CONTENTS

1. INTRODUCTION

The Ministry of Environment and Water Resources (MEWR), on behalf of the Government of Singapore, has commissioned PM Group to conduct an International exercise to benchmark the performance of the Pharmaceutical and Nutritional plants in Singapore against equivalent facilities around the world. The focus of the benchmarking study relates to Energy Efficiency and Greenhouse Gas Emissions.

As part of the study this '***Best Practice Guide'*** document has been prepared. The purpose of the Best Practice Guide is to serve as an educational and reference document to help plant owners and operators identify and implement measures to optimise energy performance on their facilities. The guide outlines system-specific best practice in energy efficiency for the pharmaceutical and nutritional industries in Singapore with a particular focus on the largest energy using systems as identified through the benchmarking exercise. Best practice measures covering design, operation & maintenance and retrofit opportunities have been identified on a system by system basis arising from an aggregated review of the best performing plants involved in the study, and information derived from current relevant author experience and documented information for the industry.

1.1 OVERVIEW OF THE PHARMACEUTICAL SECTOR

For the purpose of the benchmarking study and the associated study outputs, the pharmaceutical sector is categorised into four main sub-sectors;

- Active Pharmaceutical Ingredients (API) from Organic Synthesis
- Biopharmaceuticals from Biologics Based Processes
- Secondary/Finished Products
- Nutritionals

In all sub-sectors energy demand can generally be split into two main categories of end use, Process and Buildings.

- Process: Energy that is directly used in the manufacturing process or associated support activities e.g. Cleaning, Nitrogen generation, WIFI,
- Buildings: Energy use associated with building e.g. ACMV, Chilled Water for Air Conditioning, Lighting.

Energy is generally purchased as electrical or thermal (e.g. gas) and is then either consumed directly by the end user or converted into another useable form. For example electricity is used directly in a lighting system whereas it is used by a chiller system to generate chilled water which is then used for building or process cooling.

1.2 BENCHMARKING EXERCISE

1.2.1 GENERAL

During 2010 a major energy benchmarking exercise was undertaken including a detailed assessment of the performance of individual systems across 12 participating Singapore sites covering 22 individual pharmaceutical and nutritionals manufacturing plants. The details of and outputs from the benchmarking exercise are presented in a series of customised reports presented separately to the participating sites. This section presents a high level overview of the aggregated results for the purpose of highlighting the key areas of energy use associated with the sector.

1.2.2 SYSTEM INFLUENCE ON CO_2 EMISSIONS

The following graphs show the relative influence on overall site CO_2 emissions of the various systems. These graphs are an aggregate of all results of the participant sites in Singapore and provide a good overview. It is important to note that the nutritional facility results and the pharmaceutical facility results are shown on separate graphs as their respective energy profiles differ significantly. The nutritional facilities CO_2 emissions are largely influenced by production activities, whereas the pharmaceutical facilities are highly influenced by Chilled Water and Air Conditioning & Mechanical Ventilation (ACMV).
The following table shows the service abbreviations used in the graphs.

Abbreviation	Service
CHW Elec	Chilled Water Electricity – Electricity Consumed by Chillers and Circulation Pumps
ACMV Elec	ACMV Elec – Electrical power consumed by Fans and Air distribution systems.
CTW	Cooling Tower Fans and Cooling Water Circulation Pumps
Other Elec	Combined total for electricity used in small power, lighting systems, general offices, warehousing, non production/utilities.
Proc Elec	Electricity used by process directly – product pumping, agitators etc.
LTC	Electricity Used by low temperature/production chillers and pumping systems
ACMV Thermal	Thermal energy used in absorption chillers or heating hot water systems.
Proc Thermal	Thermal energy used directly by process.
Misc Util	Electrical energy used across less significant pumping systems e.g. process water, WWTP pumping, boiler feedwater pumps etc.
CA/N2	Electrical energy used in compressed Air and nitrogen generation systems.
Solv Rec	Thermal energy used in solvent recovery in API plants.
WWTP Therm	Thermal energy used in waste water treatment in API plants.

Figure 1.1a – *Individual System Influence on CO_2 Emissions – Pharmaceuticals*

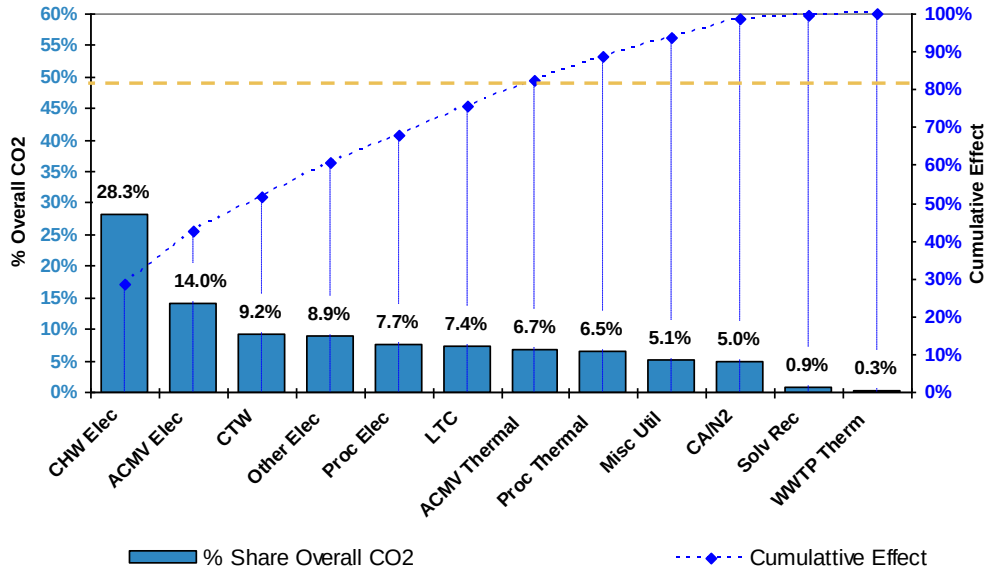
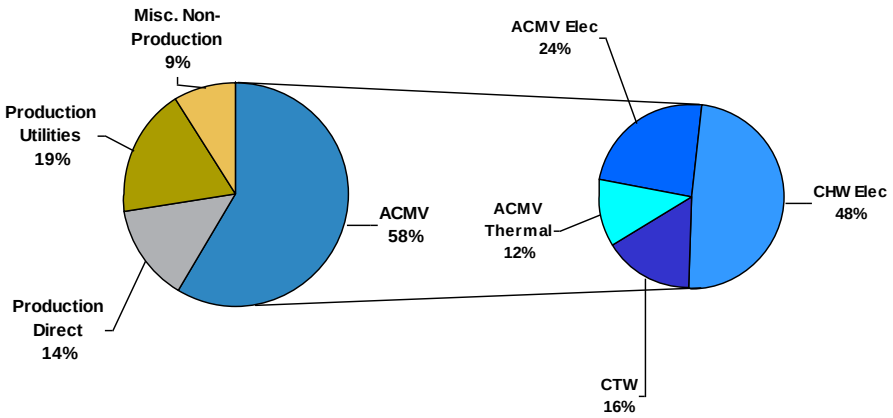


Figure 1.1b – *Activity/Service Influence on CO_2 Emissions - Pharmaceuticals*



As can clearly be seen from figures 1.1a and b, chilled water and ACMV in particular should be the main focus areas for energy efficiency improvements in the pharmaceutical industries.

Figure 1.2a – *Individual System Influence on CO_2 Emissions - Nutritionals*

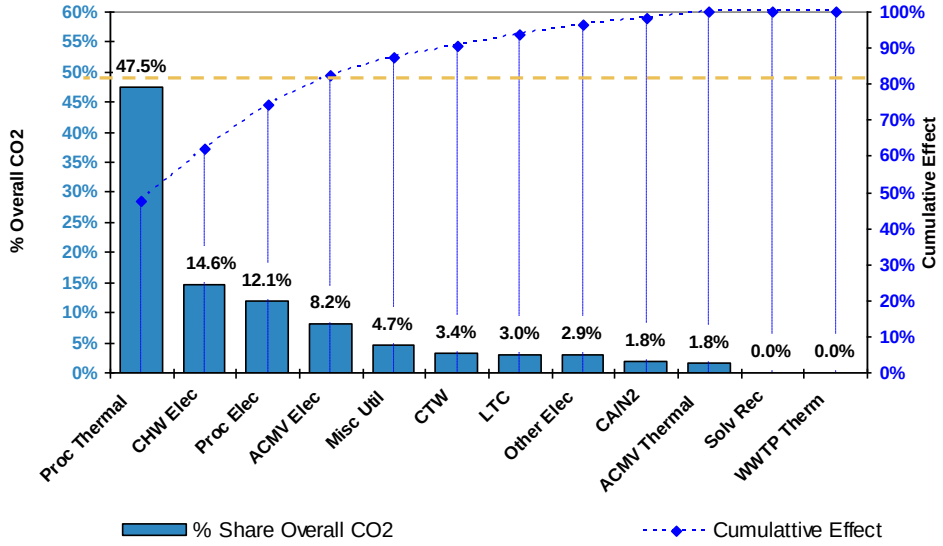
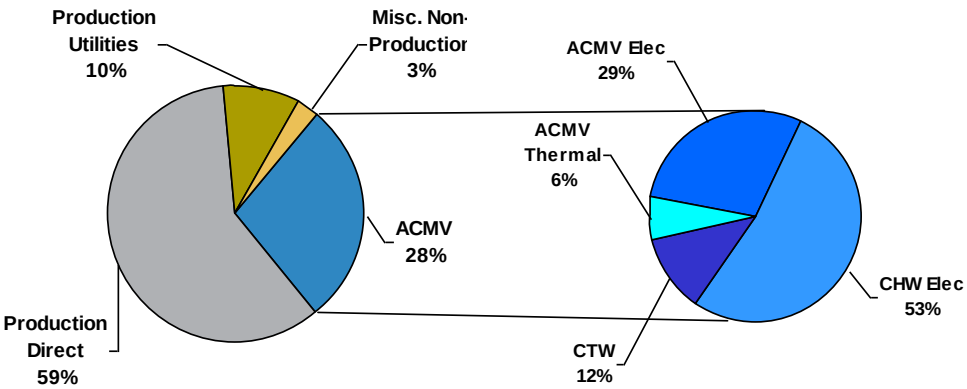


Figure 1.2b – *Activity/Service Influence on CO_2 Emissions - Nutritionals*



As can clearly be seen from figures 1.2a and b, the thermal energy used in production is the largest driver and should be the primary focus for energy efficiency improvements in the nutritionals sector.

1.3 PURPOSE OF THIS BEST PRACTICE GUIDE

This guide outlines system-specific best practice in energy efficiency for the pharmaceutical and nutritional industries in Singapore with a particular focus on the larger energy users as identified by the benchmarking exercise. The guide discusses opportunities for energy efficiency in three phases of a system lifecycle;

- **Design** – Top Tips that outline current best practice technologies available among pharmaceutical plants and Best Available Techniques (BAT) that have been successfully demonstrated in individual plants in Singapore or abroad. Details on BAT are provided below.
- **Operation and Maintenance (O&M)** – What to look for in relation to energy wastage and maintenance practices, so as to operate systems energy efficiently.
- **Retrofit** – Opportunities are prioritised based on estimated Return On Investment (ROI). Design best practice will also be relevant for all Retrofit solutions.

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Best Available Techniques (BAT) are defined as the "*most effective and advanced stage in the development of an activity and its methods of operation*".

- **B 'best'** in relation to techniques means the most effective in achieving a high efficiency level with minimum emissions.
- **A 'available techniques'** means those techniques developed on a scale which allows implementation in the relevant class o**f activity under economi**cally and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced within the State, as long as they are reasonably accessible to the person carrying on the activity.
- **T 'techniques'** includes both the technology used and the way in which the installation is designed, built, managed, maintained, operated and decommissioned.
- At the installation/facility level, the most appropriate techniques will depend on local factors. A local assessment of the costs and benefits of the available options may be needed to establish the best option.
- The choice may be justified on:
  - The technical characteristics of the installation/facility;
  - Its geographical location;
  - Local considerations;
  - The economic and technical viability of upgrading existing installations / facility.
- It is the responsibility of the EED Expert within the EED process to ensure that BAT are utilized insofar as is practically possible during the duration of the project.

The information in this guide has been drawn from (i) best practice measures employed by the best performing plants (in Singapore and internationally) as identified in the benchmarking study (ii) the experience of PM Group in the design of large scale pharmaceutical and nutritional manufacturing facilities worldwide, and (iii) a number of current internationally recognised publications, all of which are referenced within the document.

This guide does not aim to provide tuition in the principles of engineering design, operation and maintenance, nor act as a substitute for life cycle costing (LCC) analysis on appropriate energy efficiency measures, which may be under consideration. For individual

sites, the actual payback and ROI associated with a given energy efficiency measure will vary depending on local utility rates, facility activities, configuration, size, location, and operating characteristics. Hence, the information presented in this Best Practice Guide is provided as a checklist of viable and proven options for consideration and site-specific evaluation.

2. ENERGY EFFICIENT DESIGN (EED) FOR INDUSTRY

2.1 SUMMARY

Energy Efficient Design (EED) methodology assists investors to design, construct and manage projects so that they consume the minimum quantity of energy during their subsequent operation. It also places operational phase energy management on the design agenda.

EED Methodology has two key aspects: Project organisation and design activities. EED Methodology hence requires changes to the traditional project organisational structure to ensure that the EED activities are systematically implemented throughout the lifecycle of the project.

The use of Energy Efficient Design (EED) methodology is considered Best Available Technique (BAT) when planning a new installation or significant upgrade. This is a structured process that assists investors to design, construct and manage installations so that they use energy efficiently and at the lowest total cost possible. Experience has shown that if EED is considered during the planning and design phases of a new plant, saving potentials are higher and the necessary investments are much lower, compared with optimising a plant in commercial operation. The application of EED is seen as particularly relevant to the pharmaceutical industry and its application is addressed in detail in Section 2.

2.1.1 ORGANISATION

The Investor will appoint an **EED Owner** from within its organisation who will liaise directly with the **EED Expert** in the design team.

The **EED Owner** should report directly to senior management within the investor organisation. This will ensure that the commitment required for successful EED implementation is present and that the EED methodology is anchored within the investor organisation. If the EED owner reports into the investor project team there is a risk that EED will succumb to project cost and schedule constraints.

The **EED Expert** is responsible for the implementation of the EED Methodology during the project lifecycle. Typically these roles will be fulfilled by existing personnel within the Investor & Design Companies.

2.1.2 METHODOLOGY

There are two principal activities under the EED Methodology.

- EED - the three phase approach
- Design for Energy Management

At present, energy efficiency is incorporated into new designs in an informal or ad hoc basis. Companies will often rely on checklists to incorporate energy-efficient technologies or systems into new installations.

However, to illustrate the ineffectiveness of this scenario, a design checklist for Water for Injection (WFI) systems is considered. This checklist might address generation technology but is unlikely to address the more fundamental question of 'Is WFI actually required?"

Checklists also tend to address systems in isolation rather than holistically and hence fail to address system-integration opportunities.

Project teams are also not responsible for the running costs of the equipment they design. The involvement of the end user is thus a key part of the proposed organisational structure to support EED.

Therefore, in summary, the EED methodology should be implemented to:

- Minimise the operational energy consumption of a project.
- Minimise the capital costs associated with the purchase of equipment by specifying only the minimum required to meet energy service requirements.
- Where Energy Management Systems exist, support clauses pertaining to design, specification and procurement of energy efficient systems.
- Ensure operational phase energy management is placed on the design agenda, i.e. Design for Energy Management.

EED requires the Investor to commit the necessary resources to deliver the desired outcome. Experience is that a payback of one to two years is generally realised on EED investment costs.

2.1.3 KEY TOPIC

- EED General Guidelines

2.1.4 MAIN REFERENCES

- Energy Efficient Design Methodology – SEAI.

- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

2.2 EED METHODOLOGY

2.2.1 DESIGN ACTIVITIES

EED methodology has a three step approach;

- Facility Energy Balance Phase - The EED Expert prepares an energy balance for the project. Ideally this should be done at the concept design phase. The purpose of the energy balance is to establish the overall extent of energy use, identify the significant energy users, and highlight high-level opportunities for energy saving.
- Analyse & Challenge Phase - review and challenge the proposed design and suggest energy saving initiatives. An energy savings register should be prepared.
- Implementation Phase - the project team should agree on what alternatives will be accepted and incorporated into the next design phase. This phase concludes with a Project Summary Report that highlights the achievements of the EED three-phase approach.

The other core design activity relating to EED is Design for Energy Management. In order for an installation to be efficiently operated, the design process must account for the operational requirements to manage energy consumption.

The Venn Diagram (or Onion Diagram) illustrates how each element of the design process influences overall energy consumption. The Energy Service is worth highlighting here as it is often overlooked in striving to achieve improved energy efficiency. The Energy Service is defined as the desired outcome that requires the consumption of energy. The Energy Venn Diagram is essentially an engineering tool that can be used in challenging design requirements and subsequently developing a list of energy saving opportunities

A number of existing engineering tools could also be employed by the EED expert in developing a list of energy saving opportunities. For instance Process Integration Tools (modelling and simulation software), Lean Manufacturing Tools (control charts, pareto analysis, regression analysis) and Financial Analysis Tools (simple payback, net present value, internal rate of return) could all be employed.

From the life-cycle economics perspective, the full range of expenses must be considered over the lifetime of the project, including the costs of construction; financing; energy; operations and maintenance; periodic replacements; and even disposal of system components.

These costs are generally expressed in terms of net present value, making it possible to compare costs that occur during different time periods over the lifecycle of a process or system. Net present value accounts for the time-value of money. Taking the lifecycle economics approach, energy-efficiency investments may be attractive to investors even with simple paybacks as long as 15 years.

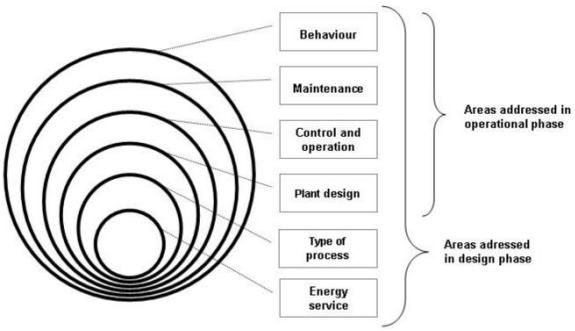


Figure 2.2.1 – EED Venn Diagram.

2.2.2 DESIGN FOR ENERGY MANAGEMENT

The other main EED activity is known as Design for Energy Management. In order for an installation to be efficiently operated, the design process must account for the operational requirements to manage energy consumption.
It is a weakness of current design practices that operational-phase energy management is not usually considered at this time. Consequently the management systems and engineering hardware required for optimal energy management must instead be put in place in the operational phase of the plant. This is likely to be more expensive and less effective because utility systems in particular, will not be configured so that required operational data can readily be measured.
The primary output of Design for Energy Management (DFEM) is the 'Energy Metering Plan'. This should address issues such as; end user energy management policies, energy monitoring and supporting energy metering

requirements, energy reporting requirements, etc.
It must be understood that energy metering is not energy monitoring. Energy metering generates data (kWh, Therms etc) and the data accumulates. No corrective action happens. The goal of energy monitoring is to track actual performance and correct anomalies. In terms of the design of an energy metering system, it is important that electrical and mechanical systems be configured in such a way as to provide useful and informative energy-consumption data. This should be addressed by the EED expert from the basic engineering stage of a project and continuing through to detailed design. The cost of installing energy metering as part of the project is a fraction of the cost of retrofit.
Deciding which plant systems to monitor should be based on the potential for;

- Economic return based on system scale and managing those systems' efficiency.
- Correcting losses incurred due to plant upset.
- Correcting losses incurred due to incorrect operation.
- Correcting losses incurred due to fouling or inadequate maintenance.

DFEM also encourages a design review from the perspective of operational phase troubleshooting. For instance do test points on a heat exchanger allow for clear identification of fouling in that exchanger?

The EED expert is responsible for the management and execution of day-to-day activities pertaining to DFEM. The EED owner should ensure that the requirements of the investors EMS or energy policies are understood and addressed.

2.2.3 REFERENCES

- 'Energy Efficient Design Methodology' – SEAI
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.
- 'Design for Energy Management'– SEAI

3. ENERGY MANAGEMENT

3.1 SUMMARY

Good energy management practices are required to ensure best energy performance and continuous improvement.

The way to achieve this is to have a structured energy management system (EnMS) which commits the organization to good energy practices and ensures a structure is in place to maintain energy performance at a consistently high level.

In 2011 it will be possible to have an organisation's energy management system certified to "ISO 50001- Energy Management Systems". This standard is currently in draft form and is expected to be approved in 2011.

On existing sites, where existing infrastructure does not allow for ideal data collection, an energy management system can be put in place using what ever resources are available, and any shortcomings addressed through continuous improvement.

3.1.1 TOPICS

The topics covered in this section are

- Energy Management System
- Energy Metering and Data Collection
- Energy Responsibilities and Reporting
- Energy Awareness

3.1.2 REFERENCES

- www.iso.org - "ISO 50001- Energy Management Systems".

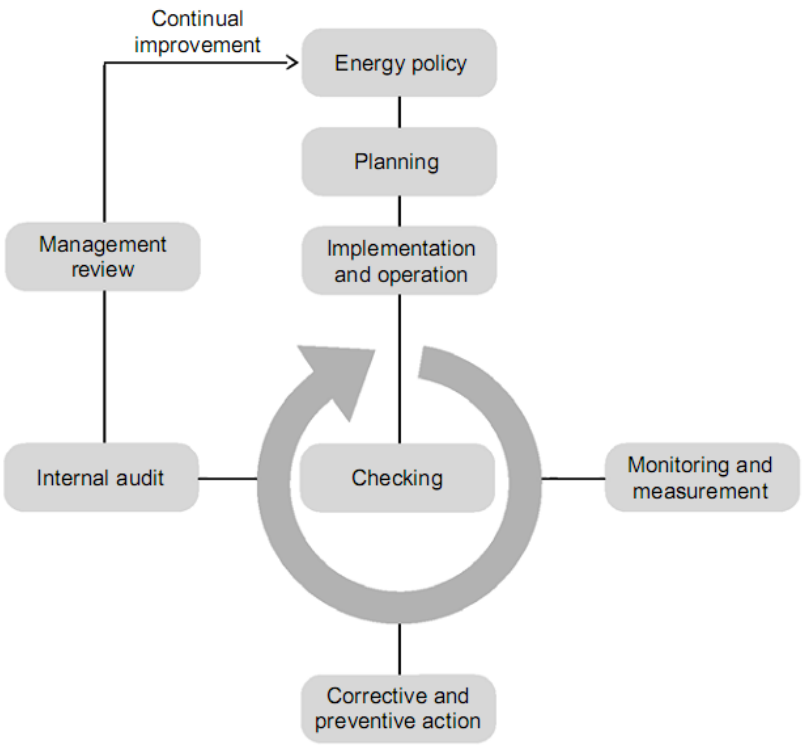


Figure 3.1 – ISO 5001 Energy Management System Model

3.2 ENERGY MANAGEMENT SYSTEM

3.2.1 OVERVIEW

- Energy Policy – High level energy policy for site signed and supported by director level.
- Defines and Documents System
- Clear objectives and measurable targets.
- Action plans and procedures to achieve objectives and targets.
- Structured approach to energy related communication and training.
- Procedural Checks and corrective actions.
- Commitment to reviews and continuous improvement.

