DEVELOPMENT OF ENERGY CENTRE COOLING PLANT

A dissertation submitted to the
Department of Electrical Engineering, University of Moratuwa
in partial fulfilment of the requirements for the
Degree of Master of Science

by
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Abstract

This work study reviews the conceptual development of optimization strategies of an Energy Centre based on operational task of daily thermal load contours and interaction of weather profiles of the environment in the selected area of the project. The weather profile analysis was primarily done by the interactive plotting of temperature/humidity sensor data against historical data. Gray Model was also employed in order to predict much accurate data patterns in the fuzzy areas of weather prediction process. However, by introduction of genetic algorithm on the historical samples would able to predict the anticipated weather profile more accurately and thereby the thermal load required for the future trend on the following day. The current thermal energy storage (TES) technologies and their applications using the traditionally available methods are the common practice of any ice storage design in the industry; however in this analysis dedicated low freezing media (Glycol) is used to chill the common chilled media (water) and also the chilled media is used as storage medium with phase change. Latent heat storage on the other hand, is a young and developing technology which has found considerable interest in recent times due to its operational advantages of smaller temperature swing, smaller size and lower weight per unit of storage capacity. Design methodology and its prime results of simulation show the effectiveness of the proposed solution for an Energy Centre for efficient operation.

DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

Mahinda Gallage

I endorse the declaration by the candidate.

UOM Verified Signature

Professor Lanka Udawatta

Acknowledgement

Thanks are due first to my supervisor, Professor Lanka Udawatta for his great insights, perspectives, guidance and sense of humor. I have been battling with my health for at least a year prior to the final date of submission of this assignment. I strongly believe that if not for his great support on literature collection and putting them in the right track and continuous supervision of my work, I would not have made this possible and my heartfelt thanks goes to his sincere thoughts towards me and of understanding my actual situation.

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It is not fair if I do not write few words about Mrs. Himali Wanigasekara, who took her own interest of proof reading and editing the language at the last minute, before this report went for printing. I should thanks to her for completing it timely manner without any hesitation.

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List of Abbreviations and Symbols

Acronym	**Definition**
BMS	Building Management System
TCP/IP	Transmission Control Protocol/Internet Protocol
TES	Thermal Energy Storage
CWP, ChW	The Chilled Water Plant ,Chilled water
BACnet /IP	Building Automation Control Network protocol over the Internet protocole
ITES	Ice Thermal Energy Storage
COP	Co-efficient of Performance
CPCS	Chilled plant Control System
GCPCS	Glycol Chiller plant Control System
HXCS	Heat Exchanger Control System
VFD, VSD	Variable Frequency Drive , Variable Speed Drive
Ms/TP	Master – Slave/ Token – Passing
ANN	Artificial Neural Network
θ	Ambient temperature in °C (Air in temperature of cond.)
χ	Coefficient of Performance: 1/Efficiency
τ	Glycol supply temperature °C (Evaporator to the system)
φ	Chilled water temperature of the system °C
$\alpha_i, \omega_i, \mu_i$	Polynomial functional constants (Curve)
ψ	Chiller part load ration (PLR)
$f_C(\chi, \theta, \tau)$	Thermal(cooling) capacity by the Chiller operation with χ COP, θ ambient and the τ refrigerant temperature
$f_I(\chi, \theta, \tau)$	Thermal(cooling) capacity by the Ice storage with χ efficiency, θ ambient and the τ refrigerant temperature
$B(\theta, \varphi)$	Thermal(cooling) capacity of the Base load chilled water
$f_T(\chi, \theta, \tau, \varphi)$	Objective function of Total Cooling of the Energy Centre
Open Protocol	Standard Convention for Communications available to all to develop compliant devices that can talk to each other consistently and coherently

Contents

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Chapter 1

Introduction

1.1 Background of the project

Energy Conservation, Green Building, Sustainability, Adaptability and Intelligent Controls: - these are the paradigms which have to be addressed and prioritize among the many tasks in design and development of any kind of human installation in the present world. The living sphere of the globe is very specific to the human being where they are always in command of control. The conceptual design of the proposed project has also been influenced by the aforementioned paradigm.

The work that has been carried out initially within the role of control aspects in this project investigates viability of proposed contemporary cooling control concept on a massive bio-sphere. However, after the introduction of proposed intelligent control architecture, it is expected to be functioned with improved controllability and adaptability. Moreover, after completion of relevant commissioning procedures, the predicted behavior of the environmental control dynamics of the bio-sphere should converge progressively to their relevant set points on realization of self autonomous behavior.

The project which has been proposed here is a massive Gardening complex (which is known as 'Garden' hereafter in this report) which will be completed with different type of living plants, birds and butterflies etc. The environment is artificially created within the space of extreme out door conditions. There will be massive building complex (Dome) and its indoor conditions should be controlled to the living conditions of the bio sphere. In some seasons their living conditions are largely deviated from the out door environmental conditions. The changes are monitored by the instantaneous variations of environmental dynamics modeled and integrated in to the building control system. The proposed proactive control system should control the indoor environmental variables like temperature and humidity to relevant set points without exceeding their threshold limits thereby not degrading its bio sphere. The design rule of control structure on this nature of installation is fundamentally considered to be highest life safe priority level in the building automation industry. The achievement of the latter task with minimum resource (optimization) deployment will be the next challenge for the engineers, who were in the designing team.

The multiple teams were assigned (see the figure 1.1) to carry out the major design and development work of this project and each team or personnel was given a specific task and were requested to share their results with other teams in the identification process, thereby perfecting the integrated control model.

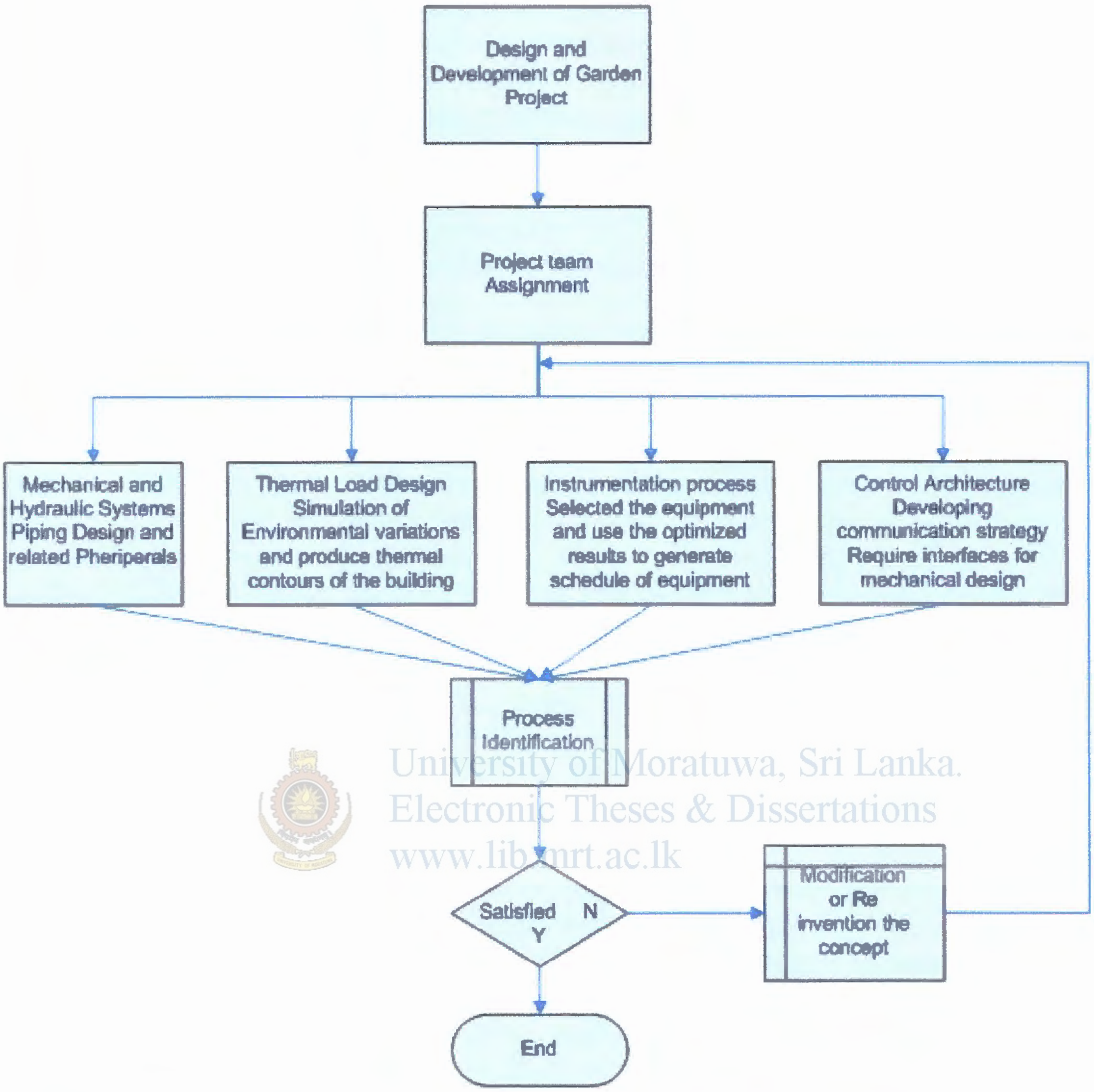


Figure 1.1 Flow Chart for Project teams Assignment and their functions

The mechanical hydraulic team, who carried out the piping design, the thermal load design team, who completed simulation of environmental condition and produced the thermal load contours of the installation, the instrumentation and process team, who selected the equipment (chillers, ice storages, pumps, heat exchangers etc.) by matching its thermal contours with the performance data of equipment and finally designing the specific control architecture and methodologies team, who proposed intelligent control system in order to integrate and control the proposed mechanical equipment. All the above mentioned teams will lastly integrate their individual sub control modules (embedded control strategies within the equipment) and produce an integrated control structure for the system operation of the Energy Center. The final control matrix [Chapter 6] will be produced by careful investigation of interactive process of Mode operation explained in the Chapter 3.

The mapping results of thermal load contour [Figure 1.2] of the selected environmental control project in 24 hours cycle during the summer peak day indicates that peak hour load requirement and it could only be achieved by operating as many number of chillers in the peak demand period. The indoor condition of the Garden will be maintained by the delivery of massive volume flow of chilled air and this will be done by the Air Handling Units and chillers located in the Energy Center of the project. With the exposure of extreme ambient condition the chillers will not be efficient (low COP) and it is the definite fact that many numbers of chillers should be employed to satisfy the cooling load demand of the Garden.

The feasibility study of the project has shown that the capital investment of the mechanical equipment was unimaginably high due to the nature of environmental factors. The cooling load required to match peak load hours is recognized as the most critical process throughout the total load cycle. The simulation results are also supported with the above mentioned conclusion by predicting the behavior of the chiller system. Many numbers of chillers are in operation for only a few hours of the 24 hour cycle, whereas they are in almost idle condition rest of the period of the whole cycle. However, the existence of these idle chillers in the chiller system is an essential task to meet the peak load during the peak hours. The simulation results also proved that these chillers work few hours during the whole operational cycle. In this scenario, the mechanical design team realized that optimization of mechanical equipment selection will be one of the critical factors to be addressed for the viability assessment of this nature of a project [1].

Then the adoption of thermal energy storage [TES] concept came into picture suggesting peak load demand to be replaced by TES, which also furnish an added advantage to produce off line cooling during low ambient (night) period of the day utilizing efficient operation of chillers. Operation of chillers during night and producing offline cooling (ice) closely match with our energy saving application which also implies to minimize their low efficiency operation during the day (high ambient inefficient chillers) [see the manufacture performance data table 2.1 and table 2.2]. Implementation of TES for the mechanical design, was a very good decision, however it is also revealed that the optimum number (Optimization [minimization]) of equipment in any single circuit expected to operate depending on instant load variation equally plays a very important role in the process of load curve tracking [2]. (The best combination to operate among the TES, chillers, Heat Exchangers and pumps etc. to achieve minimum energy input by aiming the predicted output).

The radical approach of offsetting the peak load with pre-stored cooling (ice storage) energy produced by the chillers during the time slots (low ambient) where the efficiency of the chillers are optimal (Max COP) is considered to be a very important analogy in ice manufacturing operation of the TES. The proper estimation or the prediction of peak thermal capacity required for the next day operation will also help to schedule mechanical sources requirement (number of efficient chillers and the ice banks) and this as a concept will finally optimize(minimize) total day's energy requirement of the plant. Therefore load prediction methodology is required in order to justify allocation of resources required for the next day's operation of the energy centre cooling plant [3], [4] and section 5.4.

The anticipated weather pattern from a computer model based on genetic algorithm (GA) [5]-[10] will provide the inputs to the process of computation of predicted refrigeration (cooling) load requirement for the next 24 hour operation. This will be used to compute the capacity of number of ice banks required and the chillers to be operated within the algorithmic procedure of the control network thereby triggering the multiple sub control loops to operate (i.e. ice manufacturing, melting, during the night) (Figure 1.1).

Inaccurate prediction will result the deficit or surplus ice production in the ice banks. If sufficient ice could not be made due to diversified operation of scheduled chillers for ice build operation, (chillers may be busy meeting daily load on priority basis of its day's operation), and the next day peak load will not be met due to inadequate support from the ice storage. Then the system surveillance criteria will enforce to operate additional non-scheduled chillers in order to maintain the system sustainability of the Garden. The additional no-scheduled chiller operation will not be benefitted our ultimate goal of energy minimization since the chillers will operate with low COP during the high ambient condition (inefficient time slots) of the day.

This will loose the control of target minimization of total energy input to the system. Similarly the surplus of ice in the ice banks will also loose its target minimization of total energy due to the fact that wastage of energy on over production of ice.

For the last few decades, especially when energy crises hit its hard on the world economy, many design engineers as well as the experienced energy auditors looked forward for optimization of energy function of any system they designed and proposed Energy Optimization since it is a mandatory requirement of sustainability concept. Finally, this application will also make an attempt to optimize (minimize) the system input energy depending on instant resource allocation, equipment efficiency and the predicted load requirement of the next day. It was studied that non liner behavior of daily weather profile (Figure 1.2) has a major impact on the proposed control model. However the design notes proposed here will move forward a further step deeming the system's sustainability and adaptability to achieve optimum degree of performance of the system. This could be highlighted as the prime objective of the author in this report.

It is also understood that, the successful design of the specific Garden project is mainly focused on the following criteria based on many analytical concepts put forward by the design team:

1. Optimizing of mechanical equipment requirement in the stage of resource planning
2. Adoption of continuous weather profile estimation methodology within the control software in order to estimate refrigerant loads
3. Introduction of instance resource allocation technique (combination of Chillers and the Ice banks) within the control strategy in order to match the estimated refrigerant loads.

4. Optimization (minimization) of Total energy input to the ITES system.

Optimization was done in the different levels throughout its entire life cycle [11] of the project implementing different control strategies (Tactical, Autonomous, Predictive and Strategic) in order to achieve minimization of energy in the total operation. The ultimate Goal of synthesis of control matrix has been achieved by generalizing its mode operation within the operational schedules of the 24/7 /365 cycles. This will be explained in the last part of chapter 2 of this report.

1.2 Objectives of the Research

General

It is standard practice that the utilization of TES (Thermal Energy Storage) to shift the cost effective peak time load with the burning ice, which was build in the night before, where the Air cooled Glycol Chillers are operating with high COP factor due to low ambient temperature as well as the utilization of low demand charges of electricity. The proposed scheme of cooling system of the Energy Center was based initially on the full shift of the load by utilization of night build ice store. This was recognized as an expensive cooling process since the capital investment for the number of additional chillers that has to be employed to manufacture ice was considerably high and there were no significant benefit compared to the initial capital investment. Optimization process of initial equipment selection done by the Instrumentation and process design team had come up with the following design parameters, as per their outputs, which has been used to achieve the mechanical design. [Appendix A]

There were many sub systems that have been identified as major influence factors on the resultant output of the total integral system. Therefore optimization result of these sub system will fundamentally define very accurate picture of their functional behavior and this will help to design intelligent control system.

When the stage of initial resource planning, each ITES circuit will be included with the followings:

Glycol Chillers in every ITES circuit =3; Chilled Water chillers in every ITES circuit=1; Number of ICE banks =60

1.2.1 The Objectives of Energy Optimized Control

The design team was requested to reinvestigate concepts as whole design process of mechanical electrical and instrumentation and come up with a sustainable and economically sound solution for optimum energy consumption of the plant before implementation of the design work of the project (see the figure 1.2). In this scenario, my role was to propose control architecture and relevant algorithm as per the hydraulic system [Appendixes A.] proposed by the mechanical engineering team.

1.2.1.1 Objective no.1

Selection of optimum numbers of equipment in every ITES circuit such a manner that (Optimization of Energy) Minimum energy input to the system in every specific operation as explained in Mode operations of Chapter 3.

1.2.1.2 Objective no.2

Proposing procedures to control the Mode of operations explained, [chapter 3] in line with above Objective no.1 and alternative procedures based on adaptability and sustainability of the system. The control procedures are explained in the Chapter 3 in great details and Control matrix are given in the section of analysis of results in Chapter 6.

