CHAPTER 2

ENERGY POLICY AND MODEL DEVELOPMENT

Chapter 1 laid the basis for the current HWLC-situation in South Africa, wherein various problems and possible solutions were already identified. This chapter will use the information at hand to focus on the design of a HWLC-system from a consumer driven perspective, also satisfying the needs of the utility and municipality. The ideal HWLC-system would first be modulated holistically from a national perspective where after specific problem areas would be handled individually.

2.1 MODULATING HWLC FROM A NATIONAL PERSPECTIVE

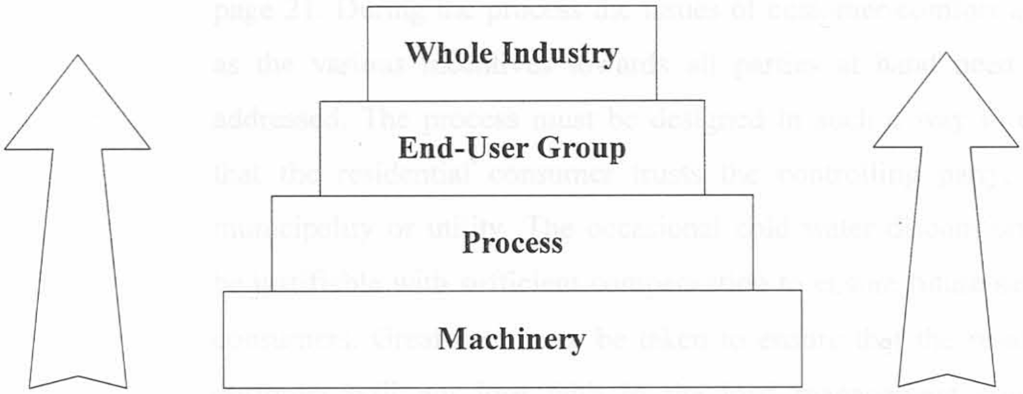

Figure 2.1: Illustration of energy-conversion models.

If one uses the energy conversion methodology (figure 2.1) developed by Delport [20], then load shifting from a supplier perspective would be postulated as follows:

- **Whole Industry:** This can be seen as the national load-profile. At the end of the day all DSM-efforts are initiated due to the peaky nature of the national profile. So, for the purpose of this study, all controllable hot water load will be seen as part of the whole industry
- **End-User Group:** This is the controllable load of each municipality. The aim of every municipal load-control system is to optimise the switching of hot water loads to ensure a minimum cost in terms of the tariff being used. The communication between the two levels is of great importance to link the energy shifted on municipal level with the national level. In this case the best option of communication would be to adapt the tariff in such a way to "force" the municipalities to shift their loads when the national peak occurs. The long-term option would be link all the HWLC-systems to a central controller, directly controlling the loads according to the supplier's needs.

- **Process:** This is the HWLC-algorithm for switching the hot water loads and also the monitoring of the system dynamics as described in section 1.7 on page 21. During the process the issues of customer-comfort as well as the various incentives towards all parties at hand need to be addressed. The process must be designed in such a way to ensure that the residential consumer trusts the controlling party, either municipality or utility. The occasional cold water discomfort must be justifiable with sufficient compensation to ensure future satisfied consumers. Great care must be taken to ensure that the residential customer will not lose faith in the load management controller resulting in the bypassing of the installed HWLC-unit.
- **Machinery:** This is the physical device. The limitations on switching must be known for each type of switch used; i.e. the amount of switching actions per minute, maximum current, the dead-time of the system, maximum definable groups, etc.

  Another important aspect regarding machinery is the ratings of the switchgear and transformers connected to the grid. If load is restored, what is the maximum dI/dt that the system can withstand without reducing the lifetime of any components. This also links up with the process: What is the predicted cold-load pickup and will it be more than the installed capacity of the region? The result of switching must not infringe on the life cycle of critical hardware. It will totally defy the purpose of DSM.

Thus, at the end of the day the primary objective remains optimal load shifting in terms of the national load. The whole process of energy shifting and the dynamics of these actions have to be taken into account to ensure optimal control. Now that the HWLC-perspective is fixed, the load-control process can be transformed into an end-user model.

2.1.1 End-User Model

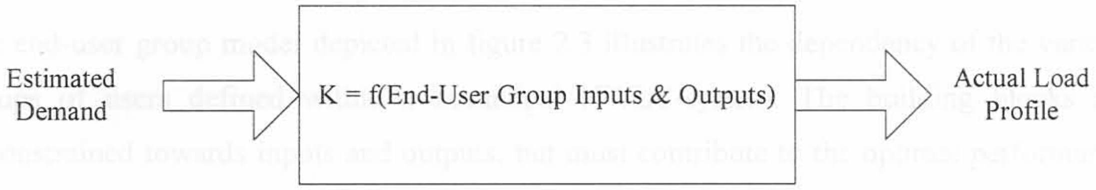

Figure 2.2: National load management modulation on a system level.

Figure 2.2 illustrates the HWLC-system from a global perspective with the estimated demand from which the possible peak period can be derived as main input. The system must react to the input values to minimise the load in a controlled fashion. The control is escalated down to the end-user group by manipulating the various local inputs to obtain the required global output as result of the summation of the local outputs. To understand the system, modelling must be done on a micro scale with the optimal system output as common goal. This micro scale model is known as an end-user model and requires the following inputs [20]:

- End-user Group Configuration,
- Electricity Tariff,
- Required Production Profile,
- System & Process Limitations and Constraints,
- Management Rules and
- Buffer Systems.

