CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter will stimulate the reader to pursue in the field of consumer-orientated control and to expect the unexpected. Utilities and municipalities have dominated HWLC-strategies since infancy. It is inevitable that some emotions would be stirred when the paradigms starts to shift towards consumer-orientated control.

5.1 OVERVIEW

Chapter 1 introduced the reader to the South African electrification crisis and the benchmarks set by Eskom to contain this problem. Various options have been mentioned on both supply and demand-side while the reader was guided to realise the potential of HWLC as energy management solution.

The dog-eat-dog world of today hardly offers any solution without a price. The problems hampering HWLC was not known at the pioneering stages of implementation and it resulted in a negative experience by the general public. Direct - and indirect control strategies have been discussed, which led to the various objectives of the utility, municipality and residential consumer. Unattended effects of human behaviour on the national load-profile were examined to facilitate the possible pitfall areas and to find a sphere of mutual satisfaction.

The final segment of chapter 1 was dedicated to work done in the field of HWLC-system dynamics. Imperative trends such as cold-load pickup and load restoration were discussed, based on the work done by other researchers in the field. The discussion flowed into incorrect application of various tariff structures and other deficiencies encountered by existing HWLC-systems.

From there on it was possible to define an HWLC-methodology, only applicable for optimal load control on a national level. A micro level model was derived to pursue national savings on municipal level. Global compatibility constrained the model definition, which made it impossible to define the inputs to the bone. System details are unique to each control system and can be dealt with during the implementation phase.

Model inputs are therefore not system specific and defined as the:

- End-user group configuration,
- Electricity tariff,
- Required production profile,
- System & process limitations and constraints,
- Management rules and
- Buffer systems.

The processed inputs resulted in the following measurable outputs:

- Electricity load-profiles and
- Buffer system-levels.

Specific problem areas identified during the model description included:

- Cold-load pickup,
- Pro-active control,
- Consumer group configuration,
- Minimise risk of cold water and
- Savings distribution.

A methodology for each problem was formulated with the intention of directing the correct application within the end-user model. Two methodologies required specialised mathematical procedures to prepare the model-input-data.

Chapter 3 was dedicated to develop the load reaction - and the temperature prediction models.

Finally Chapter 4 painted the picture of load control on campus. The University of Pretoria can be seen as a pioneer for new ventures in HWLC, but experience in the field had a price tag attached to it.

5.2 CONCLUSIONS AND RECOMMENDATIONS

This dissertation will not necessarily convince every municipality to alter their load control strategies, but the defined methodologies can be used as the foundation for future development. This section carries the conclusions and recommendations made by the author in respect of the work done to date.

5.2.1 End-User Model

The end-user model was developed as a guide to integrate consumer friendly HWLC into new - or existing HWLC-systems, leaving enough freedom for system specific criteria. Chapter 4 used the University of Pretoria as example to illustrate the process of filling the skeleton model with flesh according to user – and system specifications. The end-user model can be applied to any HWLC-system, controlled by utility or municipality, as long as the system specific objectives set by the utility, municipality and residential consumers are met.

The management rules can only be defined once the specific needs of the residential consumers have been determined and can easily be revealed by creative market research activities. Consumer needs will vary between:

- ☐ High - and low income groups,
- ☐ Costal - and inland provinces,
- ☐ Rural - and urban municipalities, etc.

HWLC-systems can only be as successful as the accuracy of its consumer group configuration. The next paragraph will take a closer look at the advantages of dividing users into groups according to their hot water requirements.

5.2.2 Consumer Group Configuration

Research has shown that most of the HWLC-systems in South Africa use a random consumer distribution technique. This means that the population of a specific user group is randomly scattered across the entire controllable region and all the user groups contains the same amount of members. The reasons for this is to:

- ☐ Distribute the load reaction over all the transformers and switchgear when a specific group is restored,
- ☐ To cancel the behavioural differences out between various residential areas and
- ☐ It is easier to calculate the savings when all the user groups have the same installed capacity.

At the time when these systems were developed, the random distribution technique was almost unbeatable. Today's computer technology allows researchers and programmers to implement complex algorithms into the control strategies. It is possible to divide the users into smaller user groups and to calculate their individual contribution in terms of utility bill reductions.

"You cannot measure without influencing the results."

