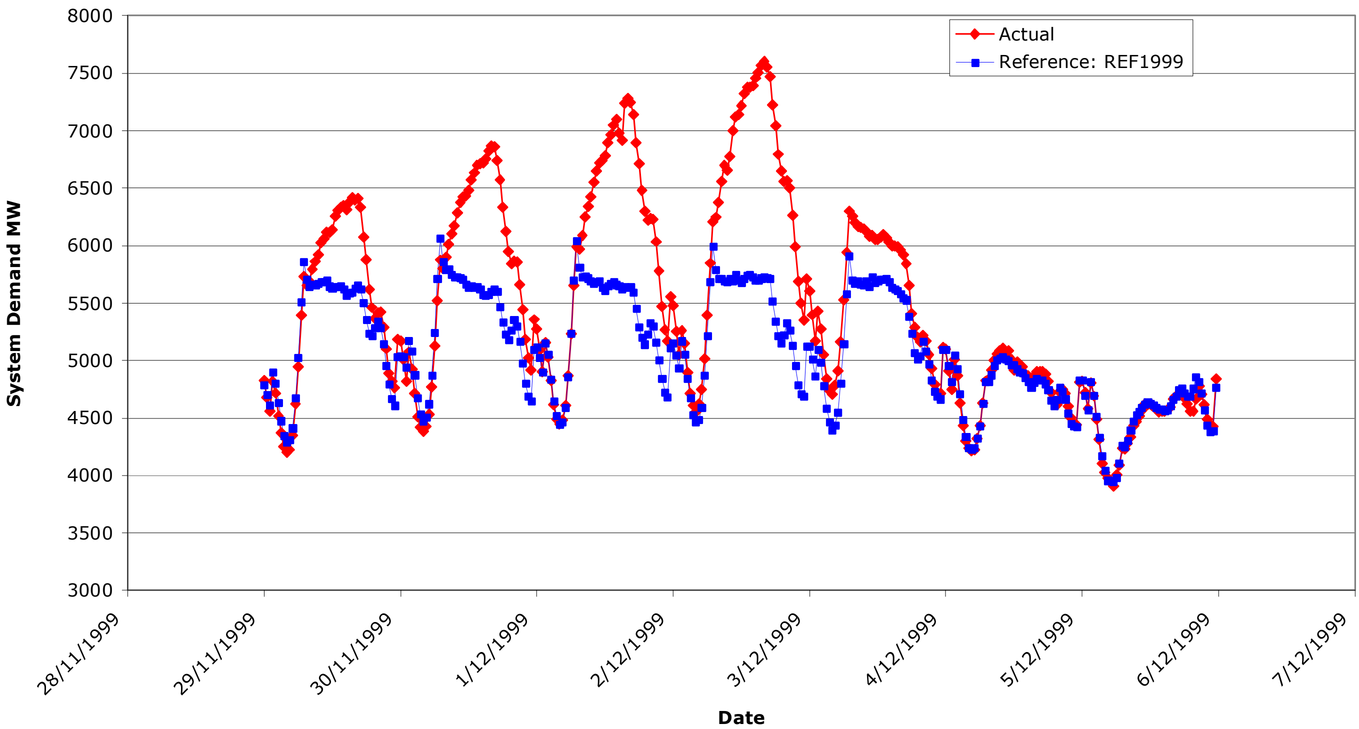
December 2004

Report for VENCORP and the Australian Greenhouse Office

Electrical Peak Load Analysis Victoria 1999 – 2003

Final Report – Version 08

Load Profile for 1 Week Period with Reference Load (no cooling)



Prepared by Energy Efficient Strategies

FOREWORD

This report was prepared by Energy Efficient Strategies under contract to The Victorian Energy Networks Corporation. Substantial contributions to the project were made from the Australian Greenhouse Office with regard to ownership, penetration and household data.

Readers should bear in mind that, while we have used the most comprehensive data available to develop our estimates, some data gaps do exist and these present limitations regarding the accuracy of some of these estimates.

Further information is available from Mr Philip Woodall, of The Victorian Energy Networks Corporation.

Energy Efficient Strategies

Warragul, Victoria

November 2004

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

ABS	Australian Bureau of Statistics
AC	Air-conditioner
AGO	Australian Greenhouse Office
BOM	Bureau of Meteorology, Australia
EES	Energy Efficient Strategies P/L
GWA	George Wilkenfeld and Associates
MD	Maximum Demand
MEPS	Minimum Energy Performance Standards
NAEEEC	National Appliance and Equipment Energy Efficiency Committee
NEMMCO	National Electricity Market Management Company
RIS	Regulatory Impact Study
SEAV	Sustainable Energy Authority of Victoria – formerly EEV
VENCorp	The Victorian Energy Networks Corporation

Electrical Peak Load Analysis

Victoria 1999 - 2003

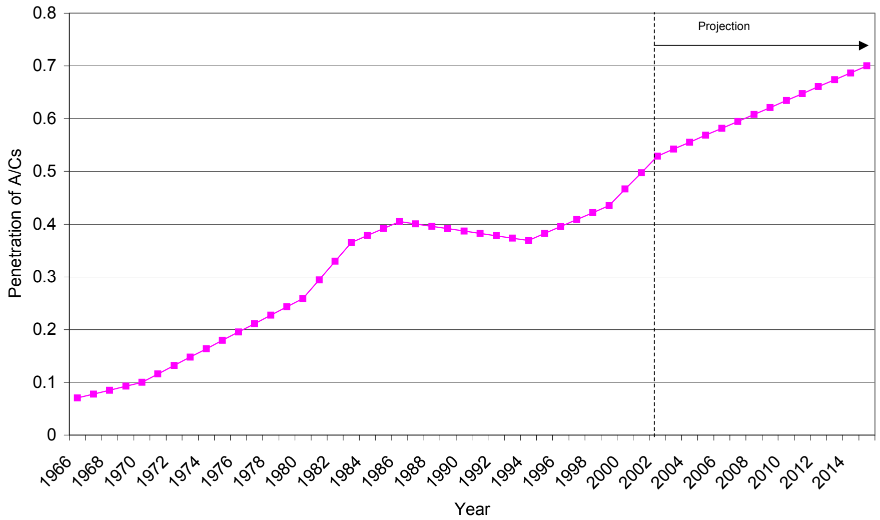
Executive Summary – January 2005

Prepared by Energy Efficient Strategies for VENCORP

BACKGROUND

From the mid 1990's, rapid increases in the penetration of air-conditioners (see Figure A), particularly in the residential sector, has resulted in Victorian peak electricity demands consistently occurring during summer. Prior to this, peak demand consistently occurred in the winter season.

- **Figure A: Penetration of Residential Air-conditioners – Victoria 1966 - 2015**



Summer system peaks invariably coincide with severe weather conditions (high temperatures). The ten highest peak demand days between 1999 and 2003 all had maximum daytime temperatures of 35^{0}C or more. Whilst other factors may be playing a part, it seems apparent that these peaks in electricity demand are being driven largely by the use of space conditioning equipment (principally refrigerative air-conditioners in the case of Victoria). Generation capacity and transmission and distribution capacity can also be reduced by extremely high temperatures, which further exacerbates the problem.

The observed increases in peak demand over the past few years present two main problems. Firstly, there is the issue of a potential impending inability of the supply system to meet extremes of peak demand without significant new investment in the electricity supply system (this is an issue for a number of states). Secondly, there is a cost factor; supply costs escalate exponentially on days of extreme peak demand because of the low utilisation of the assets to cover the short duration peaks. As a result, there may be a cross subsidy from electricity customers that do not use air conditioning to those that do. However, this report does not examine this issue.

Until approximately 2 years ago, forecasts provided by Vencorp of the critical peak (half hour) Victorian electricity Maximum Demand (MD) were usually accurate to ±2%

(+150 MW), which was considered acceptable for operational purposes. More recently however this forecast has varied by approximately ±4% and this growth in the variance is now considered unacceptable.

The purpose of this study is to help inform future planning and policy formulation designed to deal with these issues. Of particular interest was the development of a method to improve the accuracy of short term peak forecasts as well as defining options and data requirements for examining longer term likely future peak demand growth by using micro forecasting approaches and the associated factors that are likely to drive future demand.

OBJECTIVES OF THE STUDY

The objectives of this study were as follows:

1. Provide building thermal models covering the range of typical Victorian residential dwellings (houses/units/flats), including relevant parameters such as orientation, shade and proportions of total Victorian housing stock to allow use in an aggregate Victorian model, with actual weather;

2. Provide models of relevant appliance use/occupant behaviour for residential buildings relating to period from 1 November through 31 March, essentially the Victorian daylight saving period.

3. Define weather parameters needed, including period for modelling;

4. Calibrate the model and backcast over the last 4 years to demonstrate a likely stable model for residential temperature sensitive component of Victoria's maximum demand;

5. Provide an assessment of one (or up to 3) scenario/s of likely change in the next 10-15 years in the points 1 and 2 above, particularly in light of the 5 star government initiatives. At least one scenario could include the future AC unit sales econometric model outlined above.

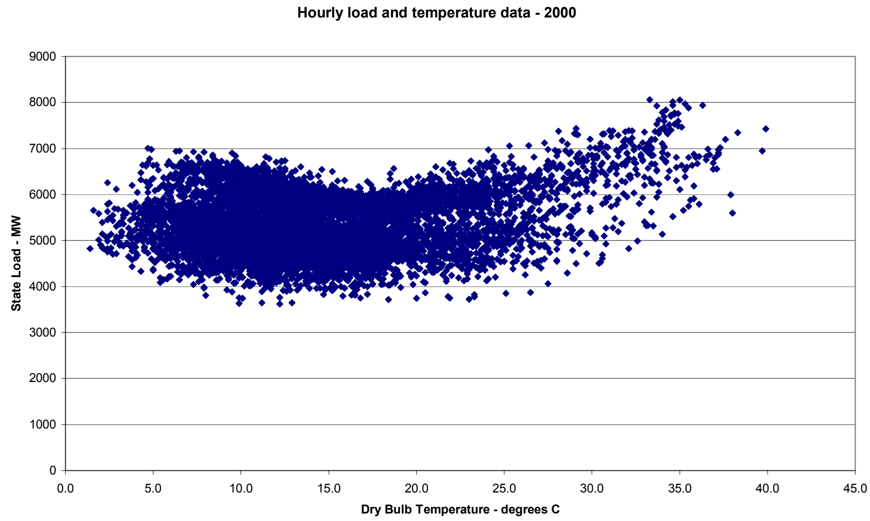
The project was originally envisaged in two stages; the first was the establishment of a methodology to model peak system loads on hot days while the second was using this model to examine long term potential impacts of air conditioners on system peak loads, taking into account a range of factors such as trends in ownership, population growth and building shell design. This report primarily fulfils objectives 1 to 4. Some work towards objective 5 has been undertaken as part of this report, but further work will be required to fully quantify these future scenarios. This report is being finalised and published in the interest of documenting the work done to date prior to the forthcoming summer peak period.

STUDY METHODOLOGY - OUTLINE

Analysis of weather and load data from 1999 – 2003 revealed that simple correlations of temperature (either hourly or daily maximums) are a poor basis for predicting system peak loads, even when day of the week and holidays are taken into account. There is a clear trend in terms of the load impact of temperature (both high and low), but the demand range for any particular temperature is huge – see Figure B for the year 2000, other years analysed show a similar pattern.

There are clearly a range of other factors that affect cooling (and heating) load in addition to temperature: these are solar radiation, wind and humidity and user behaviour (eg occupancy, socio economic factors, holidays, day of the week). There is no simple way to take into account these factors for particular days in the future.

• **Figure B: Hourly load versus temperature - 2000**



This study explored the possibility that a modelling tool based upon building thermal performance, housing data and appliance stock modelling could provide a reasonably accurate tool for predicting the magnitude of peak loads. The tool used existing peak load data provided by VENCORP from the summers of 1999 – 2000 to 2002 – 2003 to trial the method and hourly weather data for the period was also compiled.

The demand modelling tool consisted of two main components that contribute to the total state load:

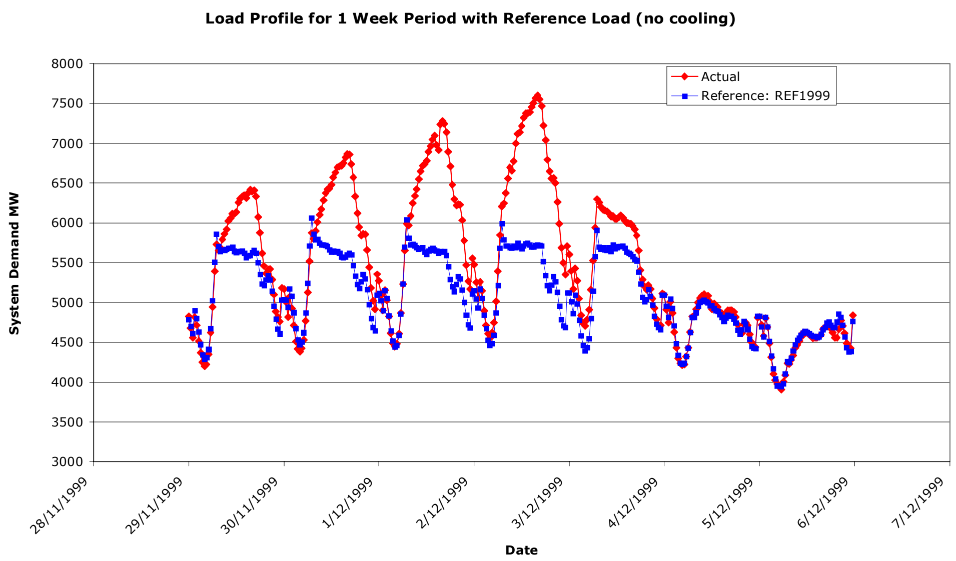
- The weather insensitive component (ie the base load) and,
- The weather sensitive component (ie in summer, the load associated with space cooling)

ESTIMATING THE WEATHER INSENSITIVE COMPONENT OF THE LOAD

The approach used was to examine load data and to select a so called “reference” period during each summer where there was no obvious peak load activity due to air conditioning (see Figure C). Once a reference was selected, it was then possible to compare peak days to the reference days to provide an initial estimate of the magnitude of the air conditioner (weather sensitive) load on the system.

This approach is empirical in nature and quantifies the effect of all temperature sensitive loads on the electricity system, not just residential and commercial air conditioner loads. However, this approach appears to provide a sound starting point for further analysis and allows days of interest to be identified for more detailed building shell modelling and analysis.

• Figure C: Load Profile for 1 Week Period with Reference Load (no cooling)



ESTIMATING THE WEATHER SENSITIVE COMPONENT OF THE LOAD

The model developed utilized a building shell thermal performance modelling tool (AccuRate) to predict residential cooling loads (at a household level). AccuRate is the new building shell analysis tool developed by CSIRO under contract to the Australian Greenhouse Office for use in the National Home Energy Rating Scheme (NatHERS). The AccuRate module required two main inputs:

- Input based on the design and construction characteristics of a representative (reference) house.
- Input based on weather data specially prepared for the study period.

Alternative occupancy scenarios were set up for this study. The AccuRate program was then run and output data for both cooling load and internal temperature was extracted from the output files. This was then weighted to account for the different occupancy scenarios and zoning factors estimated to apply in the stock of Victorian housing.

The hourly weighted cooling loads for the reference house were then scaled and weighted to provide an estimate of the temperature sensitive component of the state demand. The factors applied to convert Accurate output to state level demand were:

- Total households in the state
- Penetration of air conditioners in housing
- The average efficiency of the installed air-conditioners
- The “Utilization” factor to account for user behaviour that will tend to constrain the actual hours of operation of the space cooling appliance.
- The “Commercial sector” factor to account for the commercial sector contribution to the total space conditioning related cooling load.

In the analysis, those days that were either public holidays and or summer school holidays were excluded from consideration. In general the model tended to overestimate the magnitude of the peaks on these days, which clearly was a function of changed occupancy factors.

KEY FINDINGS OF THIS STUDY

THE NATURE OF THE WEATHER SENSITIVE COMPONENT OF MAXIMUM DEMAND

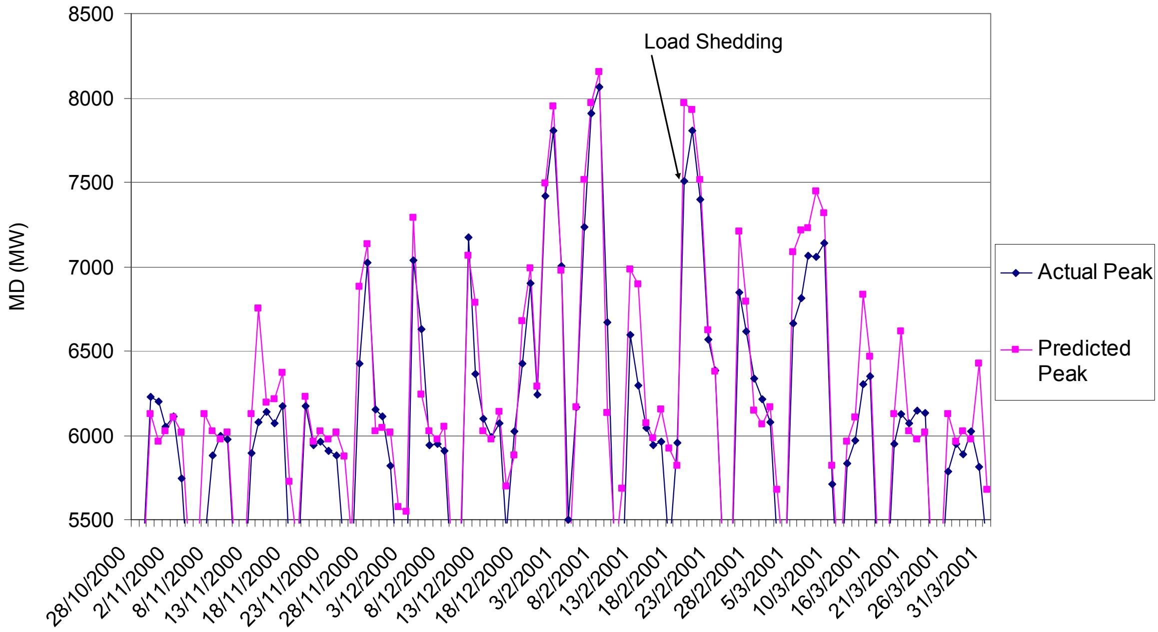
- Simple correlations of temperature (either hourly or daily maximums) are generally a poor basis for predicting system peak loads, even when day of the week and public holidays are taken into account.
- The vast majority of the weather sensitive component of the state peak load appears to be driven by the residential and small commercial users. However, this peak increase and sensitivity is clearly tempered somewhat by larger commercial loads and industrial loads, many of which are likely to be less temperature sensitive.
- Following a protracted period of hot weather (and associated high cooling loads) once the net cooling load increase falls below about 500MW, the residential load component is somewhat lower than the state load on these days (in a relative sense). This suggests that some of the larger commercial centres continue to have an elevated cooling load requirement after a sustained period of hotter weather.

THE MAXIMUM DEMAND PREDICTION MODEL

- Generally the maximum demand prediction model developed by EES closely tracked the actual peak load especially on days of maximum peak demand – see Figure D.

- On days of minor peaks (< 500MW above base level) the EES model tended to overestimate the peak loads. Whilst these peaks are not of great interest in terms of forecasting future capacity requirements (but they may be of some interest for the purposes of system control), it may be possible to improve the accuracy of prediction of these lower peaks by undertaking further refinements to the model, especially the utilization factor.

• Figure D: Actual Peak Load V Predicted Peak Load – Summer 2000 - 2001



- Of the 453 days simulated between 1999 and 2003, 19 of those days had underestimates of MD that exceeded 250MW. Only six of these underestimates occurred on days when the MD exceeded 7000MW and 5 of these occurred immediately after a cool change.
- In the critical peak load range (above 7000MW) the EES model could predict peak loads to an accuracy of approximately +200MW (+3%) to –400MW (-6%). This accuracy estimate excludes days of cool change which are typically at the lower end of the MD days (< 7400 MW).
- On the ten days of highest MD (excluding 29/1/ 2003 which was found to be anomalous – see Table A) the accuracy of the model was found to be +194MW (+2.5%) to – 280MW(-3.5%).

- **Table A: Ten Days of Maximum Peak Demand (in order high to low) – 1999 – 2003**

Date	Day	Max External Temp (C)	Peak Demand (MW)*	Variation Actual to Predicted (MW)	Error
24/2/2003	Monday	34.5	8193	-280	3.4%
29/1/2003[1]	Wednesday	36.8	8129	527	-6.5%
8/2/2001	Thursday	36.3	8066	-90	1.1%
4/2/2003	Tuesday	35.3	8043	53	-0.7%
7/2/2001	Wednesday	35.5	7909	-63	0.8%
2/3/2000	Thursday	35.7	7839	194	-2.5%
2/2/2001	Friday	34.9	7807	-143	1.8%
20/2/2001	Tuesday	34.9	7804	-125	1.6%
14/2/2002	Thursday	35.1	7633	-143	1.9%
3/2/2000	Thursday	38.8	7627	-181	2.4%
15/2/2002	Friday	35	7617	61	-0.8%

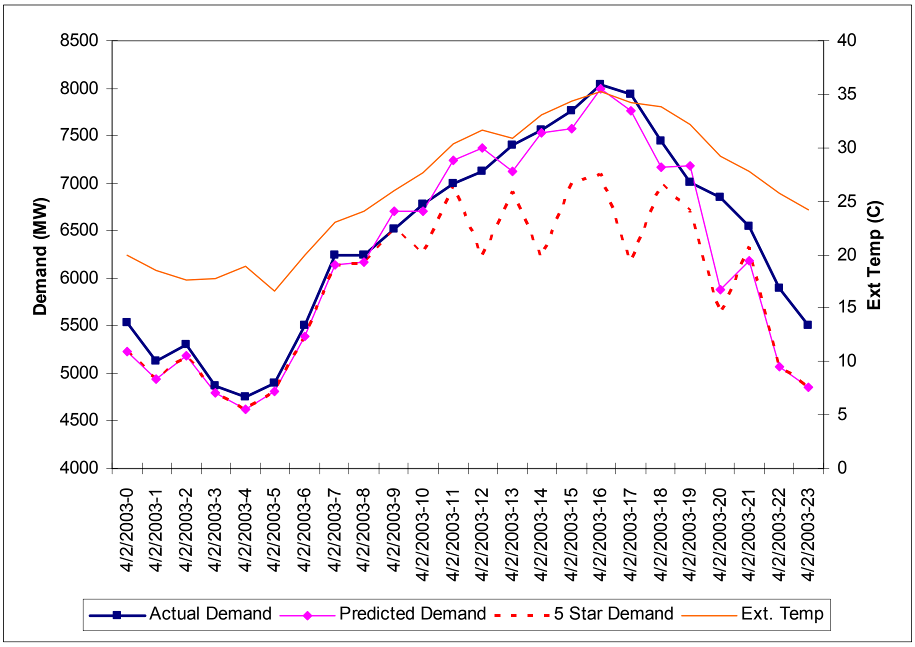
Note 1: Whilst the School holiday period officially ended on the previous day it is thought that most private schools did not go back until later that week. This would have left a significant number of dwellings occupied when normally they would not have been occupied. In reality this day should possibly have been excluded from the study period on the basis that it forms part of the holiday period (at least for a significant portion of the population).

LIKELY IMPACTS OF HIGHER PERFORMANCE BUILDING SHELLS

As part of this study a preliminary assessment was made of the likely impacts on daily maximum summer demand that would result from the widespread adoption of a 5 star building shell performance standard (as introduced for new housing to be built in Victoria after 30 June 2004).

Comparing the predicted MD levels as modelled for the 40 days of highest demand in the study period, it was found that on average the application of the 5 star standard (to the entire stock) reduced the MD by 533MW. The greatest reduction in MD was observed on 4/2/2003 (the 4th highest MD in the study period) where the reduction was almost 900MW or more than 11% of the MD – see Figure E.

Figure E: Comparison of Standard Reference House and 5 Star Reference House – 4/2/2003



CONCLUSIONS

The main conclusions from this study are:

- Simple correlations of temperature (either hourly or daily maximums) are a poor basis for predicting system peak loads, even when day of the week and holidays are taken into account.
- Generally the MD prediction model developed by EES for this study closely tracked the actual peak load especially on days of maximum peak demand.
- Accuracy of the model is reasonable but could be improved with additional work in the following areas:
  - *Reference House*: Development of a more comprehensive suite of reference buildings (including commercial buildings) to more accurately represent the stock both now and in the future.
  - *Evaporative cooling*: Develop a more representative model to account for those buildings serviced by evaporative coolers.
  - *Zoning*: Further research would be required to more accurately estimate constraint levels for different space cooling configurations
  - *Utilization factor*: The utilization factor is based on a relatively simple function and its accuracy is limited, especially on days of low to moderate cooling demand. Further refinement of this factor may result in a more complex function that could more accurately account for user behaviour.
  - *Cool Change*: A function needs to be developed to more accurately model load patterns following a cool change
- In order that the model could be used for longer term predictions of MD additional work would be required both in the areas noted above as well as in:
  - *Reference Week*: Long term projection of the weather insensitive component of the load
  - *Occupancy:* Real data derived from ABS surveys could improve the accuracy of the model. More importantly such data collected over time would assist in making accurate predictions that account for likely trends in occupancy rates.

RECOMMENDATIONS

The following recommendations have been prepared for consideration by VENCORP in order to refine and implement the outcomes of this study.

AREAS OF FURTHER RESEARCH

It is recommended that VENCORP commission the following broad areas of research to improve the body of knowledge in selected critical areas with regard to air conditioning:

- Evaporative cooling systems – undertake selected research into the practical performance and impact on peak load of evaporative systems relative to refrigerative systems
- Examine the impact of cool changes on system peak loads as they move across the state and examine whether other data sources or techniques can possible improve peak load predictions (such as prediction models from CSIRO)
- Undertake selected end use load monitoring to establish the relationship between weather and air conditioner loads in a number of real households to improve modelling assumptions (especially with respect to occupancy and zoning effects/assumptions)
- Establish key variables of importance with regard to air conditioning demand and the role of correlation analyses can play based on the existing data sets
- Investigate options and possibly develop suitable outputs from existing thermal modelling systems for large commercial buildings that may better reflect the temperature sensitive load impacts of this segment.

TRANSFER OF THE MODELLING OUTCOMES TO VENCORP

It is recommended that EES undertake further work with VENCORP to transfer the key outcomes of the research to date and to ensure that VENCORP are able to develop the most practical and accurate peak load prediction system possible as a result of this work in the short term:

- Development of generic weather types such as single hot days, increasing heat, decreasing heat, high wind events, examine variations of solar radiation
- Generation of building cooling load demands based on generic weather patterns
- Work with BOM to establish practical forecast options for short term weather for key variables
- Establish stable reference load shapes for mild weather by day of the week, including the impact of holiday periods, which can be adjusted year to year through natural load growth
- Work with VENCORP to build a practical short term daily peak load model based on short term weather forecasts and known base load information (day of week and holidays) together with changes in household numbers and air conditioner ownership trends from year to year and which can interface with their normal forecasting systems.

REFINEMENTS TO THE MODELLING SYSTEM DEVELOPED BY EES

It is recommended that the following improvements to the EES modelling system be commissioned on a coordinated basis as part of future work on this project:

- Refinement and adjustment of the AccuRate model to reduce or eliminate load cycling on an hourly basis during peak days to better assess the longer term impact of efficient building shell designs
- Incorporation of a large commercial building simulation module if this proves to be feasible
- Incorporation of an evaporative cooling simulation module based on further research into this technology type
- Development of a cool change function to more accurately model demand immediately following a cool change, based on the additional research into this effect and possible prediction systems
- Possible segmentation of the building shell simulation model into several climatic regions within the state (provided the necessary data files are available from the BOM) if this improves overall system predictions.

UNDERTAKE LONG TERM SCENARIO ANALYSIS

VENCORP should commission EES to undertake selected scenario analysis to examine the longer term impact of a range of issues on peak system demand:

- Increases in air conditioner ownership
- Impact of increasing or decreasing the share of evaporative systems
- Impact of building trends (size of homes and trend towards whole house conditioning, ducted systems)
- Trends in occupancy and zoning
- Trends in air conditioner efficiency (as a result of MEPS and other energy efficiency programs)
- Impact of building shell efficiency on likely long term peak load impacts
- Options for load control to limit peak demands (peak load clipping)

ABOUT THIS STUDY

This executive summary report was prepared by Energy Efficient Strategies under contract to The Victorian Energy Networks Corporation (VENCORP). Substantial contributions to the project were made from the Australian Greenhouse Office with regard to modelling, ownership, penetration and household data. The main report titled, *"ELECTRICAL PEAK LOAD ANALYSIS –VICTORIA 1999-2003"*, is available from VENCORP.

Readers should bear in mind that, while we have used the most comprehensive data available to develop our estimates, some data gaps do exist and these present limitations regarding the accuracy of some of these estimates.

Further information is available from Mr Brett Wickham, of The Victorian Energy Networks Corporation, Melbourne.

1. Introduction

1.1 Background

It is the responsibility of VENCorp to provide short run (1-7 days) and long run forecasts (up to 15 years) of Victorian electricity and gas demand on the respective transmission networks. Historically these forecasts have been produced separately, although they may have been based on econometric studies sharing a common macro economic growth forecast, and/or household appliance surveys. More recently there has been less emphasis on household appliance surveys overall, but quarterly sales of air conditioners (AC), including for use in commercial premises, have been included in electricity peak (half hour) demand forecasts.

Rapidly increasing Victorian AC penetration from 1990 has resulted in Victorian peak electricity demands consistently occurring during summer from 1997, compared to being consistently occurring in winter prior to 1989. Victorian daily electricity energy consumption remains typically lowest for the year in summer, highest in winter and intermediate in spring and autumn.

Until approximately 2 years ago, forecasts provided of the critical peak (half hour) Victorian electricity Maximum Demand (MD) were usually accurate to ±2% (+150 MW), which was considered acceptable for operational purposes. More recently this forecast has varied by approximately ±4%, and this growth in the variance is now considered unacceptable. VENCorp is now seeking to improve the forecasting process using micro forecasting approaches.

Most recently, summer MD forecasts have been assessed as the total of temperature sensitive and insensitive components, where AC dominated the temperature sensitive component: Forward forecasts of sales/installation of AC units has been modelled econometrically, mainly depending on:

- Average temperature of the previous summer;
- Historical AC unit stocks;
- Household disposable income (ability to purchase new AC); and
- A relevant building index, reflecting housing starts.

The AC component of MD has been forecast based on the Melbourne (Bureau of Meteorology) CBD daily average temperature (ie average of overnight minimum and daily maximum) of the day being forecast and the previous day, amalgamated to an equivalent single day average temperature. This forecast is only considered for Monday-Friday, excluding the five weeks from just before Christmas to end of January, when electricity demand patterns are materially different from other summer weekdays. This report provides an alternative approach to forecasting system peak loads for Victoria (to that described above) based on a modelling of likely user behaviour to particular weather events.

1.2 Motivation for this Report

Capacity shortfalls or several system operation problems on days of extreme temperature have occurred in some systems in the past few years (eg Perth in early 2004, Queensland for past few summers in addition to Victoria). In the absence of significant new generating capacity being brought on-line in the next few years such occurrences are likely to increase.

Summer system peaks invariably coincide with severe weather conditions (high temperatures). The ten highest peak demand days between 1999 and 2003 all had maximum daytime temperatures of 35C or more. Whilst other factors may be playing a part, it seems apparent that these peaks in electricity demand are being driven largely by the use of space conditioning equipment (principally refrigerative air-conditioners). Generation capacity and transmission and distribution capacity can also be reduced by extremely high temperatures, which further exacerbates the problem.

Air-conditioners are principally used in the commercial and residential sectors in Victoria. Statistics on the penetration of air-conditioners in the commercial sector are not readily available, but in the residential sector, ABS statistics indicate that currently there are approximately 1 million households in Victoria with some form of space cooling appliance installed. This represents a significant increase in stock penetration from 1999 when the number of households with space conditioning equipment was approximately 750,000 (approximately a 10% increase in stock per year).

The average cooling input power of the stock of residential air conditioners is estimated at 1.9kW (based upon registrations of air-conditioners in Australia for energy labelling since 1990). This means that the potential weather related load associated with the residential sector space cooling equipment alone is in the order of 2000 MW (if all installed air conditioners were running at rated output). This capacity equates approximately to the increase in required generating capacity observed on the hottest days over the past 5 years. Of course part of this additional load will be coming from commercial sector air conditioners and other weather sensitive components of the load (eg refrigeration). In each of these sectors the “use factor” (ie the proportion of A/C units actually in operation at any one time) is expected to be less that 100% (especially in the residential sector where a proportion of dwellings are likely to be unoccupied typically during week days[1] at the time of the system peak which typically occurs in the mid afternoon).

[1] Whilst a property may be unoccupied that does not necessarily mean that its air-conditioning system will not be kept in operation. Some building owners may choose to maintain the operation of their space conditioning equipment in their absence (especially on the hottest of days) so as to ensure acceptable comfort conditions immediately upon their return. This practice is thought to be most common amongst the higher socio economic groups, however the relatively low cost of electricity would mean that a broad section of the community may in fact choose this option. Remote access controls are now also available to activate air conditioners via internet or phone lines.

