

# A review of domestic hot-water consumption in South Africa

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*A review is given of domestic hot-water consumption for five different types of dwellings in the developed and developing communities of the Johannesburg Metropolitan area, South Africa. The types of dwellings are houses, town houses, apartments, traditional houses and shacks. The consumptions were determined with direct measurements over a period of one year (1996) in 770 dwellings. The hot-water consumptions were taken monthly with the exception of 310 dwellings — where the measurements were also logged, resulting in hourly hot-water consumptions. The results of the two types of measurements are presented for the different types of dwellings: firstly, hot-water consumption per person per day for the different months of a year; and secondly, hourly hot-water consumption per person per day as a function of winter weekdays.*

## Nomenclature

$C_p$	heating capacity of water at constant pressure, J/kg.K
$d$	number of days in the relevant month
$m_g$	assumed hot-water consumption at a temperature of 65°C
$m_h$	measured hot-water consumption, litres
$n$	number of people per dwelling
$T_g$	reference temperature of 65°C
$T_f$	feed-water temperature, °C
$T_m$	measured hot-water temperature, °C

## Introduction

The heating of domestic hot water is an important component of energy consumption in the residential sector in many countries. The energy consumed in the residential sector in the USA, for example, is second only to space heating in the residential sector. However, reliable performance data on domestic water heaters are limited, and the available information is dated.<sup>2</sup> Due to this problem, the values used for sizing and the performance of hot-water equipment are usually not accurate and produce incorrect results when compared to measured test data.

Becker & Stogsdill<sup>3</sup> found that the utility industry, consulting engineers and water-heater manufacturers are meeting difficulties in developing new equipment and more efficient systems, as well as in analysing existing ones. For

these reasons, a survey was conducted in the USA. The survey included the research of published literature, enquiries at laboratories, manufacturers, the government and trade and professional organisations, as well as an extensive computer literature search. Of the 36 references collected, nine were found to contain data directly related to patterns of hot-water use. In order to process the information effectively, a database, containing more than 30 million data points, was established from the nine pertinent reports.

Owing to South Africa's very mild climate, hot-water consumption — and not space heating — is the largest user of energy in the domestic sector. Estimates vary, but figures as high as 40% to 50% of the monthly electricity use of an average middle-to-upper income household have been quoted for water heating in the South African Energy Policy Discussion Document.<sup>13</sup>

Three sources of reference on hot-water consumption are known in South Africa: the first being Basson<sup>1</sup> in which a value of 50 litres per person per day is quoted for developed communities. The second source of information on hot-water consumption is that of Meyer & Greyvenstein,<sup>6</sup> which endorses the value of Basson in summer, but adapts the value for the rest of the season with a cosine function. This implies that the average hot-water consumption per person varies between a minimum of 50 litres during December (summer) and 75 litres during June (winter). This data are, however, only used in and applicable to the average developed community of South Africa. The third source on hot-water consumption rates is that of Beute<sup>4</sup> in which a figure of 35 litres per person per day for people in developing communities is suggested. The figure is, however, an estimated consumption, which was not based on any direct measurements.

No reliable data therefore exist for hot-water consumption in South Africa, although the values of Meyer & Greyvenstein<sup>6</sup> are used by many engineers in industry. Even though there is a possibility of using the database developed by Becker & Stogsdill<sup>3</sup> for the USA, Schipper<sup>14</sup> found that Americans use up to seven times more hot water than the citizens of certain developed European countries. Schipper, as well as Vine,<sup>15</sup> concluded that hot-water consumption is influenced by cultural and social norms. Therefore, although a well-established database system is available on the hot-water consumption patterns of Americans, it cannot be applied to the South African situation.

The building of large numbers of new dwellings and electrification in South Africa have opened up a large mar-

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ket for hot-water storage systems, and many companies around the world are trying to develop cheaper hot-water storage systems. Hot-water systems under consideration for the developing communities are instant water heaters, solar systems, paraffin systems, and small storage tanks. For the developed communities it is solar and hot-water heat pumps. Cost is the major concern in the developing communities while efficiency and environmental impact are getting more important in the developed communities. Before optimising hot-water heating systems for both the developed and developing communities, the average daily hot-water consumptions as well as the peak hot-water consumptions are necessary to determine the hot-water storage capacity and optimum heating capacity.

