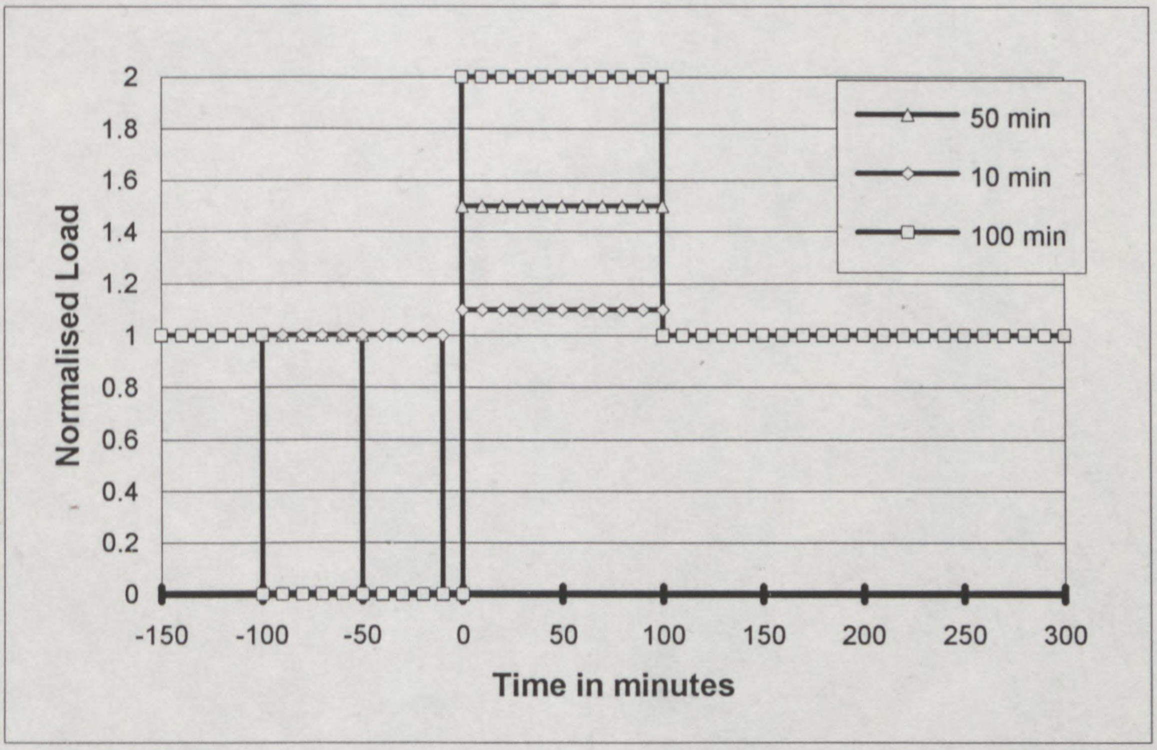


Figure 40 The influence of: a) element size, and b) disconnecting time, on the hot water load after a disconnection, and for a constant hot water consumption

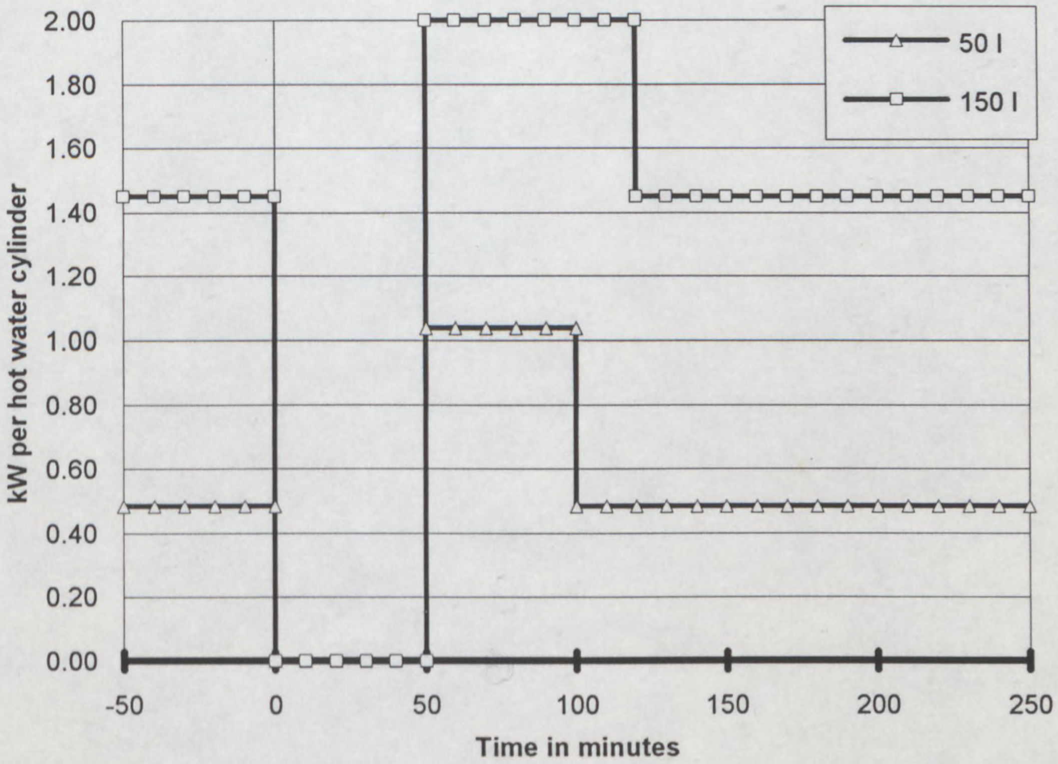


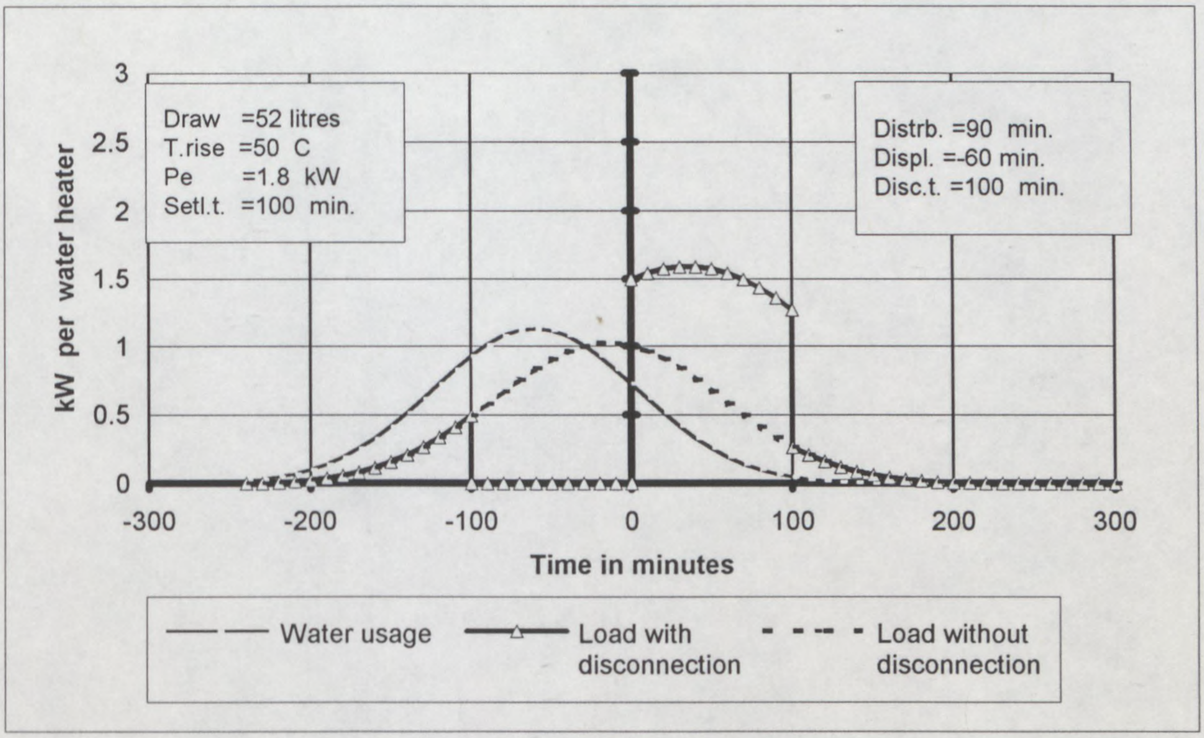
Figure 41 The effect of water consumption on the hot water load after a disconnection

7.5.3. Different constant levels of water consumption

Figure 41 indicates the effect of different levels of water consumption with all other factors kept constant. It is noticeable that the absolute value of the increase of the load is the same in each case, but the percentage increase after connection is smaller for larger values of water consumption and the length of the settling time is longer.

7.5.4 Normally distributed water consumption with elements of different sizes

Figure 42 shows that in the case of normally distributed water consumption, a larger element once again increases the magnitude of the electrical load, but it decreases the settling time.



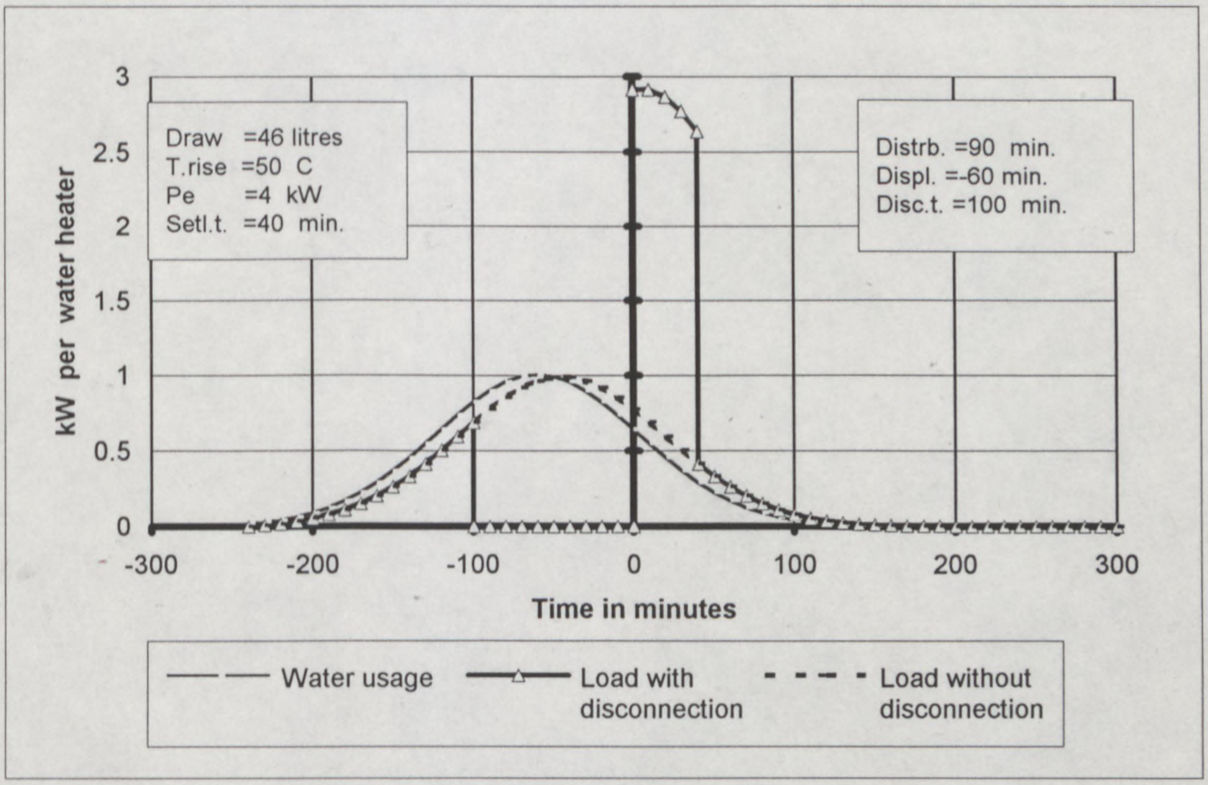


Figure 42 The influence of element size on the hot water after a disconnection for a normally distributed water consumption

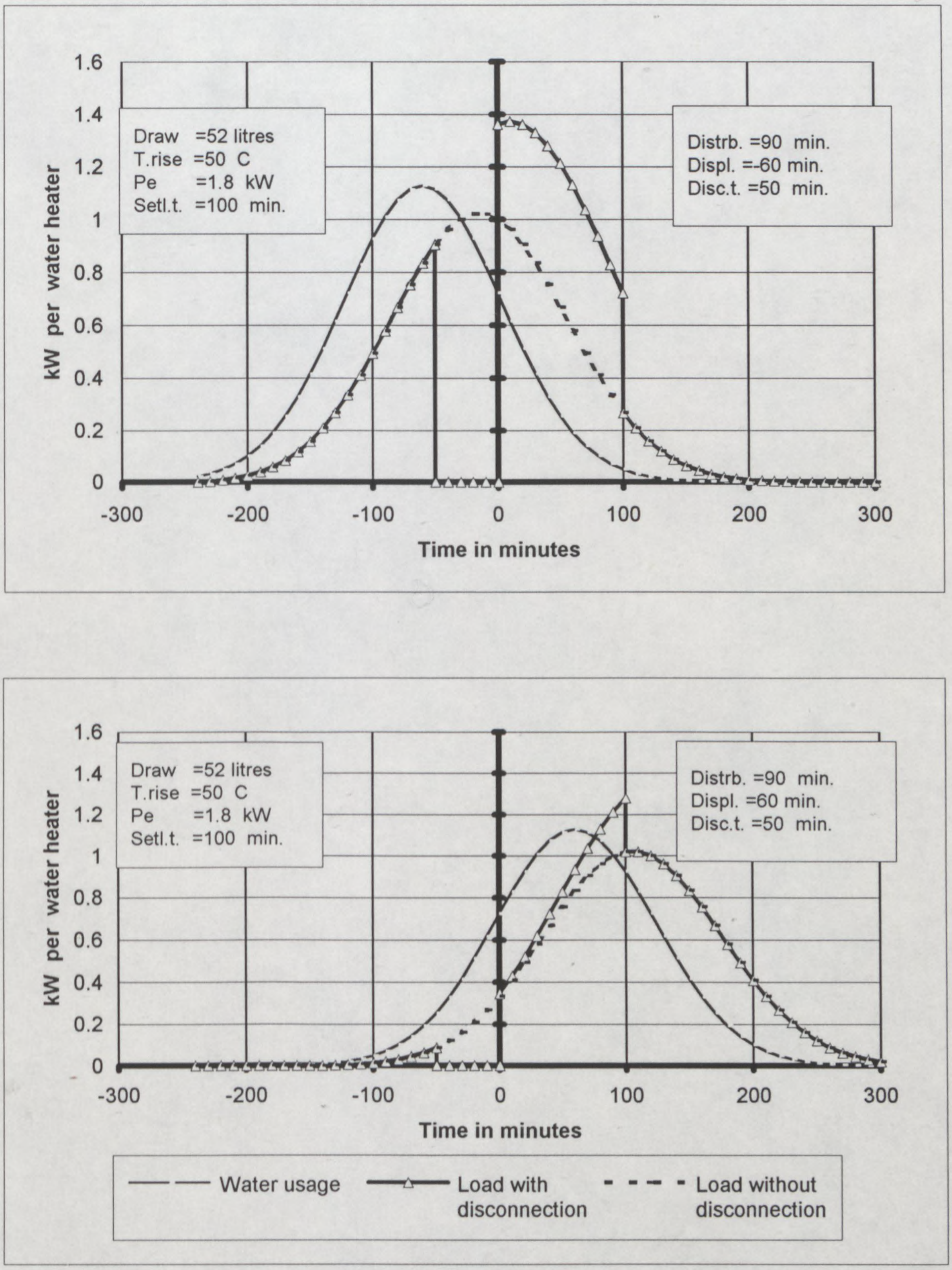


Figure 43 The influence of the timing of the disconnection with respect to the normally distributed water consumption pattern

7.5.5 Timing of the disconnection with respect to the normally distributed water consumption pattern

Figure 43 shows that the jump in the electrical load when the load is connected again is dependent on the water consumption at the time 0 - t_s where t_s is the settling time. In Figure 43 this would be at -100 minutes.

In the case of Figure 43b for example, there is hardly an increase in electrical load when the supply is connected again because the water consumption at - 100 minutes was very low, whereas the jump in the electrical load in Figure 43a was considerable because in this case the water consumption at - 100 minutes was considerable.

This phenomenon can cause unexpected errors when measuring the hot water load by disconnecting the hot water load at regular intervals and measuring the drop in the total load. However, this method of measuring the total hot water load of all households which have some form of centrally controlled load control on their hot water cylinders seems a very convenient way of measuring the hot water load. Figure 44 also shows that the readings may contain larger than expected errors. For example: if the hot water load is disconnected for about 10 minutes at a time, from -10 to 0 minutes as shown in Figure 44a, then the reading at this time will be correct, but there will be a considerable error if another reading were taken at time 80, 90 or 100 minutes, because the effect of a disruption at time -10 minutes causes a noticeable difference in the load at time 50 to 100 minutes.

7.5.6 Varying the disconnection time

The load after the supply has been disconnected is dependent on the duration of the disconnection. Figure 44 for example shows that the increase of the load after a short disconnection of 10 minutes results in a minimal increase after reconnection, but after a short disconnection of 100 minutes the increase is about 50%.

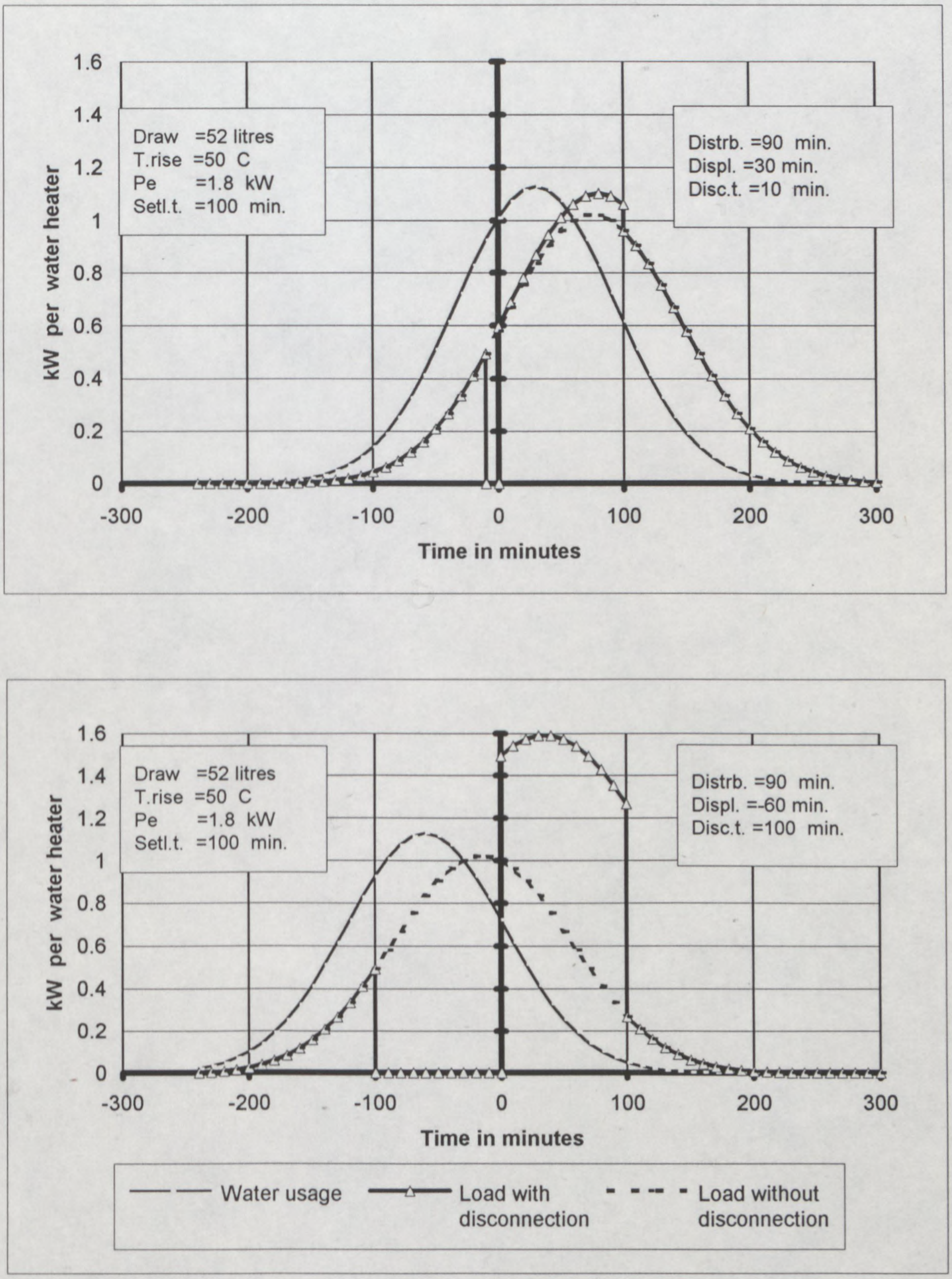


Figure 44 The influence of varying the disconnection time on the hot water load after a disconnection

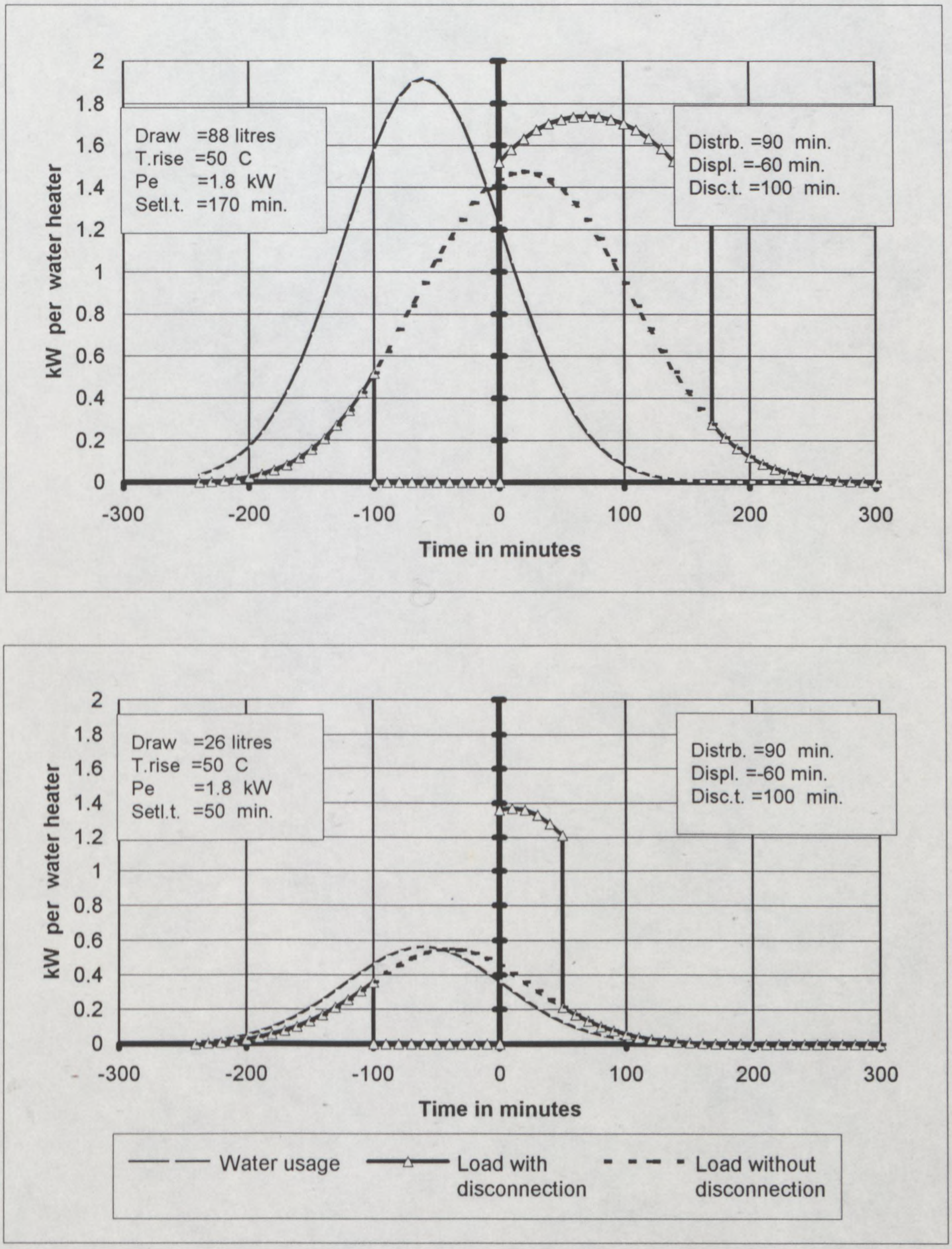


Figure 45 The influence of the water consumption on the hot water load after a disconnection

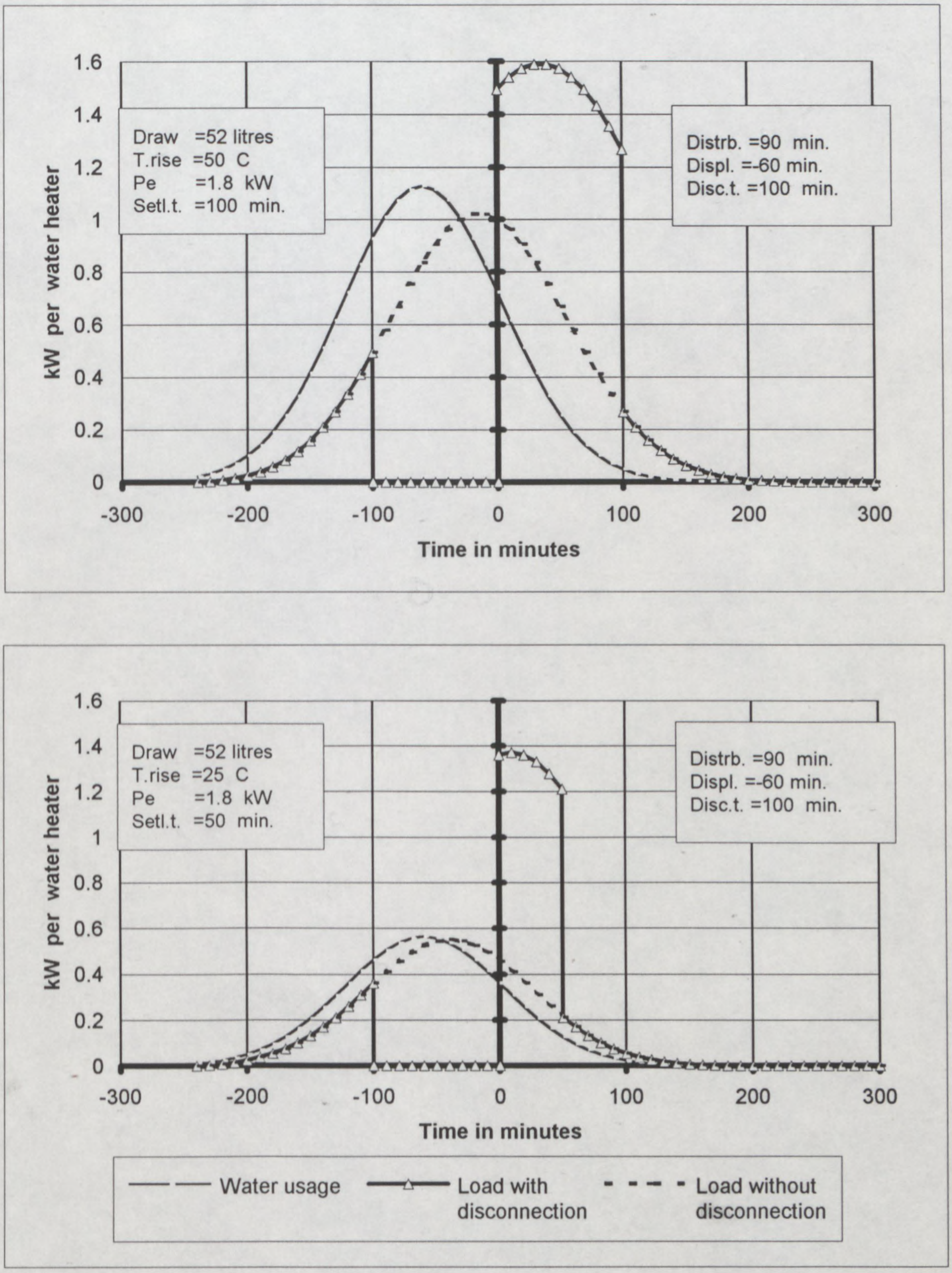


Figure 46 The effect of varying the temperature rise with constant normally distributed water consumption

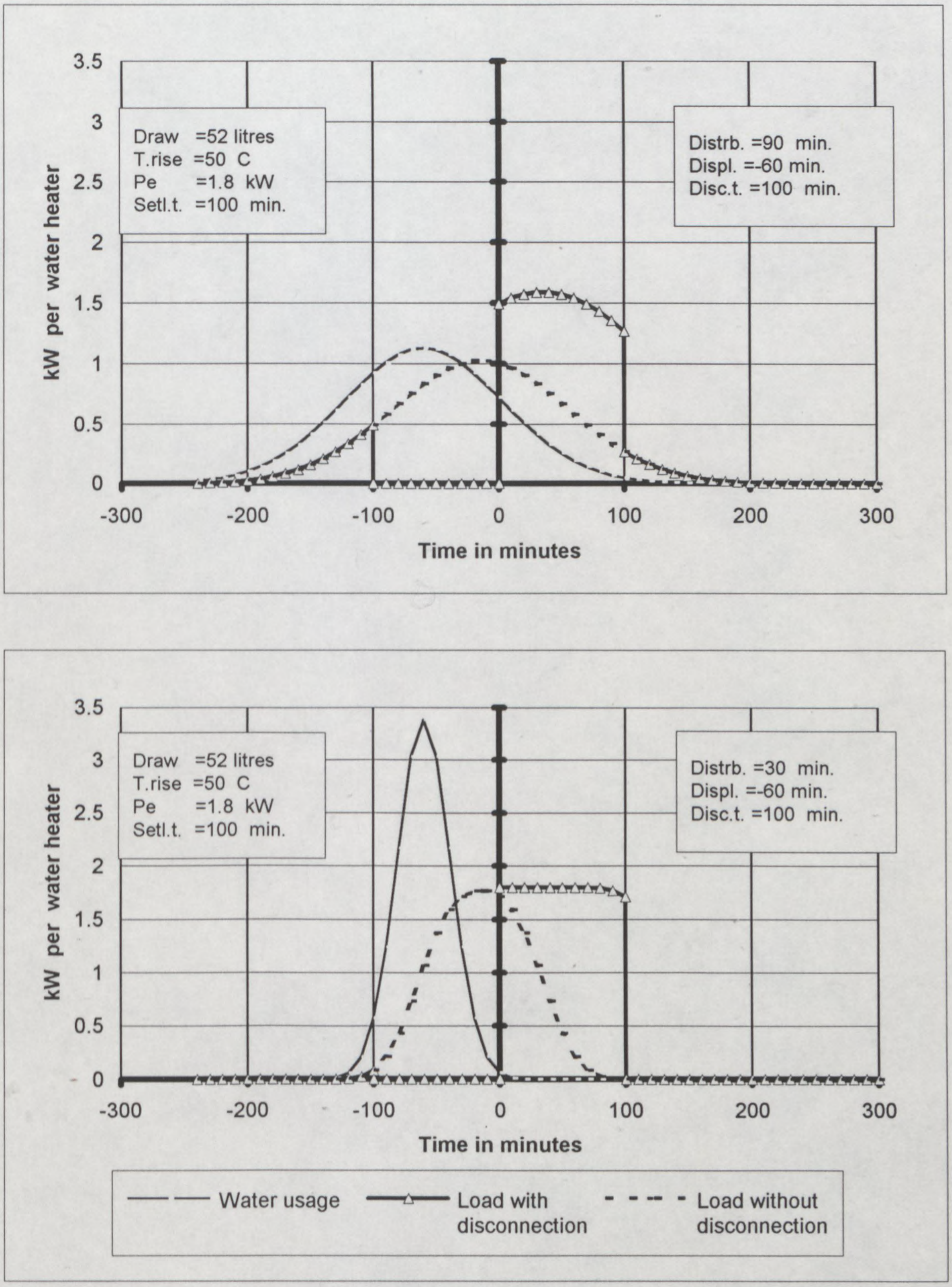


Figure 47 The effect of varying the distribution of normally distributed water consumption on the pattern of the hot water load after a disconnection

7.5.7 Varying the water consumption with a normally distributed water consumption pattern

Increasing the water consumption has the effect of increasing the settling time while the percentage increase in the electrical load after disconnection decreases. The small increase in the electrical load at time t = 0 in Figure 45a is very noticeable. This is due to the long settling time and because the water consumption at time (0 - t_s) (where t_s = settling time) is very small. This phenomenon was explained in section 7.5.5.

Readings taken by municipalities who are able to control the domestic hot water cylinders centrally have shown that the power consumption is especially large when the hot water load is switched on again after a short disruption of supply. From this it can be concluded that most of the draws of hot water must be relatively small because Figure 45 clearly shows that large percentage increases in load occur for small quantities of water per cylinder at a time, resulting in short settling times.

7.5.8 Varying the temperature rise with constant normally distributed water consumption

The decrease in temperature rise as illustrated in Figure 46 will probably be due to hot weather while high values of temperature rise will occur during winter.

Decreasing the temperature rise has the effect of shortening the settling time, and causes a larger percentage increase in electrical load, but in absolute terms the increase remains the same.

7.5.9 Varying the distribution of the water consumption

Figure 47b shows a narrow water consumption pattern: the distribution factor is 30 minutes, and the displacement of the hot water usage is 60 minutes before time=0. It is clear from Figure 47b that a narrow distribution of water usage may result in an electrical hot water load with a square load pattern. In this example the water consumption has already dropped to virtually nothing at the time the electrical supply is restored. If the distribution of the water consumption is bigger, such as in Figure 47a, then the electrical hot water load has a more normally distributed pattern.

7.6 Energy losses of the hot water system

7.6.1 The standing loss

A 150 ℓ hot water cylinder has a standing loss of about 100 Watt (Uken & Beute, 1991:22) This loss amounts to nearly 1000 kWh per year per hot water cylinder. Although this loss does not influence the maximum demand unduly, it does constitute a large loss which leaves much scope for energy conservation and consequent conservation of the environment.

A considerable reduction in standing loss can easily be achieved by increasing the insulation around the hot water cylinder, at very little extra capital cost. This improvement is especially important in the present South Africa because an unusually large number of houses will most probably be built during the next few years and if we ensure that the hot water cylinders installed have a low value of standing loss, large savings in both monetary and environmental terms will be possible.

An important energy loss to consider is caused by the conduction of heat away from the hot water cylinder by the pipes. This loss is important because it takes place 24 hours per day, even while no hot water is used. This loss is considerable in proportion to the standing loss. Tests carried out by the Building Technology Division of the CSIR on 150 litre hot water cylinders have shown that this pipe loss constitutes from 15 to 45% of the total standing loss for different types of hot water cylinders (Simpson, 1990:9).

These results show the importance of lagging at least the first few meters of the hot water pipe and the overflow pipe to reduce the heat which conducts away via the pipes.

It is possible to save about 400 kWh per hot water cylinder per year (Uken & Beute, 1991:44) and Eskom would like to see 3 million homes electrified during the next 5 years (de Beer, 1992:2). If only 500 000 of these houses use an energy efficient hot water cylinder, then 200 GWh will be saved each year by the occupants of those houses.

7.6.2 The loss of heat in hot water piping due to cooling between uses

Pipe losses in hot water systems differ greatly from household to household, depending on :

- the length of the hot water pipe,
- the type of pipe used,
- the covering of the pipe,
- the frequency of use of hot water,
- the time between uses of hot water,
- the amount of water used per draw,
- the ambient temperature,
- the rate of hot water flow.

Measurements have shown that a large proportion (sometimes as much as 50 %) of the hot water drawn from a hot water cylinder consists of low volume draws, yielding only 2-5 litres, separated by relatively short intervals. 50 % of the draws measured followed the previous draw by not more than 20 min. (Carrington *et al.*, 1985:65).

It follows from these measurements that the energy loss in hot water piping is considerable, and that pipe losses constitute a considerable portion of the losses in hot water systems, especially because of frequent low volume draws which are spaced in such a way that the water left in

Table 27 Losses in pipes due to pipes cooling between draws of hot water

Consumption	Energy lost in pipes due to cooling between uses	
kWh per month	kWh/month	% of consumption
146	31	21%
240	42	18%
275	51	19%
478	74	15%
510	63	12%
650	64	10%
781	91	12%

the pipe has usually cooled to room temperature by the time hot water is used again. If the temperature of the water left in the pipe has dropped below 35 C by the time hot water is used again, this cool water is usually discarded.

The energy losses in the pipes during the above tests are tabulated in Table 27.

Each time hot water is used, about 2 litres are wasted (assuming the hot water pipe to be approximately 16 m long, and 12,5 mm in diameter), because the water in the pipes will have cooled. Measurements show that water is drawn about 40 times per day per hot water cylinder. If we assume that a quarter of these draws were done more than 15 minutes after the previous draw, so that the water in the pipe has cooled by the time hot water is needed again, then about 20 litres of hot water per day will be wasted. This represents a loss of 7 000 litres per year per hot water cylinder. Measurements of the electrical energy in a few municipalities in the Western Cape have shown that the average household uses about 300 kWh per month to heat water. This represents an annual hot water consumption of about 60 000 litres per year, with the temperature rising by about 50 C (from 20 C to 70 C), so the energy lost in the pipes is about 12 % of the total energy required to heat the water. The electrical power required per household for the heat lost in the pipes is then about 420 kWh per year.

7.6.3 The loss of heat due to radiation from the pipe while the water is flowing through the pipe

Measurements in typical domestic installations have shown that the temperature of the water at the hot water cylinder is from 2 to 5 C higher than at the point where the water is used when the temperature setting of the hot water cylinder is 70 C. This means that the energy lost due to heat conducting and radiating from the hot water pipe as the water flows through it is from 4 to 10 %. Copper pipes are normally used, and these pipes are often embedded in cement which is a reasonably good conductor of heat. Many older hot water installations have deposit build up in the pipes which drastically reduces the rate of flow, thus increasing the time during which the hot water is in the pipe, and thus in turn increasing the energy loss. When similar measurements are carried out with insulated pipes, it is apparent that insulation provides a considerable reduction in heat loss.

7.6.4 Summary of the loss in hot water systems

An accurate estimate of the heat lost in hot water systems nation wide would require many measurements and a statistical analysis of the measurements. But to obtain an indication of what an individual consumer can save by careful planning of his hot water system is not too difficult.

Table 28 gives an indication of the total losses of the hot water system. It can be used to estimate possible savings. It shows for example that a typical value of the efficiency of the hot water system supplying 200 litres per day, as in column 5, at 65 C is 66 %; this means that the losses constitute 34 %. Table 33 on page 141 analyzes these losses on a national scale.

The losses in Table 28 have been calculated for different rates of hot water consumption and different inlet and output temperatures. Assumed values of consumption rates and temperatures are listed in the top three rows.

The standing losses listed in Table 28 are based on laboratory measurements undertaken by the Division of Building Technology at the CSIR (Simpson, 1990:9). They have been calculated as a function of the difference between the hot water and room temperatures. The room and the inlet water temperatures are assumed to be 15 C, which can be considered as the average of the summer and winter indoor temperatures.

The values of the energy losses in hot water pipes, which are listed in Table 28, are based on the results listed in Table 27 and on measurements which were made in houses in the Cape. Details of the measurements are given in appendix D.

By comparing the values in the seventh and eighth column of Table 28 it can be seen that the efficiency of the hot water system is very heavily influenced by the setting of the thermostat. The efficiency of the hot water system with thermostat settings of 45 and 70 C is 72 and 66 % respectively. The saving is approximately 100 watts: nearly 20 % of the losses are saved by reducing the thermostat setting.

The quantity of water used per hot water cylinder is also a very important factor. Extra hot water cylinders in the house are very wasteful, because one rarely finds that all hot water cylinders are used to their capacity. The first column shows that a hot water cylinder which only supplies 50 litres per day has an efficiency of only 41 %.

Table 28 Energy losses of the hot water system for different rates of water consumption

	hot water cylinder								HWC with solar panel			
Consumption litres per day	50	100	200	400	**200**	114	182	333	50	200	**285**	154
HWC temp C thermostat setting	65	65	65	65	**65**	85	70	45	65	65	**50**	80
inlet water temp. C	15	15	15	15	**20**	15	15	15	48	48	**48**	48
room temp. C	15	15	15	15	**20**	15	15	15	15	15	**15**	15
Adjusted consumption l/day at 65 C	**50**	**100**	**200**	**400**	**200**	**160**	**200**	**200**	**50**	**200**	**200**	**200**
kWh/day	2.9	5.8	11.6	23.3	**10.5**	9.3	11.6	11.6	1.0	4.0	**0.7**	5.7
kWh/month	87	174	349	698	**314**	278	349	349	30	119	**20**	172
Standing loss kW/month	83	83	83	83	**75**	117	92	50	83	83	**58**	108
Pipe loss kW/month	43	64	108	195	**88**	138	121	60	28	50	**14**	91
kWh/100 l excl. losses in pipes	11.4	8.6	7.2	6.5	**6.5**	8.3	7.3	6.6	7.5	3.4	**1.3**	4.7
kWh/100 l at 65C	14.2	10.7	9.0	8.1	**7.9**	11.1	9.4	7.6	9.4	4.2	**1.5**	6.2
Efficiency excl. losses in pipes	51%	68%	81%	89%	**81%**	70%	79%	87%	26%	59%	**25%**	61%
Efficiency incl. losses in pipes	41%	54%	65%	71%	**66%**	52%	62%	76%	21%	47%	**22%**	46%
Gross energy excl. losses in pipes	171	258	432	781	**389**	395	441	399	113	202	**78**	280
Gross energy kWh/month	**213**	**322**	**540**	**976**	**477**	**533**	**562**	**458**	**141**	**252**	**92**	**371**
Saving (as a result of using a solar water heater) in kWh per month									72	224	**385**	105
Savings (as compared to system without solar heater) in %									34%	47%	**81%**	22%

Another factor which also influences the efficiency very heavily, but which cannot be shown in Table 28, is the size of individual draws of water.

Table 28 shows that the use of solar panels, to preheat the inlet water to the hot water cylinder, offers a considerable saving, but not if the thermostat setting is very high. In order to obtain maximum benefit from the solar panels the electrical supply should be disconnected whenever possible. Automation could help to switch the electrical supply off during hot days, and to switch it on during cold days and in the early morning if the water which remained from the previous day is predicted to be insufficient for the morning's use.

Careful planning can reduce the loss to less than half by:

* using an energy efficient hot water cylinder with as much insulation as possible,

* using a vertical rather than horizontal hot water cylinder to improve stratification (reducing the likelihood of hot and cold water mixing with each other),

* lagging the hot water pipes, paying particular attention to the pipes near the hot water cylinder,

* positioning all the hot water taps near the hot water cylinder,

* setting the thermostat to the lowest acceptable temperature,

* using solar panels to preheat the water,

* using the kettle rather than the hot water tap for small quantities of hot water,

* using flow restricters in shower heads and wash basin taps,

* not installing more than one hot water cylinder in the house. It would be better to install an instant water heater as the second water heater.

The losses can also be reduced to 2 % by positioning an instant water heater at each point of supply.

7.7 The effect of using an instant water heater instead of a hot water cylinder

It is clear from a number of considerations that the use of instant water heaters will be an energy saving feature.

7.7.1 The merits of using an instant water heater

The following advantages can be expected:

* There will not be the standing energy loss which is a 24 hour per day characteristic of the conventional hot water cylinder.

* There will be very little energy loss in the hot water pipes because instant water heaters are normally installed at the point where the hot water is needed. The energy saved in this way will be in the order of 20 to 25 % for the normal household, but can be more in cases where the hot water cylinder is far from the point of use.

* People will be encouraged to have showers, which are not energy intensive, instead of baths.

* Water savings will also be experienced. A South African municipality has reported a reduction in water consumption of 16.5 % in a group of 115 flat units when comparing the water used in flats equipped with hot water cylinders with the water used in flats equipped with instant water heaters. Although the accuracy of this report could not be confirmed, it does show that there is a potential saving in both water and electrical energy if instant water heaters are used. It is also noteworthy that the average German household uses less hot water than a corresponding South African household; this may be because instant water heaters are used in Germany and large quantities of hot water are not as readily available as is the case with hot water cylinders.

* The peak of the domestic hot water consumption occurs before the peak of the national maximum load, so the load due to instant water heaters will not increase the national peak value unduly.

But the following factors must also be taken into account:

* The energy storage feature of hot water cylinders will no longer be available for maximum demand control.

- * The peak value of the electrical supply for the hot water load will increase if the hot water consumption remains the same.

- * The duration of the peak of the electrical load will be limited to the actual time the hot water is used.

- * The peak of the electrical load will coincide with the peak of hot water usage. In the case of the hot water cylinder it will occur after the peak of hot water usage.

- * The electrical supply to the dwelling has to be large enough to provide for the instantaneous electrical load presented by the water heater. This often needs to be a 3 phase supply. It is usually necessary for the electrical connection to the consumer to be much larger than it would be if hot water cylinders were used. Typically a 50 amp (10 mm^2) 3 phase supply is used instead of an 80 amp (16 mm^2) single phase connection.

7.7.2 The load presented by instant water heaters

The connected load of instant water heaters is much larger than the connected load of hot water cylinders. The rating of the instant water heater should be at least 21 kW while the rating of the hot water cylinder is usually about 3 kW.

