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**Characterisation of dwelling electricity demand with reference
to DCHP**

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Glossary

CHP	Combined Heat and Power
CSV	Comma Separated Values
DCHP	Dwelling CHP
GW	Gega Watt
RMS	Root Mean Square value
kW	Kilo Watt
lm	Lumen
W	Watt

Nomenclature

C_p	Specific Heat at Constant Pressure
H_l	Latent heat
k	thermal Conductivity
M	Mass
T	Temperature
T_a	Ambient Temperature
T_{ev}	Appliance Evaporator Temperature
W_a	Relative Ambient Humidity
$W_{appliance}$	Relative Humidity in appliance
W_e	Electrical Power
W_t	Thermal Power
ρ	Density

Abstract

The research relates to the introduction of dwelling micro combined heat and power to the domestic sector as a mean of improving the efficiency with which primary energy is used, and the economic efficiency of supplying electricity via the national grid.

Such small generators may constitute Stirling engine or solid polymer fuel cells. This research is orientated towards the electrical demand side issues. The context is to maximise the feasibility of such technologies when the typical domestic consumer's heat demand varies significantly with season and the associated electrical power varies substantially every minute of the day. The main issue was to ensure that the system could effectively and economically satisfy a considerable proportion of the electricity demand – the typical demand profile is very peaky by virtue of the way inhabitants behave at home and the design of domestic appliances.

To derive the characteristic of dwelling electricity demand, a total of 45 dwellings were sampled, monitored and classified, in order to analyse the parameters influencing the shape, magnitude and duration of the profile data collected. A survey was issued to complete the research regarding appliances time of use. Then a model was designed with an interface allowing dynamism.

The research concluded there are attractive reasons for micro combined heat and power to be implemented in dwelling. It could save up to 15% of primary fuel. On an annual basis, and with the 15 dwelling data provided by British Gas, the average saving for a constant 1kW_e DCHP is determined to be £44.78, and the saving is increased to £124.61 for a system that would allow a turndown from 1kW_e DCHP during winter to 500W_e DCHP during summer. Furthermore utility companies should be gaining from this introduction because peak power demand reduction on the grid should reduce costs.

Chapter I: Introduction

1) The Aim

The work aims to develop a dwelling electrical load model using monitored data combined with a probabilistic approach to determine the viability of dwelling alternative electricity generation systems.

A comprehensive electricity load model would allow an energy utility to adequately predict the magnitude and time variation of its load and therefore enable it to operate its generation capacity more efficiently. A load model is an indispensable tool for accurate short and long term capacity planning. The reason for concentrating on dwelling electricity demand is that while commercial and industrial electricity demand is considered for economical reasons, dwelling electricity demand seems to be less researched.

The dwelling electricity demand involved developing a number of elemental components, which describe the operation of individual types of dwelling electrical equipment. These models required the development of a time of use function for various appliances. The intention was to combine appliance ownership, the usage of different appliances and their load signature to derive realistic power consumption of dwelling.

The impact and the viability of implementing a DCHP system (Dwelling Combined Heat and Power system), which generates heat and electricity, depend on energy price and DCHP usage. In that context, the analysis of domestic energy use is relevant, as well as the DCHP use mode

2) Literature review

At the beginning of project, the amount of available literature was found to be extensive, but as the analysis was progressing it was observed that the nature and accuracy of results is relatively difficult to crosscheck. Furthermore the data available were from other countries (mainly North America, but also France, Portugal and Sweden).

It should be noticed that over the past 10 years, the British Electricity Industry has moved from state to private ownership and has been radically restructured in the process. While public ownership industry statistics were supplied and published in a number of handbooks and periodicals. However, with the move from state to private ownership and the vertical break up of the industry the objectives of the new players who have emerged is different. Profit maximisation, within the constraints of the regulatory regime and competition is one of their goals. The firms are now trying to protect their own interests. One of the ways they do this is by restricting the flow of information and statistics, which were available in the past, and are now confidential.

“Characterisation of energy consumption in the domestic sector”^[45], described the monitoring and analysis of 25 individual dwelling in Portugal. “Demand side

management end-use metering campaign in residential sector”^[46], shows three-dimensional analysis of French dwelling by monitoring each appliance. Nutek^[40] characterised the electricity consumption of individual dwelling by monitoring each individual appliance. A PhD thesis titled “A residential electrical load model”^[47] was submitted in 1982, which described steps in designing a model for multiple dwelling in USA.

The available information on dwelling electricity demand was classified and used as required. It was noticed that the information related essentially to electrical energy over long period (month, year) rather than specific data at short interval duration.

Some of the approach that had been used in load modelling was based on periodicity and weather effects. It should be observed that considering the small amount of energy consumed by each individual dwelling, it is much easier to consider the residential sector as a whole. In general, no specific relationship between appliances and load was made for demand models in the UK although equipment characterisation is used in some models. The first part of the literature review is about the ownership of appliances in the UK dwelling. The information was derived from statistical reviews and different surveys essentially produced and published by Building Research Establishment.

Specific data concerning electrical appliances were required to determine electricity usage individual component. The information gathered regarded essentially load demand and duration for individual appliance. Useful functions were derived when necessary. The main source of information were consumer magazines, such as, “Which” in the UK and “50/60 millions de consommateurs” in France. The appliances time of use is the most vital part of the process of characterisation, but the data available and usable are very limited. The only appliance that had been studied in the literature is the television^[39].

Gaps rapidly appeared and it would not have been possible to build a model with the available data, therefore it was decided to involve monitoring and surveying.

3) The electrical national demand

To start the analysis, the national electricity demand was analysed to determine the pricing issue. The pool price increases with the demand, but the rise is shown not to be always proportional. While it might be proportional for low to medium demand, the peak demand shows an exponential increase of the pool price. Furthermore different pricing scenario will be used to determine energy bill. This data was made available by the pool price information.

The electrical national demand describes all the electricity but the breakdown between national and residential electricity demand is not available. The information is given every half an hour over a few years, which represent a large amount of data. This is all contained and available in a file that needed to be analysed.

4) Knowledge of domestic load curve

The knowledge of the demand was very limited, only a few houses had previously been monitored and the results were analysed to be composed of a base load and peaks, but it was difficult to determine the meaning of the measurements. The load factors were particularly low in individual dwellings, of the order of 8%. This needed to be investigated to find out how the electrical energy was consumed during the day, and essentially to find out when the load was high enough and constant enough to allow for alternative electricity generation to be considered.

5) Energy context of the study

Inhabitants in a dwelling require heat and power. In the UK gas is used generally for heating purposes while electricity covers power demand. This choice is generally due to economical reasons because gas is cheaper than electricity. Gas is generally used for space, water heating and cooking while electricity covers the rest. It should be noticed that electricity is much more convenient because it could cover all the energy dwelling requirements, while gas is generally limited to heating purposes for technical reasons.

Characterising the electrical demand of individual dwelling will permit to determine the energy bill in different scenarios, therefore special care will be given to the two main energy resources currently used in dwelling: electricity and gas. It should be observed that gas is a primary fuel while electricity is derived from a primary fuel.

6) DCHP characteristics

Many different generator technologies could be used for DCHP, such as gas turbines, steam turbines, combined cycle, reciprocating engine and Sterling Engine. To ensure practicality, the DCHP maintenance should be less or at least equal to conventional boiler maintenance. The heat to power ratio of the system should be relative to domestic usage, to increase the DCHP system efficiency and use duration.

Conventional electricity generation at hydro, thermal or nuclear power stations gives average efficiency of 37%, a figure that is lowered to 33% if losses during transport and distribution are taken into account. Approximately 63% of heat is inevitably lost, as there is no possibility of making use of it at the large electricity generating stations, and furthermore, thermal energy consumed by the user is generated in units, which even in the most favourable case reach an efficiency of around 90%. Due to the utilization of the residual heat, cogeneration systems show an overall efficiency of around 80%, a large primary energy saving.

The best compromise is found with the Stirling Engine^[18], which operates on a closed cycle with heat supplied by external combustion and transferred to the working fluid via a heat exchanger. The maintenance is similar to a conventional boiler, the heat to power ratio is about 5 to 1, and the overall efficiency could reach 80%.

Chapter II: Generality of English housing

The description of the English housing characteristics is vital because it is the background of the project. The chapter will characterise the inhabitants and their level of electrical appliance ownership.

1) Household

The number of inhabitants has a direct impact on the amount of energy spend in the dwelling, because certain inhabitant's activities will result in consuming energy.

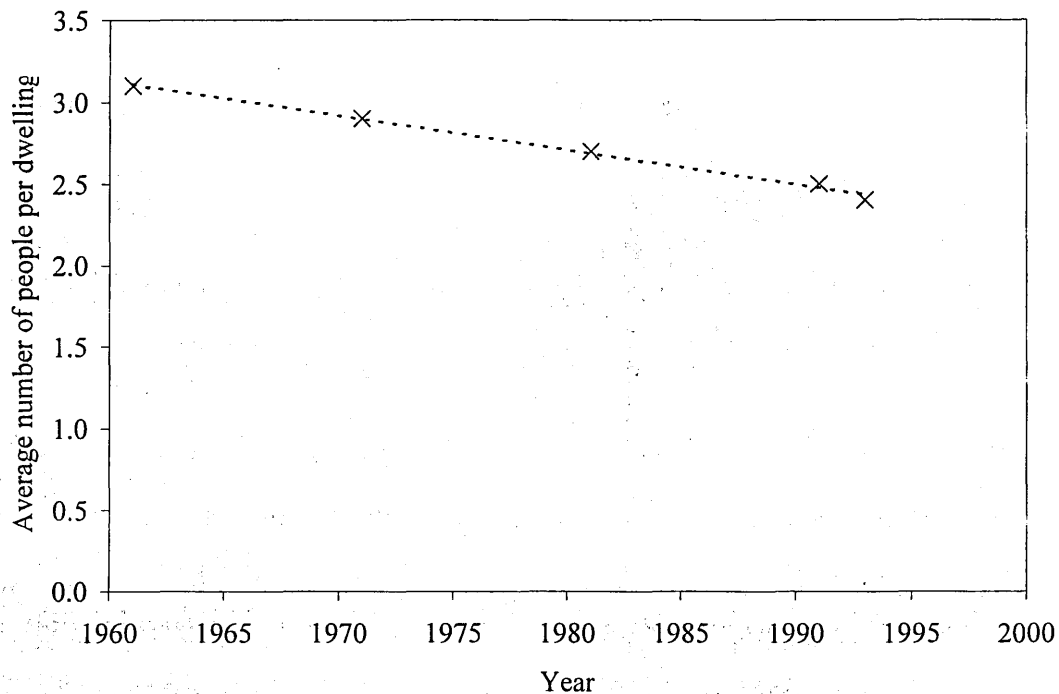


Fig. II- 1 Average number of people per dwelling^[41]

Fig. II- 1 shows that there is a tendency of the size of the average English household to reduce since the 1960. This will influence the choice for the monitoring and surveying target.

The next step is to look at people's activities. To derive such a characteristic the employment is used because it will be possible to determine pattern of occupancy of dwelling.

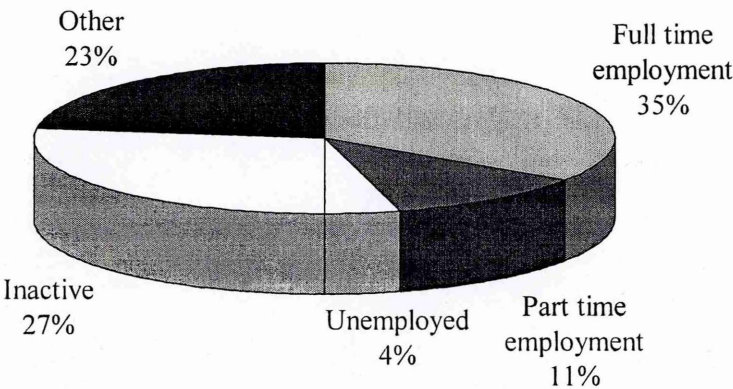


Fig. II- 2 People and employment in 1994^[42]

Fig. II- 2 shows that almost half of the population is employed and that the other half is composed of 27% of inactive and 23% with other activities. Therefore it is possible to deduce that the population might be divided into two main parts, about 30% could spend most of their time at home while 70% could potentially be active outside their home.

It should be noticed that while nobody is home, appliance such as kettles, televisions, cooking appliances, wet appliances would not be used, because they generally need to be manually triggered. If one inhabitant is constantly present then all these appliances could be used at any time during the day.

2) Dwelling type

To understand the dwelling characteristics, one of the factors that could prove to be relevant, is the dwelling type, because the level of investment in a dwelling may show an impact on the appliances owned and used.

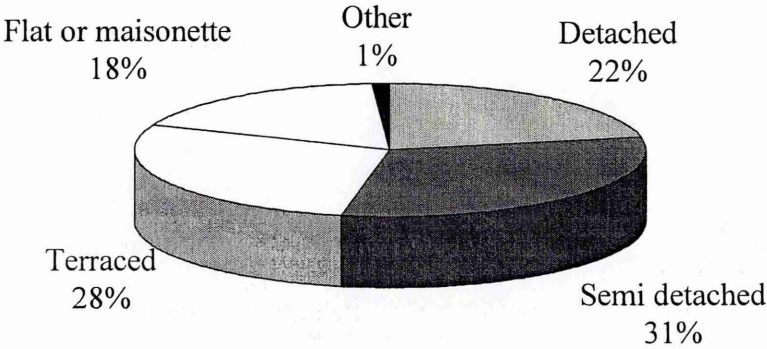


Fig. II- 3 House type^[35]

It can be determined that there are four main dwelling types. For the purpose of the study the target will be reduced to terraced, semi-detached and detached dwellings, because flats or maisonettes may have energy sharing scheme. The targeted dwelling electricity demand is more and more flattened as the number of total inhabitant increases, which allow alternative option such as DCHP to cover their needs. Furthermore it can be seen that the targeted houses are almost evenly distributed which will be considered in the research.

3) Main electrical appliances ownership since 1975

The electrical appliance ownership will be the base for the study, because to be able to use an appliance, one should own it in the first place. This part of the analysis looks at the

evolution of ownership, so that the project will not run out of date explicitly at its conclusion but could be modified to accommodate for future changes and progresses. If the main electrical appliances are considered, then four main groups could be derived.

The heating could be classified as major if only energy consumption was to be considered. This type of appliances will be omitted because of low level of electrical appliance ownership. It is analysed in Chapter IV that only 7% of dwelling are using electricity for space heating purposes.

Therefore the most common appliances owned are refrigeration appliances. Their ownership represents the number of dwelling with the appliance over the total number of dwelling.

Fig. II-4 shows that their ownership and therefore their use have increased through the years. While refrigerator ownership has been high since 1975, the deep freezer has shown an impressive penetration into English dwelling. It should be noticed that for the purpose of this graphical display, the Deep freezer are including Fridge Freezers.

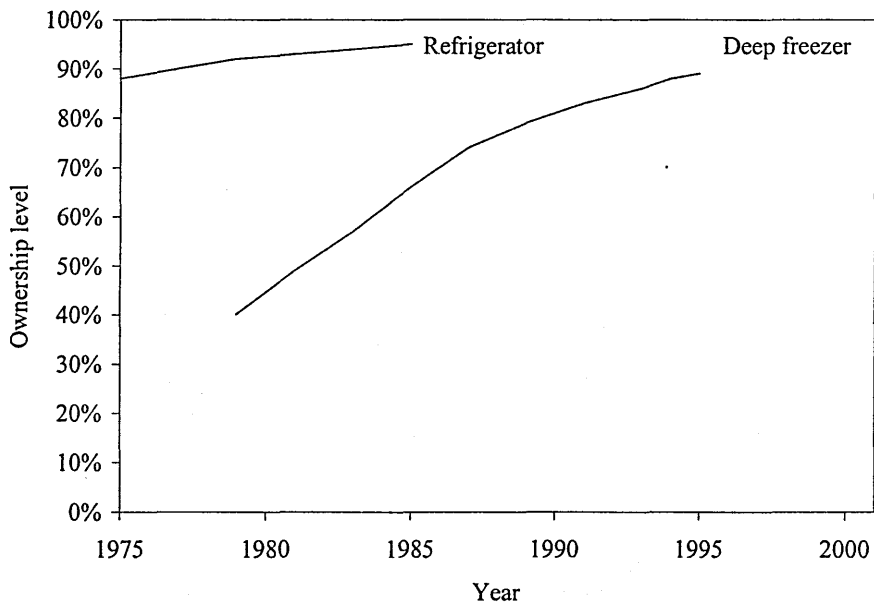


Fig. II- 4 Ownership of refrigeration appliances^[34]

Refrigerator and deep freezer represent now typical appliances, which are commonly used in dwelling. More than 90% of household uses them.

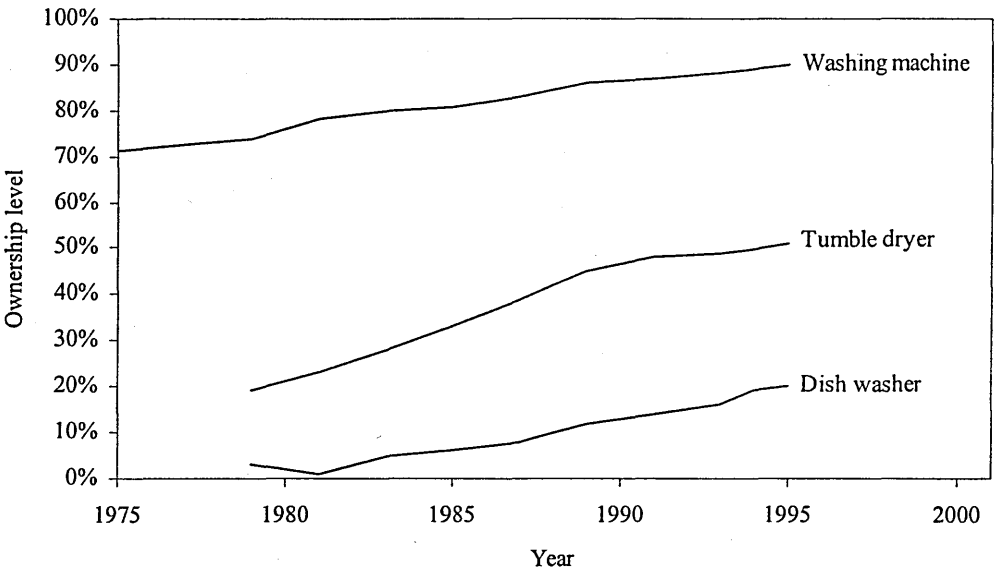


Fig. II- 5 Ownership of wet appliances^[41]

The second type of electrical appliance to penetrate intensively the English dwelling is the wet appliance. They represent the washing machine, tumble dryer and dish washer. Their respective level of penetration, which is displayed in Fig. II- 5 shows the regular increase of washing machine, followed by tumble dryer. The explanation for such a difference may reside in the fact that while washing machine has become indispensable, the tumble dryer is still considered as a practical but not essential appliance. The dishwasher has only recently made an apparition, essentially due to its practicality.

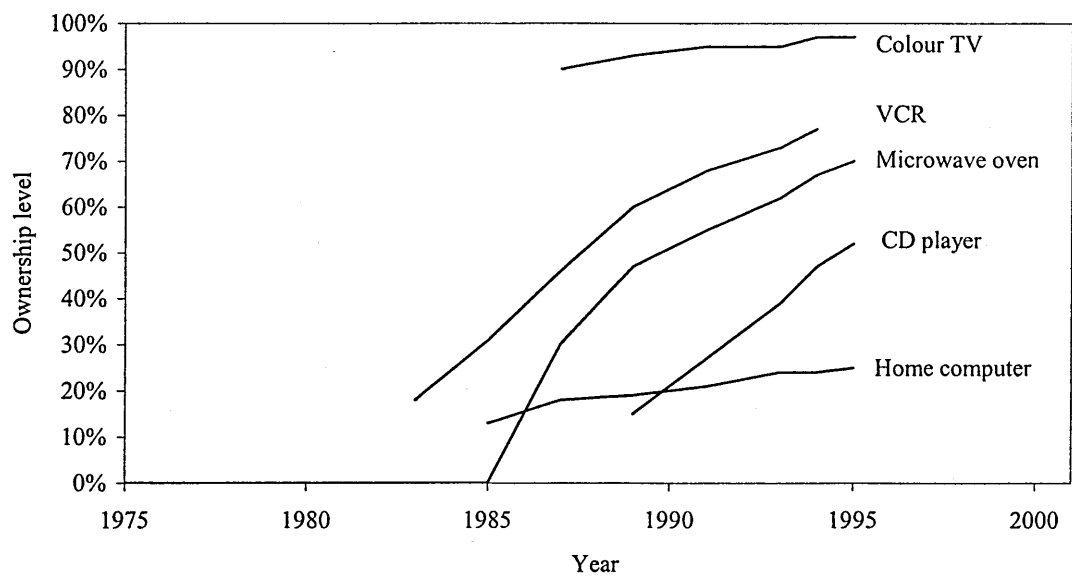


Fig. II- 6 Ownership of electronic appliances^[41]

Recent evolution of the market and household habits, combined with improvements in standard of living, has developed a new type of electrical appliances. These appliances are derived from new arising technology. A typical example is the colour television, which started from almost none in 1975 to get close to a 100% ownership in 1995. Similar increase in ownership might be similar for other appliances described in Fig. II- 6.

4) Energy consumption

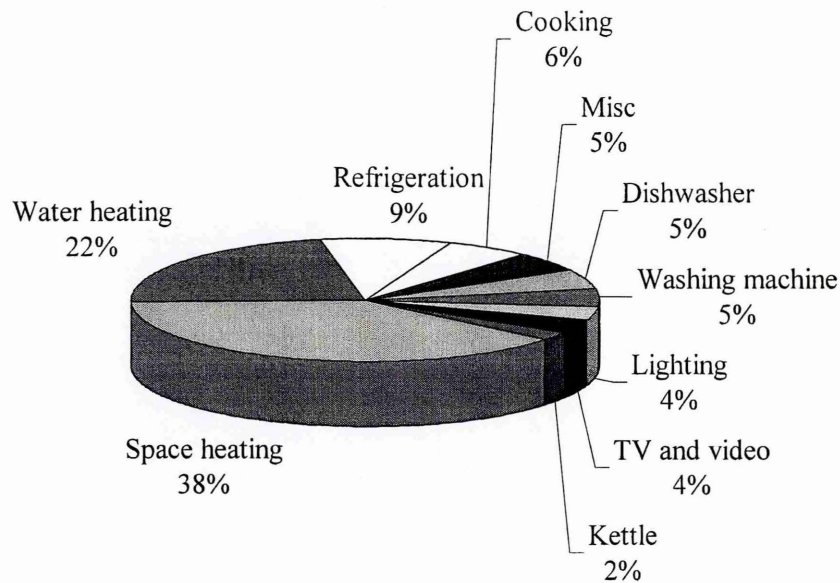


Fig. II- 7 Energy consumed per appliances^[37]

To determine the relative importance of appliance consumption, Fig. II- 7 shows that space and water heating energy consumption represent 60% of the total consumption. The other appliance types are mainly represented by the refrigeration with 9%, cooking and kettle with 8%, and a whole range of appliances only representing less than 5% of the total energy consumed. Therefore 60% of this energy is derived mainly from gas, and 40% is mainly electrical energy.

5) Energy price

There are two main energies, which are usually available in dwellings, namely the electricity and the gas. Both can be supplied by adequate distribution systems, although gas might be distributed in bottle containers.

Other sources of energy such as coal and petrol are also available for domestic consumption but their usage is somehow limited due to relative complicated system, and poor economy. It should be observed that coal is difficult to transport and store, while petrol price is varying through time.

i) Gas price

Gas is generally used in dwelling for heating purposes. This covers space heating, water heating and sometimes cooking. The gas is cheaper than electricity, due to the fact that gas is a primary energy that only needs processing and pumping to ensure distribution. Depending on distributor and contract, prices may vary from 1.5 to 2.5 p/kWh. The standing charge can be assumed to be about £10 per quarter.

ii) Pool electricity price

Electricity is a derived energy. Its intrinsic value is greater due to its facility to use and its high compatibility with a most of energetic processes. The electricity is usually generated in power station with primary energy. The process is to transform heat into power and then power into electricity. During the processes, more than half of the energy is wasted. Then the electricity has to be transmitted, transformed, and distributed.

a) The demand and availability of electrical energy

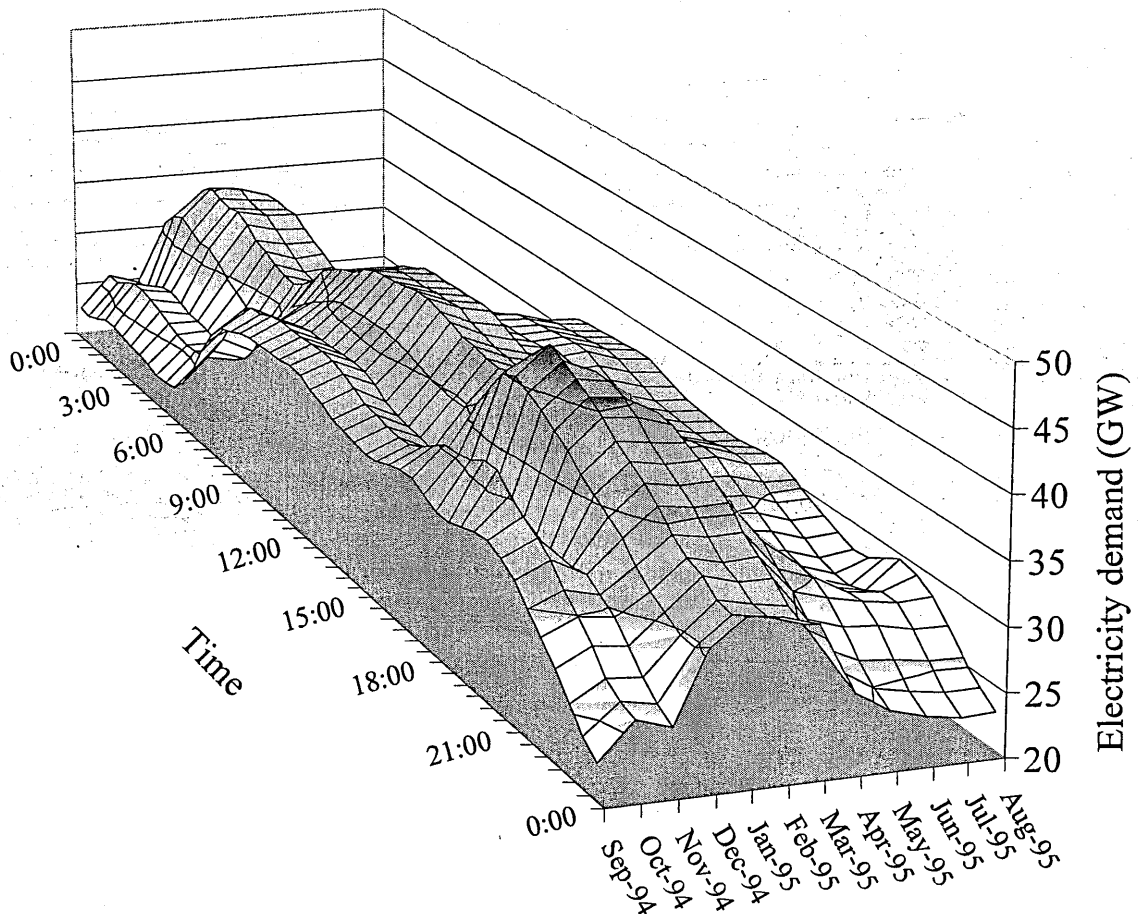


Fig. II- 8 Monthly average electricity demand

The Fig. II- 8 is derived from pool electricity data. It was constructed using monthly averaged data that needed to be derived from row data, and then displayed on a 3-dimension graph to be able to access daily variation. The analysis shows that there is a seasonal variation of the demand, winter shows a maximum, while summer shows a minimum. On a day to day basis, there is a small peak in the early hours (essentially during winter period), followed by a second peak in the morning hours, and the maximum peak is obtained around 17h00. This type of graph will be used throughout the project, it takes into account two time reference (daily and monthly).

b) The price

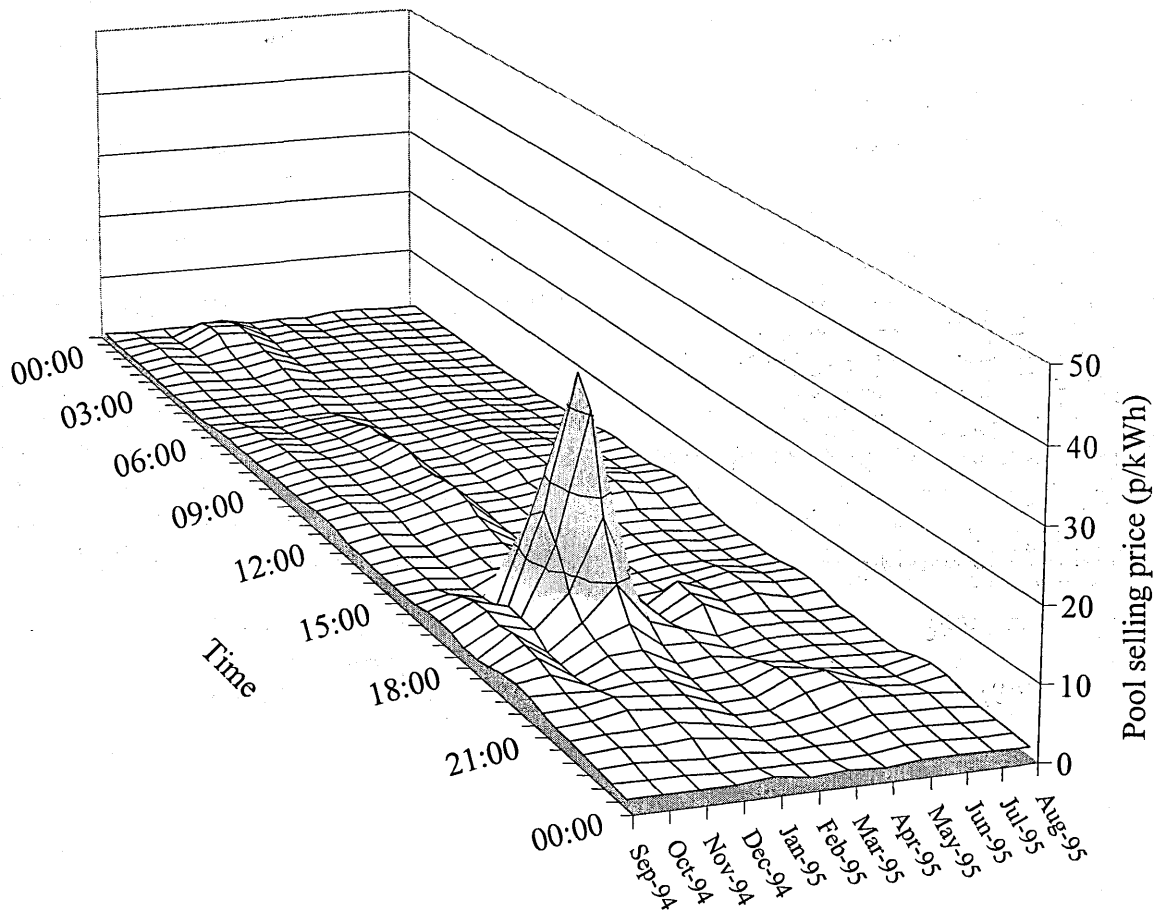


Fig. II- 9 Pool selling price

This analysis of the half-hour average price of electricity shows the impact that the demand can have on the electricity price. It is during the winter month, between 15h00 and 18h00 that the electricity is the most expensive, and its price can get to very high value (up to 34.60 p/kWh) compared to a usual value of 1p/kWh.

ii) Domestic electricity price

At the moment electricity prices in the domestic sector is determined as an average over the year. Actual projects are looking at real time of use pricing principals, and the infrastructure required needs to be developed to allow monitoring.

Two tariffs are currently available to the domestic sector. The “Standard” tariff is generally composed of a standing charge and a constant charge per unit consumed. The “Economy 7” tariff has a greater standing charge and allows access to cheaper electricity during 7 hours of the night.

6) Conclusion

This first approach of the study tends to show an increase in appliance ownership. To analyse energy usage, derive the cost implications, and determine possible alternatives, the study of the parameters influencing the appliances usage is necessary.

Chapter III: The monitoring process

To determine the dwelling electricity consumption, the first step was to characterise the power demand of individual appliances. Different measurement apparatus were used depending whether the tests can be conducted in the laboratory or in situ.

1) The requirements and the apparatus

i) Desired data

The electricity consumed in a dwelling is characterised by two variables, the voltage and the current, which are both alternating quantities. They are described as sinusoidal function of time, therefore,

$$v(t) = V_0 \cos(\omega t + \varphi_v)$$

$$i(t) = I_0 \cos(\omega t + \varphi_i)$$

where $v(t)$ is the voltage, and $i(t)$ is the current

V_0 is the voltage peak value

I_0 is the current peak value

ω represents the frequency, and t the time

φ_v is the voltage phase, and φ_i is the current phase

Eq. III- 1

Generally measurement of such quantities would be impossible because of its frequency of variation (50Hz). Therefore a RMS value is defined as the Root Mean Square value. In the case of the main voltage it is known that the RMS value is 240V. For a purely sinusoidal variable it is known that the RMS value is equal to the peak value divided by the square root of 2.

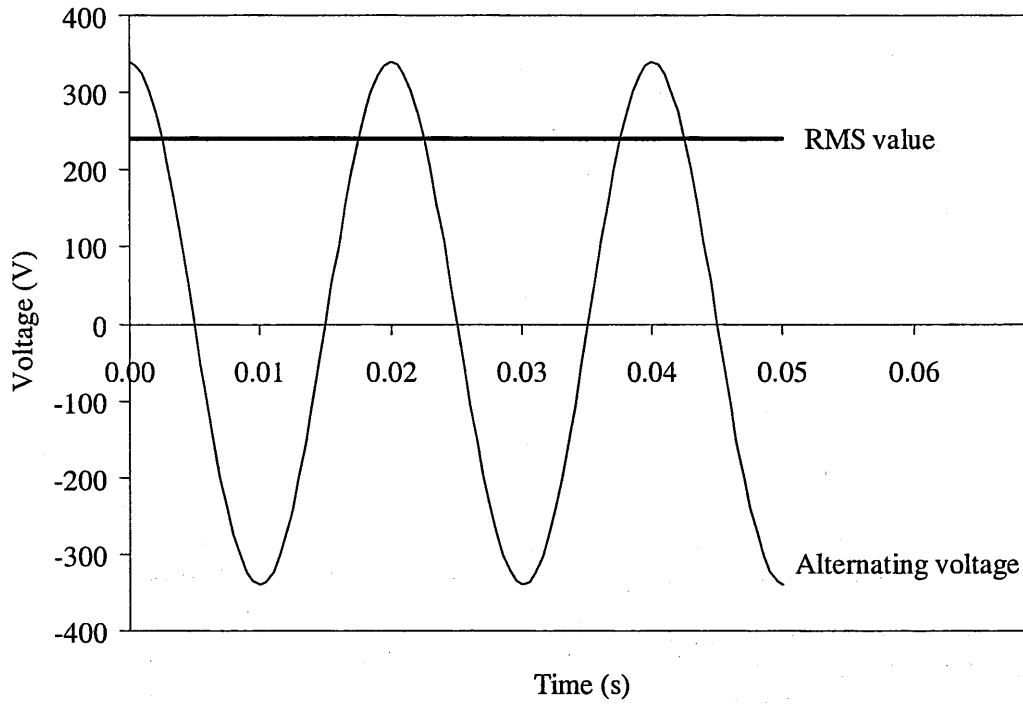


Fig. III- 1 Alternative and RMS value of main voltage

The RMS value, as described in Fig. III- 1, is the value observed during measurement. Then the power is defined as follows,

$$\begin{aligned}
 p(t) &= v(t) \times i(t) \\
 &= V_o \cos(\omega t + \varphi_v) \times I_o \cos(\omega t + \varphi_i) \\
 &= \frac{V_o I_o}{2} [\cos(2\omega t + \varphi_v + \varphi_i) + \cos(\varphi_v - \varphi_i)]
 \end{aligned}$$

Eq. III- 2

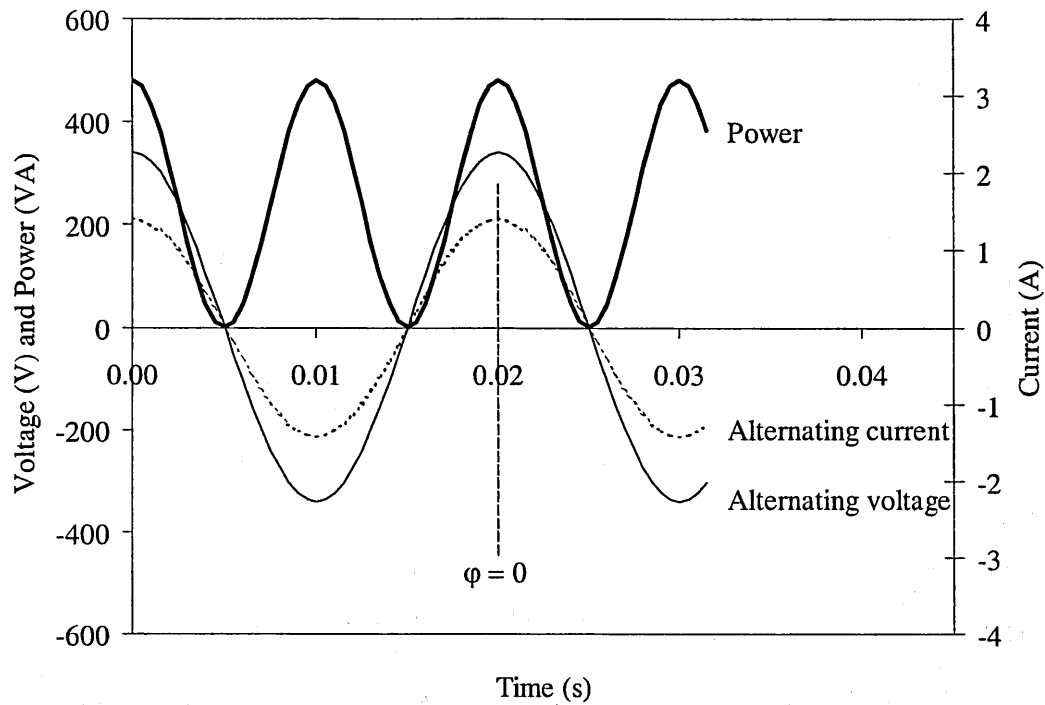


Fig. III- 2 Power demand of a pure resistive load

In the case of a pure resistive load then the voltage and the current have similar phase and the power would have the characteristics described in Fig. III- 2. It can be seen that the power is always positive. Its shape is sinusoidal, as derived in Eq. III- 2, and its frequency is twice the original frequency.

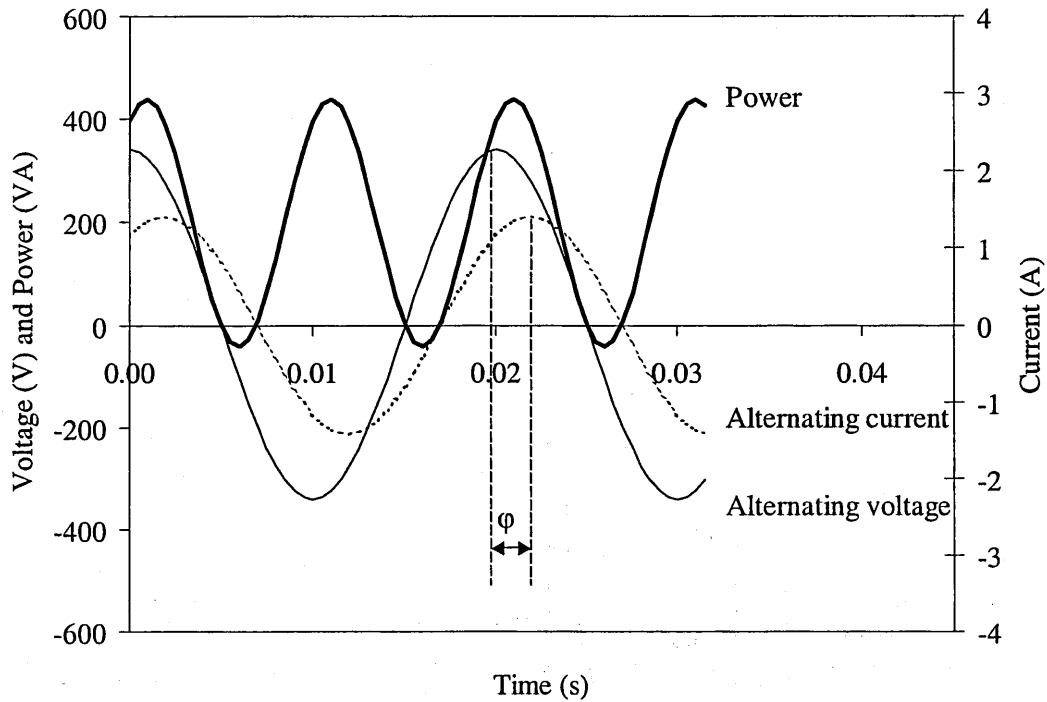


Fig. III- 3 Power demand of a composed load

Another case is when the phase difference is different from 0. The determined power is then sometimes negative, as shown in Fig. III- 3. Part of the energy is not directly used. It is accumulated in the electrical system and then for a short period of time the energy is exported.

Therefore it can be derived that the mean power is equal to,

$$P = \frac{V_o I_o}{2} \cos(\phi_v - \phi_i)$$

$$= V_{RMS} I_{RMS} \cos \phi$$

where ϕ is the phase difference between $v(t)$ and $i(t)$

and $\cos \phi$ is defined as the power factor

The main interest in the research is the mean power demand and the power factor.

ii) Apparatus with instantaneous reading only

The **Infratek Watthourmeter 102A** apparatus is recognised for its high precision in energy and power measurement. The disadvantage of such apparatus is its important size and the requirement for complete reconnection of the electric system. Therefore its use is

limited to the laboratory. The typical accuracy of the Infratek Watthourmeter 102A to measure power demand is described as follows in the instruction manual,

$$\text{Accuracy} = \pm(0.5\% \text{ full scale} + 0.5\% \text{ reading})$$

Eq. III- 3

The full scale is changed depending on the setting of the apparatus; either 2 or 20kW are in use. Therefore the accuracy changes as shown in Fig. III- 4.

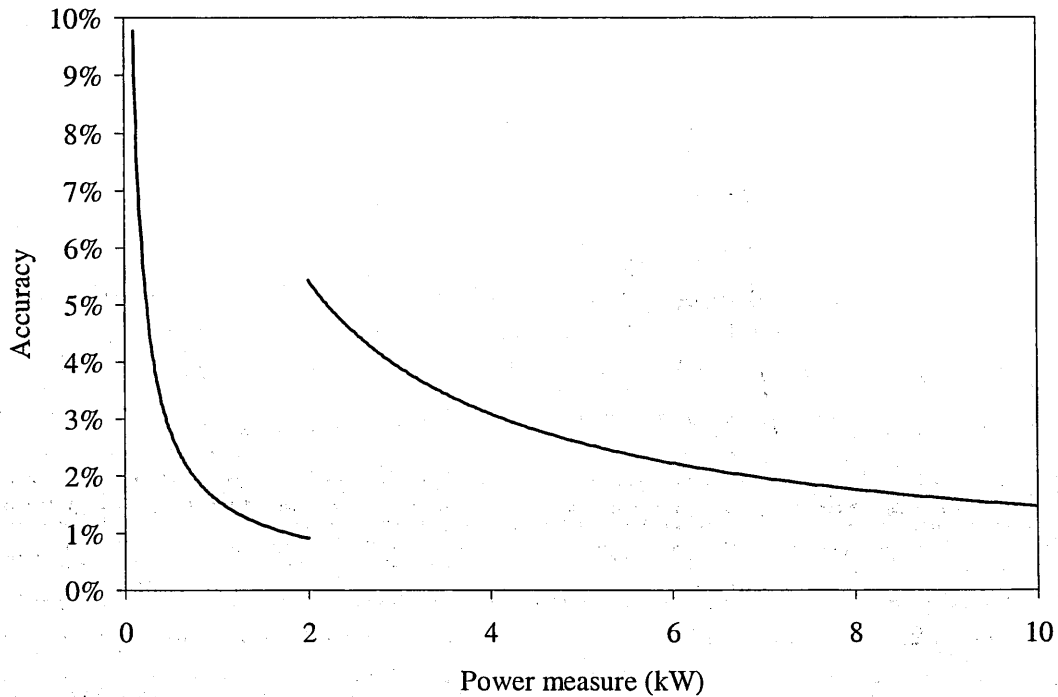


Fig. III- 4 Accuracy of the Infratek Watthourmeter 102A

Therefore it can be deduced that for power demand higher than 200W, the accuracy of such apparatus is better than $\pm 5.5\%$.

The **ITT Instruments MX 1200 S** was used to determine the power demand and the power factor. This apparatus uses the technique of induction clamp to determine the current through a wire. Using the Ampere theorem it is shown that considering a magnetic field on a trajectory Γ , the circulation C of magnetic field is defined as follows,

$$C = \int_{\Gamma} \vec{B} \cdot d\vec{l}$$

where B is the magnetic field
 dl is the infinitesimal part of Γ

Therefore

$$dC = \vec{B} \cdot d\vec{l} = B dl \cos \theta = B_t dl$$

where θ is the angle between B and dl

Or, if B_t is the mean tangential component of the trajectory, then

$$B_t = 1/L \int_{\Gamma} B_t dl$$

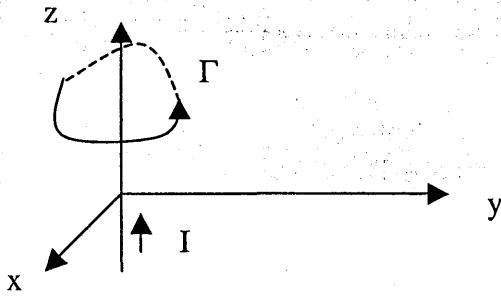
where L is the length of Γ

Hence

$$C = L B_t$$

Eq. III- 4

Now considering that Γ is surrounding a wire in which a current I is circulated, then in cylindrical coordinates all point are defined by r , θ and z



For $d\vec{l}$:

$$\begin{aligned} dl_r &= dr \\ dl_\theta &= r d\theta \\ dl_z &= dz \end{aligned}$$

For B :

$$\begin{aligned} B_r &= 0 \\ B_\theta &= \mu_0 I / 2\pi r \\ B_z &= 0 \end{aligned}$$

Therefore

$$dC = \frac{\mu_0 I d\theta}{2\pi}$$

where μ_0 is the vacuum permeability

Hence

$$C = \int_{2\pi}^0 dC = \mu_0 I$$

Eq. III- 5

Therefore the clamp detects the magnetic field around the wire, which is directly proportional with the current. The current input has to be in the range 20 to 1000A. The advantages of this technique are no need for reconnection and the interaction of the apparatus on the measure is limited. To determine the voltage a standard connection is still required. The voltage input must be in the range 20 to 750V. The power range may be varied from 20 to 200kW for active power measurement and 20 to 200kVA for apparent power measurement. The typical accuracy of such appliance is $\pm 400W$ and $\pm 400VA$ respectively. It can be deduced that this apparatus cannot be used directly for precise measurement.

To increase the accuracy and permit smaller current to be measured, the electric wire is looped a few times around the clamp. Therefore with ten loops, the current range is reduced to 2 to 100A, and the accuracy is then $\pm 40W$ and $\pm 40VA$ respectively for active and apparent power.

The main advantage of this apparatus is the possibility to determine directly the power factor of power demand. The range is from 0.30 to 1.00 and 1.00 to 0.30 for capacitance and inductance respectively. The accuracy is determined to be 0.05 considering technical specification of the apparatus.

iii) Apparatus with memory

This type of apparatus is directly connected to the mains electricity board in the laboratory, and therefore can not be moved from its original place. The only laboratory based apparatus is the Power Units HRS 101. Three Power Units HRS 101 are connected with the main and give reading controlled and saved by a computer. The advantage of the method is that there is virtually no limitation in the memory size (but the size of the hard disk). The Power Units HRS 101 controlled by a computer are able to produce one measure every 0.020 second. It was calibrated using the Infratek Watthourmeter 102A.

The result is displayed in Fig. III- 5

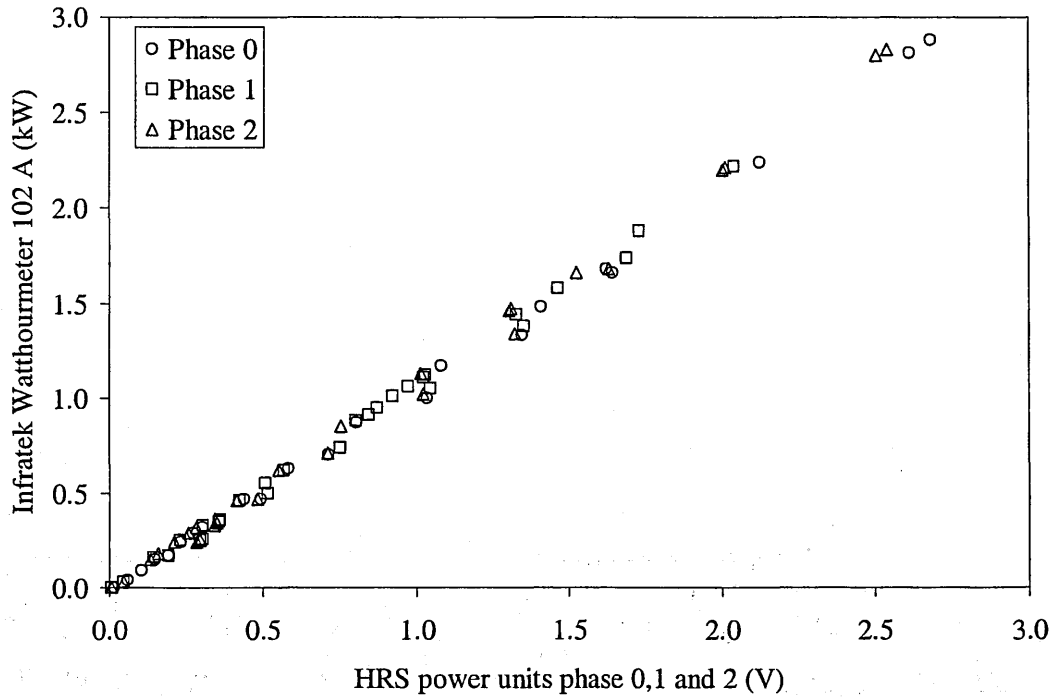


Fig. III- 5 Calibration of the Power Unit HRS 101

The results of the calibration are as follows,

$$\text{Power (phase 1 in kW)} = 1.066 \times \text{Reading (V)} - 0.024$$

$$\text{Power (phase 2 in kW)} = 1.087 \times \text{Reading (V)} - 0.022$$

$$\text{Power (phase 1 in kW)} = 1.110 \times \text{Reading (V)} - 0.028$$

The standard deviation applied on the linear regression show that the average standard error is 37W. The conversion to 12 bits over 20kW gives an error of 5W, therefore the total accuracy is ± 42 W

Another type of apparatus is the DataLogger Grant 1200 series (12bits). This apparatus is characterised by the fact that it is portable, it has independent batteries and is able to save information, which can easily be downloaded in a computer. This system has the possibility to measure the current in a wire using a clamp. The DataLogger Grant 1200 series is calibrated using the Infratek Watthourmeter 102A.

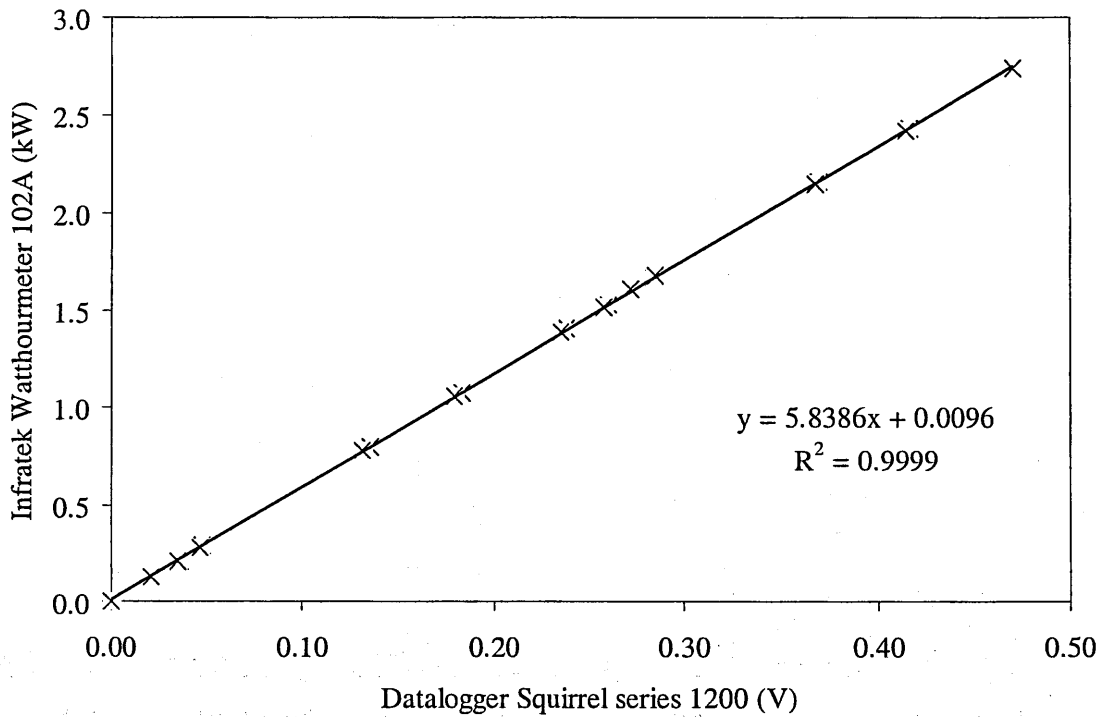


Fig. III- 6 Calibration of the DataLogger Grant 1200 series

The result of the calibration is as follows,

$$\text{Power (kW)} = 5.84 \times \text{Reading (V)} + 0.01$$

Eq. III- 6

If the voltage is assumed to be 240V RMS then the corresponding power can be determined theoretically to be equal to

$$\begin{aligned} \text{Power (kW)} &= \frac{25\text{A/V} \times 240\text{V}}{1000} \times \text{Reading (V)} \\ &= 6 \times \text{Reading (V)} \end{aligned}$$

where 25A/V is the induction clamp characteristic
240V is the RMS voltage characteristic

Eq. III- 7

Therefore it can deduced that the error in calibration is limited. The working instruction indicates that the accuracy is as follows,

$$\text{Accuracy} = \pm(0.5\% \text{ reading} + 0.25\% \text{ full scale})$$

Eq. III- 8

The conversion to 12 bits over 24kW gives an error of 6W, therefore the accuracy, which is dependent on the measurement, is displayed in Fig. III- 7.