The purpose in this paper was to summarise results from measurements taken on hot-water consumption in the developed and developing communities of South Africa. This data can also be used for the rest of Africa until better data are gathered. The data are a review of work already published in international literature by the author on this subject. Since the results are specifically valid for South Africa, it was also the purpose of this paper to present these results, which were probably not known to many South African engineers, to a predominately South African audience in a South African journal. The already published work in this regard can be divided into results for houses,<sup>9</sup> town houses,<sup>11</sup> apartments,<sup>12</sup> traditional houses,<sup>8</sup> and shacks.<sup>10</sup> The emphasis of the work is on the data and not on investigating the social behaviour of hot-water consumption, except where this could be easily determined.

### Description of houses

According to the latest household survey of the Central Statistical Service (1995), there are 8 687 607 dwellings in South Africa of which 5 790 446 or 66.7% are defined as houses or parts of houses. The other categories of dwellings are traditional dwellings (14.1%), shacks (7.8%), apartments (4%), hostels/rooms (3.5%), town houses/semi-detached houses (2.7%), shacks on same site as house (1%), and other (0.39%). Different categories of dwellings are defined according to the materials used for the construction of the walls and roof. The dwellings considered in this study are given in Table 1. Hostels/rooms were not considered for logistical and budget reasons. Most traditional houses do not have electricity and therefore do not have any storage tanks. The traditional houses selected, however, did have electricity and hot-water storage tanks and most of them were situated on farms or smallholdings where access to electricity was provided by the farmer, even though the dwellings were not constructed from bricks, etc.

For the purpose of this study, dwellings were divided into three groups that represent the developed and developing communities of South Africa. The groups are dwellings of low, medium, and high density. Low- and medium-density dwellings represented the developed community and high density dwellings the developing community. The dwelling densities in dwellings per square kilometre

(dwellings per square mile) and number of occupants for each group were also determined in the survey. The age of occupants was not taken into consideration and every person (irrespective of age) was counted as one occupant.

**Table 1** Densities and number of occupants for different categories of dwellings considered

Category	Density [dwellings/km <sup>2</sup> ]	Occupants per dwelling
<b>Houses</b>		
Low density	845	3.1
Medium density	2 029	3.8
High density	3 857	6.2
<b>Traditional</b>	1 720 to 40 000	5.7 to 8.2
<b>Shacks</b>	60 000	3.8
<b>Apartments</b>		
Low density	4 960	2.2
Medium density	8 734	3.3
High density	26 874	3.8
<b>Townhouses</b>		
Low density	3 810	2.1
Medium density	8 116	3.3
High density	25 195	3.7

### Domestic water heating

The methods used in South Africa for heating domestic hot water are: solar heating, heat pumps, gas heating, and electrical elements. Although South Africa is one of the countries in the world that are most suited for solar heating, an insignificant number of dwellings are fitted with solar water-heating systems. The reason for this is the high capital cost and the low cost of electricity. Domestic hot-water heat pumps<sup>6</sup> have only recently started to penetrate the residential market and the number of units in use is therefore very small. Unlike many countries in the world, natural gas is not readily available in South Africa and is therefore not distributed to dwellings via pipelines. Therefore, gas in pressurised bottles is usually only used in rural areas where electricity is not available. Most of the houses in South Africa with access to electricity use electric geysers for water heating. The geyser consists of an insulated hot-water storage tank and an immersed electrical resistant element.

### Monthly measurements

Measurements of hot-water consumption were taken in the Johannesburg Metropolitan area for a period of one year (1996) in 770 dwellings. The hot-water consumptions were taken monthly, except in 310 dwellings where the measurements were logged, resulting in hourly hot-water consumptions. The measurements were taken as shown in Table 2.