These inputs are then processed by the end-user group model delivering the following outputs [20]:

- Electricity Load-Profiles
- Buffer System-Levels

2.1.2 End-User Model Inputs

Input 1: End-user Group Configuration

The end-user group model depicted in figure 2.3 illustrates the dependency of the various groups of users defined within a municipal HWLC-system. The building blocks are unconstrained towards inputs and outputs, but must contribute to the optimal performance on national level rather than group level.

Residential consumers must be placed in groups with the same hot water requirements and behaviour. The system requires the TADMD of each group afterwards and can be obtained by means of channel separation tests. The TADMD is used as an accurate resemblance of the hot water energy consumption a selected the group at a specific time and type of day.

According to section 1.6.1 on page 16, the hot water load consumption patterns can be summarised into five categorical days:

- Monday and the day after a public holiday.
- Regular Tuesdays, Wednesdays and Thursdays.
- Friday and the day before a public holiday.
- Saturday.
- Sunday and public holidays.

In order to compensate for seasonal variations, TADMD-profiles of each user group must be extracted at least for every season but preferably for every month of the year.

Each TADMD-profile can also be seen as the amount of energy available for HWLC and is therefore defined as energy storage buffers. Each group has an energy buffer, as illustrated by the circles in figure 2.3, whereas the squire depicts HWLC-algorithms that must utilise these storage buffers according to certain constraints.

The HWLC-algorithms can either be used to curtail the stored energy during national peak hours or to manipulate the remaining energy in the storage buffer to control the MD during load restoration periods. During load restoration the cold-load pickup effect of one group can be minimised by shedding other groups with remaining storage capacity.

The temperature inside the hot water cylinder also lower bounds the capacity of each group. Customer-comfort-levels may not be infringed and therefore the available capacity must be adapted to ensure that the minimum cylinder temperature will never be less than stipulated by the residential consumer group agreement.

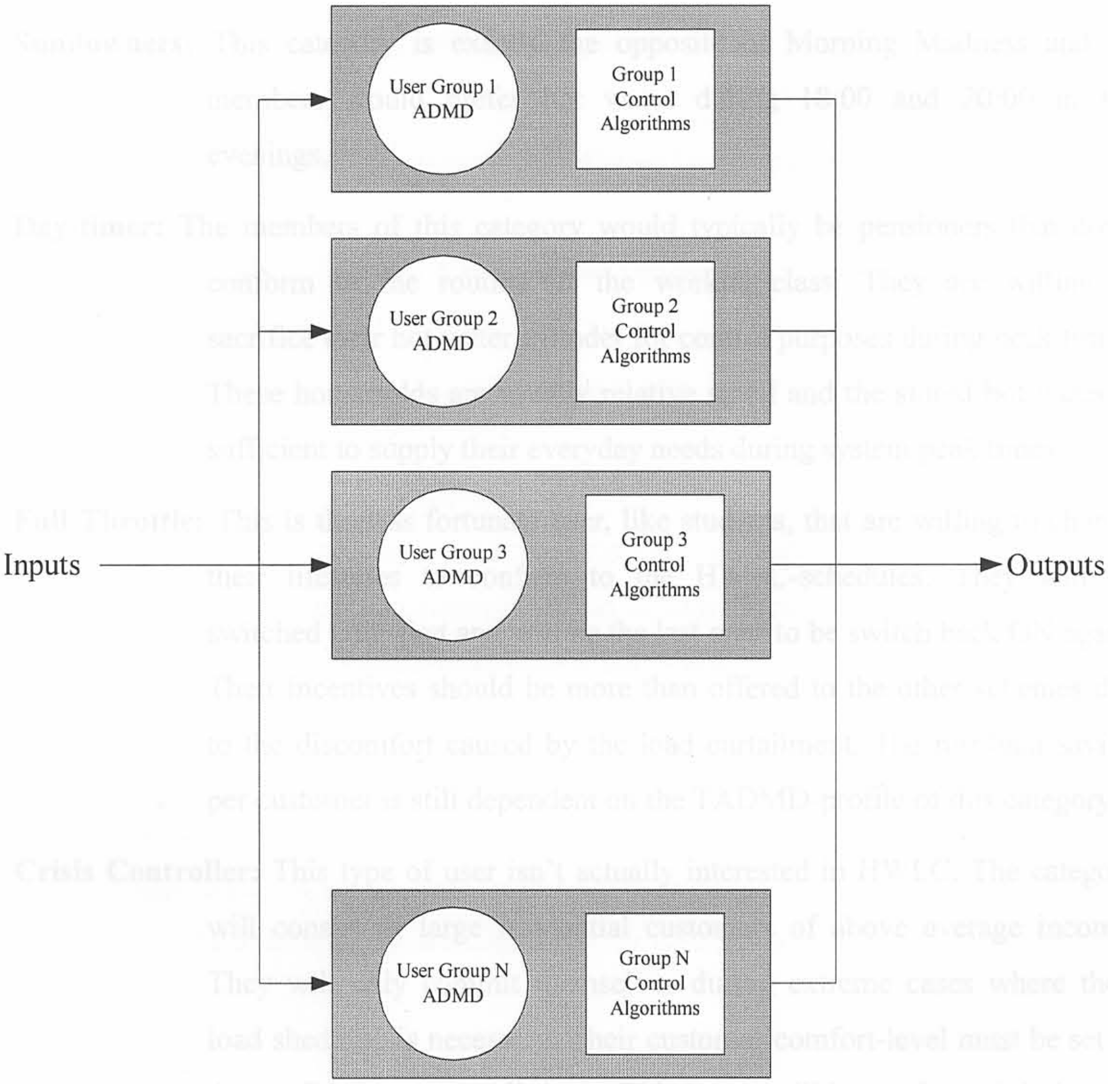

Figure 2.3: End-user group model for load-control from a national perspective.