Generally supply authorities do not encourage their consumers to install instant water heaters because of the large connected load. They fear a low load factor for the distribution network, but this fear is not always justified. It is true that the connection to individual users needs to be larger, but this is not the case for a combination of anything more than about 25 consumers as will be shown later. The total energy used by an instant water heater is less than that used for a hot water cylinder because the hot water system as a whole is more efficient. The diversity factor is also much higher as will be shown later.

For the purpose of the discussion which follows two diversity factors are defined:

i) The instant diversity factor:

> The instant diversity factor is defined as the total installed capacity divided by the instantaneous maximum value of load for however short a time this load may be sustained.

ii) The 30 minute average diversity factor:

The 30 minute average diversity factor is defined as the total installed capacity divided by the maximum value of the 30 minute average of the load. Here the average value is a 30 minute running average which is measured continuously; it is not the average which is measured only once during each successive 30 minute cycle.

7.7.3 A model representing the electrical load of instant water heaters with normally distributed water consumption

In order to evaluate the diversity factor a mathematical model is developed which will represent the electrical load of a number of instant water heaters. This load will then be used to determine the maximum load and the diversity factor for different hot water requirements. The load will also be compared to hot water cylinder loads which supply the same amount of hot water.

Equation 7, derived for the model in the early part of this chapter, has shown that the demand for hot water can be represented by the formula:

$$n(t)=\left(\frac{N_{tot}}{\sigma\sqrt{2\pi}}\right)e^{-\frac{1}{2}\left(\frac{t-t_o}{w}\right)^2} \quad . . . 47$$

where :

t = time in minutes

t_o = time at which most people use hot water

w = a measure of the width of the distribution in minutes.

The model integrates n(t), giving values from 0 to 1. Random numbers are then generated and, by using the integrated function as a look-up table, the model then determines when individual water heaters are likely to be on. During a cycle of use, each water heater is assumed to switch on a specified number of times depending on the total water consumption during the cycle and the number of draws per cycle. The random number generator generates the required number of random numbers.

The time the water heater is on for each random number generated depends on the size of the element and the number of litres drawn. For example: if the rating of the element is 21 kW and 20 litres are used, the element will have to be on for approximately 3 minutes, and if the rating of the element is 3 kW then the element will be on for approximately 23 minutes for the same quantity of water.

Figure 48 shows typical load patterns generated by this model. The resulting load pattern is a random pattern, which means that each time the model is used, the load pattern will be different even if the same parameters are used. This represents what will happen in practice, because on one occasion for example, 2 out of 15 households may be using hot water simultaneously, while on another day under similar circumstances 3 out of the 15 households may use hot water simultaneously.

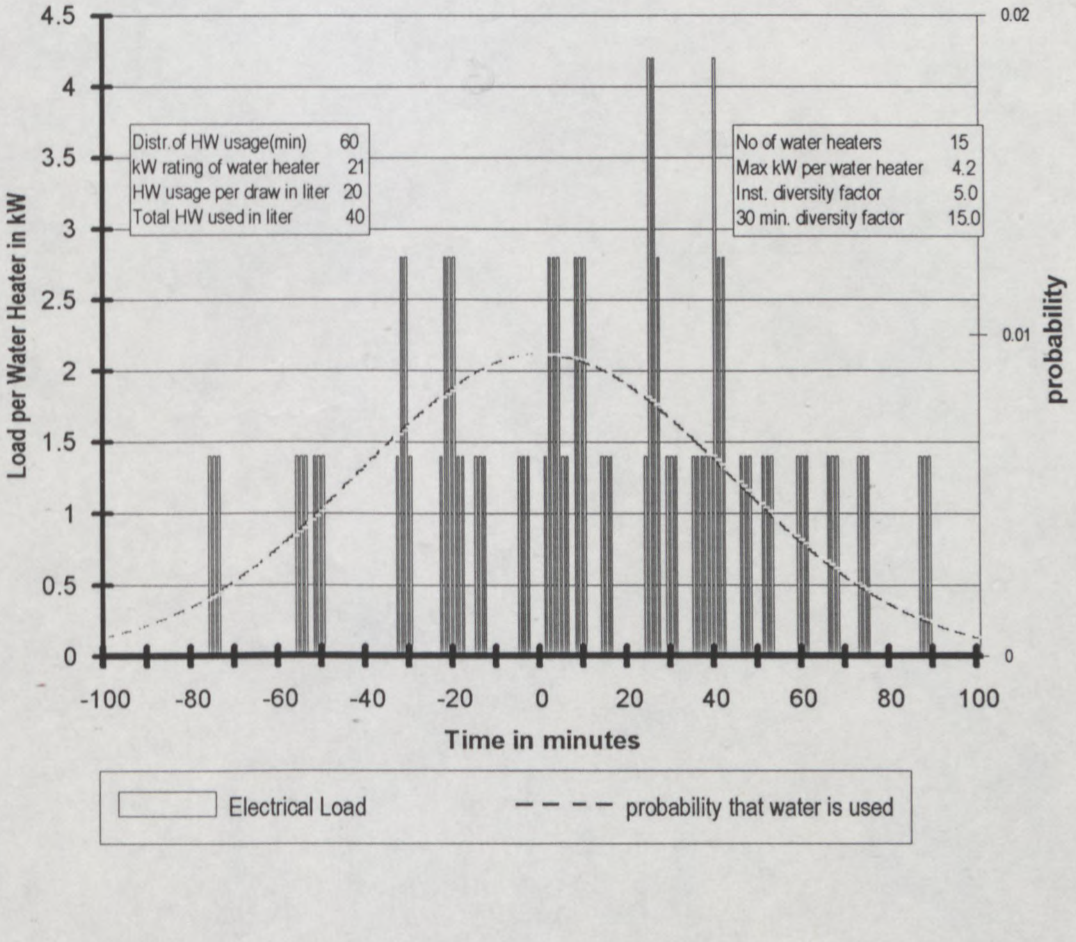


Figure 48 Electrical load presented by 15 instant water heaters supplied by the same source

7.7.4 Mathematical representation of the probability of large electrical loads of short duration due to instant water heaters

The probability of an individual household consuming hot water at a particular time is known as explained above, and a model was developed to generate typical load patterns, but the probability of a certain number of households in a group of households using hot water simultaneously still needs to be calculated to determine the probability of large peaks occurring. Knowledge of the probability of large loads, even if they are of short duration, is needed to design the distribution network for consumers with instant water heaters who obtain their electricity from the same point of supply.

In the case of the hot water cylinder the diversity factor of the water heaters is usually assumed to be the same as the rest of the appliances in the house, but seeing that the instant water heater presents such a large load which is on for such a short time it would not be correct to use the same diversity factor for the instant water heater.

A method is now developed to calculate the probability of a large load occurring due to a number of instant water heaters being switched on simultaneously.

We can assume that the households are independent of each other, each demanding hot water at random according to the normal distribution curve with a peak at the time of approximately the peak of probability density function as in equation 47.

If:

p = the probability of occurrence of an event in each trial, and

q = $1-p$
= the probability of non-occurrence

then:

the probability of exactly
k occurrences in
n trials in a Bernoulli sequence

is given by the binomial probability function:

$$P_{(X=k)} = \binom{n}{k} p^k (1-p)^{n-k} \quad . . \quad 48$$

where the binomial coefficient:

$$\binom{n}{k} = \frac{n!}{k!(n-k)!} \quad \ldots\ldots 49$$

and the probability of realizing a particular sequence of exactly ***k*** occurrences in ***n*** trials is equal to:

$$p^{k}(1-p)^{n-k} \quad \ldots\ldots 50$$

(Anders, 1990:58)

The binomial distribution of the random variable ***X*** has a mean value of:

$$\mu_X = np \quad \ldots\ldots 51$$

and a standard deviation of:

$$\sigma_X = \sqrt{npq} \quad \ldots\ldots 52$$

The above formulae can be used to calculate the diversity factor of the electrical load representing a group of water heaters, or to calculate the effective maximum demand per water heater for a group of water heaters which are fed from the same point of supply.

As an example, the probability of coincidence will be calculated for 15 water heaters connected from the same point of supply. It is assumed that the use of hot water is normally distributed with a value of 60 minutes for ***w***, the width of distribution, as used in equation 47, and that for the cycle under consideration the water used is 2 draws of 20 litres each. The electrical load for this case was generated by a random generator and is represented in Figure 48.

In Figure 48 it happened twice that three water heaters were on simultaneously, once for two minutes and once for one minute. It happened for 11 minutes that two water heaters were on simultaneously, and for the rest of the time either only one or none at all were on.

A more accurate estimate of the probability of different numbers of water heaters being on simultaneously is required. A method of calculating the probability that a certain number k water heaters, in a group of n water heaters, will be on simultaneously, will now be developed.

Equation 48 is used to calculate the probability of k heaters being on simultaneously for each minute under consideration. It is obvious that the probability of this happening will be different for different times. At time t_o

Table 29 Water heaters: probability of coincidence.
15 heaters(21kW)
40 litre consumption in a cycle
60 min distribution factor

No of coinci-dences	t= 100	t_o t=0	tot
0	.974	.653	162
1	.025	.279	33
2	.0003	.058	4.7
3	3E-6	.008	.51
4	2E-8	8E-4	.04
5	7E-11	6E-5	.003
6	4E-13	4E-6	1.7E-4

(values in column 3 of Table 29) the probability for a large number of heaters being on simultaneously will be much greater than at a time far away from t_o (values in column 2 of Table 29) where people are less likely to use hot water. The values for the probability of k heaters being on simultaneously are added for all the minutes during the cycle, and this gives the fourth column in Table 29.

The probability of 0,1,2,3,4,5 and 6 water heaters being on simultaneously was calculated for each minute during the session under consideration. Some of the values are listed in Table 29. The sum of all the probabilities for each value of the number of heaters being on simultaneously was calculated to determine the expected frequency during one session that a particular number of heaters would be on simultaneously.

It can be seen from Table 29 that the probability is 0.00017 that 6 water heaters are likely to be on simultaneously during any one session, or it may happen for a minute during 1 in every 6 000 (=1/.00017) cycles that 6 water heaters are on simultaneously, and it is likely that for 5 (or 4,7) minutes during any session two water heaters will be on simultaneously.

7.7.5 Use of the model to determine the maximum demand presented of a load consisting of instant water heaters

Using the mathematical model the expected load curve of the hot water system was drawn for various conditions. The maximum kW load per water heater was calculated for each condition.

Figure 48 and Figure 49 show typical load curves for 5 and 15 instant water heaters respectively, while Figure 50a and Figure 50b show the same loads, but for hot water cylinders. Comparing these figures, the following becomes clear:

* The hot water cylinder load is much smoother than the load of the instant water heaters.

* The maximum value of kW per water heater is much smaller for the load for the hot water cylinders than for the instant water heaters. This is especially so for a small number of water heaters.

* The duration of the maxima in the case of the instant water heater is very short. If the electrical distribution system can handle these short pulses without dropping the supply voltage too much, then we need not be too concerned about these pulses.

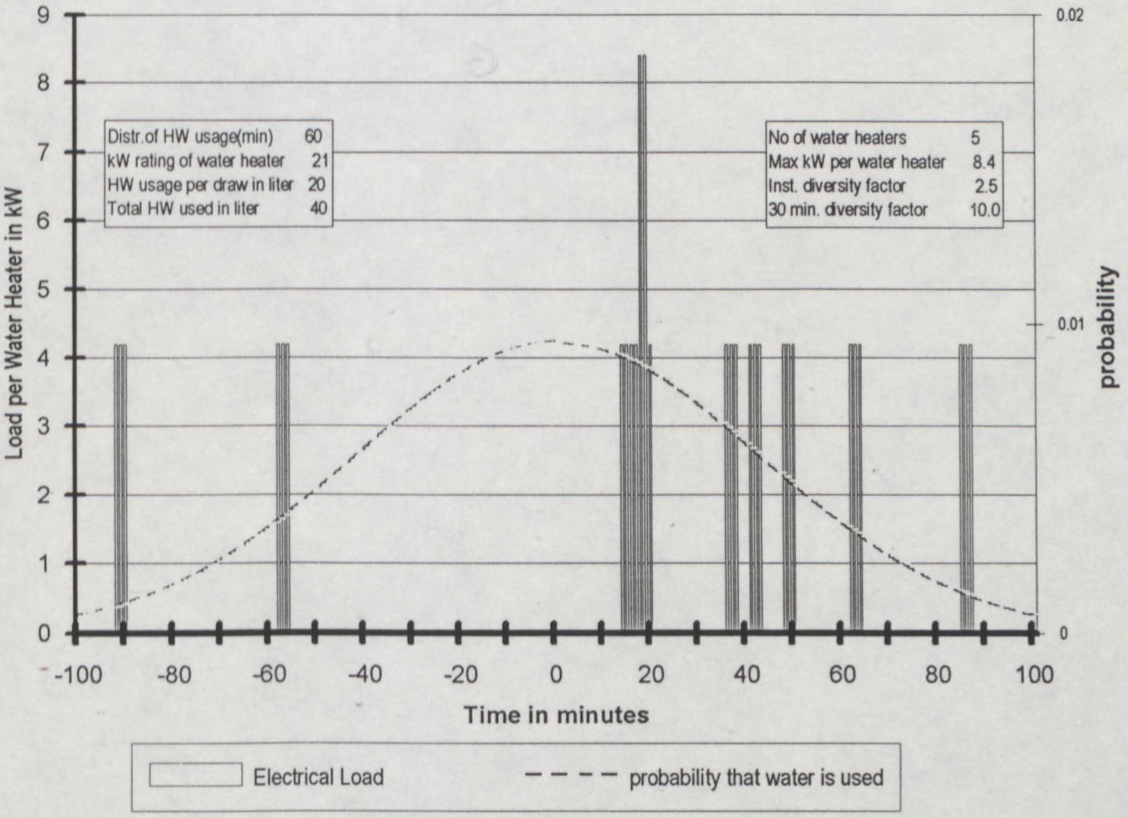


Figure 49 Electrical load presented by 5 instant water heaters supplied by the same source

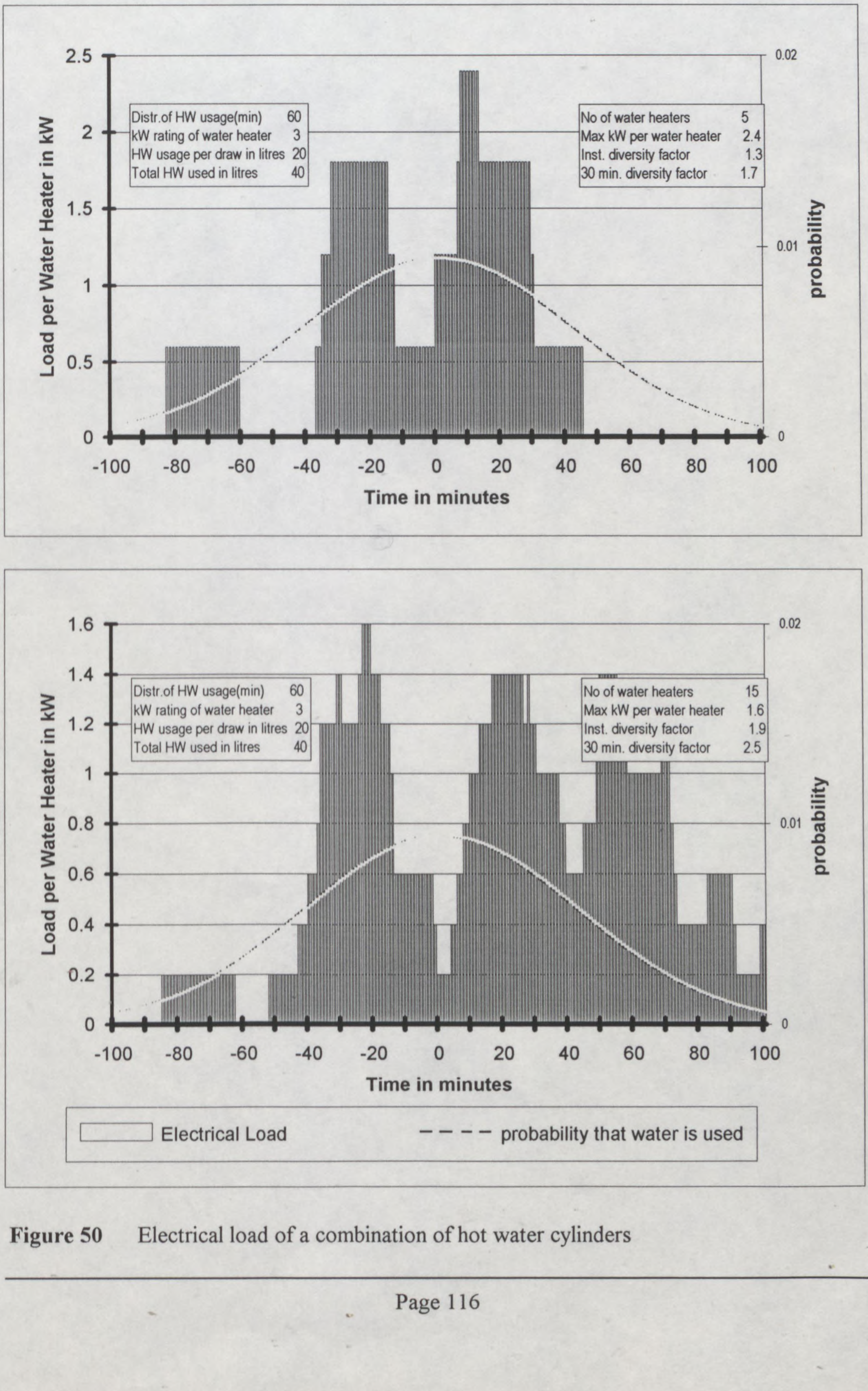
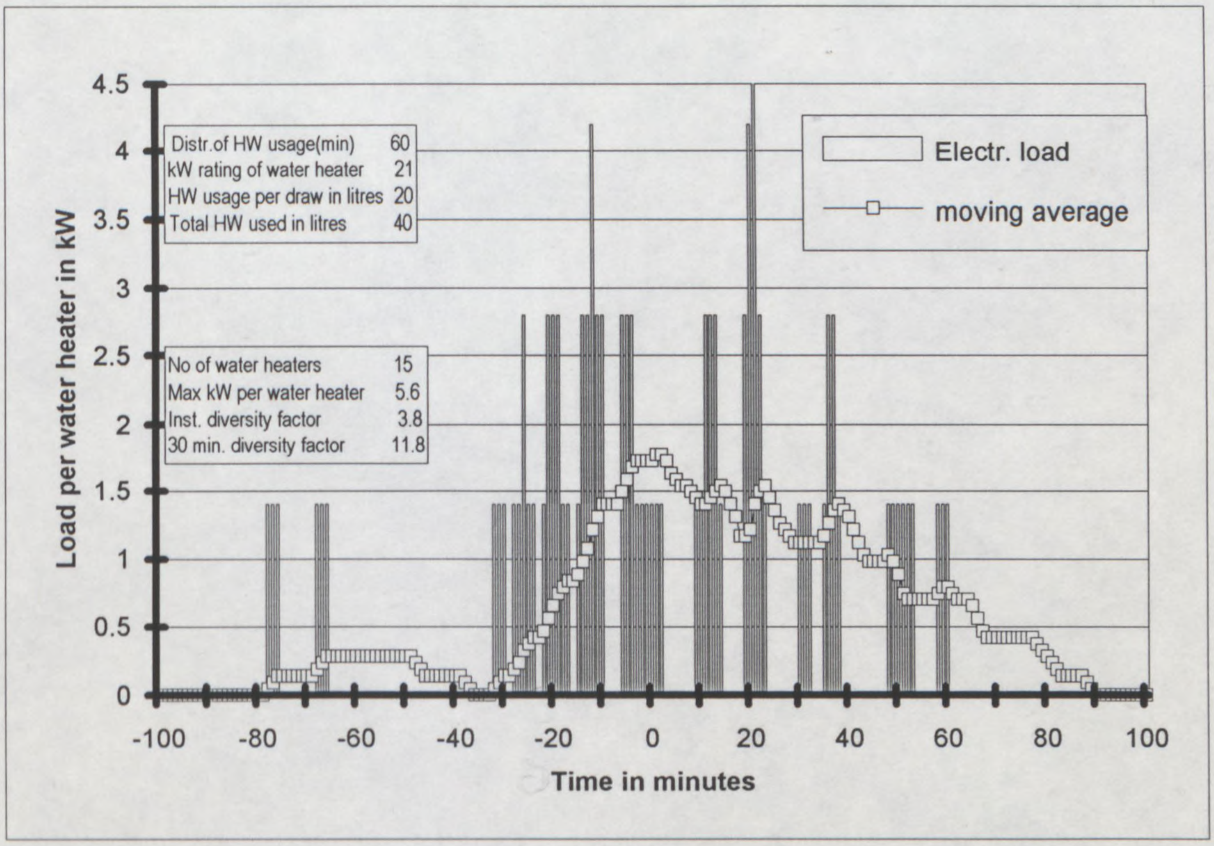


Figure 50 Electrical load of a combination of hot water cylinders



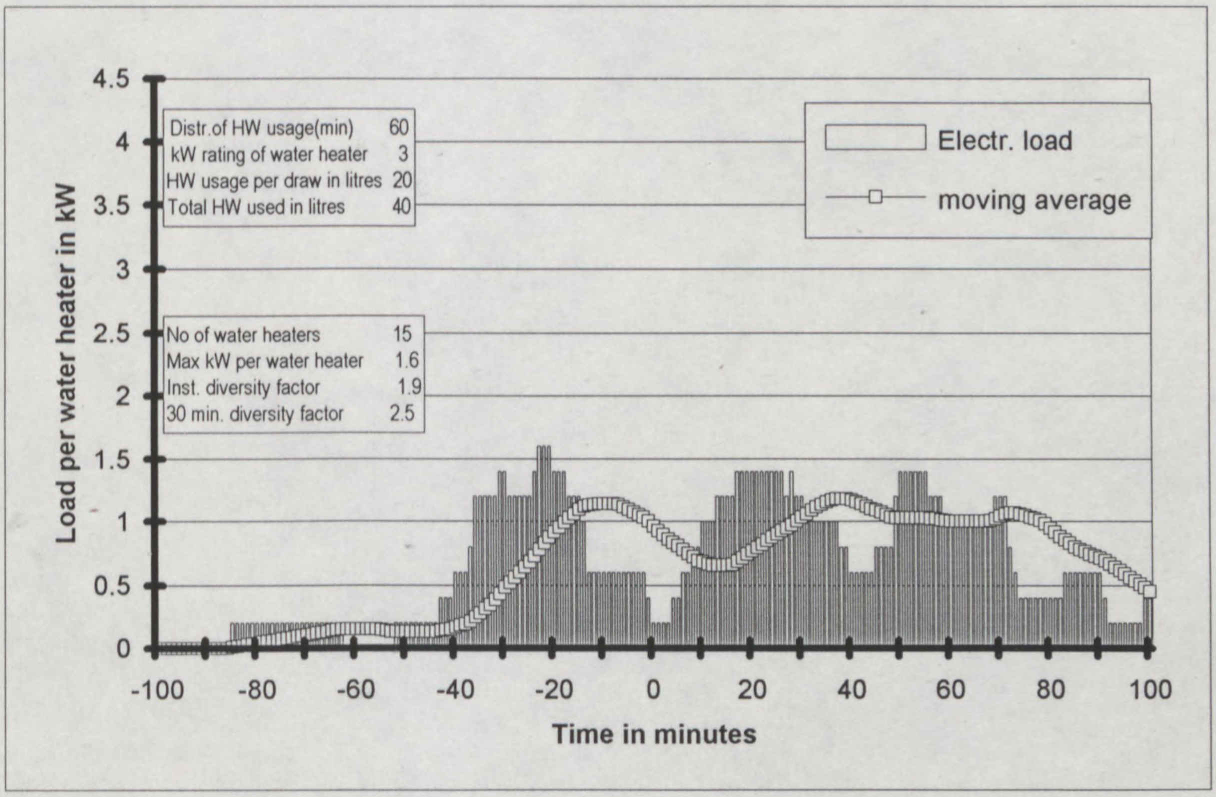


Figure 51 Half hourly electrical load of:

a) Instant water heaters b) Hot water cylinders

- * Figure 51 shows sample half hourly moving average loads for 15 consumers. Figure 51a shows it for instant water heaters, and Figure 51b shows it for hot water cylinders. It can be seen that the hourly or half hourly averages, which are important for the loading of the generating system and for accounting purposes, for instant water heaters do not differ substantially from those for hot water cylinders.

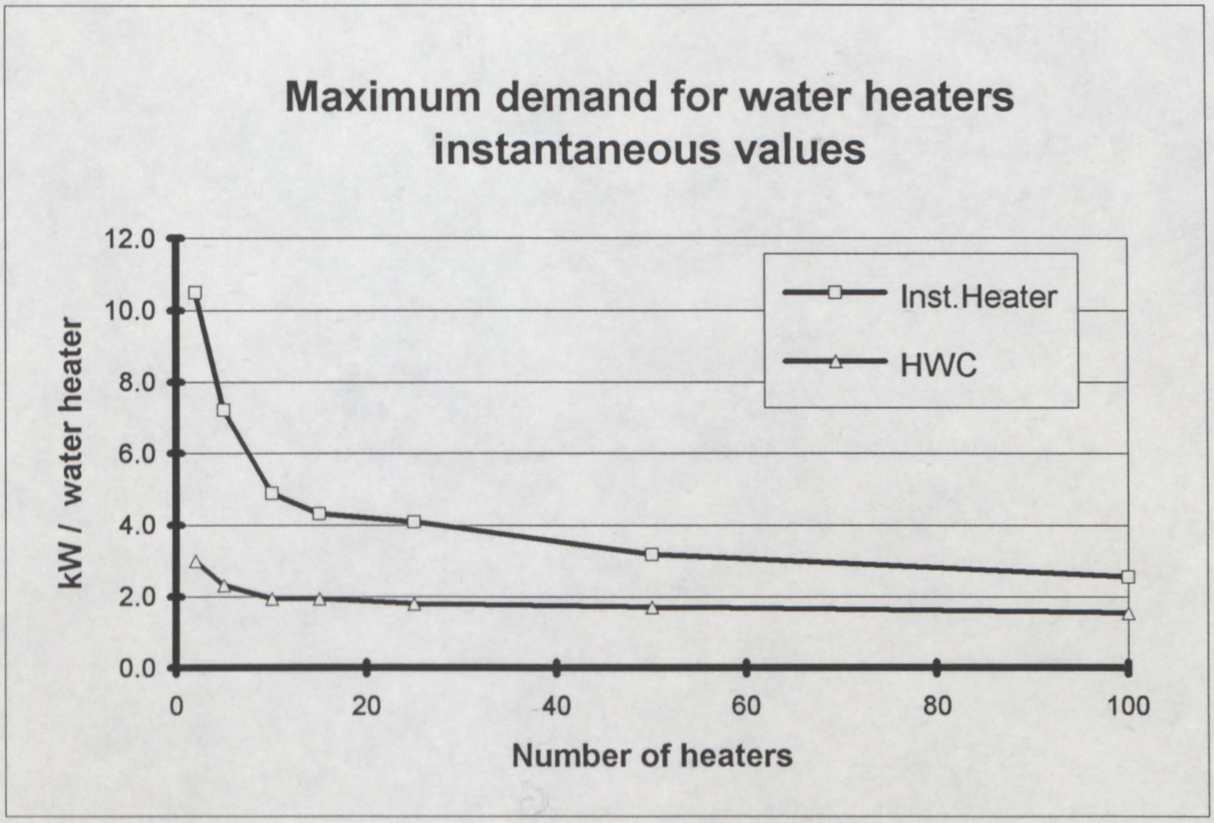
- * In the case of the hot water cylinders the instant electrical load curve lags behind the normal curve of the water consumption by about 10 to 15 minutes (half the time it takes to heat the water used by one draw, as was also derived in equation 27 on page 80). This lagging must not be confused with the lagging which results from taking a moving average.

The model was used repeatedly to obtain typical load patterns for 2, 5, 10, 15, 25, 50 and 100 instant water heaters (21kW). About 5 load patterns were obtained for each number of heaters. The tests were carried out for normally distributed water consumption with the following parameters per cycle:

distribution of water usage:	60 min.
water used per cycle:	40 litres
water used per draw:	20 litres
temperature rise of water:	50 C

In each case the instantaneous maximum demand as well as the 30 minute average maximum demand was noted. The experiment was repeated for hot water cylinders with 3 kW elements. The average value of the maximum demands obtained in this way was calculated. The results are given in Figure 52. A comparison is made between the kW per water heater for instant water heaters and the kW per water heater for hot water cylinders. It can be seen that there is a considerable difference in the case of the instantaneous maximum demand, especially where the number of heaters is low, but in the case of the 30 minute average maximum demand, especially where there are a large number of heaters, there is hardly any difference.

The above results show that as far as the supply to a group of 25 or more consumers is concerned, there is no need to differentiate between a group of instant water heaters and a group of hot water cylinders. The supply to an individual consumer using an instant hot water cylinder, however, will differ from that to a consumer with a hot water cylinder.



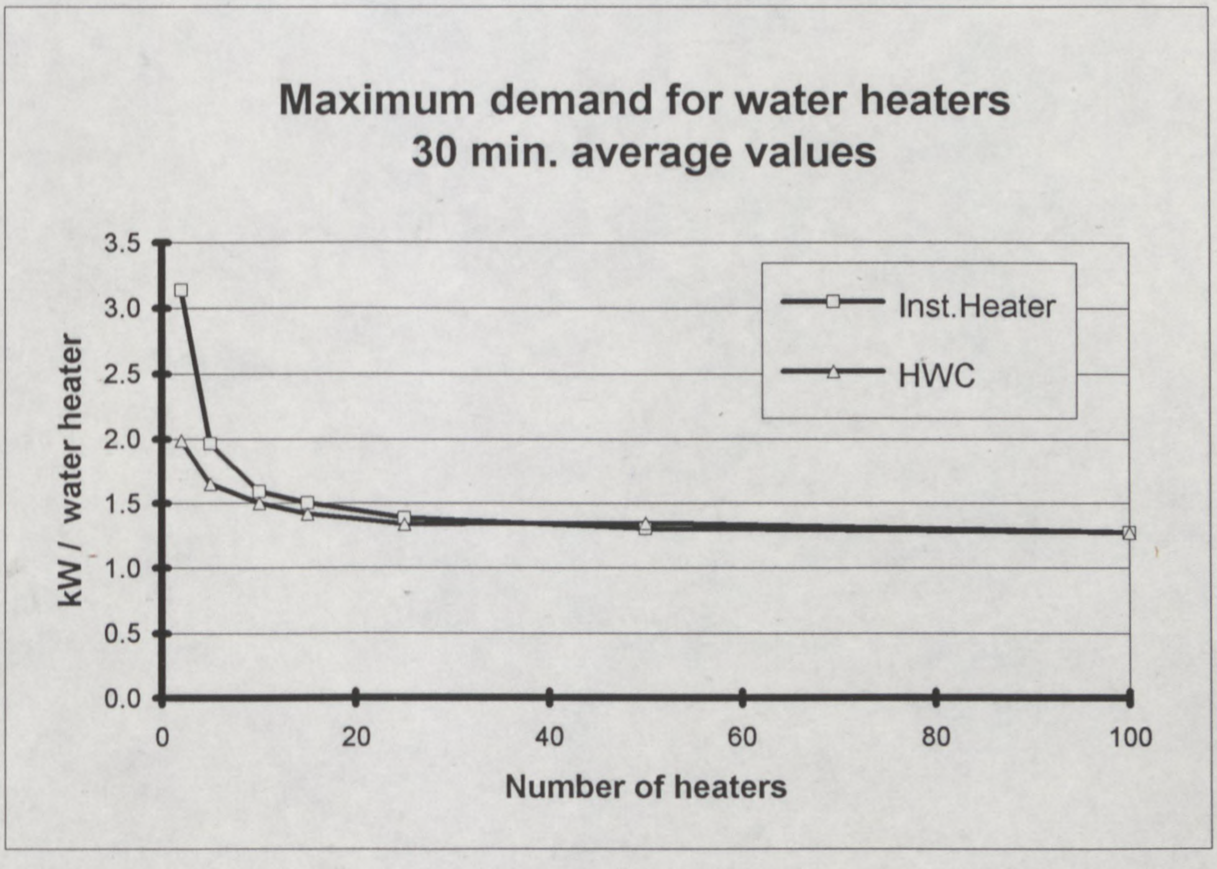


Figure 52 Maximum demand per water heater for various numbers of water heaters

7.7.6 Use of the model to determine the diversity factor of instant water heaters

The readings which were taken to calculate the maximum demand were also used to calculate the diversity factors as defined on pages 109 and 110. Figure 53 compares the 30 minute average diversity factor for instant water heaters with that for hot water cylinders. There is a large difference between the values for instant water heaters and those for hot water cylinders.

Figure 53 also shows the individual readings in the form of a scatter diagram. It can be seen that where the number of consumers is less than 25, the variation in the individual readings can be quite large, but this is to be expected.

The average power consumed heating 40 litres during the cycle under consideration, is 1,15 kW if it is assumed that the cycle is 60 minutes long. Using this information the lowest maximum demand which can be expected must be 1,15 kW, and the highest diversity factor which can be expected for 21 kW instant water heaters will be:

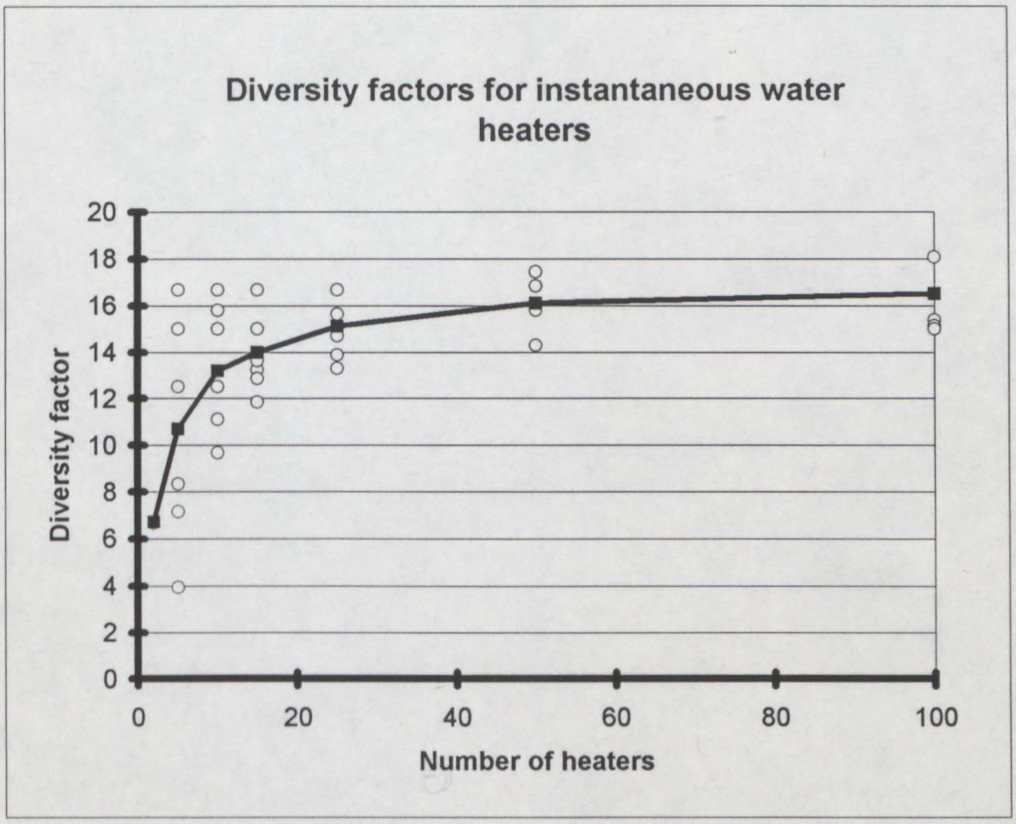
$$21/1,15 \quad = \quad 18$$

and for 3 kW hot water cylinders it will be:

$$3/1,15 \quad = \quad 2,6$$

Measurements were carried out by a German electricity supply authority: Vereinigung Deutscher Electrizitätswerke (VDEW) to determine values of the diversity factor of households with instant water heaters. A residential area with blocks of flats with different numbers of units (3,4,6,14,62 and 100) was used for this measurement. Each flat was installed with an instant water heater of 21 kW and the average connected load per flat was 32,5 kW. The highest peak in each group was recorded (hourly average) to determine the diversity factor of the households. Figure 54 shows the results of the measurements (Engel, 1989).

The values of the measurements compare reasonably well with the theoretical values of Figure 53, but the values of Figure 53 are somewhat lower. The reason for the difference must be that the consumption of hot water was lower that 40 litres per cycle, because according to the above calculation the maximum theoretical value of the diversity factors is 18, while Figure 54 has a maximum of about 24.



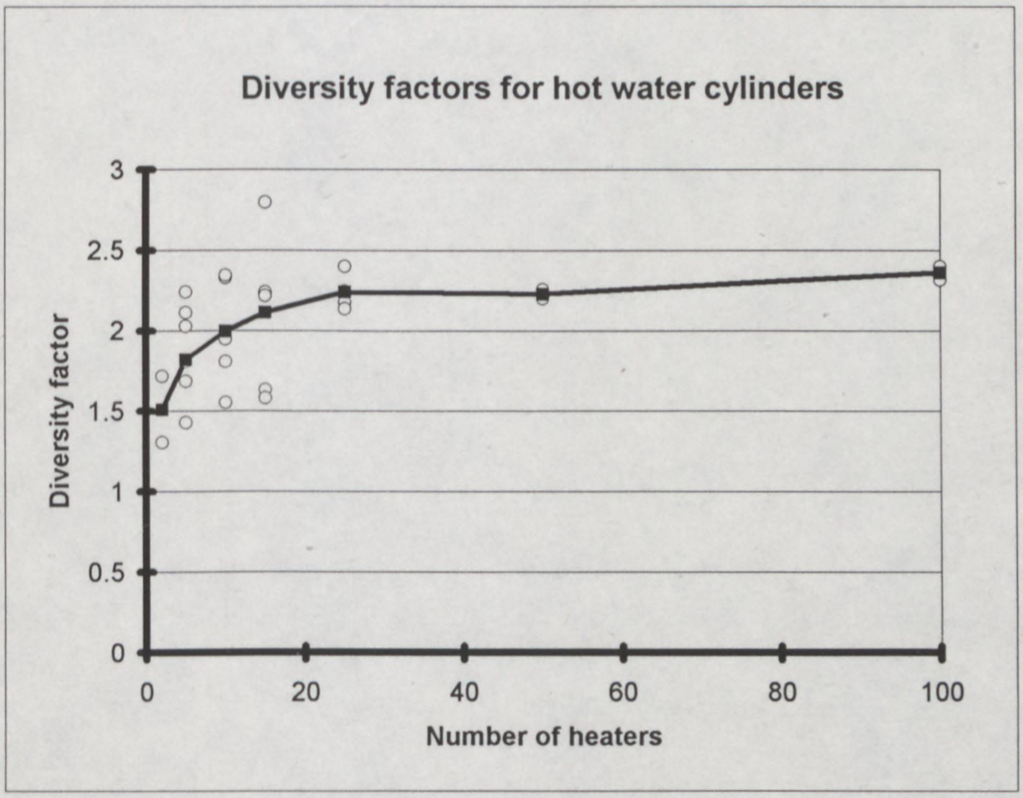


Figure 53 Thirty minute diversity factors for various numbers of water heaters

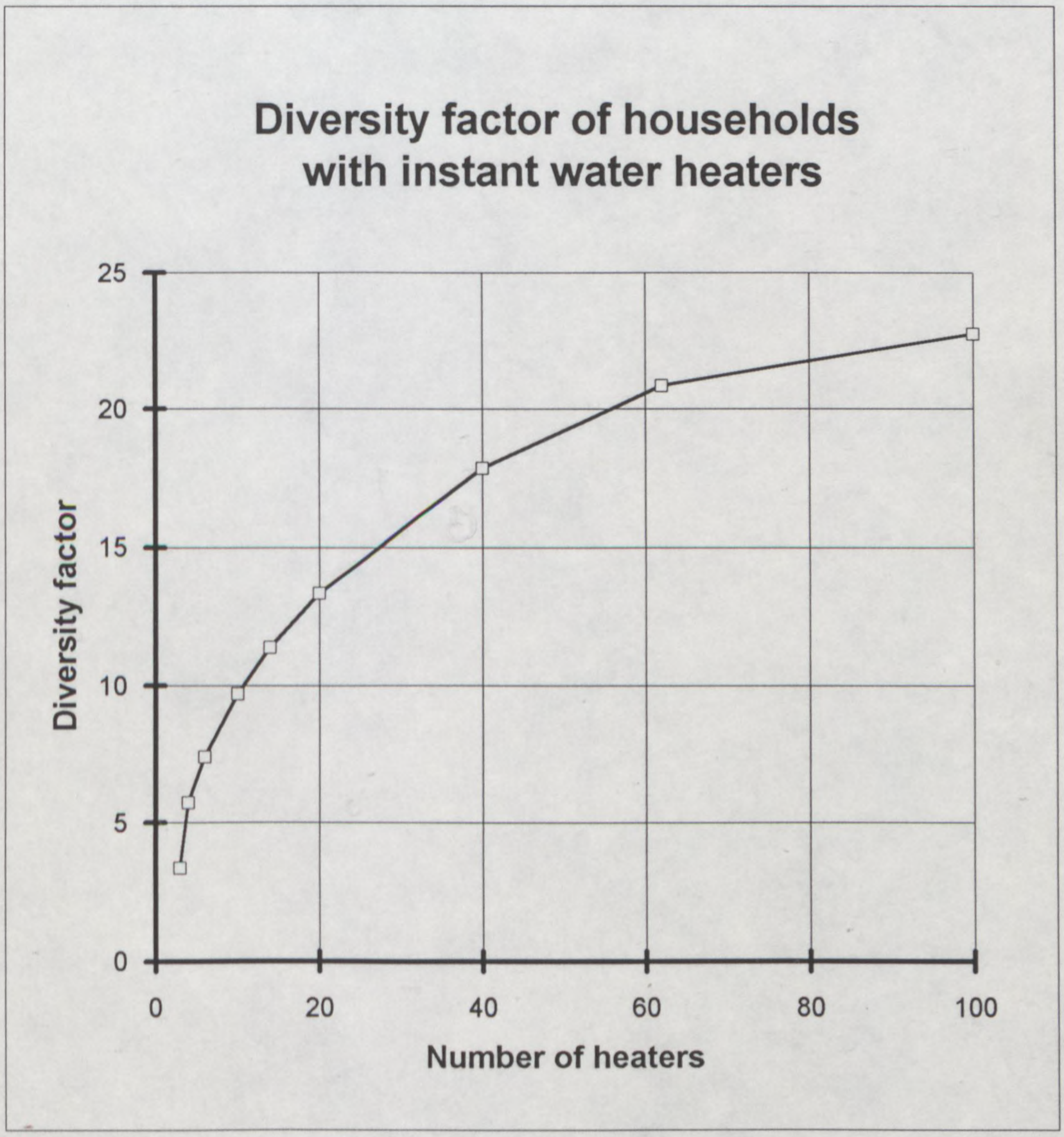


Figure 54 Diversity factor as used by VDEW in Germany

7.7.7 The influence of the instant water heater load for the future

The hot water load is an extremely important part of the domestic load. It is a load which can be used for demand control, but energy saving considerations must also be carefully considered.

During the next few years large sections of the South African community will be using electricity for the first time, so now is the time when many consumers can be influenced to use electricity in a way which will conserve energy and which will be most economical.

The following points need to be considered:

* when one studies the load curve for a residential area, whether it be a developing community like Soweto or Tembisa near Kempton Park, or whether it be a developed residential area like Durbanville, and compares it with the national maximum demand curves, it becomes clear that the morning peak of the residential load will be earlier than the national maximum load (09:00) and that the evening peak (21:00) will be later than the national evening maximum load (19:00), so an increase in the national load, due to the residential sector using instant water heaters instead of hot water cylinders, will not necessarily result in a corresponding increase in the national maximum demand.

* The evening peak of the urbanising community is normally also much higher than the morning peak. This also causes peaks of the newly urbanising community to be less significant.

* In a matter of a few years it may happen, as the urbanising community becomes westernised, that the load curve of the urbanising community will become more and more like that of the westernised community, with the same peaks.

* The difference between the national load at 19:00 and the load at 21:00 is in the order of 1 000 MW, which is about 5 times the peak load of Soweto.

It can be seen that:

* Careful positioning of the hot water load, especially in the urbanising community, is essential.

* The positioning of the load will be influenced by the type of water heater which is used.

* The use of an instant water heater instead of the hot water cylinder causes:

- a reduction in energy consumption;
- a change in the domestic load pattern, which may under some conditions, especially in the newly urbanising community, be beneficial;
- the loss of the hot water load as a load which can be used for load shifting.

7.8 Measurements of hot water consumption of individual consumers

In order to calibrate the hot water model, the electrical energy consumption has been measured at a number of households, 24 hours per day, over a period of about 14 days per household. The readings have been averaged over 15 minute intervals. Commercially available data loggers have been used. Different channels of the instrument have measured the following data simultaneously:

1. The total electrical supply.
2. The electrical supply to the hot water cylinder.

Other channels of the recording instrument, where and when available, have been used to measure some of the following loads at the same time:

Stove
Lights
Plugs
Swimming pool
Kitchen.