The observed increases in peak demand over the past few years present two main problems. Firstly there is the issue of a potential impending inability of the supply to meet extremes of peak demand without significant new investment in the electricity supply system (this is an issue for a number of states). Secondly there is a cost factor; supply costs escalate exponentially on days of extreme peak demand because of the low utilisation of the assets to cover the short duration peaks. Whilst this cost is driven largely by those who own and operate space cooling equipment for maybe only a few hours a year, it is borne by all who use the electricity supply and this represents a substantial cross subsidy from users who do not have air conditioning to those that do have air conditioning (and contribute to the peak system load). This issue is not investigated in this report.

The purpose of this study is to help inform future planning and policy formulation designed to deal with these issues. Of particular interest is the development of a method to improve the accuracy of forecasts of likely future peak demand levels (short term and long term).

1.3 Project Scope, Aims and Objectives

The primary aim of this project is to:

> ***Assist VENCorp to better fulfil its Victorian peak electricity demand forecasting responsibility***

The specific objectives were to:

1. Provide building thermal models covering the range of typical Victorian residential dwellings (houses/units/flats), including relevant parameters such as orientation, shade and proportions of total Victorian housing stock to allow use in an aggregate Victorian model, with actual weather;
2. Provide models of relevant appliance use/occupant behaviour for residential buildings relating to period from 1 November through 31 March, essentially the Victorian daylight saving period.
3. Define weather parameters needed, including period for modelling;
4. Calibrate the model and backcast over the last 4 years to demonstrate a likely stable model for residential temperature sensitive component of Victoria's MD;
5. Provide an assessment of one (or up to 3) scenario/s of likely change in the next 10-15 years in the points 1 and 2 above, particularly in light of the 5 star government initiatives. At least one scenario could include the future AC unit sales econometric model outlined above.

The project was originally envisaged in two stages; the first was the establishment of a methodology to model peak system loads on hot days while the second was using this model to examine long term potential impacts of air conditioners on system peak loads, taking into account a range of factors such as trends in ownership, population growth and building shell design. This report primarily fulfils objectives 1 to 4. Some work towards objective 5 has been undertaken as part of this report, but further work will be required to fully quantify these future scenarios.

This report is being finalised and published in the interest of documenting the work to date prior to the forthcoming summer peak period.

1.4 Approach to Project

1.4.1 Overview

The following steps represent the overall approach to this project. This report covers many of these steps, although some of the longer term scenario work is to be completed at a later stage.

- Establish current and projected household numbers for Victoria;
- Establish current and future ownership and stock of air conditioners by type of air conditioner in Victoria to at least 2010;
- Obtain half hourly weather data (temperature, solar radiation, wind speed and direction, humidity etc. in Australia Climate Databank format) for Melbourne for the period 1998 to 2003;
- Select a range of representative houses for Victoria and have these in a format suitable for building shell modelling (several house types were modelled for this report);
- Establish attributes of the housing stock in Victoria in terms of average house size, insulation levels and construction type that affects energy performance (brick, lightweight, suspended floor, slab etc) together with trends to 2010 (this work is to be undertaken at a later stage);
- Examine half hourly state load electricity data supplied by VENCorp and identify peak load events that are of particular interest over the period 1998 to 2003;
- Examine load data for selected residential load points and the Melbourne CBD for selected periods;
- Use the new generation of house modelling software called AccuRate (developed by CSIRO) to simulate hourly cooling load demand for the range of representative houses selected;
- Weight the simulation cooling load data for selected house types by a range of factors such as air conditioner ownership, size limits, occupancy factors, plant efficiency and the prevalence of each type of housing in Victoria to examine the potential contribution of cooling to system peak loads. While this approach would also be used for longer term scenario analysis, the report focuses on the impacts over the period 1999 to 2003 where detailed weather data was available;
- Further analyse the data to establish the primary and secondary factors that may influence the residential peak electricity load (eg day of the week, other occupational factors such as holidays, state electricity restrictions on peak days); and

- Reconcile November to March Victorian half hourly temperature sensitive residential electricity demands, determined by the above process, against the difference of actual total, and assessed commercial, Victorian half hourly temperature sensitive electricity demands.

1.4.2 Data Sources

The following data sources were used for this project:

- Half hourly load data provided by VENCORP for state July 1998 to June 2003.
- Half hourly load data provided by VENCORP for selected load points for December 2002 to February 2003. This data is comparable to (although not identical to) publicly available state load data published by NEMMCO (2004).
- Weather data for Melbourne airport 1999 to 2003 purchased from the Australian Bureau of Meteorology.
- EES stock modelling files that provide estimates of households, population and air conditioner ownership for the period 1980 to 2010, based on various reports and documents from the Australian Bureau of Statistics.
- A number of reference house building shells for use in simulations prepared by EES for this project.
- Modelling software AccuRate from CSIRO, which has been used with permission from the Australian Greenhouse Office.

1.5 Project Team and acknowledgments

This study was undertaken by Energy Efficient Strategies (Victoria) for The Victorian Energy Networks Corporation (VENCORP)

The study was conducted by Lloyd Harrington and Robert Foster of Energy Efficient Strategies.

A number of organisations were contacted during the project and their cooperation and assistance is gratefully acknowledged. We would like to particularly thank staff of the following organisations:

- CSIRO: Mr Angelo Delsante
- Bureau of Meteorology, Climate Data Centre

Notwithstanding the individuals and organisations that have assisted during this project, the content and form of this report, and all of the views, conclusions and recommendations expressed in it, are those of Energy Efficient Strategies.

2. Project Results

This section sets out the key results to date of the project commissioned by VENCorp. The key results discussed in this section are:

- Peak load analysis of Victorian state load data from 1999 to 2003;
- Examination of factors that appear to influence peak load including weather data;
- Analysis of load data for selected load supply points in Victoria;
- Correlation options for estimation of load data;
- Development of a more sophisticated load prediction tool by EES for this project.

Later sections of this report set out weather data, load data analysis and the software tools used in more detail.

2.1 Peak Load Data Analysis - Correlations

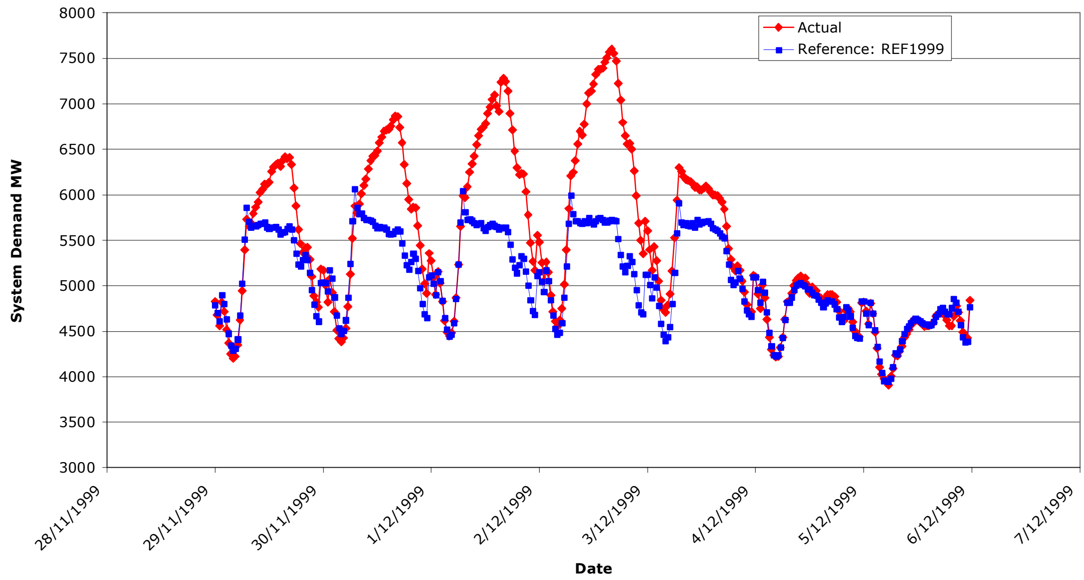
The approach used for this project was to examine load data and to select a so called "reference" period during each summer where there was no obvious peak load activity due to air conditioning. Once a reference was selected, it was then possible to compare peak days to the reference days to provide an initial estimate of the magnitude of the air conditioner (weather sensitive) load on the system.

This approach is empirical in nature and quantifies the effect of all temperature sensitive loads on the electricity system, not just residential and commercial air conditioner loads. However, this approach appears to provide a sound starting point for further analysis and allows days of interest to be identified for more detailed building shell modelling and analysis.

The full details of the reference periods selected for each year and the periods of interest with respect to peak loads in the period 1999 to 2003 are fully documented in Appendix A.

As an example, the actual load compared to the reference load (half hourly) for the week of 28 November 1999 is shown below (see Figure 1)

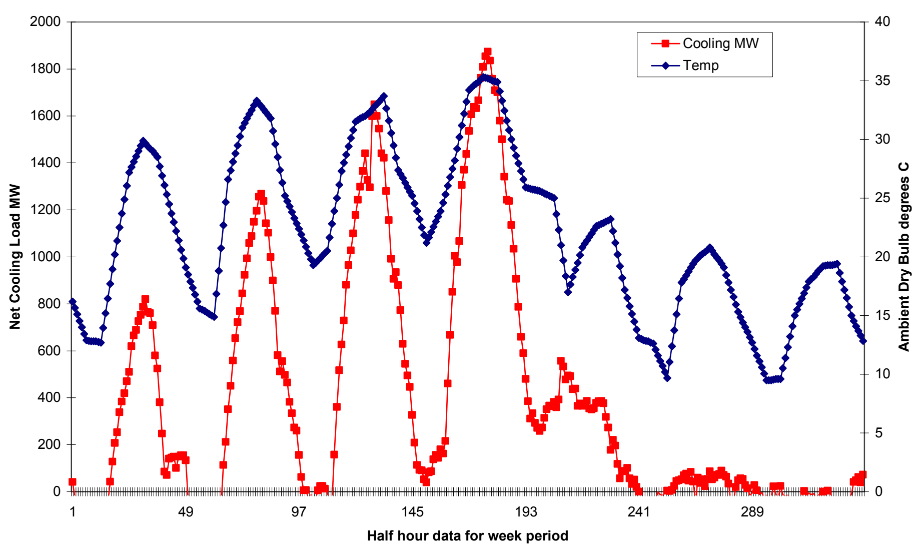
Figure 1: Load Profile for 1 Week Period with Reference Load (no cooling)



The cooling related load is the difference between the actual load profile (red curve) and the reference load (blue curve).

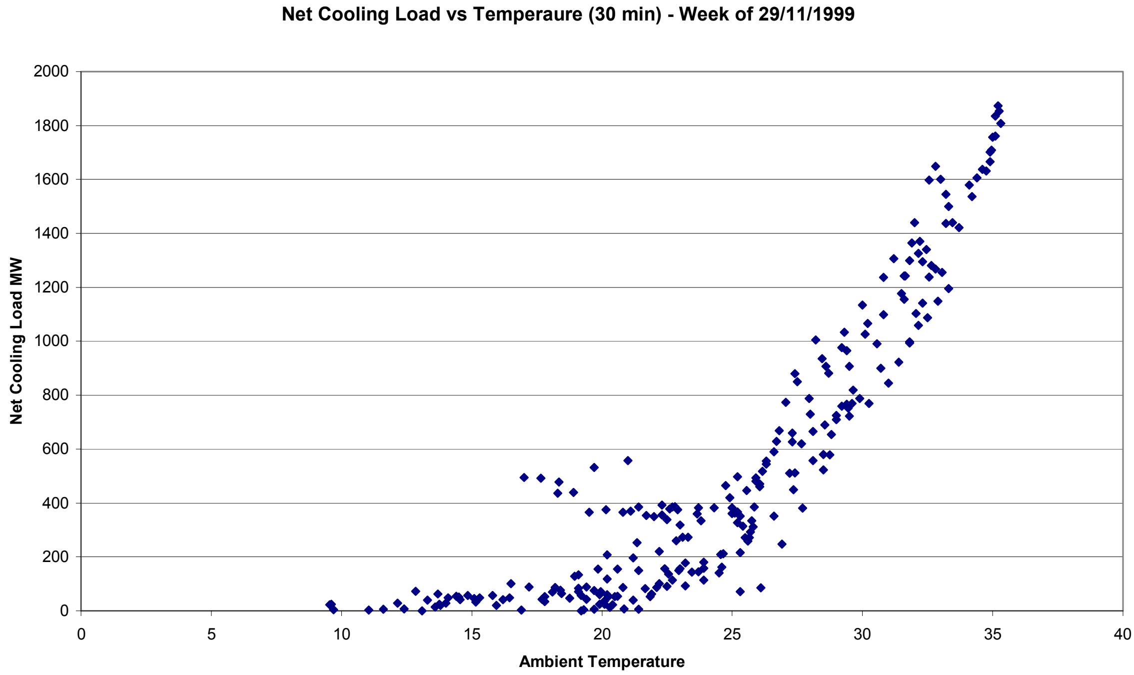
This same week can be examined in terms of net cooling load (difference between actual and reference load for the state) and a trace of hourly temperature for the same period.

Figure 2: Net Cooling Load vs Temperaure (30 min) - Week of 29/11/1999



The cooling load for this period is clearly correlated to temperature. This style of analysis was undertaken on every week for the analysis period. When the temperature versus load data for the week is examined, a clear temperature and net cooling load relationship is shown. However, because this week was consistently hot, this visual correlation is substantially better than for many other weeks examined over the period of interest. The system load response to weather is rather more complex and appears to also depend on a range of factors such as wind speed, solar radiation, humidity, temperature of previous day (duration of the hot sequence of days) and overnight minimum temperatures.

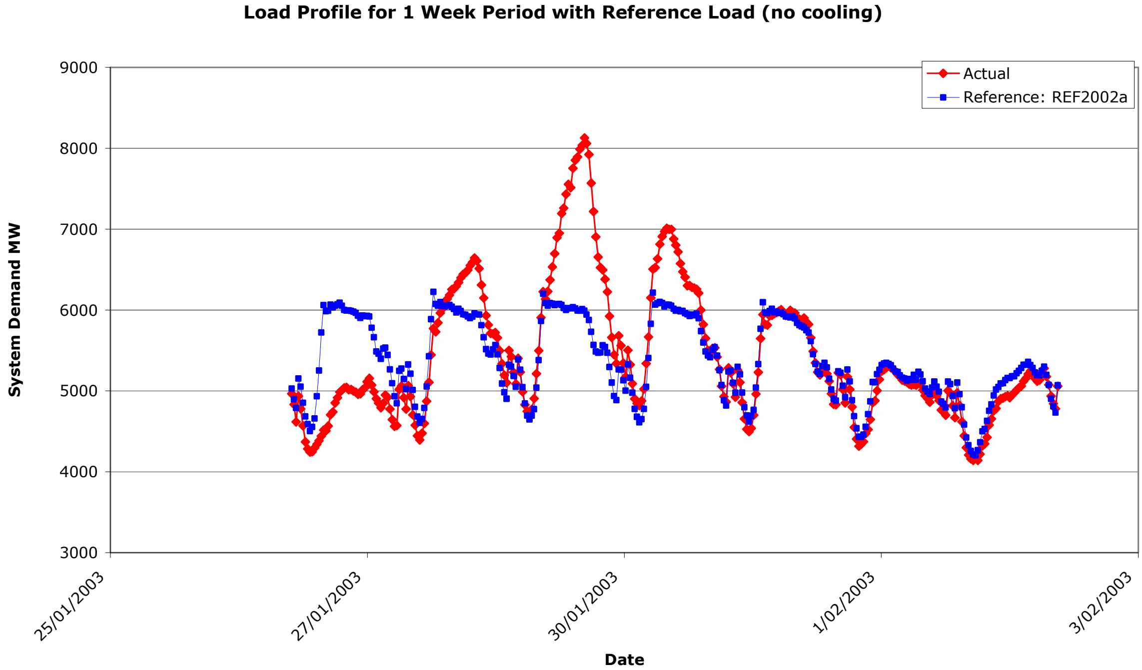
Figure 3: Net Cooling Load vs Temperaure (30 min) - Week of 29/11/1999



Even in this very consistent week, there is still a variation of up to 600MW (10% of state load) or more for any particular temperature during this period (see Figure 3). The system cooling load clearly depends on time of day and the temperature of previous hours and days.

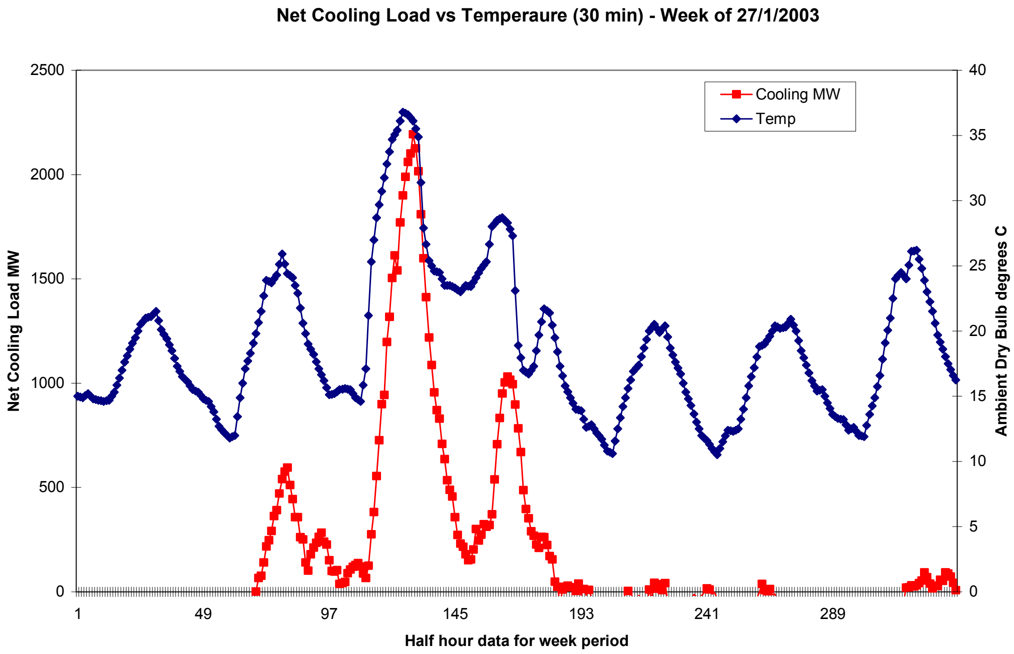
This can be more clearly understood when considering a different week which occurs later in the analysis period (27 January 2003 – see Figure 4).

Figure 4: Load Profile for 1 Week Period with Reference Load (no cooling)



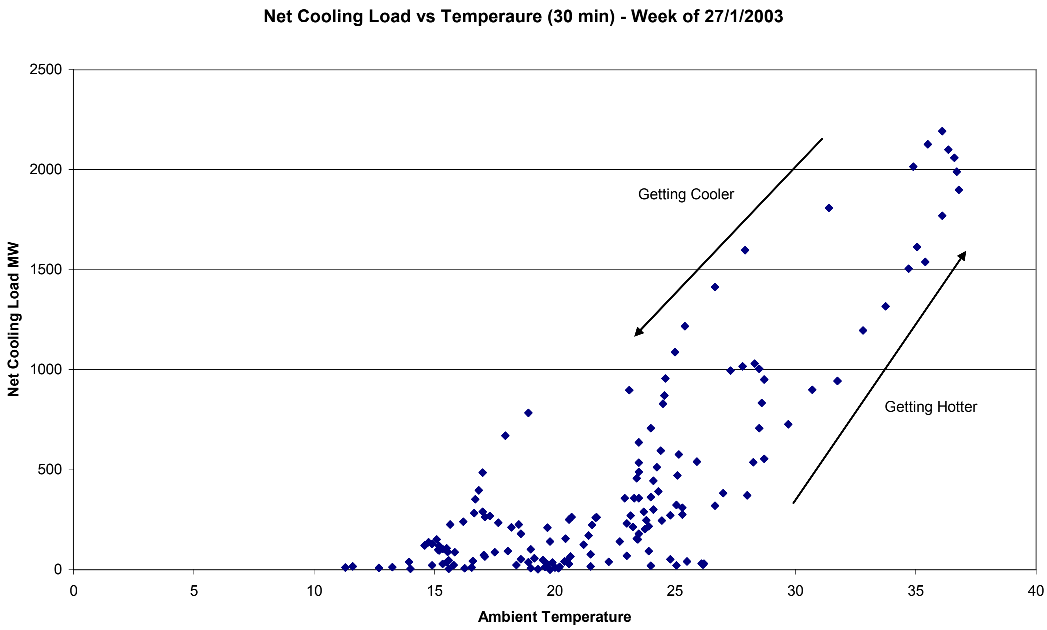
The actual load is higher than the reference on the first day as this is still part of the holiday period (Australia Day long weekend). This data can be represented as net cooling load and temperature for the particular week in question (see Figure 5).

Figure 5: Net Cooling Load vs Temperaure (30 min) - Week of 27/1/2003



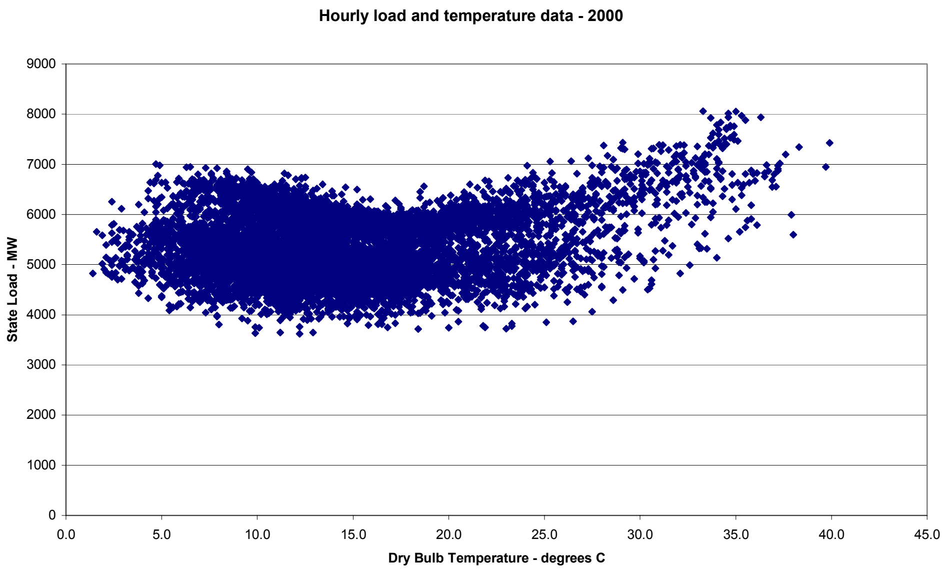
The correlation for this week is somewhat worse as shown below in Figure 6.

Figure 6: Net Cooling Load vs Temperaure (30 min) - Week of 27/1/2003



This chart shows that there is significant thermal lag in terms of demand when examining half hourly data. The high overnight temperature on the evening of 29 January 2003 generates cooling load overnight and a higher than expected cooling load for the following day (for the temperature). Therefore the approach of hourly correlation of temperature with load is of little value in terms of a predictive model. This is confirmed when examining data for a whole year (see Figure 7)– there is a clear trend in terms of the load impact of temperature (both high and low), but the demand range for any particular temperature is huge. Other years analysed show a similar pattern.

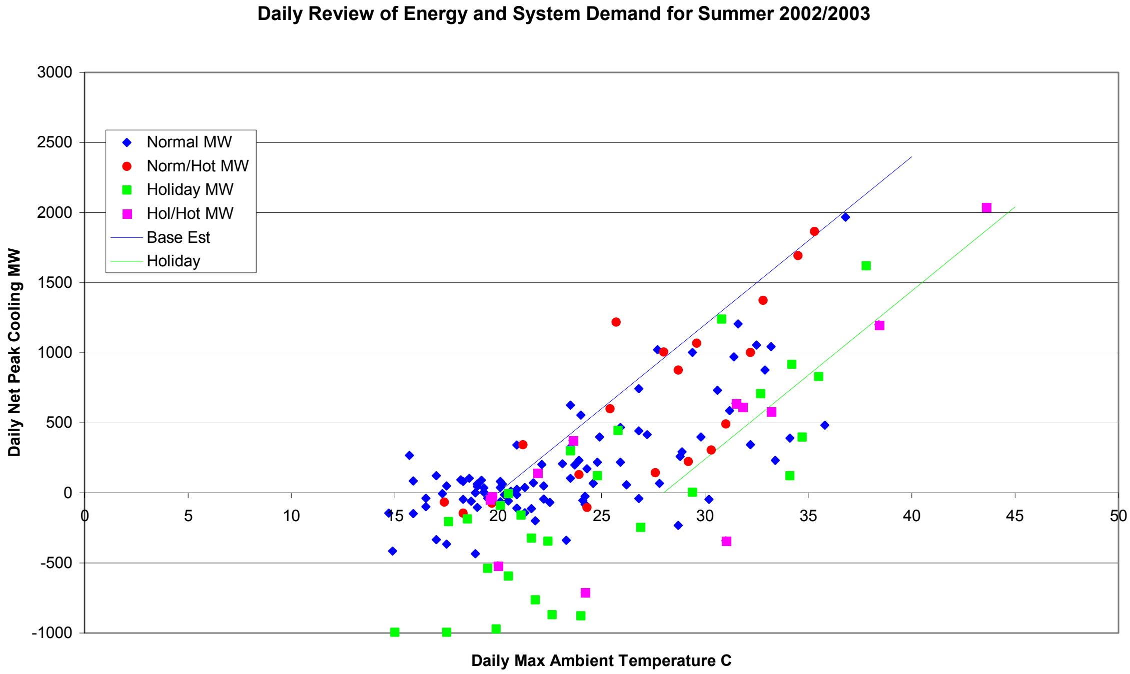
Figure 7: Hourly load and temperature data - 2000



Clearly thermal lag creates some of the anomalies with regard to the difference between system load and temperature, but there are also many other complicating factors (day of the week, holidays, etc). The next phase of the analysis was to consider daily peak loads and see if there was any stronger correlation with daily peak temperature – this was assumed to remove some of the variation associated with thermal lag.

The figure below shows an analysis for the summer 2002/2003. Individual days are classified as normal (ie not holidays), normal following a hot day (the previous day >30°C), holiday period and holiday period following a hot day. Two very approximate functions have been placed on the figure to allow comparisons between years.

Figure 8: Daily Review of Energy and System Demand for Summer 2002/2003



The salient points regarding this figure are:

- Holiday peaks are generally lower by about 500MW to 1000MW (but not always and this is erratic).
- Days after a hot day do not appear to be unusually high in terms of demand in most cases.
- The blue line of fit gives an approximate estimate of the maximum expected net cooling demand in most cases: the equation is (Daily max temp – 20) × 120 MW. The green line is 960MW below this value. This is relative to the expected reference value for the day.
- The correlation analysis is not improved by the inclusion or exclusion of weekends.

- This analysis is static in that increases in ownership and penetration of air conditioners (and of household numbers) from year to year will increase the expected peak values each year.

Similar figures for other years are shown in Appendix D.

The conclusions from this analysis are that simple correlations of temperature (either hourly or daily maximums) are a poor basis for predicting system peak loads, even when day of the week and holidays are taken into account. There are clearly a range of other factors that affect cooling load in addition to temperature: these are solar radiation, wind and humidity and user behaviour (eg occupancy, socio economic factors). There is no simple way to take into account these factors for particular days in the future. Therefore a building simulation approach has been developed to see if this improves the estimates of system peak loads. This approach seeks to model the cooling demand on typical residential buildings as a function of the hourly weather sequence experienced and to compare this to net cooling load for the state.

2.2 Selected Load Point Analysis

To assess the impact of air conditioners from different sectors, load data for selected load points was supplied to EES by VENCorp for further analysis. This data covered the period December 2002 to February 2003 inclusive. The purpose of this analysis is to better understand the main components that are driving the peak load in Victoria.

The initial 11 load points were selected to be primarily residential in nature, although there will clearly be a significant component of small commercial load (especially retail) in each of these supply points. The load points were:

1 Templestowe 66 kV supply to TXU

2 Templestowe 66 kV supply to AGL

3 Templestowe 66 kV supply to CitiPower

4 Templestowe 66 kV supply to Alinta

5 Ringwood 66 kV supply to TXU

6 Ringwood 66 kV supply to Alinta

7 Ringwood 22 kV supply to TXU

8 Ringwood 22 kV supply to Alinta

9 Frankston 66 kV supply to Alinta

10 Keilor 66 kV supply to Powercor Australia

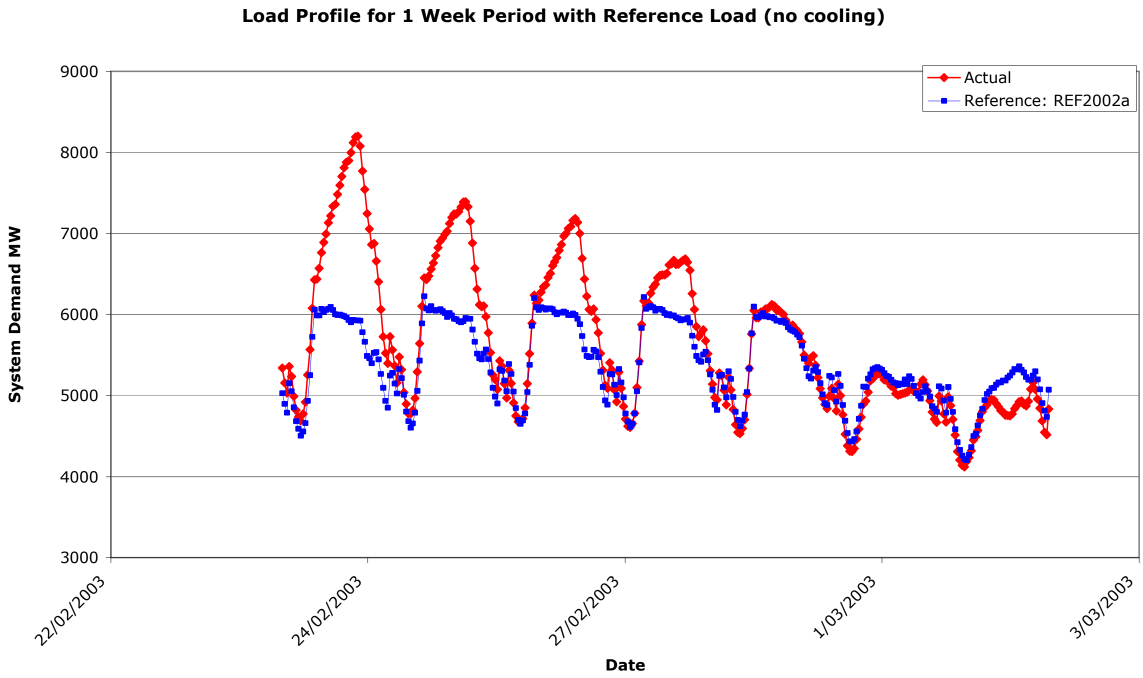
11 Keilor 66 kV supply to AGL

These load points are numbered in this fashion in the following figures. These 11 supply points covered about 9% of average system load for the state.

In addition, load data for the same period was supplied for the east and west supply points to the central business district (CBD) of Melbourne.

A period of interest for load analysis is the week of 24 February 2003. The state load for this week is shown below (Figure 9). When considering this, it important to note that the pervious day (Sunday 23 February 2003 – not shown in this figure) was 32.5°C and exhibited a significant cooling load above the reference for a Sunday.

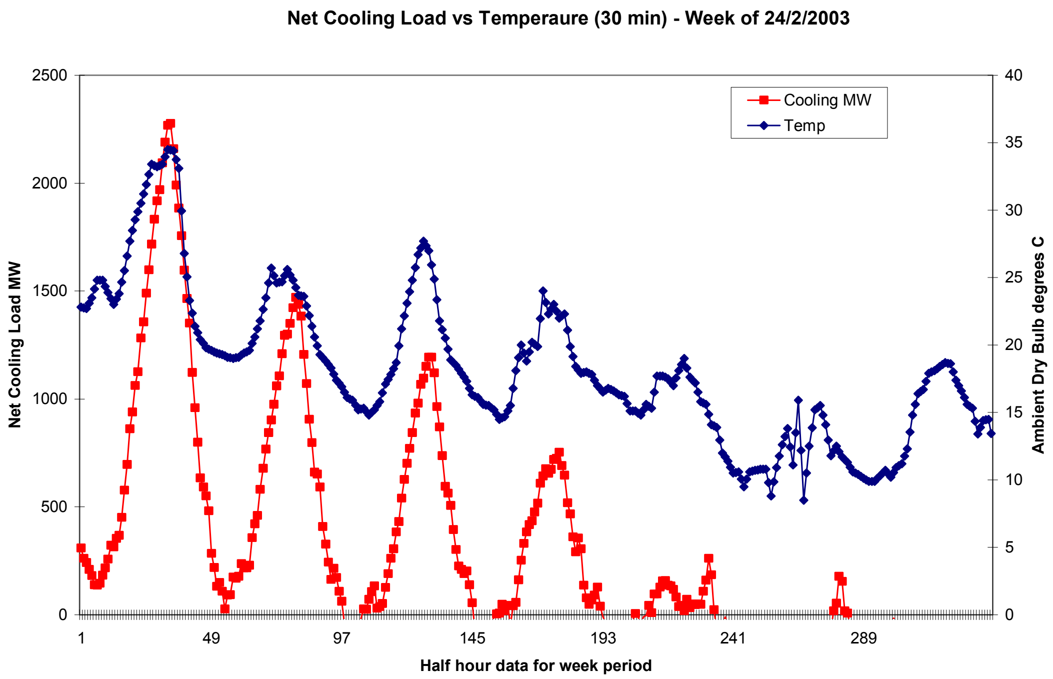
Figure 9: Load Profile for 1 Week Period with Reference Load (no cooling)



It is also important to note that an altered reference file was developed for this particular analysis for two reasons. Firstly, the original reference period was in November 2002 and the selected load point data only covered December 2002 onwards. Secondly, on closer inspection it was found that the original reference period developed for 2002 had some warm Mondays included within the period so gave a higher reference than is warranted for this day of the week. In the period of interest for this particular analysis, the maximum peak occurs on a Monday. This underlies the importance of reference curves and that further work to develop generic curves for each year is warranted in future.