For the purpose of this methodology, these five categories have been identified relating the main consumption patterns:

- ☐ **Morning Madness:** This is the type of person that would prefer to have hot water in the morning between 6:00 and 9:00. The primary objective of this category is to minimise cold-load pickup effects during the morning load restoration cycle and for load curtailment during the evening. These users may also be switched off during the morning peaks only if the load-controller is certain that the average cylinder temperature remains above the minimum allowable temperature between 6:00 and 9:00.
- ☐ **Sundowners:** This category is exactly the opposite of Morning Madness and its members would prefer hot water during 18:00 and 20:00 in the evenings.
- ☐ **Day-timer:** The members of this category would typically be pensioners that don't conform to the routine of the working-class. They are willing to sacrifice their hot water cylinder for control purposes during peak times. These households are usually relative small and the stored hot water is sufficient to supply their everyday needs during system peak times.
- ☐ **Full Throttle:** This is the less fortunate user, like students, that are willing to change their lifestyles to confirm to the HWLC-schedules. They will be switched OFF first and will be the last ones to be switch back ON again. Their incentives should be more than offered to the other schemes due to the discomfort caused by the load curtailment. The resultant saving per customer is still dependent on the TADMD-profile of this category.
- ☐ **Crisis Controller:** This type of user isn't actually interested in HWLC. The category will consist of large residential customers of above average income. They will only commit themselves during extreme cases where their load shedding is necessary. Their customer-comfort-level must be set to "ensure" hot water at all times. This group will be used to minimise the effect on the MD due to cold-load pickup after peak periods.

These categories can then be subdivided into three switching levels:

☐ Lenient,

☐ Regular or

☐ Frequent

depending on the occupant-versus-hot-water-cylinder ratio. A high ratio would result in a lenient switching level.

Input 2: Electricity Tariffs

The tariffs set forth by the supplier is the most important form of communication to depict the needs regarding the national load-profile. Municipalities must then react on the pricing signal to conform to optimal savings. Some municipalities might have different tariffs to specify the need of the supplier on a controlled basis.

An optimal choice for HWLC would be a TOU-tariff with a weekly schedule, changing monthly. The municipalities would easily accept this proposal because they have enough time to react to the change in tariff. A monthly MD charge must also be incorporated in the tariff to ensure that the peak isn't just shifted to another time of the day. The municipalities must be forced to control their cold-load pickup after the peak periods minimising its effect.

The municipality has a problem with the extreme diversity among the residential customers. The load management controller must be able to control the groups as if they were individual clients as illustrated in figure 2.3. Each group has it's own TADMD-profile and switching scheme that will control the group with customer-comfort as limiting parameter. If a client experiences problems with his current group setting, he can apply for a transfer to a regular or lenient switching level of the current group, or even to another group that might conform to the needs of his specific lifestyle. Each group will have its own tariff structure to ensure fair compensation for their contribution and particular form of discomfort.

Each time a group is selected for control, a database entry will be logged. With the TADMD of every group and the state of each switch known at any time of the day, the savings could be calculated in respect of the shifted energy. Any additional costs due to an increase in the MD as result of load shifting will be deducted from the total savings before it is distributed amongst the groups.

The load-controller must be intelligent enough to ensure that the cost of possible MD set point changes will be less than the savings due to the energy shifting during that time period. Take the Megaflex tariff as example:

$$\begin{aligned}
\text{MD Cost} &= \text{Energy Savings Cost}\\
(\text{MD Cost Per kW})(\text{Increased kW}) &= (\text{Effective Cost Of Saving})(\text{Amount of kWh Shifted})\\
(\text{R}14.67/\text{kW})(1\text{kW}) &= (35.4\text{c/kWh} - 14.85\text{c/kWh})(\text{E})\\
\text{E} &= \underrightarrow{71.39\text{ kWh}}
\end{aligned}$$

Thus with the Megaflex tariffs of 2001, the load management controller must be able to shift more than 71.39 kWh out of the peak time to justify an MD increase of 1kW.

Input 3: Required Production Profile

The required production profile is the requirements set forth by the utility, municipality and the end user as discussed throughout section 1.5 on page 10 .In general

- The utility requires a national load-profile with unity load factor,
- The municipality wishes to manipulate their local load-profile in order to minimise their utility bill while
- The end-user requires a HWLC-system that is "invincible" according to his preference lifestyle.

Input 4: System & Process Limitations And Constraints

The system limitations is defined by the HWLC-machinery, as described in section 2.1 on page 38. Each supplier of HWLC-hardware must also supply an ISO-OSI product specification document before installation to ensure that system time- and command constraints will be within the HWLC-application layer specifications.

All the process-limitations and constraints are mutual-inclusive with the end user group configuration and can therefore be omitted.

Input 5: Management Rules

Management rules depicts the governing body that protects all the parties involved. In other words, it is the set of rules that defines how the HWLC-system will be operated in terms of:

- ☐ Savings distribution,
- ☐ Risk of cold water,
- ☐ Customer-comfort-level infringement policy,
- ☐ Effects of human behaviour on the national and local load and
- ☐ Minimum allowable temperature of each user-group and - category.

The whole idea is to generate a win-win situation between the residential consumer, municipality and supplier by means of a predefined set of management rules.

2.1.3 End-User Model Outputs

Output 1: Buffer Systems and Buffer System Levels

The basis of HWLC is to manipulate the stored energy in the hot water cylinders (buffer system) according to the available energy. The TADMD of each user group is an indication of the available energy of that group at a certain time of the day and can be used to calculate the total amount of buffered energy available for HWLC-purposes.