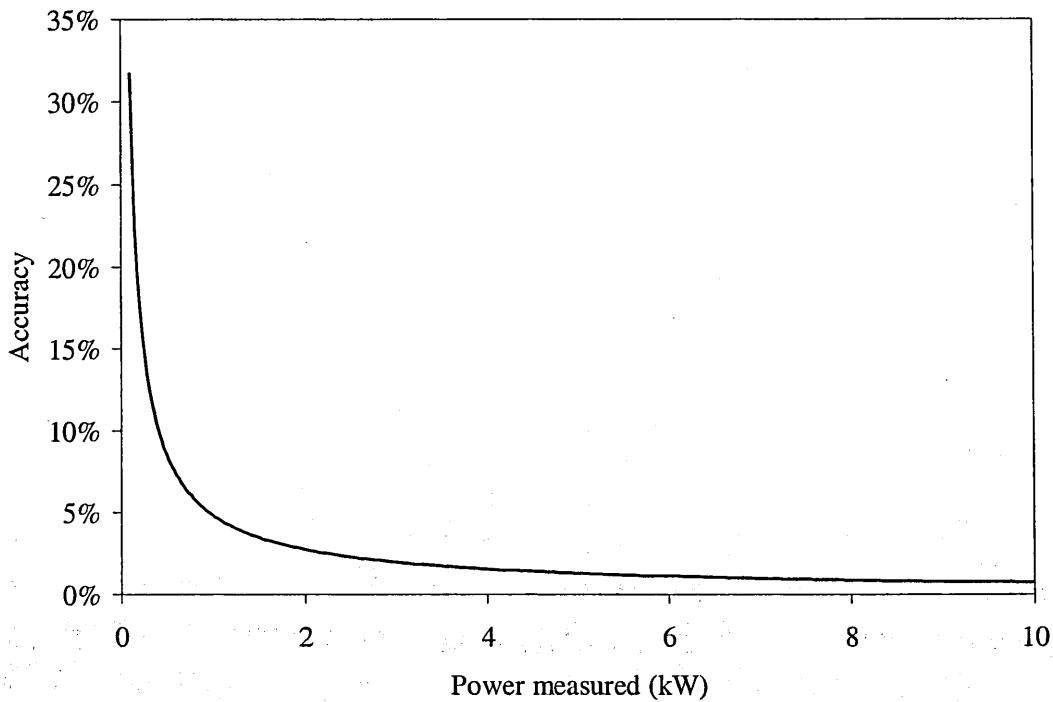


Fig. III- 7 Accuracy of the DataLogger Grant 1200 series

Therefore it can be deduced that for power demand higher than 500W, the accuracy of such apparatus is better than $\pm 7.7\%$.

The limitation of this apparatus in the monitoring process is the memory content. The original model has 42000 data slots, permitting to save up to 42000 data input. There is a possibility to double the memory using a special extension. This is available on one of the Datalogger Grant 1200 series. The minimum interval between two measurements is one second.

One of the DataLogger Grant 1200 series is modified so that it includes the possibility to determine the power factor. This modified DataLogger Grant 1200 series has to be recalibrated because it uses another type of clamp, necessary to compare the phase of the directly connected voltage and the current.

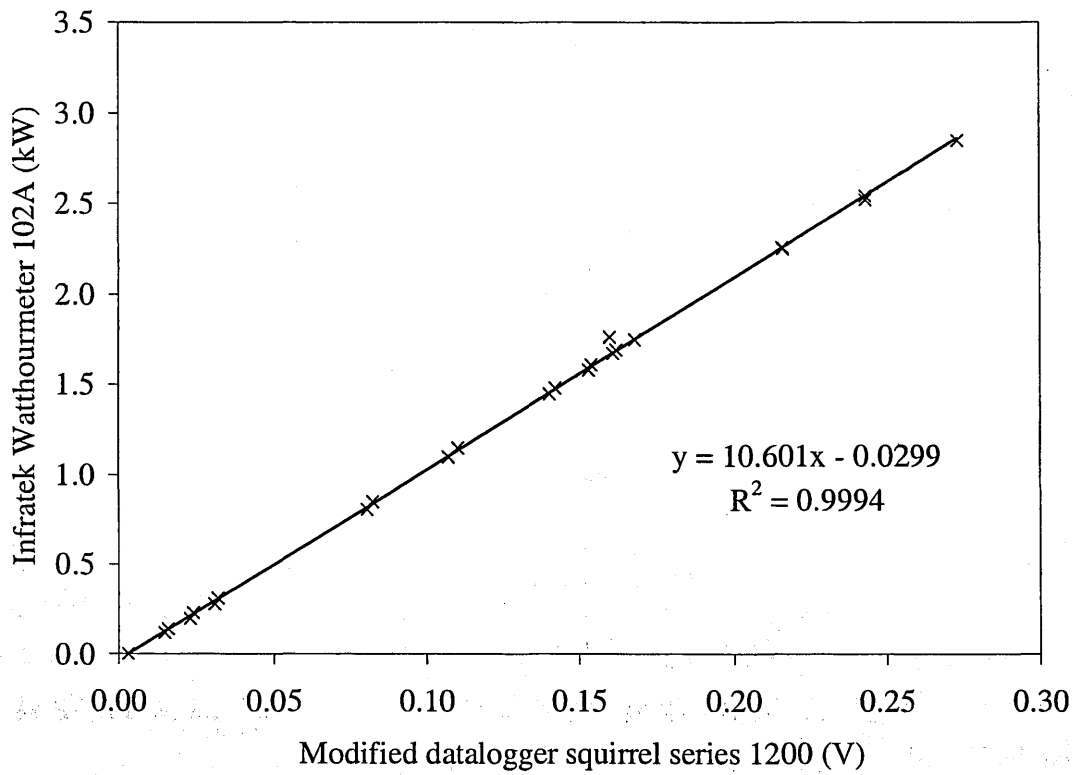


Fig. III- 8 Calibration of the modified DataLogger Grant 1200 series for power

The results of the calibration are displayed in Fig. III- 8 and Fig. III- 9. They both show linear relationship between power and reading and between power factor and second reading. The equations deduced for calibration are as follows,

$$\text{Power (kW)} = 10.60 \times \text{Reading (V)} - 0.03$$

$$\text{Power factor} = -1.31 \times \text{Reading (V)} + 1.22$$

Eq. III- 9

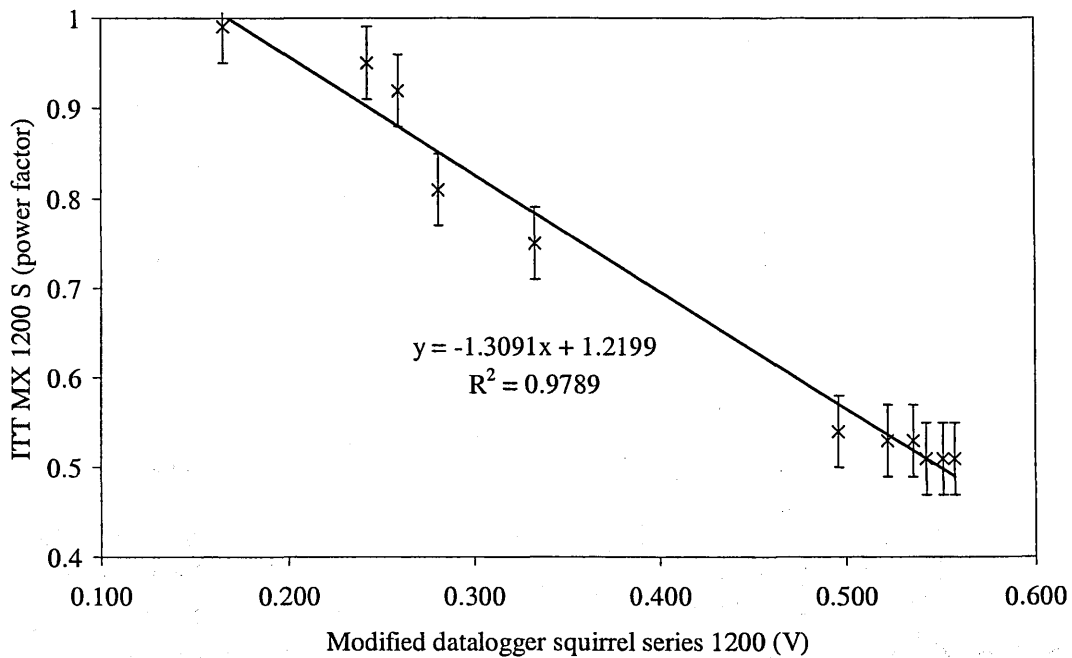


Fig. III- 9 Calibration of the modified DataLogger Grant 1200 series for power factor

2) The monitoring of individual appliances

The power demand of main electrical appliances in a dwelling is tested to derive their energy consumption, power demand profile and power factor. When possible the tests are conducted in the laboratory using the Power Units HRS 101. The result of these tests are calibrated and directly downloaded in the memory of the computer. Some of the tests are realised in situ so that real working conditions are respected. These measurements are derived using either the ITT Instruments MX 1200 S or the DataLogger Grant 1200 series when memorisation of results is required. The results of these investigations are displayed and discussed in Chapter IV.

3) Monitoring of individual dwelling

i) Time base choice

Four dwellings (CR02, CR10, CR17 and CR21) are monitored on a one second time base. Then the data is sampled to different time interval to determine the influence of the time base. The first part of the analysis compares the error in energy calculation for diverse interval time. It should be noticed that one second being the smallest programmable time interval, it is considered as the reference. The errors are limited to a few percent until one minute and are increasing considerably afterwards.

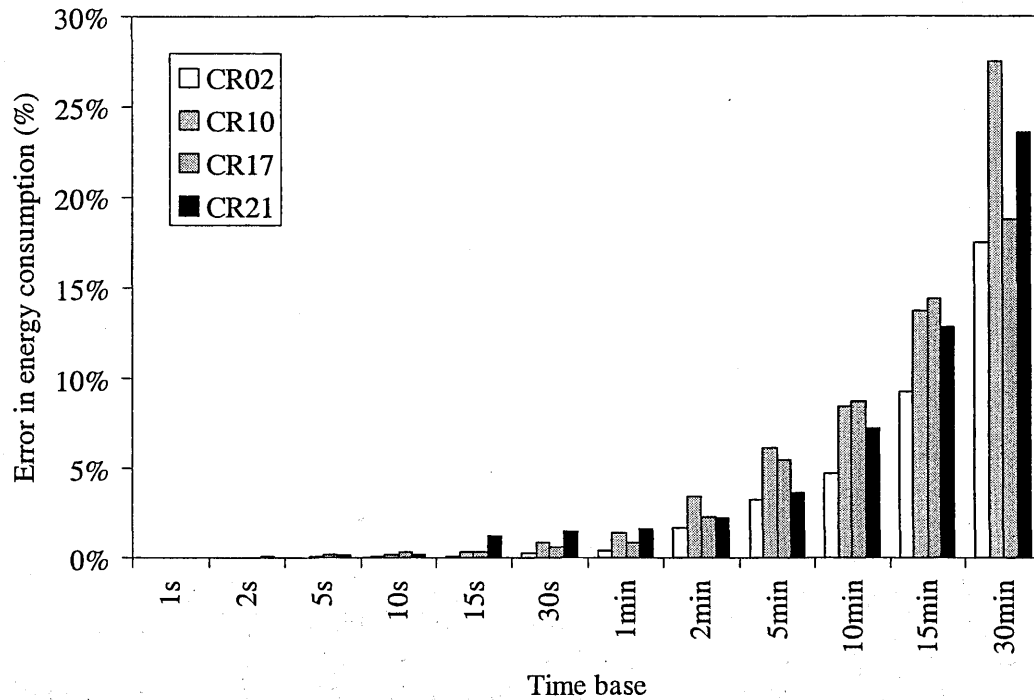


Fig. III- 10 Error on energy considering different time base

Fig. III- 11 shows the same graph type, but concerning maximum power demand. In this case the errors are more important, reaching maximum of more than 60%. But as a general rule, it can be observed that the errors are limited for interval time shorter than one minute. The dwelling 17 shows higher errors, which are analysed to be derived from the use of a microwave during the monitoring period.

This analysis shows that electrical appliance generally function for period exceeding one minute. The exceptions are the microwave and electric hob for specific settings. The power demand of appliances will be analysed in depth in Chapter IV.

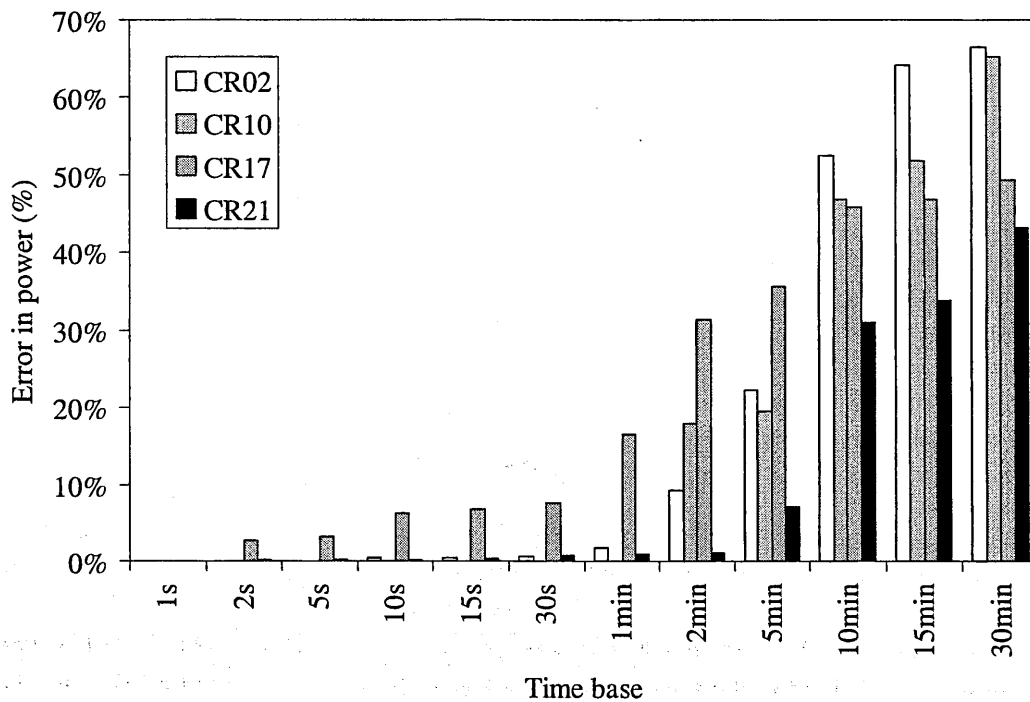


Fig. III- 11 Error on power considering different time base

Considering the energy and maximum power errors, it was decided to choose one minute as the maximum time interval limit to ensure that energy and power error are limited to a minimum. By the time the project started, British Gas was monitoring dwelling electricity demand on a minute time interval; therefore one minute is chosen as a reference for the project, ensuring compatibility between Cranfield and British Gas database.

ii) The British Gas data

The data available from British Gas was on a compressed format, not directly exploitable in normal environment (Lotus 123 data type). The data was therefore converted using a micro Lotus 123 program to CSV format. Then the data needed to be converted to a common format to be able to reconcile all the data.

iii) The Cranfield data

The first step to create a database was to determine specifications: the number of dwellings to be monitored, as well as the monitoring period. To characterise any processes, the precision is dependent upon true data and its analysis. Therefore the sample and the monitored periods should be as large as possible, but there are practical limitations due to time scale and resources.

The first step to create a database is to determine a sample. It was decided for economical, security and safety reasons, that Cranfield staff will be targeted. Cranfield staff were initially approached with a mail, to determine if they were interested in the programme. Then follows a personal approach to determine different parameters and arrange for monitoring dates. The objective of this meeting is to limit disturbance in people activity. It proved to be necessary but extensive work, and a lot of planning.

The monitoring period was limited by the memory of each apparatus. Using the DataLogger Grant 1200 allowed us to capture 14 days of data with one reading every minute.

The process to install the DataLogger is to access the electrical power meter. Usually the meter has two wires connected to the main, and two wires connected to the electrical appliances. Because the clamps are measuring the alternating current, only one of these wires has to be clamped. Instantaneous reading of the current was then available on the DataLogger so that the set-up can be tested before leaving the apparatus for the desired period. At the end of the measurement the clamp is removed from the wire and the DataLogger is removed from the dwelling.

Back to the laboratory, the data was downloaded in a computer using an interface program designed by the apparatus manufacturer. The data is processed using calibration information to ensure integrity in conversion, and loaded on the database in a common format.

iv) Format of the reconciliated database

The database is composed of two types of CSV files, which describes the electricity consumption of dwelling. The main advantages of using CSV files is that they are human readable and easily loaded by main spread sheets (Excel, Euraka, Lotus 123).

Each dwelling had an information file, which contains general information. The file structure and the retrievable information were formatted as follows,

Name	, Emmanuel, ,
Poscode	, MK428QH, ,
Number of Day	, 013, ,
Mean Power (kWh)	, 12.07, ,
Maximum Power (kW)	, 07.81, ,
HouseType	, Semi-Det, ,
HouseHold	, 2a&2c, ,
Bedrooms	, 3, ,
Floor area	, Unknown, ,
Space Heating	, Gas, ,
Water Heating	, Gas, ,
Fridge	, 1, ,
Freezer	, 1, ,
Washing Machine	, 1, ,
Tumble Dryer	, None, ,
Dish Washer	, None, ,
Television	, 1, ,
Video Recorder	, 1, ,
Kettle	, 1, ,
Cooker	, 1, ,
Toaster	, 1, ,
Microwave Oven	, 1, ,
Vacuum Cleaner	, 1, ,
Shower	, None, ,
Iron	, 1, ,
Home Computer	, 1, ,
Hi-Fi/Amp	, 1, ,

Fig. III- 12 Information file structure

Note that this file contained generic information about the dwelling, and average power demand over the measured period as well as maximum power demand. These characteristics were derived from the daily data files, which are described as follows.

Each day monitored was stored individually as a file with the following information:

- The directory or path represents the name of the dwelling,
- The name of the file represents the date (DYYMMDD, where YY, MM and DD represent the two digits year, month and days),
- The summary information is an aggregation of the measurement (energy, time of use, load factor, electrical aggregated energy)
- The data (time, power, aggregated electrical energy, power factor when available).

```

Name :           ,,Emmanuel
Date :           ,,Thu,960229,Whole Day
Electricity (kWh) ,,11.34
Mean Power (kW)  ,,00.47
Max Power (kW)   ,,05.66
Load Factor (%)  ,,00008

Power (kW)       ,,00.25,00.50,00.75,01.00,01.50,02.00,03.00
Period above (min)
,,00619,00396,00252,00170,00108,00057,00034
Elec. below (kW) ,,04.25,06.36,07.69,08.53,09.59,10.23,10.96

Time of use (h)  ,,00-07,07-09,09-12,12-14,14-18,18-20,20-24
Elec. Load F.   ,,00011,00017,00014,00014,00010,00030,00022
Electricity (kW) ,,00.21,00.69,00.24,00.24,00.30,01.67,00.67

```

```

Time(min), Power(kW), Energy(kWh)
0000      ,      00.05,      00.00
0001      ,      00.05,      00.00
0002      ,      00.05,      00.00
.....   ,      .....,      .....
.....   ,      .....,      .....
.....   ,      .....,      .....
1437      ,      00.06,      11.34
1438      ,      00.06,      11.34
1439      ,      00.06,      11.34

```

Fig. III- 13 Data structure

British Gas provided 15 dwellings and their monitoring over about a year period, while this research provided 30 dwellings with a monitoring period averaging 2 weeks. The completed database represents 45 individual dwellings, with 8813 days of monitoring. All the data was compiled in a CD-ROM that contains 444 MB of used memory to ease its use and allow mobility.

The architecture of the database was organised as follows,

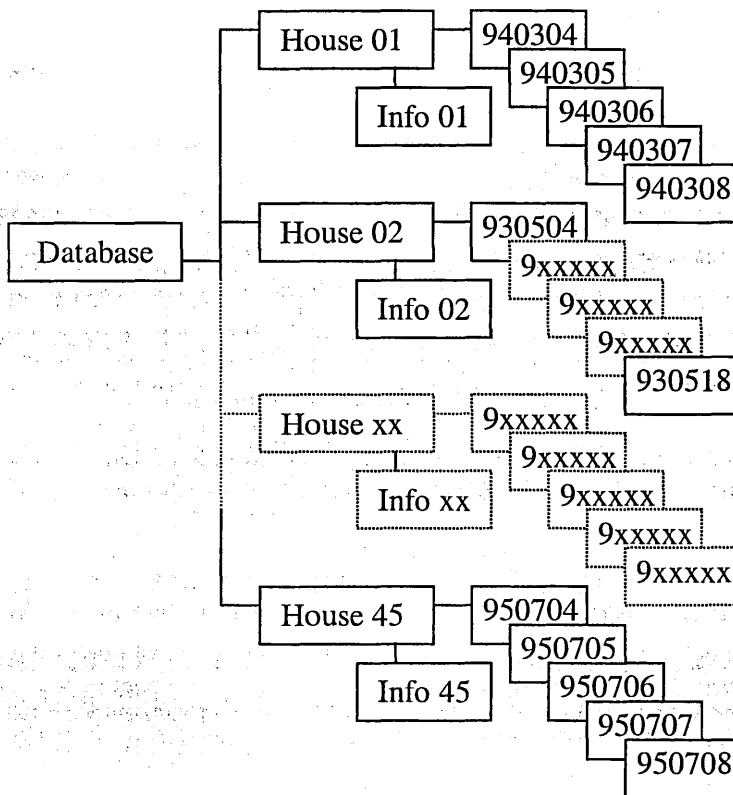


Fig. III- 14 Schematic of the database

4) The recognition program

When electrical appliances are used, they create power demands, which could be analysed directly because of their characteristics. For instance, a kettle that would create a 2 kW power demand for a few minutes only. It may therefore be possible to determine typical characteristics for any electrical appliance so that it can be recognised within a total demand curve.

A Turbo Pascal computer program was designed to detect these changes in demand as well as their duration. It was able to detect changes in power demand from one minute to another, and determine the duration of the peak by checking similar negative changes of the same amount. By adjusting the demand change and the duration, it should be possible to isolate the individual use of an electrical appliance.

There were limitations of this technique. First there is a probability that more than one appliance could be switched on or off in the same minute. Secondly some appliances have overlapping characteristics, which causes the detection to be inaccurate. Therefore this technique was essentially used for appliance with discernible characteristics and a critical analysis of the result was required to determine the validity of the data obtained. Furthermore, the program's results are dependent on the accuracy of the power range and duration range specified, therefore the smaller the ranges the better the results. This imply working out the appliance characteristics precisely for individual dwelling , to get acceptable results.

Systematically the following appliance signature were analysed with the recognition programme:

- Kettle (1.8 to 2.2 kW for up to 10 minutes)
- Hot Water System (2.0 to 3.0 kW for more than 10 minutes and less than 3 hours)
- Electrical shower (6 to 10 kW for up to 20 minutes)
- Cooking appliances (0.5 to 3.0 kW for a few minute, repeating)
- Wet appliances (1.5 to 2.5 kW for 10 to 60 minutes for the heating period)

The results of these analyses are used in Chapter IV, but it should be noticed that due to the complexity of the variation only few results were qualified for appliances time of use reference.

5) Conclusion

The monitoring, processing, formatting and upgrading processes were long and exhaustive that required skills in data management as well as coherence to ensure that all the validity and usability of the data monitored.

The first approach, which was a direct analysis of the data, was found to be difficult to use to the complexity of the electricity demand in individual dwelling. This analysis was necessary to ensure the validity of the research and develop the requirement for the future step that would need to be achieved.

It introduces the requirements to analyse precisely the available and derivable information for each individual appliance, so that each of them can be aggregated to determine the complete individual electricity demand.

Chapter IV: The appliances

To understand how the electricity is consumed in dwellings, electrical appliances have to be analysed to derive the intrinsic reason for this consumption. In this chapter, the main appliances are characterised from their design to derive general energy consumption as well as their known usage

1) Space heating

There are different space heating systems available on the market using different fuel type. . The different primary fuel used for the purpose of heating water in dwelling are analysed in Fig. IV- 1 and Fig. IV- 2.

The 1994 Cranfield survey, by Mansouri I.^[37], is the result derived from questioning a thousand households, from which 647 have responded to this particular question:

What is the main type of fuel used for heating your home?

The question is followed by a proposition of answers: natural gas, electricity and other.

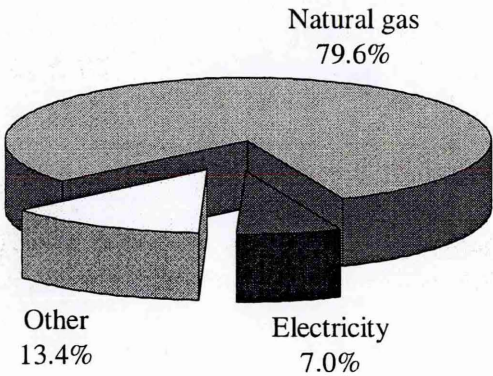


Fig. IV- 1. Cranfield survey (1994) for space heating fuel^[37]

Another survey from 1991 was derived from a larger sample of the population, 20 000 household were questioned. The two surveys show similarity of high percentage of natural gas use, more than 65%, and a low percentage of electricity use, less than 10%.

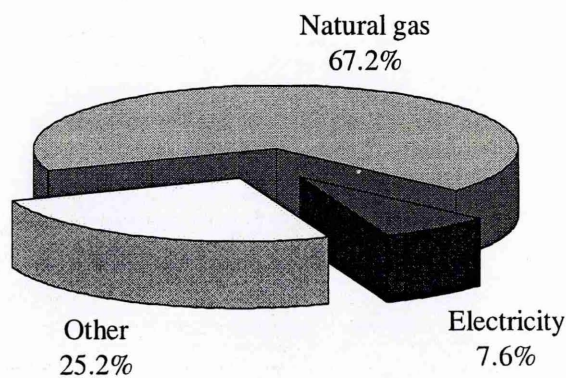


Fig. IV- 2. Main provision for space heating from English house condition^[31]

This demonstrates the limited use of electricity for space heating in dwelling.

Nevertheless, gas heating system commonly use a circulation pump rating a few hundreds watts that is used to export the heat from the boiler.

Electricity users control their heating system with a thermostat, and therefore their heating system maybe switched on all day^[31]. Dwelling direct electric heating has system, which can consume from 2 to 3kW for each appliance. In the case of heat store, the power rating of the heating system may vary from 3 to 5kW depending on the house size.

The latter example will be the only illustrated in the model: the electrical heating system with storage capacity rating from 3 to 5 kW. They generally require air fan to dissipate the heat though the dwelling. These have power rating of a few hundred watts. The heat is accumulated when electricity is available at a cheaper rate and dissipated when required, which may be when premium rate are applied.

2) Water heating

Water heating systems are used to heat water to a determined temperature and store it until its use. There are different systems available on the market. The different primary fuel used for the purpose of heating water in dwelling are analysed in Fig. IV- 3 and Fig. IV- 4.

The 1994 Cranfield survey, by Mansouri I.^[37], is the result derived from questioning 1000 households, from which 631 have responded to this particular question:

How is the hot water provided in you home?

The question is followed by a proposition of answers: natural gas, electricity and other.

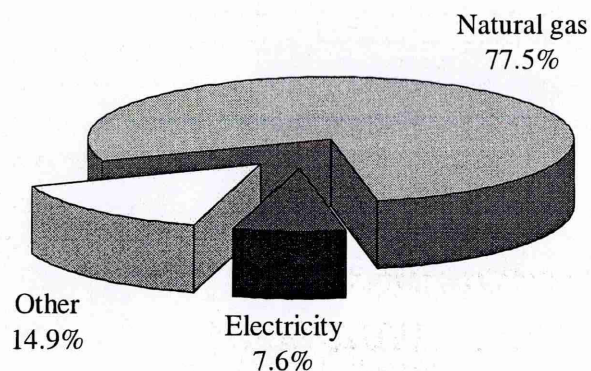


Fig. IV- 3. Cranfield survey (1994) for water heating fuel^[37]

Another survey from 1991 was derived from a larger sample of the population, 20 000 households were questioned. The two surveys show similarity of high percentage of natural gas use, more than 65%, and a low electricity use, less than 20%. This report concerns the electrical demand, therefore only the electric immersion system will be considered.

It should be noted that the percentage of dwelling using electric immersion heater is reduced to 18.4% during winter and increase to 28.1%^[31] during summer due essentially to central heating pattern use.

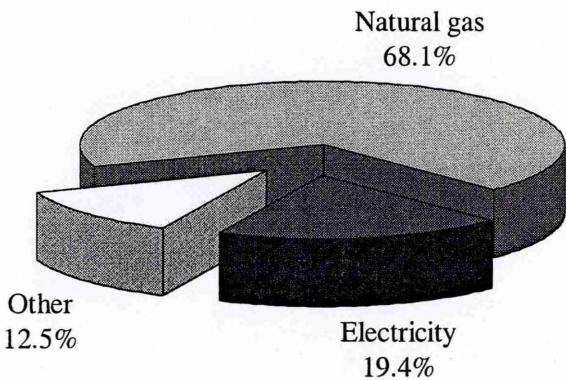


Fig. IV- 4. Main provision for water heating from English house condition^[31]

It is generally composed of an insulated cylinder associated with an internal heating resistance controlled by a thermostat. The insulation of hot water cylinder is very important to avoid excessive standing loss. Different techniques are in use from the segmented plastic and fibreglass jacket, to the integral foam. Manufacturers advise to select different capacity of hot water system depending on the number of people leaving in dwelling as shown on Tab. IV- 1.

Number of people	Capacity advised (l)
1	120
2	144
3 and more	210

Tab. IV- 1. Manufacturer advice^[4]

Considering electric system, the heating element has generally a power rating varying from 2 to 3 kW. During heating period the heat is generated at the level of the element. The heat is then dispersed though conduction through water, and natural convection created by temperature difference. But the mixte is not perfect, therefore creating stratification in the cylinder. The thermostat is generally set to 65°C essentially to avoid legionnaires disease. The amount of hot water consumed per person has been analysed in a report^[25]. It is quoted to be on average 22.9 litres per person and per day.

3) Refrigeration appliances

Refrigerators and freezers keep food at a lower temperature than the ambient temperature. Before the advent of the refrigerator or “ice box”, people stored their food in cellars, outdoor window boxes in the winter or, as the weather warmed, underwater in a nearby lake, stream or well. The first electric refrigerators with tiny ice compartments were introduced in the 1920s and ‘30s. Mass production of modern refrigerators did not get started until after the Second World War. Today, refrigerator technology has become quite sophisticated with environmental concerns a top priority. The insulation is designed to reduce heat loss, avoid thermal bridges and reduce pollution. The design and construction of automated assembly systems for refrigeration compressors presents engineers and manufacturers with a unique set of challenges. These compressors must be built to exacting specifications from a multitude of components each held to extremely close tolerances. Additionally, comprehensive and accurate on-line testing is a must because of increasingly strict regulations regarding refrigerant and since completed compressor’s outer shell must be destroyed to make any repairs. Households use one or a combination of three appliances type that are defined as follows,

- **Refrigerators**, store chilled food at about 5°C,
- **Freezers** store (and sometimes freeze) food at -18°C,
- **Fridge-freezers** has two compartments in a two doors unit to store food at chilled temperature (5°C) and frozen temperature (-18°C).

Construction of refrigeration appliances is very similar and in simple terms comprises a plastic inner cabinet that is assembled within an outer steel or plastic shell. Insulation between the inner cabinet and the outer steel shell is provided using material such as polyurethane foam. Access to the cooled space is gained via a full-length insulated door. The door cabinet boundary is closed using flexible strips mounted on the door, these are magnetic and are attracted to the cabinet thus sealing the gap. The insulated cabinet is cooled using either an absorption or a vapour compression refrigeration cycle. Absorption systems (gas fridge) were commonly used in the UK until the 1950’s. Absorption system may operate from gas at lower cost per unit of energy, but the initial cost, size and mass of this system have made it unattractive for major appliances where electric power is available. Typical operating efficiency of the three most practical refrigeration systems are as follows for a

-18°C freezer and 32°C ambient temperature^[29]

- Thermoelectric approximately 0.09W_t/W_e
- absorption approximately 0.44W_t/W_e
- vapour-compression approximately 1.30W_t/W_e

Because of its simplicity, thermoelectric refrigeration could replace other systems if an economical thermoelectric material were developed^[29]. However now, vapour compression system have come to dominate, because they have greater efficiency and lower capital cost than absorption systems.

i) Operation principle

The four main components that make up an air to air vapour compression cold appliance are displayed in Fig. IV- 5. The refrigerant follows an anticlockwise path around the system, in keeping with the convention for a net work input.

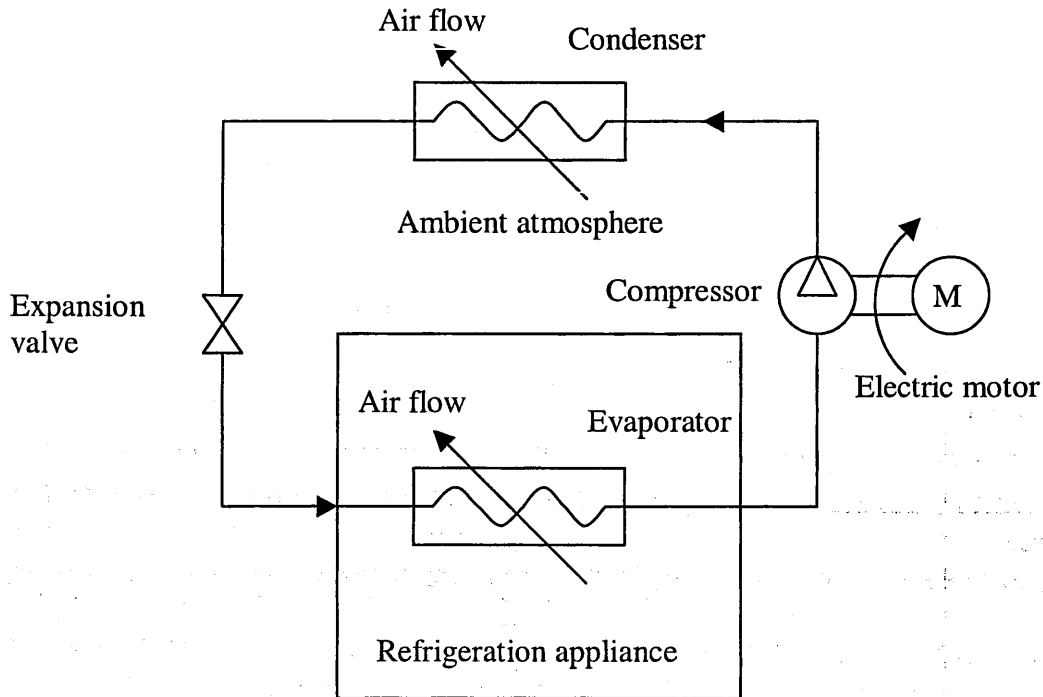


Fig. IV- 5. Schematic of cooling operation

In the compressor, low temperature and low pressure refrigerant vapour is compressed to a higher pressure and temperature. The compressor must be driven by an external power source, for example an electrical motor, and so requires a power input W_c . In the condenser, the refrigerant is made to condense at approximately constant pressure to become a liquid, thereby giving out heat Q_c . To make it condense the refrigerant liquid must be cooled by the air at a lower temperature. In the expansion valve, the refrigerant liquid is expanded to a low pressure and low temperature. There is no heat input or output and any heat transfer effects are small and can be neglected. In the evaporator, the refrigerant liquid is made to become a vapour at the condition required for entry to the compressor. In order for the refrigerant to boil, it requires a heat input Q_{ev} that it receives from the air passing over the evaporator coils inside the cold appliance. For this to be achieved, the air must be at a higher temperature than the refrigerant. The system is referred to as air to air because the heat transferred into the refrigerant at the evaporator is from an air source, and that delivered by the refrigerant in the condenser is to an air sink. Vapour compression is to cool down the air, which surrounds the evaporator in the refrigerator. Basically, the system makes use of the fact that liquid's boiling point increases with pressure.

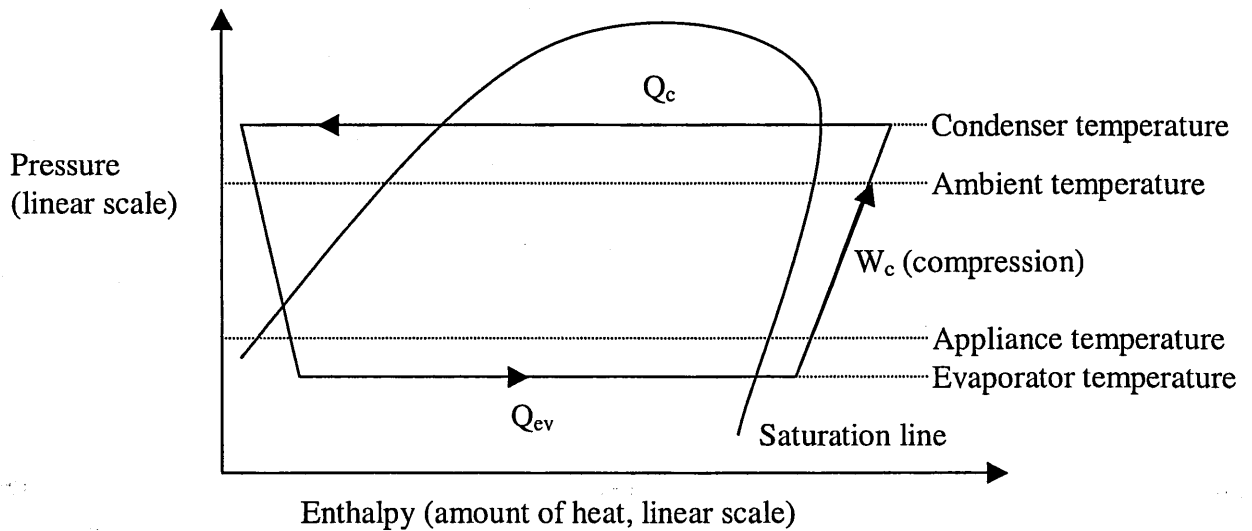


Fig. IV- 6. Mollier diagram for basic vapour compression cycle

Although the four main components are open, the system as a whole is closed, the refrigerant completes a cycle and the system obeys the first law of thermodynamics. Therefore,

$$\sum Q_{cycle} + \sum W_{cycle} = 0 \quad \text{Eq. IV- 1}$$

$$Q_{ev} + Q_c + W_c = 0$$

According to the sign convention, Q_c is a heat output from the condenser and should be negative. The refrigerant used was CFC R12 until it was replaced by HCF R134a to protect the environment. The coefficient of performance (COP) is defined in terms of the heat transferred out of the air at the evaporator, divided by the work input at the compressor, therefore,

$$COP = \frac{\text{Refrigeration effect (at evaporator)}}{\text{Work input (at compressor)}} = \frac{Q_{ev}}{W_c} \quad \text{Eq. IV- 2}$$

As shown in Fig. IV- 6, and that in most refrigeration cycles, Q_{ev} is greater than W_c , therefore the COP is above one^[39].

ii) Ownership of refrigeration appliances

In the United States, households are advised by manufacturers to buy refrigerator with large volume, from 450 to 550 litres for two persons. In Europe the size of refrigeration appliances is much smaller (from 80 to 270 litres). ADEME^{[5] [6] [7]} and "Que choisir"^[26], two French consumer magazines, published guidelines concerning the capacities of refrigeration appliances. The mean volumes are displayed in Fig. IV- 7.



Fig. IV- 7. Appliances volume versus number of people in dwelling

Therefore, it is predicted that needed volume increases with the number of people in dwelling. It should be noticed that in Europe, refrigerators are available with volume in the range 100 to 250 litres, which covers the need for 1 to about 4 persons. The size of freezers depends whether they are included, as in a fridge-freezer, or on their own. In fridge-freezer, the nett freezer capacity can vary from 60 to 120 litres. The range is extended from 80 to about 500 litres for stand-alone freezers. The basic need could be defined as owning a refrigerator and a freezer compartment. The introduction of fridge-freezers was successful because of its simplicity. Any increase in need requires getting another appliance or exchanging an appliance for a larger one. Ownership data for refrigeration appliances in the literature are ambiguous because some sources include fridge-freezer with refrigerator, while other include fridge-freezer with freezer. This has resulted in excessively high ownership levels being reported in either of the categories and discrepancies. Therefore the only source is a survey conducted in 1994 by Mansouri I. ^[37] over 537 households.

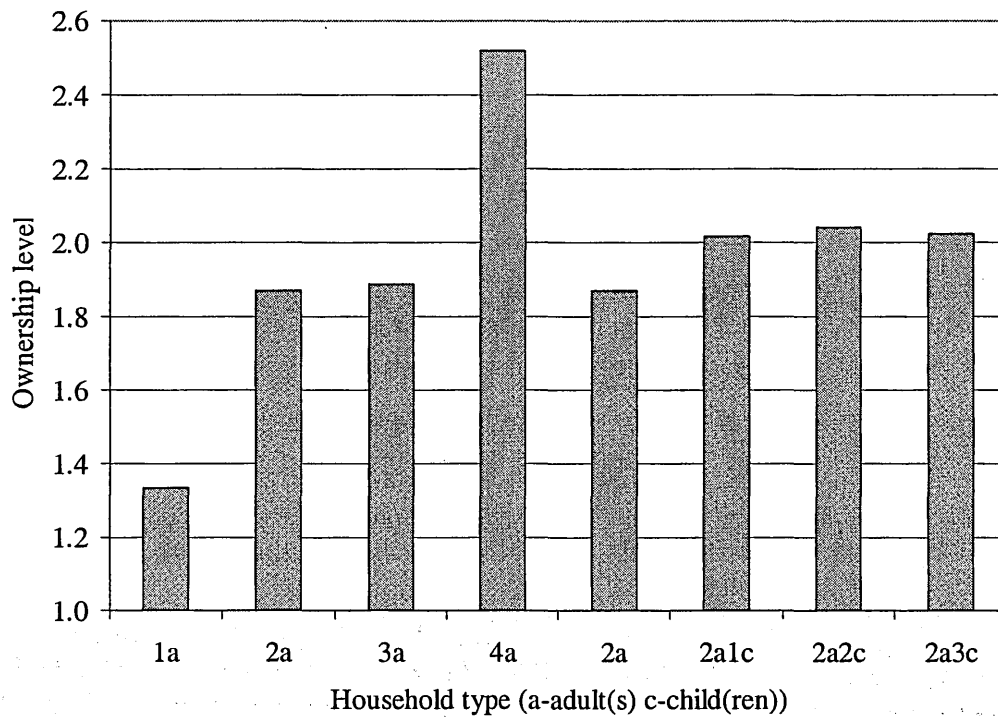
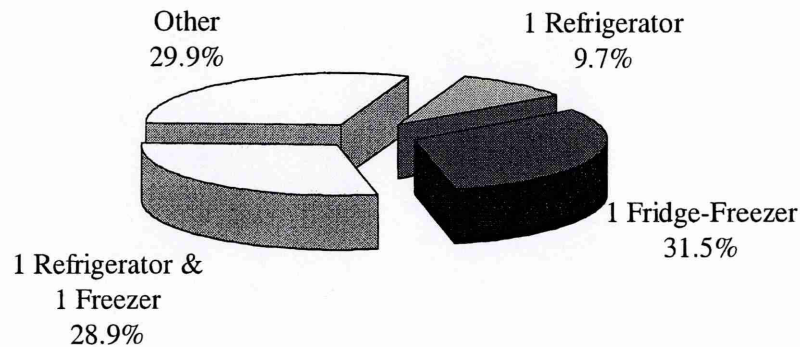


Fig. IV- 8. Average refrigeration appliance number for different household types^[37]

The number of refrigeration appliances owned per household type, shown on Fig. IV- 8, reflects the fact that 69.8% of one adult households have only one appliance. The two adults household, whether they have none to three children, have on average two appliances, therefore the influence of children is limited. The three household types have on average two refrigeration appliances. The four adults' household types have between two and three refrigeration appliances. Fig. IV- 9 shows the analysis of the most common ownership combination.

Fig. IV- 9. Refrigeration appliances^[37]

It can be deduced that there are three most common combinations of refrigeration appliance ownership,

- **9.7%** of the sample own **one refrigerator**,
- **31.5%** of the sample own **one fridge-freezer**,
- **28.9%** of the sample own **one fridge and one freezer**.

It can be noticed that 27.0 % of one adult household own one refrigerator only, and the trend decreases with the number of household, because of the increase need for a frozen compartment. To generalise the household ownership of refrigeration appliances, the majority of the sample owns either a fridge-freezer or a fridge and a freezer.

Therefore considering the refrigeration appliance data available and the different volume needed, appliance type can be characterised as shown in Tab. IV- 2.

Appliance	5°C compartment	-18°C compartment
Refrigerator	1 to 4 adults (100 to 250 litres)	N/A
Freezer	N/A	1 to 5 adults (80 to 270 litres)
Fridge-freezer	1 to 3 adults (90 to 220 litres)	1 to 2 adults (60 to 120 litres)

Tab. IV- 2. Characterisation of refrigeration appliances

Considering the volume needed per household and the refrigeration appliances available in the market, it can be assumed that one or two people's household will use a fridge-

freezer. Up to four people’s household, the best option is a refrigerator and a freezer, while for larger household a combination of more than two appliances are required.

iii) Power rating

Refrigeration appliances are composed of a few energy-consuming devices. The main one is the electric motor driving the compressor. An internal light switches on every time the door is opened. The frost-free characteristic uses electric heater. Fan can be used to enhance the performance of the condenser or to provide “cold ventilation” inside the appliance. Tab. IV- 3 gives information on power demand.

Device	Refrigerator	Freezer	Fridge-freezer
Compressor	50 to 100W	100 to 200W	100 to 400W
Internal light	15W (max)	15W (max)	15W (max)
Frost-free heater	N/A	400W	400W
Fan	20W	20W	20W

Tab. IV- 3. Power of cold appliance devices^[37]

It is generally observed that compressors are in the range 100 to 200W. The internal light will not be considered because its power consumption is 15W maximum, and its use is limited to door opening period. Only a limited number of appliances have the frost free option and although the free frost heater generates a high power demand, its duty is short in time and hence its energy consumption is small. The different fans are available on a limited number of appliances, therefore they will not be considered. The refrigeration appliances function in cycle, which are directly dependent on the ambient conditions. The cycling power demand of a fridge-freezer in use in a dwelling is displayed in Fig. IV- 10. The data used to generate the demand was derived from experiments in the laboratory.

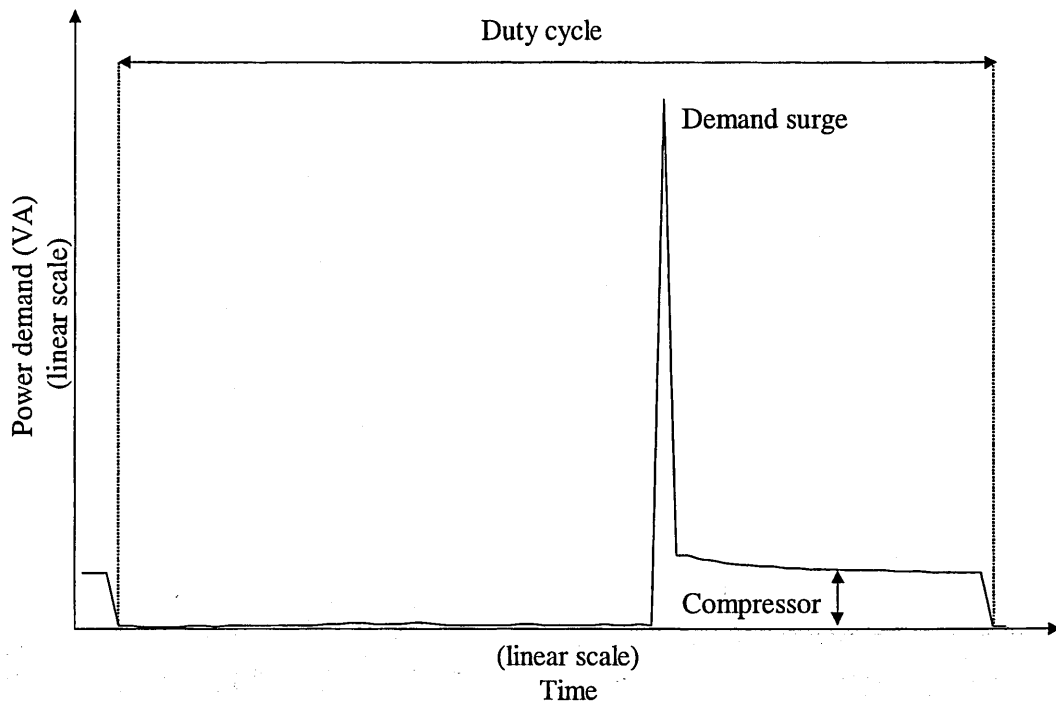


Fig. IV- 10. Cycling power demand of a fridge-freezer

In general refrigeration appliances make use of thermostats which are connected to a switch controlling the compressor. When the temperature is higher than a set level the thermostat activates the electric motor that drives the compressor, to initiate heat absorption via the evaporator in the cold appliance. The result is to reduce the inside temperature to a lower level. When the temperature reaches the lower limit, then the thermostat and the control system switch off the electric motor automatically. The cycle displayed in Fig. V-10 is mainly characterised by the end of the previous cycle, then the electric motor is switched off. During that time the inside temperature of the appliance rises to the limit and the electric motor is turned on again. The compressor generates a surge in power demand due to starting torque for a period determined to be shorter than one second. Then the compressor power demand gets to its nominal value and slowly decreases slightly due to larger initial friction, which reduces when the compressor reaches working conditions. It should be noticed that motors used for refrigeration purposes have power factor of the order of 0.7^[15]. Five refrigeration appliances were tested in the lab and in situ using the apparatus. The average power factor of motor was determined to be 0.6.

In order to compare refrigeration appliances, the concept of adjusted volume is introduced. The adjusted volume of a particular appliance is the sum of the volumes of the different compartment weighted by a coefficient according to the compartment internal temperature. A larger coefficient is given to maintain a lower temperature. GEA (1993) and EU commission directive 94/2/EC give the coefficients in Tab. IV- 4.

Compartment	Internal temperature	Coefficient
Fresh food	5°C	1.00
No Star	0°C	1.25
1 Star	-6°C	1.55
2 Stars	-12°C	1.85
3 & 4 Stars	-18°C	2.15
3 & 4 Stars (free-frost)	-18°C	2.45

Tab. IV- 4. Coefficient for refrigeration appliance compartment

Then the power rating of electric motors driving compressors can be related to the adjusted volume of refrigeration appliances. Fig. IV- 11 shows experimental measures over 10 different appliances.

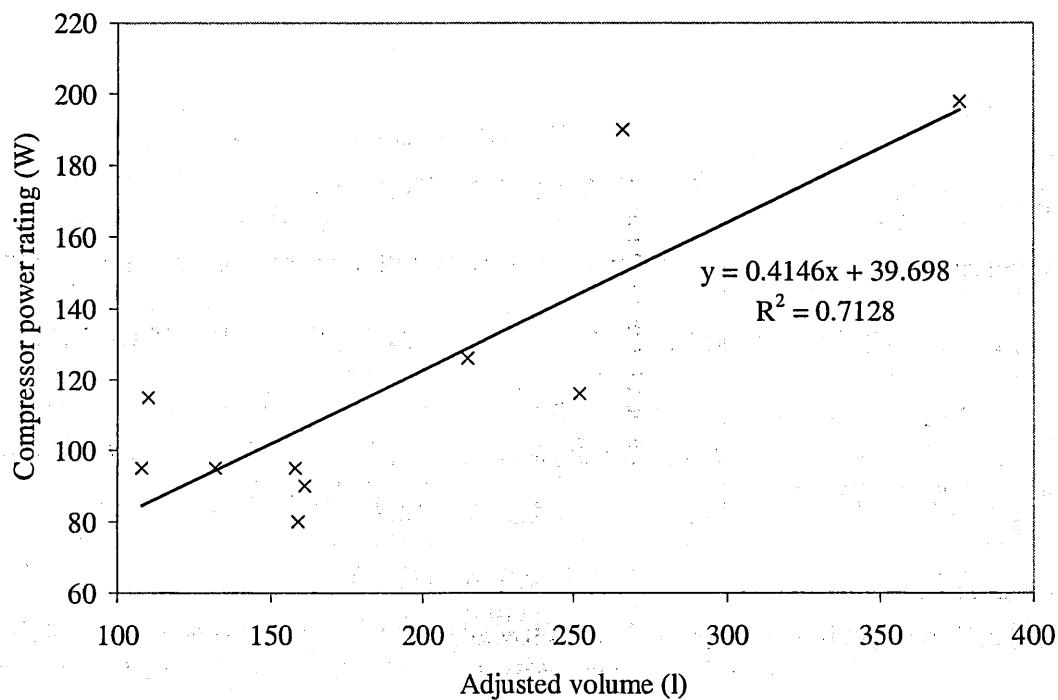


Fig. IV- 11. Power rating of refrigeration appliance compressors

The R-squared Value is only 0.7128 due to the fact that 10 different appliances are considered. Therefore a relationship between compressor power rating and adjusted volume can be derived,

$$Power\ rating\ (W) = 0.4146 \times Adjusted\ volume(l) + 39.698$$

Eq. IV- 3

Refrigeration system manufacturer's^[17] technical specifications are used to determine the refrigeration effect of an absorption system. The analysis is displayed in Fig. IV- 12.