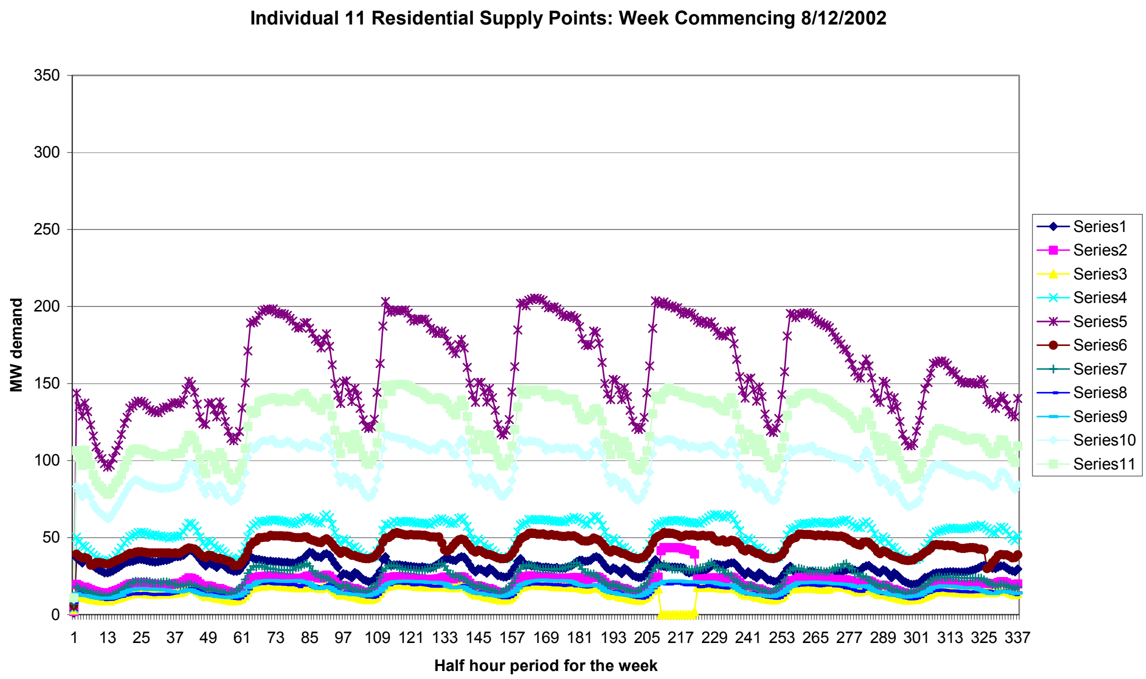
The net cooling and temperature profile for this week is shown in Figure 10.

Figure 10: Net Cooling Load vs Temperaure (30 min) - Week of 24/2/2003



Half hourly data for the 11 residential load points for the reference week (8 December 2002) which is the reference period for this analysis, is shown in Figure 11:

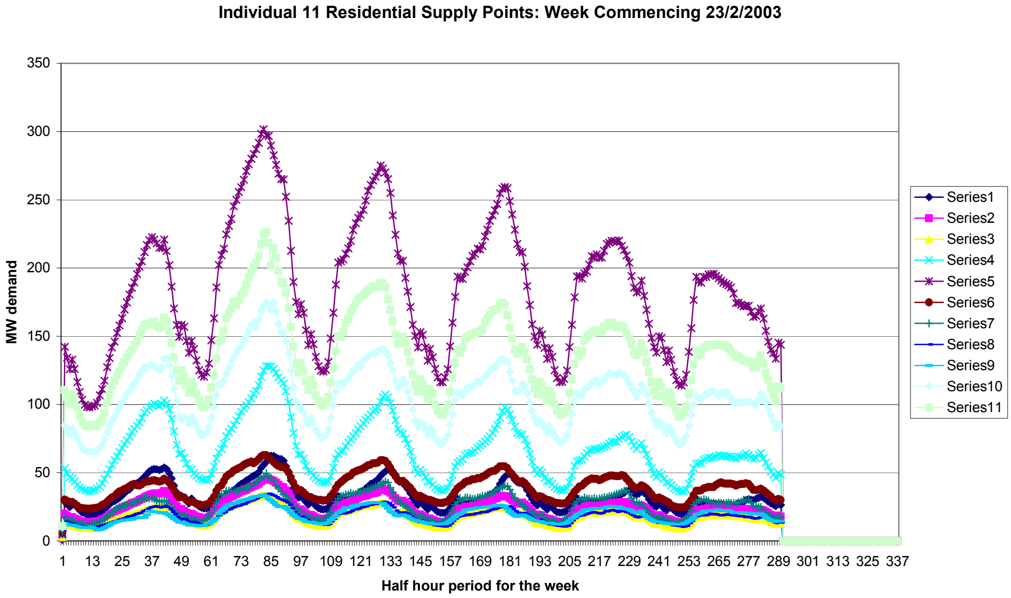
Figure 11: Individual 11 Residential Supply Points: Week Commencing 8/12/2002



Note: the period shown runs from Sunday to Saturday

The load curve for the peak week of 24 February 2003 for the same load points is shown in Figure 12 (note that the scale has been locked to be the same as the previous figure for comparative purposes).

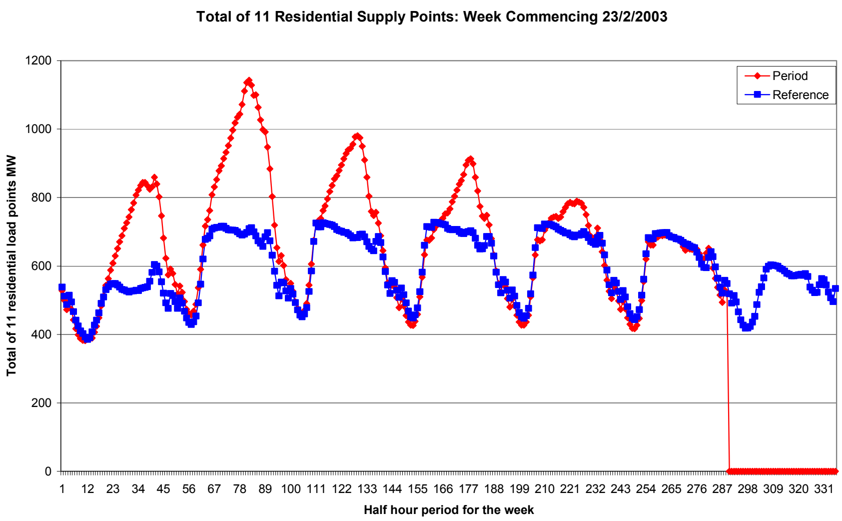
Figure 12: Individual 11 Residential Supply Points: Week Commencing 23/2/2003



Note: the period shown runs from Sunday to Saturday

All of the load points clearly respond to the higher temperatures during this week. The total of these 11 points can be examined for both the reference week and the peak week in February 2003 as shown in Figure 13. This figure bears a close similarity to the state load figure above for the same period (note that the figure below commences on Sunday 23 February 2003 so the second peak below is the first peak in the state load data). Data for 1 March (last day below) was not provided.

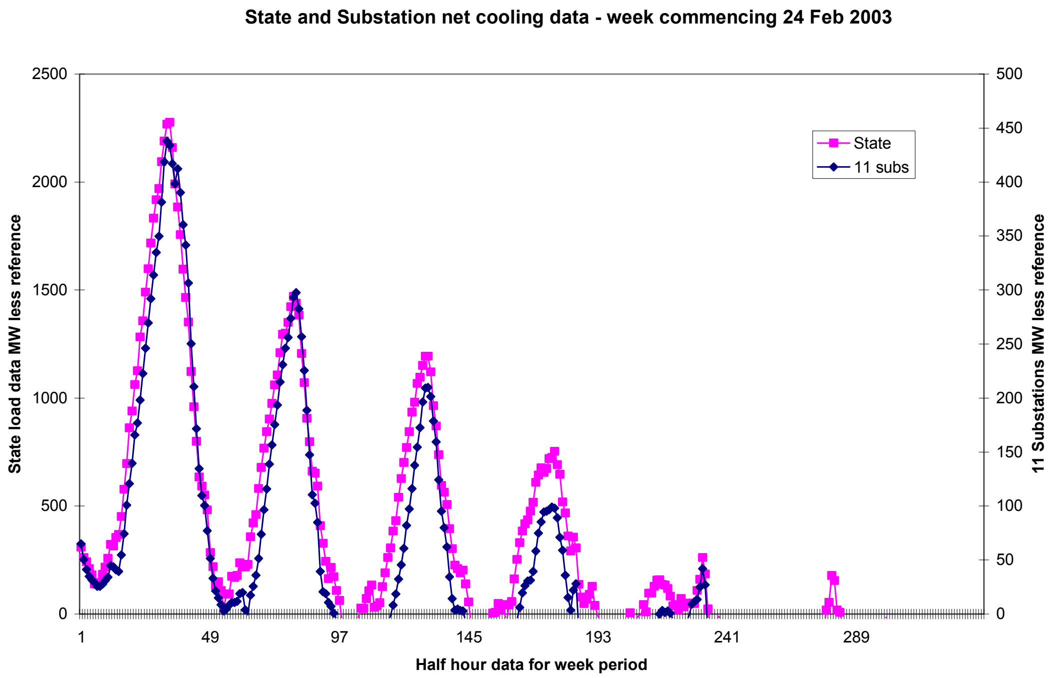
Figure 13: Total of 11 Residential Supply Points: Week Commencing 23/2/2003



Note that the peak load increase due to air conditioning (temperature sensitive loads) is about a 70% increase over the reference for this particular period (around 700MW reference compared to a 1100MW peak) for the 11 residential load points. Figure 13 (although similar in shape to the state load profile) starts at zero while the state figure starts at 3000MW)

When analysed further, the net cooling load (actual load minus the reference load) for this week can be compared for the state and the 11 load points as shown below (note state net cooling load and 11 load points are plotted on different scales).

Figure 14: State and Substation net cooling data - week commencing 24 Feb 2003

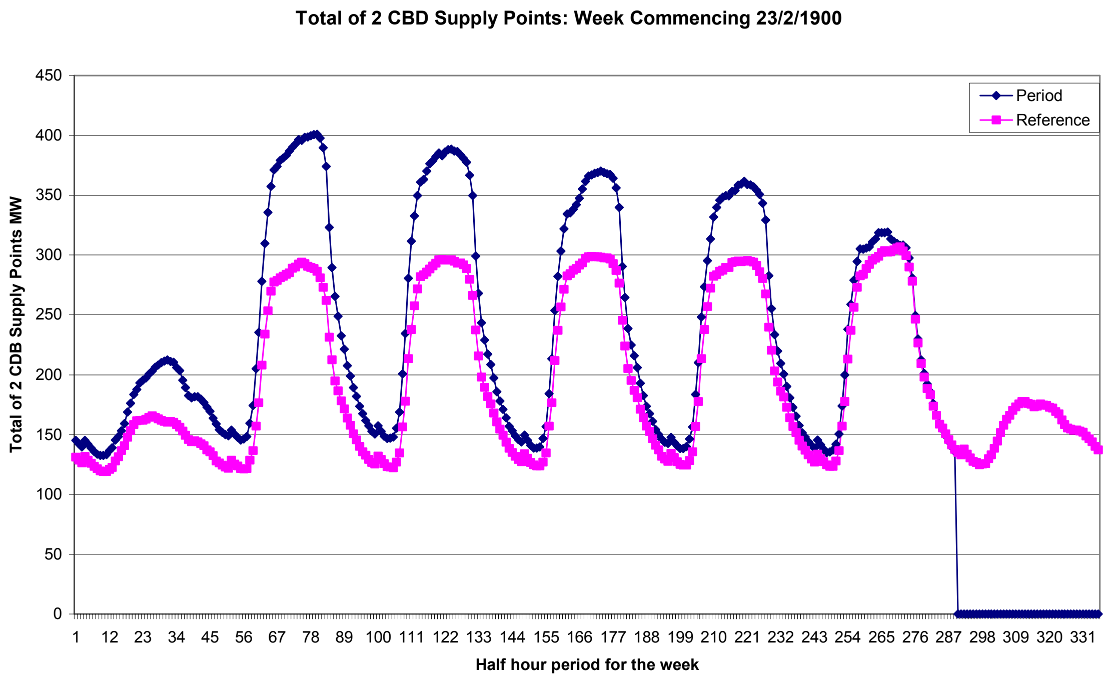


This figure clearly shows that the net cooling load for the primarily residential load points is driving the state load.

An important point is that following a protracted period of hot weather (and associated high cooling loads) once the net cooling load increase falls below about 500MW, the residential load component (represented by the 11 load points in blue above) is somewhat lower than the state load on these days (in a relative sense). This point is confirmed in the residential building shell modelling undertaken for this project which appears to under-predict the net cooling load following a series of very hot days in some cases. This would suggest that some of the larger commercial centres continue to have an elevated cooling load requirement after a sustained period of hotter weather.

The data for the Central Business District was also considered for the same period. This, together with the same reference week, is shown below in Figure 15.

Figure 15: Total of 2 CBD Supply Points: Week Commencing 23/2/2003



Although there is a noticeable load increase during this peak week, the increase in CBD load is only about 33% higher than the reference period for the day of Monday 24 February 2003. In comparison, residential load appears to increase by 70% on this day while the state load increase is about 37% on this day. Clearly residential load centres (with the mix of small commercial users) is the main driver for the state peak loads on hot days. Amazingly, the load factor for the CBD remains quite constant during the hot days, suggesting a more uniform load increase for these days. The first day shown above is a hot relatively warm Sunday. It is interesting to also note that the CBD cooling load for the Thursday (4^{th} peak) is still significant, even though the ambient peak temperature on this day was only 25°C. In fact the net cooling load for all 4 days are surprisingly similar given that the peak daily temperatures from Monday 24 Feb 2003 to Thursday 27 February 2003 were 34.5°C, 25.7°C, 27.7°C and 24.0°C, while the maximum for Friday was 19°C.

Consider the load factor data for the selected load points shown in Table 1 below. The load factor for the 11 residential load points is very poor on the peak day of Monday 24 February 2003 (an average of 71% on the Monday), but this improves through the week as the weather becomes cooler by Friday (back to 86% which is more typical). The load factors for the reference week are also provided for comparison (87% for the 11 load points). By Friday of this week, the load factors are more or less back to the reference load factor. The energy demand increased from 15094MWh (reference Monday) to 17365MWh on Monday 24 February 2003 (15% increase in energy but with a 59% increase in peak load).

The load factor for the CBD is about 69% on the hot Monday and is 71% for the Friday and the reference period. However, the energy demand increased from 5084MWh (reference Monday) to 6427MWh on Monday 24 February 2003 (26.4% increase in energy with a 36% increase in peak load).

The conclusion from this analysis is that the vast majority of weather sensitive component of the state peak load is driven by the residential and small commercial sectors. However, this peak increase and sensitivity is clearly tempered somewhat by large commercial loads and industrial loads, many of which are unlikely to be temperature sensitive.

Table 1: Daily Load Factors for Selected Days and Load Points

No.	Supply Point	Mon 24/2	Wed 26/2	Fri 28/2	Reference Load Factor
	Maximum Daily Temp °C	34.5	27.7	19.0	
1	Templestowe 66kV-TXU	65%	65%	83%	83%
2	Templestowe 66kV-AGL	68%	72%	84%	80%
3	Templestowe 66kV-CitiPower	69%	72%	80%	77%
4	Templestowe 66kV-Alinta	66%	65%	84%	85%
5	Ringwood 66kV-TXU	73%	73%	83%	84%
6	Ringwood 66kV-Alinta	72%	74%	82%	87%
7	Ringwood 22kV-TXU	63%	66%	77%	75%
8	Ringwood 22kV-Alinta	67%	72%	81%	82%
9	Frankston 66kV-Alinta	67%	73%	79%	81%
10	Keilor 66kV-Powercor	72%	79%	87%	88%
11	Keilor 66kV-AGL	71%	78%	86%	87%
	Total 11 residential	71%	74%	86%	87%
	CBD East	70%	71%	73%	73%
	CBD West	68%	67%	70%	70%
	Total CBD	69%	69%	71%	71%
	State	79%	83%	90%	90%

2.3 Peak Load Prediction Model

This study explored the possibility that a modelling tool based upon building thermal performance, housing data and appliance stock modelling could provide a reasonably accurate tool for predicting the magnitude of summer peak loads. The tool used existing peak load data provided by VENCORP from the summers of 1999 – 2000 to 2002 – 2003 to trial the method.

The model developed utilized a building shell thermal performance modelling tool (AccuRate) to predict residential cooling loads (at a household level). More detail on the AccuRate simulation model is provided in Appendix F. The AccuRate module required two main inputs:

- Input based on the design and construction characteristics of a representative (reference) house (see section 5.2 and Appendix F).
- Input based on weather data for the study period (see section 3)

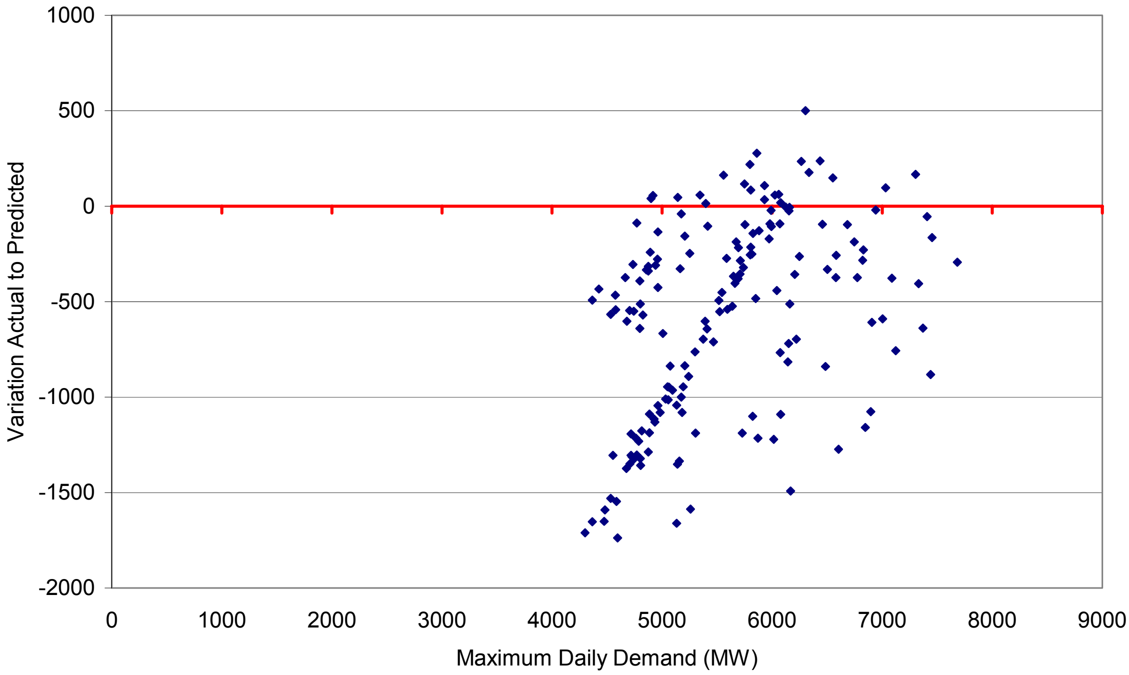
Alternative occupancy scenarios were then set up by altering the plant operation schedules in the AccuRate scratch files (see section 5.3.1). The AccuRate program was then run and output data for both cooling load and internal temperature was extracted from the output files. This was then weighted to account for the different occupancy scenarios (see section 6.2.1) and zoning factors (see section 6.2.2) estimated to apply in the stock of Victorian housing.

The hourly weighted cooling loads for the reference house was then analysed to determine each days maximum cooling demand for the state. The factors applied to convert Accurate output to state level demand were:

- Total Stock of households in the state (see section 6.2.3)
- Penetration and ownership of air conditioners in housing (see section 6.2.4)
- The average efficiency of the installed air-conditioners (see section 6.2.5)
- The “Utilization” factor (see section 6.2.6) to account for user behaviour that will tend to constrain the actual hours of operation of the space cooling appliance.
- The “Commercial sector” factor (see section 6.2.7) to account for the commercial sector contribution to the total space conditioning related cooling load.

In the analysis below those days that were either public holidays and or summer school holidays have been excluded from consideration. In general the model tended to overestimate the magnitude of the peaks on these days (see Figure 16).

Figure 16: Variation of Actual load to Modelled load as a function of peak demand – Public and School Holidays Only



This overestimation is assumed to relate to the fact that on these days commercial buildings are not fully occupied and homes are often vacated while householders are on holidays. It is also common for large sections of industry to shut down during the summer holiday period in January (from Christmas) which reduces the base load on the state system. It may be possible to accurately model these days if a consistent set of holiday base case scenarios can be determined. This may be important because many large cooling peaks occur in January, but these tend to be masked somewhat by reduced base load for the state. These relative peaks are important however for system control purposes (even though they rarely reach the level of a summer system peak). However, the variation from predicted to actual for the holiday period was found to be somewhat erratic even when an approximate reference load was developed.

The following four figures (Figure 17 to Figure 20) present the results for each of the four summers examined. Each figure presents both the actual peak load (blue line) and the load predicted by the simulation model (pink line).

Figure 17: Actual Peak Load V Predicted Peak Load – Summer 1999 - 2000

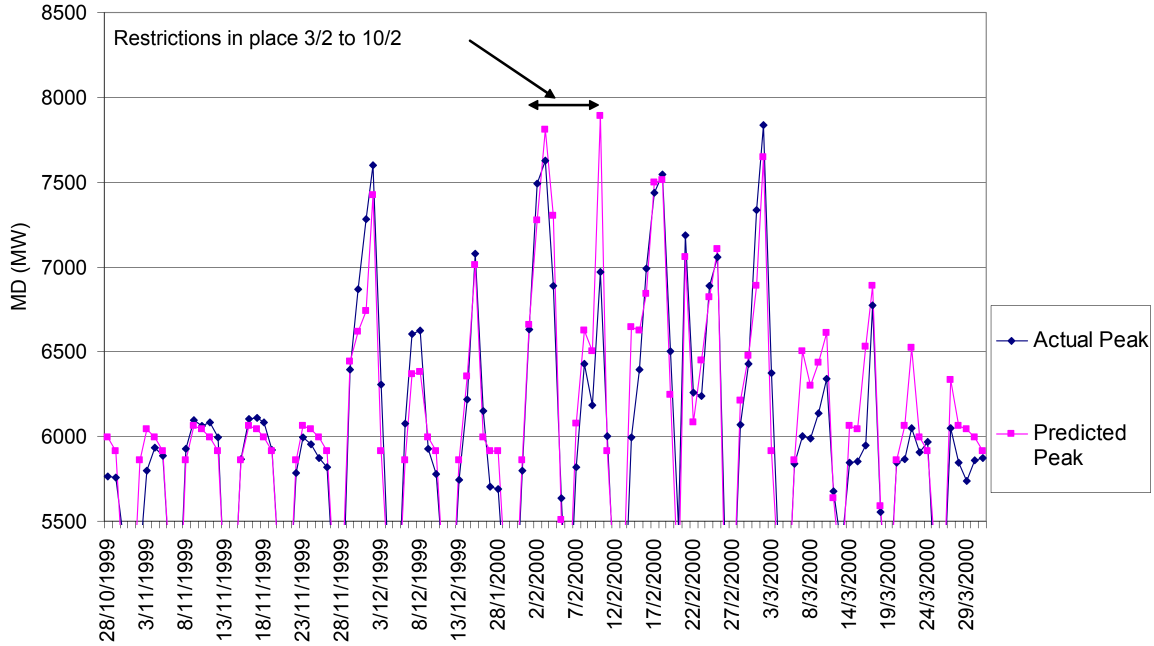


Figure 18: Actual Peak Load V Predicted Peak Load – Summer 2000 - 2001

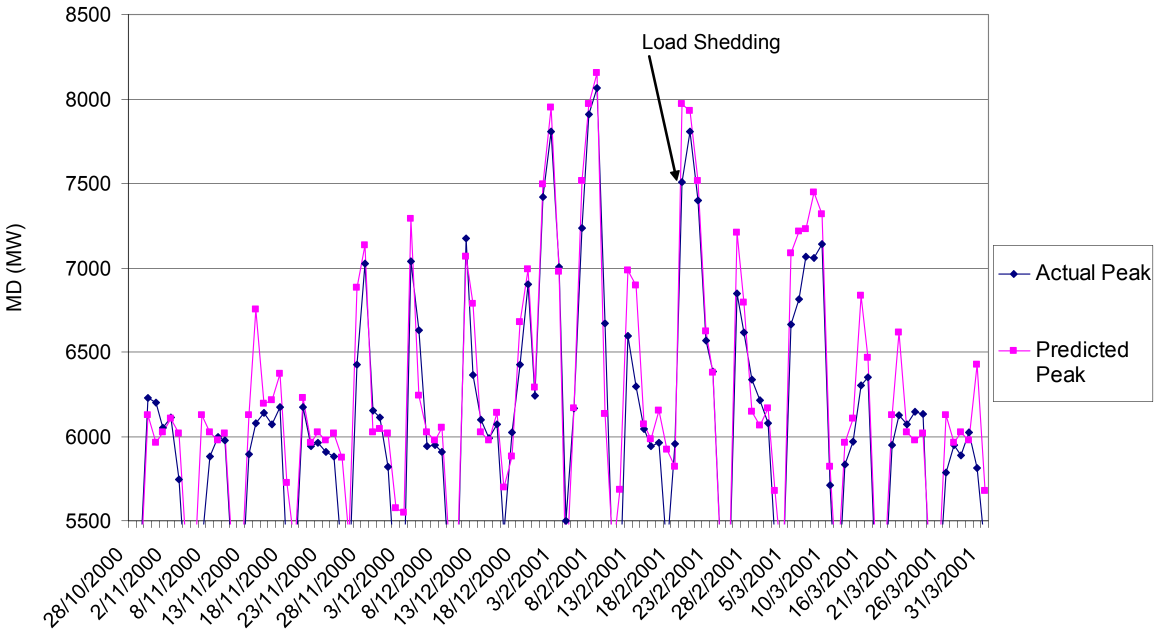


Figure 19: Actual Peak Load V Predicted Peak Load – Summer 2001 - 2002

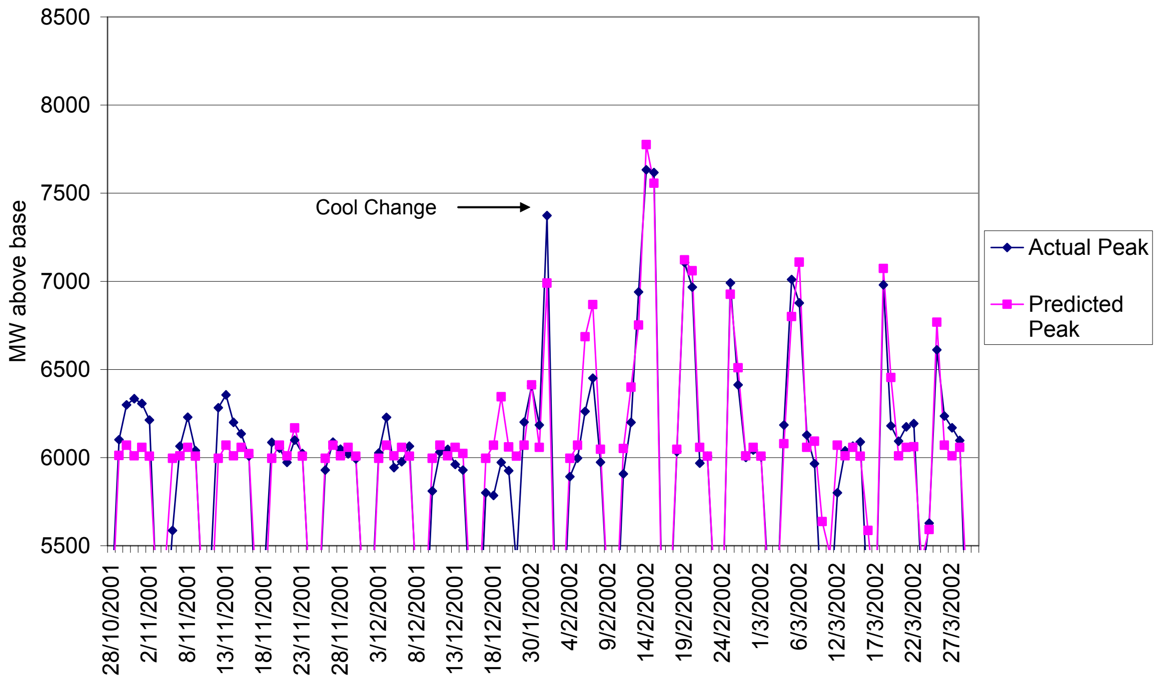
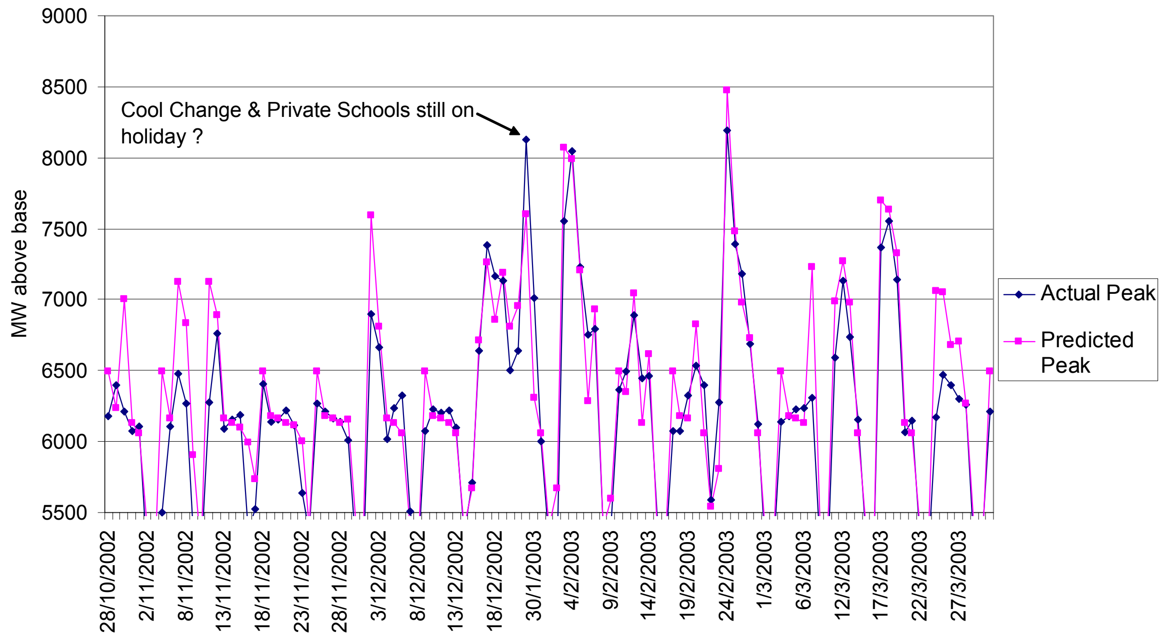


Figure 20: Actual Peak Load V Predicted Peak Load – Summer 2002 - 2003



From these figures the following observations were made:

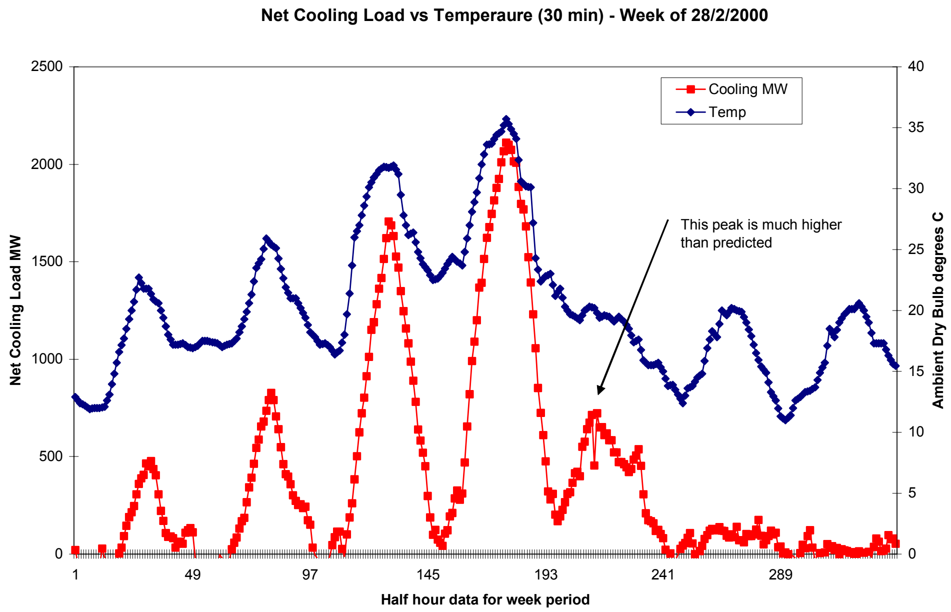
- Maximum summer peak loads were generally about 2000MW above the base case (which is approximately 6000MW), ie a one third increase in total demand.
- The summer of 2001 – 2002 was apparently a milder summer where the temperature sensitive component of demand did not exceed 1500MW above the base level.
- Generally the MD prediction model developed by EES closely tracked the actual peak load especially on days of maximum peak load. The exception to this was between 3/2/2000 and 10/2/2000 (see Figure 17) when the model overestimated the peak by up to 1000MW. Advice from VENCorp confirmed that load restrictions were in place during this period due to supply shortages. Such restrictions would (at least in part) explain much of this disparity.
- On days of minor peaks (< 500MW above base level) the EES model tended to overestimate the peak loads. Whilst these peaks are not of great interest in terms of forecasting future capacity requirements (but they may be of some interest for the purposes of system control), it may be possible to improve the accuracy of prediction of these lower peaks by undertaking further refinements to the model, especially the utilization factor (see section 6.6). See also the previous section (2.2) which found that the residential net cooling load on mild days following hot spells was smaller than the comparable state peak load which suggests that commercial loads are more important in these cases.
- Of the 453 days simulated between 1999 and 2003, 19 of those days had underestimates of MD that exceeded 250MW (see Table 2). Only six of these underestimates occurred on days when the MD exceeded 7000MW. An analysis of each of these 19 days revealed that these underestimates could be accounted for by a few common factors as discussed in the following points.
    - Twelve of the days exhibited a common weather pattern that included a cool change. This suggests that the EES model tends to underestimate loads in the hours following a summer cool change. On these days significant overnight cooling is clearly visible (this is very unusual for the state load profile) which may be a combination of commercial and residential loads. An example of this effect can be found in Figure 21.
    - Four of the days for which the EES model underestimated the peak load were simply unseasonably cold days where maximum temperatures were as low as 15^{0}C; on these days space heating (some of which would be electrical) would have been invoked by some householders and businesses. The model as configured for this study does not however account for heating loads, hence the underestimate.
    - The remaining 3 days included a Saturday and a Sunday where the MD was less than 6500 MW as well as Wednesday 1/12/1999. The reason for the discrepancies on these days are at this stage unclear.