The customer-comfort-levels directly influence the amount of extractable energy of each group and is therefore defined as the buffer system level. If the buffer system level is too low, then the risk of cold water will increase significantly.

Output 2: Electricity Load-Profiles

The load-profiles for each user group must be mutually inclusive to the contribution of lowering the peaks on national level. Optimal regulating of this profile requires that the dynamics of each HWLC-system must be understood and simulated in order to conform to the management rules.

One can apply the developed model on a new or even existing HWLC-system. Existing HWLC-systems does not particularly compensate for the effects of cold-load pickup beforehand and does not take customer-comfort into account. The main focus from here on will specifically be on the understanding and modulating these unresolved requirements.

2.2 TAKING A CLOSER LOOK AT COLD-LOAD PICKUP

What is this so called cold-load pickup (CLP) effect and why is everybody making such a fuss about it? The exact nature and dynamics of cold-load pickup are not yet defined and it is also the one effect that is capable of destroying the future of HWLC single-handedly.

During August 1999, Eskom conducted various experiments on a municipal HWLC-system with 9,000 installed devices. The objective of one of the experiments was to determine the savings-potential of HWLC as an energy shifting mechanism without any MD control. The results were catastrophic and without even looking in detail at figure 2.4 one can clearly see the problem at hand.

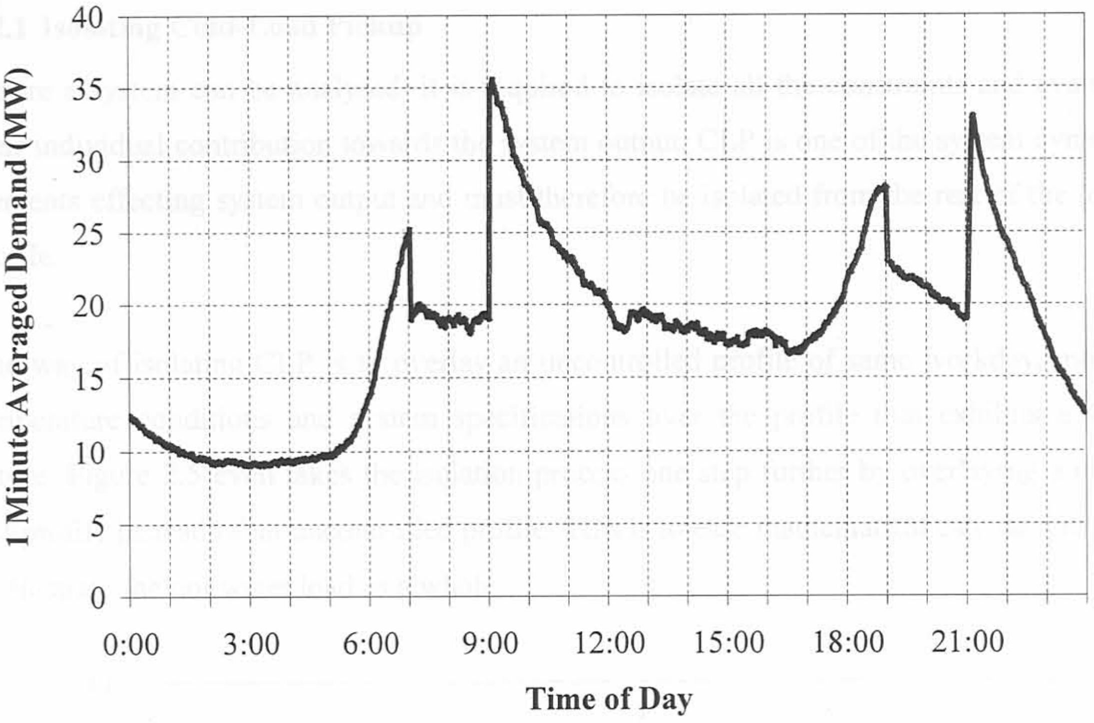

Figure 2.4: Energy shifting without MD control.

The initial examination of the load-profile can be very demoralising. A demand of only 6 MW was removed from the system during the morning peak period and when the load was restored an enormous increase in demand of 16 MW is noticeable. It appears as if the demand increased round about 3 times over the two-hour period. This increase is very common in the HWLC-circles and is known as cold-load pickup. In order to contain this phenomenon the only option would be to consider pro-active control.

Pro-active control requires that the load-controller is capable of predicting the outcome of CLP before any actions are taken. When CLP is mathematically defined, one can develop a HWLC-system that is capable of simulating the control actions the previous day and optimally schedule the control actions in advance. The first step in the mathematical process would be to isolate CLP from the total load-profile.

2.2.1 Isolating Cold-Load Pickup

Before a system can be analysed, it is required to isolate all the constraints and evaluate their individual contribution towards the system output. CLP is one of the system dynamic elements effecting system output and must therefore be isolated from the rest of the load-profile.

One way of isolating CLP is to overlay an uncontrolled profile of same weekday, month, temperature conditions and system specifications over the profile that exhibits a CLP nature. Figure 2.5 even takes the isolation process one step further by overlaying a notch test profile instead of an uncontrolled profile. This is to ease mathematical calculations and to illustrate the hot water load as a whole.