3.2.2 ENERGY POLICY

- Commitment of top management/directors to achieve energy performance continuous improvement.
- Commitment to make resources and information available to achieve measureable objectives and targets.
- Commitment to comply with all statutory requirements related to energy use.
- Commitment to use and purchase energy efficient products and services.
- Policy is widely communicated and understood within the organisation.

3.2.3 SETTING OBJECTIVES AND TARGETS

- First step is to conduct an energy review on site. Energy review should identify main energy users and establish energy baseline.
- Energy Review should be carried out in accordance with a repeatable procedure so that continuous improvement can be measured.
- From the energy review the site should establish key Energy Performance Indicators (EnPI) to facilitate monitoring of energy performance.
- From the energy review, the site should establish energy objectives and targets. Objectives and targets shall be documented and take into account legal requirements, significance of energy use, ease of implementation, support of stakeholders and financial return as a minimum.
- Each objective and target shall have an action plan. an owner, a measurable target, a timeframe for implementation and a clear structure for communication of progress and results.

3.2.4 CHECK AND REVIEW CYCLE

- A key element of an energy management system is a structured review cycle to assess performance, re-evaluate targets and implement continuous improvement.
- Outputs of the energy review, significant energy users, EnPI's and effectiveness of action plans should be reviewed and assessed under a procedure of the Energy management System.
- A structured review of legislation should be carried out at regular intervals and the procedures updated to comply with legislative changes.
- External audits of the energy management system should be carried out to ensure compliance.
- Management audits should be carried out to ensure compliance with the energy policy, to ensure its relevance and to support continuous improvement measures.
- Corrective action plans should be documented where appropriate.

3.2.5 DOCUMENTATION

- All energy management system procedures should be documented and subject to review and change control
- All records of energy consumption, action plans or audits should be filed and held to demonstrate compliance with system.

3.2.6 REFERENCES

- www.iso.org - "ISO 50001- Energy Management Systems".

3.3 ENERGY METERING AND DATA COLLECTION

Data collection and processing is the initial activity for any energy evaluation and conservation measures.

Before commencing data collection, a data collection plan should be formulated.

While there are different challenges for new and older sites, there are basic elements which must be followed, as outlined below.

When starting out on this process, obtaining an initial assessment of consumption is more important than having all data to a high accuracy. If a consistent and repeatable system for gathering data from information available is in place, data accuracy can be dealt with through continuous improvement.

3.3.1 DATA COLLECTION PLAN

- The data collection plan details out the data that needs to be collected at a high level and how this data is to be collected.
- New Builds should formulate a data collection plan early in the design process, and ensure that metering requirements are incorporated in the design. Many organisations have corporate requirements for energy metering.
- Before formulating plan, the site should compile a list of all direct data sources available on site e.g. energy bills, incoming metering, electricity metering, and second level metering of utilities, temperature trending and ACMV/BMS trends.
- The next step is to identify the main incoming energy sources and the main energy consuming systems on site (any system consuming over 10% of site consumption). For these items, the information required to compile energy performance indicators (EnPI) should be listed. The information for EnPI's for other systems should be listed as secondary.
- A gap analysis should then be carried out against direct data available and required information.
- If direct metering is not available, the site should identify other means to obtain or estimate the required information. E.g. use operation conditions of pumps or compressors to work out consumption. Any estimation should be derived from actual operating conditions rather than theoretical data.

3.3.2 METERING

- The site should have an aim to gather all main EnPI data through direct metering through a central automated recording system.
- The gap between an existing site's infrastructure and a fully automated information gathering system can be filled through continuous improvement projects in stages.
- Have a small levy on all projects to create a fund for installation of metering.
- Install meters opportunistically in line with metering plan.
- The aim should be for data to be accurate to +/- 5%. All new meters should comply with this requirement. Critical utility meters should be incorporated in the site's meter calibration plan and rotations. ASHRAE Guideline 22 recommends the system performance measurement error for chiller plant (including chiller, chilled water pump, condenser water pump, and cooling tower) shall be within +/-5%.
- Even if data accuracy is questionable on a meter, data should be gathered, because if the readings are consistent, data will be suitable for showing improvement in performance.
- Data/meter accuracy can be addressed through continuous improvement.

3.3.3 DATA COLLECTION

- On line trending of main EnPI's is recommended.
- Show a target line on all trends so that major deterioration in performance can be quickly seen at point of data collection and action quickly taken before analysis.
- If instrumentation not currently available trend some parameter that best represents plant performance.
- Where manual records are used, whether through maintenance logs or meter readings, always have expected values or error values on the sheet so that major deterioration in performance can be detected at time of data collection.
- On all log sheets, have a comments section, which allows the person collecting data make observations which may not be evident during data analysis.

3.4 ENERGY RESPONSIBILITIES AND REPORTING

In many organisations the responsibility for energy management and budgets rests with the department responsible for operation of utilities systems.

In reality this department can only directly influence the efficiency of generation systems and often has no influence on the activities of consumers.

The sites with best energy performance are structured such that responsibilities for energy performance and benefits from good performance are spread across all stakeholders.

In return all stakeholders should be provided with sufficient accurate information to enable them analyse current situation and compile improvement objectives and targets.

3.4.1 RESPONSIBILITIES

- Clear commitment from top management to provide direction and resources for effective energy management is critical.
- Owners of generation systems should be responsible for efficiency of generation systems.
- End users should be responsible for their consumption. End users should be given training by generation system owners and energy specialists in order that they understand the impact of their energy use.
- It can sometimes be difficult for non-technical personnel to relate their actions to base energy consumption. (i.e. compressed air usage is reflected in electricity consumption and costs)
- Each site should have an energy conservation team, which comprises of a broad mix of skills and functions. .

3.4.2 REPORTING

- Coupled with linking energy performance to stakeholder's rewards, there is a responsibility on the energy manager function to provide reliable information.
- The reporting system must be robust and reliable.
- For an initial period (usually 1 year) very lenient targets should be communicated to stakeholders, to enable them to engage with the system and understand their energy use profiles and baseline without penalty.
- As time passes more stringent targets can be agreed with consumers, based on energy reduction measures, action plans and continuous improvement activities.
- Reporting systems should be documented under the energy management systems.
- Level of detail communicated to stakeholders should be commensurate with their requirements and contain relevant information only.

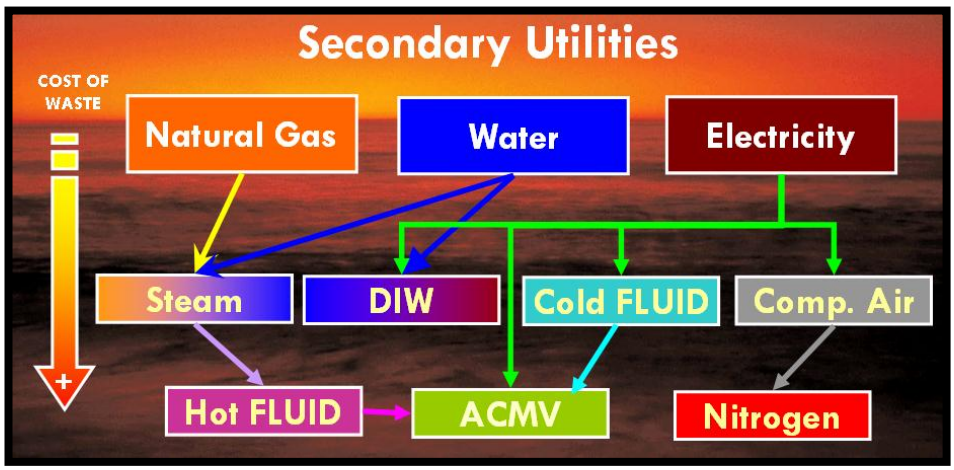


Figure 3.4 – Relationship between incoming utilities and secondary utilities consumption.

3.5 TRAINING AND GENERAL ENERGY AWARENESS

Energy awareness and training activities are a key element of any energy management system.

Energy training usually relates to specific competence requirements of an individual with regards to their normal job function. This is usually documented, structured and integrates into site training systems for other aspects of a person's job function.

General energy awareness contributes to a culture of energy conservation on sites and should encourage a positive attitude to energy conservation in people's lives outside of the work environment.

3.5.1 TRAINING

- A level of energy competence should be included in job function specifications for all levels within the organisation.
- Energy competence requirements should be commensurate with the responsibilities of the position.
- A system should be in place to inform any visitors or site contractors of the site expectations of them as regards energy consumption.
- The energy competence requirements, training records and training structures should be auditable and subject to the same requirements for targets, action plans and continuous improvement as other elements of the energy management system.

3.5.2 ENERGY AWARENESS

- The objective of the energy awareness function is to communicate site energy performance and activities in a way that can be understood by all on site and thus encourages positive engagement in energy conservation activities.
- One of the main challenges is to communicate what is essentially highly technical information on site energy performance in a way that can be easily understood by non technical personnel.
- This is essentially a "public relations" function, and often external assistance in this field can be of benefit.
- It is essential that non-engineering functions are represented on site energy teams to ensure effective communications.
- Promotions that encourage energy savings in the home and in the wider community should be encouraged. Improvement in general energy awareness will carry over to work activities.
- Submission of energy conservation ideas by all personnel on site should be encouraged and a system put in place to demonstrate that these ideas are being evaluated. Recognition should be provided for personnel who submit good conservation ideas.

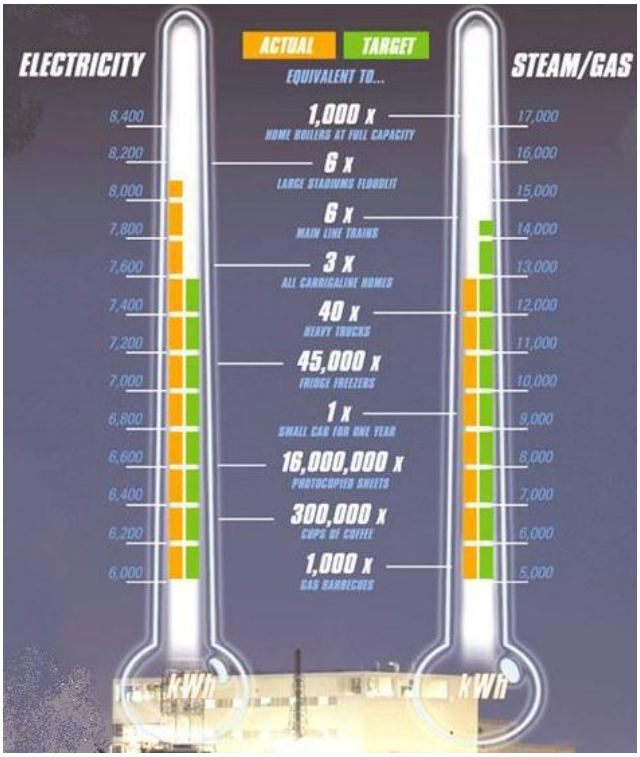


Figure 3.5 – A graphic way of communicating energy consumption.

4. LIQUID CHILLING SYSTEMS & REFRIGERATION

4.1 SUMMARY

The 2010 benchmarking study carried out for the pharmaceutical industry in Singapore has indicated that electrical energy consumption of cooling plant and associated systems accounts for 40% of all CO_2 emissions. Therefore improvements in the energy efficiency of cooling systems will produce larger energy savings relative to other smaller site energy users.

There are a number of techniques, ranging from simple changes in operating parameters to large scale plant modifications, which will provide returns on investment.

The Best Available Technology (BAT) approach advocates that the selection of cooling systems is dependant on:

- Process cooling requirements
- Onsite limitations & restrictions
- Local Climate & Environment

Once these constraints have been accounted for the BAT approach requires the following:

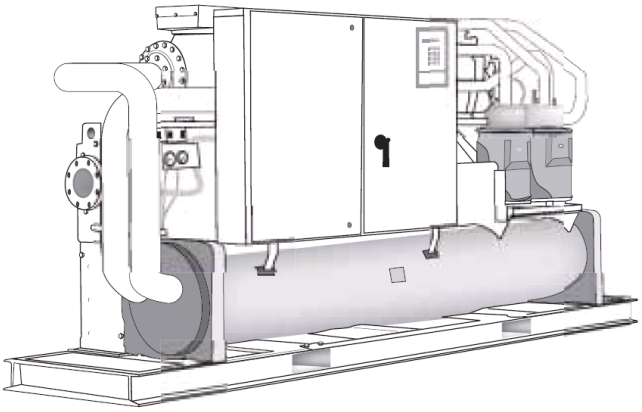
- Reduction of direct energy consumption by applying low energy equipment and reducing resistance to both water and air flow.
- Where there are variable cooling loads provide energy efficient modulation of cooling output.

4.1.1 KEY TOPICS

- Chilled Water System General Guidelines
- Efficient Part Load Operation
- Vapour Compression Compressor Chillers
- Absorption Chillers
- Solar Assisted Cooling (SAC)
- Low ΔT Syndrome
- Refrigerants
- Low Temperature Liquid Chilling.
- Refrigerated Warehousing and Coldrooms

4.1.2 MAIN REFERENCES

- Industrial Cooling Systems (ICS) BREF



4.2 CHILLED WATER SYSTEM GENERAL GUIDELINES

Reference should also be made to section covering Hydronics and Pumping Systems for related guidance on best practice systems design.

4.2.1 DESIGN

Top Tips

- Excessive over-sizing of equipment relative to actual cooling loads is one of the largest contributors to energy wastage.
- Accurate projected cooling load profiling is critical to the correct selection and efficient operation of chiller equipment.
- Simulation software should be used to generate annual cooling load profiles as well as sensitivity analysis on load diversity to avoid over sizing of systems.
- Specify two port variable flow constant temperature systems. Consider pressure independent two-port control valves.
- Consider the end user temperature requirements carefully and split low temperature and high temperature requirements into separate chiller systems. Specifically do not let a small, low temperature load define the chiller operating temperature when most of the loads could operate with a higher temperature e.g. small +2ºC process load and large +8ºC ACMV loads
- Multiple chiller installations should have automatic isolation valves, to isolate the chiller when not operational to prevent unwanted circulation and temperature mixing.
- Size primary chilled water and condenser water pumps to correspond to the flow requirements of individual chillers. Where manifold pumping is provided for multiple chillers consider staging of pumps/chillers carefully.
- In primary secondary systems with hydraulic decoupling insure primary flow is slightly greater then secondary flow at all times. The use of flow meters is preferable to bypass temperature monitoring for sequencing additional chillers.
- Low flow design with higher differential temperatures will provide a more energy efficient system, by reducing pumping and condenser related fan power.
- Variable Primary Flow should be considered for systems larger then 1 MW with two port valve installations. A detailed plant sequence of operation is required.
- Where possible avoid addition of glycol into chilled water systems.

4.2.2 O&M

What to look for

- Increase chilled water temperatures to highest limit. This can be done by automatic reset if climatic conditions or process requirements allow increased chilled water temperatures during certain periods.
- Primary chilled water pumps and condenser pumps should only operate when required.
- Install automatic water treatment to maintain control of corrosion and fouling.

4.2.3 RETROFIT

Opportunities

- Replace or modify three port valves to two port valves in order to implement variable flow pumping. A two port valve configuration facilitates variable flow which decreases pumping energy. Circulation pumps will require VSDs to benefit from variable flow.
- For existing systems that are significantly oversized consider installing a small capacity high efficiency lead chiller for the base load.
- Provide electrical pulse metering for chiller power to monitor chiller electrical consumption and operation patterns.

4.2.4 REFERENCES

- BSRIA BG 4/2007 Design Checks for HVAC.
- LBNL-57260-Revision.
- GPG 316 Undertaking an industrial energy survey – BRESCU – BRESCU.
- GPG 225 Industrial Cooling Water Systems – BRESCU.
- Trane Multiple Chiller-System-Design and Control Applications Engineering Manual.

4.3 EFFICIENT PART LOAD OPERATION

4.3.1 DESIGN

Top Tips

- Install a chiller system load management system which sequences the most efficient equipment combination in relation to the cooling load. This includes chiller, cooling towers and pumps.
- Avoid manual controls by installing automatic controls or thermostatic controls for end users.

4.3.2 O&M

What to look for

- Sequence chillers with the same efficiency characteristics from the smallest capacity to the largest capacity.
- Sequence chillers with different efficiency characteristics in order of the most efficient to the least efficient.
- Automatically shutdown chilled water systems including chillers, pumps and cooling towers in the event of no cooling load.
- The use of hot gas bypassing is very wasteful and should be avoided.
- Monitor electrical chiller loads versus an appropriate cooling load indicator to see if there is a correlation. This will indicate if there is sufficient control of the system.
- Monitor actual chilled water temperature versus the setpoint to eliminate overcooling.

4.3.3 RETROFIT

Opportunities

- For existing systems that are significantly oversized consider installing a small capacity high efficiency lead chiller for the base load.

4.3.4 REFERENCES

- BSRIA BG 4/2007 Design Checks for HVAC
- LBNL-57260-Revision
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- GPC 225 Industrial Cooling Water Systems–BRESCU.

4.4 VAPOUR COMPRESSION CHILLERS

4.4.1 DESIGN

Top Tips

- Specify and install "A" rated Eurovent Certified Equipment or ARI 550/590 certified equipment within minimum efficiencies as set out in Table 6.8.1 ASHRAE 90.1 -2007.
- Selection of Air Cooled or Water Cooled is dependant on the availability of good quality water for heat rejection, and lifecycle analysis. Water Cooled will have lower energy consumption over the lifetime of a project; however there will be increased maintenance costs, water & water treatment costs. For Singapore water cooled chillers should always be considered.
- Choice of compressor will depend on the size of the load, the load profile, maintenance expectations, energy efficiency, and available space.
- For very large installations > 3 MW centrifugal compressors are preferred.
- N+1 should be specified for critical services delivery. i.e. an additional chiller is required if the essential load is <50% of the total load
- Where ACMV systems require reheat then consider a heat pump arrangement and recover reject heat as a 'free' reheat source. This avoids the use of primary thermal energy source for this purpose e.g. gas fired steam boiler.

4.4.2 O&M

What to look for

- Reciprocating chillers require more maintenance then Centrifugal, with Centrifugal chillers requiring more maintenance then Screw/Scroll chillers.
- Allow adequate space around air cooled condensers to prevent air recirculation.
- Check system capacity is adequate to prevent cycling at low loads. Install buffer vessel if required.

4.4.3 RETROFIT

Opportunities

- Downsize or right size capacity of replacement equipment. Replacement equipment should be sized for the peak observed loads as opposed to original system design, which may be well over sized.
- If contemplating a refrigerant change out on existing ageing equipment, consider a new high efficiency chiller. By combining with other building retrofits (e.g. lighting retrofit to reduce electrical and cooling loads) to improve energy efficiency, replacement costs can be offset.

4.4.4 REFERENCES

- ASHRAE Standard 90.1 – 2007.
- ARI 550/590
- SS 530:2006
- BSRIA BG 4/2007 Design Checks for HVAC
- http://www.eurovent-certification.com/
- LBNL-57260-Revision
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- GPC 225 Industrial Cooling Water Systems – BRESCU.

4.5 ABSORPTION CHILLERS

Absorption Chillers use heat to provide cooling instead of the mechanical action of compressors which are electrically driven.

4.5.1 DESIGN

Top Tips

- Specify and install ARI 560 certified equipment within minimum efficiencies as set out in Table 6.8.1 ASHRAE 90.1 -2007.
- Consideration should be given to Absorption chillers if there is waste heat available from CHP plants or thermal processes.
- Consideration should be given where electrical infrastructure is poor and on site electrical capacity is an issue.
- The generation of conventional fossil fuel heat dedicated for absorption chillers should only be considered where the differential between fossil fuel prices and electricity is large enough to provide economic viability as determined by lifecycle costing.
- The efficiency of conventional fossil fuel heat dedicated for absorption chillers is grossly inferior to modern water cooled plant, due to the poor COPs of Absorption chillers (0.6 – 1.2). Therefore in terms of energy & CO_2 reduction, this may not be the optimum solution.
- An alternative heat generation source for Singapore would solar panels for hot water generation to provide solar cooling.
- Absorption chillers are not suitable for cooling loads that require quick response. Preference would be to use as base load lead chillers due to the longer start-up and shutdown times and inflexible load variation characteristics.
- Adsorption chillers that provide superior response and operational flexibility are available but a significant cost.
- If high pressure steam (6 – 10 bar) is available consider two stage absorption for an increased efficiency of 40% above single stage.
- Absorption chillers require increased flow rates for pumping and heat rejection, which requires larger cooling towers & pumps.
- The economics of absorption chillers should be assessed on a case by case basis.

4.5.2 O&M

What to look for

- Absorption chillers should only be used where skilled personnel are available.
- Vacuum monitoring is required, and may need to be restored when necessary.
- Corrosion monitoring in the form of chemical analysis is required for Lithium bromide/water units.
- Lithium bromide/water units are limited to not lower then 5°C chilled water production. Ammonia/water units are not limited.
- Cooling output is sensitive to heat input temperatures, with significant reductions in operating capacity for small reductions in heat input temperatures.
- Heat rejection in the form of cooling towers is required. Cooling output is sensitive to condenser water temperature, with significant reductions in operating capacity for small increases in condenser input temperatures.

4.5.3 RETROFIT

Opportunities

- If waste heat is available onsite then absorption cooling should be assessed.

4.5.4 REFERENCES

- ASHRAE Standard 90.1 – 2007.
- ARI 560
- SS 530:2006
- http://www.eurovent-certification.com/
- LBNL-57260-Revision
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- GPC 225 Industrial Cooling Water Systems – BRESCU.
- GPC 256 An introduction to Absorption Cooling – BRESCU.

4.6 SOLAR ASSISTED COOLING (SAC)

Solar assisted cooling is the combination of solar collector technology with thermally driven heat pumps using sorption processes such as absorption, adsorption and chemisorption. The application of this technology is largely dependant on an appraisal of the suitability of absorption chiller plant to the proposed project. Solar collectors can provide a low energy solution to the required heat source. However, this combination technology can have high capital investment compared to conventional Vapour Compression Cycle (VCC) solutions and a full LCC should be carried out prior to proceeding.

4.6.1 DESIGN

Top Tips

- SWOT analysis can be an effective tool for assessing SAC technologies particularly as they are not a single integrated component selection decision. (SWOT – Strengths, Weaknesses, Opportunities, Threats)
- SAC systems should be considered where there is a need to utilise absorption chiller plant in a project.
- Using the solar collectors for hot water production & SAC can improve the ROI.
- SAC systems generally assist in reducing the peak site electricity demand as a result of their optimised use during peak cooling periods of high solar radiation
- There may be potential for SAC in desiccant D-H cycles where there is a dual need for cooling process air and heating of regeneration air streams. This can improve the ratio of usage.
- SAC systems can demonstrate poor overall system efficiency when collector solar fraction is combined with absorption chiller performance.
- The of potential for SAC relates to the incidence of solar radiation peaks with corresponding peaks in cooling loads in office buildings with large glazed envelopes.
- SAC systems can experience longer life spans and lower maintenance costs due to a reduction in the amount of moving parts and vibrations.
- SAC investment can be significantly higher than Vapour Compression cycle chiller plant, in some cases up to 5 times.
- SAC systems will require higher footprint and plant space compared to VCC systems.
- There can be between 36-53% reductions in primary energy with SAC systems when compared to conventional systems.
- Solar collectors are the dominant capital cost item in initial capital costs and achieving the high kW power output for some cooling installations can be unrealistic given the space requirements.
- Consideration should be given to PV driven VCC systems when assessing SAC solutions.

