SMART Control Algorithm for the HVAC System

Thesis Report

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STATEMENT OF CANDIDATE

I, Jason I Harrison, declare that this report, submitted as part of the requirement for the award of Bachelor of Engineering in the School of Electronic Engineering, Macquarie University, is entirely my own work unless otherwise referenced or acknowledged. This document has not been submitted for qualification or assessment at any academic institution.

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ABSTRACT

In industry, HVAC systems comprise slightly over 40% of the total electrical usage of any given building or property type (Department of Environment and Energy, 2013). With the constant demands we are placing on our environment it is evident we need to research ways to drive down this usage with the view to ultimately becoming a carbon neutral community.

This thesis presents a new engineered self-learning control algorithm that can be used for all buildings to improve system performance to reduce overall energy usage, focusing on minimising peak electrical loads during the times that energy providers charge premium tariffs. The ultimate outcome is to minimise costs for the building through the manipulation of the HVAC System.

This thesis focuses on practical ways that a portfolio or campus of buildings can use the indoor thermal characteristics of the building to reduce the peak electrical usage throughout the occupied day. Investigations were made around the benefits of integrating forecast weather data, indoor air requirements and electrical tariffs simultaneously within any given building to increase the efficiencies of the building (and thereby reduce the demands which relate to the overall operating costs of the building).

Contents

List of Figures

List of Tables

List of Graphs

Abbreviations

CO2	Carbon Dioxide
AHU	Air Handling Unit
API	Application program interface
BMCS	Building Monitoring and Control System
BMS	Building Management System
D/A	Digital to Analog Converter
DDC	Direct Digital Control
GHG	Greenhouse Gases
HVAC	Heating Ventilation and Air Conditioning
kW	Kilo Watt
kWh	Kilo Watt Hours
NABERS	National Australian Built Environment Rating System
OA	Outside Air
RTP	Real-Time Pricing
VAV	Variable Air Volume

CHAPTER 1:

1.1 Introduction

The commercial building sector across Australia accounts for approximately 10% of the total energy consumption with this leading to around 12.5% of the overall GHG emissions (ASBEC, 2008). With the demand this energy consumption continues to place on our environment we need to look at ways to reduce this footprint on our environment and decrease the operating cost for the commercial building sector.

In industry, it is widely known that undergoing a building performance upgrade is the most ideal way of achieving an increased energy performance of that building and delivering on energy savings as a way of reducing greenhouse gas emission (Australian Government, 2017). On top of the carbon footprint reduction, it also has other benefits for the building owners including reducing the outgoing costs of electricity, increasing the value of the asset and also reducing the risk of obsolescence in the future.

For industry, energy performance for a building (NABERs Rating) is one of the driving factors to attract new tenants (Office of Environment & Heritage, 2017). Within the premium and A-grade building market there has been a large focus on retrofits and upgrades whilst the B, C and D-grade buildings provide an ever increasing opportunity for these types of works, especially seeking the implementation of low-cost initiatives that have a direct favourable impact on the total energy usage. Figure 1 below shows how the 'untouched' B, C and D grade markets represent approximately 50% of the total market space across the Australian commercial property sector.

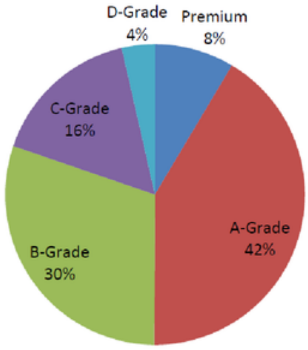


Figure 1 Breakdown of Australian commercial office by PCA grade, 2015 PCA Office Market Report

The next chapter will provide a brief outline and overview into the HVAC system together with an overview of the current market trends in the area of my chosen project and research area.

1.2 Background

The Building Monitoring and Control Systems (BMCS) is the central control system that facilitates commercial buildings to decrease the energy and assist with reducing a building's cost and carbon emissions. Over the past 12 months energy prices have spiked well over 19per cent and this trend is continuing as demand grows and some of the older power plants close down (Harmsen, 2017). The environment and corporate social responsibility is becoming more central in business thinking and decision making. For example 'Earth Hour' is held annually where business, industrial and domestic electricity users are encouraged to switch off all lighting for an hour.

Building Regulations are forcing improvements in electricity consumption through tightening up the design, coupled with enhanced construction methods, to ensure that the building has improved air and heat tightness. The less air and heat escaping the building, the more energy efficient that building becomes. Previously with lower energy prices the focus wasn't always around running the HVAC plant more efficiently or managing your peak usage of electrical power. Also with this focus on improving the performance of a building central to business decisions, existing and prospective tenants are being educated further in the effects of managing tight comfort controls and this is now allowing the BMCS to have wider control of the zone temperature set points which in turn results in lowering the energy required to heat or cool a space (a Ghahramani, 2016). To maximum the benefits derived, it is imperative to develop a control algorithm that takes these factors into effect, and then to continue to drive efficiencies through this self-learning algorithm.

1.3 Project Goal

The goal of this project is to create and test a SMART building management control algorithm to determine the most efficient way to cool and heat the building to reduce overall building electrical usage and the peak electrical usage for any given day. This in turn will lower the overall cost of running the HVAC System.

This thesis has developed a self-learning SMART control algorithm to be implemented into a building management system to predict the required start-up set points and building demand management for the HVAC system. The intention of this new algorithm is to take the various inputted data points, day weather forecast, current zone floor temperature and the electrical loading tariff rates and from this generate a building start-up strategy that will ensure the building meets the required set point but at the same time also ensuring that the electrical load is managed effectively to maintain the peak electrical load. The SMART control algorithm will then effectively update the indoor zone temperature set point and also limit main plant accordingly to ensure the overall objectives are met.

CHAPTER 2:

2.1 Literature Review

The literature review below has been broken into three distinct sections to provide a detailed insight into the proposed research area. The HVAC background will be explored and the key sub-sections that come together to produce a high level of comfort for the occupant will be discussed. Thereafter, the BMCS system will be discussed to give an awareness into the evolution of the BMCS systems. Lastly the current market trends around energy efficient strategies will be investigated and critically reviewed. This will demonstrate the basis of why the chosen research area is key and why the development of a suitable SMART control algorithm developed for use in the commercial building sector is of paramount practical, environmental and cost importance.

2.2 HVAC Systems

Heating Ventilation and Air Conditioning (HVAC) is defined as "the simultaneous control of temperature, relative humidity, cleanliness and distribution to meet the requirements of the conditioned space" (Rezo, 2005). Climate control is another terminology for HVAC, which undertakes the control and monitoring of humidity and temperature within a space whilst maintaining safe and healthy conditions. To achieve these conditions the basic principles are closely related to thermodynamics and heat transfer (Zohuri, 2016). With ongoing awareness and learning as time went on that there is a limit to our energy resources, constant improvements to the way the HVAC system performs has continued to evolve to ensure that whilst comfort is met, at the same time the aspiration is for minimum energy usage with zero waste.

HVAC systems have eight key functions that combine together to provide a space the correct conditions. They are: cooling, heating, ventilation, humidification, dehumidification, filtration, distribution and air volume control. The three main functions - being heating, cooling and ventilation - will be introduced and detailed below as they are very closely interrelated.

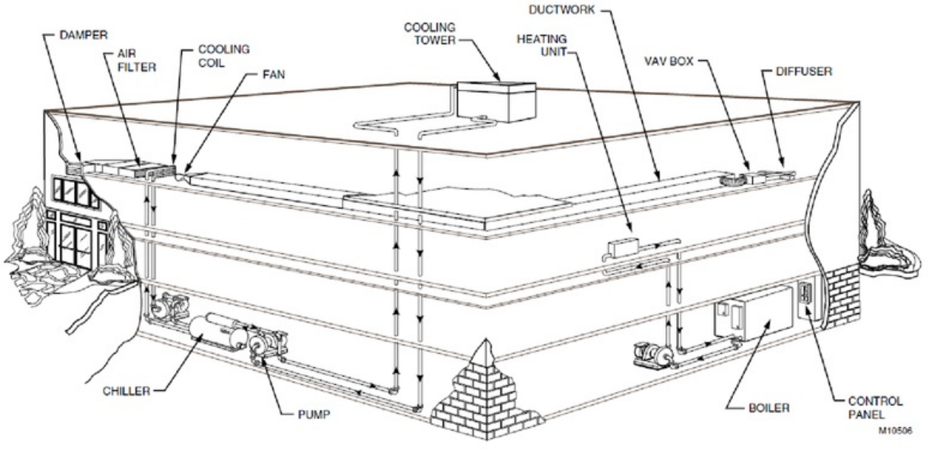


Figure 2 Typical HVAC System in a Small Building (Honeywell Limited, 1997)

2.2.1 Heating

Heating systems can be either fed from a central or local system. Central heating is often used in colder climates where the source can be from a boiler, furnace or heat pump which heats water for distribution across the entire building or campus. The system contains piping from the main heat sources to distribute the heated fluid to the air systems. In boiler systems, a pump will circulate the water around to ensure it is distributed to all areas of the circuit (Honeywell Limited, 1997).

Local heating is usually in the form of an electric heater element. It uses a filament that glows hot when electricity passes through it. These are situated in a duct through which the air passes through prior to the warmed air leaving the grills and into the area to be heated. If the system has electric heating as its primary way of heating it is much less efficient than central hot water systems therefore is used in climates where heating is only required for a few months throughout the year (Connection Magazines, 2017). However, the cost of installing the boilers, pumps and pipe work required for central hot water systems can outweigh the cost of the additional energy consumed in electrical systems, thereby requiring area of a certain size and scale and/or long periods of the year when heating is required.

2.2.2 Cooling

The cooling process is complex as it requires a refrigeration process to effect the removal of heat from the space. Heat can be removed by a number of different processes including radiation, convection or conduction using the various mediums of water, air or refrigerants. In simple terms, to remove heat from a space the source needs to be colder than the existing air in the space for it to be effective and the transfer to occur. The human body uses radiation to gain or lose heat depending on the temperature difference between the body surface and the mean radiant. The radiant temperature is the average temperature of all surfaces that surround us, which radiate heat to and absorb radiant heat from, our bodies. (Canadian Safe Boating Council, 2017).

For the human body to feel comfortable, the body must maintain stability which means releasing the heat at the same rate as it is produced. It has been found that the body produces approximately 350,000 joules of heat per hour (Ogin, 2017). If the human body is in an area where the air temperature is cooler than the human body, it will lose heat and give that individual a cold feeling.

In industry it has been found that the number one complaint that people highlight in the workplace is that the space is too hot with the second being it is too cold (Mills, 2004). There are a number of factors that can contribute to this feeling, with improper ventilation and poor indoor air quality being the two most notable. It has been found that the optimal air temperature for a human is between 21°C and 24°C. The faster the air moves across the human body the faster the heat loss is felt (Wallace, 2009).

2.2.3 Ventilation

Ventilation is a crucial factor to providing comfort and clean air throughout any building as it is estimated that Australians spend around 90% of their time indoors (Australian Government, 2017). The main objective of the ventilation process is to remove moisture, odours, gasses, smoke, heat, dust and airborne bacteria from the air and to ensure that the indoor air quality is clear from any stagnation. During the ventilation process it includes the exchange of outside air as well as the circulation of air inside the building, often known as the return air. The two main methods for ventilating a building are mechanical or natural.

Through the use of mechanical fans the "contaminated" inside air is replaced with cleaner outside air to control and enhance the indoor air quality. In industry there is now a standard (WELLS Building Institute) that is used to compare the quality of the internal air to ensure building owners are effectively managing the health risk that poor air can cause (International WELL Building Institute, 2017). This standard is focused around the quality of the filtration and cleaning protocols of the air conditioning system, and microbial control of the air system. This mechanical process is effective in areas with low humidity whilst in humid climates a lot of energy is required to remove the excess moisture before ventilating the office area. In addition, other supplementary fans are used to extract the odours and smoke from both the toilets and kitchens.

2.3 Building Management Control Systems

Due to the rapid growth and development of the HVAC industry in 1973 there was an energy crisis which forced the HVAC industry to think about controls differently to counteract the rapid energy crisis (M Schwedler, 2013). It was thought that if there was a way to reduce the waste from heating and cooling, an enormous amount of money could be saved (with later thoughts also turning to the impact on the environment). This shift in thinking about HVAC pushed engineers to find a new way to manage the energy consumption and the logical step was to use computers. As this shift continued during the 1980s a new microprocessor and computer revolution unfolded and the building automation industry welcomed this concept and called it direct digital control (DDC).

As the new age of control systems developed, the system needed a master system to bring the data back to a centralised system that could then control, monitor and manage all the services systems installed throughout the building. The services can include heating, ventilation and cooling for the HVAC system and the other equipment that helps a building function such as lighting and the hydraulics. This was called either a Building Monitoring System (BMS) or a Building Management and Controls System (BMCS). The purpose of the BMCS is to build and engineer an automated control system that will operate the system in the most efficient way possible, irrespective of the heat load (AIRAH, 2011).

The BMCS is a standalone computer that has the capability to calculate pre-programmed requirements to use the inputs, such as indoor temperature sensors and outputs, such as fan on/off or valve actuator open/close signals to meet the heating, cooling and ventilation needs of the building without human intervention. The inputs and outputs are connected back to controllers that are placed strategically throughout the building but all of which are connected back to the central BMCS via a network cable (Schnieder Electric, 2017). Information can then be passed between the controller networks to ensure that the programmes that have been written can function efficiently and effectively with the live input data. Due to the large data set that is being passed around the controller network and then back to the BMCS, if there are abnormalities between the information coming in versus what was expected, the system can force an alarm to be activated to notify the onsite engineering team to then allow for remedial attention and action.

As technology continues to advance at a rapid rate, the BMCS has continued to become more central and key to ensuring the performance of each commercial property is managed effectively and most efficiently to maintain the electrical usage, which is a major cost for the building owner or occupier. In a recent technical article the writer has referred to many commercial buildings as “Smart buildings”. This relate to the BMCS moving into an integrated software system which connects all aspects of the building back to a central server display to enable “Smarter” decisions to be made. It is noted that this makes occupants more productive with lighting, thermal comfort, air quality, physical security, sanitation and lower costs and environmental impact than buildings that are not connected (Tracy, 2016). The BMCS plays a key factor in effecting our living and working environments, from both a comfort and a cost perspective.

Building owners can save over 15-20% of their total energy bill every year by efficiently controlling the HVAC system. The DDC and BMCS are in their own rights energy management systems (Staig, 2007). Each individual controller throughout the building holds its own program and communicates back to the central BMCS server and takes commands to run as efficiently as possible, which is critical for reducing the electrical usage throughout the building.

2.3.1 The Basic DDC Control Loop

There are three elements that make up a basic DDC control loop: input, process and output. The input is the first part of the process and is either in the form of a sensor or device. It is measured by the DDC in either an analog or digital method and can include such inputs as outside or indoor temperature, humidity, air or water pressure, current, voltage and air or water flow rates to name a few (Smith, 2013).

Once the input has been connected to the DDC or controller, the logic or programming that has been engineered then processes the information. Based on the internal processing of the DDC the controller will then output a signal to take action accordingly. In building controls the output can be in the form of a relay, damper actuator, and valve actuator. The system is then completed and will continue to cycle through the program to correct the output should the input change in the control loop.

