action matters for business

i am your optimisation guide

heating, ventilation and air conditioning systems

NSW GOVERNMENT | Office of Environment & Heritage

AIRAH

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Foreword

This publication has been developed through an industry–government partnership between the NSW Office of Environment and Heritage's (OEH) Energy Efficient Business (EEB) team and the Australian Institute of Refrigeration, Airconditioning and Heating (AIRAH).

It aims to support the adoption of energy-efficiency initiatives in NSW businesses and brings together expertise from both organisations and across industry.

OEH's EEB team provides assistance to NSW businesses to reduce their energy consumption and costs, while enhancing productivity. The team has developed a suite of technology guides like this publication. These guides, which include resources on lighting, industrial refrigeration and cogeneration, are available free to download from the OEH website: www.environment.nsw.gov.au/business.

AIRAH is an independent, specialist, not-for-profit technical organisation providing leadership in the heating, ventilation, air conditioning and refrigeration (HVAC&R) sector through collaboration, engagement and professional development. AIRAH's mission is to lead, promote, represent and support the HVAC and related services industry and membership. AIRAH produces a variety of publications, communications and training programs aimed at championing the highest of industry standards. AIRAH encourages world's best practice within the industry and has forged a reputation for developing the competency and skills of industry practitioners at all levels.

This publication would not have been possible without input from the following contributors – Vince Aherne (AIRAH), Mark Henderson (SEiD), Jon Clarke (Norman, Disney and Young), John Penny (Viscon Systems), Paul Bannister (Energy Action/Exergy), Lasath Lecamwasam (Engineered Solutions for Building Sustainability), PC Thomas (Team Catalyst), Andrew Smith (A.G. Coombs Advisory), Alex Koncar (Greenkon Engineering), Steve Hennessy (WT Sustainability) and Patrick Riakos (OEH).

Disclaimer

HVAC systems are complex and the extent of actual or potential energy savings will vary greatly from one HVAC system to another.

The examples and energy-savings potential discussed in this guide are not intended as specifications for implementation, nor should they be considered to provide instruction on how to complete measurement and verification calculations for the NSW Energy Savings Scheme.

It is advisable to employ specialist engineering support when developing a business case for any of the energy-efficiency opportunities outlined in this guide. OEH has a panel of specialists who will be able to assist with any optimisation project.
Visit www.environment.nsw.gov.au/business/energy-efficiency-expert.htm.

Contents

List of acronyms

The abbreviations and acronyms used in this guide have the following meaning:

AC – air conditioning
ACP − accredited certificate provider
AHU – air handling unit
AIRAH – Australian Institute of Refrigeration, Airconditioning and Heating
BMS – building management system
CAV – constant air volume
CHW – chilled water
CO – carbon monoxide
CO_2 – carbon dioxide
CW – condenser water
DCV − demand control ventilation
DDC – direct digital control
DSPR − duct static pressure reset
DX – direct expansion
EC − electronically commutated
EDH – electric duct heater
EEV – electronic expansion valve
ESC – Energy Savings Certificate
ESS – Energy Savings Scheme
FCU – fan coil units
FTS − fixed time schedule
GHG – greenhouse gas
HHW – heating hot water
HLI − high level interface
HVAC – heating, ventilation and air conditioning
HVAC&R – heating, ventilation, air conditioning and refrigeration
HW – hot water
IAQ – indoor air quality
IPART − Independent Pricing and Regulatory Tribunal

KPI – key performance indicator
M&V – measurement and verification
MBM − Metered Baseline Methods
NABERS − National Australian Built Environment Rating System
NCC – National Construction Code
NGA – National Greenhouse Accounts
NOX − nitrogen oxide
O/A – outdoor air
OEH – Office of Environment and Heritage (NSW)
O&M – operations and maintenance
OSS – optimum start/stop
P – proportional control
PI – proportional integral control
PID – proportional integral derivative control
PIAM&V – Project Impact Assessment with Measurement & Verification
R/A – return air
RESA – Recognised Energy Savings Activities
RH – relative humidity
S/A – supply air
SCHW– secondary chilled water
SMART − specific, measurable, attainable, realistic and timely
TXV – thermostatic expansion valve
VAV – variable air volume
VFD – variable frequency drive
VSD – variable speed drive
WB − wet bulb

one

Introduction

Heating, ventilation and air conditioning (HVAC) contributes significantly to business energy use and operating costs, typically consuming the largest proportion of energy in commercial buildings.

In a commercial building, HVAC electricity consumption can typically account for around 40 per cent of total building consumption and around 70 per cent of base building electricity consumption (DCCEE *Guide to Best Practice Maintenance & Operation of HVAC Systems for Energy Efficiency*).

Unlike other more costly energy-efficiency strategies such as plant upgrades, improving the performance of HVAC via control systems (i.e. optimisation or building tuning) can provide immediate reductions in energy use and energy costs. The returns on investment are often able to be measured in months, not years and additional benefits can include:

- enhanced occupant comfort
- improved reliability of systems
- reduced ongoing maintenance costs
- improved building performance, as recognised in rating schemes such as National Australian Built Environment Rating System (NABERS) and Green Star.

Optimisation of controls is a cost-effective way to improve the efficiency and performance of HVAC systems, both in older and modern buildings. This guide has been compiled to assist those involved in facilities management, building operation and systems maintenance.

This guide outlines 20 HVAC optimisation strategies and how they can be applied. These strategies can save up to 50 per cent of total HVAC energy use, or up to 80 per cent of energy use in individual HVAC components.

HVAC optimisation is sometimes as simple as changing control algorithms, altering control schedules and set points, and carrying out minor mechanical repairs and alterations to existing equipment and systems.

To achieve the benefits of optimised controls, it is essential for building owners and facility managers to see optimisation as an investment rather than a cost, while directing building operators and service providers to include controls optimisation within their responsibilities and key performance indicators (KPIs).

Energy savings unlocked by HVAC optimisation activities can potentially generate revenue using the NSW Energy Savings Scheme. By undertaking measurement and verification, savings can be demonstrated and Energy Saving Certificates (ESCs) can be generated and sold to offset the costs of the optimisation or to facilitate future energy-efficiency interventions.

> **“Unlike other more costly energy-efficiency strategies such as plant upgrades, improving the performance of HVAC via control systems can provide immediate reductions in your energy use and energy costs.”**

How to use this guide

The guide discusses technical concepts involved in optimising HVAC systems. It is intended to assist all those involved in the running of these systems to plan and manage energy-saving opportunities.

Energy Management Consultants
Technical Service Providers

- Improve your understanding of energy-efficiency opportunities for various types of HVAC systems.
- Improve value of service delivery to clients and cost-effectiveness of energy-efficiency recommendations.

Building Owners
Building Managers

- Improve your understanding of potentially cost-effective energy-efficiency opportunities for your building’s HVAC system.
- Inform improvements to your HVAC maintenance scope of work to ensure ongoing energy efficiency.

Facility Managers
Sustainability Managers
Building Operators

- Use as a toolkit for improved operation of HVAC systems.
- Inform improvements to your HVAC maintenance scope of work to ensure ongoing energy efficiency.
- Make a stronger case to building owners for investment in HVAC energy efficiency.

Table 1 on the following page lists the 20 HVAC optimisation strategies that represent energy-saving opportunities. Guidelines are provided for optimising the control parameters within each strategy. The information provided on each strategy includes:

- a summary of the optimisation strategy
- an outline of the principle and equipment involved
- a description of current practices that may suit a particular opportunity for optimisation
- an indication of the energy-saving potential and other benefits, costs and risks
- notes on the application and implementation of the optimisation.

While the guide refers to the optimisation of existing HVAC systems, the underlying control and management logic also applies to new or replacement systems. For a list of documents referenced and additional resources relevant to HVAC optimisation, refer to Appendix B.

Your key optimisation opportunities

Table 1 summarises the key optimisation strategies and provides guidance for their application for different types of HVAC systems. The energy-savings potential is specific to each strategy and non-cumulative; however, the identified energy-savings potential will naturally be greater with the adoption of two or more of these strategies.