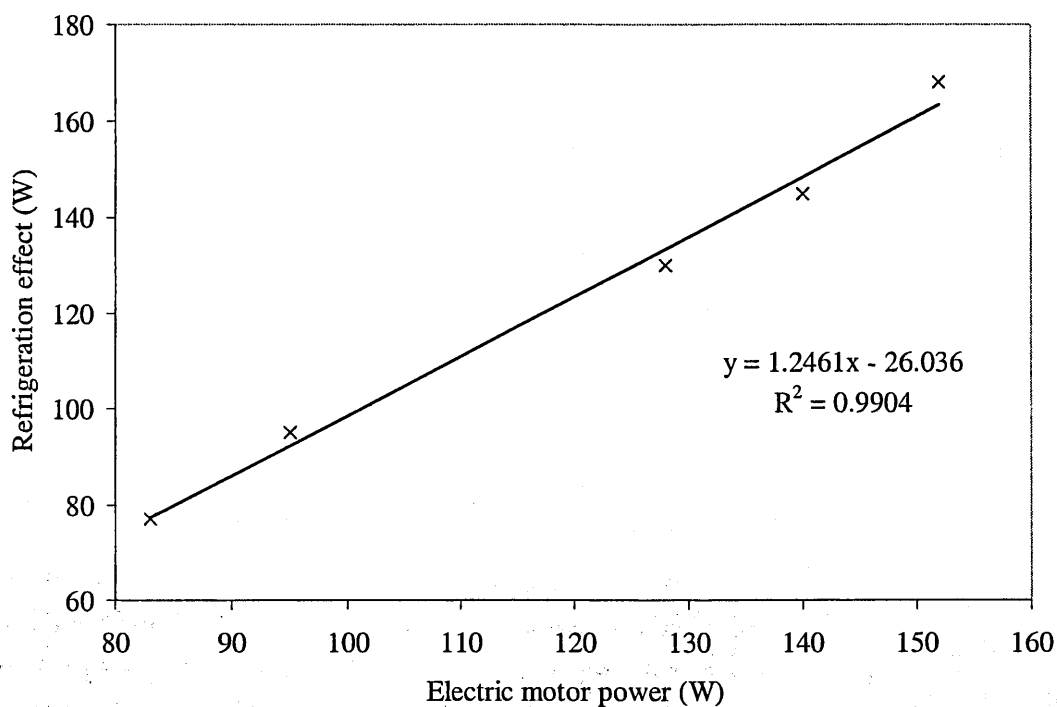


Fig. IV- 12. Refrigeration effect of systems

It is therefore deduced that knowing the appliance power input, it is possible to determine the refrigeration effect,

$$\text{Refrigeration effect } (W_t) = 1.2461 \times \text{Power rating } (W_e) - 26.036$$

Eq. IV- 4

iv) Adjusted volume and the refrigeration energy consumption

To generalise with all the refrigeration appliances, the efficiency index is used. It is calculated by dividing the annual energy consumption of an appliance by its standard annual energy consumption. The standard annual energy consumption is calculated in accordance with EU directive 94/2/EC based on refrigeration appliances available on the EU market. The efficiency index is defined as described in Tab. IV- 5.

Index	Energy consumption compared to average
A	---55%
B	55%---75%
C	75%---90%
D	90%---100%
E	100%---110%
F	110%---125%
G	125%---

Tab. IV- 5. Efficiency index

57 refrigeration appliances were tested by different consumer guides (Which^[27], 60 millions de consommateurs^[4], and Que choisir^[24]) to determine their daily energy consumption. These are compared to the average refrigeration appliance available on the EU market derived from manufacturer's measures. Although a direct comparison of appliances models is not straightforward, because of the different features offered by different machines, comparison of energy consumption provide an efficiency guide, which is especially useful if applied to competing appliances. The experimental conditions of the data follows the standard EN 153, which assumes,

- 25°C ambient temperature
- empty appliance
- no door opening

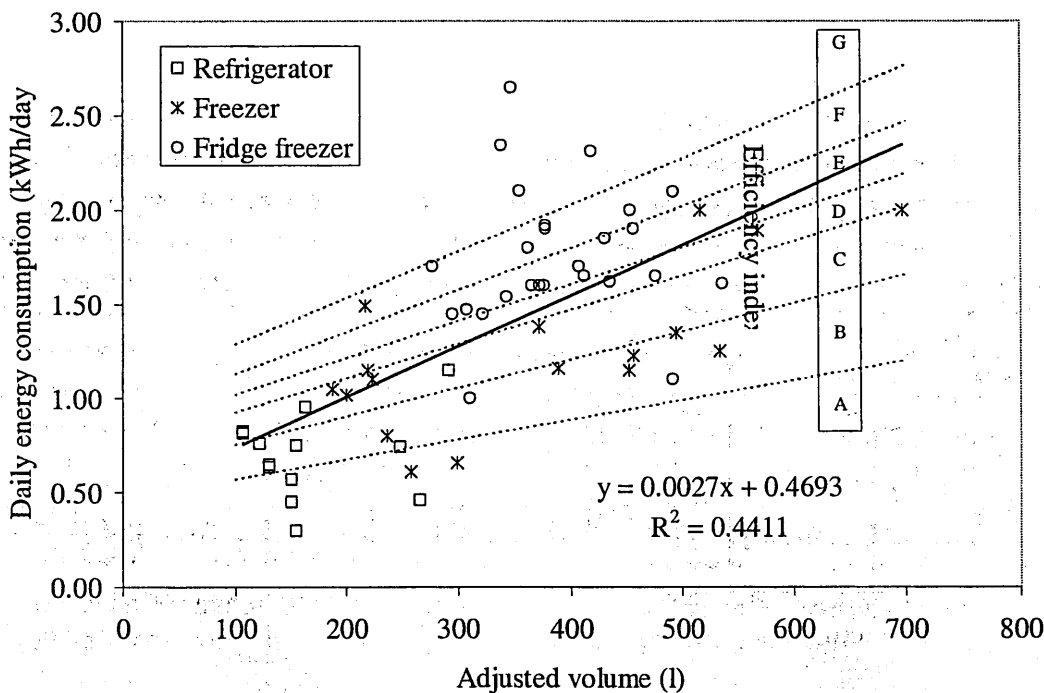


Fig. IV- 13. Refrigeration appliance energy consumption^{[27][4][24]}

Ut can be seen therefore that minimum and maximum energy consumption can vary within a 3 to 1 ratio between different models. The index efficiency D represents the average EU refrigeration appliance efficiency. The plain line is a linear regression of the actual energy consumption of the considered appliances. Therefore it will be derived a general characterisation for all types of refrigeration appliance,

$$\text{Energy (kWh/day)} = 0.0027 \times \text{Adjusted volume (l)} + 0.4693 \quad \text{Eq. IV- 5}$$

Considering the coefficient for adjusted volume, it is possible to determine formulae for each appliance types,

$$\begin{aligned} \text{Energy (kWh/day)} &= 0.0027 \times \text{Fridge volume (l)} \\ &+ 0.0058 \times \text{Freezer volume (l)} \\ &+ 0.4693 \end{aligned} \quad \text{Eq. IV- 6}$$

Note that the freezer volume is 0 litre for refrigerators, and the fridge volume is 0 litre for freezers.

The consumption of refrigerator is relatively low and varies between 0.57 and 1.15 kWh/day. As a reference, ADEME^[7] indicates that refrigerators consume between 0.60 and 1.00 kWh/day.

The freezer energy consumption is much dependent on the volume due to the increase of heat exchange surface and greater temperature gradient.

The fridge-freezer energy consumption is relatively higher than for fridge and freezer on their own. This can be explained either by the use of two small compressors, resulting in lower efficiency, or system special constriction reducing its efficiency.

v) Insulation and energy consumption

The energy consumption is directly dependent on the insulation of appliances. The insulation in refrigeration appliances is generally 30 and 40mm thick respectively for typical refrigerator and freezer compartments. Low energy refrigeration appliances have insulation thickness up to 70mm. Increasing insulation thickness is a well-known route to a low energy consumption product. But insulation thickness do not appear to have been designed or optimised in a detailed way, rather they have evolved at certain sizes which are governed by the jigs in cabinet assembly. Increasing insulation would be considered by manufacturers to be excessively disruptive and costly to their operations.

vi) Temperature control and energy consumption

The temperature control setting is important because to achieve lower temperature in refrigeration appliances an increase in energy consumption is observable as shown on Fig. IV- 14. The ambient temperature was determined to be constant at 19°C. The characteristics of the fridge-freezer are as follows,

- efficiency index E,
- fridge capacity 119 litres
- freezer capacity 62 litres
- estimated energy consumption 544kWh/year.

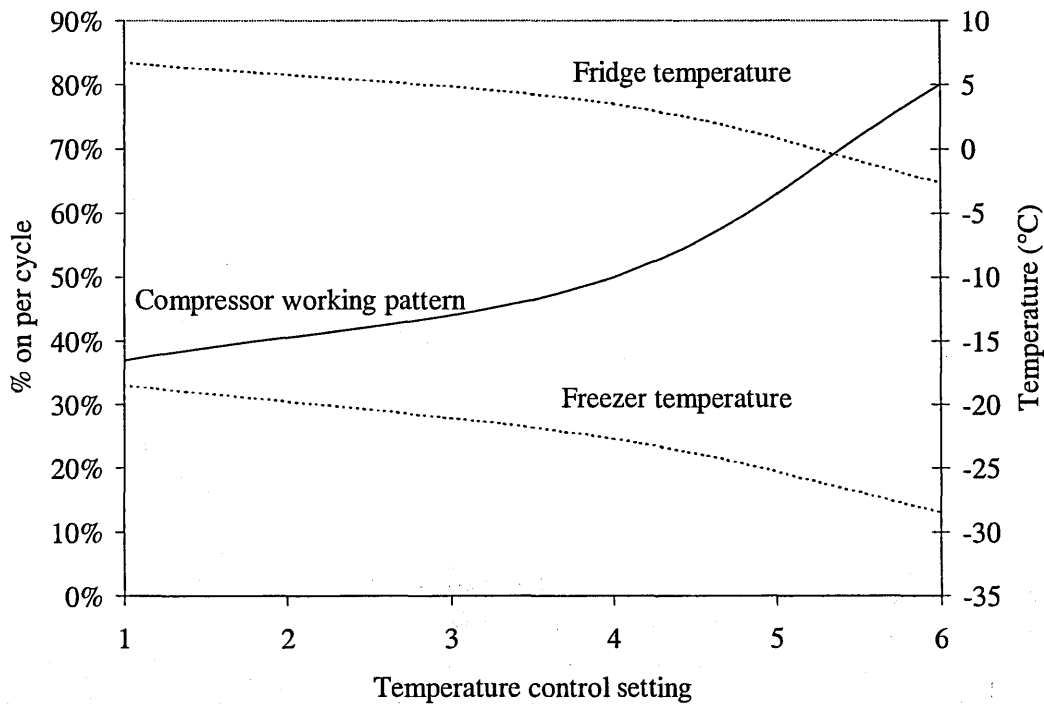


Fig. IV- 14. Temperature control and energy consumption.

The temperature for the fresh compartment should be 5°C and the freezer compartment should be -18°C. These temperatures are achieved for temperature control setting 1 or 2. In that range the electric motor driving the compressor is on 40% of the time. Now if the temperature setting was increased to 6 then the duty cycle would be increased to 80%, which doubles the energy consumption because the temperature of the compartments have a greater gradient with the ambient temperature, which increases the heat loss. For the rest of the study it will be assumed that households use appropriately the control of refrigeration appliances, therefore avoiding excess consumption.

vii) Ambient temperature and the energy consumption

The ambient temperature is an important parameter, which determines the energy consumption of refrigeration appliances. 60 millions de consommateurs measured the daily consumption of 14 fridge-freezers in different ambient temperature. All the tested appliances were of similar size (between 213 and 299 litres). It should be noticed that refrigeration appliances are designed to function at different temperature ranges or climatic classes. The class N (from 16°C to 32°C) is well adapted for a kitchen. But other climatic classes exist which are defined in Tab. IV- 6.

Climatic class	Temperature range
N	16°C-----32°C
SN	10°C-----32°C
ST	18°C-----38°C
T	18°C-----43°C

Tab. IV- 6.Climatic classes^[29]

In temperate climate, such as UK, the temperature variation in dwelling is delimited by the N climatic class. But certain appliances are designed to function in different ambient temperature as shown on Fig. IV- 15.

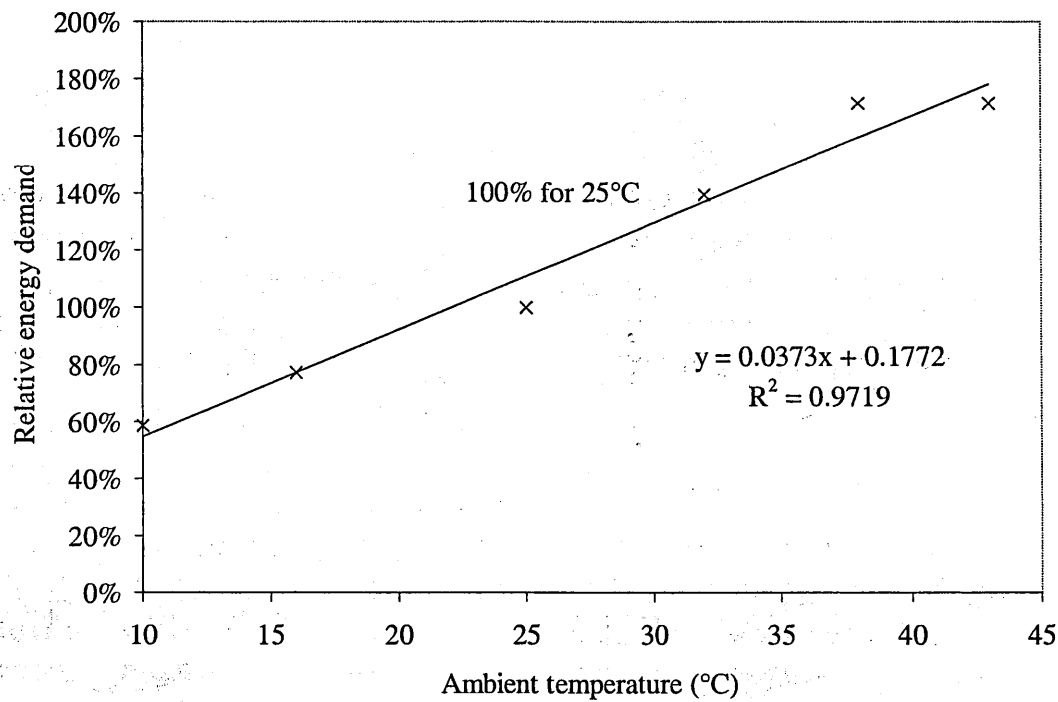


Fig. IV- 15. Energy consumption variation with ambient temperature

The variation analysed with a linear regression gives the following relationship,

$$Relative\ energy = 0.0373 \times T_a + 0.1772$$

Eq. IV- 7

The variation observed corresponds to an increase of 3.73% in energy consumption every 1°C-temperature rise. Alissi M.S.^[11] reported experimental variation of the order of 4.6% per 1°C-temperature rise.. DECADE^[13], quoted 1.8% per 1°C rise, although some units experienced a doubling in energy use when external temperature rose from 18° to 26°C because the appliance could no longer remove the heat load and operated continuously. Enclosing refrigerators in fitted cabinet cuts off the flow of air around the appliance and may increase considerably the energy consumption.

viii) Relation between appliances use and energy consumption

a) The door opening

Theoretically, the effect of door openings can be determined. Every time a door is opened, air in the appliance is changed. Considering that the “air” is composed of air and water, depending on the difference of humidity inside and outside the appliance, the air has to be cooled down to the appliance temperature, and the excess of humidity has to be condensed on the evaporator. Therefore these different processes can be exploited to derive the refrigeration energy needed.

The energy required to cool down the air from ambient temperature to the appliance temperature can be expressed as follows to,

$$E = M_{air} C_{p_{air}} (T_a - T_{appliance})$$

Eq. IV- 8

The energy required to cool and freeze the water content of the “air” can be expressed as follows,

$$E = M_{air} (W_a - W_{appliance}) (C_{p_{water}} (T_a - 0) + H_{f_{ice}} + C_{p_{ice}} (T_a - T_{ev}))$$

Eq. IV- 9

The air mass is defined as follows,

$$M_{air} = \text{number of openings} \times \text{appliance volume} \times \% \text{ of air changed} \times \rho_{air}$$

Eq. IV- 10

Considering a fridge-freezer with the following characteristics,

- fridge capacity 119 litres, freezer capacity 62 litres
- estimated energy consumption 544kWh/year (or 1.50kWh/day)

The following assumption are suggested,

- fridge: temperature 5°C, evaporator temperature -10°C, 25% full (75% of air), door opened 20 times a day, 80% air change per opening,
- freezer: temperature -18°C, evaporator temperature -25°C, 50 % full (50% of air), freezer door opened 10 times a day, 100% air change per opening,

General and matter thermophysical properties are determined as follows,

To determine extreme conditions the ambient temperature is varied from 16°C to 32°C, the air relative humidity being respectively 0.0050 and 0.0160,

- $W_{appliance} = 0$ (assumed to be negligible)

- $C_{p_{air}} = 1.007 \text{ kJ/kg}^\circ\text{C}$
- $\rho_{air} = 1.1614 \text{ kg/m}^3$
- $C_{p_{water}} = 4.180 \text{ kJ/kg}^\circ\text{C}$
- $H_{l_{ice}} = 332 \text{ kJ/kg}$
- $C_{p_{ice}} = 2.040 \text{ kJ/kg}^\circ\text{C}$

The energy required due to door openings is determined to be less than 2%.

Alissi M.S.^[11] describes how a large fridge freezer was tested with and without door openings. The sequence of door openings are based on a well established standard energy testing procedure specified by ANSI/AHAM (1979), which is required by the United States Department of Energy for labelling program. It is a test lasting for 24 hours divided into 8 hours without any openings, and 16 hours during which the refrigerator and the freezer are opened for 25 seconds every 24 minutes and 60 minutes respectively. The increase in energy consumption due to door openings is determined to vary between 17% and 28%. These large results are essentially due to the roughness of the testing procedure with the fridge's and freezer's door being opened 40 and 16 times respectively for an important lapse of time.

b) The food

Food in a refrigeration appliance creates two effects. When food is brought in, its temperature is generally higher than the appliance; therefore heat has to be removed to lower food temperature to the required level. A process of evaporation of water from the food is occurring as well. This only occurs in refrigerator compartment because food is directly exposed, while in freezer compartment aliments are generally wrapped. To determine the influence of these processes a theoretical approach is defined. The energy required to cool down the imported food is determined as follows,

$$E_{fridge} = M_{imported\ food} C_{p_{food}}(T_{initial} - T_{fridge})$$

$$E_{freezer} = M_{imported\ food} (C_{p_{food}}(T_{initial} - 0) + H_{l_{food}} + C_{p_{food}}(0 - T_{freezer}))$$

Note that the $C_{p_{food}}$ may vary with the temperature range

Eq. IV- 11

Evaporation creates water that must be cool down to the evaporator temperature. The energy require for this process is quantified as follows,

$$E_{fridge} = M_{evaporated\ water} (C_{p_{water}}(T_{fridge} - 0) + H_{l_{ice}} + C_{p_{ice}}(0 - T_{ev}))$$

Eq. IV- 12

The mass of evaporated water is defined as follows,

$$M_{evaporated\ water} = M_{food} \times \text{Evaporation Rate}$$

Eq. IV- 13

The mass of food is defined as follows,

$$M_{food} = \text{Appliance Volume} \times \% \text{ food} \times \rho_{food}$$

Eq. IV- 14

The following is assumed,

- food is considered as water ($\rho_{food} = 1000\text{kg/m}^3$),
- evaporation occurs at a rate of 1% per day,
- the same conditions as in a) are assumed for the appliance,
- food import: 2kg per day for the fridge, 0.5kg per day for the freezer

The calculation show that the introduction of food in refrigeration appliance and evaporation of water represent 7.5% to 10.1% of the total energy consumed depending on the ambient temperature. It is demonstrated that in extreme condition the “refrigeration utilisation” represent 12% of the total consumption of the appliance. Therefore a large proportion, in average 90% of the total consumption, is due to heat loss through the walls and door.

4) Washing machine

There are a wide range of washing machines available on today's market, based on a number of different configurations. In the standard IEC 456^[6] all machines are divided into six main groups.

- Horizontal drum type electric washing machine

An electric washing machine in which the textile is placed in a horizontal-axis drum and partially immersed in the washing water, the mechanical action being produced by rotation of the drum about its axis, the movement being periodically reversed.

- Agitator-type washing machine

A machine in which the textile material is substantially immersed in the washing water, in which the mechanical action is produced by a device rotating about its axis with a motion which may be continuous or may reverse after a number of revolutions.

- Washer-dryer

A washing and spinning machine also incorporating a means of tumble-drying the wash load.

- Washing and spinning machines

A horizontal drum type electric washing machine in which, at the end of the wash cycle, the water is removed from the textile material, with a centrifugal force, with or without heating force.

- Twin tubs

A washing machine and a separate spin extractor in the same appliance.

Within these main groups there are a wide range of different systems developed by different manufacturers, which influence energy consumption. In this study emphasis is placed upon horizontal-axis washing and spinning machines, because they account for the largest proportion of the current market in UK. The agitator-type and impeller-type washing machines dominate the American market, but the trend in the United States of America today is towards the typical European front-loading machines. This trend serves to reduce energy and water consumption (top-loaders machines have to be filled so that all the clothes are immersed, whereas the front-loaders only need to be partially filled).

i) Operation principle

The washing process is complicated and it is only during recent years that the physical and chemical basis for the washing process has been fully clarified^[19]. From an energy point of view, the important properties are the following.

a) Mechanical work

The washing water is supplied with the main water under low pressure, therefore no energy is required to fill the machine with water. The mechanical work in the washing process leads to the formation of turbulent streams in the washing bath. This causes the soil to vibrate, and at a certain point the soil particles will reach a limit where they will be carried away from the fabrics surface and into the washing water. Then the “dirty” water has to be removed using a water pump. The mechanical work is generated by electric motors.

b) Temperature

Any temperature rise will cause the molecules to vibrate more and consequently become more energised. In the process this means that the soil particles will come in contact with the water molecules more often. The result is an increase in washing effect. Temperature rise is generated using a heating element.

c) Cycle duration

The cycle duration is mostly dependent on the degree of cleanliness. But there will exist an optimal duration for any washing process; going beyond this will not improve the desired washing result. In many cases it will actually worsen the final result. This can happen in cases where the detergent concentration is chosen so that there is sufficient to remove the soil from the fabric but not to keep it from resettle on the fabric fibres^[2]. Therefore knowing the desired temperature and mechanical work, and their timing requirements, the energy consumption of washing machine can be determined.

ii) Ownership of washing machine

The ownership of washing machine is widespread. It can be assumed that only one machine can be owned per dwelling, therefore it can be derived that more than 87% of UK dwellings has a washing machine. These observations were derived from a survey conducted by Cranfield University^[37] in 1994 (569 answers) and from the English House Condition^[31] in 1991 (9965 answers). Both surveys are described in more detail in Chapter V.

iii) Energy consumption

The European Union has taken steps to label electrical washing machine for household. Contrary to the washing performance, all results on the energy label are related to a 60°C wash, based on the test methods in this standard IEC 456. Tab. IV- 7 gives the energy efficiency class as a function of the energy consumed per kilogram of dry load.

Energy efficiency class	Energy consumption kWh/kg
A	$E \leq 0.19$
B	$0.19 < E \leq 0.23$
C	$0.23 < E \leq 0.27$
D	$0.27 < E \leq 0.31$
E	$0.31 < E \leq 0.35$
F	$0.35 < E \leq 0.39$
G	$0.39 < E$

Tab. IV- 7. Washing machine labels

The washing machine labelling scheme is derived from the Commission directive 2/12/EC published in 1995. The limits for the different energy classes will be revised and updated occasionally.

The data displayed in Fig. IV- 16 is gathered from 7 European countries for standard models used in Europe, mainly front loader machines. The 7 countries include Denmark, The Netherlands, Portugal, Sweden, Finland and France, but unfortunately not the UK. The values derived from Moller are compared to two washing machines, which were tested in the laboratories using the power unit HRS 101. The first machine is a Hoover Logic 800 De Luxe E and the second is a Hotpoint model 18370 Electronic De Luxe. Each programme was run three times to ensure the validity of the observation. It can be observed that the 90°C and the 60°C are close to the Moller mean consumption, but the 40°C shows a relative high energy consumption. The observations suggest that the Hotpoint washing machine has a high-energy consumption, but is a reasonably good indicator of what is in use today, especially considering that this is a 7 year old model.

ADEME^[6] provided guidelines for washing machines, which are displayed in Fig. IV- 16. These values show consistency with the Moller average. The 90°C and the 60°C programmes show good correlation between measured values and average derived from the literature^{[1][2][20][21]}. The 40°C programme shows a high-energy consumption for the Hoover washing machine. This could be explained by the fact that this machine was extensively used, which damaged the bearing, therefore increasing the spinning power consumption. This explains the increase for the low temperature programme, for which the mechanical energy had an increased importance.

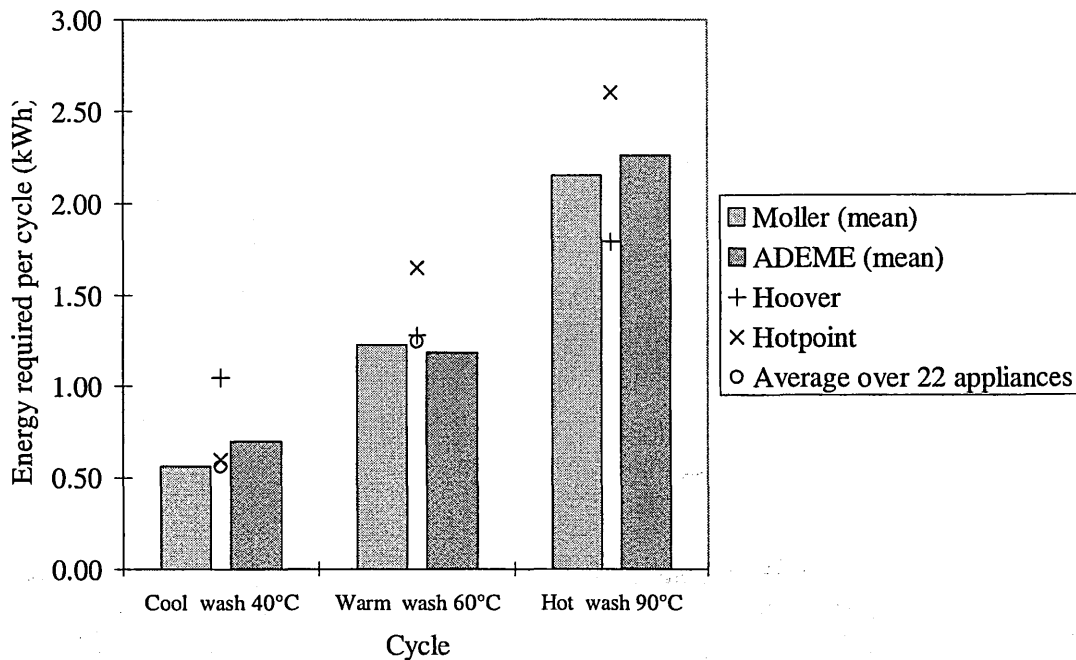


Fig. IV- 16 Measured energy consumption per cycle compared to average

iv) Power rating

The power rating of the different components of a typical washing machine can be described, based on manufacturer's data and laboratory tests. The washing machine uses a control system, which operates a definite sequence of events. The power consumption of the controller is so small that it was difficult to detect, therefore it will not be considered.

The first event is the immersion of the textile. This process is controlled by valves, which are connected to the mains water. The consumption of valves is typically less than 20W, and the valves are only activated during water filling, which usually happens only a few times during each cycle, for a few minutes only each time. Therefore the valves energy consumption will be neglected. The heating element is usually of the order of 2.3kW to ensure that the water can be heated up at a rate approaching 2°C/minute. Therefore it can be deduced that depending on the inlet water temperature and the desired cycle, the heating time will vary. Experiments in the laboratory show that heating periods vary between 10 and 60 minutes.

The motor has a general function, which is to spin the drum. But the rotational speed may vary from 25 to 30 rotations per minute for gentle action, from 50 to 60 rotations per minute for normal action and from 500 to 1500 rotations per minute for spin action.

Therefore the power demand of the motor is generally of the order of 500W.

An outlet pump is used to remove the water from the drum. The pump power rating is of the order of 100W and only lasts for a few minutes during each cycle.

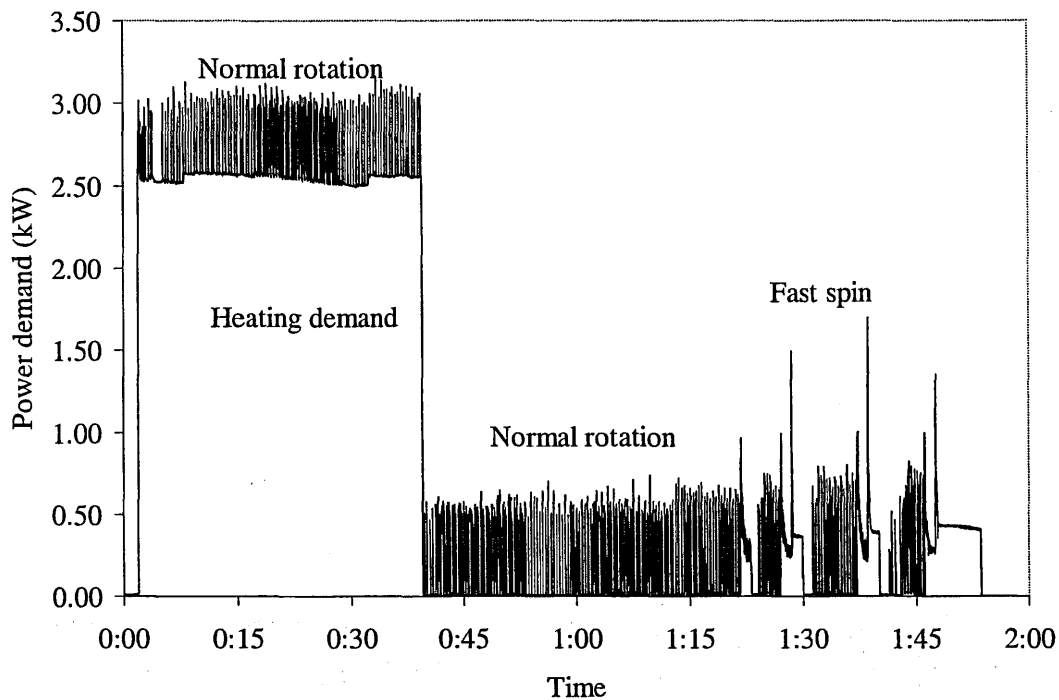


Fig. IV- 17 Power demand for a 90°C cycle (1 second interval)

The power demand of different cycles was measured in the laboratory using the Power Unit HRS 101. Fig. IV- 17 shows the power demand of the Hoover Logic 800 De Luxe E washing machine during a 90°C cycle, with 1 second reading intervals, to detail the power demand signature as much as possible.

The main characteristic is the heating demand rated in that case at 2.5kW. The black area represents the mechanical power required to achieve normal rotation. The motor is switched on and off because the drum is rotated clockwise and anticlockwise alternatively. Then at the end of the cycle, the spinning takes place. It is characterised by three short spinning periods lasting a few minutes and a long spinning period lasting 7 minutes. Every time the motor starts spinning, the first step is first to get to rotate at normal speed, and then it accelerates to reach spinning speed, which creates surge in current and explains the peaks of the spinning periods.

The 40°C and 60°C cycle show the same sequence, but the heating and the spinning periods are reduced. It should be noted that in certain case the heating period could be divided into two or even three parts. Especially at low temperature, the desired temperature is reached faster, allowing relatively more time for cooling, and therefore other heating periods may be required.

The purpose of the study is to characterise electricity demand with a 1-minute definition therefore the shape of a washing machine power demand in that condition is of interest.

Therefore the data measured to obtain Fig. IV- 17 is sampled to extend the time interval required to produce Fig. IV-18.

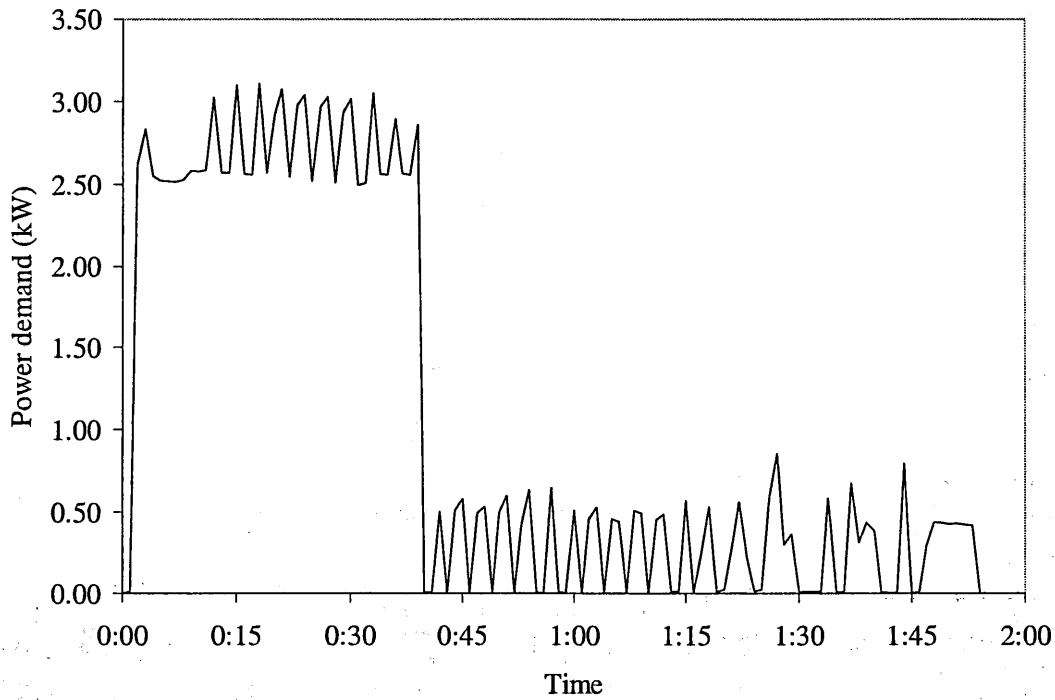


Fig. IV- 18 Power demand for a 90°C cycle (1 minute interval)

Therefore it is possible to characterise the power demand of a washing machine by its heating and mechanical power demand.

v) Cycle duration

The duration of cycles is derived from the consumer magazine which?^[28]. The test carried out involved 19 different washing machines. The data available is limited to the 60°C and the 40°C cycles, which will be shown to be the most representative. The average washing duration for a 60°C is determined to be 94 minutes, while the 40°C cycle shows a shorter duration of 77 minutes. This results corroborates with the two machines tested in the laboratories.

vi) Usage pattern of the different cycles

With the respect of the usage pattern of washing machine, the number of surveys carried out in UK is limited. A recent survey has been undertaken by Cranfield^[37] in 1994 on a sample representing 569 dwellings. It shows that the 90°C cycle is relatively less used compared to the 60°C and the 40°C cycles.

- Cold wash 40°C 47%
- Warm wash 60°C 47%
- Hot wash 90°C 6%

Therefore it can be deduced that 94% of uses are for the 40°C and the 60°C cycles. This is essentially due to recent increase of detergent efficiency. It should be noticed that washing machine have different available option. The “gentle action” option reduces the number of rotation and drum rotational. The “half load” option reduces the amount of inlet water, which has mainly the effect of saving heating energy. The survey also shows that it is used by less than 25% of the households.

vii) Number of use per week

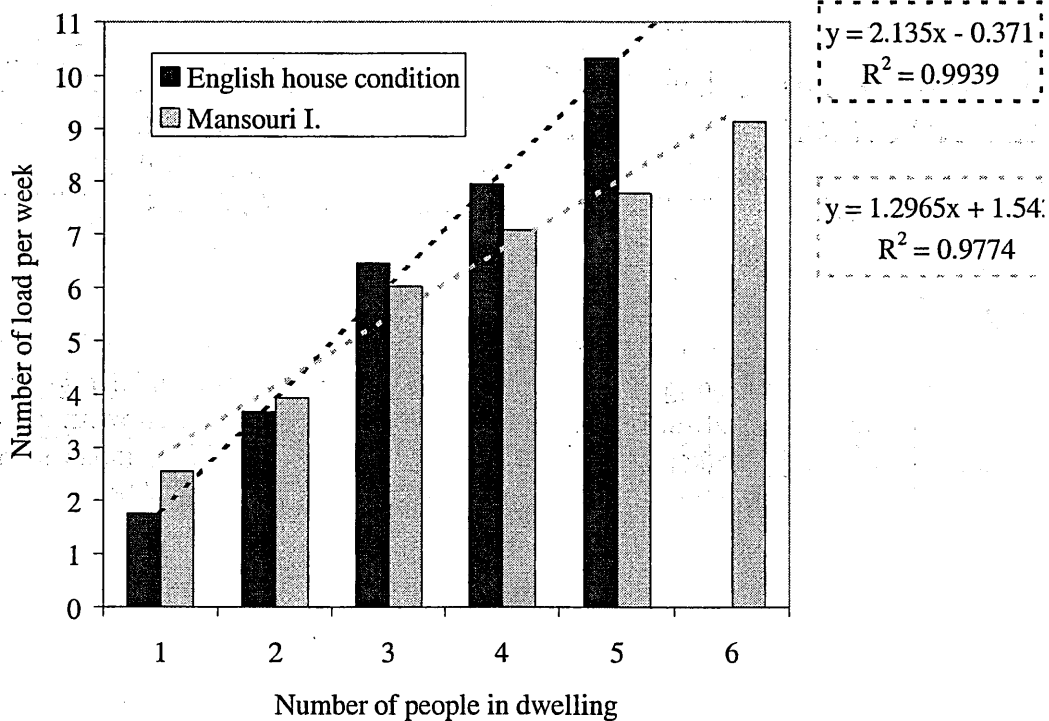


Fig. IV- 19 Washing machine average weekly use

The washing machine is generally used periodically. Because its use is not intensive, the period of investigation has to be widened to a week. Fig. IV- 19 shows the close relationship developed by two surveys. One was reported in the English house condition^[31], and Cranfield conducted the other one in 1994^[37].

A linear approximation gives the following result,

$$\text{Cycle per week} = -0.37 + (2.13 \times \text{Number of people}) \text{ for English house condition}$$

$$\text{Cycle per week} = 1.54 + (1.30 \times \text{Number of people}) \text{ for Cranfield} \quad \text{Eq. IV- 15}$$

The coefficients show an important difference. The sample used to obtain the English house condition is composed of 8643 households, while the 1994 Cranfield survey only 569. But Cranfield survey was analysed deeper to determine the influence of adult and children. Assuming a linear correlation, the following can be derived,

$$\text{Cycle per week} = 0.95 + (1.55 \times \text{Number of adult(s)})$$

$$\text{Cycle per week} = 4.04 + (1.50 \times \text{Number of child(ren)}) \quad \text{Eq. IV- 16}$$

Therefore the difference between the influence of adults and the influence children is determined to be negligible.

viii) Time of use

A report on electrically heated hot water determined the energy consumed per appliance. Washing machines have been monitored for period of a week with hour interval. Analysing the energy consumption of washing machine in 15 dwellings, it is concluded that there are 4 types of behaviour^[25].

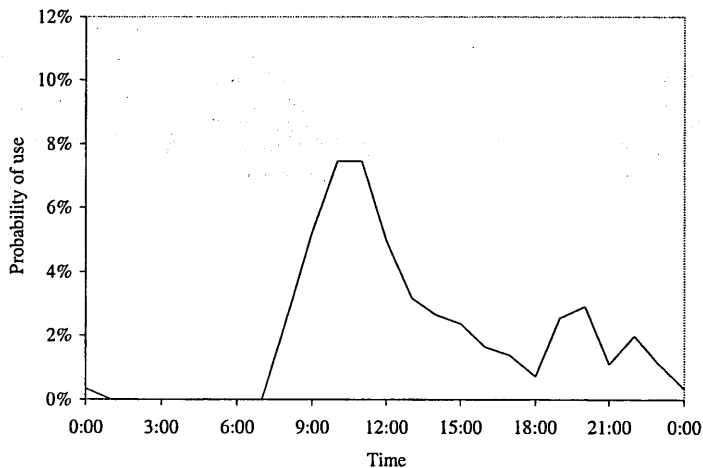


Fig. IV- 20 shows the average washing machine use over 8 dwellings, which have a similar pattern. This is characterised by a large morning peak, between 9 and 10am, and a smaller peak just after 6pm when people are coming back from work.

Fig. IV- 20 Washing machine use “morning/evening”

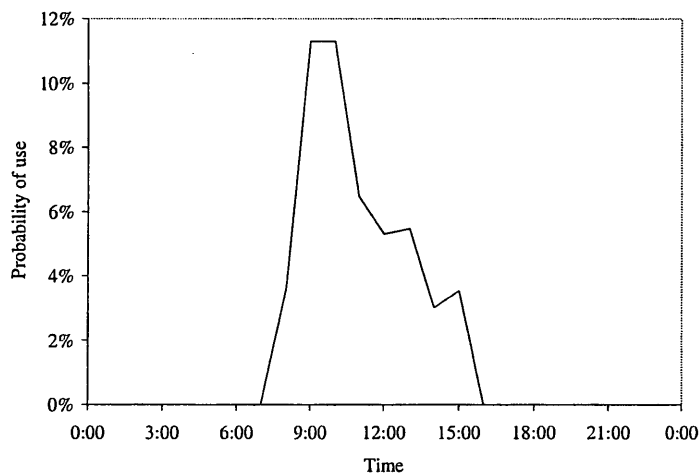


Fig. IV- 21 shows the average over 3 different dwellings. In that instance, the washing machine is used essentially in the morning, between 9 and 10am, and in the early afternoon. The probability of use reaches level higher than 10% due to the fact that the use is only spread over 8 hours.

Fig. IV- 21 Washing machine use “morning”

It can be deduced that in a large majority of the sample the washing machine is used during the morning period.

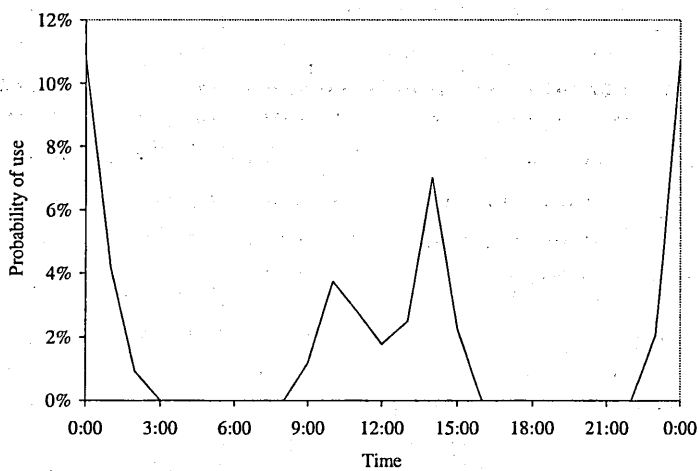


Fig. IV- 22 shows the average over 2 dwellings. This time the use appears to be divided into two distinct parts, the usual morning/early afternoon and a large evening peak. This can be explained by the use of off peak electricity.

Fig. IV- 22 Washing machine use “morning/night”

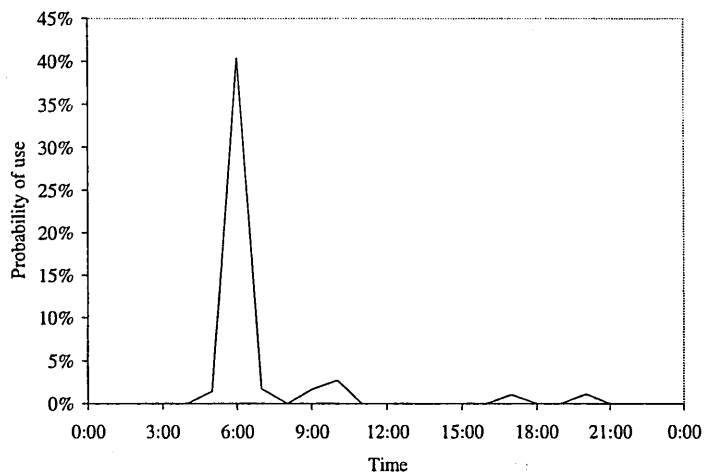


Fig. IV- 23 shows the average over 2 dwellings. They both use their washing machine, almost exclusively at 6am. At this time of the day the electricity price is very cheap, considering economy 7 tariff.

Fig. IV- 23 Washing machine use “night”

Therefore there is a tendency to use washing machine at night, which may be by economy and/or perhaps tranquillity.

The data available on the database was used to derive washing machine time of use. The first step was to design a pattern recognition programme. This programme is able to read through the database and determine when the washing machine was switched on by checking the power step change in power demand.

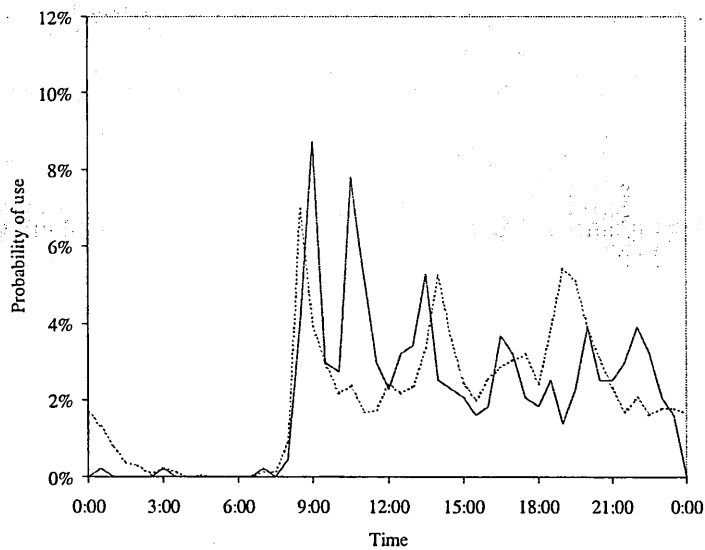


Fig. IV- 24 shows how the washing machine is used in 2 different dwellings. The probability data are very similar with a high morning peak. Then the use seem to be spread almost equally through the day

Fig. IV- 24 Washing machine use “day”

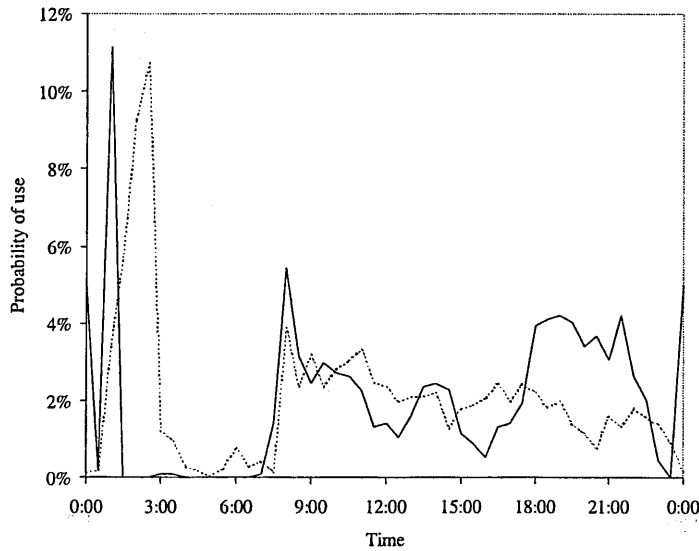


Fig. IV- 25 shows how 2 dwellings use their washing machine. This time it is composed of a combination of night and day use with a large night peak.

Fig. IV- 25 Washing machine use "night and day"

It is therefore shown that there is three main components to the probability of washing machine use,

- "Night" from midnight to 7am
- "Morning" from 7am to 3pm
- "Evening" from 6pm to 9pm

Further work is necessary, especially concerning the washing machine time of use. This will involve the use of a survey, which has been designed to determine the time of use of appliances such as washing machine. The result and analysis of the survey are displayed in Chapter V.

5) Tumble dryer

i) Operation principle

In a tumble dryer, the laundry load is gently tumbled in a front loading horizontal axis drum. Hot air is blown through the drum, evaporating moisture from the load. Two drying systems are now offered.

- Vented dryer

Moisture laden exhaust air is simply exhausted from the machine either directly to the surrounding or via a hose externally.

- Condensing dryer

The hot moist drum exhaust air is passed through a heat exchanger where moisture is condensed. Dry air is then re-circulated to the drum. Condensate is collected in a dispenser within the machine and must be removed by the operator. Cooling is provided by secondary room air. After heat exchange the secondary air is exhausted to the room. The condensing feature is designed to improve the dryer's convenience, not its efficiency. Condensing dryers typically use more energy than comparable vented machine and take longer to dry a laundry load.

a) Mechanical work

Most machines now offer a reverse tumbling action. It is claimed that this improves contact between hot air and damp clothes, thereby improving drying efficiency. The reverse tumbling action and a short unheated tumble at the end of drying cycle are claimed to reduce creasing. Mechanical work is used to rotate the drum and circulate the air.

b) Control

The majority of tumble dryers are time controlled; the operator loads the machine and sets it to operate for a fixed time. At the end of the drying time the operator will return to the machine and either remove the dried laundry load or extend the drying time to remove further moisture. Use of time based drying in this way gives considerable scope for wasteful over drying of the laundry load. Many design include sensing exhaust air temperature to avoid over drying. A rise in air temperature, which means that drying is complete, causes the heater element to switch to a reduced power consumption setting.

ii) Ownership of tumble dryer

The ownership of tumble dryer in the UK is still limited. It can be assumed that only one machine can be owned per dwelling. Considering 1994 Cranfield survey^[37], it is therefore deduced that out of 665 households 54% have a tumble dryer. Another survey, the

English House Condition^[31] in 1991 (9965 answers) shows a 44% level of ownership. Both surveys are described with more precision in Chapter V.

iii) Energy consumption

The EU Labelling Committee has adopted the labelling directive for tumble dryers with the efficiency shows as in Tab. IV- 8 And Tab. IV- 9.

Energy efficiency class	Energy consumption kWh/kg
A	$E \leq 0.51$
B	$0.51 < E \leq 0.59$
C	$0.59 < E \leq 0.67$
D	$0.67 < E \leq 0.75$
E	$0.75 < E \leq 0.83$
F	$0.83 < E \leq 0.91$
G	$0.91 < E$

Tab. IV- 8 Efficiency classes for air-vented dryers

Energy efficiency class	Energy consumption kWh/kg
A	$E \leq 0.55$
B	$0.55 < E \leq 0.64$
C	$0.64 < E \leq 0.73$
D	$0.73 < E \leq 0.82$
E	$0.82 < E \leq 0.91$
F	$0.91 < E \leq 1.00$
G	$1.00 < E$

Tab. IV- 9 Efficiency classes for condenser dryers

A drying cycle typically consumes between 2.2 and 3kWh depending on the amount of water, which has to be removed^[6]. It should be noted that in a drying cycle, 90% of the electricity consumed is used by the heater element.

iv) Power rating

In Fig. IV- 26, the power demand of an empty tumble dryer is shown. Note that to increase the detail level, the data has been recorded with a 1-second interval period.

The model tested is the Electra Sensair tumble dryer and the apparatus used the Datalogger Squirrel 1200 series. The first part is the normal heating demand, followed rapidly by a reduced heating demand due to the fact that the tumble dryer is empty during testing. During these heating periods, the drum is rotated and ventilated using an electric motor. Then the unheated period starts with constant reversed rotation of the drum and then the cycle finishes with alternative reversed rotation of the drum. The heat element

consumes an important part of the electricity in the process, typically rated at 1.5 to 2.5kW. The motor, which rotates the drum and powers the fan, is typically rated at 300W.

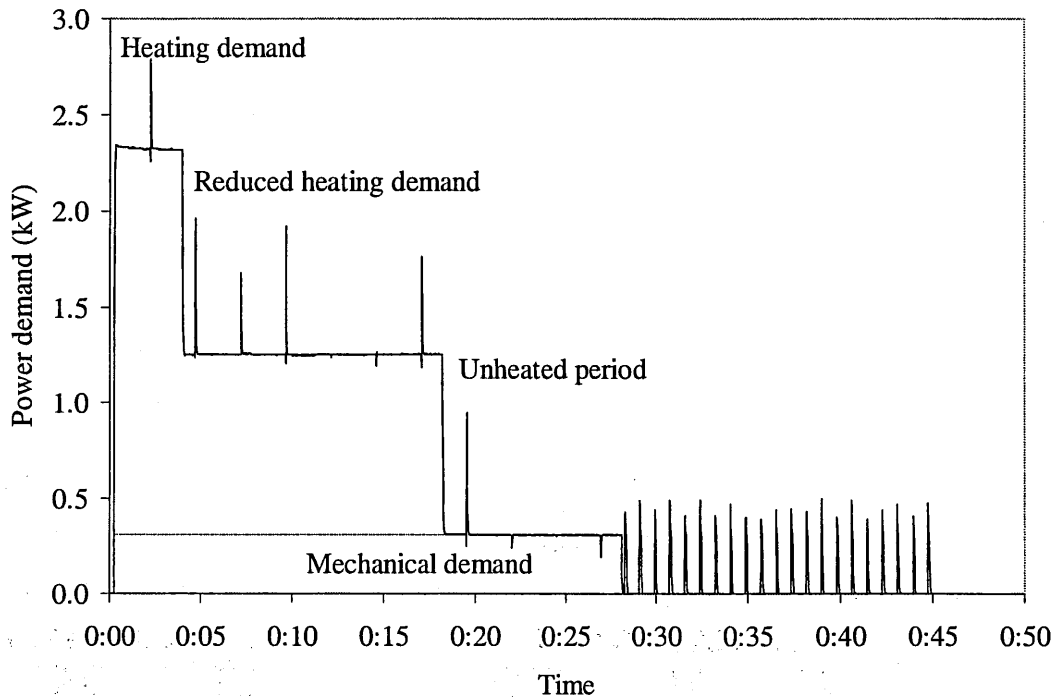


Fig. IV- 26 Tumble dryer power demand (1 second interval)

The purpose of the study is to characterise electricity demand with a 1-minute definition therefore the shape of a tumble dryer power demand in that condition is of interest.