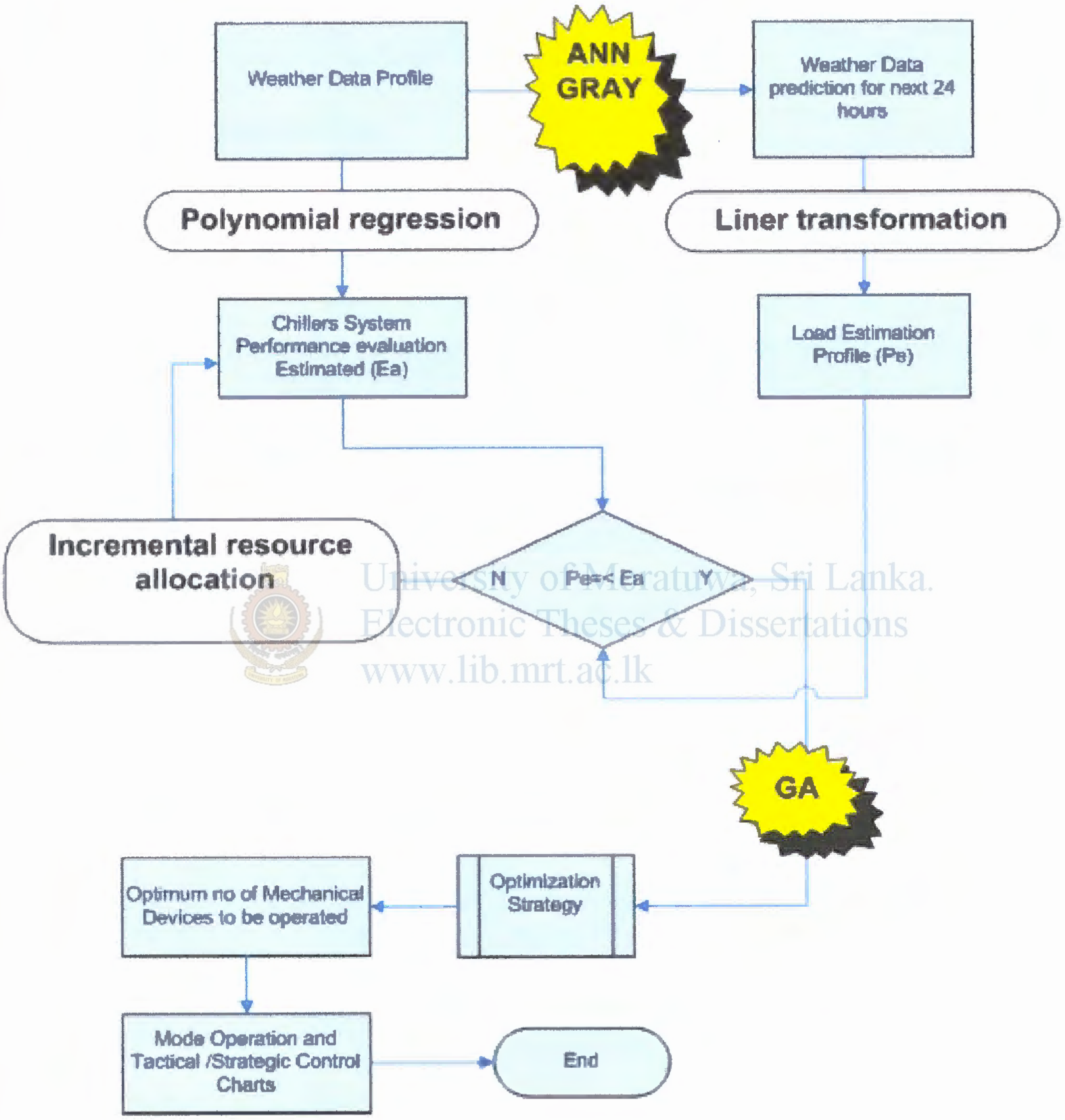


Figure 1.2 Flow Chart for the Research Objectives

1.2.1.1.1 Objective Function for Optimization of Energy

The integrated design task of the project was involved with many sub systems, which were to be completed with research components. The objective functions of stochastic models of prediction of whether data profile and load profile optimization process the decision making was influenced by the posteriori preference articulation technique (search & →decide articulation technique) [12]-[14]. The Objective function of Total Energy of individual mode operation involved many internal parameters of the chillers such as leaving media temperature, ambient temperature and the COP, however the major impact in the process of optimization are high lighted as follows:

The data flow of control decision:

1. Cooling Load profile prediction methodology based on daily weather profile and ANN methods proposed in the computation process [15]. Instantaneous value of Load Profile is $W(\theta)$
2. Objective function $[f_\Omega(\chi)]$ to be minimized on instantaneous values of θ,χ, τ and φ
3. System static constrains are τ=3.3 and φ=4.4; χ is to be maximize and θ to be optimum temperature value of the day.

$$f_\Omega(\chi, \theta,\tau, \varphi)= W(\theta) -[\eta_1 f_\delta(\chi, \theta, \tau) +\eta_2 f_\Delta(\chi, \theta, \tau)+B(\theta, \varphi)]$$

$f_\delta(\chi,\theta,\tau)$: Thermal (cooling) capacity by the Chiller operation with χ COP
$f_\Delta(\chi,\theta,\tau)$: Thermal(cooling) capacity by the Ice storage with χ efficiency
$B(\theta, \varphi)$: Thermal (cooling) capacity of the Base load chilled water Chiller
η_1, η_2 : Number of Chillers and Ice Banks to be used in the optimum configuration. The no of chillers in the system is completed with Optimization based on operational and capital before operation of the project at the design stage.

χ : Coefficient of performance of the Chillers
θ : Ambient temperature
τ : Leaving chilled media temperature (Glycol)
φ : Chilled water supply water temperature of the system

The Objective function ($f_\Omega(\chi, \theta , \tau, \varphi)$ will be optimized to achieve the following criteria.

Ice discharge operation (Day time when ambient approaches to its highest values (θ))

1. Any given time of the day's operation, the total energy required in the predicted load contour should be met within its specific Mode operation.

2. Minimum number of Chillers should be selected based on maximum number of ice bank operation while achieving item no.1.
3. Chillers are to be operated with best COP (χ) by assigning part load conditions.

Ice Charge Operation (Night time when ambient is low (θ))

4. Maximum number of Normal Chillers should be selected based on minimum number of ice bank operation. All other ice banks are busy on ice manufacturing.
5. Chillers (ice charge Mode) are to be operated with best COP (χ) by assigning part load conditions on Ice charge operation Mode.

1.3 Chapter Summary

The introduction section of Chapter 1 is mostly focused on elucidating the background of the selected project and applicable fundamental strategies, which has been employed in the mechanical design of the system. It is also reassessed the design team concerns, based on current phenomena such as adaptability, sustainability and green building. There are many optimization processes involved in many sub control modules in the main process, however in this report; only the control procedures have been high lighted. No detail analysis has been included on optimization techniques. Generating the control procedures are very important tasks in this project since it is required to program the software modules of the Control Jargon proposed by the Building Control manufactures. The combination of equipment in any control Mode operation should be selected in order to match the cooling load requirement within the selected time slot and optimized based on system input energy. The primary goal of the optimization process is to select the best combination of equipment to be operated to achieve the periodical cooling load requirement of the load curve at any given time slot. The objective function, which is formulated in section 1.2 describe the instant total energy input to the chiller system. The boundary values of Ambient temperature (θ), Chiller COP (χ) efficiency factor, glycol supply temperature (τ) and the system chilled water supply temperature (φ) of the ChW chillers are considered as main constrains in the process optimization of the objective function. The complete analysis of this will be a research objective of another project based on multi objective functions with multi input/outputs variables and this will be presented in a later session in detail, since it is beyond the scope of this report. The optimization process will be influenced by many environmental conditions, which will act as multiple constrains in the process.

Chiller plant control system (CPCS) or chiller management system described in section 1.7 will function to minimize the input electrical energy to the system as of its general control procedure. The control mechanism of CPCS will fundamentally carry out the sequencing of chillers in the plant based on system chilled water temperature. It also handle many functions such as power failure recovery, routing alarms within the network, equalizing wear and tear and limit of power input to the chiller by controlling current to its compressor (current set point). The addition and subtraction of chillers to and from the system will be done based on the cooling requirement of the building monitored by the chilled water supply temperature. In this control method, the feedback signal (change of return chilled water temperature) will not be fast enough to trigger the next action in the sequence. Therefore it is required to be adopting the mission critical control procedures in the process.

The tactical and strategic controls (section 1.8) are introduced in addition to the latter based on the instantaneous result of optimizing objective function and Mode control in order to perform proactive actions and tight control of the integral system.

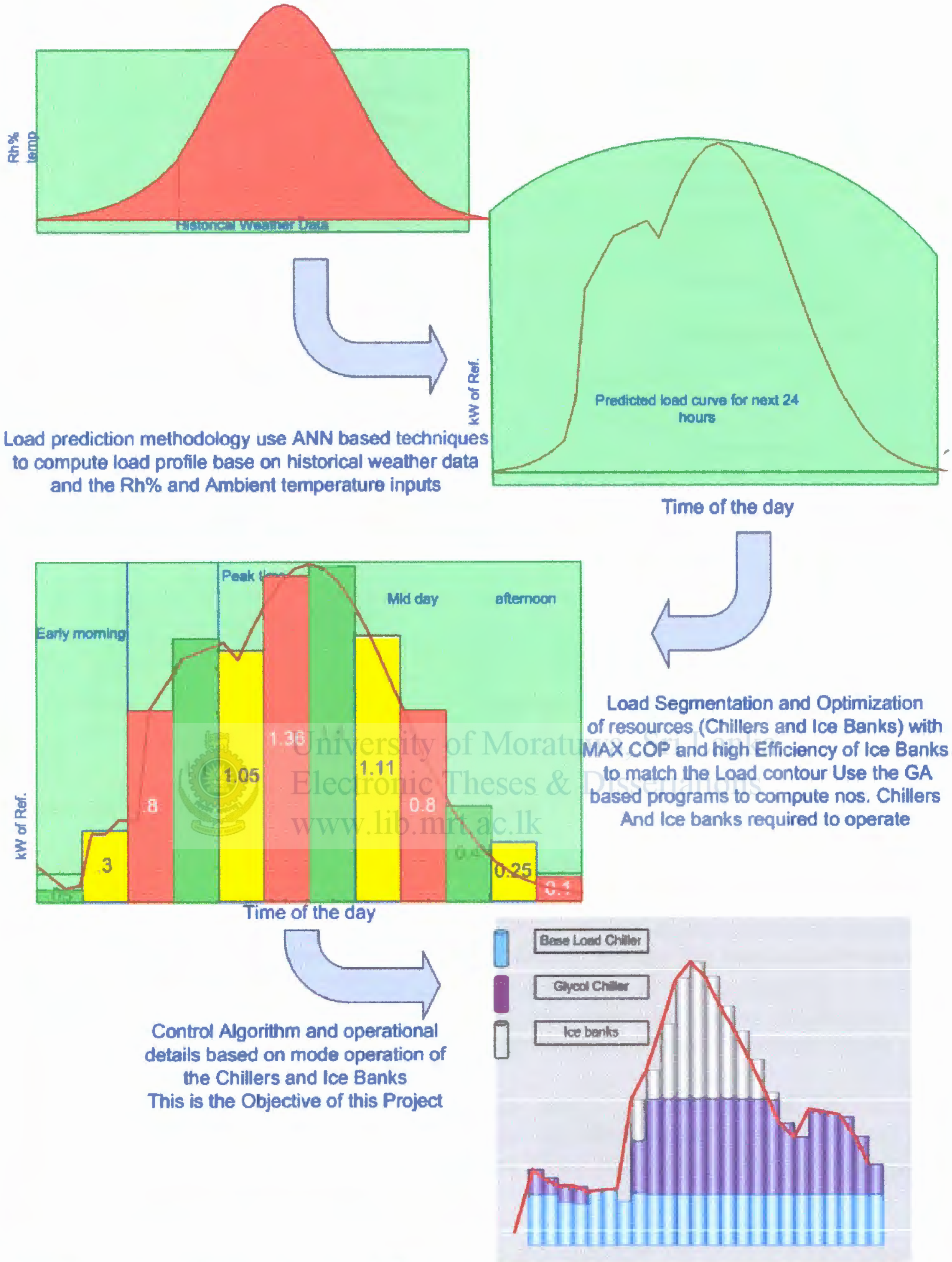
Chapter 2 furnishes the details of concept development of cooling system based on mechanical design proposed by the mechanical team. In this section ice thermal energy storage (ITES) and general mechanical piping and devices used are explained.

The control mode operation is discussed in great detail, with all devices operation in order to have tight control of the system. Every individual modes of operation with its relevant flow arrangement and subsequent devices to be controlled targeting the ultimate goal of energy optimization are deemed. The individual mode operation and their interaction, such as interruption, alarms and alerts to be served in hazard situations are discussed in the Chapter 3.

In Chapter 4, the control strategies of sub systems of the main cooling process are explained. There are three sub control loops as indicated in section 4.1 A, B and C, are highlighted as call paths of repetitive sub routines in the control software, are used in the multiple control modes. Different Combination of these subroutines will perform specific tasks and these will be elaborated in the final part of the report. Then the CPCS system architecture and subroutines are outlined and top down method is used as the design criteria for the design of control software. The figure 4.3 explains the modular control software architecture utilizing the cascaded method. The logic sequence or rules of control operation are mentioned in the sequential format will facilitate the software programmers to code their subroutines for the different field control modules.

Analysis of seasonal load demand profile is the main discussion of the Chapter 5. The typical seasonal demand, summer and winter profiles are widely discussed here. This is an important task since there is a major impact from the load demand profile on the minimization process of the Objective function explained in Chapter 1. Then it moves to explicate load profile prediction methodologies, which is supported by the load profile prediction software. The daily operation task of normal CPCS operation and its limitations are discussed by concluding the Chapter 5.

Chapter 6 is devoted to the results and analysis of the work done throughout project objectives. Firstly it explains the results of optimum equipment selection. Secondly it moves to show the calculation of COP at extreme condition of the ambient, where the results will be used to determine the chiller operation is appropriate in these conditions to be continued. Then it will progress to the final target of the project report, producing the tactical and strategic tables suitable for daily operation. Additional system design considerations will be reinvestigated and advice the commissioning engineers to proper tuned up using the variable values of time constant of the PID loops. The relevant priorities of the loops should be maintained when they specially handle the cascaded PID programming.



Load prediction methodology use ANN based techniques to compute load profile base on historical weather data and the Rh% and Ambient temperature inputs

Load Segmentation and Optimization of resources (Chillers and Ice Banks) with MAX COP and high Efficiency of Ice Banks to match the Load contour Use the GA based programs to compute nos. Chillers And Ice banks required to operate

Control Algorithm and operational details based on mode operation of the Chillers and Ice Banks
This is the Objective of this Project

Figure 1.3 Control Procedures and Research Objective No.1

1. 4 Load Profile or thermal contour of the Garden

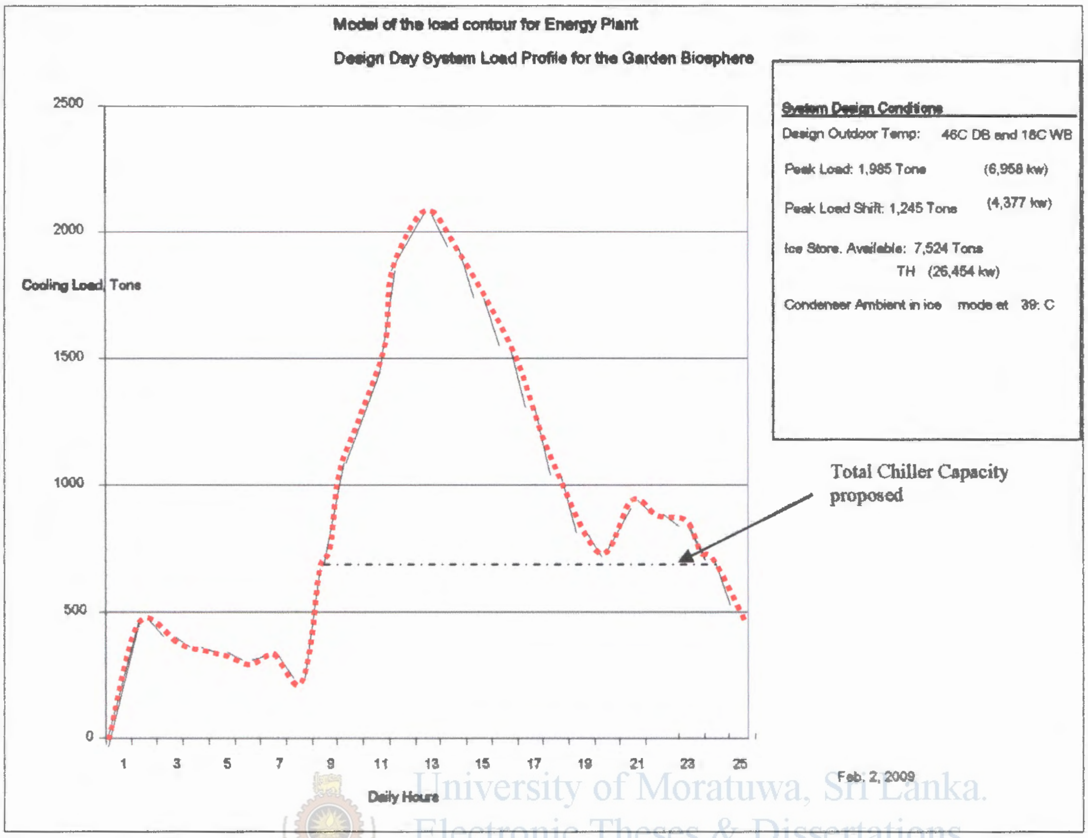


Figure 1.2 Thermal Load Contour of the Control Environment (Garden)

The above Graph (figure 1.2) shows the simulation results of the building of the subject project. The variation of cooling capacity is computed using an outdoor ambient temperature and the model synthesis by the performance data of the mechanical equipment efficiencies based on environmental conditions. During the day the rises of solar azimuth will start penetration of solar radiation around the building envelope resulting to increase its surface temperature. Similarly when the sun sets, heat absorbed by the building will radiate back to the environment by doubling its surface temperature to optimum levels [16].

The above graphics shows simulated results (i.e. nearly 98% accurate) of load variation based on ambient temperature and the time of the day, allowing designers to compute load estimation, thereby offering opportunity to do the proper sizing of the equipments supposed to used in the design.

The graphical data shown above will indicate the base line value of the estimation on average building load; however it will be updated daily by the GA model [17]-[20] running within the Load profile estimating software described in a later chapter of this report.

1.5 Thermal Energy Storages (TES)

In any environmental controlled cooling application the thermal loads are the largest component appeared in afternoon peak loads, which will be served by electric utilities reaching its optimum levels. Increased use of cool storage (Thermal Energy Storage) would shift this massive electrical load from peak to off-peak periods. This shift would permit utilities to defer construction of additional generating capacity, reduce customers demand charges and avoid its inefficient and costly operation of refrigeration equipment (i.e. chillers) in high ambient condition.

Although the number of cool storage installations in commercial buildings is growing, it also represents only a small fraction of real application used inefficiently. One major barrier to the use of cool storage equipment has been the uncertainty associated with its performance due to inaccurate system control built with standard mechanical system.

The thermal storage which will be considered in this application is water based ice storage tanks cooled by the low temperature freezing point liquid called Glycol. In full load operation, Glycol media will be chilled by the 3 numbers of Glycol chillers and circulate through a coil that is immersed in a water tank. This is Glycol in water out arrangement. When the chilling media (Glycol) is circulated through the coil, the ice will form outside the coil within the tank. Once the ice is fully formed in the tank controls will automatically stop the flowing Glycol through the tank by signalling to the chillers system and its integrated controls to stop the chillers. There is also ice harvesting meters within the tank, which gives the signal to control equipment indicating that they have already harvested.

When the system requires the additional cooling during the peak time, the formed ice will be burned by warm chilled water through the tanks. Ice chilled water will be circulated within the system to meet the peak load. This will be known as phenomena of load shifting.

In this project four TES circuit have been employed as sub systems of each individual ITES circuits (Chapter 2) which are configured to perform ice building in the ice charging Mode by utilizing glycol chillers (during low ambient time slots), concurrently to discharge low temperature chilled water in the Discharge mode (burning ice by the chillers in the Peak mode) by meeting the peak load during the high peak hours.

1.6 Glycol and Chw Chiller Operation

Each ITES circuit is completed with three nos. of Glycol media chillers and single Chilled water based load chiller ensuring all operative options subsist in a single (ITES) circuit. The mechanical architecture proposed for the cooling strategy will also fulfill the tactical and strategic control requirement for the multiple and simultaneous operations described in the chapter 3, which is known as Chiller Mode operation.

Glycol chillers will generate very low temperature glycol media, which can be utilized to build ice within the ice tanks. When the chillers have to work hard to produce low temperature chilled media and (quite naturally) its internal mechanical system will not be efficient. (Refer table 2.1 and table 2.2) Its COP factor will drop down to considerably low value. If the chillers are also operated simultaneously under the high ambient condition with Glycol media to produce low temperature glycol then its COP factor will be drastically dropped down to low value due to double inefficient condition acting on the chiller system. This indicates that the Glycol chiller should be operated in the low ambient condition (at least during the night time) in order to save big portion of energy from its inefficient operation of ice manufacturing.

The glycol chillers are set primarily to build the ice required for the ice storage in the night operation; however when there is an emergency the Glycol chillers also work on partially to fulfill the unexpected load requirement of the Chiller Plant. These conditions refer to the impulsive logic sequences in control algorithms, which are essentially embedded in to the Central control algorithm of the system.

The main function of the Chilled water base load chiller is to fulfill the minimum base load capacity of the building load. Every ITES circuit will be completed with single base load chiller and making available total four base load chillers to the Chiller Plant System.

1.7 Chiller Plant Control System

Chiller plant control system is a software based integrator which acts intelligently to sequences starting, modulating and limiting of chillers operation to optimize the overall chiller plant energy efficiency. Fundamentally any chiller plant control system is defined with two or many number of Chillers with different capacities and network communication interfaces.