The below figure shows the process for a simple control loop. The process is undertaken inside a controller and compares the measured value of the controlled variable to a desired value or set point. The result of the output then goes to the actuator to enable the system to be able to lessen the deviation between the actual and the desired values. The current trend is for DDC shifting quickly as technology continues to give the engineer more flexibility and ability to develop more complex designs to aid in the more efficient running of the HVAC plant.

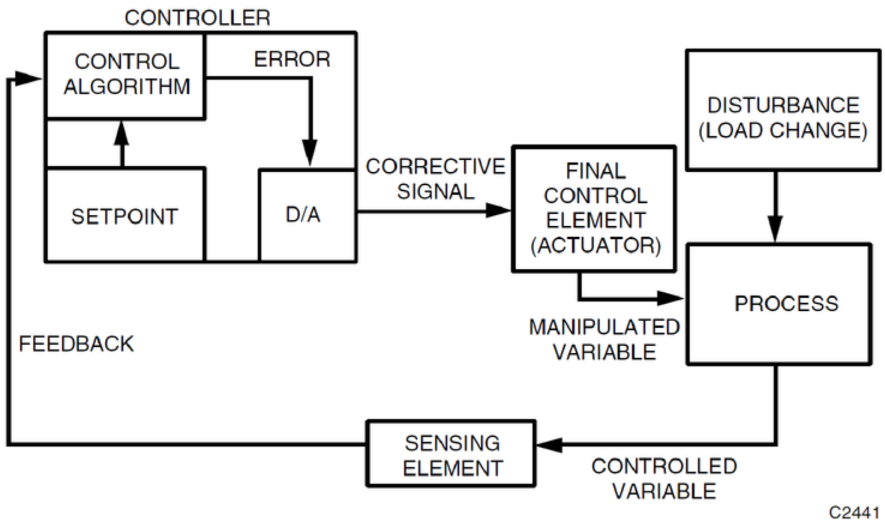


Figure 3 Simple Control Loop (Honeywell Limited, 1997)

2.4 Current Market Trends for Buildings Energy Reduction

Due to the size of the HVAC industry globally many engineers have undertaken research and tested new ways of implementing and designing the HVAC system. The BMCS has had to adapt to new designs and systems and also respond with new control algorithms that can be used to optimise the HVAC to operate as efficiently as possible. Below provides a basic overview of some of the current principles already in operation/use within industry:

BMS Strategy	**Strategy Description**	**Strategy Critique**
Optimum Start / Stop Programs	The Optimum Start / Stop program learns the time response of the system in order to calculate a start and stop time for the heating or cooling system so that the building is warmed or cooled up when the occupied period begins (Siemens Building Technologies Ltd, 2000).	It looks at the indoor temperature in isolation of the weather forecast or electrical demand tariffs. Only focused on the shutting down of the plant and doesn't take into effect the electrical tariff rate charges.
Night Purge Programs	Night Purge is highly effective and is used to help pre-cool a building during the night. It works by opening the louvres and pushing the overnight cool air into the building (Honeywell Limited, 1997).	Research has shown that even though it uses the lower outside conditions the mechanical power usage to bring the cool ambient in outweighs the value.

Enthalpy Programs	Enthalpy program works out which source of cooling a space is more efficient. It determines whether the return or outside air temperature will be more efficient to use to cool a space (Honeywell Limited, 1997).	Enthalpy helps determine which air mixture should be used at the time and point however there is no foresight used based on weather forecast data so delay between settings can have an adverse effect on the energy usage.
Load Reset	The Load Reset works in a way where it takes the maximum or average valve position for the building and resets the chilled water supply temperature (Schnieder Electric, 2017).	On start-up the valves tend to open fully which therefore affects the load reset capability on start-up.
Zero Energy Band	Represents a "dead band" where the system can turn off heating or cooling for that space. E.g. between 21-23 degrees (Honeywell Limited, 1997).	Has an effect on maximum loading at times as the system may not respond quickly enough which in turn causes more energy being required to bring the temperature back to the desired band.
Load Shedding	Load Shedding requires a look up table to be engineered so that based on the total usage, the system can shed a specific amount of power during high demand times (Ausgrid, 2017).	Load shedding doesn't take into consideration the indoor air requirements. It is based purely on the power grid demand and total electrical energy usage.

Table 1 Existing Energy Saving Principles Review

2.4.1 Mathematical Building Load Modelling

Further to the above strategies, research has been spent on a system that tries to predict the HVAC load control in buildings through a mathematical process (Y. Ma, 2015). The Multiple Processing Control (MPC) has been built around trying to predict the future behaviour of the system and then based on predicted output try and optimise the system accordingly. There are four fundamental components of a building MPC, being:

1. A real-time capable dynamic building model

2. Predictions of the main disturbances

3. A performance criterion combining conflicting goals

4. A real-time optimising algorithm

There are multiple steps throughout the MPC that need to work together to predict the disturbances that may occur so the model can counteract effectively. The flaws in this mathematical process is that it doesn't consider the electrical loading necessary to meet the needs of the building and has a greater focus on just cooling and the thermal comfort of the occupants. It also requires much computation to ensure that the model is updated and processed for each cycle to be effective and to provide feedback to the building. Also, if the building model isn't accurate or there are slight changes to the building without the model being updated, then the output from the MPC won't be correct. Through using the negative feedback loop to feedback the information into the new SMART control algorithm the response time will be more effective as well as the algorithm being dynamic and flexible with the actual building conditions near real-time.

2.4.2 Managing Smart-Grid Power

A further area of research that has been investigated is the control of distributed energy consumption via a Real-Time Pricing (RTP) in a Smart Grid (Kai Ma, 2014). The demand management is more focused on the residential market however is starting to creep into the commercial market (B Hannes, 2013). If a user signs up to this system, they are eligible for certain considerable cost rebates due to the nature of the program. The program is implemented by a market based pricing control and is automated through an EMC (energy management control system) which is connected to the energy system with RTP feedback. For this the energy providers have control over the consumer's electrical supply and can reduce or even shut down the electrical supply at very short notice. This initiative is about the energy providers having the flexibility on controlling the peak load for their electrical supply stations. An issue with this, however, is it doesn't provide the users the flexibility to use the HVAC equipment to manage the electrical load and thermal properties. If the user can look at the upcoming electrical peaks, they could look to pre-empt the peak load for the grid and prepare the building for the upcoming peak power (Kai Ma, 2014).

2.4.3 Predictive Model Control versus BMCS Control Methods

Despite the above control methods and concepts there are certain differences that have been found between using predictive modelling for energy efficient buildings (M Killian, 2016) versus BMCS Control methods. One example around the predictive model is that it requires another Supervisory Control layer to house the computation required for the MPC due to the large data model that is built. This model is very time-consuming to model for each individual building. With this model created, the issue remains that when the external temperature drops quickly, it will in turn require heating/cooling which potentially wasn't foreseen within the predictive model. When this occurs, the Proportional, Integral and Derivative (PID) control will respond to the temperature being below set point which will increase the peak load dramatically. The reason for this is that the predictive model works off the HVAC system that has been prepared and which is either pre-heating or pre-cooling the building before the occupied time. This in turn causes incorrect pre-start-up temperatures throughout the building. BMCS control methods are easier to implement and don't require the complete building model to function. For example with Optimum Start / Stop Programs such are implemented based on an algorithm requiring limited data for the building only, being the rate of cooling or heating the space by 1 degree. Even though this can be seen as building model data, such data can be discovered through a number of trends and limited building data compared to what is needed for the MPC model.

As the focus continues to shift towards ways to reduce the carbon footprint that the heating, cooling and ventilation of buildings is causing to our environment and the rising costs of electricity, the attitude will continue to focus on the BMCS as the key piece to driving energy efficiency strategies. Building owners are investing large amounts of time and money into ensuring their buildings are achieving "Five Star" energy ratings (Office of Environment & Heritage, 2017). This means that ongoing research can continue to be explored to further reduce energy consumption and maintaining the peak electrical load. This can be developed through a self-learning predictive algorithm that combines the above concepts. Below are four key requirements that need to be explored when implementing a building control strategy in a smart grid (M Killian, 2016):

- Knowledge about the current thermal energy storage capacity in the building
- Ability to optimally handle predictions of electricity prices
- Implementations of load shedding
- Demand response management

2.5 Conclusion

In review of the current market trends and environmental considerations, it is evident that there has been development of sound engineering which has enabled a firm basis for savings across heating, cooling and ventilation considerations in building. However, it is clear that work on combining these various strategies and developing a self-learning SMART algorithm is required to more effectively focus on the start-up of the HVAC system which will ultimately enhance operating efficiencies and reduce the overall energy consumption and peak electrical load for any given building.

CHAPTER 3:

3.1 Experimental Procedures

The thesis has been broken into three sections for the experimental data and procedures and also the delivery of the new SMART control algorithm. Below details the methodology and the basis for the prototype delivery of the new algorithm:

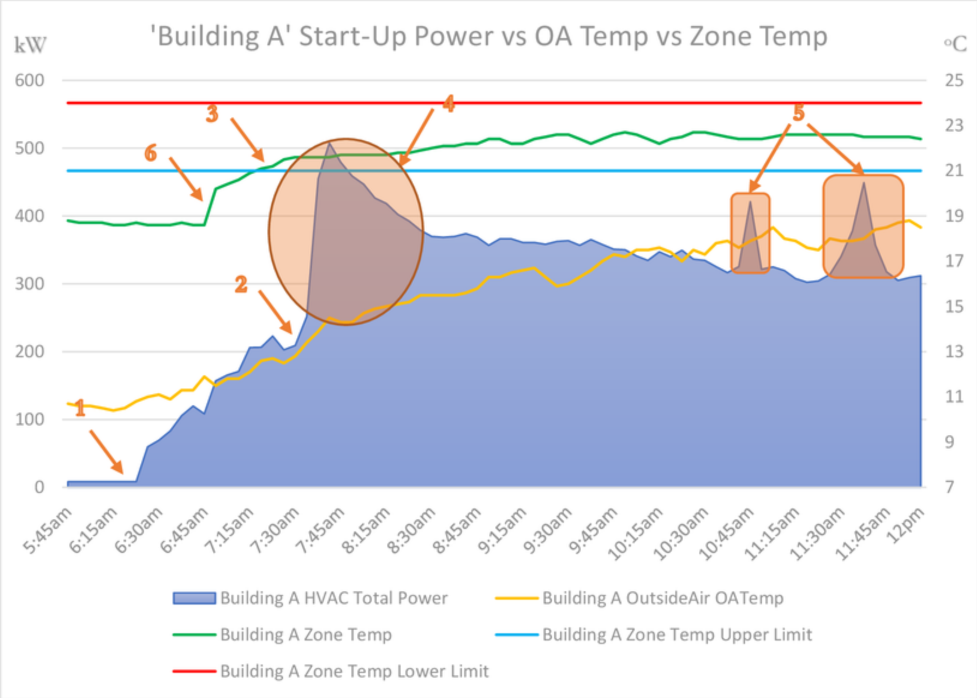
1. Current Building Trend with Manual predictive energy load profile.

2. Development of the new SMART Control Algorithm.

3. Deployment of the SMART Control Algorithm within a Commercial Building in North Ryde.

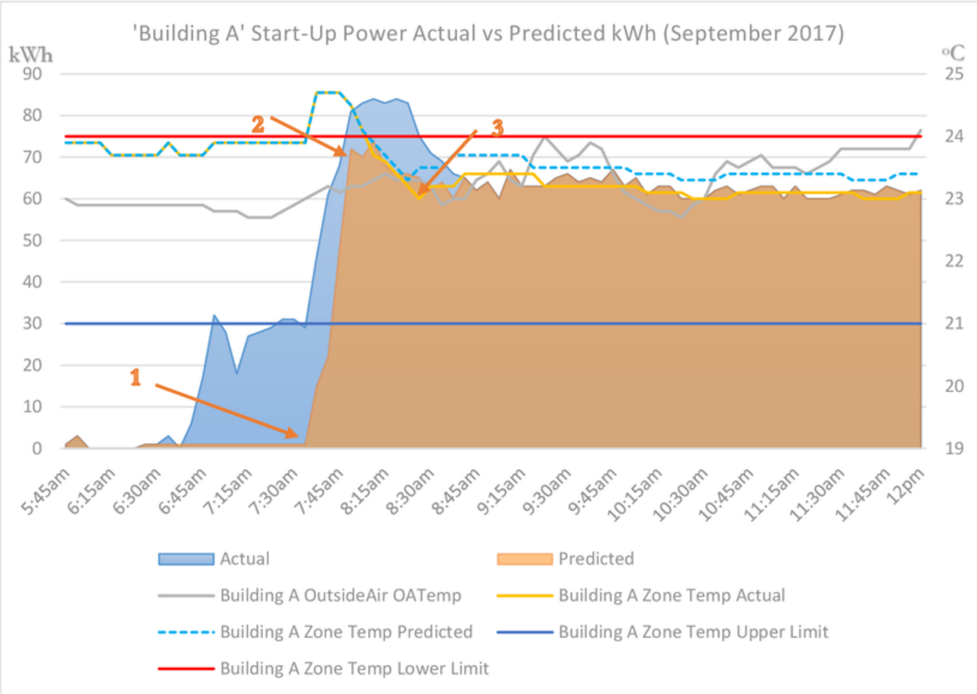
3.1.1 Current Building Trend with Manual predictive energy load profile

The industry problem that is being discovered throughout this thesis relates to the energy usage within any commercial building. The maximum power demand is also an area of concern and if both the total energy and the maximum power is managed effectively not only will the operational costs be reduced but the carbon emissions will be lowered considerably. As part of the pre-work to determine the expected outcome of the new SMART control algorithm the below graphs demonstrate a common issue that has been found in many commercial buildings. The issue is that the BMCS is set and fixed to produce an outcome that is desired without taking into effect any of the conditions that will be encountered throughout the day. The new SMART control algorithm is based on an optimisation process that is entirely automated and self learns as it is deployed within the building. It focuses on pre-cooling or heating the building when the power is cheaper and the ambient temperatures are stable with lower occupancy throughout the building. It aims to let the building drift slowly up or down to the correct temperature to ensure a high level of comfort for the tenants when the building is occupied. The aim is the ensure that when the peak ambient conditions occur throughout the day the building is 'pre-set' to overcome the required extreme mechanical input to meet the tenant conditions.



Graph 1 'Building A' Start Up Power vs OA Temperature vs Zone Temp

Graph 1 is the operational data from a Building in Macquarie Park in September. The building occupancy hours are 8am until 6pm Monday to Friday. As marked above, the building is being set to occupied mode just after 6:15am (Point 1). From 6:15am until 7:30am (Point 2) the building load is stable albeit gradually increasing however at 7:30am all electric duct heaters (Point 4) are enabled causing the power usage to spike considerably. However, this is unnecessary due to the average zone temperature for the building being within the required set point limits (Point 3). The effect this has on the electrical load is considerable with not only the energy usage (kWh) being increased but also the actual power (kW) demand being very high compared to the rest of the day. This unnecessary usage would adversely affect the maximum demand tariff costs in addition to being a waste of power (and thereby unnecessary impact on the environment). It is also evident the affect the late morning change has had on the building with the peak kW spiking twice within the hour towards the end of the morning (Point 5). This clearly demonstrates that due to the fixed set points and static design of the BMCS the system isn't managing the energy usage of the building as effectively or efficiently as it could. The other point to note from the above graph is that at Point 6 where the average building zone temperature has jumped as a result of the building being occupied. At that time, the fans would be enabled, however the actual temperature reading was at a variance of over 2 degrees to when the fans should actually have commenced – this would have primarily been caused by the air in the office space being stagnant. The BMCS had started the system in response to the readings but didn't take into account the actual temperature of the space. It can be noted that if the system was self-learning and had understood that this may occur, it could have delayed commencement of the system, resulting in greater energy savings.