The data in Table 28 on page 106 are used to compile Figure 55, which can be used to convert hot water consumed in litres per day to the electrical energy (in kWh per month) required to heat this water by 50 C and to supply the associated losses, for various temperature and usage conditions. The water consumption c in litres per day can also be calculated from the energy e in kWh per month by using the formula:

$$c = -47{,}7 + 0{,}46 \times e \quad \cdots \; 53$$

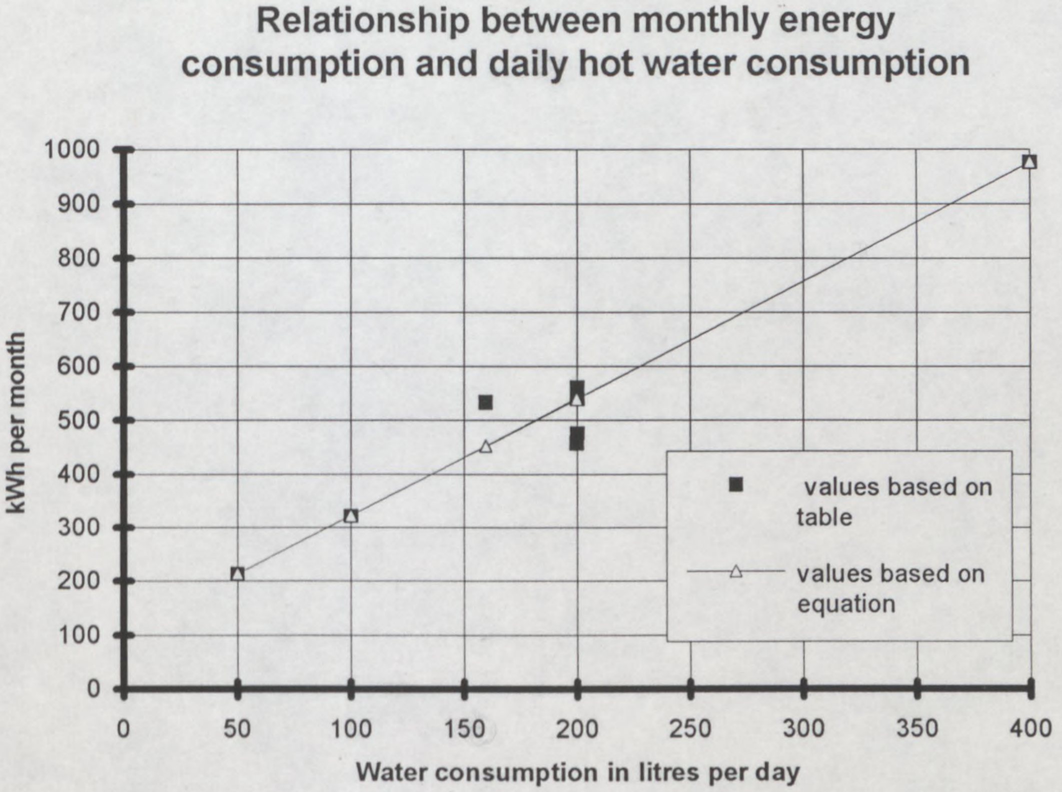


Figure 55 The energy required to supply the losses of a hot water system using a hot water cylinder and to heat water to 65 C

The values given in Figure 55 make allowance for the standing loss of the hot water cylinder, and also for the loss of heat in the hot water pipes. The value of the standing loss is based on tests performed by the Division of Building Technology at the CSIR (Simpson, 1990:9).

In cases where the temperature setting of the hot water cylinder is not 65 C the water consumption is converted to an equivalent quantity at 65 C.

The readings which were taken in houses in the Cape area were done in different areas, giving a good cross section of consumers. The chosen households were not a carefully selected statistical sample, but the average of the readings taken will give a good indication of what the average consumption of hot water is for most households.

The readings were taken in autumn, which can be taken as the average between summer and winter. Many more measurements will have to be taken at different times of the year and at different locations, selected on a sound statistical basis, for the results to be accurate enough to represent the whole South African community

The average value of the energy required for the hot water system was between 350 and 400 kW per month per household for the households where electricity consumption was monitored. Using the graph in Figure 55 this is converted to a hot water consumption of about 125 litres per household. The average number of persons per household was about 3,5, giving a consumption of about 35 litres per person. This is somewhat lower than the 50 to 75 litres per day in the literature.

Some supply authorities have equipment to control the hot water load of their consumers. With the help of this equipment, the hot water load was measured at four municipalities in the Western Cape. These readings will be discussed in section 7.10. The results obtained from these readings also indicate that the monthly energy consumption for water heating does not exceed an average of 350 to 400 kWh per month for the middle to upper class household.

After the readings were made, the households were given information about the readings and they were questioned about their use of electricity and hot water in detail to determine the following about the use of hot water:

- time of use, and
- purpose for which the hot water was used.

Considering the time of use of the hot water, the following components were identified:

- **Morning load.** This consists of hot water needed for the shower, bath, wash basin and kitchen sink.
- **Evening load.** This consists of hot water needed for laundry, dish washing and bathing. Bathing is usually late in the evening for adults, but early in the evening for small children.
- **Midday load.** This is a small load because not many people are at home at midday.
- **Unpredictable load.** This represents that portion of the load which is present at different times of the day for those who are active outside normal hours. This load is small in comparison to the other loads.

- **Standby loss.** This represents the heat needed to keep the water in the hot water cylinder hot.

The use of hot water is categorized below. Some details obtained from the measurements and the survey discussed earlier are also given:

- **Bathing**. This seems to be the largest component of use.

- **Showering**. In most cases a shower is more economical than a bath.

- **Wash Basin.** Using hot water in the wash basin can be very wasteful, especially if the hot water cylinder is far away from the wash basin.

- **Kitchen sink.** Hot water is used here for washing dishes and for food preparation. Efficient use of hot water depends very much on the energy efficient attitude of the members of the household.

- **Laundry washing**. There seems to be a tendency to use cold water in the washing machine. In these cases very dirty clothes are often soaked in hot water before washing them in the washing machine. In this way energy is saved because hot water is only used when needed.

Measurements and calculations are for the water heated by the hot water cylinder, but it is not only the hot water cylinder which supplies hot water. Water is also heated by:

- **the kettle,**

- **the dish washer,**

- **most washing machines,**

- **the hot plate,**

and in various non-electric ways.

The survey which was carried out in some developing areas of the Cape (Appendix E) indicated that electrified households which do not have running hot water also use electricity for heating water, but not conveniently, so they tend to use less than half the amount of hot water which households with running hot water do.

The average measured domestic load in the selected households is given in Figure 56.

The results obtained by the measurements discussed in this section and the description of the hot water load are used to analyze the electrical load for water heating for the Cape Peninsula area and for South Africa in section 7.11.

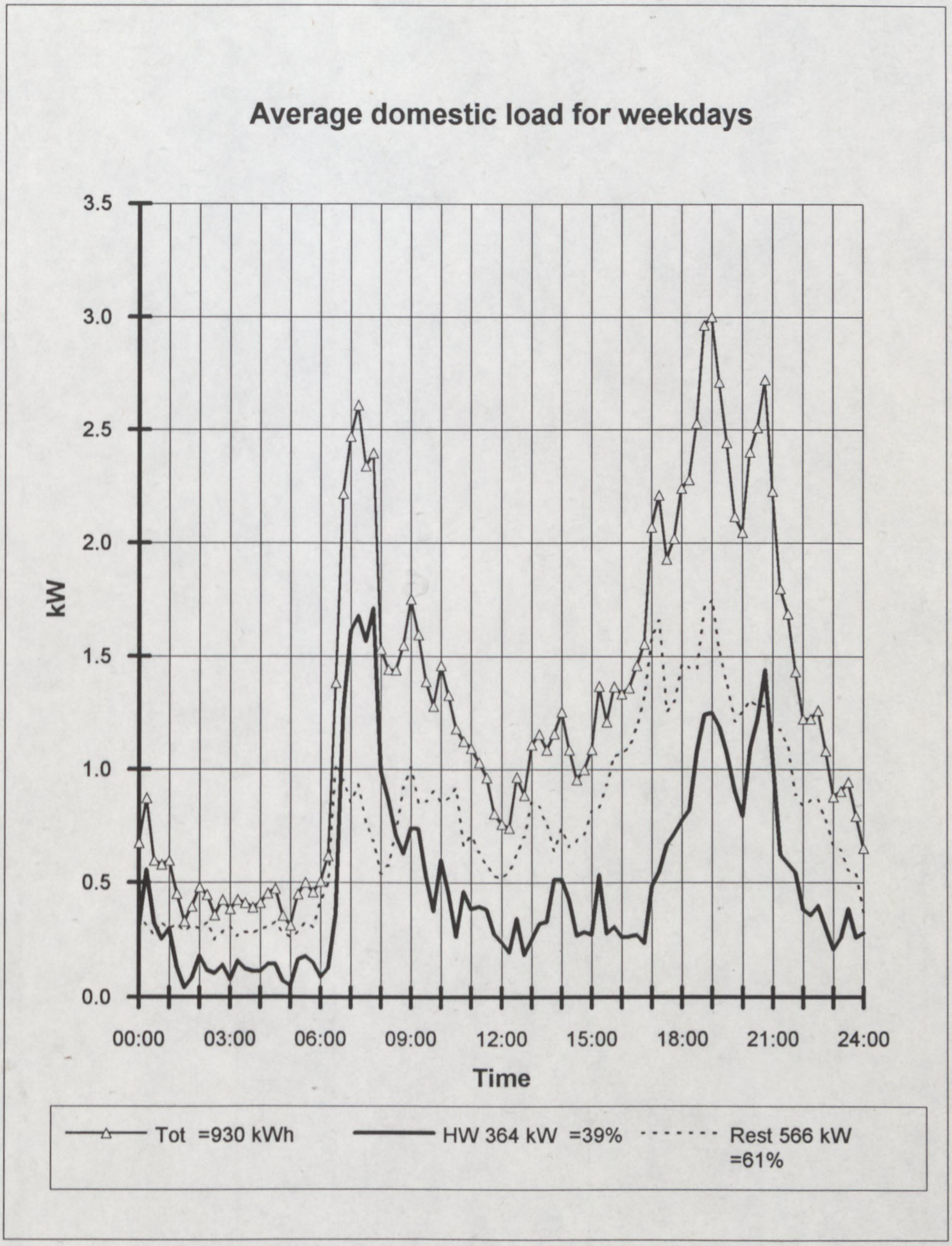


Figure 56 Measured average domestic load

7.9 The correlation between water heating and other domestic electrical loads

It can be seen from Figure 56 that a strong correlation exists between the hot water load and the rest of the electrical load, and it is also clear from the graphical representations of the load that the correlation is displaced somewhat in time.

Various statistical methods are used to determine the correlation between variables. If correlation exists between two variables X and Y, it is possible to represent the relationship by the regression equation:

$$Y' = a + bX$$

where **X** is the independent variable and **Y'** is a corresponding dependent variable on the regression line. Actual values of **Y** are not necessarily on the regression line, but the values of **a** and **b** are such that actual values of **Y** are as near as possible to the regression line. The correlation function is a measure of how closely the regression line represents the relationship between **X** and **Y**: if all the points lie on the regression line, there is perfect correlation. The correlation coefficient measures the direction and strength of the statistical relationship between an ordered pair of observations of two random variables. It is a dimensionless number that can take on values between -1 and +1 only. A value of +1 means perfect correlation with the pair in phase, and a value of -1 also means perfect correlation, but with the pair opposite in phase. A value of 0 means that the pair is not correlated (Edwards, 1979:22).

The correlation coefficient is defined as:

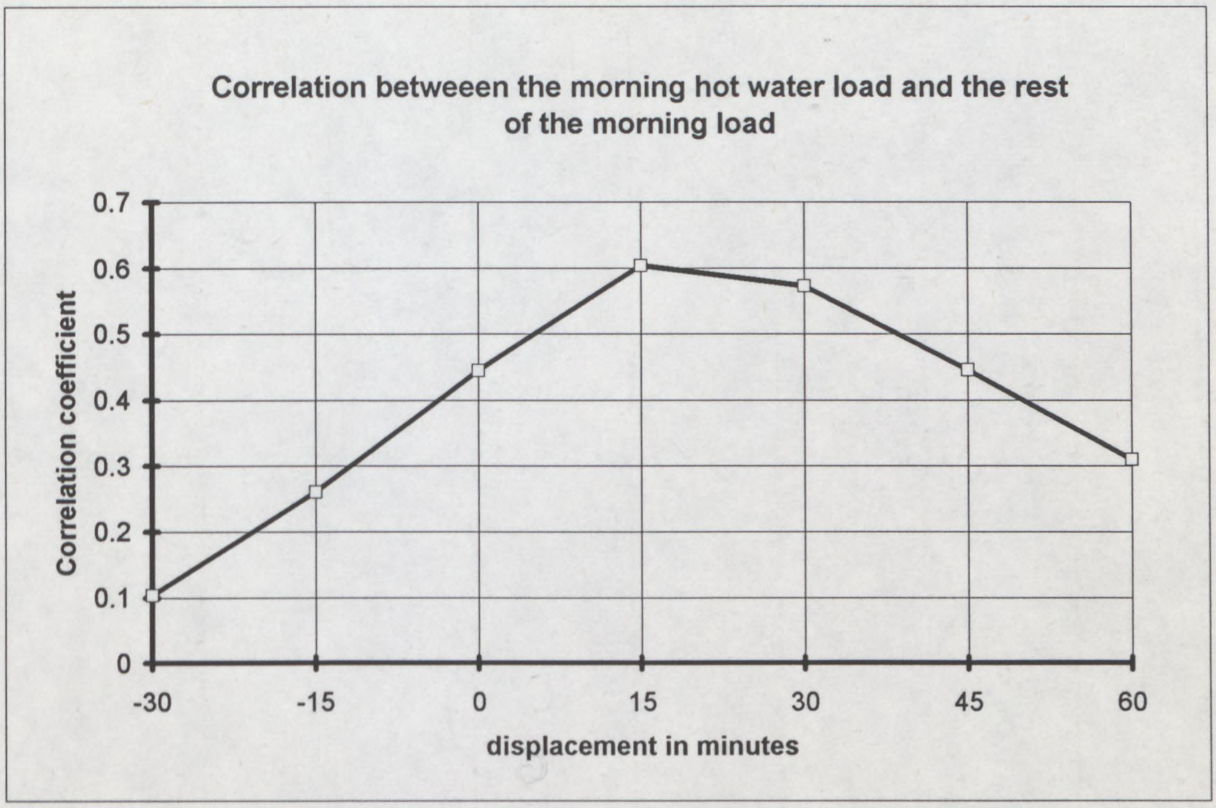
$$r = \frac{\sum_{t=1}^{n}(x_t \times y_t)}{(\sum_{t=1}^{n} x^2)(\sum_{t=1}^{n} y^2)}$$

where r = correlation function between series X and Y

x_t = $X_t - \mu_x$ with:

X_t = element number t of series X

μ_x = mean value of series **X**



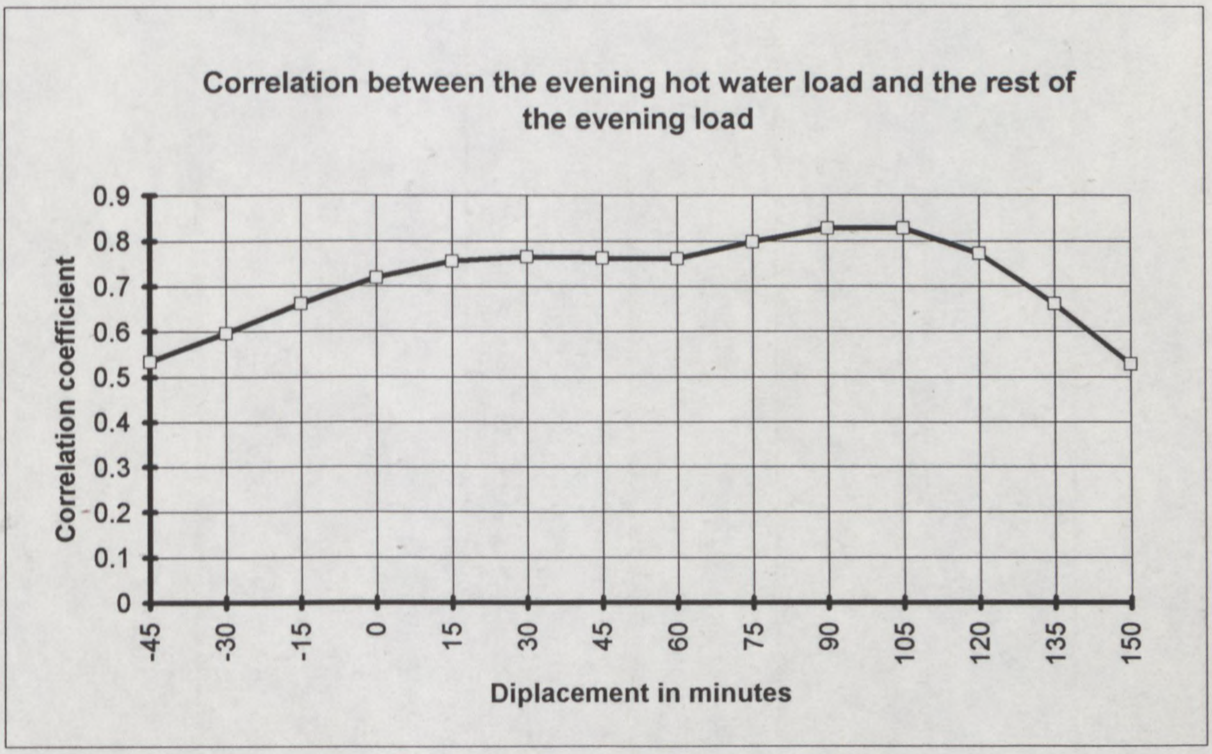


Figure 57 Correlation between hot water load and the rest of the domestic load

But the type of correlation which is being investigated is not quite the same as the normal correlation coefficient, because one of the variables must be displaced in time.

The auto-correlation coefficient which measures the correlation between a function and the same function displaced in time, is a univariate function which is used widely for forecasting economic trends (Pankratz, 1983:5). A function closely related to the auto-correlation coefficient and the correlation coefficient is the cross correlation coefficient (Beute, 1965:9).

The cross correlation function is useful to determine by how much the hot water load is displaced from the rest of the electrical load. The cross correlation function is defined as:

$$r_k = \frac{\sum_{t=1}^{n-k}(x_t \times y_{t+k})}{(\sum_{t=1}^{n} x^2)(\sum_{t=1}^{n} y^2)} \quad \ldots \; 55$$

where r_k = cross correlation function between series X and Y with Y displaced by k intervals

x_t = $X_t - \mu_x$ with:

X_t = element number t of series **X**

μ_x = mean value of series **X**

(Pankratz, 1983:35)

To quantify the correlation between the hot water load and the rest of the electrical load, the cross correlation function has been calculated for different values of displacement. The function has been calculated separately for the morning and the evening loads. The results are shown in Figure 57. It can be seen from Figure 57 that during the morning, the hot water load lags about 20 minutes behind the rest of the domestic load. This must be because the electrical energy for heating the hot water is needed after the hot water is used. The delay in time depends on the size of the element in the hot water cylinder and the amount of water which is drawn. The time the element stays on after the hot water is used is:

$$\Delta t_{on} = q/P_e \quad \text{seconds}$$
$$= q/(60.P_e) \quad \text{minutes}$$

where: P_e = power rating of hot water cylinder

$q = m.C_{water}.\Delta t$ joules

with $\Delta t = t_{thermostat} - t_{inlet}$

C_{water} = specific heat capacity of water

The following table shows a few examples of the time required:

Table 30 Time required to heat water in a hot water cylinder

Water	Temp. of water		Rating of	Time
litre	cold	hot	HWC(kW)	min
100	15	65	3	116
100	20	65	3	104
100	15	65	2	174
60	15	65	3	70
50	15	65	3	58
40	15	65	3	46
10	15	65	3	12
20	20	65	2	32

It was shown earlier, on page 80, that the power for the hot water load reaches a maximum at time:

$$\Delta t_{on} / 2$$

so the displacement in time between the use of the hot water and the maximum of the hot water load is half the value in the last column of the above table.

The displacement between the morning hot water use and the peak of the electrical hot water load is about 20 minutes, as derived from the correlation function calculation, so the time the hot water has to be on to reheat the water in the morning must be about 40 minutes. The most popular element size in the municipal areas under investigation is 3 kW, so the amount of water which is used per hot water cylinder must be about 40 litres.

During the early evening the displacement between the use of hot water and the maximum of the electrical hot water load is about 35 minutes, so it follows that the use per hot water cylinder must be about 60 litres which is much more than in the morning. This can be expected, because the use in the evening consists largely of bathing, which requires more hot water than other uses do.

Figure 57 also shows that there is another time, later in the evening, about 100 minutes after the peak of the non-hot water electrical load, when there is a large hot water load. This load must be due to bathing, late in the evening, before going to bed.

The above calculations show that the correlation between the hot water load and the load of the rest of the house can in many instances be attributed to the delay in heating the water after water usage. Where this is the case, it follows that the usage of hot water takes place at the same time as other household activities which use electricity.

In some instances, especially in the morning, it has been found that the peak electrical load of water heating either coincides with or precedes the peak electrical load of other domestic activities. It is important to be able to compare the position of the peak due to hot water with that due to the rest of the domestic load, and to take account of the relation between national and local peaks, when considering a change from hot water cylinders to instant water heaters, or if the installation of load control equipment based on the control of water heating is considered.

7.10 Measurements of the total hot water consumption of groups of consumers

In addition to the measurements done in individual households as discussed in section 7.8, the total municipal domestic load was also measured at a number of municipalities. It was possible to measure the hot water load by using the equipment which is normally used by supply authorities to manage the municipal load by controlling the supply to hot water cylinders in the case of most of their domestic customers.

A typical result of these measurements, after the measurements have been manipulated, is shown in Figure 58.

The total load thus estimated is compared to the total hot water load as calculated by Coetzee (1989:27) from measurements taken by a few municipalities. Coetzee has investigated the effect of the use of heat pumps for domestic water heating on electricity demand.

Figure 59 shows the hot water load curves for the municipalities of Roodepoort, Kempton Park and Queenstown. Coetzee (1989:25) found the shapes of these hot water load curves to be very similar, with an average standard deviation of 15% from the mean, so the average shape of these curves was taken to be representative for the whole hot water load of South Africa.

Measurements were made in the Durbanville municipal area during March 1992 and the daily hot water load curve was found to be very similar in shape to those in Roodepoort, Kempton Park and Queenstown. The standard deviation of the national load, as derived by Coetzee from the readings taken at Roodepoort, Kempton Park and Queenstown, referred to above, with respect to the hot water load of Durbanville is only 10%. The results are displayed in Figure 60 a & b.

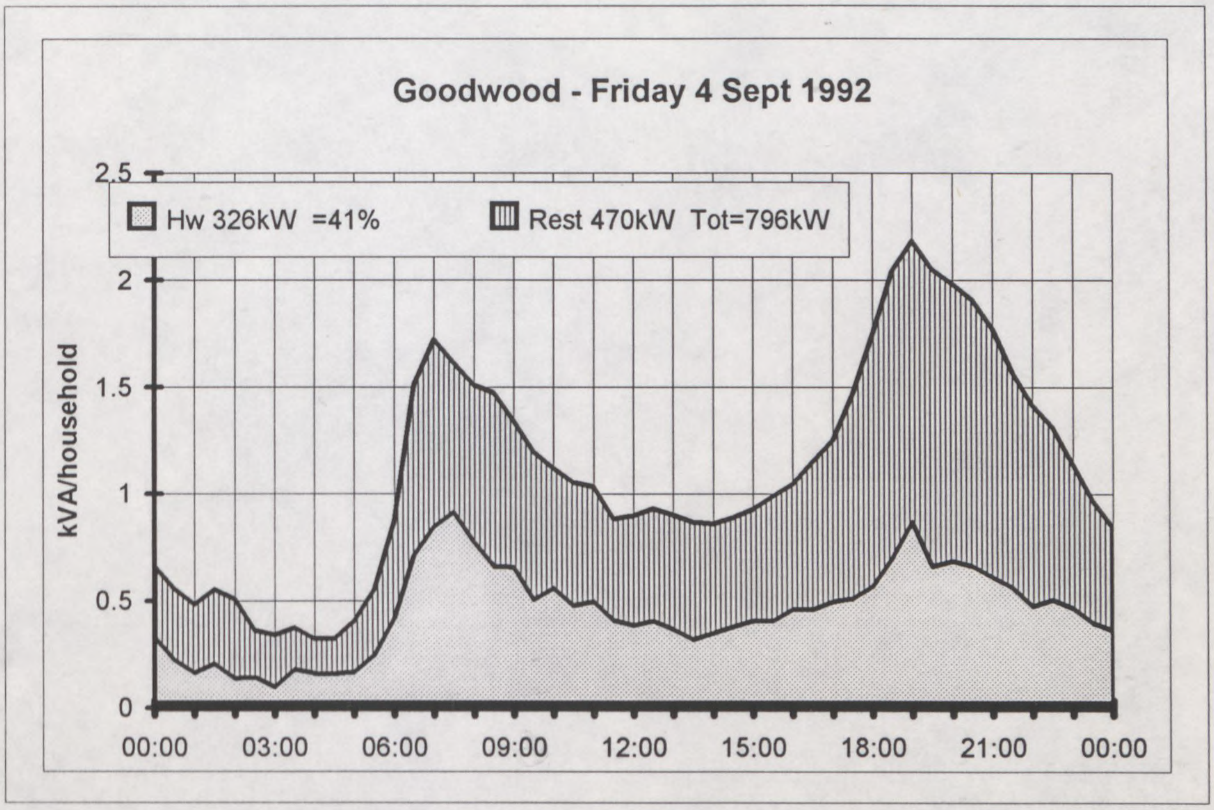


Figure 58 Domestic load per household for the Goodwood municipal area

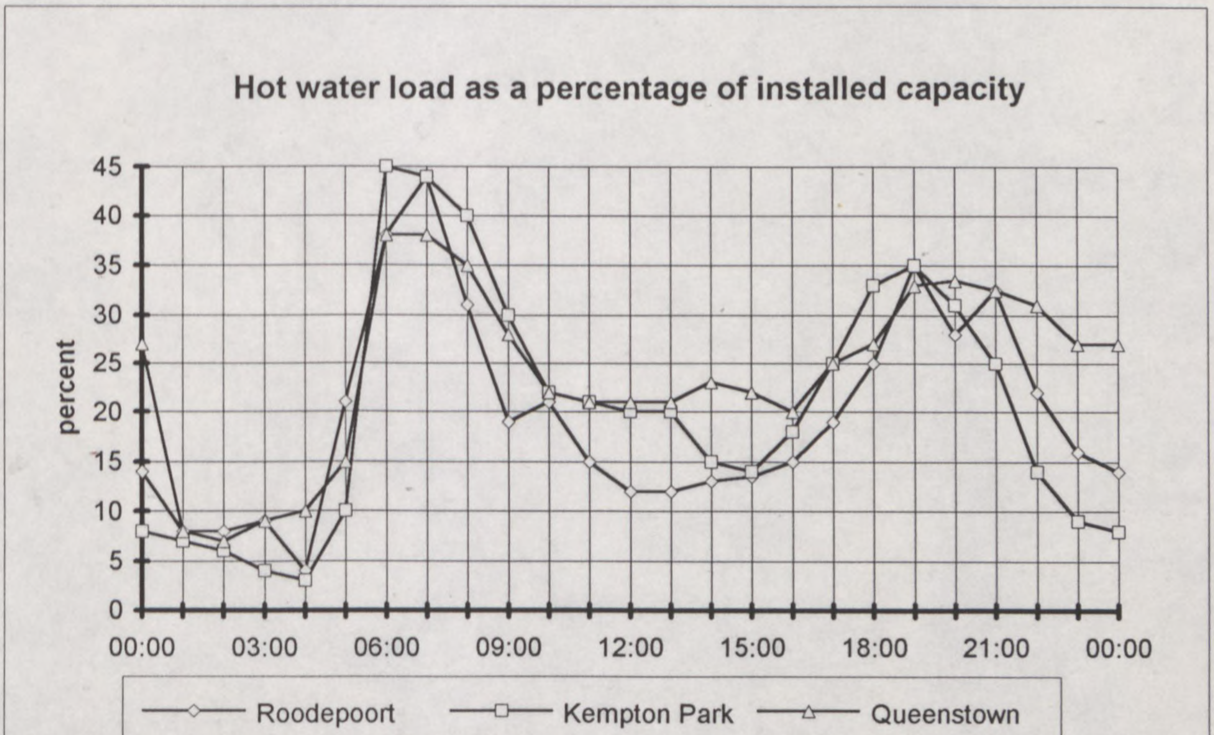


Figure 59 Hot water load for Roodepoort, Kempton Park and Queenstown

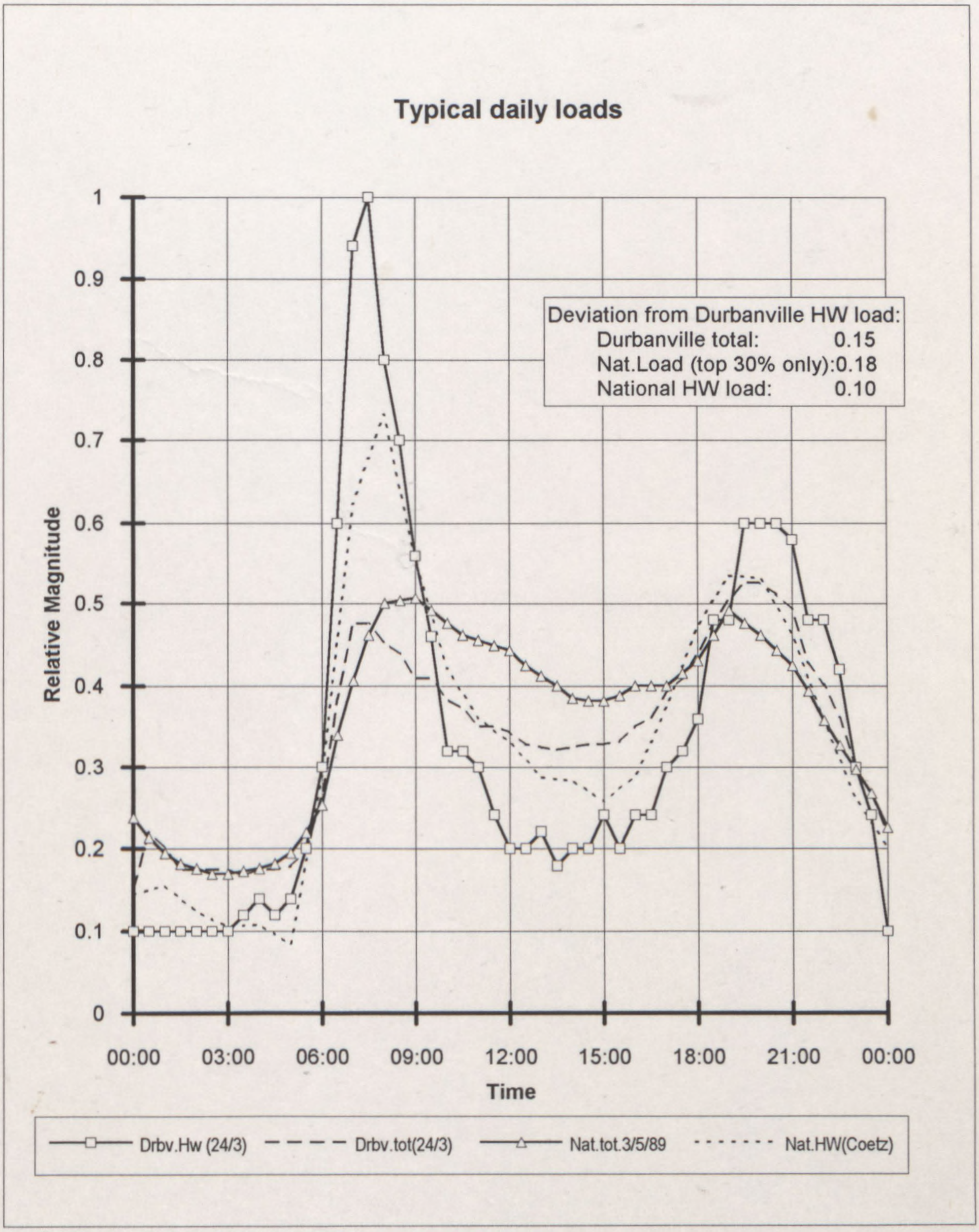


Figure 60 Normalized daily hot water loads and the peak of the national load

7.11 An analysis of the daily domestic hot water load

The figures in Table 31 and Table 32 have been used to calculate the total hot water load for the Cape Peninsula and the whole of South Africa respectively.

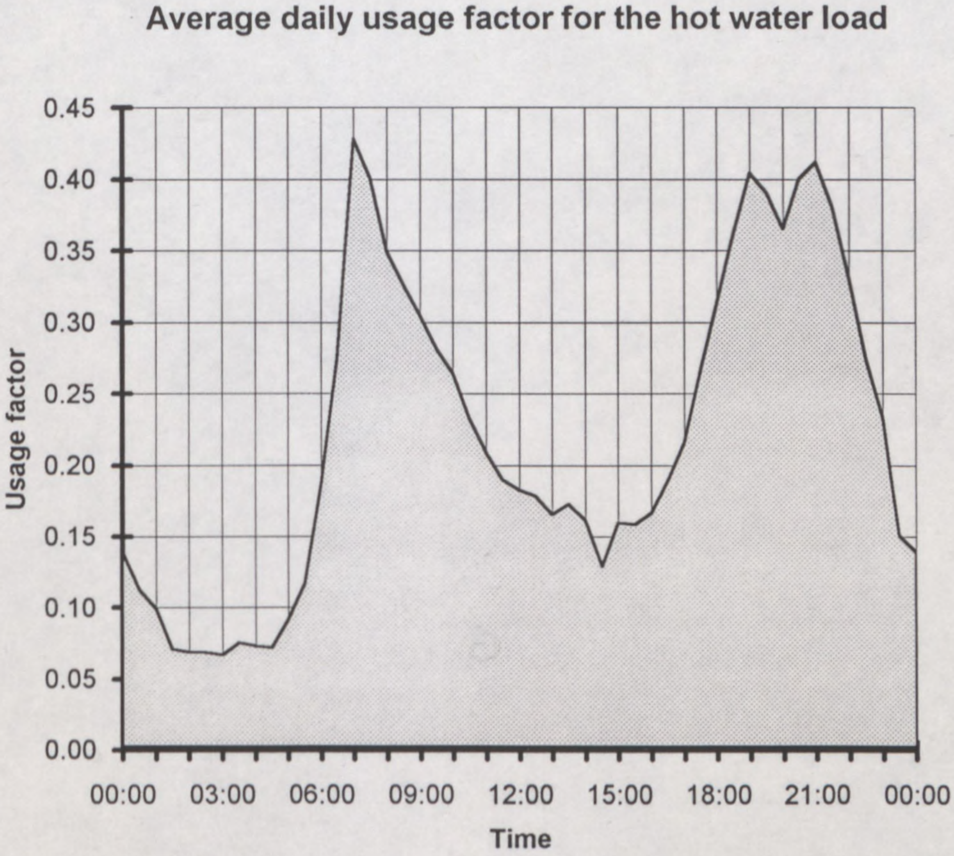
The values in these tables refer to the variables of the model which has been developed in chapter 2; the second column of the tables give the names of the variables which are used in equation 2 in chapter 2 on page 12. The equation is:

$$L_{jg} = \sum_{c=1}^{r} \frac{N_{gc}}{S_{gc}} \int_{t=0}^{n} L_{gcjht} dt \quad . . \ 56$$

The factors e,o and u are dimensionless numbers.The values displayed in Table 31 use the population numbers (N) and levels of electrification (e) as found in previous chapters. The percentage households with water heaters (o) has been estimated from surveys done, and discussions with supply authorities.

The Cape metropolitan area is considered as one of the geographical regions (g) and for the purpose of these tables the race groups are used as the category factor (c). It must be said that race groups do not constitute a satisfactory grouping category: a grouping based on standard of living would be more satisfactory, but seeing that population figures based on race are readily available and similar figures based on standard of living are not readily available, race group figures were used for this example. Subsequent use of the formula may well make use of a grouping based on standard of living.

The usage factor (u) is time dependent and it also depends on the amount of hot water used. It is not measured in litres as may appear from Table 31. The usage factor must be defined as a function of time; it should have the shape of the electrical load curve for hot water as for example in Figure 58. The value of u will also differ between summer and winter, and between weekdays, Saturdays and Sundays. Figure 61 gives values of the usage factor for a typical day. It can be seen from Figure 61 that nearly half the water heaters are on between about 07:30 and 08:00.



igure 61 Typical daily usage factor (u) for the hot water load

The records of the supply authorities which have helped with the measurements show that the larger elements seem to be more popular, so the value of P in equation 56 has been taken as 2,5 kW. If the value of P was found to be smaller, u would no doubt have had a larger value because it has not been found that the size of the hotwater element influences the use of hot water.

Factors for equation 56 have been found in a similar way for the whole of South Africa.

Table 31 Factors used to calculate the domestic hot water load for the Cape metropolitan area

	var. in eq. 56	Cape Town Metropole - 1990			
		Blacks	Col&Ind	Whites	Total
Population (000's)	N	600	1,400	700	2,700
Number per household		5.3	4.1	3.1	4.0
Number of households		113	341	226	680
% with electricity	e	27%	91%	99%	79%
% with hot water	o	56%	88%	97%	83%
% of population with hot water		15%	80%	96%	70%
H W per person day(ℓ)					
Summer		10	33	45	31
Winter		15	40	60	40
Average daily hot water/household	u,P	66	150	163	140
Total HW per day(Mℓ)					
Summer		1	37	30	68
Winter		1	45	40	86
Total HW/year(Gℓ)		0,4	15	13	28
Total energy in GWH/year	L_{jg}	28	1 003	877	1 908

Table 32 Factors used to calculate the domestic hot water load for South Africa

	var. in eq. 56	South Africa: 1990			
		Blacks	Col&Ind	Whites	Total
Population (000's)	N	27 619	3 920	5 118	36 657
Number per household (000's)		5,3	5,2	3,1	4,8
Number of households (000's)		5 211	754	1 651	7 616
% with electricity	e	28%	86%	99%	44%
% with hot water	o	54%	93%	97%	64%
% of population with hot water		15%	80%	96%	33%
H W per person day(ℓ)					
Summer		10	20	45	27
Winter		15	30	60	37
Average daily hot water/household	u,P	66	130	163	153
Total HW per day(Mℓ)					
Summer		41	63	221	325
Winter		62	94	295	451
Total HW/year(Gℓ)		19	28	94	142
Total energy in GWH/year	L_{jg}	1 307	1 979	6 410	9 697

To heat the domestic hot water for South Africa using hot water cylinders, requires 4,3 million hot water cylinders using a total energy of 7 063 GWh per year. Of this energy 20% (1 413 GWh per year) is lost in the hot water pipes. The standing losses at 1000 kWh per hot water cylinder amount to an additional 2 634 GWh per year, giving a total of 9 697 GWh per year or 24 GWh per winter day and 15 GWh per summer day. In the case of the metropolitan area of Cape Town, the total energy is 1 908 GWh per year, or 3,2 GWh per summer day and 4,5 GWh per winter day.

The above figures are tabulated in Table 33.

The very low overall efficiency of the hot water cylinder of about 60% is a very bad characteristic of the hot water system. Other sources have measured values as low as 48% for the efficiency (Crawford, 1991:3.4). In this particular case the loss of heat in the hot water pipes has not even been taken into account. The low value is a matter of great concern and should be addressed. The worth of the ability to transfer load should be evaluated against the more efficient instant water heater.

The different components of the hot water load as discussed so far have been estimated and added to give the total hot water load. Figure 62a indicates the hot water load for the metropolitan area of Cape Town, while Figure 62b indicates the hot water load for the whole of South Africa. The factors used to calculate these loads are given in Table 34.

The resultant total value is compared to an estimate of the total South African hot water load by Coetzee (1989:34).

It is important to note that a small percentage increase in the use of hot water by the developing community of South Africa will soon constitute a much larger percentage increase in the use of electrical energy for water heating, because of the large numbers involved. The same argument would apply for other domestic uses of electrical energy.

Table 33 Electrical energy for hot water

	1990	
	CT	RSA
Total hot water per year (Gℓ)	28	142
No of HWC (000's)	576	3 007
Energy to heat water to 60C in GWh/day during		
Summer (20 C)	3,17	15,12
Winter (15 C)	4,52	23,58
Total energy in GWh/year		
a. to heat water	1 403	7 063
b. standing loss	505	2 634
c. loss in pipes (20%)	281	1 413
d. gross energy (a+b)	1 908	9 697
e. nett energy (a-c)	1 122	5 650
Overall efficiency	58 %	58 %

Table 34 Domestic hot water load for South Africa and the Cape Town metropolitan area for an average winter day: factors used to calculate the components of the hot water load.

Factors used		South Africa	Cape Town Metropole
No of people /HWC		4.5	4.5
Size of element kW		2.5 kW	2.5 kW
Morning Load	28%	6 602 MWh	1 266 MWh
Peak at (h)		7 h	7 h
Spread over (h)		1.5 h	1.5 h
Midday Load	18%	4 244 MWh	788 MWh
Peak at (h)		11 h	11 h
Spread over (h)		4 h	4 h
Evening Load	31%	7 310 MWh	1 358 MWh
Peak at (h)		19 h	19 h
Spread over (h)		2 h	2 h
Unpredictable Load	13%	2 986 MWh	554 MWh
Standing Loss	10%	2 358 MWh	438 MWh
Total	100%	23 580 MWh	4 380 MWh

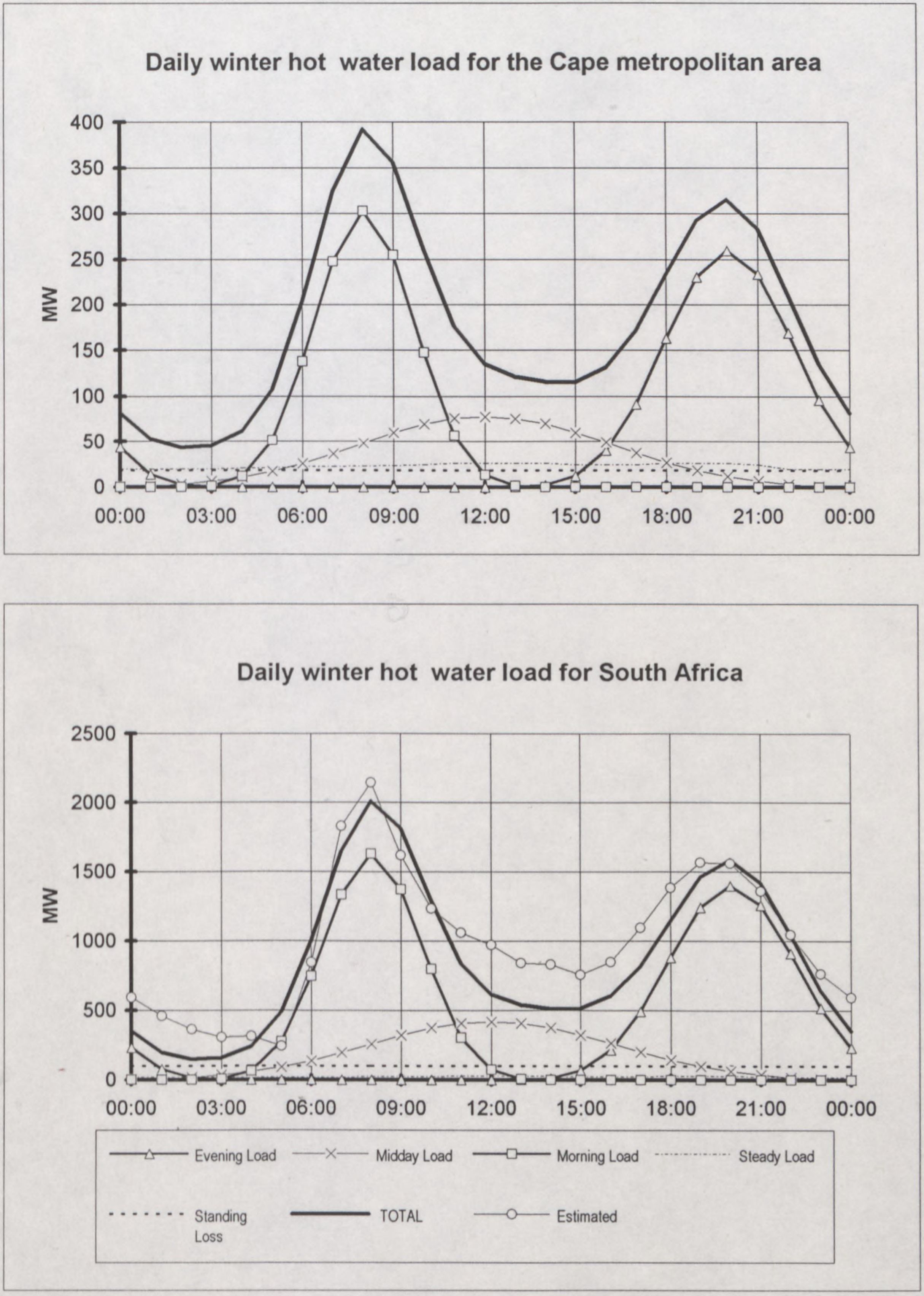


Figure 62 Components of the daily winter hot water load for the Cape metropolitan area and for South Africa

7.12 The effect of using a heat pump for water heating

Using a heat pump for water heating is very effective in reducing energy consumption. A typical value of the coefficient of performance for a heat pump heating water from 20 C to 55 C with a mean outside temperature of 17 C is 2,5 (Coetzee, 1989:88). This represents a major energy saving of 60%. The energy consumption will drop to 40% of its original value, so the maximum demand for heating the water will also drop to 40% of the original value.

The reduction in maximum demand could even be made greater than 60%, by controlling the time when the heat pump is operating, especially if a larger water cylinder is installed, allowing for more control of the time the heat pump is switched on because of the larger capacity of the hot water cylinder.