Theoretically Individual chillers are designated to operate as base, peak, or swing units based on capacity and efficiency. The CPCS software determines based on (internal strategies programmed) which chiller to run in response to current load requirement and status of the Plant. The software is also responsible for minimizing mechanical wear and tear of the whole plant by rotating individual chillers and equalizing their running time.

The CPCS gives the highest priority by understanding the importance of maintaining chilled water production while protecting the chillers from the costly damage. This will be done by deploying alternative chillers on line while shutting down and putting the faulty chillers on off line.

Many faulty alarms are set out to the outside world to inform the current status of the whole plant as well as the individuals while CPCS not forgetting its target. For example if no water flow is detected in the pipe lines of the chiller, the start sequence is aborted to protect the chiller. The next chiller in the sequence is immediately started to maintain the cooling. In the event of any problem, the operator receives an alarm notification and diagnostic message to aid in quick and accurate troubleshooting.

When the CPCS is integrated with any Building Management System performing building control functions, the CPCS manager (this is the core part of coordination with other software module) optimize the total building operation with the requirement of the others.

The CPCS often communicate with open systems protocol allowing other systems to share its data for integration purposes. By doing this, the total task of Energy optimization will be done with ease. This type of chiller plant automation enables to adopt unique energy-saving strategies. As an example this will provide better tool for controlling cooling towers, pumps, and chillers from the perspective of overall system energy consumption. The software intelligently evaluates and selects the lowest energy consumption alternative.

Trend reports and Snapshots showing system status just prior to an emergency shutdown helps operators determine the cause. If emergency conditions justify an immediate manual shutdown, the operator can override the automatic control.

In this application, CPCS software is used by configuring ChW-CPCS and Glycol -CPCS managing two individual task simultaneously within the same main task of production of Chilled water in required capacity.

1.8 Tactical and Strategic Controls

Tactical and Strategic controls are two sub segmented criteria of the device operation when operating sub system under the command of main control operation. The task of developing a control sequence for an ice storage system can be simplified by dividing control into two categories, tactical and strategic. Tactical control defines how to perform a certain function whereas Strategic control defines when to perform that function.

For Example In this application it is considered the following sub modules to achieve the overall control function by interaction between them.

Within the ITES module, it is considered the following sub system to be operating its own control jargons.

1. Glycol Chiller Plant manager with 3 nos. Chillers to be operate as explained in the Chapter 3. (strategic)
2. ChW / Glycol main Heat Exchanger system will be ramped up/down based on temperature sensor at the down stream flow of the Chilled water system. (figure 3.1) (tactical)
3. Ice storage charge / discharge function based on ice harvesting sensors and the ice quantity required by the load predicting system. This is determined by the software tool within the CPCS system (tactical→ strategic→ tactical)
4. All other individual pumps based on its specific requirement are defined in Chapter 4. (tactical)

1.9 Modeling of Energy Equations

The Objective function mentioned above section 1.2 indicate that there are three mechanical components are consuming electrical energy and these could be defined as total energy function as given from the formula $f_\Omega(\chi, \theta,\tau, \varphi)= W(\theta) -[\eta_1 f_\delta(\chi, \theta, \tau) +\eta_2 f_\Delta(\chi, \theta, \tau)+B(\theta, \varphi)]$

$f_\delta(\chi,\theta,\tau)$:Thermal (cooling) capacity by the Glycol Chiller operation with χ COP
$f_\Delta(\chi,\theta,\tau)$:Thermal (cooling) capacity by the Ice storage with χ efficiency
$B(\theta, \varphi)$:Thermal (cooling) capacity of the Base load chilled water Chiller

η_1, η_2 are the Number of Chillers and Ice Banks to be used in the optimum configuration. The no of chillers in the system is completed with Optimization based on operational and capital before operation of the project at the design stage.

For the chiller, a model is based on regression functions that describe how the cooling capacity and the energy efficiency vary with operating conditions, as well as the power consumption varies based on instantaneous part-load ratio of the chiller. The chiller model can be described by the following Polynomial function [21].

$$\mathrm{CAPFT}_{(\mathrm{Glycol})} = \upsilon_1 + \upsilon_2\,\tau + \upsilon_3\,\tau^2 + \upsilon_4\,\theta + \upsilon_5\,\theta^2 + \upsilon_6\,\tau\,\theta \longrightarrow \quad 1$$

$$\mathrm{EIRFT}_{(\mathrm{Glycol})} = \omega_1 + \omega_2\,\tau + \omega_3\,\tau^2 + \omega_4\,\theta + \omega_5\,\theta^2 + \omega_6\,\tau\,\theta \longrightarrow \quad 2$$

$$\mathrm{EIRPFPLR}_{(\mathrm{Glycol})} = \mu_1 + \mu_2\,\psi + \mu_3\,\psi^2 \longrightarrow \quad 3$$

Where ψ is the Part Load Ratio of the Chiller measured as Evaporator output χ to the full load condition.

$$\Psi_1 = \frac{\underline{\text{Evaporator kW output at part load condition (Actual)}}}{\text{Evaporator kW output at full load condition} \rightarrow \text{(catalogue data } K_1)}$$

Evaporator kW output at part load condition (Actual) = Ψ K
$f_\delta(\chi, 50, 3.3)$ Electrical power input = $\chi_1\ \Psi_1\ K_1$ (3.3 C leaving Glycol and 50C temperature)
Using the above 1, 2 and 3 the following could be simplified to

$$f_\delta(\chi, \theta, \tau) = f_\delta(\chi, 50, 3.3)\ \mathrm{CAPFT}_{(\mathrm{Glycol})}\ \mathrm{EIRFT}_{(\mathrm{Glycol})}\ \mathrm{EIRPFPLR}_{(\mathrm{Glycol})}$$

$$f_\delta(\chi, \theta, \tau) = \chi_1\ \Psi_1\ K_1\,\mathrm{CAPFT}_{(\mathrm{Glycol})}\ \mathrm{EIRFT}_{(\mathrm{Glycol})}\ \mathrm{EIRPFPLR}_{(\mathrm{Glycol})}$$

$$\begin{aligned} f_\delta(\chi, \theta, \tau) = \chi_1\ \Psi_1\ K_1\ &(\upsilon_1 + \upsilon_2\,\tau + \upsilon_3\,\tau^2 + \upsilon_4\,\theta + \upsilon_5\,\theta^2 + \upsilon_6\,\tau\,\theta) \\ &(\omega_1 + \omega_2\,\tau + \omega_3\,\tau^2 + \omega_4\,\theta + \omega_5\,\theta^2 + \omega_6\,\tau\,\theta) \\ &(\mu_1 + \mu_2\,\psi_1 + \mu_3\,\psi_1^2) \longrightarrow \quad 4 \end{aligned}$$

Similarly for the Chilled water Chillers power input $B(\theta, \varphi)$

$$\begin{aligned} B(50, 4.4) &= \chi_2\ \Psi_2\ K_2 \quad (\Psi_2 = 1 \text{ due to the chillers are running with full load}) \\ B(\theta, \varphi) &= B(50, 4.4)\ \mathrm{CAPFT}_{(\mathrm{ChW})}\ \mathrm{EIRFT}_{(\mathrm{ChW})}\ \mathrm{EIRPFPLR}_{(\mathrm{ChW})} \\ &= \chi_2\ K_2\,(\upsilon'_1 + \upsilon'_2\,\varphi + \upsilon'_3\,\varphi^2 + \upsilon'_4\,\theta + \upsilon'_5\,\theta^2 + \upsilon'_6\,\varphi\,\theta) \\ &\quad (\omega'_1 + \omega'_2\,\varphi + \omega'_3\,\varphi^2 + \omega'_4\,\theta + \omega'_5\,\theta^2 + \omega'_6\,\varphi\,\theta) \\ &\quad (\mu'_1 + \mu'_2 + \mu'^2_3) \longrightarrow \quad 5 \end{aligned}$$

Where $K_3 = K_2\,(\mu'_1 + \mu'_2 + \mu'^2_3)$

$$\begin{aligned} B(\theta, \varphi) &= \chi_2\ K_3\ (\upsilon'_1 + \upsilon'_2\,\varphi + \upsilon'_3\,\varphi^2 + \upsilon'_4\,\theta + \upsilon'_5\,\theta^2 + \upsilon'_6\,\varphi\,\theta) \\ &\quad (\omega'_1 + \omega'_2\,\varphi + \omega'_3\,\varphi^2 + \omega'_4\,\theta + \omega'_5\,\theta^2 + \omega'_6\,\varphi\,\theta) \rightarrow \quad 6 \end{aligned}$$

For the Ice tank storage energy will be calculated using the model developed using thermodynamic fundamentals [22]. The charging performance is related to the temperature rise from brine inlet to outlet as well as the Glycol flow rate. Temperature difference of 3.3 C between storage tank and chiller is used in the optimization simulation, given that it is generally used in consideration of the low-temperature charge capacity of the chiller. The charging rate of ice-storage tank CR is related to its average charge temperature (ACBT): Where d_i is coefficient that may be determined from the performance curve. The ice-storage tank can be viewed as a heat exchanger. The discharging rate of the tank Q_{ice} may be expressed as

$$\mathrm{ACBT} = d_0 + d_1\,\mathrm{CR} + d_2\,\mathrm{CR}^2$$

$Q_{ice} = UA\,\Delta T_{Log\ mean,\ ice}$

Where $\Delta T_{Log\ mean,\ ice} = [(\tau_1 - T_f) - (\tau_2 - T_f)] / \ln((\tau_1 - T_f)/(\tau_2 - T_f))$

For Water freezing temperature $T_f = 0\ C$

$\Delta T_{Log\ mean,\ ice} = (\tau_1 - \tau_2)/\ln(\tau_1/\tau_2)$

$UA_{ice} = (e_0 + e_1 y + e_2 y^2 + e_3 y^3 + e_4 y^4 + e_5 y^5 + e_6 y^6)\,Q_{s,\ nominal}/\Delta T_{ice\ nominal}$

$Q_{s,\ nominal}/\Delta T_{ice\ nominal} = K_4$; this is the data specific to the manufacturer.

So that $Q_{ice} = UA\,\Delta T_{Log\ mean,\ ice}$

$= K_4 (e_0 + e_1 y + e_2 y^2 + e_3 y^3 + e_4 y^4 + e_5 y^5 + e_6 y^6)(\tau_1 - \tau_2)/\ln(\tau_1/\tau_2)$

$f_\Delta(\chi, \theta, \tau) = \chi_3 K_4 (e_0 + e_1 y + e_2 y^2 + e_3 y^3 + e_4 y^4 + e_5 y^5 + e_6 y^6)(\tau_1 - \tau_2)/\ln(\tau_1/\tau_2)$

Where e_i are the curve constants and y is the fraction of ice remaining in the ice bank.

Chapter 2

Concept Development of Cooling System

2.1 Summary of Concept Development

In this chapter, it will be abstracted the synthesis of control strategies for a chiller plant management system of an Energy Centre complete with a fully configured Chiller Plant Control System (CPCS). The development of detail design will be a responsibility of the engineering team in order to achieve the specific performance requirements out lined in latter part of this report and the full mechanical drawings and specifications setout.

This report is written to describe in simple terms how the Energy Centre cooling plant control is designed to operate within the given environmental criteria. The adoption of autonomous behavior will not predict steady state, however anticipated weather profile and prediction using Genetic algorithm will facilitate to control the plant for a definitive target and this will be the aim of further research on this subject.

The conceptual development in this stage investigates:

- Provides an overview of the component of the full mechanical system
- Considers the various modes of operation, based on the load profile
- Details the various control strategies for local loops
- Investigates possible daily chilled water demand profiles with the anticipated weather profile.
- Discuss control strategies for predicating and matching the cooling load in the buildings. The further studies on this stage will be done in future research in order to develop the software algorithms required for the enhancement of control system.

The objective of the design is to present a reasonably concise but comprehensive initial description of the sequence of operations for the Energy Centre Cooling Plant with separate identification of individual control functions and modes of operation. These descriptions will be developed by the specialist engineering team at the project execution stage

These systems are by necessity very complex but will be explained as simply and coherently as possible. Modes of operation of the various elements of the cooling plant are explained along with the operation of the various sub system control routines and their associated sensors and control devices.

Typical load profiles encountered are discussed with suitable modes of operation selected to meet demand. The prediction strategies used to match modes of operation to varying demand are laid out. A typical Cooling Package Control Software architecture is elaborated.

2.2 General System Descriptions

The cooling system plant is composed of three mains parts:

- Tertiary variable volume systems supplying chilled water to the chilled water coils in the various air handling and fan coil equipment. (see the Figure 2.1 overleaf)

- Secondary site-wide variable volume distribution system

- Primary chilled water production circuits in the Energy Centre.

The Primary Chilled Water Plant (CWP) is designed with four (4) Ice Thermal Energy Storage (ITES) modules. Each module comprises a base load chiller, 3 glycol chillers, a bank of ice storage vessels and all associated pipe work, valves, pumps, and associated equipment.

Each ITES module acts as chilled water generators, capable of producing 7,032 KW (2,000 Tons) to give a total of 28,128 KW (8,000 Tons) maximum plant cooling capacity. See Figure 2.1 overleaf and the schematics in Appendix A. The primary production plant is modular. As more phases of the gardens are developed further ITES modules will be added. The ITES modules in the Energy Centre will be controlled by a dedicated Chiller Plant Control System (CPCS). The CPCS will provide information for monitoring on the central Building Management System (BMS) via an open protocol serial communication link.

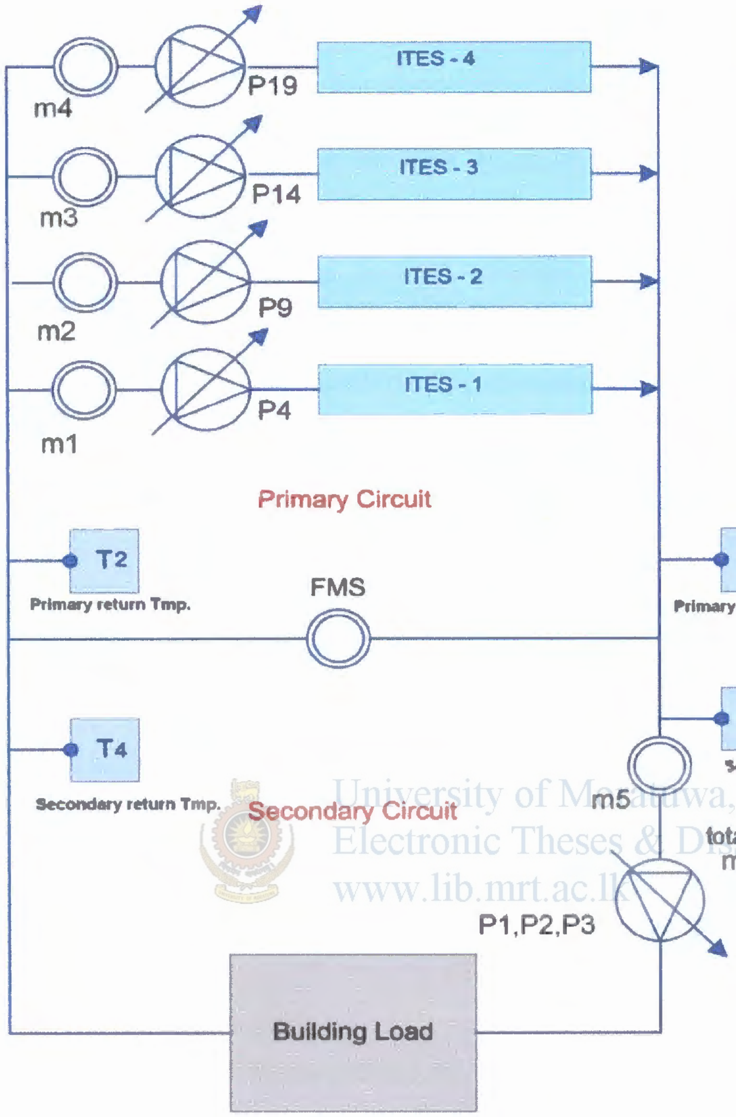


Figure 2.1 Chilled Water Plant simplified schematics on the selected project

The above figure 2.1 shows that the simplified version of the schematics shown in the Appendix A.

Where T1, T2, T3, T4: Temperature sensors mounted on the pipe lines of the system.

m1, m2, m3, m4, m5 are flow metering devices located on the different part of the piping system adjacent to every pump systems.

Theoretical requirement of hydraulics in order to have proper thermal balance flow should be maintained m1+m2+m3+m4 > m5

FMS: bypass pipe flow sensor

The ITES cooling plant is designed to deliver chilled water to the secondary chilled water distribution system at a constant supply temperature of 4.44°C (40°F). The secondary chilled water cooling system is designed to achieve a return temperature rise of 10°C (18°F) under ideal design conditions. The secondary system will have variable speed pumps which will deliver a variable flow through the distribution loops responding to changes in the secondary system cooling demand. The tertiary system load for cooling in the International Gardens and building complex will be supplied by multiple variable volume circuits each feeding chilled water coils fitted with two port valves.

Differential pressure sensors will be used to measure the instantaneous load and the associated pumps will be controlled by variable speed drives (VSD) to match that demand. The differential pressure measurement will generally be located at approximately 2/3rd of the distance to the longest or index branch of each discrete circuit.

The ITES modules will be added in sequence by the CPCS as the cooling load from the gardens and buildings increases.

2.3 ITES System Description

There will be four ITES modules in the primary chilled water production circuit once the complex is complete. These act as parallel ChW generators as shown above in a simplified overview in Figure 2.1.

Each ITES module will consist principally of:

- Base load air cooled chilled water chiller
- Two parallel glycol to water heat exchangers
- Ice Storage tanks
- Three Glycol air cooled chillers
- Associated pipe work, valves, sensors etc.

The base load chiller will cool the return primary chilled water first and will have sufficient capacity to meet the building cooling load on its own during low demand situations. When the base load chiller loading starts to increase toward full capacity; the glycol circuit will be primed and readied for operation. The glycol system will provide supplementary cooling via the two numbers parallel glycol to water heat exchangers (see Appendix A).

2.3.1 Base Load Chillers

Each Base Load Air Cooled Water Chiller has a capacity of 1,120 kW (319 Tons) at an ambient temperature of 49°C. Each Base Load chiller is piped in series with two number Glycol/chilled water heat exchangers. The ITES chilled water circuits are connected to the main supply and return chilled water headers of the chilled water production circuit.

The higher temperature water side of Glycol/Water Heat Exchangers and base load chilled water chiller is connected to main chilled water circuit via a set of variable speed pumps.

The VSDs for these pumps will be used to soft start these pumps and then modulate them between their minimum and their maximum pumping capacity. They maintain the flow around the production (primary ChW) circuit to exceed secondary demand.

2.3.2 Glycol Heat Exchangers

Each ITES system module will have two flat plate exchangers designed to help cool down the return chilled water to the final delivery temperature of 4.44°C (40 °F). They will be used in situations of higher demand where there is a greater cooling demand than can be met by the base load chiller alone. The chilled water will be pumped through the heat exchangers after first being partially pre-cooled by the base load chiller.

The lower temperature glycol side of the Heat Exchangers will be cooled by a glycol circuit circulated by a set of dedicated parallel pumps (the Glycol Heat exchanger pumps).The heat exchanger glycol circuit will in turn be cooled by a glycol system containing Ice storage tanks and air cooled glycol chillers. This glycol sub system will be cooled by the three air cooled glycol chillers each installed with its own dedicated shunt pump. The glycol chillers will be pumped in a parallel configuration to the main Glycol header.