Table 1: Summary of opportunities and guidelines and their applications

Page	Optimisation strategy	Energy-saving potential (Individual, non-cumulative)	Central water-cooled CHW system w/AHUs	Central water-cooled CHW system w/FCUs	Central air-cooled CHW system (AHU)	Central direct expansion (DX) plants – AHUs	Ducted direct expansion (DX) systems	Small direct expansion (DX) systems (split and packaged)	Operation 24/7	Regulated relative humidity (museums, galleries etc.)	Variable occupancy spaces	Enclosed spaces with combustion engines
13	1. Optimum start/stop	Up to 10% of total energy consumed by HVAC services	Y	Y	Y	Y	Y	N	N	N	Y	N/A
18	2. Space temperature set points and control bands	Up to 20% of total energy consumed by HVAC services	Y	Y	Y	Y	Y	Y	Y	Y (Limited)	Y	Y
24	3. Master air handling unit (AHU) supply air (S/A) temperature signal	Up to 15% of total energy consumed by HVAC services	Y	N	Y	Y	Y	N	Y	Y	Y	Y
29	4. Staging of compressors and chillers	Up to 10% of energy consumed by chillers	Y	Y	Y	Y	N	N	Y	Y	Y	Y
35	5. Duct static pressure reset (DSPR)	Up to 30% of energy consumed by fans serving AHUs	Y	N	Y	N	N	N	Y	Y	Y	N/A
40	6. Temperature reset: hot water (HW) temperature reset	Up to 5% of energy consumed by HW heaters	Y	Y	Y	Y[1]	Y[1]	N	Y	Y	Y	N/A
40	7. Temperature reset: chilled water (CHW) temperature reset	Up to 15% of energy consumed by chillers	Y	Y	Y	N	N	N	Y	y (Limited)	Y	N/A
40	8. Temperature reset: condenser water (CW) temperature reset	Up to 15% of energy consumed by chillers	Y	Y	N	Y[2]	Y[2]	N	Y	Y	Y	N/A
45	9. Retrofit of electronic expansion valves (EEV)	Up to 15% of energy consumed by retrofitted AC compressors	Y	Y	Y	Y	Y	N	Y	Y	Y	N/A
49	10. Economy cycle	Up to 20% of energy consumed by AC compressors	Y	N	Y	Y[1]	Y[1]	N	Y	Y (Limited)	Y	N/A

Page	Optimisation strategy	Energy-saving potential (Individual, non-cumulative)	Central water-cooled CHW system w/AHUs	Central water-cooled CHW system w/FCUs	Central air-cooled CHW system (AHU)	Central direct expansion (DX) plants – AHUs	Ducted direct expansion (DX) systems	Small direct expansion (DX) systems (split and packaged)	Operation 24/7	Regulated relative humidity (museums, galleries etc.)	Variable occupancy spaces	Enclosed spaces with combustion engines
54	11. Night purge	Up to 20% of energy consumed by AC compressors, during start-up time	Y	N	Y	Y	Y	N	N	N	Y	N/A
59	12. Demand control ventilation (DCV): carbon dioxide (CO_2)[3]	Up to 20% of space cooling and heating energy required for pre-treating of outdoor air (O/A)	Y	Y	Y	Y[2]	Y[2]	N	Y	Y	Y	N/A
59	13. DCV: carbon monoxide (CO)	Up to 80% of energy consumed by carpark ventilation fans	N/A	N/A	N/A	N/A	N/A	N/A	Y	N/A	Y	N/A
67	14. Optimised secondary chilled water (SCHW) pumping	Up to 30% of energy consumed by SCHW pumps	Y	Y	Y	N	N	N	Y	Y	Y	N/A
71	15. Variable head pressure control (air-cooled condensers)	Up to 30% of energy consumed by condenser fans	N	N	Y	Y[4]	Y[4]	N	Y	Y	Y	N/A
74	16. Variable head pressure control (water-cooled condensers)	Up to 30% of energy consumed by CW pumps	Y	Y	Y	Y[2]	Y[2]	N	Y	Y	Y	N/A
81	17. Energy management planning	Up to 50% of total energy consumed, depending on depth and commitment	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
86	18. Energy management training and awareness	Up to 10% of total energy consumed	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
88	19. Energy-efficiency maintenance	Up to 20% of total energy consumed by HVAC services	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
93	20. Management of system control software	Up to 10% of energy consumed by HVAC services	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Notes: 1 Hot water space air heating; 2 Water-cooled; 3 Not applicable for 100 per cent O/A supply applications (operating theatres, pet shops, morgues, laboratories with animals, battery rooms, etc); 4 Air-cooled

The role of HVAC controls in reducing energy use

The main components of a typical HVAC commercial system are outlined in Figure 1. Central to many of the optimisation strategies outlined in this guide are the controls.

HVAC controls regulate the heating and/or air conditioning of designated areas, usually through a sensing device that compares the actual state of the space – for example, its temperature – with a target state. The control system then draws a conclusion as to what action needs to be taken – for example, start the heating element.

These control systems range from built-in proprietary controllers, to independent direct digital controls (DDC) or building-wide building management system (BMS) controls.

A BMS consists of a number of DDC that communicate via a network infrastructure and report to a computer, referred to as a head-end, supervisor or operator workstation. This central computer sends operational parameters such as set points and time schedules throughout the system and to individual plant controllers. The controllers can send back operational information such as temperature, alarms and system performance.

BMSs are also referred to as building management and control systems, building automation systems or building automation and control Systems. For consistency, the term BMS is used throughout this guide.

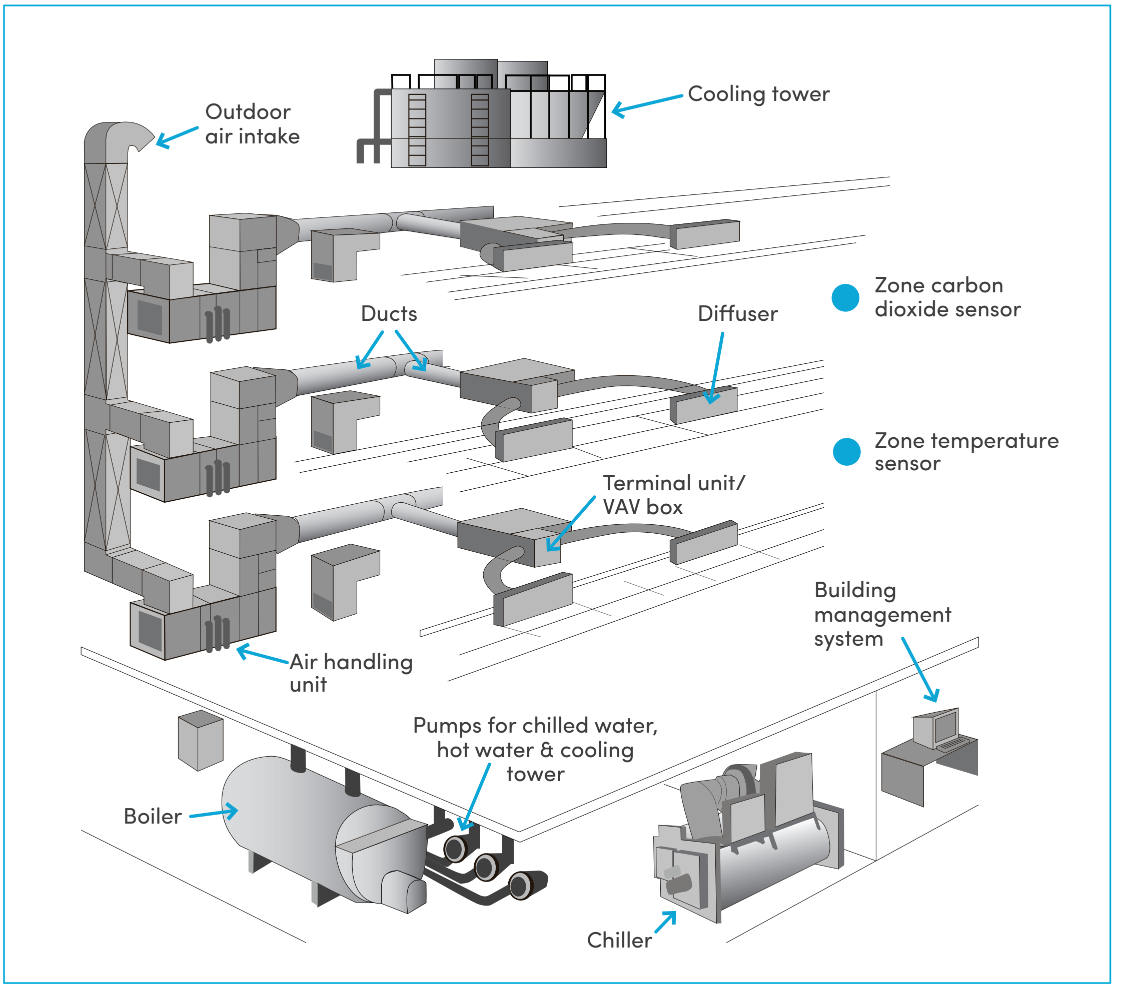
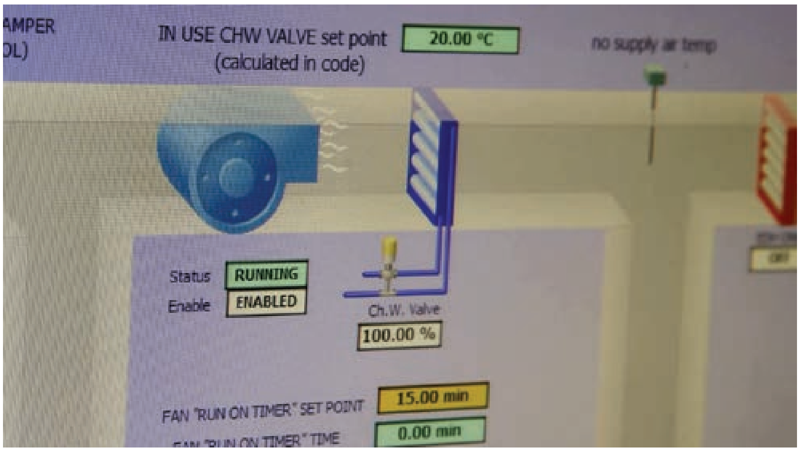


Figure 1: Main components of a typical commercial HVAC system



A building management system (BMS) is an extremely valuable tool in the HVAC optimisation process

The BMS is an extremely valuable tool in the HVAC optimisation process. As well as providing control logic and supervision functions, many BMSs can perform diagnostics, indicate trends and measure performance. BMSs can vary in the way they manage plant controls, the way they represent the control system and the quality and quantity of the data produced. Updating or upgrading a BMS system is often the first step in an energy-efficiency project.