4.6.2 O&M

What to look out for

- Look for sufficient storage of heat generated by the solar collector during periods where it may not be required.
- Ensure all the relevant safety features of the solar collector installation have been installed (i.e. high temperature safety release, high pressure safety release).

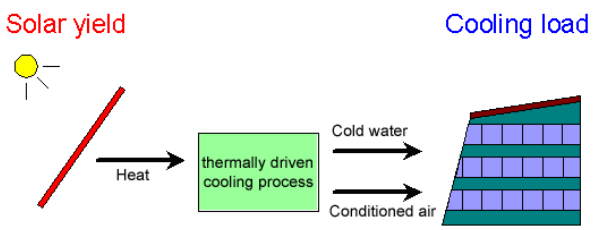
4.6.3 RETROFIT

Opportunities

- Carry out an assessment of the solar fraction for either PV for VCC chillers or flat plate/vacuum tube panels for absorption chiller to establish potential suitability.

4.6.4 REFERENCES

- Advances in Building Energy Research Volume 2, Ch.5 “solar air conditioning: a review of technological and market perspectives” - earthscan publishing. ISBN 978-1-84407-517-1
- South Bank University, London – *“a study of the economic perspectives of solar cooling schemes”*
- Solar thermal technologies for buildings – M. Santamouris – Ch.2 pp17-35 *“Active solar heating and cooling of buildings.”* ISBN 1 902916 47 6



4.7 Low ΔT Syndrome

An important feature of variable flow chilled water systems is the design ΔT (difference between supply and return temperatures) is theoretically constant. This is because the flow is varied so as to match the load thus achieving a constant ΔT. In practice the actual ΔT is generally much lower than the planned design levels. The result is that additional chillers need to be sequenced to maintain flowrates, even though chillers are not fully loaded. This increases pump and chiller energy consumption.

4.7.1 DESIGN

Top Tips

- Eliminate three port valves, however end of line single by-pass valves controlled to provide pump minimum flow are required.
- Automatically close end of line bypass valves that are installed to insure chilled water on demand.
- Avoid selecting coils for a ΔT lower then the design plant ΔT.
- Ensure control valves are not over-sized. Over-sized control valves are likely to hunt.
- Process equipment requiring cooling should be specified with automatic control valves instead of manual valves.
- Specify pressure-independent two port valves. These have a proven track record in achieving design ΔT.

4.7.2 O&M

What to look for

- Remove improper air setpoints to allow appropriate cooling coil control. If the air setpoint is too low the control valve will open fully. As a result air setpoint will not be achieved regardless of how much chilled water is flowing.
- Maintenance and cleaning of filters and coils is required as a preventative measure.
- Control valves should be interlocked to close when the associated AHU is off.
- ACMV Coils should be piped counterflow.
- Chilled Water Reset on small systems is beneficial but on large systems with high pumping distribution losses it may cause an increase in pumping energy over reduced chiller energy due to poorer coil performance at higher temperatures. This will cause increased flowrate and lower ΔT.
- Over pumping chillers can be used to compensate by increasing flow and fully loading the chiller.
- Check for passing valves i.e. valves that pass cooling fluid even when they are closed.

4.7.3 RETROFIT

Opportunities

- Control valves with inadequate close off capability can be mitigated by installing VSDs on the circulation pumps.
- Replace or modify three port valves to two port valves on existing variable flow systems.
- Replace inferior performing two port valves with industrial grade two port valves such as pressure-independent valves.

4.7.4 REFERENCES

- Degrading Chilled Water Plant Delta-T: Causes and Mitigation – Steven T.Taylor P.E.

4.8 REFRIGERANTS

Refrigerant choice is critical in any cooling application. In many countries environmental legislation on Global Warming and Ozone Depleting Substances means that there are no longer simple options with regard to refrigerant choice.

4.8.1 DESIGN

Top Tips

- Consider the long term future of the refrigerant. Is there any planned phase-out legislation?
- Consider specification of non HFC refrigerants with zero Ozone Depletion Potential (ODP) & Global Warming Potential (GWP) such as Ammonia, CO_2 before defaulting to HFC refrigerants.
- For a particular application, the ideal refrigerant is one with a high thermal capacity and low pressure difference at the required operating temperatures
- Specify refrigerant leak detection systems.
- Consider Refrigerant recovery in the form of automatic refrigerant pump down systems.
- Where HFC's are used, ensure fully brazed/welded systems are present. Avoid flared & screwed fittings

4.8.2 O&M

What to look for

- Carry out leak checks on equipment as part of maintenance routine.
- Ensure alarm outputs from refrigerant detectors are connected to an alarm system that is monitored at all times.
- Maintain a register of equipment containing refrigerants and refrigerant usage on site.
- Compile corrective action plans for any units that leak more than 15% of their refrigerant charge in a calendar year.
- Reduce compressor head pressure and operating pressures to improve energy efficiency, and wear & tear.
- Monitor refrigerant suction/discharge pressures & temperatures as part of regular maintenance.
- Maintain correct levels of refrigerant, to avoid poor operational performance.
- Monitor in line suction filters for excessive pressure drop.
- Monitoring of refrigeration for excessive oil, water and debris should be carried out periodically.
- Maintain and monitor compressor lubrication levels.

4.8.3 RETROFIT

Opportunities

- Drop-in HFC replacement refrigerants are now available for CFC and HCFC gases. HFC's have Zero Ozone Depleting Potential.
- Due to their typically smaller molecular size, HFC's are more prone to leaks. Flared and screwed joints should be minimised on HFC systems.
- Nitrogen/Helium pressure testing should be carried out on any system that is to be retrofitted with a HFC refrigerant.
- Leak detection systems should be installed on all HFC systems with a refrigerant charge of greater than 100kg's.
- Leak Detection system alarms should be relayed to a permanently occupied location e.g. security station or control room.

4.8.4 REFERENCES

- EN 378 Parts 1 to 4.
- BSRIA BG 4/2007 Design Checks for HVAC
- LBNL-57260-Revision
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- Institute of Refrigeration www.ior.org.uk
- GPC 225 Industrial Cooling Water Systems – BRESCU.

4.9 LOW TEMPERATURE LIQUID CHILLING

Low temperature liquid chilling systems cover generation and distribution of coolant at temperatures ranging from +4ºC to -50ºC. Typical examples would be

- Chilled water from +4ºC to 0.5ºC without the addition of anti-freeze
- Generation of brines or non-aqueous process cooling fluids for temperatures less than +4ºC.

Typically these systems would use bespoke industrial refrigeration systems as opposed to ACMV type centrifugal chillers.
Many of the points covered already in section 3.0 also apply to these systems.
This section covers additional points specific to process cooling only.

4.9.1 DESIGN

Top Tips

- Challenge user requirements to ensure highest possible circulation temperature can be applied. This is particularly applicable in energy intensive systems below -10ºC.
- In practice these systems can run at very low capacities for long durations between process demands. Ensure end-user estimates of plant activity are realistic.
- Chillers with flooded evaporators are more efficient, more robust and less sensitive to load variations than chillers with DX evaporators.
- Where no safety risk on loss of process cooling systems is present, consider using bespoke systems with multiple compressors and heat exchangers rather than individual liquid chillers. These systems can utilise all system heat exchanger surface areas and sequence multiple compressors for maximum efficiency while maintaining a high level of redundancy and reliability.
- If a small user is driving the central circulation temperature to be less than what the major users require, consider an individual system for that user.
- Where possible use plate heat exchangers on evaporators and condensers to minimise temperature difference between refrigerant and process fluids.
- Sustainable Refrigerants – Consider Ammonia or CO_2 refrigerants.
- On non-aqueous systems (e.g. Dowtherm or Syltherm), it is critical that an effective means to remove moisture from the fluid is present to avoid chiller heat exchangers fouling with ice crystals.

4.9.2 O&M

What to look for

- Saturated Suction temperatures consistently lower than design conditions indicate probable fouling of heat exchangers or low refrigerant charge.
- Saturated discharge temperatures consistently higher than design conditions indicate probable fouling of condenser or poor cooling tower performance.
- Increase in pressure drops across heat exchangers indicates fouling.
- Persistent running of large units at low capacities should trigger an engineering review of system configuration.

4.9.3 RETROFIT

Opportunities

- Given the energy intensity of these systems, if they are found to be running at very low loads or there is major site profile changes, technical and economic reviews of should be triggered.
- It is better to give a high weighting to actual plant operating characteristics when known rather than theoretical process calculations when carrying out system reviews.

4.9.4 REFERENCES

- EN 378 Parts 1 to 4.
- 2009 ASHRAE Handbook - Fundamentals
- 2010 ASHRAE Handbook - Refrigeration
- Institute of Refrigeration www.ior.org.uk
- GPC 225 Industrial Cooling Water Systems – BRESCU.

4.10 REFRIGERATED WAREHOUSING AND COLDROOMS

Refrigerated spaces would typically be regarded as any space where temperatures too low to be maintained with conventional ACMV equipment and where there is a temperature difference of over 5ºC to ambient rooms. Many of the points covered already in section 3.0 apply to the refrigeration systems of these areas. This section covers the items particularly relevant to the storage space.

4.10.1 DESIGN

Top Tips

- Select the lowest U-Value building envelope material possible.
- Ensure that there is an intermediate temperature zone between the access doorways of low temp. (-10 ºC or below) rooms and ambient.
- If there is likely to be a large number of movements in and out of low temperature rooms, consider installing de-humidifiers to remove moisture from the space.
- Ensure that doors have automatic door closing and that alarms are present when doors are left open for extended periods.
- Cooling or pull-down of product temperature should be carried out in special chambers and not in general storage areas.
- Where possible any drives or heat generating equipment should be kept out of the space being cooled.
- Product freezers should have a set-back mode for when freezing cycle is finished.
- When selecting air coolers, ensure that fin-spacing is kept sufficiently wide enough to prevent excessive defrosting.
- Ensure compressor configuration allows for efficient operation from 10% to 100% of expected system load.
- Consider having multiple compressors matching specific loads, i.e. have a large compressor to run when a freezer is pulling down product, and a smaller compressor for storage mode or weekend running.
- Select refrigeration system with the highest evaporating temperature possible and the lowest condensing temperature possible. This will mean generous coil surface areas throughout system.
- On rooms over +2ºC allow for the possibility for air defrost of coils.
- Use recovered heat for defrosting where possible.
- For sub-zero rooms, use recovered heat for low temperature space heating systems.

4.10.2 O&M

What to look for

- Check condition of building fabric and condition of doors. Any malfunctions or damage can lead to moisture ingress in to rooms.
- Check all coils for excessive frost. Frost comes from either ingress air or from product/personnel activity. Frosted coils do not cool efficiently.
- Check that “warm” product is not being placed in storage areas not designed for product pull-down.
- Ensure that all doors are closed and not left inadvertently opened.
- Check for evidence of oil being trapped in evaporator coils. (Particularly relevant in low temperature rooms.)

4.10.3 RETROFIT

- Given the energy intensity of these systems, their performance should be regularly reviewed and any deterioration should trigger a full system review.

4.10.4 REFERENCES

- EN 378 Parts 1 to 4.
- 2009 ASHRAE Handbook - Fundamentals
- 2010 ASHRAE Handbook - Refrigeration
- Institute of Refrigeration www.ior.org.uk
- GPC 225 Industrial Cooling Water Systems – BRESCU.

5. ACMV

5.1 SUMMARY

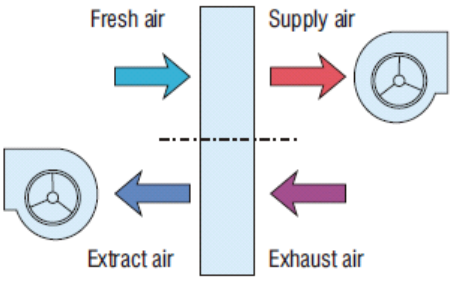
The 2010 benchmarking survey of pharmaceutical plants in Singapore has indicated that electrical energy consumption of Air Conditioning and Mechanical Ventilation (ACMV) and associated systems accounts for 14% of all CO_2 emissions (excluding chiller and cooling tower related energy use).
When cooling energy is added this figure increases to 51.5%. A significant proportion of this load is electrical energy to drive fans in Air Handling Units (AHUs) to meet ventilation and cooling requirements. The other significant component is cooling.

5.1.1 KEY TOPICS

- Ventilation
- Air Handling Systems
- Dehumidification
- Heat Recovery
- Static Cooling & Heating Systems
- Fume hoods
- Laboratories

5.1.2 MAIN REFERENCES

- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.



5.2 VENTILATION

5.2.1 DESIGN

Top Tips

- Airtight buildings and enclosures will allow efficient operation of ventilation systems. Specify building air tightness for a minimum of 5 $m^3/(h.m^2)$ at 50 Pa and perform air permeability tests post construction.
- Reduce excessive air supply and challenge Air Change Rate (ACH) specifications, which generally exceed those required to achieve end user requirements.
- Overall ventilation system efficiency is called Specific Fan Power. It is expressed in kW/(m3/s) or W/(l/s). Efficient systems typically have values <1.5, while industrial systems with high filtration requirements may have values up to 3.0. Refer to ASHRAE Standard 90.1 – 2007 Section 6.5.3.1 for permissible levels.
- Reduce ventilation system pressure drop, by specifying low velocity AHUs (<2 m/s face velocity), design ductwork systems to achieve low resistance (< 1 pa/m), increase filter surface area.
- Design ductwork for uniform flow profile to avoid excessive system effect for centrifugal fans.
- Select Fans for high operating efficiency. Additional capital costs will be recouped quickly by lower operating costs. Avoid excessive over sizing.
- Consider Housed Centrifugal Airfoil Fans.
- Specify VSDs on all major supply and extract systems – including constant volume systems.
- Select motors with minimum efficiency requirements as per ASHRAE Standard 90.1 – 2007 Section 10.
- Consider direct drive fans to remove maintenance requirements of belts and improve energy efficiency. Direct drive maybe limited to certain applications.
- Duct Leakage Specification should be Class C (HVCA DW 144) or equivalent SMACNA standard for industrial applications. Duct leakage testing should be completed.

5.2.2 O&M

What to look for

- Grilles and filters that are clogged with dust and debris should be cleaned regularly.
- Dampers which have been closed or over ridden fully open and are not at original commissioned settings, should be restored to original positions.
- Areas that have under gone a change of use should have ventilation requirements reviewed and reduced if possible. This can be achieved by air flow rebalancing and the changing of fan pulley ratios.
- Regular maintenance and replacement of Fan Belts is important. Insure belts are correctly tensioned and aligned.
- Ensure Bearings are lubricated.
- Check for ductwork leakage and initiate repairs. Leakage can increase energy consumption by up to 30% in industrial buildings.
- Maintenance cleaning of ductwork and fan impellers should be implemented to remove contaminants.

5.2.3 RETROFIT

Opportunities

- Consider conversion from V belt to Synchronous belts particularly for motors started by Soft Start or VSD. Watch for drives which are misaligned, and poor structural rigidity of drives which would not be suitable for a conversion.
- Duct Leakage Repair should be implemented on older high pressure systems, which will deteriorate over time.
- When replacing motors purchasing new more efficient motors may be preferable to rebuild. An economic analysis is required.
- Over sized fans should be retrofitted with VSDs.
- Recommissioning and air balancing of ventilation systems should be carried out where it is determined that ACH rates are excessive.
- Re-examine the ACMV filtration requirements and consider reducing filtration levels and increasing filter surface area to reduce filter pressure losses.

5.2.4 REFERENCES

- LBNL-57260-Revision.
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- GPC 257 Energy Efficient Mechanical Ventilation Systems – BRESCU.
- CIBSE Guide F, TM42:2006
- ASHRAE Standard 90.1 – 2007
- BG 4/2006 Air Tightness Testing – BSRIA
- Improving Fan System Performance US Dept of Energy Efficiency & Renewable Energy.

5.3 AIR HANDLING SYSTEMS

5.3.1 DESIGN

Top Tips

- Assess outdoor air requirements carefully and use the minimum required for Indoor air quality. This applies across many applications including the API manufacturing sector where single pass ventilation systems using large amounts of outdoor have been the norm. Best practice as identified in the MEWR reports should be considered.
- In climates with humid outside air such as Singapore, for industrial/cleanroom applications the use of primary/secondary AHUs is preferred for humidity control and to reduce excessive reheating. The primary AHU provides the fresh air make up requirement, which is dehumidified. This feeds secondary recirculation AHUs that provide the required ACH rates and sensible cooling.
- Localised Fan Filter Units should be considered for Industrial Applications with high ACH rates (<40 ACH) & HEPA filtration requirements. This will reduce the size of central AHUs, with associated fan power, dehumidification and reheat energy usage. Additional plant space is required local to point of use. These are not suitable where solvents are likely to be present.
- Demand control ventilation should be specified for Air Handling systems by varying fresh air supply based on space contaminants (CO_2). This principle could be applied to administration areas by controlling outdoor air intake based on CO_2 levels. It could also be applied in an API facility by controlling outdoor air intake based on presence of solvents.
- VAV systems should incorporate, independent pressure control VAVs with position feedback, and demand control ventilation linked to space CO_2.
- Refer to other sub-sections in section 7.0 also.

5.3.2 O&M

What to look for

- If possible turn off air handling systems when not required, either by time schedule, or occupancy detection. Implement optimum start control for variation in weather conditions.
- If AHUs must remain operational during non production hours or periods of no occupancy (e.g. cleanrooms) consider reduced temperature setback or reduced ACH rates setback. This can be time scheduled, interlocked with lighting system or via occupancy sensors.
- Consider disabling cooling when rooms are unoccupied. Apply where temperature is for occupant comfort only but where ventilation must be maintained.
- VAV systems should incorporate supply air temperature reset, demand based duct static pressure reset (reduces fan energy by 50%), VAV shutoff linked to space occupancy sensors, dual maximum control logic for periods of no or low load.

5.3.3 RETROFIT

Opportunities

- In climates with high average annual temperatures modify unnecessary once through air handling systems to provide recirculation.
- Install air exhaust heat recovery. It may be possible to recover cooling energy by using exhaust air to pre-cool incoming outdoor air. Thermal wheels provide very efficient heat transfer. The exhaust air temperature can be further reduced by using absorption cooling in the exhaust air stream
- VAV systems can be recommissioned to include demand control ventilation linked to CO_2, supply air temperature reset, demand based duct static pressure reset, VAV shutoff linked to space occupancy sensors, and dual maximum control logic for periods of no or low load.
- Single zone constant volume systems can be converted to VAV by adding VSDs to the fans and modifying controls. Supply grilles may require alteration to operate under lower flow conditions to occupant comfort.
- For systems with extensive reheat consider minimising reheat by altering controls to reset AHU air supply temperature higher so at least one open reheat in the system closes.

5.3.4 REFERENCES

- LBNL-57260-Revision.
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- GPC 257 Energy Efficient Mechanical Ventilation Systems – BRESCU.
- ASHRAE Standard 90.1 – 2007
- Advance Variable Air Volume System Design Guide - EDR

5.4 DEHUMIDIFICATION

5.4.1 DESIGN

Top Tips

- Slightly pressurize Buildings to minimise building infiltration latent loads.
- In conventional AHU design minimise reheat after dehumidification by using heat recovery equipment after the cooling coil in the AHU, or use waste or solar reheat.
- Enthalpy wheels can be used to reduce dehumidification requirements in series with cooling coils.
- In climates with humid outside air or for applications with high outdoor air requirements consider the use of primary (DOAS) /secondary AHUs for humidity control and to reduce excessive reheating. The primary (DOAS) AHU provides the fresh air make up requirement, and is dehumidified. This feeds secondary recirculation AHUs which provides the required ACH rates and sensible cooling,
- If a waste heat stream is available then the use of rotary desiccant technology in conjunction with primary (DOAS) /secondary systems (in series or parallel) rather then cooling coils can offer further energy savings by separating latent and sensible cooling. This will reduce cooling coil sizes (sensible load only), reduce mechanical refrigeration plant sizes and allow elevated chilled water temperatures. Waste heat could be from a CHP plant
- The use of a wrap around heat pump across a rotary desiccant device can be used to pre-cool the process air before the desiccant drying. The heat rejection from the heat pump can be used for regeneration of the desiccant wheel
- For low humidity design (<40% RH), which cannot be easily achieved by cooling-coil dehumidification, the use of rotary desiccant technology is required. Consider heat regeneration using exhaust airflows as opposed to outside air. Waste heat or Solar Water Heat can be used as a regeneration source, avoid electric resistance regeneration heating.

5.4.2 O&M

What to look for

- Consider widening humidity control bands to minimise reheat, and additional humidification due to hunting of controls.
- Cleaning maintenance should be scheduled regularly for cooling coils and latent heat recovery devices to maintain efficiency and prevent contamination issues.
- Regular maintenance of filtration systems is the most effective method maintaining clean cooling coils.
- Duct leakage maintenance is required to prevent dry air mixing with humid air reducing dehumidification efficiency. This should be implemented on older high pressure systems, which will deteriorate over time.
- Efficiency of latent heat exchange units should be monitored periodically to observe efficiency is being maintained and monitor degradation of desiccant mediums over time.
- For rotary desiccant systems the required reactivation temperature can vary between 38°C and 120°C depending on the amount of moisture removal required. Waste heat from refrigeration, CHP, process heat, and solar heat are all options.

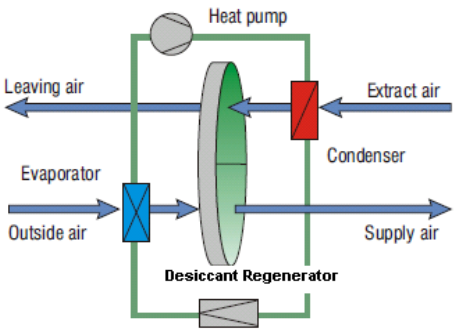
5.4.3 RETROFIT

Opportunities

- Heat pipes can be successfully applied in retrofit scenarios as a wrap around solution for cooling coils, in particular where dehumidification is the primary driver.
- The conversion of existing conventional ACMV systems to primary (DOAS) / secondary configurations requires lifecycle costing and is dependant on plantroom space availability. Significant reductions in operational costs are likely with this approach.

5.4.4 REFERENCES

- CIBSE Guide B2
- ASHRAE Handbook—Systems & Equipment, Chapter 23



5.5 HEAT RECOVERY

Where air is exhausted from a building the energy associated with heating, cooling, humidifying, and dehumidifying is lost to the atmosphere. For all air handling systems and in particular 100% fresh air systems this can represent a significant amount of energy which can be recycled by heat recovery equipment to condition incoming air. Systems are available to recover heat, cooling energy, and moisture.