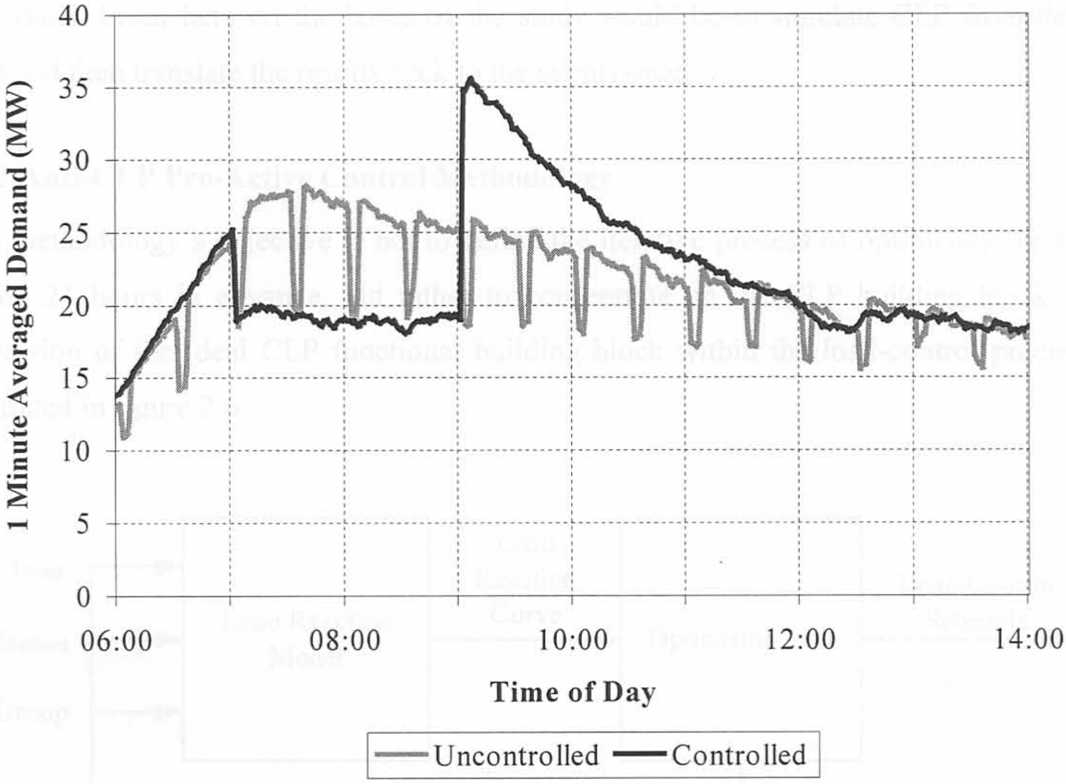

Figure 2.5: Uncontrolled and controlled load-profile overlay.

The overlay process suddenly enlightened two important facts:

- The increase in the MD is only 8 MW and not 16 MW as initially noticed because an uncontrolled load would have caused an MD of 28 MW on that specific day.
- The total load-profile consists of the base-load, regular consumption for the day and the increase in demand caused by CLP. Therefore

$$\textit{Total Load} = \textit{Base-Load} + \textit{Real-time HWL Consumption} + \textit{CLP} \tag{2.1}$$

The research done from the days of Beute to modern day Calmayer all have one thing in common. That is, all the experiments regarding the dynamics of CLP during load-control were monitored from the supply-side and not on individual hot water cylinder level. With the technology available at that time their work was outstanding but not entirely true for all conditions. From here on the bases of the study would be to simulate CLP from device level and then translate the results back to the supply-side.

2.2.2 Anti-CLP Pro-Active Control Methodology

This methodology's objective is not to define the iterative process of optimising the load-profile 24 hours in advance, but rather to concentrate on the CLP building block. The interaction of the ideal CLP functional building block within the load-control process is illustrated in figure 2.6.

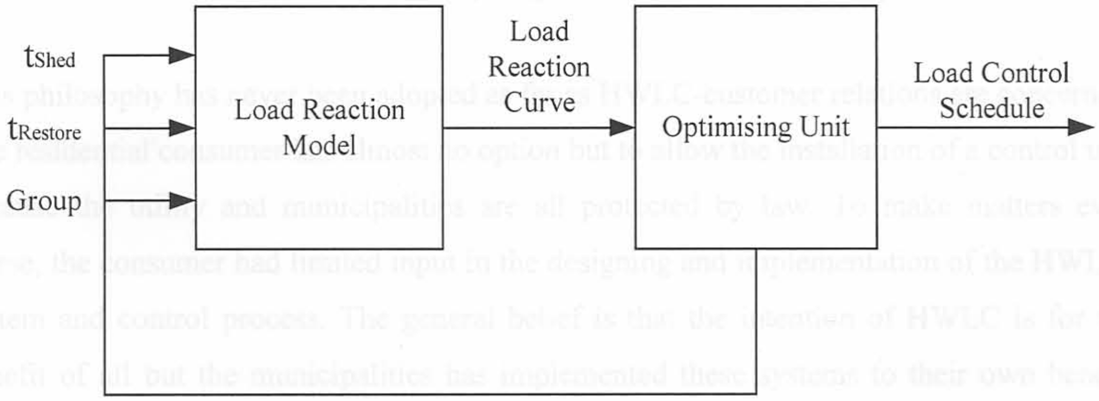

Figure 2.6: Interaction between the Load Reaction model and the Optimising unit.

During each iteration of the optimising process, the load-profile-optimising module passes three input variables to the CLP calculation module:

- ☐ The selected HWLC-group for the current iteration.
- ☐ The time of the day that the group must be switched off (t_{Shed}).
- ☐ The time of the day that the supply of the group must be restored ($t_{Restore}$).

These inputs are then used in a mathematical data manipulation process (section 3.1, page 63) on the system constraints of the selected group. The optimising module must repeat this process for all the user groups selected for control. The results obtained for each group must then be summated in order to construct the predicted national load-profile. The optimising unit must verify that all the system requirements set forth by utility, municipality and residential consumer were met, or else repeat the iteration again before it publishes the load-control schedule.