It is important to ensure that optimisation capabilities of existing BMS and DDCs are taken advantage of and are not disabled. Facility operation staff need to understand the value of the optimisation and schedules need to be checked periodically to ensure they remain aligned with building use.

Refer to the Australian Institute of Refrigeration, Airconditioning and Heating's (AIRAH) Application Manual DA – 28 *Building Management and Control Systems* for further information on specifying and installing a BMS.

Modern BMSs have functions that allow KPIs to be defined and monitored, with exception reports and alarms generated for various levels of faults. In the case of HVAC system optimisation, key items should be highlighted that will initiate an alarm signal if specified operating range or limits are exceeded.

Did you know?

BMSs have steadily reduced in price over the past 30 years. They have also become more user-friendly and reliable, providing they are specified correctly, installed and commissioned by competent personnel and their operators are trained on their functionality. Any BMS installed within the last five to 10 years is likely to be capable of employing optimisation strategies.

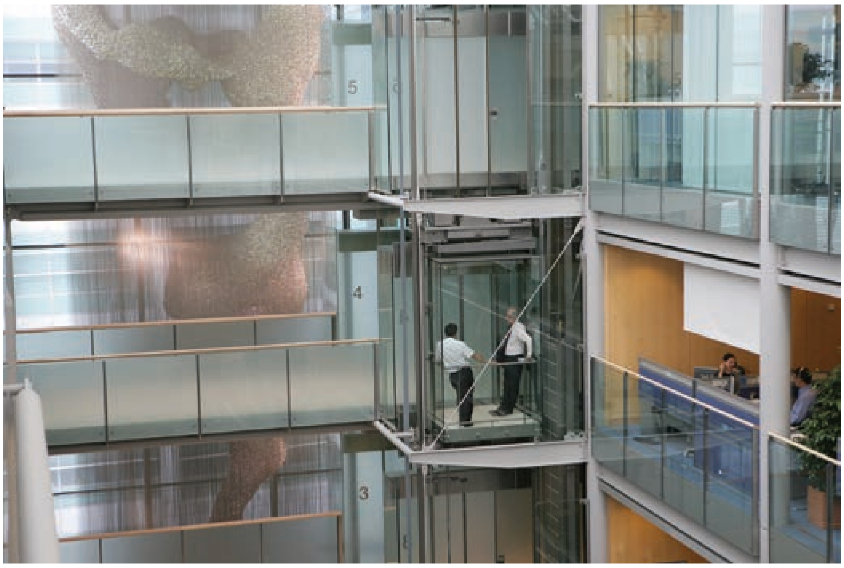
Where is energy wasted?

The structure of buildings influence energy consumption of HVAC equipment and components. The thermal performance of a building's facade, air leakage and internal electrical loads within a building will affect the operation and performance of HVAC systems.

Energy wastage can be built into the design and construction phase of buildings. Minor alterations during operation, made to provide a quick fix for compliance or equipment problems, can accumulate to contribute to energy waste.

This wastage is often masked by the HVAC system itself, which continues to provide adequate comfort to occupants, but at a higher energy cost.

A list of the main areas of energy wastage in HVAC systems can be found in Appendix A.



Along with a reduction in energy use, a correctly implemented HVAC optimisation strategy can also improve tenant comfort and satisfaction

How to approach optimisation

HVAC optimisation typically involves changing control algorithms, altering control schedules and set points, and carrying out minor mechanical repairs and alterations to existing equipment and systems.

The process of optimisation involves a systematic collection of information from the BMS and facilities staff, together with historic utility data and energy data collected from key items of equipment. The analysis of energy data often uncovers inconsistencies between what is expected and what is actually happening.

An effective HVAC optimisation process relies on an engaged and informed operating and maintenance (O&M) team, DDC or BMS control of HVAC systems and accessible, accurate HVAC documentation.

A new or upgraded BMS (achieved by programming new energy-efficiency algorithms into an existing system) can provide significant opportunities for HVAC optimisation and strategies such as optimum start/stop (OSS), economy cycles, pressure control set point reset and demand control ventilation (DCV) systems can be easy to incorporate, correct or retune.

The key to saving energy through HVAC systems is to focus on identifying and prioritising the most cost-effective opportunities and implementing them in a structured manner. It is important to uncover and remedy the base causes of energy inefficiency in the system, rather than just address the symptoms.

Considering that HVAC systems vary from one building to another, optimisation opportunities should be studied and analysed thoroughly, including costs of implementation, reduction of operational costs, other benefits and payback periods.

Projected benefits need to be followed up and the changes resulting from system optimisation need to be monitored. Energy-efficiency interventions should be measured and validated and this information fed back into management and maintenance decisions.

Planning should provide a logical decision-making approach to evaluate, prioritise and implement optimisations that are economically feasible. A small team of technical specialists is ideal, with direction provided by the building owner.

Identifying your opportunities

The first step towards getting the most out of your HVAC system is to identify and prioritise the key energy-savings opportunities available to your system.

Control strategies for existing systems should be reviewed by technical personnel to identify improper control sequences such as pressure and flow rate parameters, and inappropriate set points for temperature and humidity – both of which can lead to energy wastage.

There is a basic conflict between optimising the efficiency of distribution systems and optimising the efficiency of source equipment. For example, in distribution systems, raising the hot water (HW) temperature and lowering the chilled water (CHW) temperature can generate a greater temperature differential across the system, reducing required water flows and the energy used for fluid distribution. For sources of heating and cooling, however, it is more efficient for the central plant to produce cooler HW and warmer CHW. Resolving these conflicts will result in more energy-efficient systems.

Adjusting building temperatures up or down during unoccupied periods is not a new strategy; however, it requires regular review. Using indicators of occupancy such as occupancy sensors or CO_2 sensors to automatically adjust outdoor air (O/A) flows and temperature set points, or turning off equipment during periods of low occupancy, can create significant energy savings.

Did you know?

HVAC system loads primarily come from five sources:

Source	Conditioning required
Building envelope	Heating and cooling
Lighting	Cooling
Occupancy	Cooling
Equipment and appliances	Cooling
Outdoor air	Heating and cooling

Loads are either sensible or latent and the proportion of latent load needs to be known so that it is appropriately managed.

Key considerations in HVAC optimisation

HVAC optimisation does not typically require much capital to implement as it focuses on the optimisation of existing systems rather than large-scale equipment upgrades and asset replacements. In addition to this, measurement and verification (M&V) of energy savings from optimisation strategies can be used to create and sell Energy Saving Certificates (ESCs) under the NSW Energy Savings Scheme (ESS), as described in Appendix C.

While estimated energy, greenhouse gas (GHG) and money savings are typically the criteria used when presenting a business case for HVAC optimisation, other factors can also influence the proposition:

- Tenant satisfaction: Will optimisation improve service quality?
- Asset value of facility: Will optimisation provide a basis for higher rent or better tenants, thereby achieving a higher asset value?
- Reliability: Will the optimised system be more reliable?
- Maintainability: Is the system capable of being maintained (with appropriate training) by local/regional maintenance staff or contractors?

- Liability: Could a failure cause litigation, an insurance claim, or damage products or furnishings?
- Compliance: Is the system causing non-compliance with the National Construction Code or other mandatory requirement? Will the modification cause non-compliance or improved compliance?

Funding requests for optimisation activities should be supported by robust business cases that include a cost-benefit analysis, an assessment of the return on investment and consideration of the above factors. For a comprehensive guide on building the business case, see OEH's *Energy Efficiency and Renewables Finance Guide*. Each proposed optimisation measure should be carefully evaluated in terms of cost payback and indirect benefits such as improved comfort and productivity.

The HVAC optimisation process can involve significant labour costs. If the HVAC optimisation is delivered or managed using in-house staff, the implementation cost can be significantly reduced.

HVAC optimisation strategies can substantially reduce energy use; however, they can also lead to unexpected results if not implemented correctly. When selecting a strategy, the complete HVAC system chain must be considered. Systems controls need to be integrated from the delivery (terminal unit) side back to the supply (central plant) side so that there is no conflict between set points and control logic.

For example, in a typical HVAC cooling system, the system chain incorporates the cooling tower, chiller, AHUs and terminal devices such as a variable air volume (VAV) box. The air flow demand of the VAV box can be influenced by the supply air (S/A) temperature, which in turn is related to the CHW temperature. This system could include a CHW temperature and an S/A temperature reset strategy. Potentially, these two control strategies, operating in conflict, could introduce instability into the cooling system.

The selection of optimisation strategies such as temperature resets should be biased towards the equipment or condition that provides the greatest energy-saving impact. The operation of multiple control strategies should be cascaded and coordinated to prevent the possibility of the benefits from one strategy being cancelled out by another.

> **“HVAC optimisation does not typically require much capital to implement as it focuses on the optimisation of existing systems rather than large-scale equipment upgrades and asset replacements.”**

Implementation

A range of technical service providers can assist facility managers and building owners to plan and implement individual energy-saving projects, including:

- energy management consultants
- energy efficiency maintenance providers
- BMS/controls contractors
- HVAC design consultants
- HVAC contractors and maintenance providers.