Graph 2 'Building A' Start Up Power Actual vs Predicted kWh (September 2017)

Graph 2 has been modified to give the predicted output once the SMART control algorithm is implemented in the building. There are a number of conditions that will be checked prior to the self-learning algorithm making the decision to commence the operation of the HVAC system.

1. Current Indoor Average Zone Temperature. Based on the conditions within the minimum and maximum dead band the system should not have enabled the HVAC plant to commence at 6.45am, but rather delay until 7.30am. (Point 1)

2. As the HVAC system was set to the occupied mode, the system should have identified that the required space temperature set point could have been lifted towards the upper limit. This would have meant the system was not required to provide full cooling after 7.45am, but would still have been able to maintain tenant comfort within the temperature dead band and continue to meet the desired conditions. With this, the peak load would have been reduced as shown at Point 2.

3. Throughout the morning the zone temperature set point could have continued to climb towards the upper limit resulting in the HVAC plant "backing off" resulting in the energy usage dropping with limited mechanical cooling required. Temperatures at all times were still within the acceptable temperature dead band.

Table 2 below gives the predicted result of the SMART control algorithm in operation.

	6am – 7am	7am – 9am
Outside Temp (Degrees)	22.9	23.1
Actual Energy (kWh)	137	1,483
Actual Cost ($)	$ 20.55	$ 370.75
Predicted Energy (kWh)	14	1,138
Predicted Cost ($)	$ 2.10	$ 284.50
Difference kWh	-123	-223
Difference Cost ($)	$ (18.45)	$ (55.75)
Total % Savings	89.8%	23.3%

Table 2 'Building A' Predicted Savings

Throughout the year the different seasons bring about different energy saving opportunities for each building. The above saving estimator has been calculated based on the Spring Season (assumed to comprise 90 days) i.e. would be able to be achieved for around 3 months each year. Based on this, it can be estimated that the potential savings over the 3 month period would be around 22,490kWh, with a total cost saving of

$ 6,678 for the quarter. This provides the building with around a 19% saving based on the total building energy spend during those 3 hours for that particular quarter. The energy savings also result in 31,346 kilograms less of carbon emissions which is the equivalent of driving 6.7 cars for one year, purely based on the 3 hours' data.

3.1.1.1 Industry Survey

To help understand the current market for the usage of the BMCS system, the following survey was undertaken to capture data from building owners and operators as to where the majority of their focus and time is being directed in addressing cooling, heating and ventilation aspects within their respective buildings. The industry survey was sent to three industry professionals' groups to seek their insight. Overall there were 68 useable responses received, giving a margin of error of less than 12% for the results detailed below. The respondent's position title is detailed below in Table 2.

Positon Title	Percentage of Respondents
Facility Managers	53%
Property Managers	17%
Building Consultants	30%

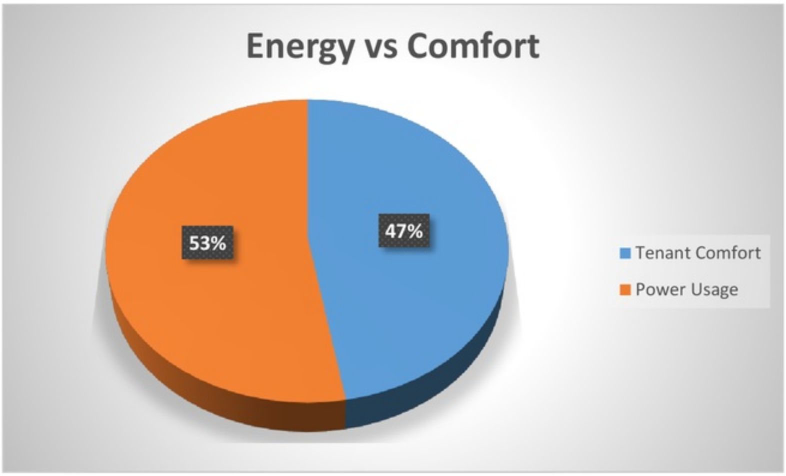
Table 3 Breakdown of Survey Responses via Position Title

As noted in Table 2 the industry survey has a strong representation for those industry professionals actively involved in the day to day operational running of commercial buildings.

The survey was divided into three main areas seeking feedback as to where the respondents' focus was being directed within the building operations each week:

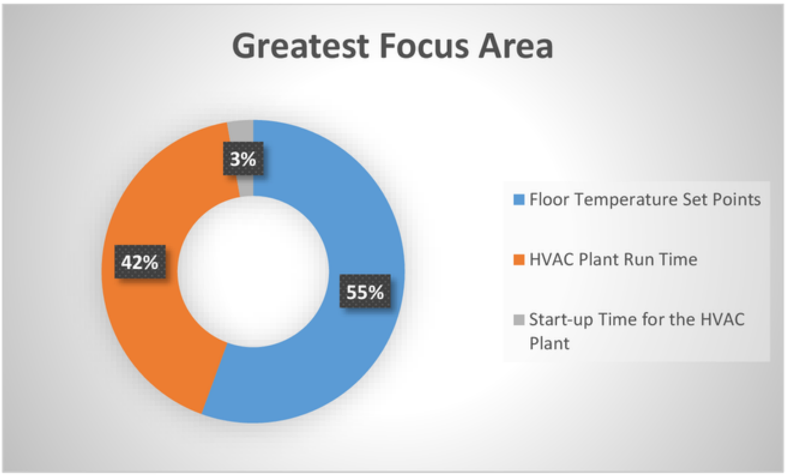
1. Energy Focus
2. Tenant Comfort
3. HVAC Equipment

This data has been collated to identify where the gap is between the current operation and what the new SMART Algorithm will be capable of delivering once implemented and engineered into the building.



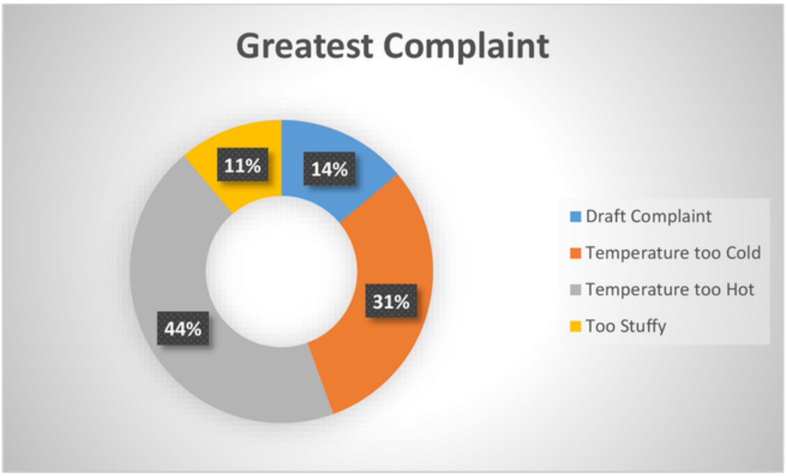
Graph 3 What is your greatest focus area when operating a building

It was interesting to see that the results presented in Graph 1 show that the principal focus area within the building was split virtually 50/50. It shows that notwithstanding the cost of energy continues to increase, there remains a high focus on the comfort for the tenants. From this result it is clear that whilst the new SMART control algorithm will manage the electrical usage and peak demand, it needs to ensure it closely manages the tenant comfort levels to maximise the zone temperature across the space. This needs to be carefully considered during the design of the response time for the tweaking and adjustments of the set point.



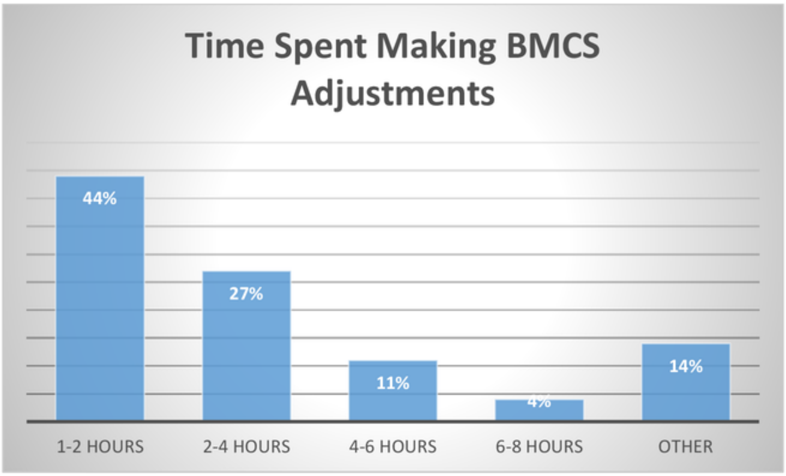
Graph 4 What is the greatest focus area around the HVAC plant when managing a building

With the BMCS becoming more accessible and connected online, this allows the building operators to make real time changes to adjust the operation of the heating, cooling and ventilation system. Graph 2 shows what adjustment is made more regularly. The results indicate that the operators are making more regular floor temperature set point changes. This shows that as the outside conditions are changing and the building occupancy rates change, building operators are required to effect continuous adjustments to most effectively and efficiently satisfy the needs of the tenants. The second most important focus area for the building operators related to the HVAC plant run time. The run time, in conjunction with the adjustment to the floor temperature set point changes, are also the major contributors to the energy usage for a building and command virtually all of the building operators' focus in managing their buildings.



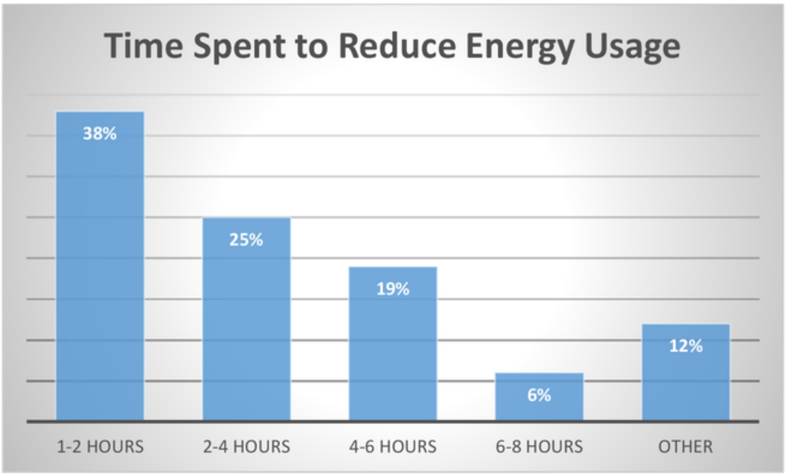
Graph 5 What is the number one complaint from the building tenants

Graph 3 provides more detail into the reasons why tenant comfort is such a high priority when operating and managing a building. It can be seen that 75% of the tenant complaints being received are related to the temperature applying to the occupied space. By changing the zone temperature set point by +/- 1 degree can save over 10% of the energy for the given equipment (Office of Environment and Heritage, 2016). Having regard to the above findings, the building operators should regularly adjust the zone temperature set point (both up and down) to try and overcome the complaints that are being received and enhance the energy efficiency of the building.



Graph 6 How many hours do you spend in front of the BMCS making adjustments

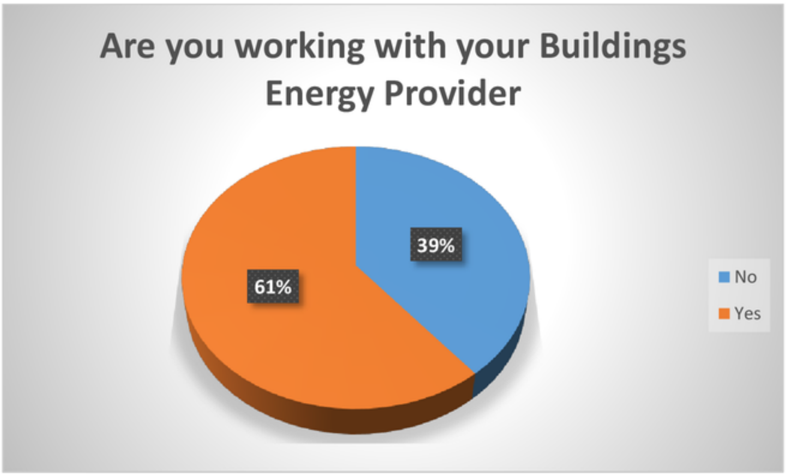
Over the course of the working week, it was found that a minimum of in excess of 5%* of the entire working week is currently being devoted to making adjustments on the BMCS (*Based on a standard 38 Hours Working Week). Nearly one third of respondents (29%) are spending more than 10% of each week making adjustments on the BMCS. This represents considerable time for someone to be spending to simply adjust the values on the BMCS, providing further credibility to the need for the development of a self-learning algorithm which is capable of adjusting the values to reduce the operational time spent by building operators in front of the BMCS. Following review of these responses, together with the research gathered in the literature review, it can be seen that having a dynamic set point which keeps the building operation more comfortable as the set point adjusts with the outdoor weather temperature would be the desired optimum outcome.



Graph 7 How many hours do you spend trying to reduce the building energy usage

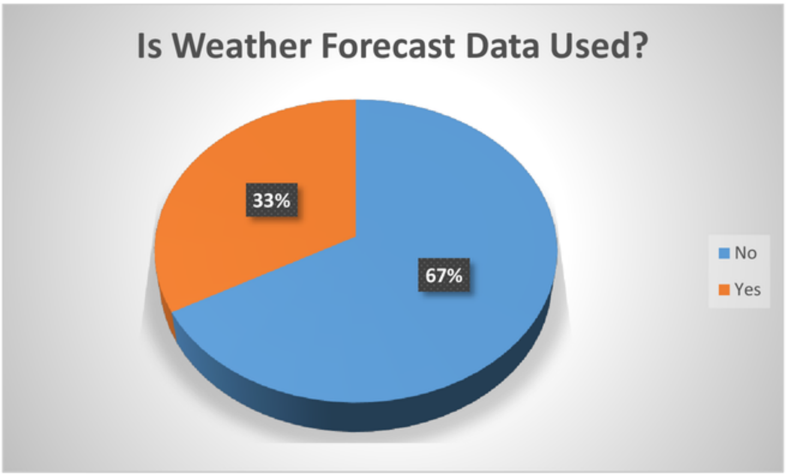
It can be seen that yet again minimum time of over 5% of the working week is devoted to adjusting values on the BMCS to help reduce the energy usage for the building. Over one third of operators (37%) are investing in excess of 10% of the working week in trying to reduce the building energy usage.

Upon combining the results from Graph 6 and Graph 7, a minimum of over half a day of the working week is spent sitting in front of the BMCS making adjustments for the issues created and raised by the tenants rather than devoting time to looking at what is needed to be done to improve the overall performance of the building. Approximately one third of operators are in fact spending over one full day of their working week undertaking these adjustments. The new SMART control algorithm needs to be capable of constantly updating the system response to reduce the time that is currently spent by the building operators in reviewing the BMCS.