The traditional form of notch testing involves switching all the devices OFF on the half-hour for five minutes, switching them back ON afterwards. The five-minute shedding interval has a significant CLP effect on the data, affecting the resultant ADMD values. Thanks to the increased data delivery rate of radio-controlled units, the notch interval period can be decreased to 30-seconds. CNES is currently conducting tests to determine the optimal notch interval length, minimising the CLP effect and still be able to measure the notch value, and the optimum period between notches. The outcome of these experiments will minimise the measurement uncertainty and result in more accurate consumer consumption profiles.

The consumer group configuration proposal on page 41 allows the user to specify the time during the day in which he wishes to extract hot water from the cylinder. Stated from another perspective, the user can select specific periods in the day that the controller may extract energy below the 40°C threshold. This group distribution strategy allows the HWLC-system to extract the optimal amount of energy from each hot water cylinder, without infringing on comfort-levels.

The proposed consumer groups are only a guideline and consumption can primarily be categorised into four time intervals:

- ❑ Morning (6:00 – 10:00),
- ❑ Midday (10:00 – 18:00),
- ❑ Sundown (18:00 – 20:00) and
- ❑ Evening (20:00 – 6:00).

These intervals coincide with the national peak times and will be complemented when controlled according to a TOU-tariff. The categorisation of users into specific consumption intervals will refine the accuracy of the load reaction model, the average cylinder temperature model as well as the savings distribution. This can be illustrated by taking another look at the ADMD profile of South Africa.

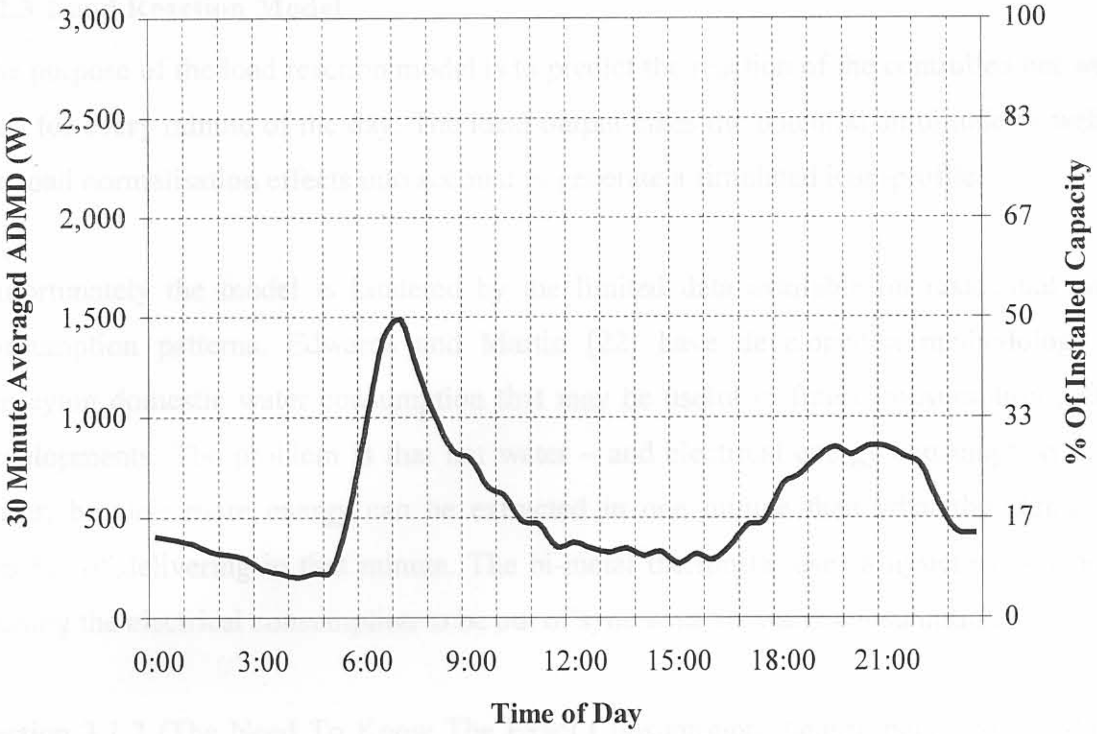

Figure 5.1: South African winter ADMD and percentage profile.

