# CHAPTER 4

# UNIVERSITY OF PRETORIA
# THE ROAD TO OPTIMAL CONTROL

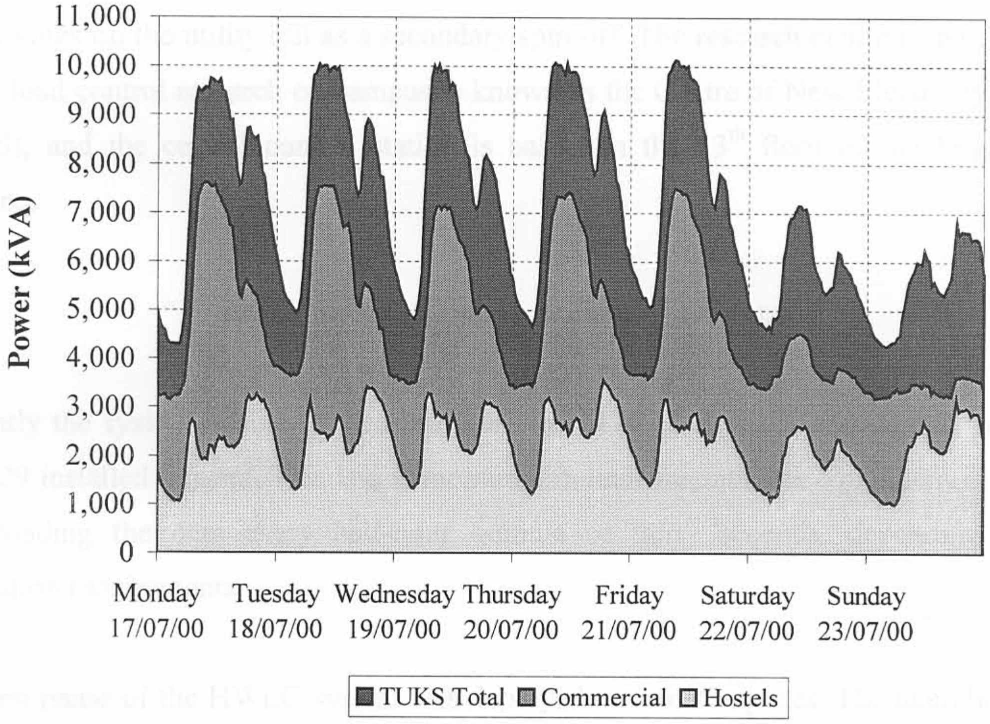

**Figure 4.1: Disaggregated load-profile of the University of Pretoria.**

The load-profile of the University of Pretoria exhibits the nature of a small town embracing commercial and residential sectors. HWLC at the University of Pretoria is in its fourth year of integration. No expenses have been spared on the implementation of available technology and still no ideal solution has been produced. Development has been done on municipal level with the intention to upgrade the proposal as soon as the utility also supports the drive towards mutual benefit.

This chapter will not walk the mile of the ups and downs experienced to date, but rather portray the real-life application of customer-orientated control.

## 4.1 END-USER MODEL

The HWLC-system design was based on the end-user model described in section 2.1.1 on page 40. The difference between a good and excellent HWLC-system is availability, accuracy and timely delivery of data. The next paragraph will bring more insight concerning the hardware selected for the University of Pretoria HWLC-system.

### 4.1.1 System & Process Limitations and Constraints

The role of the University of Pretoria HWLC-system is primarily for research purposes with savings on the utility bill as a secondary spin-off. The research centre responsible for all the load control research on campus is known as the Centre of New Electricity Studies (CNES), and the central control station is based on the 13th floor of the Engineering Building.

***"You can only know what you are able to measure."***

Currently the system is able to measure more than 120 electricity consumption points by using 29 installed loggers. The data is measured in real-time and the equipment is capable of uploading the data every half-hour, minute or thirty seconds, depending on the application requirements.

The first phase of the HWLC-system was deployed on two campuses. The main hot water consumers such as hostels and other residences have been selected for control purposes with the possibility of future network extension.