Therefore the data measured to obtain Fig. IV-26 is sampled to extend the time interval required to produce Fig. IV-27.

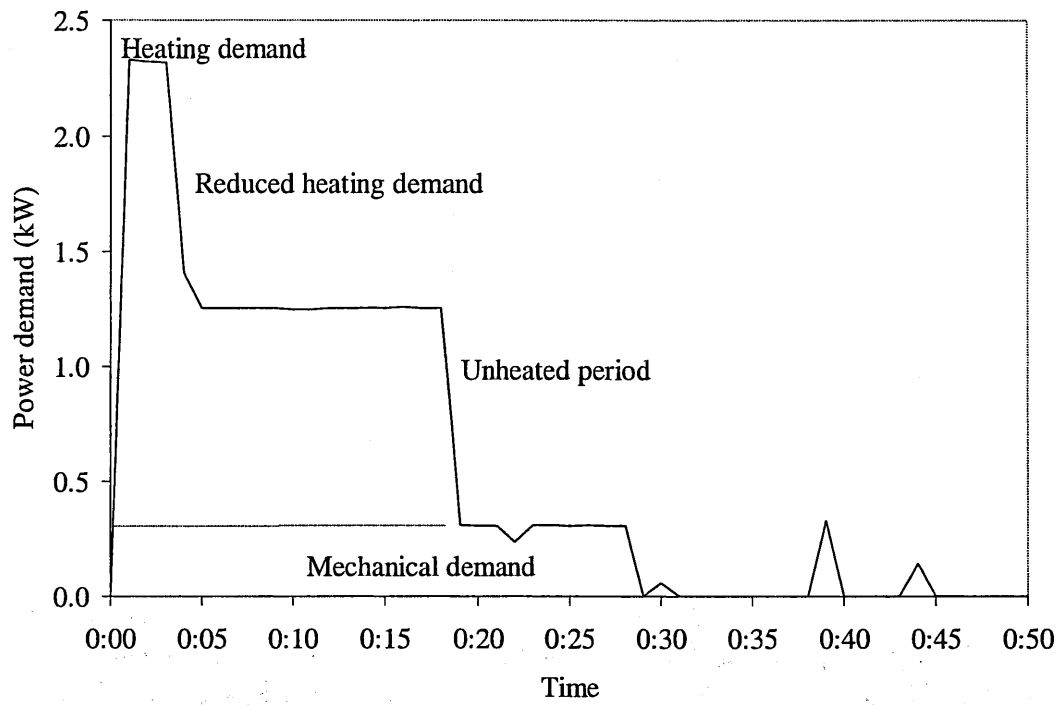


Fig. IV- 27 Tumble dryer power demand (1 minute interval)

v) Cycle duration

The cycle duration will depend on the amount of water contained in the clothes and the desired dryness. Timers can be set to a period time varying up to one and a half hour. To dry 5 Kg of washed cotton clothes the duration may vary from 1h10 to 2h00^[23].

vi) Number of use per week

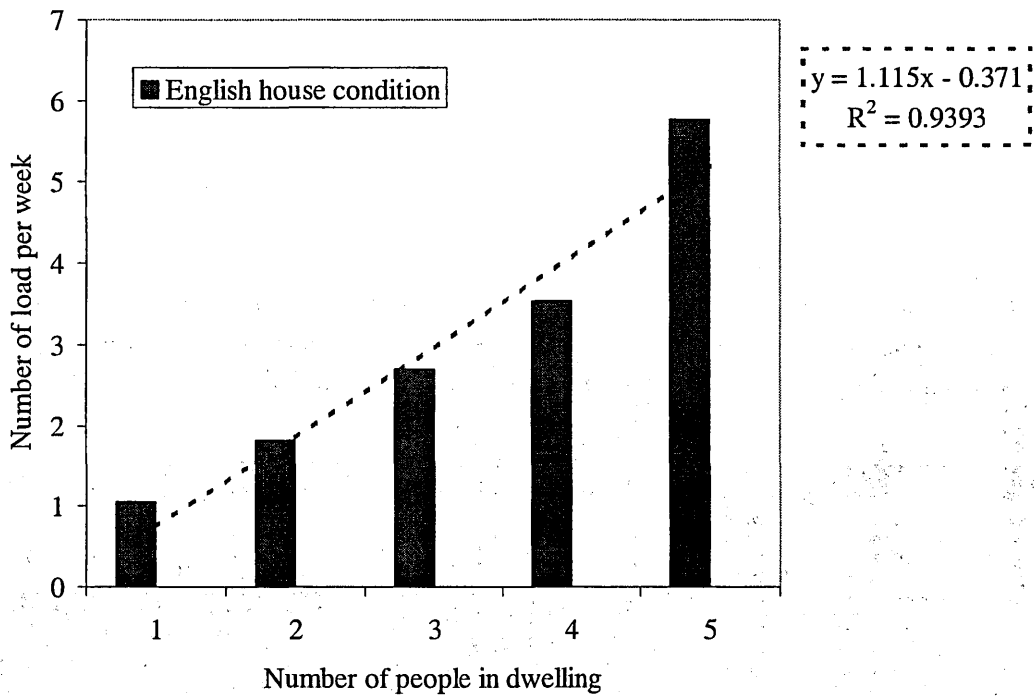


Fig. IV- 28 Tumble dryer weekly average use

The English house condition survey^[31] is the only survey, which characterise the number of use as a function of the number of people in the dwelling. The following equation can therefore be deduced,

$$\text{Cycle per week} = -0.37 + (1.12 \times \text{Number of people}) \text{ for English house condition}$$

Eq. IV- 17

vii) Time of use

The information relative to the time of use of tumble dryer is very limited. This shows the requirement of finding other means of information, which could be derived from a survey.

6) Dish washer

i) Operation principle

The dishwasher is the appliance used for cleaning food soiling from domestic crockery, cutlery, glasses, and cooking utensils. The load is cleaned by hot detergent solution sprayed over the load. The hot solution is pumped from the machine sump to up to four rotating arms within the machine from which the sprays issue.

a) Mechanical work

A pump is used to spray the hot solution.

b) Temperature

The chemical action of the detergent upon the crockery soiling is the most important factor in dishwasher performance. The mechanical action of water sprays upon soiling is less significant. To ensure that the detergent solution effectively washes all types of soiling from the washing load, a solution temperature of 60°C is required. Most machines operate at 65°C to be sure that the washing solution temperature exceeds this critical temperature.

ii) Ownership of dishwasher

Although still relatively small in value compared with markets such as refrigerators and washing machines, the dishwasher market has become one of the fastest growing sectors in domestic appliances. It can be assumed that only one machine can be owned per dwelling. It is therefore deduced from the English House Condition^[31] that out of 9965 households in 1991, 17% have a dishwasher. A more recent survey^[37] realised by University in 1994 shows that 43% of 628 households have a dishwasher. Both surveys are described with more precision in Chapter V.

iii) Energy consumption

Fig. IV- 29 displays the average consumption of dishwasher as given by March consulting group^[33] and ADEME^[6]. These values are compared to the average energy consumption derived from different consumer magazines^{[3][22]}, and two machines, which have been tested in the laboratory (the Hoover crystaljet 3000 and the Zanussi Z30)

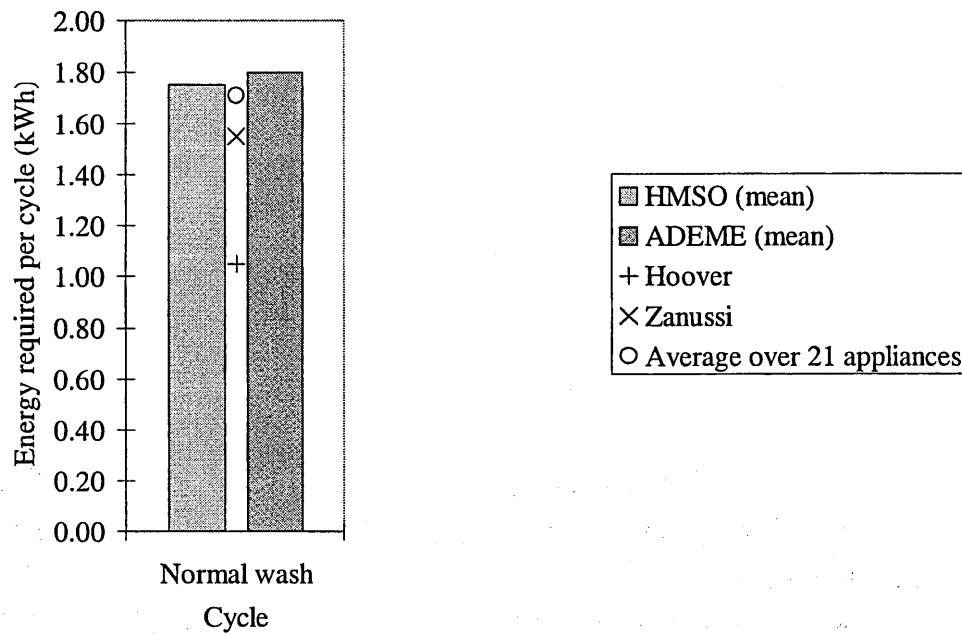


Fig. IV- 29 Measured energy consumption per cycle compared to average

It can be noticed that the values given by ADEME, HMSO and the average corroborate very closely, while the Zanussi machine is relatively below and the Hoover machine consumption is very low. It is due to the fact that the test were realised with empty machine, the energy required to heat up the crockery, cutlery, glasses, and cooking utensils is not considered.

iv) Power rating

The electricity consuming components of a dishwasher are the heater element, which may be rated from 2 to 2.7kW, and the spray pump, which consumes between 200 and 250W.

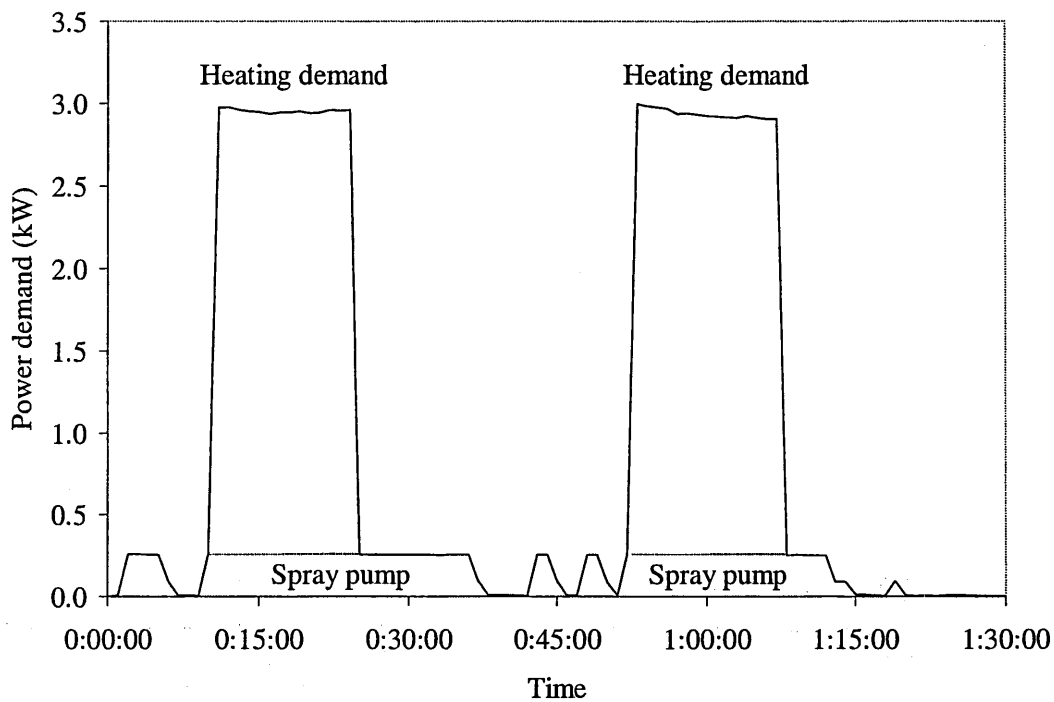


Fig. IV- 30 Power demand of a dishwasher during a normal cycle (1 minute interval)

Fig. IV- 30 shows the power demand of a Zanussi Z30 dishwasher during a “normal cycle”, measured with the Power Unit HRS 101.

The normal cycle is composed of different steps. First the water is allowed in the machine, and sprayed to remove the worst soiling from the crockery. Then the water is heated for about 15 minutes and still sprayed. This whole process is repeated again once before the water pumped out.

Most machines offer usually three programs.

- “normal” wash at 65°C
- unheated prewash or “rinse and hold”
- “intensive” or “pot and pans” wash at temperature between 65 and 75°C.

Other programmes options, which are often offered in up market machines are 50°C economy, quick washes and a 40°C glasses wash.

v) Cycle duration

The duration of a “normal” cycle can vary from 1h02 to 1h22^[22].

vii) Number of use per week

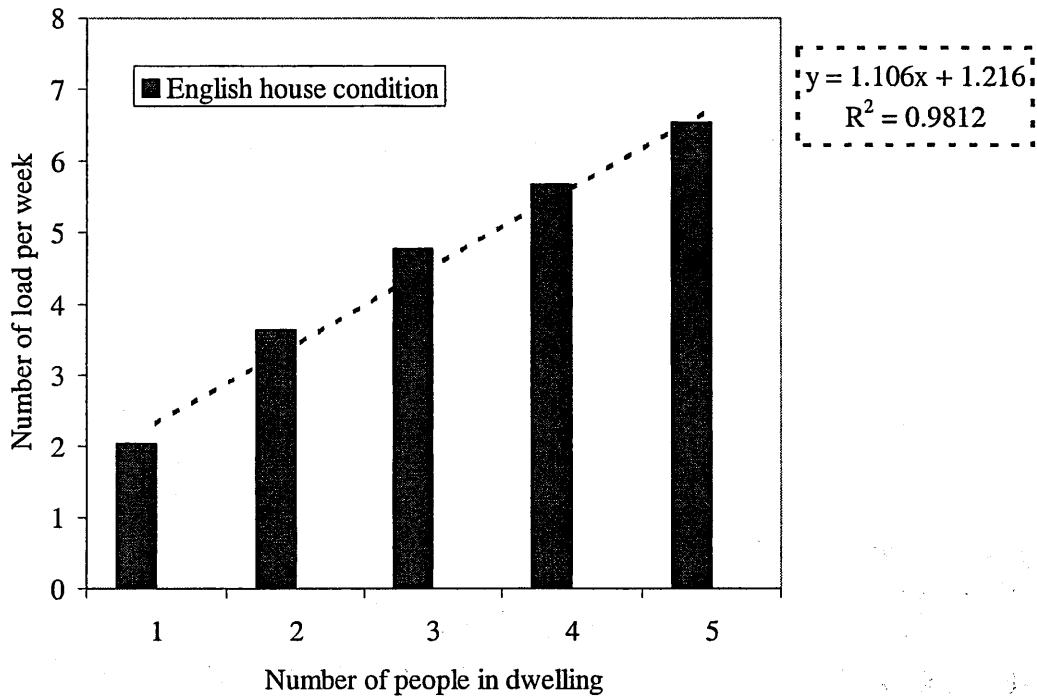


Fig. IV- 31 Dishwasher average weekly use

The English house condition survey^[31] is the only survey which characterise the number of use as a function of the number of people in the dwelling. The following equation can therefore be deduced,

$$\text{Cycle per week} = 1.22 + (1.11 \times \text{Number of people}) \text{ for English house condition}$$

Eq. IV- 18

viii) Time of use

The information about the time of use of dishwasher is very limited. Therefore the need to design a survey appears.

7) Television

i) Operation principle

The television set receives information using either an antenna or a decoder, depending if the waves are sent through the air or through a cable. The information is then decrypted to obtain sounds and images on a screen using coding sequences. The televisions are used as a mean of entertainment, education and information.

ii) Ownership of television

“Regional Trends 31”^[41] suggests that 98% of household own at least one television. “March et al”^[33] estimates that 50% of household own two or more televisions. BRE^[30] shows a 1.47 average of televisions per household.

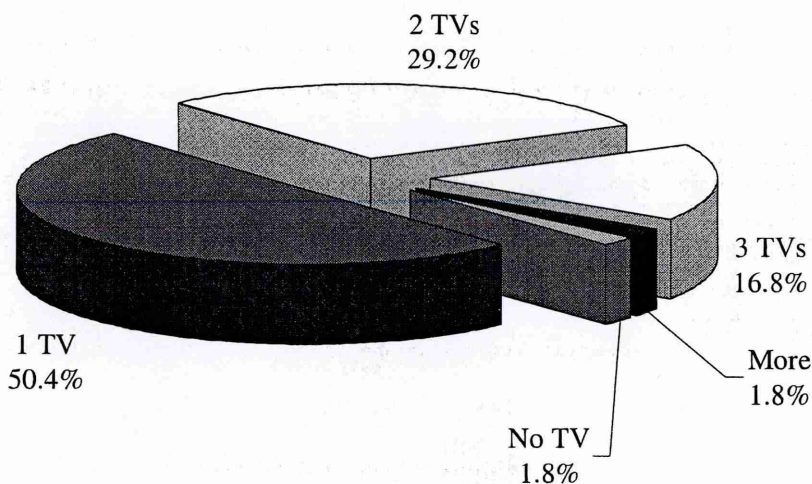


Fig. IV- 32 Ownership of television^[37]

Ownership levels for black and white television sets have decreased as they have been gradually replaced by colour sets. Ownership of several colour televisions per household is now commonplace. A survey^[37] conducted by Cranfield university in 1994 shows that colour televisions were owned by 97% of the respondents and on average every household owns 1.6 colour televisions. Fig. IV- 33 shows television ownership by different family type.

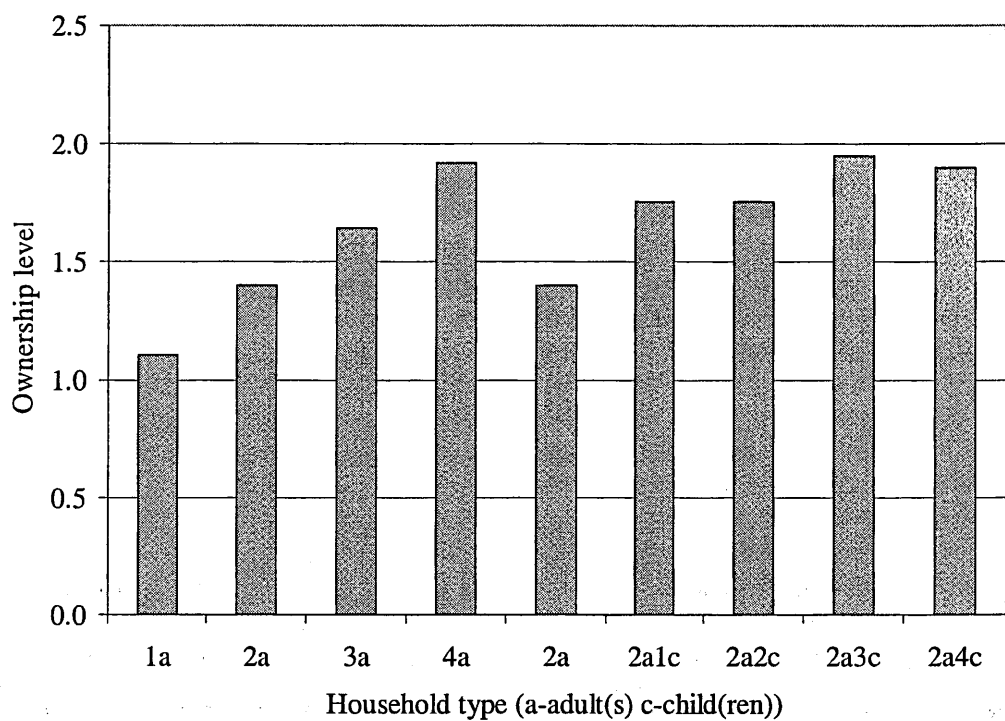


Fig. IV- 33 Television ownership by family type

iii) Power rating

The power rating of televisions varies from 50 to 150W depending on the technology, and especially the size of the screen. This range is based on observation of different type of apparatus available on the market. Some models include a standby mode, which may consume up to a few watts. Therefore the televisions can be in three different modes,

- Disconnected
- Standby
- On

iv) Daily usage

Fig. IV- 34 shows that the viewing time depends on the number of people living in the dwelling. This property will be developed in Chapter VI to derive the model.

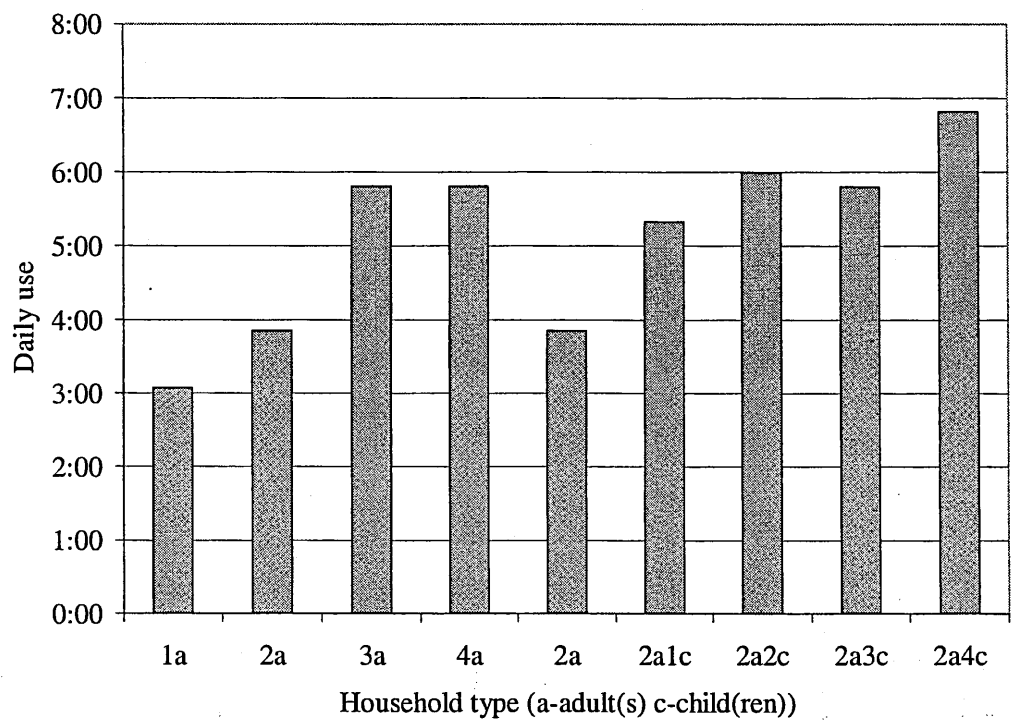


Fig. IV- 34 Television daily use by household type^[37]

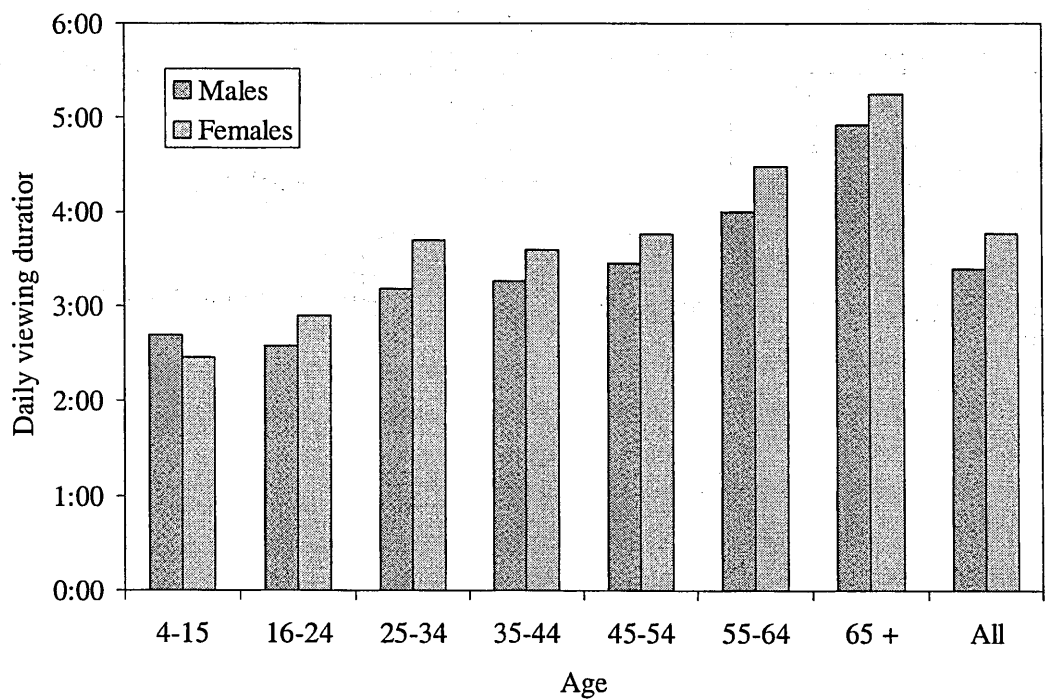


Fig. IV- 35 Television daily use by people age

Fig. IV- 35 shows that there is a direct relation between the people's age and the television viewing duration. The data are derived from "Social Trends 22"^[42]. Persons aged 65 and over tend to watch television almost twice as much as children aged between 4 and 15.

v) Time of use

To determine the time of use of televisions, national television audience^[42] is used. The probability of use is derived from the average television audience in UK during the 4th quarter in 1992. The sample considered is all persons aged four and over.

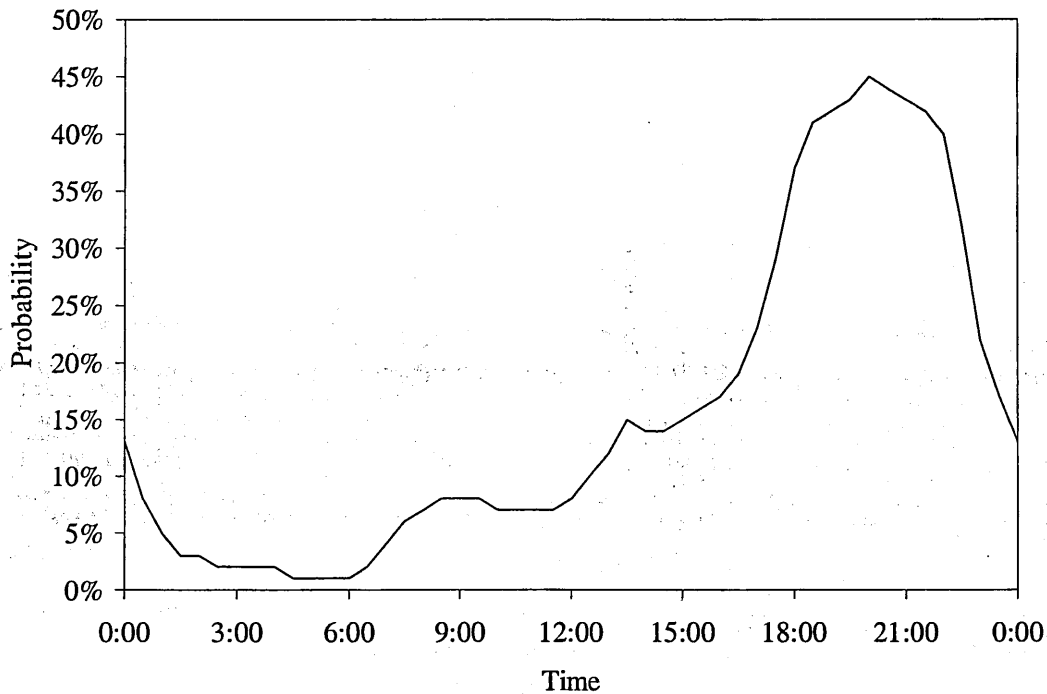


Fig. IV- 36 Television average national audience^[42]

Fig. IV- 36 describes the average audiences (including satellite, cable and video) during a day. It can be noticed that on average nearly half the population aged four and over watched television between 19h30 and 20h00. This is traditionally the times when series are scheduled.

8) Video cassette recorder

i) Operation principle

The video cassette recorders are generally linked to televisions to provide images and sounds. They make use of magnetic tapes. Video cassette recorders and tapes can be used to record or/and view programs.

ii) Ownership of video cassette recorder

“Regional Trends 31”^[41] suggests that 75% of household own at least one video cassette recorder in UK in 1995.

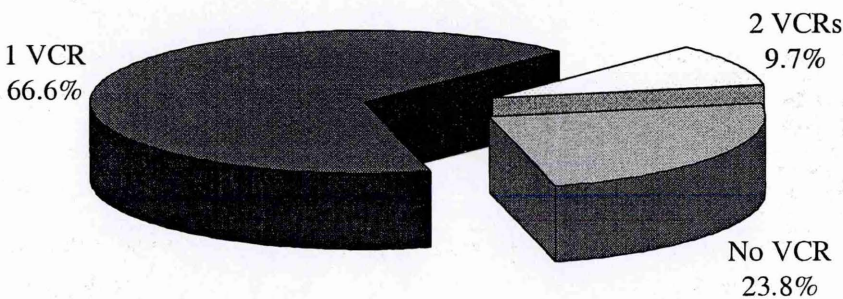


Fig. IV- 37 Ownership of video cassette recorder^[37]

In a survey^[37] conducted by Cranfield University in 1994, the average ownership of video cassette recorders are found to be 0.86 per household, which is relatively low because 24% of households do not own any. It should be noticed that 10% of household own two video cassette recorders.

Fig. IV- 38 shows that the ownership is dependent on the family type. For instance, it seems that there is a direct link between the number of people and the video cassette recorders ownership, irrespective of adults or children.

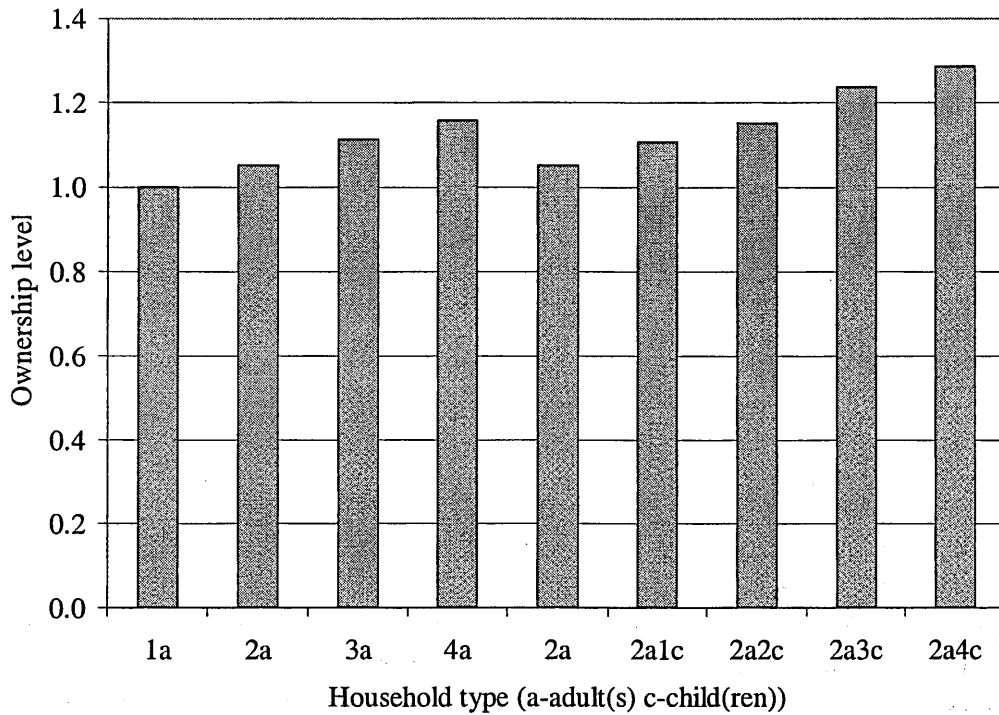


Fig. IV- 38 Video cassette recorders ownership by family type

iii) Power rating

The power rating of video cassette recorders varies from 20 to 40W. This is based on measurements of different type of apparatus available on the market. Video cassette recorder can be in three different mode,

- Disconnected
- Standby
- On (either recording, reading, fast forwarding or rewinding)

The main difference with a television is that the standby mode power consumption is very close to the on mode power consumption. On a particular appliance the difference is determined to be only a few watts.

iv) Daily usage

As a general rule, video cassette recorders use increases with the number of people in the dwelling, but the variation is limited between 1h30 and 2h00. Therefore Fig. IV- 38 shows that there is a relative stability in video cassette recorders use.

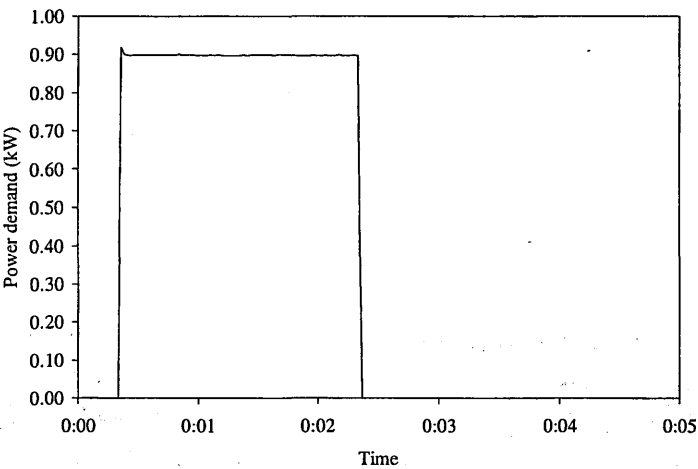
v) Time of use

For this study the time of use is not relevant because the difference of power consumption between the modes (standby, playing and fast forwarding) is very limited.

9) Cooking appliances

Cooking appliances are used to heat up food. This activity could take place just before a meal is eaten, but is totally user dependent. This section analyses the main cooking appliances.

i) Toaster and kettle.

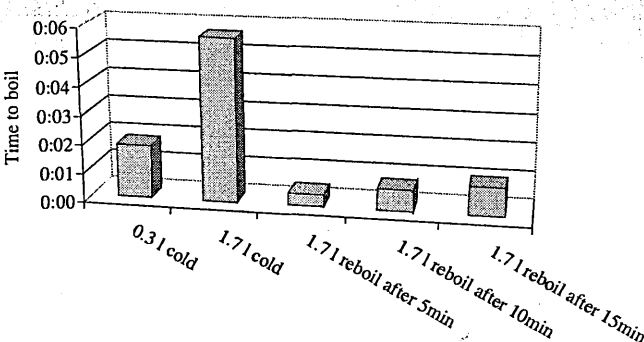


Toasters and kettle are two different appliances type, which can be associated by their power demand signature and functioning pattern. Toasters and kettle can be controlled manually or automatically by mean of timers and thermostats respectively. A rectangular signature represents the power consumption of cooking appliances, such as toasters and kettles.

Fig. IV- 39 Toaster power demand

Toaster usually have power rating that is between 800 and 950W, and their usage duration is of the order of a few minutes.

There are different types of kettles on the market. The maximum volume could vary from 0.5 to 2.0 litres, and the power rating from 0.75 to 3 kW. Kettles have similar power demand as toaster, and usage duration varies up to a few minutes.



The duration of use is largely dependent on the amount of water that is to be heat up as well as its initial temperature

Fig. IV- 40 Kettle duration of use

ii) Oven

The oven is designed as an insulated enclosure in which heat is exchanged from the heating element to the air and then to the product to be cooked. The processes used are convection and conduction. Electrical ovens are using thermostats, which measures the temperature of the enclosed air, and control the power of the heating element.

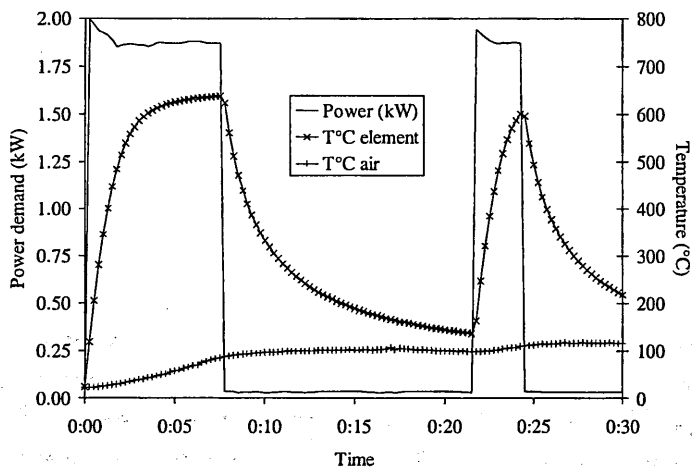


Fig. IV- 41 Power demand and temperatures

Then the power is directly controlled by the thermostat, and will switched on every time the temperature is lower than the desired level, and switched the power off when the temperature is higher than the desired level.

Oven have power rating varying between 1.0 to 3.0kW, depending on the size of the enclosed volume. It should be noticed that to increase the convection, forced convection ovens have internal fans with power rating of the order of 100W.

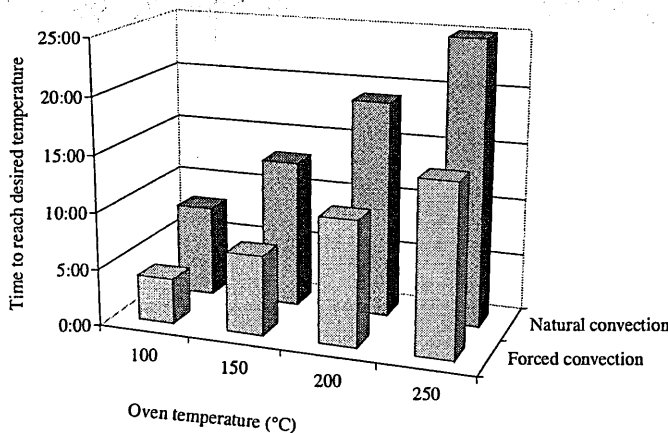
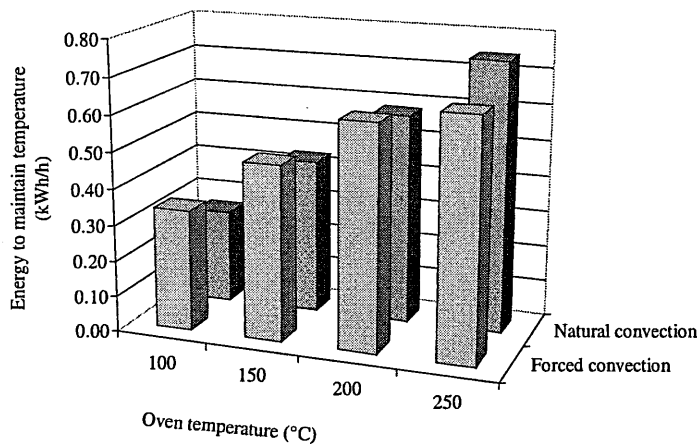


Fig. IV- 42 Time to reach temperature

Fig. IV- 42 shows the operation of a electrical oven. To begin, the enclosed air as well as the heating temperature is about 20°C. The power is switched on and the element temperature raises to 600°C within 7 minutes. By convection the air is heated up to 100°C, which was the chosen temperature for this experiment.

The advantage of forced convection oven over natural convection oven is essentially the preheating duration, which is halved.



The energy required to keep the oven's temperature is almost unaffected

Fig. IV- 43 Energy to maintain temperature

iii) Microwave oven

The operating principle of microwave oven is that generated microwave are directed onto the product. This wave interacts essentially with the water molecules to create molecular vibration and therefore increase the temperature of the product.

A timer generally controls the old microwave oven; while recent models include functions such as defrost and power control. It should be noticed that the power control is achieved by switching on and off alternatively the microwave generator.

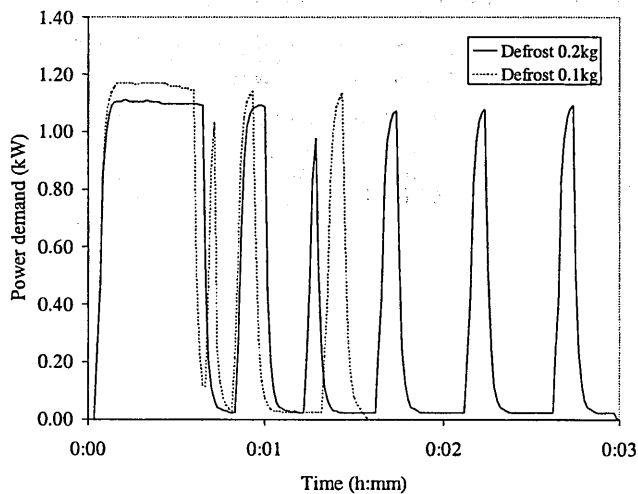


Fig. IV- 44 shows the power demand of a microwave when programmed to defrost 0.2kg of meat. To be able to display this data a time interval was one second because cycles last for less than one minute.

Fig. IV- 44 Microwave power demand for automatic programme

The power rating of microwave is usually in the range 650 to 1200W. The controller and timer in most recent models requires up to a few watts.

vi) Hob ring

The operating principle of hob ring is to control cycles of the power being passed though a heating element. The heat generated is passed to a pan in which the food is heated up. The user with an external knob controls the cycle types.

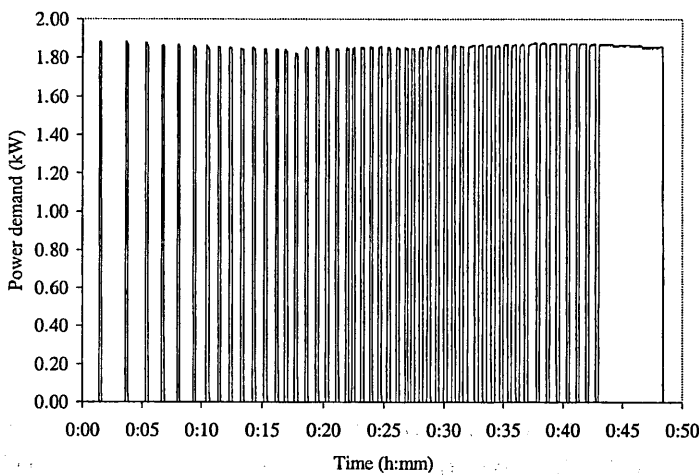
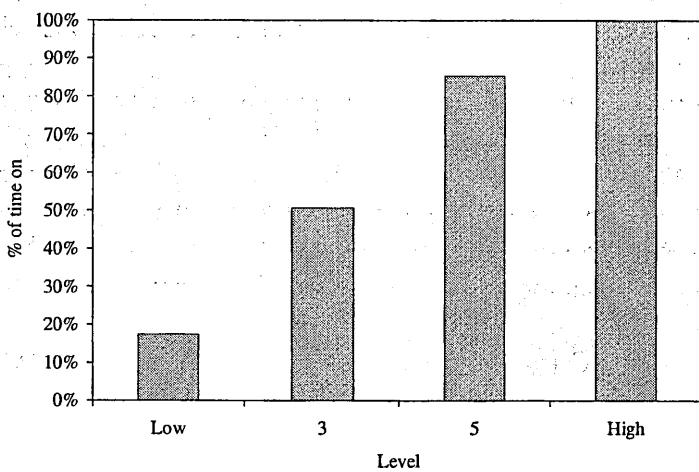


Fig. IV- 45 shows the different power demand pattern for settings being changed from the lower to the higher setting. It is therefore analysed that hob rings power demand signatures are totally user dependent.

Fig. IV- 45 Power demand for different settings



This graph shows that the cycle and therefore the signature of the appliances may vary from 20 to 100% “on” time.

Fig. IV- 46 Percentage of time on for different setting

v) Other cooking appliances

The appliances that were characterised do not represent an exhaustive list of cooking appliances. They represent appliances, which are commonly used in dwelling. Appliances such as deep fryer, mixer, electric knife, can opener, fruit juicer, coffee machine are not analysed in this section due to their limited ownership and reduced energy demand.

10) Lighting appliances and others

Lighting is one of the most indispensable utility in a dwelling. Different lighting systems are available on the market.

i) Lighting

Most households use normal light bulbs GLSs. They contain a wire, which is heated by passing an electric current through it, causing its incandescence. The filament is made of tungsten, and is enclosed in a glass bulb containing an inert gas. The efficacy of a typical 100W bulb is about 12lm/W.

Tungsten halogen lamp, like the conventional incandescent lamp above, consists of a tungsten filament inside a bulb, which glows when heated. However, it also contains a halogen such as iodine or bromine within the bulb, which reduces lumen depreciation by eliminating bulb wall blackening. The efficacy is increased to about 20lm/W.

The third common option is compact fluorescent lamp, CFLs, which are composed of a bulb with an electrode at each end. The bulb contains a small quantity of mercury droplets, which vaporise during the operation of the lamp. The bulb contains inert gases such as argon or krypton at low pressure.

The power rating of these appliances is in the range from 40 to 500W and the dwelling equipment would depend on the technology chosen, and the level of lighting required.

It is common belief that lighting accounts for a substantial share of domestic electricity usage, especially during winter period, however “in the UK there have been hardly any field studies on lighting usage” is quoted from the Load Research Group^[16]. A major reason for the lack of data on domestic lighting usage is the difficulty of acquiring it. A large amount of recording equipment is needed to track lighting electricity demand at many points of use in a customer's dwelling.

ii) Other

a) Electronics

Nowadays, electronic appliances are present in most dwelling. Clocks, alarms, fax machines, phones and answering machines are commonly owned. They are generally constantly plugged. The power demand generated by transformers used to power such appliances is generally of the order of a few watts only. Other electronics appliances such as high fidelity sound system better known as Hi-Fi, computer, electronic and video games have power demand of the order of 100W.

b) Bathroom and cleaning

The appliances that are found in the bathroom and for cleaning are generally hairbrush, hair dryer, shaver, iron and vacuum cleaner. Their power rating varies from a few watts to 1.5 kW, but their usage is generally limited to only a few minutes every day.

Electric shower is a special appliance because its power demand may be up to 10kW. Again their usage is limited to a few minutes every day.

c) Miscellaneous

All other specific appliances such as sewing machine, drill, tools, sun bed, barbecue, air pump for aquarium are not characterised in this research.

11) Conclusion

The investigation, which was under taken in this chapter, concerned main appliances. The results obtained were very valuable to the research even though there was a lack of information regarding time of use of appliances.

There was therefore a requirement for deriving the information from another canals. Two options were available, one involving more specific monitoring, and the other involving a survey to characterise in more detail the appliances.

Further work is to be considered to update and extend the information contained in this chapter.

Chapter V: The survey

1) The reasons for a survey

Technical information about appliances, such as power consumption, is generally widely available in the literature, but how these appliances are used is unknown. This research was therefore faced with the fact that very limited information was available to describe when appliances are used. Two options could then solve this issue.

The first option was to monitor individual appliances to derive when they were used. This implies accessing appliances in private dwelling and leaving measurement apparatus for an acceptable period to obtain sufficient information. To a certain extent this was achieved, but only a limited number of individual appliances were studied due to limitations in the number of dataloggers and time.

The second option was to question people about their habits. The advantage of this option is that no apparatus was required, but a questionnaire. The technique usually achieves less than 10% response rate and provides information of lower quality than the energy monitoring. To ensure the validity of the answers a large number of dwellings had to be surveyed.

It was decided to design a survey because the equipment required and the time involved for monitoring would have delayed considerably the project.

2) Design of the questionnaire

The aim of the questionnaire is to answer questions, which have not been answered in the literature review. Therefore the first step is to determine the questions, which were critical for the project. They were analysed to be appliances usage characteristics and time of use (to determine when and how appliances are used).

a) Selection of appliances to be surveyed

Considering the average electricity demand of a dwelling described with precision in Chapter II, it can be deduced that the electrical appliance types are the following by importance in energy consumption,

- Space heating
- Water heating
- Refrigeration appliances
- Cooking appliances
- Dishwasher
- Washing machine
- Tumble dryer
- Lighting
- Television and video cassette recorders
- Kettle

To simplify this selection it should be noticed that the space heating, water heating and refrigeration are all generally user independent. The user can only modify their settings. It would not be useful to ask about lighting because its use was shown to be highly dependent on the time of the year considered, and it would be very difficult for the user to characterise. Cooking appliances use is a part that should be derived from another Cranfield research project^[36]. Therefore all these appliances will not be mentioned in the questionnaire.

The other appliances usage were user dependent, therefore the time of their use have to be characterised if a model is to be constructed.

The questionnaire should not be too long to avoid annoying people. Therefore the list was limited to the following appliances, which they are commonly owned and used in dwelling,

- Kettle
- Toaster
- Washing machine
- Tumble dryer
- Dish washer
- Iron
- Hair dryer
- Vacuum cleaner
- Television

b) The presentation of the survey

It was decided to start the questionnaire with an introduction to the subject, helping people to understand why the questionnaire was issued, and how to answer it. The multiple-choice type of questions was adopted to simplify the user's participation and the process of integrating all the results together.

c) General questions

Then the beginning questionnaire must be designed to be attractive. The first part of the questionnaire is composed of general questions such as,

- Number of adults and children living in their dwelling
- Number of bedrooms in their dwelling
- Their electricity tariff
- The average number of weekend spent away every month

Note that there was no specific question about the age of the people and their income as some people found it embarrassing.

d) Questions related to the appliances

It should be noticed that the questionnaire was intentionally appliance orientated. This was to avoid respondents characterising their personal use of the appliance, when the interest was how the appliance is used. Depending on the appliance, different questions format were used. There were three types of questions in the questionnaire.

i) Questions about number of uses in a defined period

The use of one particular appliance was necessary to define its importance in the energy demand. It was important to define approximately the periodicity of appliance usage. For example, it was asked how many times on average is the kettle used daily, because this appliance is generally used on a daily basis, while for the iron the question used a week basis.

ii) Questions about usage duration during each use

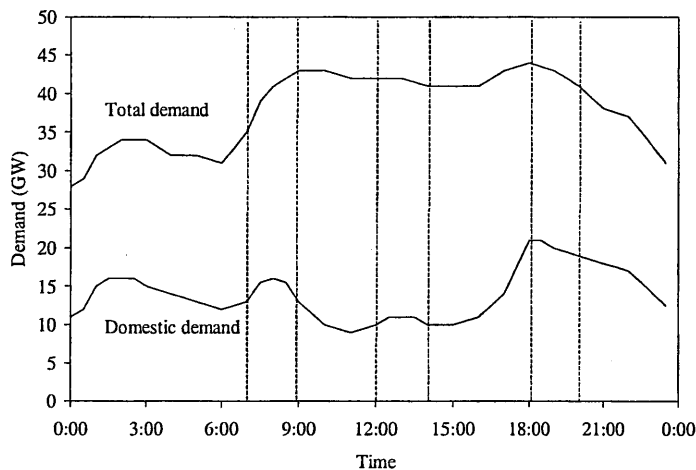
This type of question appeared for appliances, which have to be switched on and off by the user, such as iron, hair dryer and vacuum cleaner. The answers will help to define typical usage pattern.

iii) Questions about time of use

These questions had the finality to characterise the time of use of appliances. It is practically impossible to determine exactly the appliance time of use with a questionnaire, because people would not be able to give a precise time, and even if they would, would it be the last use, or the one before the last? Here the multiple-choice types of question oblige to define usage in different time intervals. The intervals were defined as follows,

- 12pm to 7am "low demand"
- 7am to 9am "medium peak demand"
- 9am to 12am "low demand"
- 12am to 2pm "small peak demand"
- 2pm to 6pm "low demand"
- 6pm to 8pm "maximum peak demand"
- 8pm to 12pm "decrease of demand"

These intervals are convenient because they corroborate with specific activities of people and national domestic power demand too, as described in Fig. V- 1.



Note that the choice of the intervals were based on demand level. For instance, the evening peak was derived from choosing the greater possible demand average over 2 hours.

Fig. V- 1 National and domestic demand^[32]

Then the questions concerning time of use were sectioned into two parts to determine any change in behaviour between weekday and weekend day. A blank questionnaire is displayed in Annexe I.

3) Process of sampling dwellings

To obtain trends of use a large number of dwellings had to be targeted, but there is always a practical limit to this number and the response rate is unknown until the end. Therefore one thousand blank questionnaires were printed using Cranfield University facilities.

Then the problem was to determine the targeted dwellings. Five random copies of the Bedfordshire phone book containing addresses were used. It was decided to avoid surveying extended families, therefore in case of similar names, only the two first were retained.

The process of sending the questionnaire took some time because each questionnaire was accompanied with a prepaid addressed envelope, therefore minimising respondent's effort.

4) Information collection and methods

It took about a week before responses to be sent back. In total, 458 valid responses were collected, representing a 45.8% of response rate. This relative high response rate, compared to the usual 10%, and is probably due to the fact that the questionnaire contained information about its aim and is totally impersonal.

The data were collected using a visual basic program, which creates a CSV file. This file is constructed as a database, which makes it accessible with the visual basic for typical individual observation.

5) General analysis of the results

i) Analysis and comparisons

First to check the validity of the sample, the distribution of responses by number of people in dwelling is compared to national statistics obtained from “Social trends 27”^[44].