Not all of the residential consumers require hot water at the same time. The peak consumption occurs between 7:00 and 8:00 during no-control conditions, and only 50% of the installed capacity is utilised. Let's use the example again where the total population size of controllable cylinders is equal to 9,000 units. Assume that 3,500 cylinders will never consume hot water during the morning interval. The result is that the net population of hot water cylinders is equal to 5,500 cylinders between 6:00 and 10:00 in the morning.

In this example when shedding occurs from 6:00 to 10:00:

- ☐ The load reaction model will clip the $LR_{\text{Higer Boundary}}$ at 16,500 instead of 27,000 kW,
- ☐ The decreased value of the water mass used in the average temperature model will give a more realistic value of the cylinder temperature, and
- ☐ Only the users that contributed to the savings for this period have to be compensated.

The specific details of the influence of the consumer group configuration on these models will be discussed in the subsequent paragraphs.

5.2.3 Load Reaction Model

The purpose of the load reaction model is to predict the reaction of the controlled hot water load for every minute of the day. The ideal output takes the potential amplitude as well as the load normalisation effects into account to generate a simulated load-profile.

Unfortunately the model is hindered by the limited data available on residential water consumption patterns. Edwards and Martin [22] have developed a methodology for surveying domestic water consumption that may be useful in future consumption pattern developments. The problem is that hot water – and electrical energy consumption is not linear, because more energy can be extracted in one minute than what the element is capable of delivering in that minute. The bi-metal thermostat uses a hysteresis set point, causing the electrical consumption to be out of sync with the water consumption.

Section 3.1.2 (The Need To Know The Exact Consumption Pattern, page 66) has shown that the TADMD on its own is does not supply enough information for predicting the exact hot water load reaction but it is possible to say that:

- The CLP is only a function of the amount of cylinders that would have consumed energy during T_{Shed} and
- The load normalisation curve can be constructed by using the calculated CLP, the amount of energy extracted during T_{Shed} and the real-time consumption during normalisation.

These results can also be verified with a real-life example by using the August 1999 test results described in section 3.1.6 on page 82. This time the profile of the Emergency Interrupt Test (Wednesday) is compared to that of the Wholesale Electricity Test (Friday).