The following generic steps should be followed when implementing any of the HVAC optimisation measures outlined in this guide:

Step	Action
1	Prepare a technical specification for the optimisation containing performance and quality control requirements.
2	Obtain quotations from appropriate contractors (BMS, maintenance, HVAC) to do the work.
3	The selected contractor implements the optimisation(s) and demonstrates that the initiative was properly implemented and commissioned.
4	The contractor updates the system's 'functional description' so that it fully reflects the new control strategies and new control parameters.
5	The maintenance contractor and facility manager are trained to understand the new control strategies and parameters, and the impacts of any variations on the operation of the HVAC system.
6	The new controls and features are added to the energy efficiency maintenance checklist so that their operation can be regularly monitored and checked as part of the routine maintenance program.
7	The system is monitored to validate the predicted energy and cost savings and the additional benefits from the optimisation.

Where multiple initiatives are being implemented simultaneously, the steps for each strategy are combined into a single implementation plan.

Potential savings

Typical scenarios of HVAC optimisation accompany a number of the opportunities outlined in this guide. These scenarios are provided for illustration only. The energy saving and simple payback period calculation examples included with these scenarios are indicative estimates of the potential savings that could result from implementation of the given optimisation scenario.

For each individual building and system, the opportunities need to be investigated in detail and a detailed business case developed. Due to the complexity and variety of possible systems and estimating the resulting savings, scenarios are not provided for all of the optimisation strategies covered in this guide.

Simple payback period

Calculating a simple payback period is the most basic of economic analysis tools and the simplest to apply. It is applicable in situations where a reduction in operating costs relative to business as usual (or some other alternative) will be achieved. Simple payback roughly calculates the number of years before capital is recovered but does not include savings beyond that time and therefore does not calculate return on investment.

Simple payback period can be calculated using the following equation:

$$\text{payback period (Years)} = \frac{\text{total investment (\$)}}{\text{savings per year (\$)}}$$

If non-energy impacts and benefits are to be included in the analysis, then

$$\text{payback period} = \frac{\text{optimisation cost +/- non-energy impacts}}{\text{annual energy savings +/- non-energy benefits}}$$

The advantages of this simple payback analysis is that it is intuitive and easily understood, does not rely on discounting and does not require a stipulated optimisation strategy life span to be defined.

Other methods that will provide a more accurate estimate include net present value, internal rate of return, life cycle costing and life cycle analysis.

System supervisory control optimisations

This section provides an overview of HVAC optimisation strategies that are primarily implemented through the supervisory control systems. This section identifies four optimisation opportunities:

Opportunity 1 – Optimum start/stop programming

Opportunity 2 – Space temperature set points and control bands

Opportunity 3 – Master air handling unit supply air temperature signal

Opportunity 4 – Staging of chillers and compressors.

Opportunity 1 — Optimum start/stop programming

UP TO 10% HVAC ENERGY REDUCTION

Strategy summary

This strategy involves the optimisation of the HVAC system's start and stop times. Automated starting and stopping of HVAC equipment reduces system operating hours, maintenance costs, energy costs and greenhouse gas (GHG) emissions while maintaining occupant comfort levels.

An optimum start/stop (OSS) energy-saving control strategy/function uses the BMS or HVAC controller to determine:

1. the shortest period of time required to bring each zone from current temperature when systems are off, to the set point temperature.
2. how early heating and cooling can be shut off for each zone so that the indoor temperature remains within specified margins (albeit drifting).

An optimum start/stop program provides a reduction in operating hours of HVAC plant by delaying start-up time and stopping the system sooner than the currently scheduled fixed stopping time, while still maintaining acceptable comfort conditions. Most modern building management systems include proprietary optimum start functions. Optimum stop is typically custom-programmed.

Principle and equipment

OSS is programmed into the control system using an algorithm that needs to be linked directly to normal building time schedules and integrated with after-hours building control arrangements as well as any warm-up or cool-down programming.

Optimum start calculates the latest time to start HVAC plant and air conditioning (AC) equipment, based on current indoor and O/A temperature conditions and historical thermal response times for the building to achieve set point, so that comfort space temperature requirements are met when occupants arrive at the scheduled occupancy time. Optimum start controls must be linked to any warm-up or cool-down control strategies.

Optimum stop calculates the earliest time to stop HVAC plant while still providing the required comfort conditions and ventilation requirements for a building's occupants before the scheduled end of occupancy.

The algorithm is self-adaptive as it monitors and memorises heating and cooling thermal response times of the building at various combinations of outdoor and indoor air temperatures and uses them when calculating the starting and stopping times of HVAC system.

Morning warm-up and cool-down – On days of extreme temperature, the greatest daily demand for heating or cooling may occur in the morning as the building is prepared for occupancy because a significant and rapid change in temperature is needed. The goal for an optimum start procedure is to provide as much cooling as possible to cool down the building (or heating as possible to warm up the building) for the least amount of energy possible, while avoiding demand spikes and set point overshoot.

Minimum required information

The minimum information required for an OSS program includes:

- 365 day time schedule
- O/A temperature
- space or zone temperatures and set points
- OSS temperature set point (which is typically 1–2°C less than space temperature set point)
- OSS enabling time (earliest time limit)
- log of recent (up to one week ago) historical data.

Minimum required equipment

The minimum equipment required for an OSS program includes:

- field sensors/controllers (air temperatures, switching)
- controllers and data processors
- OSS software
- trend-logging capabilities.

OSS control is generally limited to larger systems that include BMS/DDC controls, with the OSS program typically being included in the BMS software. Smaller self-contained controllers, however, can often be specified to incorporate optimum start – a cost-effective method.

Recommendation

When selecting an OSS program, several factors should be checked, the most important of which is a full understanding of how the program calculates the starting and stopping time. It is also important to provide awareness training to HVAC system operators. The OSS function of the BMS could be disabled if HVAC operators do not know how to use it or have negative experience with a previously unsuccessful attempt to use it.

Current practice

Many existing HVAC systems are started prior to occupancy by a fixed time schedule, regardless of season, space temperature and O/A temperature (see Figure 2). For systems that do not have optimum start, HVAC plant is typically scheduled to start two to three hours before the scheduled occupancy time, all year round. For example, a HVAC system is started at 6am for scheduled occupancy starting at 8.30 or 9am, which can be extremely wasteful in energy and plant wear and tear.

During peak winter or summer conditions, early start-up of HVAC plant is required; however, starting times can be delayed during milder weather conditions. For example, if the O/A temperature is 30°C during a hot summer morning, the plant may need to start two hours before the occupancy time. If O/A temperature in the morning is around 20°C, however, the plant's starting time can be a lot closer to the scheduled occupancy time.

Figure 2 illustrates a very inefficient fixed time schedule that has been programmed on a BMS with HVAC starting at 6am and ending at 12pm, five days a week, every week.

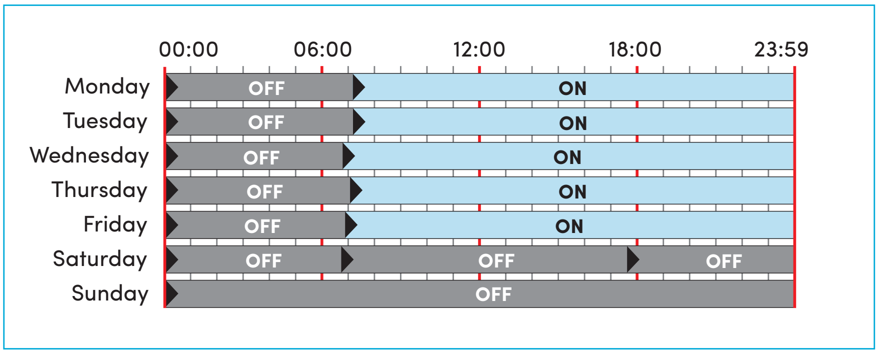


Figure 2: Fixed time schedule for HVAC system on a building management system

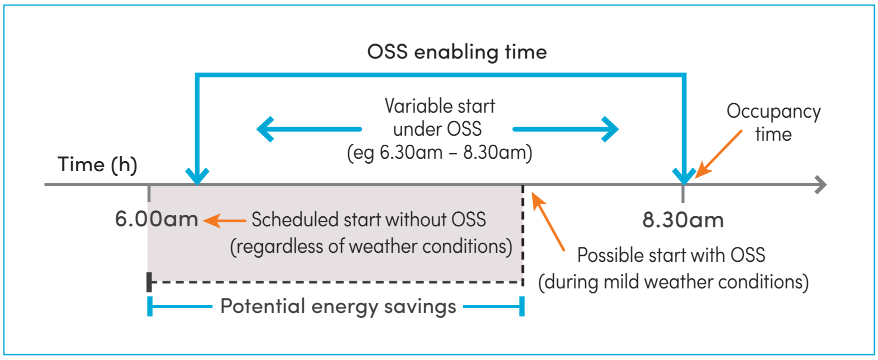


Figure 3: Potential energy savings of optimum start

Opportunity for optimisation

Introduction of a new OSS program

By using an OSS control function via the BMS, the HVAC plant automatically starts and stops on a variable time schedule. This minimises operating hours, energy consumption, energy and maintenance costs and GHG emissions. The program adjusts start/stop times by taking into account O/A temperature, space or zone temperatures and the thermal response time of the building, using adaptive learning techniques.

Optimisation of an existing OSS program

BMS programmers must ensure that:

- occupancy time is set correctly and that it matches the occupants' needs. This should be checked and possibly re-adjusted when tenancies change
- OSS enabling time is sufficient for the seasonal air temperature requirements
- the OSS program runs together with early morning warm-up and cool-down programs to maximise the energy efficiency of the HVAC system
- the most recent (e.g. three to five days) trend-logging data is part of the calculation algorithm
- space temperature limits are set correctly (e.g. no greater deviation from the temperature set point than 2°C)
- adaptive characteristics of the OSS program minimise the time difference between occupancy starting time and the time when the OSS program achieves the required comfort space temperature.