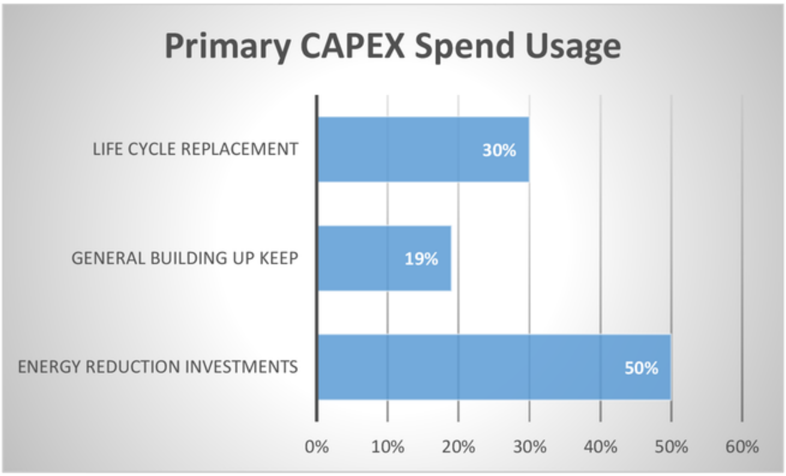
Graph 8 Are you working with your buildings energy provider on power management initiatives

It can be seen that 61% of the responses are currently working with the building energy providers that are delivering the electrical supply to their building. Such collaboration with the energy providers demonstrates a maturity and desire for energy efficiency and cost effectiveness across the market place. It can be noted that both parties are seeing the value of working together and exploring ways to innovate and reduce the energy usage (with a flow on favourable impact on energy costs) for the building. The new SMART control algorithm will be able to build on this existing collaboration and look to continue to add to the benefits that are currently being achieved through the current working efforts.



Graph 9 Do you look at the weather forecast to make manual adjustments to the BMCS

The result shown in Graph 9 is different from what was expected based on the research that had been undertaken above in the literature review. Every building is effected by the weather conditions which creates an effect on the exterior walls which in turn effects the indoor air temperature. For example when the sun is out during the day the solar effect on the building can require the building to use mechanical cooling even if the outdoor temperature isn't warmer than the indoor temperature set point. Even though the current building operators aren't using the weather forecast data to make decisions that will affect the operation for the building, the new SMART control algorithm will use the weather forecast data to determine what set points the building should be set to prior and during the occupied day.



Graph 10 What is your focus when planning for CAPEX spend

With CAPEX planning a key component to running a building, it is interesting to note Graph 10 shows that when planning for CAPEX, 50% of the planned spend is around energy reduction investment. This could result in a potential investment into a piece of equipment that is not required to be replaced from "lifecycle" perspective but could be replaced in seeking a more energy efficient option. This response shows that there is a major focus and shift towards a desire by building owners and operators to reduce the energy usage for the building.

3.1.2 Development of the new SMART Control Algorithm

To implement the new self-learning SMART control algorithm efficiently the below process map details the steps taken when controlling the HVAC System start up time and also what the required zone temperature set point ("SP") is set to. This process will be explained in detail before it is developed in the Niagara Framework for trial in the chosen North Ryde Building.

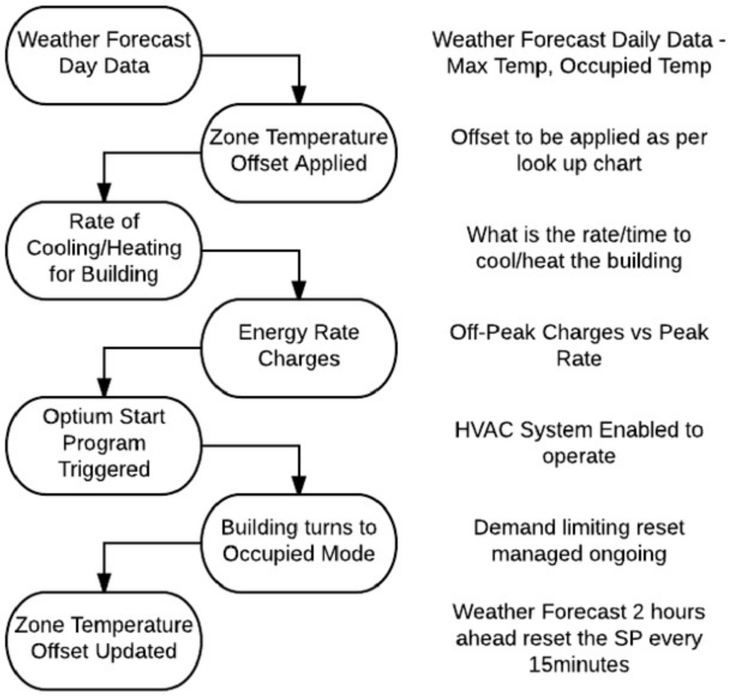
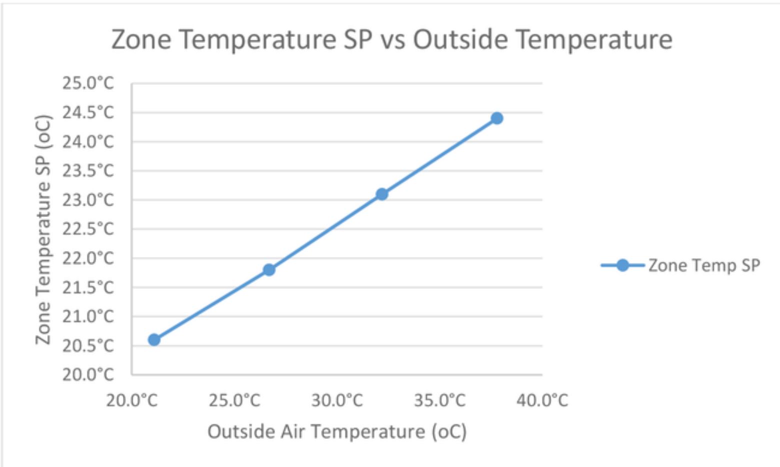


Figure 4 Process Map for new SMART Control Algorithm

1. **Weather Forecast Day Data:** The algorithm starts each day with this cycle to look at the weather forecast data before it makes a decision about when the HVAC system should start and also what

set points it should target. The forecast data has a level of accuracy of over 90% for the day (A Zhu, 2014) so would enable the algorithm to pre-plan for what the building may require for the day. The intention is to use this data to be able to work out how most efficiently to manipulate the building to ensure it can handle the anticipated ambient load accordingly. In Sydney, temperatures throughout the day span an average of approximately 8.5 degrees for a given day hence the rate of change from the lower ambient to the more extreme temperatures in the middle of the day occurs relatively quickly (say 1 degree every 90 minutes during assumed 12 hours of daylight). As the temperature changes, the stress on the HVAC system is considerable if it isn't already operating and driving the space temperature accordingly. The energy usage can be adversely affected and peak load building kilo Watts can hit maximum values due to the lack of planning.

2. **Zone Temperature Offset Applied:** Once the system has determined what the forecast data is for the day, it would build a profile for what the zone temperature set points should ideally be throughout the day. The intention is it will use this profile for the whole day and this will be set unless the actual temperature varies by more than 1 degree from the forecasted data. Graph 11 gives an indication on the relationship between what the indoor temperature should be versus the outside air ambient temperature (Engineering Toolbox, 2017). This represents the foundations of the zone temperature set point relationship however with every building responding differently to the outside conditions (due for example to differing building materials and techniques as well as insulation, etc) the data will be modified as required as the building establishes its own unique set point chart to achieve the most efficient internal conditions.



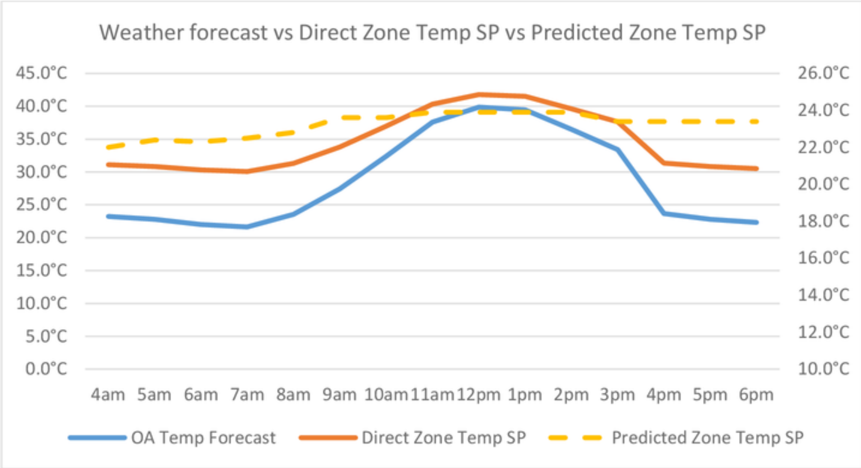
Graph 11 Zone Temperature SP vs Outside Air Temperature

To give an indication on what the zone temperature set point day chart may look like see Graph 12 below. The weather forecast data was taken from the forecast data for February 2017 which gives a wide spread temperature range for the chosen day. The blue line is the actual temperature for the day and gives a clear picture on the actual ambient experienced throughout the day. It should be noted the wide spread of temperatures throughout the day and also the relatively rapid rate at which the temperature is predicted to increase during the morning prior to achieving the daily maximum. The orange line shows what the relationship would be if the above look up chart was used. The formula for the above function is as follows:

$$y = 0.2284\,x + 16.748$$

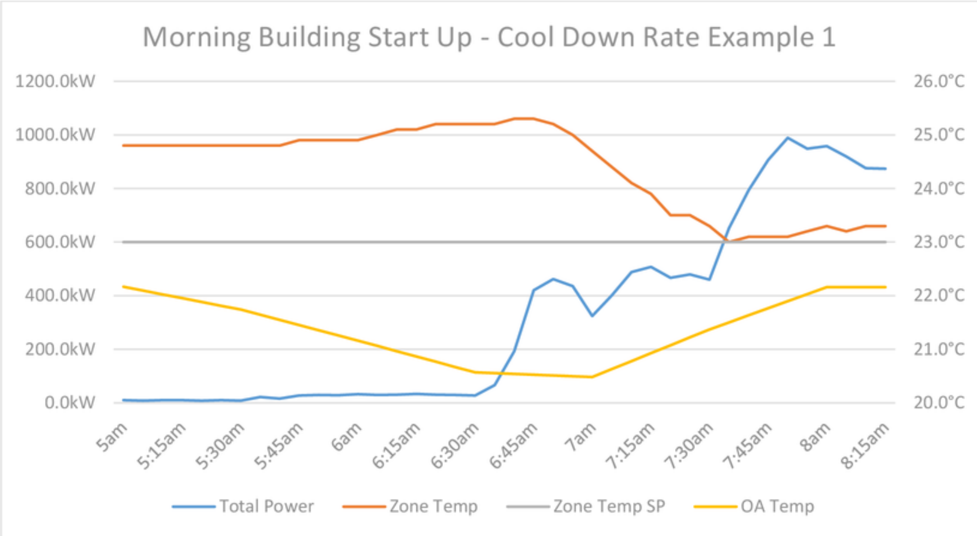
Equation 1 Zone temperature set point vs outside air temperature

Based on this data, the SMART control algorithm would determine what the optimal zone temperature set point for the day should be to ensure that by the time the day reaches its maximum temperature, the system is not required to go to 100% capacity to meet those conditions at that particular time. The dotted orange line is what the algorithm has determined the best set point for the day should be. With the daily maximum forecast set to achieve 40 degrees, the building needs to enable the cooling earlier in the day despite the lower morning temperatures to achieve this function. The system doesn't need to overcool in the morning (due to the lower over night and morning outside temperatures) but does need to hold the required temperature between 22 degrees and 24 degrees which would more effectively utilise the power usage (as well as limiting the tenant complaints throughout the day). Effectively the zone temperature will be held at a fairly constant temperature towards the upper temperature limit for the building requirements. Each building has various commercial contracts that dictate the maximum and minimum temperatures that are required within the tenanted space hence the desired set point isn't able to be a constant within Equation 1 above.



Graph 12 Weather Forecast vs Zone Temperature SP

3. **Rate of Cooling/Heating for Building** Once the above has been confirmed and the proposed set points have been forecast, the system needs to collate this with the rate of cooling/heating within the building. It is at this step that the SMART control algorithm determines how the building is going to achieve the desired zone temperature set point having regard to the current conditions. The rate of cooling and heating is different as each building has varying systems and building insulation which may result in different times being required to achieve the desired conditions.

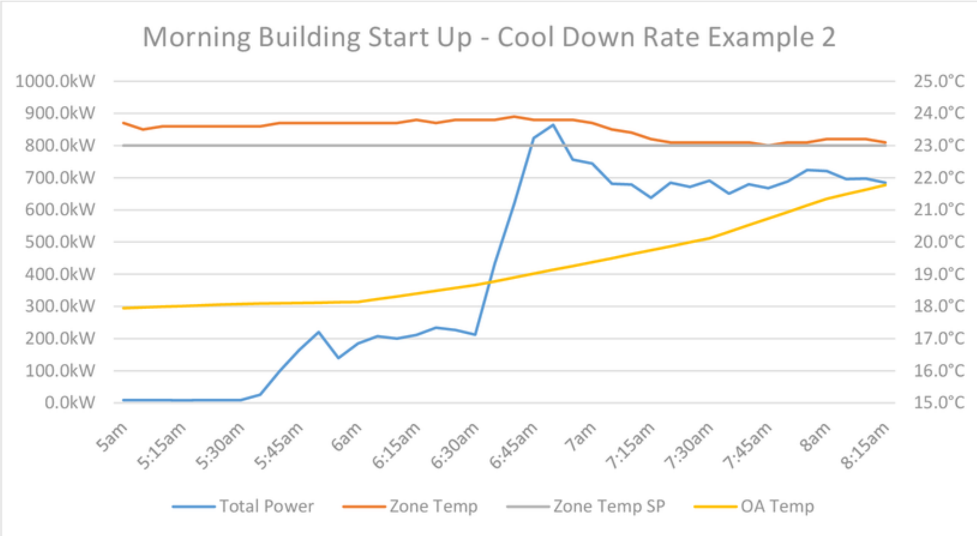


Graph 13 Morning Building Start Up - Cool Down Example 1

Graph 13 represents the chosen building where the prototype SMART Control Algorithm will be deployed. It gives an indication on the cooling rate for the building versus time, after also taking into account the outside air temperature. This example shows that the time for cooling to achieve a 2.3degrees reduction from the overnight, unoccupied temperature is 55 to 60 minutes. It also shows that once the zone temperature average was down to the predetermined set point, the building continued to cool and the power usage continued to increase.

TIME	ZONE TEMP AVERAGE	OA TEMP
6:40AM	25.3°C	20.5°C
7:35AM	23.0°C	21.5°C
MAXIMUM OA TEMPERATURE	23.6°C	

Table 4 Rate of Cooling Summary – Example 1



Graph 14 Morning Building Start Up - Cool Down Rate Example 2

Graph 14 is another example from the same building to show the various cooling rates that will be achieved. From this example yet again an alternate cooling rate would be applied into the SMART control algorithm to ensure that the HVAC system will be able to respond and reduce to meet the chosen set point. This example shows that the building reduced 0.9degrees in 30 minutes.