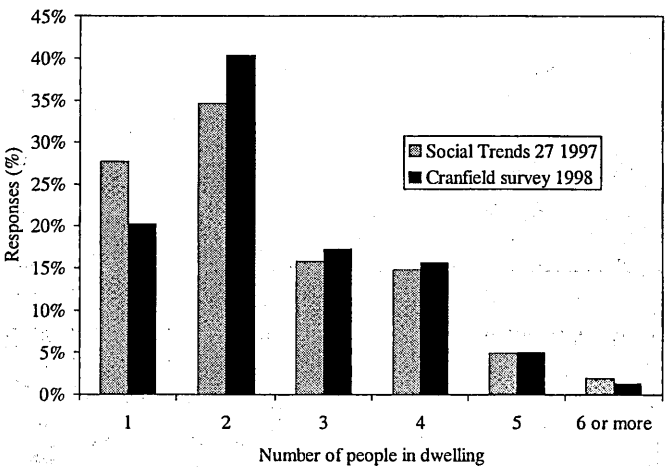
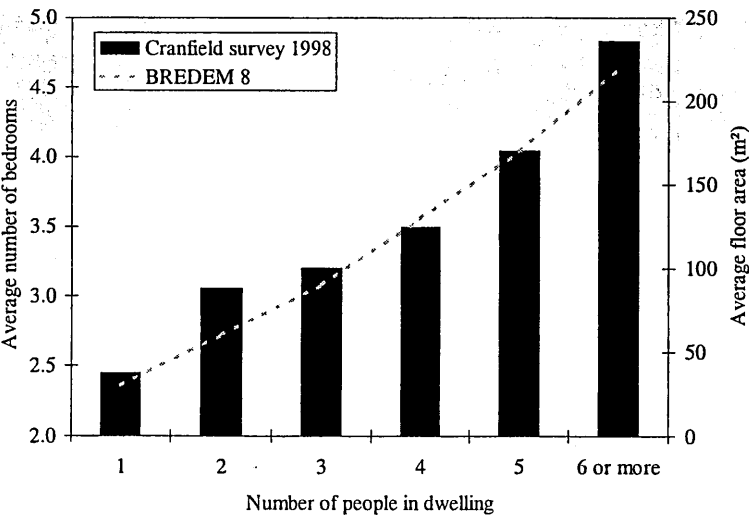


Fig. V- 2 shows that both distributions are relatively similar. Noticeable differences occur only for the one and two people dwelling, and they are limited to a few percentages. The average number of people per dwelling is found to be 2.41 and 2.49 respectively for the “Social trends 27” and the Cranfield survey 1998.

Fig. V- 2 Distribution by number of people in dwelling



BREDEM 8^[11] described the national average floor area. The average number of bedrooms by number of people in dwelling is determined for the Cranfield survey 1998. Note that for one person dwelling the average number of bedrooms reaches 2.45, which seems high

Fig. V- 3 Number of bedrooms and floor area by number of people in dwelling

Fig. V-3 shows how it is possible to relate the number of bedrooms in a dwelling to the floor area. The following relationship is derived

$$\text{Floor area (m}^2\text{)} = 86.9 \times \text{Number of bedrooms} - 189.0$$

Eq. V- 1

Note that this equation is only valid for number of bedrooms strictly superior to two, to ensure that the floor area is always positive.

To characterise the electricity demand, one of the important parameter is the electricity tariff. In the UK, mainly two tariffs are available to the domestic sector. The standard tariff is composed of a base price for connection and constant unit price through the day. The off peak “Economy 7” tariff is also composed of a base price for connection, which is relatively higher than the standard tariff base price, but the unit price is very cheap during 7 hours at night, and just over the standard tariff unit price during the rest of the time. The tariff is generally chosen by the user, therefore it can influence his electricity consumption

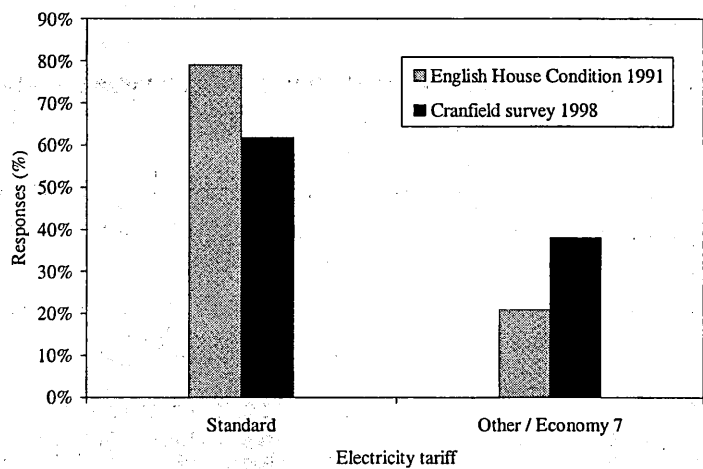
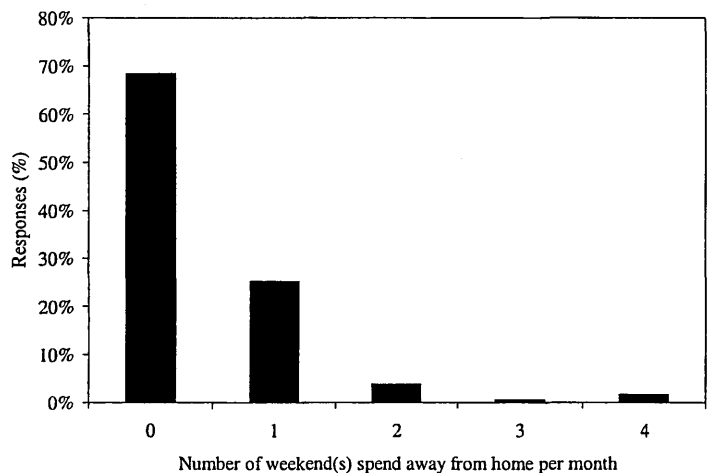


Fig. V- 4 shows the survey responses by electricity tariff, and the distribution is compared to published data in “English house condition”^[31] Cranfield survey 1998 overestimates the dwelling using the Economy 7 tariff by about 20%.

Fig. V- 4 Responses by Electricity tariff

This could be due to an evolution of the electricity market through the years but the Cranfield survey 1998 sample is limited to Bedfordshire area. For representation purposes this could be a problem, but it also means that the sample using Economy 7 tariff will be well represented.

It is assumed that people spend most of the week at home out of working hours, essentially due to their work. But during weekend people are much freer to spend time away from home. Therefore to determine their behaviour, the last of the general question is “how many weekend on average do you spend away from home per month?”.



The responses are displayed in Fig. V- 5. 68.5% of the responses is no weekend is spent away from home per month.

Fig. V- 5 Number of weekend spend away from home per month

This high rate of nil responses may be due to the fact that people might have been afraid to answer this question truly for security reason, even if the questionnaire is totally impersonal. They addresses were only used to send the questionnaire and there was no possibility to know who answered a particular questionnaire.

The average number of weekend spend away is found to be 0.42 per month, which would mean that on average 5 weekends a year are spent away from home.

The survey shows high similarities with other independent research^{[31][11][44]}, which is a first step in proving its validity and value.

6) Results for the electric kettle

The ownership of kettle is found to be 99.6%, which almost mean that there is a kettle in virtually every dwelling.

i) Kettle daily usage

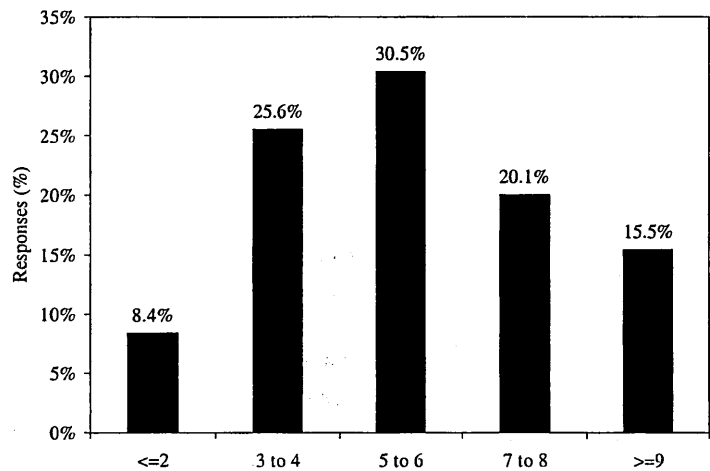


Fig. V- 6 Kettle daily usage

Fig. V- 6 shows how people responded when ask how many times daily they used their kettle. The average usage is determined to be 5.7 times a day.

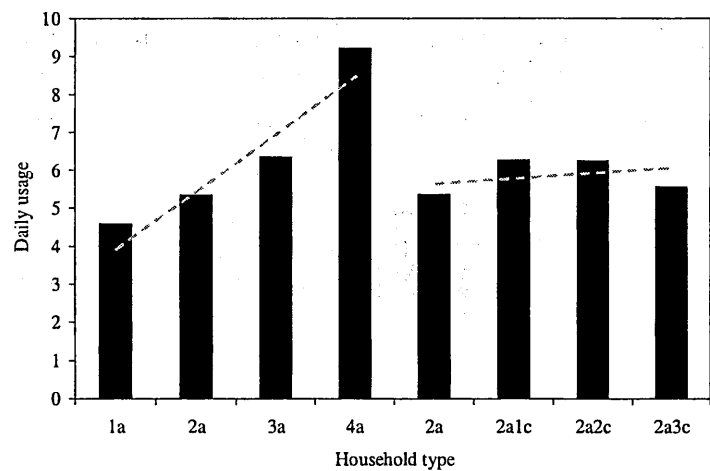


Fig. V- 7 Kettle daily usage by family type

Fig. V- 7 shows the influence of the number of adults and children on the kettle usage. It can be noticed that the influence of adults is more pronounced than the influence of children.

Linear regressions show slope of 1.49 for adults and only 0.06 for children for the whole sample. Therefore it is deduced that the following formulae can used to determine the kettle daily usage,

$$\begin{aligned} \text{Kettle daily usage} &= 1.49 \times \text{Number of adults} \\ &\quad + 0.06 \times \text{Number of children} \\ &\quad + 2.66 \end{aligned}$$

ii) Week and weekend day kettle usage

To determine if there is any disparity in usage depending of the day of the week, people were asked to indicate when the kettle was mostly used.

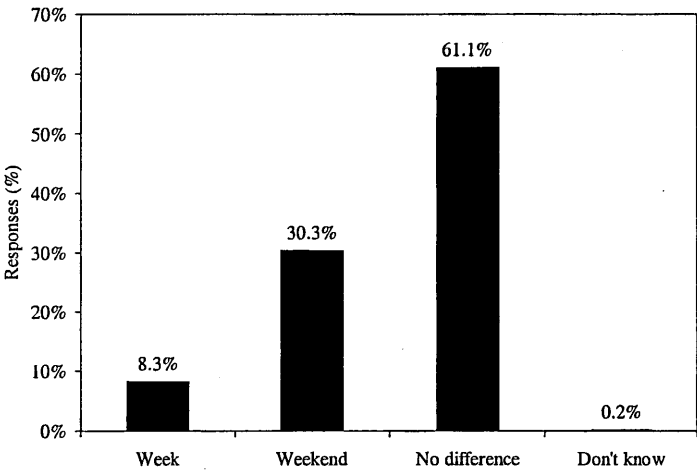


Fig. V- 8 shows that for a majority (61.1%), there is no difference of usage. It should be noted that 30.3% of the dwelling surveyed, the kettle is used mostly during weekend. It is therefore with precaution that it will be assumed an absence of difference.

Fig. V- 8 Disparities in kettle use during a week

iii) Kettle time of use

No specific time of use questions were issued in the questionnaire because they would be difficult to answer and the kettle time of use is directly deduced from the database using the recognition pattern program in Chapter IV.

7) Results for the electrical toaster

The ownership of toasters is found to be 81.4%, which means that there is a toaster in almost every dwelling.

i) Toaster daily usage

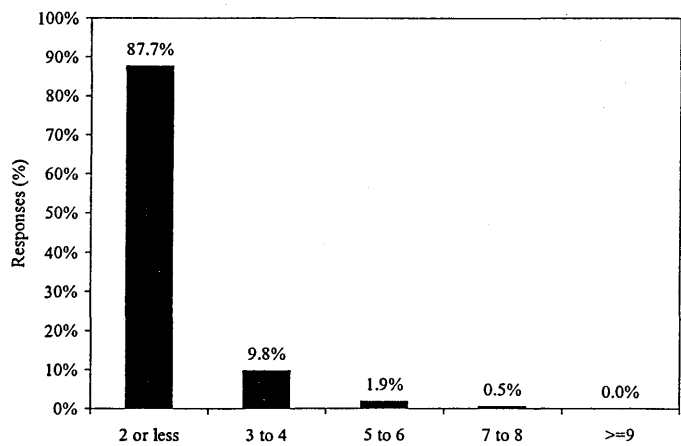
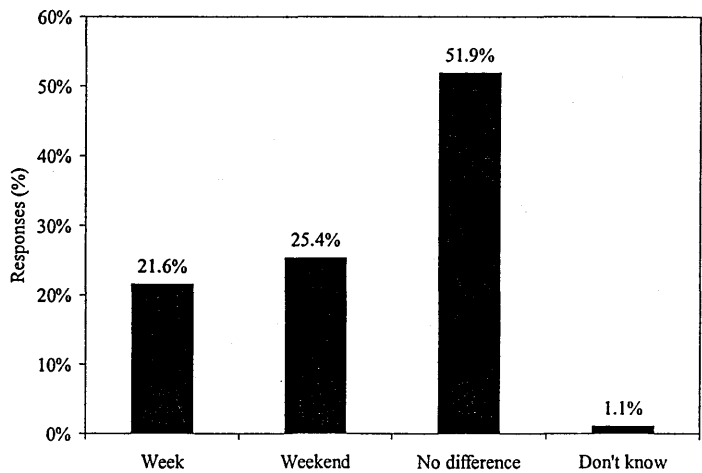


Fig. V- 9 shows how people responded when ask how many times daily they used their toaster. A large majority responded that their toaster was used twice or less daily. The average usage is determined to be 2 or less a day.

Fig. V- 9 Toaster daily usage

Due to the limited spread out of responses, the study of uses as a function of number of people cannot be defined.

ii) Week and weekend day toaster usage

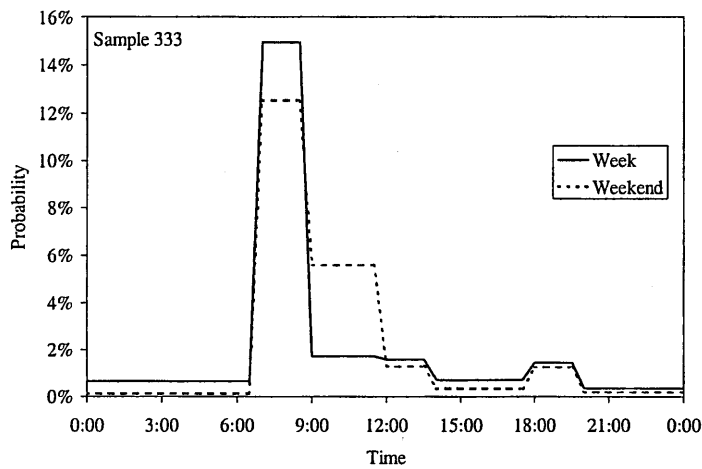


The difference in usage between weekday and weekend day is determined to be limited in 51.9% of the sample responses as shown in Fig. V- 10.

Fig. V- 10 Disparities in toaster use during a week

It will therefore be assumed that there is no difference between weekday and weekend day usage.

iii) Time of use of toaster



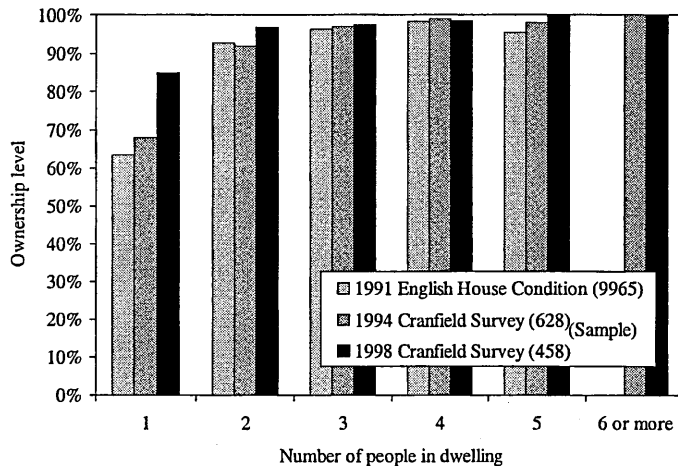
The toaster time of use is characterised by a large morning peak and a general low daily usage. This is mainly due to breakfast requirement. The morning peak is extended during weekend essentially due to increase in free time.

Fig. V- 11 Toaster time of use

8) Results on washing machine

i) Ownership

The ownership of washing machine is dependent on the household composition. The need for a washing machine increases with the number of inhabitant.

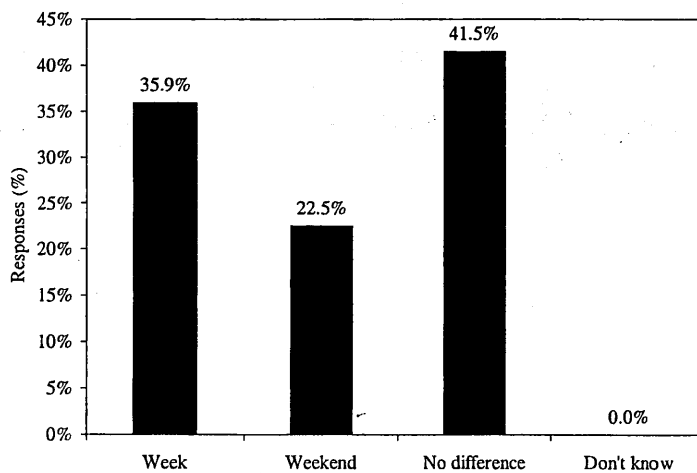


Two different sources were used to crosscheck the validity of the sample. A very high correlation can be observed between the three individual studies.

Fig. V- 12 Ownership of washing machine by number of people in dwelling

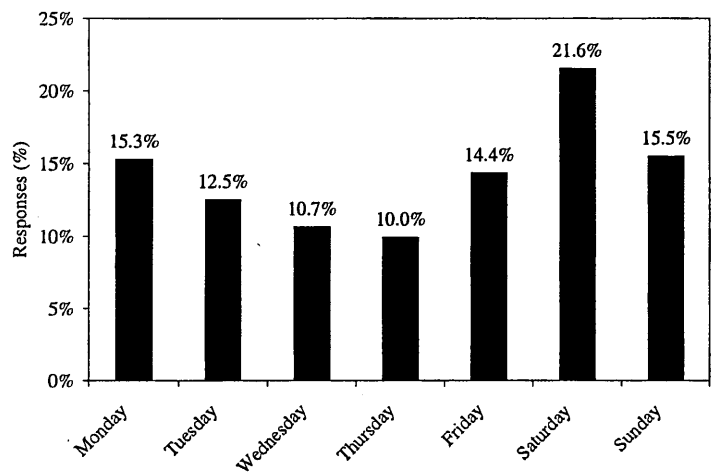
It can be deduced that the vast majority of households have a washing machine, especially for dwelling composed of at least 2 people.

ii) Weekly usage of washing machine



Some time ago, Monday was known as washday. Such behaviour has changed in time and must be characterised. Fig. V- 13 shows that differences in weekday and weekend day usage is very difficult to quantify, even though the “No difference” between weekday and weekend day shows the highest percentage of responses.

Fig. V- 13 Disparities in washing machine use during a week



Understanding the difficulty, people might have had to answer, made it easier to design the questionnaire. Fig. V- 14 is derived by asking the sample which day of the week they used their washing machine.

Fig. V- 14 Washing machine day of use

It is clearly shown that the washing machine is slightly more used often during the weekend.

iii) Time of use of washing machine

The use of a washing machine varies through the day. There are two peaks associated with its use, one from 7am to 12am, which is shown to be weekday and weekend day, and another from 6pm to 8pm, which only shows during weekday.

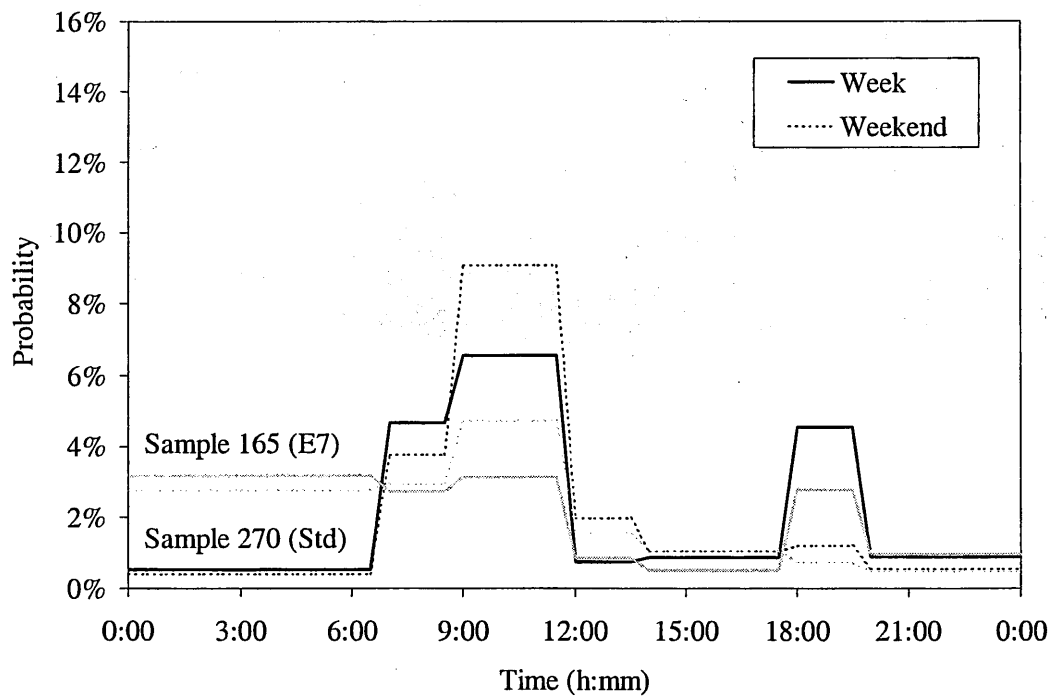


Fig. V- 15 Washing machine time of use

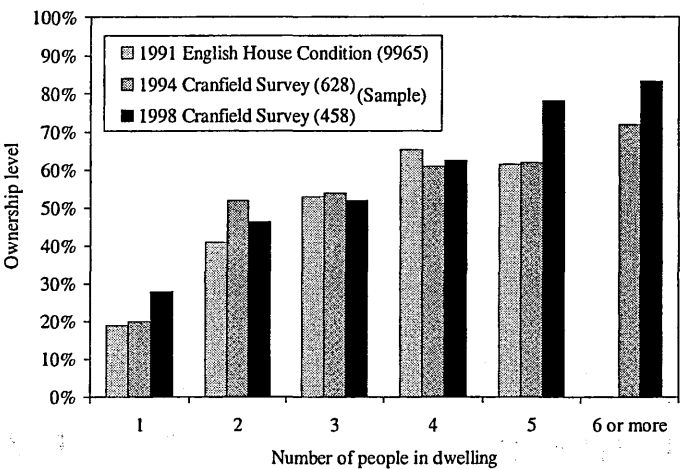
This could be explained by the fact that during weekend the washing is more likely to be run in the morning, while during weekday when time is lacking in the morning, it might be done after work or shifted using timers.

Economy 7 electricity tariff has an impact on when the washing machine is used. Households on normal electricity tariff tend to use their machine during daytime, while it is determined that almost half the two peaks are shifted to night time for household under Economy 7 tariff. This change is mainly due to the availability of cheap electricity during night hours.

9) Tumble dryer

i) Ownership

The ownership of tumble dryer is dependent on the household composition. The need for a tumble dryer increases with the number of inhabitants.

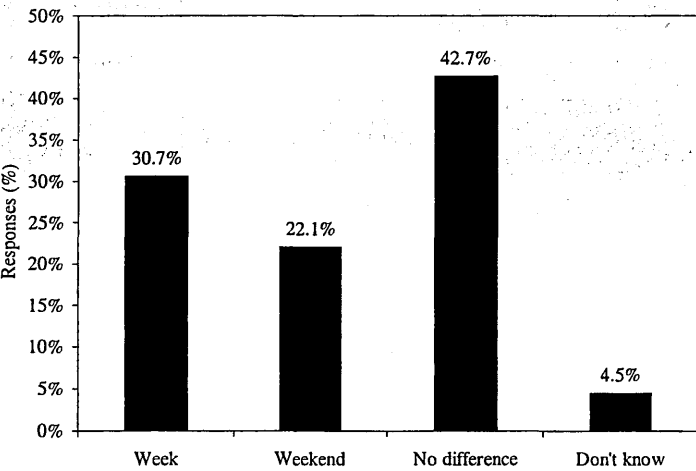


Two different sources were used to crosscheck the validity of the sample. A high correlation can be observed between the three individual studies.

Fig. V- 16 Ownership of tumble dryer by number of people in dwelling

The level of ownership increases from 20% for single inhabitant household to 70% for 6 or more inhabitants. On average, the ownership can be assumed to be 50% for dwellings with at least two inhabitants.

i) Time of use of tumble dryer



As seen for the washing machine, there does not seem to be particular day of the week or the weekend when the tumble dryer is more used, as seen in Fig. V- 17.

Fig. V- 17 Tumble dryer use during a week

This follows the result for the washing machine. It should be noticed that the use of the two appliances is correlated in time, washing clothes in the first place and drying them afterwards. There could be an absence of the drying process if the weather permits natural drying.

Fig. V- 18 shows the direct correlation between washing machine and the tumble dryer use. The tumble dryer time of use show high level of similarities with washing machine time of use, but the peaks are slightly displaced in time. This is due to washing machine duration cycle.

While standard tariff users display two important peaks, for economy 7 user, these two peaks are lowered to about half, and mainly replaced by night usage. This change is mainly due to the availability of cheap electricity during night hours.

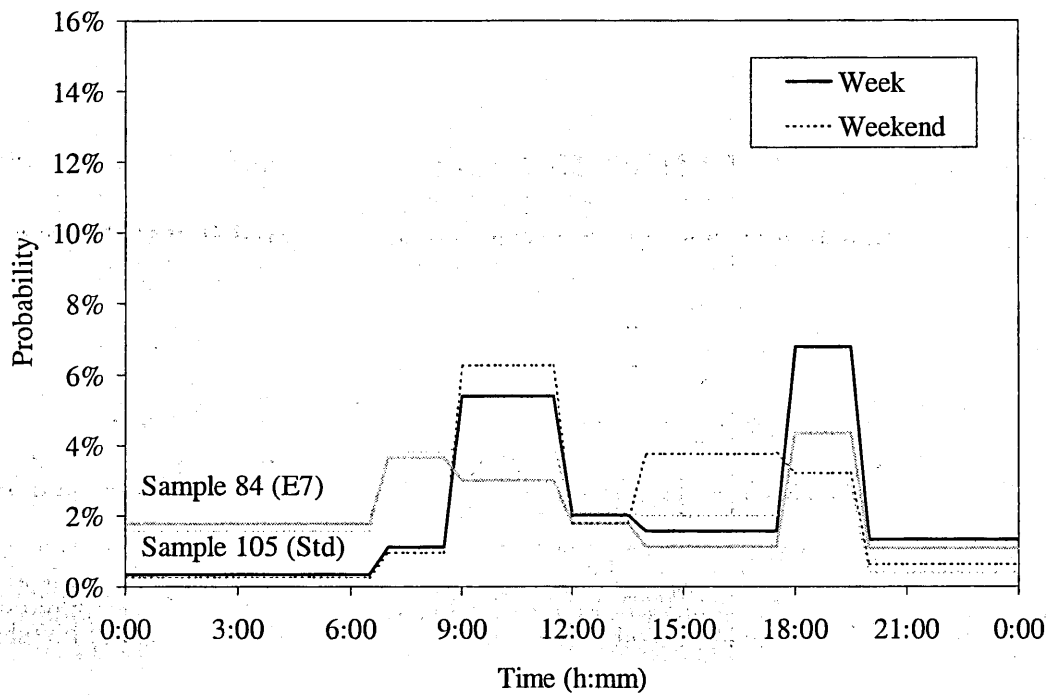
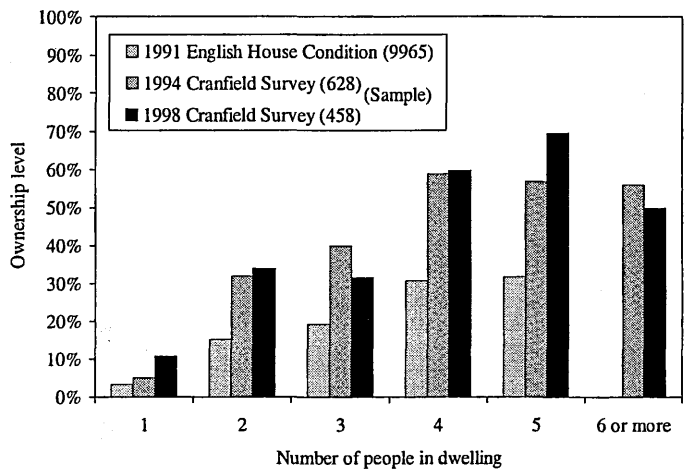


Fig. V- 18 Tumble dryer time of use

10) Results for the dishwasher

The ownership of dishwashers is dependent on the household composition. The need for a dishwasher increases with the number of inhabitants.



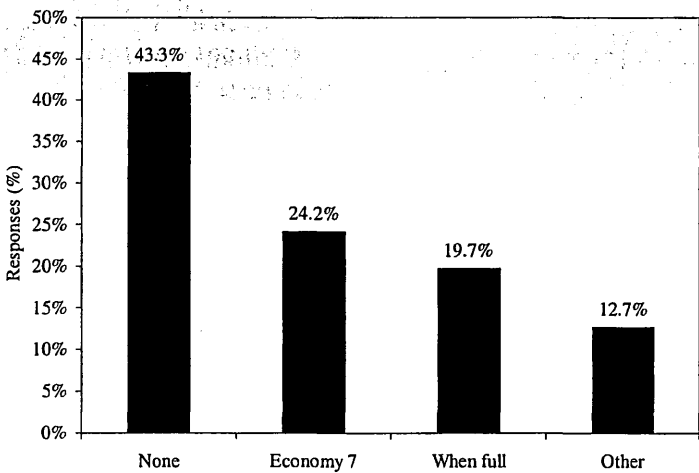
Two different sources were used to crosscheck the validity of the sample. Due to the fact that the dishwasher market has not reached yet its maturity, the change since 1991 might be an important factor in the differences between the three individual studies.

Fig. V- 19 Ownership of dishwasher by number of people in dwelling

The ownership is increasing with the number of people. As it stands in 1998 the overall ownership of dishwashers in the sample is determined to be 34%.

i) Time of use of dishwasher

When asked if their dishwasher was used after a meal, 40,1% of the households sampled responded “yes”. This means that almost 60% do not relate their dishwasher use to a meal. To get an indication of the reason, an open question was given to explain the “no”.



The result of this question is displayed in Fig. V- 20. Mainly four answers came out. The “none” answer shows that no reason was answered.

Fig. V- 20 Reason given for not using dishwasher after meal

The two interesting answers are “Economy 7” which represents almost a quarter of the sample, while “When full” makes a fifth of them. Therefore it is deduced that the dishwasher’s operation mainly depends on meal time, the electricity tariff used and its capacity.

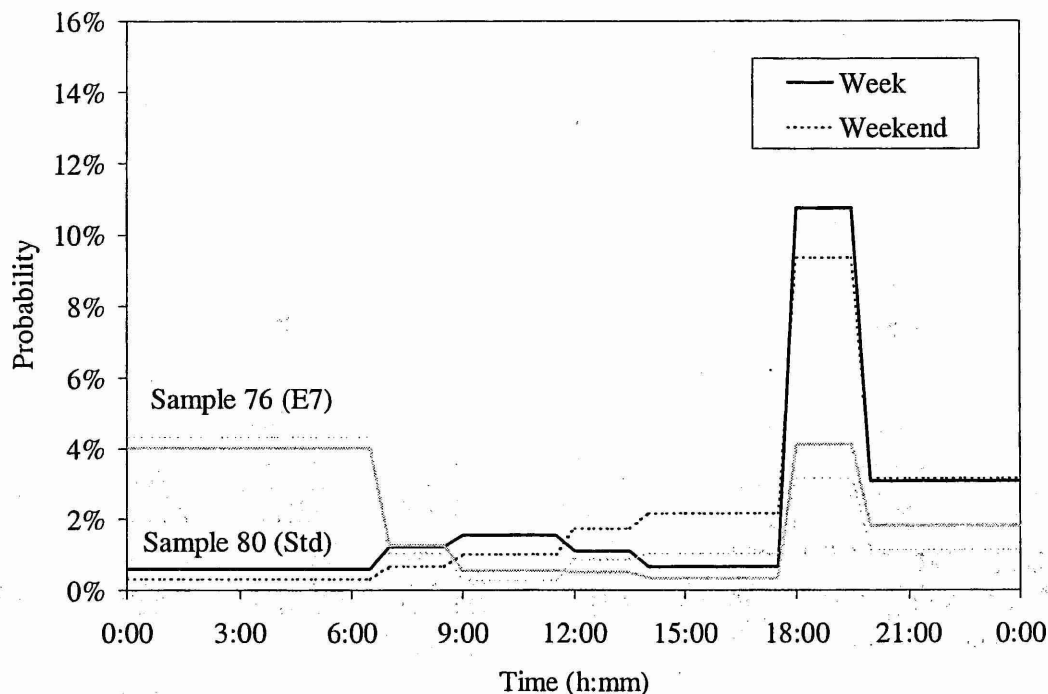


Fig. V- 21 Dishwasher time of use

Fig. V- 21 shows how the dishwasher is used on a day basis. It displays a relative high use during night time and an evening peak between 6pm and 9pm which is very significant. The night base will be explained by the use of economy 7 electricity tariff. The evening peak confirms that more than 40% of household using a dishwasher makes use of it after a meal. Furthermore, the meal considered is determined to be the dinner. The impact of the economy 7 electricity tariff is well defined here again with a decrease in the evening peak which is shifted in the night time.

11) Results for the iron

The level of iron ownership was deduced to be 96.7% in the given sample. This means that almost every household has an iron.

i) Iron usage characteristics

To quantify the iron usage two questions were issued, one relative to the number of time the iron is used weekly, while the other relates to the duration of use per usage.

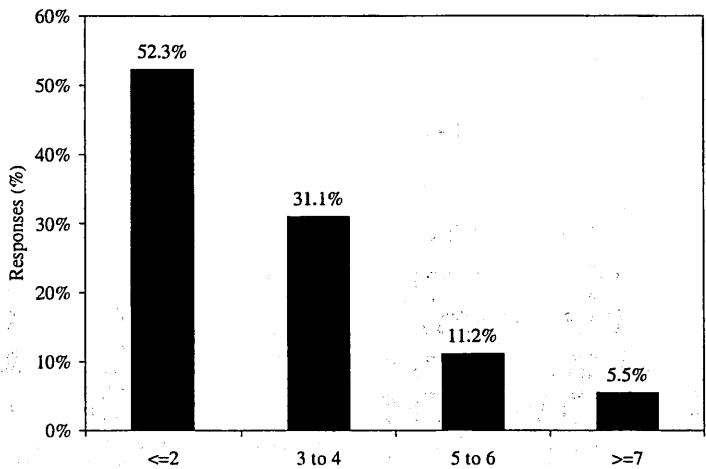


Fig. V- 22 Number of times the iron is used per week

Fig. V- 22 shows that the iron is only used a limited number of times a week, for more than half of the sample. The average is calculated to be 2.7 times per week.

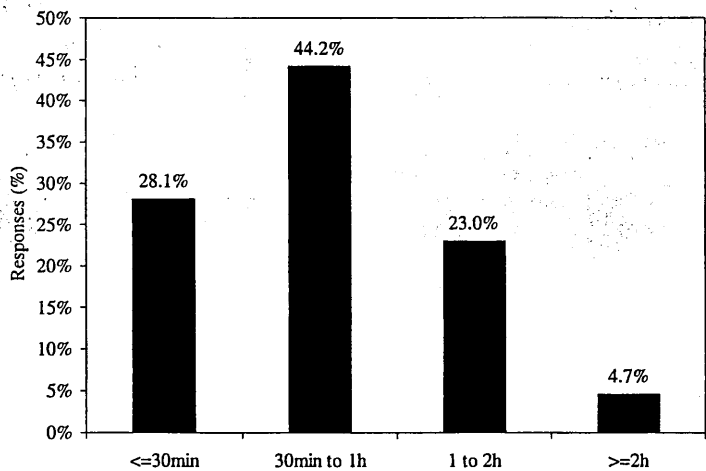


Fig. V- 23 Duration of iron usage per session

Fig. V- 23 displays the answer relating the duration of use per session. The responses show that in more than 40% of the duration is in the range 30 minutes to an hour. The average is determined to be of the order of 51 minutes.

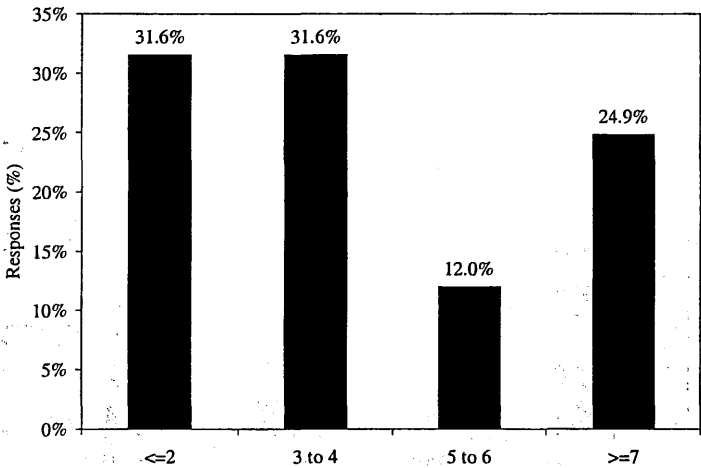
Therefore it can be deduced that on average the iron was used on average $2.7 \text{ times} \times 0\text{h}51\text{min} = 2\text{h}16\text{min}$ every week. Considering that the hourly consumption of iron is of the order of 0.100 kWh, the weekly consumption can be estimated at 0.227 kWh, or less than 0.100 kWh per session.

12) Results for hair dryer

The level of hair dryer ownership was determined to be 74.9% of the sample. This means that almost three quarter of the households own an hair dryer.

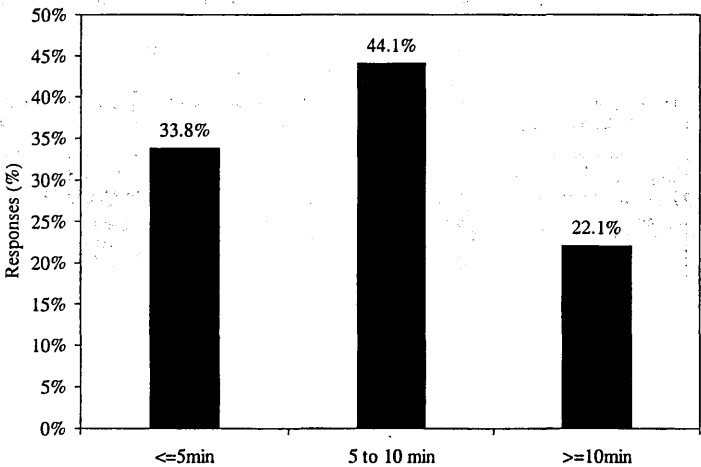
i) Hair dryer usage characteristics

To determine the hair dryer usage, the methodology used for the iron is repeated. Fig. V- 24 shows how many times the air dryer is used in a household, while Fig. V- 25 shows the duration per session.



It is therefore derived that on average hair dryers are used 4.1 times a week

Fig. V- 24 Number of hair dryer use per week



It is derived that on average during on average hair dryer are used 6 minutes per session.

Fig. V- 25 Hair dryer usage duration

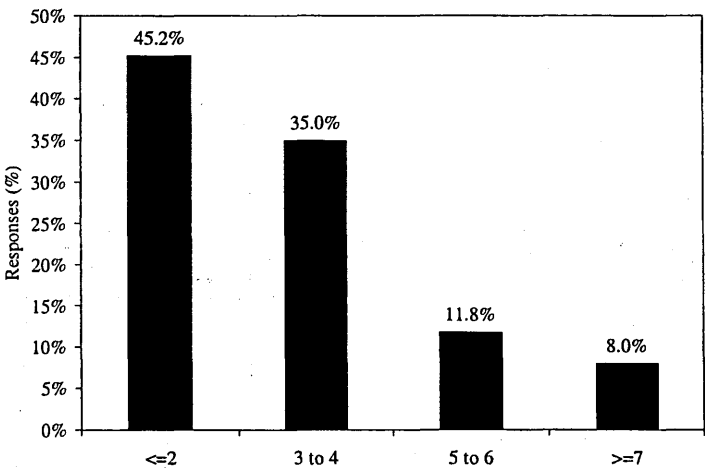
Knowing that the power demand of such appliance is of the order of 1.50kW, it is therefore calculated that the air dryer would on average consume 0.600 kWh per week, or 0.150 kWh per session.

13) Vacuum cleaner

The ownership level of vacuum cleaner in the sample is determined to be 99.3%. Therefore vacuum cleaner may be assumed to be found in almost every dwelling.

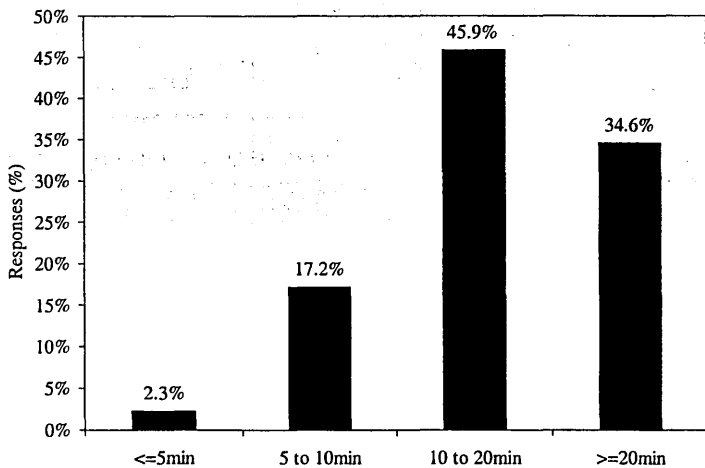
i) Vacuum cleaner usage characteristics

Again a similar method is adopted to determine vacuum cleaner usage characteristics. Fig. V- 26 shows how many times the vacuum cleaner is used in a household, while Fig. V- 27 shows the duration per session.



It is therefore derived that on average vacuum cleaners are used 3.0 times a week.

Fig. V- 26 Number of vacuum cleaner use per week



It is derived that on average vacuum cleaners are used 16 minutes every session.

Fig. V- 27 Duration of vacuum cleaner use per session

Knowing that the power demand of such appliance is of the order of 1.000 kW, it is therefore calculated that the air dryer would on average consume 0.800 kWh per week, or 0.269 kWh per session.

14) Television

The level of ownership for television is determined to be 98.7%, which demonstrates that nearly all dwelling have at least one appliance.

i) Time of use of television

The television is the only appliance which has been studied and monitored^[42]. The reason for this interest in television time of use is due to channels competitions to get audiences, and the television being used as a marketing tool. Knowing that the information relating television audience was available, the comparison between available national statistics and data derived from the survey is possible.

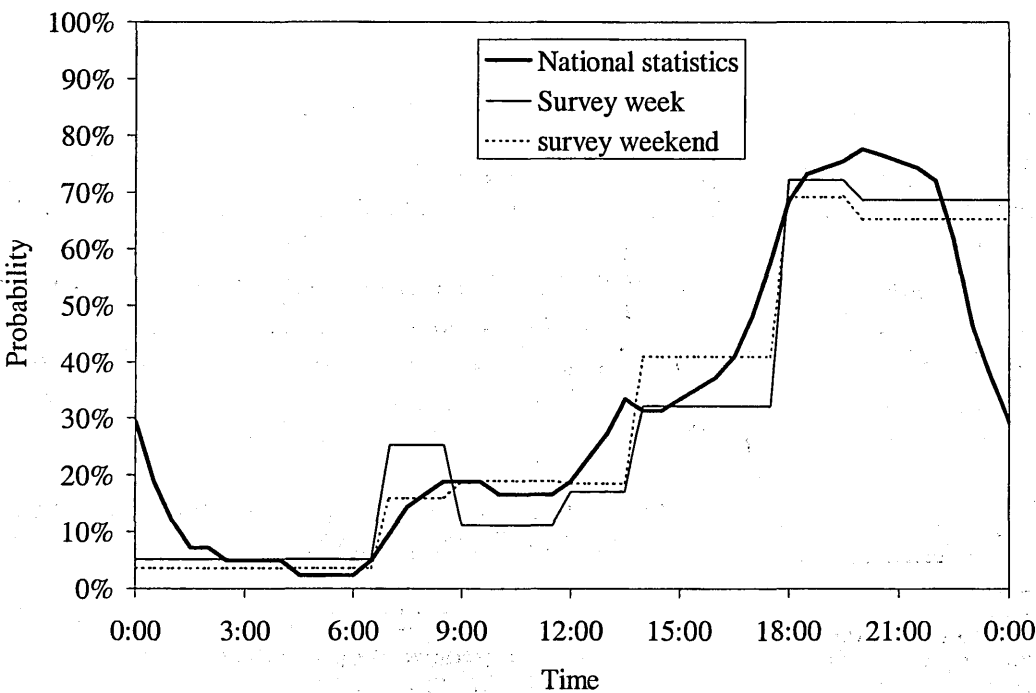


Fig. V- 28 Television time of use

Fig. V- 28 permits to compare actual data with data derived from the survey. The level of definition is not similar, but it can be observed that the shapes are similar. This shows the level of accuracy and demonstrates the validity of the survey.

15) Conclusion

In this chapter, different electrical appliances have been reviewed to determine how and when they were used. The high rate of response (45.8%) showed the survey's design was right and could be used for other research.

During the first level of analyses, general information was compared with accurate sources, which demonstrated the survey's value. As the analysis was getting further, it was possible to correlate television data with actual monitored data.

It was then possible to derive "when" appliances were used during a day period. This allowed to determining the level of energy consumed by certain appliance so that important appliances can be determined.

Therefore, when appropriate, the information gathered was used to derive a model of electricity consumption in individual dwelling.

Chapter VI: The model and the interface

The information reviewed in Chapter II, regarding the context of the research, Chapter IV, regarding the appliance, and Chapter V completing the appliance usage information permitted the design of a dynamic model able to characterise the individual dwelling power demand.

1) The model

The model is designed to take into account the following parameters.

i) The model input

The number of inhabitants was used as a parameter because it is acknowledged that appliances ownership and use depended on this number. During the survey analysis, it was possible to detect different trends for children and adults. Therefore the inhabitant number input parameter was divided into number of adults and number of children.

The size of the house was analysed as a parameter because the space both heating system and the lighting load depend on it.

Seasonal variation was also considered. The outside temperature influences how the space heating system is used. Considering a typical house, the main cold water temperature fluctuates during the year between 6 and 15°C^[10]. External light is changing too with the season. Therefore a monthly input was included in the input to reflect seasonal changes.

The appliance stock is determined manually or by using an automatic choice option. It should be noticed that appliance ownership data was used to derive the automatic choice.

The appliance “usage” is mainly derived from the findings of Chapter V with the survey. They were combined with a probabilistic approach to derive when and for how long appliances were used. Note that seasonal variation in the survey’s results is not considered. Nevertheless, the survey allowed determining weekday and weekend variation, which are included in the model.

ii) The equation used

a) Space heating model

Assuming as a first approach that the heating system should compensate for the heat loss through the walls, the floor, the windows and the roof, the energy required to keep the dwelling at a constant temperature can be determined. U values for the wall, the floor, the windows and the roof are assumed to be respectively 0.76, 1.50, 4.30 and 0.50 $\text{Wm}^{-2}\text{K}^{-1}$. The following relationship can therefore be derived,

$$\text{Energy required (kWh)} = 0.143 \times \text{Dwelling size } m^2 / \Delta^\circ\text{C}$$

where $\Delta^\circ\text{C}$ represents the temperature gradient between the inside and the outside of the dwelling

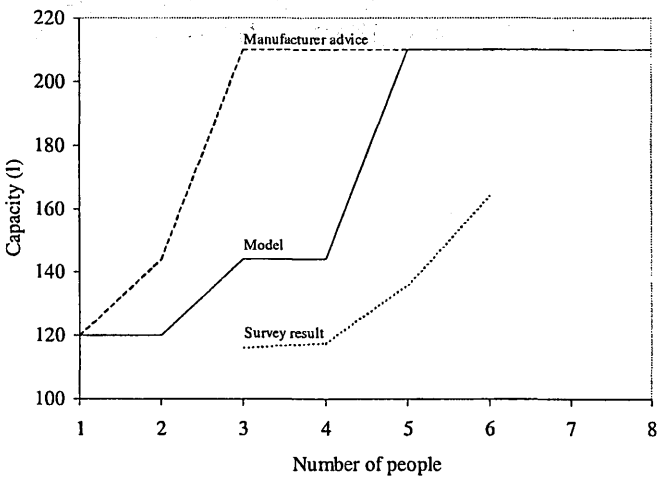
Eq. VI- 1

Knowing the energy required and the power available, it was possible to derive the signature of the space-heating appliance. The timing was based on the fact that the power demand would occur during the night hours, to take full advantage of the Economy 7 tariff, when applicable. Note that the mean to circulate hot fluid would have to be considered during daytime.

The Eq. VI- 1 will be integrated in the model to determine the energy required to heat the dwelling, then dividing the energy by the power will give the duration of the required heating period.

b) Water heating model

The hot water cylinder volume is determined using a combination of manufacturer advice and the results of a survey^[25].



Due to disparities between the two sources, a compromise is adopted, which is displayed in Fig. VI- 1.

Fig. VI- 1. Hot water capacity model

To reduce considerably the amount of calculation, it is assumed that there is no stratification in the hot water cylinder, therefore the water temperature is considered to be uniform.

The model will be based on the standing loss through the cylinder surface,

$$\text{Standing loss} = (l \times A \times (T_{\text{water}} - T_a)) / k_{\text{insulant}}$$

where l is the insulation thickness
 A is the surface area of the cylinder

Eq. VI- 2

To determine the surface area, the diameter of the cylinder is assumed,

$$A = 2\pi(D/2)^2 + 2\pi(D/2)L$$

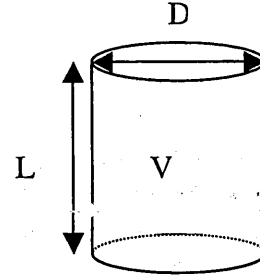
where D is the cylinder diameter
 L is the cylinder height

$$\text{Or } V = 2\pi(D/2)^2 L \text{ therefore } L = 4V/\pi D^2$$

where V is the cylinder volume

Hence

$$\text{Area} = 2\pi(D/2)^2 + 2\pi(D/2)(4V/\pi D^2) = (\pi D^3 + 8V)/2D$$



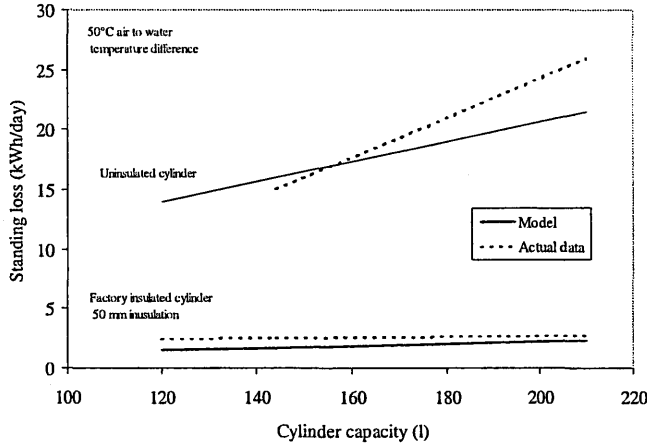
Eq. VI- 3

When hot water is used, it is replaced by cold tap water, therefore the energy withdrawn from the cylinder is determined to be,

$$E_{\text{water used}} = V_{\text{water use}} \times C_{p\text{water}} (T_{\text{water}} - T_{\text{cold inlet}})$$

Where $E_{\text{water use}}$ is the energy withdrawn
 $V_{\text{water used}}$ is the mass of hot water used

Eq. VI- 4



To check the validity of the model, the standing losses are compared to measured values.

Fig. VI- 2. Standing loss generated by the model compared to actual ones^[10]

Actual data are compared to the model. The differences are shown to be limited even though the stratification was not considered.

Knowing the energy required and the power available, it was possible to derive the signature of the water-heating appliance. The timing was based on the fact that the power demand would occur during the night hours, to take full advantage of the Economy 7 tariff, when applicable.

c) Refrigeration model

The model was based on the heat loss through the walls and door of refrigeration appliance. The heat loss is determined as follows,

$$\text{Heat loss} = (l \times A \times (T_a - T_{\text{appliance}})) / k_{\text{insulant}}$$

where l is the insulation thickness
 k is the insulant thermal conductivity

Eq. VI- 5

To determine the surface area, the appliance is assumed to have a cubic form, therefore,

$$A = (V^{1/3})^2 \times 6$$

Where V is the appliance volume

Eq. VI- 6

As shown in Chapter IV, the direct heat loss represents on average of 90% of the total consumption. Therefore the heat loss is weighted with a 0.9 coefficient to determine the total energy consumption of the refrigeration appliance.

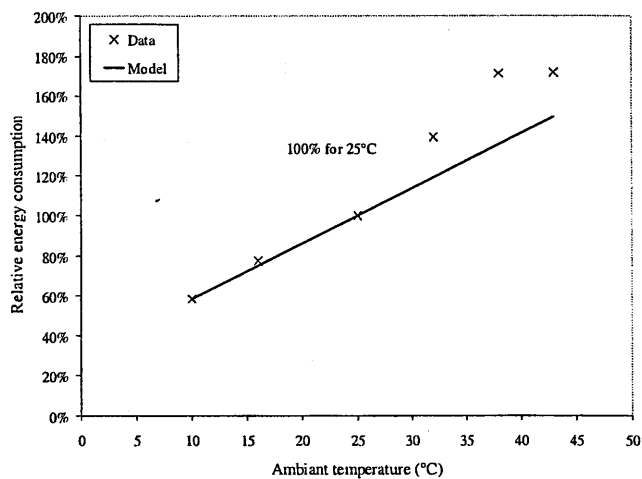


Fig. VI- 3. Heat loss model against data

The last check for the validity of the model is to compare demand profiles generated by the model with actual ones.