The HWLC-market is mainly dominated by low frequency power line communication devises and radio-controlled units. Various requirements have been set for the University of Pretoria installation in which the radio-controlled devices excelled predominantly. The requirements included:

- ☐ Price,
- ☐ Speed,
- ☐ Features,
- ☐ Installation and
- ☐ Future network expansion.

Power line communication injectors are used to modulate the control data onto the power lines. The injectors are very expensive and power line communication can only be economically feasible for installations where the injector cost is distributed over large volumes of HWLC-units. The other disadvantage of low frequency power line communication is that only 6-8 commands can be transmitted every half hour in comparison to the radio frequency command ratio of 60 commands per half hour. Both scored equally in terms of installation and future network expansion, but the radio-controlled devices are a step ahead in the features department.

Radio-controlled load switches enable the utility or municipality to uniquely address more than 16 million devices on a single frequency. Switches can also be dynamically classified into specific groups, which enable the load controller to address all the devices contained to the same groups with a single command. Finally, the load controller also has the ability to switch all the devices on a single command, typically used during notch testing.

In summary, the load controller is capable of addressing a switch:

- ☐ Uniquely,
- ☐ Within group formation or
- ☐ As part of the installed fleet every 30 seconds.

Now that the hardware specification is fixed, the next step would be to extract the user information as required by the end user group configuration.

### 4.1.2 End-User Group Configuration

During July 2000, tests were conducted at CNES to calculate the contribution of in-house residential hot water cylinders relative to the total demand of the University of Pretoria. The study included a total of 16 residences with radio-controlled HWLC-devices already in place. A traditional control procedure was generated to notch all the controllable hot water cylinders simultaneously with the results shown in figure 4.2 and figure 4.3.