5.5.1 DESIGN

Top Tips

- ASHRAE 90.1 2007 requires recovery on individual supply fans in excess of 2,400 l/s or greater and a minimum of 70% or greater outside air supply. Recovery should be a minimum of 50% efficient. This is subject to exceptions.
- Only specify equipment that is Eurovent Certified or performs to ARI 1060 – 2005.
- Minimise reheat after dehumidification by using heat recovery equipment after the cooling coil in the AHU.
- Cooling recovery can be accomplished by the same equipment where outside air temperatures exceed exhaust air temperatures for a large proportion of the year.
- In order to prevent over sizing of non critical ACMV systems only size reheating coils in AHUs for the required heating duty with heat recovery assist. This will highlight faults with heat recovery equipment when they occur and encourage quick remedial action, while reducing up front capital cost.
- Enthalpy wheels provide the highest heat and cooling energy recovery efficiencies and energy savings but are not suitable where cross contamination is an issue. An example would be multi-product facility or where high potent API could be present in the exhaust air stream. The risk of cross contamination should not however be over-stated. Generally a small amount of leakage of exhaust air into the supply air stream is not an issue.
- When coupled with VAV, Enthalpy wheels are even more efficient than when coupled with constant volume systems
- Run around loops are the most versatile heat exchanger allowing separation between supply and exhaust as well as multiple locations.
- For exhaust with potential contamination issues consider run-around loops for heat recovery or separating general exhaust from contaminated exhaust, so recovery can be performed on general extract.
- Plate heat exchangers have no moving parts and require minimal maintenance.
- In warm humid climates consider a wrap-around loop around the cooling coil if enthalpy wheels are not appropriate.
- Latent heat recovery should be considered in humid climates where dehumidification is a year round requirement.
- Consider a bypass for heat exchange equipment to reduce pressure drop when heat recovery is not required.
- For the sensible/enthalpy wheels the position of the supply and extract fans can be positioned to prevent or minimise leakage from exhaust to supply air streams.
- Consider filtration requirements pre entry to the heat exchanger to maintain cleanliness.

5.5.2 O&M

What to look for

- Cleaning maintenance should be scheduled regularly to maintain efficiency and prevent contamination issues.
- Efficiency of heat exchange units should be monitored periodically to observe efficiency is being maintained.

5.5.3 RETROFIT

Opportunities

- Run around coils are the most suitable candidates for retrofit due to ease of installation.
- Heat pipes can be successfully applied in retrofit scenarios, in particular where dehumidification is the primary driver.

5.6 STATIC COOLING SYSTEMS

Static cooling systems are a generic name given to chilled beam and chilled ceiling installations. These systems are hydronic and use radiant and convective heat transfer to cool a space. Systems can incorporate heating and ventilation (chilled beams).

Using water for primary heating and cooling is much more efficient then traditional air systems. Air systems can be sized primarily as Dedicated Outside Air Systems (DOAS) significantly reducing fan power costs.

The use of high temperature cooling allows chiller plant to operate more efficiently. The use of low temperature reheating allows the recovery of waste heat rather than using primary energy i.e. gas fired boilers.

5.6.1 DESIGN

Top Tips

- These systems are suited to applications where ventilation is not the primary driver and where internal humidity loads are moderate.
- In climate with high humidity well sealed building envelopes are required.
- DOAS are sized to provide ventilation requirements and humidity control. Typically 1.5 – 3.0 l/s per m^2.
- Primary air supply will require dehumidification to prevent condensation on cooling devices. Alternatively water temperature can be controlled to prevent condensation by sacrificing cooling output.
- The DOAS can supply air at negligible temperature difference to room temperatures. This will eliminate reheating by allowing cooling and heating to occur local to the spaces as required.
- Static Cooling systems use higher chilled water temperatures than conventional air-conditioning systems [13°C to 17°C] versus [4°C to 7°C]. A chiller dedicated for static cooling operates at 15% - 20% higher efficiency than for a conventional system (for cooling loads independent of ventilation).
- Active Chilled Beams with air supply are capable of cooling outputs of up to 120 W/m^2.
- Passive Chilled Beams are primarily used to counteract perimeter solar gains but can also be used for internal space cooling with cooling outputs limited to 80 W/m^2.
- Radiant cooling panels are capable of cooling outputs of up to 100 W/m^2.
- Thermally Active Building Systems (TABS) use embedded emitting elements in the main building structure to provided radiant cooling (outputs of up to 100 W/m^2). These systems are slow response acting and operate to maintain temperature in a controls range rather then a constant setpoint.

5.6.2 O&M

What to look for

- Maintenance levels are low with cleaning required once every 5 years.
- Inlet water temperature must be always above the space dew point temperature.
- Space dew point should be adequately controlled prior to water circulation.
- Two port on-off control valves is the most suitable control application.

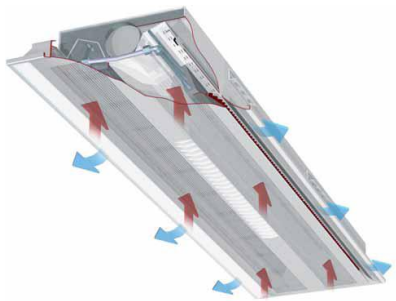
5.6.3 RETROFIT

Opportunities

- Active and passive beams have been used successfully in retrofit applications with low suspended ceiling heights.

5.6.4 REFERENCES

- Chilled Beam Application Guidebook - REHVA
- Low temperature heating and high temperature cooling - REHVA
- http://www.labs21century.gov/



5.7 LABORATORIES

Laboratories are highly energy intensive, often using four to six times more energy per m^2 than a typical office building. Existing technology is capable of reducing energy use in Laboratories by 30 to 50%.

5.7.1 DESIGN

Top Tips

- Ventilation accounts for close to 50% of the electrical energy use in a typical laboratory. Reducing a laboratory's ventilation requirements can reduce the cost to build and operate a facility.
- Prevent over sizing of ACMV systems by accurate estimates of internal lab loads. Measurement of equipment loads in comparable labs is recommended to right size plant. Probability based analysis should be used to determine diversity loads.
- Optimise Ventilation requirements by challenging conventional practice & standards. ASHRAE Lab Guide-2001 recommends 4-12 ACH. Consider safety requirements, ACMV first cost and energy consumption. Use lifecycle costing to inform decisions.
- Provide occupancy control to allow ventilation to shut off or setback during unoccupied periods. Reducing setback ventilation to 4 ACH as a minimum rate proposed by NFPA 45-2000 standard.
- Control banding can be used to classify handling chemicals and hazards according to their associated health risks. This can result in different ACH rates for increasing levels of risk.
- Task Ventilation Control should be considered for specialised laboratories or areas where local ventilation devices are used such as glove boxes, biological safety cabinets, & local exhaust ventilation.
- Consider the use of CFD to study different ventilation rates and provide a greater understanding of their ability to remove airborne pollutants from labs.
- Design for reduced pressure drop throughout the entire systems including AHUs, ductwork, and terminal devices.
- Varying supply and exhaust flows based on actual usage. A 25% reduction in airflow results in about a 58% reduction in the fan power required. ASHRAE 90.1 standard requires variable-air-volume (VAV) systems, with some exceptions.
- Minimise reheat by placing areas with dissimilar internal heat gain density on separate air handling systems.
- Consider heat/cooling energy recovery to reduce energy consumption associated with once through air. Cross Contamination issues need to be addressed when selecting heat recovery equipment.
- Where containment devices such as fume hoods are not required, consider the use of chilled beams versus VAV for ventilation driven & cooling driven requirements, to reduce reheat, fan loads.
- Consider high temperature cooling and low temperature heat sources if reheat is required.

5.7.2 O&M

What to look for

- Commissioning of ventilation systems for laboratories should include extensive demonstration in all modes of actual user operation. This includes variation of sash heights for fume hoods, door opening and pressurisation relationships. A good practice procedure is ANSI Z9.5-2003, the System Mode Operational Test (SMOT).
- To minimise reheat for areas with less stringent temperature and humidity requirements consider disabling the heating system serving reheat units.

5.7.3 RETROFIT

Opportunities

- Recommissioning of static system pressures for VAV systems could result in reducing operating setpoints.
- Temperature or airflow setback during unoccupied periods.
- Convert Constant Volumes systems to VAV.
- If exhaust systems have common manifolds consider heat/cooling energy recovery.

5.7.4 REFERENCES

- LBNL-57260-Revision.
- ASHRAE Laboratory Design Guide
- GPC 257 Energy Efficient Mechanical Ventilation Systems – BRESCU.
- CIBSE Guide F, TM42:2006
- ASHRAE Standard 90.1 – 2007
- http://www.labs21century.gov/

5.8 FUME HOODS

Fume hoods are commonly installed in biopharma & nutritional facilities in quality assurance laboratories. Fume hoods are containment devices, for exhaust hazardous gases and protect workers from breathing harmful substances.

The energy required to heat and cool make-up air and electrical energy to drive fans in Air Handling Units (AHUs) to meet ventilation requirements for laboratory fume hoods is a significant portion of laboratory ACMV energy consumption.

5.8.1 DESIGN

Top Tips

- Avoid auxiliary hoods
- Specify variable volume fume hoods which adjust exhaust flow based on face velocity across the sash.
- Consider occupancy sensor & automatic sash control on VAV fume hoods.
- Consider low velocity fume hoods which operate at face velocities <0.5 m/s.
- Manifolding exhausts combined with the use of a VAV fume hood system results in significant energy savings by taking advantage of operational diversity. Manifolding exhausts simplifies an energy recovery system. A manifold system is also typically less expensive to construct and maintain than a configuration with a separate fan for every hood.
- Specify high efficiency lighting systems for fume hoods.
- Exhaust fans should be specified with VSDs and bypass air dampers to maintain minimum velocities for plume dispersion and dilution.
- The use of stepped fan operation with exhaust manifolds to track load is efficient option which will provided redundancy.
- When sizing common make up supply & extract air handling systems allow for fume hood use diversity. The greater the number of fume hoods the greater the attainable diversity.

5.8.2 O&M

What to look for

- If possible turn off air handling systems
- Unused fume hoods should be disabled and the exhaust duct closed.
- Avoid using fume hoods as storage for chemicals and instruments as this will mean continuous operation.
- Restrict Sash opening heights
- Use Setback Exhaust Duct Static Pressure during unoccupied periods.
- Consider user training to improve sash management to encourage keeping sashes closed

5.8.3 RETROFIT

Opportunities

- Consider VAV retrofit controlled by occupancy sensor & automatic sash control.
- For VAV fume hood systems consider retro commissioning by introducing a static pressure reset strategy on supply fans to reduce fan energy requirements.
- Consider restricting sashes by installing sash stops at 18 “height.

5.8.4 REFERENCES

- LBNL-57260-Revision.
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- GPC 257 Energy Efficient Mechanical Ventilation Systems – BRESCU.
- CIBSE Guide F, TM42:2006
- ASHRAE Standard 90.1 – 2007
- NFPA 45-2000
- http://www.labs21century.gov/

6. HEAT REJECTION

6.1 SUMMARY

All mechanical cooling systems that remove heat by cooling spaces or processes must ultimately reject that heat to the environment.

The environment can include the atmosphere, the earth, or a body of water.

The Best Available Technology (BAT) approach advocates that the concept of heat recovery should be employed where possible and when no further recovery and re-use of heat is possible, only then should it be released into the environment.

Optimising heat rejection systems is dependant on:

- Process cooling requirements
- Onsite limitations & restrictions
- Local Climate

Once these constraints have been accounted for the BAT approach requires the following:

- Reduction of direct energy consumption by applying low energy equipment and reducing resistance to water and airflow.
- Reduction of water consumption and heat emissions to water.

6.1.1 KEY TOPICS

- Cooling Towers
- Heat Recovery
- Sea Water Cooling

6.1.2 REFERENCES

- Industrial Cooling Systems (ICS) BREF

6.2 COOLING TOWERS

6.2.1 DESIGN

Top Tips

- VSDs should be specified for fans.
- Max flow rating of tower divided by the nameplate rated motor power should be ≥ 3.23 L/s per kW for axial/propeller towers and ≥ 1.7 L/s.kW for centrifugal fan towers.
- Limit approach temperature to 2.25 °C.
- Consider Hybrid Cooling Towers or closed circuit towers for water consumption reduction and lower running costs (approx 35%). However Capex is likely to be higher. A combination of open circuit and closed circuit should be considered.
- Tower location should prevent air intake recirculation. Location should also avoid fresh air intakes and flue outlets.
- Collect water by rain-water harvesting, reject water from high purity water systems, etc for use in cooling towers to minimise the use of potable water.
- Include side stream separators in open tower circuits to reduce fouling.
- Try to locate open towers at equal or higher elevation than user points to reduce static head pumping costs.
- Oversize PHE to offset fouling effects.
- Design to avoid fouling of chilled water circuit with strainers, filters & water treatment.

6.2.2 O&M

What to look for

- Run Multiple Towers with VSDs at low speeds rather then staging in series as load ramps up to save fan energy.
- In units with multiple one or two stage fans, sequence fans efficiently by starting each fan in sequence at low speed, and then in sequence at high speed.
- Limit operating approach temperatures to 2.25 °C, as incremental increase in chiller efficiency is unlikely to outweigh increased fan consumption.
- Use fixed approach control as opposed to fixed temperature condenser water control.
- Near Optimal Control (BSRIA) is preferred to fixed approach control.
- Using monitoring systems to indicate if water and electrical consumption follows cooling load. This will indicate how well the system is controlled.
- Monitor fouling on Cooling Tower.
- Monitor air bypass or recirculation on cooling tower.
- Review Site Water Make-up quality with a view to optimising water blow-down performance.
- Ensure regular maintenance programme for testing cooling tower water quality.

6.2.3 RETROFIT

Opportunities

- Install VSDs on single speed fans or when replacing damaged fan motors
- Install water meters linked to BMS for make up water monitoring.
- Install VSDs on condenser water pumps to avoid pressure throttling.
- Provide electrical pulse metering for fan power to monitor tower consumption and operation patterns.
- Consider recycling AHU condensate and rainwater for make up water.
- Alter control strategy to best practice.
- Install and maintain automatic bleed control.

6.2.4 REFERENCES

- ASHRAE Standard 90.1 – 2007
- SS 530:2006
- BSRIA BG 4/2007 Design Checks for HVAC
- BSRIA AG 7/98 Library of System Control Strategies
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- GPC 225 Industrial Cooling Water Systems – BRESCU.

6.3 HEAT RECOVERY

6.3.1 DESIGN

Top Tips

- While low temperature heat, in the range of 30 - 60°C, is typically available it can be a limiting factor is terms of application.
- Preheating of Domestic Hot Water (DHW) is the most common application.
- Low Pressure Warm Water (LPWW) systems operating in the range 30 – 50°C can be used for ACMV reheating.
- Applications for process heating are site dependant. Consider using Process Integration or "Pinch" for identifying heat recovery opportunities particularly where batch processing is predominant.
- Increasing the condenser water temperature will reduce the cooling capacity and the efficiency of the chiller, therefore a dedicated heat recovery chiller, which is optimised for the task, is preferred for large amounts of heat recovery.
- If a 30°C circuit is used for ACMV reheating then return cooling tower water can be used for this purpose!
- For water cooled condensers using a plate heat exchanger (PHE) to link to the heat recovery circuit before condenser water entry to the cooling tower is the most practical solution. This avoids fouling of heating equipment.
- Consider use of additional or double bundle condensers on both water and air cooled chillers.
- Heat recovery is not suitable for absorption chillers or standard centrifugal chillers. Consult manufacturers for special heat recovery options regarding centrifugal chillers.

6.3.2 O&M

What to look for

- In periods of peak cooling, heat recovery may be suspended to maintain cooling capacity.
- Chillers that can control the leaving condenser water temperature and have temperature set-point reset are an advantage.
- Alternatively a temperature controlled bypass valve can be installed to maintain the desired leaving condenser water temperature.
- Regular cleaning of PHE is required to prevent excessive fouling.
- Schedule periodic checks of heat recovery systems to monitor system performance. Record parameters related to effectiveness in an operating log.

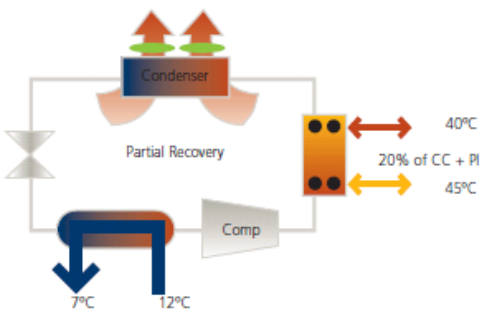
6.3.3 RETROFIT

Opportunities

- Adding a PHE for heat recovery between the condenser and the cooling tower is most economical method.
- If site has a requirement for smaller chiller to serve part load cooling, installing a heat recovery chiller as the lead chiller is an option provided a corresponding heat load is available onsite.
- Add thermal storage to improve heat utilisation where there is a time delay between supply and demand.

6.3.4 REFERENCES

- BSRIA BG 4/2007 Design Checks for HVAC
- LBNL-57260-Revision
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- GPC 225 Industrial Cooling Water Systems – BRESCU.



6.4 SEA WATER

6.4.1 DESIGN

Top Tips

- Sea Water is huge cooling resource with temperatures in Singapore ranging from 24°C to 31°C.
- Use of once through Sea Water for cooling will reduce the requirements for desalinated water for cooling towers in areas where fresh water is a limited resource.
- Extracting from lower depths will produce colder water.
- Higher first day capital cost and increased maintenance costs will be outweighed by increased efficiency and reduced water costs compared to air cooled chillers and water cooled chillers.
- Large District Sea Water Cooling Systems serving a number of sites are more cost effective.
- High Salinity and Chlorinity approx 35% requires careful design for corrosion.
- Sea water can be used directly in chiller condensers by specifying Titanium tubing in the condenser sections.
- Alternatively use Titanium plate heat-exchangers (PHE) to hydraulically isolate chillers from sea water system. Consider over sizing PHE to offset fouling effects.
- Marine Studies are required to quantify risk related to thermal discharge.
- Dedicated Sea Water Pump house required on the waterfront, which should include intakes at the bottom of Sea walls, settlement chambers to reduce suspended solids, mesh screens for primary filtration.
- Sea Water pipework systems should be sized for < 2 m/s, with self cleaning strainers. For long distances booster pumps maybe required.
- Sea Water Cooling Towers are an option however careful selection of materials is required to control corrosion.

6.4.2 O&M

What to look for

- Biofouling requires dedicated treatment in the form of Chlorination or Biocides that are sufficiently biodegradable. Consult water treatment expert at early stage.
- Substantial maintenance is required to prevent blockages and replace equipment damaged by corrosion (filters, valves, pump impellers etc). Standby component are recommend for these items.
- Monitor fouling on PHEs.

6.4.3 RETROFIT

Opportunities

- For existing plant Titanium PHEs connected to the condenser water circuit either to supplement or replace exiting cooling towers may be practical depending on the site. Leak detection is required for heat exchangers.
- For existing plant direct systems are considered technically and economically the most applicable solution.

6.4.4 REFERENCES

- Industrial Cooling Systems (ICS) BREF
- BSRIA BG 4/2007 Design Checks for HVAC

7. HYDRONIC SYSTEMS

Hydronic system design, if not given appropriate consideration can affect performance of generation equipment, heat dissipation equipment and pumping energy costs. A thorough assessment of the fluid flow, pressure and temperature characteristics of the system under a range of different load patterns is important to ensure the efficiencies and performance levels quoted at design load can be achieved at part load operation. Typically 82% of the time a Hydronic system will operate at or below 50% of its design load.

7.1 SUMMARY

A survey of industrial plants in Singapore has indicated that electrical energy consumption of Air Conditioning & Mechanical Ventilation (ACMV) equipment and associated systems accounts for 17% of all electrical energy usage. (Excluding chiller and cooling tower related energy use).

A significant proportion of this load is electrical energy to drive pumps in cooling system to meet air conditioning requirements.

Furthermore, the efficient control of Hydronic systems can contribute to a reduction in overall generation plant operating loads where 40% of all electrical energy usage can be attributed to cooling generation plant.

The Best Available Technology (BAT) approach advocates the optimisation of energy efficiency using a systems approach.

The main areas for improved energy efficient performance in Hydronic systems are:

- control of the ΔT at production units and terminal units,
- Differential pressure control through the distribution system and effective variable speed pumping.

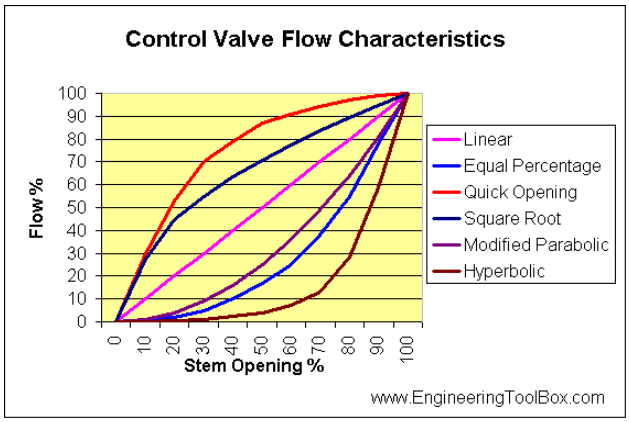
Selecting suitable production-distribution architectures to meet the requirements of the installation can also provide added energy and operational performance.

7.1.1 KEY TOPICS

- Control Valve Selection
- Differential Pressure Control
- Hydronic System Architecture
- Hydraulic Incompatibility
- Maintenance & Water treatment

7.1.2 REFERENCES

- Total Hydronic Balancing – Tour Andersson. Author: Jean Pierre Petit jean
- BSRIA A Guide to HVAC Building Services Design Calculation BG30/2007
- CIBSE Guide H – Building System Controls ISBN 978-1-906846-00-8
- BSRIA HVAC Design Checks BG4/2007
- CIBSE KS07 – Variable Flow Pipework systems: valve solutions (supplement)
- TA Hydronic College – Dr Jean Christophe Seminar and technical articles. http://www.tourandersson.com/en/Technical_library/Technical-Notes-/



7.2 CONTROL VALVE SELECTION

Choosing between 2 Port control and 3 Port control should be the first decision in the design and selection of any Hydronic system. The type of flow control employed will have an impact on schematic design, layout design, components selection, pumping solutions and the overall operation of the system. 2 Port control, variable flow water systems are becoming more predominant as a result of the benefits obtained in pumping energy savings.

7.2.1 DESIGN

Top Tips - General

- Select control valves with an Authority (N) as close to 0.5 as possible but < 0.3.
- Check the change in authority at turn down ratios, partial load and flow conditions.
- Select control valves with an equal % flow characteristic that matches the heat output to the flow-rate characteristic of terminal or dissipation unit.
- Preventing the variation in differential pressure across the controlled circuit will improve the stability of control authority.
- Always consider the global circuit characteristic (GCC) when designing distribution circuits and selecting control valves. The GCC is made up of the control characteristic function of the:
    - Valve Actuator
    - Valve characteristic (K_V)
    - D_P Variation effect on valve (Authority)
    - Terminal Characteristic
- For ACMV applications always select valves with Equal % characteristics.
- Valve range-ability should be > 50:1.
- Valve leakage characteristic should be no more than 0.05% of Kvs.
- The close off pressure rating should be at least 1.5 times the expected maximum differential pressure that the valve is likely to experience.
- Always contact the valve manufacturer to obtain valve specific flow coefficients and always ensure correct notation and units are used (SI, Imperial, Continental)
- Always ensure valves are correctly sized for their application.
    - Undersized valves will provide a high resistance to flow when fully open leading to higher pumping costs
    - Oversized valves will have a low ΔP compared to the controlled circuit when fully open leading to instability of control.
- Don't rely on industry rule of thumb guidelines. Carry out project specific calculations to establish the correct K_v value for the particular conditions.
- Consider 2 port variable flow control through a terminal unit for the design approach. This increases return water temperature in cooling, thus increasing ΔT and chiller COP at partial load.
- 3 port variable-flows through the dissipation unit cause a reduction in return water temperature due to diverting supply water. This reduces ΔT thus reducing chiller COP at part loads.
- Always check with manufacture that the valve selection is specific to diverting or mixing application in 3-port scenarios.
- Variable flow control is more important in cooling applications due to the lower ΔT and thus higher pumping energy with higher flow-rates.
- Pressure independent two-port valves provide superior performance to pressure dependent valves.