The problem, however, is the high capital and maintenance cost of the heat pump. At its present cost, the heat pump is economically viable if the hot water used per installation is reasonably high. For example, assuming that the heat pump costs R 1 300, is seems economically viable in the Johannesburg area if the family size is more than 5, and in the Cape Peninsula if the family size is at least 6, but in the Bloemfontein area it is not even economically viable with a family size of 8. The reason for the difference between the regions is that the coefficient of performance is dependent on the ambient temperature, and the price of electrical energy varies from city to city.

It can be assumed, however, that the cost of the heat pump will decrease as the technology improves, so within the next few years the heat pump should be more economically advantageous.

7.13 The effect of income on the use of hot water

The third world component of the South African population is moving from rural to peri-urban surroundings, and from informal settlements to electrified townships and eventually to the suburban environment. During this transition the energy source changes from wood to paraffin to coal or gas and then to electricity (Viljoen, 1989:126). This transition takes place as the income increases.

The use of electricity for water heating can only take place in electrified townships and suburban houses, so as urbanisation takes place and the standard of living improves, more and more hot water cylinders will be installed. An estimate of the rate of urbanisation and the rate at which the standard of living will improve over the next few years will help to determine the electrical power required for the provision of running hot water in the homes of the urbanising community.

A survey in the newly urbanised areas of South Africa has revealed that when the economic means of the household improves and the house is electrified, the provision of hot water is not one of the first uses of electricity. It is rather a TV set (60%), a refrigerator (57%) and an electric iron (59%) which the urbanising community prefers (Uken & Sinclair, 1991:64), more is said about this in Appendix F. After this the family may obtain a kettle (55%) to heat water and a HiFi set (43%) for entertainment. In the case of squatters the television set (21%) and the HiFi set (19%) are very popular with the fridge (8%) as the only other appliance of any significance.

The ownership of hot plates follows after all of the above appliances with a 36% ownership for the formal sector and 1 or 2% for squatters. The ownership of running hot water will of course be lower still.

The ownership of electrical appliances by people earning more than R 1 250 per month is typically about 3 times as much as for those earning less than R 600. In the case of hot plates the figures are 42% and 13% respectively, while in the case of television sets the figures are 78% and 26%. One can expect that as the income of the urbanising community increases, there will be a large increase in the ownership of electrical appliances, and there will also be a large increase in the number of hot water installations in the newly urbanising community.

7.14 An estimate of the hot water consumption for the year 2000 and possible energy saving measures

An estimate of the hot water energy required for the year 2000 has been made based on projected population figures and electrification rates. The results are tabulated in Table 36. It is very noticeable that the increase in hot water energy is expected to be 60 %, while the population increase is only expected to be 30 % over the same period. This is due to the fact that the percentage of the South African population who have hot water in their homes is expected to rise due to increased living standards and to electrification projects.

It is clearly very important to consider improving the efficiency of the domestic hot water installation, especially if one considers that the overall efficiency is as low as approximately 60 % if the wastage of hot water in the pipes is also taken into account. This can be improved to approximately 75 % by:

1. Improving the thermal insulation of all hot water cylinders so that the standing loss can be reduced by 50 %;
2. halving the losses in hot water pipes, by insulating the pipes and by more careful use of hot water.

Table 36 shows that the above energy conservation measures will bring about an energy saving of about 20 %. The actions required to bring about this saving are:

1. Reducing the standing loss by legislation. This can easily be done by changing the SABS regulation 151-1992 governing the standing loss of hot water cylinders.
2. Motivating the public to use hot water more wisely by not using small quantities of water unnecessarily, and by insulating hot water pipes so that the loss in hot water pipes will be reduced.

These measures should not be too hard to implement, especially considering that the standing loss of hot water cylinders in South Africa is as much as double that applicable to hot water cylinders in countries like the USA and New Zealand. Table 35 clearly indicates that the standing loss of South African hot water cylinders can be improved considerably (Uken & Beute,1991:22).

To implement a change in the specification for standing loss will, however, take a few years, and once implemented the change will only be effective for new installations.

Table 35 Standing loss of hot water cylinders

	loss in W/ℓ		
Capacity in litres	SABS spec.	RSA tested	USA spec
50	1,4	1,2	0,8
100	0,9	0,9	0,5
150	0,7	0,7	0,4
200	0,6	0,6	0,4

Table 36 Electrical hot water energy forecast

	1990		2000			
	CT	RSA	CT	CT with conservation measures	RSA	RSA with conservation measures
Population (000's)	2 700	36 657	3 433	3 433	47 665	47 665
No with Hot Water	70%	33%	70%	70%	39%	39%
H W per person day(ℓ)						
Summer	31	27	35	35	26	26
Winter	40	37	50	50	35	35
Total HW per day(Mℓ)						
Summer	68	325	84	84	478	478
Winter	86	451	121	121	644	644
Total HW/year(Gℓ)	28	142	37	37	205	205
No of HWC (000's)	576	3 007	806	806	4 294	4 292
Energy to heat water to : 60						
in GWh/day during:						
Summer with temp.in C 20	3,17	15,12	3,91	3,91	22,21	22,21
Winter with temp. in C 15	4,52	23,58	5,56	5,56	33,67	33,67
Total energy in GWh/year						
a. to heat water	1 403	7 063	1 867	1 680	10 198	9 178
b. standing loss	505	2 634	706	353	3 760	1 880
c. loss in pipes (20%)	281	1 413	373	187	2 040	1 020
d. gross energy (a+b)	1 908	9 697	2 573	2 033	13 958	11 058
e. nett energy (a-c)	1 122	5 650	1 493 =58%	1 493 =73%	8 158 =58%	8 158 = 74%
Energy Saving (GWh/year) as a result of energy conservation measures				540 =21%		2 900 = 21%

8 ANALYSIS OF THE PRESENT AND FUTURE NATIONAL LOAD

8.1 Introduction

The present policy of Eskom and many other parties in South Africa is to make electricity available to the developing sector of South Africa at the highest possible rate. This will result in a sudden increase in the domestic component of the national electrical load. The expected increase in the domestic load is investigated in this chapter.

It will also be shown in this chapter that the size and shape of the national electrical load is determined by the appliances used and by the way the appliances are used. The influence of appliance ownership and use on the national electrical load will be illustrated by analysing the effect which the hot water load has on the national load curve, and by investigating ways in which the hot water system can be used to control the national load.

8.2 The rate of increase of the national load

The electrical energy sold per year by Eskom for the last 30 years is shown in Figure 63, and the typical national maximum demand of the electrical energy sold by Eskom is shown in Figure 64 (Eskom, 1991:42). The data are extrapolated on a logarithmic scale as shown in Figure 63 and Figure 64 . Two lines have been drawn, one based on 1961 to 1991 data, and the other based on 1980 to 1991 data. It is clear from these two lines that there was a dramatic decline in the rate of increase in the electrical energy used per year during the eighties. There are many reasons for this, but one important reason is the economic decline South Africa has experienced during the eighties.

Figure 63 Annual national loads since 1961 and projected loads for the next few decades

Figure 64 Past and predicted typical winter maximum demand of the energy sold by Eskom for the years 1960 to 2030

It is possible to make a reasonable prediction of the national electrical load for the next few decades by using data shown in Figure 63 and Figure 64, literature such as the report: "The present and future national electricity demand", written for Eskom (Lane *et al.,* 1991), and a prediction of future economic development in South Africa.

If the South African economy does not develop in the near future, the expected growth in electrical energy consumption can be based on the slow growth experienced during the eighties, but if the economy does develop, one can expect a growth based on data since 1960.

Presently there is international concern about the use of non-replenishable resources. South Africa is aware of the need to conserve energy, so one can expect a need for increased measures to conserve energy. International pressure will also assist in the drive to introduce additional energy saving practices, so a growth in energy consumption as high as was experienced in the sixties cannot be allowed.

Considering what has been said, predicted electrical energy requirements for the next few decades can be expected to lie between the two lines shown in Figure 63 and Figure 64.

It can be seen from Figure 63 that the predicted national electrical energy consumption for the year 2000 is expected to lie between 200 to 280 TWh/year depending on the economic activity during the next decade. For the purpose of the discussion which follows, 230 TWh/year is used; this represents an increase of 5.5 % per year. The 230 TWh/year for the year 2000 does not include the expected extra domestic load due to electrification projects which are planned for the developing communities.

8.3 The influence of the domestic sector on the national load

The annual electrical domestic energy consumption is estimated to be about 15% of the total national load. Although this seems a small percentage, it will be shown from Figure 65 that the domestic load is extremely important on the day of maximum peak.

The domestic sector is known to be very sensitive to temperature changes; there is also a large variation between winter and summer domestic loads. Table 37 on page 154 shows that the ratio of winter load to summer load is 1,2 for the national load, and 1,7 for the domestic load. This means that during winter the domestic load is more than 15 % of the national load:

it is:

$$15*(1,7/(0,5*(1,2+1,7)) = 18\ \%$$

of the national load.

On a typical winter day the load factor **f** for the day defined as:

$$f=\frac{average\ load\ for\ the\ day}{maximum\ demand\ for\ the\ day} \qquad 57$$

for the domestic load is about 55 % , and the load factor of the national load is about 85 %. This means that on a typical winter day, at the time of the system peak the domestic load will constitute

$$18*(0,85/0,55) = 26\ \%$$

of the national load, because the peak of the national load now more or less coincides with the peak of the domestic load. This once again makes the domestic load more significant than it is normally considered to be.

On the day of peak nation-wide demand the domestic load is an even higher percentage of the national load, because the domestic load is not only very sensitive to seasons, but also to temperature: the year's maximum demand normally occurs on a very cold day.

The peak demand of the national load on 8 July 1992 was 22,64 GW. Eskom has estimated the peak domestic load on that day to be 6,7 GW (Surtees,1992:4). This is just under 30 % of the national load, which is as much as double the 15 % representing the annual domestic energy in relation to the national annual energy mentioned earlier.

The national load on the day of system peak, 18 July 1992, as shown in Figure 65, will now be analyzed. The domestic load can be considered to have a base load of 1,6 GW (the lowest load value at about 03:00), plus a contribution of 5,1 GW to the system peak (at about 19:30), while the non-domestic load can be considered to have a base load of 14,1 GW with an additional contribution of 1,8 GW also a large variation between winter and summer domestic loads. Table 37 on page 154 shows that the ratio of winter load to summer load is 1,2 for the national load, and 1,7 for the domestic load. This means that during winter the domestic load is more than 15 % of the national load:

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5,1/(5,1+1,8) = 74 %

of the system peak.

The types of domestic load which will be discussed are:

- * the load of the westernised community;
- * the load of the newly urbanised community;
- * the hot water load.

The measurements which have been made at various municipalities in the Western Cape, and other readings which were obtained from Eskom (Eskom, 1992), are the basis of the information in Figure 68.

The following characteristics can be noted about the above loads:

compared with the load shape of the developed community, the load shape of the developing community:

- * has a lower morning peak;
- * has an earlier morning peak;
- * has a more symmetrical morning peak (in the case of the developed sector the rate of increase of load leading up to the morning peak is higher than the rate of decrease after the peak);
- * has a higher evening peak;
- * has a bigger difference between winter and summer loads.

In addition to the above factors it has been found that the load of the developing community is much more dependent on weather conditions.

- * The evening peak at the township of Katlehong on a cold day (12 C) in January 1991 was 35% more than on other days that month when the temperature was 19 C (Berrisford & Bluff, 1991:4.2).
- * The ratio of the winter load to the summer load is much bigger for the developing community than for the developed community. This has been found by analysing the kWh used per month:
  - ♦ in Midrand and Goodwood,
  - ♦ in Soweto,
  - ♦ in Durbanville for hot water only, and

- by the total Eskom network.

The calculated values of

winter load / summer load

are listed in Table 37.

Table 37 The ratio winter to summer load for various types of loads

Ratio	winter load --------------- summer load
developed community	1.3
developing community	1,7
hot water load	1,6
national load	1,1

Compared with the load shape of the developed community the load shape of the hot water load:

- * has a morning peak which is higher than the evening peak (in the case of the domestic load the evening peak is higher than the morning peak);
- * has a later morning peak.

Each of the above loads can be expressed in terms of the probability curves which are defined in chapter 7. For each peak i of each load curve j the peak value Pp_{ij}, the time of the peak t_{ij} and the distribution factor σ_{ij} need to be defined. The total load at time t can then be defined as:

$$P_{tot}(t)=\sum_{j=1}^{n}\sum_{i=1}^{m}Pp_{ij}erf(\frac{t_1-t_{ij}}{\sigma_{ij}}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 58$$

Typical values of the ratio evening peak to morning peak

$P(t_e)/P(t_m)$

where:

$P(t_m)$ = morning peak load, and

$P(t_e)$ = evening peak load

are:

developed community:	1,2
developing community:	1,4
hot water load:	0,7

Typical times of the peaks, t_m and t_e are:

developed community:	7:30 & 19:30
developing community:	6:30 & 19:00
hot water load:	8:00 & 20:00.

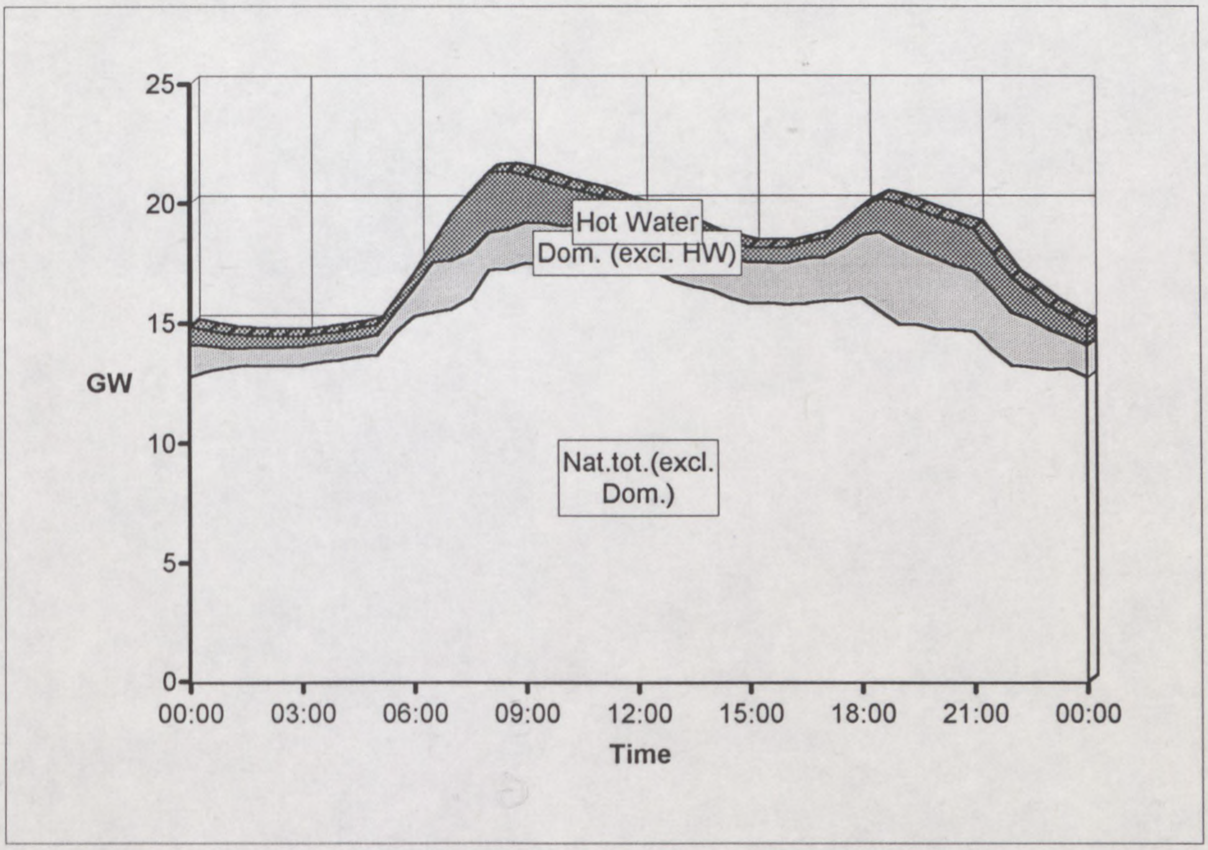

Figure 66 National electrical load - day of maximum demand - 1990

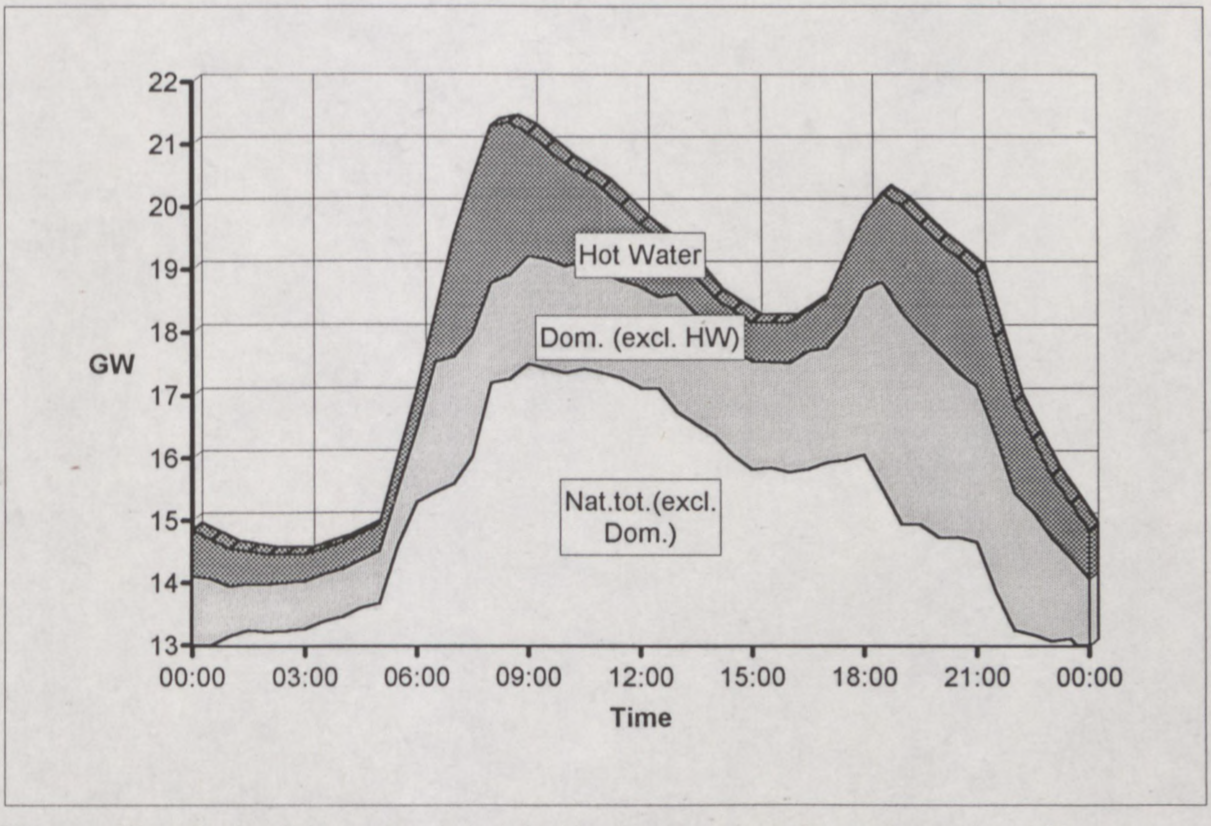

Figure 67 Peak of the national electrical load - day of maximum demand - 1990

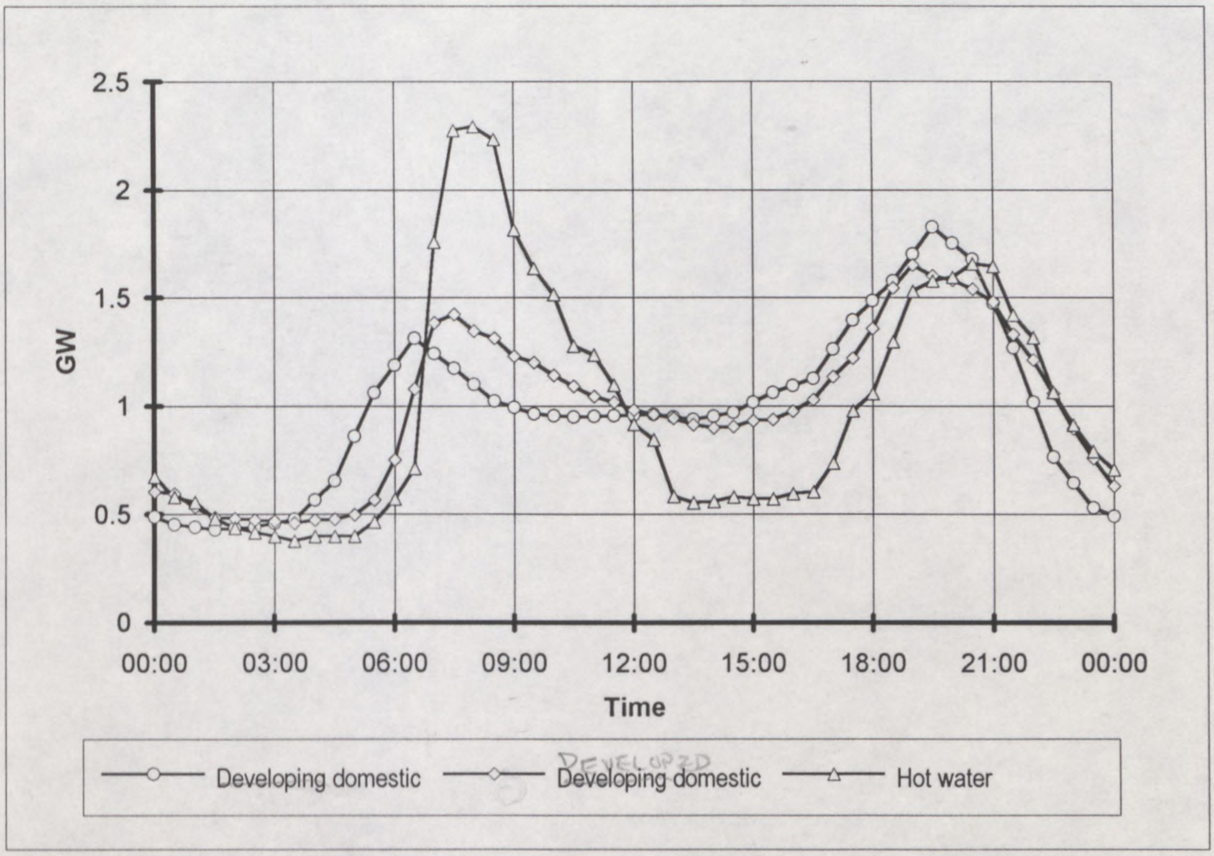

Figure 68 Comparison of various types of domestic loads

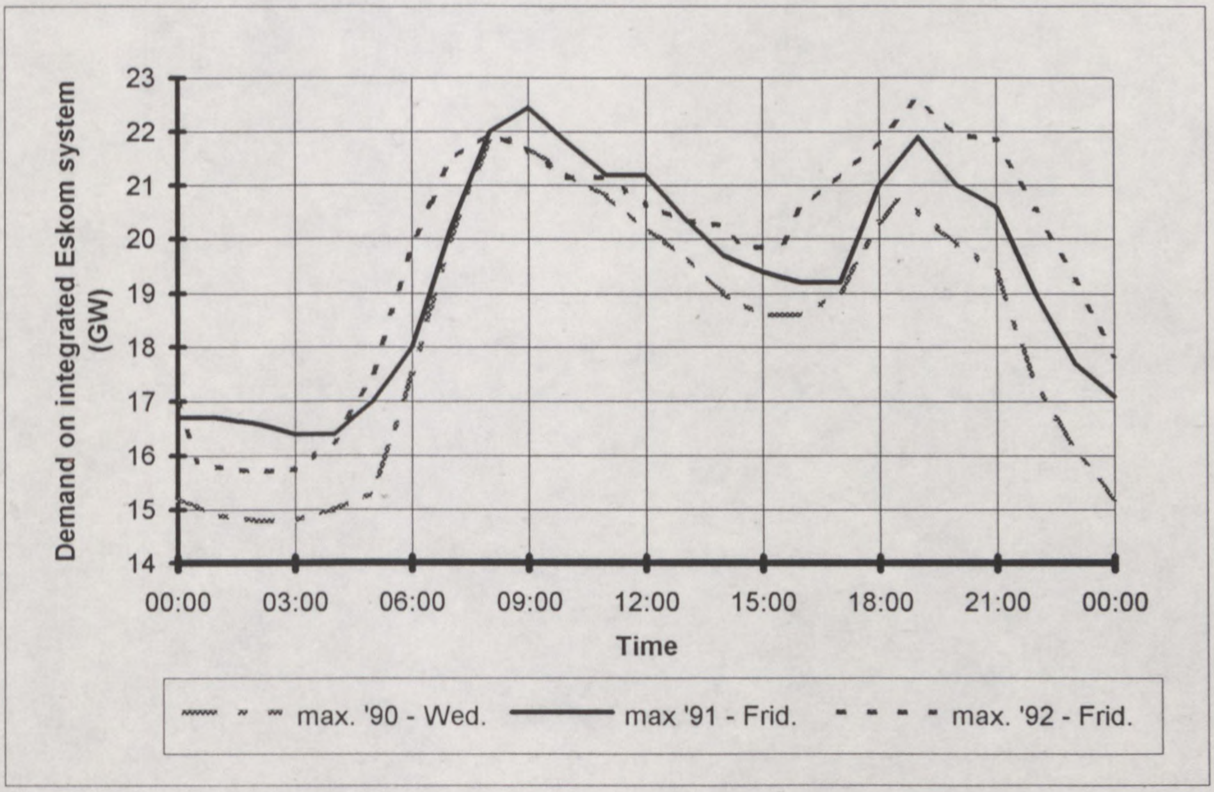

Figure 69 Eskom's days of maximum demand for 1990, 1991 and 1992

8.4 The influence of increased housing and electrification for the developing sector on the national load

Eskom has a policy to electrify as many houses as possible and to motivate occupants of the newly electrified homes to use electricity as their main source of energy. Other pressure groups also exist who aim to improve the living conditions of the underdeveloped sector of the South African community, and electricity is seen as an important way of improving these living conditions.

So it is very likely that large scale electrification will take place during the next decade. Eskom has already started their program of electrification.

8.4.1 Characteristics of the electrical domestic load of the developing sector

The questions which need to be answered to predict the additional electrical load due to the provision of electricity in the homes of the developing community are:

* how many houses will be electrified during the next decade,
* what will be the monthly electrical energy consumption per consumer,
* what is the load pattern of this additional load ?

In chapter 5 the number of houses which are likely to be electrified during the next decade has been discussed. For the analysis which follows, the effect of various numbers of houses will be shown, but to illustrate the effect of the hot water load three million houses will be used.

The Load Research section of Eskom Engineering Investigations has made an analysis of the average monthly consumption per house for both the developed and the developing community. It was found from Eskom's statistical yearbook that the country-wide average is between 700 and 800 kWh. Based on a 60% sample of electrified urban developing households in the PWV area, the community's average monthly consumption per household was found to be between 600 and 700 kWh. The community kWh includes the consumption due to losses and community services such as street lighting (Berrisford & Bluff, 1991:4.4). The variation between minimum summer and maximum winter loads for developing communities is reported to be between 1,6 to 3,4 and even up to 6 for very low income areas. This is much higher than the average winter to summer load ratio of 1,7 as given in Table 37 on page 154.

It appears from the load pattern of the developing sector that for the purpose of designing the distribution network, and for the purpose of determining the influence of the developing network on the national electrical load during the cold months, the load per household for the developing sector must be taken to be much more than the average winter consumption. A modest increase of 20% has been allowed for in the graphs which follow, but more can be allowed for by assuming a higher winter monthly average electrical load per house.

In the graphs which follow the average monthly electricity consumption per household must allow for the energy used by the community, because when an area is electrified, one of the first connections will be for community activities such as street lighting, community centres, clinics and schools, and the electrical distribution network must provide for these loads.

8.4.2 The time of Eskom's annual peak demand

Eskom's annual peak demands have historically always occurred during the morning over the winter period, but in 1992 the annual peak demand has occurred for the first time in the evening. This is representative of a more prominent domestic load. This shift is significant and affects the influence which an additional domestic load will have on the shape of the national load.

Two factors which must have had a large influence on this change are:

i) the increase in the domestic load of the developing community, and

ii) the downturn in the economy which has caused a reduction in energy requirements for the industrial sector.

The increase in the domestic load can be expected to continue during the next decade at least, but hopefully the economy will soon experience an upturn, which may increase the morning peak again.

The next two sections will deal with the influence of an additional domestic load on the national load while the national load:

i) has a morning peak as was experienced during the day of maximum demand of 1990, and

ii) has an evening peak as was experienced during the day of maximum demand of 1992.

8.4.3 A prediction of the load shape of the national load for the year 2000, based on the national load shape of 1990

In determining the load shape of the national load for the year 2000, the following procedure is followed:

* The load shape of the developed sector for 1990 as determined by measured samples as discussed in section 8.3 is subtracted from the national load for 1990 to determine the non-domestic load for 1990.

* The load shape of the hot water load as determined by measured samples as discussed in section 8.3 is subtracted from the domestic load (excluding hot water) for 1990.

* The total national load, the hot water load and the domestic load (excluding the hot water load) is proportionally increased in line with the predicted load for 2000 as discussed in section 8.2.

* The extra domestic load is added. The extra load is assumed to have a load pattern for the developing community as discussed in section 8.3. The magnitude of this load is obtained by multiplying the assumed number of houses by the energy consumption per month.

Figure 70 and Figure 71 show the additional domestic load due to electrification in relation to the total national load, while Figure 72 and Figure 73 show the additional domestic load in relation to the national system peak.

It can be seen from these graphs that the additional load presents a considerable extra load to the national grid. The effect of the first number of houses is not as great as the later ones, because at first the major increase will be to the evening peak, which is lower than the morning peak.

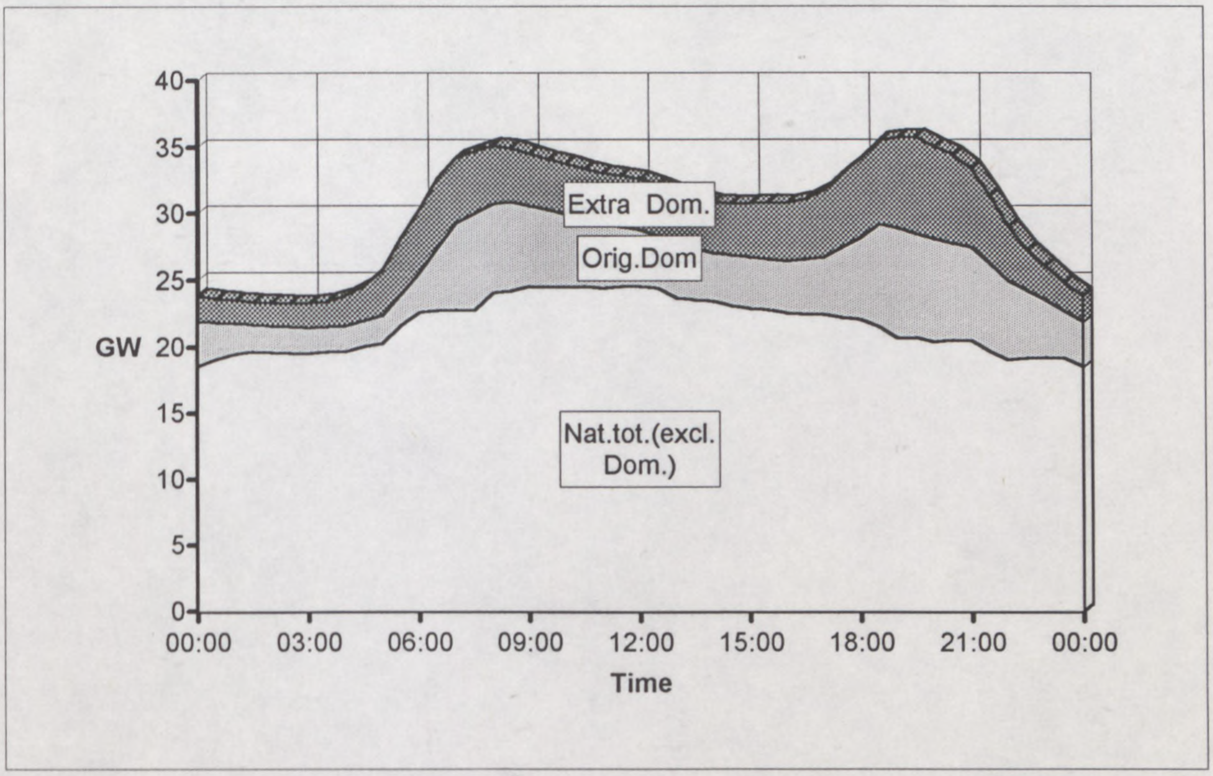

Figure 70 National domestic load for the year 2000 if 3 million extra houses are electrified, with a load of 800 kWh per month (including the community load)

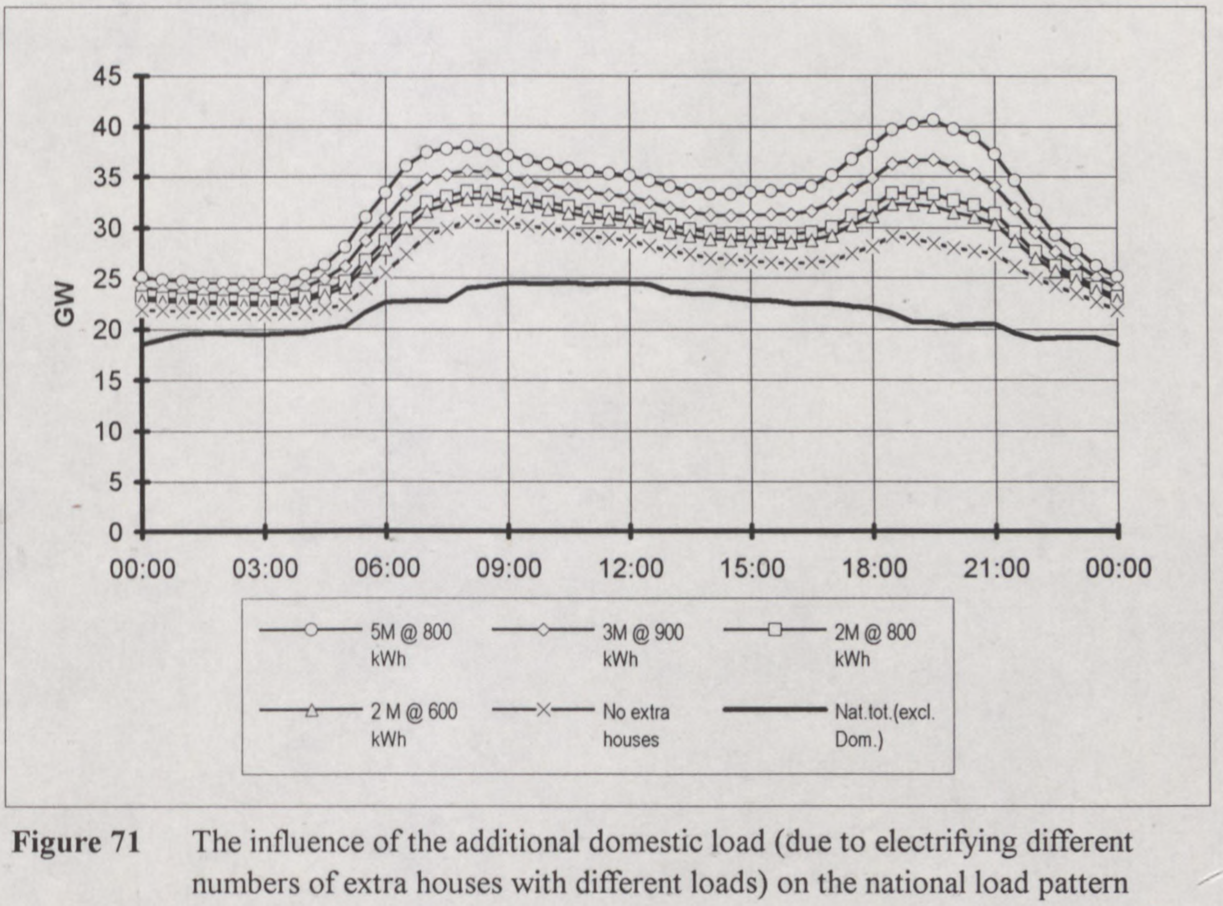

Figure 71 The influence of the additional domestic load (due to electrifying different numbers of extra houses with different loads) on the national load pattern

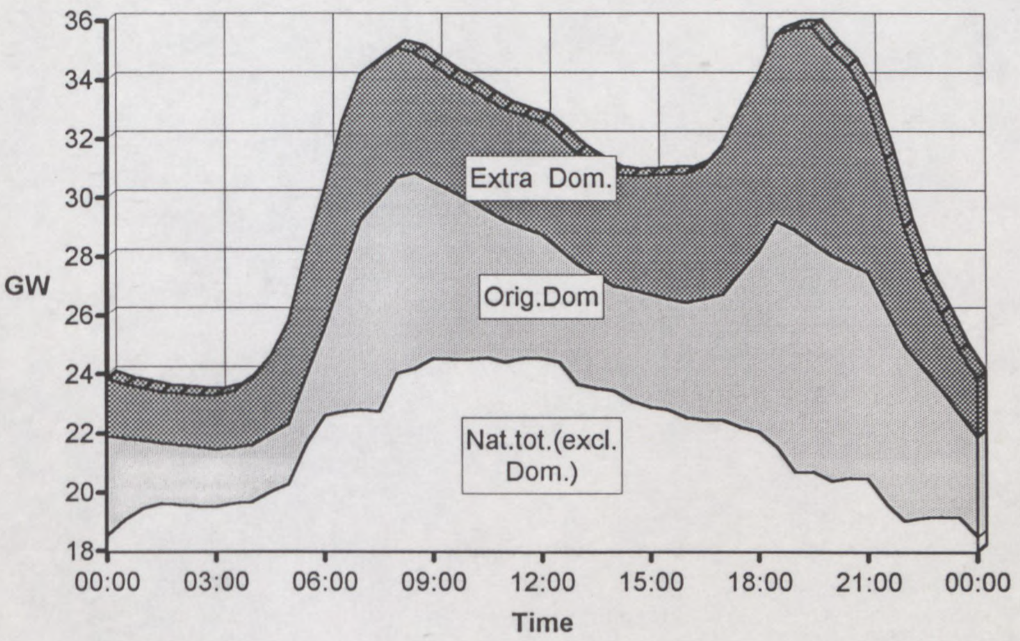

Figure 72 Peak of the national domestic load for the year 2000 if 3 million extra houses are electrified, with a load of 800 kWh per month (including the community load)

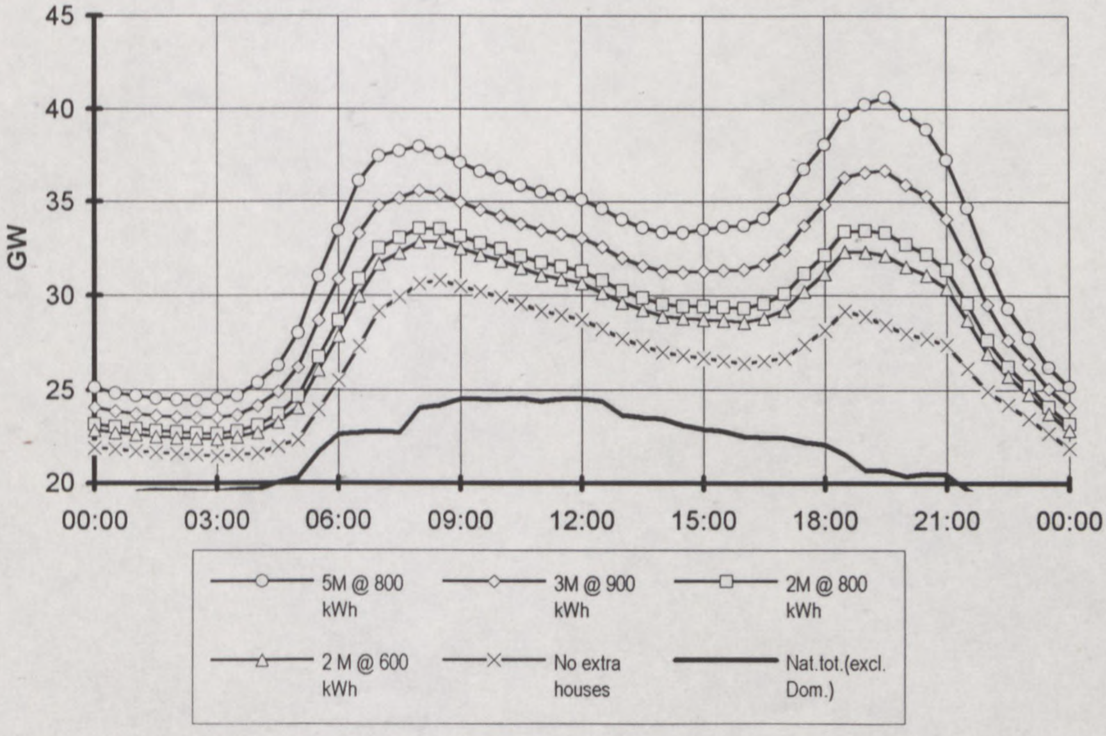

Figure 73 The influence of the additional domestic load (due to electrifying different numbers of extra houses with different loads) on the national load pattern

Once an additional 5 GW have been added to the evening peak, the evening peak will become larger than the morning peak, and the increase in the peak will be due to an increase in the evening peak, and not to an increase in the morning peak. It can be seen from Figure 71 that the evening peak will equal the morning peak when about two million houses are added at 800 kWh per month.

In the developing community the evening peak for cold winter days is at least twice that of the morning peak, so the national system peak will rise at twice the rate it did before the system peak became an evening peak.

8.4.4 A prediction of the load shape of the national load for the year 2000, based on the national load shape of 1992

The purpose of the discussion in this section is to investigate the nation-wide wave shape, not the average daily nation-wide energy consumption, so for comparison purposes the predicted daily and annual energy consumption for 2000 in this section is assumed to be the same as what it was for the previous section. However, the shape is different. It is based on the wave shape of the 1992 winter load. If the downward trend in the economy and energy levels during 1992 were considered, the predicted energy levels for 2000 would probably be less.

Figure 74 and Figure 75 show that if the shape of the 1992 load curve is used , the predicted load curve for 2000 will have a very pronounced evening peak. The evening peak will be caused mainly by the domestic load.

It can be seen from Figure 76 that the hot water load has more influence on the morning peak than on the evening peak.

Comparing the increases of the national system peak discussed in this section with the previous section, it can be seen from Figure 73 and Figure 75 that the increase in system peak due to 2 million houses in this section was about 5 GW, while in the previous section the same additional domestic load caused an increase in the system peak of only 2.5 GW. It follows then that due to South Africa having had for the first time this year an annual system peak in the evening, that the increase in the annual peak due to an increased domestic sector from the developing community will be much more than what it would have been otherwise.