Figure 3 compares variable start time (6.30–8.30am) of HVAC equipment under an OSS schedule and a fixed-scheduled start time (6am) without an OSS schedule. This shows the opportunity to implement the OSS strategy and the potential energy savings. System start is selected for the latest possible time rather than a fixed time.

Energy-saving potential, costs, benefits and risks

Optimising the starting and stopping of HVAC equipment requires minimal investment and is typically a very cost-effective HVAC energy-efficiency improvement. It immediately reduces the energy consumption of HVAC systems and can typically save up to 10 per cent of total energy consumed by HVAC services. Greater energy savings are expected during mild weather conditions, when plant can be started later and stopped earlier, than during extreme summer or winter weather conditions.

The full energy-saving potential will only be achieved if heating and cooling plant control is also optimised for warm-up and cool-down during OSS control.

As well as reducing the energy use of AC equipment, the OSS strategy reduces system operating hours which can also reduce maintenance costs and extend system working life.

To reduce adverse impacts on indoor air quality (IAQ) in compliance with AS 1668.2, it is important to ensure that sufficient outdoor ventilation air is supplied while the building is occupied. This can be achieved efficiently through the adoption of demand control ventilation (DCV) using carbon dioxide (CO_2) sensors (refer to Optimisation Opportunity 12).

The optimum start algorithm relies on a tight building envelope which has little air infiltration and may not work well with very leaky buildings.

Application notes

The OSS HVAC optimisation strategy can be applied to any HVAC system, from the smallest room air conditioners and air-cooled split or packaged systems found in typical residential and light commercial HVAC applications, to large centralised plants with multiple chillers, air handling units (AHUs), fan coil units (FCUs) and variable air volume (VAV) boxes, found in typical commercial buildings.

Getting started

The system should be configured to achieve the outer limits of thermal comfort, typically 1 to 2°C less than the space temperature set point, rather than the exact space temperature set point.

O/A intake should be minimised where possible during building warm-up/cool-down when there are no occupants and warm-up/cool-down program operation should be locked out during occupied hours. Supply air (S/A) temperature limits, of around 32–35°C (dependant on S/A diffuser type and room heights), should also be set to prevent stratification of overheated air. Building warm-up/cool-down programs can also be locked out on outdoor temperature sensing to prevent operation during mild weather.

O/A intake can be maximised in cool-down optimum start if economy mode conditions permit (see Optimisation Opportunity 11).

Minimum ventilation rates in accordance with AS 1668.2 must continue to be provided when the building is occupied. For optimum stop, chillers, boilers and valves can be turned off; however, ventilation and IAQ need to be maintained while the building remains occupied.

If the heating or cooling system has a weather-compensated flow temperature program for energy efficiency, this feature should be disabled during the optimum start period, to reduce the duration of the warm-up and cool-down time.

For buildings that have gas-fired heating systems, auxiliary electric resistance heat should be locked out during the warm-up cycle.

OSS programming needs to be integrated with any arrangements for after-hours AC operation.

Energy monitoring can be used as an enhancement for OSS – starting the system earlier but at a lower capacity can use less energy than starting later at high capacity, to achieve the same outcome.

Optimisation scenario

An office building in Sydney uses 2500 megawatt hours (MWh) of electricity and 2100 gigajoules (GJ) of natural gas per annum (pa) for its base building (house) services.

The building occupancy hours are from 8.30am to 5.30pm Monday to Friday.

The BMS starts the HVAC system via a time schedule at 6am to ensure that space conditions are achieved before occupants arrive and stops it at 5.30pm.

After introduction of the OSS program and its monitoring over a year, it was found that, on average, the HVAC system would start at 7.45am and would stop at 5.15pm.

This reduction in operating hours of 120 minutes or two hours per day represented a reduction in operation of the HVAC system of 17.4 per cent. The energy savings of the HVAC system was measured as 12 per cent.

In this building, the HVAC system consumes 70 percent of the total base building electrical supply and 100 percent of the natural gas supply. The benefits of this optimisation scenario are calculated below:

Electricity saving calculation

2,500 MWh x 0.7 x 0.12 = 210 MWh pa

Assuming an average electricity cost of 15 c/kWh, or $150/MWh, the electricity cost saving is $31,500 pa

Using the National Greenhouse Accounts (NGA) factor for electricity for NSW of 1.06 tonnes (t) of CO_2/MWh,

Emissions reductions = 210 x 1.06 = 223 t CO_2 pa

Therefore this optimisation strategy results in an emission reduction from electricity of 223 tonnes CO_2 equivalent pa.

Gas saving calculation

2100 GJ x 0.12 = 252 GJ pa

Assuming an average cost of gas of $15/GJ, the natural gas cost saving is $3,780 pa

Using the NGA factor for gas for NSW of 65.4 kilograms (kg) CO_2/GJ,

Emission reductions = 252 x 65.4 = 16,480 kg CO_2 pa

Therefore, this optimisation strategy results in an emission reduction from gas of approximately 17 t CO_2 equivalent pa.

Overall savings	
Cost savings	$35,280 pa
GHG emission reductions	240 t CO_2 pa
Typical cost of implementation	~$5000 pa for ongoing optimisation
Simple payback period	0.2 years (less than 3 months)
Additional benefits	Significant water savings from reduced load on cooling towers

Opportunity 2 — Space temperature set points and control bands

UP TO 20% HVAC ENERGY REDUCTION

Strategy summary

For this strategy, the space or zone temperature set points are reset and optimised to reduce the energy consumption of the associated HVAC systems, without overly compromising the comfort of building occupants.

> **Did you know?**
>
> **Typically, changing the space temperature set point by 1°C can affect the energy consumption of associated cooling or heating equipment by around 10 per cent. There are actually two effects at play in such a scenario: (1) a change to the set point (or the centre point of the control range) and (2) a change to the dead band (or the width of the control range), increasing the temperature gap between heating and cooling.**

Principle and equipment

The impact of space temperature set points and temperature control bands on the energy consumption of HVAC systems is often overlooked, even though it is one of the most simple and cost-effective ways of improving the energy efficiency of systems and buildings.

The following HVAC control parameters must be considered when optimising space temperature control for energy efficiency:

- **Temperature set point** – the desired temperature to be maintained.
- **Dead band** – the temperature band between heating and cooling, within which heating or cooling equipment is not operated.
- **Proportional band (heating or cooling)** – the temperature band within which heating or cooling equipment operates by modulating its output between 0–100 per cent. Also known as throttling range.
- **Deviation** – the difference between the actual (measured value) and set point. Also known as offset.
- **Differential** – the difference between the switching on and switching off operating points in an on/off type controller (a thermostat or pressure stat).
- **Overshoot** – the amount of excess where the actual value exceeds the target value or set point.

Energy saving is achieved by increasing the cooling-mode temperature limit to the highest acceptable space temperature and reducing the heating-mode temperature limit to the lowest acceptable space temperature, while avoiding unacceptable levels of occupant discomfort. These limits are defined by the system set points, dead band and proportional band. Widening the dead band extends the time that the system neither cools nor heats, while widening the proportional band reduces the time the system operates at full capacity.

The main limitation in setting space temperature set points and control bands is determined by occupant thermal comfort. It is the temperatures at the edges of the control band that need to be considered as well as the set point. Guidelines from Comcare, the Australian Government's health and safety scheme for federal workers, suggest 20°C to 26°C as an acceptable temperature range for indoor work spaces in Australian Government buildings.

Some reference documents to assist with space temperature set points and temperature control bands are:

- **Safe Work Australia,** ***Managing the work environment and facilities – Code of Practice***
- **ComCare Australia,** ***Air-conditioning and thermal comfort in Australian public service offices: an information booklet for health and safety representatives***
- **ANSI/ASHRAE Standard 55** ***Thermal Environmental Conditions for Human Occupancy***

Links to these documents are found in Appendix B.

The acceptable limits for winter and summer internal temperature is dependent on numerous factors including:

- the extent of insulation on external walls
- the characteristics and extent of glazing
- whether window blinds are used
- the proximity of work spaces to external walls or facades
- space humidity
- the type and adjustment of supply air diffusers (draughts and/or the 'dumping' of cold air on occupants will lead to complaints even when space temperature is acceptable)
- occupant culture: if staff can be encouraged to dress appropriately for the season, energy savings of 10-15 per cent can be typically achieved.

It is important for facility managers to discuss these issues with staff and to decide on temperature set points that are acceptable to the majority of occupants while delivering positive energy-efficiency outcomes.

Occupants adapt to lower space temperatures in winter and higher temperatures in summer, and this effect of 'adaptive comfort' can be used to maximise energy efficiency by having seasonal temperature set points.

In some cases, the contractual requirements of existing leasing agreements may limit the extent of possible changes and these should be checked before any optimisations are implemented.

Recommended HVAC settings for maintaining acceptable comfort conditions with reasonable energy efficiency are:

- Winter: 20-22°C
- Summer 24-26°C.

A pragmatic summer setting for an office environment is 23°C set point with 2°C dead band and 1°C proportional bands. It is also possible to have control dead bands of up to 3°C and proportional bands up to 2°C without compromising comfort conditions. The larger the dead band the larger the energy savings, but also the larger the potential for temperature variations within the occupied spaces.