From here glycol will be pumped to either the Ice storage banks or direct to the Heat Exchanger system by another set of system distribution pumps (P7-1 to P7-4 in ITES-1 circuit). All of these pumps are driven by VSDs. These pumps will be responsible for Glycol circulation through the Ice Storage in the different modes of operations of the Glycol sub-system e.g. Ice build, ice discharge or ice discharge plus glycol cooling operations.

2.3.3 Ice Storages

Each ITES module will have 57 nos. of Ice Thermal Storage Tanks including three built-in spares

Glycol is circulated through the Ice storage tanks via sets of parallel pumps (Glycol system pumps) connected to main supply header of three Glycol chillers, which are arranged in parallel configuration. The three Glycol Ice Chillers are capable of delivering 1,077 kW (307 Tons) cooling capacity at -5.6°C (22°F), with 30% ethylene Glycol at 35°C ambient temperature to Ice Tanks to store thermal energy in surrounding water, forming ice and rendering chilled water at -2.2°C (28°F).

Each ITES System will be designed to charge full tanks of thermal ice storage capacity 25,526 kWh (7,260 Ton-Hrs) in ten hours, excluding spare tank capacity. With four modules of ITES systems in full operation, the total ice system storage capacity will be 102,104 kWh (29,040 Ton-Hrs).

2.3.4 Glycol Chillers

The three glycol chillers in each ITES will be capable of delivering 1,077 kW (307 Tons) cooling capacity at -5.6°C (22°F), with 30% ethylene glycol mix at a 35°C ambient temperature. This will be pumped to the Ice Tanks to store as latent thermal energy in surrounding water by forming ice and returning chilled water at -2.2°C (28°F). The same Glycol Ice Chillers will each deliver 1,107 kW (315 Tons) direct cooling to the heat exchanger circuit with a 30% ethylene glycol mix and at 3.33°C (38°F) and returning at 10°C (50°F) under 49°C (120.2°F) ambient temperature conditions.

On peak days, the total glycol chillers' capacity will not be sufficient to meet the peak-cooling load and the leaving glycol solution from the glycol chillers must be further cooled by the ice storage tanks to the final delivery temperature of 3.33°C.This glycol mix will then be used cool the chilled water via the two heat exchangers to produce a 4.44°C chilled water supply for distribution to the gardens secondary cooling system.

The following table illustrates chiller rating changes with different outdoor ambient temperatures.

Glycol Air Cooled Chiller Operating Characteristics Comparison								
Unit Description	Ambient Temp.	Medium	Capacity		Fluid Temp.		Efficiency - COP	Power
	°C		kW	Tons	Entering	Leaving		kW
Trane RTAC 500	35	30% Ethylene Glycol	1077	307	-2.22°C	-5.6°C	7.6 EER - 2.23 COP	485.1
Trane RTAC 500	25	30% Ethylene Glycol	1220.5	348	-2.22°C	-5.6°C	2.92 COP	417.9
Trane RTAC 500	49	30% Ethylene Glycol	1107	315	10 °C	3.33°C	5.9 EER - 1.71 COP	646.3
Trane RTAC 500	25	30% Ethylene Glycol	1661	474	8.94°C	3.33°C	11.4 EER -3.35 COP	498.3

Table 2.1 Chiller performance data for different Glycol leaving temperature and different ambient conditions.

[The capacity of the Chiller on lower ambient is higher with the same leaving fluid temperature conditions as per above performance data]

Base Load Air Cooled Chiller Operating Characteristics								
Unit Description	Ambient Temp.	Medium	Capacity		Fluid Temp.		Efficiency - COP	Power
	°C		kW	Tons	Entering	Leaving		kW
Trane RTAC 500	30	100% Water	1497.6	427	14.4 °C (58°F)	5.6 °C (42°F)	EER - 3.33 COP	411.7
Trane RTAC 500	35	100% Water	1412	402	14.4 °C (58°F)	5.6 °C (42°F)	EER - 2.73COP	436.9
Trane RTAC 500	49	100% Water	1120	319.0	14.4 °C (58°F)	5.6 °C (42°F)	6.2 EER - 1.82 COP	616.1

Table 2.2 Chiller performance for different ambient conditions for the same chilled water leaving and same delta T

The changing capacities and potential cooling efficiencies of the chillers in different external ambient conditions, combined with a variation of cooling demands in the Gardens, requires the ITES equipment to operate in different modes during the course of the day.

2.4 Sequencing the ITES Modules

ITES circuits will be rotated based on a weekly schedule in order to equalize operational hours and mechanical wear and tear. Every week there will be a schedule within the system marked with sequence numbers. The ITES circuit prioritized as lead will be started first automatically. The supply and return headers will be monitored by the CPCS and employ one or a combination of control algorithms to ADD operation of the ITES operation.

2.4.1 Adding the ITES Modules

At least one ITES module will be always be enabled by the CPCS to support the continuous operation of the cooling system. The ITES modules will be added in sequence based on the bypass flow in the main chilled water plant bypass as measured by the flow meters in the system and by the flow sensor in the bypass. If the bypass flow reduces to a pre-determined set point an ITES module will be added.

The CPCS will start an additional ITES module to prevent the whole system operating with negative flow in the bypass and therefore losing system temperature control. The same procedure will be repeated until all the ITES are enabled by the CPCS. The switching levels for adding ITES modules will be determined during commissioning on site taking into account such factors as system thermal inertia and time lags for start up of equipment.

2.4.2 Subtracting the ITES Modules

If the system supply temperature is satisfied and system bypass flow through the bypass is greater than 110% of nominal flow of an ITES module for greater than the required trend observation period, then the CPCS "subtract ITES Module request" flag will becomes active. The CPCS will ensure that an ITES module is disabled as soon as possible for efficiency sake while ensuring that the cooling system will continue to operate with positive flow in the de-coupler.

Chapter 3

System Control Modes

3.1 System Control Modes of Operation

The ITES equipment and sub-systems need to operate in a number of modes in order to match both instantaneous and stored cooling capacity to that required by the chilled water demand of systems in the gardens and buildings. The modes of operation are explained in more detail in this next section. Typical sequences used to match the demand profile will be discussed in a later section.

Principal modes or operation are:

1. **Base Load Chiller** (Operation Only)
2. **Chiller Priority** (Base Load Chiller + Mid Temp Glycol Chiller Cooling)
3. **Ice Priority** (Base Load Chiller + Ice Cooling)
4. **Peak Load** (Base Load Chiller + High Temp Glycol Chiller + Ice Cooling)
5. **Ice Build** (Base Load Chiller + Ice Build only)
6. **Ice Build plus Cooling** (Base Load Chiller + Low Temp Glycol Chiller)

3.1.1 **Base Load** (Base Load Operation Only)

This scenario could occur on many occasions during winter and mid seasons, in fairly low external ambient conditions, when the building load is less than the capacity of the base load chiller.

In a summer season, this might also occur during early mornings typically say between 6 AM to 7 AM.

3.1.1.1 Control sequence

The only chiller which will be operational in this mode is the Base Load Chiller, which should be sufficient to ensure a supply of chilled water at a temperature of 4.44 C.

The secondary and tertiary ChW distribution circuit pumps will be modulated by their respective VSDs. The differential pressure sensor reading and system differential pressure set point, as measured during commissioning, will be fed in to a PID loop and output will be relayed to VSD controller via the network. If there are multiple circuits in each segment, the min/max values of a matrix of individual pressure sensor readings will be used to control the VSD pump speed. The primary ChW flow around the lead ITES module primary circuit will be controlled to slightly exceed the flow in the secondary distribution circuit.

When the CPCS decides to enable a new ITES module due to an increased secondary load, it will first start by initiating the appropriate combination of primary ChW pumps and then ramp up to the speed set point determined by the CPCS and transferred via the CPCS network to the appropriate ChW pump VSD.

Up to two primary pumps within an ITES will be operated to provide ChW through the production circuit and maintain a slight surplus flow through the primary ChW bypass pipe. The primary circulation pumps can be operated, when required, in a two run/one standby combination. Only a single pump will be enabled during Base Load Mode when only the base load chiller system is operating.

Two primary circulation pumps will be enabled when the ITES system operates in the various modes that require the base load chiller plus glycol heat exchanger cooling. The 3rd pump in the sequence will operate only in the standby mode when a duty pump has failed. The lead, first lag and standby pumps should be rotated based on a weekly schedule. Once the primary ChW flow has been proved, the base load chiller will initiate its own integral start-up sequence by bringing its dedicated shunt pump on line. The chiller will load up using its internal loading mechanism based on a set point requirement (4.44C).

In the 'base load chiller only' mode, the CPCS will command the Glycol sub system to be off line along with its associated peripherals (pumps, chillers and valves). The Base Load chiller will be started and stopped and controlled in conjunction with its associated individual shunt pump to maintain the primary ChW flow temperature set point during varying volume demands from the secondary distribution circuits. Once it is enabled by the CPCS, the chiller performs its internal house keeping routine and communicates to the CPCS whether chiller is healthy to start.

The chiller shunt pump flow volume will be controlled within the maximum and minimum values which are allowable by the chiller characteristics.

The CPCS also performs the following operations:

- Run ChW primary pump to maintain slight surplus in ChW bypass flow sensor.
- If the lead primary pump fails to start then start the next in sequence (Standby).
- Request chiller healthy status (safety check procedure) from chiller control module
- If the Chiller has fault alarms (auto reset or manual reset) which still are current the CPCS marks the chiller as faulty and initiates the appropriate glycol HX cooling mode. See sections below.
- If chiller healthy, start-up chiller shunt pump (VSD) via local control and then ramp its speed to preset value
- Prove the flow through the chiller
- Confirm closed position of SV-1, 2, 3 and SV-4 valves (Anti-freeze protection of the Heat exchanger)
- Bring the base load chiller into operation by starting its own dedicated pump

The CPCS will monitor trends and log as follows

- ChW supply flow temperature, measured after the main by pass of all the secondary ChW circuits
- Flow measurement data for the secondary ChW system
- ChW return flow temperature, measured before the main by pass of all the secondary ChW circuits
- Data for power consumption within the chiller
- Alarms produced by the chiller control module.

The CPCS will continually monitor the chilled water supply temperature and note its rate of change. The CPCS will monitor the base chiller loading.

If:

- the chiller approaches full load
- the supply ChW temperature is greater than 4.4 °C by more than a fraction of a degree for more than pre-programmed time period of time

Then the CPCS will enable the associated ITES glycol sub-system. In other words once demand has increased to a level where the base load chiller cannot meet demand alone and the glycol sub system will be enabled and primed. The CPCS will select the most appropriate mode of operation for the glycol sub system based on the available internal strategies. This will enable the CPCS to match the predicted levels of the cooling demand profile computed within CPCS and the most efficient use of the rest of the. See next sections for details.

3.1.2 **Chiller Priority** (Base Load Chiller + Mid Temp Glycol Chiller Cooling)

If the Base load chiller does not have enough capacity to keep control of leaving ChW temperature (4.4°C) on its own the ITES can go into Chiller Priority or Ice Priority mode.

Where the base load chiller is not available the ITES may operate in Chiller Priority mode alone with no base load chiller. The CPCS will calculate the most appropriate mode given the various data available. Chiller Priority will be selected when most appropriate.

For example:

1) When load increases above the base load chiller capacity during a summer morning but the CPCS calculates that stored ice must be retained for peak load coverage for later in the day.
2) In the evening after completion of the ice burn cooling.

In the scenario where glycol chillers are needed, the CPCS will switch the glycol chillers on to 'Chiller Priority' mode with a supply temperature (3.3 °C) which will fulfill the cooling load requirements of the system. This means the ice storage is isolated and supplementary cooling is provided directly by the glycol chiller.

The following schematic diagram (Figure 3.1) shows the proposed hydraulic flow within the glycol circuit. While controls operating on this mode of operation, the chilled glycol media flows through the piping system as indicated in light brown color line of the figure.

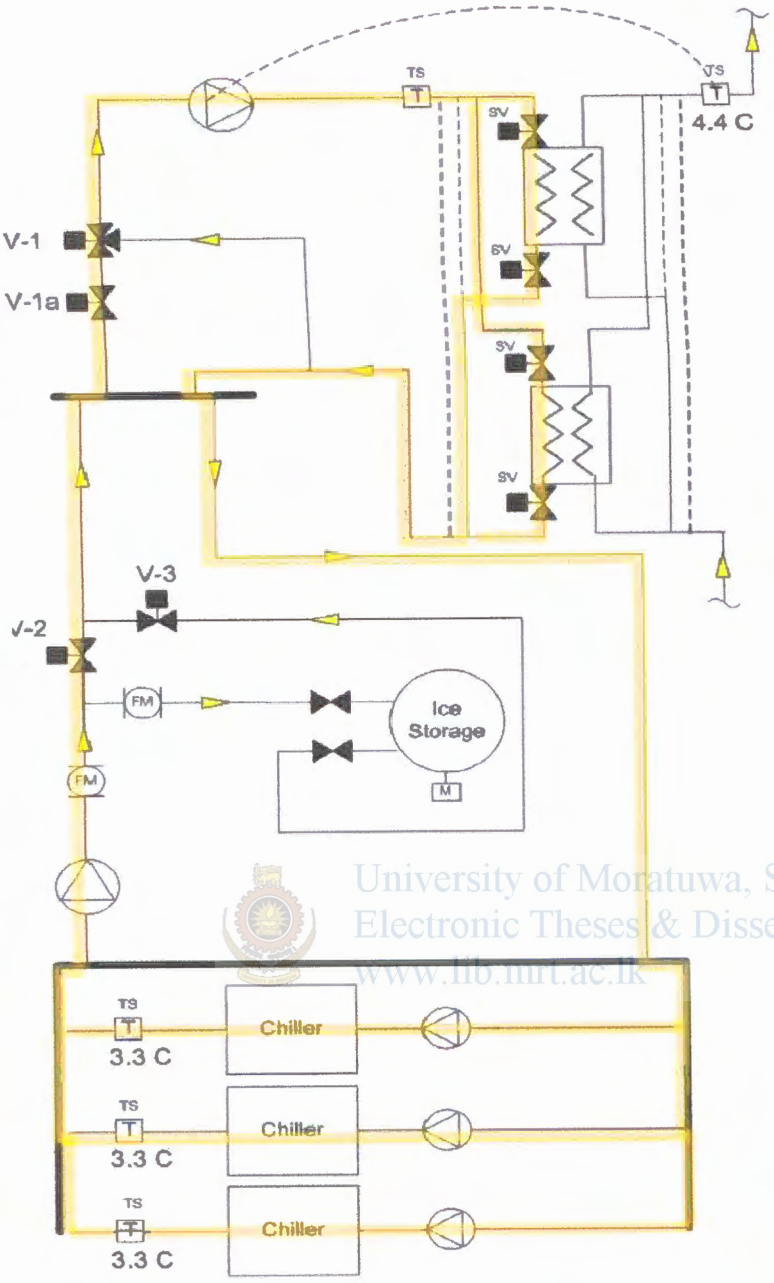


Figure 3.1 Glycol flow through the Circuit when Chiller Priority Mode

3.1.2.1 Control sequence

The Base load chiller will be running at full capacity. The glycol system should be operated when the base load chiller approaches full capacity. The heat exchanger glycol circuit operates under a variable supply volume, constant supply temperature strategy to maintain the ChW supply temperature set point. The valve controls are operated to ensure a steady 3.3 C of supply temperature of glycol into the heat exchanger. The CPCS will put the glycol chillers into medium temperature cooling mode, with the chiller supply set points adjusting to 3.3 °C.

Start-up operation of the glycol chillers:

- Valve V-1, V-1a and V-2 will be fully opened
- Heat exchanger isolation valves SV-1, 2, 3, and SV-4 will be opened
- Valve V-3 will be fully closed to prevent flow to the ice tanks
- Glycol primary pumps are soft started to preset value
- Heat exchanger pumps will be modulated based on the ChW leaving temperature of ChW side of the heat exchangers (set point is 4.44C)
- VSDs of glycol primary pumps will be controlled up to slightly exceed (min 5% above) the speed of heat exchanger pumps and % speed will be calculated by the PID loop as in the commanded by CPCS

- Dedicated Glycol Chiller shunt pumps will be started and flow proven
- Glycol chillers will be started after proving the flow and all other internal safety routines
- Chiller will be sent its set point of 3.3C from the CPCS
- Flow through the main glycol bypass pipe will be measured and recorded
- Temperature variations of system measured by the supply temperature sensor and return temperature sensor will be monitored and recorded.

Sequencing and staging of the chillers will be controlled to maintain a slight surplus in the bypass line. When cooling demand from the building falls the lag glycol chillers are sequenced out until only one chiller is adequate to meet the glycol cooling demand.

3.1.2.2 Sequence of operation of Glycol Chillers on Chiller Priority Mode

a. Addition of Glycol Chillers

When the glycol system is enabled from the CPCS the first chiller in the sequence will be started after first checking all the safeties interlocks. The next glycol chiller will be added based on maintaining the bypass flow in the main glycol chiller bypass. This will be calculated by using the various flow measuring devices in the system, VFD drive values and a flow sensor in the de-coupler.

If the by pass flow reduces to less than the 5% of pre-determined level of one glycol chiller flow then the priority chiller in the sequence will be added. This will prevent the system operating in negative flow and potentially losing system temperature control. The same procedure will be repeated until all the glycol chillers are enabled by the CPCS.

b. Subtracting of Glycol Chiller

If the system glycol supply temperature is satisfied and system bypass flow through the de-coupler is greater than 110% of nominal flow of one glycol chiller the CPCS "subtract request" software flag will becomes active. This ensures that glycol chiller is disabled as soon as possible for efficiency, while ensuring that the glycol system will continue to operate with a positive flow in the de-coupler

The heat exchanger pump will ramp down to minimum speed to match the falling cooling demand. When the VSD has reached the minimum permitted frequency, the VSD speed will be limited at that value. Any further decrease in cooling demand will be matched by adjusting the base load chiller flow temperature set point.

When the chiller loading (as monitored by the CPCS) has dropped low enough that there is sufficient spare base load chiller capacity to allow shut off of the minimum residual glycol cooling, without compromising the primary ChW flow temperature, then the ITES will revert to Base Load Mode operation.

Shut down of Chiller Priority operation

This will initiate the following procedures within the control algorithm

- If the demand continues to falls, single base load chiller operation is the only possibility that remains.
- The last glycol chiller in operation will be switched off after checking its safety routines
- The chiller dedicated pump will be switched off
- Primary Glycol pump VFD will be regulated to its min preset value and switched off
- Heat Exchanger pump VFD will be regulated to its min preset value and switched off
- All the associated valves will be closed

3.1.3 **Ice Priority** (Base Load Chiller + Ice Cooling)

If the Base load chiller cannot keep control of leaving ChW temperature (4.4°C) on its own the ITES can go into Chiller Priority or Ice Priority mode. Where the base load chiller is not available the ITES may operate in Ice Priority mode with no base load chiller.

The CPCS will calculate the most appropriate mode given the various data available. For example Ice Priority will be selected as load increases above base load chiller capacity during a winter or mid season morning, when stored ice need not be retained for peak load coverage later in the day. Ice Priority could be also is used to meet cooling demands greater than base load but smaller than can be met by Chiller Priority where the chiller is running at minimum volume. In Ice Priority Mode the base load chiller will be running at full capacity.

The glycol system should be operated when the base load chiller approaches full capacity. The heat exchanger glycol circuit operates under a variable flow volume, constant flow temperature strategy to maintain the ChW flow temperature set point. The valve controls are operated to ensure a steady 3.3 C of supply flow temperature of glycol into the heat exchanger.