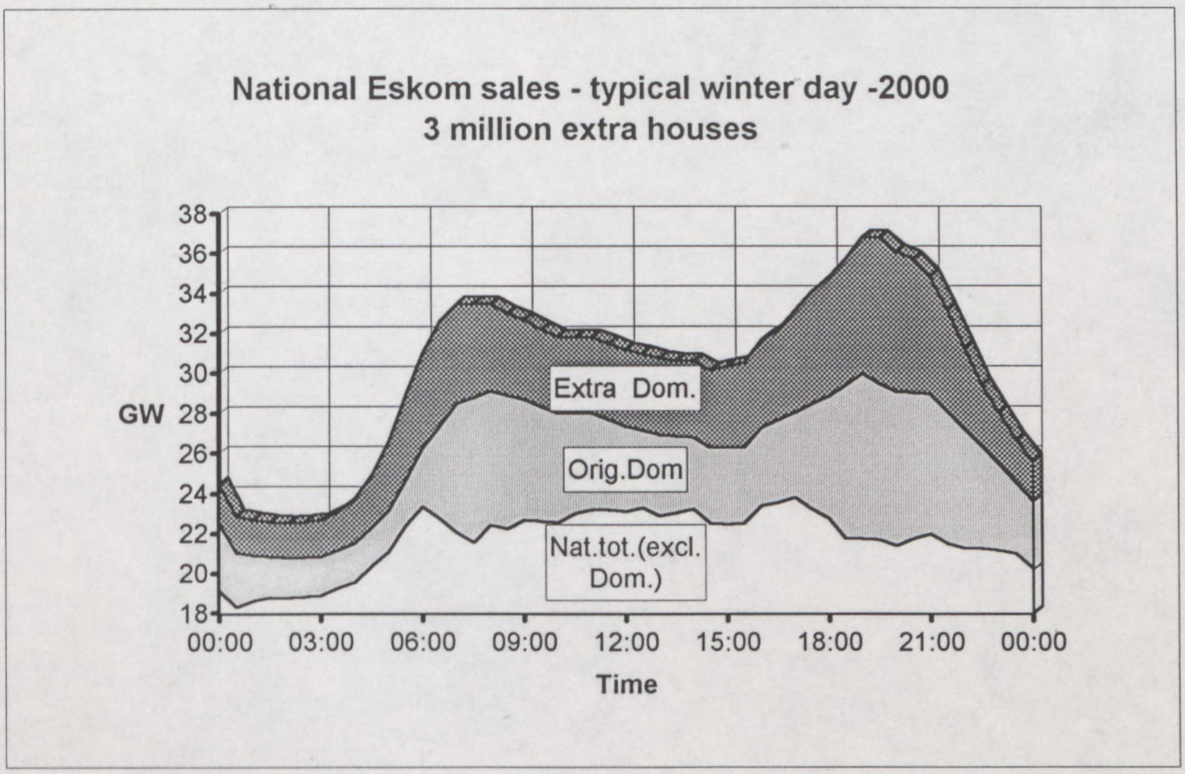

Figure 74 Peak of the national demand for the year 2000 if 3 million extra houses are electrified, each using 800 kWh per month (including the community load) (prediction is pased on the 1992 national load)

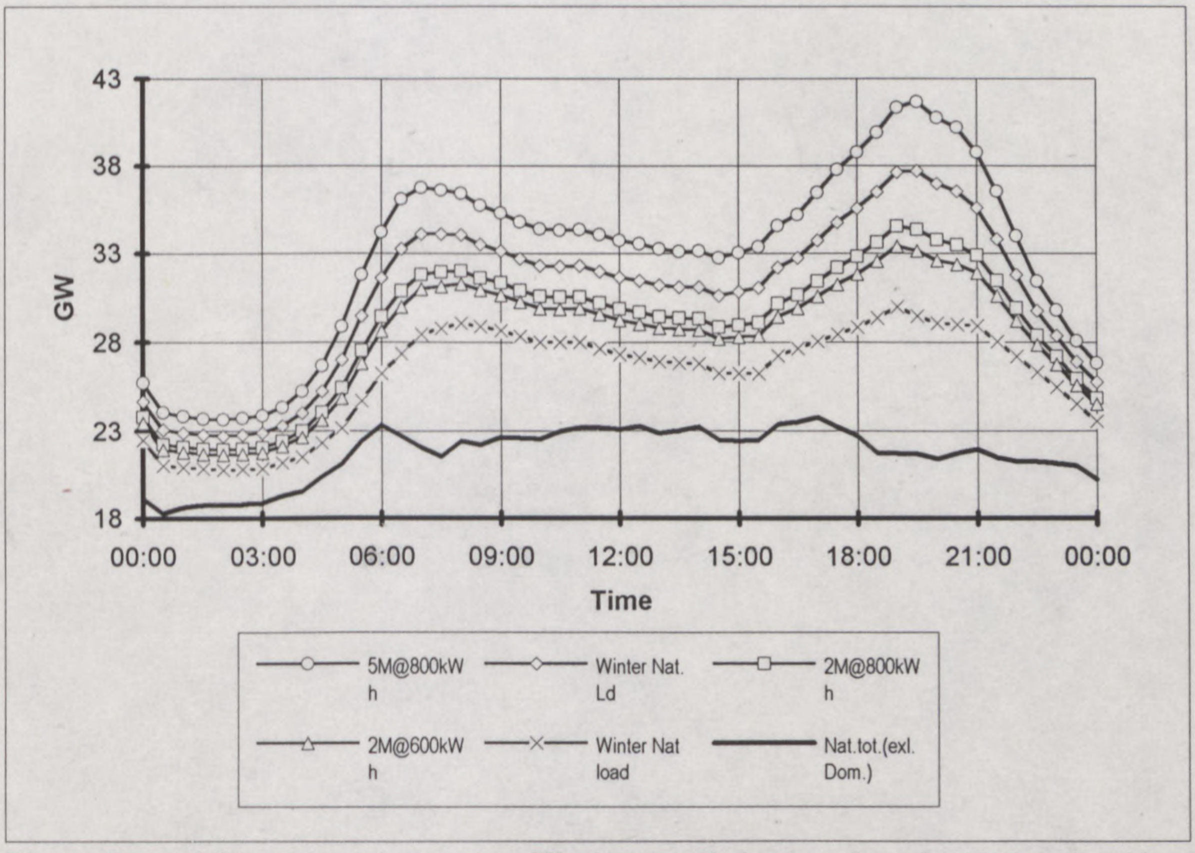

Figure 75 Additional load due to electrification (prediction based on the 1992 national load)

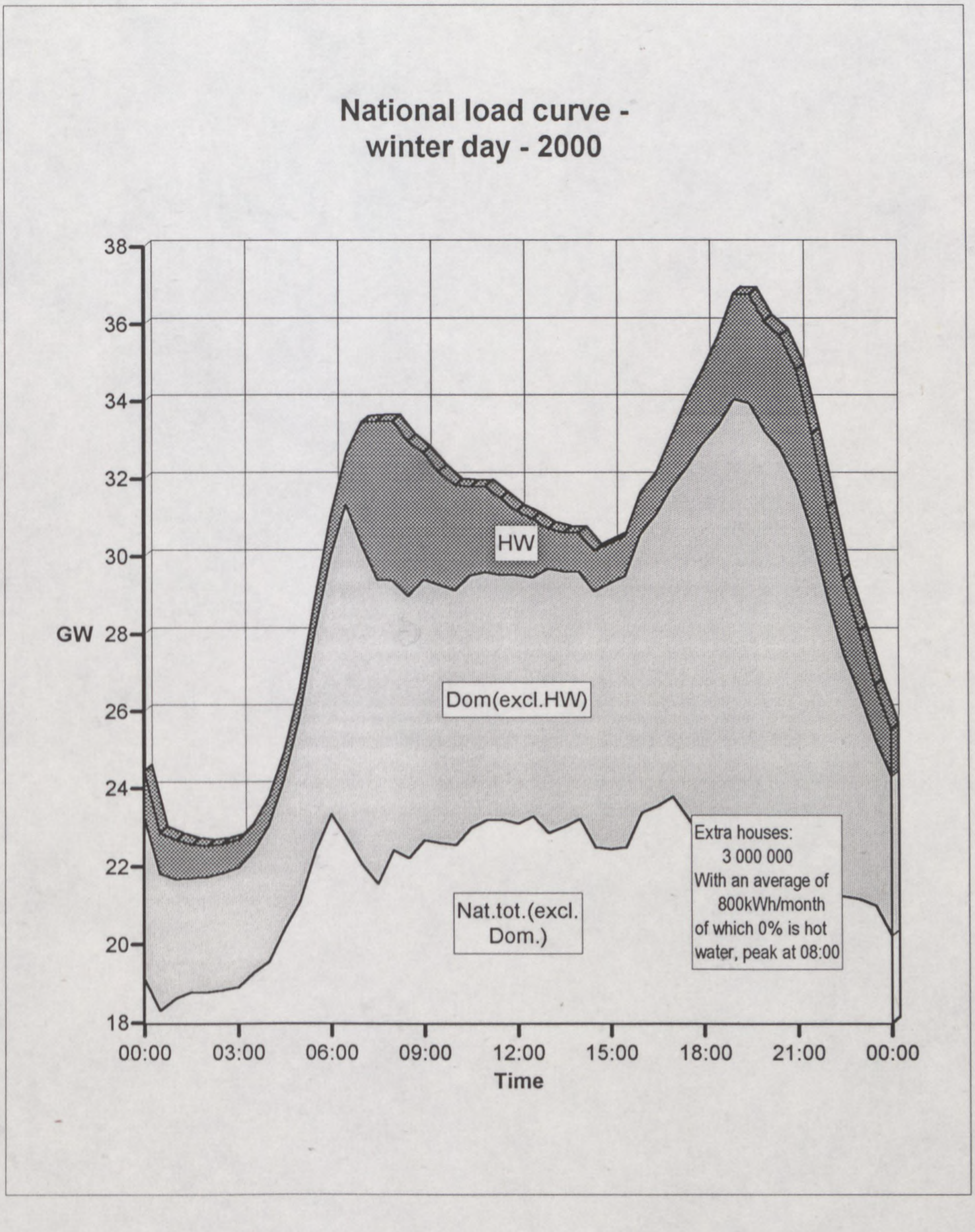

Figure 76 National load curve for the year 2000, indicating the hot water load (prediction based on the 1992 national load)

8.5 The influence of the hot water load on the national load

The discussion in this section is based on the prediction as discussed in section 8.4.3.

Figure 68 on page 156 has shown that the hot water load is characterised by a large morning peak which is only slightly earlier than the national morning peak. So it follows that if the extra load, due to an increased load from the developing community as discussed in the previous section, has as part of the load a hot water load similar in pattern to the hot water load in Figure 68, then the time when the national evening peak is as large as the morning peak will be delayed until the domestic load is bigger.

When comparing the hot water load of an upper class suburb with that of an average suburb, it seems that the morning hot water peak is higher in the upper class suburb. This is probably due to the menial work done by people living in the average suburb which requires them to bath in the evening after getting dirty at work rather than in the morning.

Figure 77 shows the total national load with the extra domestic load which does not have a hot water load component, and Figure 78 shows the total national load with an extra domestic load which does include a hot water load. It is clear that in the first case the evening peak is higher than the morning peak, while in the second case, the morning peak is higher. In the first case the peak is below 36 GW, and in the second case the peak is above 36 GW.

Graphs similar to figure 59 have been drawn for different numbers of houses and different loads per household: from this information Figure 79 has been constructed. Figure 79 shows that the evening peak will equal the morning peak when an additional two million house are electrified, but if the houses have a hot water load of 25% as part of their load, the evening peak will only equal the morning peak once five million houses have been electrified.

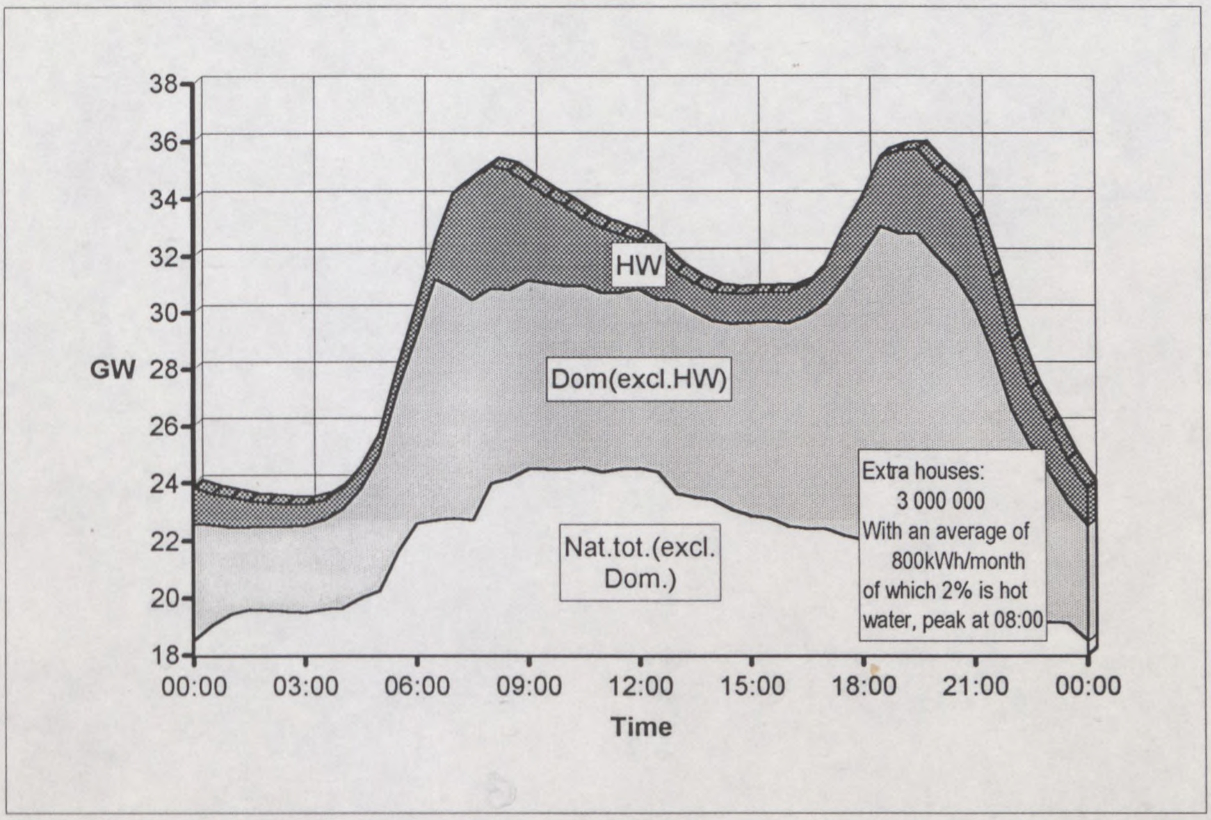

Figure 77 National load curve for the year 2000 if the extra domestic load includes only a 2% hot water component

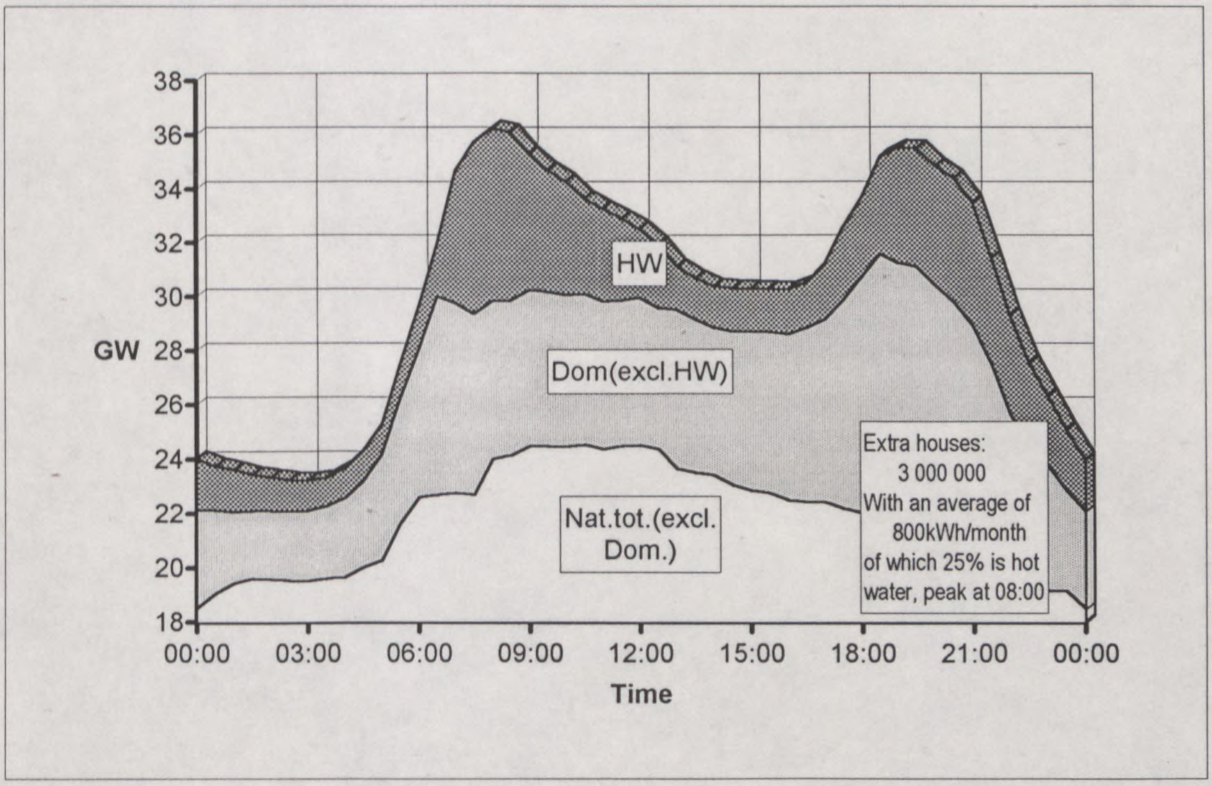

Figure 78 National load curve for the year 2000 if the extra domestic load includes a 25% hot water component

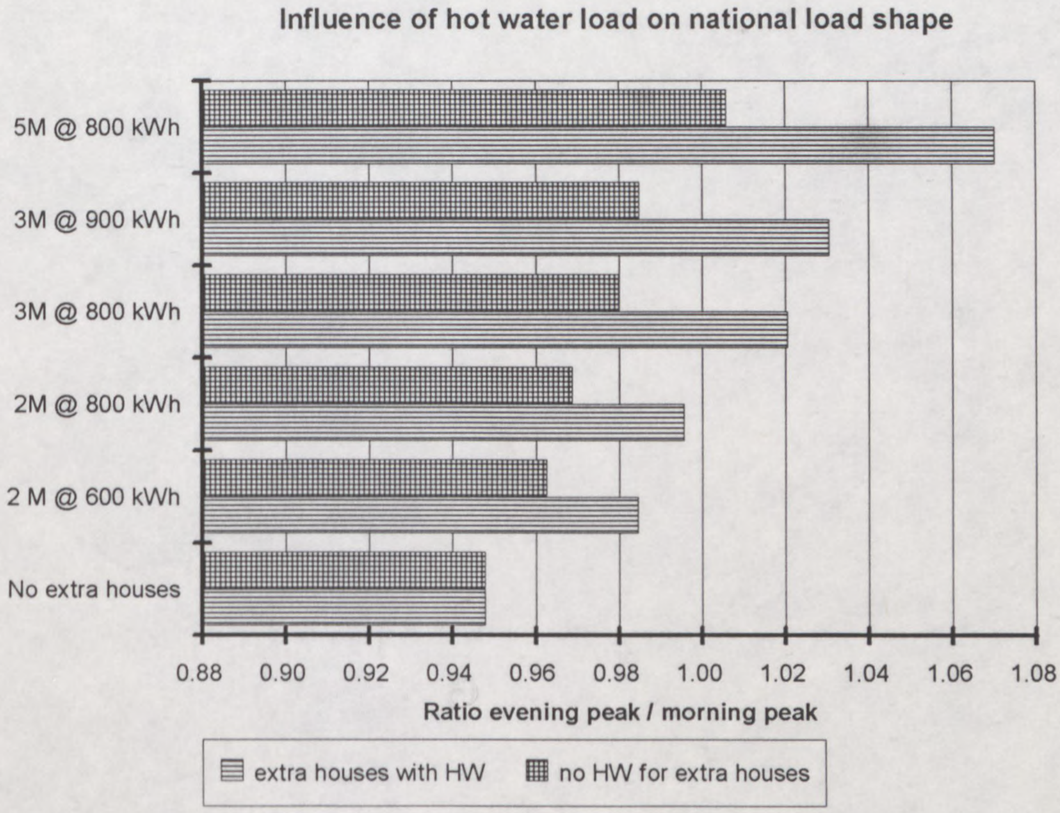

Figure 79 The influence of the hot water load on the relative size of the morning and evening peak of the national load

In developed countries the domestic load is as much as twice as high a percentage of the national load as it is in South Africa, so it can be expected that the South African domestic load will become a larger component of the national load. This will result in a national load with an evening peak rather than a morning peak, so it appears that, although the morning peak of the hot water load is undesirable at present, the morning peak of the hot water load will not present such a problem in the future.

The hot water load is a load which can be manipulated, because the heating of the water does not have to co-incide with the use of the hot water, so end-use management of the hot water load is possible, and needs investigation.

8.6 Possible demand-side measures for the hot water load and its effect on the national load

The water heater is an appliance which has a lifetime of nearly 20 years, so any change in the pattern of the national load shape due to improvement in the design of the appliance will in all probability take a decade to take effect. A large number of houses will be electrified in the near future, so now is an opportune time to implement energy conservation. The measures implemented now in the newly electrified houses will be effective immediately, and it will not be necessary to wait a decade for them to be effective.

In order to illustrate the scope of the measures which are going to be discussed, the scenario analysis which follows will assume in each case that all the hot water systems in the country will respond to the measures and the results will be given as such. If it is found that a certain fraction of the consumers respond to the proposed measures, then also only a proportionate fraction of the illustrated benefits will be obtained.

8.6.1 Load shifting

Water need not be heated when it is being used, so the heating load can be shifted to off-peak times. This is already done by a number of municipalities, with much success, but some individuals do not want the heating of their water controlled by the supplier of electricity. For the benefit of the individual consumer it may be better to apply the demand side management by varying the price of electricity at off-peak times.

The apparatus which many municipalities have installed for load control could be used by the consumer to control that part of his electrical load which can be used at off-peak times. The apparatus would switch as it does at present: that is, it would be on when the national load is low (electricity tariff also low), and it would be off when the national load is high (tariff also high). But the consumer can be given the option to bypass the control temporarily if his particular home situation warrants it at a certain time. The apparatus can also be used by the consumer to control other loads such as the washing machine, the swimming pool pump and the dish washer. The consumer will reap the benefits in these circumstances by using electricity at a lower tariff.

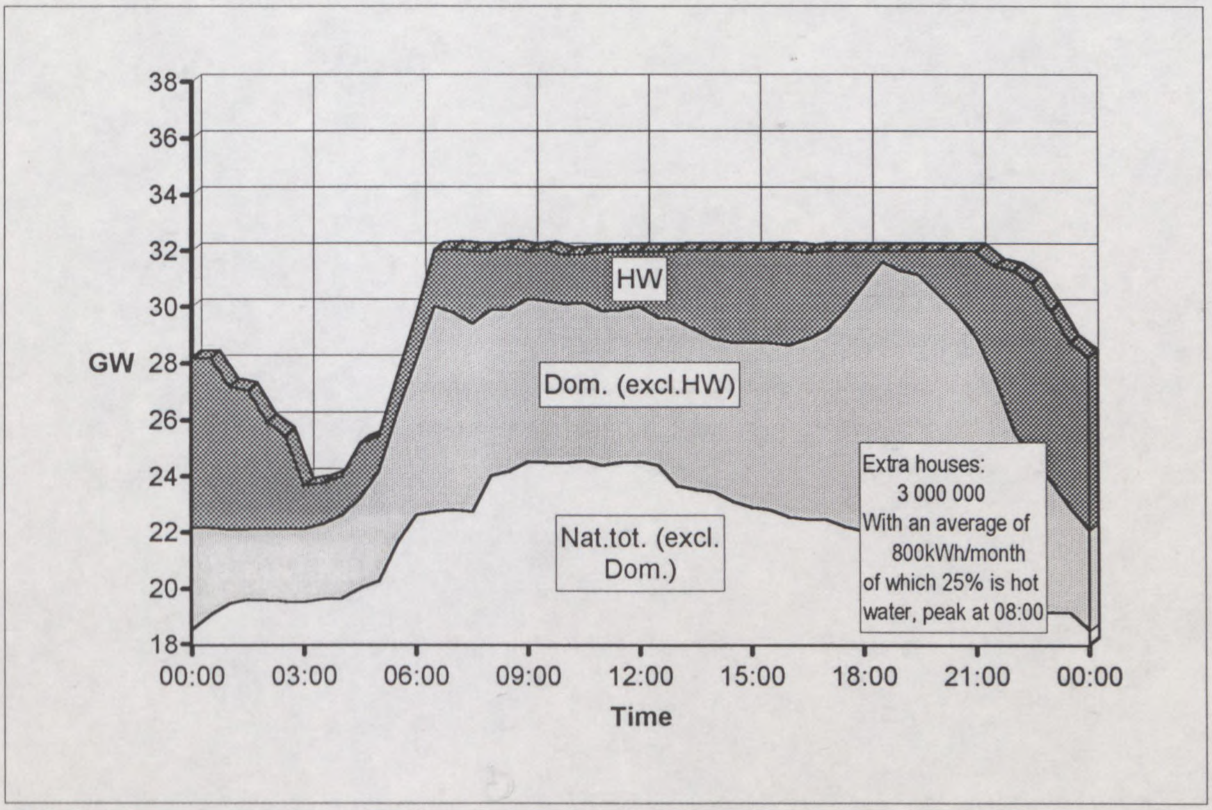

Figure 80 Shifting the peak of the hot water load (based on Figure 78)

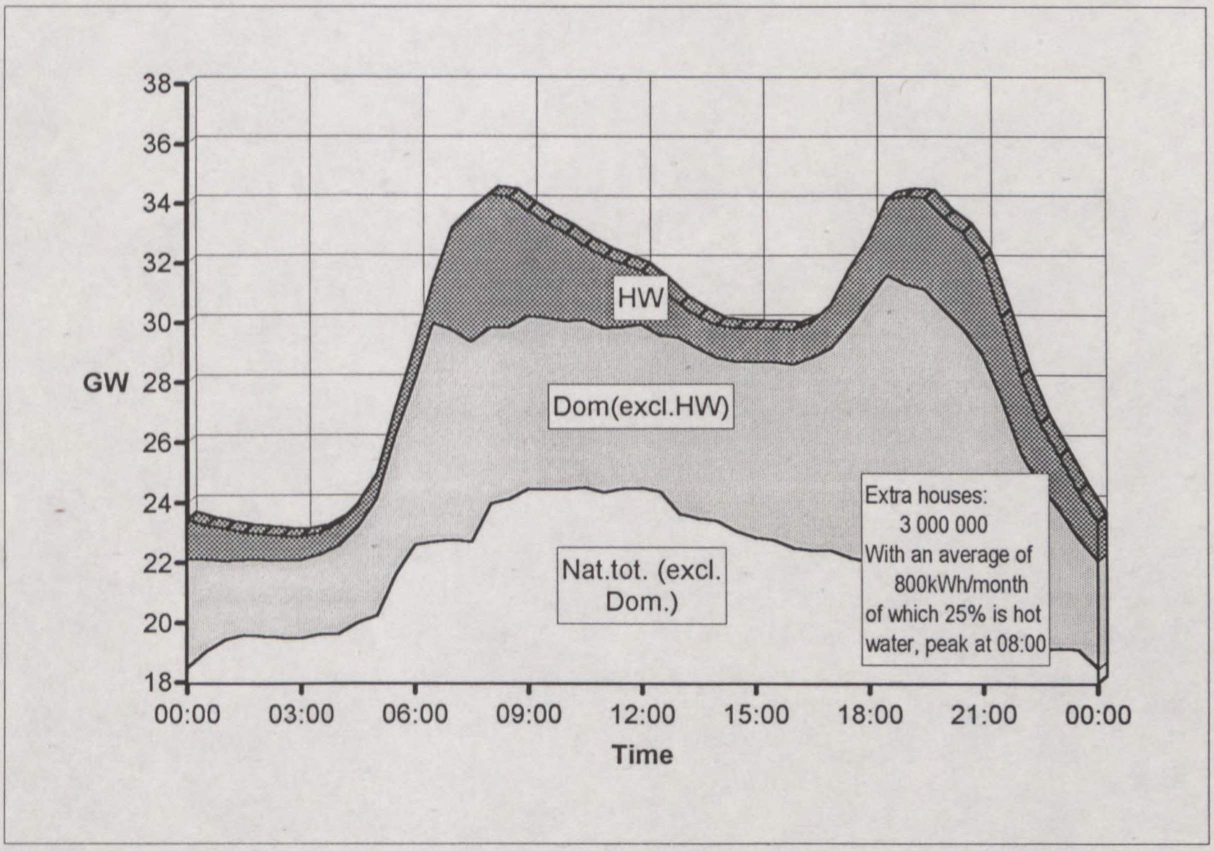

Figure 81 The effect of more efficient hot water systems on the national load

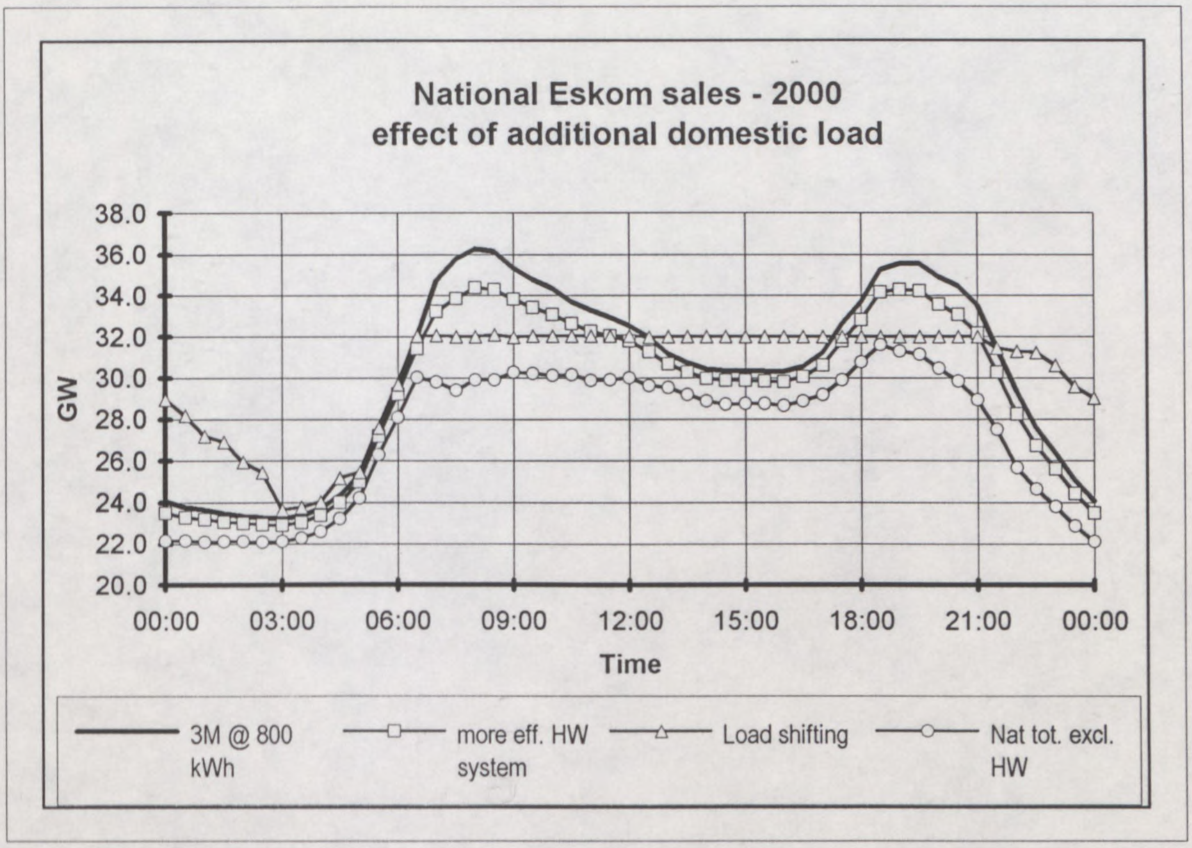

Figure 82 Comparison of various demand side measures as applied to the hot water system the hot water

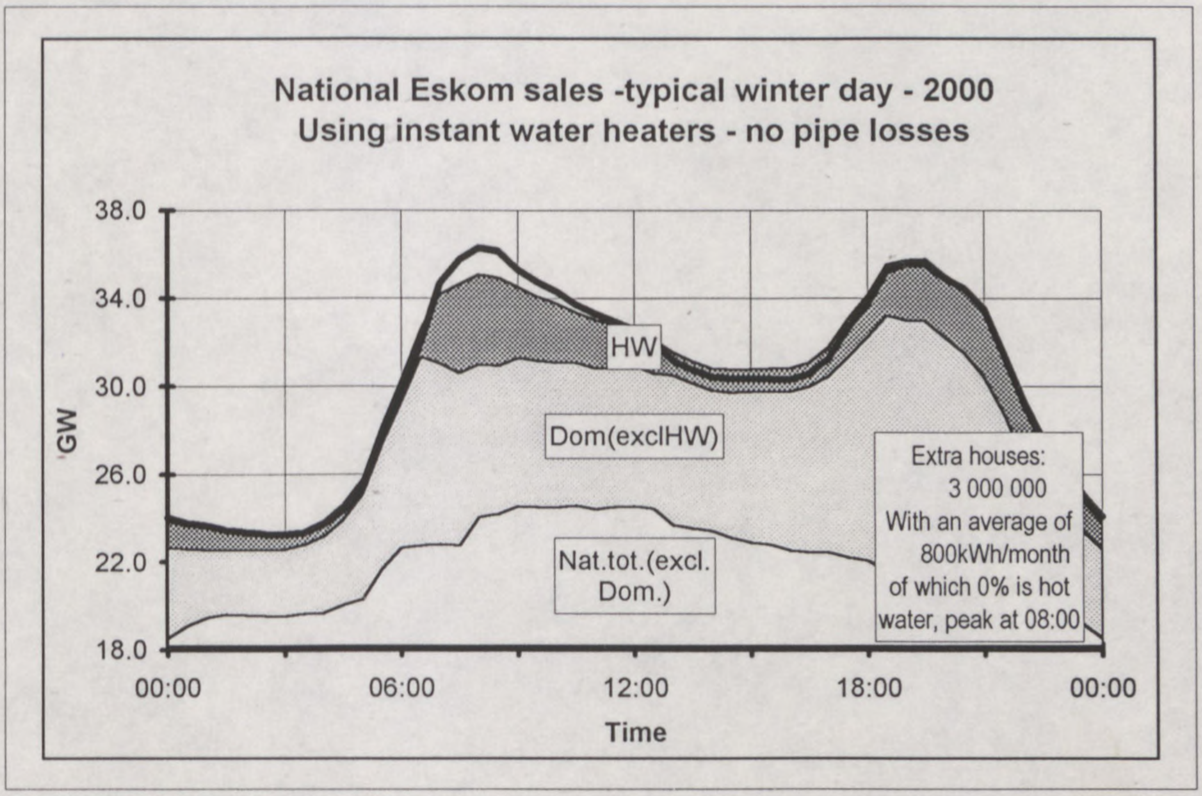

Figure 83 The national load profile for the year 2000 if instant water heaters are used at the point where hot water is used

The possible benefits of this method is illustrated in Figure 80. The maximum demand will reduce by 4 GW. This approximates the total generating capacity of Majuba power station in Volksrust, which is due to start sending out electrical power in 1996, and is due for completion in 2001.

8.6.2 Improving the efficiency of the hot water system

It has been shown in chapter 7 that there is much room for improvement in the efficiency of the hot water system. A reduction of 30 % by improving the design of the hot water system, and by more efficient use of hot water by the consumer, is feasible.

Figure 81 shows the national load for the year 2000 if the energy used for water heating per house were reduced to 70% of what it is now. The drop in the peak value of the national load from 36 to 34 GW is very noticeable.

8.6.3 More options of demand side management for the hot water load

The options for improving the hot water load which have been discussed so far are compared in Figure 82.

Other options which exist to change the electrical load due to water heating include solar-assisted water heating, instant water heating and the use of off-peak energy for water heating.

Figure 83 shows the national load curve for the year 2000 if all domestic water heating is done by using instant water heaters; the national load which will exist if no change is made to water heating is also shown on this graph. To obtain the optimum efficiency, the water heaters will have to be installed at the point where the hot water is used, so that there are no energy losses in hot water pipes. The efficiency improvements will cause a drop of approximately 2 GW in the national peak.

It can be seen from Figure 83 that the national peak will move to a slightly earlier position, because of the absence of the delay of the electrical load due to heating the cold water which entered the hot water cylinder after hot water was used, which is characteristic of the hot water cylinder.

Solar heating and off-peak electrical heating can be combined very effectively. The afternoon and evening hot water load can be supplied by solar heating during the day, but electrical heating during early morning off-peak time can be used to heat the water for use during the morning peak period.

The cost involved in changing present hot water installations on a large scale will be prohibitively expensive. If each of the present just over 2 million domestic consumers spends R 100 on energy efficiency improvements, the cost will be R 200 million, which is little in comparison to the capital expenditure of Eskom to extend their generating and distribution network. According to Eskom's annual report of 1991 (1991:34) the estimated capital expenditure contracted for is R 4 773 million, of which R 1 634 million is expected to be incurred within one year. The cost of Majuba power station, which is due for completion in 2001, will probably be in the order of R 10 000 million, and to this must be added the cost of transmission and distribution.

Since the cost to improve the efficiency of hot water systems will be considered too much by most consumers, it would be worth considering a monetary incentive to encourage them to change their hot water systems.

The cost involved in improving the efficiency of new installations, however, is a different matter. In many instances there is no extra cost, just an improved design. What is needed is the availability of information and motivation for the developer of new domestic installations. The prospective home owner or occupier must also be made aware of the continuous savings in energy costs which can be achieved.

A simple measure such as each of 4 million consumers reducing the setting on their hot water cylinder by 5 C will result in a national saving of 500 GWh per year.

9 CONCLUSIONS

9.1 Introduction

The electrical domestic load is determined by the number of people, their access to electricity, the appliances they own and their habits and attitudes towards electrical energy. The access to electricity is determined by the economic condition of the individual and of the country as a whole. A household's successful access to electricity requires the house to be connected to the electrical grid, appliances and the ability to pay for the electricity.

This study has shown that the ownership of appliances is a vital component in determining the domestic electrical load.

South Africa will have an estimated 47 to 50 million people by the turn of the century, and between 67 and 73 million by the year 2020. A high level of population growth will most probably be accompanied by low economic activity, and relatively low levels of electrification. This will result in a slow increase in electrical energy consumption, probably in the region of 170 TWh per year by the turn of the century and 210 TWh by the year 2010.

If economic development does take place, and stability is experienced, which in turn promotes investments from overseas countries, then all South Africa's people will experience improved living conditions. Electrification projects will ensure that most South Africans will have the use of electricity in their homes and the demand for electrical energy will increase rapidly, not only for domestic purposes but also for industry and commerce. The national electrical energy consumed per year is then likely to be in the order of 250 TWh by the turn of the century, and 350 TWh by the year 2010.

9.2 The need for electrification

South Africa has an ever growing population which are in need of improved living conditions. Electricity is seen as a very effective means of improving living conditions.

Urbanisation will promote development and a slower increase in population growth. Urbanisation will also help to make electricity available to more people because of decreased electrification costs.

Factors which increase the rate of electrification are:

* decreased population growth,
* increased urbanisation,
* a stable environment, and
* increased economic development.

All these factors influence each other in a way which will increase electrification even more.

An increase in levels of electrification will take place, but what is not certain is the time it will take for this to happen.

It is for everyone's benefit that the improvements in living conditions should take place as soon as possible. Electricity is needed to help make this happen.

9.3 Ways to implement electrification policies

It is the policy of Eskom to provide electricity to nearly 3 million additional households by the turn of the century, but Eskom does not have the supply rights for all these households.

The electricity distribution industry in South Africa is very fragmented. This has been said to be one of the causes of the backlog of electrification (NEC, 1992:23).

An appropriate organisational structure is required to attend to electrification. It is unlikely that the large number of present distributors of electricity will all be able, and sufficiently motivated to electrify the developing areas near them.

9.4 Provision of additional electrical energy

The increases in electrical energy consumption in South Africa, and similar increases which are so much needed for development elsewhere in Africa, can be provided for by hydro-electric power from the Inga and Zaire basins, where the potential hydro-electric power is in excess of 100 GW (860 TWh per year) (Du Plessis, 1992:15). Fossil fuel power stations must not be built, especially if power can be generated from renewable energy sources.

9.5 The importance of the domestic electrical load

Even though the domestic load constitutes only 15 % to the national load, it contributes approximately 30 % to the national peak, and it is likely to contribute more by the turn of the century. The domestic component of the national electrical load is likely to increase dramatically during the next decade.

Proper planning of the use of electricity by the domestic sector can have a considerable effect on the peak of the national load. The estimated cost of R 4 800 million to electrify 2,4 million homes by the turn of the century must be seen against the saving which can be achieved by domestic end-use management which will reduce the national maximum demand. For hot water systems alone, this study has identified possible savings up to 4 GW in the national maximum demand, while a 4 GW power station can cost as much as R 10 000 million.

9.6 The need for demand-side management of the domestic load

The importance of the domestic load must not be underestimated. If the domestic load is such an increasingly important load it needs to be managed. Planning is required to implement demand-side management strategies. Knowledge about the domestic load is essential before demand-side management can be implemented.

South African conditions are different to those in developed countries, so the information which is available for developed countries cannot be used indiscriminately. Data must be collected for South African conditions, and South Africa must find ways of managing end-uses of domestic energy for South African conditions.

An added benefit of such studies will be that South Africa can help the rest of Southern Africa by making this knowledge available to them. Africa is realising that ways must be found to speed up development. Co-operation between the countries in Southern Africa is vital in achieving this. There are signs that this is starting to take place in the field of power generation and distribution (du Plessis, 1992:9).

Detailed knowledge about end-uses of domestic energy is required for proper planning.

In this study models have been developed which are applied to the domestic load. Measurements have been made to calibrate the model both by measuring the load of individual consumers and by measuring the load of a combination of consumers.

9.7 The need for a common model to be used by all who collect data

This study has confirmed that data about the domestic load in South Africa are scarce. It also happens all too often that where data are available from different sources, the data are not compatible, and it is not possible to use all that are available. It is necessary to define a standard way in which to record data, so that data can be exchanged.

Not only must accurate data about the electrical load which is measured be available, but also data about the users whose data is measured. Information about living standard, ownership of appliances, the occupants in the house and other personal information is just as important as the electrical measurements.

When data are available, they must be manipulated and interpreted. This once again must be done in a way which makes it possible to derive usable results from the shared data.

A model with clearly defined parameters, including personal data about the members of the household, is needed to facilitate interchange of data.

Two models have been developed in this study: one in Chapter 2 and the other in Chapter 7. The first model defined in Chapter 2 is used to model the total load for all domestic uses, or for a particular appliance or use, in an area locally or nationally. The model used in chapter 7 is suitable for normally distributed loads and can be used as a sub-model of the model in Chapter 2.

The models have been found to be very useful to model the hot water load which has been investigated during this study.

South African load researchers will have to decide on a model, define it clearly and unambiguously, and use it consistently. The results must be kept in a central database, and load researchers must have easy access to the data.

The model which has been developed in this study is suitable to be used for this purpose, but the success in using the model will depend on the manner in which researchers agree to use it and the way in which the results are managed in a central database.

There may be merit in conducting surveys in cooperation with other surveys such as the All Media Products Survey (SAARF, 1991), so that the data collected for their purpose can be used to provide personal data about, for example, living standards, which will help to analyze the electrical data. Cooperation will also help to obtain statistically representative samples of the population for measuring.

To collect data effectively, non-intrusive measuring apparatus is required. In measuring the hot water load as discussed in Appendix C, many complaints were received about the noisy switching of the hot water control equipment during night time. For consumers to accept electrical measuring equipment in their homes, equipment must be designed which is not easily noticeable by the consumer. As much as possible of the measuring equipment must be kept outside the house.

In order to make full use of the model the need for data must be emphasised. The cost of collecting the data is small in comparison to the high cost of building a new power station and distribution network. Demand-side management strategies cannot be implemented successfully if data are not available.

9.8 The increase in appliance ownership and its influence on electricity consumption

Over the last three years the developing sector has had an annual increase in the ownership of electrical domestic appliances of 10 %. This is an indication of the high rate of development which is taking place in the developing sector of our community.

By studying the trend of increase in appliance ownership and the electrification policy of Eskom, it has been estimated that an additional 15 million appliances will be bought by the developing sector before the turn of the century. At a cost of R 160 per appliance this amounts to R 2 400 million. This corresponds with Eskom's estimate (NEC, 1992:36).

9.9 The importance of the domestic hot water load

Demand-side management is what is needed, but for demand-side management to be effective, there must be a load which can be manipulated. The hot water load is a load which can be managed effectively, because:

- the time of use of hot water does not need to co-incide with the time of heating the water;
- the hot water load is a large component of the domestic load (30 to 50 %);
- the peak of the hot water load is very near the national morning peak.

The hot water load also affords an opportunity for strategic energy conservation measures, because the losses in the hot water system have been shown to be typically as high as 40 %.

It has been shown that energy conservation measures for hot water systems are relatively easy and very cost effective to implement during the planning stage of housing projects. South Africa has moved into a decade with a phenomenal increase in the number of houses that are expected to be built and connected to the national grid compared to previous decades. This decade of development presents ideal opportunities for proper domestic energy planning. These opportunities must not be squandered.

10 RECOMMENDATIONS

10.1 Energy savings measures for domestic hot water systems must be implemented.

A typical value of the energy lost in hot water systems is 40 %. Cost-effective ways to halve this loss have been identified.

10.2 Research is needed to obtain a thorough understanding of individual behaviour patterns as far as electrical energy consumption is concerned.

Consumers must respond individually for demand-side management to be effective. Knowledge about their behavioural pattern is vitally important, as it is very difficult to ensure that the domestic sector responds to demand-side management incentives.

10.3 Research is needed to quantify the end-uses of domestic electrical energy.

The domestic component of the national load constitutes approximately 50 % of the peak of the national load. This study has investigated the hot water component of the domestic load. All domestic end-uses of electricity need to be quantified on a national scale. This knowledge is required to plan extensions to the national generation and distribution network and to plan end-use demand management strategies.

10.4 A national data base must collate data on domestic energy use.

Data on domestic energy use must be accessible to all interested parties. In South Africa where data on domestic end-uses are very scarce, all researchers must work together so as to get the maximum use from such data as are available.

10.5 The public must be educated about efficient use of electrical energy.

The behaviour of the individual consumer determines the use of energy. Demand-side management options cannot be successful without the co-operation of the individual. The attitude of people regarding the use of energy is extremely important. Suppliers and distributors of electricity must realise their responsibility to educate through schools, radio, television and the printed medium.

10.6 Mathematical models must be used to analyze the domestic load.

Data which are obtained from measurements and surveys must be statistically representative of the whole population. Mathematical and computer models must enable these data to be used effectively for scenario planning and 'what if' analysis.

10.7 An organisational structure must be established to attend to electrification.

Electricity must be made available to the South African developing community to improve their living conditions. Policies alone are not sufficient; a body is needed to implement the policies. It cannot be assumed that the present fragmented electricity distribution industry will take the initiative in supplying electricity to the developing community in their area.

10.8 Energy efficiency standards for appliances are needed in South Africa.

Most developed countries have energy conservation programs.

South Africa has not seen sufficient need for energy conservation to implement energy efficiency standards for household appliances, but it must now be realised that the domestic sector is becoming a large component of the national electrical load. Energy is no longer a matter for national concern only: the international community is involved. South Africa must accept its responsibility to conserve energy not only for the sake of the South African environment, but also for the sake of the environment of the world.

10.9 Innovative domestic appliances are needed to facilitate demand-side management.

The use of sophisticated electronic control is no longer limited to high-cost equipment and sophisticated users. Mass production makes it affordable and user friendliness makes it easy to use. Ways must be found to make a time or other differential tariff available to the domestic consumer. Cost-effective control equipment for appliances must be developed so that the consumer can benefit from differential tariffs. South Africa can be a leader in the supply of domestic appliances with appropriate controls, suitable for the developing world.