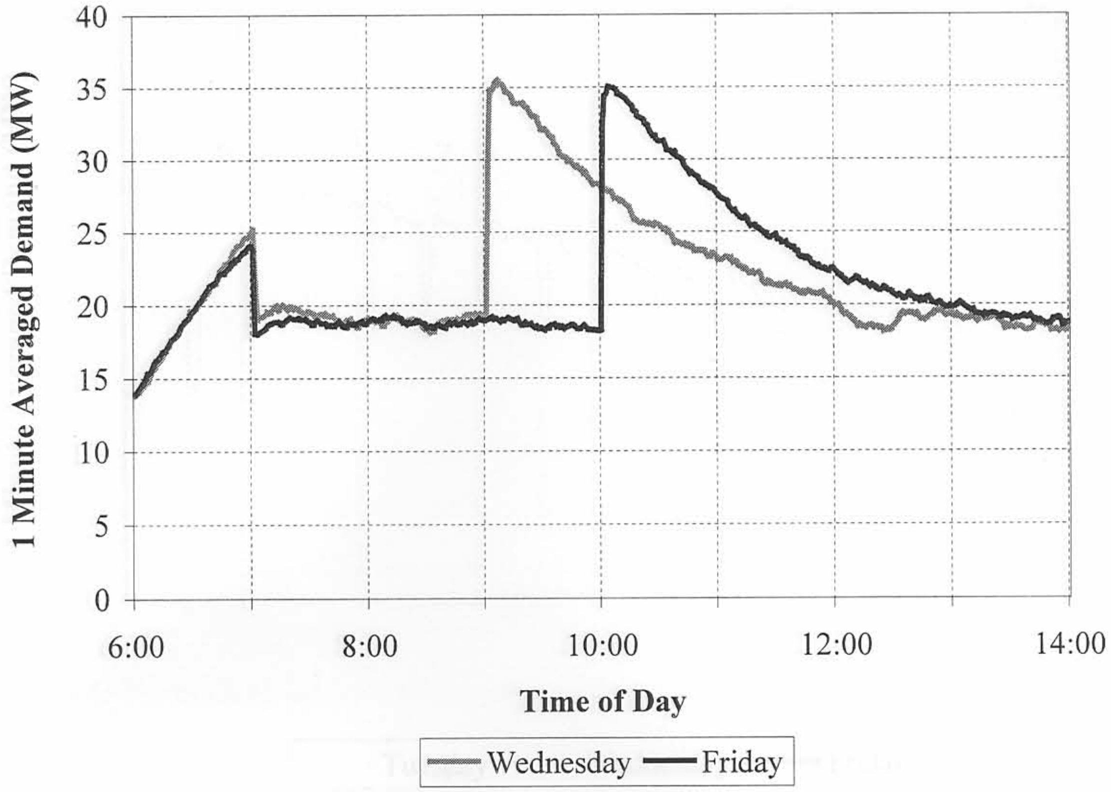

Figure 5.2: August 1999 municipal load curtailment tests.

At first sight, the results in figure 5.2 are rather surprising. The Friday load was restored at 10:00, an hour later than on Tuesday, with almost equal potential amplitude values. The load reaction value in both tests are equal because the amount of consumers that required hot water was the same for both these days. The CLP value is therefore not a function of the shedding period length, but indeed a function of the morning consumer group population.

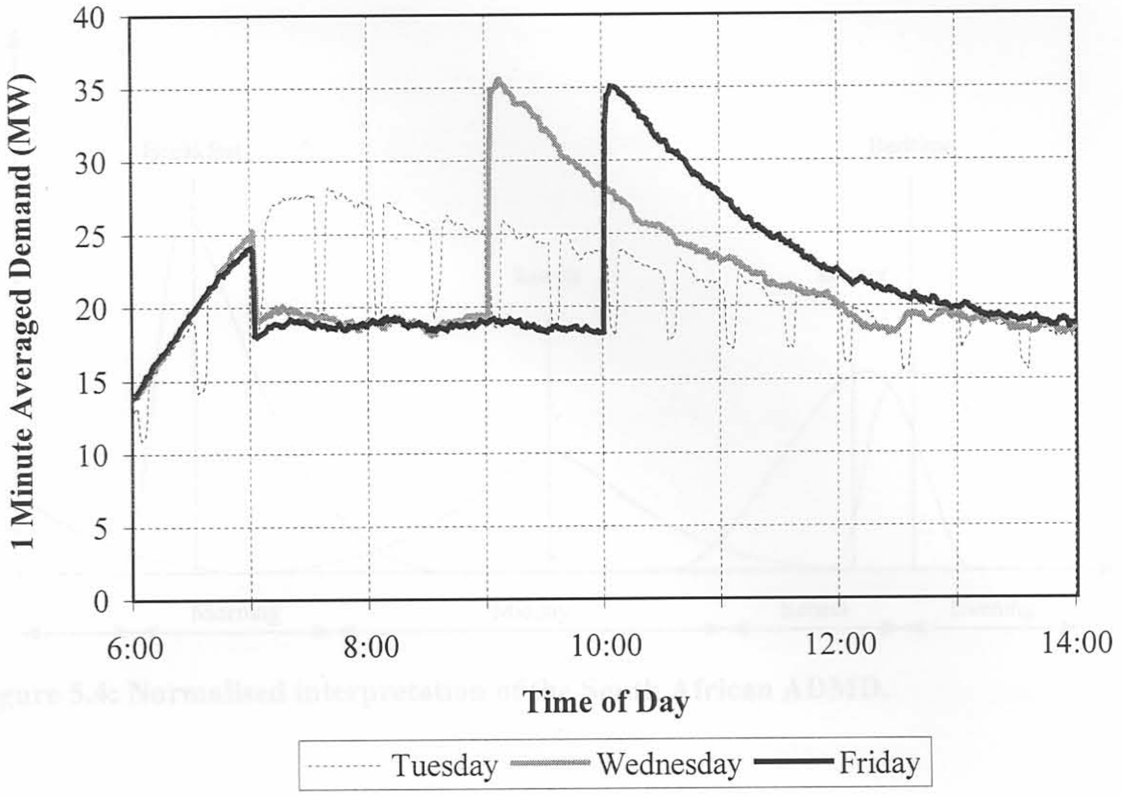

Figure 5.3: Difference in the load normalisation.