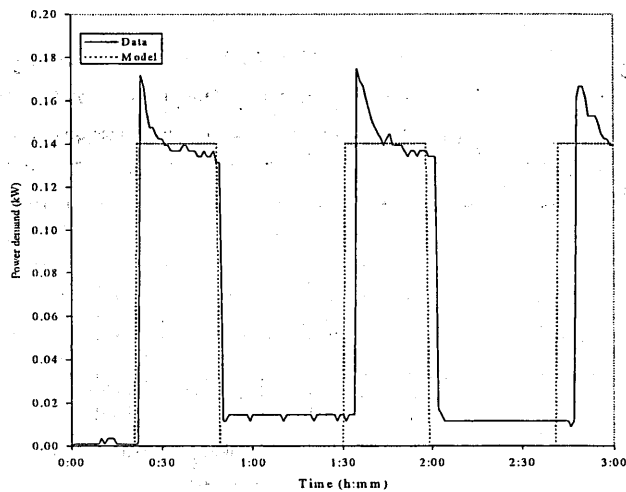
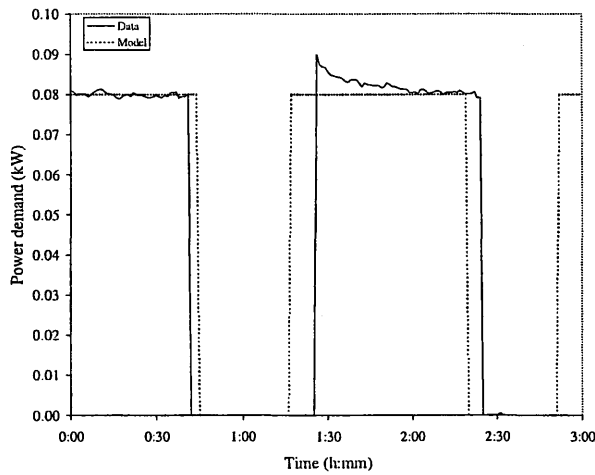


Fig. VI- 4. Fridge-freezer data and model

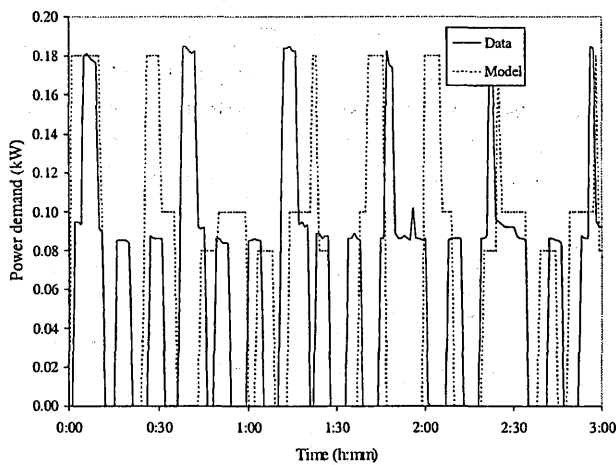
Then the influence of the ambient temperature is checked against monitored data in Fig. VI- 3. The correlation coefficient is determined to be 0.988 between the data and the model.

The signature that is created by the model for a fridge freezer in given condition is similar to the actual data. The main difference is the power surge at the beginning of each cycle.



The signature that is created by the model to simulate a freezer in given condition was similar to the actual measured data.

Fig. VI- 5. Fridge-freezer data and model



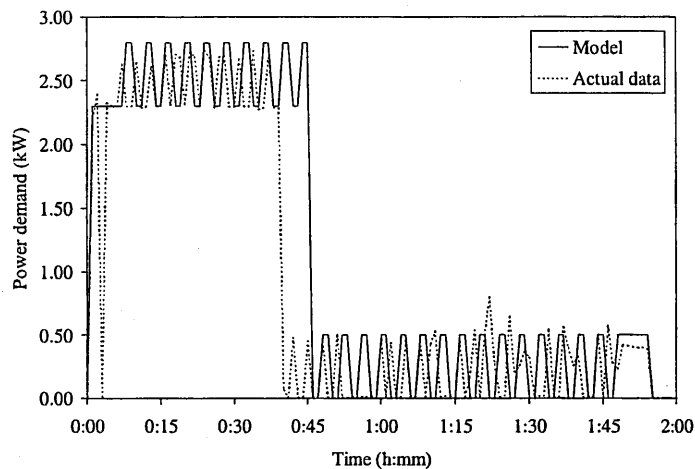
The signature that is generated by the model for a refrigerator and a freezer in given condition was similar to the actual data.

Fig. VI- 6. Refrigerator and freezer data and model

Therefore the model was compatible with individual monitored data. Generated power demand signatures were similar to actual monitored signatures. Hence the refrigeration model was tested and integrated to the general model.

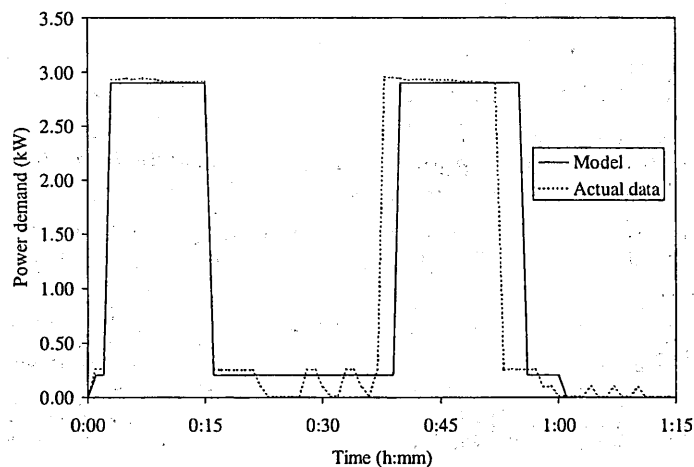
d) Wet appliance model

The energy consumption of wet appliances has been averaged in Chapter IV. Taking into account the power rating of each element of the appliances it is possible to derive the heating period. During cycles, the mechanical power required is superimposed, therefore creating the profile demand of each appliance.



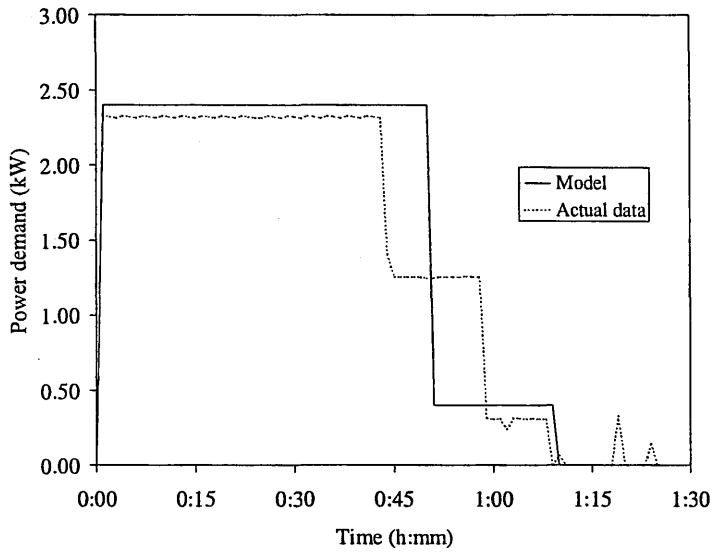
The washing machine is characterised by a heating period, which duration depends on the temperature chosen, and mechanical power to rotate the drum. The comparison between actual and generated data demonstrates the validity of the model.

Fig. VI- 7 Washing machine power consumption model compared to actual data



The dishwasher power demand signature is characterised by two heating periods, and the water pump that is activated most of the time during the cycle.

Fig. VI- 8 Dishwasher power consumption model compared to actual data



The tumble dryer signature is characterised by the mechanical power required to rotate the drum and the heating demand. Note that the heating period is finished before the rotation, to avoid damaging the clothes.

Fig. VI- 9 Tumble dryer power consumption model compared to actual data

Therefore the model was compatible with individual monitored data. Generated power demand signatures were similar to actual monitored signatures.

Then the number of usage of the individual wet appliances is determined using first part of Eq. IV- 15, Eq. IV- 17 and Eq. IV- 18 (respectively for washing machine, tumble dryer and dishwasher). These equations were chosen because they relate the survey conducted for the English House Condition^[31] over 20 000 households.

The result of the calculation was a number of uses per week, which had to be divided by 7 to determine the daily usage. Because the usage number had to be an integer, a random number (limited to the range 0 to 1) was compared to the decimal two first digits to determine if the result would be rounded up or down. Therefore the rounded uses number was defined.

Then the starting time used the results derived from the survey. By accumulating the time of use probability from Fig. V- 15, Fig. V- 18 and Fig. V- 21 (respectively for washing machine, tumble dryer and dishwasher), probability curves were obtained starting at 0 for 0h and finishing at 1 at 24h. Every time a wet appliance was used a random number (limited to the range 0 to 1) was generated and computed against the probability curve to define the event starting time, as shown in Fig. VI- 10. In the sample given, a random number of 0.7 would mean that the appliance would be switched on at 15h00.

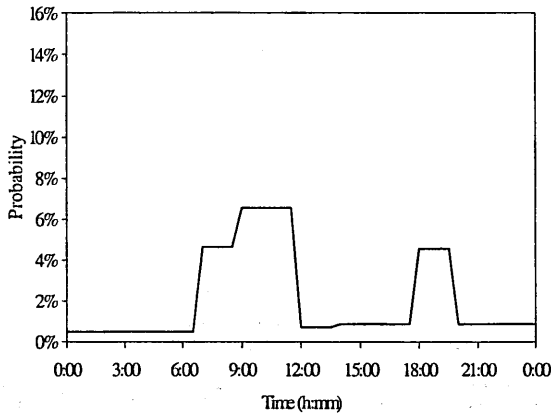


Fig. VI- 10 Time of use

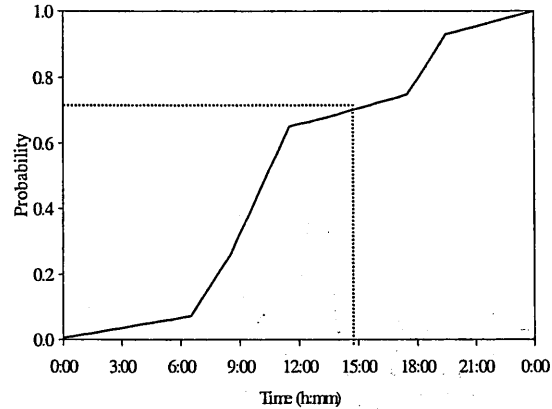


Fig. VI- 11 Probability curve

Note that for low time of use probability the gradient of the probability curve is small, therefore the chance of any event is limited.

Hence the wet appliances model was tested and integrated to the general model.

e) Video system model

The power demand of television sets and the videocassette recorder are derived from observation described in Chapter IV. To determine the power demand of video systems, the following method is used. The average national audience has been described in Chapter IV. It is assumed that the initial curve can be used to derive the probability of one person watching one television. Now considering two people and one television set, the probability of watching television increases. To determine this increase, the two people are considered individually. Assume that $P(t)$ is the probability of one person to watch television at a time t then the probability of not watching television is $(1-P(t))$. Therefore the probability of the two people not to watch television is $(1-P(t))^2$. Hence the probability of the television being watched by one or both people is $(1-((1-P(t))^2))$.

A similar hypothesis can be made for n number of people, and the probability of watching television will be equal to,

$$Pn(t) = 1 - (1 - P(t))^n$$

where $Pn(t)$ is the probability of n people to watch television
 $P(t)$ is the probability of 1 person to watch television

Eq. VI- 7

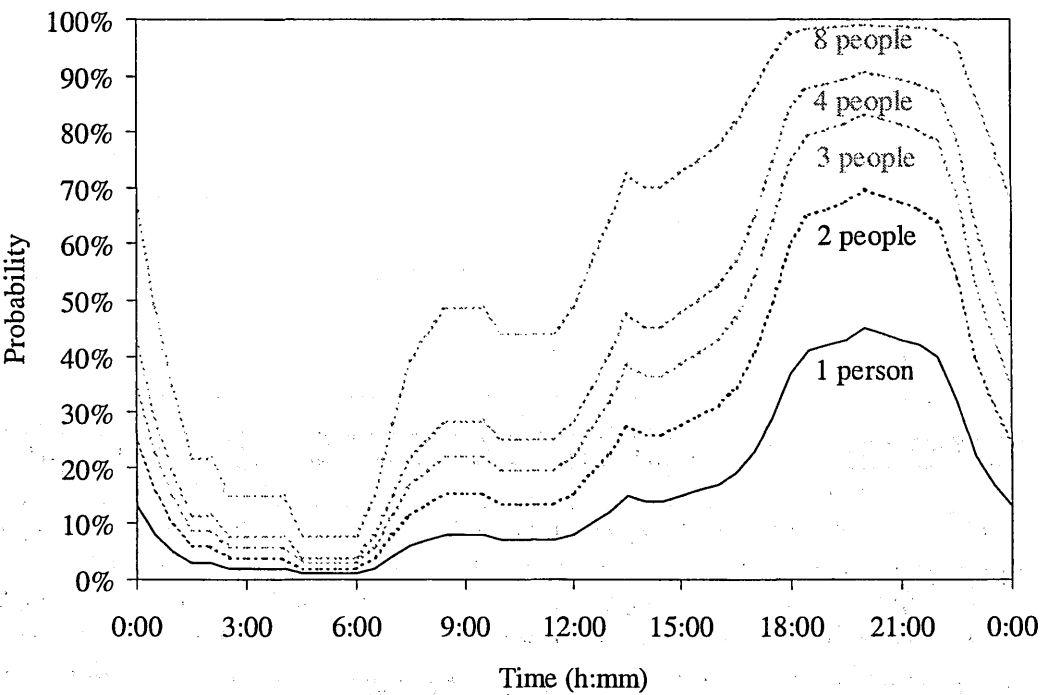


Fig. VI- 12 Television probability of use for different number of people

Fig. VI- 12 shows the increase in probability of television use as the number of people in the dwelling increases.

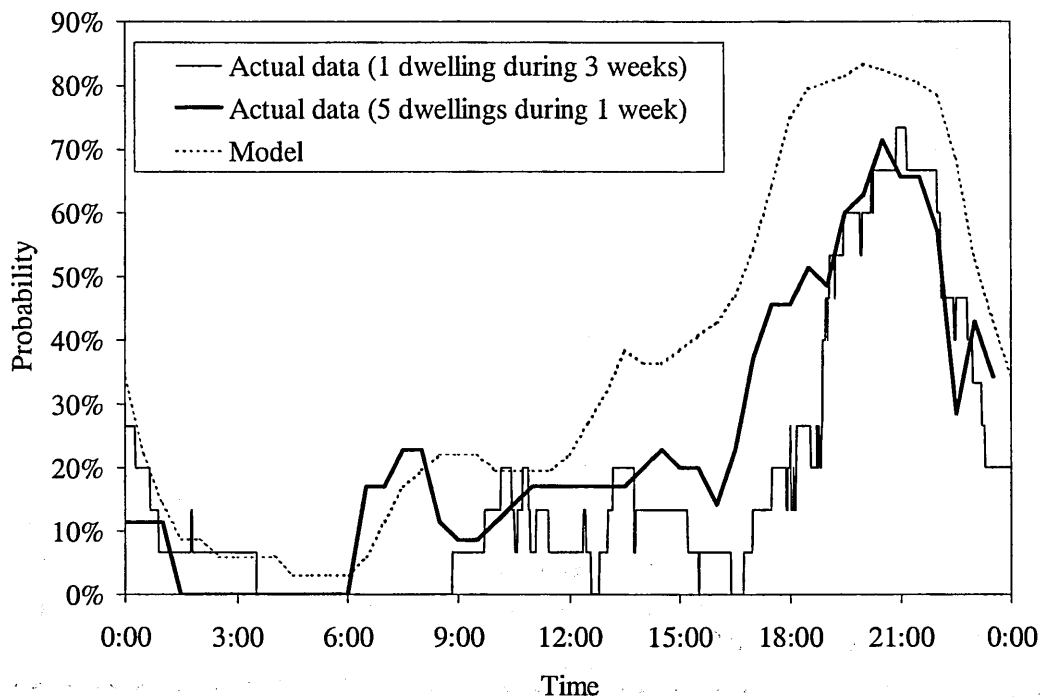


Fig. VI- 13 Actual probability of television usage in three person dwellings and model

Fig. VI- 13 shows a comparison between measured television usage in three people's dwelling and the model. To derive actual data different methods were used. The first is the monitoring of the considered appliance in a dwelling. The advantage is that its results are real observation in situ. The disadvantage is the requirement for dataloggers during long period of time (three weeks). The second method is to survey people about the way they used their television. This method is generally easy and does not require any technical apparatus but a well-designed questionnaire. The disadvantage of such method is the high uncertainty about the information given.

The comparison between actual data and the model shows that there was a correlation even if the actual data are generally less than the model value. This is due to the fact that all the dwellings studied were composed of three full-time working persons.

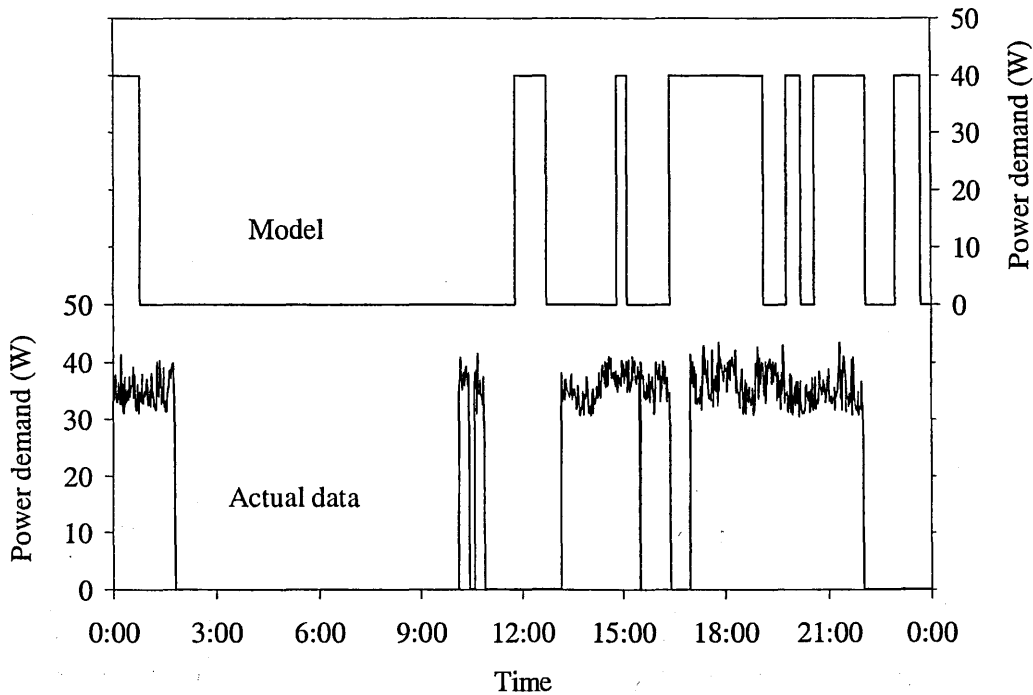


Fig. VI- 14 Television power demand actual data and model

Fig. VI- 14 shows that the difference between the model and the actual data is limited. It should be noticed that while the model shows constant power demand when the appliances is on, the measured data is disturbed by noises which are the main reason for the power demand to vary.

The television model was therefore included in the model. Note that the Videocassette model was included too. It was determine in Chapter IV that the power demand of such appliances was constant assuming that they were never unplugged, and left on standby.

f) Cooking appliance model

The information gathered in the literature review, the monitoring and the part derived from a Cranfield research project^[37] did not allow the complete integration of the major cooking appliances. Raw data for the project, concerning monitoring of cooking appliances, were not available; therefore the analysis was not possible.

Therefore appliances that were integrated to the model were the toaster and the kettle because their usage had been analysed in Chapter IV and V.

g) Lighting model

The lack of information regarding lighting use was a main issue. For domestic lighting to be monitored, it must be possible to isolate and meter the lighting circuit and to be confident that this is not also feeding other uses. However a significant number of lights are not on this circuit but on individual plugs, which could be used for other purposes. Therefore the monitoring was compromised.

The survey did not contain any lighting questions because they were considered as seasonal dependent, therefore answers would be difficult to integrate.

Therefore there was a need for more information and data to describe the lighting load with precision.

h) Electronics and other appliances model

These appliances were not considered in this project because although their use might represent a major part in the dwelling energy consumption, the research scope prioritised main appliances against specific appliances.

iii) The model output

The model output is a day load curve, which can be defined from 30 down to 1-minute time interval. The load curve is associated, and characterisation such as load factor and average over predefined period as well as percentage above and below a certain level of demand.

2) The interface

Visual Basic was used to design the required functionalities of the model. An executable is created from the Visual Basic that could be run on any computer as long as the operating system is compatible with Microsoft Windows 95 and the resources file are available.

The first screen allows the user to choose from the 4 options, which are as follows,

- DataBase Access
- Individual Model
- Pool Information
- MCHP Simulation

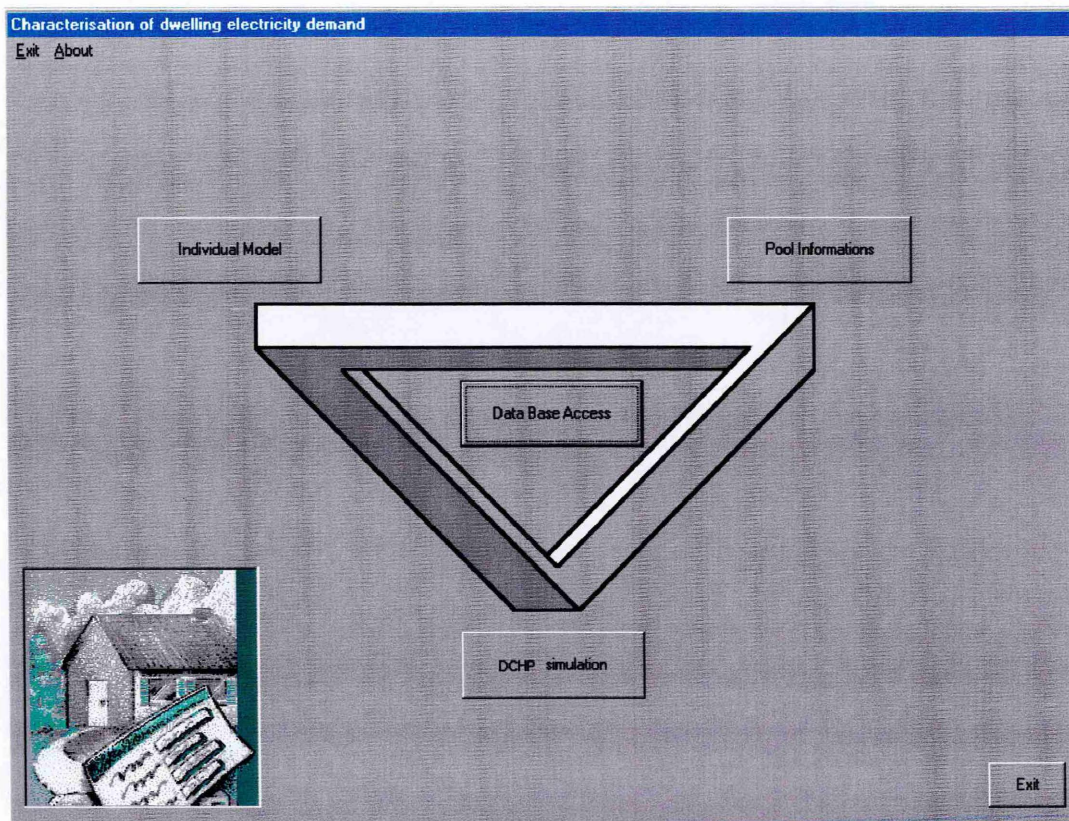
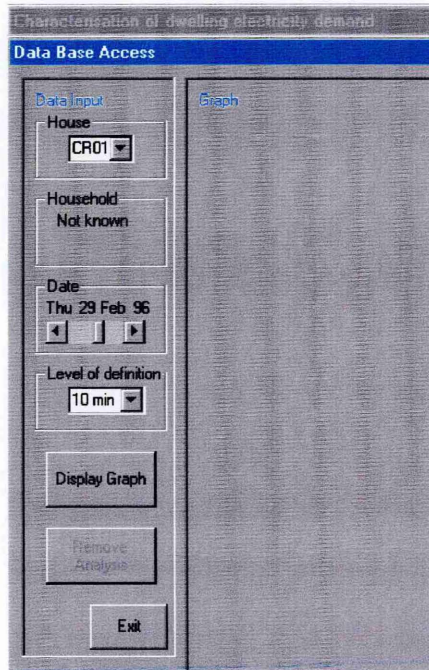


Fig. VI- 15 Interface presentation

The first advantage of having this type of interface is in the graphical utility that can be used to display the formatted measured data, which is stored in the database.

i) Database access

The structure of the database is directly used to access the information. On the left hand side a window indicates the required input such as chosen dwelling, date and definition.



The house box allows the user to choose a dwelling.

The household box gives the household description when available.

The date scroll bar permits to get the required day data.

The levels of definition proposed are 1, 10 and 30 minutes intervals.

When these 4 choices are finished then the display graph button gives access to a graphical representation of the data.

Fig. VI- 16 Data input window

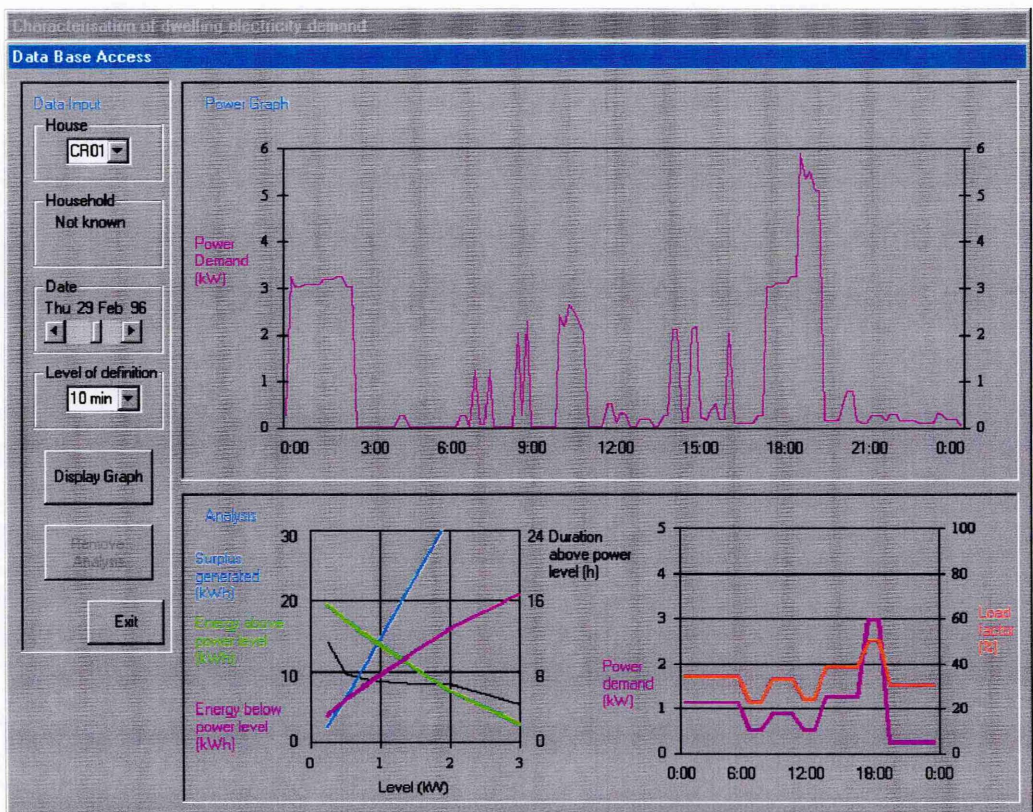


Fig. VI- 17 Database access

When the data is accessed, three graphs are displayed.

The first one, which is on top, is the power demand during the chosen day, with specific information regarding the total daily energy consumption as well as the load factor.

The second graph, below on the left, analyses the energy above and below a dynamic level. If a horizontal straight line was to be drawn on the first graph at a certain level, which is the X-axis, then the energy above is represented by the green curve and the energy below by the purple curve. The blue curve is the energy below the line that is not consumed, and the black curve shows how long the power demand is above the dynamic level. Fig. VI- 18 shows an example of the analysis.

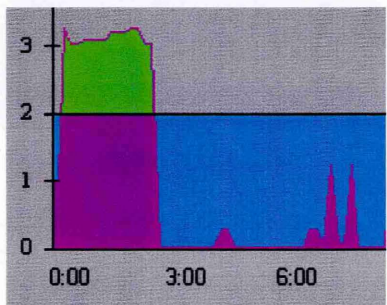


Fig. VI- 18 Database access

This calculation characterises how much energy is under/over a certain power level, which could be eventually the DCHP power rating.

The third graph represents the power demand averaged in red, and the load factor in purple, over pre defined periods.

It should be noticed that the two last graphs could be removed, to leave more space for the power demand graph by clicking on the “Remove Analysis” button.

The functionality allows the user to access at a click of a button any of the 8813 days monitored data.

ii) Individual model

The structure of the individual model window is similar to the database access one. The left hand side window contains the general input relative to the dwelling characteristics, such as number of adults, number of children, house size, date, electricity tariff and definition level. All these inputs can be adjusted as required.

The window on the right hand side contains only the different type of appliances that had been categorised as follows,

- Heating (Space heating and Water heating systems)
- Refrigeration
- Wet appliances
- Television
- Cooking (only kettle and toaster are considered)
- Lighting (no lighting in the current model)
- Electronics and others

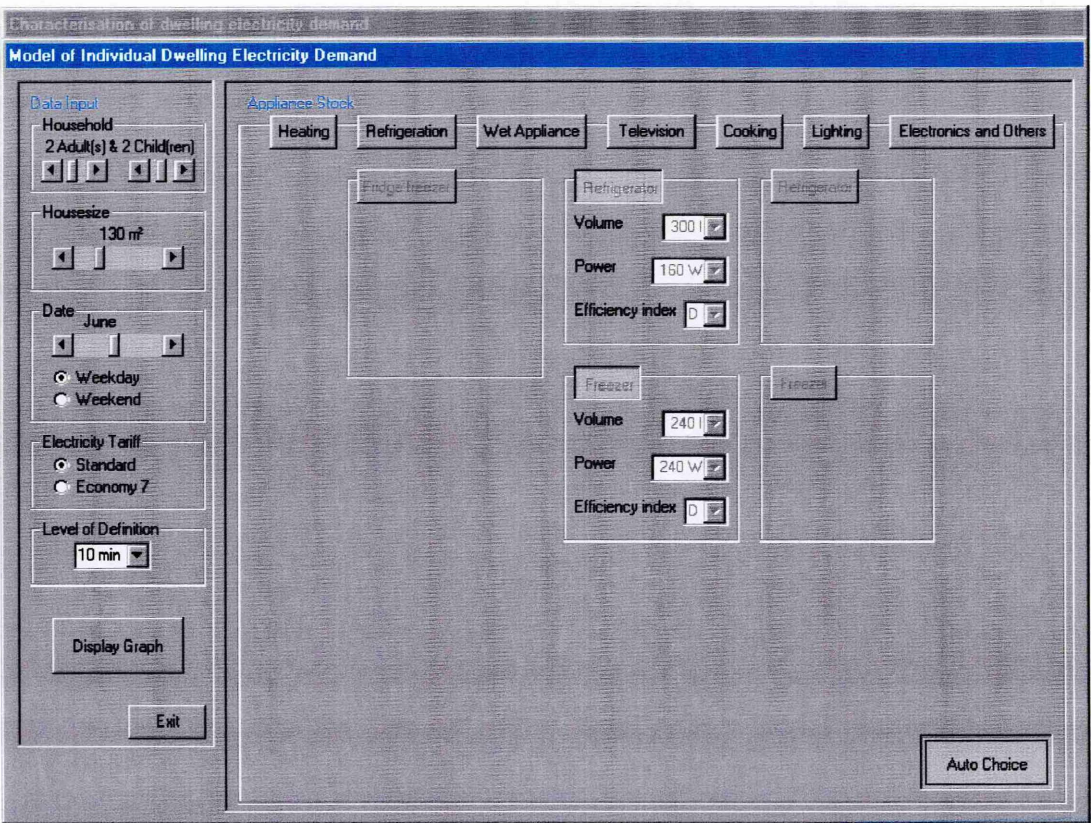


Fig. VI- 19 Individual model window

Clicking on the top button named after appliance types, allows browsing through the available appliances. By default all the appliances are disabled, and clicking on the appliance button can enable them. This indicates that the appliance is owned and used by the model during power demand calculation. Furthermore, when enabled the appliances window shows specific appliances information that can be amended as required to ensure true interactivity.

To facilitate the use an automatic choice is available on the bottom right end side to automatically choose the average ownership level for a specific dwelling. The information used is derived from the ownership analysis carried out in Chapter IV and V.

Once the appliances required have been chosen the display graph button aggregate all the given information to derive the dwelling electricity demand during one day as shown in Fig. VI- 20.

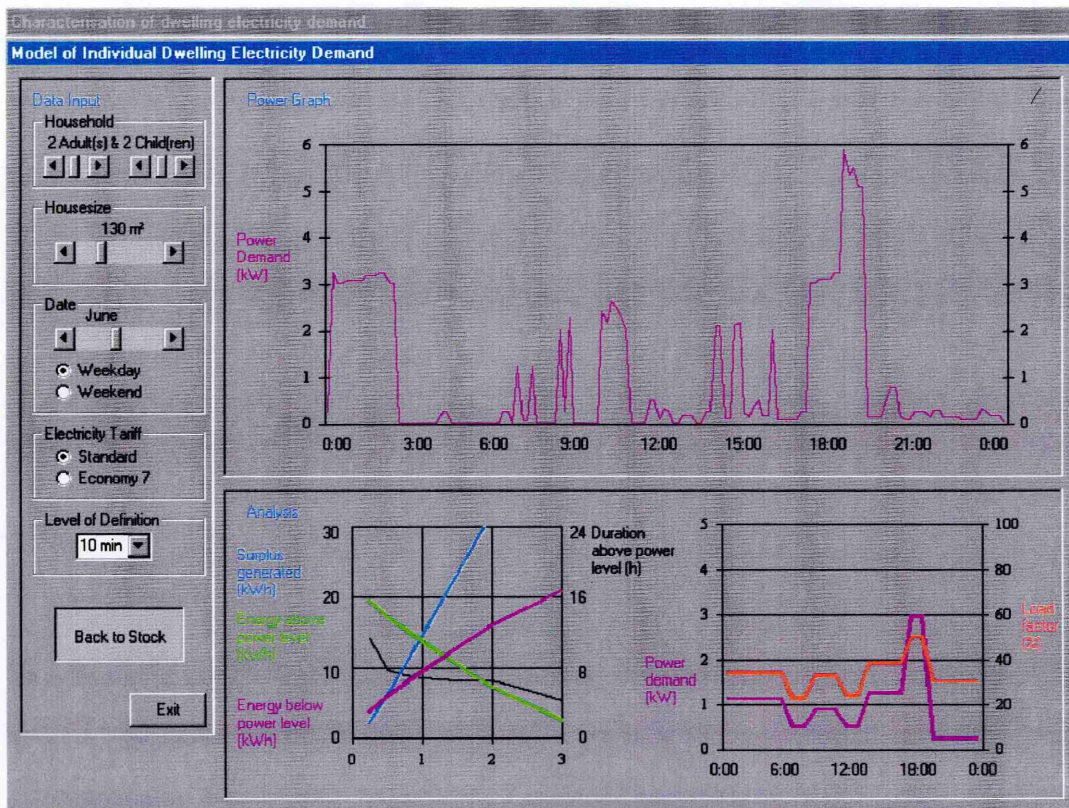


Fig. VI- 20 Individual model power graph and analysis

Similar analysis graphs as in the database access are available, so that the data derived from the model can be directly compared to the actual data.

iii) Real electricity pricing

The information is accessible by clicking on the pool information button. Pool electricity pricing information was available from September 1993 to December 1997, on half hour time interval basis. The left hand side window allows the date selection and the following,

- Gross demand or Availability or Transmission Loss
- System Marginal Price or Pool Purchasing Price or Pool Selling Price
- Standard domestic electricity tariff or Economy 7 tariff

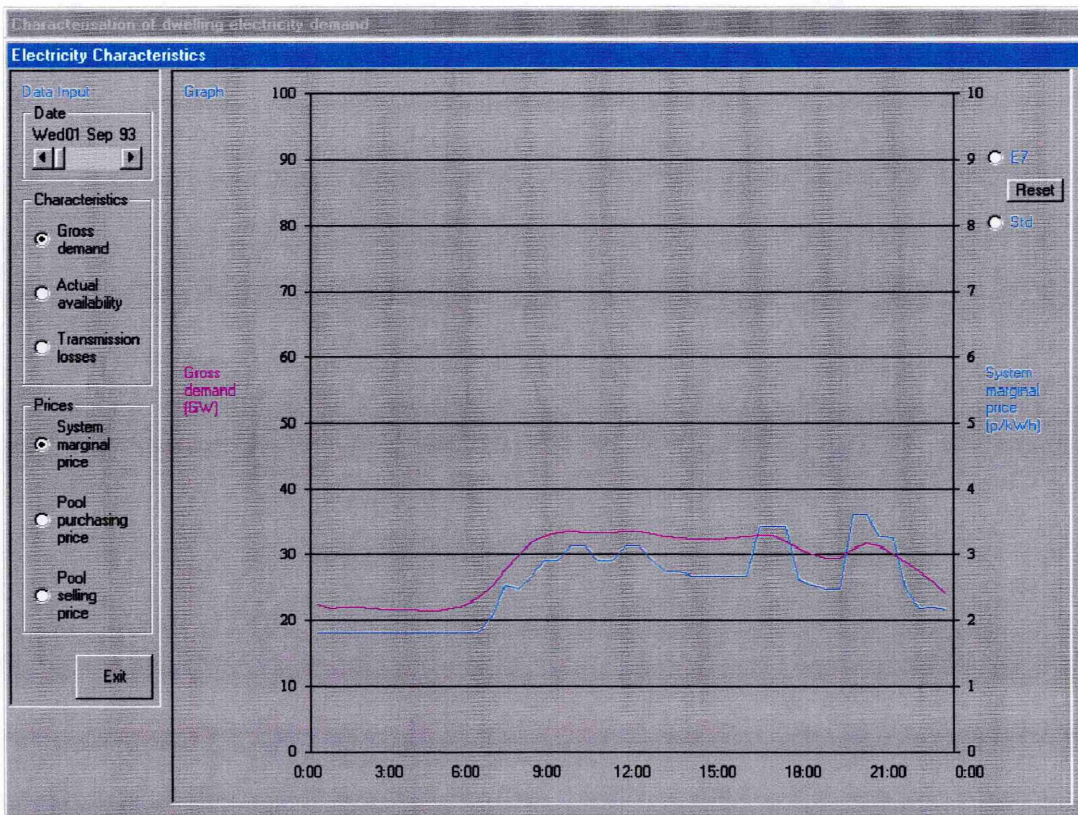


Fig. VI- 21 Individual model power graph and analysis

iv) The DCHP simulation

The DCHP simulation is using the following data to determine the DCHP economic viability,

- Power demand data
- Pricing options (Standard, Economy 7 or Pool Selling Price)
- DCHP pattern of use (24h or twice a day or once a day)
- DCHP sizing (0 to 3 kW_e)

These alternatives are then compared to conventional tariff to determine the influence of electricity pricing, DCHP pattern of use and sizing. It should be noted that these three parameters can be adjusted by the user to determine the best settings, as shown on Fig. VI- 22.

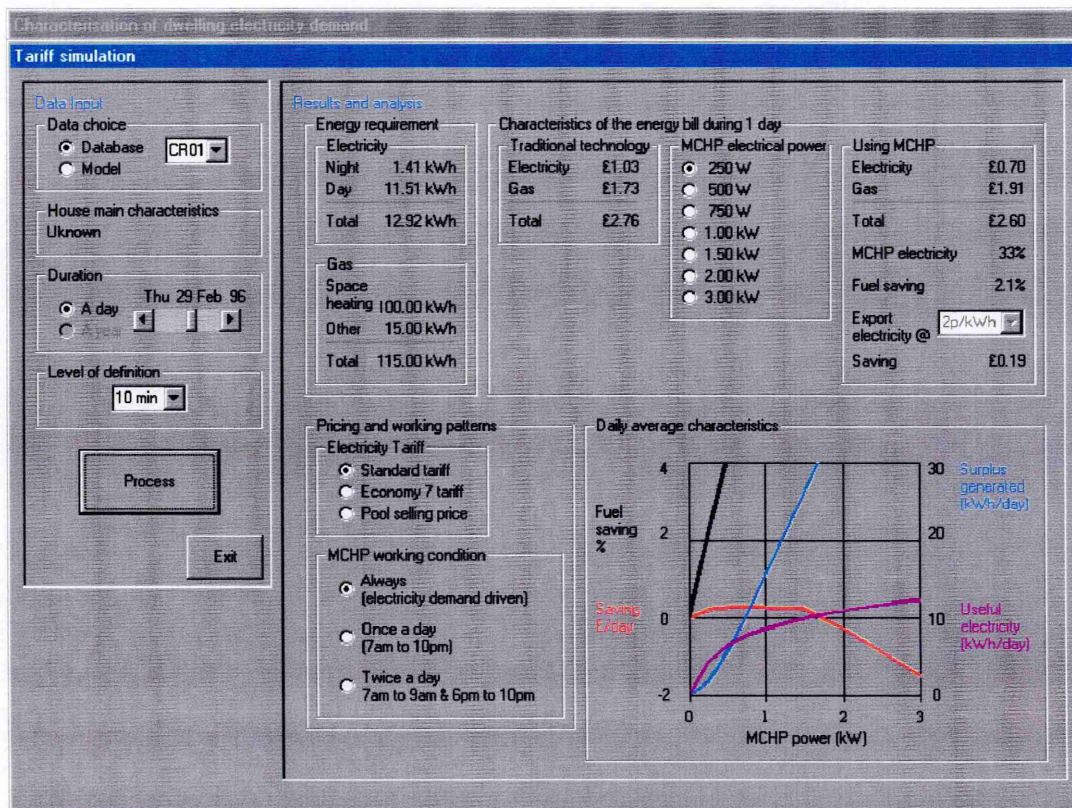


Fig. VI- 22 DCHP simulation window

3) Conclusion

The designed model was therefore completed as much as possible. It included the following electrical appliances:

- Space heating
- Water heating
- Refrigeration
- Wet appliances
- Video system
- Cooking (only represented by kettles and toasters)

The other cooking appliances and the lighting could be integrated into the model if the information was available. This explains why in Fig. VI- 19 they appear on the individual model window.

The interface was designed to be “user friendly”, and to allow flexibility. Being able to display the dwelling power day demand at the touch of a button was a good improvement. Once the power demand data is available, then it is possible to create a fast and reliable model allowing data aggregation, and derive the implication of implementing alternatives energy supply such as DCHP.

Chapter VII: Results

The daily power demand, the output of the model, and the DCHP simulation are described and analysed in this chapter.

1) Individual dwelling load curve

The major appliance types were considered and analysed, and their consumption aggregated when appropriate to generate a power demand model.

i) The electricity demand

The data obtained are available for a range of precision, allowing the user to limit the processing period depending on the desired resolution. It starts on a 30 minute base and can be changed to other time bases as low as 1-minute. One of the desired results of this investigation is the construction of a model able to simulate different scenarios. The consumption is mainly dependent on dwelling and household characteristics, as well as outside conditions such as cold water input temperature and external ambient temperature.

The result is therefore an interactive model, which could evolve in time to keep up to date, because appliance efficiency increases and main characteristics and always evolving. New appliances may appear and create new energy demands too.

i) Statistical analysis

To ensure the integrity of the model, the monitored demand and the simulated demand are characterised using typical statistical tool, such as minimum, mean, peak demand and load factor.

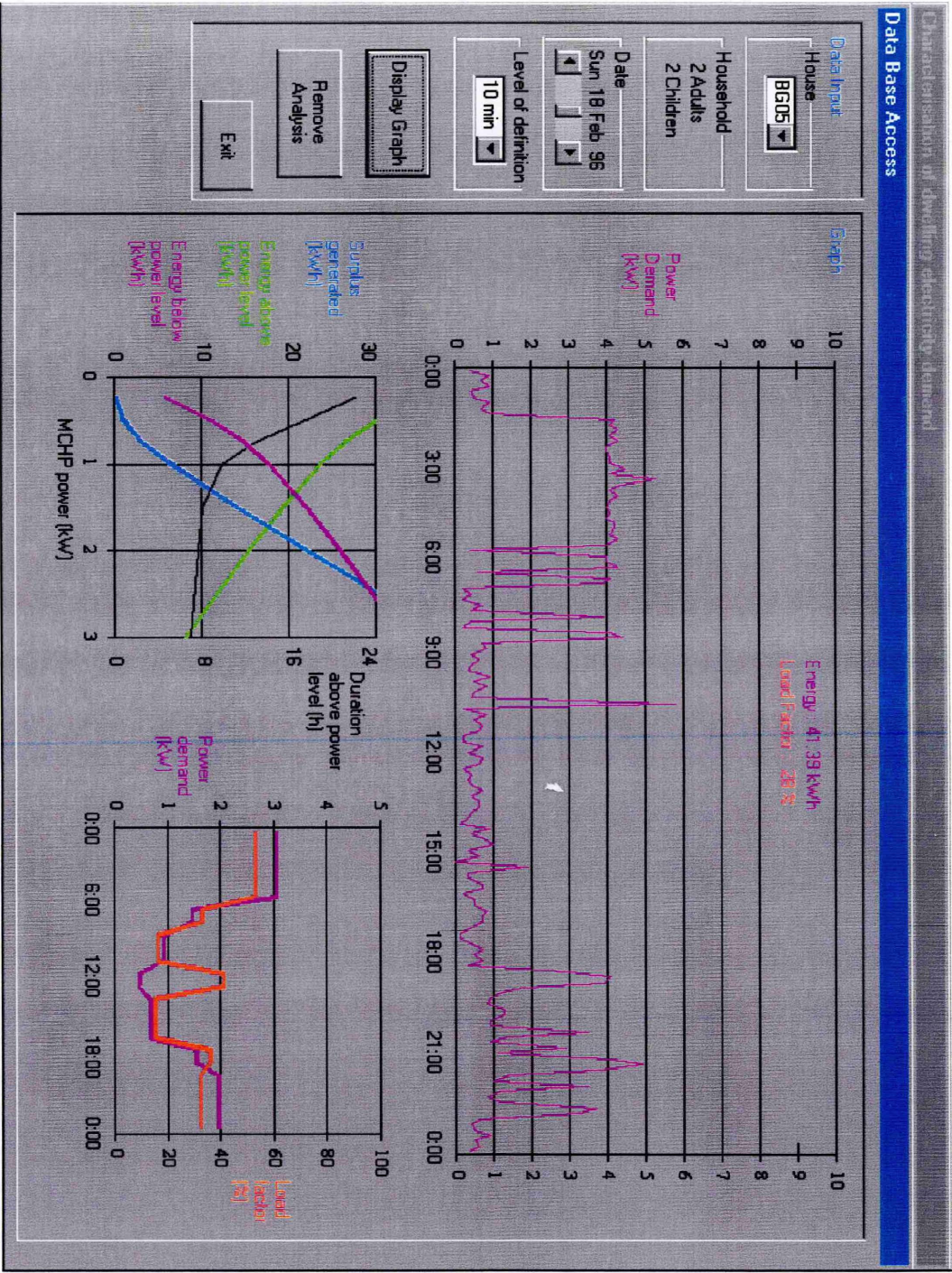


Fig. VII- 1. Real data BG05 18 February 1996

The database was accessed to create Fig. VII- 1. The power demand is derived from a dwelling with 2 adults and 2 children on the 18 February 1996. The derived information permits to characterise precisely the power demand during this day.

Using similar input, the model was able to generate day profiles. The results of the simulations are displayed in Fig. VII- 2, 3, 4 and 5.