**Table 2** Number of dwellings measured

Category	Number of dwellings
<b>Houses</b>	
Low density	100
Medium density	100
High density	100
Total	300
<b>Traditional houses</b>	90
<b>Shacks</b>	200
<b>Apartments</b>	
Low density	30
Medium density	30
High density	30
Total	90
<b>Townhouses</b>	
Low density	30
Medium density	30
High density	30
Total	90

Different dwellings in Johannesburg were selected according to Table 2 and a water meter was installed in each, just upstream of the hot-water tank. The water meter was a volumetric-type domestic water meter operating on the rotary principle. The maximum inaccuracy of the meter, which occurred at flow rates lower than 15 l/h, was less than 5%. If the flow rate was higher than 22.5 l/h, the inaccuracy was less than 2%. After installation of the water meter, the geyser thermostats were set at a temperature of 65°C, which is the factory setting on most geysers. When the dwellings were selected, care was taken to ensure that the capacities of the geysers allowed enough hot water, which would ensure that most of the hot water would be used at approximately the hot-water storage temperature.

On the last day of every month the reading on each meter was taken to obtain the total household consumption. The hot-water temperature was also checked to ensure that the water was still stored at 65°C. The number of people staying in a house was verified and the average hot-water consumption per person per day for the relevant month was calculated.

University students took the measurements over a period of one year. Each student had to take ten measurements at different dwellings at the end of each month. It was, however, not always possible to take the measurements on the last day of the month, as the occupants were not always at home. In such cases the necessary adjustments were made to the data by adding an extra day or two for calculation of the consumption.

Shacks are invariably occupied illegally, on unused land, as near as possible to city centres. The occupants are usually unemployed or, if employed, earn below the bread-line. The largest settlements are found next to rivers or

streams from which water is used for domestic purposes. In the case of shack owners, however, electrical heating methods cannot be afforded and are usually not available. The most common method of hot-water heating is on open fires in pots.

Two hundred shacks in Johannesburg were identified from more than twenty different squatter settlements and the owners were issued with a specially calibrated pot and a thermometer. The calibration marks on the pot and thermometer were in different colours as illiteracy is general. Each day coloured score sheets were issued on which the owner marked the colour of the pot, the colour of the thermometer and a clock, on which the approximate time of use was drawn.

Clean score sheets were handed out and used sheets were collected daily by university students who also wrote the date on the score sheets. In the beginning the students supervised the process of heating the water and filling in of the score sheets until the owner was confident enough to do it alone. From the score sheet the amount of water, feed-water temperature, hot-water temperature and time of use could be deduced. The measurements were taken over a period of one year. Each student had to take measurements in ten shacks daily. The volumes of hot water per person per day were calculated, but adjusted to a hot-water temperature of 65°C using the first law of thermodynamics, based on the assumption that the amount of heat used would be the same:

$$n m_h d C_p (T_m - T_f) = n m_g d C_p (T_g - T_f) \quad (1)$$

Heat losses to the environment were not taken into consideration. The hot-water consumption at a temperature of 65°C therefore reduced to

$$m_g = m_h (T_m - T_f) / (65 - T_f) \quad (2)$$

The reason a reference temperature of 65°C was used, was that it is the average storage temperature in most hot-water storage tanks in the developed community of South Africa.<sup>7</sup>

Average daily ambient temperatures and ground temperatures at a depth of 300 mm were also measured in Auckland Park, Johannesburg. It could be assumed that the feed-water temperature to the storage tanks was equal to the ground temperatures at a depth of 300 mm.<sup>7</sup> The results of these measurements are given in Figure 1.

### Results of monthly consumptions

The results of the measurements of hot-water consumption are given in Figures 2 to 6. Average hot-water consumptions in litres per person per day are given as a function of the different months of the year for low-, medium-, and high-density dwellings, where relevant. The maximum standard deviations from the average values are given in Table 3.