10.10 Renewable energy sources must be used wherever possible.

South Africa must implement cost-effective solar water heating systems, assisted by electrical heating, where required, on a much larger scale than it has up till now.

Africa has to develop its large hydro-electrical power potential resources. South Africa with its technical expertise, especially in the high-voltage field, can play an important part in this development.

APPENDICES

APPENDIX A

Levels of electrification in South Africa

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Notes:

- Numbers in the tables of this appendix are in thousands unless otherwise indicated.
- Only a sample of the available date are given.

* The living standard on a scale from 1 to 8 is calculated, based on factors such as the possession of appliances, the availability of running water, electricity and telephone, the size of the dwelling and the employment of a domestic servant.

Groups 1 and 2 jointly form group C, the lowest living standard, groups 3, 4 and 5 form group B, and groups 6, 7 and 8 jointly form group A, the highest standard of living.

* South Africa is divided into the following geographical zones for the purpose of these tables:

A. Witwatersrand,
B. Northern Transvaal,
C. Orange Free State,
D. Natal,
E. Eastern Cape,
F. Northern Cape,
G. Western Cape,
H. Transkei.

* For the purpose of the tables in this appendix the population is divided into the following divisions based on community size:

urban	communities 250 000 or more,
villages	communities from 500 to 39 999,
rural	rural areas and communities less than 500.

	Electrification - 1989											
	Whites			Col & Ind.			Blacks			All Races		
	h'holds	with el	%	h'holds	with el	%	h'hoild	with el	%	h'holds	with el	%
Total	1644	1638	100%	712	539	76%	4743	1156	24%	7099	3333	47%
Living Standard												
A												
B												
C												
Zone: (geographical area)												
A	648	647	100%	66	66	100%	838	609	73%	1552	1322	85%
B	227	225	99%				1356	169	12%	1583	394	25%
C	138	138	100%	20	9	45%	480	120	25%	638	267	42%
D	209	209	100%	166	162	98%	1021	159	16%	1396	530	38%
E	123	122	99%	72	44	61%	374	60	16%	569	226	40%
F	29	28	97%	56	12	21%	89	13	15%	174	53	30%
G	269	268	100%	333	246	74%	109	19	17%	711	533	75%
H	0	0					476	7	1%	476	7	1%
Motropolitan areas												
Bloem	34	34	100%				27	8	30%	61	42	69%
CT	171	171	100%	180	180	100%	109	19	17%	460	370	80%
Dur	118	118	100%	108	108	100%	178	102	57%	404	328	81%
ELnd	24	24	100%	5	5	100%	55	20	36%	84	49	58%
Jhb	194	194	100%	45	45	100%	272	233	86%	511	472	92%
Kim	11	11	100%	8	8	100%	16	13	81%	35	32	91%
PE Ut	53	53	100%	32	29	91%	99	26	26%	184	108	59%
Ptmb	22	22	100%	14	14	100%	26	12	46%	62	48	77%
Pta	153	153	100%	8	8	100%	119	103	87%	280	264	94%
Pwv	634	633	100%	66	66	100%	815	612	75%	1515	1311	87%
Reef	235	235	100%	11	11	100%	335	216	64%	581	462	80%
Sow							197	180	91%	197	180	91%
Vaal	52	52	100%	1	1	100%	89	60	67%	142	113	80%
WCape	98	97	99%	153	72	47%				251	169	67%
Living Area												
Urban	1217	1216	100%	458	440	96%	1666	48	3%	3341	1704	51%
Villages	260	259	100%	122	70	57%	381	112	29%	763	441	58%
Rural	168	163	97%	132	29	22%	2696	996	37%	2996	1188	40%

Appendix A.1 Electrification in South Africa

	Electrification - 1990											
	Whites			Col & Ind.			Blacks			All Races		
	h'holds	with elc	%	h'holds	with elc	%	h'hoilds	with elc	%	h'holds	with elc	%
Total	1651	1643	100%	747	582	78%	4931	1288	26%	7329	3513	48%
Living Standard												
A	1612	1597	99%	404	401	99%	393	356	91%	2409	2354	98%
B	49	46	94%	292	182	62%	1984	933	47%	2325	1161	50%
C	0	0		51	0	0%	2556	0	0%	2607	0	0%
Zone:	(geographical area)											
A	676	675	100%	76	74	97%	938	642	68%	1690	1391	82%
B	204	203	100%	0	0		1348	168	12%	1552	371	24%
C	137	135	99%	23	10	43%	496	157	32%	656	302	46%
D	209	209	100%	169	167	99%	1070	187	17%	1448	563	39%
E	125	123	98%	73	44	60%	392	82	21%	590	249	42%
F	30	30	100%	58	14	24%	90	8	9%	178	52	29%
G	269	268	100%	348	274	79%	116	31	27%	733	573	78%
H	0	0		0	0		482	13	3%	482	13	3%
Motropolitan areas												
Bloem	34	34	100%	0	0		29	13	45%	63	47	75%
CT	175	175	100%	189	184	97%	116	31	27%	480	390	81%
Dur	121	121	100%	109	109	100%	210	114	54%	440	344	78%
ELnd	25	25	100%	5	4	80%	58	33	57%	88	62	70%
Jhb	199	199	100%	47	44	94%	297	318	107%	543	561	103%
Kim	11	11	100%	8	8	100%	17	15	88%	36	34	94%
PE Ut	57	57	100%	34	30	88%	109	31	28%	200	118	59%
Ptmb	22	22	100%	13	13	100%	27	13	48%	62	48	77%
Pta	157	157	100%	8	8	100%	132	117	89%	297	282	95%
Pwv	669	668	100%	76	74	97%	902	646	72%	1647	1388	84%
Reef	262	262	100%	18	18	100%	383	267	70%	663	547	83%
Sow							214	193	90%	214	193	90%
Vaal	51	51	100%	2	2	100%	91	45	49%	144	98	68%
WCape	94	92	98%	159	90	57%				253	182	72%
Living Area												
Urban	1245	1243	100%	482	465	96%	1812	1111	61%	3539	2819	80%
Village	245	245	100%	133	81	61%	357	101	28%	735	427	58%
Rural	161	155	96%	132	37	28%	2763	77	3%	3056	269	9%

Appendix A.1 Electrification in South Africa

	Electrification - 1991											
	Whites			Col & Ind.			Blacks			All Races		
	h'holds	with elc	%	h'holds	with elc	%	h'hoilds	with elc	%	h'holds	with elc	%
Total	1645	1643	100%	749	592	79%	5052	1433	28%	7446	3668	49%
Living Standard												
A	1570	1565	100%	352	351	100%	481	456	95%	2403	2372	99%
B	74	68	92%	368	320	87%	2172	978	45%	2614	1366	52%
C	0	0		30	0	0%	2399	0	0%	2429	0	0%
Zone: (geographical area)												
A	674	673	100%	75	75	100%	976	708	73%	1725	1456	84%
B	207	203	98%	0	0		1390	202	15%	1597	405	25%
C	136	135	99%	24	14	58%	521	142	27%	681	291	43%
D	207	206	100%	166	165	99%	1079	233	22%	1452	604	42%
E	125	125	100%	73	41	56%	400	89	22%	598	255	43%
F	29	28	97%	59	16	27%	91	7	8%	179	51	28%
G	267	263	99%	352	283	80%	137	32	23%	756	578	76%
H	0	0		0	0		458	20	4%	458	20	4%
Motropolitan areas												
Bloem	34	34	100%	0	0		28	11	39%	62	45	73%
CT	171	171	100%	186	186	100%	137	32	23%	494	389	79%
Dur	119	119	100%	109	109	100%	218	127	58%	446	355	80%
ELnd	24	24	100%	9	10	111%	50	25	50%	83	59	71%
Jhb	199	198	99%	45	45	100%	309	262	85%	553	505	91%
Kim	11	11	100%	9	9	100%	18	16	89%	38	36	95%
PE Ut	56	56	100%	34	30	88%	109	30	28%	199	116	58%
Ptmb	22	22	100%	13	13	100%	31	14	45%	66	49	74%
Pta	157	157	100%	8	8	100%	135	124	92%	300	289	96%
Pwv	661	660	100%	75	75	100%	939	706	75%	1675	1441	86%
Reef	257	256	100%	19	19	100%	393	271	69%	669	546	82%
Sow	0	0		0	0		228	207	91%	228	207	91%
Vaal	48	48	100%	2	2	100%	102	48	47%	152	98	64%
WCape	96	92	96%	162	97	60%	0	0		258	189	73%
Living Area												
Urban	1230	1229	100%	479	470	98%	1899	1182	62%	3608	2881	80%
Village	259	258	100%	128	75	59%	452	158	35%	839	491	59%
Rural	155	147	95%	142	48	34%	2700	93	3%	2997	288	10%

Appendix A.1 Electrification in South Africa

	ELECTRIFICATION - Blacks - 1991 figures - (000's)														
	No of people			No of households			Urban			Villages			Rural		
	yes	no	%	yes	no	%	yes	no	%	yes	no	%	yes	no	%
Total	6774	20108	25%	1433	3619	28%	1183	717	62%	158	295	35%	92	2607	3%
Liv.Standard															
1	0	7999	0	0	1446	0%	0	0		0	0		0	1446	0%
2	0	5457	0%	0	953	0%	0	104	0%	0	69	0%	0	780	0%
3	374	3568	9%	140	656	18%	101	231	30%	5	109	4%	34	316	10%
4	1340	2108	39%	342	391	47%	272	247	52%	33	86	28%	37	58	39%
5	2520	817	76%	495	147	77%	409	113	78%	73	27	73%	13	7	65%
6	2181	154	93%	387	25	94%	343	21	94%	37	4	90%	7	0	100%
7	335	5	99%	65	1	98%	54	1	98%	10	0	100%	1	0	100%
8	23	0	100%	4	0	100%	4	0	100%	0	0		0	0	
Income															
399	76	8251	1%	170	1656	9%	113	138	45%	11	93	11%	46	1425	3%
699	254	5275	5%	207	906	19%	175	191	48%	16	83	16%	16	632	2%
1199	617	4988	11%	490	811	38%	430	273	61%	48	89	35%	12	449	3%
1999	698	1099	39%	286	174	62%	241	84	74%	35	14	71%	10	76	12%
2499	1546	274	85%	117	39	75%	89	13	87%	24	10	71%	4	16	20%
3999	2225	180	93%	105	27	80%	92	13	88%	10	6	63%	3	8	27%
5999	801	39	95%	45	6	88%	33	4	89%	11	0	100%	1	2	33%
6000+	56	2	97%	12	0	100%	9	0	100%	2	0	100%	1	0	100%
Zone															
A	3411	1158	75%	708	268	73%	691	222	76%	5	11	31%	12	35	26%
B	891	6634	12%	202	1188	15%	91	24	79%	76	106	42%	35	1058	3%
C	546	2149	20%	143	379	27%	119	91	57%	17	63	21%	7	225	3%
D	1155	5141	18%	233	846	22%	171	147	54%	38	43	47%	24	656	4%
E	445	1715	21%	90	311	22%	69	122	36%	12	49	20%	9	140	6%
F	35	427	8%	8	84	9%	0	3	0%	6	6	50%	2	75	3%
G	164	456	26%	32	105	23%	32	105	23%	0	0		0	0	
H	127	2427	5%	20	438	4%	10	4	71%	5	16	24%	5	418	1%
Metropolitan areas															
CT	164	456	26%	32	105	23%	32	105	23%						
PE U	144	433	25%	30	79	28%	30	79	28%						
EL	130	100	57%	25	25	50%	25	25	50%						
Dur	610	507	55%	127	91	58%	127	91	58%						
Pmb	67	90	43%	14	17	45%	14	17	45%						
Kim	89	11	89%	16	2	89%	16	2	89%						
Bloemf	52	67	44%	11	17	39%	11	17	39%						
PWV	3433	1038	77%	701	222	76%	701	222	76%						
Pta	648	46	93%	124	11	92%	124	11	92%						
Reef	1177	534	69%	266	111	71%	266	111	71%						
Jhb	170	84	67%	55	25	69%	55	25	69%						
Sow	1169	87	93%	207	21	91%	207	21	91%						
Vaal	270	289	48%	48	54	47%	48	54	47%						

Appendix A.1 Electrification in South Africa

	ELECTRIFICATION - Blacks - 1990 figures - (000's)														
	No of people			No of households			Urban			Villages			Rural		
	yes	no	%	yes	no	%	yes	no	%	yes	no	%	yes	no	%
Total	6059	21347	22%	1289	3643	26%	1111	701	61%	101	255	28%	77	2687	3%
Liv.St	6059	21347		yes	no		yes	no		yes	no		yes	no	
1	0	9596	0%	0	1713	0%	0	0		0	0		0	1713	0%
2	0	5236	0%	0	843	0%	0	127	0%	0	75	0%	0	641	0%
3	409	3357	11%	187	522	26%	140	125	53%	12	105	10%	35	292	11%
4	915	1973	32%	293	374	44%	265	297	47%	12	47	20%	16	30	35%
5	2646	920	74%	453	153	75%	397	121	77%	37	22	63%	19	10	66%
6	1862	265	88%	314	38	89%	271	31	90%	36	6	86%	7	1	88%
7	227	0	100%	42	0	100%	38	0	100%	4	0	100%	0	0	
8	0	0								0	0		0	0	
Incom	6059	21347		1289	3643			700			256				
399	562	9446	6%	181	1798	9%	142	135	51%	8	78	9%	31	1585	2%
699	896	5478	14%	257	916	22%	226	204	53%	16	75	18%	15	637	2%
1199	2637	5069	34%	518	733	41%	458	269	63%	38	77	33%	22	387	5%
1999	1088	1030	51%	185	148	56%	157	68	70%	22	17	56%	6	63	9%
2499	374	162	70%	63	26	71%	56	12	82%	7	6	54%	0	8	0%
3999	262	106	71%	46	14	77%	41	10	80%	4	2	67%	1	2	33%
5999	166	56	75%	29	8	78%	22	2	92%	5	1	83%	2	5	29%
6000+	74	0	100%	10	0	100%	9	0	100%	1	0	100%	0	0	
Zone	6061	21347		1288	3643			701							
A	3017	1402	68%	642	296	68%	634	245	72%	3	8	27%	5	43	10%
B	752	6961	10%	168	1180	12%	80	34	70%	48	96	33%	40	1050	4%
C	667	1955	25%	158	339	32%	131	76	63%	9	54	14%	18	209	8%
D	924	5817	14%	187	883	17%	156	139	53%	23	30	43%	8	714	1%
E	419	1767	19%	82	310	21%	71	116	38%	8	53	13%	3	141	2%
F	54	457	11%	8	82	9%	0	3	0%	6	4	60%	2	75	3%
G	161	364	31%	31	85	27%	31	85	27%	0	0		0	0	
H	67	2624	2%	12	468	3%	8	3	73%	3	10	23%	1	455	0%
Metropolitan areas															
CT	161	364	31%	31	85	27%	31	85	27%						
PE U	142	425	25%	31	78	28%	31	78	28%						
EL	187	127	60%	33	25	57%	33	25	57%						
Dur	485	574	46%	114	96	54%	114	96	54%						
Pmb	72	68	51%	13	14	48%	13	14	48%						
Kim	85	11	89%	15	2	88%	15	2	88%						
Bloem	62	72	46%	13	15	46%	13	15	46%						
PWV	3048	1229	71%	647	256	72%	642	245	72%						
Pta	650	72	90%	117	15	89%	117	15	89%						
Reef	1110	618	64%	266	116	70%	263	108	71%						
Jhb	46	240		25	58	30%	25	58	30%						
Sow	963	75	93%	193	21	90%	193	21	90%						
Vaal	279	223	56%	44	43	51%	44	43	51%						

Appendix A.1 Electrification in South Africa

	ELECTRIFICATION - Blacks - 1989 figures - (000's)														
	No of people			No of households			Urban			Villages			Rural		
	yes	no	%	yes	no	%	yes	no	%	yes	no	%	yes	no	%
Total	5233	21585	20%	1156	3587	24%	996	670	60%	112	269	29%	48	2648	2%
Liv.Standard				yes	no		yes	no		yes	no		yes	no	
1				0	0										
2				0	0										
3				0	0										
4				0	0										
5				0	0										
6				0	0										
7				0	0										
8				0	0										
Income															
399	492	12604	4%	198	2217	8%	167	198	46%	13	111	10%	18	1908	1%
699	1173	4822	20%	336	758	31%	302	231	57%	16	82	16%	18	445	4%
1199	2173	3472	38%	396	506	44%	342	180	66%	43	64	40%	11	262	4%
1999	878	540	62%	139	83	63%	116	49	70%	22	9	71%	1	25	4%
2499	240	61	80%	35	9	80%	27	8	77%	8	1	89%	0	0	
3999	196	77	72%	39	11	78%	31	2	94%	8	2	80%	0	7	0%
5999	59	7	89%	11	1	92%	9	1	90%	2	0	100%	0	0	
6000+	23	3	88%	4	0	100%	3	0	100%	1	0	100%	0	0	
Zone															
A	2796	1127	71%	610	228	73%	606	198	75%	0	0		4	30	12%
B	675	7258	9%	168	1187	12%	79	37	68%	66	98	40%	23	1052	2%
C	443	2078	18%	120	359	25%	106	91	54%	13	51	20%	1	217	0%
D	790	5450	13%	159	863	16%	131	128	51%	18	39	32%	10	696	1%
E	299	1760	15%	60	315	16%	53	117	31%	7	60	10%	0	138	0%
F	91	417	18%	13	76	15%	0	0		3	11	21%	10	65	13%
G	108	388	22%	19	90	17%	19	90	17%	0	0		0	0	
H	31	3106	1%	7	469	1%	2	9	18%	5	10	33%	0	450	0%
Metropolitan areas															
CT	108	388	22%	19	90	17%	19	90	17%						
PE U	129	381	25%	26	72	27%	26	72	27%						
EL	119	188	39%	20	35	36%	20	35	36%						
Dur	474	486	49%	102	76	57%	102	76	57%						
Pmb	66	74	47%	12	14	46%	12	14	46%						
Kim	75	16	82%	13	3	81%	13	3	81%						
Bloem	40	101	28%	8	19	30%	8	19	30%						
PWV	2829	1054	73%	612	198	76%	612	198	76%						
Pta	515	84	86%	103	15	87%	103	15	87%						
Reef	840	612	58%	216	119	64%	216	119	64%						
Jhb	120	105	53%	53	23	70%	53	23	70%						
Sow	1011	63	94%	180	17	91%	180	17	91%						
Vaal	343	190	64%	60	24	71%	60	24	71%						

Appendix A.1 Electrification in South Africa

APPENDIX B
Appliance ownership

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Notes:

- * Numbers in the tables of this appendix are in thousands, and percetages ownership are percentages of electrified households unless otherwise indicated.
- * Only a sample of the available date are given.
- * For detail on living standards and geographical areas see appendix A

Ownership of refrigerators
as a percentage of those with electricity

	1988				1990				1991			
	White	ol&In	Blacks	All	White	ol&In	Blacks	All	White	ol&In	Blacks	All
Total:												
No	1651	747	4932	7330	1651	747	4932	7330	1651	747	4932	7330
%	96%	90%	54%	80%	97%	90%	56%	81%	94%	90%	59%	80%
Zone (geographical area)												
A	95%	89%	55%	76%	96%	91%	57%	77%	94%	87%	59%	77%
B	96%		44%	74%	97%		50%	76%	96%		49%	73%
C	93%	89%	43%	70%	95%	80%	45%	68%	93%	86%	43%	68%
D	98%	96%	60%	86%	98%	96%	67%	87%	97%	95%	66%	84%
E	95%	77%	70%	85%	97%	84%	59%	82%	96%	83%	72%	85%
F	100%	75%	92%	92%	97%	71%	75%	87%	96%	75%	86%	88%
G	98%	89%	68%	93%	98%	87%	65%	91%	95%	88%	72%	90%
H			43%	43%			69%	69%			75%	75%
Metropolitan area												
Bloem	91%		75%		88%		77%	85%	91%		55%	82%
CT	96%	90%	68%	92%	98%	92%	65%	93%	94%	95%	72%	93%
Dur	98%	97%	60%	86%	98%	97%	64%	86%	98%	96%	60%	84%
ELnd	92%	60%	80%	84%	100%	75%	58%	76%	100%	30%	96%	86%
Jhb	96%	89%	58%	77%	96%	93%	57%	77%	96%	87%	60%	77%
Kim	100%	75%	62%	78%	100%	88%	60%	79%	100%	89%	69%	83%
PE Ut	98%	86%	58%	85%	98%	93%	58%	86%	100%	87%	70%	89%
Ptmb	95%	93%	83%	92%	91%	100%	85%	92%	77%	92%	71%	80%
Pta	90%	100%	69%	82%	91%	100%	73%	84%	86%	100%	73%	81%
Pwv	95%	89%	55%	76%	96%	91%	57%	78%	94%	87%	61%	77%
Reef	96%	91%	39%	69%	97%	89%	47%	73%	96%	89%	54%	75%
Sow			64%	64%			62%	62%			67%	67%
Vaal	98%	100%	80%	88%	96%	100%	78%	88%	100%	100%	71%	86%
WCape	99%	81%		91%	99%	77%		88%	97%	75%		86%
Area												
Urban	95%	93%	54%	79%	96%	93%	56%	80%	94%	93%	59%	80%
Villages	98%	90%	66%	89%	98%	83%	69%	89%	95%	84%	72%	86%
Rural	97%	52%	35%	79%	99%	54%	39%	75%	99%	63%	34%	72%
Liv.Standard												
A					98%	97%	93%	97%	97%	98%	93%	96%
B					48%	72%	42%	47%	51%	58%	43%	47%
C					0%	0%	0%	0%	0%	0%	0%	
Comparing with ownership for 1981:												
	No	%										
Whites:	1320	87%										
Blacks	3572	3%										
All	5384	29%										

Appendix B.1 Ownership of refrigerators for different years

Ownership of refrigerators - 1991 survey

	Coloured and Indians - (000's)							
	total	with electr.		own appl.		bought	ought	creas
	no	no	%	no	%	no	own %	0-91
Total	749	592	79%	530	90%	25	5%	2%
Zone								
A	75	75	100%	65	87%	3	5%	-3%
B	0	0		0		0		
C	24	14	58%	12	86%	0	0%	50%
D	166	165	99%	157	95%	7	4%	-2%
E	73	41	56%	34	83%	2	6%	-8%
F	59	16	27%	12	75%	1	8%	20%
G	352	283	80%	250	88%	11	4%	5%
H	0	0		0		0		
Metropolitan								
Bloem	0	0		0		0		
CT	186	186	100%	177	95%	8	5%	5%
Dur	109	109	100%	105	96%	5	5%	-1%
ELnd	9	10	111%	3	30%	0	0%	0%
Jhb	45	45	100%	39	87%	1	3%	-5%
Kim	9	9	100%	8	89%	0	0%	14%
PE Ut	34	30	88%	26	87%	1	4%	-7%
Ptmb	13	13	100%	12	92%	1	8%	-8%
Pta	8	8	100%	8	100%	1	13%	0%
Pwv	75	75	100%	65	87%	3	5%	-3%
Reef	19	19	100%	17	89%	1	6%	6%
Sow	0	0		0		0		
Vaal	2	2	100%	2	100%	0	0%	0%
WCape	162	97	60%	73	75%	4	5%	6%
Area								
Urban	479	470	98%	437	93%	23	5%	1%
Villages	128	75	59%	63	84%	1	2%	-6%
Rural	142	48	34%	30	63%	1	3%	50%
Liv.Standard								
A	352	351	100%	344	98%	16	5%	-12%
B	368	320	87%	186	58%	9	5%	42%
C	30	0	0%	0		0		

Appendix B.2 Ownership of refrigerators for 1991

Appliance ownership

as a percentage of blacks with electricity

		1989										
					Living Area			Metropolitan Areas				
Appliance		Total			Urban	Villag	Rural	CT	Dur	ELnd	Pwv	Sow
TV	TV	59%			58%	71%	60%	74%	55%	74%	61%	66%
Stove - a	Stove	69%			69%	80%	56%	77%	68%	77%	74%	86%
Stove - electrical												
Stove - hotplate												
Stove-el + Hot Plate												
Stove - non electrical												
Utility Ap	Iron/K	70%			70%	84%	44%	77%	72%	36%	74%	84%
Fridge or	Fridge	54%			54%	66%	35%	65%	64%	58%	57%	62%
Heater	Heater	40%			41%	46%	23%	19%	26%	21%	50%	62%
Kitchen	KAppl	11%			12%	14%	0%	16%	8%	9%	17%	20%
Washing Machi		1%			1%	0%	0%	0%	1%	0%	2%	1%
Washing Machi		5%			5%	4%	0%	3%	1%	0%	5%	3%
Washing Machi		2%			2%	1%	0%	10%	1%	0%	3%	3%
Washing	WMch	8%			8%	5%	0%	13%	3%	0%	9%	7%
Freezer	Freez	1%			4%	10%	4%	3%	5%	0%	5%	7%
Mico Wa	Micro	2%			2%	2%	0%	6%	2%	3%	2%	4%
Tumble	Drier	1%			1%	1%	0%	3%	0%	0%	1%	1%
Dish Wa	DWsh	1%			1%	2%	0%	0%	1%	0%	1%	1%

Appliance ownership

as a percentage of blacks with electricity

		1990										
		1990	Living Std		Living Area			Metropolitan Areas				
Appliance		Total	A	B	Urban	Villag	Rural	CT	Dur	ELnd	Pwv	Sow
TV	TV	60%	96%	47%	61%	66%	47%	74%	55%	74%	61%	66%
Stove - a	Stove	70%	93%	61%	69%	93%	62%	77%	68%	77%	74%	86%
Utility Ap	Iron/K	69%	93%	60%	70%	85%	36%	77%	72%	36%	74%	84%
Fridge or	Fridge	56%	93%	42%	56%	69%	39%	65%	64%	58%	57%	62%
Heater	Heater	42%	72%	30%	43%	51%	12%	19%	26%	21%	50%	62%
Kitchen	KAppl	14%	32%	7%	14%	15%	3%	16%	8%	9%	17%	20%
Washing Machi		1%	4%	0%	1%	1%	3%	0%	1%	0%	2%	1%
Washing Machi		4%	12%	1%	4%	8%	4%	3%	1%	0%	5%	3%
Washing Machi		2%	8%	0%	3%	3%	0%	10%	1%	0%	3%	3%
Washing	WMch	8%	24%	2%	8%	12%	6%	13%	3%	0%	9%	7%
Freezer	Freez	6%	14%	2%	5%	9%	5%	3%	5%	0%	5%	7%
Mico Wa	Micro	2%	7%	0%	2%	3%	3%	6%	2%	3%	2%	4%
Tumble	Drier	0%	1%	0%	0%	0%	0%	3%	0%	0%	1%	1%
Dish Wa	DWsh	1%	1%	1%	1%	1%	0%	0%	1%	0%	1%	1%

Appendix B.1 Ownership of refrigerators for different areas

Appliance ownership

as a percentage of blacks with electricity

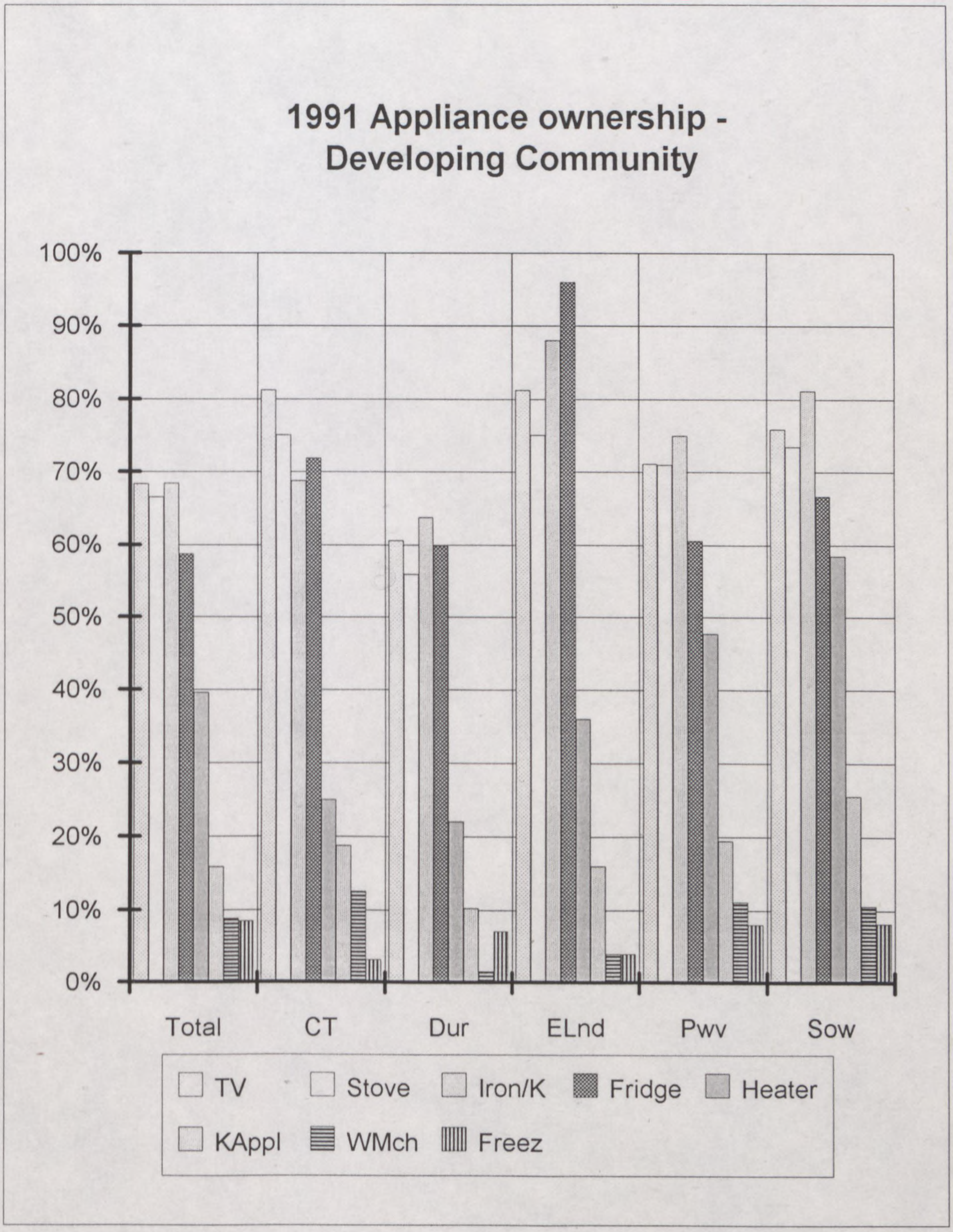
		1991										
		Living Std			Living Area			Metropolitan Areas				
Appliance		Total	A	B	Urban	Villag	Rural	CT	Dur	ELnd	Pwv	Sow
TV	TV	68%	97%	55%	70%	70%	47%	81%	61%	81%	71%	76%
Stove - a	Stove	67%	90%	56%	67%	77%	41%	75%	56%	75%	71%	73%
Stove - electrica		52%	80%	39%	92%	43%		66%	54%	66%	54%	56%
Stove - hotplate		27%	30%	26%	28%	27%	18%	16%	26%	16%	32%	46%
Stove-el + Hot		79%	110%	65%	119%	71%		81%	80%	92%	87%	102%
Stove - non elec		27%	31%	24%	26%	30%	29%	13%	6%	13%	32%	34%
Utility Ap	Iron/K	68%	88%	59%	69%	80%	40%	69%	64%	88%	75%	81%
Fridge or	Fridge	59%	93%	43%	59%	72%	34%	72%	60%	96%	61%	67%
Heater	Heater	40%	62%	29%	41%	47%	11%	25%	22%	36%	48%	58%
Kitchen	KAppl	16%	32%	8%	17%	14%	5%	19%	10%	16%	19%	26%
Washing Machi		1%	3%	0%	1%	0%	0%	0%	0%	4%	1%	1%
Washing Machi		5%	15%	1%	5%	7%	1%	9%	1%	0%	6%	5%
Washing Machi		3%	8%	0%	3%	2%	0%	3%	1%	0%	4%	5%
Washing	WMch	9%	25%	1%	9%	9%	1%	13%	2%	4%	11%	11%
Freezer	Freez	8%	16%	5%	8%	8%	10%	3%	7%	4%	8%	8%
Mico Wa	Micro	2%	6%	0%	2%	1%	1%	0%	2%	0%	3%	3%
Tumble	Drier	1%	2%	0%	1%	2%	0%	0%	0%	0%	1%	0%
Dish Wa	DWsh	1%	2%	0%	1%	1%	0%	3%	0%	0%	1%	1%

Average annual increase from 1989 to 1991

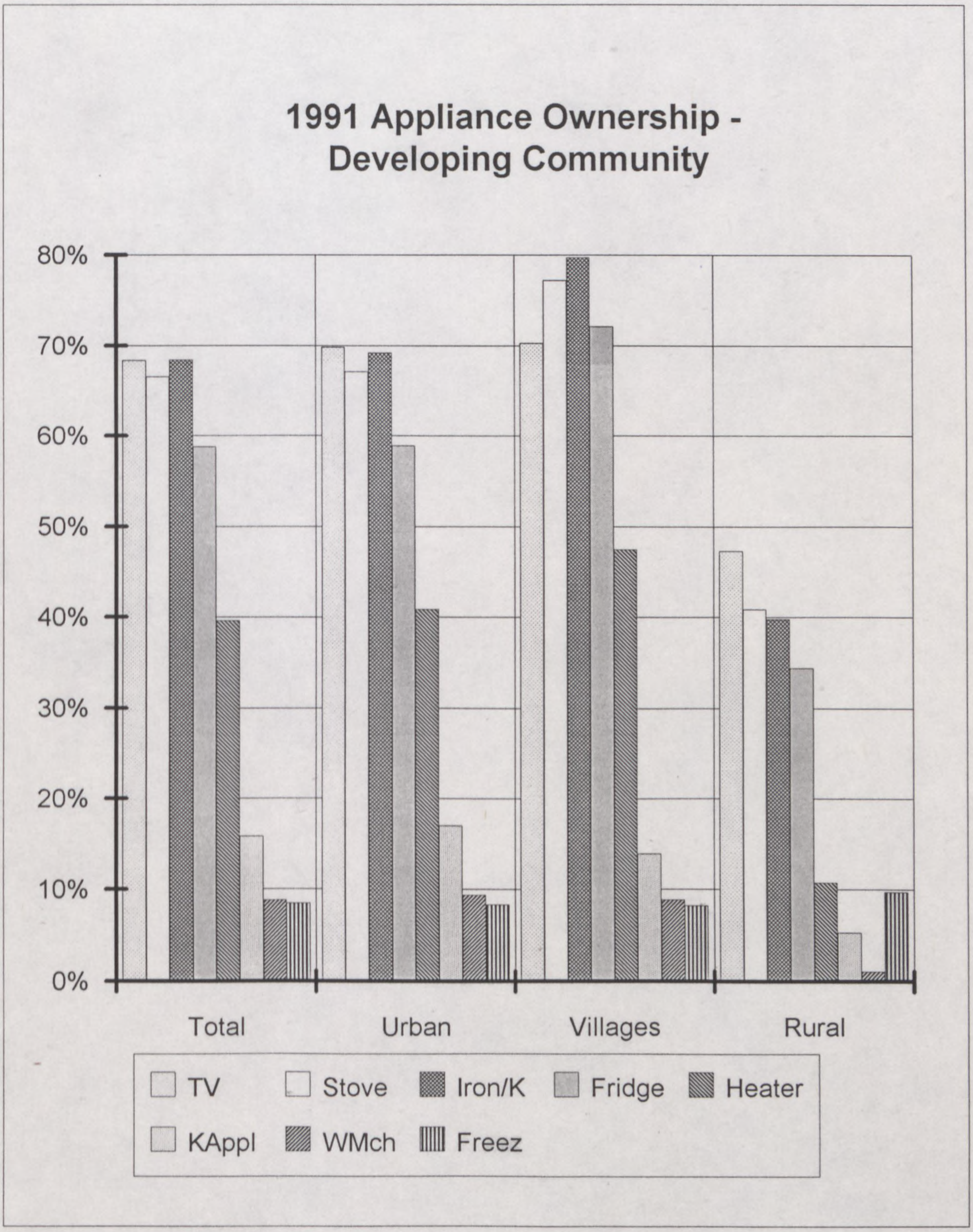
from 1989 to 1991

		Incr	Living Std		Living Area			Metropolitan Areas				
Appliance		Total	A	B	Urban	Villag	Rural	CT	Dur	ELnd	Pwv	Sow
TV	TV	4.5%	0.6%	8.3%	5.9%	-0.1%	-6.6%	3.5%	2.7%	3.5%	4.8%	5.0%
Stove - a	Stove	-1.4%	-3.6%	-5.8%	-0.8%	-1.6%	-7.7%	-1.2%	-6.3%	-1.2%	-1.3%	-6.3%
Utility Ap	Iron/K	-0.9%	-5.3%	-0.8%	-0.3%	-2.1%	-2.0%	-4.3%	-4.1%	25.8%	0.4%	-1.4%
Fridge or	Fridge	2.3%	0.2%	0.3%	2.6%	3.0%	-0.5%	3.7%	-2.1%	19.2%	1.7%	2.2%
Heater	Heater	-0.3%	-9.3%	-1.1%	0.2%	1.0%	-6.1%	2.8%	-2.1%	7.4%	-1.4%	-1.9%
Kitchen	KAppl	2.3%	0.1%	1.5%	2.7%	-0.2%	2.7%	1.3%	1.2%	3.5%	1.0%	2.7%
Washing Machi		0.0%	-1.0%	-0.3%	0.0%	0.0%	0.0%	0.0%	-0.4%	2.0%	-0.3%	0.0%
Washing Machi		0.3%	2.3%	0.0%	0.2%	1.2%	0.5%	3.1%	0.0%	0.0%	0.7%	0.9%
Washing Machi		0.3%	0.1%	0.1%	0.3%	0.5%	0.0%	-3.3%	0.0%	0.0%	0.7%	0.9%
Washing	WMch	0.6%	1.4%	-0.3%	0.5%	1.8%	0.5%	-0.2%	-0.5%	2.0%	1.1%	1.7%
Freezer	Freez	3.9%	2.0%	2.4%	2.0%	-0.8%	2.8%	-0.1%	0.9%	2.0%	1.4%	0.7%
Mico Wa	Micro	-0.1%	-1.6%	-0.2%	0.0%	-0.3%	0.5%	-3.2%	-0.1%	-1.5%	0.3%	-0.1%
Tumble	Drier	0.1%	1.4%	0.1%	0.0%	0.5%	0.0%	-1.6%	0.0%	0.0%	0.2%	-0.5%
Dish Wa	DWsh	-0.3%	0.6%	-0.4%	-0.4%	-0.6%	0.0%	1.6%	-0.4%	0.0%	0.1%	0.2%

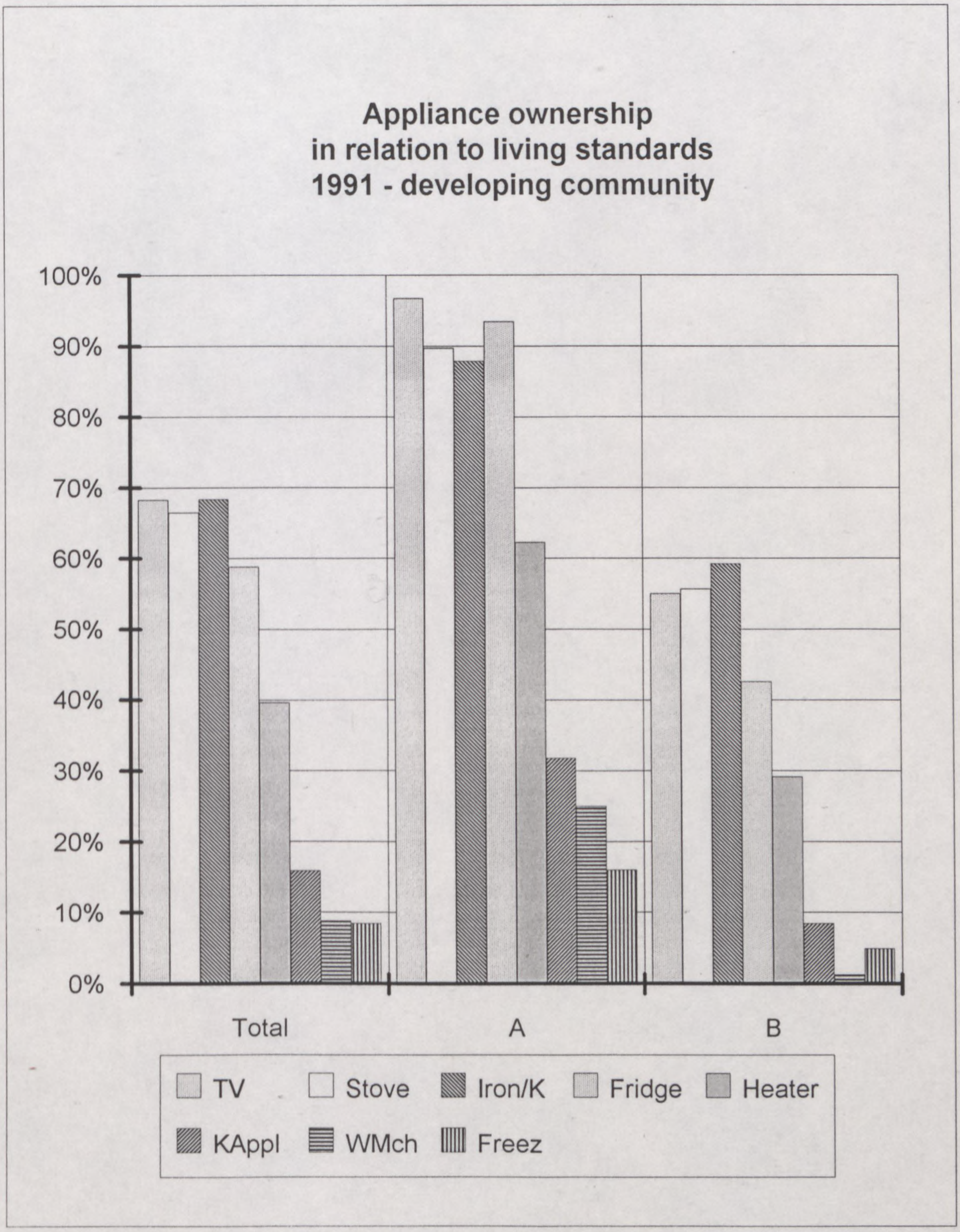
Appendix B.3 Ownership of appliances



Appendix B.4 Appliance ownership in different metropolitan areas for 1991



Appendix B.5 Appliance ownership in different living areas for 1991



Appendix B.6 Appliance ownership in different living standards

APPENDIX C

Measurement of the total domestic hot water and total domestic load supplied by supply authorities

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Appendix C.1 Description of the measurements taken, and the calculations used, to determine the domestic hot water load of an average household using an electric hot water cylinder.

* The equipment used by the municipality to limit the maximum municipal load by disconnecting domestic hot water cylinders at the time of load peak is adjusted so that it will not respond to the total municipal load.

* Using the load control equipment, all the controlled hot water cylinders are disconnected for a few seconds while the drop in the total municipal load is recorded.

* The total domestic hot water load is the drop in the total municipal load when all hot water cylinders are disconnected.

* The hot water load of an average household is the total municipal hot water load divided by the number of households with controlled hot water cylinders.

Appendix C.2 Description of the measurements taken, and the calculations used, to determine the domestic load of an average household using an electric hot water cylinder.

Example of calculating the daily domestic load for an average household supplied by a municipality.

Basis of calculation:

1. Monthly accounts are used to determine the domestic load as a percentage of the total municipal load.

   Table 38 lists an example where the domestic load constitutes 52 % of the total load.

Table 38 Monthly energy consumption for different types of consumers

Type of consumer	Number	Monthly consumption		
		Average kWh	Total MWh	% of total load
Domestic	11779	730	8 600	52 %
Small business	988	1660	1 640	10 %
Large business	79	79000	6 240	38 %
Total	12846	1300	16 700	100 %

Table 39 Domestic consumers with and without hot water controllers

Domestic consumers with or without hot water controllers	Number	Household kWh per month	Total MWh/month	% of total municipal load
with	8 000	830	6 640	40 %
without	3 800	515	1 960	12 %
Total	11 800	730	8 600	52 %

2. The percentage of the domestic load which is controllable is determined on the basis of the number of households which have controllers to control their hot water load.

   Table 39 provides an example where the consumers with and without controllers are listed. During installation of the controllers, the consumers selected are those with large hot water cylinder elements; these are normally larger consumers. The average monthly consumption of those with controllers is taken to be approximately 15 % above the normal consumption of 730 kWh per month.