7.2.2 O&M

- Carry out a survey of the conditions of all control valves in the system. Check the condition of all actuators.
- Service all valves regularly including routine checks for any dirt or grit build up in the mechanical valve assembly.
- Be aware of leakage across older valves, allowing energy losses from the system when it is assumed there is zero flow. Replace any valves that do not close correctly.

7.2.3 RETROFIT

- Consider replacing certain components on the global valve assembly to improve the GCC. Review BAT actuator solutions for valves controlling AHU plant.
- Consider installing process quality control valves on large AHU plant to improve control performance.

7.2.4 REFERENCES

- Total Hydronic Balancing – Tour Andersson. Author: Jean Pierre Petit jean
- BSRIA A Guide to HVAC Building Services Design Calculation BG30/2007
- CIBSE Guide H – Building System Controls ISBN 978-1-906846-00-8
- BSRIA HVAC Design Checks BG4/2007
- CIBSE KS07 – Variable Flow Pipework systems: valve solutions (supplement)
- http://www.tourandersson.com/en/Technical_library/Technical-Notes-/

7.3 DIFFERENTIAL PRESSURE CONTROL

Variation in pressure across sub circuits as a result of control valve modulation in adjoining circuits will change the differential pressure characteristic across the control valve and subsequently affect valve authority. As a control valve modulates its own circuit it also causes a transfer of primary circuit pressure from the circuit components onto the valve again affecting its authority. It is crucial to control differential pressure in variable flow water systems to achieve effective performance.

7.3.1 DESIGN

Top Tips - General

- Always consider the use of differential pressure control in variable flow water systems.
- Maintaining constant ΔP across Hydronic circuits gives better stability of control authority and pressure stabilisation. This reduces the risk of underflow in some circuits and overflow in others.
- The larger the ΔP change across the control valve, the larger the distortion of the valve characteristic.
- Consider the use of PICV (Pressure independent control valve)
- Any decision on which ΔP control solution should consider investment costs, operational issues and net savings on pump energy and generation plant performance. A detailed analysis should be completed in consultation with manufacturer data.
- The flow setting range on some PICVs is limited making it difficult to select valves for some low flow applications. Always contact the manufacturer for specific data.
- Some small diameters PICV do not necessarily maintain an equal percentage characteristic under all operating conditions. Always clarify the characteristic of each particular PICV and judge the level of control achievable.
- The DPCV component of the PICV must have enough pressure across it to enable the spring to move and control. This minimum is typically in the range 15–20 kPa for 15–32 mm diameter valves.
- The full load pump pressure must not exceed the manufacturer's recommended maximum differential pressure value for the PICV.
- There needs to be some path open to flow to prevent the pump operating against a closed system. A simple solution is to incorporate 4-port valves, with built-in bypasses, on end of branch terminal units.

7.3.2 O&M

- Always consider the use of differential pressure control in variable flow water systems.
- Carry out an inventory survey of the existing system and establish current installation characteristics such as line size, Kv valves, and differential pressures, to compare against Best Practice.

7.3.3 RETROFIT

- Consider installing DPCV on existing systems with 2 Port Control
- Consider replacing 3 Port control valves in constant flow systems with PICV units.

7.3.4 REFERENCES

- Total Hydronic Balancing – Tour Andersson. Author: Jean Pierre Petit jean
- BSRIA A Guide to HVAC Building Services Design Calculation BG30/2007
- CIBSE Guide H – Building System Controls ISBN 978-1-906846-00-8
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- CIBSE KS07 – Variable Flow Pipework systems: valve solutions (supplement)
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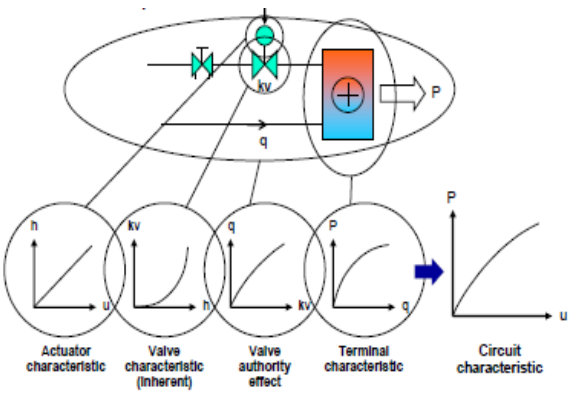


7.4 HYDRONIC SYSTEM ARCHITECTURE

This section provides some best practice tips when designing the distribution system strategy, in other words, decision such as primary/secondary vs. variable primary flow solutions. Reference to the literature is recommended for more detailed information in terms of project specific design decisions.

7.4.1 DESIGN

Top Tips - General

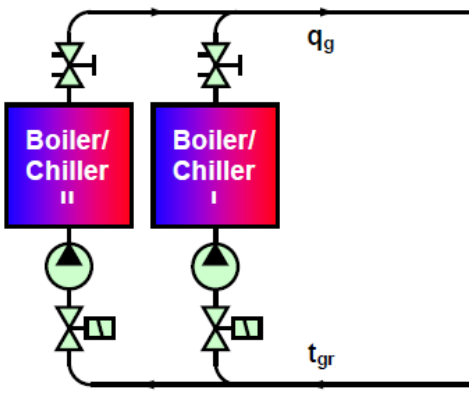
- Always assess the suitability of different types of distribution architecture for hydronic systems.
- Consider hydraulic decoupling of generation and dissipation equipment using primary-secondary circuit design.
- Consider the potential energy and operational cost improvements using a variable primary flow system solutions.
- Always design distribution systems with the physical building layout in mind, particularly when deciding on the number of sub distribution branches.
- Always connect the secondary distribution flow circuits to the side of the manifold header nearest the primary flow connection and vice versa for the secondary return branches.
- Provide high and low vents and drains throughout the Hydronic system at strategic locations.
- In primary-secondary systems, size primary pumps on generation side of primary-secondary system with low head.
- Ensure constant flow through each generation unit (variable through staging in sequence)

Top Tips – Variable Flow Systems

- Variable speed pumps should always be used for variable volume two port systems.
- Always locate the variable speed pump remote Differential Pressure (DP) controller at the index circuit based on the highest circuit pressure drop (excluding pipe losses as these change globally). **(When DP control is used)**
- The index circuit is not necessarily the circuit with the highest proportion of piping; it is specifically related to the ΔP across the terminal unit and sub branch.

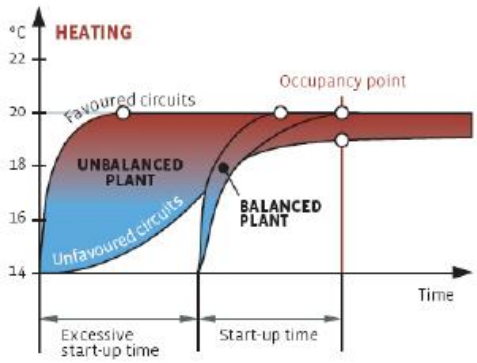
Top Tips – Variable Primary Flow Systems (VPF)

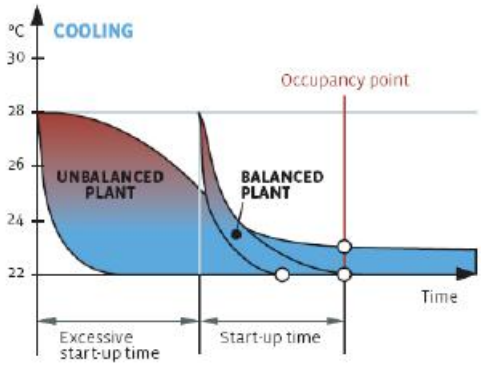
- Always check the minimum flow limit of generation plant equipment.
- Always check the allowable flow-rate change range of generation plant equipment. (specifically evaporators)
- Operate the VPF system with a flow meter controlled bypass valve, normally closed to avoid lowering the ΔT. Only open to protect evaporator minimum flow.
- Always assess flow interactivity through chiller plant during sequencing on/off plant. Always slowly introduce 2nd chiller, otherwise the flow will half to 1st chiller when 2nd chiller engaged causing an evaporator fail safe scenario.
- Use slow acting valves to control all large load terminal units (AHU plant) to avoid sudden changes in system flow through chiller plant.
- Consider staggering start/stop times of all AHU plant on VPF circuit.
- The flow interactivity is not as much a concern with heating systems as generation plant can handle changes in flow.
- Chillers must be balanced using FODRV valves to avoid chillers with differing pressure drops receiving different proportions of the flow adjustment.
- Selection of the bypass control valve is crucial. Consult manufacturer for detailed valve data.



7.4.2 O&M

- Consider annual rebalancing and recommissioning of all Hydronic systems to ensure efficient operation at full load and part load.
- Review noise generation at control valves and assess the need for valve reselection.
- Excessive noise generation may be due to valve cavitation or damage due to valve hunting.
- Be aware of the “leakage effect” of valves that have been installed for long durations (>5yrs). This “leakage” effect can cause energy leakage from the system where heat transfer is taking place at otherwise closed loops.
- Check and repair all general leaks in Hydronic systems.





7.4.3 RETROFIT

- In existing systems 2 Port controlled without DP controllers consider installing these to improve valve authority at partial load operation.
- Consider installing isolation valves on generation equipment and balancing valves to provide even flow distribution.
- Provide good water treatment using electronic monitoring of water quality.

7.4.4 REFERENCES

- Total Hydronic Balancing – Tour Andersson. Author: Jean Pierre Petit jean
- BSRIA A Guide to HVAC Building Services Design Calculation BG30/2007
- CIBSE Guide H – Building System Controls ISBN 978-1-906846-00-8
- BSRIA HVAC Design Checks BG4/2007
- CIBSE KS07 – Variable Flow Pipework systems: valve solutions (supplement)
- TA Hydronic College – Dr Jean Christophe Seminar and technical articles. http://www.tourandersson.com/en/Technical_library/Technical-Notes-/

7.5 HYDRAULIC INCOMPATIBILITY

Where two circuits share a common section, the system must be balanced to ensure that the two flows do not interact in such a way as to prevent the desired performance being achieved. This can prevent the design boiler/chiller heat/cooling output being delivered to the heat emitters/absorbers. The total pump flow on the primary side must be at least equal to that on the secondary and this must be established during balancing.

7.5.1 DESIGN

Top Tips - General

- Always assess the interaction between pumps in series on Hydronic systems and assess that the correct flow direction is achieved in any bypass arrangement.
- Where there is a variable primary pump consider the use of a hydraulic decoupler or buffer to act as a bypass and low pressure sink.
- Always size the hydraulic decoupler (manifold header) with negligible pressure drop (<0.5 m/s) to avoid cross pumping interference with primary and secondary circuits.
- Consider the use of injection circuits on all terminal AHU plant. This provides hydraulic decoupling of the primary pump and the high coil resistance. It also provides constant volume flow through the terminal. Be aware of degrading ΔT when considering this solution.
- Always monitor the flow direction through any bypass to ensure correct direction of flow.
- Always consider connection of the fluid thermal expansion vessel to the systems pressure neutral point at the suction side of the pump.

7.5.2 O&M

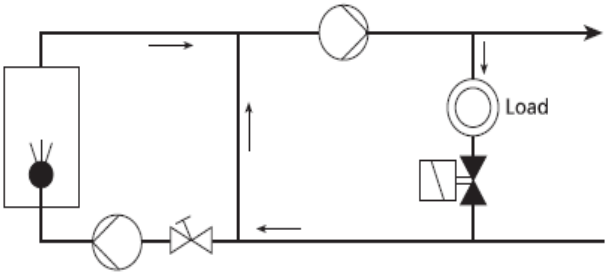
- Undertake a survey of pumping operations to ensure there is no hydraulic incompatibility present in the Hydronic system.
- Replace any pumps or alter any piping configurations which may be causing hydraulic incompatibility.
- Consider operating primary pumps as constant low-head pumps on primary circuits.
- Consider the use of VSD control on secondary circuit pumps to reduce the influence of larger secondary distribution pumps.

7.5.3 RETROFIT

- Consider replacing existing primary-secondary manifolds with low pressure headers where there may be undesirable circuit interactivity.

7.5.4 REFERENCES

- Total Hydronic Balancing – Tour Andersson. Author: Jean Pierre Petit jean
- BSRIA A Guide to HVAC Building Services Design Calculation BG30/2007
- CIBSE Guide H – Building System Controls ISBN 978-1-906846-00-8
- BSRIA HVAC Design Checks BG4/2007
- CIBSE KS07 – Variable Flow Pipework systems: valve solutions (supplement)
- TA Hydronic College – Dr Jean Christophe Seminar and technical articles. http://www.tourandersson.com/en/Technical_library/Technical-Notes-/
- BS 7074 Part 2: 1989 Application, selection and installation of expansion vessels and ancillary equipment for sealed water systems



7.6 MAINTENANCE AND WATER TREATMENT

Design, O&M and retrofit are all covered as general items in this section. This is due to the fact that good system management and operational procedures are at the core of good water quality. The following top tips provide an overview of the things to watch for. Consult additional reference documentation for more detailed data.

7.6.1 DESIGN

Top Tips – Flushing and Cleaning

- The type and extent of cleaning and cleaning agents will depend on system type, size, whether it is open or closed systems materials and system age. Consult a specialist when assessing the correct cleaning requirements.
- The flushing water supply pipe should, in the absence of any other priorities, be sized such that the minimum flushing flow rates in the system can be achieved without the need to interrupt the process while break tanks re-fill.
- Bypass low flow regulating valves and flow measurement devices during the flushing process to avoid excessive velocities and unacceptable high pump head.
- Avoid deg legs at all points in the system. Where this in impractical install flushing drain points to ensure good circulation of cleaning chemical agents.
- Strainers should be able to withstand higher pump head and should have mesh suitable for chemical agents. Consult manufacturer's data.
- Consider the installation of de-aerators, preferably pressure differential type or combined air-dirt separators.
- Consider the use of automatic dosing systems over dosing pots to allow controlled and monitored control of treatment agents and biocides.
- Provide adequate bypass arrangements on all sensitive equipment to avoid flushing through these items.

Top Tips - Treatment

- When the balanced flush is completed, stabilise the system immediately with 500 ppm biocide followed by corrosion inhibitor to give a nitrite reserve within the range 300–500 ppm. If the system is not going to be re-circulated routinely after inhibition, a much higher dosage level must be used to allow for this.
- On completion of the flushing and cleaning activities described above, final water samples should be taken to record the final water quality and condition.
- This is especially important if the system in question is part of a larger system which, when connected, may be subject of an overall water quality audit.
- On larger installations consider the use of side stream filtration units. Always provide correct cleaning of side stream filtration unit as this can be a source of bacterial growth.
- Consider the installation of end of line bypass branches to ensure good circulation of chemicals and treatment throughout the overall systems.
- High point drains and low point vents should be provided throughout the systems and at all terminal units and operating equipment.
- Chemical cleaning should not be attempted unless the system has been thoroughly clean-water-flushed to the satisfaction of the cleaning specialist.
- The required chemical circulation time for a successful clean is usually between 12 and 72 hours, to run either continuously or intermittently
- A typical chemical cleaning programme is likely to include some or all of the following procedures. Consult a specialist or approved chemical treatment guidelines for information on each stage:
    - Static flushing
    - Dynamic flushing
    - Degreasing
    - Biocide wash (for systems at risk from bacteria)
    - Removal of surface oxides (for systems with mild steel components)
    - Effluent disposal/final flushing
    - Neutralisation (for inhibited acid cleans only)
    - Passivation
    - Corrosion inhibitor and biocide dosing.

7.6.2 REFERENCES

- BSRIA AG1.2007 – Pre commission cleaning of pipework systems
- CIBSE AM14:2010 – Non Domestic Heating Systems

Agents	Actions
Degreasing agents	To remove grease or oil
Inhibited acid cleaners Formulated products	To remove surface oxides
Biocides Biodispersants	To remove biofilms and reduce bacteria levels
Passivators Corrosion inhibitors Biocides	To minimize the rate of corrosion and control bacteria

8. CLEANROOMS

Cleanrooms can be the most energy intensive part of industrial facility operations. Very high air change rates, high filtration levels and continuous operations can lead to excessive fan and thermal energy consumption. Challenging the ACH rate, decentralising the ACMV plant and implementing a setback mode are realistic areas to help reduce energy consumption.

8.1 SUMMARY

A survey of industrial plants in Singapore has indicated that electrical energy consumption of ACMV and associated systems accounts for 17% of all electrical energy usage. (Excluding chiller and cooling tower related energy use).

A significant proportion of this load is electrical energy to drive fans in Air Handling Units (AHUs) to meet ventilation and cooling requirements in cleanrooms.

Cleanrooms are controlled environments maintaining both particulate and microbial growth levels below certain acceptable threshold limits. This is achieved through the use of high efficiency filtered air supply. However, very often the volume of air used to achieve regulatory compliance is far in excess of the amount actually needed to satisfy threshold limits.

Cleanroom ACMV systems can often operate at very high total system pressures due to the high filtration requirements.

Special attention should be given to filtration requirements and fan power consumption when considering best practice design guidelines for clean spaces.

Best practice design of clean spaces begins at the cultural level in an organisation.

Challenging and establishing the qualification and approved protocol acceptance criteria for clean spaces is the best way to improve overall ACMV energy performance and reduce fan power consumption.

Early implementation of an EED methodology for any project, new build or refurbishment, is particularly important in the context of cleanroom design. This will champion the technologies and solutions that are most effective at meeting the design brief with the least amount of energy consumption.

The Labs 21 Program has developed an online energy benchmarking tool for cleanroom and laboratory spaces (U.S. EPA/DOE 2005).

Benchmarking can help to provide information on the performance of a given facility, relative to that of peer facilities, by comparing the facility energy performance.

8.1.1 KEY TOPICS

- Cleanroom Layout Design
- Reduced Recirculation Air Change Rates
- Improved Air Filtration Quality and Efficiency
- Cleanroom Set Back Modes
- Gowning Procedures

8.1.2 MAIN REFERENCES

- Eudralex Volume 4 EU Guidelines to Good Manufacturing Practice Annex 1 Manufacture of Sterile Medicinal Products
- Camfil Farr – Clean Room Filter A Guide
- ASHRAE – 2007 Handbook HVAC Applications
- ISPE Guidelines
- http://www.labs21century.gov/

8.2 CLEAN ROOM LAYOUT DESIGN

It is important to consider the clean room layout when looking at overall ACMV design for clean spaces. Often the source of demand for additional energy consumption can rest in the clean room layout.

8.2.1 DESIGN

Top Tips

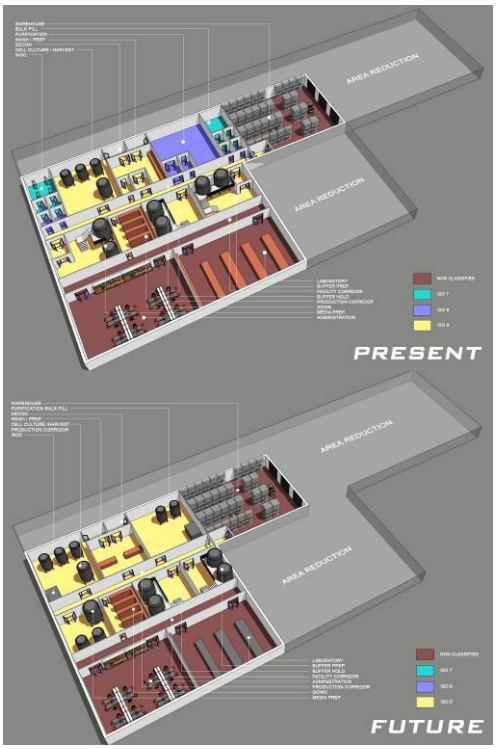
- Review the space cleanliness requirements of all processes with the core process technology specialists to establish areas that could have classification downgraded.
- Establish what specific components of a process system require a clean space and transfer all items such as vessels, pumps, piping, valves, platforms etc not required to be within a clean space into an adjoin accessible grey space (not classified).
- Always consider the use of proprietary modular build clean room structures. This generally improves construction build, washable surfaces, and room leakage rates.
- Challenge room heights and create sub sections within rooms to allow additional height only where required, reducing net room volume of clean space.
- Minimise the use of exposed surfaces with high radiant heat loads. This reduces the local cooling requirements.
- Consider the use of low level returns to improve the transfer of clean air to lower levels providing improved coverage of the space.
- Minimise corridor volume by challenging width and height.
- Use containment devices such as Isolators, RABs etc to minimise the use of high grade cleanrooms.

8.2.2 RETROFIT

- Challenge the occupancy accessibility requirements to establish if operations can be carried out more remotely, reducing particulate generation.
- Consider modifications to existing layouts to declassify some clean spaces, within regulatory and GMP requirements.
- Consider barrier/isolator technology to reduce classification levels
- Carry out a leakage review of clean spaces and improve air tightness at any areas where excessive leakage is identified.
- Complete a comparison of existing facility with similar facilities within the company or local industry to establish benchmark data and compare to see if improvements can be achieved.

8.2.3 REFERENCES

- ISO14644-1
- Eudralex Volume 4 EU Guidelines to Good Manufacturing Practice Annex 1 Manufacture of Sterile Medicinal Products
- Camfil Farr – Clean Room Filters: A Guide
- ASHRAE – 2007 Handbook HVAC Applications
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.
- ISPE Guidelines



8.3 REDUCTION IN RECIRCULATION AIR CHANGE RATES

The net air volume flow-rate that is used to control contaminants in clean spaces is the driving force behind total ACMV design. The larger the air volume flow-rate the larger the systems needed, the higher initial capital cost and the higher Life Cycle Cost of the installed systems. Exploring ways of reducing the air volume flow-rate, while maintaining validated production environments, is an important step towards best practice design.

Reference should be made to section covering ventilation systems for related guidance on best practice systems design.

8.3.1 DESIGN

Top Tips

- Agree which guidelines will be used for the basis of compliance, i.e. EU Eudralex / ISO14644 / Organisation specific criteria.
- Establish the occupancy states basis for testing, commissioning and validation early on, i.e. “at rest/in operation” etc.
- Establish the source of potential contaminants early in the design. Eliminating these at source is the most effective way of reducing air change rates.
- Remove where possible all exposed piping, valves and fittings into grey spaces zones with minimal connections to vessel and skid equipment.
- Consider the use of demand controlled ventilation to ensure energy consumption matches demand.
- For high air change areas consider decentralising or decoupling recirculation air requirements i.e. air changes for room cleanliness from temperature, humidity and pressure requirements. This can be achieved through the use of self-contained fan filter units or by using primary/secondary air handling system.
- Review the clean room volumes at design stage to challenge and minimise the resultant air change rate (ACH^{-1}). For instance large equipment volumes should be extracted from the room volume.
- Use Risk Analysis techniques to plan for air change reduction programme.
- When planning an air change reduction programme consider the use of fixed particulate monitoring as an effective way to collect comprehensive real time data regarding In Operation room cleanliness levels
- Always establish the maximum allowable recovery time in the clean space as this will affect the amount of airflow required.