It could be concluded that the consumption in houses, apartments, and town houses was much higher than in traditional houses and shacks. The reason for this was that

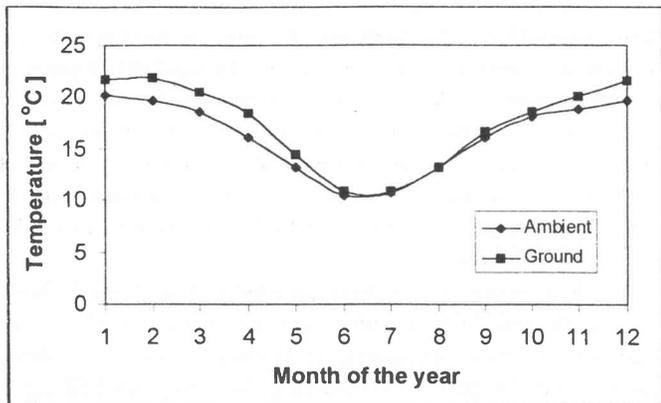


Figure 1 Measured average ambient temperatures and ground temperatures during 1996

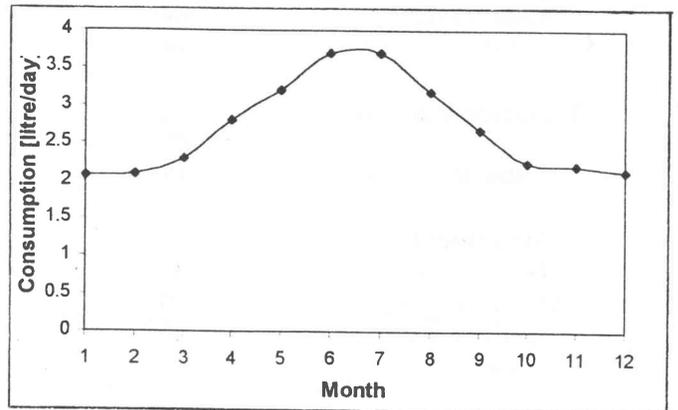


Figure 4 Average hot-water consumption in shacks per person per day

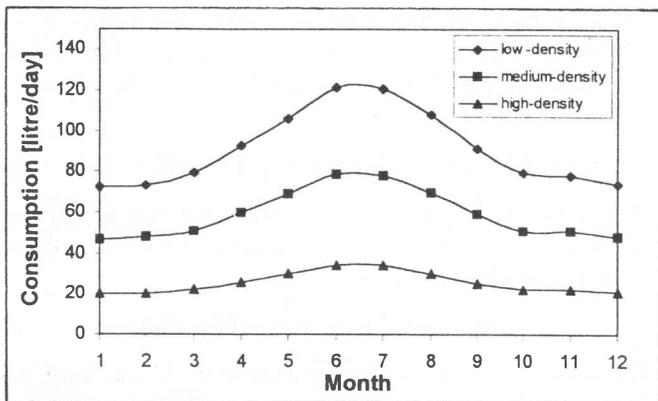


Figure 2 Average hot-water consumption in houses per person per day for low-, medium-, and high density houses

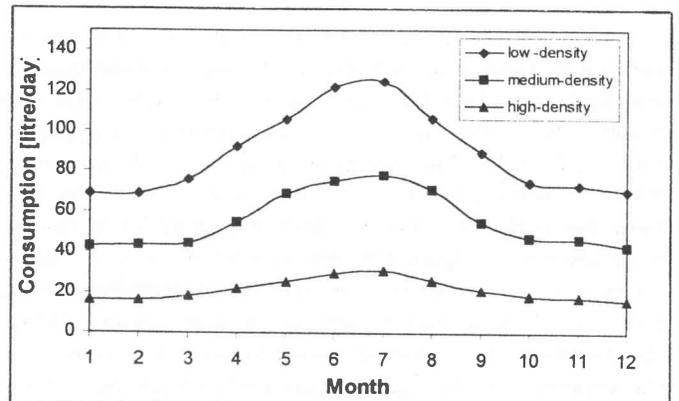


Figure 5 Average hot-water consumption in apartments per person per day for low-, medium-, and high-density apartments