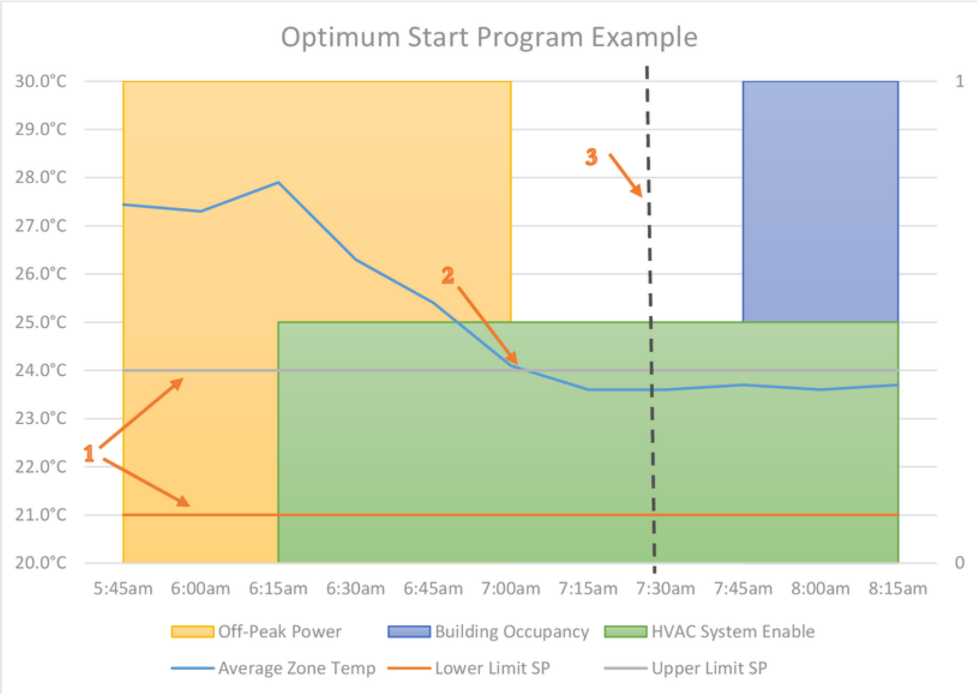
TIME	ZONE TEMP AVERAGE	OA TEMP
6:45AM	23.9°C	19.0°C
7:15AM	23.0°C	19.7°C
MAXIMUM OA TEMPERATURE	26.1°C	

Table 5 Rate of Cooling Summary - Example 2

4. **Energy Rate Charges:** The next step in the SMART control algorithm is to determine the optimal way to start the plant based on the energy tariff charges. Energy tariff rates have been increasing consistently over recent years, with building owners being charged based on a number of different factors. These include time of day charges (peak, off-peak, shoulder) and maximum kW demand

charge for a 12 month period. Based on this, it is possible to determine which operational start is going to meet the tenant conditions but at the same time be the most energy and cost efficient. Similarly to the previous step, a look up table has been developed on an ongoing basis as the operation of the plant continues throughout varying times to achieve the desired outcome occur. This step confirms whether it would be more energy (and cost) efficient to run the plant at 100% capacity for a shorter period of time rather than operating the plant for longer periods but demand limiting the total kW's.

5. **Optimum Start Program:** With steps 3 and 4 utilised to determine the various options the building has to meet the required zone temperature set point for the day. The SMART algorithm now determines which method is best and will command the plant as to when to commence operation. It is from here that the plant will remain in operation at the preferred demand to ensure the tenant comfort is met throughout the entire occupied day. The process will ensure that the correct signals are sent to the HVAC System which would then be able to manipulate the building in the best way to enable cooling or heating of the space. It can be noted that this step would represent the most critical as it is what ensures that the tenant comfort is going to be met in accordance with the required building guidelines.



Graph 15 Optimum Start Program Example

Graph 15 gives an indication on how the SMART control algorithm will function. Point 1 indicates the dead band and temperature comfort parameter the building needs to operate within. Seeing as though the current average zone temperature is over 4 degrees outside the set point the HVAC system needs to be enabled to bring this back within the dead band prior to the building occupancy. The Yellow shaded area above indicates when the building power is operating at the lower off-peak power rates. Due to the large actual temperature difference, the plant will commence at 6:15am to ensure the maximum requirement of the main HVAC system power demand is used within the off-peak time. Once the power converts to the more expensive peak rates, the system will be running at a stable/lower rate. Point 2 above shows that the average zone temperature would now be within the required comfort set dead band and the HVAC system can now be demand limited. Point 3 shows the latest time that the plant can commence and still ensure that the HVAC system can be engaged and the required statutory ventilation rates are maintained prior to the building occupancy.

6. **Building turns to occupied mode:** Once the building has started up and the HVAC system has been manipulated to ensure conditions for the building are met prior to the building occupancy, the HVAC system is now required to continue to operate to maintain the conditions whilst pushing the electrical demand and usage down. It is at this step that the building is set to operate in 'coast' mode with the intention that no major step changes in the HVAC system are required to meet the conditions. This is due to the building being optimised to operate prior to the building load increasing which would otherwise result in greater stress being put onto the HVAC system to bring the temperature back within the required guidelines. With the pre-work undertaken on the HVAC system for the building, the negative feedback loop (Figure 5 below) will now be in effect with the external temperature data and internal temperature conditions being input to the algorithm to continue to enhance the building conditions.

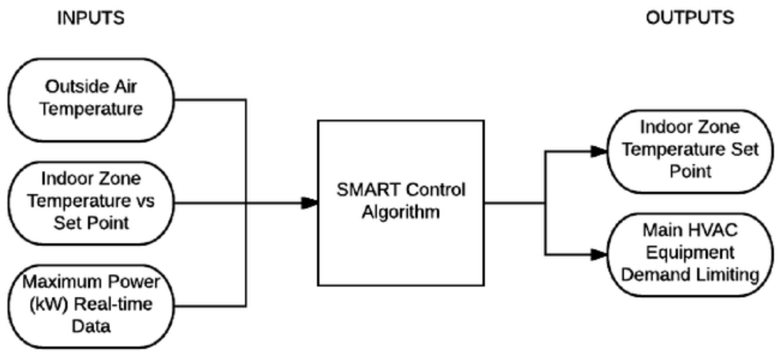


Figure 5 SMART Control Algorithm Negative Feedback Loop

Figure 5 gives details on the negative feedback that is occurring within each controller cycle whilst the system is in occupied mode. It is continually comparing the real building data with the set points and if any of the input data is outside the required dead band limits the control algorithm will make the required adjustments to ensure the system continues to operate as per the design of the SMART control algorithm.

7. **Zone Temperature Offset Applied:** As noted in step 2 the zone temperature set point has been predicted for the entire day based on the weather forecast data. The SMART control algorithm will maintain this unless the actual outside air temperature varies more than 1 degree from the forecasted data. This check is undertaken every 15 minutes for the remainder of the occupied day for the building. If the temperature is outside the parameters above, the zone temperature set point will be reset for the rest of the day and a new zone temperature predicted set point range will be set. This process is via a continual negative feedback loop that will ensure the HVAC system is kept updated on the outside air temperature conditions to ensure it maintains the building tenant comfort and minimises the energy usage. It should be noted that it is at this step that the system will also manage the maximum kW usage for the building. This is due to the system not requiring to necessarily revert to 100% capacity from a step change or rapid rise of the outside conditions that would have a direct impact on the building thermal loading.

The above process continues to cycle real-time throughout the day until the end of the building occupied day and the building becomes disabled. It is at this point the SMART algorithm is then reset and the data is stored in the history memory. The operational data is stored so learning can occur from the historic operation which enables the self-learning algorithm to continue to become more efficient each day. The control algorithm will be able to produce the updated learning patterns to allow evaluation of the data to confirm how the building operates and what areas may require some additional work to help reduce the overall energy usage. The history will also be used to demonstrate the benefit from the SMART control algorithm and will be able to provide the building operator an insight into the workings of the algorithm. This may result in CAPEX spending being required to achieve necessary plant upgrade or improved insulation for the building.

3.1.3 Deployment of the SMART Control Algorithm within a Commercial Building in North Ryde.

While much research has been based on individual components of the BMCS control algorithms, less study has been undertaken on the electrical power management and tracking within the BMCS system. Energy providers invest time and effort into ways to manage the power grid effectively but this normally stops once the power has been fed into the different power grids/distribution nodes for each building. Similarly BMCS engineers spend considerable time on perfecting control loops to ensure the tenant comfort and conditions are met but do not necessarily take into account what impact these algorithms have on the electrical loading or charges. This thesis however, aims to incorporate another function and focus on ways to manage the start-up energy to not only minimise the peak electrical surge but also to ensure the tenant comfort is met within the design guidelines of the tenant lease. From reviewing the research gathered as part of the thesis it was noted that seeking to achieve optimal operational efficiencies was involving considerable human operation and investment. The purpose of the new self-learning SMART Control algorithm will minimise the time spent in this regard but will also improve the accuracy of the outputs that are being input to the HVAC system.

Figure 6 Oracle Head Office North Ryde (City of Ryde, 2017).

- **Building Owner/Tenant:** Oracle Corporation Australia

- **Address:** 4 Julius Ave, North Ryde NSW 2113

- **Building Size:** 11,055m^2

- **Brief Building Description:** The building consists of two levels of car park (1 and 2) and six levels of tenancy space (3 through 8). The building is split into 2 towers, West and East with a mirror of equipment in operation for each tower. All major HVAC plant is located on the roof

(2 x Chillers, 2 x Cooling Towers, 2 x Pre-Conditioning AHU, 6 x AHU) with VAV boxes located across each level to provide the local cooling/heating (Electric Duct Heaters).

- **Internal Design Parameters:** 23.0°C +/- 1.5°C between 7am till 6pm Monday to Friday

- **Current HVAC Operation:** Currently the building operates based on the Facility Manager setting the required building operation time. Once the time schedule is set, the building will change between the occupied/unoccupied time and enable all plant to operate. The building is set to 23.0 degrees with this fixed set point being used to dictate the required cooling/heating. The building then turns on/off the required HVAC plant without any interaction or consideration to the electrical tariff charges, peak load or weather (temperature) forecast. Should the tenants raise a call for a temperature complaint, the building operators merely adjust the temperature set point as required to address and hopefully overcome the complaint.

- **SMART Algorithm setup/deployment:** The system onsite is an open vendor Tridium Niagara 4 framework technology. The Tridium system runs on the JAVA framework and the new SMART Algorithm will be written based on logic function block programming which will be compatible with the existing technology. Figure 7 below depicts the basic site system architecture:

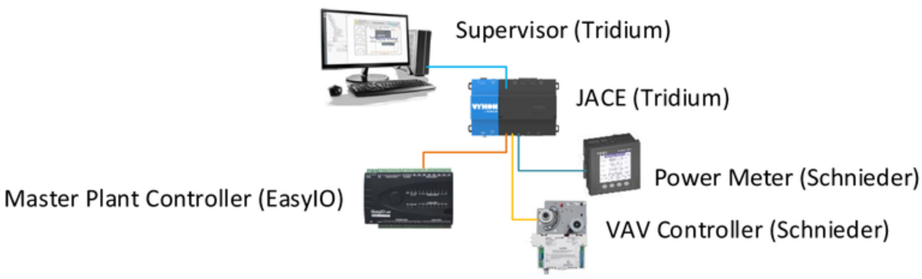


Figure 7 Oracle North Ryde Basic System Architecture

The system design for the new SMART control algorithm can be broken into the below sub-categories:

- **Supervisor (Tridium):** This is the master computer that handles the monitoring and display for the Building Operations team but also enables long term operating history to be stored. The data for the entire BMCS is stored at 5 minute intervals at this layer, resulting in a solid platform to review and verify the new SMART control algorithm performance.

- **JACE (Tridium):** The SMART control algorithm will be deployed into this controller. It is at this layer that the system runs the control algorithms and drives the control algorithm outputs down to the lower field controllers. The entire control logic programming will be stored and cycled through to ensure the smooth operation of the HVAC system. The JACE controller will receive a direct feed from the Bureau of Meteorology via a web API.

- **Master Plant Controller (EasyIO):** These controllers have been installed into the main plantroom on the roof top of the building. These controllers run the inputs and outputs for the Chiller, Boiler and Air Handling Unit equipment.

- **VAV Controllers (Schneider):** Throughout the 6 levels across the Oracle building these controllers have been installed to manage the Variable Air Volume (VAV) items of equipment. These are the controllers that manipulate the air volume going onto the floor as well as maintaining the temperature against the set point. These controllers will be written / controlled by the JACE controllers which are located across the office floor, controlling the individual space comfort conditions.

- **Power Meter (Schneider):** To enable the BMCS to be able to manage the power usage and demand for the building there are a number of meters connected back to the BMCS. The BMCS reads this data real time and will ensure that the power demand management strategy is maintained to reduce the peak load charge that affects the overall energy cost and usage for any given building.

- **Energy Tariff Rates/Charges:** Oracle is procuring its energy rates yearly with their current rates set from 1/04/2017 to 31/3/2018.

Peak Rate	Shoulder Rate	Off Peak Rate
7am – 9am, 5pm – 8pm	9am – 5pm, 8pm – 10pm	All other times
18.9539 c/kWh	16.9118 c/kWh	9.0156 c/kWh

Table 6 Oracle Retail Charges

The charges above represent only the raw cost of the c/kWh charges. The power bill for any commercial building also includes the following components which are further factors that can be considered when managing the overall power for the building. For most buildings, the Retail Charges generally equates to approximately half of the total cost of the energy bill for any given month.

- **Environmental Schemes:** This fee relates to the charge that the government places on the energy providers. The building owners can access this fee should they participate in energy initiative schemes. For example in undertaking a LED Lighting upgrade the building owner will have access to funding based on the savings that can be found from the installation works. The building owner will need to apply to the energy provider and local government to determine what the initiative is and what projected savings will be achieved once the project is implemented.

- **Network Charges:** The Network Charges are on top of the base Retail Charges and relate to the cost of maintaining, building and servicing the network that delivers power to the business. There are certain charge rates for the Peak, Shoulder and Off Peak rates. These are based on a multiplier dependent on the amount of kWh used and the unit price. The next charge is the Capacity charge which is based on the maximum kVA peak load which can prove costly should the building have an issue which results in a very high peak load during the day. This charge is then carried throughout a 12 month period. This component can be managed through effective power demand limiting techniques to ensure that this is maintained and reduced as much as possible to help reduce the overall fee.