8.3.2 O&M

- Rebalance and recheck all volume flow-rates annually to identify any unplanned adjustments or changes to the system operating points.
- Replace pre-filtration regularly to reduce fan power consumption.
- Challenge filtration levels particularly pre-filtration levels. Also check filter surface areas and increase these to reduce filter pressure losses.
- Recalculate leakages rates from clean room boundaries and reseal any obvious sources of leakage. This will reduce volume of air required for pressurisation.

8.3.3 RETROFIT

- Carry out a full system resistance study to establish the main sources of system pressure drop and consider retrofitting lower resistance solutions.
- Consider installing low level return air walls in grade D and C areas to promote good mixing and entrainment of air throughout the clean room. This improves the chance of achieving cleanliness at lower ACHs.
- Consider installing local self-contained FFU which will provide filtered recirculation of air locally and reduce centralised system capacities.

8.3.4 REFERENCES

- ISO14644-1
- Eudralex Volume 4 EU Guidelines to Good Manufacturing Practice Annex 1 Manufacture of Sterile Medicinal Products
- Camfil Farr – Clean Room Filter A Guide
- ASHRAE – 2007 Handbook HVAC Applications

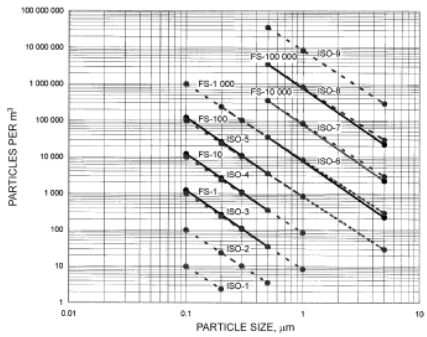


Fig. 1 Air Cleanliness Classifications by U.S. *Federal Standard* 209 and ISO 14644-1

8.4 IMPROVED AIR FILTRATION QUALITY AND EFFICIENCY

Air filtration is the core capability for a pharmaceutical ACMV system. For this reason best practice design in the area of filter selection and maintenance can provide real improvements in performance and efficiency.

8.4.1 DESIGN

Top Tips

- Always consider upgrading the primary AHU pre filtration from panel filter to bag filter to reduce ambient air loading on HEPA filters downstream.
- HEPA filters for re-circulating air should be protected with minimum 85% rated bag or rigid media filters.
- Consider re-circulating from BSL 2+ or higher by using double HEPA filter arrangement so as to reduce energy intensity of air conditioning.
- Replace pre-filters based on ΔP monitoring not on schedule.
- Always locate outdoor air intakes locations away from potential sources of pollutants and contaminants.
- Always ensure there is minimal air leakage around AHU filters by following filter manufacturer advice on filter installation. This reduces the particulate burden on final filter step.

8.4.2 O&M

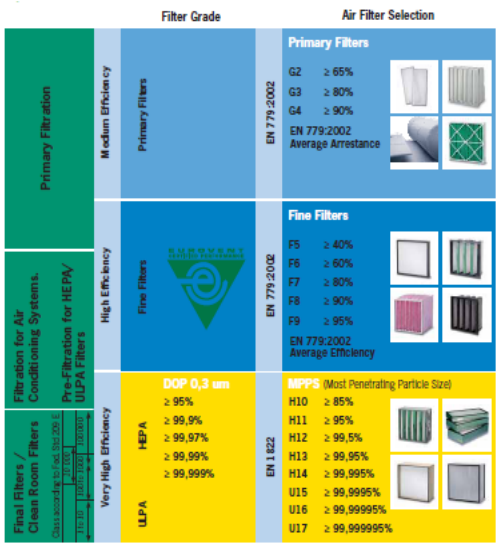
- Always install filter pressure drop monitoring on all pre filters in AHU plant.
- Implement a scheduled preventative maintenance plan for checking filter status but change out filters based on differential pressure.
- Check for filter media damage such as rips or holes and replace damaged filters.
- Make sure media is sealed in the frame to avoid bypass air.
- Check to ensure that the bank of filter frames is rigid and well reinforced to avoid collapse.
- Caulk any cracks between filter frames or between the bank of frames to prevent leaking of unfiltered air.
- Pay special attention to filter holding frame seals, gaskets, and filters that they match the filter holding frame size — all of which can cause bypass air.

8.4.3 RETROFIT

- Review all filter steps on existing systems to ensure optimum filters arrangement is in place.
- Specify maximum possible surface area for each filter step. This reduces the pressure loss for the same filtration capability.
- Use glass fibre filters not synthetic filters.
- Install ΔP monitoring on filters if not already in place.

8.4.4 REFERENCES

- ISO14644-1
- Eudralex Volume 4 EU Guidelines to Good Manufacturing Practice Annex 1 Manufacture of Sterile Medicinal Products
- Camfil Farr – Clean Room Filter A Guide
- ASHRAE – 2007 Handbook HVAC Applications



8.5 CLEANROOM SETBACK MODES

Continuous operation of qualified ACMV systems irrespective of the occupancy and production profiles results in unnecessary energy consumption for no quality gain. While difficult to achieve, as it involves engineering, quality and cultural challenges, implementing setback operational modes can lead to significant operational cost savings.

8.5.1 DESIGN

Top Tips

- Cleanroom ACMV setback during non-production and non-occupancy periods should be considered as an operational energy savings initiative.
- Consider the use of actuated air controllers to regulate the air change rate based on occupancy status. These should be used in conjunction with AHU fan VSD.
- Select all volume flow controllers with good authority in the mid-range of the supply air volume set-point.
- Consider a good turn down ratio on supply air controllers to give good opportunities for set-back scenarios.
- Consider the installation of localised FFU to provide air filtration requirements with centralised systems providing pressurisation requirements. This provides decoupling of pressure regimes with air cleanliness allowing safe reduction of ACH in certain areas without affecting the overall pressurisation strategies.
- Consider the use of pressure independent controller units in air systems. This enables greater control of supply air quantities.

8.5.2 O&M

- Involve all stakeholders when assessing the potential for introducing set back strategies.
- Review the pressure regime and assess whether the system has dynamic capabilities to offset any increase in pressure differentials during set back modes.
- Review the AHU zoning strategy to assess whether further segregation is required.
- Consider continuous particulate monitoring during re-qualification of system with setback modes to allow smoother acceptance of the setback.
- Consider declassifying Cleanrooms from a higher class of cleanliness to a lower class of cleanliness permanently, provided that the lower class still meets production requirements for contamination control and air change rates. For example many companies use Grade C environment around Isolators when Grade D would satisfy regulatory requirements.

8.5.3 RETROFIT

- Challenge the design basis for the retrofit works.
- Consider decentralising the AHU systems to introduce localised control of pressure and environmental parameters.
- Consider the requirements for dehumidification and the introduction of a primary secondary AHU strategy to minimise cooling loads.

8.5.4 REFERENCES

- ISO14644-1
- Eudralex Volume 4 EU Guidelines to Good Manufacturing Practice Annex 1 Manufacture of Sterile Medicinal Products
- Camfil Farr – Clean Room Filters: A Guide
- ASHRAE – 2007 Handbook HVAC Applications
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.
- ISPE Guidelines

8.6 CLEAN ROOM GOWNING PROCEDURES

Due to the high generation of contaminants from humans, occupancy levels, gowning procedures, cleaning procedures and airflow rates are closely interlinked. It is important when considering the ACMV design criteria associated with clean spaces to engage suitably qualified quality control specialists as increasing gowning levels may lead to overall reductions in ACMV energy consumption. The energy intensity of cleaning and/or disposing cleanroom garb must also be taken into account.

8.6.1 DESIGN

Top Tips

- Be aware of the basis for validation protocols and gowning requirements when making assessments on the level of filtration required to maintain clean spaces within acceptable quality control limits.
- Consider a LCC assessment of increased gowning protection versus reduced ACMV site energy consumption due to the high cost of gowning at pharmaceutical facilities.
- Review step change requirements in gowning procedures for a change in cleanroom classification

8.6.2 O&M

- Challenge the current gowning regime for improvements in particulate reduction.
- Carry out a cost benefit analysis of the current gowning procedures based on existing systems and operational data and establish a baseline that meets the current validation criteria. Explore the opportunity to change or improve this situation.

8.6.3 RETROFIT

- Implement regime change based on the O&M recommendations above.

8.6.4 REFERENCES

- ISO14644-1
- Eudralex Volume 4 EU Guidelines to Good Manufacturing Practice Annex 1 Manufacture of Sterile Medicinal Products
- Camfil Farr – Clean Room Filters: A Guide
- ASHRAE – 2007 Handbook HVAC Applications
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.
- ISPE Guidelines

9. HEAT & STEAM DISTRIBUTION

9.1 SUMMARY

Heat consumption in the form of steam is used in all of the pharmaceutical and nutritional facilities in Singapore. However for nutritional plants it is by far the single biggest energy user. In these plants thermal energy consumption, in the form of steam, accounts for 47.5% of all CO_2 emissions. A significant proportion of this load is for process requirements.

9.1.1 KEY TOPICS

- Steam Boilers
- Steam Distribution & Condensate

9.1.2 MAIN REFERENCES

- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

9.2 STEAM BOILERS

9.2.1 DESIGN

Top Tips

- Where a heating utility of up to 80ºC is sufficient for either process or ACMV end use consider a heating hot water system instead of steam. This system will still require a boiler but the generation equipment is much less expensive and it is more efficient.
- Review available boilers types taking into account safety, application, efficiency (Refer to ASHRAE 90.1 - 2007 Table 6.8.1F & SS 530:2006 Table 4) and future needs (i.e. Watertube, Firetube, Vertical, Electric boilers).
- Verify design operating pressure requirements and review economics of steam distribution sizing before fixing on a generation pressure. The lower the pressure the more efficient the boiler plant.
- Introduce de-aerated feed water to reduce thermal shock on boiler.
- Test local water quality and review the need for filters, softened water for make-up. If possible use reverse osmosis make-up water to reduce boiler blowdown and chemical usage.
- Include flow meters for make-up water, fuel in and steam out to analyse energy use.
- Include microprocessor air/fuel control with steam pressure control.
- In multiple boiler operations review sizing basis of boilers to meet anticipated lead/lag load profile sequencing.
- Design with a view of using dual fuel burners for options of fuel competition.
- Include blowdown heat recovery.
- Include an economiser within design of boiler stack where possible.
- Specify VSD controlled burners to cater for varying load profiles.
- Increase standard boiler insulation thickness (to 100 mm) & density (to 150 kg/m^3) to improve efficiency. Ensure removable sections for weld inspections including cladding.
- Review the introduction of turbulators or alternative tube design to increase surface area / efficiency (up to 2%).
- Try to include three element level control into boiler operation. (Control of steam out, feedwater in, and fuel in).
- Include for O_2 Trim within boiler flue to adjust air/fuel ratio for efficient burner control.
- Review combustion air quality and louvre sizing for efficient boiler operation.
- Review NOx & SOx levels and local code requirements.
- Include for automatic blowdown & TDS control.

9.2.2 O&M

What to look for

- Ensure regular maintenance programme for testing water / steam quality with a view to optimising water blow-down performance and chemical dosage amounts.
- Review periodically flame type to check burner performance.
- Check steam trap performance to ensure correct operation.

9.2.3 RETROFIT

Opportunities

- Replace high / low burners with modulating VSD type or better efficiency motors.
- Install energy meters linked to EMS for monitoring and optimising.
- In multiple boiler operations alter control sequencing strategy to best practice.
- Install and maintain automatic blowdown and TDS control.
- Consider boiler insulation upgrade along with energy recovery measures.
- Include sight glasses for checking steam trap operation.
- Review reducing of boiler steam pressure.
- Replace continuous pilot flames with electric ignition type.
- Increase boiler feedwater temperature by heat recovery.

9.2.4 REFERENCES

- ASHRAE Standard 90.1 – 2007
- SS 530:2006
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- SAFED Guideline PSG2 Operation of steam boilers -2000
- HSE Guidance note PM5 - 2000
- Treatment of Water BS 2486 - 1997

9.3 STEAM DISTRIBUTION & CONDENSATE

9.3.1 DESIGN

Top Tips

- Ensure adequate pipework and fittings insulation is incorporated into design.
- Ensure pipework is laid to fall in direction of steam flow especially at trapping points (i.e. minimum 12mm every 3m).
- Ensure adequate size for steam trapping locations to collect condensate.
- Provide safe steam trap arrangements for maintenance to work on live systems.
- Ensure globe or gate valves are used throughout installation.
- Label system correctly including pressure.
- Ensure correct selection of trap type.
- Ensure system velocities on main runs do not reach high velocities (i.e. <30 m/s) and branch lines also (i.e. <15 m/s).
- Minimise dead legs and trap at ends.
- Ensure adequate condensate tank size to cater for start-up and fault finding for maintenance to react.
- Aim to recover greater than 90% condensate.
- Remove as much oxygen and carbon dioxide from condensate as possible by incorporating a de-aerator before feeding boilers.
- Consider flash steam recovery via a sparge pipe in the condensate tank.
- Provide adequate trapping points for distribution network, target every 15m.
- Avoid sizing pipework based on velocity alone, check pressure drops (target 0.1 bar over 100m) and review optimum size.
- Where pressure reduction is required consider a steam separator before assembly.
- Ensure strainers are installed in correct position for both steam and condensate.
- Take steam branches off at top of distribution main to maintain quality and dryness.
- If steam main pipework has to rise due to site restrictions install a trap at each rising point.
- Install flow meter in condensate return so as to verify there is no degradation in the amount of condensate recovered.

9.3.2 O&M

What to look for

- Ensure regular maintenance programme is in place for checking trap operation and leaks.
- Check insulation quality and ensure high standards are maintained especially at fittings.
- Avoid group trapping operation.
- Listen to see if water hammer is occurring along distribution.

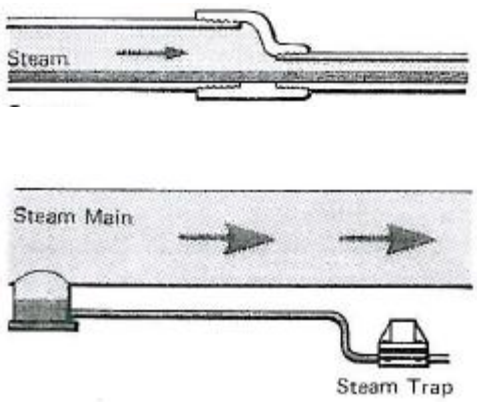
9.3.3 RETROFIT

Opportunities

- Repair or replace any steam traps that pass or system leaks.
- Install / replace isolation & control valves during shutdown if passing.
- Consider alternative heating sources if steam supply is insufficient.
- Upgrade condensate pipe sizes if too small and causing blockages.
- Install extra traps on sloping steam pipework if water hammer is occurring.
- Consider steam trap alternatives if operation is not satisfactory. This can be done from steam trap monitoring.

9.3.4 REFERENCES

- GPC 316 Undertaking an industrial energy survey – BRESCU.



10. PROCESS SYSTEMS

10.1 SUMMARY

Process systems, are systems that are more directly associated with the production process. In Singapore, most thermal heat demand can be attributed to process systems.

A survey of Singapore industrial plants has found that process thermal demand results in 47.5% of CO_2 emissions for nutritional plants and 6.5% of CO_2 emissions for pharmaceutical plants. Process Electrical demand results in 12.1% of CO_2 emissions for nutritional plants and 7.7% of CO_2 emissions for pharmaceutical plants.

Process system energy demands are service based systems supplied with heating and cooling from utility generation systems e.g. Steam and low temperature chilling, covered in previous sections. As such, a lot of potential savings and improvements can be realised by challenging the energy service using EED techniques. e.g. Does the low temperature fluid temperature really need to be set at -20˚C, if the lowest process temperature requirement is 0˚C? Ensuring the utility supplied is appropriate to the end user demand is also important e.g. Can tower water based cooling water meet a condensing requirement currently serviced by a low temperature fluid?

Process Heating and cooling systems requirements define the lowest and highest temperature requirements on the site. By challenging these temperatures, improvements in the efficiencies and COPs of utility systems can be obtained. Scheduling processing to optimise the utilisation of plant is also beneficial, especially chilling plant. eg 3 months at 100% as opposed to 6 months at 50%.

GMP (Good Manufacturing Practice) Water is relatively energy intensive to produce though in many cases total energy consumption is small. Water for Injection (WFI) and Pure Steam (PS) are by far the most energy intensive to produce. Biologics plants will have significant energy use associated with WFI demand and should therefore consider it a significant energy user. Energy use associated with GMP water is also significant in Nutritional plants, due to the large quantities used, although of the less energy intensive grade. Minimising end use consumption can yield significant reductions in energy consumption, cost effectively.

Solvent Recovery is exclusively employed in API plants. It will increase site energy demand, but from a global energy consumption perspective it is better practice than off site disposal or recovery. It is an effective use for any 'free steam' that arises from tri- generation plants.

10.1.1 KEY TOPICS

- Process Heating & Cooling
- GMP Water
- Solvent Recovery

10.1.2 REFERENCES

- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.
- Energy Efficient Design Methodology – SEAI.

10.2 PROCESS HEATING & COOLING

Systems can be either single fluid (e.g Syltherm) or mixed service (steam, glycol). Refer also to section 4.9. This is of most significance in API and nutritional plants.

10.2.1 DESIGN

Top Tips

- Control philosophy should ensure operation of distribution and jacket pumps only when on load.
- Control philosophy should minimise crossover mixing of hot and cold systems. This has been proven to be a major cause of poor efficiency in API plants.
- Condensers and coolers should maximise use of tower water based cooling. If lower temperatures are required, this can be done by installing a secondary low temp condenser after the primary condenser.
- Minimise the use of tempered loops e.g. A +5˚C loop fed off a -20˚C low temp system.
- Consider installing a tower water cooled exchanger on the hot-cold balance line on a single fluid system. This minimises the impact of a hot 'slug' of fluid from the hot system to the cold system in a heating to cooling load switching scenario.
- Ensure piping and jackets well insulated and avoid the running of hot and cold mains in direct proximity.
- Refer also to section 4.9.
- Nutritional Plants: Consider membrane separation processes as an alternative to evaporation/concentration. This is significantly more energy efficient and technology is expected to improve in this area.

10.2.2 O&M

What to look for

- Match the supply temperature to the end user requirement, no more, with a reasonable approach temperature that will still meet process cycle times.
- Ensure all heat exchangers, condensers and jackets are regularly inspected and flushed to minimise fouling.
- Ensure process plant is rigorously leak tested, this optimises the efficiency of overhead condenser vacuum distillations
- Ensure maintenance of insulation to a high standard.
- Set up an appropriate metric to monitor performance (e.g. MWH cooling per m^3 reactor or tonne produced). Track this as a warning indicator of reduced efficiency. Does the ratio of heating to cooling make sense?
- What are the theoretical process heat /cool requirement versus what you use? Use this as a guide to setting an improvement target.

10.2.3 RETROFIT

Opportunities

- Refer to Section 4.9
- Focus on minimising the energy service and optimising the utilisation of existing plant to increase efficiency.
- Coolant switching e.g. to Tower Cooling Water.

10.2.4 REFERENCES

- Energy Efficient Design Methodology – SEAI
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission

10.3 GMP WATER

GMP Water is high grade water used for direct process use and process plant cleaning. It is generated using membrane (Reverse Osmosis (RO)) and deionisation techniques for purified water and additionally by distillation in the case of Water for Injection (WFI)). Storage and distribution can be either hot, cold or ambient systems depending on the grade and end use. WFI is by far the most energy intensive due to the distillation step.

10.3.1 DESIGN

Top Tips

- Do not over specify the grade of water required for the end use i.e. Do not specify WFI where purified/DI water is acceptable. Challenge company QA requirements versus regulatory requirements.
- For WFI, specify more efficient Vapour Compression Stills instead of Multi Effect stills for large capacity systems.
- Use Tower based cooling water instead of chilled water for point of use coolers.
- Storage and distribution temperatures should be as close to ambient as quality requirements will allow.
- Ensure piping and tanks well insulated.
- Install non heat methods of sanitization e.g. Ozonation.
- Distribution ring main pumps should have VSD drives.
- Do not oversize the generation, storage and distribution systems. Reference real demand profiles for similar plant.
- Evaluate and Install Process Analytical Technology (PAT) in CIP cleaning systems. This will reduce water consumption by determining end point of cleaning as early as possible.

10.3.2 O&M

What to look for

- Challenge CIP cleaning methods to minimise water consumption. Lowest grade and quantity to meet user requirements.
- Minimise the quantities of reject or dumped water.
- Reuse reject water in other systems e.g. Boiler Water, Tower Water Make up etc.
- Use High efficiency sprayballs.
- Set up appropriate water consumption metric to monitor performance and serve as a warning of declining performance and track effectiveness of improvement measures (e.g. m^3 water per tonne product).

10.3.3 RETROFIT

Opportunities

- Sprayball upgrades and installation of PAT (Process Analytical Technology) are most viable in a retrofit scenario.
- Replacement of generation systems will be difficult to justify on a cost basis unless in a major plant expansion.

10.3.4 REFERENCES

- ISPE Baseline Guide- Water and Steam Systems
- Energy Efficient Design Methodology – SEAI
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission

10.4 SOLVENT RECOVERY

This section is relevant to API plants only.

10.4.1 DESIGN

Top Tips

- Evaluate more energy efficient membrane based processes (Pervaporation) as an alternative to distillation, especially for high water content streams or azeotropes.
- Use Cooling Tower Water based cooling in reflux condensers and coolers.
- Do not over specify the purity requirement.
- Maximise the tower efficiency (more packing height/trays) to minimise the required reflux ratio.
- Maximise heat recovery potential e.g. Feed Preheater.

10.4.2 O&M

What to look for

- Ensure regular inspection and cleaning of towers and heat exchangers to minimise fouling.
- Continuously monitor performance looking for evidence of declining efficiency (Track the MWH per litre of solvent recovered).
- Ensure recovered solvent specification is no higher than required by end user.

10.4.3 RETROFIT

Opportunities

- Switching existing chilled water condensers to cooling tower water. Alternatively install a primary cooling tower water loop followed by a secondary chilled water loop to provide staged cooling.
- Evaluate additional site waste solvent streams on site for recovery to maximise utilisation of existing plant.

10.4.4 REFERENCES

- ISPE Baseline Guide- Water and Steam Systems
- Energy Efficient Design Methodology – SEAI
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission

11. MOTORS

11.1 SUMMARY

Electrical motors are one of the main energy consumption sources in industry accounting for 64% of final energy demand.

Motors operate ACMV systems including pumps, fans, refrigeration compressors, compressed air systems, vacuum systems and also operate laboratory & bulk manufacturing equipment (including mixers, pumps, centrifuges, and dryers).

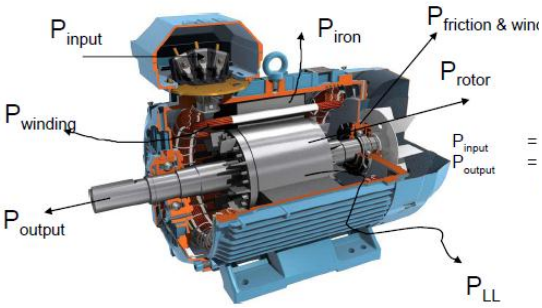
The energy efficiency measures described in the following section apply to any system that uses motors.