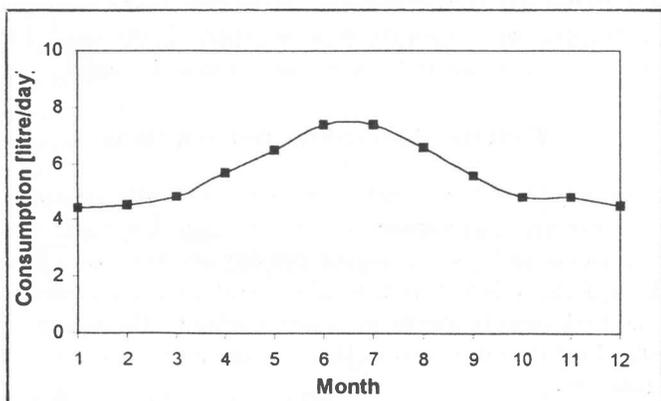


Figure 3 Average hot-water consumption in shacks per person per day

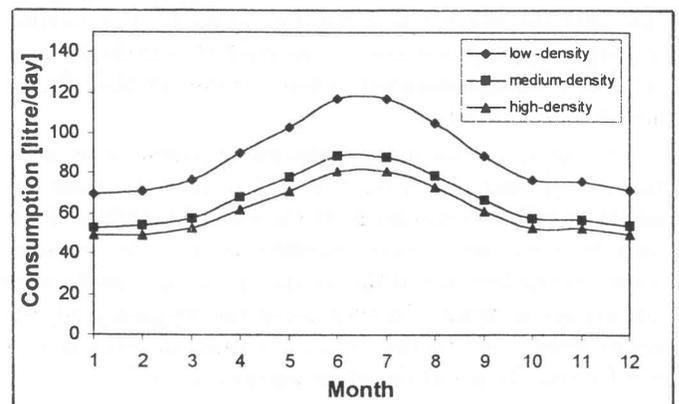


Figure 6 Average hot-water consumption in town houses per person per day for low-, medium-, and high-density town houses

the last two are occupied mainly by the developing community. It could also be deduced that the average hot-water consumption was low in the summer months (October to March) and the highest consumption occurred during midwinter (June/July). In general it increased by approximately 70% from summer to winter.

**Table 3** Maximum standard deviation from the averages for the different types of dwellings

Category	Summer standard deviation	Winter standard deviation
Houses	±17%	±30%
Traditional	±20%	±34%
Shacks	±16%	±26%
Apartments	±8%	±23%
Townhouses	±9%	±14%

### Hourly measurements

Thirty houses (10 in each category of low-, medium- and high-density), 30 traditional houses, 30 apartments (10 in each category of low-, medium- and high-density), and 30 town houses (10 in each category of low-, medium- and high-density) were fitted with digital flowmeters just upstream of the hot-water geyser, and measurements were taken with a 60 minute-interval recorder. The maximum inaccuracy of the meter was less than 3%. Again, all the geyser thermostats were set at 65°C and measurements were taken over a period of one year. In the selection of houses care was taken to ensure that the capacity of the geyser allowed enough hot water. This ensured that most of the hot water would be used at approximately the geyser storage temperature. The dwellings selected had monthly hot-water consumptions very close to the monthly average values in Figures 2, 3, 5, and 6, respectively, thus assuring that the users were not outside the standard deviations given in Table 3. In the case of shacks the score sheets provided sufficient information to determine the hourly consumptions.

### Results of hourly consumptions

It was found that measurements of average hourly hot-water usages had to be divided into four categories, namely, summer weekdays, summer week-ends, winter weekdays, and winter week-ends. It was important to distinguish between these categories as it was found that each category differed from the other on the specific times that peaks occurred and on consumption. The average winter weekly hot-water usages were the highest and are given in Figures 7 to 11. The results for summer weekdays, summer week-ends and winter week-ends are not given here. These results, however, can be found in the publications of Meyer & Tshimankinda,<sup>8</sup> Meyer

& Tshimankinda,<sup>9</sup> Meyer & Tshimankinda,<sup>10</sup> Meyer & Tshimankinda,<sup>11</sup> Meyer & Tshimankinda.<sup>12</sup> The maximum deviation from the averages for all dwelling measurements varied between ±17% during summer and ±30% during winter. Therefore 95% of the measurements were within 17% of the average during summer, but in winter these were higher, ±30%, from the average. Results of summer weekdays, summer week-ends and winter week-ends, which differed from the results given in Figures 7 to 11, are given in Meyer & Tshimankinda,<sup>9</sup> Meyer & Tshimankinda,<sup>11</sup> Meyer & Tshimankinda,<sup>12</sup> Meyer & Tshimankinda,<sup>8</sup> Meyer & Tshimankinda.<sup>10</sup>