Pricing Details Account: [redacted]

Charges	Usage	Unit Price	Loss Factor	Total Price (excl GST)
Retail Charges				
NSW Peak	56,572.592 kWh	18.9539 c/kWh	1.05786	$11,343.13
NSW Off Peak	122,954.032 kWh	9.0156 c/kWh	1.05786	$11,726.42
NSW Shoulder	114,787.872 kWh	16.9118 c/kWh	1.05786	$20,535.91
Environmental Schemes				
NESC	294,314.496 kWh	0.1340 c/kWh	1.04790	$413.27
LRECs	294,314.496 kWh	1.2868 c/kWh	1.04790	$3,968.65
SRECs	294,314.496 kWh	0.2800 c/kWh	1.04790	$863.55
Network Charges				
EA310 - Peak	69,026.320 kWh	4.3990 c/kWh		$3,036.47
EA310 - Shoulder	102,334.144 kWh	2.1052 c/kWh		$2,154.34
EA310 - Off Peak	122,954.032 kWh	1.3871 c/kWh		$1,705.50
EA310 - Capacity	1,194.000 kVA	35.7417 c/kVA/Day		$13,229.43
EA310 - Supply Charge	31 Days	4,806.2586 c/day		$1,489.94
Market Operator Charges				
AEMO Ancillary Fee	294,314.496 kWh	0.0343 c/kWh	1.04790	$105.79
AEMO Market Fee	294,314.496 kWh	0.0374 c/kWh	1.04790	$115.35
Metering Charges				
Meter Charge		1,350.00 $/mtr/pa		$229.32
GST				$7,091.70
Total (excl GST)				$70,917.07
TOTAL for NMI [redacted]				**$78,008.77**

Figure 8 Sample Energy Bill showing various Charge Rates

Having regard to the above additional charges, the actual blended rate for the 3 charge periods (peak, shoulder and off-peak) actually cost considerably more than what was displayed in Table 6. Table 7 following shows the blended rate charge versus the raw retail charges:

	Retail Charges (c/kWh)	Environmental Scheme (c/kWh)	Network Charges (c/kWh)	Misc (c/kWh)	Total (c/kWh)
Peak	18.9539	0.566933333	4.399	0.0239	**23.94373**
Off Peak	9.0156	0.566933333	1.3871	0.0239	**10.99353**
Shoulder	16.9118	0.566933333	2.1052	0.0239	**19.60783**

Table 7 Combine Charges for c/kWh

As detailed, there is an approximate 21% increase in per kWh charges with the inclusion of the various additional charges.

3.1.3.1 New SMART Control Algorithm Deployment into the onsite BMCS System

The steps outlined below detail the existing programming that has been installed onsite at Oracle and how the newly designed SMART Control algorithm will be deployed and engineered into the BMCS.

1. Existing Niagara JACE control logic backed up and downloaded prior to commencing the integration of the new control logic.

2. New SMART control algorithm copied to the site Niagara JACE for deployment across the whole site.

3. Weather data integration via the Weather-Underground API was configured to allow the Niagara JACE to receive the weather forecast day data.

4. Electricity Charges and rate zones added into the SMART Control Algorithm.

5. Mapping of the required outputs and new values based on the SMART Control algorithm requirement were completed with all linking occurring at 'priority 10' to ensure that the signals

were transmitted successfully during the operation (Chiller Demand Limiting, Zone Temperature Set point, HVAC System enable).

6. History points were setup to be able to track the changes and system outputs to verify the success of the deployed algorithm.

3.2 Conclusion

This chapter has brought to light the foundations of the SMART Control Algorithm. It outlines the development through a step by step process of the SMART Control Algorithm and details the predicted benefits that it will bring to the industry, including the delivery of cost savings to the building. With the algorithm developed, the test case building was discussed to introduce the implementation process that will be performed for the industry trial.

CHAPTER 4:

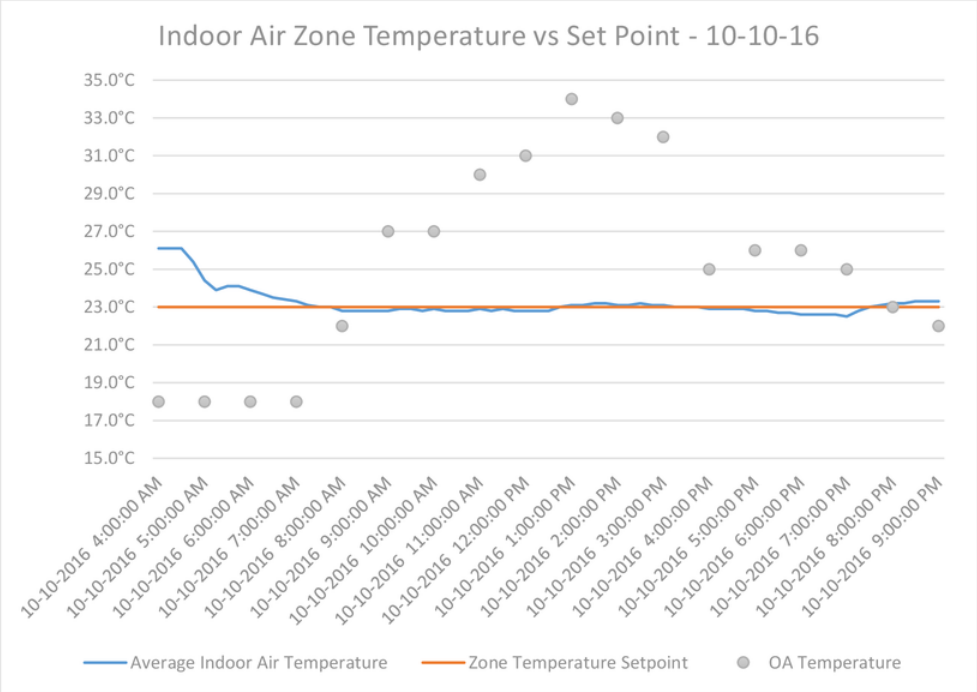
4.1 Results

With the SMART control algorithm developed and implemented over a two week period, the results recorded from this period will be compared against the energy and zone temperature data for the building from the prior year. This data will form the major component of the baseline which is to be utilised to determine the success of the project. Comparison of the baseline data with the actual data recorded during the trial period will be discussed to demonstrate the various benefits achieved from the different components of the SMART control algorithm.

4.1.1 Baseline Data

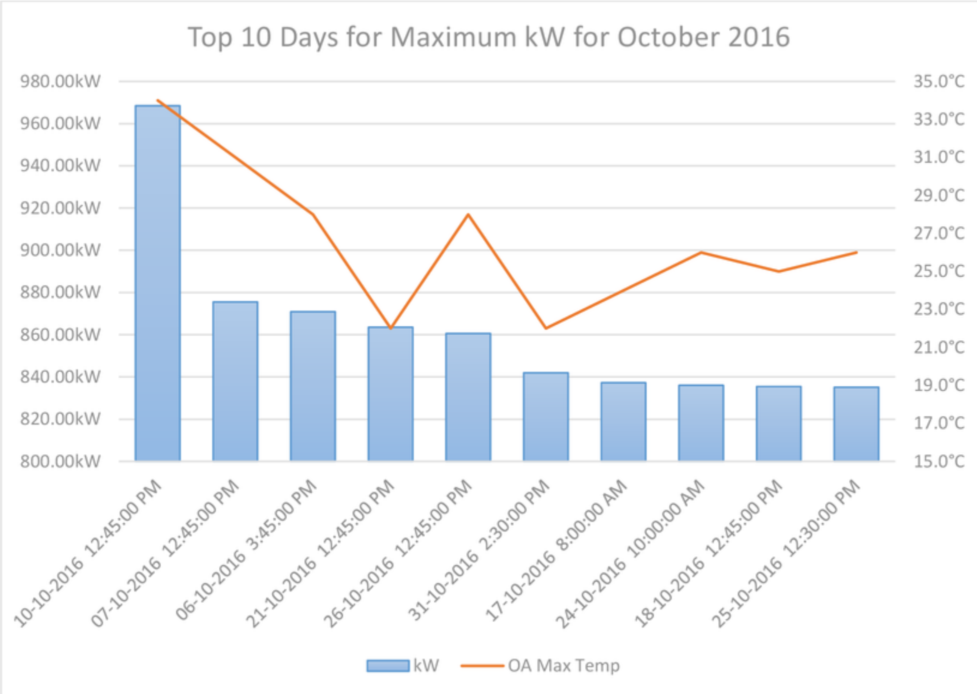
As part of the initial stages of the deployment, baseline data was needed to be able to compare the operation for the building prior to the algorithm being installed. This was based on the need to determine the current daily energy usage as well as the peak electrical demand during this particular time of year. This data would then form the basis of proving whether the new SMART control algorithm had been successful and will provide the outcomes that form the goal of this thesis project. It should be noted that different savings are estimated throughout the year based on the various seasons and periods. With the data gathered post implementation of the SMART control algorithm it would then be used to determine the total year savings with the algorithm deployed over the full 12 months. The data shown below has been captured from the online energy supplier portal, ERM Business Energy for the electrical data and the onsite HVAC system data from the Niagara 4 framework supervisor.

The zone temperature data quoted throughout this chapter has been averaged to provide a total building snapshot. Across the Oracle building, there are 64 zone temperature sensors used to record the local temperature at each particular zone. These sensors monitor the VAVs which control the set point that has been set for the building. The sensors are recording actual data every 5 minutes which is then saved within the Supervisor historical records onsite. The average data has been determined after the 2 highest and the 2 lowest readings were removed, with the remaining sensors' data then being averaged.



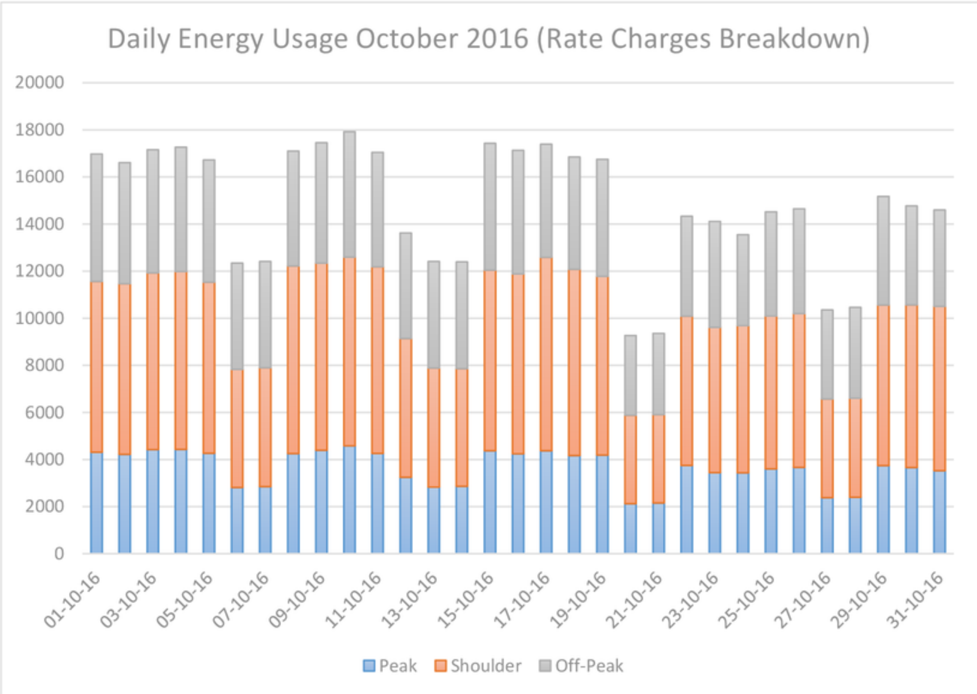
Graph 16 Indoor Air Zone Temperature versus Set Point

Graph 16 depicts the indoor conditions from the 10th October 2016. This shows how the building is currently operating which is also consistent with the industry survey results recorded. Most building operators merely set the system to a static set point and only update if there are temperature complaints in the difference zones. This graph shows how the building is currently operating. It shows that despite the outside temperature rising to over 34degrees the indoor temperature remains at a fixed 23 degrees. The HVAC system started at 4:25am in 2016 to cool the office floors down to the temperature set point. This profile is from the warmest day that was recorded in October 2016 and will be used as the comparison for the new SMART control algorithm. What can be noted is that the HVAC system has managed to control the zone temperature to the required set point which shows that the system is very precise and the new SMART control algorithm will be able to move the set point and demand limit the main HVAC plant which will enable the building to benefit from the cost saving benefit.



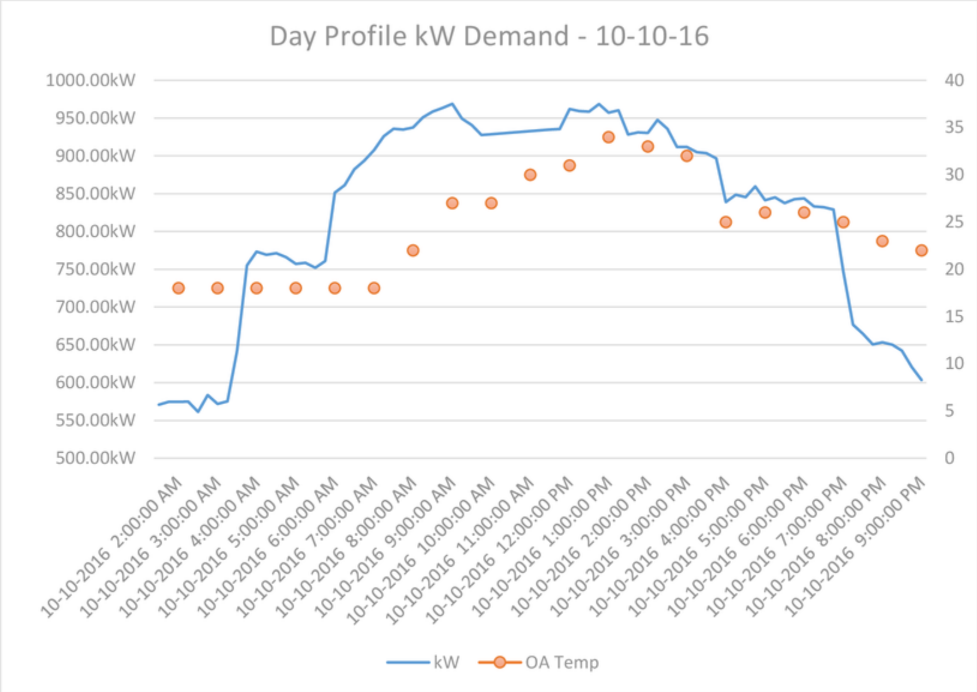
Graph 17 Top 10 Days for Maximum kW for October 2016

With a key component of the new SMART control algorithm being the management of the maximum kW usage for the period, Graph 17 shows the Maximum kW usage for October 2016 and gives an insight into how the building performed over the entire month. This information forms part of the required result as it was found that the Network Charges – Capacity is a considerable cost to the building's monthly power bill (refer Section 3.1.1 above for greater detail). In reviewing the daily profile from the energy interval data, despite the ambient temperature (on the 10/10/16) being at least 6degrees warmer than any other day throughout the month, the building HVAC system started at the same time, 5:45am. Based on the pre-work that has been undertaken, if the HVAC system was aware of the higher OA temperature it could have been able to turn the system on earlier thereby ensuring that the building could have gradually brought the indoor temperature down prior to the peak of the day. This would result in a lower maximum kW than the high spike that was evident for that day.



Graph 18 Daily Energy Usage October 2016 (Rate Charges Breakdown)

The second part of this thesis' expected outcomes was to reduce the total energy being consumed to run the building. Graph 18 provides an overview of the daily usage and what retail charge rate it therefore falls into. It can be noted that the off-peak power usage for the 10th October (the warmest OA temperature day) was 5,321 kWh as compared to the average of 5,155kWh - a 166kWh difference only (or $18.25 from a cost perspective). However, due to the building not preparing efficiently for the high peak load (i.e. by commencing the HVAC system earlier) the shoulder showed a difference of 384kWh resulting in a $76.46 increased cost for that one day compared to the average. If the building had started and cooled the space earlier, the overall cost could have been reduced whilst maintaining the tenant comfort within the expected limits.