It is important to note that any changes to indoor temperature ranges should be applied gradually, for example by 0.3°C at a time, until a balance has been struck between achieving system energy savings and maintaining an acceptable standard of thermal comfort for building occupants. This gradual change will allow occupants to acclimatise to the changes.

Did you know?

Controllers use three basic behaviour types or modes: P – proportional, I – integral and D – derivative. While P and I modes are used as single control modes, a D mode is not used on its own. The difference lies in the action of the controllers:

P – provides reliable control for stable systems

PI – helps in reducing steady state error (reduces offset)

PD – helps in achieving steady state conditions quickly (reduces overshoot)

PID – helps in reducing steady state error and also attaining steady state conditions quickly.

Often, savings in energy can be gained by changing PI or PID control of temperature to P-only control, where permissible.

PI control typically works very well in application-specific controllers supplied by manufacturers, where significant loop tuning and development has been carried out to optimise the operation of the equipment.

> **A pragmatic summer setting for an office environment is 23°C set point with 2°C dead band and 1°C proportional bands.**

Minimum required equipment

The level of cooling and heating provided by different air conditioning services depends on their control capabilities, control strategies and control parameters. Typically, a temperature sensor and controller regulates this duty. Temperature controllers are found in DDC-type controls and BMS, and these consist of temperature sensors and separate switching (or modulation) mechanisms with the ability to program various control algorithms that can be used for energy efficiency.

Control of space temperature is achieved by either switching heating or cooling devices on or off, or by modulating the output from HVAC equipment, based on the deviation of the space temperature from the space temperature set point, as registered by the sensor or controller.

It should be noted that different types of HVAC controllers and sensors have different capabilities and different accuracies. Some simpler thermostats cannot regulate temperature bands and have fixed differentials, fixed dead bands and adjustable temperature increment steps of 1°C only. Such thermostats are very limited in terms of implementing energy management control strategies.

On the other hand, modern HVAC DDC and BMS control systems are intelligent and flexible enough to accommodate various energy-saving control strategies, including setting optimal temperature set points and control bands.

Recommendation

Preference should always be given to HVAC controllers/temperature sensors that have adjustable temperature bands and adjustable temperature step increments of 0.1°C, so that the energy-saving potential of HVAC systems in relation to space temperature set points can be maximised.

Current practice

Typical space or zone temperature set points for many commercial office buildings, shopping centres and public facilities is 22–22.5°C all year round, typically with narrow control bands. Such tight control wastes energy due of a lack of the allowable variance in temperature that is tolerated by most occupants, especially with adaptation to winter and summer conditions.

Opportunity for optimisation

Offices and similar environments

For office environments, a typical energy saving HVAC setting would be a space temperature set point of 22°C with a 2°C dead band and a 1°C proportional band for heating and a 2°C proportional band for cooling (see Figure 4). Stretch targets for energy savings are 3°C for the dead band and 2°C for the proportional band. An optimised (for energy efficiency) setting using these stretch targets would be a space temperature set point of 23°C with a 3°C dead band and a 2°C proportional band.

Figure 4 illustrates one example of an energy-efficient setting for cooling, heating and dead band temperature ranges for an office environment. Note that there is no cooling or heating between 21–23°C (dead band). Cooling modulates from 0º–100 per cent between 23–25°C, based on the deviation of space temperature from the space temperature set point (ie a 2°C cooling proportional band). When space temperature exceeds 25°C, 100 per cent cooling is engaged. Heating modulates from 0–100 per cent between 20–21°C, based on the deviation of space temperature from the space temperature set point (i.e. a 1°C heating proportional band). When space temperature drops below 20°C, 100 per cent heating is engaged.

Transient spaces

For transient spaces such as shopping centres, food courts, malls and foyers, space temperature set points can be more lax when compared to the comfort required for an office environment. Typical acceptable bands of control are 16–18°C (heating) and 26–27°C (cooling). This means space heating is used to maintain temperatures no higher than 16–18°C; and space cooling is used maintain space temperatures no lower than 26–27°C.

Energy-saving potential, costs, benefits and risks

Optimisation of space temperature set points and control bands is one of the most cost-effective HVAC energy-efficiency improvements. It requires minimal investment and can reduce both cooling and heating energy use (see Figure 4). For VAV systems, fan energy savings are also significant.

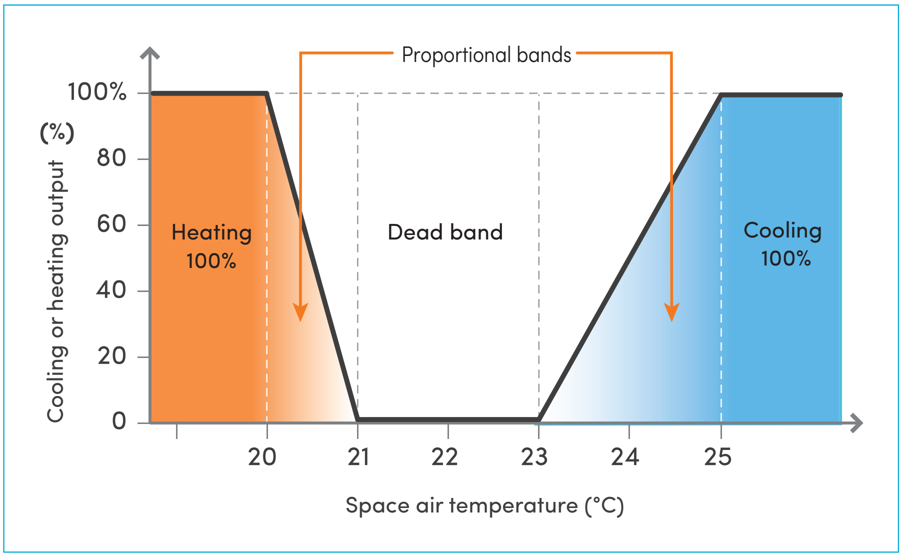


Figure 4: Typical energy efficiency temperature set point and control bands

In some cases, this strategy can immediately improve energy efficiency of the cooling/heating systems by up to 20 per cent of total energy consumed by HVAC services.

The selection of appropriate control temperatures and dead bands will also reduce the potential for heating and cooling in separate systems to operate in conflict. This can occur when spaces are served by more than one HVAC system, such as base building systems and tenants' supplementary AC systems.

Changing the action of zone control from P+I to P-only will typically provide significant energy-efficiency gains and control stability, without compromising comfort, provided control parameters (such as set points, dead bands and proportional bands) are set properly and the system design parameters (such as air and water flow rates) are being maintained.

Comfort is king

The main risk associated with space temperature set point and control bands is an increase in temperature-related comfort complaints from building occupants. This risk can be mitigated by consulting building occupants and discussing the proposed new temperature ranges, as well as the benefits, prior to implementation. Discussions should include topics such as system controls, energy savings and seasonal clothing.

It is important that any changes to indoor temperature ranges are applied gradually to reduce the perceived impact of the change for occupants.

Application notes

Optimisation of space temperature set point and control bands can be applied to any HVAC system, from small room air conditioners and air-cooled split or packaged systems found in typical residential and light commercial HVAC applications, to large, centralised, multiple-chiller cooling plants, AHUs, FCUs and VAV boxes, found in typical commercial HVAC applications.

The wider the dead band can be adjusted to, the higher the energy savings that will be realised. This is especially applicable to open-plan-type offices served by a number of VAV boxes having re-heat capability, with the potential for conflict between adjacent boxes – one box is in cooling mode with the adjacent box in re-heating mode. Considering that the best accuracy available for space temperature sensors is likely to be ±0.3°C and their calibration tends to drift slightly after a certain time, it is recommended that a minimum dead band of 1°C is maintained with a standard target of 2°C and a stretch target of 3°C.

Similarly, a proportional band of at least 0.5–1°C is recommended with a stretch target of 2°C. The associated benefits include more stable control and higher energy efficiency; the accompanying risk is an increase of occupant complaints, which depends on the type of building and the occupancy, including the type of activities and the culture. By making small incremental adjustments and monitoring feedback, changes are likely to be more successful when occupants are given time to adapt.

Getting started

The control strategy described above is typically implemented either via the BMS or a stand-alone HVAC temperature controller, which has capabilities for altering proportional and dead bands. Once the acceptable temperature set points have been determined, a BMS or HVAC control technician should be engaged to carry out the implementation and demonstrate the success of the measure via trend-logging of the space temperature. Feedback from building occupants must also be monitored as it may be necessary to fine-tune some of the settings. Control loops must be set and tuned to provide stable and reliable control with no hunting or short-cycling of controlled equipment.

Optimisation scenario

An office building with 20,000 m² Nett Lettable Area in Sydney uses 3000 MWh of electricity and 2600 GJ of natural gas pa for its base building (house) services. The NABERS Rating is 3 stars.

Global space temperature set point for AHUs is 22°C, with the space cooling band of 22–23°C and the space heating band of 21–22°C. The air distribution system is via VAV.

By modifying the space temperature set point to 22.5°C with a 3°C dead band and 0.5°C proportional band, i.e. space cooling band to 24–24.5°C and the space heating band to 20.5–21 °C, the energy consumed by the HVAC cooling equipment (chiller electricity) is reduced by approximately 20 per cent, while the energy consumed by the boilers (natural gas) is reduced by approximately 10 per cent.