In this mode the CPCS will control the ITES to burn stored ice using the heat gain returned from the heat exchangers. The glycol circulation pumped through the Heat Exchangers will carry this heat to the ice tanks via the glycol primary distribution pumps. Glycol chillers will not be permitted to operate in this mode of operation. The aim of the control strategy will be to ensure that as much ice as possible will be used before the end of the day and converted by the system in order to provide sufficient cooling to meet the demand. This process will be initiated by starting the glycol system HX and circulation pumps and switching to a preset value of speed. The chillers will be disabled by the CPCS. Enough stored ice must be retained for a possible subsequent peak load which might exceed the chiller capacity.

The schematic (Figure 3.2) overleaf shows the proposed hydraulics flow within the glycol circuit While controls operating on this mode of operation, the chilled glycol media flows through the piping system as indicated in light amber color line of the figure.

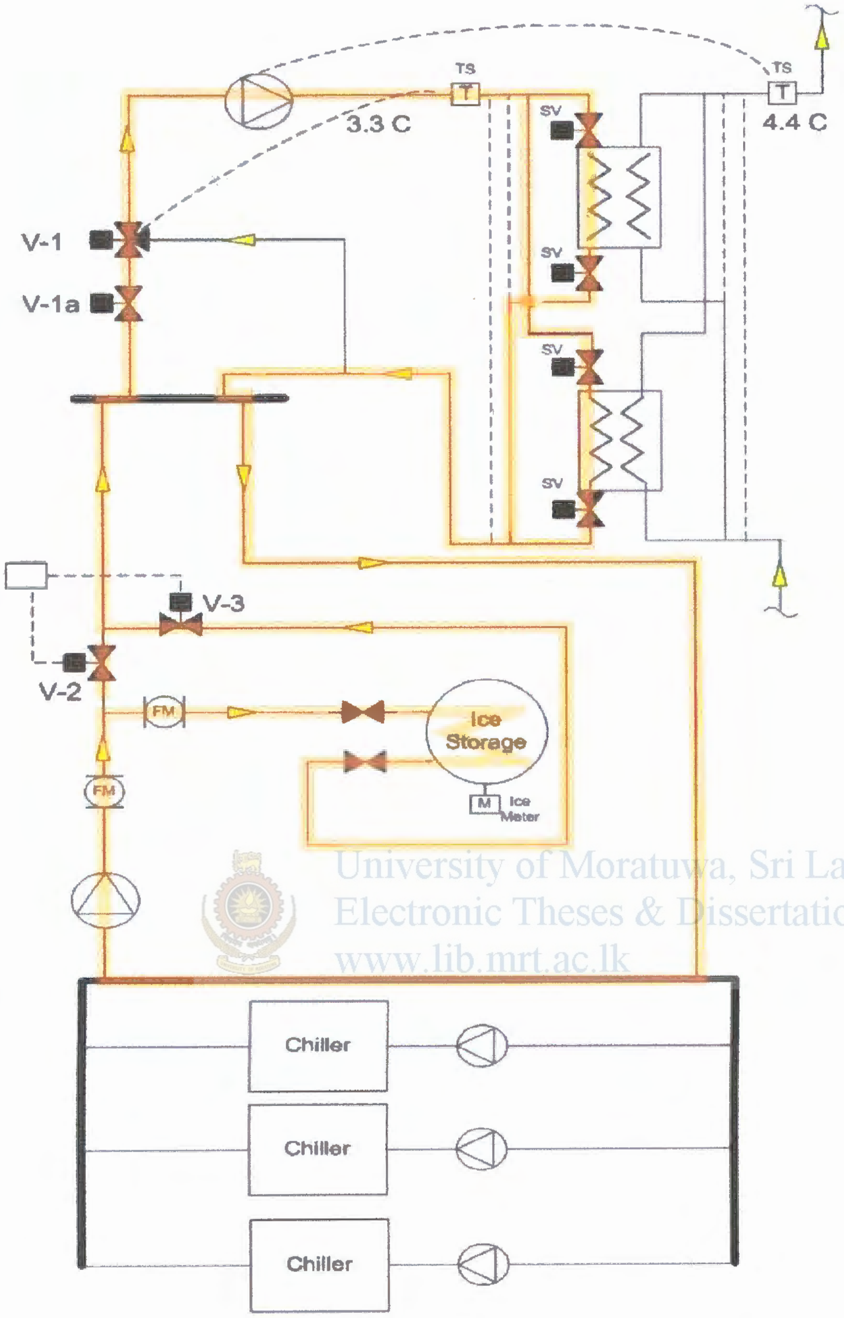


Figure 3.2 Glycol flow through the Circuit when Ice Priority Mode

3.1.3.1 Control sequence

The Glycol primary pumps (VFD) will be controlled to maintain the positive flow condition across the bypass of heat exchanger circuit.

The proportions of glycol supplied from the ice tanks and return warm glycol flow from the heat exchanger must be controlled to reach the mixed temperature (3.3°C) at the entry of heat exchangers.

This mode mostly occurs during the winter since the cooling demand during the day is considerably lower and will not require peak load within a specified time period.

The CPCS system will follow the start up procedure

- SV-1, 2, 3 and 4 will be opened to flow through the Heat Exchangers
- Valve V-1 will modulate to maintain 3.3°C to the heat exchangers
- Valve V-2 initially fully closed
- Valve V-3 is initially fully opened
- Glycol Heat exchanger pumps initiate operation and VFD will be ramped up based on the temperature set point (4.4°C) and flow temperature of leaving ChW of the ChW side of the Heat exchanger
- Glycol primary distribution pumps ramp up to preset value and keep running 5% higher speed than the set point of VSD of Heat exchanger pumps
- The mixed flow temperature, after the mixing point of glycol main line and ice circuit should be controlled to 3.3°C. This will be achieved by modulating valves V-2 (warm glycol returning from the Heat Exchanger) and V-3 (cold glycol received from Ice tanks) oppositely and proportionately. This will allow glycol to flow through the ice tanks to cause ice burning and maintain the glycol loop temperature at the design value of 3.3°C

The glycol chillers and their dedicated pumps will be kept off during the Ice Priority Mode of operation. Therefore no chiller sequencing will take place.

The cold glycol flowing out from the ice tanks may also have to be controlled within the heat exchanger circuit to its set point. This will be done by modulating valve V-1 to maintain the glycol supply temperature at 3.3C.

The process will be stopped when the CPCS detects that all usable ice is burned. Sufficient ice should be held in reserve to optimize ice build during the next cycle of operation.

3.1.4 **Peak Load** (Base Load Chiller + High.Temp Glycol Chiller + Ice Cooling)

When the day temperature reaches towards its peak summer values and the cooling demand is close to maximum, the base load chiller, ice storage and glycol chillers will all need to be utilized together to meet the needs of the building. Where the base load chiller is not available the ITES may operate in Peak Load mode with no base load chiller but further ITES modules will be needed to meet peak demand.

The peak demand will generally be a short period of the day. This should be met by burning the ice stored in the tanks combined with the operation of the glycol chillers. During Peak Load mode the glycol circulation volume will exceed the maximum value that can be cooled by the three glycol chillers alone.

The surplus glycol volume will circulate through the bypass and mix with the glycol cooled by the chillers. The mixed glycol will then be passed through the ice store as required to provide additional cooling to meet the load.

The diagram (Figure 3.3) overleaf shows the proposed hydraulics flow within the glycol circuit. While controls operating on this mode of operation, the chilled glycol media flows through the piping system as indicated in light purple color line of the figure.

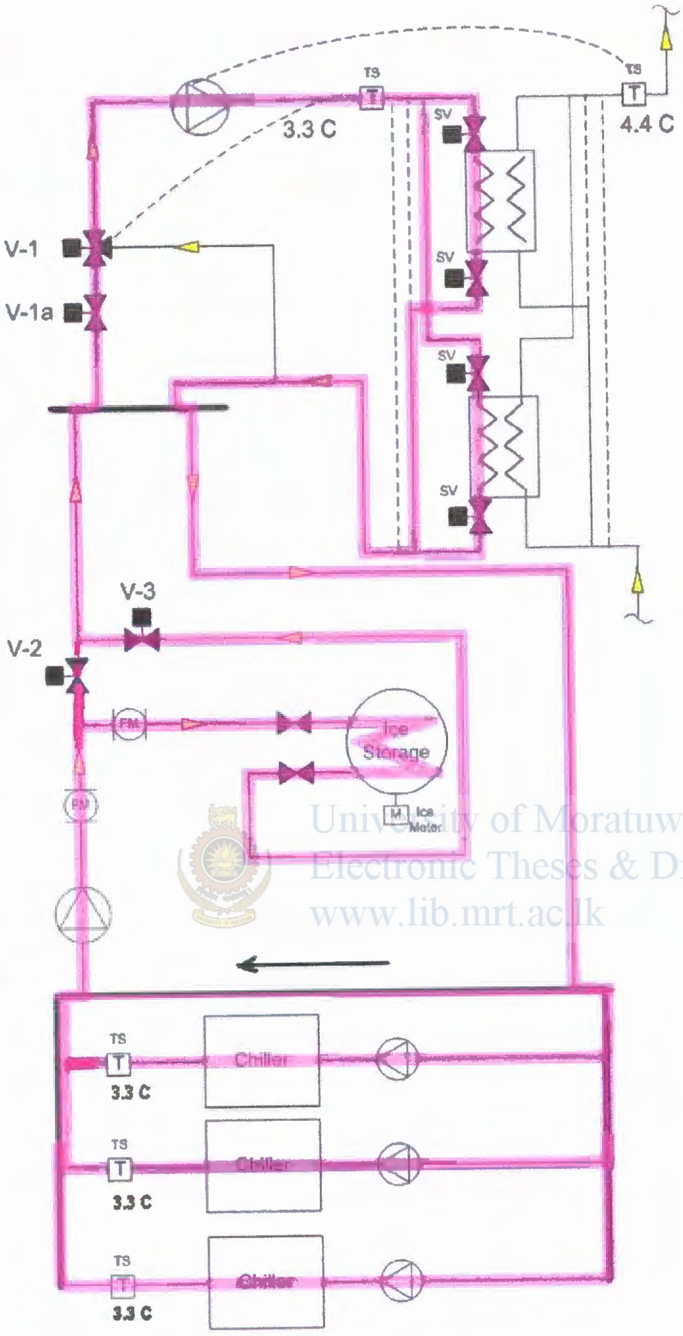


Figure 3.3 Glycol flow through the circuit when Peak Load mode

3.4. Control sequence

During Peak Load mode the glycol circulation volume will exceed the maximum value that can be cooled by the three glycol chillers alone. This additional cooling will be achieved by warm glycol flow circulating through the ice tanks.

The surplus glycol volume will circulate through the bypass and mix with the glycol cooled by the chillers and then be passed through the ice store in proportion as required to provide additional cooling to meet the load. The Glycol chillers set point will remain as 3.3°C.The HX pumps will be ramp up to maintain the chilled water flow temperature. The primary glycol pumps will follow 105% of the HX pump volumes. The glycol chillers will run at full capacity and cool the glycol returning from the HX to the coolest temperature possible at full load.

The chiller dedicated pumps will be run at full speed. Any remaining warm glycol will be diverted through the de-coupler. The mixed condition before the glycol primary pumps will be at a higher temperature than the chiller supply temperature due to warm bypass flow through the de-coupler.

The ice burn process will be much faster with this warm glycol circulation. This will generate additional cooling and an increased ice burn rate. This draw down of cooling from the ice bank will supplement the chiller capacity and allow the ITES to meet the peak load from the secondary ChW system.

Glycol cooled by the ice tanks will be at a much lower temperature (1°C) and this will be mixed with warm glycol flow flowing through the direct line by modulating valves V-2 and V-3 in proportion to achieve a resultant glycol flow temperature of 3.3°C. The cooling load demand reduces as the main heat of the day passes. This will reduce flow through the HX circuit.

The surplus flow through the glycol chiller bypass de-coupler will reduce and therefore the mixed glycol temperature and need for further cooling through by the ice store will decrease. Eventually as demand falls the chillers will be able to meet the demand on their own.

When demand falls further the chillers will be unloaded in parallel but the pumps will run at set point. When the flow through the de-coupler indicates that there is more than 110% of one chiller volume spare and therefore an excessive cooling load in the production circuit the CPCS will subtract a chiller from the system..

The CPCS will anticipate peak demand based on internal prediction strategies and change the mode to start the fast burn of the stored ice in the tanks. This will be achieved by initiating the following control procedures.

3.1.4.1.1 Control procedures

- Heat exchanger isolation valves SV-1, 2, 3, and SV-4 will be opened.
- V-1a valve will be opened by its local controls. V-1a is closed to isolate the heat exchanger circuit from the rest of glycol circuit. This will prevent glycol flow to the heat exchangers when the heat exchanger cooling demand is not operational.
- V-1 valve will be modulated to maintain the entry glycol temperature at the heat exchangers to set point (3.3C)
- V-2 will be initially open.
- V-3 will be initially closed.
- Glycol heat exchanger pumps will run and the pump VFD will be modulated to maintain the temperature set point (4.4°C) for the ChW flow temperature leaving the ChW side of the Heat exchanger.
- Glycol primary distribution pumps ramp up and run at 105% of the variable set point of VSD of Heat exchanger pumps
- The pump % speeds will be determined by the PID loops within the CPCS
- Dedicated glycol chiller shunt pumps will run and have their flow proven

- Glycol chillers will run after proving the flow and checking all safety routines.
- Glycol chillers will be sent their set point from CPCS (3.3 °C)
- Flow through the main glycol bypass and ice circuit will be monitored and recorded
- The Valve V-2 and V-3 will be modulated to maintain the resultant flow temperature to 3.3 °C.
- Temperature variations of system supply temperature sensor and return temperature sensor of the glycol secondary will be monitored and recorded.
- The ice burn process will continue until all usable ice in the storage tanks has been melted or Peak Load Mode ends. Sufficient ice should be held in reserve as calculated by the CPCS based on predicted weather conditions to optimize ice build during the next cycle of operation.

- Sequencing and staging of the chillers will be controlled to maintain a slight surplus in the bypass line.

3.1.5 Ice Build (Base Load +Ice Build Operation)

3.1.5.1 Ice Build cycle

When the cooling demand can be met by the base load chiller alone and the ice storage banks have been depleted, the glycol chillers will then run to recharge the ice store. The CPCS will initiate Ice Build Mode at the most efficient and economical time during the night using historical and predictive data. Where the base load chiller is not available the ITES may operate in Ice Build mode with no base load chiller but another ITES module will need to be enabled to meet any cooling demand.

With a full-storage configuration, a building's entire cooling load can be shifted to off-peak hours to make best use of any cheap rate electrical tariffs and reduce the strain on the local electrical infrastructure.

The glycol chiller only runs during off-peak 'night time' hours in order to store ice for use the following day. During peak daytime hours, the building's cooling is provided by the ice kW of refrigeration-hours stored within the Ice storage tanks during the night before.

The CPCS will switch the ITES equipment into ice build mode. The following schematic (Figure 3.4) shows the proposed hydraulic flows within the glycol circuit. While controls operating on this mode of operation, the chilled glycol media flows through the piping system as indicated in light blue color line of the figure.

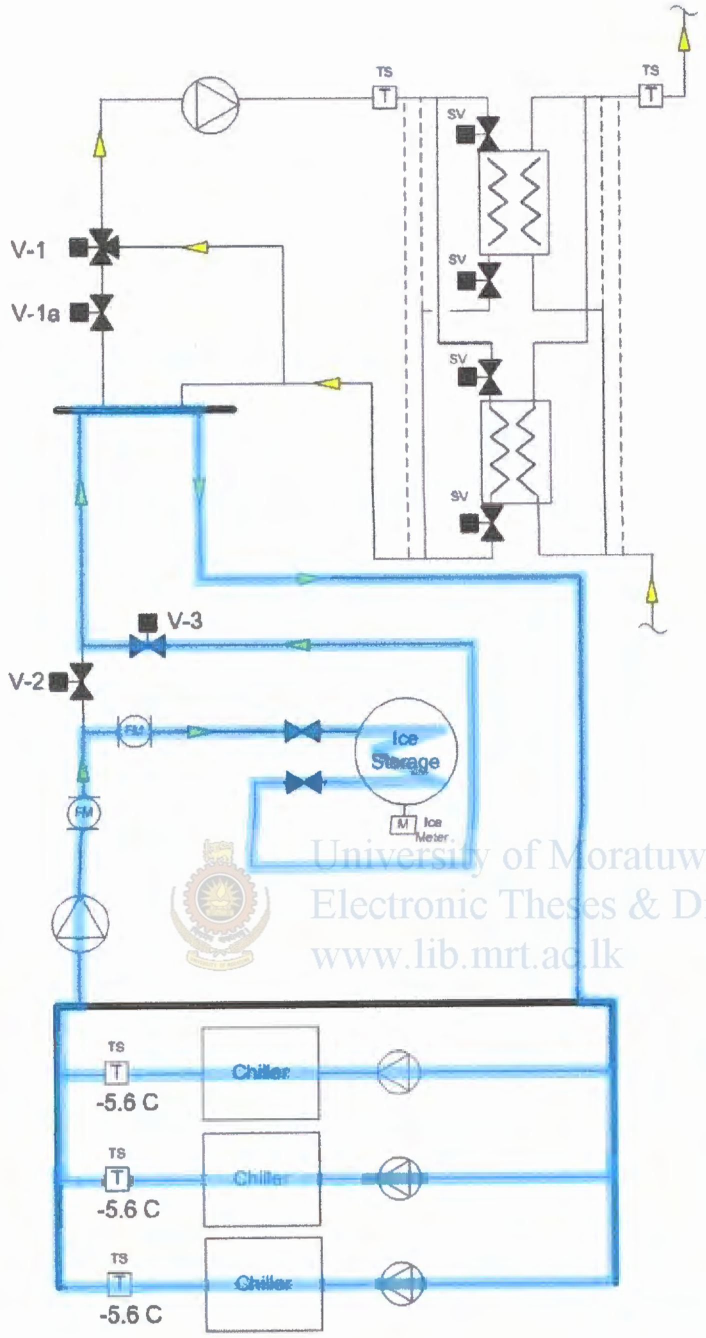


Figure 3.4 Glycol flow through the Circuit when Ice Build Mode

3.1.5.2 Control sequence

Valve V-1, V-1a and V-2 will be fully closed and V3 will be fully opened to allow low temperature Glycol to flow completely to the ice tanks bypassing Heat exchangers.

Glycol chillers will be staged in based on the demand calculated by glycol supply temperature monitored at Glycol Main Header. In this scenario, the three glycol chillers will be considered as the production loop and the Ice tanks will be considered as distribution loop. If the chillers are efficient in part load operation, it is most economical to operate them with equal loading to build ice. The staging out of chillers will be primarily based on a temperature-based algorithm (i.e. leaving temperature of the ice tanks) in conjunction with hourly estimate of thermal store in the ice storage.

The control strategy also measures the harvesting process via the ice meters to confirm that sufficient ice has been built before the CPCS stages out the glycol chillers.

The glycol chiller system pumps will be enabled first by the CPCS to initiate the ice build process. The CPCS will send set points to the VSDs and operate a suitable number of pumps based on glycol flow to the ice tanks required. However it should not be less than the minimum flow requirement of the VSD. The number of chillers operated and maximum flow requirement to build ice are determined by the CPCS based on temperature of the glycol in the ice tank. Each glycol chiller will start with its dedicated pump and be staged on line to load itself based on the set point (-5.6C) assigned in the Ice build mode by the CPCS. The process will continue loading the glycol chillers equally until the ice build is complete. The kWh of refrigeration stored as ice will be calculated by the CPCS which will ramp down the VSDs of the glycol pumps as per estimated kWh required to complete the ice build process.