Figure 5.3 was generated to illustrate the differences in the load normalisation of the two days and to verify that the load normalisation postulate is true. The morning consumer group population fixed the CLP values at 35 MW and the extracted energy is replaced immediately after the load has been restored. The load normalisation took 180 minutes (10:00 – 13:00) during the Friday test in comparison to the 155 minutes (9:00 – 11:35) on Tuesday. The only differences between these profiles are:

- ☐ The amount of extracted energy that has to be replaced and
- ☐ The real-time consumption value at the restoration time.

These results conclusively prove that the neither the potential amplitude, nor the load reaction curves are necessarily exponential, as initially stated by Calmeyer [17]. The exponential curves extracted on system level are a result of the normal distribution found in large populations. Each time interval specified on page 117 has its own normal distribution based upon a specific human behavioural activity, and is illustrated in figure 5.4.

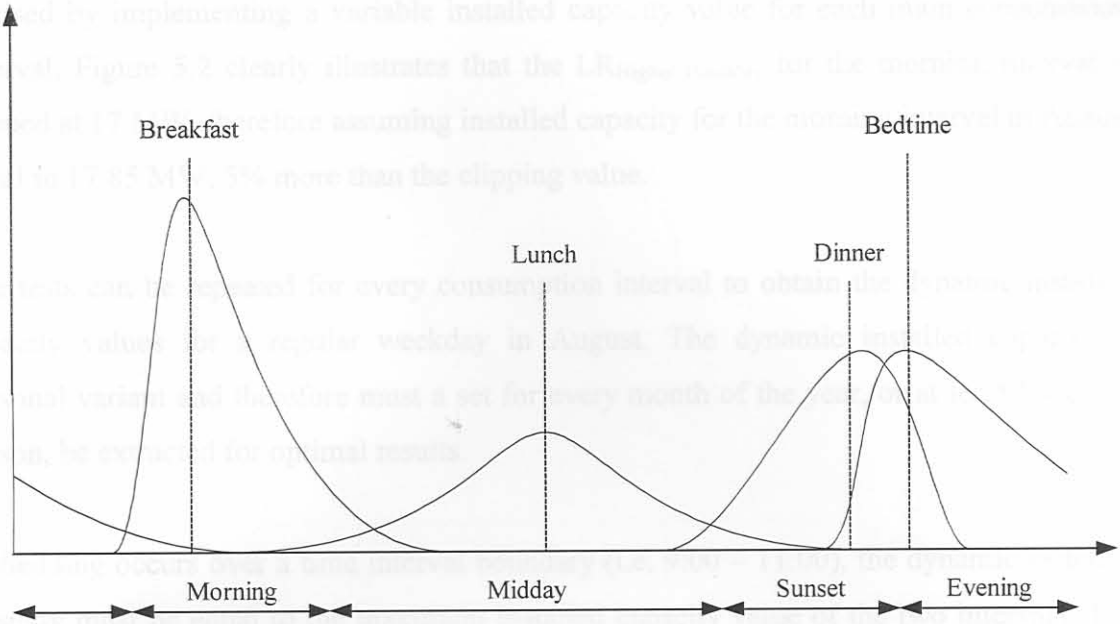

Figure 5.4: Normalised interpretation of the South African ADMD.

Say for instance the load in figure 5.3 is not restored at all. The potential amplitude will remain constant until new members from the midday interval start to consume hot water. The potential amplitude will increase as the members of the midday interval request to consume energy, with the growth decreasing after lunch. This process will repeat itself within the remaining peak consumption periods until all of the hot water cylinders have requested energy at some point or another. Clipping of the potential amplitude will occur at the installed capacity value.

Calmeyer was correct to say that the potential amplitude was limited by the installed capacity, but the growth does not occur within a single exponential stage

The load reaction model can only rise to the occasion once it is possible to estimate or measure the electrical consumption patterns of individual hot water cylinders. For the time being, the load reaction boundaries can be used to assist pro-active load control.

The improvement of the $LR_{\text{Higher Bounday}}$ prediction, mentioned in section 5.2.2, can be realised by implementing a variable installed capacity value for each main consumption interval. Figure 5.2 clearly illustrates that the $LR_{\text{Higher Bounday}}$ for the morning interval is clipped at 17 MW, therefore assuming installed capacity for the morning interval in August equal to 17.85 MW, 5% more than the clipping value.

The tests can be repeated for every consumption interval to obtain the dynamic installed capacity values for a regular weekday in August. The dynamic installed capacity is seasonal variant and therefore must a set for every month of the year, or at least for every season, be extracted for optimal results.