Table 2: Days when the modelled MD was >250MW less than actual demand

Date	Actual Demand	Modelled Demand	Actual less Modelled	Degree of Underestimate	Factor assumed to cause underestimate
3/12/1999	6303	5911	392	-6.2%	Cool Change
1/3/2000	7338	6889	449	-6.1%	Cool Change
3/3/2000	6373	5911	462	-7.3%	Cool Change
5/12/2000	6628	6239	389	-5.9%	Cool Change
9/2/2001	6668	6132	536	-8.0%	Cool Change
1/2/2002	7373	6989	384	-5.2%	Cool Change
18/12/2002	7167	6861	307	-4.3%	Cool Change
29/1/2003	8129	7602	527	-6.5%	Cool Change & Private School holiday[1]
30/1/2003	7010	6304	706	-10.1%	Cool Change
6/2/2003	6755	6288	467	-6.9%	Cool Change
13/2/2003	6443	6132	311	-4.8%	Cool Change
21/2/2003	6399	6062	337	-5.3%	Cool Change
31/10/2001	6334	6010	323	-5.1%	Cool Day - Max Temp 17.5 –Heating Invoked
12/11/2001	6283	5996	287	-4.6%	Cool Day Max Temp 14.9 - Heating Invoked
13/11/2001	6356	6070	286	-4.5%	Cool Day Max Temp 15.9 - Heating Invoked
6/12/2002	6328	6062	267	-4.2%	Cool Day Max Temp 15.7 – Heating Invoked
19/2/2000	6504	6243	261	-4.0%	Saturday
23/2/2003	6277	5808	468	-7.5%	Sunday
1/12/1999	7281	6737	543	-7.5%	Unknown

Note 1: Whilst the School holiday period officially ended on the previous day it is thought that most private schools did not go back until later that week. This would have left a significant number of dwellings occupied when normally they would not have been occupied. In reality this day should possibly have been excluded from the study period on the basis that it forms part of the holiday period (at least for a significant portion of the population).

Figure 21: Net Cooling Load vs Temperaure (30 min) - Week of 28/2/2000



➢ In the critical peak load range (above 7000MW – see Figure 22) the EES model could predict peak loads to an accuracy of approximately +200MW (+3%) to –400MW (-6%). This accuracy estimate excludes days of cool change as detailed in Table 2. With the exception of 29/1/2003 (where the MD is complicated by the timing of the end of school holidays as noted in Table 2) the cool change days are typically at the lower end of the MD days (< 7400 MW). On the ten days of highest MD (excluding 29/1/ 2003) the accuracy of the model was found to be +194MW (+2.5%) to – 280MW(-3.5%) see Table 3).

Figure 22: Variation of Actual load to Modelled load as a function of peak demand (>7000MW)

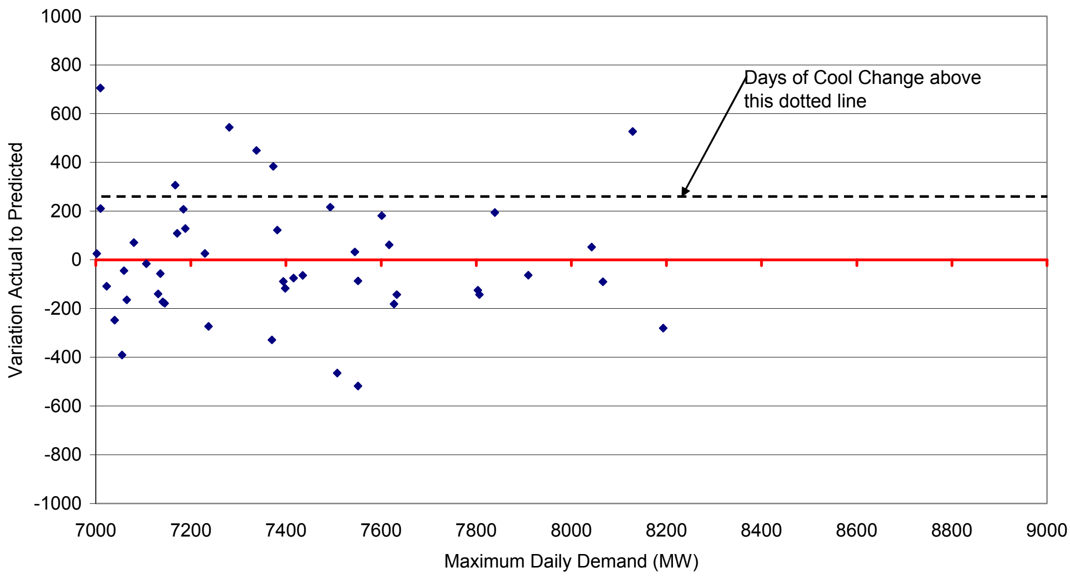


Table 3: Days of Maximum Peak Demand (in order high to low) – 1999 – 2003

Date	Day	Max External Temp (C)	Peak Demand (MW)*	Variation Actual to Predicted (MW)	Error
24/2/2003	Monday	34.5	8193	-280	3.4%
29/1/2003	Wednesday	36.8	8129	527	-6.5%
8/2/2001	Thursday	36.3	8066	-90	1.1%
4/2/2003	Tuesday	35.3	8043	53	-0.7%
7/2/2001	Wednesday	35.5	7909	-63	0.8%
2/3/2000	Thursday	35.7	7839	194	-2.5%
2/2/2001	Friday	34.9	7807	-143	1.8%
20/2/2001	Tuesday	34.9	7804	-125	1.6%
14/2/2002	Thursday	35.1	7633	-143	1.9%
3/2/2000	Thursday	38.8	7627	-181	2.4%
15/2/2002	Friday	35	7617	61	-0.8%
2/12/1999	Thursday	35.3	7601	181	-2.4%
18/3/2003	Tuesday	32.8	7552	-86	1.1%
3/2/2003	Monday	33.2	7551	-518	6.9%
18/2/2000	Friday	36.2	7545	32	-0.4%
19/2/2001	Monday	35.1	7508	-464	6.2%
2/2/2000	Wednesday	35.8	7493	216	-2.9%
17/2/2000	Thursday	35	7435	-63	0.9%
1/2/2001	Thursday	33.9	7416	-75	1.0%
21/2/2001	Wednesday	31.9	7399	-117	1.6%
25/2/2003	Tuesday	25.7	7394	-88	1.2%
17/12/2002	Tuesday	31.6	7382	122	-1.7%
1/2/2002	Friday	34.4	7373	384	-5.2%
17/3/2003	Monday	32.9	7370	-329	4.5%
1/3/2000	Wednesday	31.9	7338	449	-6.1%
1/12/1999	Wednesday	33.7	7281	543	-7.5%
6/2/2001	Tuesday	32.3	7237	-273	3.8%
5/2/2003	Wednesday	29.6	7230	26	-0.4%
21/2/2000	Monday	33.8	7188	129	-1.8%
26/2/2003	Wednesday	27.7	7184	208	-2.9%
11/12/2000	Monday	30.9	7171	109	-1.5%
18/12/2002	Wednesday	28	7167	307	-4.3%
19/3/2003	Wednesday	32.2	7145	-179	2.5%
9/3/2001	Friday	33.1	7141	-173	2.4%
19/12/2002	Thursday	29.4	7136	-57	0.8%
12/3/2003	Wednesday	31.4	7131	-140	2.0%
19/2/2002	Tuesday	32.5	7106	-16	0.2%
15/12/1999	Wednesday	36.4	7080	71	-1.0%
7/3/2001	Wednesday	32	7065	-164	2.3%
25/2/2000	Friday	33.3	7060	-45	0.6%

* Note to previous table: The reported Daily maximum demand is the maximum demand as measured on the hour. Hourly measurement is used to align with model outputs. Actual VENCorp measurements are taken every half hour and the daily MD assessed on the basis of half hourly readings may in some cases be slightly higher than the figures reported above.

2.4 Impact of Higher performance building shell on MD

As part of this study a preliminary assessment was made of the likely impacts on daily maximum summer demand that would result from the widespread adoption of a 5 star building shell performance standard (as is now required for new housing built in Victoria after 30 June 2004).

To assess the likely impacts, the reference house was modified to bring it up to a 5 star standard[2]. To achieve a 5 star rating the following improvements were undertaken:

- Ceiling insulation upgraded from R2.5 to R3.5.
- Glazing altered from single glazing to double glazing.
- Some windows on the south and west facades were reduced in size.
- Eaves were increased from 450 to 900.

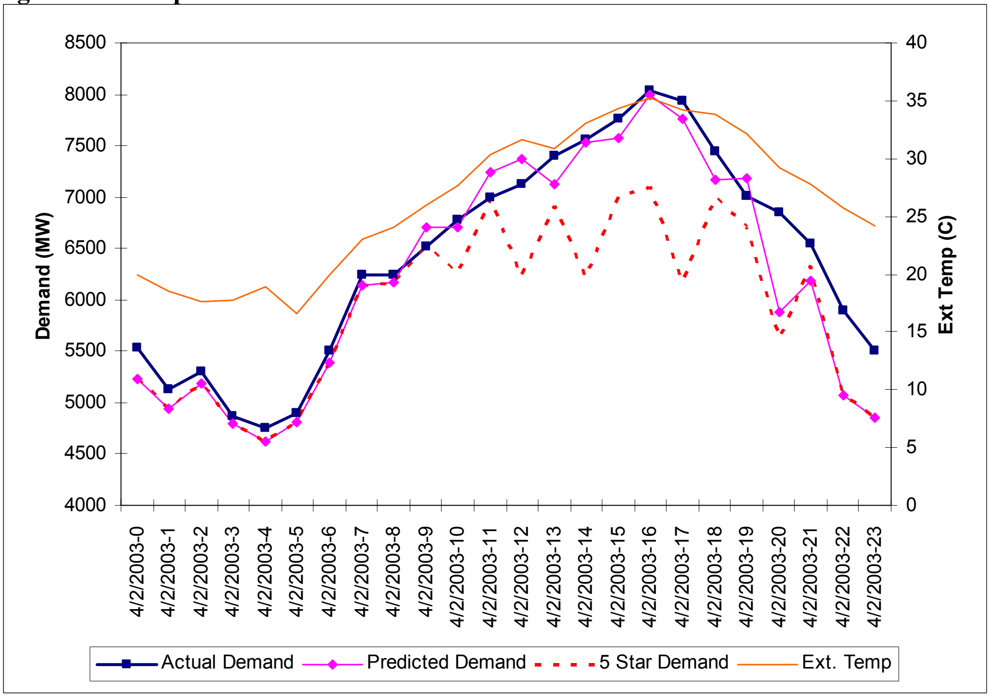
Following these improvements the modified reference house was modelled (utilizing the various operation schedules noted previously) using Accurate. The outputs in terms of predicted hourly cooling demand were then fed into the EES MD simulation model and the results compared to those obtained using the standard reference house.

The model is set up such that any proportion of the standard reference house and the 5 star reference house can be modelled. In this way trends in MD can be more accurately predicted as over time a greater proportion of the stock meets the 5 star standard. For the purposes of this analysis however, the proportion of 5 star reference houses was set to 100% to gauge the likely impact once the stock average reaches the newly introduced standard (assuming that commercial buildings exhibit a similar improvement in performance).

Comparing the predicted MD levels as modelled for the 40 days of highest demand in the study period, it was found that on average the application of the 5 star standard reduced the MD by 533MW. The greatest reduction in MD was observed on 4/2/2003 (the 4th highest MD in the study period) where the reduction was almost 900MW or more than 11% of the MD – see Figure 23.

[2] The performance standard of the original reference house was found to be 3.5 stars which is slightly higher than the estimated state average of the stock. This means that the estimates of reductions in MD resulting from a shift to a 5 star standard are likely to be conservative. For predicting trends (in a future iteration of the model) the reference house performance could be reduced to a more representative 2.5 stars

Figure 23: Comparison of Standard Reference House and 5 Star Reference House – 4/2/2003



In fact the MD reduction for the 5 star house is likely to be even greater than the estimate of 900MW. As revealed in Figure 23, the demand for the 5 star reference house tends to cycle on an hourly basis. This cycling, whilst a real effect observed in non inverter type air-conditioners, would in reality occur more frequently. More importantly such cycling would tend to average out over the state and the actual MD would be about midway between the bottom and the top of each cycle. In the comparison made above the MD for the 5 star house was assumed to be at the top of the highest cycle thereby overestimating the actual MD and underestimating the savings associated with the 5 star reference house. Future investigations could include approaches to improve the modelling results for high efficiency building shells (such as a reduction in temperature control deadbands to reduce cycling of the cooling plant).

2.5 Sources of Variation – Actual Vs Modelled MD

Following is a brief discussion of likely sources of variation between actual demand and predicted demand from the model developed by EES for this study.

2.5.1 Reference Week

The MD model utilizes a single "reference" period during each summer where there was no obvious peak load activity due to air conditioning. This reference period is used as the temperature insensitive component of the MD estimate. In reality the temperature insensitive component of the MD is likely to exhibit a small degree of variability. This variability (probably <100 MW) will add to the uncertainty of the estimate of total MD.

2.5.2 Weather Data

For this study weather data was used from a single weather station located at Tullamarine Airport, north-west of the Melbourne city centre. There are clearly limitations when using a single weather station for thermal modelling across the whole state. A more accurate model would separately model different parts of the state using weather data for each climatic region. The results of such modelling could then be weighted according to the stock of buildings in the particular climate zone.

Use of weather data from a single station means that during a cool change the simulation model will assume that when the cool change commences it will affect all buildings in the state at the same time. In reality, a significant share of space conditioned buildings will receive a cool change well ahead and well after it hits the Tullamarine weather station, depending upon their location in the state. This effect (and the extent and direction of the change) could account in part for the diminished accuracy of the model during some cool changes.

However, regional modelling of weather patterns is a significant increase in data requirements and it is unclear what improvement would result from this approach. In addition, there are few weather stations operated by the Bureau of Meteorology that collect sufficiently detailed weather data to allow full building simulations to be undertaken.

2.5.3 Reference House and Accurate modelling

The use of a single reference house (albeit with a range of operation schedules) means that the accuracy of the model in relation to particular building types is likely to be reduced. In particular the model is unlikely to accurately model the performance of thermally massive buildings (such as those in the CBD). Such buildings are likely to exhibit significant thermal lag thereby adversely affecting accuracy especially during periods of rapid change in ambient conditions (ie during cool changes).

Ideally a separate module could be developed to cover a range of building types and these could be weighted in proportion to the currently known (and future) prevalence in the state. For some building types, such a module would need to use simulation software appropriate to large commercial buildings (ie not Accurate)

2.5.4 Performance Data

The performance data used in this study was based upon the performance of refrigerative cooling appliances (ie those based on the vapour compression cycle). Whilst the majority of space cooling in Victoria is provided by refrigerative type air-conditioners, a significant minority of dwellings utilize evaporative cooling technology. For this initial study, an assumption was made that evaporative cooling energy demand will be proportional to refrigerative cooling energy demand. However, the majority of energy associated with evaporative cooling is for fan power and under normal operation the power requirement is thought to be relatively constant for most cooling conditions. It is also known that the typical power required for a central evaporative air conditioner system is somewhat lower (of the order of 30%) of that of an equivalent refrigerative system. These systems therefore offer a significant potential system load reduction with increased penetration. However, the performance and typical user profiles for evaporative air conditioner systems are not well understood (in terms of modelling their performance for this type of simulation) and it is recommended that further investigation on the current use and potential impact of evaporative cooling systems be undertaken.

2.5.5 Applied Factors

Occupancy (see section 6.2.1)

The occupancy factors used in this study were simple estimates based upon the best fit of the predicted demand to the actual demand. Real data derived from surveys like the unit records from a series of ABS surveys entitled "How Australians use their time" (Time Use Survey) (ABS4153.0) could improve the accuracy of the model. More importantly such data collected over time would assist in making accurate predictions that account for likely trends in occupancy rates. Other ways of improving this would be to undertake load monitoring of the use of air conditioners in a range of selected houses in Victoria.

Zoning (see section 6.2.2)

The constraint on cooling demand resulting from limitations on the capacity of installed space cooling equipment is an estimate only within the current model. Further research would be required to more accurately estimate constraint levels and indeed the distribution of these constraints (eg many houses with central cooling systems will have adequate capacity to cool the whole house while room air conditioners can typically only cool a portion of the home). Trends in the shift from room air conditioners to central systems will have a longer term impact on zoning estimates and this trend needs to be quantified when considering longer term forecasts of peak load. As with the occupancy factor, such research would assist in making accurate predictions that account for likely trends in zoning constraint factors.

Utilization (see section 6.2.6)

The utilization factor is applied in the model to account for the apparent reticence of some air conditioner owners to operate their appliances during mild or even moderate cooling events. The utilization curve developed for this study was based upon a reasonable fit of the internal house temperature simulated (without any cooling) versus the net cooling system load across the analysis period. This factor appears to account for much of the apparent thermal lag in the response curve of cooling load to hourly temperature, but it is based on a relatively empirical approach in this initial phase of the project. The utilization factor is based on a relatively simple curve (see Figure 29) and its accuracy is limited, especially on days of low to moderate cooling demand. However, it is applied uniformly to all modelling outputs in this project so has some reasonable basis in reality. Further refinement of this factor would hopefully result in a more complex function that could more accurately account for user behaviour and the basis of this type of factor.

3. Weather Data

A basic weather file for climate zone 21 (which includes Melbourne) is provided with the AccuRate software. This data was compiled by CSIRO and is based on the calendar year 1979. It is not known how representative this year is for Melbourne. Clearly this data is of little interest for this project as real time data in parallel with system load data is required for the period 1999 to 2003.

Inquiries failed to find any existing weather data sets compatible with AccuRate for the period 1999 to 2003 (or any other period subsequent to 1979). The only alternative appeared to be purchase of raw data from the Bureau of Meteorology and compilation of the data into the required format which was done specifically for this project.

It is believed that the Australian Greenhouse Office is in the process of commissioning the compilation of weather files for many years and many locations around Australia for use in AccuRate simulations, but the timing of this project is unclear.

Data was purchased from Australian Bureau of Meteorology National Climate Centre in Melbourne. Meteorological files were generally provided as comma delimited text files or in some cases as fixed format text files (solar data). The data was purchased in order to make up weather files for the calendar years 1999 to 2003 inclusive in the format of the Australian Climatic Database (see Annex C for details).

The main Bureau of Meteorology (BOM) weather site for Melbourne is now Tullamarine airport (station 86282). The main data sets were provided as follows:

- Hourly data for meteorological observations (wind speed, temperature, pressure etc.);
- Three hourly data for meteorological observations;
- Half hourly data for solar data.

Hourly data was extracted from the 1 minute observations for a wide range of variables. These included dry bulb temperature, wet bulb temperature, various humidity related readings, atmospheric pressure (local and corrected to sea level), wind speed and direction (16 point compass) and a reading from a ceilometer (to estimate cloud cover). Wind readings included 1 minute average reading or 10 minute average readings. The readings were mostly available although there were some patches where missing readings were common. Some composite files were provided for some periods where there were many missing readings. BOM staff reported that for some periods the data on the hour was missing but 1 minute past was available, so this was provided in some cases. BOM have only recently been releasing data from automated instruments and their primary records have not been very well cleaned at this stage. All the readings were in local standard time (Eastern Standard Time) for the whole period. The ceilometer readings were examined briefly but these appeared to correlate poorly with Oktas readings over some periods, so these were not used.

Three hourly data was also provided for the entire period. This was generally a complete and clean data set (in comparison to the one hourly data), although three single readings were missing for the 6 year period (6/8/1999 12:00, 11/8/1999 9:00 and 31/3/2004 12:00). For the missing readings, values were interpolated. There is a fair degree of human input into this particular data set so it is considered more reliable. There were also 2 wet bulb readings and about 30 Oktas readings (cloud cover in eighths) that were missing over the period. The missing wet bulb readings were obtained from the 1 hourly data file. The missing Oktas readings were manually interpolated. Oktas readings were only available at 3 hourly intervals as these are manual readings taken by visual assessment. The 3 hourly data was recorded as local time (ie EST in winter and EDST in summer) so all values were corrected back to EST.

When compiling meteorological data for the period, the hourly data was used where this was available, otherwise the 3 hourly data was used (ie the actual value every third hour or an interpolated value for intermediate points).

Details on assumptions and issues with respect to weather data are included in Appendix B together with details of estimated parameters and methods for dealing with missing data.

Compiling and cleaning the weather data for this project was very labour intensive and constituted a significant part of the total effort with respect to analysis.

For the purposes of simulation in AccuRate, the 4 years of interest were concatenated so that a continuous single simulation could be conducted over the period of interest (with some modification of the AccuRate input files to accommodate this). The weather data set commenced 1 September 1999 and terminated on 30 June 2003. The first part of 1999 was filled with 1979 data and the last part of 2003 was filled with 2003 data to make 5 complete calendar years for simulation purposes.

One issue for consideration is that it will not be possible to compile weather files required for simulation prior to peak days through each summer. The type and range of data is far too complex to obtain from the Bureau of Meteorology on a daily forecast basis.

One possible solution will be to select a range of typical days or weather sequences for simulation of a suite of events that are preloaded to a prediction model. The most likely type of day or series of days could be selected in conjunction with the Bureau of Meteorology forecasts in order to provide the best possible simulation.

Further investigations subsequent to this project could identify some typical or extreme weather sequences for further analysis. The most important variables are likely to be wind speed and temperature. Most peak load days are clear so solar radiation profiles can be readily predicted (assume clear skies). Humidity tends to be low on extreme days but may play a bigger role on some intermediate temperature days with low wind speeds where air conditioner demand may be higher.

The prediction model could be regularly updated with the latest system load profile data and reference data and updated annually with respect to ownership of air conditioners and number of households. This would also provide a sound basis for short and medium term forecasts.

4. Load Data

VENCORP provided in a spreadsheet hourly load data for the total Victorian Electricity system. These spreadsheets were organised into financial years from 1 July 1998 up to and including 30 June 2003. According to the contract for this project, the period of interest for peak days associated with air conditioning is from 1 November until the end of March for each of the years nominated.

An analysis tool was developed by EES for this project to examine the daily load data and to quantify the possible magnitude of "hot" day peaks on the Victorian electricity system.

The approach used was to examine load data and to select a so called "reference" period during each summer where there was no obvious peak load activity due to air conditioning. These periods were selected by visual inspection of the state daily load profile. A new reference period has to be selected each summer to take into account natural load growth in the electricity supply system. It was found necessary to select a separate reference period for the month of January as the system load is naturally lower during this period due to industry shut downs and school holidays. However, this was sometimes difficult due to the large number of hot days that occur in January.

Once a reference is selected it is then possible to compare peak days to the reference days to provide an initial estimate of the magnitude of the air conditioner variable load on the system. Note that this approach is empirical in nature and will quantify the effect of all temperature related loads on the electricity system, not just residential and commercial air conditioner loads. However, this approach provides a starting point for further analysis and allows days of interest to be identified for more detailed building shell modelling and analysis.

The full details of the reference periods selected for each year and the periods of interest with respect to peak loads are fully documented in Appendix A.

It was found that days where energy was greater than about 8% compared to the reference day and where peak load was about 12% greater than the reference day (on a daily basis) were likely to be of most interest.

As a general rule, the first week of November was avoided as a part of a reference week due to the long weekend associated with the Melbourne Cup (and lower than normal system demand).

As noted above, the reference period was selected visually from each year. However, a further refinement recommended for future analysis would be to generate generic reference data for each year which can be scaled with load growth data. This would also allow more reliable reference periods to be generated for the Christmas/January period if this was desired. Many large system peaks occur near the end of January and these often lie near the end of the reference period.

5. Building Simulation Tool

5.1 Modelling Tool

In this study, estimates of the component of peak load attributable to demand for space conditioning in the summer are based on estimates of cooling demand derived from a thermal performance modelling tool. The particular tool used is called AccuRate. This is a modelling tool developed by the CSIRO and is intended to replace their current modelling tool called NatHERS.

The AccuRate program used was a beta version V0.94. A particular advantage associated with this program is its capacity to provide hourly data on cooling loads and internal temperatures within the reference house.

The Accurate module requires two main forms of input:

- Input based on the design and construction characteristics of a house (see section 5.2).
- Input based on weather data for the study period (see section 3)

The Accurate software assesses factors such as insulation levels, window orientation and area, wall type and ventilation to provide an estimate of the heating and cooling energy required over a twelve-month period to maintain internal temperatures at pre-determined thermostat set points. It essentially models heat flows through the building fabric in response to internal and external temperatures.

5.2 Reference house

To conduct modelling of the thermal loads on a dwelling it is necessary to input data into the simulation program that specifies details of the construction characteristics. Ideally a simulation model should be representative of the actual stock of housing.

A truly representative model would include the main construction types found in Victoria in proportions that matched their actual market penetration. This type of detail is most important when constructing a model that would permit forecasting of future trends. In this the initial analysis undertaken for this project where we are only considering a very narrow time frame (effectively 4 years), such an accurate and sophisticated model is of less importance. On this basis it was decided that a single reference house model would be used.

The house type selected for this study was derived from an earlier study conducted jointly by the AGO and SEAV entitled *Study Of The Impact Of Minimum Energy Performance Requirements For Class 1 Buildings In Victoria* (EES 2000). In that study, a stratified random sample of approximately 240 house designs was derived from Victorian council records in the year 1999. Subsequently, the AGO selected a sub sample of 12 of these designs for inclusion in a study of the accuracy of the AccuRate software (in 2003). From this sub sample, the design that most closely represented the stock average was selected for use in this study.

A comparison of the key characteristics of the reference house and the stock average of houses constructed in the 1990s is shown Table 4.

Table 4: Reference House Characteristics

Characteristic	Stock Average or Norm	Reference House
No. Storeys	Single	Single
Floor Area	218 m^2	209m^2
		174.3m2 (NCFA)
Wall Construction	Brick Veneer	Brick Veneer
Floor Construction	Concrete Slab on Ground	Concrete Slab on ground
Roof Construction	Attic (either tiled or metal)	Tiled Attic (R 2.5)
Window Type	Aluminium Single Glazed	Aluminium Single Glazed
Window Area (as % of NCFA	29%	24%

5.3 Limitations of the software

5.3.1 Space conditioning operation schedule

The default settings in AccuRate assume that the space conditioning plant is operated between 7AM and Midnight whenever internal comfort conditions fall outside specified comfort conditions (principally air temp, humidity and wind speed are taken into consideration).

This schedule of operation is referred to as the “All day” space conditioning schedule. This type of schedule would be applicable to those householders who are home all day[3] (eg elderly, unemployed, parents of young children etc). Obviously other segments of the community would operate their space cooling equipment on

[3] This All day schedule of operation would also be applicable to those householders who choose to operate their space cooling equipment even when their dwelling is unoccupied

alternative schedules to suit their particular lifestyles. For this study two other operation schedules were considered.

School Day Schedule: In this schedule it is assumed that the household is vacant during school hours (nominally 9am to 4pm Monday to Friday) and that space cooling plant is operated when required between the hours of 7am to 9am and 4pm to 12pm inclusive, Monday to Friday.

Work Day Schedule: In this schedule it is assumed that the household is vacant during work hours (nominally 8am to 6pm Monday to Friday) and that space cooling plant is operated when required only after 6pm.

Because the work day schedule includes cooling plant operation only after 6pm (ie after the system peak which typically occurs before this time), this schedule was excluded from consideration for this study. This left only the “All day” and the “School day” schedules to consider.

The reference house was modelled in two separate runs, one for each schedule. The All day schedule used the default settings for AccuRate. For the Schoolday schedule the plant operation times were manually adjusted in the scratch files before running the AccuRate simulation.

On days of high ambient temperature the “school day” schedule showed higher levels of space cooling power demand upon afternoon start up compared to the demand from the “all day” schedule at the same time in the afternoon (on average approximately 30% higher). This is because in the “all day” schedule the internal temperatures were much lower at that time of the day (due to the operation of the cooling plant in the preceding hours). This means that after 4pm those houses operating on the school day schedule will have a greater impact on the system peak load, for this reason the “all day” and “school day” schedules were separately modelled.

Details of how these schedules are taken into account are provided in section 6.1

5.3.2 Whole house cooling

The AccuRate program assumes that the entire house (excepting some minor service areas) is space conditioned (irrespective of the type of space conditioning equipment actually installed). AccuRate is not currently able to model different zoning regimes within a house; analysis of the impact of this factor within this study is therefore limited to assuming a proportional energy reduction for a reduced conditioned area.

Details of how this factor is taken into account is provided in section 6.2.2.

5.3.3 Cooling demand met in first hour

The AccuRate program is designed such that the plant capacity is capable of reaching the target comfort conditions within one hour of start up. A concern was expressed that this may be unrealistic and that in more extreme weather conditions there may in fact be some unmet cooling demand after one hour. This would mean that AccuRate may overestimate the actual power demand when starting up (ie at 7am for the “all day” schedule and at 4pm for the “school day” schedule). However, under the all day schedule the simulation model will have been running for many hours prior to the system peak so building cooling requirement will accurately track the daily conditions.

Reference was made to an earlier study by EES entitled *Implications For Space Conditioning In Class 1 Buildings In Victoria Of Improved Building Shell Performance* (EES 2001). In this study a representative air conditioner installer was asked to size the plant capacity requirements for a range of house types and sizes using current typical industry practice. As is common in current industry practice, the shell efficiency was largely ignored in this exercise. The results showed a very consistent approach that equated to an average capacity allowance of 0.43 MJ/m^2 of conditioned floor area. For our reference house (174m^2 net conditioned floor area or NCA) this equated to a maximum cooling capacity of 74.6MJ. Over the study period the maximum cooling demand estimated by AccuRate for the reference house (school day schedule) in any one hour was 77.5MJ. This suggests that the default settings in AccuRate are likely to accurately reflect actual maximum cooling capacity deliverable from installed plant.

5.3.4 Window Openings

AccuRate is designed to switch off space cooling plant should external conditions be such that the opening of windows alone would maintain the house at comfort conditions. This is a sensible strategy when a cool change arrives. Unfortunately, when external conditions are not particularly severe the simulation tends to cycle the opening and closing of windows. In these instances the cooling plant may operate for a few hours after which the windows will be opened for an hour (often after a slight breeze occurs) then closed again and the cooling plant re-started. This is unlikely to happen in a real household where the occupant is expecting a hot day.

It was considered that this practice would not represent a realistic model of user behaviour and that in reality windows would be kept shut until a significant change had occurred. To effect this mode of operation the windows on the reference house were all set to the shut position. This would tend to provide over or underestimates of space conditioning demand at certain times of the year but for the period of interest to this study (moderate to severe summer cooling conditions) the simulation would be more representative.