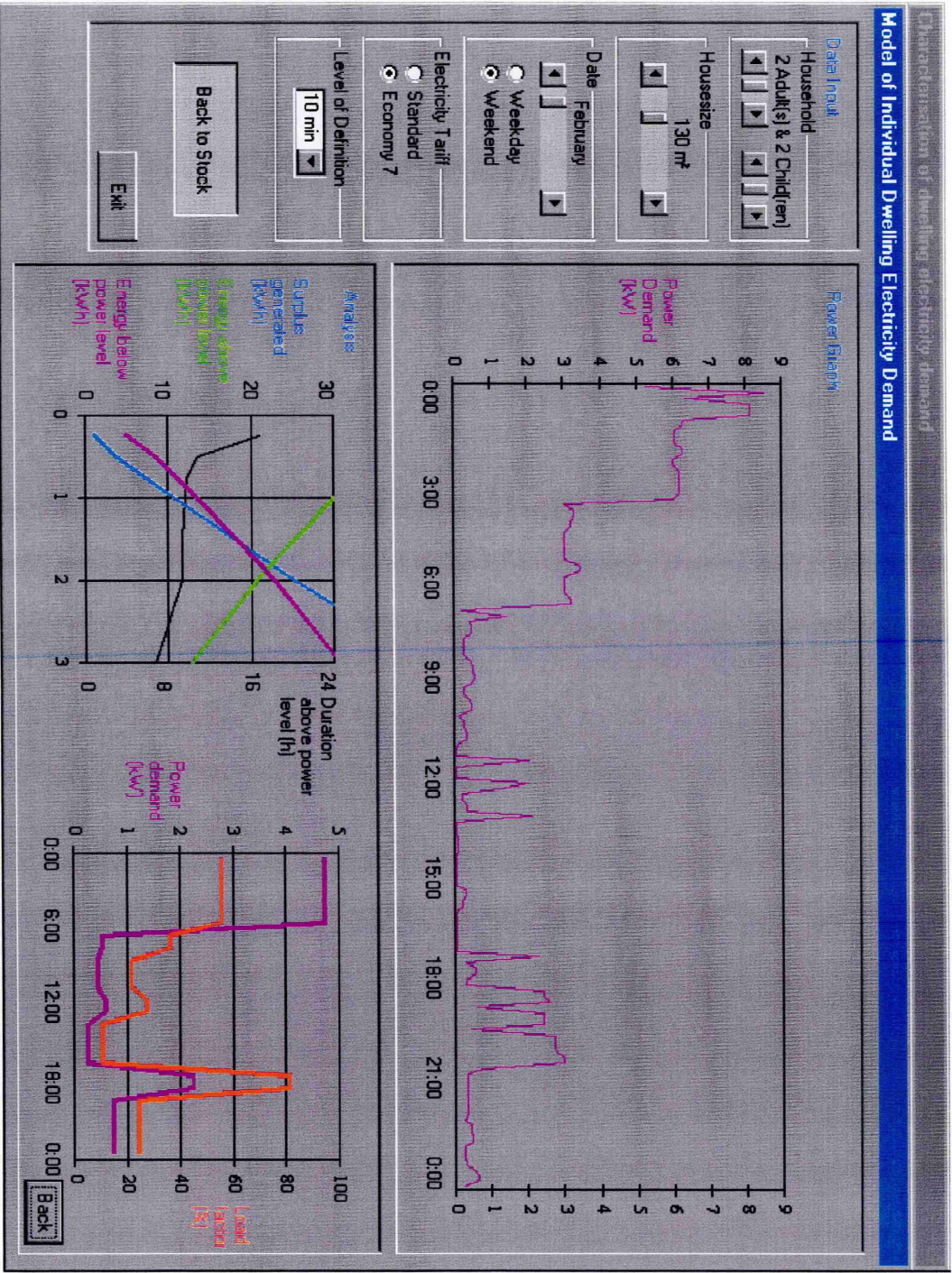


Fig. VII- 2. Simulation I (18 February 1996)

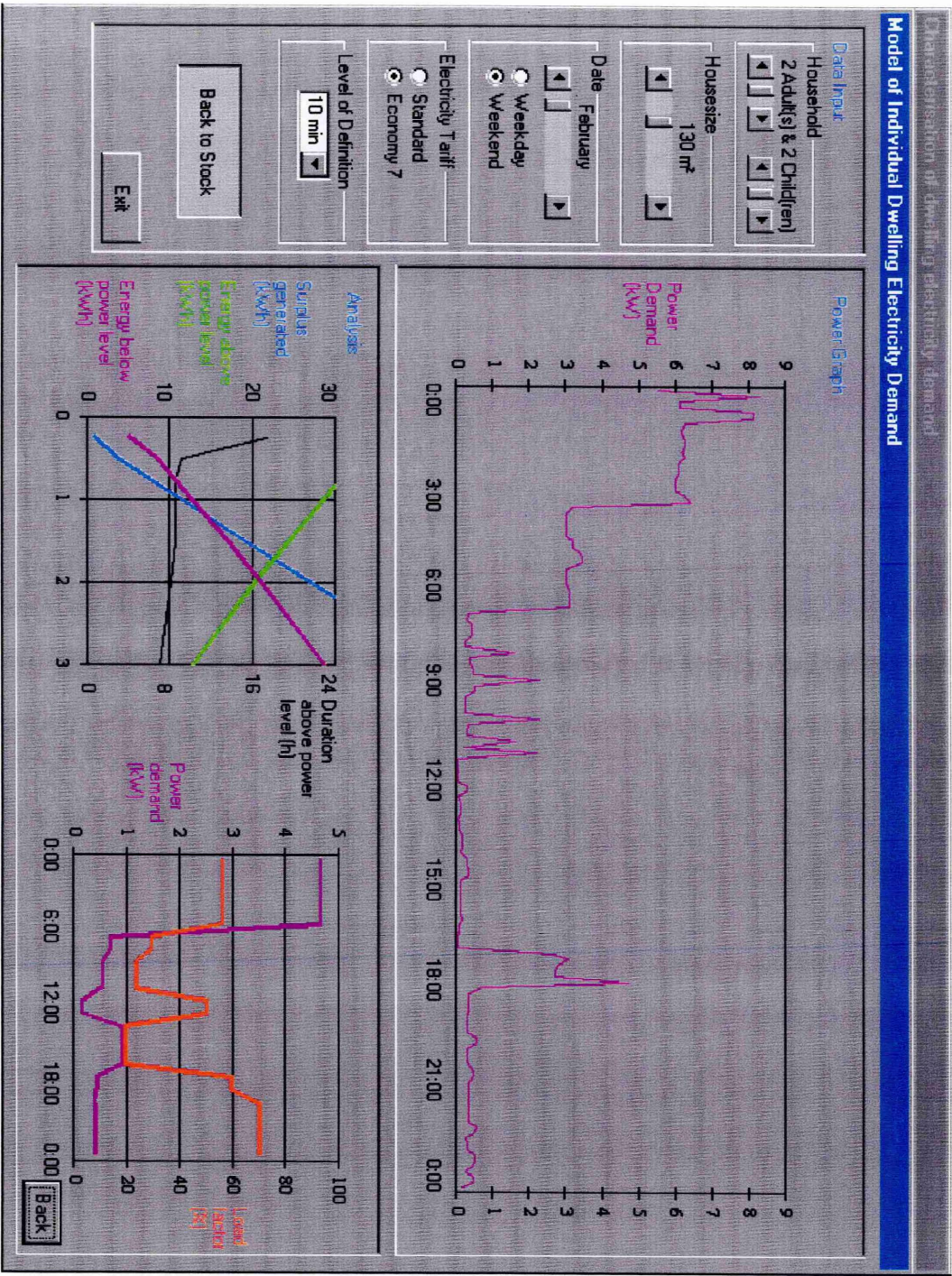


Fig. VII- 3. Simulation II (18 February 1996)

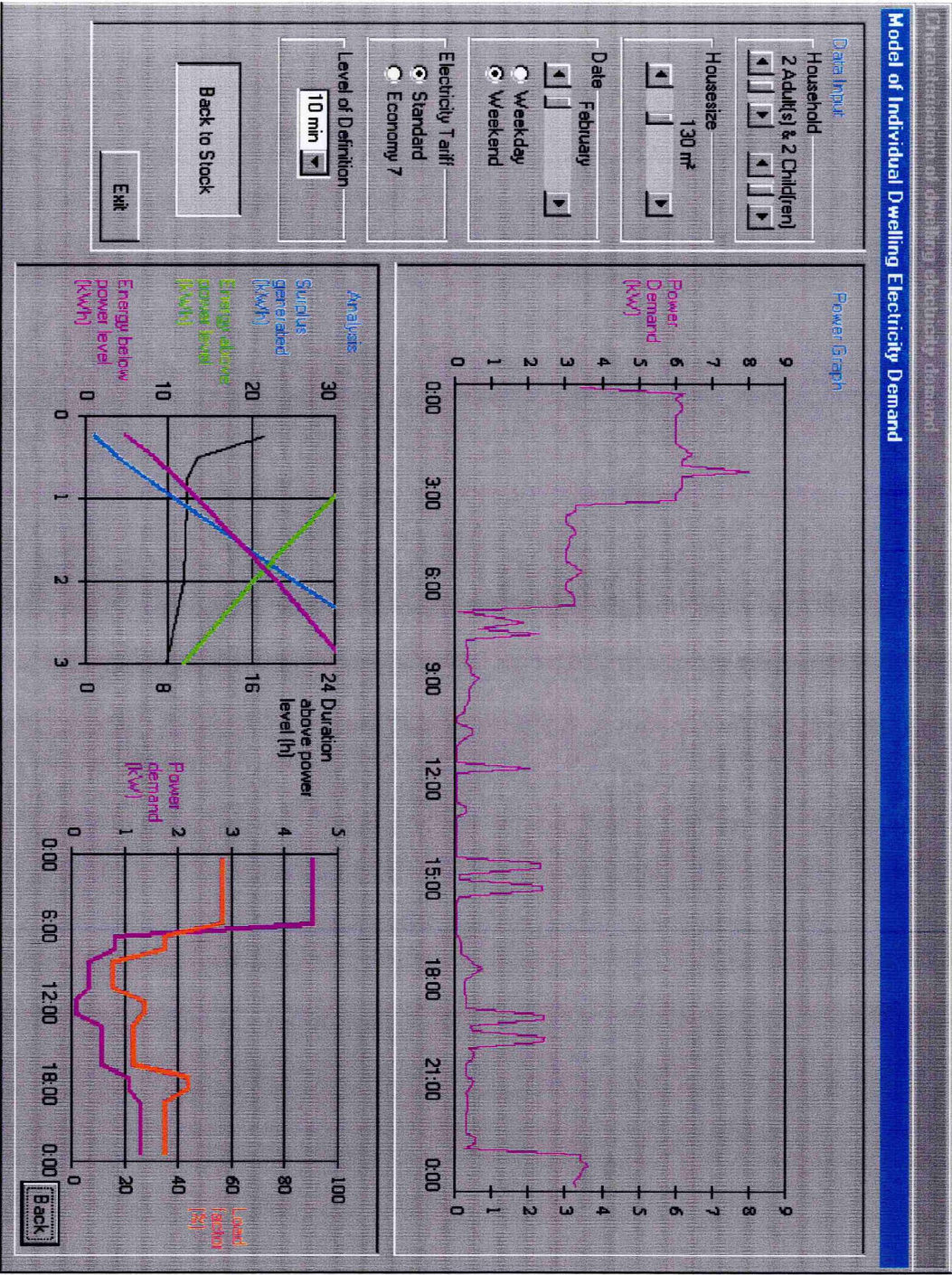


Fig. VII- 4. Simulation III (18 February 1996)

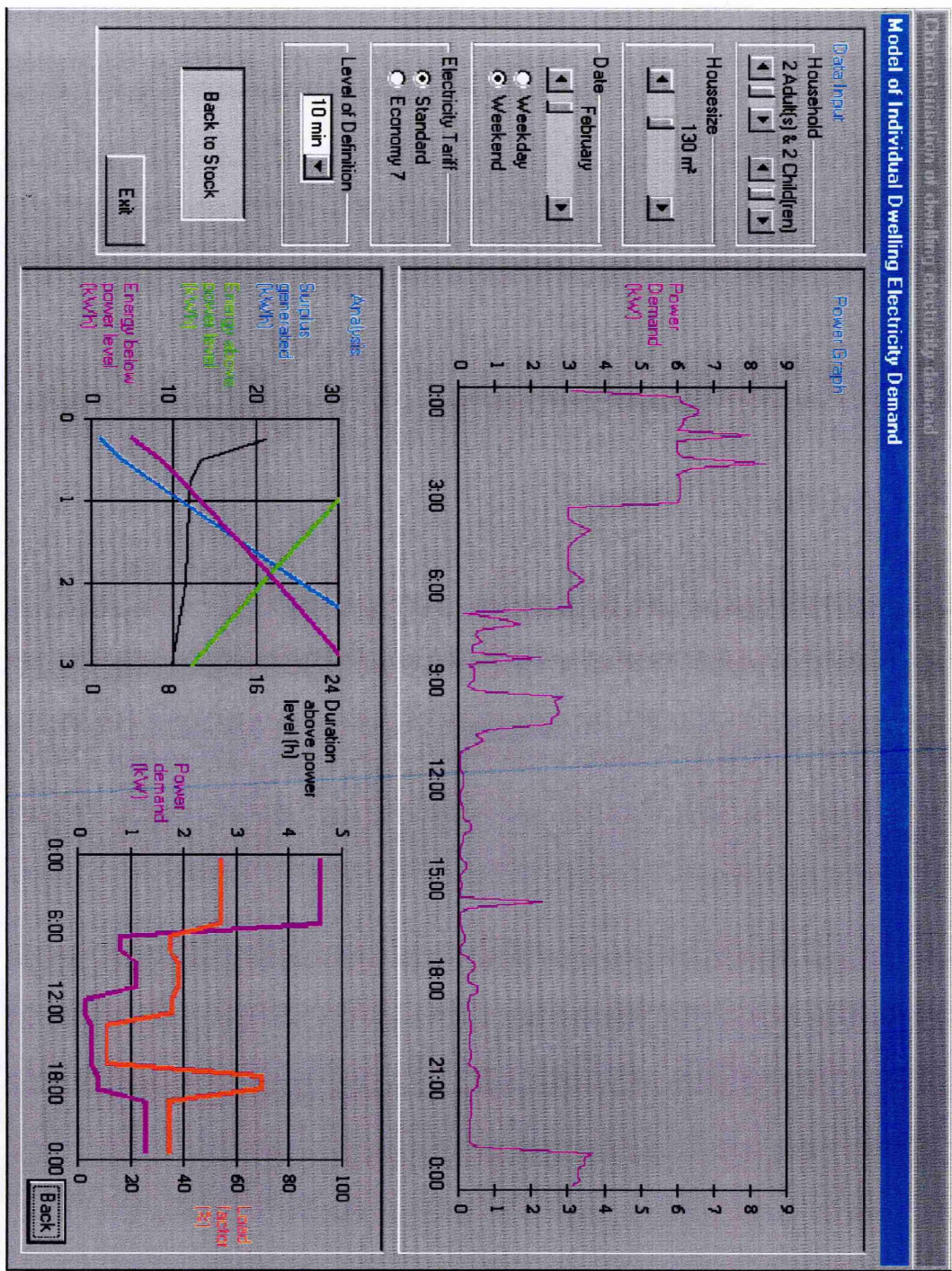


Fig. VII- 5. Simulation IV (18 February 1996)

First it should be noticed that while the results of the four simulation runs are different even though the input were kept identical, to represent the dwelling BG05 on 18 February 1996. This is due to the probabilistic approach of the model design.

Similar types of analysis are used for the real data and the model run. At first sight the level of coherence between the graphs was not evident. This was due to different timing of the most consuming appliances such as space heating and hot water electrical systems in the morning. Nevertheless the graphs representing energy analysis on the bottom left show a high degree of coherence. The power demand and the load factor analyses are similar, if the shift of power demand due to the probabilistic approach is taken into account.

Note that the model underestimated the energy consumption because appliances such as the main cooking appliances and lighting were missing in the model.

The database was accessed again to create Fig. VII- 6. The power demand is derived from a dwelling with 2 adults on the 29 August 1996. The derived information permits to characterise precisely the power demand during this day.

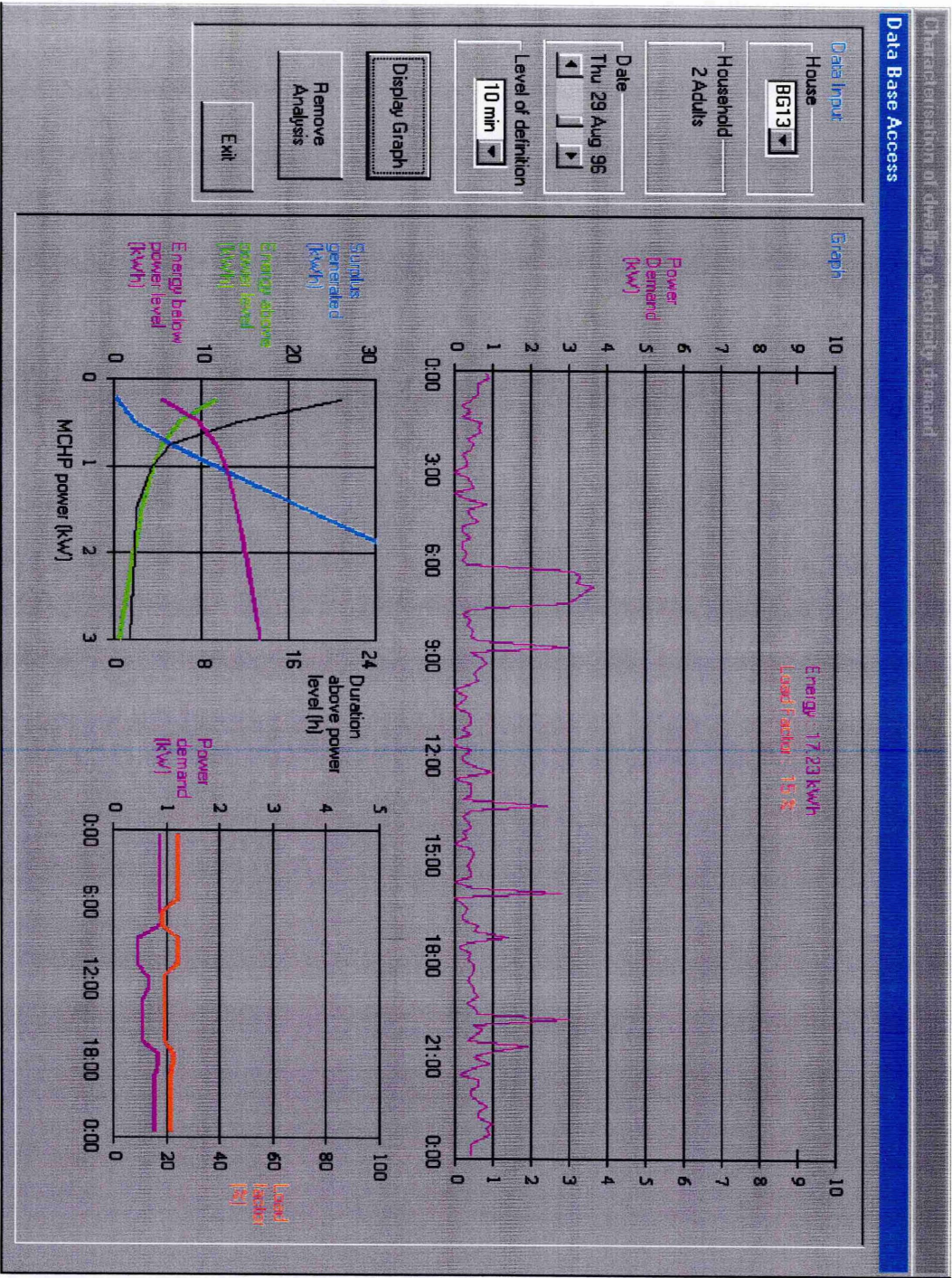


Fig. VII- 6. Real data BG13 29 August 1996

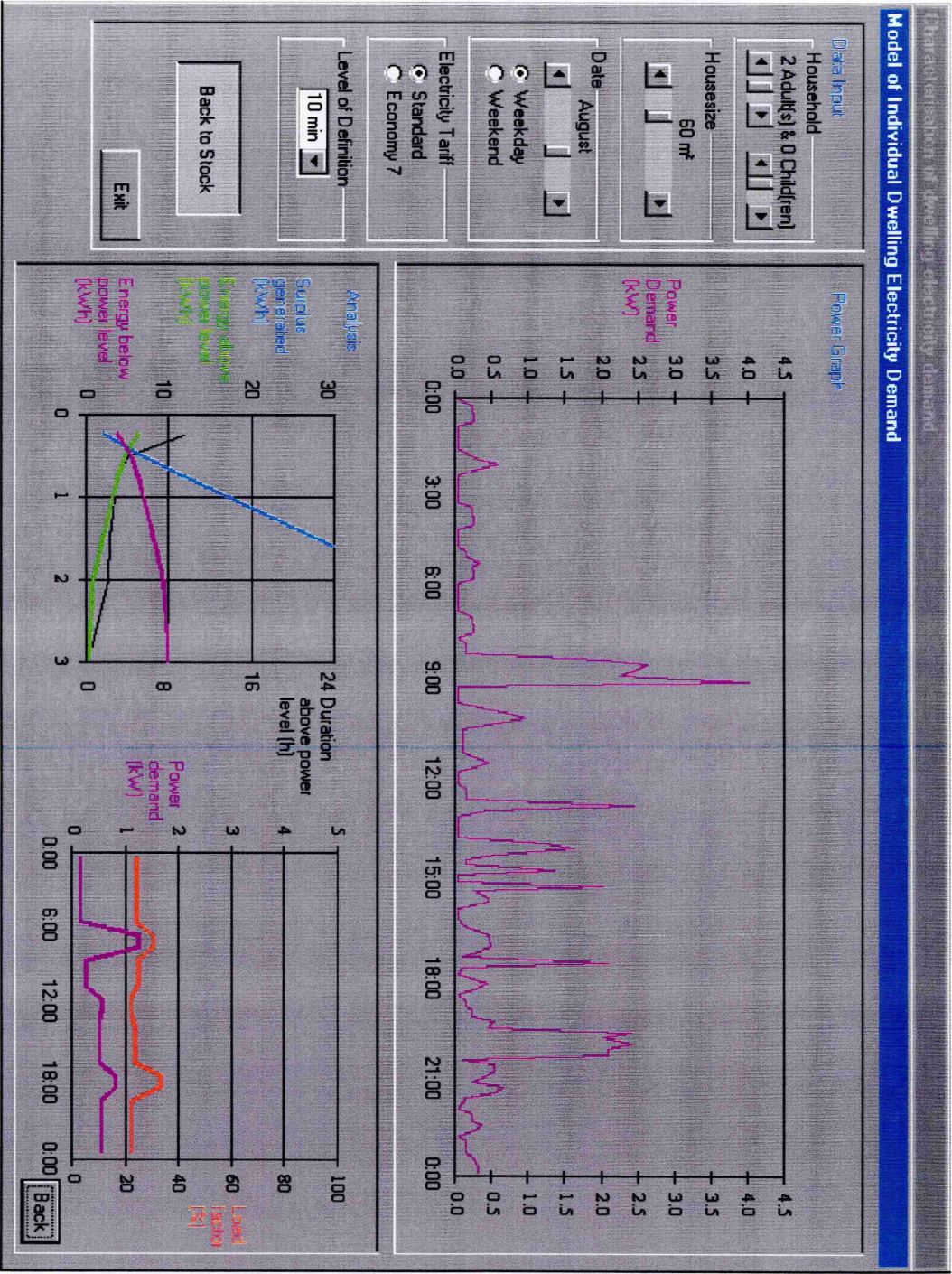


Fig. VII- 7. Simulation I (29 August 1996)

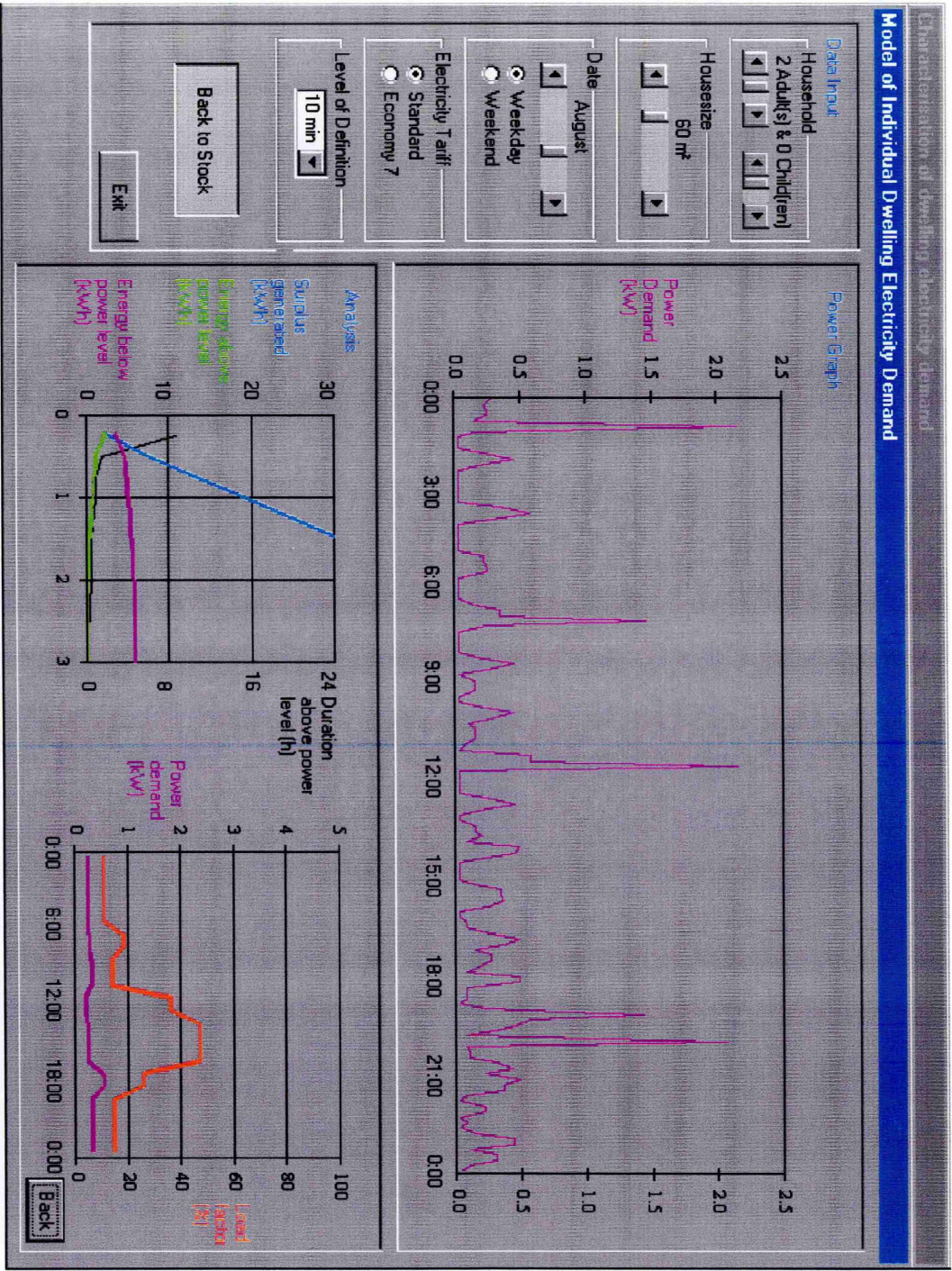


Fig. VII- 8. Simulation II (29 August 1996)

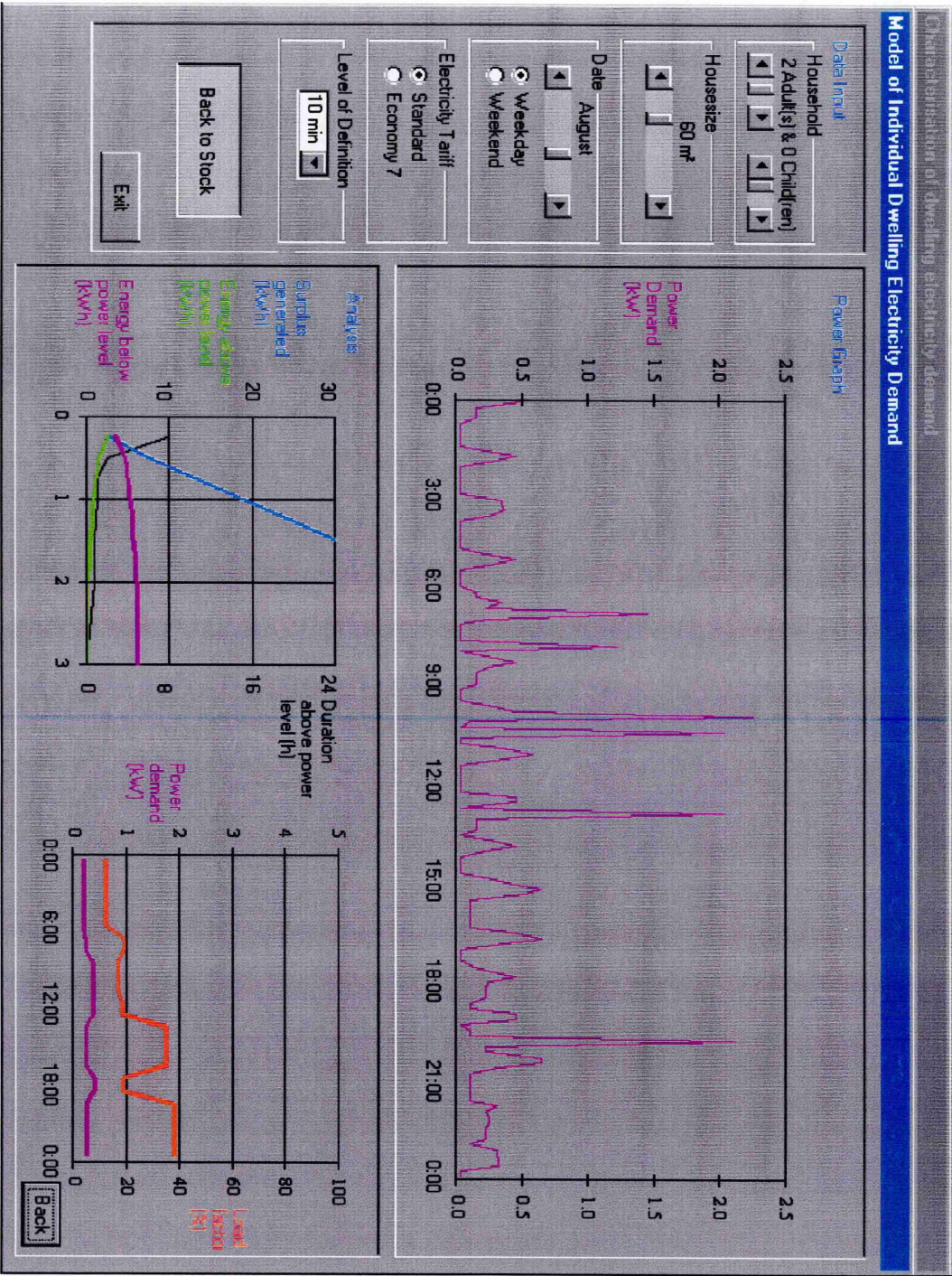


Fig. VII- 9. Simulation III (29 August 1996)

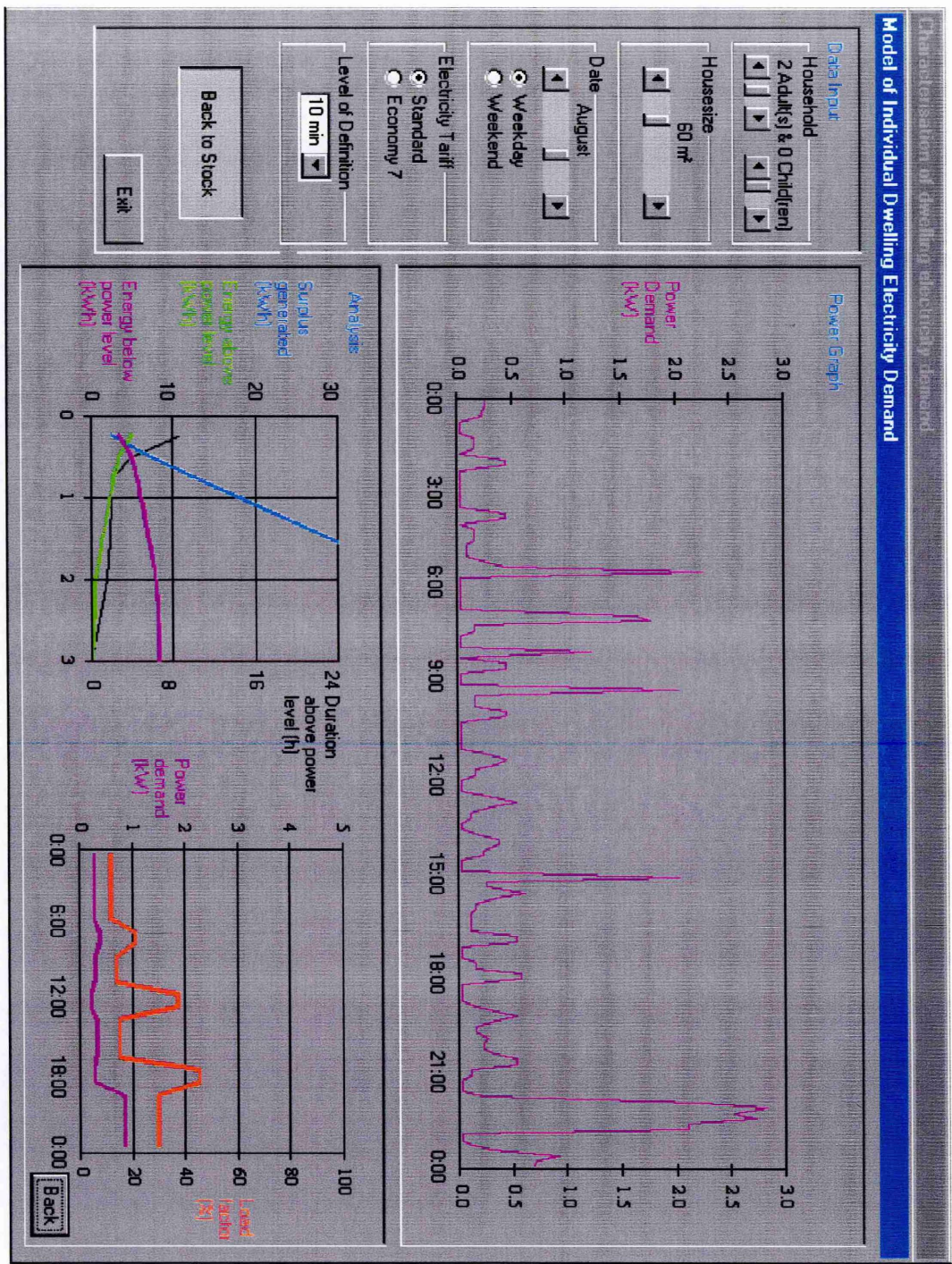


Fig. VII- 10. Simulation IV (29 August 1996)

The analyses demonstrated again the correlation between the real data and the data generated by the model. Note that other samples are shown in Annexes II.

ii) Percentage above and below level of demand

This characteristic is shown to be relatively important when considering total or partial replacement of the electricity demand by alternative system, because their power rating is generally limited due to their size and to favour economics. Both actual data and generated data have similar characteristics, which shows that the energy consumption was correctly aggregated in the model.

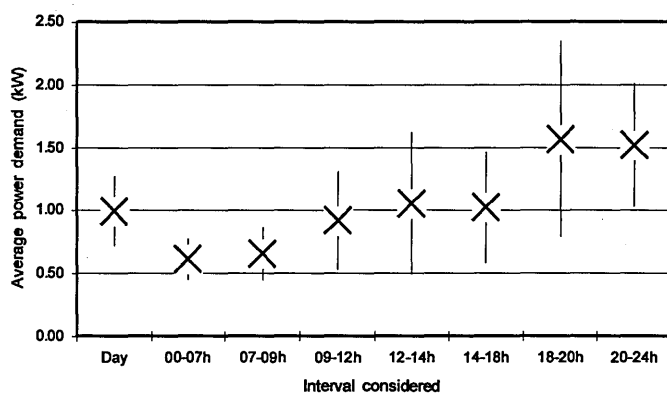
iii) Load factor and average power demand

The load factor is very important as it represents the ratio between the average power demand and the peak demand over a pre-defined period. The ideal power demand, from the utility point of view as well as from the perspective of implementing DCHP, is constant. This means a power factor equal to 100% because the peak and the average demand would be identical.

The reality is that the power demand is varying over time, which generates a power factor. On a day basis over all monitored dwellings, the daily average load factor is analysed to be 18% on average with a standard deviation of 5%. This means that in one day the power demand has peaks more than 5 times higher than its average.

Therefore the analysis was to determine parts of the day when the average power was high enough with a high load factor, which determined that electrical power was required with stability in demand.

The dwellings BG02 and BG03 were analysed over a period of one year to determine the level of power demand as well as the variation of the demand. Therefore the average power demand and the load factor have been aggregated to be displayed in 2 dimensional graphs.



The average power demand in Fig. VII- 11 is shown as increasing through the day. It should be noticed that its standard deviation is increasing too.

Fig. VII- 11. BG02 Average power demand

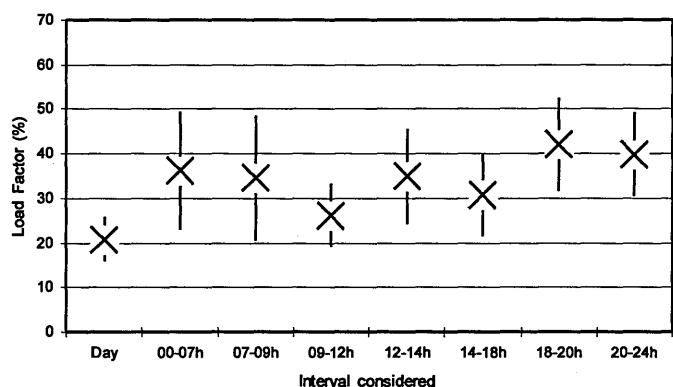


Fig. VII- 12. BG02 Load factor

The dwelling BG02 was analysed as follows. In the morning hours, the average power demand is low while the power factor increases. In the evening hours, the average power demand is high while the power factor increases. The interesting period would therefore be the evening as the power demand is 1.50 kW while the power factor is around 40%, because it shows a high and stable power demand.

The Fig. VII- 12 shows that the load factor increases as interval periods are reduced from a day to part of the day. The load factor of dwelling BG02 is varying through the day between 20 and 50%, but there is no relation between the average power and the load factor.

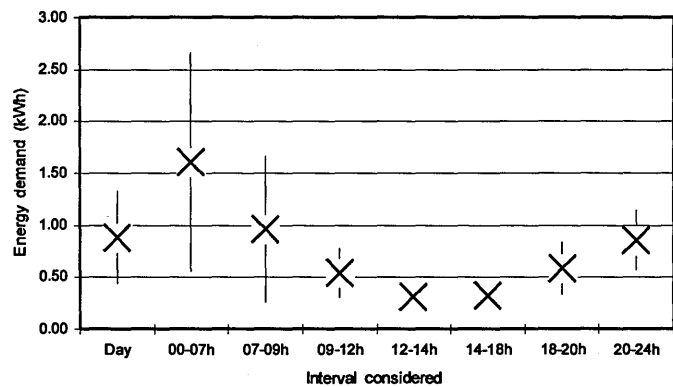
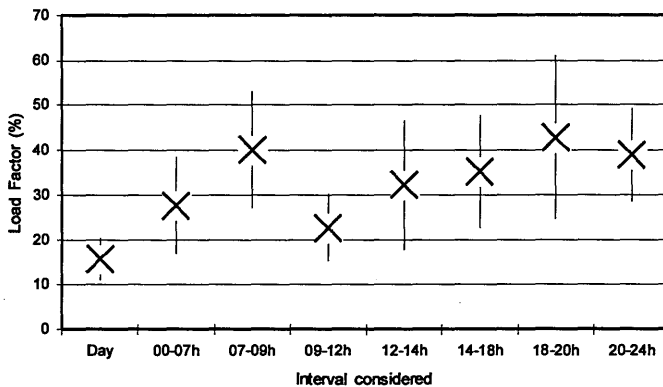


Fig. VII- 13. BG03 Average power demand

The average power demand shows a large variation in the interval 00-07h. This is analysed as electrical space heating use during the winter, which did not appear during the summer



The Fig. VII- 14 shows that the load factor is higher during the day than during the night, which might be caused by the use of Economy 7 electricity. The relation between the average power demand and the load factor is again difficult to quantify.

Fig. VII- 14. BG03 Load factor

The dwelling BG03 was analysed as follows. The average power demand is shown to be an important night peak and a smaller evening peak. The power factor is giving high in the morning hours between 7h and 9h and the evening hours between 18h and 24h. Therefore the interesting period for this dwelling regarding MCHP would be 7h to 9h in the morning and 18h to 24h in the evening.

Depending on the electricity use, different patterns of MCHP usage should be derived taking into account the power demand as well as the power factor. Ideally the average power demand should be equal to the electrical output of the MCHP, if the power factor was 100%. Actual power factor are determined to reach 40%, which imply that MCHP sizing should be relatively smaller than the dwelling average power demand.

2) Appliances use

In dwellings all electrical appliances can be considered as different as far as the electricity consumption is concerned. Some appliances are mainly user dependent such as cookers while others could almost be considered as self controlled such as refrigeration appliances. In general a combination of these two control modes determines their energy and power usage. For example a kettle would start to consume electricity when the owner switches it on and it stops once the water is boiling. The complete power load is determined by three main elements, the constant base load, the varying base load and the peaks.

i) Model advantage

The model, being based on aggregation of individual appliances power demand, allows a complete desegregation of the demand by appliances type. A result is shown on Fig. VII- 15, where is refrigeration power demand is instantly shown when the refrigeration checkpoint is activated.

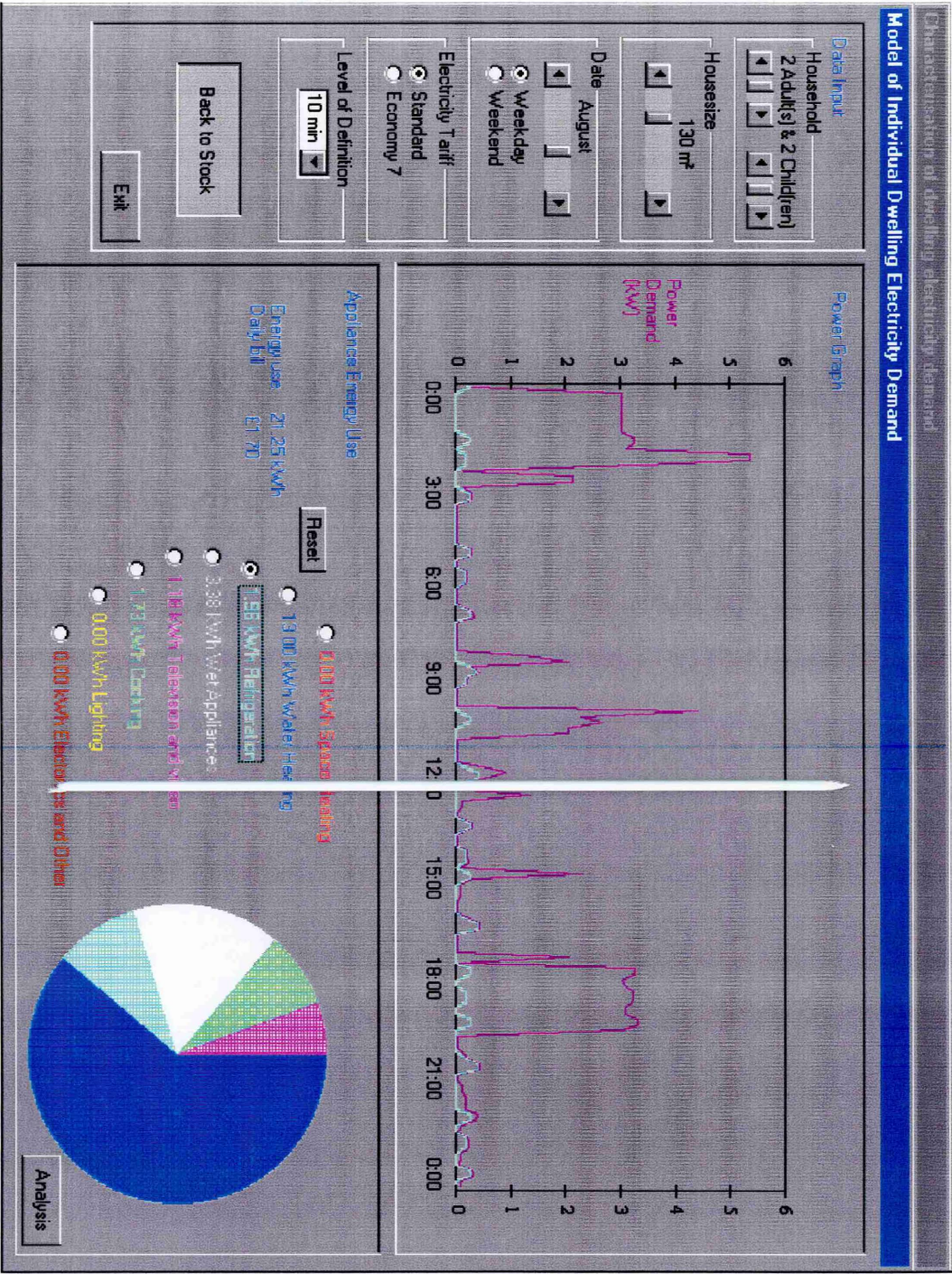


Fig. VII- 15. Desegregation advantage

This allows appliances characterisation and shows that appliances can be divided into three load types.

ii) Constant base load

The constant base load is generated by appliances, which are always consuming a constant amount of power. They are fans, water pumps, air pumps, lights (if left switched on constantly), clocks, alarms, and videocassette recorder. These appliances create a constant load during the day.

iii) Varying base load

Varying load is derived from appliances that are switched on and off with a repeating period. Refrigeration appliances are constantly being switched on and off to keep the inside of the appliances to the required temperature. Lights and television follow a daily pattern.

iv) Peaks

Peaks are traditionally due to electric cooking. The power demand is of the order of 2 to 3kW for period of time that can vary depending on cooking habits. The kettle for instance generates peaks of the order of 2kW for a few minutes only every time it is used. Wet appliances have to be considered, because their power demand creates peaks. Electric shower is the extreme with power rating up to 10kW.

3) Estimated effect on national demand

The fact that power demand is constantly varying from one minute to another is naturally controlled by the phenomena of mass. At the same time there might be a great number of major power changes in dwellings, but their mutual effect tend to lower the total impact on national demand.

i) Analysis price of the worse winter hour

It could be seen in Fig. II- 8 and 9, the price of generating electricity is dependent on the demand. In winter 1994-1995, the price to generate electricity was up to 30p/kWh on average during the January moth between 17h and 18h. At this period the national demand was averaging 42GW. Assuming that only 20GW was used by the domestic sector, and that the average domestic electricity price is 8p/kWh, it can be determined that generating utilities lost 22p/kWh delivered or £4.4 million.

i) Analysis price of the last kW generated

Analysing the pool electricity price data, it is possible to determine that the utilities are able to generate the first 25GW at 1p/kWh, the following 10GW at 3p/kWh and the next 5GW at 16p/kWh. Knowing that the price to generate 42GW is 30p/kWh, then it is possible to determine the price of the 2 last GW that had to be generated in winter 1994-1995. It is determined that the every kWh of the last 2GW would have cost more than 550p/kWh. Winter 1994-1995 might have been a period with generation availability

issue, and low external temperature, but this demonstration shows the economy scale achievable by using alternative option to main grid electricity.

Generating utilities should be in favour of reducing the probability of high demand and therefore high price occurring.

ii) Option to avoid inefficiency and loss

There are different options to avoid inefficiency and losses. The first would be to control the power demand of each appliance so that the load could be spread on a longer duration, which would allow reducing the peak demand and increasing the load factor. The second option could be to use alternative electricity generation system so that the general demand on the grid could be lowered to minimise peak demand.

iii) Using the model to simulate national demand

Through this report, individual dwelling power demands have been shown. To construct Fig. VII- 16, 200 dwelling power demands have been aggregated. It is possible to determine that the variability of the demand has decreased. Furthermore the demand tends to take the shape of the domestic demand shown in Fig. V- 1 (with a night peak due to space heating and electrical heating water systems, then a morning and an evening peak).

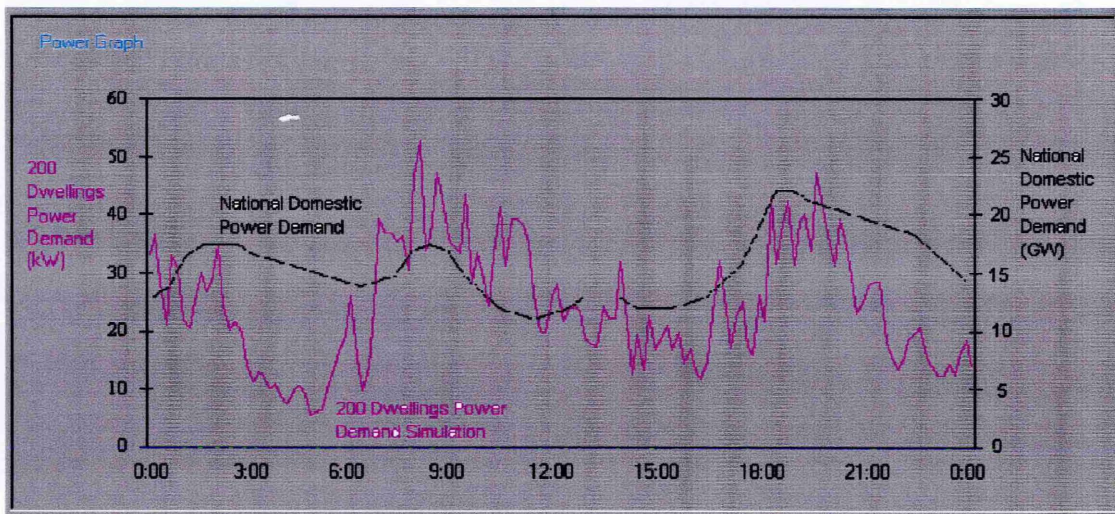


Fig. VII- 16. Aggregation over 200 simulated dwellings

4) Economics of DCHP

Therefore DCHP is a solution to the issue of high price electricity bill, because it could allow households to reduce their power demand during high demand peak.

i) Energy price

To be able to determine the gain/loss of implementing DCHP in a dwelling, the actual system and the cost associated to the energy bill should be considered. It was assumed that the energy standing charge would be unaffected by the implementation of such system, because part only of the electricity would be generated the system, therefore the standing charge for electrical connection would be identical. It is assumed that the standard tariff is 8p/kWh, while the Economy 7 tariff is 3p/kWh during the first 7 hours of the day, and 9p/kWh during the rest of the day. Gas is considered to cost 2p/kWh. The pool selling price is used to simulate a “time of use” tariff. The DCHP was assumed to have a 80% efficiency, of which 20% would be electricity power and 60% would be heat power. Electricity export to the grid was assumed to be at a rate of 2p/kWh.

ii) System price

The DCHP complete system and installation were not priced because it was not ready for commercialisation at the time this was written. Nevertheless a price of £2000 was quoted during private conversation with British Gas.

iii) DCHP economics

The data used to determine the DCHP economics are the power demand during one day as well as the gas demand that has been measured by British Gas during their campaign of monitoring. The results obtained have three degree of liberty,

- DCHP size (from 0.25 to 3.00 kW)
- Electricity tariff (Standard, Economy 7, Pool selling price)
- DCHP working pattern (Always, once a day 7-22h, twice a day 7-9h and 18-22h)

Graphical results for dwelling BG02 are shown in Fig. VII- 17, 18 and 19.

The analysis showed that the best results were obtained for both standard electricity tariff and Economy 7 tariff. The “Time of use” tariff simulated from the pool selling price gave generally negative savings. This was due to the fact that most of the time the electricity price was 1p/kWh. Nevertheless the electricity price varied to more than 30p/kWh for short periods in January 1995, which gave positive saving.

The second observation is that DCHP working pattern seemed to give better result when the machine is always running.

The sizing issue showed that it depended on the electricity consumption of the dwelling. Usually the range ensuring the best results would be between 500W and 1.50kW.

The viability of DCHP is shown to be seasonal dependent as the electricity power and mainly the heat power demand are lower in summer than in winter.

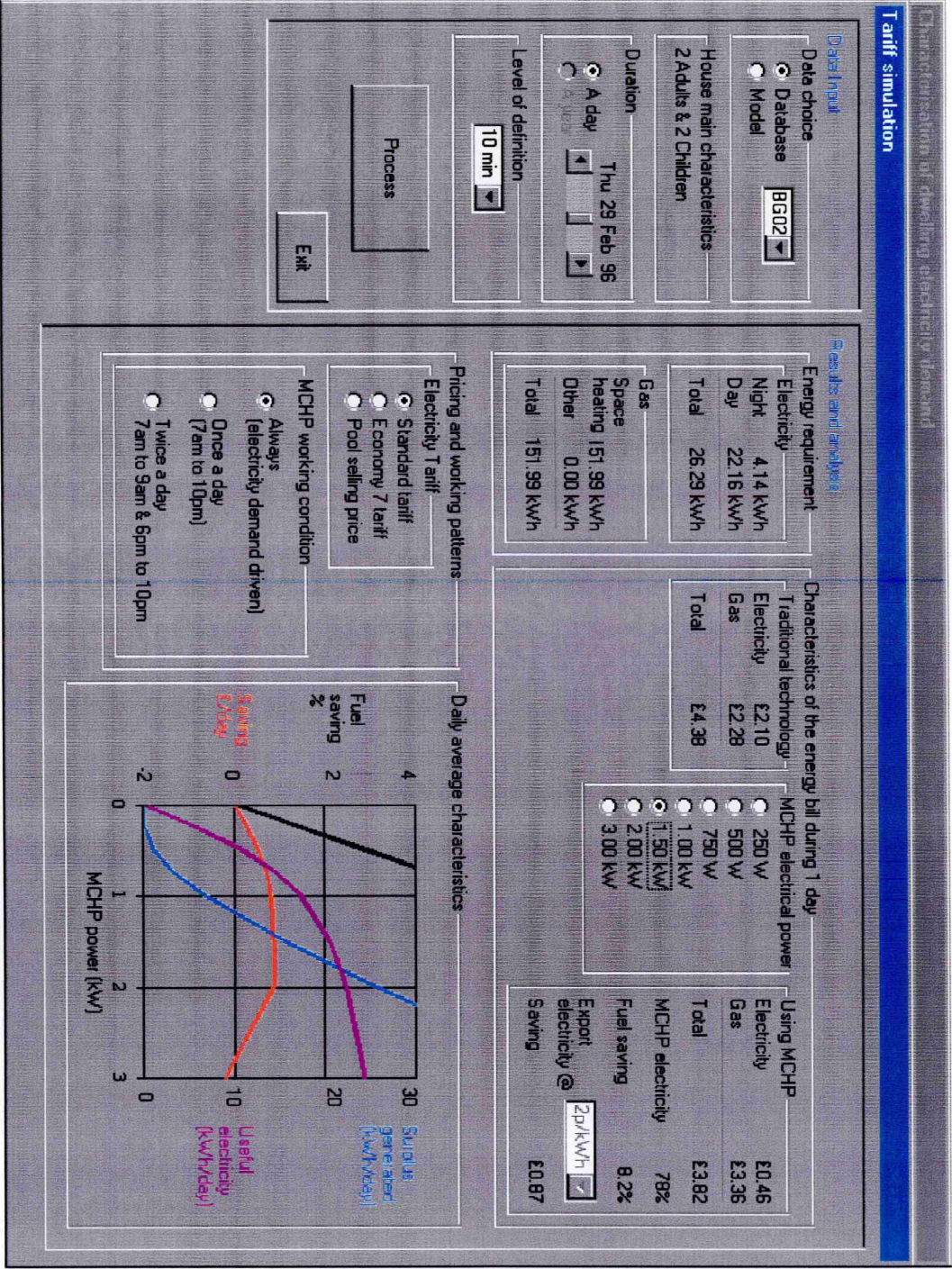


Fig. VII- 17. DCHP simulation for BG02 on 29 February 1996

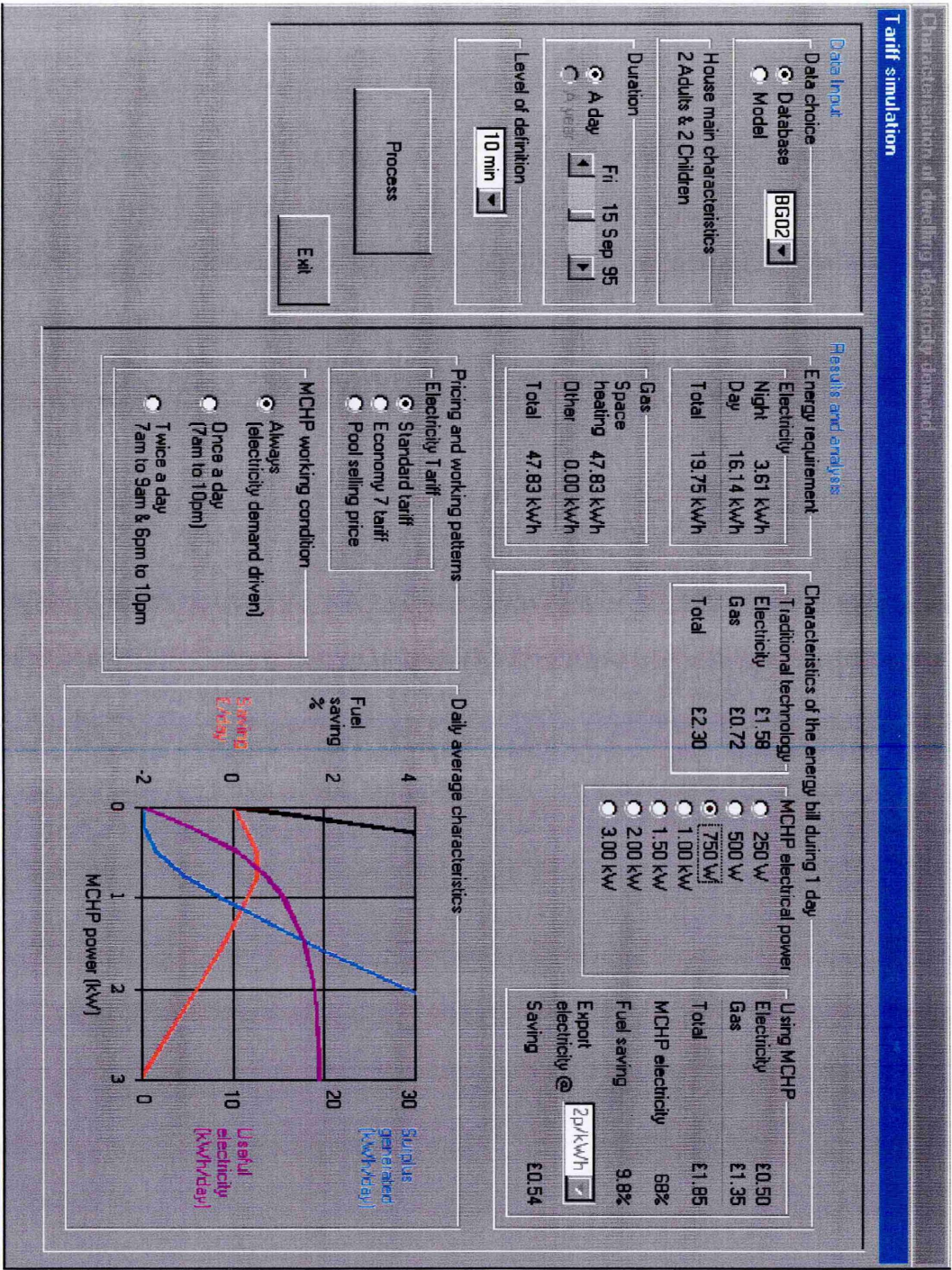


Fig. VII- 18. DCHP simulation for BG02 on 15 September 1995

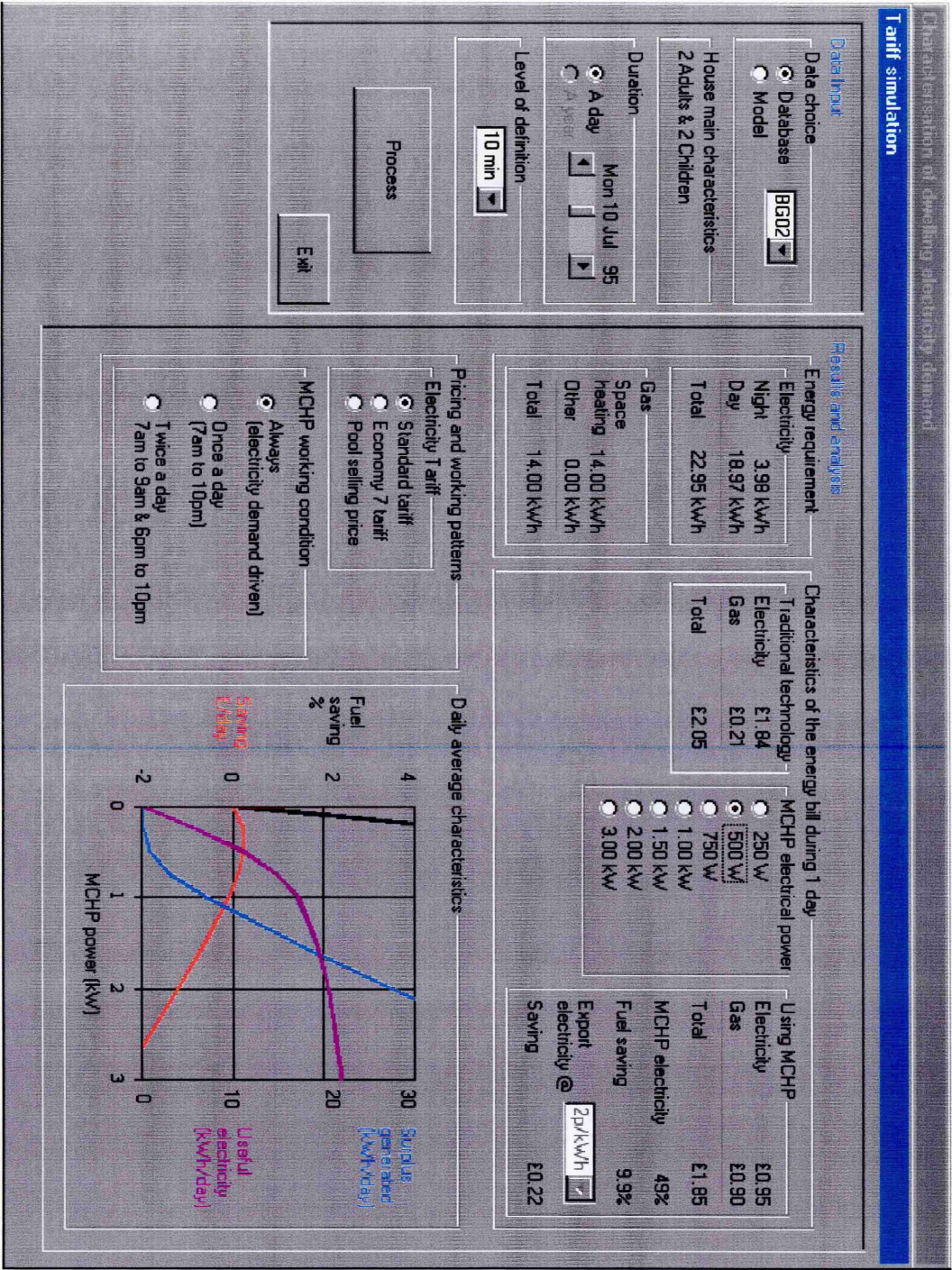


Fig. VII- 19. DCHP simulation for BG02 on 10 July 1995

Tab. VII- 1 shows a table of results, which are determined for 1kW_e DCHP during winter, 1kW_e DCHP during summer and 500W_e during summer. The data given is the average over a month period of the considered season.