Ice build will continue until the leaving temperature of the ice tanks approaches the chiller leaving temperature long enough to ensure all ice has been built. The process will be interrupted by Ice build meter alarms. Once ice build is complete, the glycol primary pumps will be ramped down to their minimum set point and chiller/ pump combinations will be turned off. Four (4) ice inventory meters will be installed for each ITES module. Two ice meters will be installed for each of the two groups with one installed at first ice tank of the group and one installed in the last tank of the group as that shown in schematic diagram. The ice meter will automatically display the tank ice inventory and will be electronically connected to the CPCS.

3.1.5.3 Start up Procedure

- SV-1, 2, 3 and SV-4 will be fully closed to isolate heat exchangers from the heat exchanger circuit.
- Valve V-1 and V-1a should be fully closed so isolating heat exchanger circuit
- Heat exchanger pumps are switched off
- Valve V-3 should be fully opened, V-2 should be fully closed
- Primary glycol pumps VSD are sent the control speed set point and ramped up
- Chillers set point will be set to -5.6 C by the CPCS
- Chiller shunt pump is started
- Chillers will be perform internal safety operational checks then start
- All chillers will be equally loaded and will be staged on after flow is proven
- Flow volumes will be recorded by CPCS for its use in predictive calculations

After performing the above start-up functions, the chillers that have been started will be equally loaded and run continuously to perform the ice build operation. The ice build will be interrupted by the CPCS when it has reached any of the following conditions

- Return glycol temperature from the Ice tanks is below set point
- Ice harvesting meters register ice stores are full to capacity
- The refrigeration requirement estimated to build ice is more than the current spare refrigeration capacity

CPCS software will be capable of staging out the chillers based on the above conditions and also ramping down the glycol primary pumps VSD when the chillers are switched off.

3.1.5.4 Shut down sequence

This procedure will be started by the CPCS initiating the following steps

- Chillers will be turned off
- Dedicated shunt pumps disabled after associated chillers are off
- All the primary glycol distribution pumps will be shut down

3.1.6 **Ice Build plus Cool** (Base Load Chiller + Low Temp. Glycol Chiller)

During night operation the glycol chillers are busy on ice build mode. However this process will be interrupted by the CPCS if the primary ChW supply temperature rises above 4.4 °C due to a demand rise in the main ChW distribution circuit. This signifies that base load chillers can no longer satisfy the cooling load alone.

Where the base load chiller is not available the ITES may operate in Ice Build Pus Cool mode with no base load chiller if cooling demand is very small or being met by another ITES module. This will be monitored by the CPCS and will activate its sub control functions to provide additional cooling.

The following schematic diagram (Figure 3.5) shows the proposed hydraulics flow within the glycol circuit. While controls operating on this mode of operation, the chilled glycol media flows through the piping system as indicated in green color line of the figure.

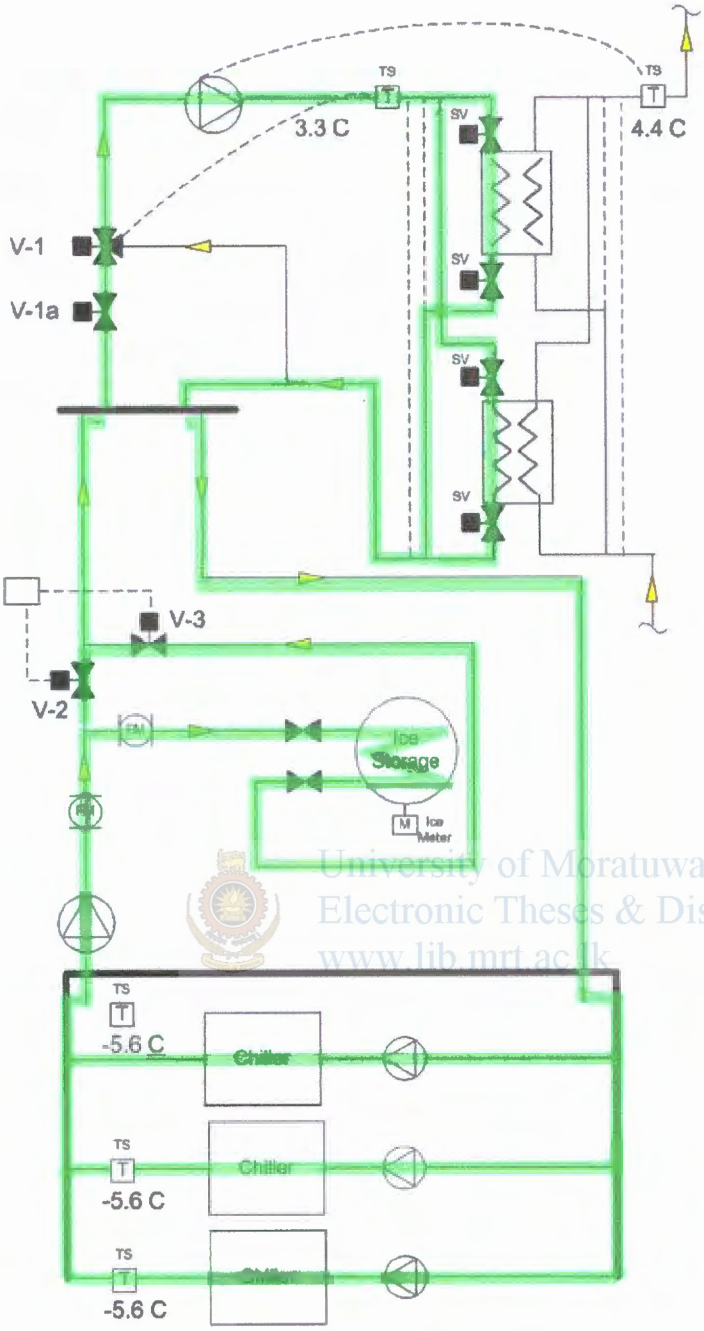


Figure 3.5 Glycol flow through the circuit when Ice Build Plus cooling mode

3.1.6.1 Control sequence

During the night time ice build mode of operation if the primary ChW supply temperature raises above 4.44°C this signifies that base load chiller can no longer satisfy the cooling demand alone. CPCS will perform following operation in order for achieving 3.3 °C within the Heat Exchanger circuit and required ChW flow condition based on the demand

The following sequence will demonstrate the additional task that has to be carried out by CPCS while the glycol system is occupied with Ice build operation.

Valve V-3 will be fully opened and V-2 will be fully closed continue to stay in the same status (current status of mode is Ice build)

Valve V-1a. will be opened and flow will be build up in the main line.

The heat exchanger pumps (VSD) will be controlled based on the ChW set point (4.4 °C) and the Leaving ChW temperature of the Heat exchanger.

Glycol primary pumps will be ramped to achieve 5% above the speed of heat exchanger pumps speed.

If the glycol flow temperature increases above 3.3 °C in the heat exchanger circuit then the valve V-1 will be modulated based on the glycol entry temperature at the Heat exchangers and its set point.(3.3 °C)

The glycol supply temperature to heat exchangers will be maintained (normally 3.3 °C) by mixing the two glycol streams from the main distribution line (cold glycol from the ice tanks) and re-circulated warm glycol leaving from the heat exchangers at 3-way valve (V-1). This valve control will be used to prevent the glycol temperature onto the heat exchanger falling below 2C.

The operation of chillers will be done by the CPCS based on the temperature changes at the main glycol supply header.

3.1.6.2 Start up Procedures

- Chillers are running in ice build mode and continue to run
- SV-1, 2, 3 and 4 will be opened to flow through the heat exchangers
- V-2 will continue to stay in off position and V-3 will continue to stay in open position

- Modulate V-1 to mix low temperature glycol (approximately between 1°C to -2.2°C) leaving from the ice tank with warm glycol within the heat exchanger circuit to reach 3.3°C (Control Loop-A as shown in Diagram 5.1)

- Glycol heat exchanger pumps VSDs will be ramped based on the temperature set point (4.4°C) and flow temperature of leaving ChW of the ChW side of the heat exchanger (Control Loop-B as shown in Diagram 5.1)

- Glycol primary pumps ramp up to preset value and keep running 5% higher speed than the set point of VSDs of heat exchanger pumps

- The output of PID loop controlled variable (VSD speed) of the Loop-B has slower response in time compared to the response of output of the PID Loop-A controlled variable (Valve position) .This is called reactive response on glycol temperature and will be tuned on site during commissioning.

3.1.6.3 Mode Exit Procedures

The heat exchanger pump VSD will ramp down to match falling cooling demand.

When the VSD has reached minimum permitted frequency the VSD speed will be limited at that value.

Any further decrease in primary ChW cooling demand cannot be met by reducing the volume of glycol supplied to the heat exchanger. A further decrease in cooling demand will be met by adjusting the base load chiller flow temperature set point so that the chiller cooling combined with the heat exchanger cooling results in the correct primary ChW supply temperature.

The base load chiller loading will be monitored by the CPCS. When this has dropped low enough to provide sufficient spare base load chiller capacity to replace the remaining minimum residual glycol cooling, then the heat exchanger cooling will be shut off without compromising the primary ChW flow temperature. The ITES will revert to Ice Build Mode operation.

Then CPCS will initiate shut down procedures:

- Base load chiller supply set point is reset to 4.4 °C

- Heat exchanger Pumps will be turned off

- V-1 will be fully closed

- VS-1, 2, 3 and 4 will be closed isolating heat exchangers

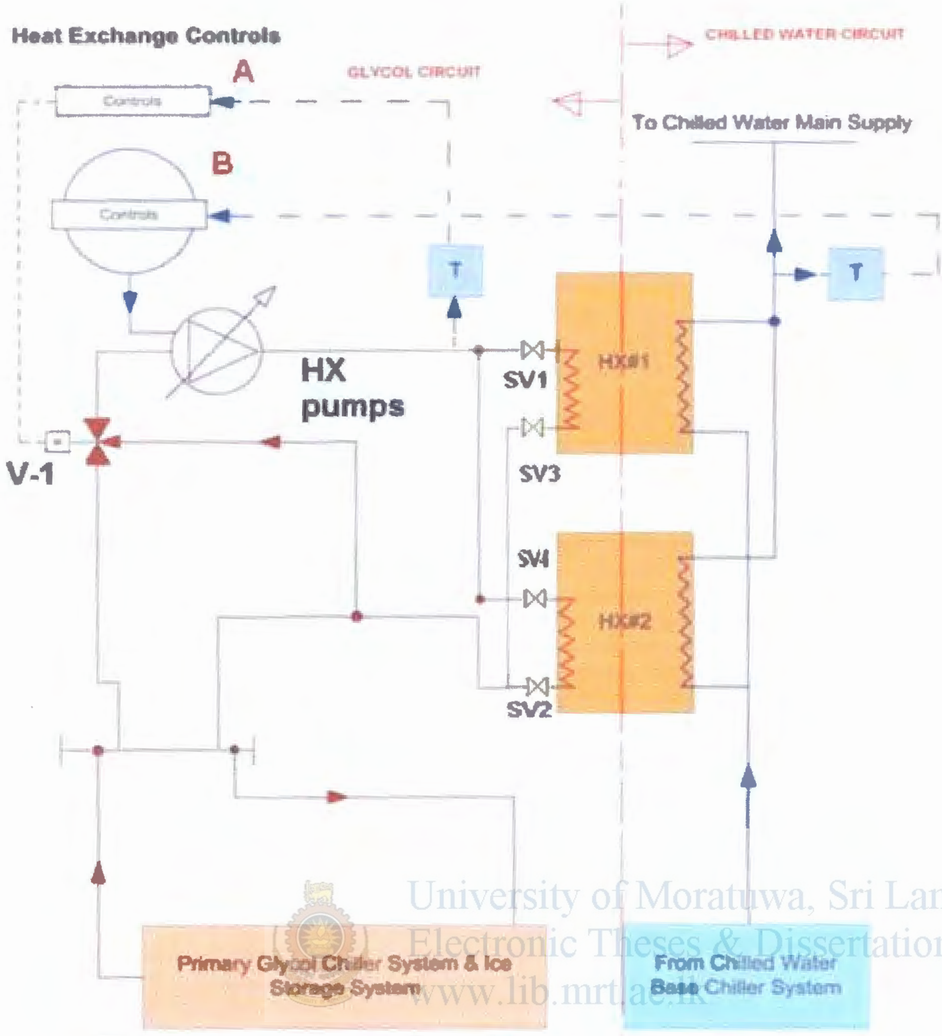
Chapter 4

Control Strategies for Sub Systems

4.1 System Control Strategies for Sub Systems

The various control elements of the sub systems are controlled independently to achieve specific conditions as measured by sensors in the system. The principal elements are:

- Control of heat exchanger mixing valve
- Control of heat exchanger circulation pumps
- Control of glycol and chilled water heat exchanger freeze protection (SV1 to 4)
- Control of ice Storage flow and bypass vales
- Control of glycol chillers and shunt pumps



The above control loop A and B are sub routines of CPCS. However they are running in Local controllers.

Control Loop A :controls the Glycol temperature (3.3°C) modulating the valve V-1
Control Loop B :controls the ChW temperature (4.44°C) modulating the VSDs of the HX pumps

Figure 4.1 Glycol sub system interface with the Main Chw System

4.1.1 Control of Heat Exchanger Mixing Valve

CONTROL LOOP A.

V-1 valve is controlled to maintain glycol supply temperature set point to 3.3 °C. The control loop will be controlled using PI controls and set point will be considered as 3.3 °C. This control loop is active in the following ITES modes of operation

Mode 3 ICE PRIORITY
Mode 4 PEAK LOAD
Mode 6 ICE BUILD PLUS GLYCOL COOLING

4.1.2 Control of Heat Exchanger Circulation Pumps

Control Loop B

The VSD of heat exchanger pumps will be controlled to maintain the leaving chilled water temperature from the heat exchangers to a set point of 4.4C. The control loop will be controlled using PI controls and set point will be considered as 4.4 °C

a. Mode 2 Chiller Priority
b Mode 3 Ice Priority
c Mode 4 Peak Load
d Mode 6 Ice Built plus Cooling

4.1.3 Glycol and Chilled water heat exchanger freeze protection:

To protect the glycol to chilled water heat exchangers from freezing during the ice build mode, freeze-stat operated solenoid valves SV-1, SV-2, SV-3, and SV-4 are to be installed on both inlet and outlet glycol pipes for each heat exchanger.

The heat exchanger pumps will be stopped and these solenoid valves will be operated to shut the line off as soon as the in-line sensor in the discharge side of the control valve V-1 pipe senses the glycol fluid temperature at 1°C (33.8°F) or below.

The solenoid operated valve will be shut and the change of state will be reported to the CPCS system and dynamically shown on the schematic diagram on the Monitor. The isolation valves should be interlocked with heat exchanger pumps and valve safety circuit of the system

4.1.4 Control of Ice Storage flow and bypass valves

Control Loop C

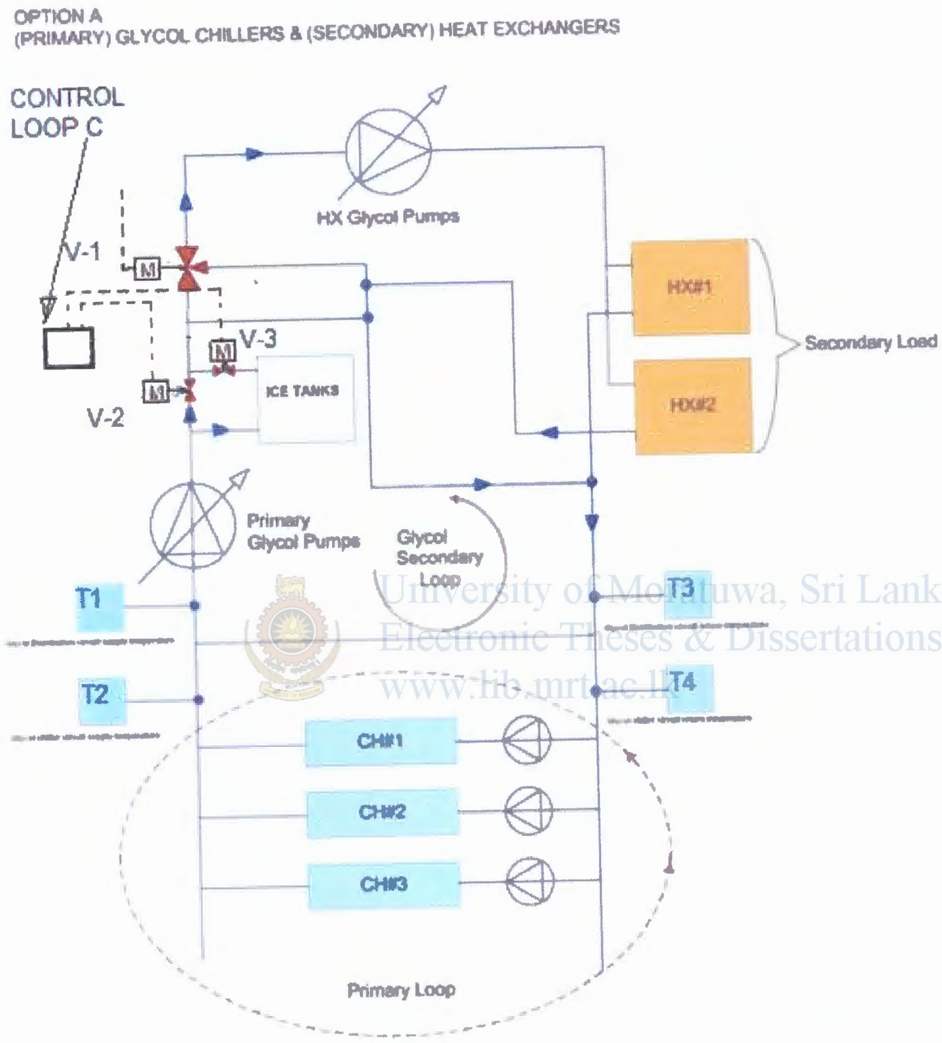


Figure 4.2 Glycol Chiller plant control with different Sub systems

Control loop C in diagram above

The valves V-2 and V-3 will be modulated oppositely and proportionately in order to achieve a HX supply glycol set point of 3.3C.

This control loop C is active in the following ITES modes of operation:

a. Mode 3 Ice Priority
b. Mode 4 Peak Load
c. Mode 6 Glycol Cooling plus Ice Build

Valve V-2 is shut and Valve V-3 is fully open in

a. Mode 5 Ice Build

Valve V-2 is open and Valve V-3 is fully shut in

a. Mode 2 Chiller Priority

4.1.5 Control of Glycol Chillers and Shunt Pumps

Generally the glycol chillers will be started and sequenced by the CPCS to ensure there is a slight surplus flow in the glycol chiller bypass pipe.

If the secondary glycol distribution increases and the flow in the bypass approaches flow reversal then another glycol chiller and its associate shunt pump are started.

When cooling demand is falling the CPCS continues to monitor the surplus flow through the bypass.

When the surplus increasingly exceeds the volume supplied by one glycol chiller (say 110% initially but adjusted during commissioning to ensure stable operation) then one glycol chiller is disabled. This surplus flow must be maintained for a suitable and stable period of time before shutting the chiller down to prevent rapid cycling. The trend as well as quantum of the surplus flow should be used in the control strategy.