In this building, where the HVAC system accounts for 70 per cent of the total base building electricity consumption and the chillers consume 25 per cent of HVAC energy, the following benefits would be obtained:

Electricity saving calculation

Reduced electricity input for chillers: 3000 MWh x 0.7 x 0.25 x 0.20 = 105 MWh pa

Assuming an average cost of electricity cost of 15 c/kWh, or $150/MWh, the electricity cost saving is 105 x 150 = $15,750 pa

Using the NGA factor for electricity for NSW of 1.06 t CO_2/MWh,

Emissions reduction = 105 MWh x 1.06 t CO_2/MWh = 111 t CO_2 pa

As such, this optimisation strategy results in an emission reduction from electricity of 93 tonnes CO_2 equivalent per annum.

Gas saving calculation

Reduced natural gas input for boilers: 2600 x 0.1 = 260 GJ pa

Assuming average cost of gas at $15/GJ, the natural gas cost saving is 260 x 15 = $3900 pa

Using the NGA factor for natural gas for NSW of 65.4 kg CO_2/GJ

Emission reductions = 260 x 65.4/1000 = 17 t CO_2 pa

Therefore, this optimisation strategy results in an emission reduction from gas of approximately 17 t CO_2 equivalent pa.

Overall savings	
Cost savings	$19,650 pa
GHG emission reductions	128 t CO_2 pa
Typical cost of implementation	~$500 pa for ongoing optimisation
Simple payback period	Less than 1 month
Additional benefits	Significant water savings from reduced load on cooling towers

Opportunity 3 — Master air handling unit supply air temperature signal

UP TO 15% HVAC ENERGY REDUCTION

Strategy summary

The aim of this optimisation strategy is to minimise the potential for simultaneous heating and cooling and reduce the amounts of cooling and heating delivered by air handling units (AHUs) and variable air volume (VAV) boxes. This strategy creates an optimised master AHU supply air (S/A) temperature signal to control the S/A temperature, minimising the mechanical cooling and heating equipment load to AHUs and VAV boxes. To achieve this, control strategies for the operation of VAV boxes and AHUs need to be well coordinated in both cooling and heating modes.

Optimised master AHU S/A temperature signals will provide a reduction in operating hours and load of HVAC plant due to reduced needs for cooling and heating of AHUs and VAV boxes.

Principle and equipment

This strategy is applied where a central AHU delivers conditioned air to numerous VAV boxes employed to serve one or more air conditioned zones. Each VAV box serves a sub-zone, with a temperature sensor located in each zone. Multiple spaces served by one VAV box are expected to have a similar heat load and similar space temperatures, and would therefore be served by one temperature sensor located in a representative location or by multiple sensors that are averaged.

Under this strategy, the BMS receives space temperature signals from each VAV zone and the VAV terminal load for each zone is determined by the deviation (or error) between the zone temperature and its associated set point. This will result in the generation of a master AHU S/A temperature signal which determines the S/A temperature. This strategy allows for differences in zone set points.

This master AHU S/A temperature signal should be based on a weighted selection of the terminal loads. A weighted signal is used to prevent faulty VAV boxes affecting the master AHU S/A temperature signal. The weighting can be based on a simple technique such as using the third-highest demand or a particular percentile demand. The strategy should also include the capability to ignore or blacklist known problem zones.

This master AHU S/A temperature signal determines how much cooling or heating is provided to the associated AHU and, in most cases, is controlled through the modulation of HW or CHW valves. Depending on how the master AHU S/A temperature signal is generated, the operation of re-heaters (electric duct heater [EDHs] or heating hot water [HHW] coils) can be greater or lesser.

The process of optimisation must take a holistic view across VAV boxes including re-heaters, AHU fan power and chiller efficiency. The lower the AHU S/A temperature, the lower the fan energy but the higher the chiller energy consumption and the potential energy required for re-heating.

Minimum required information

The minimum information required for implementing this optimisation includes:

- actual space temperatures
- space temperature set points and ranges
- master AHU S/A temperature signal
- occupancy time and 365-day schedule
- O/A temperature.

Minimum required equipment

The minimum equipment required for implementing this optimisation includes:

- field sensors/controllers (air temperature, pressures)
- controllers and data processors
- control software.

Current practice

Many HVAC systems are controlled by a BMS which generates a master AHU S/A temperature signal using a 'high select' control strategy. High select means it is the zone with the greatest deviation from the space temperature set point which dictates the selection of AHU supply temperature. This will result in over-cooling and excessive re-heating in the other zones.

It is also noted that some VAV boxes and temperature sensors will be faulty in almost every building VAV system. As such, using high select from an erroneous reading will inevitably waste energy and/or cause discomfort.

This high select control strategy and the impact it can have on the energy consumption of HVAC systems often stems from the 'business as usual' approach that this strategy provides sufficient comfort for the occupants of conditioned spaces and, as such, is good enough.

Opportunity for optimisation

1. Replace an existing 'high select' space temperature control signal with a 'customised weighted average' signal of several of the most open VAV boxes.
2. Use a floor average to generate the master AHU S/A temperature signal, especially where there is no re-heat or where it has been disabled.
3. Possible weighting scenarios (refer to Figure 5) include:
   - Average of the two worst (24°C and 26°C) is 25°C.
   - Average of the three worst (22°C, 24°C and 26°C) is 24°C.
   - High select would use 26°C. This would result in an excessive amount of cooling being sent to all spaces, which would then cause excessive re-heating in the majority of these spaces.
   - Ranking all the sensor values in order and using a particular percentile value, e.g. the 15th percentile value, to generate the master signal.
4. If the worst-case temperature signal is outside the specified cooling temperature band, this indicates a discrepancy between design and actual heat load. This discrepancy requires a design re-assessment and may also require air flow rebalancing (refer to Section 7).
5. This strategy should be implemented in conjunction with Optimisation Opportunity 2.

Figure 5 illustrates the transformation of multiple individual zone or space temperature signals into one master AHU S/A temperature signal in the most energy-efficient manner, so that AHU uses the minimum amount of energy to maintain the same level of comfort in the conditioned sub zones.

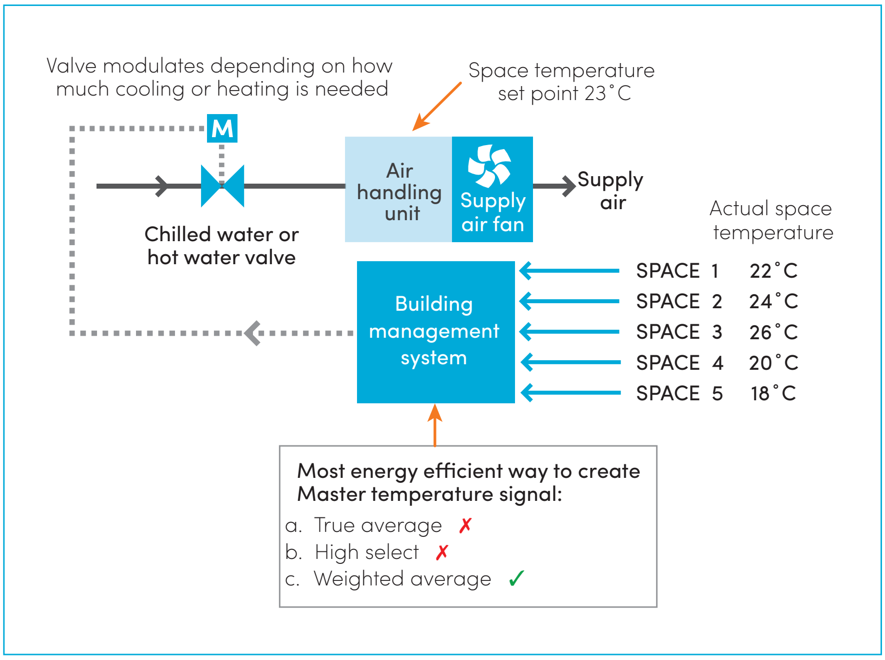


Figure 5: Control strategies to generate a master air handling unit supply air temperature signal

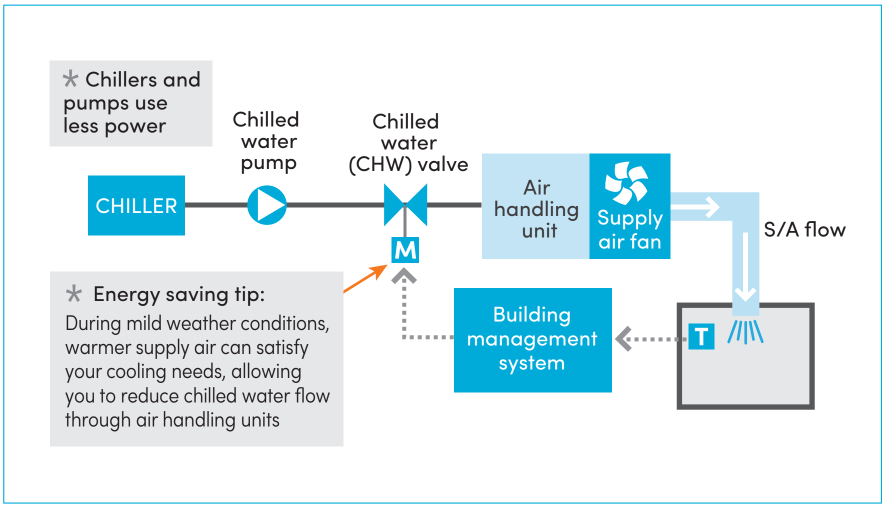


Figure 6: Opportunity for supply air temperature reset – constant air volume system

The control strategy for the AHU is usually via a PI S/A temperature control algorithm and not direct control of the heating and cooling coils. It is best practice to include a disable/enable function within the BMS or DDC for each sensor to help deal with faulty sensors. When disabled, the sensor is taken out of the control algorithm, until the defect is remedied.