Depending on the type of dwelling and essentially on its electricity power demand and heat energy demand, savings are determined to vary from 11 to 90 p/day during the winter period for a 1kW_e DCHP. Other results include savings during summer varying between -67 and 9p/day for a 1kW_e DCHP, and between -8 and 43 p/day for a 500W_e DCHP. The negative results during summer is essentially due to the reduced requirement of energy, especially heat which if not used has to be rejected from the system.

Furthermore the DCHP implementation would save primary fuel because power plant can only achieve 40% efficiency in electricity generating, while DCHP total efficiency is 80%. Fuel saving could reach up to 15% of primary fuel.

Dwelling	Winter average saving (£ per day) Assuming 1kW DCHP	Summer average saving (£ per day) Assuming 1kW DCHP	Summer average saving (£ per day) Assuming 500W DCHP
BG02	0.90	-0.17	0.12
BG03	0.63	-0.57	0.03
BG04	0.84	-0.25	0.02
BG05	0.42	-0.48	0.08
BG06	0.11	0.09	0.24
BG07	0.61	-0.08	0.17
BG08	0.82	0.06	0.43
BG10	0.45	0.00	0.37
BG13	0.54	-0.61	-0.04
BG14	0.71	-0.26	0.09
BG15	0.72	-0.01	0.33
BG16	0.21	-0.53	0.04
BG17	0.30	-0.64	-0.08
BG18	0.65	-0.46	0.09
BG19	0.36	-0.67	0.11

Tab. VII- 1 DCHP economics analysis

5) Conclusion

This chapter provides an overview of the results obtained during this research. A model for characterising the electricity power demand was designed and implemented. Its validity was verified comparing simulated data to actual monitored data. Furthermore aggregation over 200 simulated dwellings was determined to give correlated data to national domestic power demand. Differences were detected and analysed to be timing issue, due to the probability approach. For instance the space heating and water heating system were determined to be switched on at a particular time which is generally true for one individual dwelling, but could change from one dwelling to another.

Due to the fact that major cooking appliances and lighting were missing, only the actual data were processed to determine the DCHP economics. Possible direct savings were determined to be in the range between 11 and 90p/day during winter, and -67 to 9p/day during summer for a 1kW_e DCHP. The summer results improve if the DCHP power can be reduced to 500W_e, because the savings are in the range -8 to 43p/day.

On an annual basis, the average saving for a constant 1kW_e DCHP is determined to be £44.78, and the saving is increased to £124.61 for a system that would allow a turndown from 1kW_e DCHP during winter to 500W_e DCHP during summer.

Due to increase efficiency fuel savings can be achieved and are determined to reach up to 15%.

Chapter VIII: Conclusion

A residential power demand-forecasting model using a probabilistic approach was derived from monitoring appliances, dwellings and a survey. The model was developed based on an evaluation of the probable reasons for the time dependency of the residential load. The functions were utilised in a residential model in determining the probability that specific appliances will be connected to the power grid during particular time periods. The model includes the individual appliances as sub-models, to characterise the dwelling power demand and determine the significance of each appliance type.

The model was designed so that it could be updated and completed to include the missing cooking appliance and lighting models. Therefore the model would be totally representing the dwelling power demand, and could be used for DCHP simulation.

Furthermore, the total residential power demand could be generated from the model by aggregating power demand of multiple dwelling power demands representing the total population. Parameters influencing the energy and peak power demand could be determined. Hence this tool could forecast major changes in power demand for the utility companies.

In the future electricity market, as domestic tariffs begin to reflect the real cost of supplying electricity during peak time, an increasing number of consumers will seek to smooth their daily profiles, but in a manner that do not affect their individual lifestyles. Therefore, market opportunity will exist for alternative and modulation systems, which can be exploited by the appliance manufacturing and electricity supply industry.

The greatest incentives for DCHP so appear to be with the utility companies, which could provide the “energy service” of DCHP to dwellings as a means of reducing their dependence upon expensive peak period electricity price.

The widespread implementation of DCHP in the UK domestic sector potentially offers considerable benefits:

- More efficient use of primary energy for satisfying the customer’s requirement for heat and power.
- An important demand side management tool for the industry
- Financial saving for household

Due to actual deregulated market, it should be observed that unit price ratio of peak time electricity grid to natural gas is likely to increase.

On an annual basis, the average saving for a constant 1kW_e DCHP is determined to be £44.78, and the saving is increased to £124.61 for a system that would allow a turndown from 1kW_e DCHP during winter to 500W_e DCHP during summer.

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Annexe I : Survey

Cranfield
UNIVERSITY

Cranfield, February 1998

Applied Energy Group

DOMESTIC APPLIANCE SURVEY

Dear Sir/Madam,

As part of a research programme concerning electricity and gas use in British homes, we are carrying out a survey of how often, and at what time of day, people use their domestic appliances.

We would be very grateful if you, or some other member(s) of your household, could spare a few minutes to complete this questionnaire, on behalf of your household.

Just place a tick ☒ in the appropriate boxes, and mail it back to us in the enclosed FREEPOST envelope (No postage stamp required).

Yours faithfully,

Olivier Geslot MSc.

Please note :

- some questions may be answered by ticking more than one box,
- no tick is required when the described appliance is not used or owned,
- If you make a mistake, simply cross it out and continue.

GENERAL QUESTIONSHow many people live in your household? (please write in figures)☐ -Adult(s) ☐ -Child(ren)

How many bedrooms has your home? (please write in figures)

☐ -Bedroom(s)Which electricity tariff do you have?☐ -Standard ☐ -Other (For example Economy 7)On average how many weekends do you spend away from home per month?☐ -0 ☐ -1 ☐ -2 ☐ -3 ☐ -4**KETTLE**On average how many times is your kettle used per day?☐ -2 or less ☐ -3/4 ☐ -5/6 ☐ -7/8 ☐ -9 or moreWhen is the kettle most often used?☐ -Weekday ☐ -Weekend day ☐ -No difference ☐ -Don't know**TOASTER**

During which of the following periods does your toaster tend to be used?

	12pm to 7am	7am to 9am	9am to 12am	12am to 2pm	2pm to 6pm	6pm to 8am	8pm to 12pm
Weekday	☐	☐	☐	☐	☐	☐	☐
Weekend	☐	☐	☐	☐	☐	☐	☐

On average how many times is your toaster used per day?☐ -2 or less ☐ -3/4 ☐ -5/6 ☐ -7/8 ☐ -9 or moreWhen is your toaster most often used?☐ -Weekday ☐ -Weekend day ☐ -No difference ☐ -Don't know**WASHING MACHINE**

During which of the following periods does your washing machine tend to be used?

	12pm to 7am	7am to 9am	9am to 12am	12am to 2pm	2pm to 6pm	6pm to 8am	8pm to 12pm
Weekday	☐	☐	☐	☐	☐	☐	☐
Weekend	☐	☐	☐	☐	☐	☐	☐

When is your washing machine most often used?☐ -Weekday ☐ -Weekend day ☐ -No difference ☐ -Don't knowDoes your washing machine tend to be used on the same day(s) each week?☐ -Yes ☐ -No

If Yes please specify the day(s).....

TUMBLE DRYER

During which of the following periods does your tumble dryer tend to be used?

	12pm to 7am	7am to 9am	9am to 12am	12am to 2pm	2pm to 6pm	6pm to 8am	8pm to 12pm
Weekday	☐	☐	☐	☐	☐	☐	☐
Weekend	☐	☐	☐	☐	☐	☐	☐

When is your tumble dryer most often used?

☐-Weekday ☐-Weekend day ☐-No difference ☐-Don't know

DISH WASHER

During which of the following periods does your dish washer tend to be used?

	12pm to 7am	7am to 9am	9am to 12am	12am to 2pm	2pm to 6pm	6pm to 8am	8pm to 12pm
Weekday	☐	☐	☐	☐	☐	☐	☐
Weekend	☐	☐	☐	☐	☐	☐	☐

Is the dish washer used generally soon after meals?

☐-Yes ☐-No

If No please explain.....

IRON

During which of the following periods does your iron tend to be used?

	12pm to 7am	7am to 9am	9am to 12am	12am to 2pm	2pm to 6pm	6pm to 8am	8pm to 12pm
Weekday	☐	☐	☐	☐	☐	☐	☐
Weekend	☐	☐	☐	☐	☐	☐	☐

On average how many times per week is your iron used?

☐-2 or less ☐-3/4 ☐-5/6 ☐-7 or more

How long does each ironing session usually last?

☐-30min or less ☐-30min/1h ☐-1h/2h ☐-2h or more

HAIR DRYER

How many times per week is your hair dryer used?

☐-2 or less ☐-3/4 ☐-5/6 ☐-7 or more

How long is your hair dryer used per session?

☐-5min or less ☐-5 to 10min ☐-10min or more

VACUUM CLEANER

During which of the following periods does your vacuum cleaner tend to be used?

	12pm to 7am	7am to 9am	9am to 12am	12am to 2pm	2pm to 6pm	6pm to 8am	8pm to 12pm
Weekday	☐	☐	☐	☐	☐	☐	☐
Weekend	☐	☐	☐	☐	☐	☐	☐

On average how many times per week is your vacuum cleaner used?

☐-2 or less ☐-3/4 ☐-5/6 ☐-7 or more

How long is your vacuum cleaner use per session?

☐-5min or less ☐-5 to 10min ☐-10 to 20 min ☐-20min or more

TELEVISION

During which of the following periods does your television(s) tend to be used?

	12pm to 7am	7am to 9am	9am to 12am	12am to 2pm	2pm to 6pm	6pm to 8am	8pm to 12pm
Weekday	☐	☐	☐	☐	☐	☐	☐
Weekend	☐	☐	☐	☐	☐	☐	☐

When is your television most often used?

☐-Weekday ☐-Weekend day ☐-No difference ☐-Don't know

OTHER APPLIANCES

Are there any other appliances your household use several times per week?

Annexe II : Results

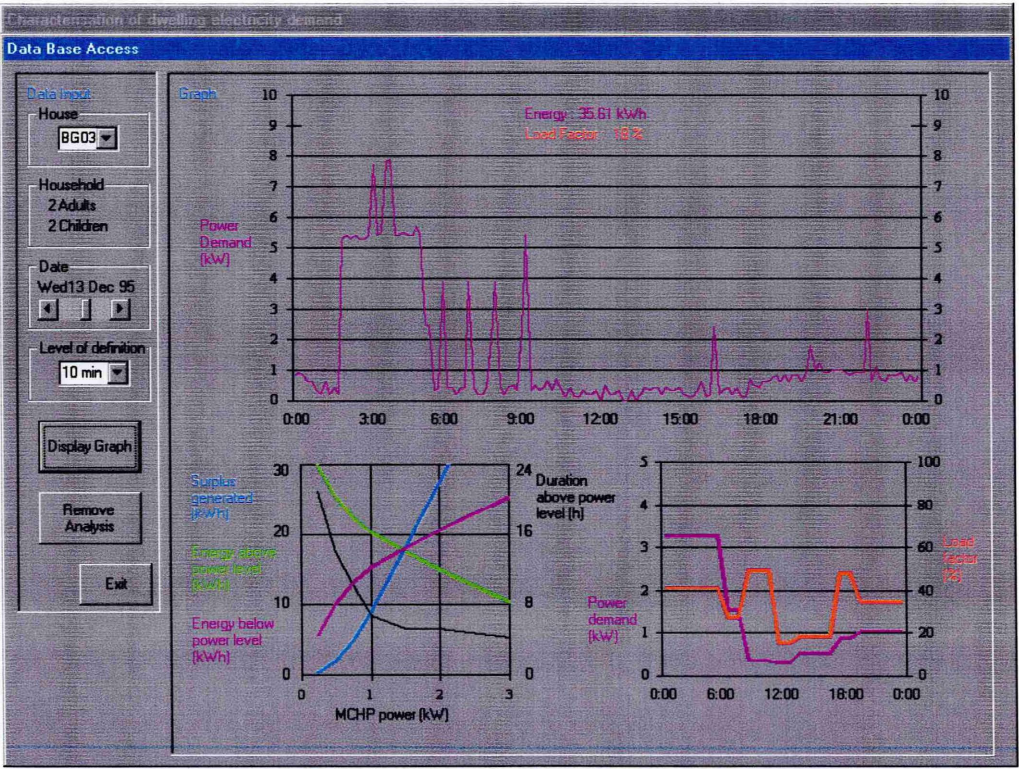


Fig. BG03 electricity consumption on 13 December 1995

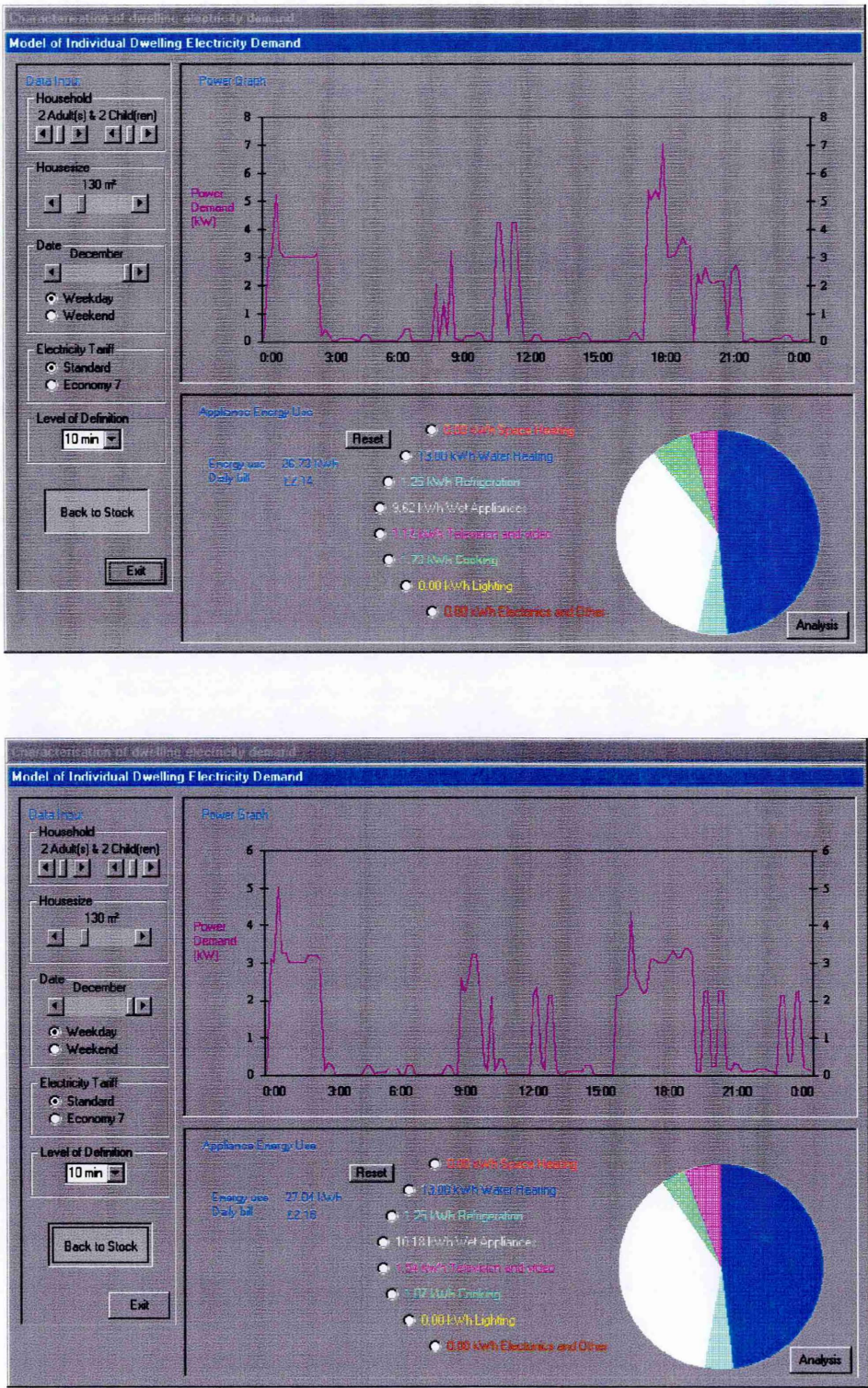


Fig. 2 adults 2 children family household simulations in December

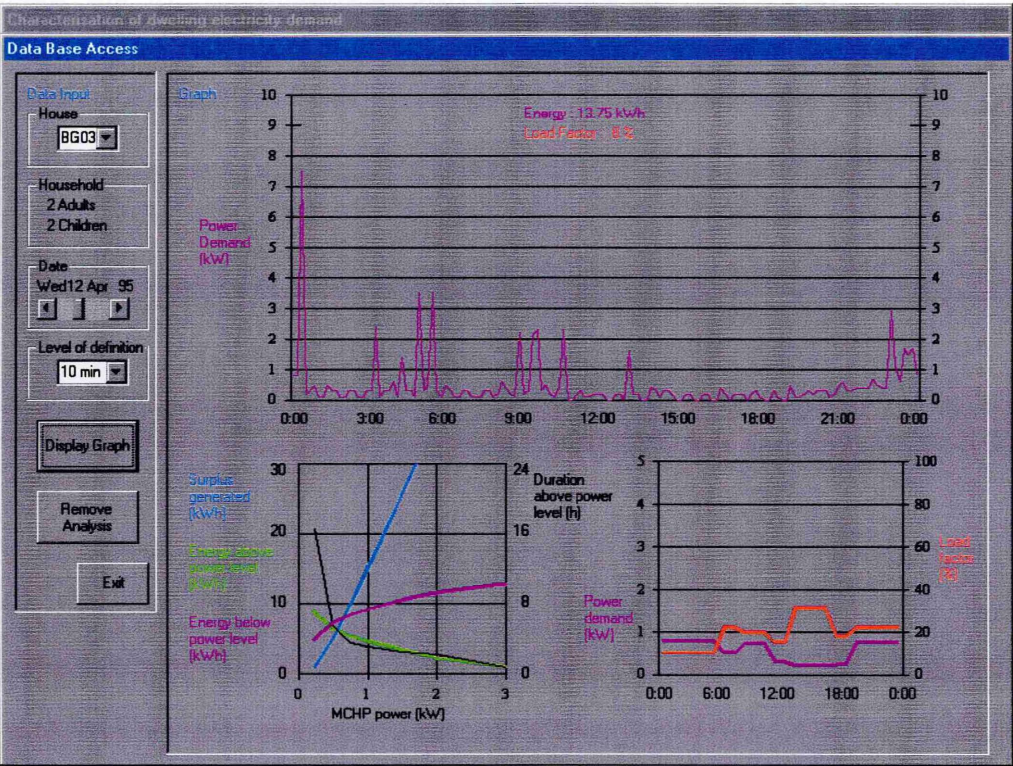


Fig. BG03 electricity consumption on 12 April 1995

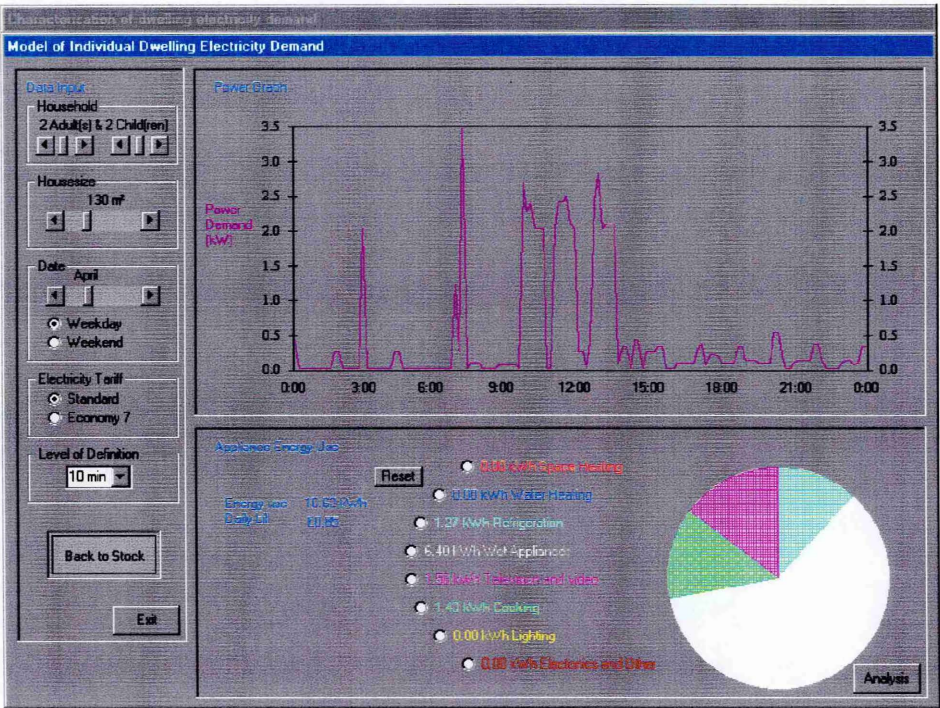
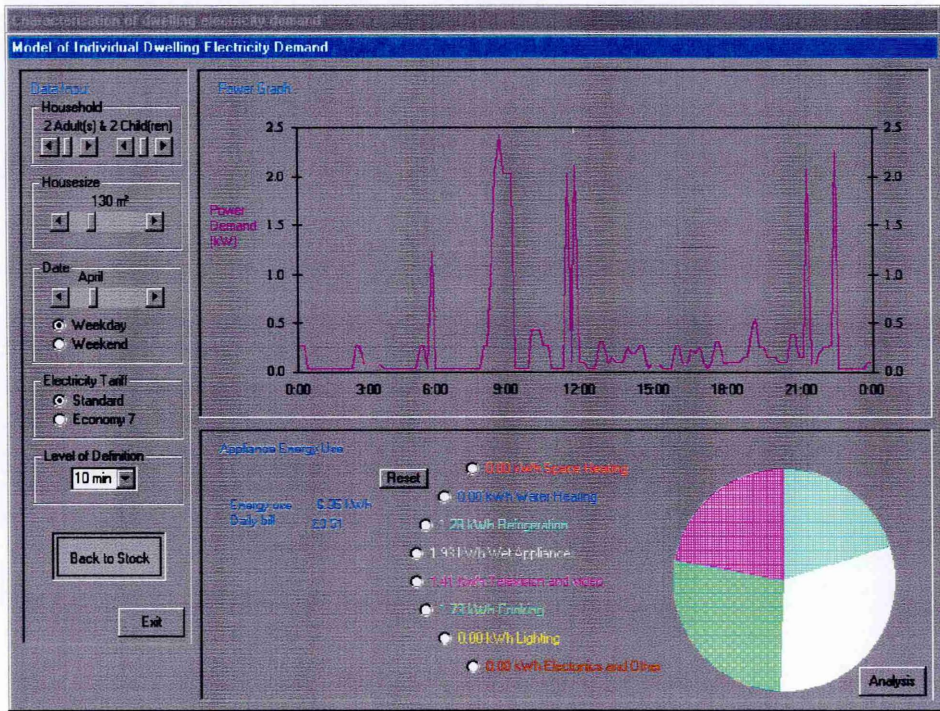


Fig. 2 adults 2 children family household simulations in April

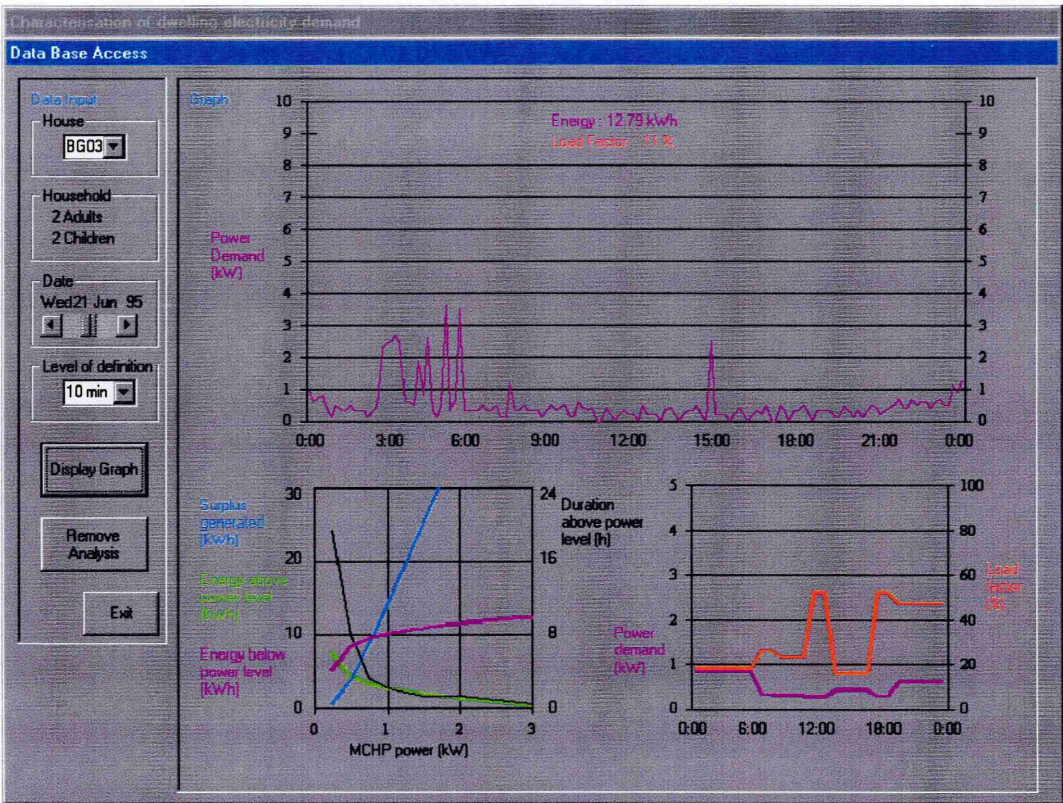


Fig. BG03 electricity consumption on 21 June 1995

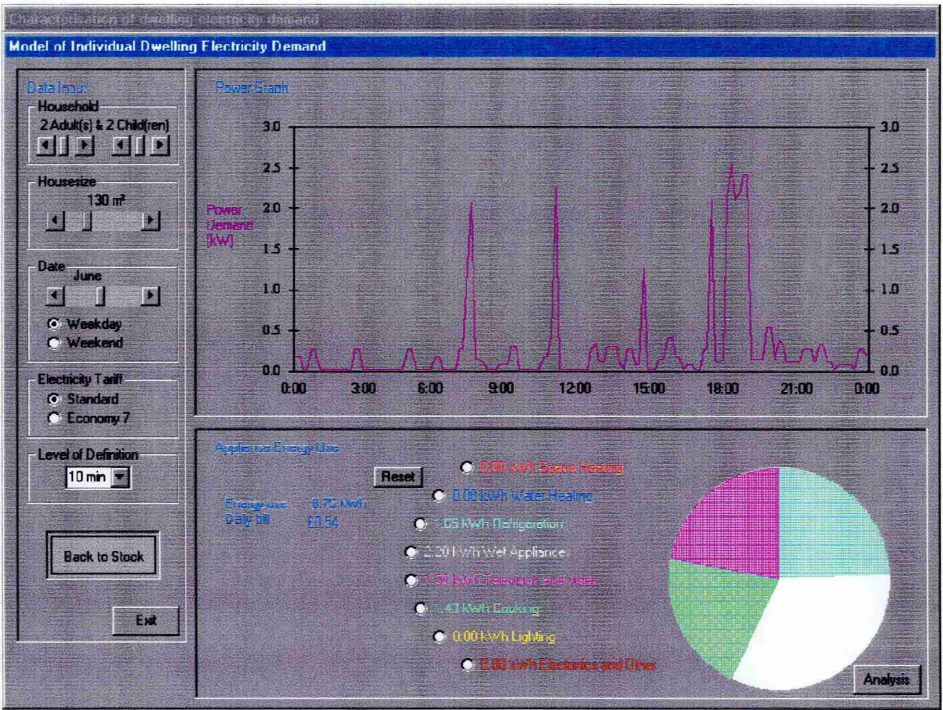
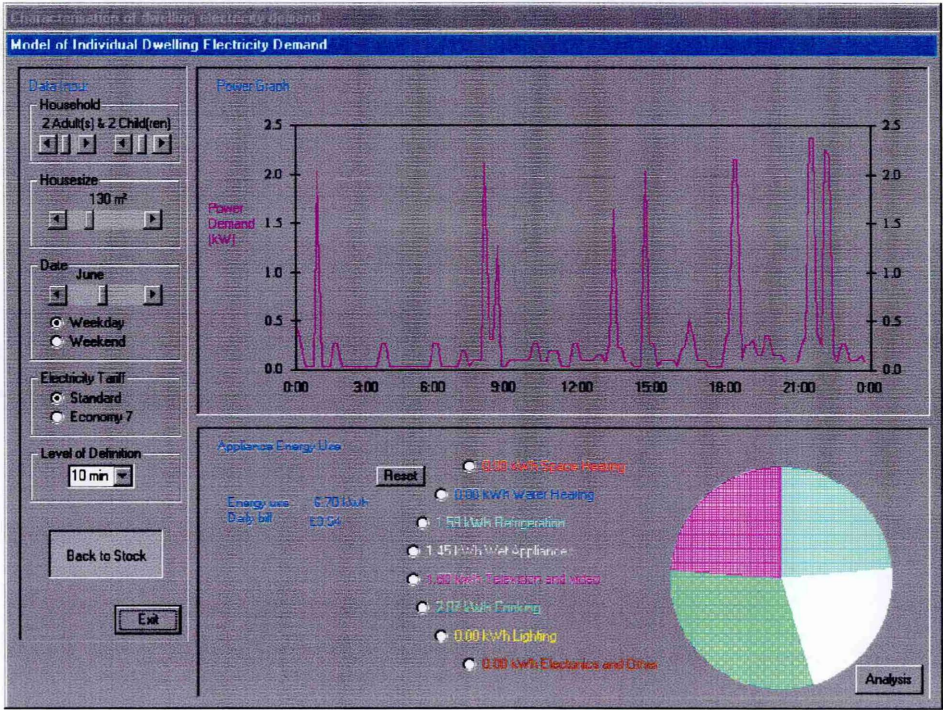


Fig. 2 adults 2 children family household simulations in June

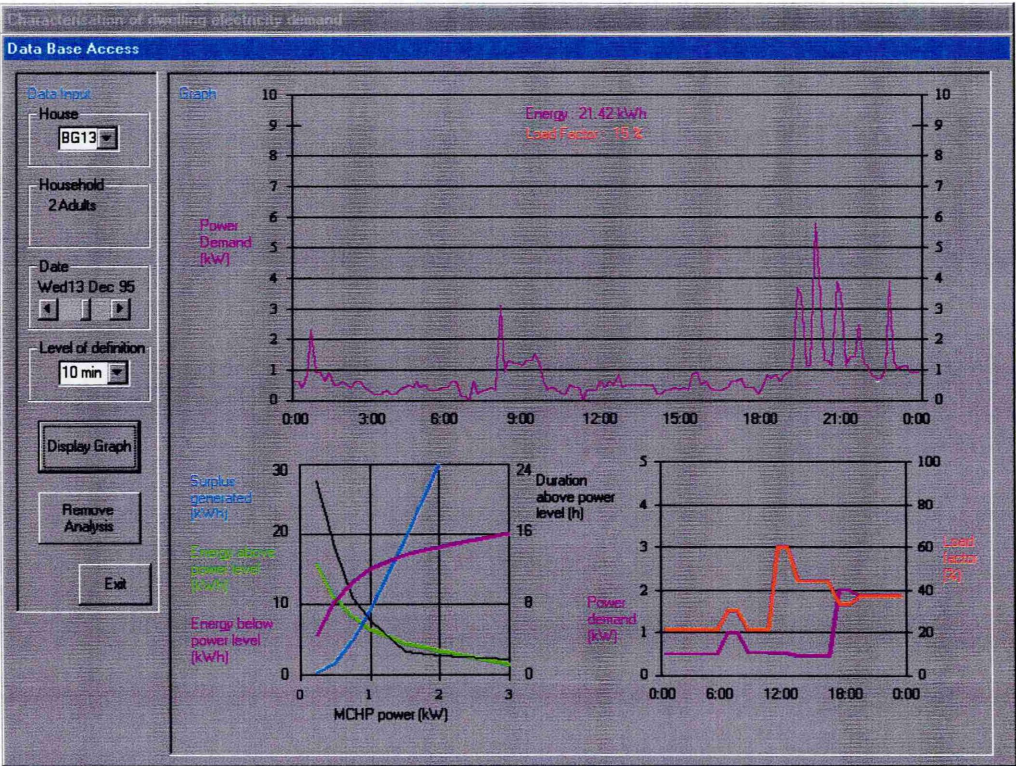


Fig. BG13 electricity consumption on 13 December 1995

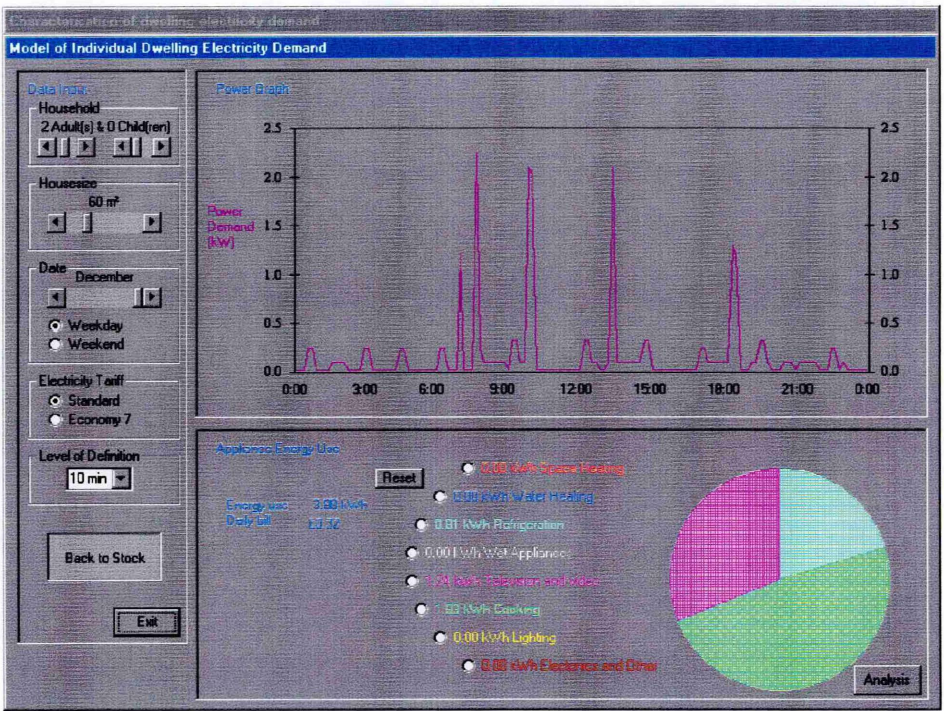
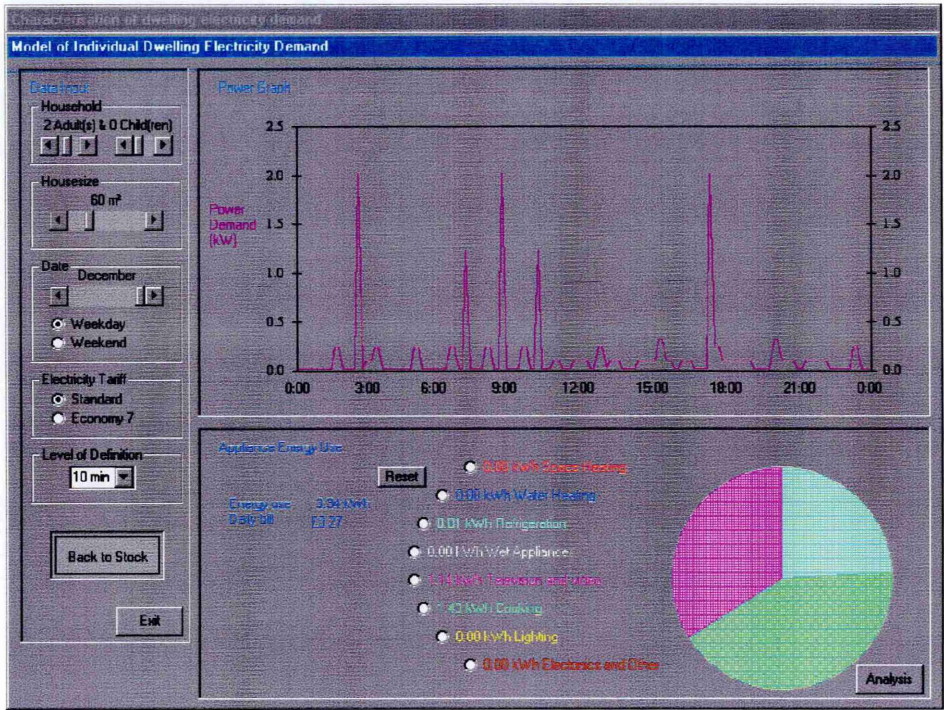


Fig. 2 adults family household simulations in December

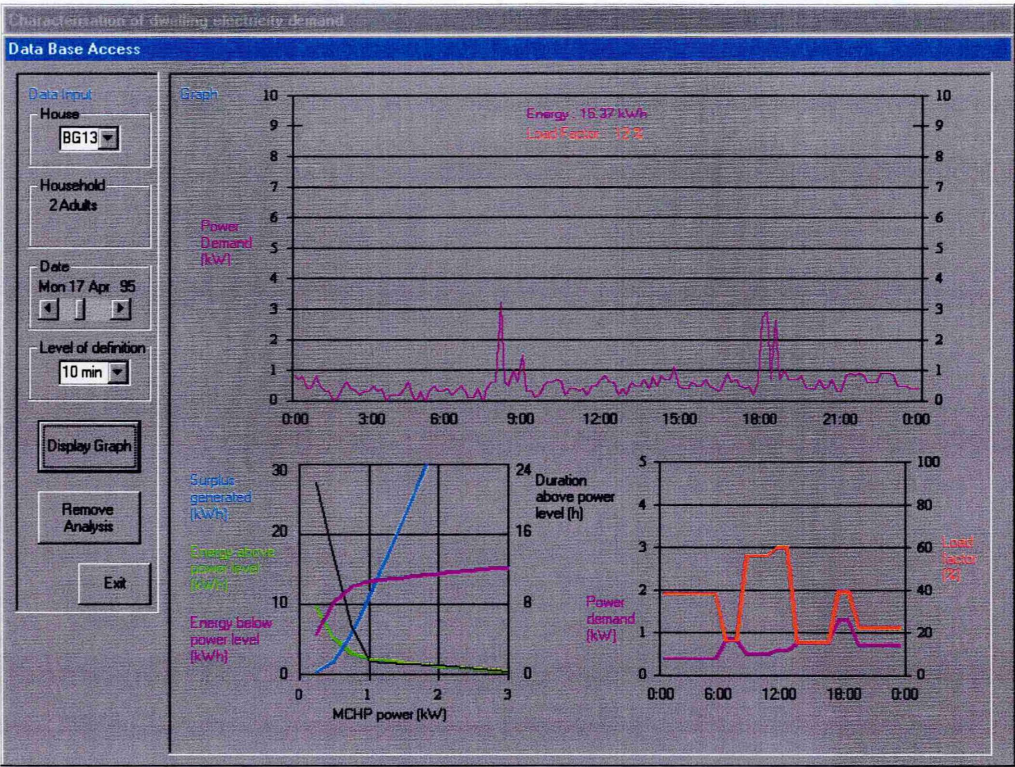


Fig. BG13 electricity consumption on 17 April 1995

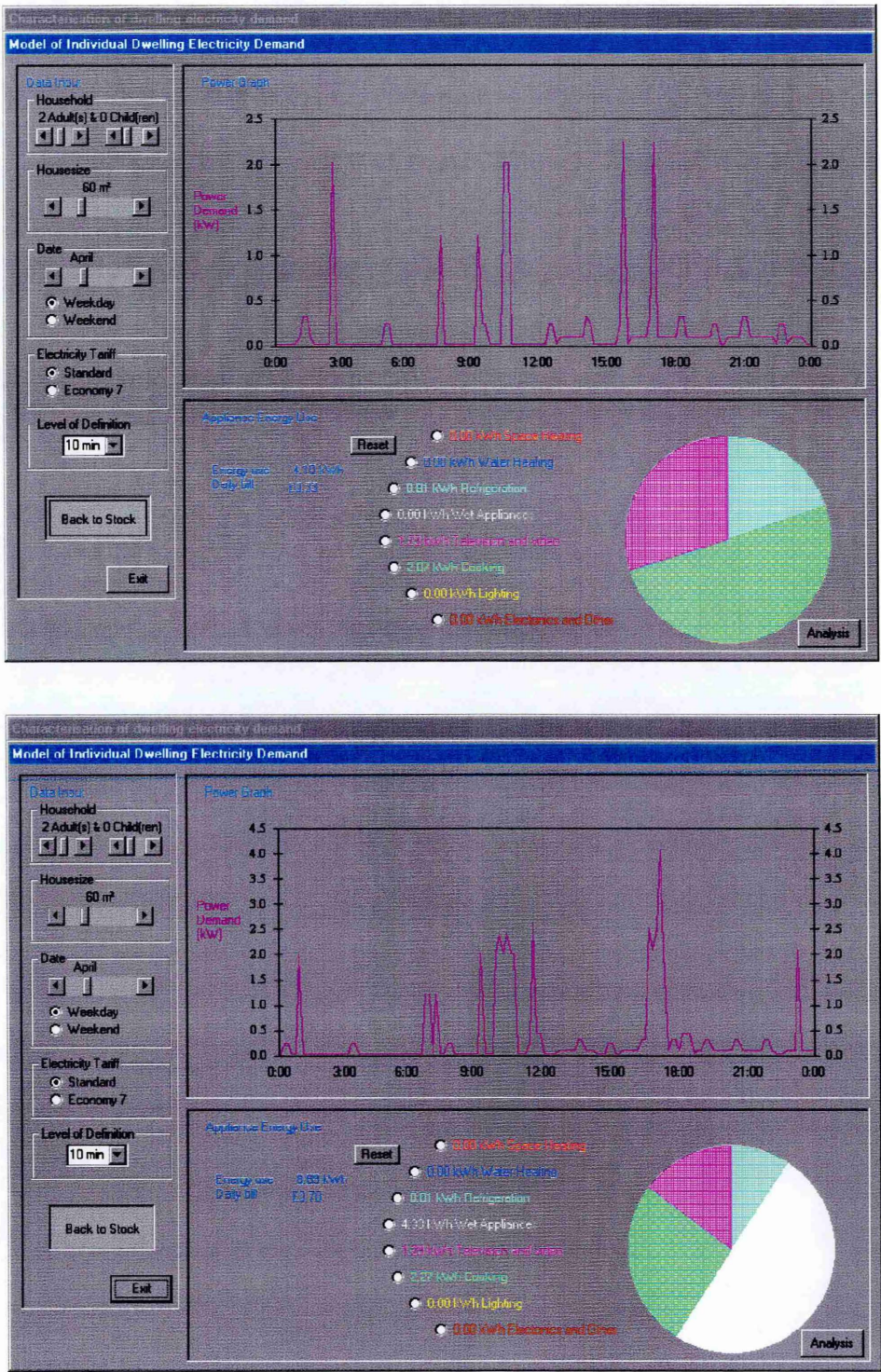


Fig. 2 adults family household simulations in April

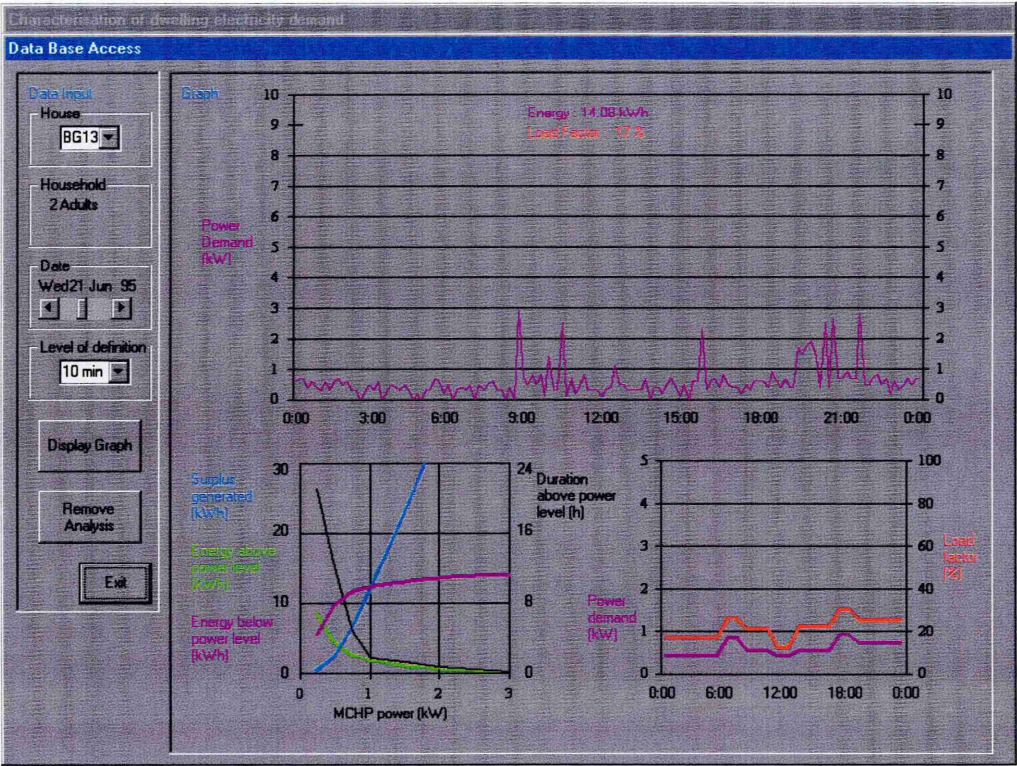


Fig. BG13 electricity consumption on 21 June 1995

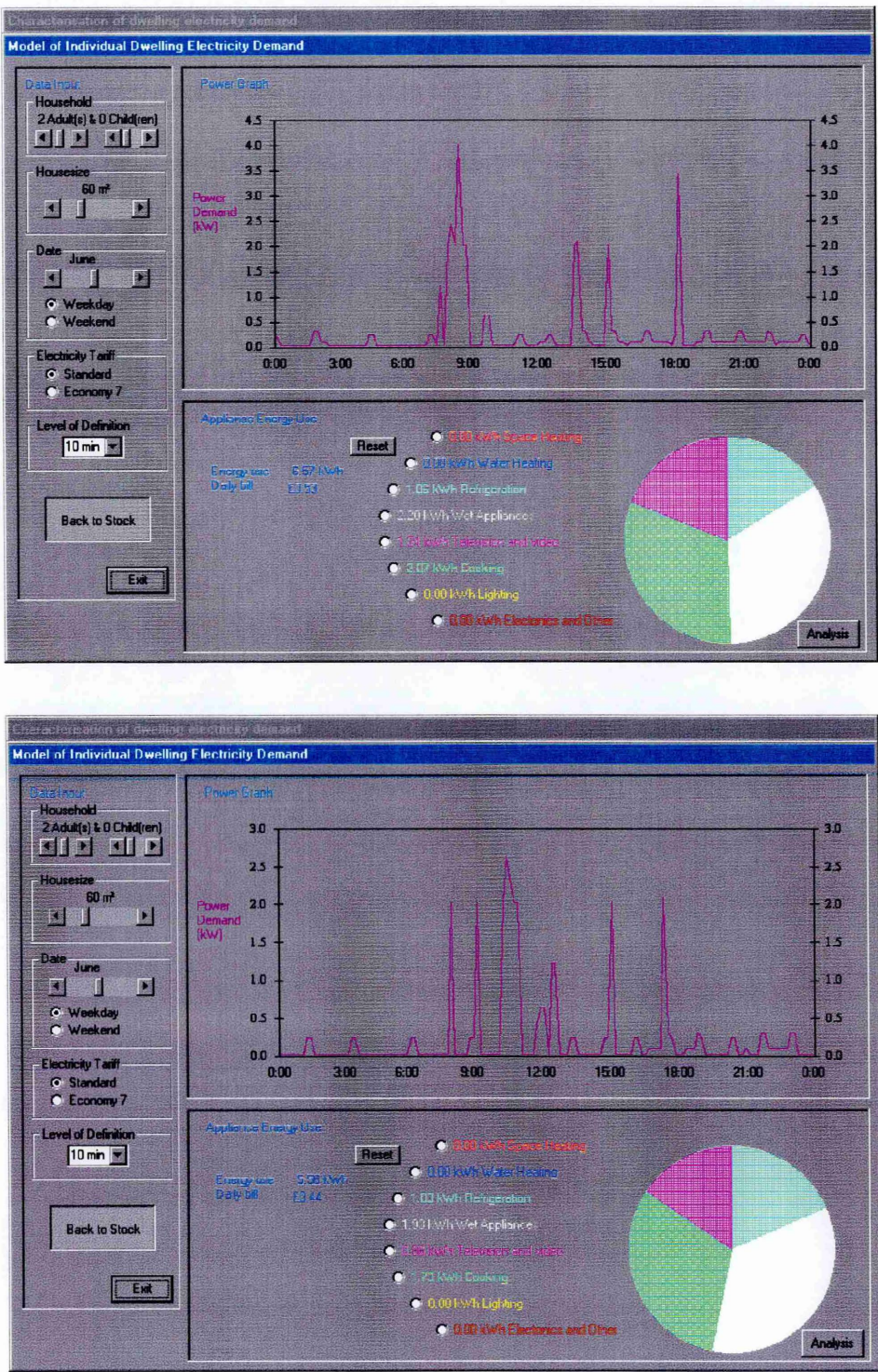


Fig. 2 adults family household simulations in June