5.3.5 Hourly Oscillations in Demand for Air Conditioning

The AccuRate simulation program simulates cooling demand by assessing at the end of each hour the conditions in each internal zone (i.e. temperature and moisture content). If each zone is within the comfort region in the Accurate internal psychrometric chart, cooling is not invoked. If however any of the zones fall outside the comfort region, cooling is then invoked[4]. The one hour time frame used by

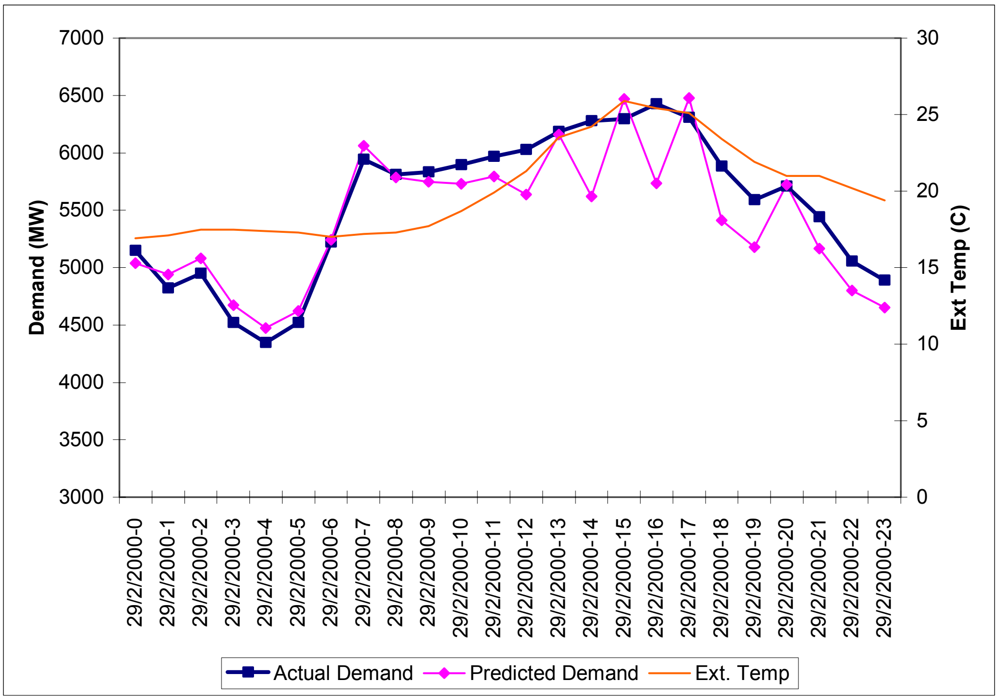
[4] Accurate in fact has an intermediate step involving the opening of windows in certain circumstances as an alternative means of maintaining comfort conditions but, as noted in section 5.3.4 this step was not used in the MD model for this study.

Accurate is not however realistic in terms of how a real air conditioner would operate. In reality the cycle time would be much less (typically of the order of 5 to 10 minutes and for inverter type air-conditioners there can be no cycling at all). For the main purpose of the Accurate simulation (the examination of total annual cooling and heating energy), the coarseness of the 1 hour cycle is not significant. However, for this study we are interested not in annual demand but hourly demand. The long cycle time means that on the less extreme days, significant levels of hourly cycling of the air-conditioner can be observed (see Figure 24 where the maximum daytime temperature was 26^{0}C). Under these conditions the air-conditioning will typically be invoked by the model for one hour, then in the following hour, because the internal comfort conditions will be maintained with no further cooling, no cooling will be invoked. In the following hour, after a slow rise in internal temperatures (ie over the previous 2 hour time frame) cooling will once again be invoked, hence the apparent oscillations in hourly demand.

On the more extreme days when internal temperature rises are significantly higher on an hourly basis, simulated air-conditioning tends to operate more or less continuously and such oscillations are less evident. For the purposes of estimating daily maximum demand (MD) the demand at the apex of any such oscillations has been taken as the MD.

There may be a number of options to reduce this apparent cyclng of the air conditioning system during simulation within AccuRate. One option may be to reduce the temperature control set points to be quite narrow (say 22.5^{o}C to 23^{o}C) which will ensure much smoother operation of the system during moderate days. However, it is unclear whether these parameters can be easily changed in the software. This may require further investigation if the software is used for further analysis.

Figure 24: Actual and simulated demand – 29/2/2000



6. Maximum Demand Modelling, Input Data & Assumptions

6.1 Modelling Overview

The output from the AccuRate simulation module provides an hourly estimate of cooling load for the single reference dwelling over the study period. As discussed in section 5, different occupancy regimes will affect the maximum cooling demand at different times of the day. AccuRate modelling was therefore undertaken for both “all day” schedule and the “school day” schedule. For each day of the study period the maximum hourly cooling load for the all day schedule (L_a) and also the school day schedule (L_s) was determined.

In order that an estimate of the maximum demand attributable to space conditioning loads (Dc) across the entire state could be made from the maximum hourly cooling loads derived from AccuRate, they needed to be adjusted to account for the following factors:

- **Occupancy Factor (F_o):** ie the extent to which a dwelling may be occupied will affect the likelihood that the cooling plant will be operated.
- **Zoning Factor (F_Z):** This is the constraint on the actual floor area of the dwelling that is serviced by space conditioning.
- **Total households in the state (N_H)**
- **The penetration of air conditioners in use in housing (P_H)**
- **The average efficiency of the installed air-conditioners (E_a)**
- **The “Utilization” factor (U)** needed to account for user behaviour that will tend to constrain the actual hours of operation of the space cooling appliance depending upon the internal temp of the dwelling.
- **The Commercial sector factor (C_c)** to account for the commercial sector contribution to the total space conditioning related cooling load.

Each of these factors are detailed in the following sub-sections. The full algorithm used to calculate the statewide maximum daily demand attributable to space cooling can be found in Appendix E.

6.2 Input Data, Applied Factors and Assumptions

6.2.1 Occupancy Factor (F_O)

As noted in section 5.3.1 different occupancy regimes will result in variations in the time and magnitude of the space conditioning demand. For this study two different occupancy regimes ("all day" and "school day") were separately modelled using AccuRate. The respective share of each occupancy regime is at this stage unknown.

The author has determined that such information should be available from the unit records from a series of ABS surveys entitled "How Australians use their time" (Time Use Survey) Cat No. 4153. These are diary based surveys from 1991 and 1997 of about 5000 households where respondents record where they are and what they are doing, of particular interest is when they are at home (and therefore likely to switch on their air conditioners) and when they are not.

At the completion of this stage of this study this data was not available so an estimate only was used. In the estimate it was assumed that the share of the "schoolday" schedule was only 10%. If the proportion of the "schoolday" schedule were set much higher than this a simulated cooling spike would occur at 4PM (ie when the schoolday schedule commences operation of the AC); such a spike is not generally obvious in the actual state demand traces. In a final version of this model it is hoped that this occupancy data can be integrated into the model thereby improving its accuracy and permitting trends in occupancy patterns to be accounted for in any forecasts undertaken.

6.2.2 Zoning Factor (F_Z)

Zoning refers to the tendency of many householders in Victoria (and indeed residents of other states as well) to condition only part of their homes. For instance, a user may choose only to cool their living areas and leave sleeping areas and service areas unconditioned in summer.

The level of zoning that a user will apply is dependant partly upon the space conditioning equipment installed. For instance, users with a small split system air-conditioner can practically only cool (or heat in the case of reverse cycle systems) one or two rooms whereas users with a large central ducted system could adopt whole house cooling if desired (although some would choose not to do so).

As noted previously, the AccuRate program assumes that the entire house (excepting some minor service areas) is space conditioned; analysis of the impact of this zoning factor within this study is therefore limited to assuming a proportional energy reduction for a reduced conditioned area.

For the purposes of this study heating and cooling loads have been calculated across two main space cooling technologies – ducted and non ducted, each technology requiring a differing zoning factor to be applied.

The zoning constraint factors used are derived mainly from the report: *Study of greenhouse gas emissions from the Australian residential building sector to 2010* (EES 1999). Whilst the factors adopted for that study were largely informed estimates, the study did reconcile total space conditioning energy consumption with ABARE top down data for the period 1985 to 1998. The adopted levels are noted in Table 5.

Table 5: Zoning Constraint Factors (*Fz*)

Air Conditioner Type	Zoning Constraint Factor
Central Ducted Reverse cycle or Central ducted cooling only	**1.0***
Wall or Split A/C	**0.3**

* In the previous study a figure of 0.9 was used. This was applied to the gross floor area of the dwelling to account for utility areas that were assumed to be unconditioned. In this study the modelling was conducted with utility zones set to be un-conditioned, therefore the constraint factor has been adjusted to 1. ie 100% of the non-utility zones are assumed to be cooled.

6.2.3 Households in Victoria (N_H)

Estimates of household numbers were based upon research undertaken by EES in the study entitled *Study Of Greenhouse Gas Emissions From The Australian Residential Building Sector To 2010* (EES 1999). In that study the primary historical source of data for households was the Australian Bureau of Statistics *Census of Population and Housing*, which has been held at 5 yearly intervals since 1961. Household types listed in the census include private, non-private (hotels, institutions, barracks, staff quarters etc) and “unoccupied”. The EES study used values for occupied private households only.

The average number of persons per household in Australia/Victoria has declined over the past 30 years and is projected to continue to decline to 2010. This means that the number of households is increasing faster than the rate of increase in population.

Household estimates to 2010 were obtained by the projection of household size data based on size trends from 1966 to 2001: see Figure 25.

For the target years examined in stage 1 of this report, household numbers as reported in Table 4 were used. It should be noted that since the EES 1999 study was completed, further ABS population and household data has been published.

At this stage this data has not been integrated into the household model. It is expected that the rate of increase in actual household numbers in Victoria will be greater than that indicated in Table 4, largely due to unexpected increases in population in Victoria in the intervening years since 1999.

Figure 25: Estimated Household Numbers: Victoria 1966 to 2015 (EES 1999)

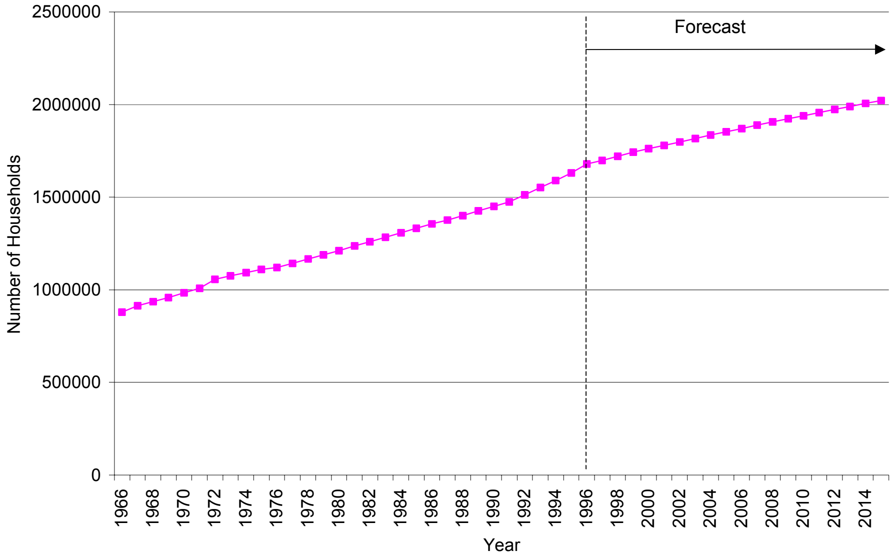


Table 6: Estimated Number of Households – Victoria 1999 – 2003 (EES 1999)

Year	Estimated Number of Households	Year	Estimated Number of Households
1966	879598	1991	1475393
1967	914475	1992	1512925
1968	936109	1993	1551260
1969	958562	1994	1590413
1970	984008	1995	1630401
1971	1008887	1996	1679198
1972	1056410	1997	1698692
1973	1075479	1998	1721217
1974	1092394	**1999**	**1742334**
1975	1109237	**2000**	**1761203**
1976	1120474	**2001**	**1779934**
1977	1142359	**2002**	**1798523**
1978	1165983	**2003**	**1816929**
1979	1188448	2004	1835152
1980	1211652	2005	1853188

Year	Estimated Number of Households	Year	Estimated Number of Households
1981	1237483	2006	1870994
1982	1259206	2007	1888606
1983	1283362	2008	1905944
1984	1306858	2009	1923042
1985	1330896	2010	1939936
1986	1355173	2011	1956662
1987	1376199	2012	1973177
1988	1399882	2013	1989518
1989	1425868	2014	2005722
1990	1450829	2015	2021785

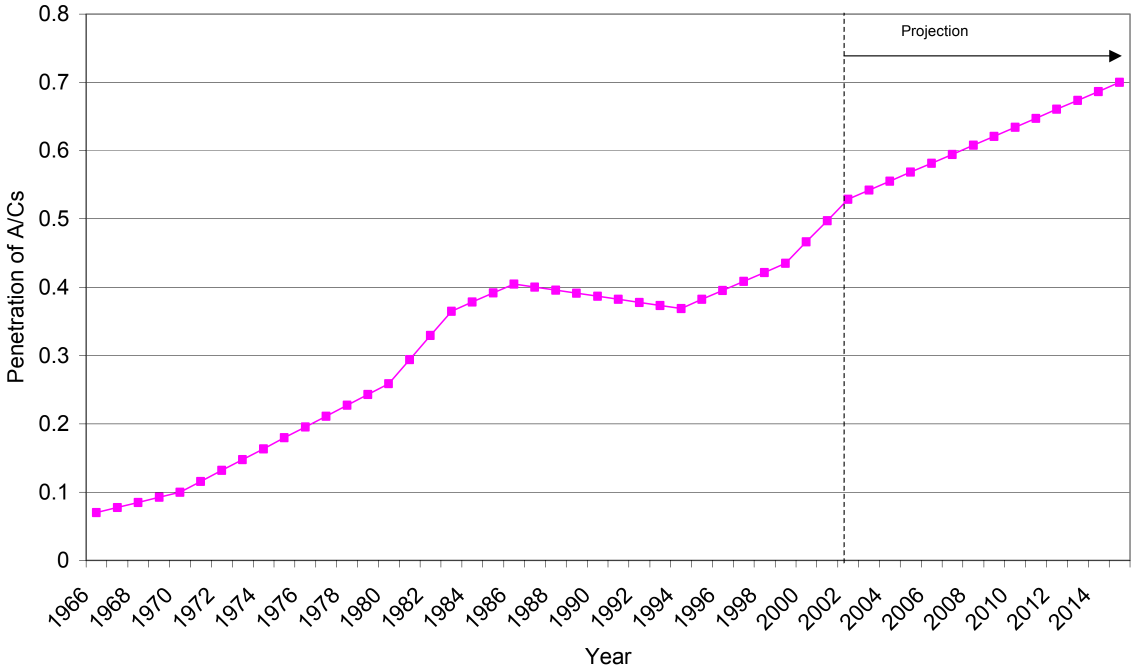
More accurate peak load forecasts (especially longer term scenario analysis) will be possible if the total number of households is segregated into major construction types known to provide distinctly different summertime thermal performance. Household numbers broken down by construction type will eventually allow trends in the penetration of each housing type to be accommodated in the peak load model. Trends in household size and type are also important. Of particular interest will be the impact of the 5 star mandatory minimum performance standard for housing that was introduced in July 2004. In this initial study only a single house type was modelled, therefore such segregation at this stage would be of no value.

6.2.4 Penetration of air-conditioners in the residential sector (P_H)

Estimates of the penetration of air conditioners in the residential sector in Victoria is based on ABS survey data. ABS has collected data at various times on the ownership of air-conditioners since 1980, the most recent survey being in 2002. These estimates are presented in Figure 26. ABS data was available for the years, 1980, 1983, 1986, 1994, 1999 and 2002. Between these dates values have been interpolated. Post 2002 a forecast has been made based upon the historical trends observed. The future projections of air conditioner penetration have not been used in this study, but the trend in Victoria (which is similar in most states) is clearly of some concern. Other sources also available provide information on total air conditioner sales and trends in penetration and ownership (BIS 2002) which supplement the ABS data series.

For the target years examined in this project, air-conditioner ownership in the residential sector as reported in Table 7 were used. The period analysed for this study has coincided with very strong growth in the ownership of air conditioners in Victoria.

Figure 26: Estimated penetration of residential air conditioners: Victoria 1968 to 2015



Source: Historical data based on ABS surveys, projections based on EES estimates

Table 7: Estimated penetration of residential air conditioners – Victoria 1999 – 2003

Year	Estimated Penetration of Air-conditioners	Year	Estimated Penetration of Air-conditioners
1966	7.0%	1991	38.3%
1967	7.8%	1992	37.8%
1968	8.5%	1993	37.4%
1969	9.3%	1994	36.9%
1970	10.0%	1995	38.2%
1971	11.6%	1996	39.5%
1972	13.2%	1997	40.9%
1973	14.8%	1998	42.2%
1974	16.4%	**1999***	**43.5%**

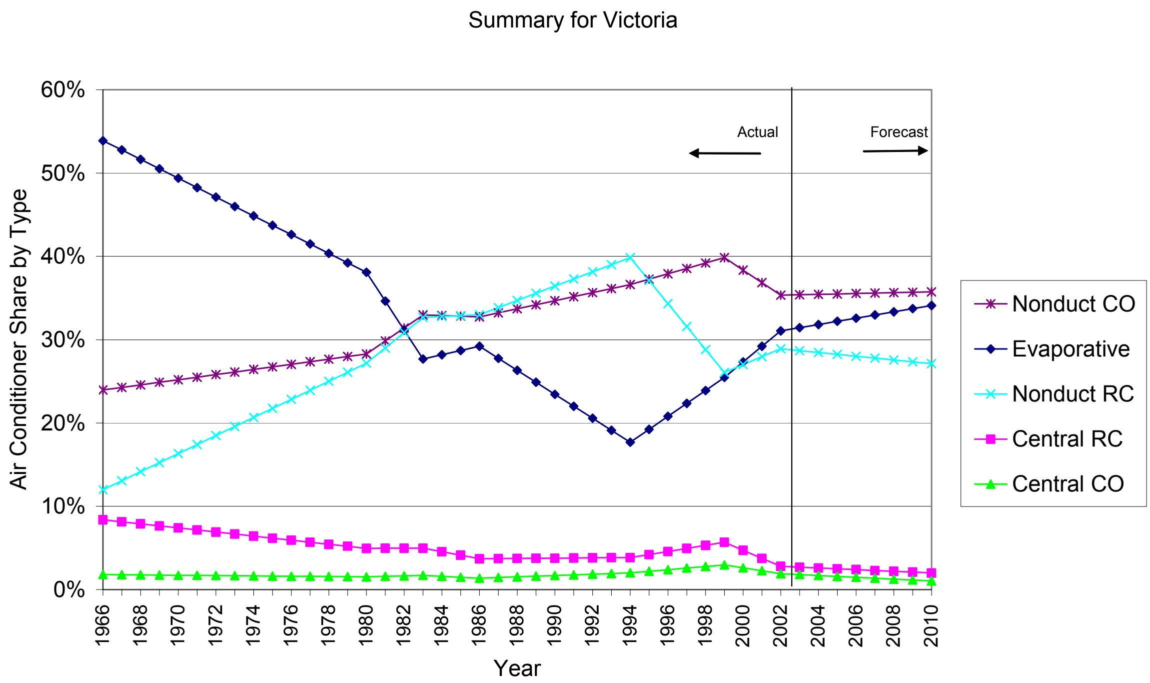
Year	Estimated Penetration of Air-conditioners	Year	Estimated Penetration of Air-conditioners
1975	18.0%	**2000***	**46.6%**
1976	19.5%	**2001***	**49.8%**
1977	21.1%	**2002***	**52.9%**
1978	22.7%	**2003***	**54.2%**
1979	24.3%	2004	55.5%
1980	25.9%	2005	56.8%
1981	29.4%	2006	58.2%
1982	33.0%	2007	59.5%
1983	36.5%	2008	60.8%
1984	37.8%	2009	62.1%
1985	39.2%	2010	63.4%
1986	40.5%	2011	64.7%
1987	40.1%	2012	66.1%
1988	39.6%	2013	67.4%
1989	39.2%	2014	68.7%
1990	38.7%	2015	70.0%

* Note: For the years analysed in this study the ratio of Non ducted to Ducted type air conditioners was set at 0.84 to 0.16. For projections beyond 2003 a change to this ratio may need to be considered.

More accurate peak load forecasts will be possible if the total number of air conditioners is segregated into major types known to provide distinctly different levels of service. Air-conditioner breakdowns by type will eventually allow trends in the penetration and ownership of each major air-conditioner type to be accommodated in the peak load model . Of particular interest shall be the possible increase in whole house cooling systems and the trends in the share of evaporative systems. In 2002, around 31% of all air conditioners in Victoria were the evaporative type.

Trends in the share by air conditioners type for Victoria is shown in Figure 27.

Figure 27: Trends in Share of Air Conditioner Type - Victoria



Source: Historical data based on ABS surveys, projections based on EES estimates

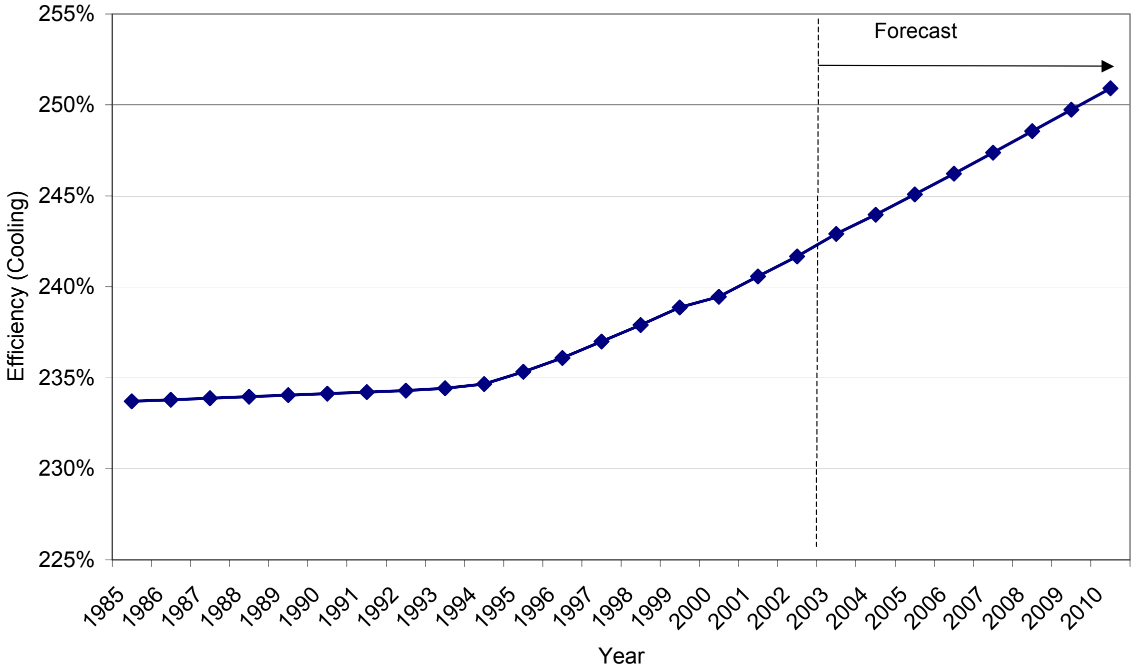
6.2.5 Average efficiency of the installed air-conditioners (E_a)

The higher the space conditioning appliance efficiency, the lower the fuel consumption (input energy) required to meet the required heating and or cooling load.

Estimates of the average efficiency of installed air conditioners in residential buildings in Victoria is based on the analysis of registration records for air conditioners in Australia over the past 15 years which has been analysed through a stock turnover model. These trends are presented in Figure 28. The overall efficiency is trending upwards gradually. The average efficiency of new air conditioners in 2003 was an EER of around 2.65 which is somewhat better than the stock installed in 2003 (average EER of about 2.4).

The Ministerial Council on Energy through the National Appliance and Equipment Energy Efficiency Committee (NAEEEC) has recently introduced mandatory minimum energy performance standards for single phase air conditioners (commenced in October 2004). This sets minimum efficiency levels of 2.3 for reverse cycle units and 2.45 for cooling only units. This may have a small impact on the average efficiency of new air conditioners. Efficiency standards for 3 phase systems have been in force since October 2001, but these are not common in the residential sector. More importantly, much more stringent efficiency levels for single phase air conditioners are scheduled to be introduced in 2006/7. These new stringency requirements will set a minimum EER for unitary systems of 2.75 and split systems 3.05. This is expected to have a significant impact on the efficiency of the stock of air conditioners over the period to 2015. It is also important to note that the most efficient products on the market have very high energy efficiency. Current Top Energy Saver Award models are required to exceed 4 stars (a cooling EER in excess of 2.9 and there are some products with an EER of as high as 4.0 available on the market in 2004.

Figure 28: Trends in average installed air conditioner cooling efficiency - Australia



For the target years examined in this project, air conditioner cooling efficiency levels as reported in Table 8 were used. This period has coincided with a minor improvement in the cooling efficiency of air conditioners installed in Victoria.

Table 8: Estimated cooling efficiency of residential air conditioners – Victoria 1999 – 2003

Year	Air Conditioner Cooling Efficiency	Year	Air Conditioner Cooling Efficiency
1985	234%	1998	238%
1986	234%	**1999**	**239%**
1987	234%	**2000**	**239%**
1988	234%	**2001**	**241%**
1989	234%	**2002**	**242%**

Year	Air Conditioner Cooling Efficiency	Year	Air Conditioner Cooling Efficiency
1990	234%	**2003**	**243%**
1991	234%	2004	244%
1992	234%	2005	245%
1993	234%	2006	246%
1994	235%	2007	247%
1995	235%	2008	249%
1996	236%	2009	250%
1997	237%	2010	251%

6.2.6 "Utilization" factor (U)

Initial modelling efforts revealed that there was an apparent reticence of some air conditioner owners to operate their appliances during mild or even moderate cooling events. AccuRate tended to overestimate the cooling load on the more moderate days and this tendency became less pronounced as weather events became more extreme.

From a series of analyses on the weather and load data available it was concluded that many owners of air-conditioners did not adopt the thermostat setting regime as specified in AccuRate, which assumes that space cooling is switched on when internal temperatures were as low as 24C. Some householders may choose not to operate their space cooling appliances until significantly higher internal temperatures are reached. This approach may result from an effort to reduce running costs, others may simply be less sensitive to higher temperatures than the AccuRate model would suggest or may adopt alternative strategies such as the use of fans or more appropriate clothing before resorting to the use of their air-conditioner.

Whatever the reason, a "Utilization" factor (U) needed to be incorporated into the model to account for this apparent user behaviour. This tends to constrain the actual hours of operation of the space cooling appliance depending upon the internal temperature of the dwelling.

A function was developed that related internal temperature to apparent utilization. The internal temperature was modelled on the reference house[5] by adjusting the AccuRate scratch file to run in "free running" mode (ie without space conditioning). Internal

[5] In this mode the reference house was further modified to increase its thermal mass by changing the construction to cavity brick and altering internal walls to be masonry. This was designed to increase the thermal lag in the dwelling. This approach was adopted to help account for an apparent lag in the actual peak load compared to that predicted by Accurate. This lag would be particularly applicable to higher mass buildings such as large commercial establishments.

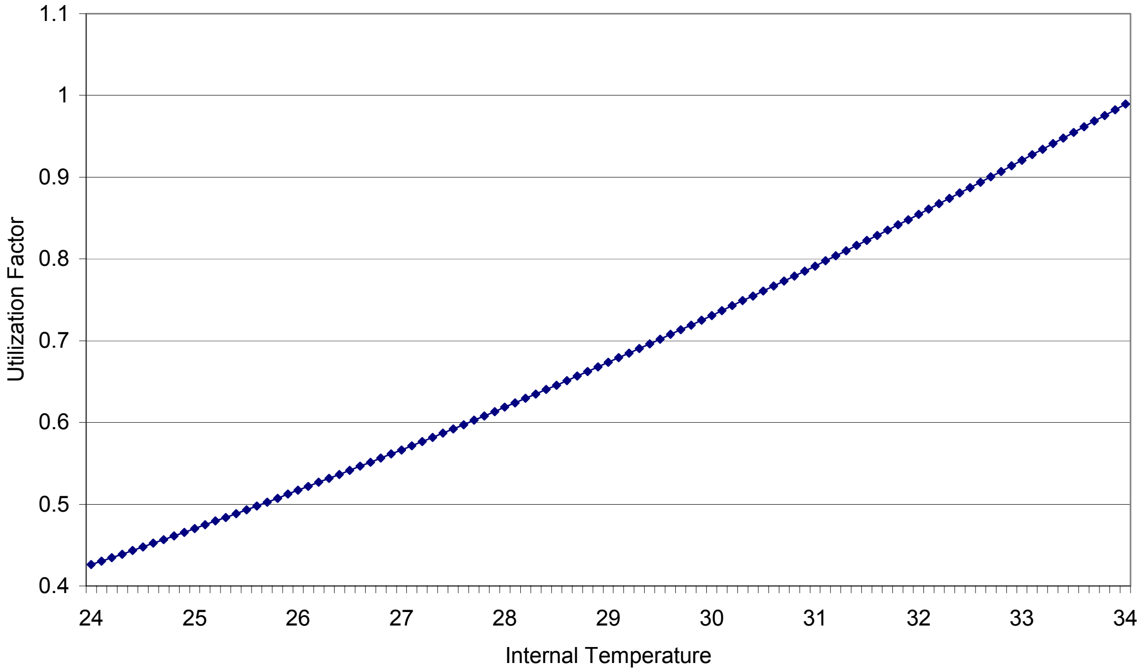
temperature data was then used from this free running mode as the basis for developing the utilization factor (see Figure 29). At relatively low internal temperatures the cooling load predicted by AccuRate is constrained by 50% or more; by the time the internal temperature reaches the mid thirties, utilization is 100%. For temperatures above 34°C the utilisation remains constant at 1.0.

The function for this curve is:

$$0.000195 \times Ti^{2.4193}$$

Where:
Ti = The internal temperature of the reference dwelling when configured with increased internal mass in free running mode.

Figure 29: Utilization Factor Vs Internal Temperature

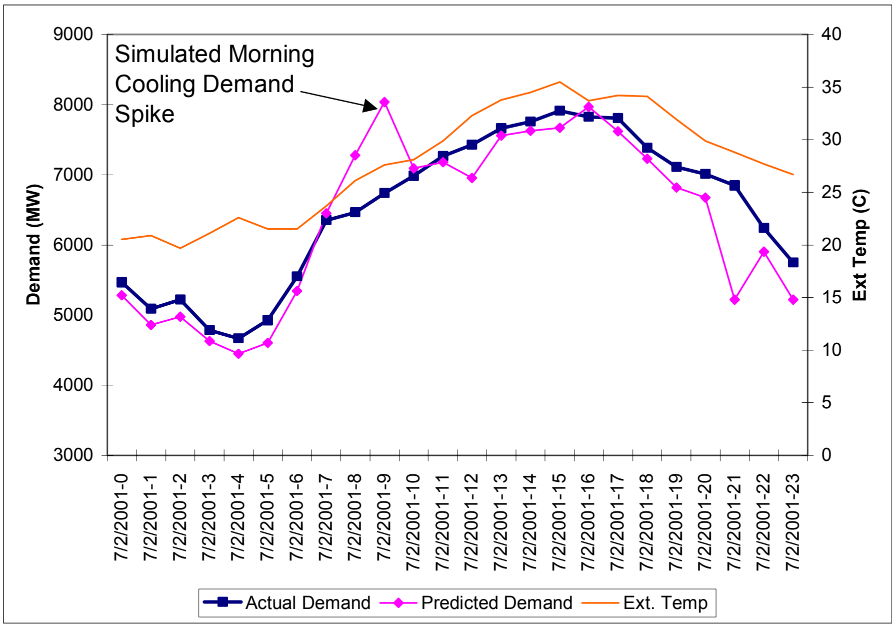


Whilst this function improves the accuracy of the model during the daytime (which is the focus of this study) it was found that the application of the utilization factor in the early morning (before 9AM) tended to result in an overestimate of cooling demand at that time (see Figure 30). This overestimate is postulated to be caused by 2 main effects:

- As noted in section 5.3.4, to create realistic model of user behaviour (especially during periods of maximum daytime demand) windows were set in the shut position. Whilst this is realistic on hot summer days, it is not realistic for typical behaviour overnight for Melbourne where the temperature is usually below 20°C. Often overnight cooling is achieved by opening windows, however with windows set in the shut position (as the default – see 5.3.4) this does not occur and internal temperatures (Ti) become excessively high and the building takes a long time to cool. The apparently high internal temperatures in the early morning means that the utilization factor is also apparently very high whereas the reality is quite different.

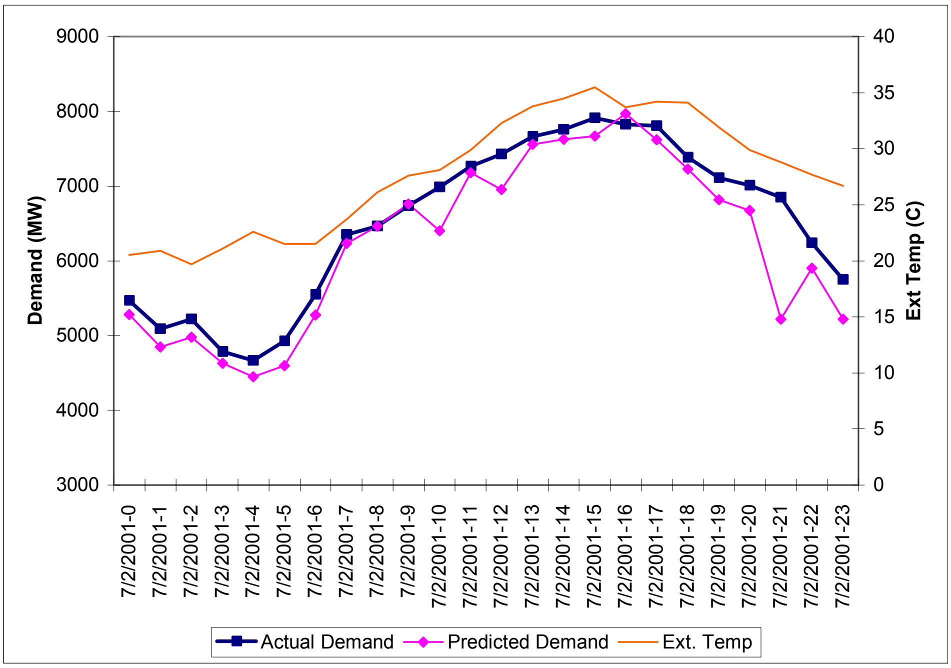
- It is postulated that in the early morning between wake up and 9-10AM there is an enhanced reticence of some air conditioner owners to operate their appliances, especially those that may be leaving the house during the morning to go to work or school.