4.1.6 CPCS System Architecture and Subroutines

The CPCS application software will be composed of 4 main control sub-functions

- ITES module plant operation within the CPCS
- Glycol chiller sub system operation within the GCPCS (sub-system)
- Heat exchanger controls with HXCS (Sub System)
- Pumps system sequencers

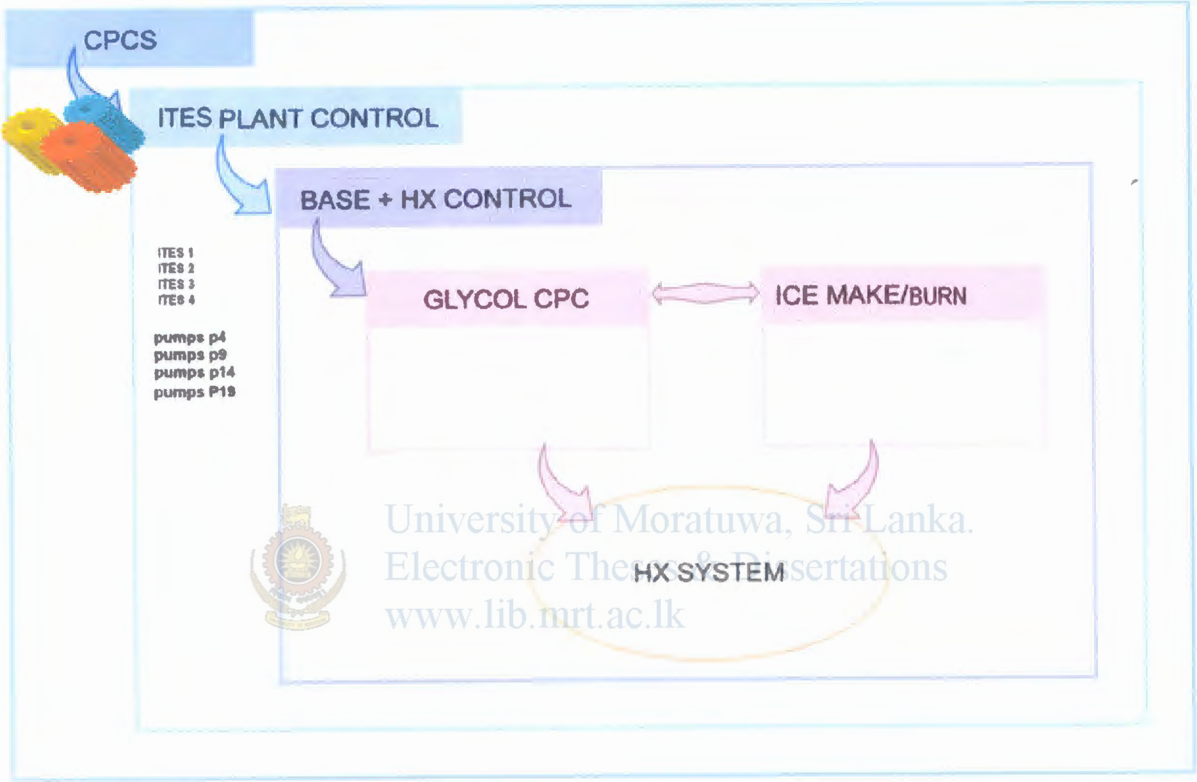


Figure 4.3 CPCS Architecture
This shows the modular architecture of the sub system communication via its internal structure

1.) The CPCS will be configured with full chiller management software.

2.) The software systems as above Fig 4.3 will be classified into sub systems. The Base load chiller system and glycol chiller plant control system (GCPCS), which controls sub functions of the glycol sub system.

3.) There will be four number ITES modules with an associated control strategy featuring all its integral CPC functions.

4.) The CPCS will compute the best operational strategy to operate plant by consulting its intelligent sub modules, such that computational algorithms, recorded weather data, recorded previous operational conditions, models derived based on latest weather updates and interactive operator inputs.

5.) The Chilled water primary pump of the lead ITES module will be started based on sequencer selection. Once the flow is established the ITES module (base chiller) will be commanded to turn on by the CPCS.

6.) The Base Load chiller set point will be communicated to the chiller controls and to the Heat Exchanger controls by the CPCS.

7.) The chiller will call for its shunt pump and once this and the primary pumps establish flow through the chiller, the base load chiller will be started.

8.) If the Base Load chiller loading approaches maximum then the CPCS will bring the glycol sub system on line to assist the base load chiller.

9.) The base load chiller will be assisted by the heat exchangers to bring down the cooling demand transferred to primary ChW from the secondary circuit.

10.) The glycol sub system will be staged in with its relevant mode of operation as commanded by the CPCS.

11.) The ChW supply temperature for the primary circuit will be the major control dynamic of the glycol sub system. The ChW temperature measured at heat exchanger leaving leg (and its set point (4.44°C)) will control the VSD of the heat exchanger pumps, thereby increasing flow in the heat exchanger circuit. (Control LOOP B refer the diagram 5.1)

12.) The varying of glycol flow through heat exchanger circuits might affect the glycol temperature at the entry of heat exchanger (3.3 °C). This will be controlled by modulation of valve V-1 in the various different modes of operations. The target is to keep the glycol temperature at a set point of 3.3 °C.

13.) The glycol chillers will be sequenced and started to maintain a small surplus primary glycol flow compared with the secondary distribution based on the glycol flow supply temperature and the return temperatures of the main glycol headers and flow sensor readings in the bypass pipe.

14.) The automatic sequence routines also reside within the CPCS software. Sequence order for the ITES modules will be computed on a weekly basis and stored within the system. If there is any fault of either the base chiller or heat exchanger system then the respective ITES module will be taken out of the sequence by marking it as unavailable to the CPCS sequencer. Once it is ready to operate once more the system module will be identified and automatically entered to its sequencer.

15.) At the operator console it should be displayed as unavailable / available. Should an entire module be taken out of the programming, the CPCS software will ignore that module in its sequencing and consider this to be an alarm state. It also should show the new sequence of chillers based on available healthy modules.

16.) The secondary chilled water distribution circuits (P1, P2, and P3) will have flow temperature sensors in the supply and return headers. The supply and return temperatures measured on both the primary and secondary sides of the main bypass line (T1, T2, T3 &T4 as shown in Diagram 2.1) will be measured and compared to confirm that there is no reversal of flow direction through the bypass. This will also be measured by the flow measurement sensor.

17.) The CPCS will continuously adjust the set points of VSDs to vary the primary glycol pumps speed through the glycol circuit (within the maximum volume flow range allowed) in order to maintain small surplus flow through de-coupler line. The flow measuring stations on secondary circuits and the supply and return temperature sensors in the respective distribution circuit headers will allow the CPCS to monitor the tonnage being consumed, to assist in determining the number of ITES system modules to operate and to manage ice burning routines by ITES modules.

18.) When the secondary cooling load increases more and more chilled water is pumped through the secondary circuits to match the opening of the systems two-way valves. In order to maintain the de-coupler flow set point the primary ChW pumps gradually ramp up to their maximum limit. This will result in an increased volume flow through the ITES modules that are enabled. Once the primary pumps start to approach to their maximum speeds they will no longer be able to maintain the positive volume flow set point through de-coupler (initially set to 2%). The CPCS will start the primary ChW pumps of next ITES module in the sequence and ramp up the pump speed to fulfil the flow requirement through secondary circuit while maintaining the small surplus flow through the de-coupler.

19.) Once the flow requirement in the secondary circuit is satisfied, the CPCS will start to allocate resources (base load chillers, glycol chillers and ice tanks) from the next ITES module to maintain the ChW temperature set point (4.4 °C)

20.) The selection and sequencing of ITES modules and operational modes will be done by the CPCS based on the load prediction profile. The selection will be done in order to generate sufficient cooling in the primary system as needed to meet the instantaneous and predicted future loads in the most efficient way.

21.) The operation of the control strategy for the distribution circuit will be determined predominantly by the system dynamics. For example, the secondary circuits will be complete with differential pressure sensors. These will feed any pressure variations through PID control loops to the VSD control on the pumps so enabling flow regulation. The software will maintain a constant DP to ensure that the distribution will not be starved or over pressurized.

22.) For optimum system operation, the maximum number of ITES Modules will be operated to maintain "Ice Priority" operation. (This scenario will be taken place when all the ITES modules are installed and in operation.)

23.) The primary chilled water pump set for each ITES modules will have three pumps, 2 for full load operation and 1 standby. The three pumps will be rotated on a weekly basis to equalize run time. The standby pump will be brought into operation in case of failure of one of the duty pumps, or whenever the secondary chilled water system fails to maintain the designed 10°K delta T and returns with a temperature higher than designed - i.e. above 15.44°C. The CPCS will automatically notify the operator by raising an alarm for immediate system maintenance and correction.

24.) Variable speed drives are supplied with set points by the CPCS in order to ensure proper flow management of the secondary circuits. The speed control system of the secondary chilled water distribution loop pumps (PI, P2, and P3) will maintain the required system differential pressures in each individual circuit.

25.) The lag/standby pump will be started if lead pumps are operating at maximum speed and the differential pressure continues to fall. All operating pumps will share the same speed signal.(same set point to the VSDs) The operating speeds of the pumps will be set within the maximum range of operating parameters, typically 20-100%.

26.) In the chiller plant control algorithm, an approach towards zero flow condition in the bypass line and possible flow reversal indicates that there is a positive demand for more cooling requirement within the buildings. So the primary chilled water pump speeds are ramped up to maintain the small surplus through the bypass and the CPCS selects and operates the appropriate mix of ITES modes to maintain the primary chilled water supply temperature set point.

27.) Theoretically if the system exactly satisfies the demand from the load then there is no flow through the main by-pass line and it is recognized as equilibrium stage of the system. In practical terms although his is the most efficient state it is more difficult to control in a real situation so the CPCS will seek to maintain the smallest possible surplus flow through the by-pass line consistent with good steady control.

28.) If the system two-way valves close in the secondary circuit, and system is operating more chillers than it is required, the excessive chilled water flow will be diverted through the bypass to the primary system return line. This causes the primary system return temperature to drop (T2 in the Diagram 2.1).

29.) When the flow volume through the by pass is greater than 110% the flow volume of one whole ITES module and the primary chilled water supply temperature is achieving its set point (4.4°C) and the 1st ITES is running with minimum resources then CPCS will subtract the first lag ITES module and the associated pumps. This threshold set point will be adjusted during commissioning. The lag ITES module will be disabled from the CPCS. This will ensure that the remaining ITES module(s) run with a small surplus flow through de-coupler and chilled water supply temperature remains at its set point.

Chapter 5

Analysis of Seasonal Load Demand Profile

5.1 Typical Seasonal Demand Profile

The graph below (Figure 5.1) shows the building load in a typical peak demand design day.

The estimated load profile is considered to be moderately consistent based on historical data recorded in this region of where the selected project located (Garden project in Middle East).

However, in our design we require that the necessary adjustment and flexibility will be included in the specialist software to cope with the local impact of climate change.

In order to achieve this, the proposed system should include a load profile prediction methodology. This will use multiple load estimate inputs, weather data records and the actual load data from the previous day. This will require interactive operator input into the control software.

In order to optimize energy usage an ice storage system is proposed. The ice storage strategy will ensure that the chillers and mechanical equipment are used in the most efficient way and reduce the size of plant and electrical load to meet peak loads.

The Ice storage system proposed, provides the system with the principal method of dealing with the peak load requirement of the building profile as illustrated in Figure 5.1

Figure 5.1 shows the distribution of loads in the primary production cycles.

- Light blue color (bottom) represents supply from base load chillers:
- Purple color (middle) the supply from glycol chillers
- Grey bars (top) cooling produced from stored ice

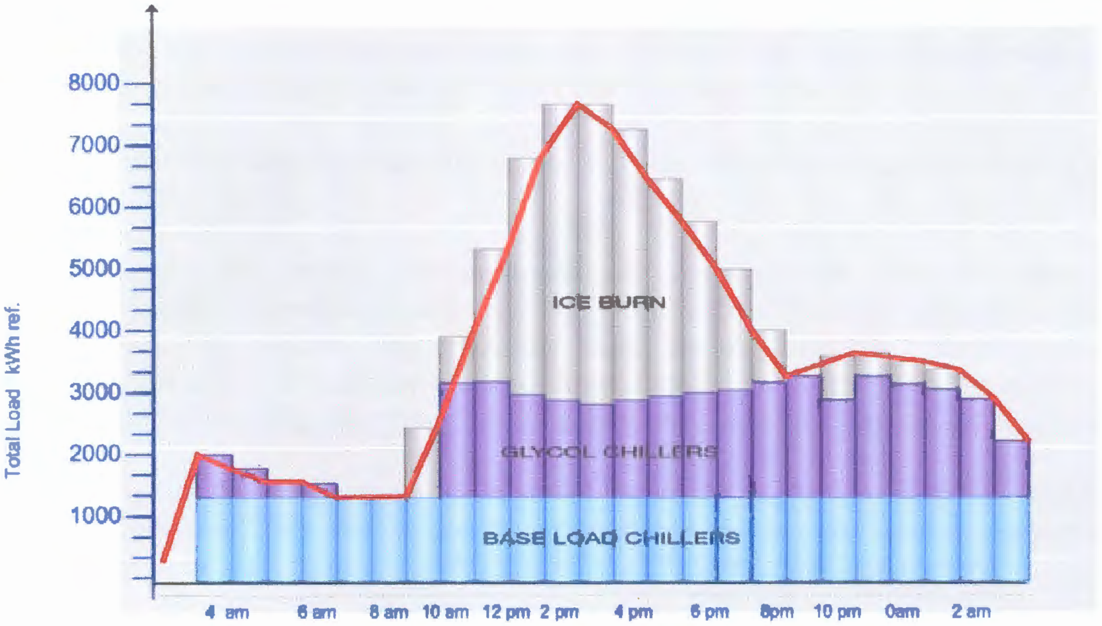


Figure 5.1
Thermal load contour of the building and its distribution from primary production cycle

The building load is the boundary curve in red illustrated in Figure 5.1; and indicates the load profile of building load in a typical design day. The load should be achieved with optimum and economical operation of the mechanical system.

The ice storage system uses standard glycol chillers to make ice at night when utilities potentially charge less for electricity and cooling demand rates are low.

The ice cooling supplements or even replaces mechanical cooling during the day when utility rates are potentially at their highest. Another advantage of ice storage is that it acts as standby cooling capacity in a situation where the base load water chiller is unable to operate, until the CPCS switches over to standby ITES modules.

On a peak day, the total glycol chillers and base load chillers capacity alone will not be sufficient to meet the predicted peak demand of the profile.

The peak load is achieved using the base load chillers, glycol chillers and the cooling produced in the ice burn process. Latent and sensible heat is absorbed from the glycol system during the melting process of ice. This is the basic concept for the design that has been proposed for the cooling load distribution to match the load profile of the cooling systems.

n a typical design day, the base load chillers should operate in combination with glycol chillers, ice storage facilities and heat exchangers to achieve all its building thermal load requirements while ensuring the minimal power input to the system.

The ITES consists of chillers, heat exchangers and variable volume pumps operating via VSD.

The optimization of daily energy consumption largely depends on the selection of the most economical modes of operation based on kWh, kVA ratings, store ice capacity and the current efficiency of chillers. The efficiency varies mainly with the external ambient conditions of the day. It is intended that the chillers should be operated for the minimum number of hours during high day time ambient conditions when they run less efficiently.

The efficiency of the chillers during night operation is higher due to low ambient temperature condition. The charged ice is burned during the day and used to support the refrigeration load in order to match peak requirement of the building load contour.

Maximizing the night time hours of operation, where low ambient conditions occur, will benefit operation through more efficient refrigeration which is then stored as ice.

In Figure 5.2,

- Light blue (bottom) represents base load chiller cooling
- Purple (middle) indicate glycol chiller cooling
- dark blue (middle) bars represent ice build
- Grey bars (top) shows peak load.

In 'Night time' operation electricity is used, at a potentially more economical tariff, rate in order to produce and store cooling required for day time operation.

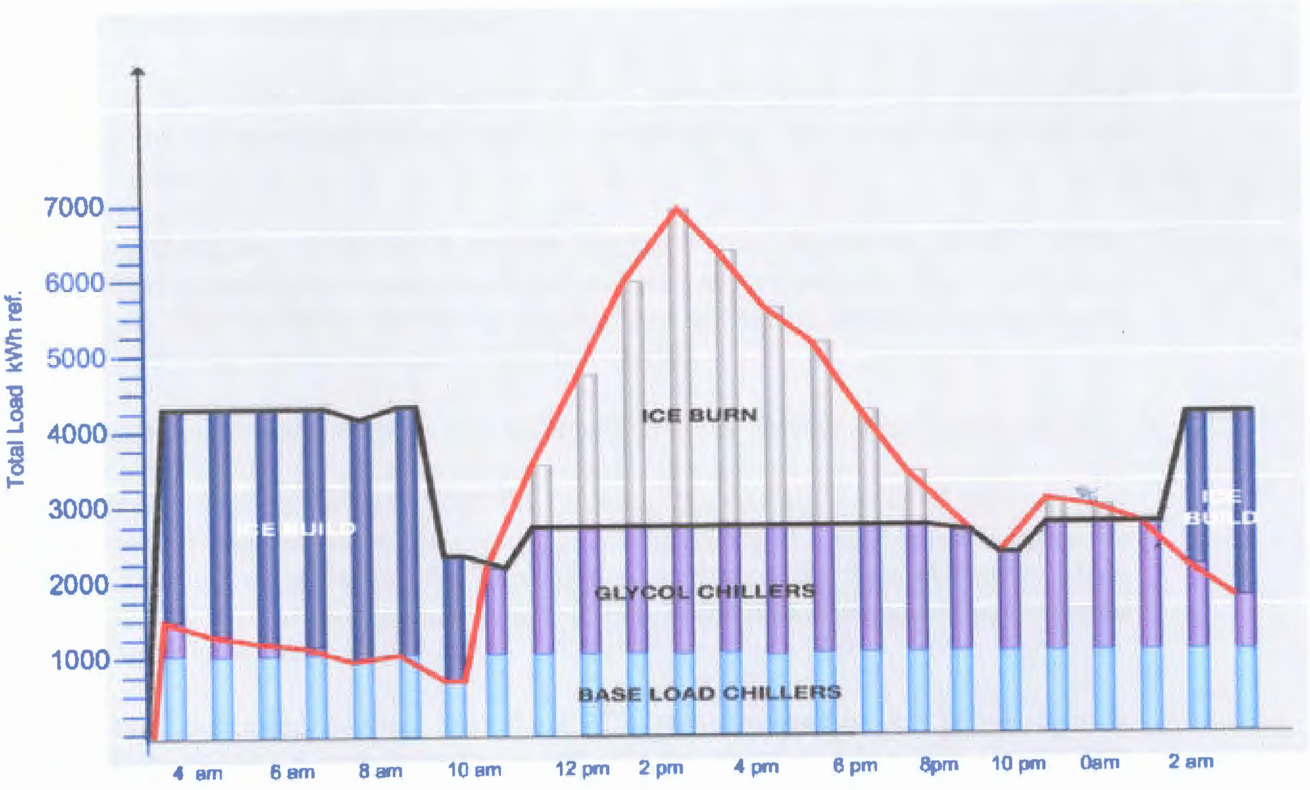


Figure 5.2 Peak load matching with Ice produced

As shown in the Graph, the ice build in the night operation will be burned to match the peak load matching. The optimization process will accurately provide the number of ice banks to be ready when the day starting and how fast it should be burned to absorb required cooling load.

5.2 Typical Summer Profile:

The cooling load on the base load water chillers is initially high but reduces through the early hours of the morning to a minimum just before dawn. (Base Load) Please refer to Graph 6.2 above

Meanwhile, the glycol chillers work at their maximum low temperature (-5.6°C) output, their efficiency gradually increasing as the ambient air temperature falls. As the ice tanks fill up towards dawn, the output of the glycol chillers is gradually reduced, and they may eventually switch off completely. (Ice Build)

For a short period of time the base load water chillers may operate alone. (Base Load)

As the cooling load increases through the morning, the cooling power of the base load water chillers is augmented by the glycol chillers operating at their normal temperature of 3.3°C for cooling operation, the flow of glycol through the heat exchanger being adjusted to maintain the design secondary chilled water circuit supply temperature of 4.4°C. (Chiller Priority)

Approaching maximum cooling load the CPCS switches part of the glycol flow is diverted through the ice bank to burn ice and delivers glycol at 1 °, which when mixed with the un-diverted flow, results in the normal heat exchanger glycol entering temperature of 3.3°C. (Peak Load)

The CPCS control strategy will aim to burn all stored ice except for the day-to-day reserve by (but not before) the end of the peak cooling period.