11.1.1 KEY TOPICS

- Drives & Systems
- Energy Efficient Motors
- Variable Speed Drives (VSDs)

11.1.2 MAIN REFERENCES

- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.
- LBNL-57260-Revision.



11.2 MOTOR SELECTION, DRIVES, & SYSTEMS

11.2.1 DESIGN

Top Tips

- Consider using MotorMaster+ or EuroDEEM Software to compare motor efficiencies & selections.
- Consider using direct drive coupling. To eliminate efficiency losses, and maintenance issues with belt systems.
- Use Synchronous belts or cogged V belts in place of V belts.

11.2.2 O&M

What to look for

- Consider a Motor Management Plan which would include;
    - Motor survey and tracking programme.
    - Guidelines for repair decisions.
    - Spare Inventory.
    - Repair Specification.
    - Preventative & predictive maintenance programme.

- Worn or slack V belts, single belt failure on multi belt drives.
- Noisy motor - drive combinations is an indication of inefficient operation and a possible maintenance issue.
- Misaligned pulleys or couplings should be repaired.
- Worn bearings in motors.
- Use vibration monitoring equipment to monitor bearing degradation.

11.2.3 RETROFIT

Opportunities

- Change pulley ratios to optimise motor speed for efficiency.
- Consider conversion from V belt to Synchronous belts particularly for motors started by Soft Start or VSD. Watch for drives which are misaligned, and poor structural rigidity of drives which would not be suitable for a conversion.
- On part loaded multi belt drive consider removing one or more of the belts to reduce power transmission

11.2.4 REFERENCES

- LBNL-57260-Revision
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

11.3 ENERGY EFFICIENT MOTORS

"Motor-driven systems account for 65% of all the electricity used in industry, giving motors a major role to play in efforts to reduce energy use". The average electrical motor will last 14 years but in just one month will consume it's capital cost.

11.3.1 DESIGN

Top Tips

- A new European standard IEC/EN 60034-30:2008, will harmonise worldwide standards for induction motor efficiency and introduces three new IE (International Efficiency) classes – IE1 for standard efficiency, IE2 for high efficiency and IE3 for premium efficiency. These replace existing European standards Eff1, Eff2 and Eff3. A new super premium class IE4 will exist in the future for new technologies.
- From June 2011 in Europe low voltage motors from 0.75kW to 375 kW (2, 4, 6 pole) will need to be IE2 standard.
- From Jan 2015 fixed speed motors larger than 7.5 kW will have to meet IE3 standard, with IE2 standard only allowed with VSDs.
- EN 60034-2-1:2007 is a new testing standard for motor efficiency.
- ASHRAE 90.1 – 2007 Chapter 10 provides minimum nominal efficiencies for general purpose motors. These are based on the NEMA Standard MG1.
- Singapore Standard SS 530:2006 Clause 6 Electric Motors specifies minimum general purpose motor efficiencies.
- Consider soft start controllers for intermittent users.
- Specify variable speed or multi-speed motors where the sub system exhibits variable demand. Part load motor efficiency figures should be examined.

11.3.2 O&M

What to look for

- Attention should be focused on the largest motor sizes & those motor with long running hours.
- If motors never operate at 100% then they are over sized. Consider replacement.
- Use high performance lubricants.
- Keep high performance motors as spares for critical applications to avoid replacement with a lower efficiency models which might be more readily available.
- Voltage imbalances, harmonic distortion or poor power factor correction can be an indication of poor motor performance.

11.3.3 RETROFIT

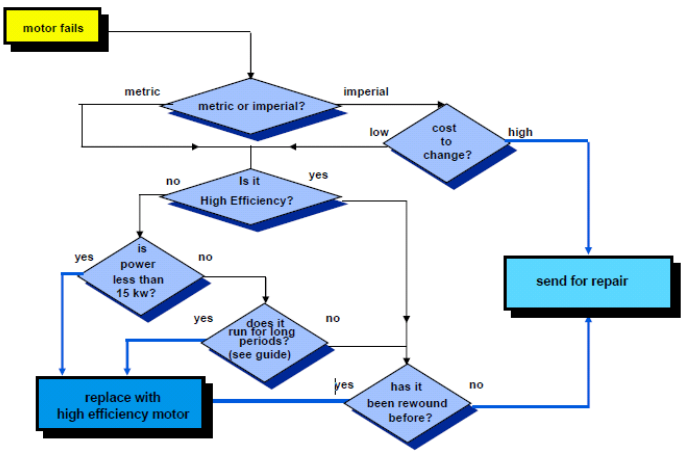
Opportunities

- Consider replacing gearboxes with variable speed drives where possible.
- Replacement of damaged or aging motors should be with high efficiency motors.
- Install start/stop control where appropriate.
- When replacing standard efficiency motors purchasing new more efficient motors may be preferable to rebuild, as rebuild can lead to increased efficiency losses. An economic analysis is required. See flowchart below.
- Consider replacing motors running more than 2,000 hours per year with IE3 motors.

11.3.4 REFERENCES

- IEC/EN 60034-30:2008
- EN 60034-2-1:2007
- ASHRAE Standard 90.1 – 2007.
- SS 530:2006
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

Efficiency level	Efficiency class (IEC/EN 60034-30)	Old CEMEP standard	Where required
Super premium efficiency	IE4	-	**Proposed**
Premium	IE3	-	USA from 2011 Europe from 2015
High efficiency	IE2	Eff1	USA, Canada, Mexico, Australia, New Zealand, Korea, Brazil (from 2009), China (from 2011), Europe (from2011)
Standard efficiency	IE1	Eff2	China, Costa Rica, Israel, Taiwan
Low	**Not categorised**	**Eff3**	



11.4 VARIABLE SPEED DRIVES

"It is estimated that 75% of pump systems are oversized, many by more than 20%. It follows that retrofitting with VSDs could match pump systems to actual system requirements more accurately and save considerable amounts of energy."

11.4.1 DESIGN

Top Tips

- Only Motors that are designed specifically for VSD use should be considered.
- Motors fitted with VSDs should have thermistors fitted or the VSDs should have electronic thermal overload protection capability.
- Place the VSD as close to the motor as possible. If not possible consider in inductor filters in the drive or harmonic suppression filters at motor end of cable.
- Power Cables from VSDs should be sized for 125% of the full load current of the drive to protect the cable against power distortions generated by the drive rectifier.
- Cables should be suitable for VSDs & should have adequate screen protection.
- Consider the motor bearing insulation or shaft grounding to prevent VSD induced bearing failure (NEMA MG.1).
- VSDs should be selected with a minimum lagging power factor of 0.95.
- When selecting medium or high voltage motors/compressors consider if a VSD can be used in conjunction with the motor either in design or for retrofit in the future.
- Avoid using single VSD units for multiple motor systems.
- Avoid motor applications that require high torque at low speed

11.4.2 O&M

What to look for

- Certain motor applications have a minimum hertz value to maintain adequate motor cooling.
- VFDs need adequate cooling and airflow, avoid locating in MCC panels without adequate cooling provision.
- Cable runs in excess of 100 m will cause "transmission line effect" and may require harmonic filters.
- Older motors insulation may deteriorate rapidly due to the high rate of voltage changes associated with VSDs. Filters are required to overcome these issues.
- Switching from grid power to emergency power while the VSD is running is not possible with most types of VSD.

11.4.3 RETROFIT

Opportunities

- VSDs can be easily retrofitted to existing 400 Volt installations, check if the motor is suitable and requires an insulation upgrade. However for installation in excess of 400 Volts reinforced insulation "inverter duty" motors are required.
- High efficiency motors are less affected by harmonics the standard efficiency types. This should be kept in mind when retrofitting. VSDs need to be selected to match the electrical characteristics of the motor.
- Electric motors driving a variable load operating at less than 50%of capacity for more than 20% of their operating time and operating more than 2000 hours a year should be considered for a VSD retrofit

11.4.4 REFERENCES

- IEC/EN 60034-30:2008
- EN 60034-2-1:2007
- ASHRAE Standard 90.1 – 2007.
- SS 530:2006
- NEMA MG 1-2006 Part 30
- BSRIA A Guide to HVAC Building Services Design Calculation BG30/2007
- BSRIA HVAC Design Checks BG4/2007
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

12. PUMP SYSTEMS

It is crucial to select, control and operate pumps at their best efficiency point (BEP).

12.1 SUMMARY

A significant proportion energy consumption in Singapore's plants is electrical energy to drive pumps in cooling and heating systems to meet air conditioning and thermal process requirements.

The Best Available Technology (BAT) approach advocates the optimisation of energy efficiency using a systems approach.

The main areas for improved energy efficient performance for pump selection and operation are:

- Selection of the pump at its BEP
- Utilising high efficiency electric motors
- Correct routine maintenance of pump impeller, rotor shaft and bearings.
- Proportional head pump control.

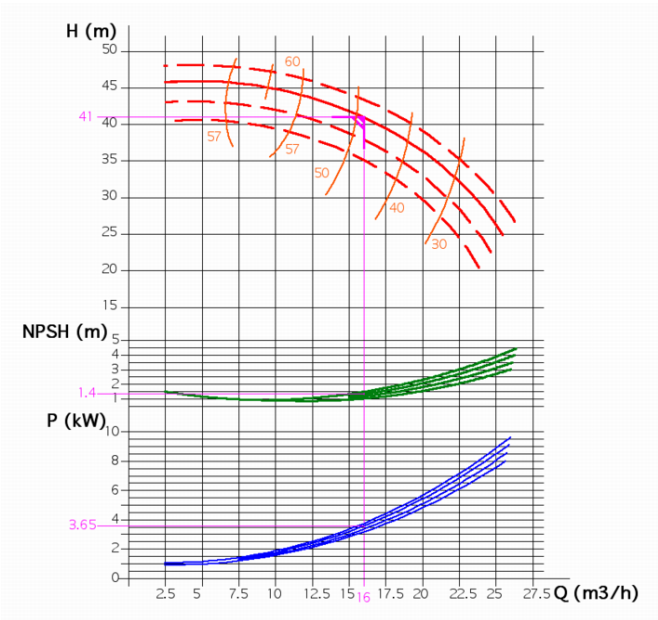
Selecting suitable production-distribution architectures to meet the requirements of the installation can also provide added energy and operational performance.

12.1.1 KEY TOPICS

- Selection and Design
- Pump Control
- Maintenance

12.1.2 MAIN REFERENCES

- DETR "Good Practice Guide 249 Energy savings in industrial water pumping" systems. www.carbontrust.co.uk
- A Guide to HVAC Building Services Design Calculation BG30/2007 - BSRIA
- Guide H – Building System Controls – CIBSE ISBN 978-1-906846-00-8
- BSRIA HVAC Design Checks BG4/2007
- "European guide to pump efficiency for single stage centrifugal pumps" http://www.europump.org/
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.



12.2 SELECTION AND DESIGN

Design and selection of pumps should concentrate on achieving the best possible energy efficiency for the optimum performance arrangement. Care should be taken when reviewing alternative pump types to ensure that any selection should be based on design load and part load operation. VSD control should be a priority along with IE3 or IE4 motors.

"Motor-driven systems account for 64% of all the electricity used in industry, giving motors a major role to play in efforts to reduce energy use"

12.2.1 DESIGN

Top Tips

- Always ensure that a pump is selected to operate at its BEP at the design system characteristics and check the change in the operating point at part load scenarios.
- Always ensure the most appropriate pump design has been selected, e.g. end suction, inline, etc.
- Always ensure that the largest impeller within the pump range has been selected when carrying out design selections.
- Be aware when considering multi stage parallel pumping that the volume flow increase is not 100% linear and the pumps can move away from the BEP when operating together. Consult manufacturer when making selections.
- Ensure a good water treatment plan in design as poor water quality will severely affect pump performance.
- Always ensure that strainers have been included in the pump piping arrangements. This prevents wear to the pump impeller.
- Always specify high efficiency motors where possible, IE3 motors at a minimum.
- Check the required minimum net positive suction head (NPSH) for a particular pump and ensure this is available at the inlet so as to avoid cavitation.
- Always consider increasing the ΔT of the Hydronic system to allow a reduction in pumping flow-rate.
- Always specify a pump to match the media being pumped in terms of viscosity, density, chemical corrosion, temperatures and operating pressures.
- Always consider redundancy requirements when designing pump arrangements. There may be a process requirement to have standby pumping capability.
- Avoid cavitation issues through correct design of the inlet piping & water flow conditions.
- Check pump turn down ratios to ensure there is no issues regarding system & equipment minimum flow scenarios.
- Size distribution pipework and terminal units for reduced pressure drop. Pipework should be sized for < 200 pa/m.
- Design pump installations so that pumps are raised above floor to allow draining.

12.2.2 O&M

What to look for

- Carry out a survey of water quality in the system to establish if a pump is losing performance due to dirt build up.
- If pumps never operate at 100% then they are oversized. Consider replacement.

12.2.3 RETROFIT

Opportunities

- Consider replacing pump impeller, neck rings, bearings and seals on older pumps. LCC for pumps show that operational costs are the main portion of cost and replacement of parts will reduce this.
- Consider painting all pumps with low friction efficiency enhancement coatings which will assist in improving operating point of the pump.
- Consider installing smaller pumps where it is evident existing pumps never operate at full speed. If pumps never operate at 100% then they are oversized.
- Where pumps are developing excessive head for the required flowrate consider reducing the Impeller size.

12.2.4 REFERENCES

- DETR "Good Practice Guide 249 Energy savings in industrial water pumping" systems. http://www.carbontrust.co.uk
- BSRIA A Guide to HVAC Building Services Design Calculation BG30/2007
- CIBSE Guide H – Building System Controls ISBN 978-1-906846-00-8
- BSRIA HVAC Design Checks BG4/2007
- "European guide to pump efficiency for single stage centrifugal pumps" http://www.europump.org/
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

12.3 PUMP CONTROL

Pump control can range from time scheduled on/off control through soft starting to full variable speed control. Effective and correctly operated pump control can result in significant improvements in Hydronic system performance and lead to quantifiable energy savings. Where variable speed control is not currently installed consideration should be given to this as part of any on-going capital investment at existing facilities.

12.3.1 DESIGN

Top Tips

- Most pumps do not operate at their BEP, generally ending up somewhere to the left of this operating point. Introducing speed control of the pump motor can allow adjustment of the pump characteristic curve to return to this point.
- The pump affinity laws show that for every 10% reduction in pump speed there is approximately 19% reduction in pump head and 27% reduction in pump power. Therefore always consider pump speed control even for pumps that will operate at constant flow.
- Speed control can also eliminate energy losses due to throttling control of pumps.
- Where there is multiple pumps in parallel consider individual inverter controllers with a common control signal.
- Reference should be made to the section on Hydronic systems for differential pressure control of pumps.
- Location of the differential pressure controller is important as pumps generate common flow and head conditions for all terminal units. Further away circuits can experience underflow and closer circuits can experience overflow with badly controlled pumps.
- Always consider differential pump head control over constant pump head control.

12.3.2 O&M

What to look for

- Carry out a survey of pump head and flow to establish if pumps are over throttled. Consider rebalancing circuits, replacing motors, replacing impellers or installing VSD control to improve electrical power consumption.
- Eliminate bypass loops and other unnecessary flows
- Implement a time scheduled on/off control where possible.
- Consider the pressure drop across major items of equipment such as AHU coils, control valves, etc to establish if there is quantifiable savings in replacing with lower resistance equipment. Alternatively consider installing booster pumps for small flow, high pressure circuits on a large system.

12.3.3 RETROFIT

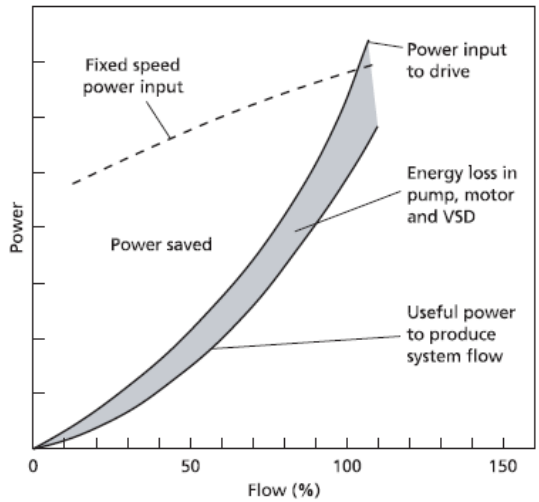
Opportunities

- Consider installing variable speed drives.
- Consider installing soft start techniques.
- Consider relocation of pump DP controller so as to achieve the optimum Differential pressure for all end users.

12.3.4 REFERENCES

- DETR “Good Practice Guide 249 Energy savings in industrial water pumping”. systems. http://www.carbontrust.co.uk
- BSRIA A Guide to HVAC Building Services Design Calculation BG30/2007
- CIBSE Guide H – Building System. Controls ISBN 978-1-906846-00-8.
- BSRIA HVAC Design Checks BG4/2007
- “European guide to pump efficiency for single stage centrifugal pumps”. http://www.europump.org/
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

Power consumption using a VSD and power saved



12.4 PUMP MAINTENANCE

Pumps performance efficiency can be said to be a product of the pump design and specification but also, crucially, it is also a product of the maintenance it receives over its lifetime.

12.4.1 O&M

Top Tips

- Always regularly check and maintain water quality at acceptable levels. Ensure there is no impact on pump performance from poor water quality maintenance.
- Use a recognised pump monitoring device to test temperature and pressure across existing pumps to verify the efficiency in operation and compare this to manufacturer data to inform replacement decision making.
- Implement a pumping systems action plan covering topics such as:
  Pumping costs, water usage volumes, systems, pump and motor specifications, metering and monitoring strategies, maintenance plans, and energy saving schemes. (refer to GPG249 for details on the content of each section)
- Always review noise levels generated by pumps in an installation and ensure there is no vibration transfer from the pump to the system or vice versa.
- Survey all existing pumps and assess whether a larger impeller size is available. Larger impellers provide improved efficiency in operation.
- Replace worn impellers and wear rings.
- Carry out bearing inspection and repair. Replace bearing lubrication regularly.
- Carryout inspection and replacement of mechanical seals and packing seals.
- Throttling of pumps as a method for system balancing and flow control can lead to wasteful energy practices.
- Consider replacing this solution with speed control using VSD (PWM type or other).
- Check that motors for pumps haven't been selected to deliver the pump power at the right hand side of their pump curve as this will result in an oversized motor. Consider replacing motors to match the actual pump power requirement as installed and operating.
- Consider permanent monitoring of performance on large pump installations (>18kW motors).Metering and monitoring of conditions upstream and downstream of a pump provides knowledge of poor performance.
- Always ensure that all documentation relating to pumps is kept up to date and filed under a maintenance log book system or otherwise. Inadequate information can lead to neglect of a pump replacement and upgrade plan.
- Maintain clean strainers on pump inlets.

12.4.2 REFERENCES

- DETR "Good Practice Guide 249 Energy savings in industrial water pumping" systems. http://www.carbontrust.co.uk
- BSRIA A Guide to HVAC Building Services Design Calculation BG30/2007
- CIBSE Guide H – Building System Controls ISBN 978-1-906846-00-8
- BSRIA HVAC Design Checks BG4/2007
- "European guide to pump efficiency for single stage centrifugal pumps" http://www.europump.org/
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

13. COMPRESSED AIR SYSTEMS

13.1 SUMMARY

The 2010 survey of pharmaceutical plants in Singapore has indicated that electrical energy consumption of compressed air systems accounts for 5% of all CO_2 emissions.

Compressed air generally represents one of the most inefficient uses of energy in industry due to poor overall system efficiency (approx 10%).

Compressed air should be used for a minimum quantity for the shortest possible time. Systems require constant monitoring and potential alternatives should be reviewed and considered.

13.1.1 KEY TOPICS

- Compressed Air Usage
- Generation
- Distribution

13.1.2 MAIN REFERENCES

- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.
- LBNL-57260-Revision.

13.2 COMPRESSED AIR USAGE

13.2.1 DESIGN/RETROFIT

Top Tips/Opportunities

- Where possible consider alternative options to compressed air (CA). There are a number of options that are more energy efficient and cost effective.
- Use Vacuum pump systems to create vacuum as opposed to CA with venturi orifices.
- Use blowers instead of CA for cooling, agitating, aspirating, mixing etc
- For cleaning or removing debris use blowers, brushes or vacuum Pump systems instead of CA.
- For moving parts consider blowers, electric actuators or hydraulics instead of CA.
- For tools or actuators consider electric motors unless reliability, and precision are primary considerations.
- Install local blowers where low grade CA use is required without drying or filtering, to reduce demand on centralised systems.
- Use low pressure blowers for applications that are suitable. (air agitation, powder handling etc).
- When there is no requirement for CA, turn off equipment, isolate local lines (this can be done with a local solenoid valve), and isolate constant bleed pneumatic controls.
- Optimise pressure control by controlling pressure at the point of use as opposed to at the compressor.
- Avoid part load operation for compressors which wastes energy by installing air receivers as a buffer to service highly fluctuating uses.
- Avoid increasing system pressure for individual applications that require high pressure by employing boosters.
- Consider installing flow meters to measure CA usage for monitoring purposes.
- Consider installing kWh meters and hours run meters on the compressor drive to measure CA usage for monitoring purposes.
- Check for CA use outside of production hours to identify rogue users and leaks.

13.2.2 REFERENCES

- BSRIA BG 4/2007 Design Checks for HVAC.
- GPC 316 Undertaking an industrial energy survey – BRESCU.
- LBNL-57260-Revision.
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

13.3 GENERATION

13.3.1 DESIGN

Top Tips

- Correct sizing of compressor air plant is critical to avoid over-sizing which is very common and results in inefficient operation.
- Identify the classification & dew point of air required for the application.
- Consider high-efficiency motors and variable-speed drives for new applications.
- Centrifugal compressors are suited to applications where the demand is relatively constant or in industrial applications as a base load plant. Selection of appropriate compressor type is subject to LCC analysis.
- Lubricant free compressors may be required for environmental compliance and are less efficient then lubricant injected.
- The selection of a compressed air dryer should be based upon the required air dewpoint and the estimated cost of operation. For constant loads with low dewpoint requirements heat regenerated desiccant dryers with low air purge rates (<3%) are suitable. For spike dominated loads consider desiccant dryers with high air purge rates (<18%) and no heat regeneration (least efficient). Integrated dewpoint analysers should be specified to minimise purging and regeneration.
- Heat Recovery can be applied to air cooled and water cooled units, which can be used for space heating, DHW heating, make up air heating, boiler makeup water preheating. As much of 80-90% of input energy is converted to heat. Air-cooled rotary screw compressors are good candidates with 80-90% recovery efficiency. Water cooled rotary screw lubricant compressors can achieve 50-60% recovery efficiency, but require an addition heat exchanger plus water isolation valves, when the unit is off. Oil free compressors offer higher temperature heat recovery opportunities.
- For Centrifugal compressors use the coldest possible air source to maximise compressor efficiency. Avoid warm air intakes.
- In some applications the use of small single compressors in series is more efficient then one large compressor.