Finally the demand specifications are met, but the residential customer remains at the bottom of the food chain. Something has to be done about this occurrence and therefore is the next section committed to the integration of the residential consumer's needs into the HWLC-system.

2.3 RESIDENTIAL CONSUMER ORIENTATED CONTROL

"The customer is always right, even when he is wrong."

This philosophy has never been adopted as far as HWLC-customer relations are concerned. The residential consumer has almost no option but to allow the installation of a control unit because the utility and municipalities are all protected by law. To make matters even worse, the consumer had limited input in the designing and implementation of the HWLC-system and control process. The general belief is that the intention of HWLC is for the benefit of all but the municipalities has implemented these systems to their own benefit without taking the needs of the consumer into account. Obviously something went wrong and the aim from here on would be at least to start the process of consumer-orientated control.

Three basic residential consumer needs have been identified throughout chapter 1:

- ☐ Consumers must have a say when they would prefer to have hot water,
- ☐ A minimum hot water temperature level should be agreed upon and formulated in the management rules and
- ☐ Incentives should be paid out to compensate for any inconvenience caused.

The first step towards residential consumer orientated control would be to address these three basic needs. Loyds [9] clearly stated in section 1.6 that the influence of any DSM option should be known before implementation and therefore should methodologies for each of these needs be formulated. The first need to be addressed is the preference group configuration and its effect on an HWLC-system.

2.3.1 Consumer Group Configuration

The motivation behind consumer group configuration is to give the residential consumer an option to choose between various control strategies. Residential consumers are currently randomly assigned to control groups in order distribute the hot water load evenly over all the groups. This solution is undoubtedly not optimal due to the diversity among user consumption.

Some users would be willing to give their entire hot water energy load for control purposes as long as they are guaranteed of hot water for a specific timeframe, i.e. between six and seven in the morning. The implication is that this type of consumer would not mind at all if the water temperature is below 40°C during the evening peak. The advantage is thus that this agreement entitles the load-controller to extract another 15°C of energy that would previously have been impossible since the client would have been listed as a risk of cold water.

Another motivation is when consumers have more than one cylinder installed on their premises. It is customary that one cylinder is dedicated to service the main bedroom area whereas the other one is used for washing and cleaning purposes. It is eminent that expectations on the two cylinders would be different and therefore is it possible that intelligent group categorisation lead to a more efficient and customer-orientated system.

A good place to start the user pattern classification process is to gather all relevant information about the actual needs of the consumer. The data must then be processed in order to identify groups with similar behavioural patterns.

A simple questionnaire can be handed out during installation and might include the following questions:

- What is the unique device address of each one of the HWLC-devices installed?
- What is your electricity account number?
- How many people occupy the dwelling?
- Do they shower or bath and at what time of the day?
- How many people are at home during daytime?
- Specify the rating (E.g. 3kW) as well as orientation (horizontal or vertical) of every hot water cylinder installed.
- What is the temperature setting of each cylinder?
- Do you switch one or more cylinders off at any time of the year; if so when and for how long?
- At what time of the year do you prefer to go on holiday and for how long?

From the data gathered, a consumer can be classified into any one of the categories defined in section 2.1.2. A consumer can only migrate from one category to another if substantial motivation was presented but control level selection (lenient, regular, frequent) can be changed easily. The consumer data is finally ready for storage in a consumer database which must at least include the following fields:

- Unique HWLC-device address,
- Rating of the installed cylinder
- Personal details such as initials, surname, physical address, phone number, electricity account number, etc and
- The selected control category and group number.

Once the categorisation process is finished, the control strategy can be evaluated on group level - opening the door for detailed system behavioural data extraction. It is possible to extract data for every day of the year, but that would be a very costly process and therefore should one study section 1.6 (page 15) again to identify the minimum data fields required to compensate for human behaviour. The data should compensate for:

- Weekly patterns in human behaviour,
- Seasonal variations and
- Various holidays.

In terms of the study made in chapter 1, weekly patterns can best be described by extracting only four types of days:

- **Monday**: People tend be reluctant to get out of bed and go to work.
- **Wednesday**: It is an accurate estimation for Tuesday – Thursday.
- **Friday**: The customarily social night of the week exhibits unique characteristics.
- **Sunday**: Saturday and Sunday could be treated separately but it would be a fair estimation to treat these days similarly.

To compensate for the seasonal variation, a set of weekly patterns should at least exists for every season but preferably for every month, depending on the size of the HWLC-system. A fair representation of customer behaviour consists of 48 (4 days per month x 12 months) profiles per group that has to be stored in the database.

Each holiday should be treated on merit. The management rules must clearly specify which type of day should be used in order to estimate the consumption pattern for that specific holiday. Let's take an example where the public holiday falls on a Wednesday. In the first place the controller should know from the management rules that it is a public holiday. In second place should the controller apply the set of management rules to determine that the holiday must be treated in the same fashion as if it was a Sunday.

At this stage the nature of the stored data is known, but no actual data has been recorded. The data for a specific type of day is stored in the form of a percentage consumption profile, illustrated in figure 2.7, and is obtained by means of a channel separation test.

A channel separation test requires that only one group is notched at a time and the resultant notch is visible on the total load-profile, which is equal to the TADMD of that group. This TADMD is then divided by the installed capacity and the result is used to plot a percentage profile for the group.