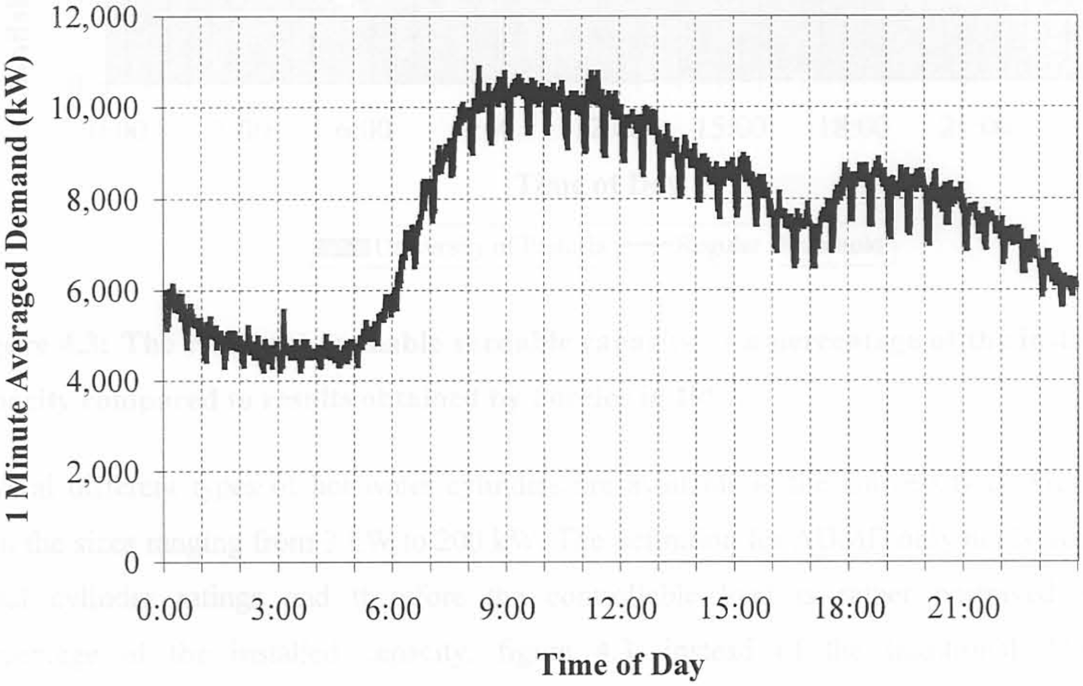

**Figure 4.2: University of Pretoria results for notch test conducted on Wednesday, 26 July 2000.**

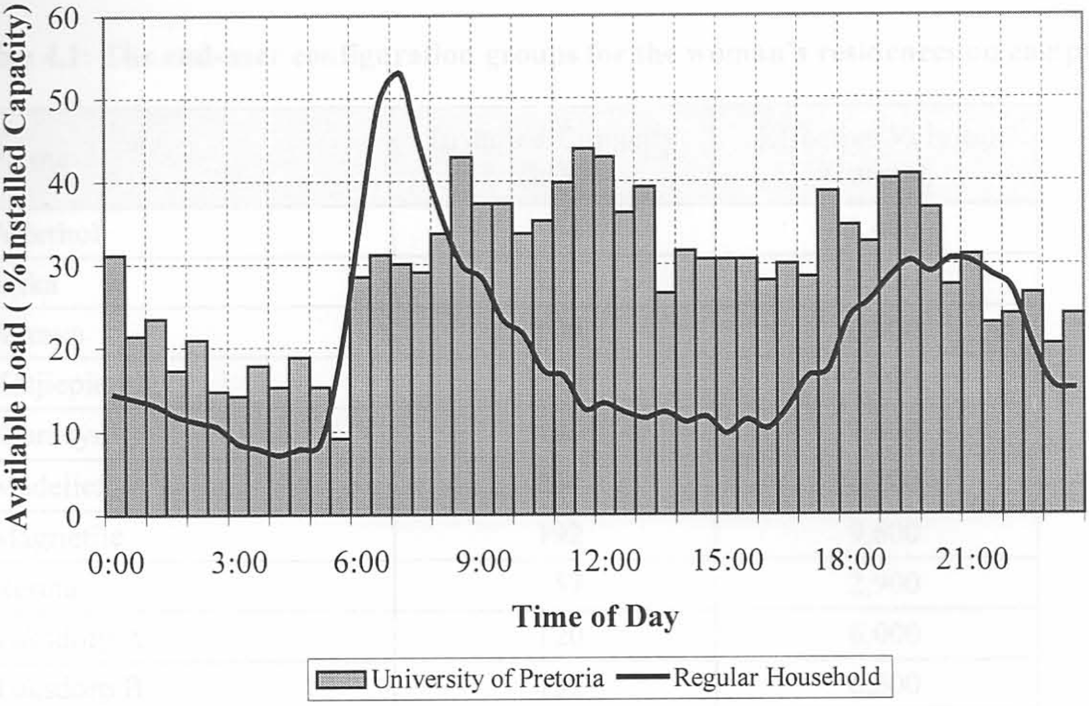

**Figure 4.3: The resultant available shedable capacity as a percentage of the installed capacity compared to results obtained by Forelee in 1997.**

Several different types of hot water cylinders are available at the University of Pretoria, with the sizes ranging from 3 kW to 200 kW. The definition for ADMD only holds true for equal cylinder ratings and therefore the controllable load is rather portrayed as a percentage of the installed capacity, figure 4.3, instead of the traditional ADMD representation.

The comparative results obtained clearly illustrates that student behaviour is not human at all. The management rules would not necessarily be the same as in a municipal environment but the system is able to contribute savings towards the national peak reduction.

In the past, channel separation tests had to be conducted to determine the contribution of each hostel towards the University of Pretoria load-profile. Nowadays this is no longer required because the consumption of every hostel and residence is measured separately. This, along with the need to disconnect the hot water supply of specific residences during holiday periods, led to the selected group configuration shown in table 4.1 and table 4.2.