Figure 30: Profile – 7/2/2001 – Without rectification to the Utilization factor



This overestimation of the utilization factor during the early morning was rectified by setting the value of Ti in the above function to 21^{0}C between the hours of midnight and 9AM. In Figure 31 below where the hot day shown (7/2/2001) followed a hot day on the 6th but with an overnight minimum of less than 20^{0}C, cooling via natural ventilation is likely to have been adopted by most households thereby significantly reducing the internal temperature compared to the case assumed in the base utilization function above, which takes no account for cooling via natural ventilation.

Figure 31: Profile – 7/2/2001 – With rectification to the Utilization factor



It should be remembered that the Utilization curve is very much an idealised trendline; actual utilization factors for individual data points can vary widely, nevertheless the application of this factor provides overall improvement to the match between predicted and actual peak loads. It is expected that further analysis subsequent to this project could incorporate further refinements to this curve in an effort to better match the simulation to reality.

6.2.7 Commercial Sector Factor (C_c)

The space conditioning energy demand model developed in this study is based upon an analysis of the residential sector (partly because the residential sector is clearly driving increased peak loads and partly due to the fact that the available data for the commercial sector is much more limited). To estimate total space conditioning related loads in summer a factor needs to be applied to the estimates for the residential sector to account for the additional load attributable to the commercial sector[6].

By comparing the actual peak loads with those predicted by the model, it was found that on weekdays the actual load was consistently 90-100% greater than the

[6] This of course assumes that both the commercial and residential sectors respond in a similar manner to climate conditions in terms of their use of space cooling equipment. At this stage the results suggest that this assumption is reasonably valid, however a more accurate model may be achieved if the commercial sector can be modelled separately possibly using CSIRO "Energy Express" software. Small commercial buildings will behave in a thermally similar fashion to residential dwellings. Analysis has shown that large commercial buildings such as the Melbourne CDB respond significantly differently to high temperature events. However, buildings of this type are only likely to be less than 10% of the total state load.

contribution estimated from the residential sector alone. On Saturdays the additional load was estimated at 10% and on Sunday nil. The commercial sector factors applied are detailed in Table 9. In reality the contribution of the commercial sector may be significantly more (or more likely less) than these allowances. If these factors are revised in subsequent analyses, there will need to be a complimentary adjustment to the residential utilization factor.

Table 9: Commercial sector factor (C_c)

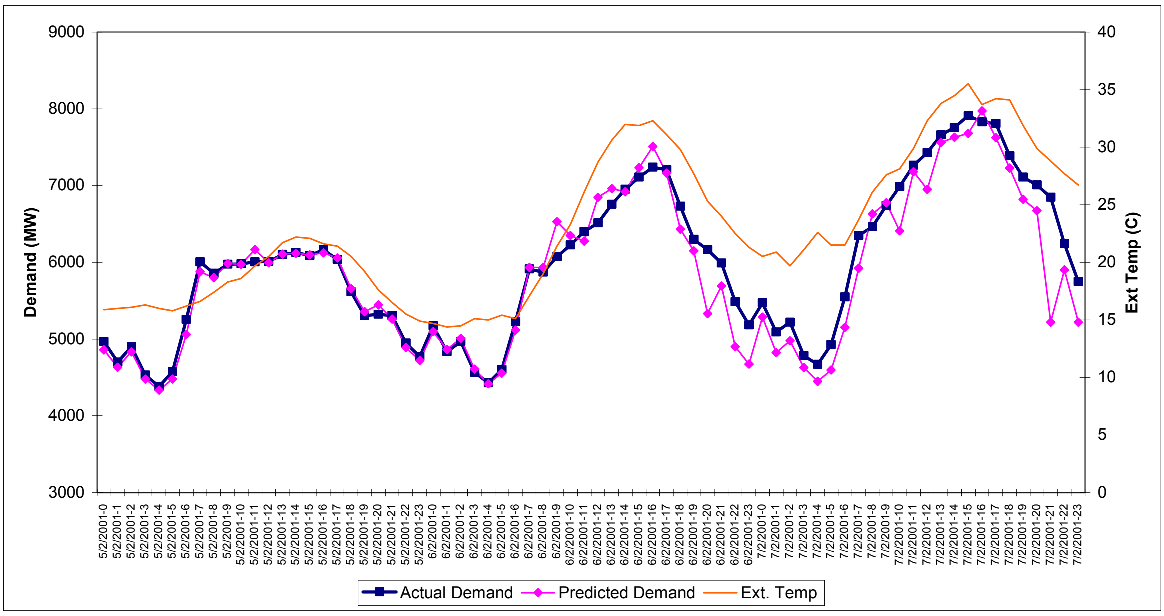
Day of the Week	Commercial Sector Factor
Monday	2.0
Tuesday	2.0
Wednesday	2.0
Thursday	2.0
Friday	2.0
Saturday	1.1
Sunday	1.0

6.3 Model Outputs

Following simulation, comparisons can be made between actual demand and modelled demand. Apart from the statistical data as presented in Section 2, the simulation spreadsheet also allows for the plotting of 3 day periods of hourly data. The plots include actual demand, predicted demand and external temperature.

In the plot for 5/2/2001 to 7/2/2001 below (see Figure 32) there is a mild day (5/2/2001 – maximum in the low 20's) followed by a moderately hot day (6/2/2001 – maximum in the low 30's) followed by a hot day with a maximum over 35^{0}C (7/2/2003). On each of these days the model tracked reasonably closely with the actual demand. Variations between actual and predicted values are mainly a result of the oscillations in the A/C operation in the Accurate module of the simulation (see section 5.3.5). Despite these oscillations, the MD on each day is predicted with a reasonable degree of accuracy.

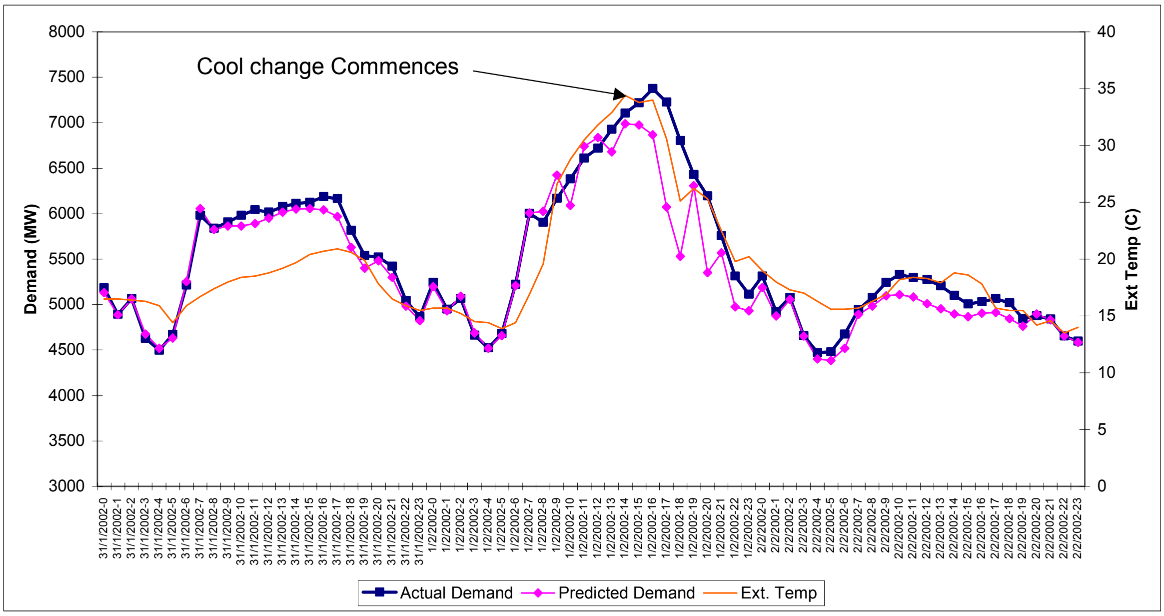
Figure 32 Sample simulation model output – 5/2/2001 to 7/2/2001



As noted previously, following a cool change the accuracy of the model was found to diminish in the hours that followed the cool change. This effect is illustrated in Figure 33. On the 1/2/2002 the temperature steadily increased during the morning to a maximum of 34.4^{0}C at 2:00PM. Between 2:00PM and 4:00PM the temperature started to slowly drop (down half a degree). Over the same period actual demand continued to grow strongly, whereas predicted demand started to fall in line with the drop in temperature. Between 4:00PM and 6:00PM the temperature dropped a further 9^{0}C down to 25^{0}C. Actual demand began to decline between 4:00PM and 5:00PM then dropped off strongly after 5:00PM. Predicted demand starting from a lower base at 4:00PM dropped off quickly after that time.

As noted in section 2.3, a cool change is a common cause for underestimation by the model of demand. It appears that there is some lag in the actual response to the apparent lower cooling demand associated with a cool change and this is not accurately accounted for in the simulation model. This lag could be a result of a real lag in cooling demand as in the case of thermally massive buildings such as in the CBD or it could be a result of behavioural factors or a combination of the two.

Figure 33: Simulation model output – 31/1/2002 to 2/2/2002 (Cool Change)



REFERENCES

ABS *Census of Population and Housing* - 1966, 1971, 1976, 1981, 1986, 1991 & 1996 (summary data reported in various Year Books and various Census reports).

ABS 2015.0, *Census of Population and Housing* - Selected Social and Housing Characteristics.

ABS 2409.0 to 2417.0, 1976 *Census of Population* - Housing Summary Files

ABS 3222.0, *Projection of the Populations of Australia*, States and Territories

ABS 4602.0, *Environmental Issues - People's Views and Practices* (issues 1994, 1999, 2002)

ABS 8212.0, *National Energy Survey - Household Appliances, Facilities and Insulation, Australia* (various issues 1980-1986)

ABS 2000 - Buildings Research and Outputs Group, Building approvals data 1987 - 1997, Victorian state and LGA data purchased by SEAV, April 2000.

BIS Shrapnel 2002, *Household Appliances Market in Australia 2002-2004*, BIS Shrapnel, Sydney, Volume 3 - Climate Control.

EES 1999, *Study of Greenhouse Gas Emissions from the Australian Residential Building Sector to 2010*, prepared Energy Efficient Strategies for the Australian Greenhouse Office.

EES 2000, *Impact Of Minimum Performance Requirements For Class 1 Buildings In Victoria*, prepared Energy Efficient Strategies for the Australian Greenhouse Office and SEAV.

EES 2001, *Implications For Space Conditioning In Class 1 Buildings In Victoria Of Improved Building Shell Performance*, prepared by Energy Efficient Strategies for SEAV.

NEMMCO 2004, *National Electricity Market Management Company*, see website http://www.nemmco.com.au for details of historical hourly load curves at a state level.

Appendix A: Peak Load Days by Year

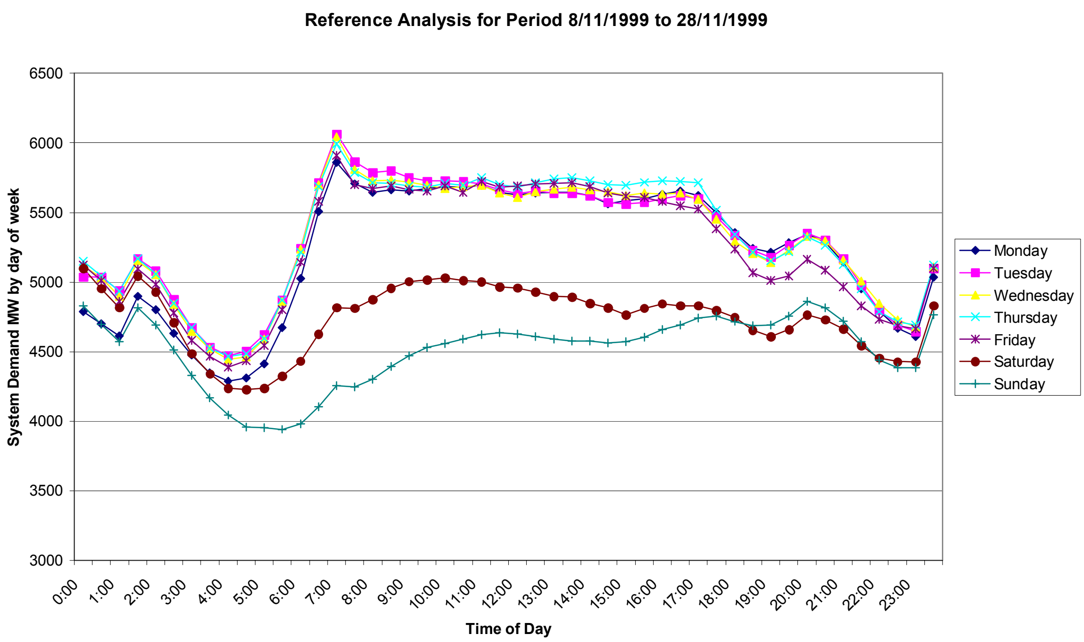
This Appendix outlines the peak load days which have been identified from analysis of the load data. Weekly profiles of selected weeks have been included in this appendix. Profiles for any week can be supplied on request (about 100 weeks are covered by this project over the 4 summers).

Summer of 1999/2000

Reference Period: 8 November 1999 to 28 November 1999.

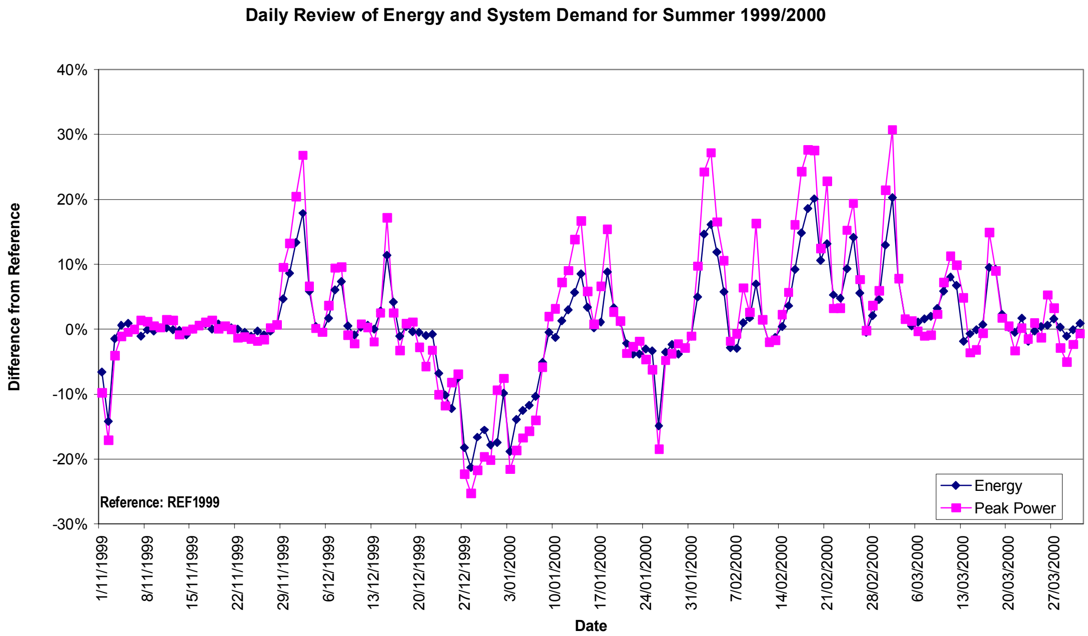
Load shape by day of the week for the reference period is shown in the figure below.

Figure 34: Reference Analysis for Period 8/11/1999 to 28/11/1999



Days of interest can be identified in the following figure:

Figure 35: Daily Review of Energy and System Demand for Summer 1999/2000



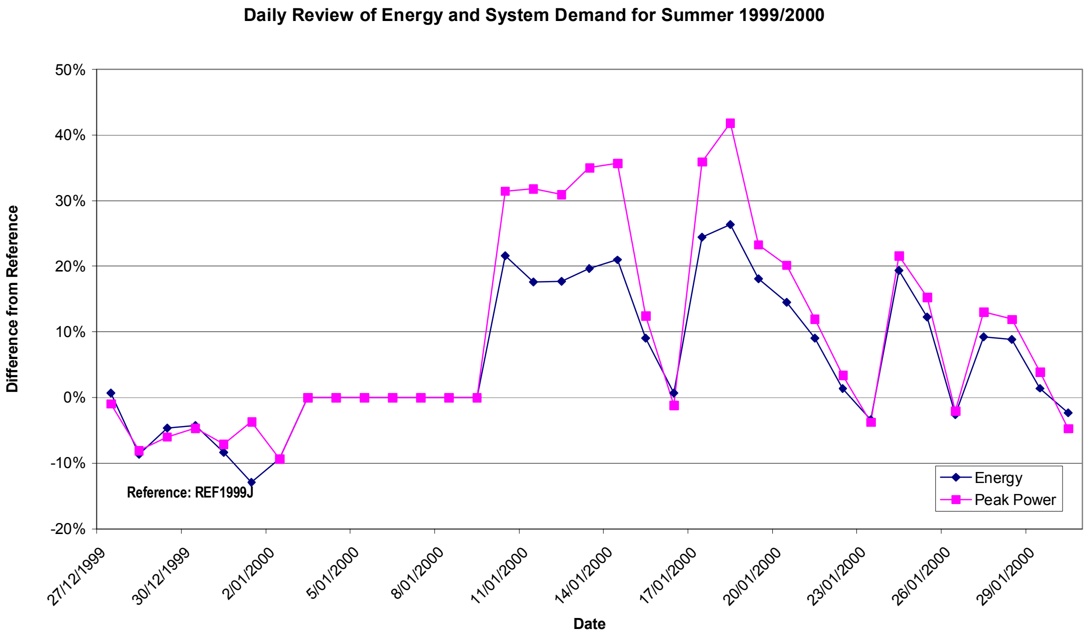
Of particular interest appear to be the periods leading up to peaks that occur on:

- 2 December 1999
- 8 December 1999
- 15 December 1999
- 3 February 2000
- 10 February 2000
- Whole period from 19 February to 2 March 2000 (including the system summer peak on 2 March)
- 11 March 2000
- 17 March 2000

When a separate reference period is selected for the month of January 2000 (3 January to 9 January 2000), the periods of interest are:

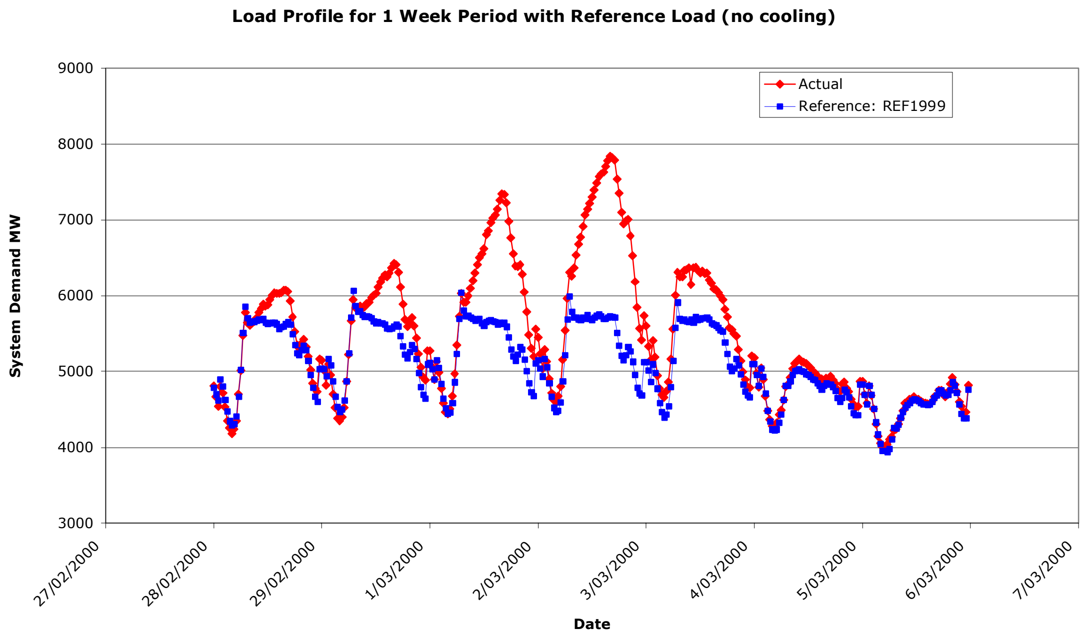
- 10 to 14 January 2000
- 17 to 20 January 2000
- The days of 24, 27 and 28 January 2000

Figure 36: Daily Review of Energy and System Demand for Summer 1999/2000



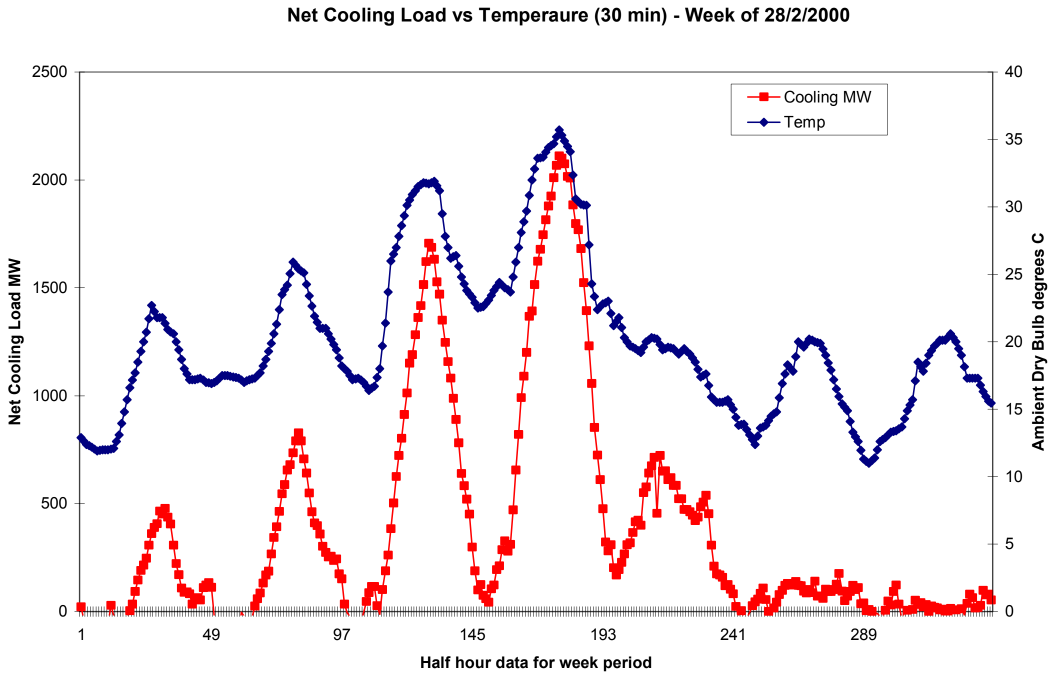
The system peak for the summer is shown is the following figure (7822MW on 2 March 2000.

Figure 37: Load Profile for 1 Week Period with Reference Load (no cooling)



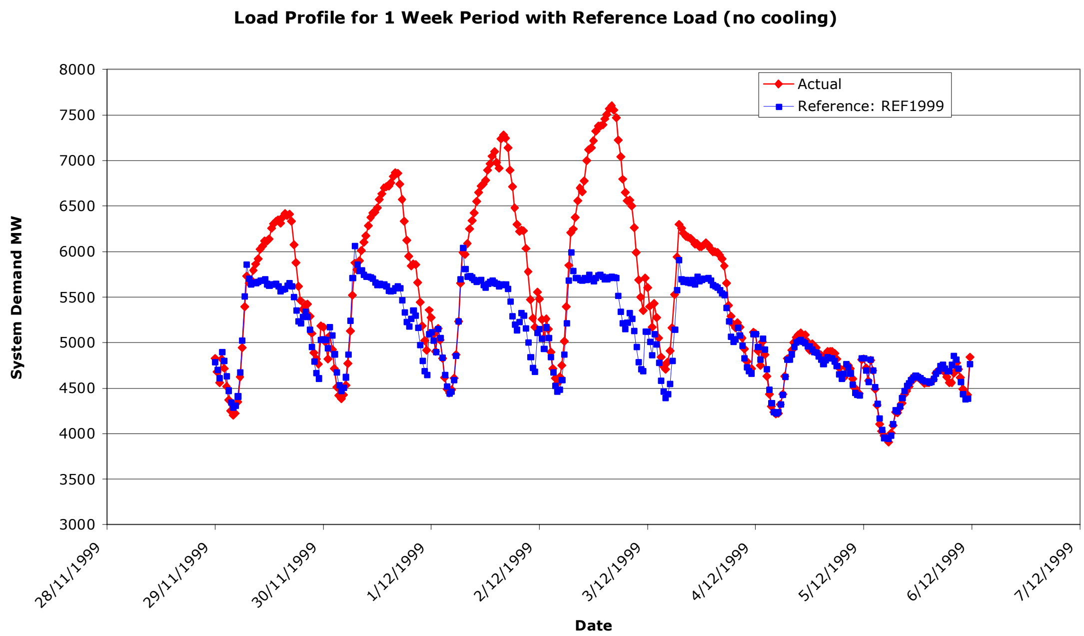
The net cooling demand and temperature profile for the week is shown below.

Figure 38: Net Cooling Load vs Temperaure (30 min) - Week of 28/2/2000



Another period of interest is also shown below:

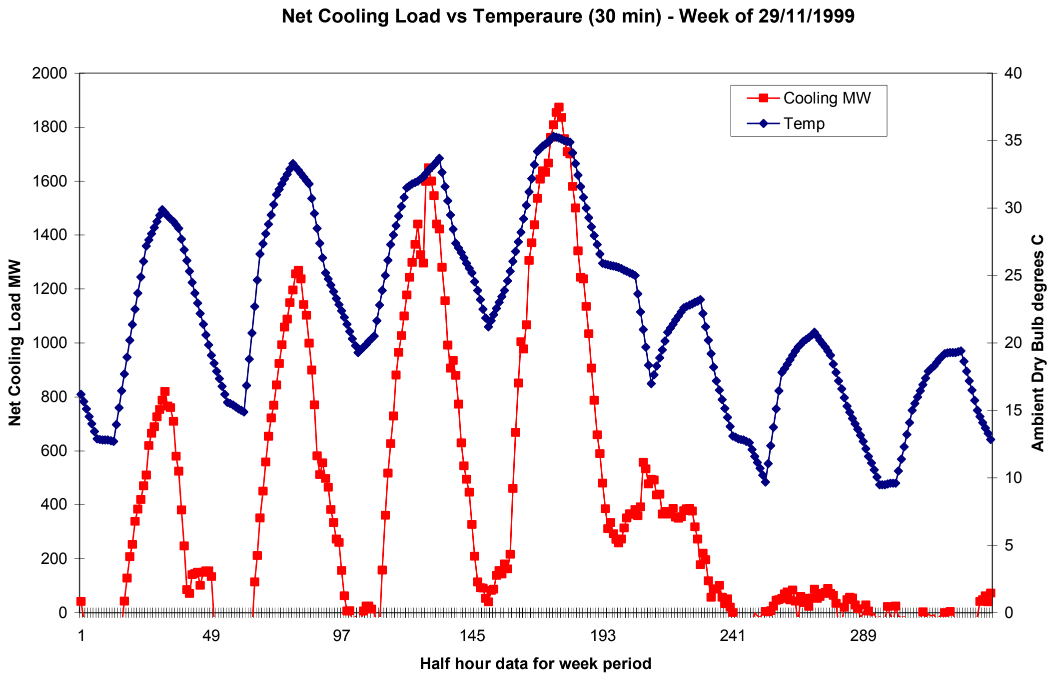
Figure 39: Load Profile for 1 Week Period with Reference Load (no cooling)



The interesting thing about this figure is that the cooling load appears to be generated during the daytime with the increase noticeable as early as 7:30am and remaining high until midnight (the peak occurs mid afternoon which is coincident with the highest thermal load in buildings). Cooling loads disappear on most evenings, except in the early morning of 3 December 1999 where there was clearly some residual cooling running all night. The temperature on 2 December 1999 was only 35°C, but clearly the run of pervious days had built up some residual demand. The overnight temperatures on the night of 2/3 December 1999 were quite high (about 26°C) until a cool change arrived at about 6am. Despite the cooler conditions on 3 December 1999 (maximum of 23°C) some residual cooling was still quite evident.

The net cooling and temperature profile for this week is shown below.

Figure 40: Net Cooling Load vs Temperaure (30 min) - Week of 29/11/1999

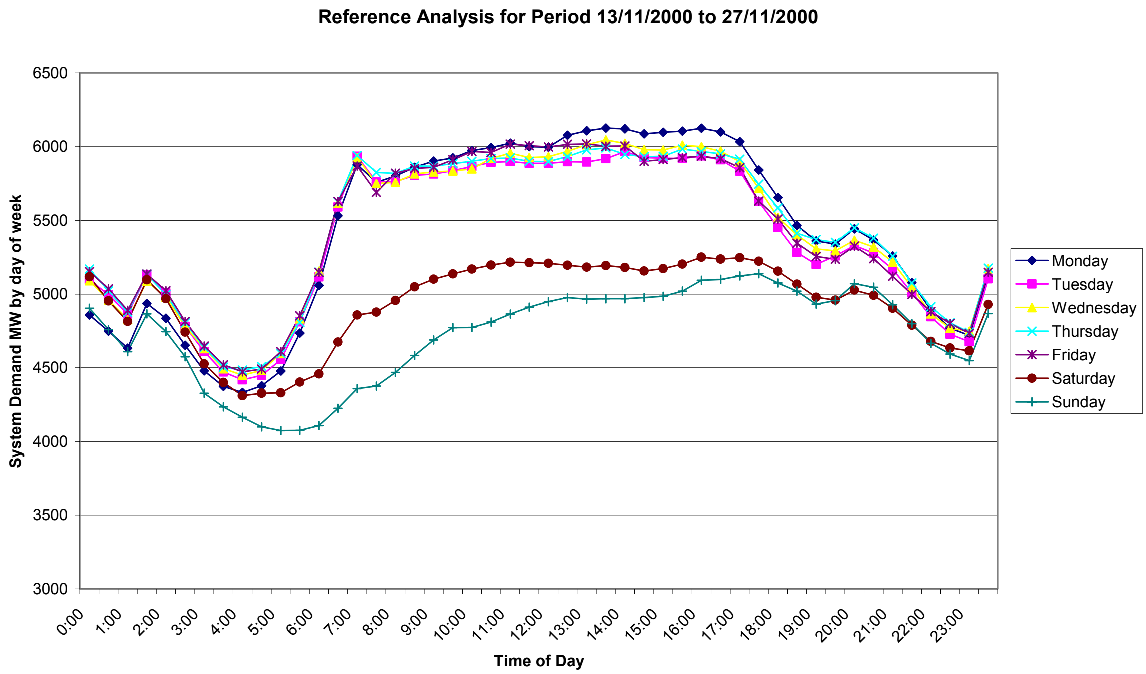


Summer of 2000/2001

Reference Period: 13 November 2000 to 27 November 2000.

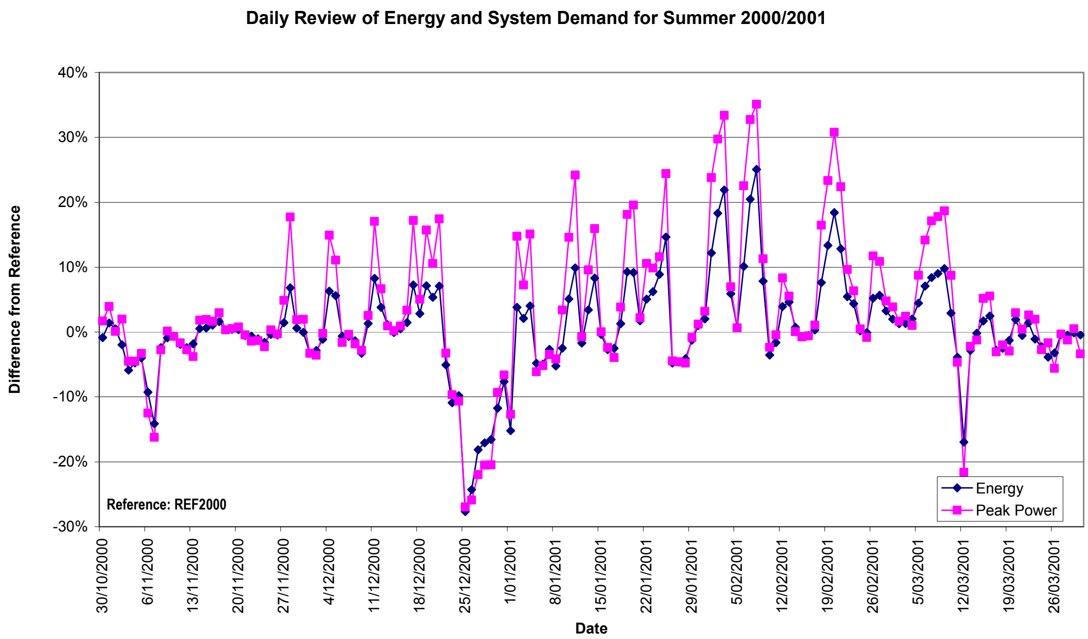
Load shape by day of the week for the reference period is shown in the figure below.