### Discussion

It can be deduced from the results that people occupying low-density houses use 3.6 times more hot water than people living in high-density houses. This is expected since, in general, high-density houses represent the low-income group whilst the high-income group live in low-density houses. It can also be concluded from Figure 2 that hot-water consumption in houses increases by 70% from summer to winter. The annual average hot-water consumptions per person per day for low-, medium- and high-density houses were 91.4, 59.3, and 25.4 ℓ, respectively. For traditional houses it was 5.6 ℓ per person per day at a temperature of 65°C. For shacks the average was 2.7 ℓ per person per day. For apartments the annual average hot-water consumptions per person per day for low-, medium- and high density apartments were 89.4, 56.0, and 21.6 ℓ, respectively. These figures were very similar to houses, with a maximum deviation of 15%. For town houses these figures were 88.6, 66.8, and 61.5 ℓ, respectively.

From Figures 7 to 11 it can be concluded that two peaks exist for winter (May to August), a morning peak and an evening peak of approximately the same size. The morning peak for high-density houses (Figure 7) was at 06:00 while it was at 08:00 for low-density houses. The same tendency existed for the evening peak, which was at 18:00 for high-density houses, and at 20:00 for low-density houses. The difference between the two peaks was 2 h. In principle the same type of behaviour was found for traditional houses (Figure 8), shacks (Figure 9), apartments (Figure 10), and town houses (Figure 11).

**Table 4** Average travel time between house and work

Category of house	Time [minutes]
Low density	21
Medium density	34
High density	85

The reason for the difference was the time difference in travel between home and work. In general it was found that people living in low-density houses stayed closer