**Table 4.1: The end-user configuration groups for the woman's residences on campus.**

| Name | Installed Capacity (kW) | Effective Volume (Litres) |
|---|---|---|
| Asterhof | 54 | 3,400 |
| Erika | 273 | 13,650 |
| Jasmyn | 130 | 6,800 |
| Katjiepiering | 70 | 3,900 |
| Klaradyn | 138 | 7,600 |
| Madelief | 204 | 10,200 |
| Magrietjie | 192 | 9,600 |
| Nerina | 57 | 2,900 |
| Tuksdorp A | 120 | 6,000 |
| Tuksdorp B | 132 | 6,600 |
| Totals | 1,370 | 70,650 |

**Table 4.2: The end-user configuration groups for the men's residences on campus.**

| Name | Installed Capacity (kW) | Effective Volume (Litres) |
|---|---|---|
| Boekenhout | 152 | 8,750 |
| Kollege | 93 | 4,900 |
| Maroela | 408 | 20,400 |
| Mopanie | 345 | 17,250 |
| Olienhout | 125 | 7,500 |
| Taaibos | 63 | 3,700 |
| Totals | 1,186 | 62,500 |

The other difference found through examination of the end-user group configuration notch data was that the men's and woman's residents had a contradictive TADMD shape. The summated result is illustrated in figure 4.4.

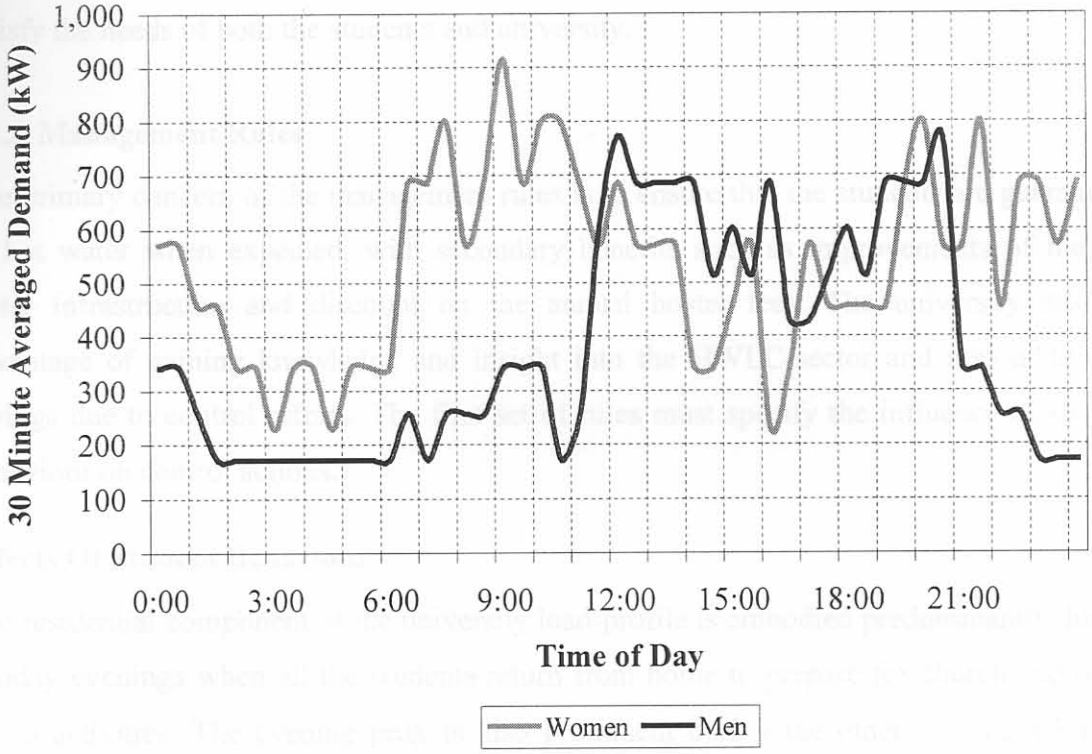

**Figure 4.4: TADMD-profiles for July, illustrating the difference in gender consumption patterns.**

Continuous notch testing throughout the first operational year ensured that a database of TADMD-profiles for every end-user group was stored. The profiles were recorded on the 15th of each calendar month with a resolution of one-minute integration intervals.

With the manipulation of these results the HWLC-system is now able to:

- Generate individual footprints for each end user group.
- Calculate the contribution of each consumer towards the total savings.
- Accurately simulate load control algorithms for optimisation purposes.
- Calculate the effect that cold-load pickup will have just before a group is restored, thus acting beforehand to compensate for the expected increase in demand.
- Predict the set point with much more accuracy.