Figure 41: Reference Analysis for Period 13/11/2000 to 27/11/2000



Days of interest can be identified in the following figure:

Figure 42: Daily Review of Energy and System Demand for Summer 2000/2001



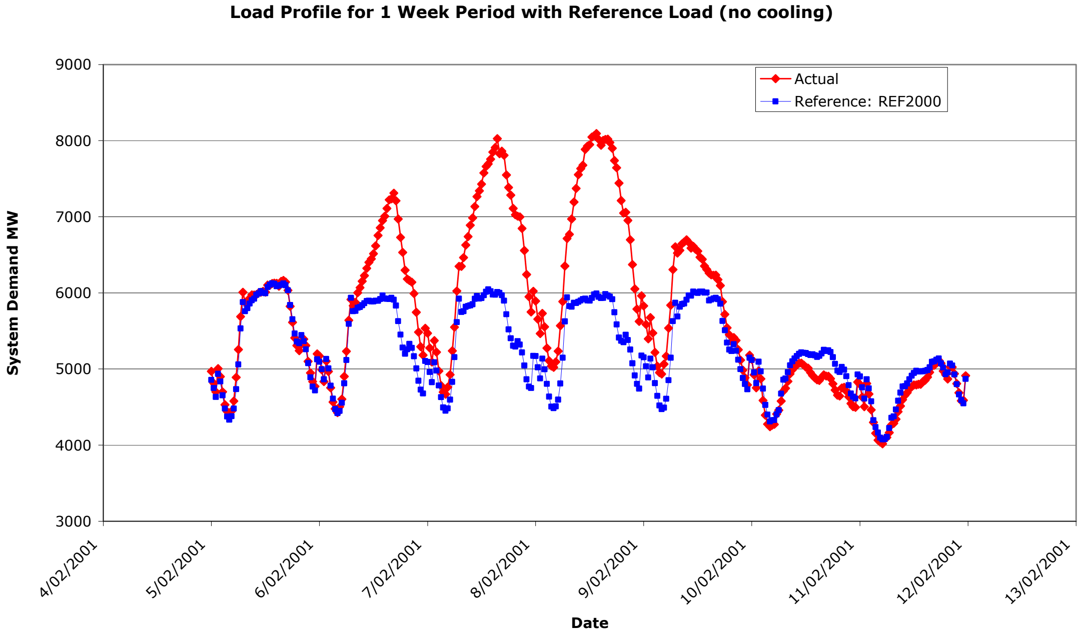
Of particular interest appear to be the periods leading up to peaks that occur on:

- Many moderate peaks in December 2000 (28/11, 4, 11, 17, 19, 21 December)
- The very large peaks just after new year (2 & 4 January 2001)
- Numerous large peaks in January 2001 (11, 14, 20, 25)
- Three very large peaks in February 2001 (2, 8, 20)
- Moderate peak leading up to 9 March 2001.

As January in this year was very hot, it has not been possible to pick a reference week to compare. However, the data suggests that the whole month was hot as the peak loads were comparable to other summer months (non holiday periods).

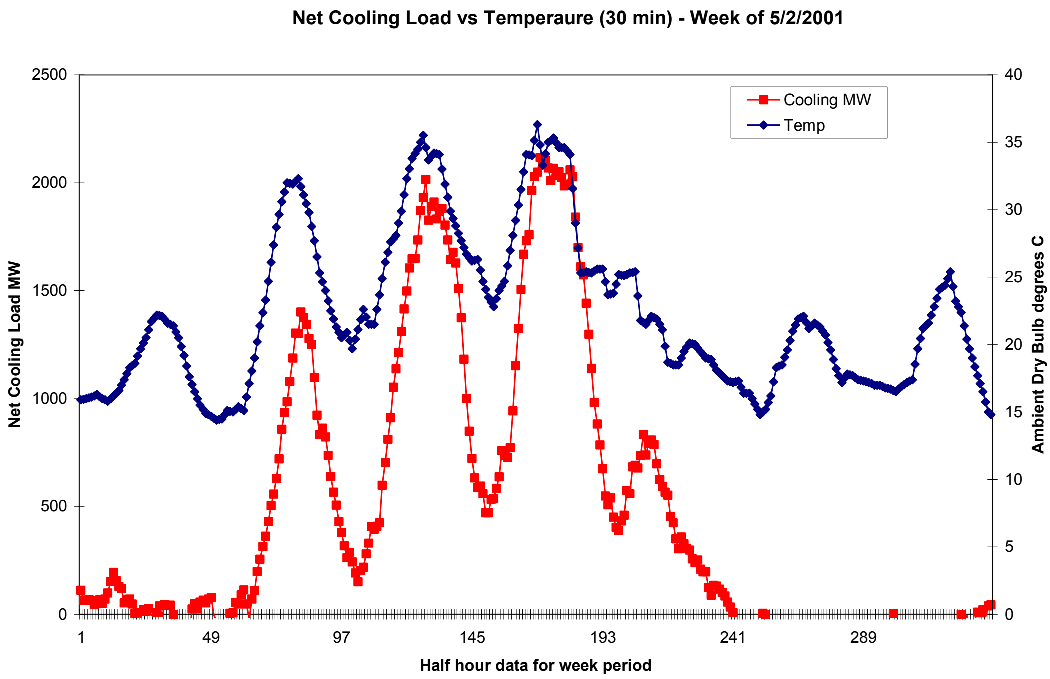
The first days where the state load reached 8000MW are shown below (7 & 8 February 2001). The data suggests that the cooling related demand was about 2000MW (33% of the base load) on those particular days.

Figure 43: Load Profile for 1 Week Period with Reference Load (no cooling)



The net cooling and temperature profile for this week is shown below.

Figure 44: Net Cooling Load vs Temperaure (30 min) - Week of 5/2/2001

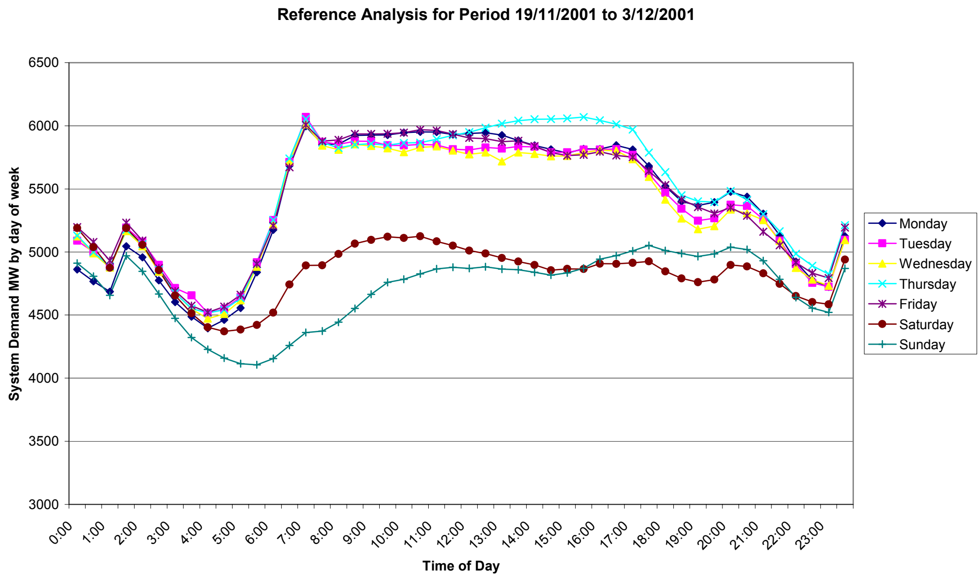


Summer of 2001/2002

Reference Period: 19 November 2001 to 3 December 2001.

Load shape by day of the week for the reference period is shown in the figure below.

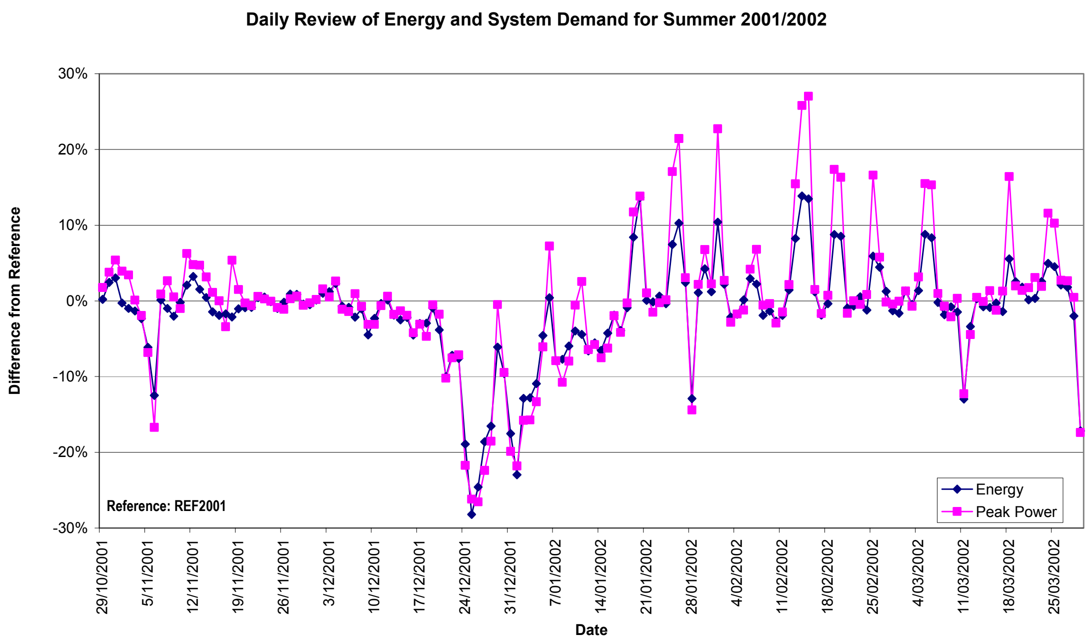
Figure 45: Reference Analysis for Period 19/11/2001 to 3/12/2001



This figure suggests that perhaps the reference period selected had some cooling load in the afternoons on the two Thursdays selected (Thursdays are normally the same as other weekday load shapes), although there is no peak load obvious on the system). This needs to be considered when looking at the data.

Days of interest can be identified in the following figure:

Figure 46: Daily Review of Energy and System Demand for Summer 2001/2002

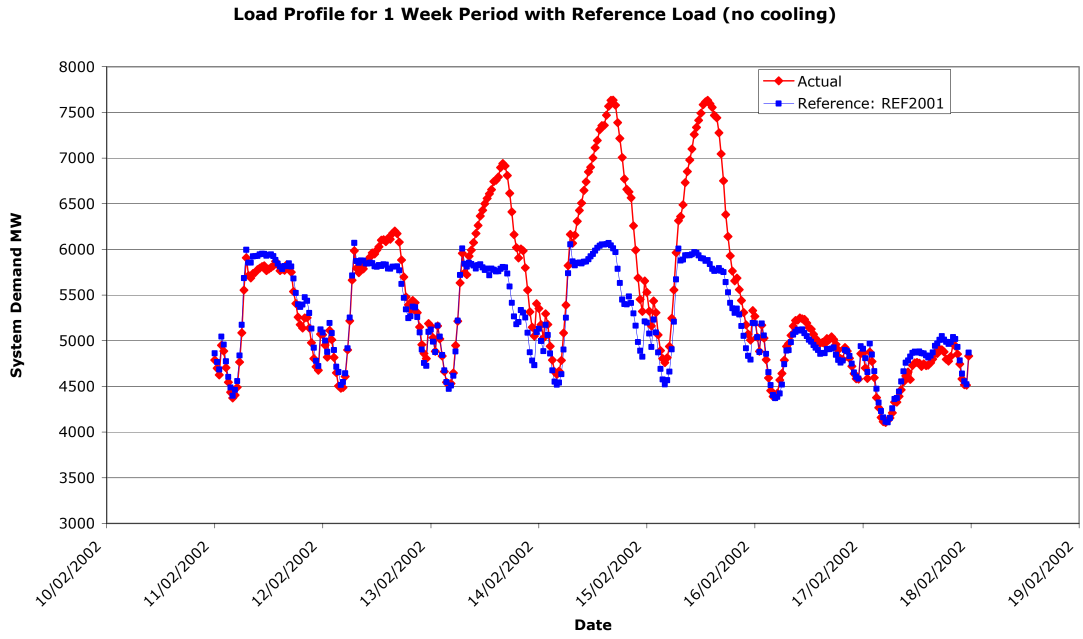


The period to Christmas was very mild in this year and there were very few peaks of note. The period of January 2002 appeared to be increasing in heat and again there was no mild week from which to select a separate reference for that month. The most notable peaks are:

- 26 January and 1 February 2002
- The highest system demand for this summer on 15 February 2002
- Moderate to high peaks on 19-20 February 2002, 25 February, 5-6 March 2002 and 18 March 2002.

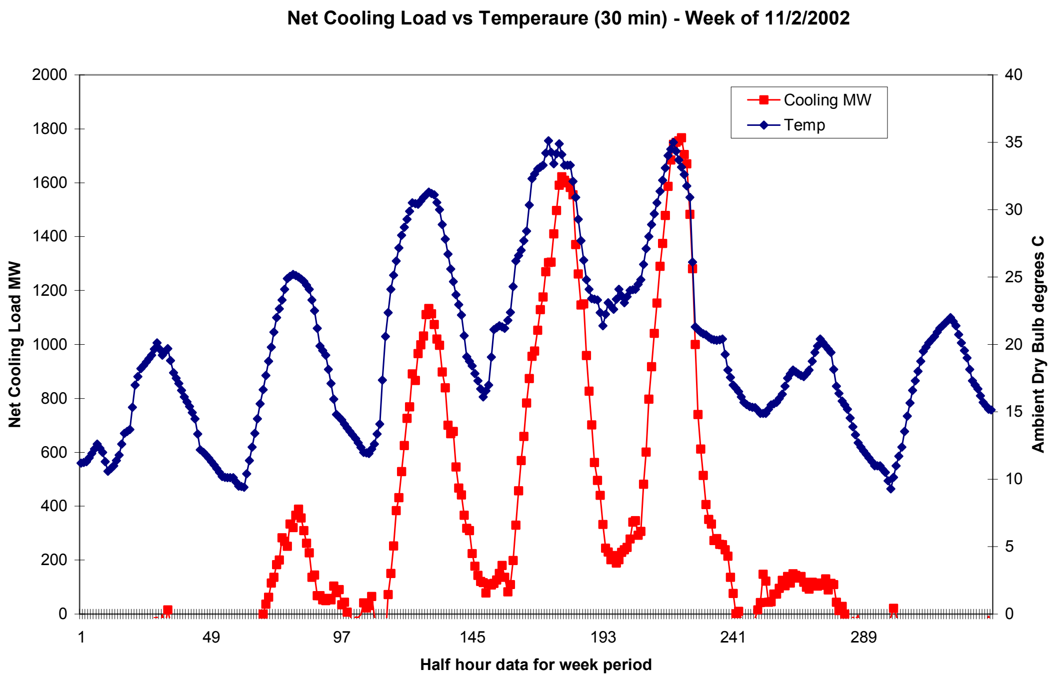
The summer system peak for 2001/2002 is shown in the following figure:

Figure 47: Load Profile for 1 Week Period with Reference Load (no cooling)



The net cooling and temperature profile for this week is shown below.

Figure 48: Net Cooling Load vs Temperaure (30 min) - Week of 11/2/2002

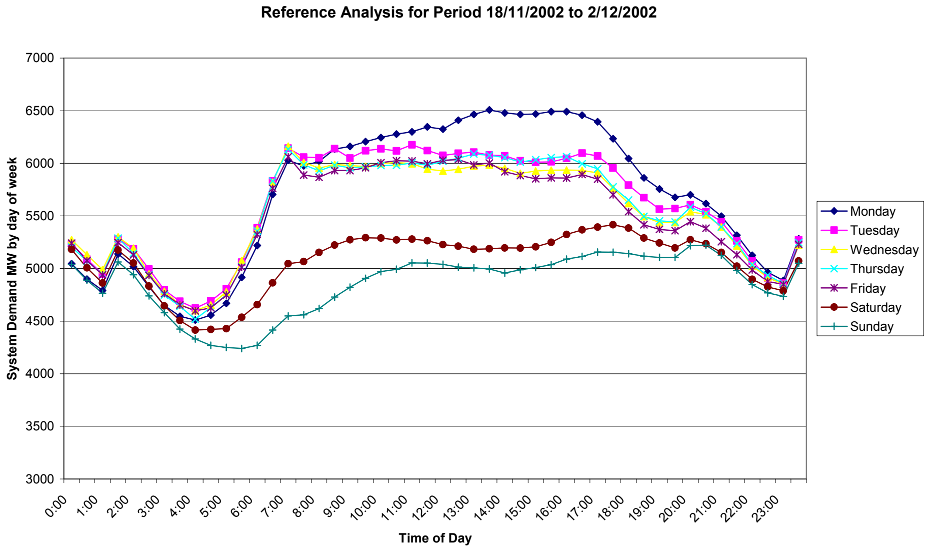


Summer of 2002/2003

Reference Period: 18 November 2001 to 2 December 2001.

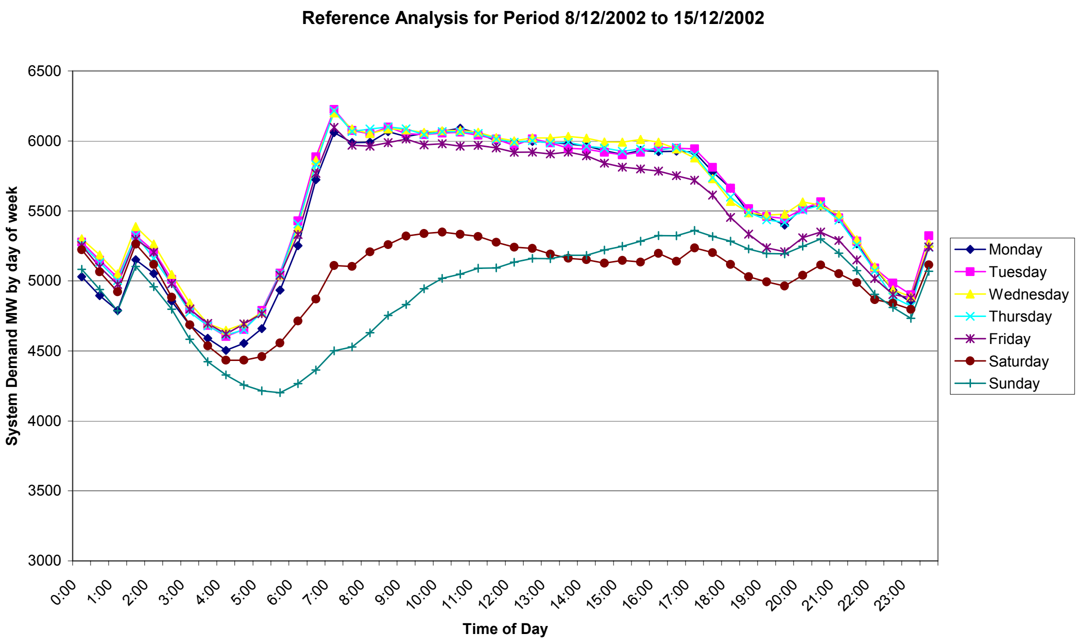
Load shape by day of the week for the reference period is shown in the figure below.

Figure 49: Reference Analysis for Period 18/11/2002 to 2/12/2002 (2002)



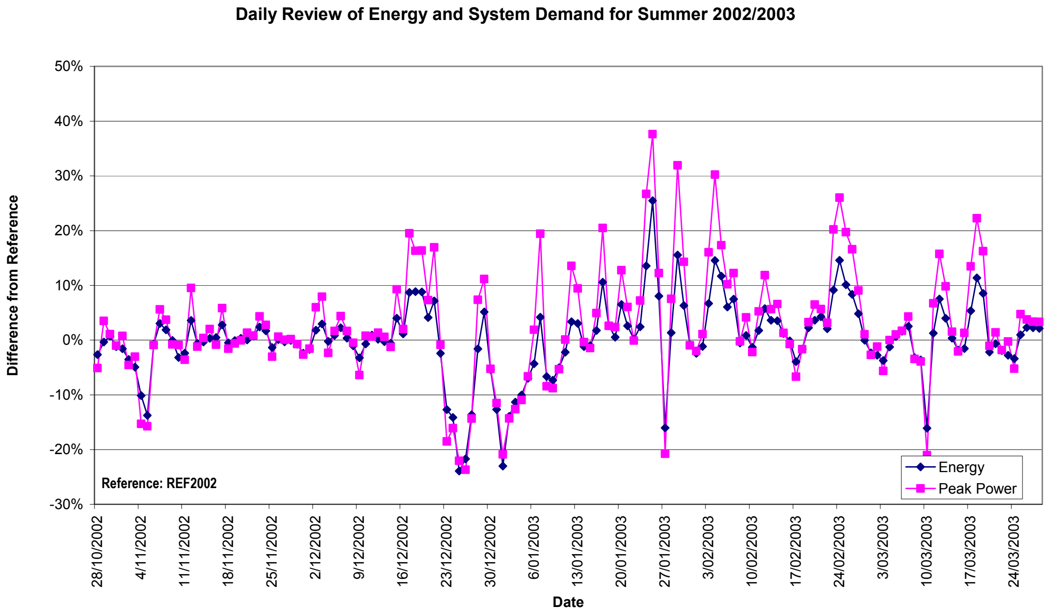
The load for Mondays in this reference period is higher than expected and is probably due to some cooling load – both the Mondays selected had slight peaks above the other days. This needs to be considered when looking at the data. An alternative reference (called 2002a) was developed for some analysis.

Figure 50: Reference Analysis for Period 8/12/2002 to 15/12/2002 (2002a)



Days of interest can be identified in the following figure:

Figure 51: Daily Review of Energy and System Demand for Summer 2002/2003

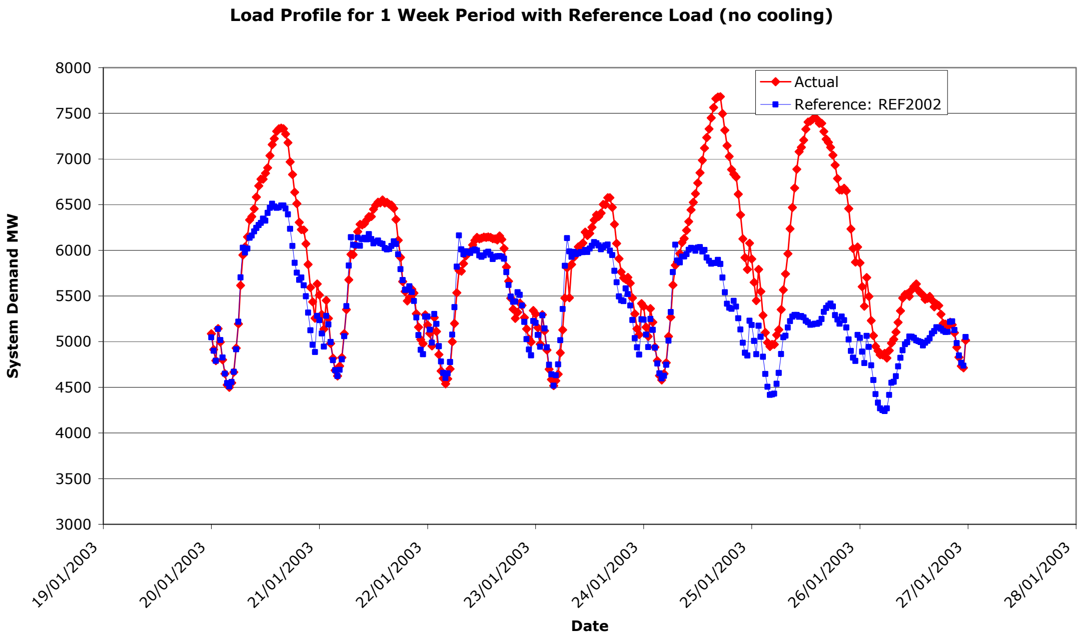


The period up to Christmas appeared to be quite mild with a moderate series of peak from 17 to 21 December 2002. Again January was quite warm and there is no separate reference period that can be used to analyse this month. But there are obvious and large peaks on 29 December 2002 and 7, 12, 17 January 2003. The most notable peaks are:

- 25 January 2003 (the peak of this summer)
- 29 January 2003
- 4 February 2003
- More moderate peaks of 24 February 2003 and 18 March 2003.

The summer system peak for 2002/2003 is shown in the following figure:

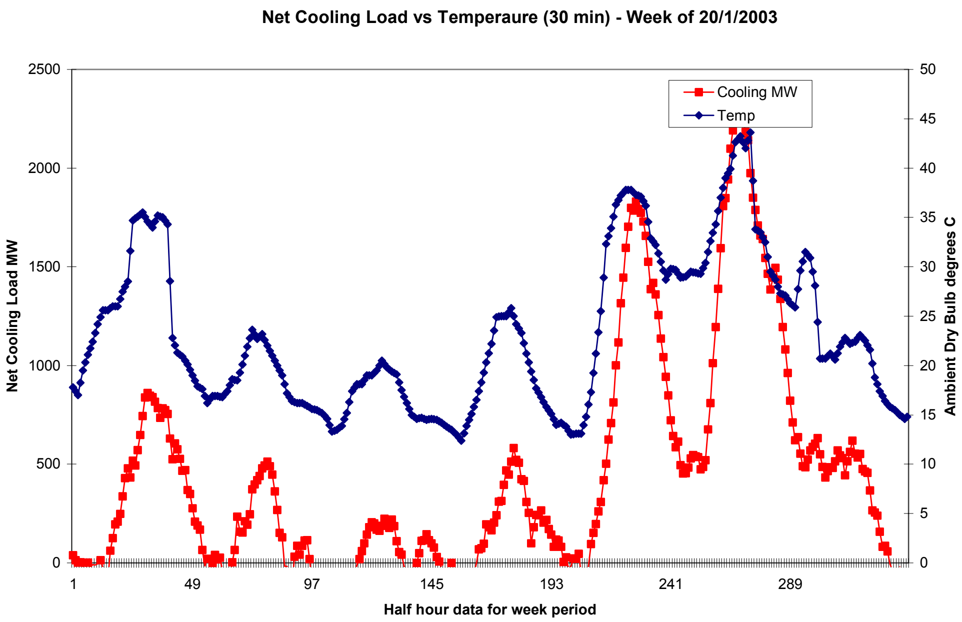
Figure 52: Load Profile for 1 Week Period with Reference Load (no cooling)



Considering that the reference for Mondays is probably a few 100 MW too high, the peak on 20 January is also significant. There is clearly a large overnight cooling load early in the morning of 25 & 26 January 2003. The peak on 25 January (Saturday, long weekend) would have been a system peak of well over 8,000MW had it occurred on a normal week day. The maximum temperature of 43°C on this day was close to the highest temperature ever recorded in Melbourne.

The net cooling and temperature profile for this week is shown below.

Figure 53: Net Cooling Load vs Temperature (30 min) - Week of 20/1/2003



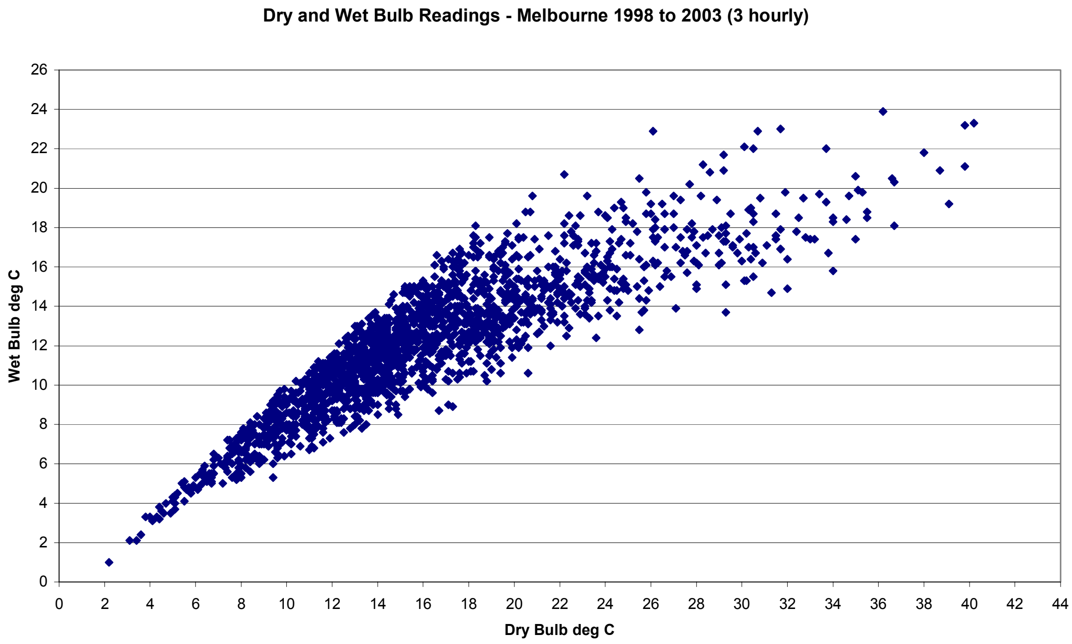
Appendix B: Weather Data

This Appendix outlines the format of the weather data obtained from the Bureau of Meteorology, the assumptions regarding missing data and the weather data format required for simulation modelling.

AccuRate, the building simulation tool used for this project, requires weather data in the Australian Climatic Database Format (ACDB) format. This is set out in Appendix C in detail.

All values required for the ACDB format were available directly from BOM measurements except for absolute humidity (units: g/kg). This is also sometimes called the humidity ratio. The most expedient way to determine this value is from dry bulb and wet bulb temperature readings. Using psychometric calculations, the absolute moisture content can be determined from these two variables. However, the calculations are extremely complex and non-linear. To facilitate an approximate reading, values for absolute humidity were determined for selected wet bulb and dry bulb temperatures in 0.5 degree steps for the range of likely combinations of dry bulb and wet bulb readings. The likely combinations are shown in the following figure based on a plot of Melbourne data for the whole period:

Figure 54: Dry and Wet Bulb Readings - Melbourne 1998 to 2003 (3 hourly)



In some cases the wet bulb reading was found to be slightly higher than the dry bulb reading, but these cases were ignored and are treated as instrument calibration error. A finer interpolation grid at 0.5°C intervals of both dry bulb and wet bulb results in an absolute moisture content estimate that is within 0.2 g/kg of the actual reading, which is reasonable for use in the building shell model.

Solar data was supplied in 2 formats; firstly as a monthly summary table (half hourly data by day) and as fixed column data. The monthly summaries were used and these provided a daily check sum value.

The main solar data available is:

- Global radiation (horizontal plane)
- Diffuse radiation (horizontal plane)
- Direct beam radiation (normal to the beam)
- Longwave radiation
- Direct beam radiation (horizontal plane)

Only the first three readings are required for the ACDB format. The data from the BOM is supplied as 10's of kJ per square metre over the half hour period. The integrated energy value is recorded at the end of the half hour period (ie 12:00 to 12:30 is recorded as 12:30).

A particular complication is the fact that all solar data is recorded in True Solar Time (TST). Midday in TST is when the sun lies directly true north of the recording position. This varies by up to several minutes (plus or minus) for each day/month (due to the wobble of the earth's rotation) over the year but generally this is on average about 21 minutes behind local EST in the case of Melbourne (Local standard time for Melbourne is based on the 150 deg East meridian and TST is about 4 minutes per degree of longitude from the local standard time meridian – for Melbourne the meridian of longitude is 144.8 degrees East, therefore TST is about $5.2 \times 4 = 20.8$ minutes after local clock time, on average). The TST time values have been offset by 30 minutes to align as closely as possible to the local standard time used for other meteorological observations. This means that there is small discrepancy between solar data (which runs from 11:51 am to 12:51 for midday) compared to the other meteorological observations which are based on clock time (12:00 to 1:00) but this should be of no major consequence. It is not possible to correct for this anomaly as solar data is only integrated over 30 minute intervals.

The solar data is summed for the relevant half hour periods into hours and then divided by 0.36 to give average Watts for the hour (eg a recorded value of 100 is actually 1000000 Joules which over a one hour period of 3600 seconds is 278 Watts, as 1 Joule per second is a Watt).

Solar records for Melbourne airport appear to start in mid June 1999. Records were kept at Laverton until November 1995 (global – diffuse records stopped in 1993).

Considerable data was found to be missing from the solar records and there is no way to patch the missing data in many cases. There were occasional half hourly data points missing over the period and these were manually interpolated – in many cases the missing data were at night so this was straight forward. More of a problem are whole days of missing data which are not uncommon for the period June 1999 to mid

2003 (the latest data supplied). A list of dates where whole days of data are missing are listed below.

Table 10: Missing Solar Data: Dates Missing by Month

Month	Global	Diffuse	Direct
Jun-1999	1-11	1-11	1-11
Jul-1999	15-23	23	23
Aug-1999	4,16,29,30	4	4
Dec-1999		5,6	5,6
Jun-2000	14		
Sep-2000		16,17,18	16,17,18
Oct-2000	4,28,29	4,15,16,28,29,30	4,15,16,28,29,30
Nov-2000		14,15,17	14,15,17
Dec-2000	5,6	5,6,21,22	5,6,21,22
Jan-2001		25	25
Feb-2001		20,21,26	20,21,26
Apr-2001	21	21	21
Jul-2001	26	26	26
Oct-2001		7,26	7,26
Jul-2002	13		
Oct-2002		7	7,23
Feb-2003		2,3	2,3
May-2003	30		

Missing data during the periods of interest for the peak air conditioner load study was problematic as the simulation model cannot run with missing weather data. Fortunately there is little global solar data missing over the summer periods apart from 5-6 December 2000. Fortunately these days were not extreme (the 5th was 29^{o}C at the end of a warmer period with a cool change in the late morning and the 6th was a cool day with a 20^{o}C maximum – both days had reasonable cloud cover). There is more diffuse and direct beam data missing over the summer periods as indicated above.