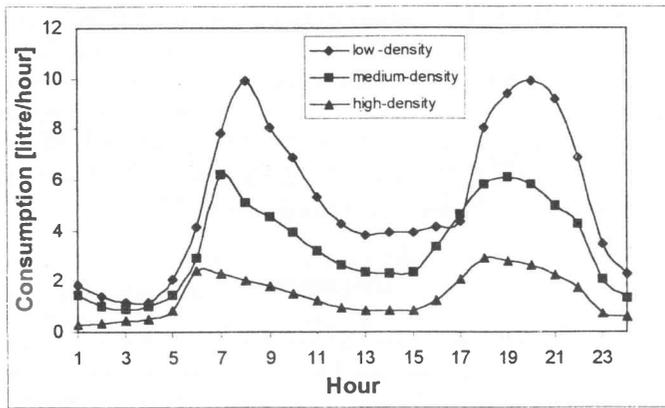


Figure 7 Average hourly hot-water consumption in houses per person

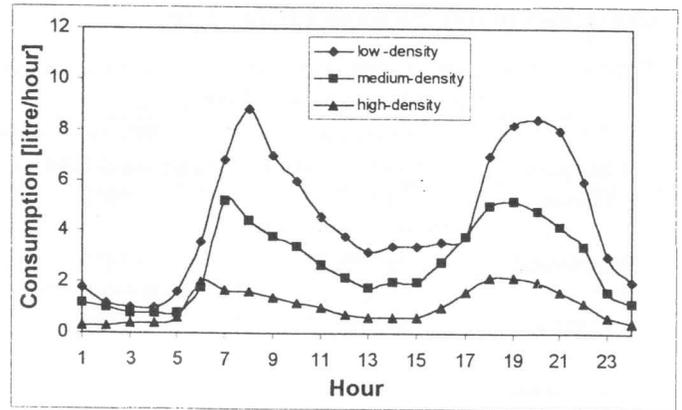


Figure 10 Average hourly hot-water consumption in apartments per person

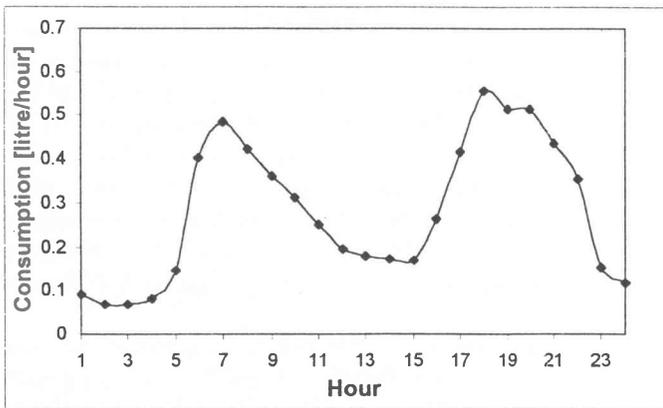


Figure 8 Average hourly hot-water consumption in traditional houses per person

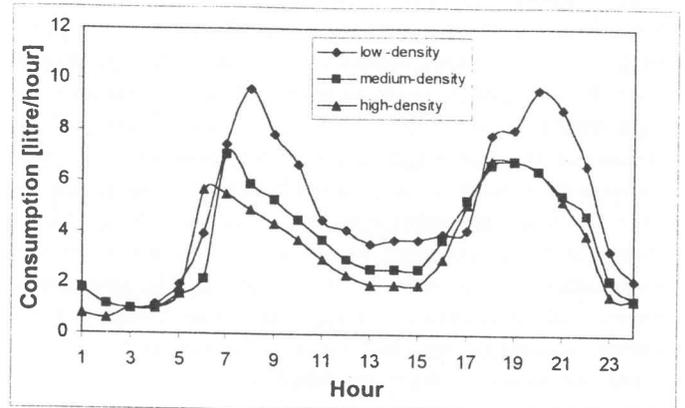


Figure 11 Average hourly hot-water consumption in town houses per person

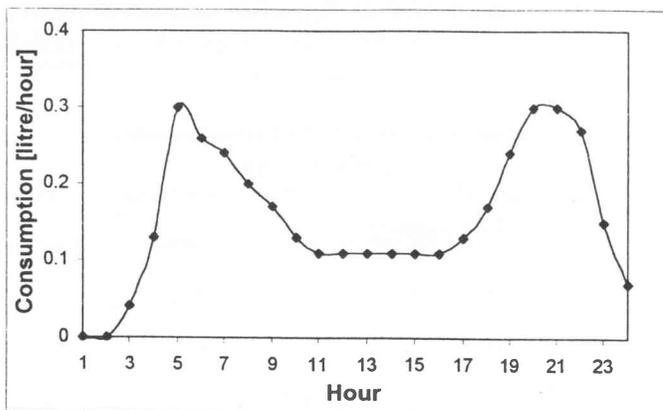


Figure 9 Average hourly hot-water consumption in shacks per person

to their place of work than people living in high-density houses, as can be seen from Table 4.

It was also found that people living in high-density houses were more dependent on public transport. The reason why the evening peak for high-density houses was earlier is that people living in high-density houses go to bed earlier as they have to get up earlier to be on time for work.

The earliest peak for all the different types of dwellings was for shacks, which was at 05:00. This makes sense since people living in shacks are dependent on public transport and furthermore the shacks are usually built on the peripheral area of cities. On the other hand, the peak for people staying in apartments and town houses was between 06:00 and 08:00 because they live closer to their work and were also closer to the city centre.

### Conclusions

It was found from measurements that people living in Johannesburg and occupying low-density houses used almost four times more hot water than people living in high-density houses. This was expected since, in general, high-density houses represent the low-income or developing community whilst low-density houses represent the high-income or developed community in South Africa. It was also found that hot-water consumption increased by 70% from summer to winter.

It was also concluded that measurements of average hourly hot-water usages must be divided into four sections, namely, summer weekdays, summer week-ends, winter weekdays, and winter week-ends. Each section differs from the other on the specific times that peaks occur and also on consumptions. In all cases, however, two peaks occur, namely, a morning peak and an evening peak. The highest peaks occur on winter weekdays.

### Acknowledgement

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