At this stage enough data is available to formulate a set of management rules that would satisfy the needs of both the students and university.

### 4.1.3 Management Rules

The primary concern of the management rules is to ensure that the students are guaranteed of hot water when expected, with secondary benefits such as improvements of the hot water infrastructure and discount on the annual hostel fees. The university has the advantage of gaining knowledge and insight into the HWLC-sector and also additional savings due to control efforts. The first set of rules must specify the influence of student behaviour on control actions.

#### Effects Of Student Behaviour

The residential component of the university load-profile is embodied predominantly during Sunday evenings when all the students return from home to prepare for church and other social activities. The evening peak is also prominent during the other weekdays but all differ in time, depending on the inter-residential activities arranged for that specific day. I.e. Tuesdays are set aside for residential rugby league from 18:00 to 21:00 and Thursdays several internal residential activities occur from 21:00 to 23:00. The student social calendar of each residence, as well as that of the university, must be used to forecast change in behavioural patterns.

Seasonal variations coincides with that found in the domestic sector but special attention must be given to the university holidays. Holidays have a considerable impact in the grid of the University of Pretoria due to the reduction of commercial activities and the change of behaviour of the residential students. In guidance of the work done in section 1.6 (page 15), the effects of different types of holidays or events can be summarised in four categories:

- **Long Weekends:** Long weekends are characterised by relatively low energy consumption throughout the course of the weekend and can be estimated as if it was a Sunday. The days before and after the long weekend exhibit the same characteristics as depicted by regular Fridays and Mondays.

- ☐ **A Single Holiday That Falls On A Weekday:** A day like this tends to have a minimal load effect on the immediate preceding and subsequent days. The holiday itself can again be estimated as a Sunday.
- ☐ **A School Holiday:** Take the December holiday season as an example. The total energy consumed decreases slightly during exam periods but dramatically decreases at the start of the student's holiday. Work still commences for another two weeks as the lecturers and other administrative personnel fulfil their duties. The demand reaches a minimum during the compulsory closure for the Christmas holiday. The load-profile follows the trend of a regular week with the only difference in the value of the base-load, and only recovers totally in February when all lectural and commercial activities commence.
- ☐ **Special Events:** Special events such as Spring Festival, Intervarsity, RAG, natural disasters, strikes, etc can all have an effect on the university load-profile. For example, the load-profile on the day of Spring Festival follows the shape of a Sunday, but each special event must be taken on it's own credit and handled individually.

The flexibility of the system is extremely useful during holiday periods when residences close down partially. The controller is able to turn of individual cylinders on selected corridors or address the whole residence as a single unit. HWLC-units controlling specific corridors can also temporarily be moved to another group for the duration of the holiday.

Although the effects of student behaviour are known, no formal control strategy has been implemented to accommodate the effects of student behaviour as of yet. The calculations of the set point determines the shedding sequence and therefore are these effects taken into account by calculating and adjusting the shed-level on a daily basis.

### Risk Of Cold Water

Pro-active control ensures that the average cylinder temperature does not go below 40°C. This is made possible by simulating the control actions and then adjusting the shed-level until optimal savings without infringement on comfort-levels is guaranteed. Alarms are raised and qualified personnel are notified when any group encounters a possibility of low water temperature levels. The students can also forward any cold-water complaint to a customer care centre, which will be attended to within 24 hours after the complaint has been received.

### System Failure

One of the main design parameters of the University of Pretoria HWLC-system was a low failure rate. The real-time consumption is measured on 5 feeders with 3 different sets of measurement options. The three measurement options are then compared to one another and the correct demand value is passed on to the load prediction module. The prediction module then calculates the predicted demand for the half-hour by means of two different algorithms, ensuring sensitivity for all possible load reactions.

With the prediction available, the controller then decides on the best action for the current load control requirement. The group(s) that best suits the action is selected for shedding or restoring and the status of each group is stored with a timestamp in the database for savings calculation and auditing purposes.