At the end of peak cooling load, when ice burn is no longer required, the CPCS switches the glycol chillers back to their medium temperature mode, pending reduction of the cooling load to the point at which ice building become economical. (Chiller Priority)

When cooling load and air temperature have both reduced after sunset, the CPCS switches the glycol chillers to low temperature ice build mode. (Ice Build)

If there is any cooling demand in excess of the base load, it is met by mixing glycol from the heat exchanger outlet with that direct from the chillers to maintain the normal 3.3°C inlet temperature. (Ice Build plus Cooling)

5.3 Typical Winter Profile:

The cooling load on the base load water chillers is low and reduces through the early hours of the morning to a minimum just before dawn. (Base Load) Please refer to Graph 6.3 below.

Meanwhile, the glycol chillers work at their maximum low temperature (-5.6°C) output, their efficiency gradually increasing as the ambient air temperature falls. As the ice tanks fill up towards dawn, the output of the glycol chillers is gradually reduced, and they may eventually switch off completely. (Ice Build)

For a short period of time the base load water chillers may operate alone. (Base Load)

As the cooling load increases through the morning, the cooling power of the base load water chillers is augmented by the glycol circuit using cool glycol from ice melt in the ice tanks mixed with warmer return glycol to achieve a 3.3°C glycol supply set point. The flow of glycol through the heat exchanger will be adjusted to maintain the design secondary chilled water circuit supply temperature of 4.4°C. (Ice Priority)

The CPCS control strategy will aim to burn all stored ice except for all the day-to-day reserve by (but not before) the end of the peak cooling period.

At the end of peak cooling load, when ice burn is no longer required, the CPCS may switch the glycol chillers back to their medium temperature mode, pending reduction of the cooling load to the point at which ice building become economical. (Chiller Priority)

When cooling load and air temperature have both reduced after sunset, the CPCS switches the glycol chillers to low temperature ice build mode. (Ice Build)

If there is any cooling demand in excess of base load, it is met by mixing glycol from the heat exchanger outlet with that direct from the chillers to maintain the normal 3.3°C inlet temperature. (Ice Build plus Cooling)

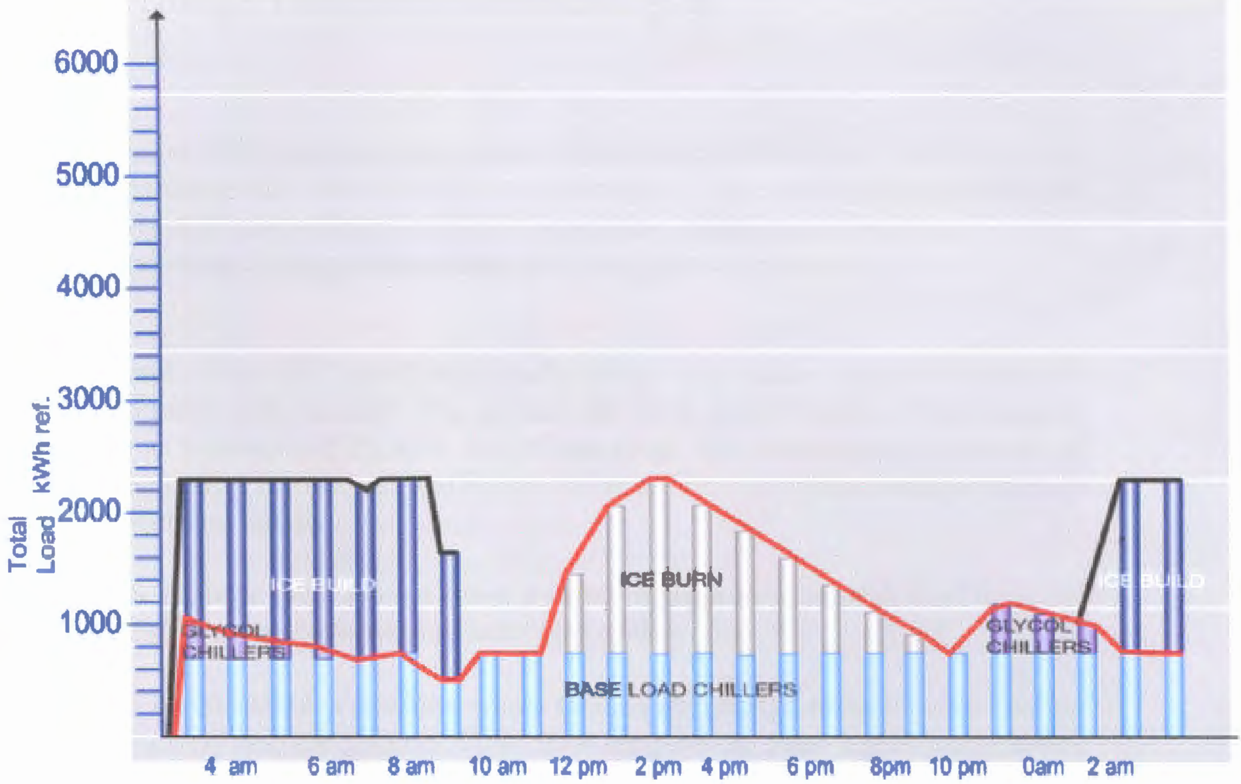


Figure 5.3 Typical Load sharing in the winter season.

The Graph shows the total ice build, base load and Ice burn operation more likely happening during the day and night time operation. However Glycol normal chiller operation seems to be very rarely happening transient periods of the different modes.

.4 *Load Profile Prediction Methodologies*

Overview

The specialist ITES supplier will supply a dedicated chiller plant control system (CPCS) including full predictive software strategies. These strategies will select the most appropriate and efficient modes of operation including ice build and burn to meet the building cooling loads as they vary throughout the seasons.

The first aim of the CPCS prediction methodology is to ensure that there is enough cooling to meet peak demand. The second aim is to use as much of the available stored ice as possible during each day of operation. This maximizes the benefit of shifting the chiller load to more efficient cooler ambient conditions and potentially cheaper electrical tariffs.

The CPCS strategy must always leave a safety margin in case peak load does not drop as quickly as predicted during latter part of day.

The CPCS cannot allow a situation where there is not enough instantaneous cooling to meet demand and the primary ChW flow temperature rises significantly above set point.

Control of the integrated system will be based on multiple control strategies and customized algorithms built in to the CPCS and its constituent control units.

The chiller plant control system (CPCS) software will be capable of incorporating all of the operational mode and predictive control strategies described in this document either with its kernel operating system or in customized programming procedures.

The main CPCS intelligent controllers will be a part of the system level network. They will be connected using BACnet/IP protocol in peer to peer level communication (horizontal system level). The communication (vertical level system) between modular local field controllers will be MS/TP protocol over twisted pair. This ensures that all local control strategies will not be interrupted by any communication barriers that lie within the same local networks.

The CPCS will be integrated with the site wide BMS via a BACnet integration interface to allow remote oversight and monitoring.

5.5 Load profile prediction using software

The specialist ITES supplier will supply a specialist CPCS including full predictive methods to match ice build and burn to building cooling loads that vary throughout the seasons.

The CPCS will calculate when to start and stop the various modes in particular Peak Load.

The CPCS strategy must always leave a safety margin in case peak load does not drop as quickly as predicted during the latter part of day.

The CPCS software must prevent any situation where there is not enough instantaneous cooling to meet a peak demand and as a result the primary ChW flow temperature rises significantly above set point.

The CPCS will be supplied with standard in built facilities for trend logging, a suite of computational numerical algorithm based estimation methods and interactive operator input facilities. These facilities will be used to calculate load profile for the next day and select a sequence of operational modes to best match the predicted cooling requirements.

The estimated load profile will be stored on a non volatile memory segment. No data losses will occur, even with any major power interruption. It will be possible to access these data without any losses.

The system will be capable of automatically producing an estimated next day operational load profile with hourly cooling load. This will be based on the predicted next day peak dry bulb temperature condition, together with possible operator input and corrections based on other weather conditions such as predicted sunlight, cloud cover, humidity, rain and possible other historical influences.

The local weather station's next day predicted peak day temperature profile will be used to compare with the system design outside peak dry bulb temperature of 49°C (120°F) so as to arrive at an approximate estimated percentage load condition of the next day.

The predicted load percentage factor will be used to determine the next day preliminary operational load profile and hourly assigned system cooling production by base load chiller, glycol chiller and stored ice.

The final predicted load profile will be stored in the CPCS by midnight every day ready for next day's operational references.

Both glycol chillers and ice storage operation will be demand limited, cross checked every 15 minutes and updated on an hourly basis for the actual system conditions encountered during daytime operation.

At the end of each hour, the CPCS will compare the predicted cooling load with actual cooling load and make necessary corrections for the next hour's predicted cooling load and the extent of ice consumption available for that hour.

The CPCS control strategy goals will be:

- to maintain the design 4.44°C (40°F) chilled water supply at all times to the secondary system
- To consume all useable stored ice before the night time period starts.
- to reserve a portion of ice, between 5% and 10%,

An ice storage reserve will be left in the ice tanks to keep the ice tank temperature low enough to be ready for next day ice making as early as possible.

This strategy will take full advantage of the system's higher efficiency when producing ice tons during the cooler "night time" period operation, compared with producing glycol cooling tons at the higher day time ambient temperature.

The CPCS will formulate its control strategy based on the predicted load profile, the system design characteristics and where possible the schedule of varying utility rates.

The operational characteristic will change significantly as the ITES system incrementally increases from one Module to ultimately all four (4) units. The amount of stored ice thermal energy will be increased from 25,451 kWh (7,260 Ton-Hrs) of one ITES module to 101,805.43 kWh (29,040 Ton-Hrs) with all four modules together, without including spare tank capacity.

In certain scenarios it may be advantageous and economical for the CPCS to operate all ITES modules together, at low load conditions, rather than simply operating one or more modules at total unit capacity to match the actual secondary load required.

5.6 Daily operations with some of the potential optimum conditions

The Limitations and mechanical equipment which are used to generate the cooling capacity required to be coordinated with correct strategy. The tactical control procedure explained below how to handle such situations, whenever it is aroused.

5.6.1 Cooling Load exceeds Maximum Chiller Capacity

Once all ITES modules are operating, the CPCS can (if all the ice tanks are completely built), begin to reduce the capacity of the glycol chillers incrementally. This will be done by demand limiting the chillers in 5% reductions by upward reset of the discharge temperature every 15 minutes.

The CPCS will modulate valves V-2 and V-3 oppositely and proportionately to allow glycol to flow through the ice tanks. The ice burning will be used to maintain the glycol loop temperature at the design value of 3.3°C.

The modulation and rate of ice burn will be controlled and monitored by the CPCS with reference to the predicted operating day load profile and subsystem (base load, glycol chillers and stored ice) operation.

5.6.2 Extreme Peak Load:

When the ChW flow through the operational ITES is no longer going to be sufficient to meet the ChW secondary flow demand then the 2nd ITES in the sequence will be started.

Having predicted the cooling load profile the CPCS will calculate the best sequence and mix of ITES modules and their modes of operation to use to meet the predicted cooling load in the most efficient manner.

This mix will reflect the number of ITES modules currently installed and the amount of ice storage available within the modules. The preferred sequencing will be set up by the CPCS specialist supplier during commissioning and the user interface will allow a trained operator to manually override the sequencing to change the order of module and mode operation.

The extreme examples will be, on one hand, "ITES in sequence" operation, i.e. one ITES operated to full capacity followed by the next ITES in sequence and so. On the other extreme when selecting the "ITES in parallel" operation the CPCS will run all the available ITES modules in parallel in the same mode and selecting the modes as required to achieve the instantaneous cooling required.

The CPCS will be designed and programmed to allow the operator to change the *CPCS sequencing* of operational modes to match the phased delivery of the gardens and associated chilled water plant.

5.6.3 Post-Peak Load Operation:

The CPCS will calculate, on an hourly basis, the capacity of Ton Hours (TH) of ice remaining, and the mechanical cooling capacity left available, and compare it to the water loop Tons demand.

The CPCS will decide whether to regulate the burning of ice. The CPCS will do this by loading up the glycol chillers and base load chillers to slow the ice burn or to limit the chiller capacity to burn more ice.

The CPCS will attempt to burn all ice except for the amount of reserve ice capacity calculated to optimize initialization of ice build during the next cycle of operation.

Chapter 6

Results and Analysis

6.1 Analysis and Conclusion

his study, primarily optimum operating strategy was proposed based on GA analysis. he following results were predicted based on load contour data analysis. By using arameters values predicted capacities Chiller operating COP were computed.

By Applying all above optimization strategies based on the total capacity requirement of he Garden and its thermal load profile the following parameters estimated.

o of total Chillers should be operated within the each ITES circuit = 4
No of Base Chiller in each circuit to be operated =1
No of Glycol (low temperature chilled media) operated Chillers = 3

nce the above parameters are being fixed with the mechanical system, the mechanical signer could have completed its hydraulics piping and pumping system. The system ntrol strategies that have to be implemented in order to control all above proposed chanical component based on strategies defined is the next challenge in this project.

OP of the Chillers

lycol Air Cooled Chiller Operating Characteristics Comparison

nit escriptio	Ambient Temp,	Medium	Capacity		Fluid Temp.		Efficiency - COP	Power
	°C		kW	Tons	Entering	Leaving		kW
rane TAC 500	49°C	30% Ethylene Glycol	1107	315	10 C	3.33°C	5.9 EER - 1.71 COP	646.3
rane AC 500	49°C	100% Water	1120	319.0	14.4 °C (58°F)	5.6 °C (42°F)	6.2 EER - 1.82 COP	616.1

ed on above optimization results and at the optimum level of ambient condition 49°C
e total capacity by 3 nos of Glycol Chillers=3x1107
= 3321 kW
lled water chiller capacity (1 no.) = 1120 kW
al Capacity on a 1 ITES circuit = 4421 kW

capacity required to match the peak load =6958 kW (this is not possible w/o ice)
Calmac ice bank capacity available capacity =25526 kWh
(10 hour night operation)
capacity with 24 hour operation of ChW. chiller= 24x1309 kWh
age due to change of ambient condition)
capacity with 14 hour operation of Glycol = Nx3x14x1384kWh (average)
N is the part load % of the chiller
calculated load based on simulated load profile= 1.3x 83496 kWh (integral value)
based on the Graph Fig 2.1)
6+24x1309+Nx3x14x1384=1.3x83496 (30% deviation factor of anticipated load)
2+58128xN = 108545
89 (efficiency) if all glycol chillers are in operation.
ver control jargon proposed will be limited to 2 in operation.
ency will be =0.89x2/3=0.59 (COP=1.7)
s acceptable as per above table COP will be 1.71

total control structure suggested with above Chapter 3, and its control procedures d be summarized in following two table based on tactical and strategic controls.

	BASE LOAD CHILERS & PUMPS	CLYCOLE CHILLERS & PUMPS	ICE TANKS	PRIMARY GLYCOL (ICE TANK) PUMP	SECONDAR PUMPS & VFDS	V1-A	V-2	V-3
chillers	ON, Partial load, 4.44 C	N/A	N/A	N/A	N/A	N/A	N/A	N/A
load chillers and	ON, Full load, 4.44 C	On, Partial Load chillers	Full	OFF	ON-Modulating	OFF	ON	ON
load chillers.	ON, Full load, 4.44 C	Full load, 3.3 C	Ice Depleting	ON-Modulating	ON-Modulating	Modulating	OFF	Modulating
load chillers and	ON, Full load, 4.44 C	OFF	Ice Depleting	ON-Modulating	ON-Modulating	Modulating	OFF	Modulating
chillers and ice	OFF	Full load, 3.3 C	Ice Depleting	ON-Modulating	ON-Modulating	Modulating	OFF	Modulating
only	OFF	OFF	Ice Depleting	ON-Modulating	ON-Modulating	Modulating	OFF	Modulating
chillers only	OFF	Partial Load 3.3 C	N/A	OFF	ON-Modulating	OFF	ON	ON
cooling with	OFF	Full load, -5.6 C	Ice Making	ON-Modulating	OFF	Modulating	OFF	Modulating
chillers	OFF	Full load, -5.6 C	Ice Making	ON	OFF	OFF	OFF	OFF

.1 Tactical Control procedures

ng Modes	When (Strategy)	Previous operating Mode
ing	All chillers and Ice tanks are OFF	
ooling with Base load chillers	All times, unless otherwise disabled for maintenance or Major failure	0
Cooling with Base load chillers and illers	If chiller base (Operating Mode 1) is unable to provide enough cooling after 10 Minutes (Adjustable), measured temperature 4.4 C on Ts.	1
ng Cooling with Base load chillers, chillers and Ice tanks	If chiller base and Glycol chillers (Operating Mode 2) are unable to provide enough cooling after 10 Minutes (Adjustable), measured temperature 4.4 C on Ts.	2
cooling with Base load chillers and Ice	If Glycol chillers are all faulty or disabled and If chiller base (Operating Mode 1) is unable to provide enough cooling after 10 Minutes (Adjustable), measured temperature 4.4 C on Ts.	1
ooling with Glycol chillers.	If chiller base (Operating Mode 1) is disables or faulty .	0
Cooling with Glycol chillers and ice	If Base load chiller is faulty or disabled .	5
g cooling with Ice tanks only	If all Chillers are faulty or under maintenance.	0
anks and providing cooling with Glycol	If night time (10 Pm - 5 AM), and Glycol chillers has spare capacity	5 0r 2
ing Tanks by Glycol chillers	If night time (10 Pm - 5 AM),	1

ble 6.2 Strategic Control Procedures

.2 Additional System Design Considerations

1. The CWP basis of design was Trane Air-Cooled Chillers and Tracer Summit equivalent of Energy Management System for the Chiller Plant Control System (CPCS) but equal and approved offerings from other manufacturers may be used to deliver the same performance. Thermal Storage Tanks selection was based on Calmac ice tanks containing a spiral-wound, polyethylene-tube heat exchanger surrounded with water which will store thermal energy by building for later use.

2. The CPCS will operate automatically on a stand alone basis using flow and temperature measurements at the primary by-pass coupler to measure cooling demand. The CPCS will communicate full information on operational modes including sensor values, valve positions, ice store, chiller and pump data to the BMS at system level.

3. The CPCS will communicate with the Building Management System (BMS) via BACnet/IP based on Ethernet CAT5 media networking or FTTP digital fibre optic shared networks. This will reduce the costs that would otherwise be incurred by using dedicated networks.

4. All the sub-system controls structures proposed are based on de-coupler system architecture, which will apply concurrent operations within the ITES and its various

cascaded loops. The control software is already available with many control software manufacturers. The supplier will need to configure them as per the proposed system requirement and customize them with tailor made sub-routines and software programs in order to achieve a fully integrated functionality.

The system hydraulics play a considerable role in the proposed arrangement of the piping network and this will dictate any variation of control structure that has been outlined above. The different modes of operation within the CPCS and GCPCS should be elaborated by the specialist supplier in order to lay out the proposed control strategies in the appropriate sub routine modules.

VSD control of the heat exchangers pumps should be interlocked with the operation of isolation valves SV-1 to SV-4.

Some complex processes will be controlled by nested PID loops due to the multiple dynamics in the system. These PID loop controls will be prioritized and tuned based on the relative reaction time of the controlled variable. The PID loops will be properly tuned during commissioning based on the relative reaction times and process delays of the various components and systems.

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