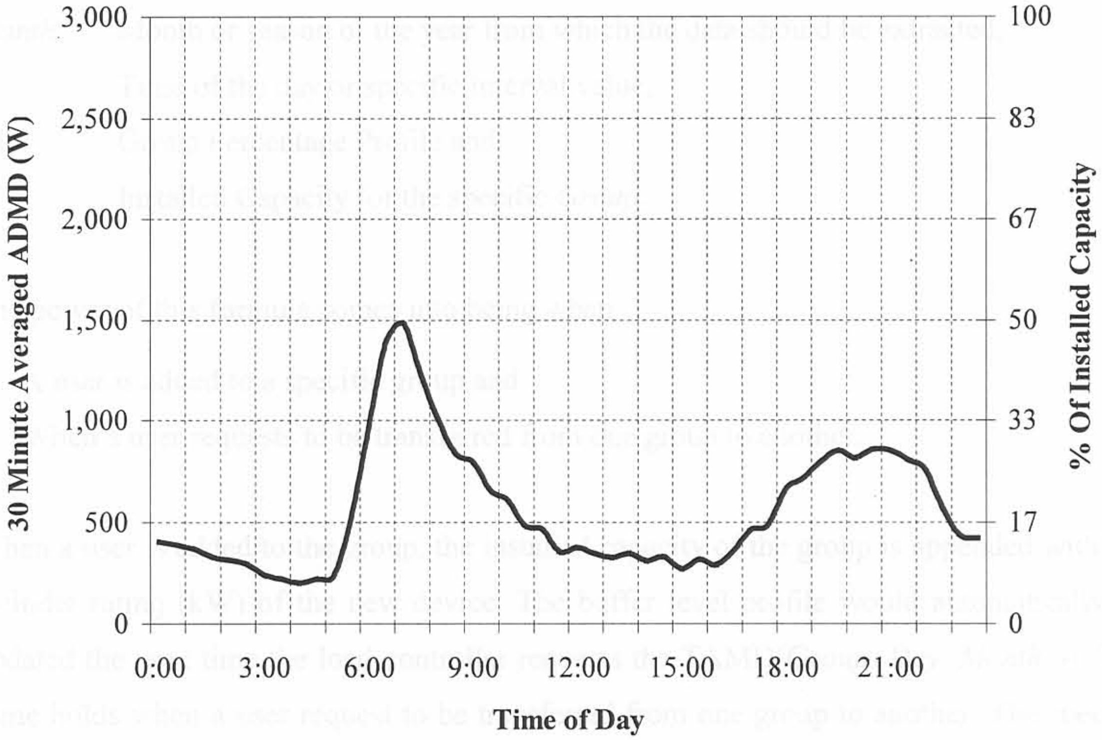

Figure 2.7: Percentage profile of the South African hot water consumption.

The advantage of using a percentage profile is that the profile is independent of the amount of devices in the group. The controllable amount of energy available in the storage buffer of each group can be obtained by

$$\mathrm{TAMD}(Group, Day, Month, t) = \mathrm{GPP}(Group, Day, Month, t) \times \mathrm{IC}(Group) \tag{2.2}$$

where,

Group	Specific group or category number,
Day	Selected day pattern,
Month	Month or season of the year from which the data should be extracted,
t	Time of the day or specific interval value,
GPP	Group Percentage Profile and
IC	Installed Capacity for the specific *Group*.

The power of this formula comes into being when

- ☐ A user is added to a specific group and
- ☐ When a user requests to be transferred from one group to another.

When a user is added to the group, the installed capacity of the group is appended with the cylinder rating (kW) of the new device. The buffer level profile would automatically be updated the next time the load-controller requests the TAMD(*Group, Day, Month, t*). The same holds when a user request to be transferred from one group to another. The specific user's installed capacity is subtracted from the old group and then added to the new group's installed capacity without interfering with the actual profile data.

Now that the process of user classification is defined, the next step would be to minimise risk of cold water. From there on one would be able to derive a process from which the average hot water cylinder temperature of each group can be determined.

2.3.2 Minimising Risk Of Cold Water

HWLC is a concept that is not all too familiar to the general public. This has numerously led to great misunderstandings, as the consumer will not hesitate to bypass the residentially installed control unit the minute that his hot water supply is insufficient, even if it wasn't as result of any load-control actions taken.

After a number of units have been bypassed, the control system is forced to shed the remaining operational devices for a longer time in order to maintain previous saving levels. This in turn causes a snowball effect because more HWLC-units are being bypassed and the honest users must endure cold water at an escalating rate. Consequences like these can be avoided by installing a more customer orientated system with a high switchable device resolution. On the consumer side the community has to be educated regarding the local and global advantages of HWLC.

Another aspect of concern is the household size versus the cylinder capacity ratio. A higher ratio indicates a greater risk of cold water. This problem can be overcome by increasing the temperature setting on the thermostat of the hot water cylinder. Care must be taken to ensure that the additional energy consumed due to the change in temperature setting during regular usage isn't more than the saving contributed by load-control actions.

2.3.3 Average Cylinder Temperature Model

The problem at hand is that the management rules require that a consumer must be guaranteed of a minimum cylinder temperature during specific timeslots of the day. The ideal solution would be to constantly measure the temperature of every individual hot water cylinder in the field and to control the cylinder temperature accordingly. With the available technology in mind this option tends to be as an Utopian dream and therefore the search must continue for a plausible solution.

Delport, Jooste and van Harmelen [21] postulated that a group of cylinders can be defined as a single cylinder with equal capacity and consumption of the summated capacity and consumption of the individual cylinders. E.g. A group consisting of ten 150 litre (3kW) hot water cylinders can be estimated as a single 1500 litre cylinder with an adjustable consumption rating of 0 – 30 kW. The TADMD-profile of the group can therefore be used as the consumption and losses pattern of a single 1,500 litre cylinder.