A dedicated technical team is also assigned to do scheduled maintenance on a monthly basis. They also functions as a 24-hour unscheduled maintenance response team during critical failures. Analysis of unscheduled maintenance ensures that components are always in stock in case of a critical failure.

### 4.1.4 Electricity Tariff

The Municipality of Pretoria is the sole supplier of electricity to the university. The main campus and residences are fed from 5 feeders, summated and billed as a single point of supply. The tariff is applied in the form of a demand charge structure and the rates are twofold:

- ☐ The consumed energy costs 9.98c per KWh and
- ☐ The monthly demand charge is fixed at R46.88 per KVA.

The current tariff structure does not promote optimal control on the municipal level for the same reasons as discussed in section 1.8.2 (Incorrect Influence Of Tariff Structure, page 28).

The HWLC-system does not benefit the municipality or even utility at this point in time. The selected control algorithms allow the controller to increase the university's demand during national evening peak times and the university is benefiting from it as well. It must be stated that nothing can be done sustain a win-win situation before another tariff, preferably TOU, is offered to the university.

### 4.1.5 Required Production Profile

The management rules cover all the required needs of the students to sustain customer-comfort-levels. This paragraph will only be dedicated to production from the university's perspective.

MD control is the only possible savings initiative encouraged by the tariff structure, thus defying the need to shift energy out of the municipal peak times. The management rules allow MD-reduction until risk of cold water comes to play. It is of utmost importance to ensure that management rules relating to customer-comfort have priority over any production requirement.

The average peak demand for the controlled campuses is in the order of 12 MVA, with a total controllable load of about 2.6 MVA. Taking the two-part tariff of R 45.50 / kVA and 9.68c / kWh into account when the HWLC-system was installed, savings accounted to R40,000 or less.

Extensive research was done in the field of hot water dynamics and these findings have been integrated into the expert load control system. As time progressed, smarter features have been implemented into the control algorithm as more information became available. Current savings range between R60,000 and R70,000 per month on a R900,000 electricity bill.