13.3.2 O&M

What to look for

- Replace filters regularly. Blocked filters cause pressure drop.
- For compressors with Kilowatt-hour & hours-run meters, regular monitoring can indicate excessive operation patterns.
- Compare on-load hours against total run hours to check for idle running.
- Install dewpoint temperature gauges to monitor the effectiveness of air dryers.
- Install temperature gauges across the compressor and its cooling system to detect fouling and blockages.
- Air filter inspection and maintenance.
- Keep compressor motors properly lubricated and cleaned.
- Inspect drain traps to check they are not stuck in either the open or closed position and are clean.
- Maintain the coolers on the compressor to ensure that the dryer gets the lowest possible inlet temperature.
- Water quality for water-cooling systems should be monitored for (pH and total dissolved solids), flow, and temperature. Water-cooling system filters and heat exchangers should be cleaned regularly.
- Air lubricant separators should be replaced regularly before specified time periods.

13.3.3 RETROFIT

Opportunities

- If your compressed air system does not have an air receiver tank, add one to buffer short-term demand changes and reduce on/off cycling of the compressor.
- Fit improved sequence control of central compressors. This will reduce compressor run hours, prevent air loss and wasted power by avoiding pressure overshoot.
- When replacing or carrying out a major overhaul of existing equipment consider a VSD.

13.3.4 REFERENCES

- GPC 316 Undertaking an industrial energy survey – BRESCU.
- LBNL-57260-Revision.
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.
- http://www.compressedairchallenge.org

13.4 DISTRIBUTION

Excessive pressure drop in distribution systems will lead to higher operating pressures then required leading to increased energy consumption, leaks and poor system performance.

13.4.1 DESIGN

Top Tips

- Minimizing pressure drop requires a systems approach in design.
- Reduce frictional pressure drop by increasing distribution pipe sizes (3% reduction in energy use). This will help to minimize pressure losses and leaks, which reduces system operating pressures and leads to energy savings.
- Size system components on the demand side (e.g., tubes, filters, fittings, filters, valves, disconnects, regulators, nozzles, lubricators and hoses) to minimise pressure drop.
- Size generation side system components (air/lubricant separators on lubricated rotary compressors and after-coolers, moisture separators, dryers, and filters) to minimise pressure drop.
- Minimize pipework distribution distances and avoid dead legs on distribution pipework.
- Select valves and instruments that do not require constant CA bleed.

13.4.2 O&M

What to look for

- Minimizing pressure drop requires a systems approach in maintenance.
- Follow manufacturers' recommendations for maintenance, particularly in air filtering and drying equipment.
- Monitor air leaks on connectors, flanges & flexible hoses. Leaks typically can lose up to 30% of air in systems. Reducing leaks to below 10% would be considered good practice. Leak detection and repair programs should be an ongoing effort.
- Monitor excessive distribution pressure which is an indicator of leaks.
- Safety valves that operate frequently are indication of poor control.

13.4.3 RETROFIT

Opportunities

- Fit zone-isolation valves that operate under time control or interlock to the area served. This will allow certain areas of site to operate independently without air going to the whole site.
- Install pressure gauges along the distribution network to facilitate leakage monitoring.
- Replace timed receiver drains with water sensing or float traps.
- Use airflow meters to measure the quantity of air used for all users.
- Maintain leak detection monitoring programmes and repairs.

13.4.4 REFERENCES

- GPC 316 Undertaking an industrial energy survey – BRESCU.
- LBNL-57260-Revision.
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

14. LIGHTING & LIGHT CONTROLS

14.1 SUMMARY

Lighting is a necessary part of any industrial or pharmaceutical installation consisting of internal lighting, external lighting, safety (standby emergency) lighting, feature lighting, display lighting, task lighting, etc. Over 15% of power consumed within buildings in this sector is potentially by the lighting installation.

An effective lighting installation is energy efficient and delivers the necessary lighting requirements for a particular application. Careful attention to the design of lighting systems will reduce the energy consumption and this involves both selecting the correct lamp/luminaire configuration and an appropriate lighting controls solution. A correctly designed lighting installation should have low maintenance and hence reduced operating costs.

Lighting is an ever changing technology with new and/or improvements to lamps, lighting controls and luminaires continually being developed. Developments in lighting technology must be continually reviewed at the design stage of a project and continuous review by facilities managers can result in cost-effective upgrades, retrofits or redesigns to existing lighting systems that will reduce both energy and maintenance costs.

The lighting installation should be separately metered within the electrical distribution system and these measurements used to analyse the lighting power consumption.

14.1.1 TOPICS

- Luminaire Selection
- Lamp Selection
- Lighting Controls
- Lighting Designs

14.1.2 REFERENCES

- Part L of the Building Regulations.
- Society of Light and Lighting (SLL) Lighting Handbook.
- ASHRAE 90.1 - 2007

14.2 LIGHTING DESIGN

14.2.1 DESIGN

Top Tips

- Identify the lighting requirements for each area.
- Determine a lighting power density allowable for the building or area under consideration.

Type of usage	Maximum lighting power density (Watts / m^2)
Offices	11
Manufacturing Facility	14
Automotive Facility	10
Warehouse	9
Workshop	15

Table based on ASHRAE 90.1-2007 Building Area Method

- Design the lighting installation to the allowable power limits of best practice recommendations – Refer to the above table. This document elaborates further on best practise in lighting design.
- Design lighting circuits taking consideration for windows.
- Design office spaces to 300lux and provide local task lighting.
- Provide dedicated lighting distribution boards or have dedicated lighting sections in final distribution boards and provide metering for the lighting installation.
- Decide on a control strategy – centralised PC based programmable system or local stand alone lighting control.
- Set the commissioning parameters at design stage – lux levels and occupancy times.
- Specify LED exit signs as these are low power – between 1 – 3W
- Consider LED down-lighters for corridor and ancillary areas.
- Include specification for ballasts and lamps.

14.2.2 O&M

What to Look for

- Lighting is installed as specified.
- Lux levels have been set throughout.
- Occupancy Sensors have been programmed to the correct timeout settings.
- Lamps have been installed as specified.
- Lighting is off when there is sufficient natural day light.
- External Lighting is not on during daylight hours.
- Turn off lighting in unoccupied areas out of hours.

14.2.3 RETROFIT

- Replace inefficient down-lighters with LED equivalent.
- Replace High Intensity Discharge lighting in high-bay areas with a more efficient and intelligent high output fluorescent.

14.2.4 REFERENCES

- Part L of the Building Regulations (Ireland).
- ASHRAE 90.1-2007.

14.3 LUMINAIRE SELECTION

14.3.1 DESIGN

Top Tips

- Consider the efficiency (rate of light emitted [lumen] by the lamp per Watt consumed of the light source) of the chosen luminaire. The greater the efficiency the less luminaires required.
- Design for the correct light intensity and colour spectrum for each task.
- Use LED luminaires for display lighting.
- Use LED lighting for emergency lighting including exit signs.
- Choose the most efficient light source to deliver the desired lighting characteristics required for the application.
- Use luminaires with a high Light output Ratio (LOR). This is the % of usable light which is distributed from the luminaire and is available from manufacturers catalogues.
- Use local task lighting in open plan office applications.
- When selecting external luminaires make the selection based on the colour rendering requirements and the lumen output of the lamp – higher lamp wattages and higher column will give a better spacing arrangement and hence reduced energy consumption.

14.3.2 O&M

What to Look for

- Luminaires with high performance optics using high purity aluminium.
- Luminaires incorporating lighting controls.
- High Frequency Ballasts in both fluorescent and discharge lighting.
- Choose 3 lamp fittings rather than 4 if this will meet the design criteria in open plan areas.
- Reflectors behind lamps to increase lumen output – this will assist in achieving high lux levels in laboratories and specialist rooms whilst minimizing the number of luminaires required.
- Check the manufacture of the ballast and ensure the losses are minimal as these differ across the range of manufacturers.
- Select luminaires that can be installed to provide effective illumination and are installed in accessible locations for ease of maintenance and Lamp replacement.
- Choose LED Luminaires where this is practical.
- Ensure luminaires are cleaned at reasonable intervals to minimise the lumen depreciation values.

14.3.3 RETROFIT

Opportunities

- Replace wire wound ballasts with more efficient high frequency ballasts.
- Add reflectors of high purity aluminium where practical.
- Replace existing lighting installations with newer more efficient solutions to gain both carbon footprint and financial benefits.

14.3.4 REFERENCES

- Osram Control Gear Catalogue
- Petina Lighting Catalogue
- GE Lighting Lamp Catalogue
- Holophane Lighting Luminaire Catalogue

14.4 LAMP SELECTION

14.4.1 DESIGN

Top Tips

- Choose lamps with a high lumen to watt ratio.
- Choose lamps with a long life expectancy. Typical lamp life for the more efficient lamps on the market. Manufacturer's data should be consulted as there are manufacturer specific long life and high output lamps available.
- Choose lamps with a high lumen maintenance factor ensuring lux levels will be maintained for longer.
- Chose lamps with a good colour rendering property to suit the application.
- Use LED lamps for display, feature or architectural lighting purposes.
- Use LED lamps for external street, footpath and landscape lighting.
- Use LED lamps with Exit Signs and standalone emergency luminaires.
- If choosing high frequency dimmable luminaires, ensure that the lamp selected is dimmable without adverse effect to the lamp life span.
- Replace low voltage or GLS type lamps with low energy LED equivalent lamps. LED technologies are continually improving and manufacturers are releasing new improved LED light sources continually.

14.4.2 O&M

What to Look for

- Quality approved lamp manufacturers.
- Lumen per watt ratio of lamps being used.
- Specify the lumen output and life of the lamp prior to procurement.
- Lumen depreciation factor of lamp.
- LED lamps in emergency lighting.
- LED lamps for external applications.
- Control gear compatible with the lamp source selected.
- Branded high frequency electronic control gear.

14.4.3 RETROFIT

- Replace existing T12 fluorescent with the more efficient T8 or T5 lamps (30% energy saving).
- Replace existing Exit Signs with LED Type.
- Review lumen output and lamp life when procuring replacement lamps.
- Replace any low voltage or GLS type lamps with their LED equivalent.
- Replace mercury lamps with metal halide.

14.4.4 REFERENCES

- GE Lamps Catalogue
- ASHRAE Standard 90.1-2007

14.5 LIGHTING CONTROLS

14.5.1 DESIGN

Top Tips

- Provide sufficient light switching points so that users can turn off lights and provide local signage to encourage this as responsible behaviour.
- Provide PIR lighting control in all spaces where this is practical.
- Use a photoelectric cell for daylight harvesting automatically switching lights off when sufficient day light exists or reduce lighting to required lux levels.
- Consider using an integrated luminaire and lighting controls solution with a combined PIR and photocell.
- Introduce zone control in open plan office areas so that lighting switches off when unoccupied. Set task areas – goal should be a maximum 10m^2.
- Provide a time managed/scheduling lighting control override to switch off lighting when areas of the plant or industrial building are unoccupied out of hours. Provide a manual override to allow lighting be turned on manually if required.
- Use the lighting controls solution for office desks where task lighting is switched by the occupancy sensors.
- Set occupancy times at a maximum of 30 minutes. 20minutes is the preferred to avoid nuisance switching.
- Choose a detector to suit the application – Passive Infra Red, Motion, High Frequency, Ultrasonic, Microwave, etc. More expensive detectors have better coverage and higher detection range.
- Use a corridor hold lighting control solution to maintain safe levels of light for predetermined time in corridors and staircases when unoccupied.
- Use a photocell and astronomical time clock combined for external lighting.

14.5.2 O&M

What to Look for

- Ensure there are sufficient quantities of PIRs and or photocells installed to provide full coverage.
- Circuiting of luminaires adjacent to windows should be designed to facilitate switching off when the lux levels are maintained from daylight.
- Provide light switches at all entry and exit doors to rooms.
- Use a sensor technology suitable for the application.
- Give consideration to using the lighting occupancy signals for integration with the building management system/ACMV controls and save installation costs.
- Ensure lux and time settings are correctly configured.

14.5.3 RETROFIT

- Adding PIRs in corridors, meeting rooms, toilet areas, open plan offices, etc can be cost effective with a short payback time.
- Add a photocell and time clock for external lighting including building mounted lighting, sign lighting, feature lighting, etc.
- Ensure settings on existing control equipment are set correctly.

14.5.4 REFERENCES

- Part L of the Building Regulations
- ASHRAE Standard 90.1 - 2007
- Thorlux Lighting Catalogue
- Flex Connectors Lighting Controls
- Steinel Lighting Controls
- Legrand Lighting Controls

15. COMBINED HEAT & POWER (CHP)

15.1 SUMMARY

For industries that have concurrent requirements for process heat, steam, and electricity, the use of combined heat and power (CHP) systems may save energy and reduce pollution.

Best Available Technology (BAT) approach advocates seeking possibilities for Cogeneration or Trigeneration inside or outside the installation (possibly in conjunction with a third party).

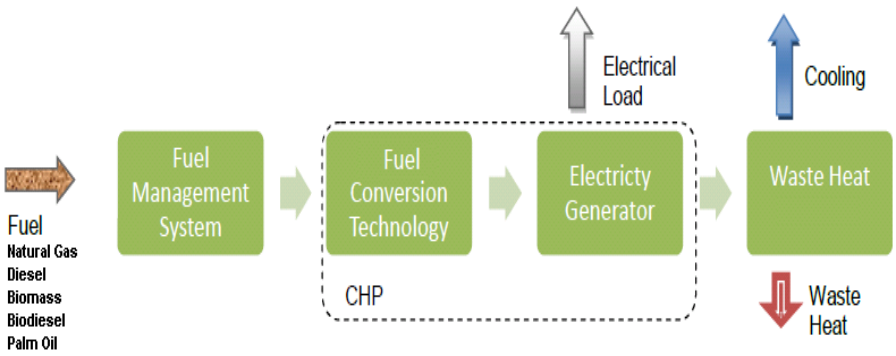
The successful implementation of CHP systems may not be solely dependant on energy efficiency optimisation but instead the availability of fuel and/or the relationship between heat price & the price of electricity.

15.1.1 KEY TOPICS

- Cogeneration
- Trigeneration

15.1.2 MAIN REFERENCES

- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.
- LBNL-57260-Revision.



15.2 COGENERATION

Policy and support mechanisms maybe required to incentivise CHP in the form taxation, grants and liberalised energy markets.

15.2.1 DESIGN

Top Tips

- Cogen should be considered if heat and electric power demands are concurrent.
- Typically in excess of 80% of the heat produced needs to be used for economic viability.
- Apply energy conservation measures related to process or building loads before considering Cogeneration.
- Operation periods in excess of 5,000 hours per annum are required for economic viability.
- The **CHPQA** standard defines minimum efficiencies (Good Quality CHP) for various CHP schemes through the use of a quality index (QI).
- Gas Turbine CHP systems are approximately 75% efficient with a heat to power ratio of 1.6:1. A minimum 3 MWe output is required typically to be economically viable.
- High pressure natural gas is required (>5 Barg) for Gas Turbine CHP system.
- Steam Turbine CHP systems are approximately 80% efficient with a heat to power ratio of 3:1 – 10 :1.
- Internal combustion or reciprocating engines have efficiencies in the 80 – 90% range with a heat to power ratio of 1.1:1 – 1.7 :1. Both low pressure steam (via exhaust gases) and MPHW/LPHW (via engine cooling jackets) are produced. There compact size makes them practical for some industrial installations.
- For back pressure steam turbines the lower the steam back pressure utilisation the higher the electrical efficiency and electrical output of the Turbine.
- Supplementary firing is possible to increase heat outputs for Gas Turbine CHP systems to produce a heat to power ratio of 5:1.
- Replacing a standard steam boiler and national grid based electricity supply with a gas fired turbine CHP will produce energy savings of approximately 20 – 30%.
- Economics will vary depend on power demand, heat demand, power purchasing and selling prices, natural gas prices, as well as interconnection standards and charges, and utility charges for backup power.
- Consider using renewable fuels in the form of Biomass, Biodiesel, Palm Oil, Landfill Gas etc.

15.2.2 O&M

What to look for

- Performance monitoring is required to detect faults, enable fine tuning, allow modifications, and audit the Return on Investment (ROI).
- Maintenance is a significant operating cost and should be contracted to specialists or the manufacturer.
- Gas fired turbine CHP will require a minimum of 2 weeks downtime with reciprocating engines requiring 5 weeks per annum. Steam Turbine CHP has the lowest maintenance costs in terms of downtime and cost.
- Process thermal demands for pharmaceutical plants are very variable, with high fluctuation in demand and operating periods. Therefore process thermal demand should be treated carefully with when sizing a thermal baseload, for Cogeneration plants. This is critical to avoid over sizing plant which will end up rejecting waste heat for prolonged periods and will reduce economic viability.

15.2.3 RETROFIT

Opportunities

- Evaluate a small scale CHP plant to replace the Lead Boiler.
- On sites with large steam demand throughout the year a CHP feasibility study with lifecycle costing should be completed.

15.2.4 REFERENCES

- www.chpqa.com
- GPC 43 Introduction to Large Scale Combined heat and power – BRESCU.
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

15.3 TRIGENERATION

Trigeneration is an extension of Cogeneration by using a waste heat chiller to provide cooling.

15.3.1 DESIGN

Top Tips

- Absorption or Adsorption chillers can use waste heat from the Cogeneration process to generate chilled water. (See section **Error! Reference source not found.**).
- Flexibility can be improved by using the Trigeneration equipment for the base load and direct fired boilers and vapour compression chillers for top up.
- The use of chilled water storage/hot water storage or buffering will also improve Trigeneration flexibility in meeting load demand.
- Underestimation of heating and cooling loads is preferable to overestimation when sizing Trigeneration plant.
- On low load consider the plant operation carefully.
- Apply energy conservation measures related to process or building loads before considering Trigeneration.
- Consider using renewable fuels in the form of Biomass, Biodiesel, Palm Oil, Landfill Gas etc.
- Economics will vary depend on power demand, heat demand, power purchasing and selling prices, natural gas prices, as well as interconnection standards and charges, and utility charges for backup power.

15.3.2 O&M

What to look for

- Intelligent control which takes into account electrical, heating and cooling demands is required for a successful installation.
- These systems required skilled/trained operators. Third party operators or ESCOs might be an appropriate solution.

15.3.3 RETROFIT

Opportunities

- For sites with existing large steam demand during winter months and large cooling demands in summer months, or a constant cooling/heating demand all year round, a Trigeneration feasibility study with lifecycle costing should be completed.

15.3.4 REFERENCES

- www.chpqa.com
- GPC 43 Introduction to Large Scale Combined heat and power – BRESCU.
- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

16. ELECTRICAL POWER SYSTEMS

16.1 SUMMARY

Resistive losses occur in cabling. Equipment with large power usage should therefore be supplied from a high voltage as close as possible.

It is BAT to optimise power supply efficiency by using techniques such as high efficiency transformers and increasing the power factor of the site electricity usage.

16.1.1 TOPICS

- Transformers
- Power Factor Correction

16.1.2 REFERENCES

- Reference Document on Best Available Techniques for Energy Efficiency – European Commission.

16.2 TRANSFORMERS

16.2.1 DESIGN

Top Tips

- Establish the largest electrical demand for the plant ensuring that accurate load estimate techniques are used and based on operation requirements.
- Determine the installation requirements - primary voltage (delta or wye) and frequency, secondary voltage, capacity in volt-amperes, Pole-mounted, pad-mounted, indoor or outdoor, impedance, temperature rise, case style, dry-type or liquid-filled, basic impulse level which is the withstand rating in kV, etc
- Choose a high efficiency transformer which will result in significant energy saving over the life of the transformer
- Select transformers with minimal no load losses – iron losses. Specify low-loss silicon steel or consider amorphous alloy cores instead of conventional cold rolled steel for transformer in the lower kVA requirements. This will ensure lower no load losses are achieved.
- Ensure that the magnetic flux densities are to be kept well below the saturation point to prevent core overheating.
- Consider the properties of the transformer windings and select copper windings as these have lower resistance per cross-sectional area than aluminium windings and thus require smaller cores which result in lower no-load losses and offer greater reliability.
- Load losses are caused by resistive losses in the windings and leads, and by eddy currents in the structural steelwork and windings. These losses are proportional to the square of the load current and are reduced by increasing the cross section of the windings. This should be considered when specifying or procuring the transformer.
- The transformer should be selected on the Total Cost of Ownership (TCO). Operating losses typically represent 30% to 70% of the TCO of distribution transformers. The pay-back periods for investing in high-efficiency transformers are relatively short, often less than two years. The Rate of Return in efficient transformers is consistently above 10% and sometimes as high as 70%.

16.2.2 O&M

What to Look for

- Confirm transformer is in line with specified criteria by checking name plate.
- Transformers are located as close as possible to main switchgear to reduce losses in supply cables.
- Keep online transformers operating at 40-50% of rated power.

16.2.3 RETROFIT

Opportunities

- Evaluation of existing transformer status from efficiency and potential reliability issues, where indications of reduced performance in either area may warrant repair, rebuild or replacement.
- Strive for the highest efficiency transformer available whilst considering TCO.
- More efficient transformers have less heat loss and do not require additional cooling.

16.2.4 REFERENCES

- NEMA – Distribution Transformer Efficiency.
- Copper Development Assoc. - Electrical Energy Efficiency Publication 116.
- ABB - Power to be Efficient.

16.3 POWER FACTOR CORRECTION

16.3.1 DESIGN

Top Tips

- One incentive for installing power factor correction is avoiding a low power factor penalty from utility companies as reactive or watt-less power is charged for with recurring costs for the highest recorded event during a predetermined time period.
- The selection of power factor correction equipment should be designed to achieve a unity power factor for best efficiency.
- The electrical system's capacity will increase as uncorrected power factor will cause power losses in the distribution system. This may result in voltage drops as power losses increase which can cause overheating and premature failure of motors and other inductive equipment.
- Corrected power factor will result in reduced heating of transformers and reduced heating in cables.
- Use capacitors that deliver highly efficient power factor correction with low watt loss, long life and reliable operation.
- Select capacitors that are suited for harmonic filter applications, are robust, heavy duty design and include environmentally friendly, self healing, metalised polypropylene film, sealed in dense resin (dry type technology) with no free liquids.
- Select capacitors in steps to achieve the overall kVAR value required such that the power factor correction equipment can easily deal with fluctuations in the reactive power demanded by the loads. Load sensing in the form of a microprocessor based controller should be used to achieve this and ensure that over current isn't generated and hence incurring potential utility charges.
- Ensure capacitors installed on the power systems are de-tuned to avoid amplification of any harmonics present.
- By installing capacitors the reactive energy required by inductive loads is not charged for by the utility company as this is provided by the capacitors.
- Power factor correction has a short term payback with long term savings.

16.3.2 O&M

What to Look for

- The power factor correction equipment has sufficient steps to ensure that optimum performance to maintain a power factor as close to unity as possible without over correction.
- Power factor correction equipment is detuned.
- Minimise operation of idling or lightly loaded motors.
- Avoid operation of equipment above its rated voltage.

16.3.3 RETROFIT

- Evaluate the existing installation as there may be benefit in locating power factor correction equipment close to larger inefficient loads however in the overall context, having the power factor correction close to the incoming supply point is the most efficient.

Installation Location	Cost	Benefit	Flexibility
At Motor	Low	Acceptable	Minimal
At Feeders	Medium	Good	Better
At Point of Common Coupling	High	Best	Maximum

Analysis of benefits in locating power factor correction equipment

16.3.4 REFERENCES

- Schneider Electric – Power Factor Correction - www.schneider-electric.co.uk
- US Department of Energy - Reducing Power Factor Cost.