The temperature prediction model requires the following inputs:

- ☐ Installed capacity of the group,
- ☐ Effective water capacity of the group,
- ☐ Uncontrolled TADMD of the group and
- ☐ The expected shedding (t_{Shed}) and restoration times ($t_{Restore}$).

The model then interprets these inputs in conjunction with a mathematical iteration process to plot an estimated cylinder temperature curve for the specific group. This mathematical process is described in detail in section 3.2 on page 87.

Both the load-controller and the load-optimising module can use the temperature prediction model to determine the average cylinder temperature of the group. Management rules force the optimising module to reschedule a group when the predicted temperature for a timeslot is below its specified temperature threshold level. The temperature threshold level of a group doesn't have to be the same value throughout the day, but the average cylinder temperature within a specific timeslot is not allowed to go below its specified level.

2.3.4 Calculation And Distribution Of Savings

This is exactly where HWLC gets a bit hairy. The municipality is fighting for the savings in order to pay for the installed hardware, whereas the residential consumer feels that he is entitled to a part of the savings due to discomfort caused by the system. Both parties have a valid argument but a win-win solution has to be presented to ensure the future of HWLC.

To solve the problem at hand, one should go back to the various objectives of the utility, municipality and residential consumer in chapter 1. In summary the aspects of concern would be to define an optimal cost-output-function for the entire HWLC-system to:

- ☐ Minimise generating costs on the utility level,
- ☐ Minimise the utility bill on a municipal level and to
- ☐ Ensure compensation for customer discomfort caused.

Savings On Utility Level

The only way a utility can save money in terms of HWLC is to utilise its generation infrastructure optimally. The tariff structure set forth to the municipality must reflect the areas where control is required, i.e. where the system isn't optimally utilised. A TOU-tariff structure would benefit both utility and municipality and in this case Megaflex in particular lends itself more towards being the "optimal" tariff structure. RTP is at the moment too risky due to the municipality's high base-load and low controllable hot water load at certain times of the day. RTP in itself would not motivate optimal HWLC-actions due to the possibility small of savings.

Currently, Megaflex's peak times also co-inside with the prominent residential peaks of the municipal load-profile. Thus, as far as the utility is concerned, optimal control would be to shift energy out of the national peak times into the off-peak times instead of the conventional peak clipping methodology. This strategy then satisfies the utility's needs and a fixed baseline is set on which the rest of the model can be developed.

Savings On Municipal Level

The total cost of a HWLC-system consists of two parts:

- ☐ **Fixed Costs**: This is the initial capital required to install the HWLC-system. Usually investors would finance these projects if the payback period is less than 3 years.
- ☐ **Operating Costs**: This includes maintenance contracts, customer care and operational personnel, consumer educational projects and any other expenses directly related to HWLC.

The operating costs are not that much, usually estimated between 10 and 20 percent of the capital cost, and can easily be covered by the MD-reduction-savings. Savings related to energy shifting actions must therefore be distributed to pay the fixed costs and to compensate the residential consumer. The actual distribution percentage will vary from installation to installation, depending on the minimum monthly down payment towards capital costs. The distribution percentage towards the consumer must increase substantially after the final capital costs down payment has been made.

Savings Distribution On Consumer Level

"Money is the root of all evil."

The main objective is to ensure that the situation doesn't change from bad to worse. The assumption is that no incentives are currently being paid out directly to the residential consumer. The next stage in the compensation process should be to distribute savings in a fair and auditable fashion between consumers. One can easily cause a riot within the residential community when certain groups receive more benefits than what their contribution were to the total savings effort. The tariff structure, in collaboration with the management rules, should also prevent unnecessary migration of consumers between groups. A large migration effort could disrupt the shape and characteristics of the TADMD profiles where after channel separation tests have to be conducted again.

"One hand washes the other"

This philosophy also holds for the selected HWLC-strategy of this dissertation. During the morning peak period between 7:00 and 10:00 most of the groups, except Morning Madness would be switched off. These groups will be restored at 10:00 where the reserves in Morning Madness will be used to minimise the cold-load pickup in terms of MD control. Morning Madness does not contribute directly to the savings, but is indeed very important during load restoration and therefore can cross-subsidisation not be avoided.

The TADMD-profile of a specific group is a representation of its amount of energy available for HWLC at any specific time of the day. From another perspective the TADMD is an indication of the amount of energy that a specific group contributed towards the HWLC-effort and can therefore be used as an indicator during the savings calculation.

The marginal saving per kWh can be obtained by:

$$p.u.Savings = \frac{TotalEnergySavings}{\sum_{n=1}^{Days} \sum_{m=1}^{Groups} SGC(n,m)}$$

where,

p.u.Savings	The marginal saving of one kWh (R/ kWh)
TotalEnergySavings	The total energy shifting saving for the billing period (R)
SGC(n,m)	Specific Group Contribution of the mth group for the nth day of the current billing month (R)
Days	The amount of days in the savings period i.e. Days in the billing month and
Groups	The amount of HWLC-groups.

The marginal saving can now be applied to each user group from which the contribution per member can be calculated. Savings can either be paid out in the form of a reduced electricity bill or directly cash in hand. Although the latter option seems frivolous, it is more of a psychological effect because the residential consumer will physically "see" the benefits of HWLC in monitory value.

2.4 CONCLUSION

Finally al three entities within the HWLC-process are mutually satisfied which concludes the methodology development process. As noted throughout this chapter, various mathematical derivations will be discussed in detail in chapter 3. The methodology might be altered some day, but for now it can be seen as a step in the right direction.