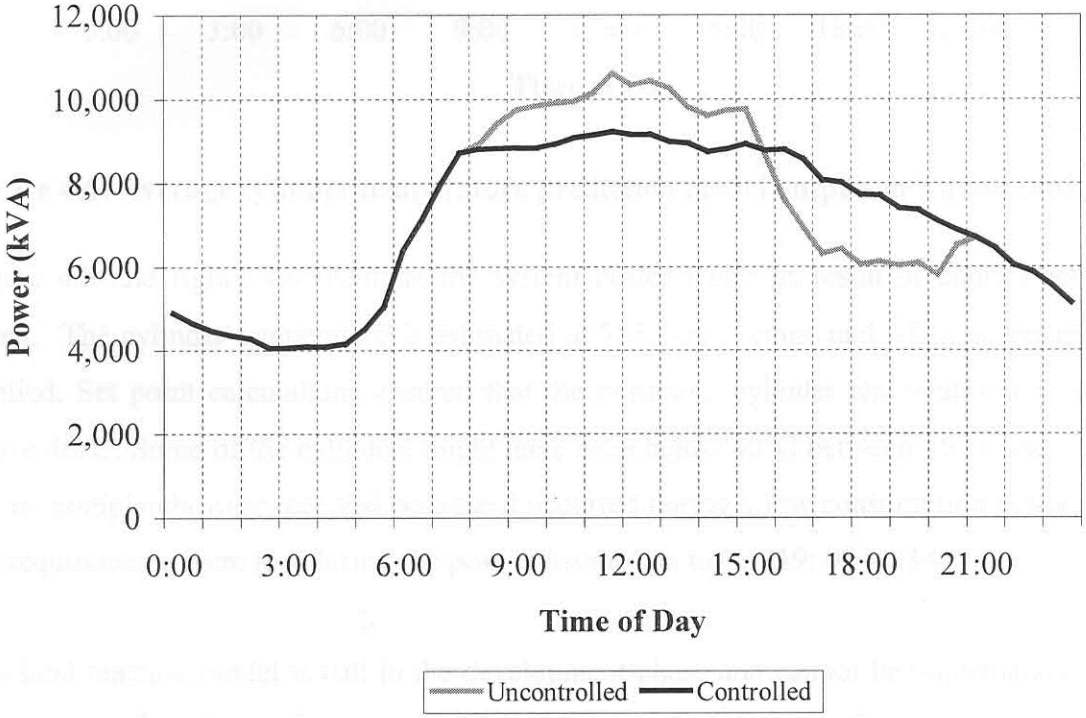

**Figure 4.5: Uncontrolled - vs. controlled load-profiles for 5 June 2001.**

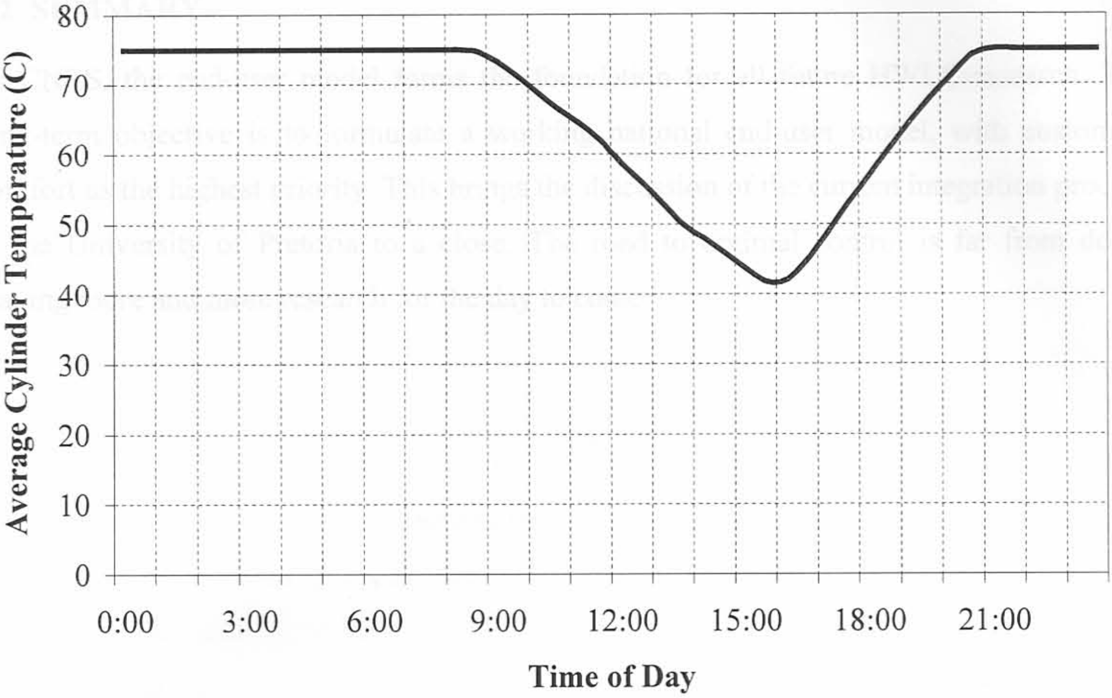

**Figure 4.6: Average cylinder temperature prediction model output on 5 June 2001.**

Figure 4.5 and figure 4.6 illustrate the system buffer levels as result of control actions taken. The cylinder temperature is estimated at 75°C on average and when no control is applied. Set point calculations ensured that the minimum cylinder temperature remained above 40°C. Some of the cylinders might have been below 40°C between 15:00 and 16:00 but no complaints were received because it occurred during a low consumption period and the requirements were met during the peak consumption times (19: 00 – 23:00).

The load reaction model is still in the development phase and cannot be implemented yet. Some interesting observations came to light in terms of the consumption pattern extraction and will be discussed in the chapter to follow.

## 4.2 SUMMARY

At CNES, the end-user model forms the foundation for all future HWLC-research. The long-term objective is to formulate a working national end-user model, with customer-comfort as the highest priority. This brings the discussion of the current integration process at the University of Pretoria to a close. The road to optimal control is far from done, leaving more and more research for the day to come.