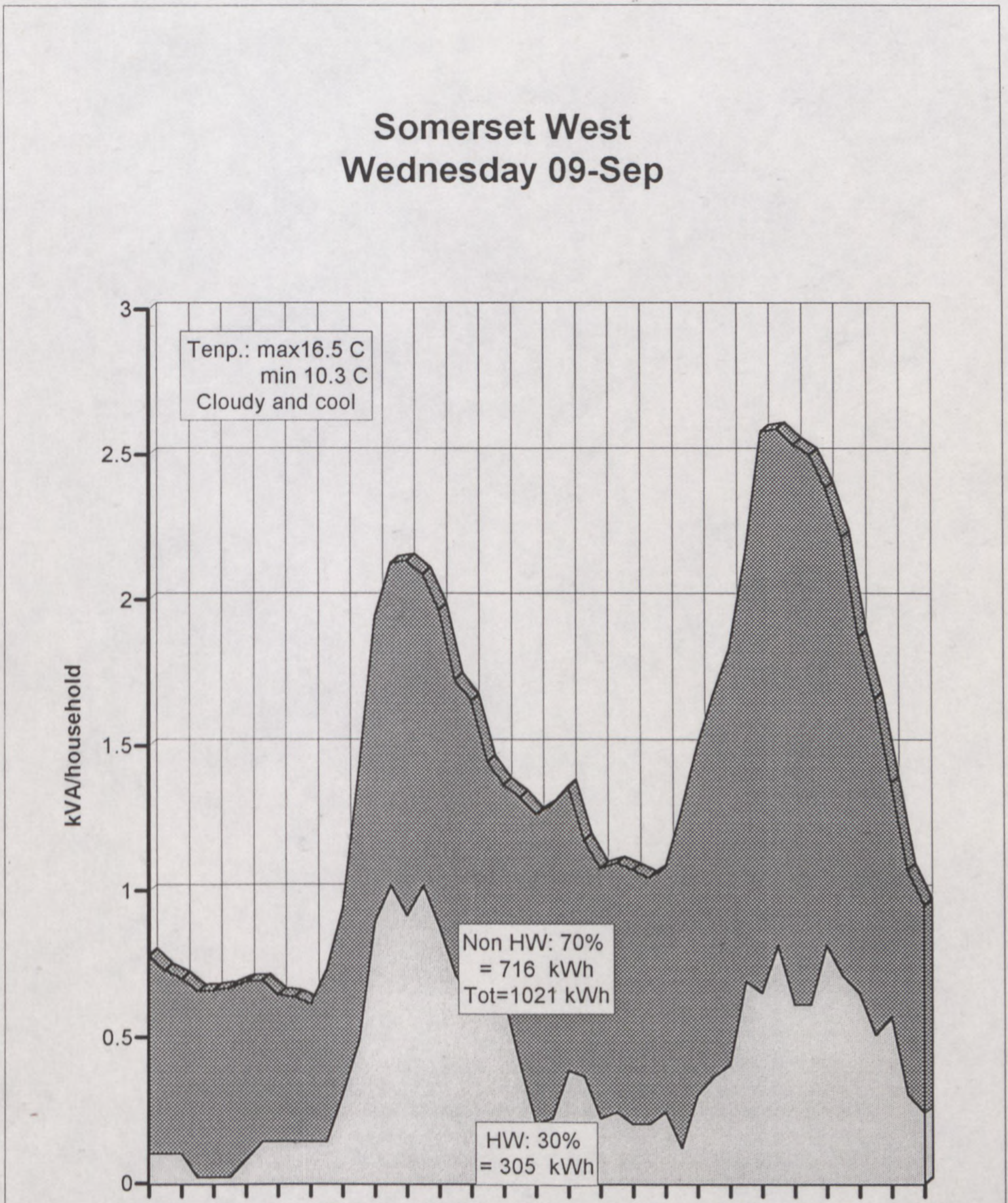
   The total consumption of the domestic consumers with hot water controllers in this example was 40 % of the total municipal load.

3. To be able to determine the load shape of the average domestic consumer, certain substation loads which supply mainly certain types of loads were recorded. The loads recorded are:

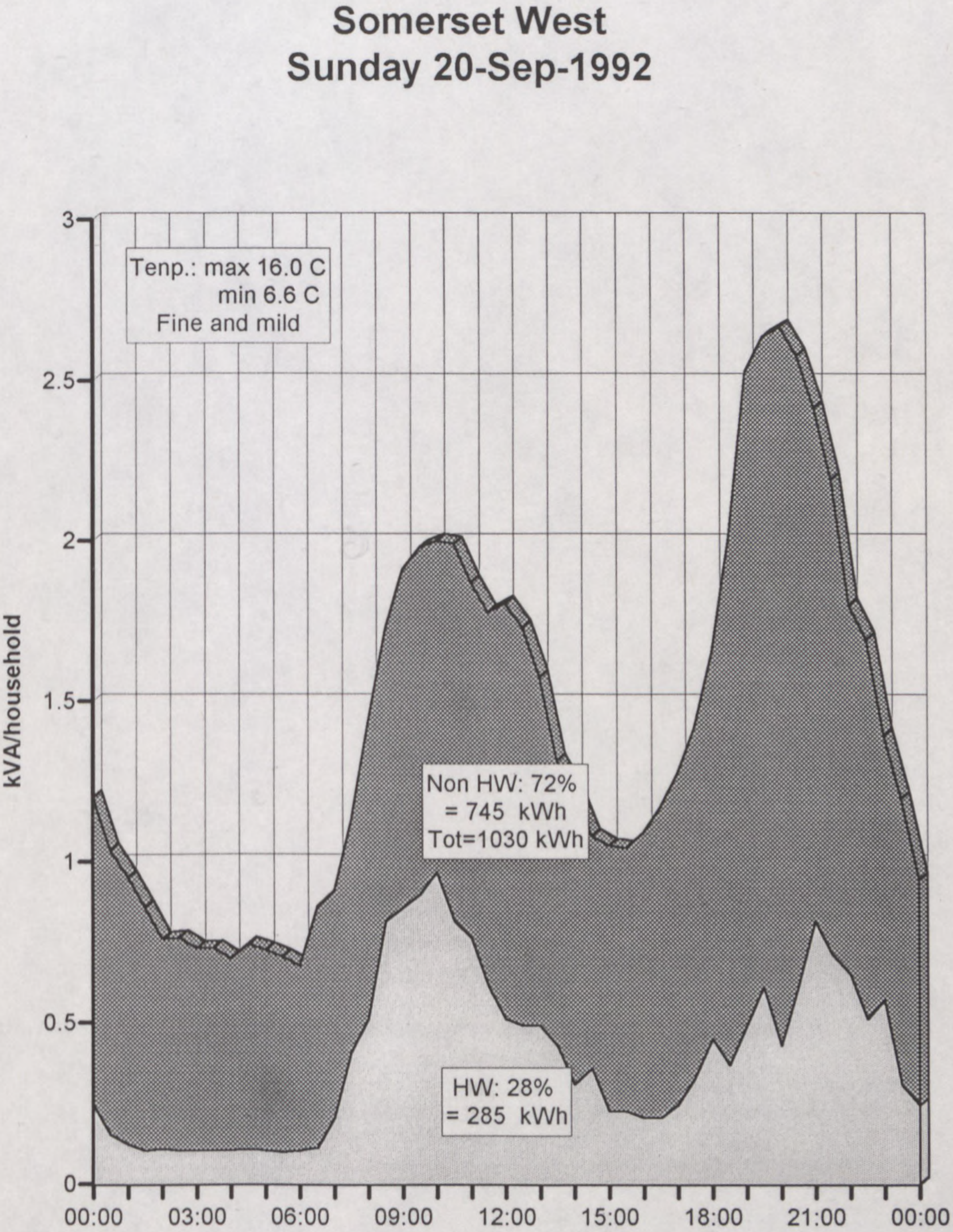
   i: light industrial load
   c: large shopping complex representing a commercial load

4. The load shape of the controlled domestic load is determined as follows:

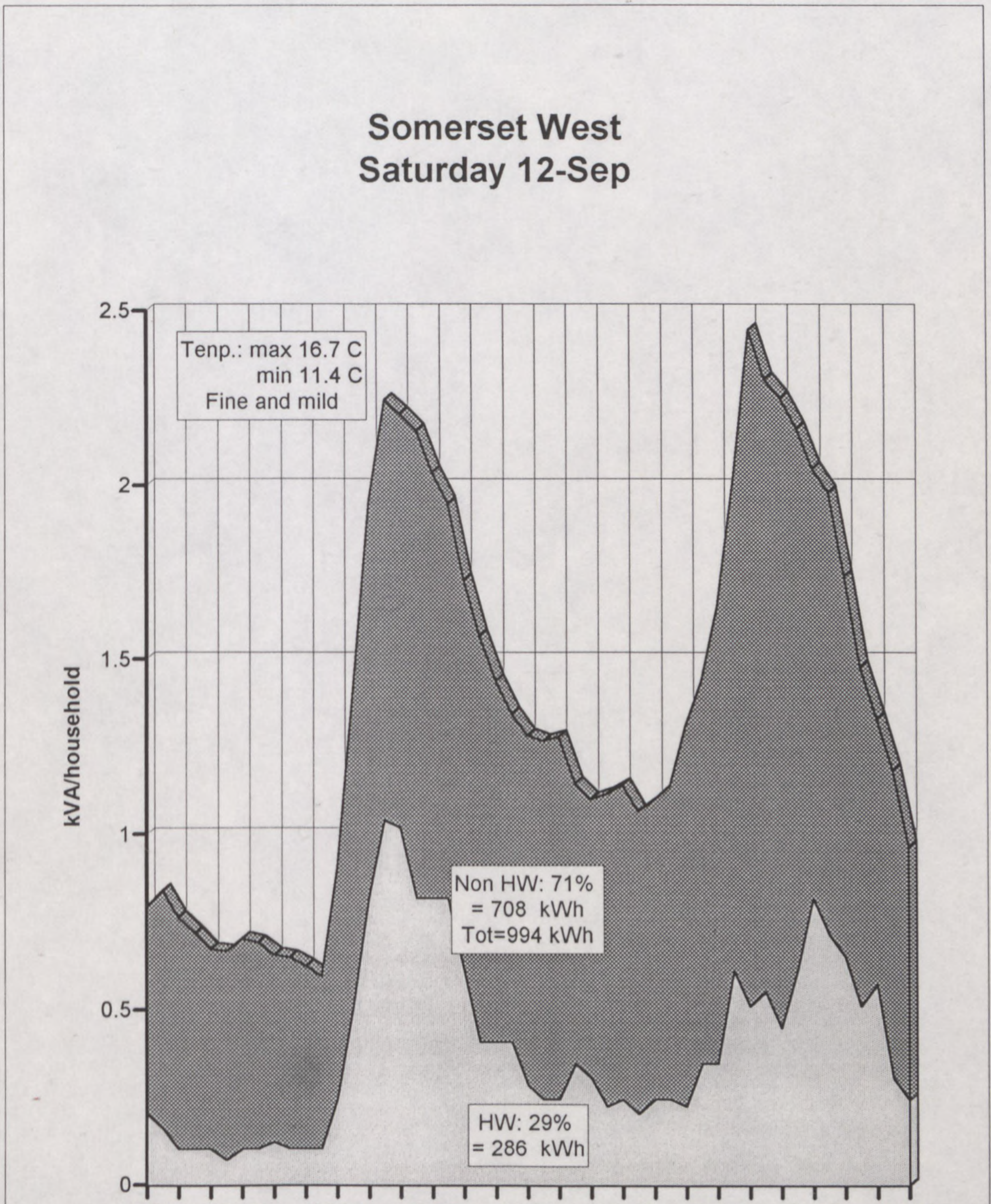
- Record total municipal load: m.
- Subtract industrial load, recorded as i above.
- Subtract commercial load, recorded as c above.
- Calculate the remaining energy,
  R=M-I-C per day
  from the daily load shape:
  r=m-i-c.
- Subtract the daily domestic energy, as determined from Table 39
  D= 8 600/30 MWh per day
  from the remaining energy per day, R.
- Determine a load with load shape similar to c above and value such that the energy per day is R-D, and subtract this from r. This is the total domestic load.
- A fraction: 40/52, of this load is the controllable domestic load.
- This load is divided by the number of households with controllers to give the load shape of an average household using an electric hot water cylinder.



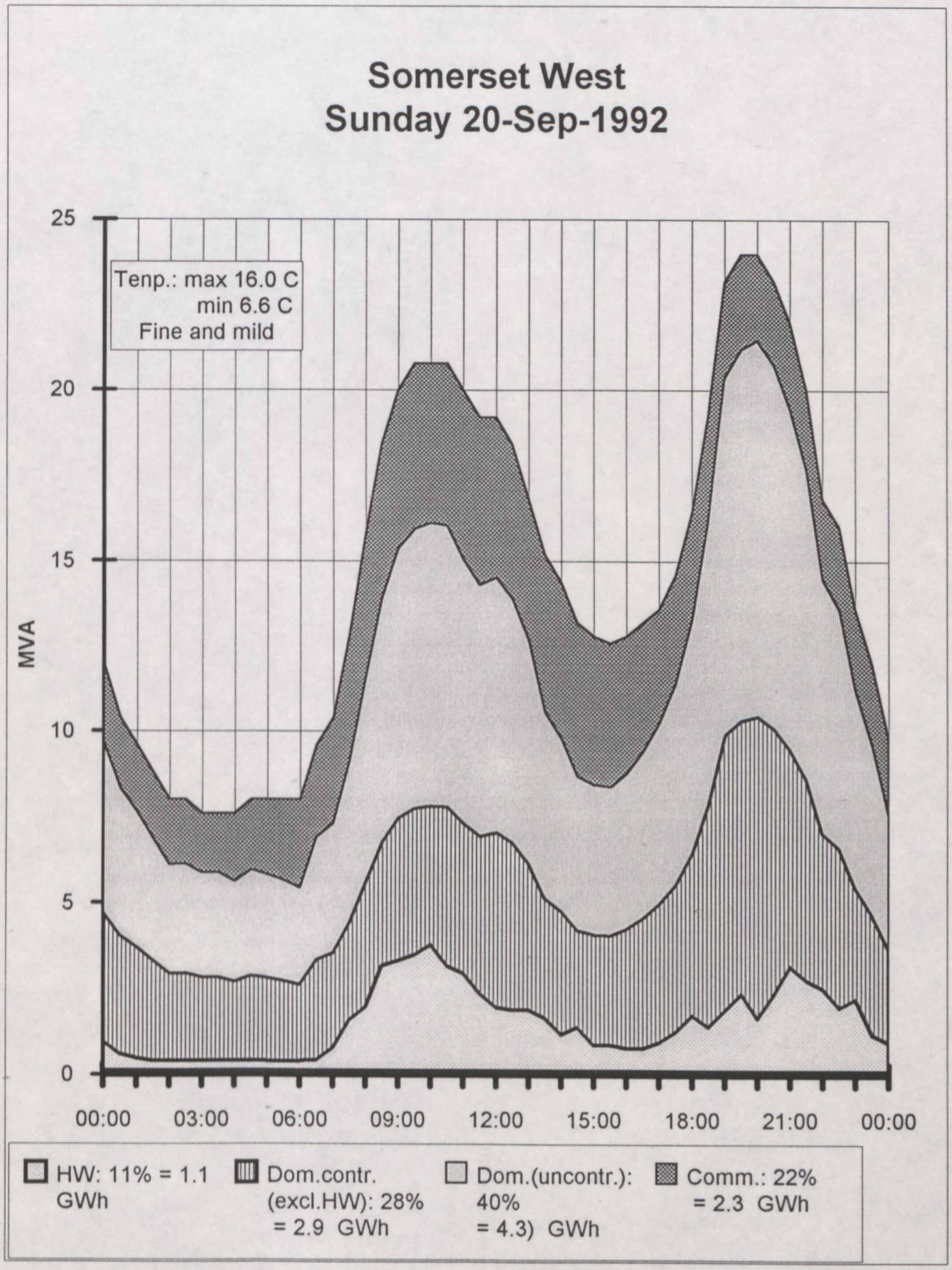
Appendix C.3 Average total domestic and hot water load for a weekday



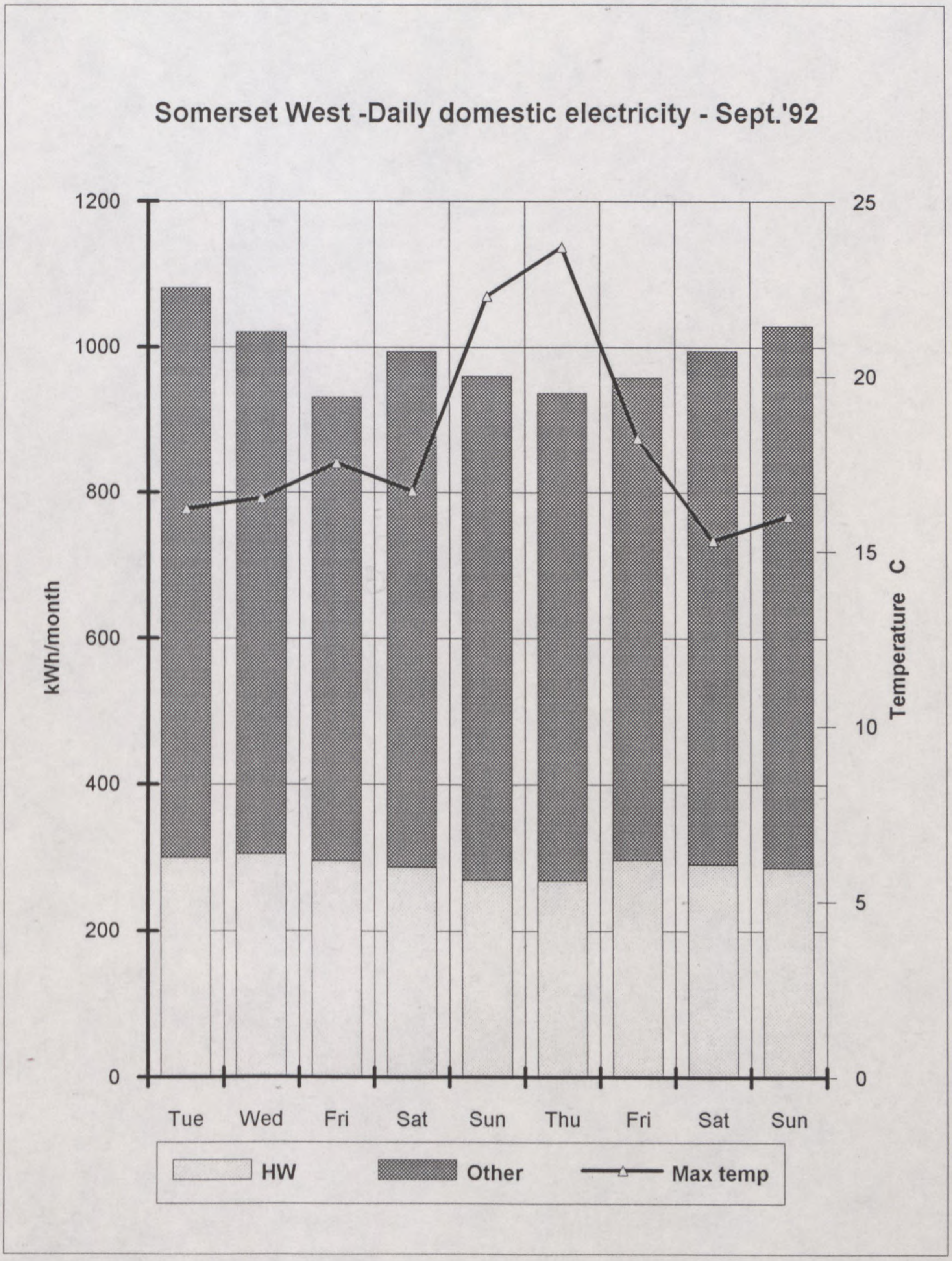
Appendix C.3 Average total domestic hot water load for a Sunday



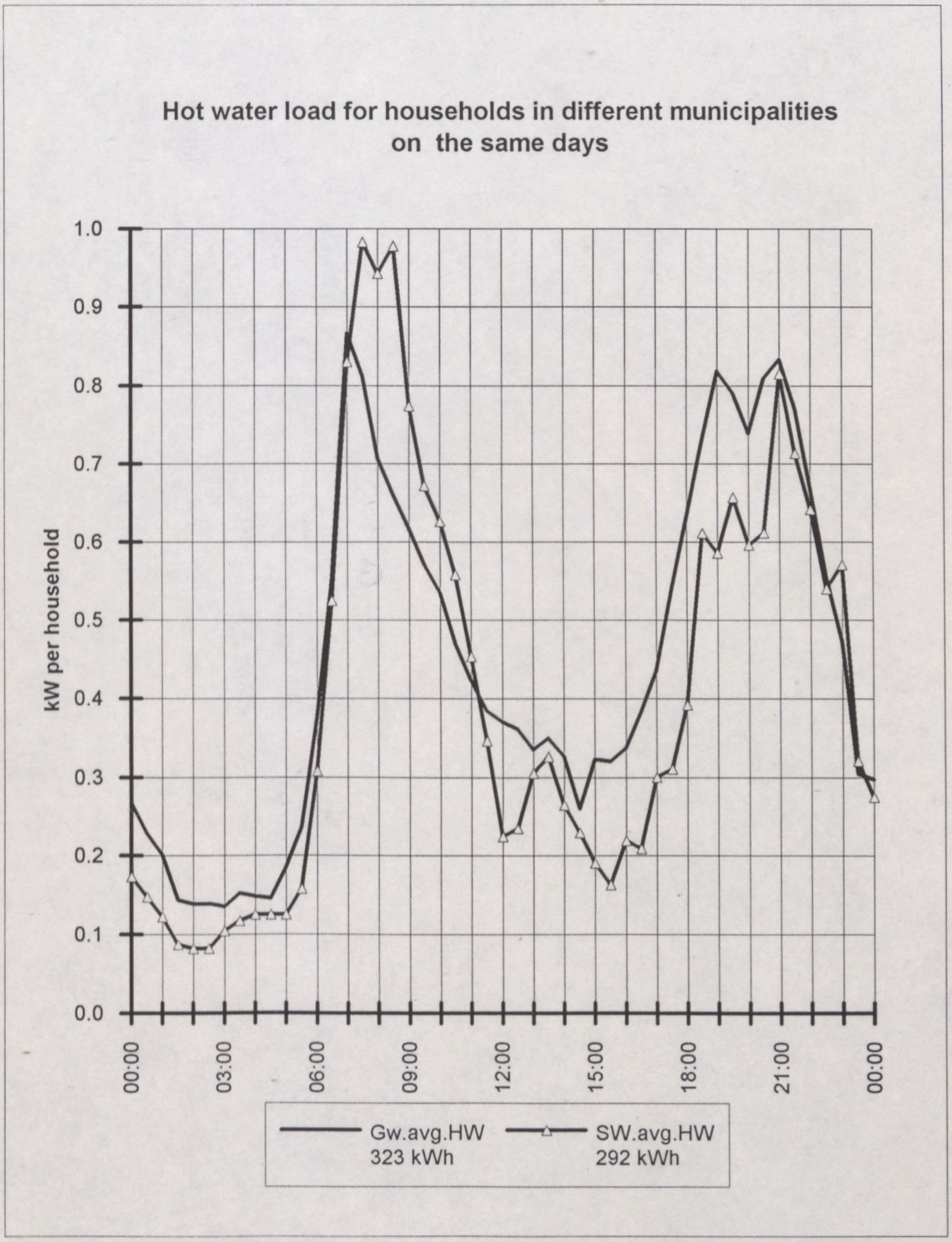
Appendix C.3 Average total domestic hot water load for a Saturday



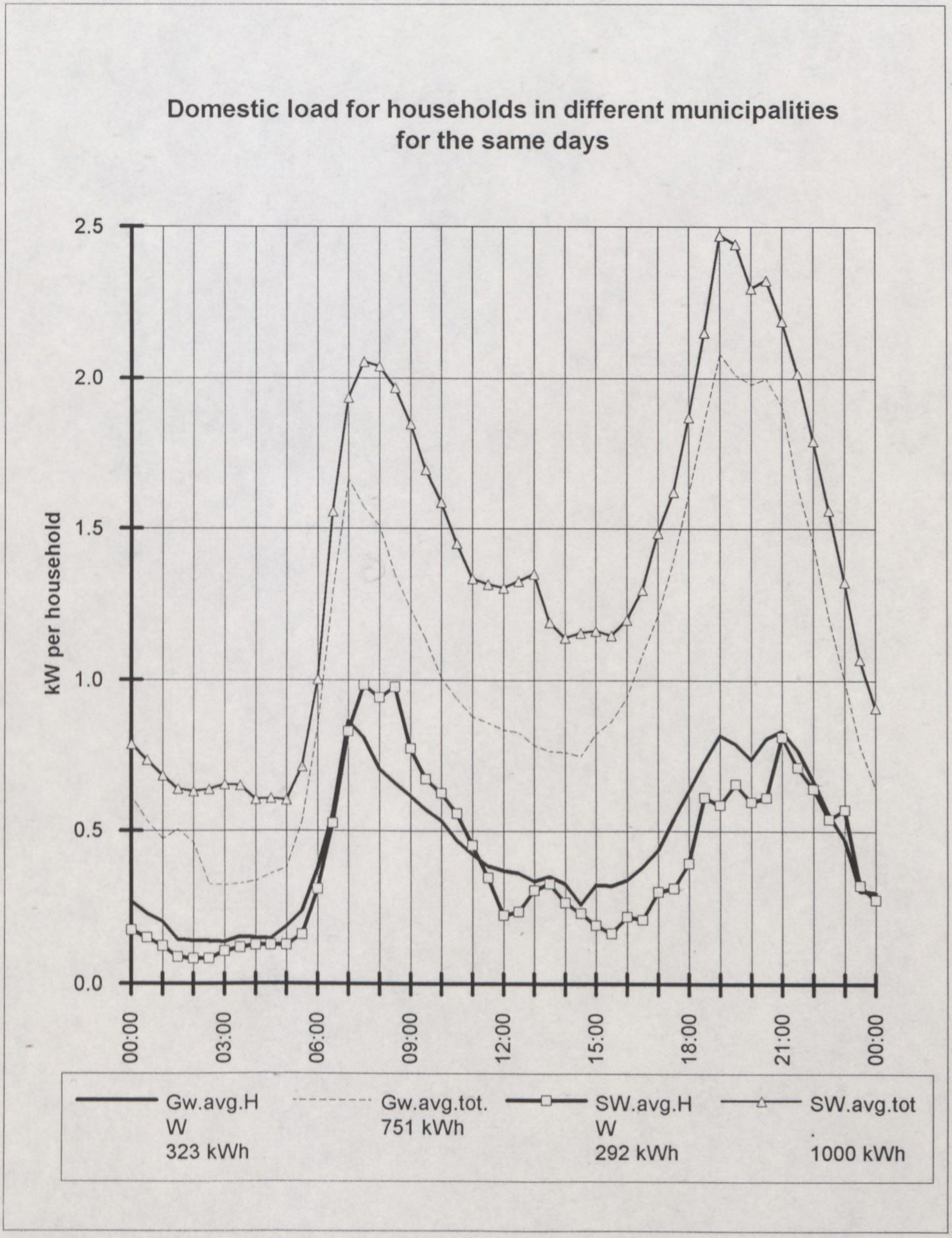
Appendix C.4 Components of the toal domestic load of a municipality



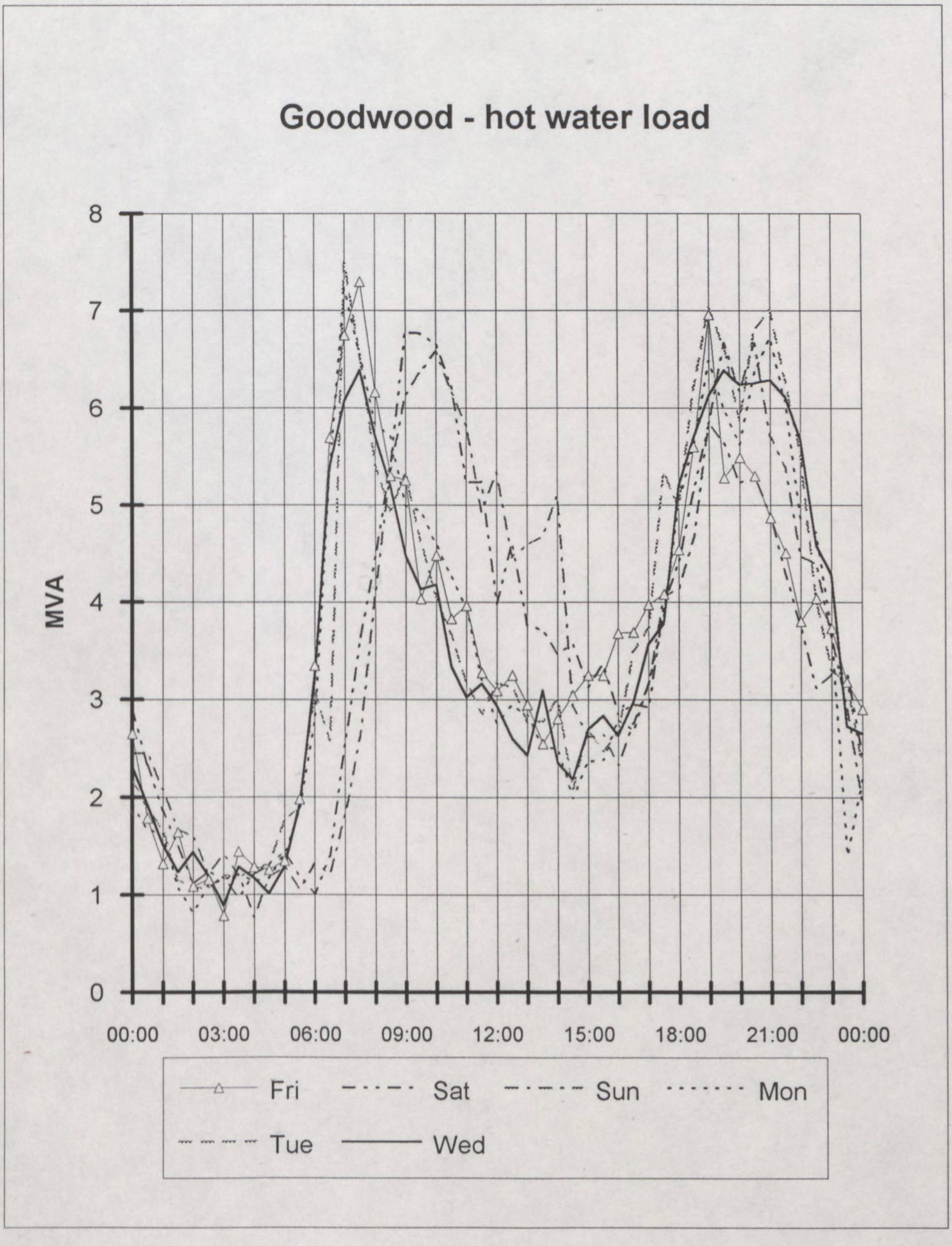
Appendix C.5 Variation of the daily total domestic and hot water loads and the corresponding daily maximum temperatures



Appendix C.6 Comparison of typical average domestic loads at different municipalities



Appendix C.6 Comparison of typical average domestic loads at different municipalities



Appendix C.7 Comparison of domestic domestic hot water loads on different days

APPENDIX D

Measurement of the domestic hot water and total domestic load for selected households

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Appendix D.1 Procedure followed to obtain the measurements

1. Households are selected to cover a reasonable cross section of the population.

2. Permission is obtained to install measuring equipment in a dwelling.

3. Recording equipment is installed to record, at 15 minute intervals, an integrated reading of:

   * total domestic load
   * hot water load

   More domestic loads are also recorded when possible, such as the load for the:

   * stove,
   * lights,
   * plugs, and
   * swimming pool.

4. The household is questioned about their use of electricity using the form shown in appendix D.2

5. The temperature of the hot water is measured at the tap nearest to, and the tap furthest away from, the hot water cylinder at litre intervals, to determine the losses of energy in the hot water pipes.

6. The recorded measurements are analyzed and a summary is compared to the readings taken as described in appendix C.

Appendix D.2 Form used to question households whose domestic load has been recorded

1	HOUSEHOLD		
	Number in household	male	female
	Under 5 years old		
	5 to 12 years		
	13 to 18 years		
	Over 18 years		
	Number of: bedrooms		
	other rooms (excl.kitchen.&bathr.)		
	Market value of house		
	Home help: Living in: yes/no		
	Char: no days/week		

2	APPLIANCE DATA (used regularly)	No	Freq. used
2.1	HOT WATER Hot water cylinders: number kW rating temperature setting Solar water heating control and operation detail eg electrical supply to HWC disconnected during summer Instant water heaters Urn Kettle Which of the appliances below: use hot water from any of the above water heaters ? ..... heat their own water ?		
2.2	COOL STORAGE Fridge Freezer		

2.3	FOOD PREPARATION Stove Hot Plate..... Microwave Kettle................................. Urn Toaster......... Food Mixer Electric Pan......................... Dishwasher Other:	.. ..	
2.4	SPACE HEATING Electric heaters:............ .... Non Electric heaters:...... When it is cold: how many heaters do you use simultaneously .... do you use your heater constantly ....Y/N		
2.5	LAUNDRY Washing Machine Top Loader, HW from HWC Y/N Front Loader Twin Tub - using HW Y/N Tumble Drier: during dry weather during wet weather Electric Iron		
2.6	SWIMMING POOL No of hours per week - summer winter		
2.7	LIFE QUALITY APPL TV Radio/HiFi Other		

2.8	LIGHTING Total wattage in living room Are lights left on in unoccupied rooms Y/N Are security lights left on Y/N How many fluorescent lights		
2.9	Other: .... Do you have a home industry at your house ? Y/N If yes, which electrical appliances do you use ?		
3	MEASUREMENT DATA		
3.1	Circuit No ...: Total supply to dwelling		
	Circuit No ...: Hot Water cylinder for: Main Bathroom Y/N Kitchen Y/N Other		
	Circuit No 3: Supplying: Stove Plugs for		
	Circuit No 4: .... Circuit No 5:		
3.2	Electrical devices which are supplied by circuits which have not been measured:		
3.3	kWh readings: at start of measurements:date:... time:... kWh ... at end: date...... time....... kWh........		
3.4	Energy consumption history: kWh readings for the last 18 months:		

5	HOT WATER USAGE DATA			
4.1	Activity: Frequency used	Time	Qty	
	Baths and Showers: For each person indicate: Frequency per week, bath or shower and time. times per week shower/bath under 5 years... .... 5-11 years ... . 12-18 years ... . over 18 years...			
	Dish washing by hand ...times per day, h/c water			
	Hand washing of laundry .... times per day, h/c			
	Use of wash basin .... times per day, h/c water			
4.2	Positioning of Hot Water Cylinder distance from HWC to: Kitchen Main Bathroom .. Other:			
4.3	Capacity of HWC: How often do you run out of hot water ?			
4.4	Temperature setting: For what purposes do you use hot water without mixing it with cold water ?			
4.5	Notes:			

5 Did the fact that your electricity consumption was monitored influence your energy consumption ?

yes / no

6 PERSONAL DATA

Name: ______

Address: ______

Tel No: work/home ______

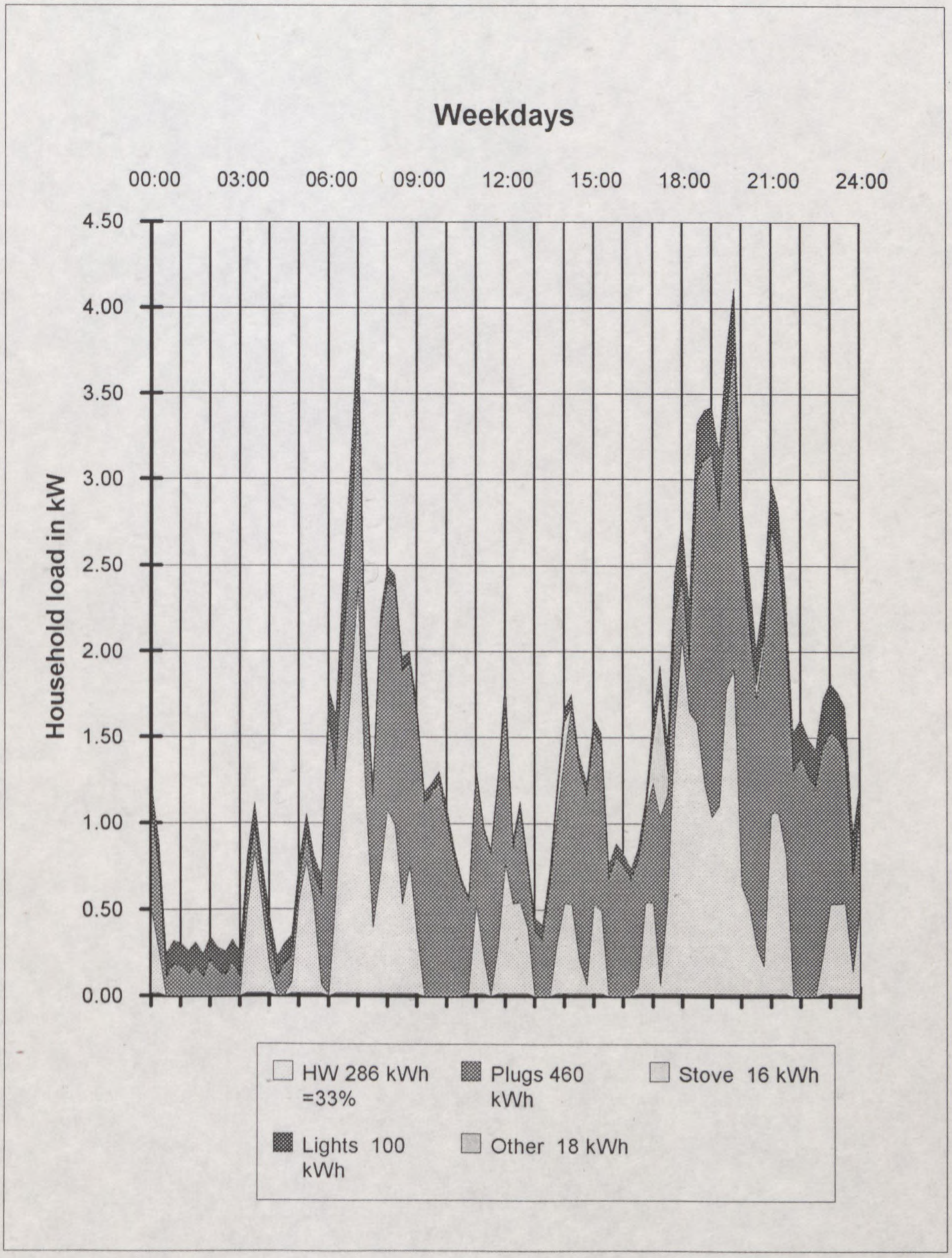
Occupation father ______

Occupation mother ______

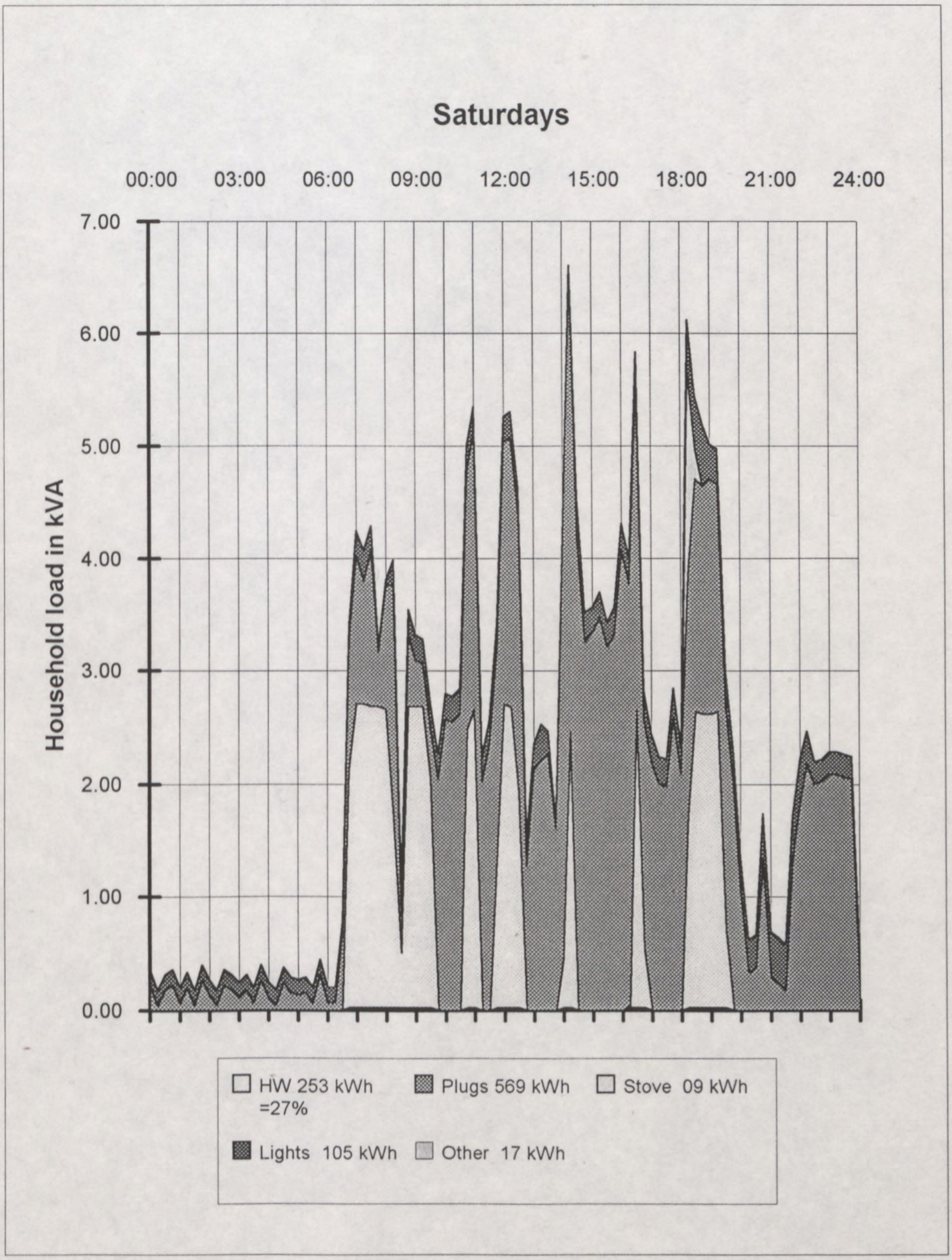
Occupation - other ______

Total income/month

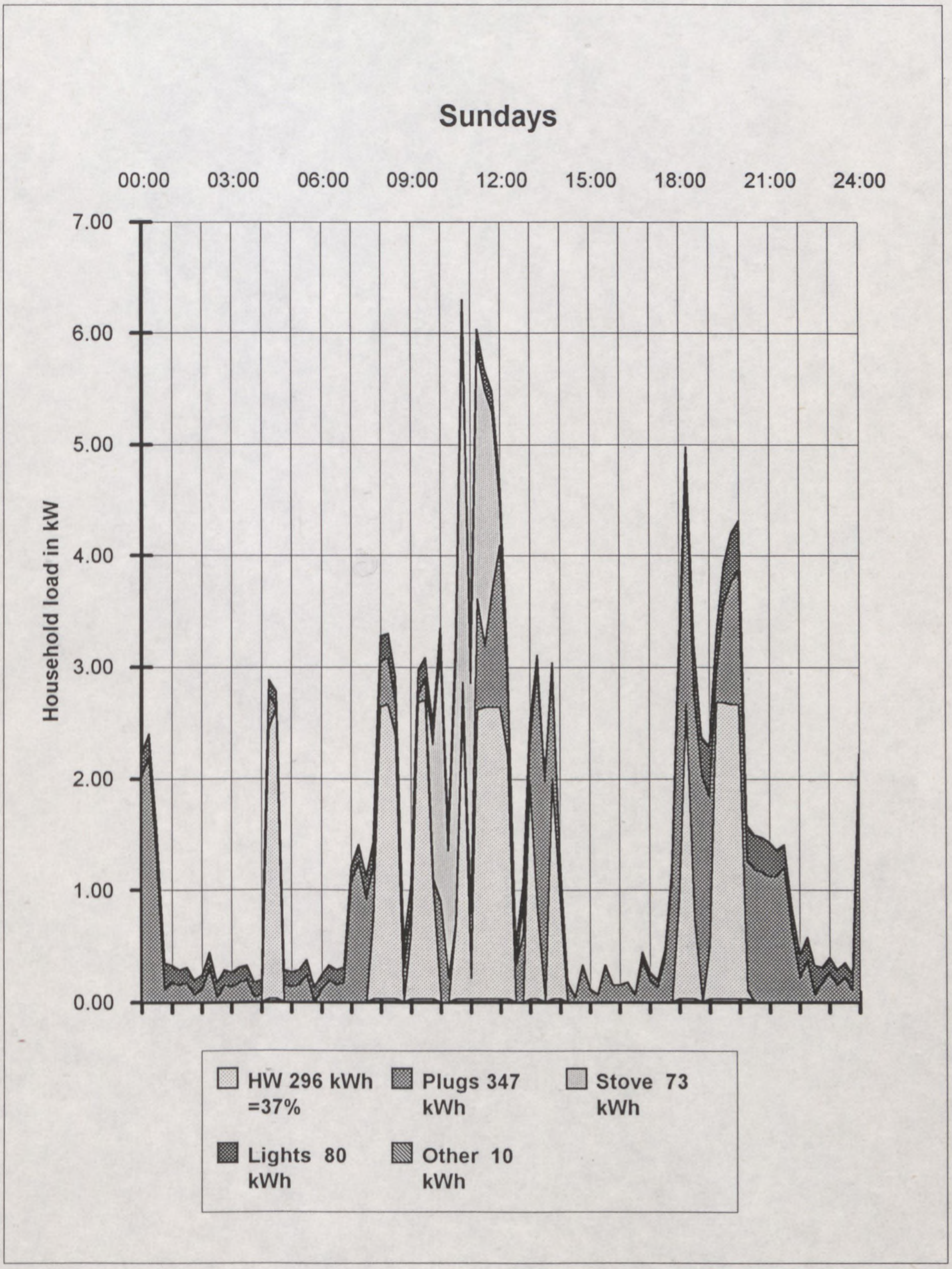
	<R 700		>R 700		
(R 000's)	>2	>4	>6	>8	



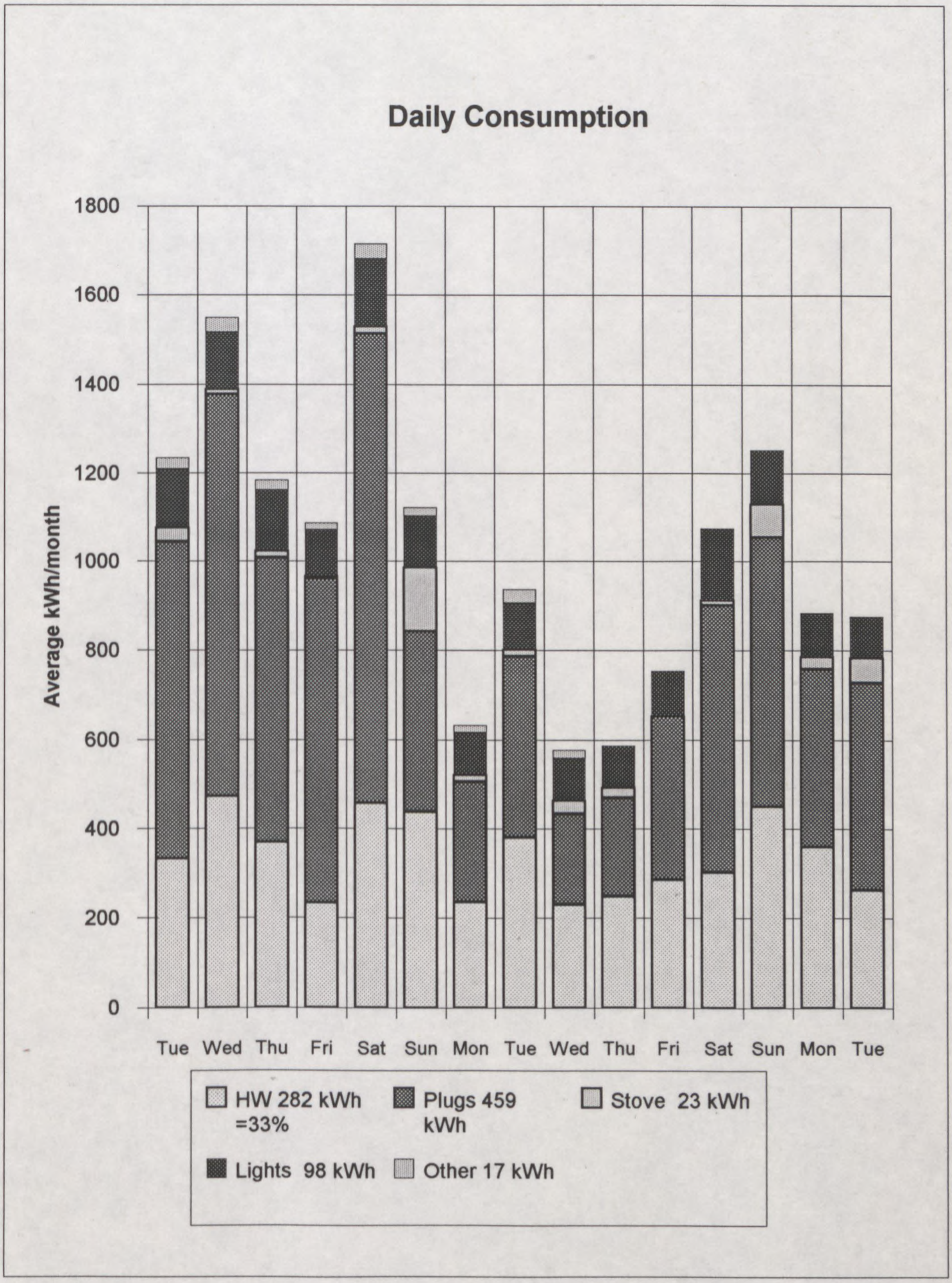
Appendix D.3 Domestic loads measured at a specific household