If shedding occurs over a time interval boundary (i.e. 9:00 – 11:00), the dynamic installed capacity must be equal to the maximum installed capacity value of the two intervals. The dynamic installed capacity will also increase the accuracy of the average temperature prediction model and will be discussed in the following paragraph.

5.2.4 Average Cylinder Temperature Model

There is always risk of cold water present during any load control action. The average temperature of a group can be equal to 55°C, but the deviation within the group could cause the minimum temperature to be less than 40°C. The classification of users into similar usage patterns, along with the variable installed capacity proposal, will ensure that the deviation around the mean temperature value decreases as illustrated in figure 5.5.

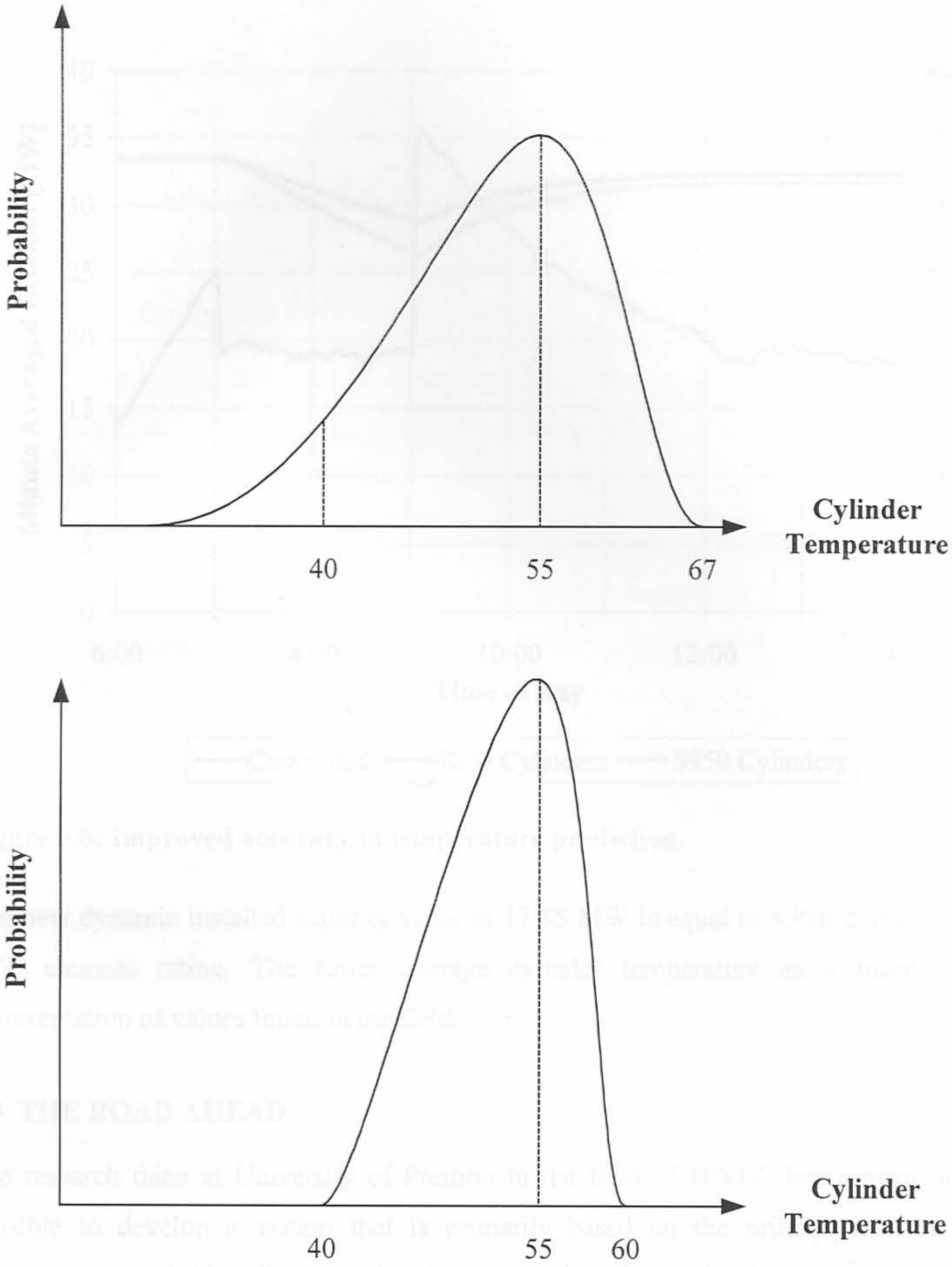

Figure 5.5: Desired effect of consumer group configuration on the average cylinder temperature.