Graph 19 Day Profile kW Demand - 10-10-16

Graph 19 above gives the kW versus the Outside Air Temperature for the warmest day in October 2016 (Time and Date AS, 2017). It can be noted the steep rise in outdoor temperature which in turn caused a major strain on the HVAC system. What can be seen here is that the morning temperature was considerably cooler and if the HVAC system commenced during the morning to pre-cool the building, the spike would have reduced due to the HVAC system not requiring to use excessive electrical demand to provide mechanical cooling to the building. This would have been achieved by a floating set point to give the building a progressive start-up.

4.1.2 Key Findings

The deployment and testing of the new SMART control algorithm commenced on the 3rd October 2017. The new algorithm was left operational for 2 weeks which enabled a practical period to determine whether the new SMART control algorithm was proven to be of benefit to the building and provide a positive cost savings to the building for the trial period.

The next two tables below summarise the key findings and results that were found after running the new SMART control algorithm.

Description	**Pre-SMART Control Algorithm (10/10/16)**	**Post-SMART Control Algorithm (Equivalent Day 9/10/17)**	**Difference**
Outside Air Temperature (Max/Min)	34°C / 18°C	33°C / 17°C	Only a 3% difference for the daily temperature
Zone Temperature Set point	23.0°C	**21.6°C – 24.0°C**	A wider spread tracking the OA Temperature
Maximum kW	968.45 kW	937.22 kW	**31.23 kW (3%) Reduction**
Daily kW Usage - Peak	4,582 kWh	3,764 kWh	**818 kWh (18%) Reduction**
Daily kW Usage - Shoulder	8,017 kWh	8,033 kWh	**16 kWh (0.2%) Increase**
Daily kW Usage - Off-Peak	5,321 kWh	4,548 kWh	**773 kWh (15%) Reduction**

Daily Running Cost	$ 3,278.60	$ 3,001.01	**$ 277.59 (8.5%) Net Saving**

Table 8 Warmest day that was recorded during the testing period

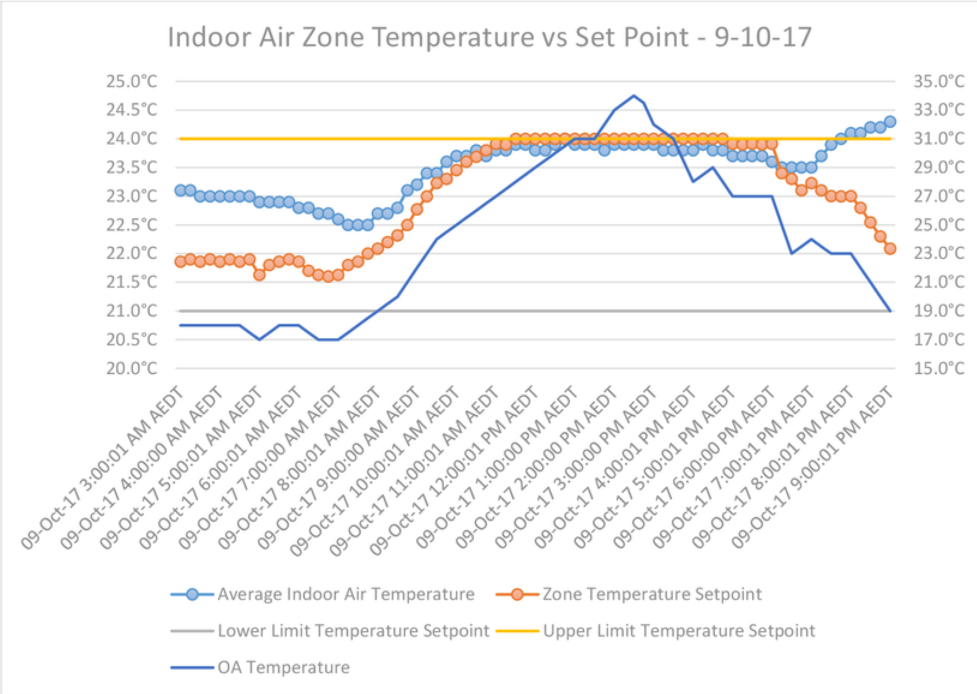
Table 8 gives a detailed review of the results that were recorded on the hottest day during the 2 week trial period. The SMART control algorithm delivered a $277.59 saving across the entire day. This dollar saving is based only on the combine charges as noted in Table 7. This saving is equivalent to 8.5% of the pre-SMART control algorithm total spend for that chosen day. It can be seen that the Peak usage had a reduction of 18% and the Off-Peak usage had a reduction of 15%. This shows that the SMART control algorithm that was deployed was effective and has resulted in considerable energy and cost savings for the building.

Description	**Pre-SMART Control Algorithm**	**Post-SMART Control Algorithm**	**Difference**
Outside Air Temperature (Max/Min)	34 °C (10th October 2016 12:30pm) / 9 °C (14th October 2016 3:30am)	33 °C (9th October 2017 2:00pm) / 16 °C (14th October 2017 12:30am)	2017 had a higher "lower" temperature (7%) than what was recorded in 2016
Zone Temperature Set point	23.0°C	**21.1°C – 24.0°C**	A wider spread tracking the OA Temperature each day
Maximum kW	968.45 kW	937.22 kW	**31.23 kW (3%) Reduction**

kW Usage - Peak	39,134 kWh	32,825 kWh	**6,309 kWh (16%) Reduction**
kW Usage - Shoulder	68,704 kWh	65,902 kWh	**2,802 kWh (4%) Reduction**
kW Usage - Off-Peak	46,401 kWh	40,533 kWh	**5,868 kWh (13%) Reduction**
Total Running Cost	$ 28,151.66	$ 25,438.09	**$ 2,713.56 (10%) Saving**

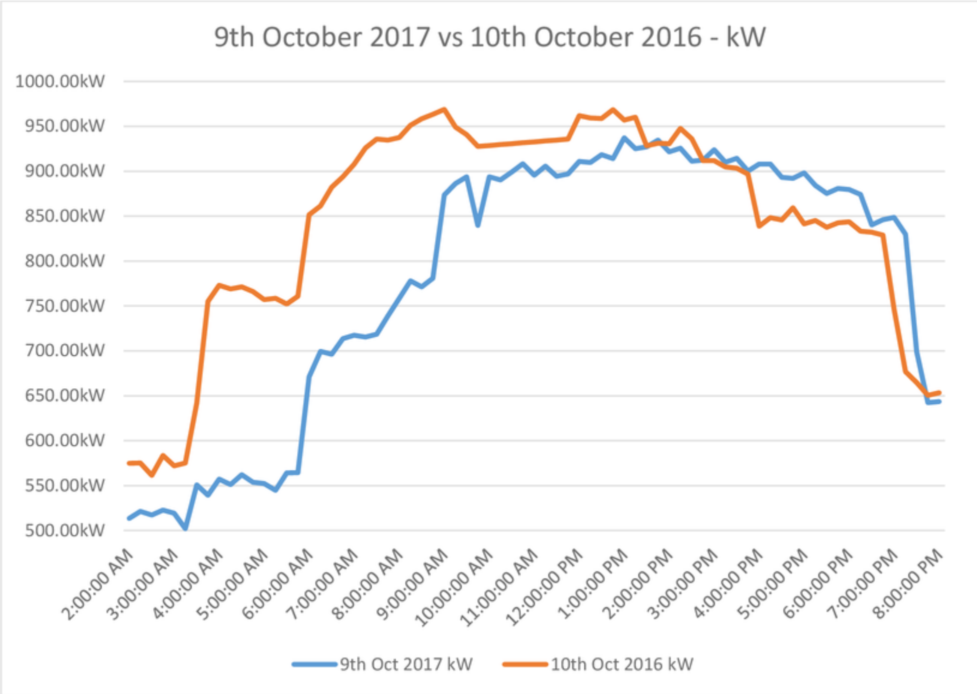
Table 9 Trial period rolled up data (3rd October till 13th October 2017 - Without Weekends)

The above table highlights the savings that were received based on running the SMART control algorithm for 9 business days. It has delivered a saving of $2,713.56 which is 9.6% of the total pre-SMART control algorithm spend for that time period. This result has shown that the chosen research area and the newly design SMART control algorithm has been of benefit to the building and the environment. It can be seen that Peak usage had a reduction of 16% and Off-Peak usage experienced a reduction of over 13%. These material saving percentages demonstrate that by tweaking the zone temperature set point, managing the demand of the main HVAC plant and managing the start enable for the HVAC system results in a meaningful saving for the building and the environment.



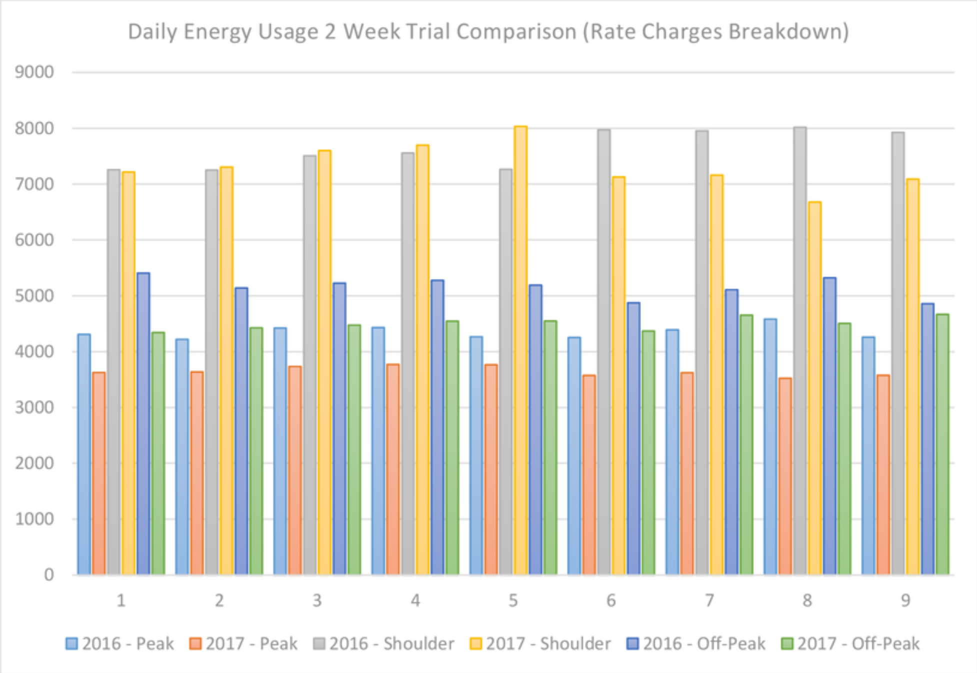
Graph 20 Indoor Air Zone Temperature vs Set Point – 9/10/17

Graph 20 shows the daily profile for the warmest day recorded during the trial period. It can be seen that the dynamic set point that is tracking the outside air temperature conditions has resulted in the HVAC system being able to slowly react to the load rather than be driven to its maximum capacity upon the outside air temperature increasing. The moving set point has given the building a rolling target which has achieved the outcome of not only reduction in the power usage but has also ensured that the building immediately responds to the climate and conditions. The onsite building engineer confirmed that with the above set point changing, the building didn't experience any number of additional complaints throughout the trial period. It is noted and acknowledged the trial would need to be extended to give a suitable indication of the results of the SMART control algorithm for tenant comfort. The next Graph 21 shows what the dynamic zone temperature set point has done to the overall energy usage for the building.



Graph 21 Daily Profile - 2016 vs 2017 kW

Graph 21 represents the day profile for the kW usage for the highest temperature recorded day during the testing period. The graph shows the extent of the power saving and how the SMART control algorithm has not only delayed the start of the HVAC system but has also enabled a slower ramp up of the equipment prior up to achieving the capacity that is required to meet the set point. It can be seen by the rolling zone temperature set point the plant has been able to maintain a much lower power consumption usage during the first 4 hours of the day. What can be observed is that the higher afternoon temperatures and heat have resulted in the power usage similar to that of 2016 but it is noted that the peak usage is lower than 2016. Based on the above graph for the single day it has shown that the SMART control algorithm was a success and has benefited the building.



Graph 22 Daily Energy Usage 2 Week Trial Comparison (Rate Charges Breakdown)

The data above in graph 22 presents the raw results from the testing period versus the baseline data from 2016. It can been seen that due to the SMART control algorithm being dynamic and changing based on the weather forecasted data the savings were varied each day, without a consistent percentage saving recorded. This goes to show that the different OA temperature days resulted in greater savings for the different rate charge time periods. Overall it should be noted that the peak and off-peak times delivered the greatest savings for the building which helped achieve the 9.6% overall saving.

4.2 Conclusion

The data captured throughout the thesis project clearly shows the success of the new SMART control algorithm. Material operating cost savings have been achieved over the two week trial period with a 9.6% reduction in the total cost to the building. The various components of the forecasted temperature data, the indoor air temperature limits, the energy data and the retail charge rates have enabled the success of the newly designed SMART control algorithm.

CHAPTER 5:

5.1 Discussion

It has been confirmed that the BMCS has a major impact on the way the commercial building operates and controls the HVAC System. It has been shown that the HVAC uses excessive power if it isn't managed efficiently which results in higher costs and also increased carbon emission to our environment. Through the literature review it was found that there has been considerable investigations into the way buildings operate and various techniques and strategies that can be used to help reduce the power usage for the building. It was noted that a number of these were based on theoretical data with limited industry connection undertaken.

What was discovered throughout the thesis was that the significant increases in electrical prices have pushed industry towards focused energy conservation standards and measures to ensure each business is focusing their efforts on reducing both their carbon footprint and their operating costs. Such initiatives include the benchmarking of buildings through the NABERs program, reduced energy rates should peak power be maintained or limited during high usage times and government body pay back for owners who invest in new technologies throughout their buildings. This thesis has catered for considerable time to be invested into industry and testing of a new SMART algorithm that ties together the electrical and HVAC systems concurrently.

There are different ways to control the HVAC system for a building and it was found through the research and industry survey that the most common way was that the BMCS was set to fixed temperature set points with the building required to control to these values regardless of the occupancy, outdoor weather temperature or cost of electricity. This thesis project was aimed at determining a way of combining the required tenant comfort conditions with the electrical and weather forecast data to provide an optimal HVAC system control without any interaction from the building operations team. A key component was to have this algorithm to be self-learning as it continued to operate throughout the building throughout the various weather seasons.

The first steps to ensuring the building would benefit from this new control algorithm was to setup manual simulations that would enable the results to be predicted from real building data. This data included actual temperature data, electrical power usage both kilo watts and kilo watt hours, average indoor temperature data and also a basic understanding on the HVAC system design. From here the data would be capable of being manipulated and collated so the SMART control algorithm could be manually applied to the historical data. It was at this step that material savings were noticed and the formula would benefit the commercial building from both an energy consumption and operating cost perspective. At this step, an industry survey was also distributed to leading industry professionals to ensure the proposed method for a new energy savings algorithm could be confirmed and verified as meeting the needs for the building operators.

The results from the testing and deployment of the new SMART control algorithm rolled up data were used to give a clear picture of the benefits of the newly designed and deployed algorithm on the site BMCS system. It was found that the zone temperature set point changes based on the temperature forecast data resulted in the highest energy saving and reduction in electrical power demand. This was due to the reduced capacity required from the HVAC plant. This has aided savings of \$2,713.56 (9.6%) of the total power utilised pre-SMART control algorithm during the comparable tested period. It can be seen that by rolling the zone temperature based on the temperature forecasted data has resulted in the majority of the savings identified during the testing. This is evidenced by the reduction in peak power usage during the morning. Each testing day the system would track between 7-10% lower than what was consumed in 2016 which results in a cost saving of \$250-\$300 per day during the spring season. This result has been achieved by the zone temperature being dynamic and responding to the weather forecast data and tracking between 21°C and 24°C dynamically each day.