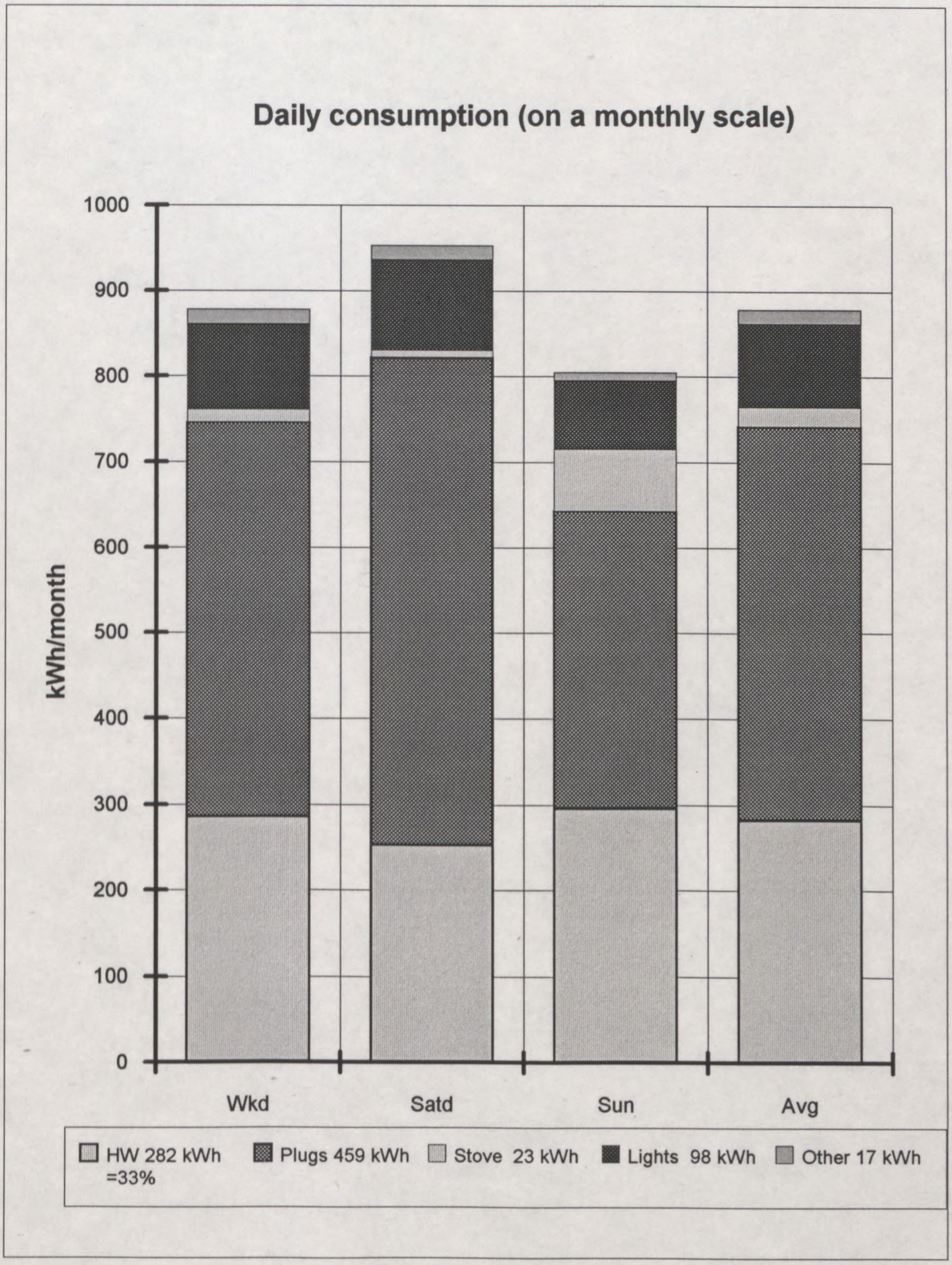
Appendix D.3 Domestic loads measured at a specific household



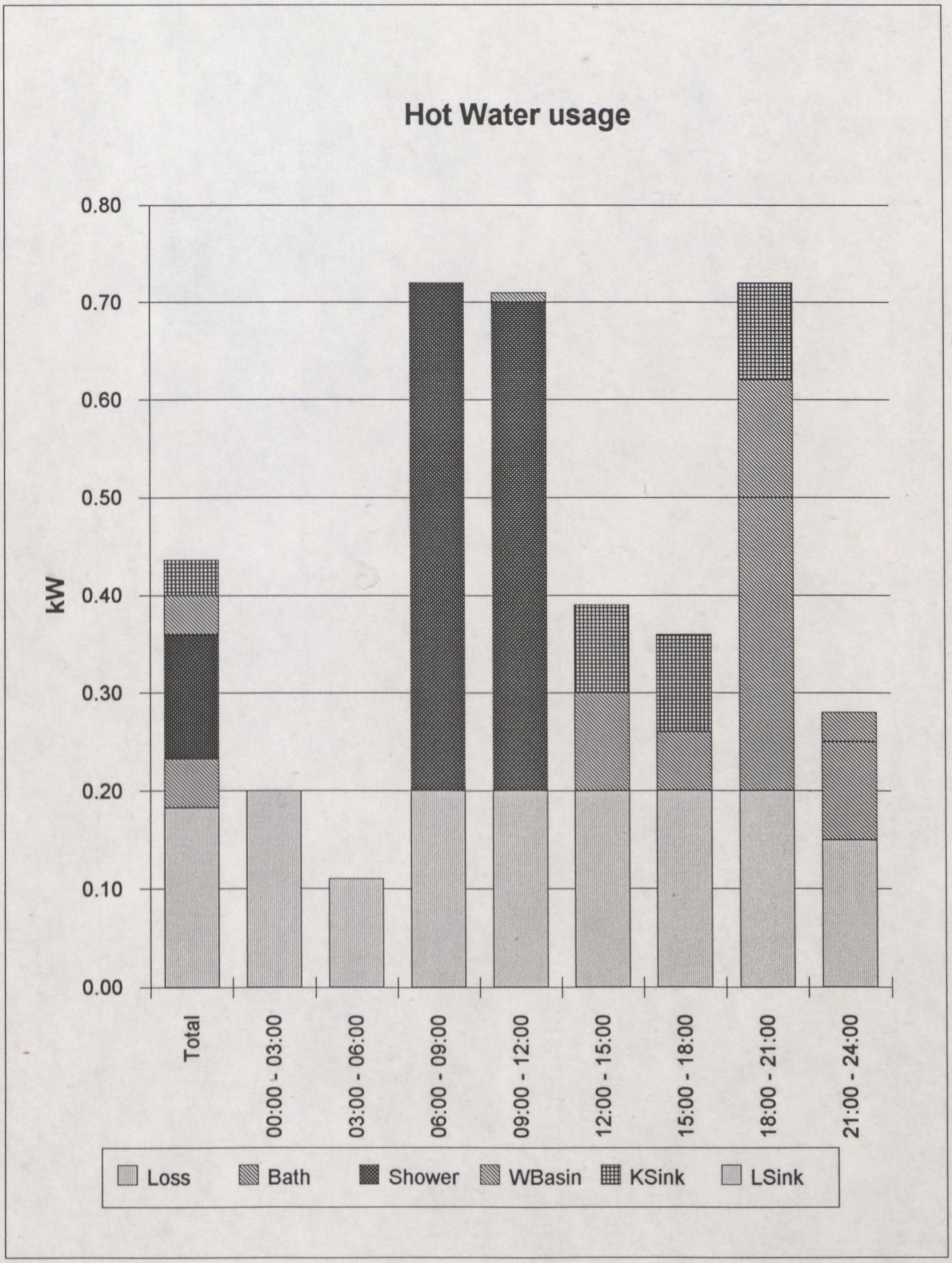
Appendix D.3 Domestic loads measured at a specific household



Appendix D.4 Household electrical energy use per day



Appendix D.4 Household electrical energy use per day



Appendix D.5 Time of use and the purpose for which hot water is used at a specific household

Appendix D.6 Test sheet used to measure energy losses in hot water pipes

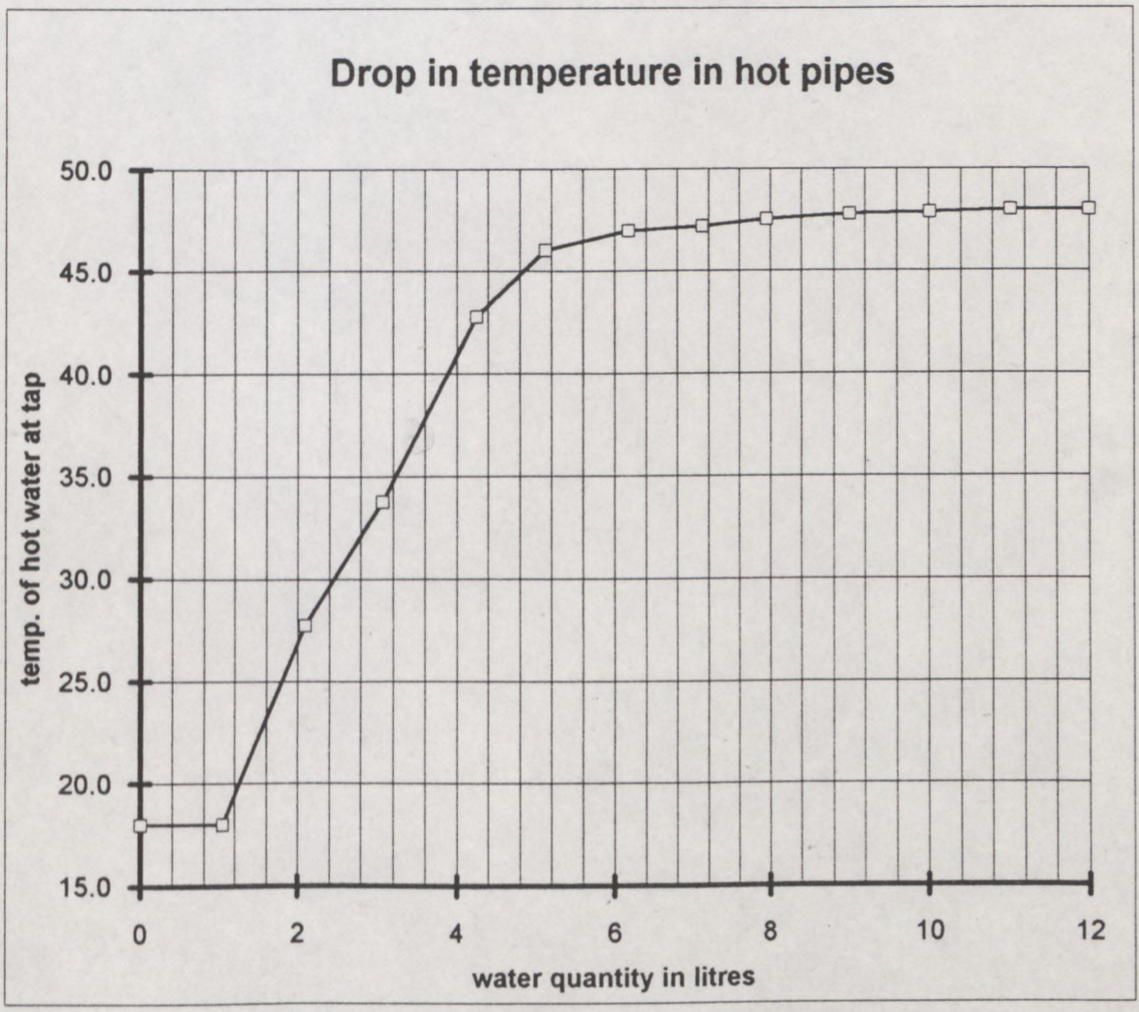
Occupant: Name: Address: Telephone number:	
Names of technicians doing the tests: Telephone numbers:	
Date and time the tests were performed	
Notes:	

Number of hot water cylinders in the house: ....

The next table is completed for each hot water cylinder in the house.

Hot water cylinder detail: Size element Thermostat setting Capacity in litres Hor. or Vert. Aided by solar heating? Temp. of cold water:		
Positioning of Hot water cylinder: room: height:		
Hot water pipe: size e.g. 12mm type e.g. copper route of pipe: eg in air in cement is there any lagging ? if yes describe please:		
How many taps are fed from the hot water cylinder?		
Running water test: (for at least the nearest and furthest tap) at the start of each test the water in the hot water pipe should be cold for this test the tap should be wide open		
	Tap no 1	Tap no 2
Position of tap e.g. for bath in main bathroom		

Length of pipe to HWC		
Temperature and time after each litre of water:	time temp. energy lost (to calculate)	time temp. energy lost (to calculate)
litres: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 continue until stable temperature is reached		
Calculation: 1. Quantity of water before water is warm: 2. Total energy lost $m(t_h-t_c)*4.187/3.6$ Wh 3. Energy lost when stable temp. is reached: $100*(t_{hwc}-t_{tap})/(t_{hwc}-t_{cold})$ %		



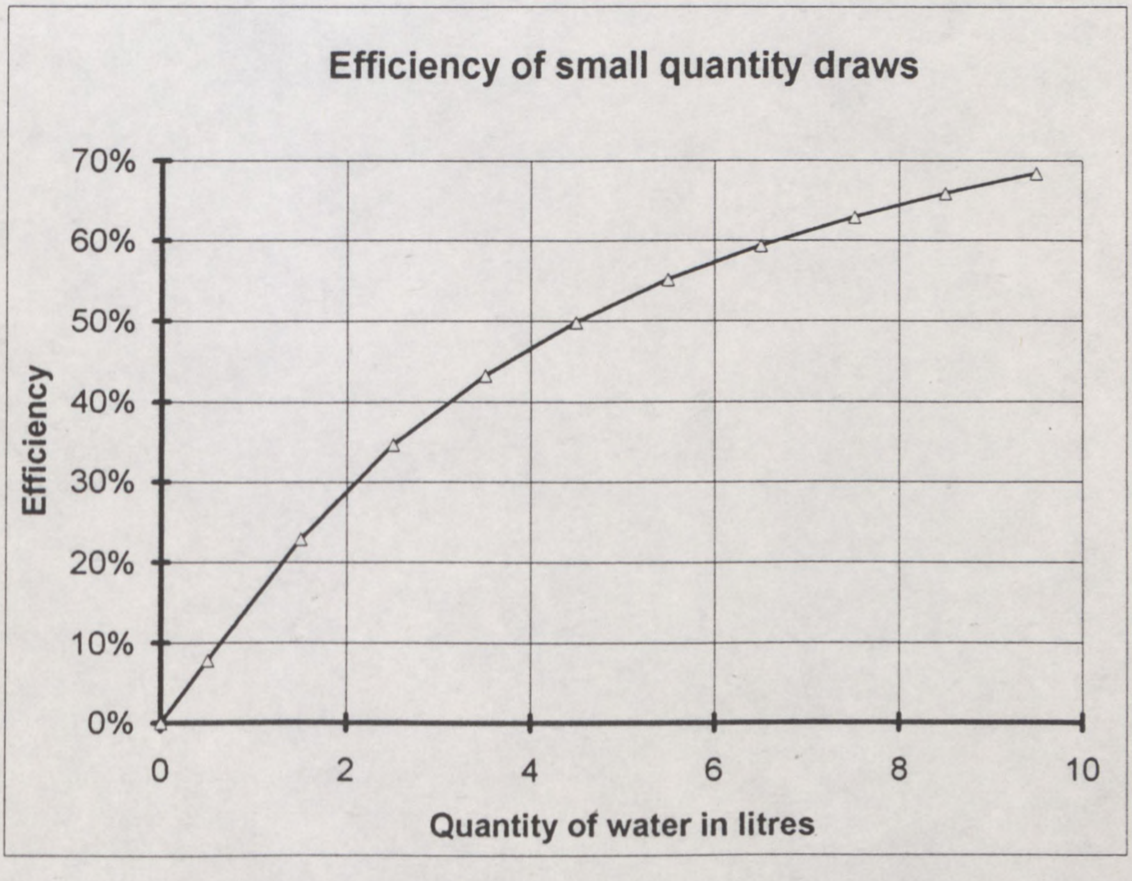
Appendix D.7 Temperature of hot water for the first few litres of water drawn

Efficiency of the hot water system for small volume draws

Cold water temperature:	18.0	C
Hot water temp. (in HWC):	48.5	C
Energy required to heat 1 litre:	35.5	Wh

Warm water			Energy				Efficiency
heated	useful	tap temp.	used	useful added	total useful	wasted	in
litres	litres	C	Wh	Wh	Wh	Wh	percent
0	0	18.0		0.0	0.0		
1	0	18.0	35.5	0.0	0.0	35.5	0%
2	0	27.7	70.9	0.0	0.0	70.9	0%
3	0	33.8	106.4	0.0	0.0	106.4	0%
4	0.5	40.5	141.9	11.1	11.1	130.8	8%
5	1.5	46.0	177.4	29.4	40.5	136.9	23%
6	2.5	47.0	212.8	33.1	73.6	139.2	35%
7	3.5	47.2	248.3	33.8	107.5	140.9	43%
8	4.5	47.5	283.8	34.2	141.6	142.2	50%
9	5.5	47.8	319.3	34.5	176.1	143.2	55%
10	6.5	47.9	354.7	34.7	210.8	143.9	59%
11	7.5	48.0	390.2	34.8	245.6	144.6	63%
12	8.5	48.0	425.7	34.9	280.5	145.2	66%
13	9.5	48.0	461.2	34.9	315.4	145.8	68%
14	10.5	48.0	496.6	34.9	350.3	146.3	71%
15	11.5	48.0	532.1	34.9	385.2	146.9	72%
16	12.5	48.0	567.6	34.9	420.1	147.5	74%
17	13.5	48.0	603.0	34.9	455.0	148.1	75%
18	14.5	48.0	638.5	34.9	489.9	148.7	77%
19	15.5	48.0	674.0	34.9	524.7	149.2	78%
20	16.5	48.0	709.5	34.9	559.6	149.8	79%
33.5	30	48.0	1188.4	471.0	1030.7	157.7	87%
63.5	60	48.0	2252.5	1046.8	2077.4	175.1	92%

Appendix D.8 Results of the readings taken in appendix D.7: Efficiency of low volume draws



Appendix D.8 cont. Efficiency of the hot water system for low volume draws

APPENDIX E

Hot water consumption patterns of selected households in townships near Cape Town

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Appendix E.1 Procedure followed to obtain information about the use of hot water by households in the developing community

1. Areas are selected to cover a reasonable cross section of the developing community who have grid electricity in their homes.

2. A questionnaire is designed to question households about their use of electrical energy, especially for hot water.

3. Interviewers are trained to fill in the questionnaire and sample surveys are done to test the questionnaire and to revise the questionnaire.

4. Questionnaires are completed and

5. The completed questionnaires are discussed with the interviewer to ensure that the data are correct.

6. The questionnaires are analyzed.

Appendix E.2 Form used to question households about their use of electrical energy.

		Owner family		Family 2		
	Do you have electricity in your house Y/N Note: This questionnaire is only for people with mains electricity in their homes.					
	How many years have you had mains electricity ?					
	How many years have you been in this house ?					
	Did you have electricity in your previous house ?					
	How many families are living in this house ? How many families are living in hokkies on the property ? How many of the families use mains electricity Note: This form can be used for 2 families living in the same house, or a separate form can be used for the second family.					
1	APPLIANCE DATA (used regularly)	No	use	No	use	
1.1	COOL STORAGE Fridge Freezer					
1.2	FOOD PREPARATION Stove Hot Plate..... Toaster......... Food Mixer Electric Pan.........................	.. ...				
1.3	HEATING of the HOUSE Electric heaters: Type: .... Non Electric heaters:......					

	During winter, do you have your heater on every day, or only on very cold days ? my heater is on **every/very cold** days are heaters in different rooms on at the same time when it is very cold? Y/N ...... how long per day do you use heaters when it is cold? ...... hours per day				
1.4	LAUNDRY Do you own an electric washing machine? Y/N If yes: Type: Top Loader/Front Loader/Twin Tub Do you use Hot or Cold water for washing ? If Hot: How do you heat the water ? How often do you use the washing machine?				
	Do you own a tumble drier? Y/N If yes: How often do you use it: during dry weather during wet weather				
	Do you own an electric iron How much do you use it per week? ..... days per week ...... hours per day				
1.5	LIFE QUALITY APPLIANCES TV Radio/HiFi Other				
1.6	LIGHTING number of electric bulbs in living room Are lights left on if there are no people in the room ? Y/N Are lights left on right through the night ? Y/N How many fluorescent lights do you have?				

1.7	HOT WATER Do you own a: Hot water cylinder Y/N Gas geyser Y/N Urn Y/N Kettle Y/N Other ways you use to heat water?				
1.8	Other appliances which use electricity: such as microwave oven, sewing machine, snackwich maker, polisher, welding machine, vacuum cleaner, tumble drier etc. .... Do you have a home industry at your house? Y/N If yes, which electrical appliances do you use ?				
2	HOT WATER USAGE DATA				
	Hot water used for washing: Please indicate per person: Baths(B) or Shower(S) (B/S) : eg B Time of day when washing (T) : eg 8 pm Times per week (wk) : eg 3/wk Hot or Cold (H/C) : eg H	B/S T wk H/C		B/S T wk H/C	
	under 5 years Winter- Bath or shower: Summer- Bath or Shower:				
	5-11 years Winter- Bath or shower: Summer- Bath or Shower:				

	12-18 years Winter- Bath or shower: Summer- Bath or Shower:				
	over 18 years Winter- Bath or shower: Summer- Bath or Shower:				
	How do you heat the water for a hot bath a hot shower				
	If you do not have a hot water cylinder: How much hot water do you use for 1 bath ? .... litres Is the hot water you add for a bath boiling? Y/N				
	Dish washing by hand ...times per day, Do you use hot or cold water for dish washing ?				
	Hand washing of laundry ... times per week, Do you use hot or cold water for laundry ?				
2.1	Please answer questions 2.1 to 2.3 if you own a hot water cylinder. Position of Hot Water Cylinder eg. in kitchen Number of hot water taps in the house: Where are the hot water taps ?				
2.2	How often do you run out of hot water ?				
2.3	For what purposes do you use hot water without mixing it with cold water ?				
3	PERSONAL DATA				
	Number in household	male	female	male	female
	Under 5 years old				
	5 to 12 years				
	13 to 18 years				
	Over 18 years				

Number of: bedrooms									
other rooms (excl.kitchen.&bathr.)									
Name:(optional) Address:									
Could we phone you if something is not clear? Y/N if yes: Tel No: work home									
Occupation father									
Occupation mother									
Occupation - other									
Cost of electricity (excluding outstanding account: Last month									
2 months ago									
3 months ago									
Cost of paraffin per month									
Cost of wood per month									
Cost of other forms of energy per month: eg. gas									
Rent or house instalment per month (optional)									
Total income/month (optional)	<R 700		>R 700		<R 700		>R 700		
(R 000's)	>1	>2	3	4	1	2	3	3	

Appendix E.3 Some of the conclusions reached after analysing the questionnaires

1. Electricity consumption varies widely from month to month.

2. Less than 10 % of the respondents use a shower.

3. More than 60 % of the respondents bath in the evening rather than in the morning.

4. Those without running hot water use less than 5 litres of hot water to bath themselves.

5. Less than 20 % use cold water for washing their laundry. While doing the questionnaires referred to in appendix E.2 it was found that the developed community normally use cold water for washing their laundry.

6. Nearly all respondents use hot water for dish washing.

7. About a quarter of the respondents use an electric hot water cylinder for water heating.

8. About a third of the respondents use non-electric ways of heating water even though they do have electricity. Half of those not using electricity to heat water use gas geysers.

9. It is difficult to obtain reliable data about electrical energy consumption by using a questionnaire. Measurements such as those described in appendix C and appendix D should be employed to record energy consumption patterns.

APPENDIX F

Ownership of electric water heaters

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Note: Unless otherwise stated, an electric water heater is considered as a device using electrical energy which supplies running hot water.

Appendix F.1 Running water and electricity in South African homes

- Running water and electricity are essential for an electric hot water system.

- The graphs in this section summarise statistical data about the availability of running water and electricity in South African homes (SAARF, 1991).

- The following details about the availability of running water in South African homes can be found from these data:

  - More than 90% of electrified homes in urban areas and in villages have running water. In urban areas more than 90 % of electrified homes of the Asian, black coloured and white population groups have running water in their homes, but only 30 % of rural black households have running water in their homes.

  - For black households:

    * only 26 % have running water and electricity in their homes,

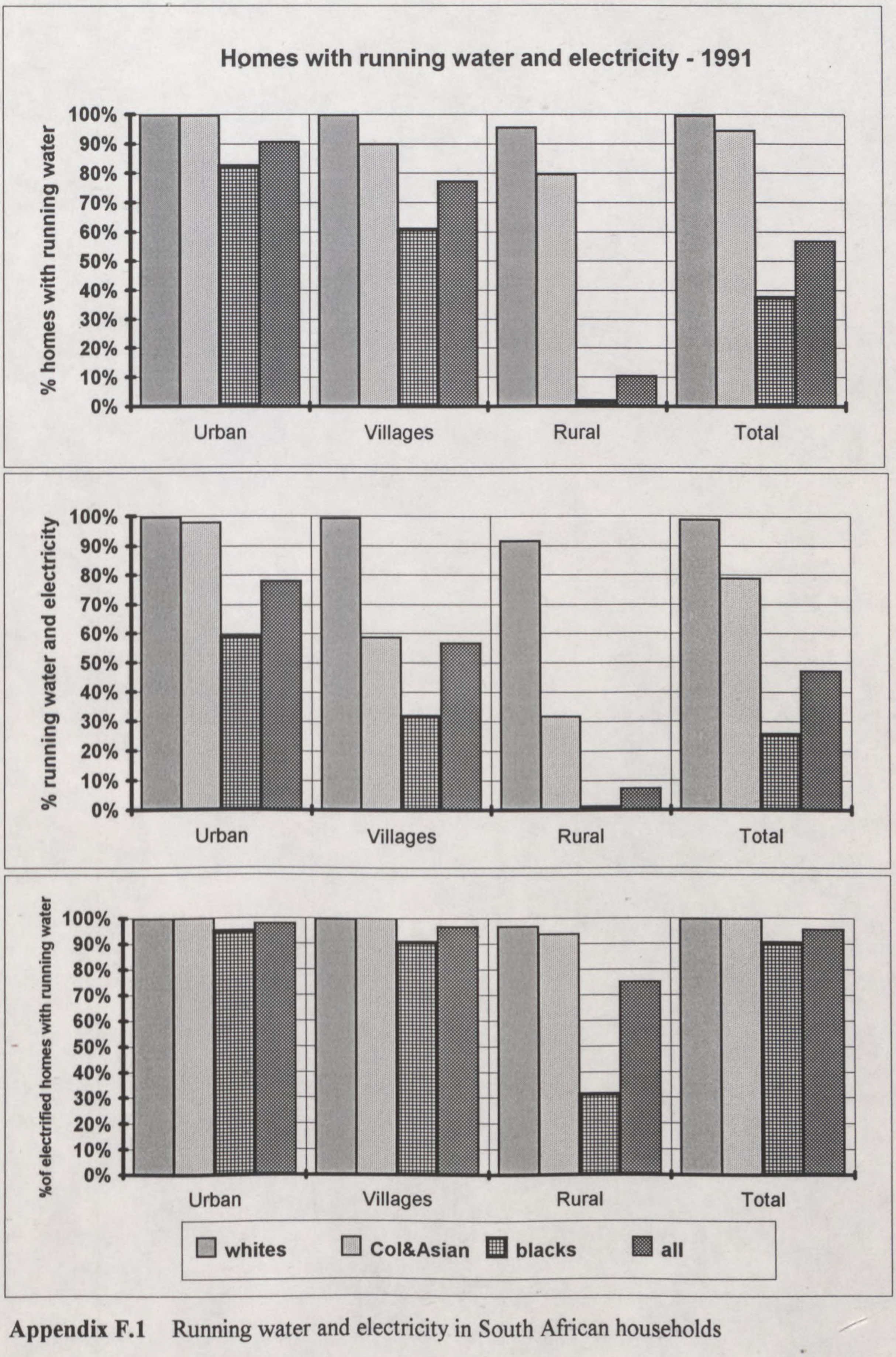
    * only 3% of rural households have electricity, 2% have running water and 1% have running water and electricity,

    * in most areas the percentage households with running water is slightly higher than the percentage households with electrical grid energy, but it is much higher in a few areas, such as the Cape where the level of electrification is very low,

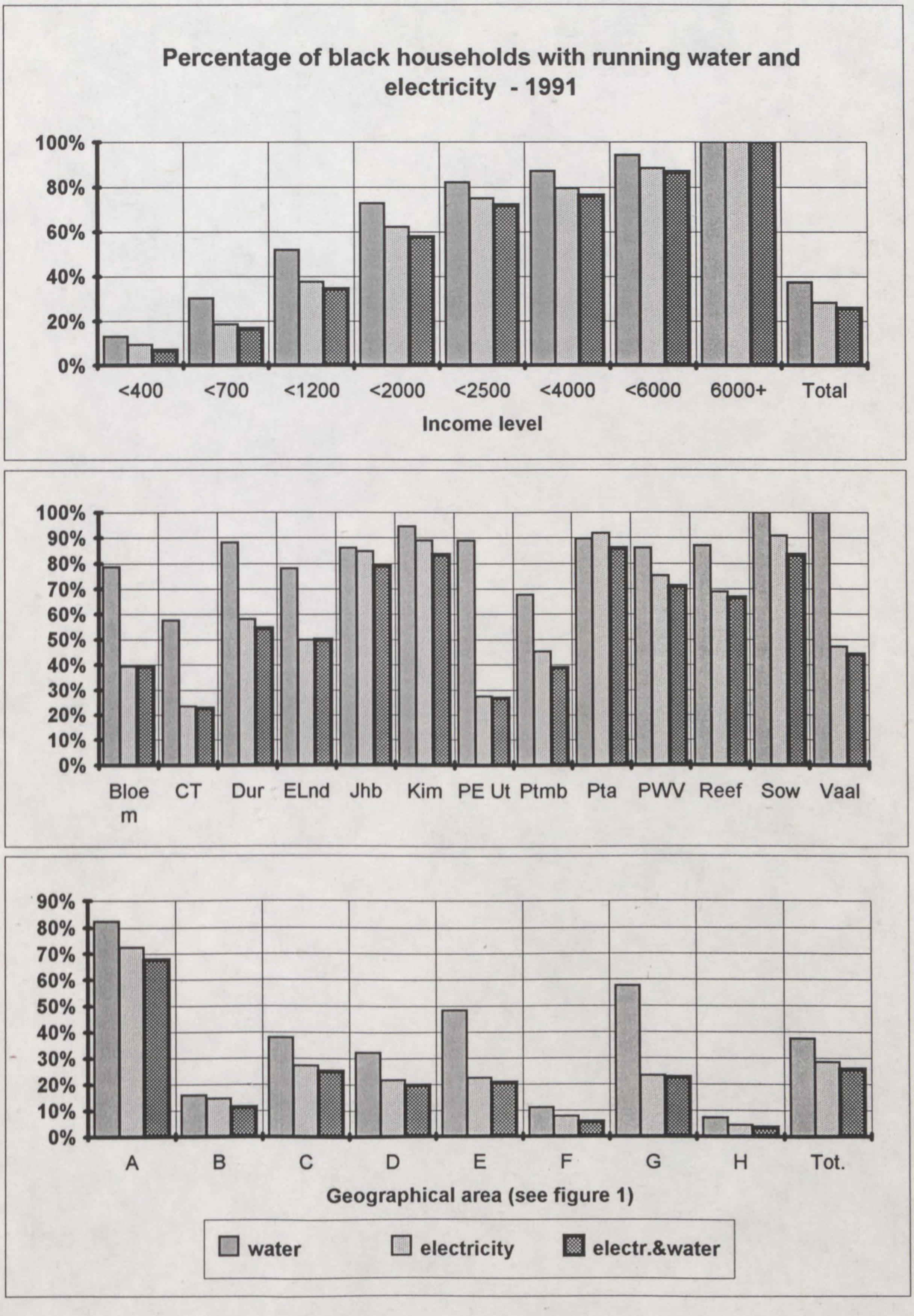
    * there is a strong correlation between the availability of running water and income or living standard,

    * there are more than 3 million households without running water, and about 2 million households with running water, and

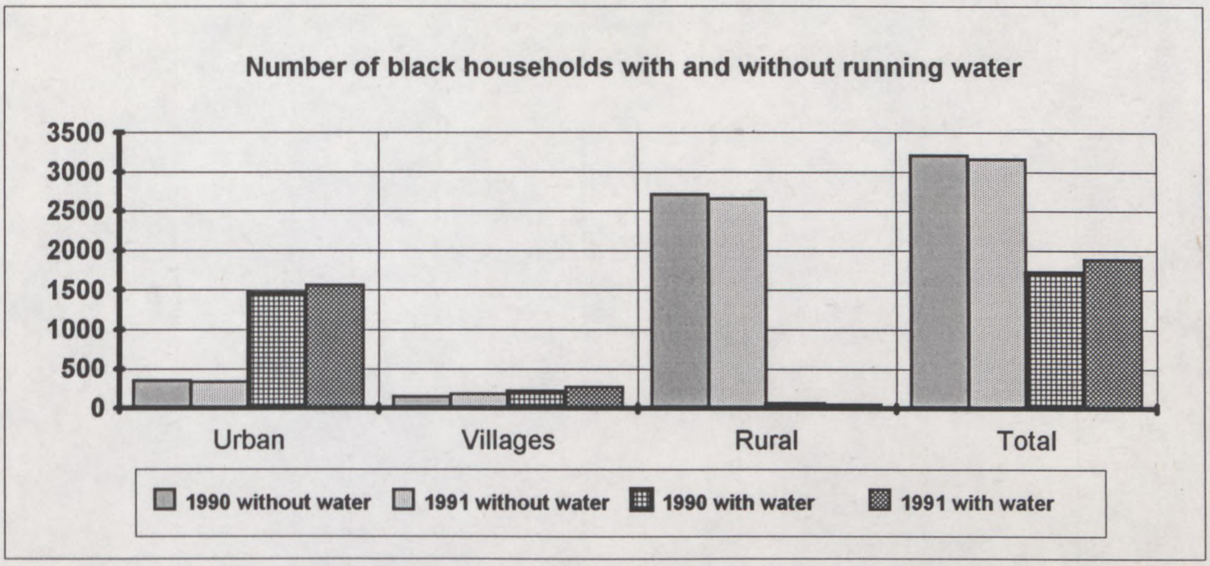
    * the number of households with running water in 1991 is about 10 % higher than what it was in 1990.

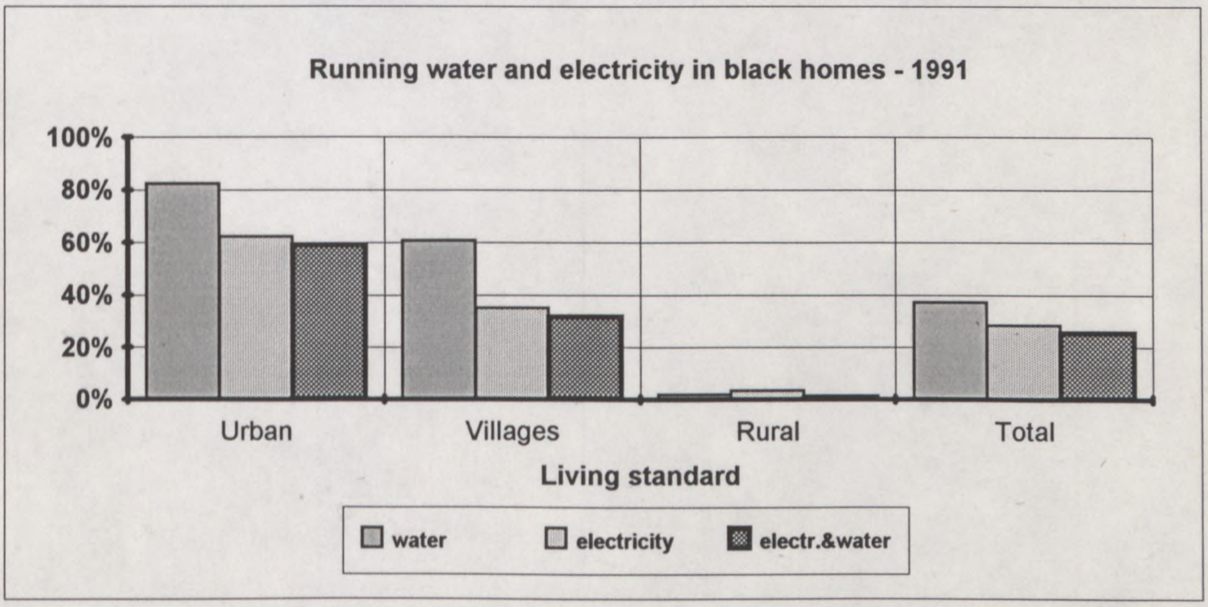


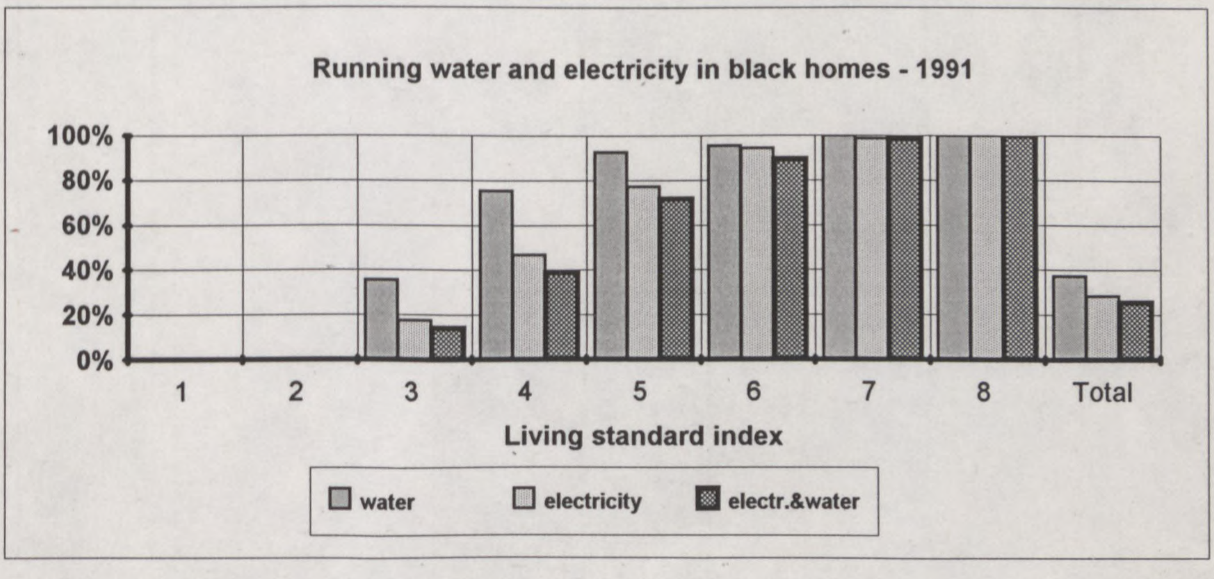
Appendix F.1 Running water and electricity in South African households



Appendix F.1 Running water and electricity in South African households







Appendix F.1 Running water and electricity in South African households

Appendix F.2 References to the ownership of electric water heaters in developing areas and related matters

1. Ownership of water heaters in electrified homes in Soweto

(Gervais, 1987:96)

Electric geyser:	23 %
Electric Urn:	6 %
Tank connected to coal stove:	2 %
Pots on stove:	30 %

Only 10 % of the respondents indicated that they definitely wanted to buy an electric water heater, while about 60 % indicated that they definitely were not considering buying an electric water heater.

2. Priorities when buying appliances

When it comes to expensive items, the data on appliance ownership indicate that recreational appliances such as TV's and hi-fi's are bought more readily than utilitarian appliances such as fridges and water heaters. It seems that most people regard electricity as a means of providing them with a more luxurious style of living (Golding & Heron, 1990:9).

3. Cost of energy to households in developing areas

The water heater is a large consumer of energy, and it is found that some consumers in Khayelitsha who do have electric water heaters keep their water heaters switched off for long periods, especially during summer, to save on energy costs. However, it has been shown that many households in Soweto using electricity together with other energy sources spend as much on energy as the average developed household using only electricity as energy source for a wide variety of appliances including an electric water heater (Barnard, 1991:105).

4. Ownership of electric water heaters in townships in the Cape area

A survey conducted in electrified homes in low income areas near Cape Town has shown that while only 3 % of households interviewed in older townships have electric water heaters, as many as 50 % of those interviewed in newly electrified areas have electric water heaters (Theron,1992:6).

It appears that it is unlikely for a household occupying a dwelling in a low income areas to install running hot water, if the dwelling does not already have running hot water.

5. Bathing facilities in urban areas

Nationwide surveys in black urban areas in 1989 indicated that the following percentages of facilities were available:

Running water:	80 %
Hot water:	9 %
built in bath	22 %
built in shower	11 %
built in bath and shower	2 %
built in wash basin	7 %

(MRA, 1989:54.2)

It appears that not many houses in low income areas are equipped to make proper use of running hot water.

6. Kwanobuhlo township customer survey

Surveys show that 58 % of electrified homes in the Kwanobuhlo township in the Eastern Cape have electric water heaters (Fenn, 1991:6).

7. Market research

Surveys conducted to determine the market penetration and the profile of the household with different appliances have identified the following characteristics of a household with an electric water heater:

- it belongs to a high income group,
- and is in the Eastern Cape;
- there is a television in the home,
- and the television is watched very often.

(Grey Marketing & Research, 1987:19)

Appendix F.3 Percentage households with running hot water

Developed sector:

Municipalities in the Cape area report that a high percentage, more than 95 %, of households in developed areas do have running hot water. Electric energy is used almost exclusively for water heating. It can be assumed that nationwide the ownership of electric water heaters in developed areas is about 95 %.

Developing sector:

A survey was conducted in what is considered to be the top secondary school in Khayelitsha asking who has an electric water heater at home. The response reveals that about half of those with electricity in their homes have an electric water heater.

Considering all the references given in section F.2 and the availability of running water in section F.1, it appears that a realistic estimate of the percentage of electrified homes with electric water heaters is 35 %. This means that about 10 % of all the houses in low income areas use electric water heating.

It also appears that the installation of electric water heating in houses in low income areas does not depend so much on the occupant of the house, but rather on those who build the houses and install the electrical installation. Not many cases have been found where the occupant of the house arranges to have a hot water system installed.

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