Even with the proposed improvements, the entire user group still stand a chance of experiencing cold water, but the individual cold water complaints will definitely be less. Figure 5.6 depicts results after the implementation of the dynamic installed capacity proposal.

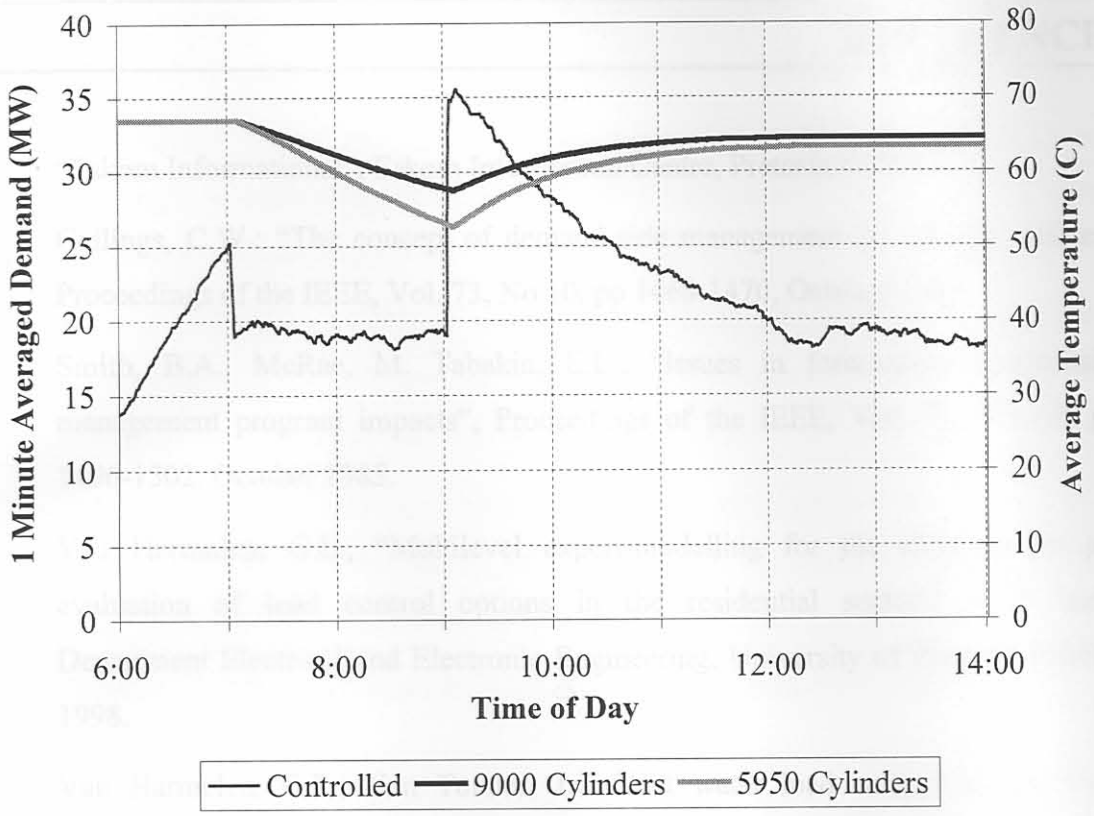

Figure 5.6: Improved accuracy in temperature prediction.

The new dynamic installed capacity value of 17.85 MW is equal to 5,950 cylinders with a 3kW element rating. The lower average cylinder temperature as a more accurate representation of values found in the field.

5.3 THE ROAD AHEAD

The research done at University of Pretoria in the field of HWLC has proven that it is possible to develop a system that is primarily based on the principles of customer-orientated control. Not all the results obtained in this dissertation have been implemented yet, but various motivations helped to reserve more funds for future development. It won't be long before the hot water consumption patterns can be derived on device level.

"The road to optimal control is a brutal one but a dense forest has many fruit."