CHAPTER 6:

6.1 Conclusions

The key objective for the thesis was to develop a new self-learning SMART control algorithm that could be deployed throughout a commercial building to reduce the overall energy usage and the maximum peak demand which would result in lowering the cost of running the building. The initial step to achieving this outcome was to review the current market trends and look into the HVAC system design for commercial buildings. This would provide a clear vision of what was required to be deployed into the BMCS to give control to the SMART control algorithm.

The first part of the thesis was spent reading research and industry articles in order to gain a deeper understanding of the field. It was around unpacking what makes up a HVAC system and what are some of the key market trends in the BMCS energy saving space. Within this, an industry survey was undertaken to obtain feedback from key industry professionals as to where their time was being spent and what focus areas the market were placing on them. These areas included HVAC, Energy, BMCS Operator Usage and tenant complaints, and were then employed to determine the principal focus areas for the new SMART control algorithm so as to maximise the effectiveness of the system design.

Once the key points were discovered for HVAC operation and design, the focus moved to determining the benefits from the new SMART control algorithm. This was achieved by using historical energy data and comparing it to the indoor operational data to observe how the new algorithm would control the plant once deployed. Oracle provided the usage of their head office in North Ryde for the trial of the SMART algorithm to test the benefits that would be seen once it was deployed. The trial clearly supported the pre-engineering that was undertaken which demonstrated that the new SMART Control Algorithm would minimise the total energy cost with a reduced peak electrical load for the building.

Oracle is the owner of the building in North Ryde and their building engineer has been very interested in the study undertaken and especially the end outcomes of the new SMART control algorithm. With the significant increase in energy pricing over the past 12 months the focus was to explore ways to reduce the energy usage for the building which in turn has a direct impact on the cost of operating the building. With the new SMART algorithm providing a direct benefit to the building, it has opened the building engineer up to looking at new ways to continually review, reduce and manage the energy usage for the building.

With electricity prices continuing to rise, the thinking within industry has now become focused on looking at ways to reduce the usage of energy within commercial buildings. BMCS have revolutionised the way HVAC systems operate however it is clear there remains further scope for research to be undertaken to determine new and enhanced ways to engineer the building to further lower the electrical demand whilst minimising the peak usage and therefore costs. Ongoing technology advancement is enabling the way forward, with the rate of future enhancements and efficiencies being expected to continue to accelerate.

6.2 Future Works

The chosen industry project that was undertaken throughout this thesis sets a baseline for future works to promote greater energy savings and cost initiatives within the commercial building space. The newly developed SMART Control Algorithm was successfully implemented and tested thoroughly in a chosen building in North Ryde. It has proven successful with great energy saving results which saved operating costs for the building. Future works could be to provide this algorithm as a turn-key energy solution to deploy it across a larger suite of buildings to realise the full potential of the saving. As this roll out continues, a better insight into different building results would be ascertained to determine if different HVAC system setups respond differently to the new control function. The basic concepts that were developed and researched are able to be scaled and adapted easily into any building that has a BMCS.

A further area for future works would be to partner with an energy services provider to develop a method that would enable the building users to connect the SMART control algorithm and to then have this BMCS algorithm connected to the energy provider's SMART grid systems. This would allow the energy providers to predict more accurately the amount of energy that is required to operate the respective building which means they could then more efficiently pre-plan the power stations/supply accordingly. With this option, building operators would be able to seek or negotiate different energy rates due to the smarter operation for the entire energy grid.

CHAPTER 7:

7.1 References

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CHAPTER 8:

Appendix A: Industry Survey Questions

As part of the thesis it was evident that seeking industry feedback was key to understanding where the focus areas are for a commercial building.

Below details the questions that were asked to draw conclusions around my chosen study area.

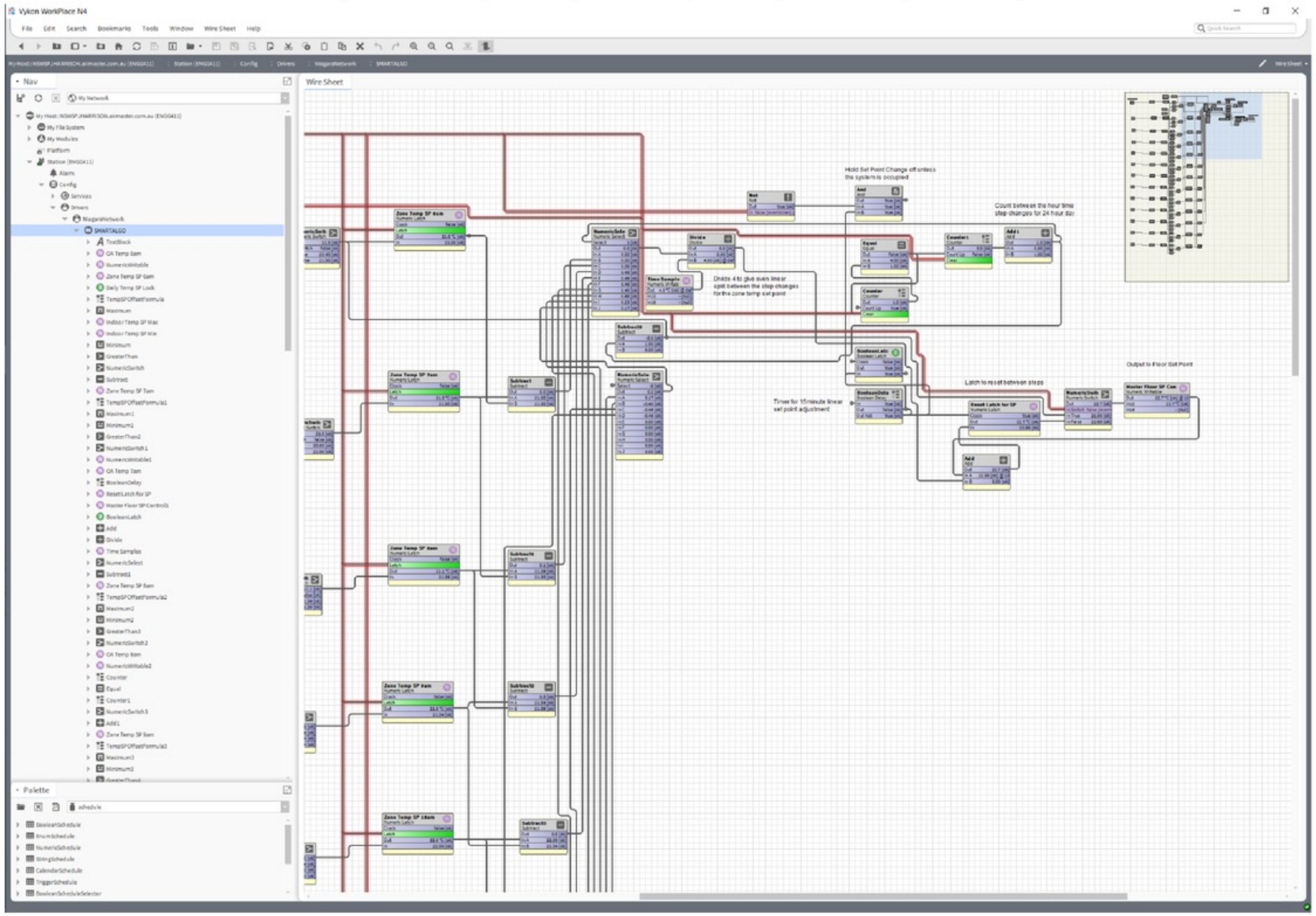
Questions	Multiple Choice Answers
Out of the below choices which one is your greatest focus area currently?	a. Tenant Comfort b. Power Usage (NABERS Rating)
What is your greatest focus area around the HVAC plant when managing a building?	a. HVAC Plant Run Time b. Start-up Time for the HVAC Plant c. Floor Temperature Set Points
What is the number one complaint from the tenants within the building?	a. Draft Complaint b. Temperature too Hot c. Temperature too Cold d. Too Stuffy

	e. Has the HVAC Plant Started this morning?
How many hours during a typical week would you spend watching the HVAC System and making manual adjustments on the BMCS for your building/portfolio?	a. 1-2 Hours b. 2-4 Hours c. 4-6 Hours d. 6-8 Hours e. Other
How many hours during a typical week would you spend trying to reduce the energy usage for your building/portfolio?	a. 1-2 Hours b. 2-4 Hours c. 4-6 Hours d. 6-8 Hours e. Other
Are you working on any electrical power management initiatives with your energy provider? Ie Peak Load Management, Time of use Charges	a. Yes b. No
Do you look at the weather forecast data and try and manually set the BMCS to overcome changing ambient daily conditions?	a. Yes b. No

When planning for CAPEX work what is your primary focus?	a. Energy Reduction Investments b. Life Cycle Replacement c. General Building Up Keep

Table 10 Survey questions delivered to industry professionals

Appendix B: SMART Control Algorithm Logic Programming - Niagara 4 Programming Tool



Appendix C: Consultation Meetings Attendance Form

Consultation Meetings Attendance Form

Week	Date	Comments (if applicable)	Student's Signature	Supervisor's Signature
1	4/8/17	Progress Meeting.		
2	10/8/17	Progress Meeting		
3	18/8/17	Progress Meeting		
4		——		GT sick
5	1/9/17	Update → Matlab Optimisation + Model.		
6	12/9/17	as above		
7	14/9/17	✓		
8	5/10/17	✓		
9	13/10/17	✓		
10	20/10/17	✓		
11	25/10/17	✓		

Appendix D: Thesis Project Plan

	Task Name	% Complete	Duration	Start	Finish	Predecessors	Resource Names
1	**Thesis Project Plan**	**95%**	**179 days**	**Tue 21-03-17**	**Fri 24-11-17**		
2	**ENGG411 Works**	**100%**	**54 days**	**Tue 21-03-17**	**Fri 02-06-17**		
3	Project Application	100%	8 days	Tue 21-03-17	Thu 30-03-17		
4	Project Scope Document	100%	10 days	Fri 31-03-17	Thu 13-04-17	3	
5	Draft Project Plan Document	100%	30 days	Fri 14-04-17	Thu 25-05-17	4	
6	Project Plan Document	100%	6 days	Fri 26-05-17	Fri 02-06-17	5	
7	**MILESTONE 1 - BACKGROUND RESEARCH**	**100%**	**21 days**	**Fri 28-07-17**	**Fri 25-08-17**		
8	Undertake Research on Thesis Topic to discover more insight into current control methods and energy demand systems	100%	5 days	Fri 28-07-17	Thu 03-08-17		
9	Analysis Different ways building HVAC Operates and how current models are developed	100%	5 days	Fri 04-08-17	Thu 10-08-17	8	
10	Compare Energy Tarriff Models - Peak vs Off-Peak	100%	2 days	Fri 11-08-17	Mon 14-08-17	9	
11	Investigate different BMS control algorithms and how they have evolved over time	100%	5 days	Tue 15-08-17	Mon 21-08-17	10	
12	Review actual data on cooling and heating rates of change based on HVAC Plant Start-up and Control Models	100%	2 days	Tue 22-08-17	Wed 23-08-17	11	
13	Investigate and start to develop an algorithm that comapres how different HVAC start-up affects the peak electrical load if not effectively managed	100%	2 days	Thu 24-08-17	Fri 25-08-17	12	
14	**Progress Report Due**	100%	1 day	Mon 04-09-17	Mon 04-09-17		
15	**MILESTONE 2 - MANUAL MODEL**	**100%**	**9 days**	**Mon 28-08-17**	**Thu 07-09-17**		
16	Collate the industry data to build a base regression model on a typical building	100%	2 days	Mon 28-08-17	Tue 29-08-17	7	
17	Review the varying factors that affect the peak electrical usage and use the model to predict building patterns	100%	2 days	Wed 30-08-17	Thu 31-08-17	16	
18	Undertake an industry survey on building simulation model and ways industry currently manages this	100%	2 days	Fri 01-09-17	Mon 04-09-17	17	
19	Input data into the SkySpark software to replicate a useable simulation model for performance checking	100%	3 days	Tue 05-09-17	Thu 07-09-17	18	
20	**MILESTONE 3 - INPUTS AND DATA FEED**	**100%**	**9 days**	**Fri 08-09-17**	**Wed 20-09-17**		
21	Using data avaliable for the building determine current frequencies and also requirements for the control algorithm	100%	3 days	Fri 08-09-17	Tue 12-09-17	15	
22	Weather feed information to be tracked and read in a manner to give realtime updates for next 24 hour period for model tracking and updating	100%	3 days	Wed 13-09-17	Fri 15-09-17	21	
23	Review the changing outside weather conditions compared to forecasted data to determine how often the data should be reset	100%	3 days	Mon 18-09-17	Wed 20-09-17	22	
24	**MILESTONE 4 - SMART CONTROL ALGORITHM**	**100%**	**8 days**	**Thu 21-09-17**	**Mon 02-10-17**		
25	Develop an alogrithm for a realtime, self learning algorithm based on the data inputted	100%	3 days	Thu 21-09-17	Mon 25-09-17	20	
26	Confirm what effect the outside weather has on the electrical usage of a building and how often we need to adapt the building changes	100%	2 days	Tue 26-09-17	Wed 27-09-17	25	
27	Build reporting functionality to record all building data for verification and performance tracking	100%	1 day	Thu 28-09-17	Thu 28-09-17	26	
28	Code the new alogrithm for the Tridium Niagara Software - JAVA and Logic Based Program	100%	5 days	Tue 26-09-17	Mon 02-10-17	25	
29	**MILESTONE 5 - TEST BUILDING SHOWCASE**	**100%**	**9 days**	**Tue 03-10-17**	**Fri 13-10-17**		
30	Implement the new control algorithm into the chosen Commercial Building	100%	1 day	Tue 03-10-17	Tue 03-10-17	24	
31	Monitor and watch the building respond to the new SMART Control Algorithm through SkySpark	100%	9 days	Tue 03-10-17	Fri 13-10-17	24	
32	Modify the control alogrithm to ensure it is running the HVAC equipment effectively and managing the electrical demand based on energy tarrifs	100%	9 days	Tue 03-10-17	Fri 13-10-17	24	
33	**MILESTONE 6 - THESIS SUBMISSION**	**70%**	**30 days**	**Mon 16-10-17**	**Fri 24-11-17**		
34	Update the thesis based on the prototype results versus the simulation model based on the data captured	100%	5 days	Mon 16-10-17	Fri 20-10-17	29	
35	Finalise the Thesis document for submission, critique results and findings	100%	10 days	Mon 23-10-17	Fri 03-11-17	34	
36	**Thesis Report Due**	100%	1 day	Mon 06-11-17	Mon 06-11-17		
37	LogBook Due for Marking	0%	2 days	Mon 13-11-17	Tue 14-11-17	36FS+4 days	
38	Seminar Abstract	0%	2 days	Mon 13-11-17	Tue 14-11-17	36FS+4 days	
39	Seminar Poster	0%	2 days	Mon 13-11-17	Tue 14-11-17	36FS+4 days	
40	Presentation and Demonstration	0%	1 day	Fri 24-11-17	Fri 24-11-17