The only other source of solar data is from satellite estimates for Melbourne (Laverton RAAF site 87031) and these are only available as MJ/m^2/day values (hourly data is not available). These appear to be generally within 10% of ground instrument readings for Tullamarine. Satellite readings are available for most days from late 1999 until mid August 2001 and then from mid January 2003 to end February 2003.

It is not possible to run the weather files through the simulation model with missing information so a method was developed to replace missing days. The data was copied and patched as set out below.

Where daily global data is available from a satellite reading, a similar day in the same or adjacent month was selected with similar global radiation reading for all missing radiation readings – temperature profiles and Oktas readings were also considered.

Where diffuse and or direct radiation data were missing but measured hourly ground data is available for global radiation, a similar day in the same or adjacent month was selected with a similar hourly global radiation profile (as far as is possible) for missing diffuse and direct radiation readings.

On some days global radiation data was missing but diffuse and direct solar data was available – in these cases a day with similar diffuse and direct daily values was selected for replacement from the same or adjacent month.

In cases where one of the hourly solar measurements is available, a very good estimate of the other missing data can be made but matching hourly data profiles as closely as possible.

List of replaced solar data

The following table indicates the source of data for missing solar radiation data.

Table 11: Data Sources for Missing Solar Radiation Records

Month	Missing Global	Missing Diffuse	Missing Direct	Basis to Replace	Replacement Data	Close match
Dec-1999		5	5	Hourly match global	21/12/1999	G
Dec-1999		6	6	Hourly match global	21/12/1999	G
Jun-2000	14			Hourly match direct	18/5/2000	G
Sep-2000		16	16	Hourly match global	15/9/2000	G
Sep-2000		17	17	Hourly match global	15/9/2000	G
Sep-2000		18	18	Hourly match global	19/9/2000	G
Oct-2000	4	4	4	Satellite daily	5/10/2000	S
Oct-2000		15	15	Hourly match global	1/10/2000	G
Oct-2000		16	16	Hourly match global	1/10/2000	G
Oct-2000	28	28	28	Satellite daily	22/10/2000	S
Oct-2000	29	29	29	Satellite daily	26/10/2000	S
Oct-2000		30	30	Hourly match global	21/10/2000	G

Continued over page

Month	Missing Global	Missing Diffuse	Missing Direct	Basis to Replace	Replacement Data	Close match
Nov-2000		14	14	Hourly match global	29/11/2000	G
Nov-2000		15	15	Hourly match global	18/11/2000	G
Nov-2000		17	17	Hourly match global	28/11/2000	F (1)
Dec-2000	5	5	5	Satellite daily	3/12/2000	S
Dec-2000	6	6	6	Satellite daily	30/12/2000	S
Dec-2000		21	21	Hourly match global	10/12/2000	G
Dec-2000		22	22	Hourly match global	11/11/2000	G (2)
Jan-2001		25	25	Hourly match global	21/01/2001	G
Feb-2001		20	20	Hourly match global	28/02/2001	G
Feb-2001		26	26	Hourly match global	28/02/2001	G
Apr-2001	21	21	21	Satellite daily	22/04/2001	S
Jul-2001	26	26	26	Satellite daily	21/07/2001	S
Oct-2001		7	7	Hourly match global	8/10/2001	G
Oct-2001		26	26	Hourly match global	27/10/2001	G
Jul-2002	13			Hourly match direct	12/07/2002	G (3)
Oct-2002		7	7	Hourly match global	20/10/2002	F
Oct-2002			23	Hourly match global	24/10/2002	G
Feb-2003		2	2	Hourly match global	4/02/2003	G
Feb-2003		3	3	Hourly match global	4/02/2003	G
May-2003	30			Hourly match direct	5/05/2003	G

Key:

G=good (reasonable hourly and total energy match)

F=fair (total energy match, some hourly mismatch – caution required for these days)

S=satellite (total daily energy match only, unknown hourly profile – caution required)

Notes:

(1) 17/11/2000 was a day of highly variable hourly global radiation – the matched day is also variable with a similar peak but the hourly values do not always match. Care is required when using this day.

(2) This was a very low radiation day after a change and a day from November 2000 was selected to match.

(3) Very good profile match (clear day) but energy about 10% different on substituted day.

Where data has substituted or estimated, the solar radiation flags have been adjusted to reflect this change. A flag of 0 means all values are measured, 1 means all values are estimated to replace missing data and 2 means that global readings are measurements but other solar readings are estimates.

Note that dummy data (from 1979) is being run up to and including 31 August 1999 – from 1 September 1999 actual solar data available is being run for the year 1999 so that load records can be examined for the period 1 November 1999 to 31 December 1999. Similarly, real weather data is being run in 2003 up to end June 2003 (the end of solar records) then the balance of the year is substituted with 1979 dummy data.

Appendix C: Australian Climatic Database Format

AccuRate, The building simulation tool used for this project, requires weather data in the Australian Climatic Database Format (ACDB) format. This is a simple text file format with fixed column widths and no delimiters. The details are set out below.

For values that are shown with a format of 10-1, a value of 14.6 would appear as 146 in the file (with no decimal point included). Dry bulb temperature has an additional column to indicate temperatures below zero.

Columns	Item	
1 – 2	location identification (e.g.ME represents Melbourne)	
3 – 4	year (e.g. 67)	
5 – 6	month (i.e. 1 - 12)	
7 – 8	day (i.e. 1 - 31)	
9 – 10	hour standard (i.e. 0-23, 0 = midnight)	
11 – 14	dry bulb temperature (10-1 °C)	
15 – 17	absolute moisture content (10-1 g/kg)	
18 – 21	atmospheric pressure (100-1 kPa)	
22 – 24	wind speed (10-1 m/s)	
25 – 26	wind direction (0-16; 0 = CALM. 1 = NNE ,...,16 = N)	
27	total cloud cover (oktas, 0 - 8)	
28	flag relating to dry bulb temperature	
29	flag relating to absolute moisture content	
30	flag relating to atmospheric pressure	
31	flag relating to wind speed and direction	
32	flag relating to total cloud cover	
33	blank	
34 – 37	global solar irradiance on a horizontal plane (1000 W/m2)	
38 – 40	diffuse solar irradiance on a horizontal plane (100 W/m2)	
41 – 44	direct solar irradiance on a plane normal to the beam (1000 W/m2)	
45 – 46	solar altitude (degrees, 0-90)	
47 – 49	solar azimuth (degrees, 0-360)	
50	flag relating to global and diffuse solar irradiance	
51	flag	}
52 – 56	Australian Met Station Number	} Some locations only
57 – 61	wet bulb temperature (10-1 °C)	}
62 – 81	Station name (first line only)	}

Values for flags relating to standard surface meteorological data (columns 28 - 32)

0	means that the value is measured value
1	means that the value is estimated to replace a missing measurement
2	means that the value is an interpolating between three-hourly measurements
3	missing value

Values for flag relating to solar radiation data (column 50)

0	means that both global and diffuse irradiance values are based on measurements
1	means that both global and diffuse irradiance values are estimated to replace a missing measurement
2	means that the global irradiance value is based on measurement but the diffuse irradiance value is estimated to replace a missing measurement
3	missing value or estimated value from cloud cover data
4	interpolated value from three hourly data

Appendix D: Peak Daily Load versus Max Temperature

These figures set out daily maximum temperature versus net cooling load for each summer period covered by the study. Note that holiday periods have been identified on the figures but reference load curves for these periods have not been developed.

The base estimate and holiday equations are constant for all figures to allow comparisons between years.

Figure 55: Daily Review of Energy and System Demand for Summer 1999/2000

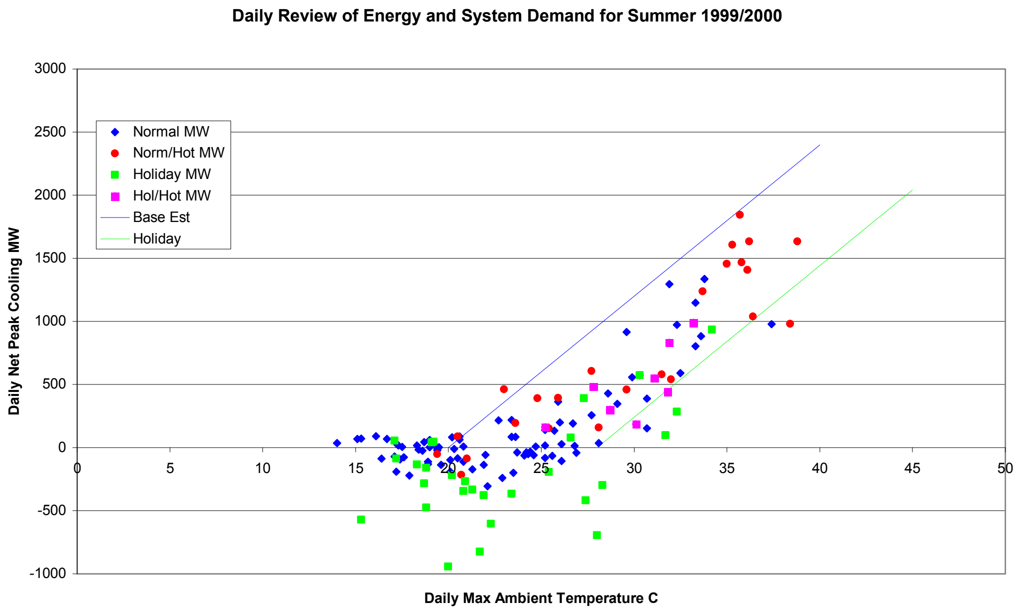
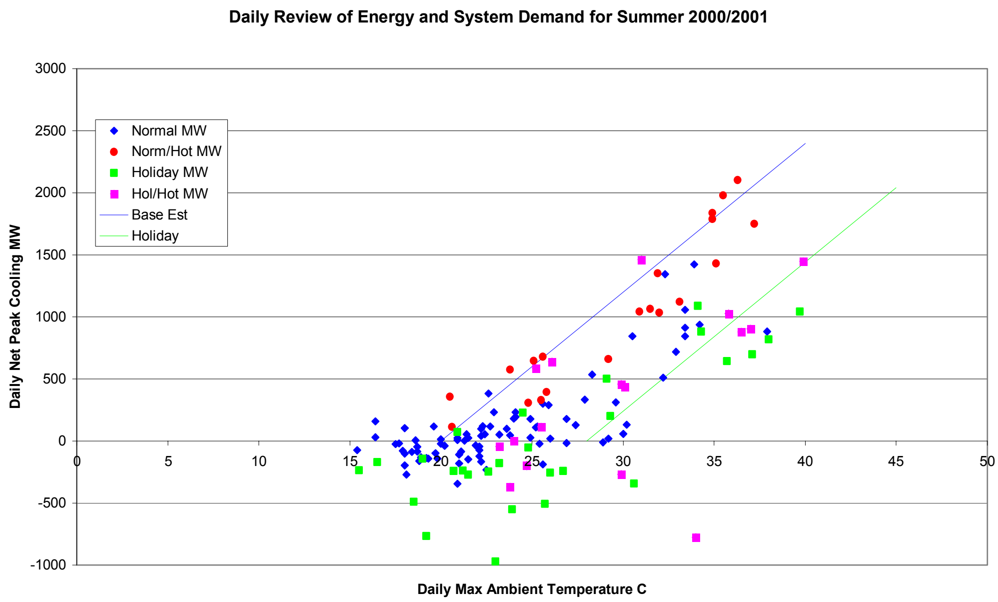


Figure 56: Daily Review of Energy and System Demand for Summer 2000/2001



Note that the summer of 2001/2002 was relatively mild.

Figure 57: Daily Review of Energy and System Demand for Summer 2001/2002

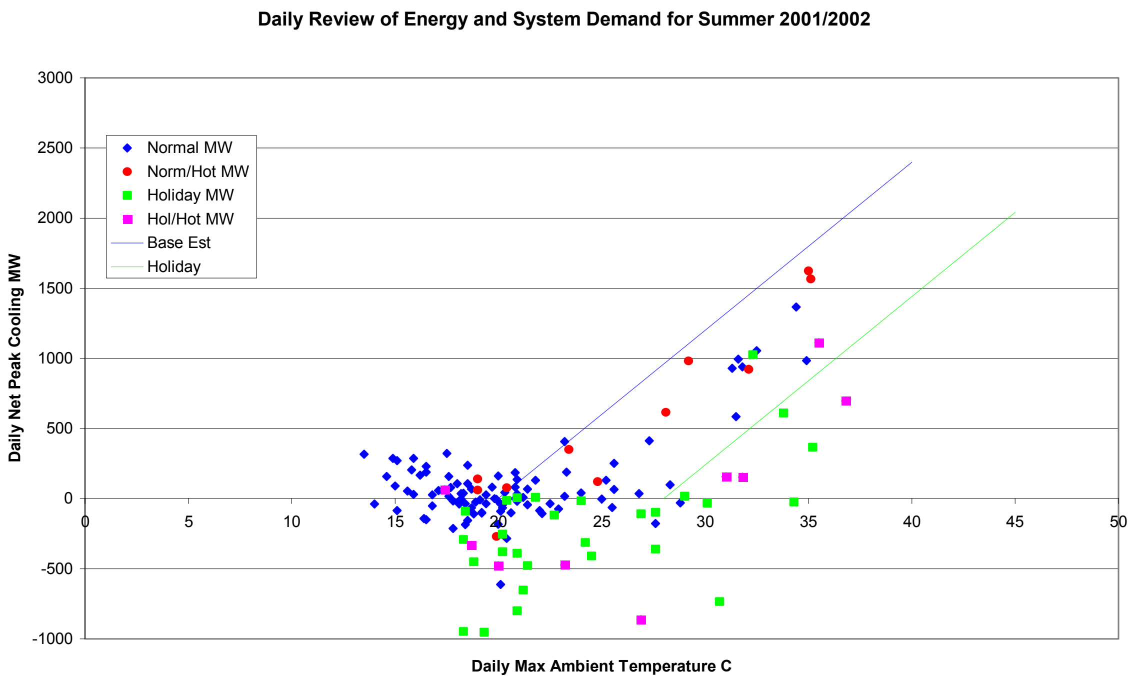
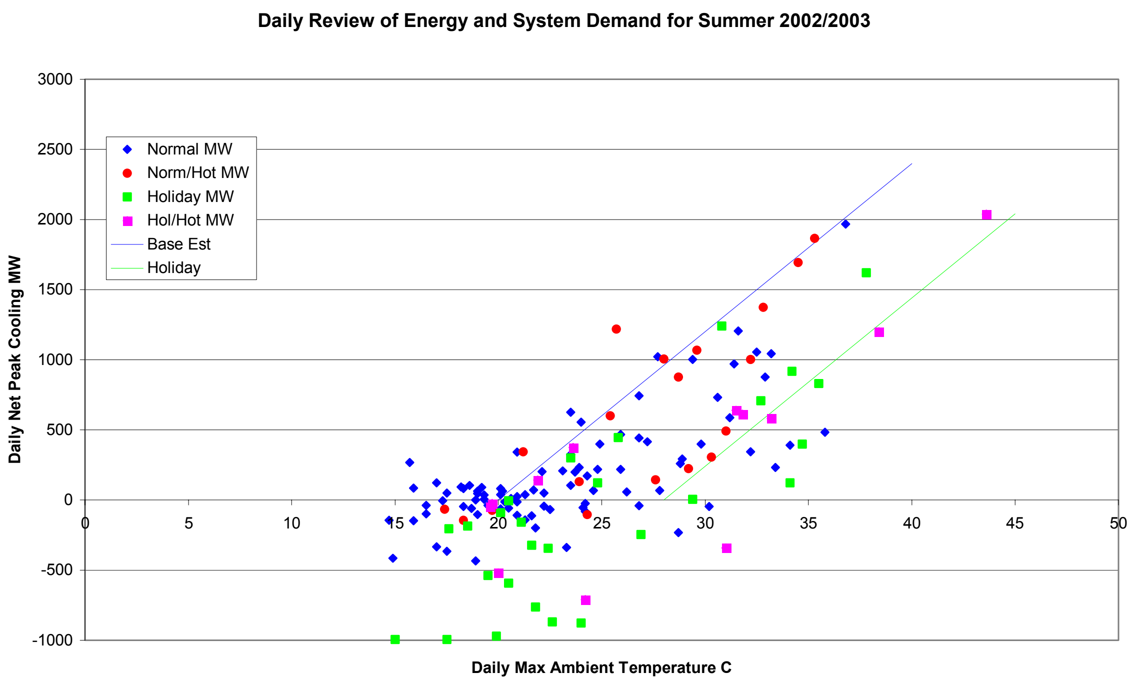


Figure 58: Daily Review of Energy and System Demand for Summer 2002/2003



Appendix E: Algorithim For Modelling Statewide Demand Attributable To Space Conditioning Loads

$$D_C = [(L_A \times F_{OA}) + (L_S \times F_{OS})] \times \frac{N_H \times P_H \times F_Z \times C_C}{3600 \times E_A} \times U$$

Where:

D_C = Estimated Demand for Cooling (MW)

L_A = The maximum daily cooling load in a one hour period estimated using the AccuRate simulation module (V0.94 – beta). The estimate is made using the reference dwelling operating in “All Day” mode for a given set of climatic conditions. All Day space conditioning operation schedule is from 7AM to Midnight inclusive.

F_{OA} = Occupancy Factor – All Day Schedule: The estimated number of dwellings in the state that operate on the “All Day” space conditioning operation schedule as a proportion of the number of dwellings that operate on either the “All Day” or “School Day” space conditioning operation schedule. (refer to section 5.3.1)

L_S = The maximum daily cooling load in a one hour period estimated using the AccuRate simulation module (V0.94 – beta). The estimate is made using the reference dwelling operating in “School Day” mode for a given set of climatic conditions. School Day space conditioning operation schedule is from 7AM til 9AM inclusive then from 4PM to Midnight inclusive.

F_{OS} = Occupancy Factor – School Day Schedule: The estimated number of dwellings in the state that operate on the “School Day” space conditioning operation schedule as a proportion of the number of dwellings that operate on either the “All Day” or “School Day” space conditioning operation schedule. (refer to section 5.3.1)

N_H = Total Stock of Households in the State.

P_H = Penetration of air-conditioners (all types) in the total stock of housing in the state.

Continued:

F_Z = Zoning Factor = $[(P_W \times F_{ZW})+ (P_R \times F_{ZR})$

Where:

P_W = Proportion of dwellings using Whole House (Ducted) Cooling amongst those dwellings with space cooling.

P_R = Proportion of dwellings using Room Type space cooling amongst those dwellings with space cooling.

F_{ZW} = Zoning Factor – Whole House Cooling: This is the estimated constraint on the actual floor area of the reference dwelling that is serviced by whole house space conditioning.

F_{ZR} = Zoning Factor –Room Type Space Cooling: This is the estimated constraint on the actual floor area of the reference dwelling that is serviced by room type space conditioning (ie window wall and split type room coolers)

C_C = Commercial sector factor – a factor to roughly account for the commercial sector contribution to the total space conditioning related cooling load.

E_A = Average efficiency of the stock of air-conditioners

U = Utilization Factor: a factor to account for user behaviour that will tend to constrain the actual hours of operation of the space cooling appliance depending upon the internal temp of the dwelling = $0.000195 \times Ti^{2.4193}$

Where:

Ti = The internal temperature of the reference dwelling following modifications to increase its thermal mass by changing the construction to cavity brick and altering internal walls to be masonry. This was designed to increase the thermal lag in the dwelling. This approach was adopted to help account for an apparent lag in the actual peak load compared to that predicted by Accurate. This lag would be particularly applicable to higher mass buildings such as large commercial establishments.

Note that between the hours of midnight and 9am in the morning the value of Ti is set at a constant 21^0C (U = 0.31)

Note: The algorithm above calculates cooling demand only. To calculate total demand the “base load” for the particular hour, weekday and year needs to be added to this value. Base load values used in this study are reproduced in the following four tables.

1999 - 2000 Reference Week Base Load Values

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	4788	5037	5119	5150	5122	5098	4828
1	4615	4939	4898	4936	4861	4816	4573
2	4802	5080	5053	5056	4984	4928	4693
3	4475	4672	4645	4672	4582	4486	4329
4	4289	4471	4444	4466	4391	4238	4045
5	4411	4622	4589	4593	4547	4238	3952
6	5027	5243	5236	5216	5143	4432	3980
7	5858	6064	6042	5994	5911	4816	4258
8	5644	5786	5727	5711	5670	4874	4302
9	5654	5748	5716	5690	5665	5005	4471
10	5687	5726	5672	5709	5689	5031	4559
11	5695	5703	5695	5748	5723	5001	4621
12	5627	5636	5606	5680	5691	4960	4627
13	5642	5639	5667	5740	5707	4897	4590
14	5623	5621	5661	5727	5684	4846	4574
15	5586	5562	5622	5696	5618	4765	4573
16	5630	5599	5632	5728	5578	4844	4658
17	5622	5599	5592	5711	5526	4831	4743
18	5355	5336	5292	5343	5234	4748	4716
19	5215	5179	5141	5151	5010	4607	4693
20	5344	5352	5328	5323	5164	4765	4859
21	5143	5167	5157	5128	4967	4665	4719
22	4791	4798	4844	4785	4734	4453	4440
23	4608	4646	4679	4691	4664	4426	4385

2000-2001 Reference Week Base Load Values

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	4858	5094	5090	5170	5153	5118	4903
1	4633	4864	4826	4877	4889	4814	4610
2	4835	5007	4979	4995	5021	4969	4745
3	4479	4610	4631	4638	4648	4527	4328
4	4333	4419	4450	4485	4473	4311	4164
5	4479	4555	4596	4597	4609	4330	4075
6	5060	5117	5155	5149	5148	4459	4108
7	5878	5934	5925	5940	5868	4858	4359
8	5800	5763	5759	5818	5819	4957	4468
9	5903	5814	5829	5867	5860	5101	4689
10	5974	5864	5849	5901	5967	5169	4773
11	6024	5898	5956	5923	6017	5216	4864
12	5996	5887	5931	5898	5997	5209	4948
13	6108	5896	6013	5978	6017	5183	4966
14	6120	5966	6021	5947	6004	5180	4969
15	6098	5922	5977	5934	5911	5173	4985
16	6124	5937	5999	5967	5935	5250	5094
17	6034	5833	5897	5916	5856	5246	5122
18	5654	5451	5519	5584	5508	5155	5074
19	5360	5201	5306	5370	5255	4979	4931
20	5443	5330	5364	5449	5324	5027	5071
21	5258	5167	5217	5256	5121	4903	4928
22	4891	4846	4865	4913	4882	4679	4665
23	4718	4677	4748	4741	4733	4614	4549

2001-2002 Reference Week Base Load Values

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	4861	5088	5123	5129	5197	5190	4912
1	4685	4878	4876	4886	4932	4875	4656
2	4957	5082	5045	5062	5090	5057	4847
3	4603	4714	4676	4675	4691	4655	4475
4	4395	4516	4472	4517	4521	4404	4228
5	4557	4642	4616	4634	4660	4384	4115
6	5175	5253	5219	5252	5208	4519	4154
7	5996	6070	6010	6054	6008	4892	4361
8	5855	5852	5810	5824	5888	4983	4443
9	5926	5877	5840	5857	5935	5096	4664
10	5946	5844	5791	5863	5945	5111	4784
11	5950	5848	5836	5893	5962	5083	4865
12	5939	5808	5774	5950	5904	5011	4869
13	5925	5819	5717	6016	5874	4953	4864
14	5844	5833	5777	6052	5839	4897	4839
15	5784	5789	5761	6058	5763	4866	4835
16	5816	5811	5807	6043	5794	4907	4942
17	5811	5770	5735	5970	5751	4913	5008
18	5522	5469	5415	5632	5529	4846	5011
19	5368	5248	5180	5400	5355	4761	4965
20	5476	5373	5336	5483	5352	4897	5038
21	5304	5259	5253	5300	5160	4831	4930
22	4923	4904	4873	4985	4917	4652	4640
23	4723	4724	4732	4824	4793	4585	4522

2002-2003 Reference Week Base Load Values

Hour	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
0	5046	5233	5274	5204	5240	5182	5040
1	4790	4946	4990	4943	4939	4862	4765
2	5017	5188	5193	5145	5129	5052	4940
3	4648	4797	4783	4747	4760	4645	4580
4	4510	4622	4600	4517	4597	4416	4330
5	4668	4807	4777	4749	4747	4429	4250
6	5218	5388	5376	5356	5324	4656	4270
7	6028	6143	6162	6132	6062	5046	4549
8	6019	6052	5955	5927	5867	5153	4620
9	6159	6049	5979	5957	5931	5274	4822
10	6244	6137	5998	5979	6005	5290	4971
11	6299	6176	5996	6003	6022	5279	5054
12	6324	6075	5927	6019	6029	5227	5041
13	6464	6106	5973	6088	5984	5183	5005
14	6478	6070	5952	6054	5919	5197	4957
15	6468	6010	5927	6034	5852	5206	5010
16	6491	6047	5936	6063	5860	5324	5089
17	6394	6069	5909	5948	5850	5394	5156
18	6046	5792	5619	5650	5540	5384	5141
19	5755	5565	5436	5453	5371	5241	5105
20	5701	5606	5540	5582	5446	5274	5216
21	5497	5445	5395	5395	5255	5154	5125
22	5125	5071	5026	5036	4987	4897	4847
23	4886	4861	4850	4858	4848	4788	4736

Appendix F: Set Up for Accurate Simulation

AccuRate is an enhanced version of the NatHERS software. It is a rating tool that assigns a star rating to a residential building (a detached or semi-detached house, unit, townhouse, or apartment) based on its calculated annual heating and cooling energy requirements.

The heating and cooling energy requirements are calculated hourly over a period of one year, using a year of real weather data appropriate for the location.

The following tables (derived in part from the Accurate "Help" files) detail the settings (both applied and default) used in the simulation of the reference house.

CONSTRUCTION SETTINGS

Element	**Construction Type and Area**					
External Walls	155.04 m^2 - Brick Veneer Construction with R 1.0 glass fibre insulation and 10mm plasterboard inner lining. Solar absorbance external = 50% Solar Absorbance Internal = 50% 4.68 m^2 – Weatherbord on 90mm stud frame with 10mm plasterboard inner lining – uninsulated Solar absorbance external = 50% Solar Absorbance Internal = 50%					
Windows	42.27 m^2 – Single 4mm thick clear glazed aluminium framed windows – frame colour medium with 50% solar absorbance Eaves – typically 450mm					
AREAS	Azimuth					
	90	**135**	**45**	**0**	**180**	**270**
Area Brick Veneer	12.68	0.36	0.36	33.69	35.34	28.44
Area Weatherboard	3.24	0	0	1.44	0	0
Window Area	17.08	1.08	1.08	7.83	11.7	5.4
Floors	148.16 m^2 – Concrete slab on ground with underlay and carpet covering. Solar absorbance external = 50% Solar Absorbance Internal = 50% 29.17 m^2 – Concrete slab on ground with ceramic tile finish Solar absorbance external = 50% Solar Absorbance Internal = 50%					

Element	Construction Type and Area
Ceilings	177.33 m^2 – 13mm plasterboard with R2.5 Glass fibre batt over. Solar absorbance external = 50% Solar Absorbance Internal = 50%
Internal Walls	74.4 m^2 – 10mm plasterboard on 90mm unventilated stud frame Solar absorbance external = 50% Solar Absorbance Internal = 50%
Roof	211.01 m^2 – Nom. 20mm concrete roof tiles Solar absorbance external = 50% Emissivity External = 90% Solar Absorbance Internal = 50%

ZONE SETTINGS

Zone	Volume and Description
Kitchen/Living	Volume = 236.68 m^3 Floor to Ceiling Height = 2.4 m Space conditioned = Yes
Bedroom 1	Volume = 44.59 m^3 Floor to Ceiling Height = 2.4 m Space conditioned = Yes
Bedrooms 2,3,4 & 5	Volume = 104.54 m^3 Floor to Ceiling Height = 2.4 m Space conditioned = Yes
Bathroom / Laundry	Volume = 39.76 m^3 Floor to Ceiling Height = 2.4 m Space conditioned = No
Roof Space	Volume = 159.69 m^3 Unsarked Ventilation = Standard Space conditioned = No

MISCELLANEOUS SETTINGS AND DETAILS

Item	Setting
Terrain Category	Suburban
Ground Reflectance	Set at 0.2
Thermostat Settings	Heating invoked below 21^{0}C Cooling invoked above 24^{0}C
Cooling – Invoking process	Thermostat dry bulb set point = 24^{o}C If at the end of the hour the zone condition (i.e. temperature and moisture content) without cooling or ventilation is within the comfort region on the psychrometric chart, cooling is not invoked. The comfort region is a parallelepiped, the boundaries of which are:

Item	Setting
	Top: Absolute moisture content = 12 g/kg Bottom: Absolute moisture content = 0 g/kg (normally it is 4 g/kg but AccuRate will not invoke cooling merely because the air is too dry) Right: ET* line based on (Cooling Thermostat + 2.5) degrees Left: Not relevant If the zone condition is outside the extended comfort region, the zone openings are closed and sufficient cooling is applied so that the zone temperature at the end of the hour is the cooling thermostat setting. Note that the cooling calculations include a model of a residential air conditioner cooling coil, so that dehumidification also occurs when cooling is invoked.
Thermal Resistance of Materials	All materials used in AccuRate are fully described by a thermal resistance (or resistances for non-vertical air gaps - see below) and a thermal capacitance. Except for non-vertical air gaps, the thermal resistance and capacitance do not change during the simulation. Non-vertical air gaps (i.e. Horizontal, Inclined 45° and Inclined 22.5°) are characterised by two thermal resistances: one for heat flow up and one for heat flow down. At each time step in the simulation, the heat flow direction in these air gaps is determined and the appropriate value of the thermal resistance is used. The up and down values are fixed (i.e. they do not change according to the temperature difference or other factors). Accurate applies air gap properties for given ranges of thicknesses, emissivities and inclinations

Appendix G - Basic Set-up of the Modelling spreadsheet

Following is a brief description of the workings of the simulation spreadsheet used to make the estimates of MD reported in this study. The description below relates to the spreadsheet entitled:

Summer Peak Model – 07

Input Data from Accurate Simulation
Hourly cooling load data derived from runs using the Accurate simulation model are loaded into columns AZ to BG of the . Data is loaded alternatively for the "All Day" and "School Day" schedules then alternatively for the standard reference house and the 5 star rated version of the reference house. Data for both "overnight cooling operation" and "no overnight cooling operation" is loaded. This data set is then pulled into the main section of the spreadsheet via offset functions in columns M,N,O & P. Cell B2 on the *3 Day Chart* Sheet controls whether "overnight cooling operation" or "no overnight cooling operation" is pulled in to columns M,N,O & P. For this study only the "no overnight cooling operation" data was used.

Weighting of Accurate Data
The Accurate data pulled into cells M,N,O&P is then weighted for the following factors:

- Proportion of buildings operating on the All Day Schedule and School Day Schedule.
- Proportion of the stock that has a reference house performance and proportion of the stock that has 5 Star performance.

The proportions of each of the above weighting factors can be adjusted on the sheet *3 Day Chart* cells C2 (operation schedule) and cell E2 (performance standard).

The results of the weightings can be found in column S.

Scaling Factors
Scaling factors for each year examined and for each day of the weeks are calculated in columns AH to AO inclusive. The factors are:

- Commercial scaling factor (AK)
- No. Households (AL)
- Penetration of Air conditioners (AM)
- Plant Efficiency (AN)

All of these factors are combined into a single composite factor in column AO. These factors are then imported into column T using a lookup function that uses a look up value based on the concatenation of the Year and day of the week (column H)

Use Factor Calculation
The "Use Factor" is calculated in column U using the internal temperature of the unconditioned heavy weight dwelling (column R) and the factors input in cells U3 to U5.
The internal temperature value is derived from a separate Accurate run that is loaded into column AQ. This value is then modified in column AR for all hours prior to that input in cell AR01 (10 AM). This modification addresses the issue of "spikes" in the morning demand for cooling. The value in column AR is simply imported into column R.

Predicted state-wide air conditioning demand calculation
The predicted state-wide air conditioning hourly demand is calculated in column V by multiplying the weighted Accurate value (column S) by the scaling factors (column T) and the Use factor (column U).

The predicted state-wide air conditioning daily maximum demand is calculated in column W at "0" hour on each day by returning the maximum value for the 24 hourly estimates for each day (as calculated in column V)

Actual State-wide demand
Actual State-wide hourly demand for 1999 – 2003 is input in column Y. The predicted state-wide daily maximum demand is calculated in column Z at "0" hour on each day by returning the maximum value for the 24 hourly estimates for each day (as calculated in column Y).

Calculation of simulated State-wide demand
The predicted state-wide hourly demand is calculated in column AB by adding the predicted state-wide air conditioning hourly demand (column V) to the reference week base load (column AA). The base load is imported to column AA via a lookup function to the sheet "Ref Load". The lookup function uses a look up value based on the concatenation of the financial year the day of the week and the hour (column I).

The predicted state-wide daily maximum demand is calculated in column AC at "0" hour on each day by returning the maximum value for the 24 hourly estimates for each day (as calculated in column AB)

Parallel calculations of State-wide demand (hourly and daily) for a scenario including only the 5 star building performance standard are carried out in columns AD and AE. These figures are used to provide a comparative demand plot in both the 3 day and the 1 day charts