Any localised extreme space temperatures require prompt action as they can compromise the efficiency of the entire HVAC system. The system controls should give the operator the ability to disregard signals from faulty zones, or from zones that are not critical for comfort.

Energy-saving potential, costs, benefits and risks

System optimisation by the generation of a master AHU S/A temperature signal via the BMS is typically a very cost-effective HVAC energy-efficiency improvement as it requires minimal capital investment. This strategy can immediately improve the energy efficiency of the HVAC system by reducing the amount of cooling and heating required by AHUs and VAV boxes and can save up to 15 per cent of total energy consumed by HVAC services.

This strategy will generally result in a wider range of temperatures across the occupied space, which may result in some occupant complaints.

Application notes

The proposed HVAC optimisation strategy typically applies to larger centralised HVAC systems of VAV-type, controlled by a BMS. S/A temperature reset can also be applied to constant air volume (CAV) systems (see Figure 6) or smaller multi-zone ducted direct expansion (DX) systems or where a smaller HVAC controller is employed instead of a BMS.

Getting started

Implementing this control strategy involves field sensors/controllers for air temperature and pressure to be available or installed as well as controllers and data processors and new or amended control software.

The master AHU S/A temperature signal should be selected based on a weighted selection of the terminal loads in the facility/building and control strategies for the operation of VAV boxes and AHUs need to be well-coordinated in both cooling and heating modes.

Optimisation scenario

An office building in Sydney uses 2,500,000 kWh of electricity and 2,100,000 megajoules (MJ) of natural gas pa for its base building (house) services. The building occupancy hours are from 8.30am to 5.30pm, Monday to Friday.

The AHU opens chilled water (CHW) and hot water (HW) valves based on the high select signal coming from the 15 VAV boxes. The VAV boxes open fully at 22°C in heating mode and at 23°C in cooling mode. It was noted that in some spaces, VAV boxes are nearly always fully open.

Modifications included in this intervention:

The high select signal was replaced by a weighted signal based on the 'average of the five most open VAV boxes'.

The operation of the VAV boxes was altered to suit temperature recommendations from Optimisation Opportunity 7.

Checking the operation of the VAV boxes identified several faulty dampers (actuators, dampers, limiters), which were rectified.

Air flows in several spaces were altered to better reflect actual heat loads (see Section 7).

The modifications enabled an increase in the master AHU S/A temperature signal by around 0.8°C and also reduced the need and extent of re-heating. The energy saving was modelled to achieve at least a 10 per cent reduction of HVAC energy consumption.

In this building, the HVAC system consumes 70 percent of the total base building electrical supply and 100 percent of the natural gas supply. The benefits of this optimisation scenario are calculated below:

Electricity saving calculation

2,500,000 x 0.7 x 0.1 = 175,000 kWh pa

Assuming an average electricity cost of 15 c/kWh, the electricity cost saving is $26,250 pa

Using the NGA factor for electricity for NSW of 1.06 kg CO_2/kWh, this represents a reduction in CO_2 emissions of 185 t pa (electricity).

Gas saving calculation

2100 GJ x 0.1 = 210 GJ pa

Assuming an average cost of gas of $15/GJ, the natural gas cost saving is $3150 pa

Using the NGA factor for gas for NSW of 65.4 kg CO_2/GJ,

Emission reductions = 210 x 65.4 = 13,734 kg CO_2 pa

Therefore, this optimisation strategy results in an emission reduction from gas of approximately 14 t CO_2 equivalent pa.

Overall savings (excluding water savings with cooling towers)	
Cost savings	$29,400 pa
GHG emission reductions	199 t CO_2 pa
Typical cost of implementation	~$3000-$5000 pa for ongoing optimisation
Simple payback period	less than three months

Opportunity 4 — Staging of chillers and compressors

UP TO 10% CHILLER ENERGY REDUCTION

The main objective of chiller staging is to match the capacity of the operating chillers to the demand of the field equipment that consumes chilled water (CHW). For optimisation, chiller sequencing must go beyond simply matching the refrigeration capacity and CHW flow rates; it must take a holistic view that considers efficiency across the full operating range for each chiller and take into account the power consumed by ancillaries including condenser water (CW) pumps and cooling tower fans. Depending on the equipment installed and the configuration of the CHW system, it may be more efficient to operate two chillers in part-load rather than one chiller at full load. The converse may be true for other systems.

Strategy summary

This strategy involves using the most efficient chiller to meet cooling demand and/or operating multiple compressors optimally by staging refrigeration compressors within the chillers and direct expansion (DX) air conditioning (AC) systems. This strategy is mainly written around primary-only CHW systems. Different strategies would apply for a primary/secondary system and it is recommended that expert advice is sought in this case.

When multiple chillers serve a facility, there are several factors that determine how they respond to actual cooling requirements from the field. Some chillers have multiple (typically twin) refrigeration circuits and modulate the cooling capacity of each compressor using means such as cylinder unloading (for reciprocating types), displacement slider control (for screw types) or variable speed drive (VSD) control of motor (for multiple types). Other chillers have banks of compressors connected to common manifolds and the compressors are brought online to meet increasing demand.

Chiller with local control panel

Staging of chillers will provide minimised energy consumption of CHW systems where several chillers share a common load. Many existing systems use CHW return temperature as a criterion for bringing the next cooling stage. To prevent energy inefficiencies associated with the premature engagement of the next chiller, the following criteria should be used instead:

- **the inability of the current chiller(s) in operation to maintain CHW flow set point**
- **the field load is greater than the maximum cooling capacity of the engaged chiller**
- **measurement of the current draw on the compressor confirms full load operation**
- **a time delay of 5–20 minutes should be applied to ensure that the above is not a short-term condition**
- **an operating chiller is switched off if the CHW flow temperature is less than the set point and the cooling load is less than the capacity of the operating chillers minus the capacity of one chiller. A time delay of around five minutes should be applied.**

See Figure 7.

Principle and equipment

For larger facilities such as typical office buildings, it is common to have multiple or modular HVAC equipment such as:

- low-load, peak-load and/or shared-load chillers
- DX AC units with multiple refrigeration circuits
- several AC units serving one space.

The reason for this modular arrangement is increased energy efficiency of HVAC systems at part-load operation, as well as meeting operational and back-up requirements of various occupants and services.

Chillers in particular require a suitable control strategy to minimise frequent switching between their operating stages. Control criteria should clearly define how many chillers are engaged and when it is an appropriate time to either bring a new stage on, turn a stage off or switch to a stage that requires less cooling capacity.

Minimum required information

The minimum information required for changing cooling stages via the BMS (i.e. staging-up or staging-down of chillers) includes:

- a reliable cooling call generated from sensors in the field, suitably attenuated, which confirms that CHW is required

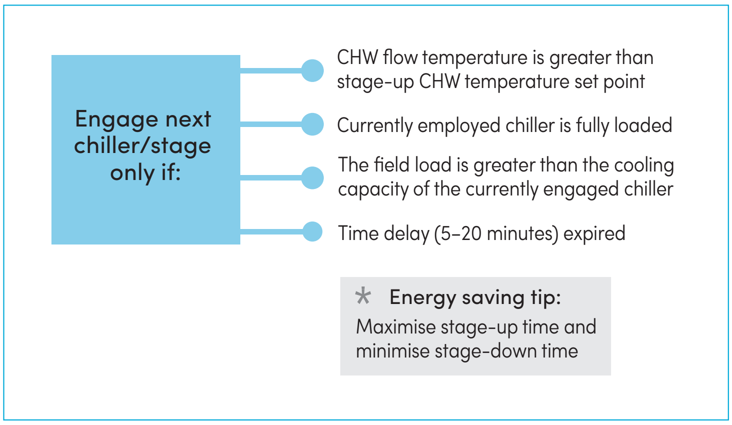


Figure 7: Chiller staging logic

- CHW flow temperature (indicating actual cooling needs)
- an indication of the cooling capacity of the present cooling stages, ideally through measuring motor current and comparing to the recommended maximum
- the efficiency characteristics of each chiller at different loads
- power consumption of the associated ancillaries
- stage-up time delay (time delay before next cooling stage is engaged)
- stage-down time delay (time delay before the existing cooling stage is disengaged).

Figure 7 illustrates the recommended system logic criteria and control parameters for the staging of chillers.

TIP: Stage-up time for chillers (particularly low-load chillers) may need seasonal readjustment during summer months to ensure that greater sudden heat loads can be accommodated by CHW systems.

Current practice

Chillers are sometimes enabled on time signals which are based on occupancy and/or prevailing ambient temperatures, which can be wasteful due to requiring longer system operating hours. This control strategy is easy to program; however, it is wasteful. Chillers must only be enabled from reliable cooling calls generated by field equipment that use CHW, such as AHUs.

Many CHW systems are controlled by the BMS, which stage the number of chillers in operation based on the CHW return temperature, with a short stage-up time (10 minutes or less). This practice does not recognise the specific energy-efficiency performance of different multiple-chiller configurations and their operational characteristics.

This control practice creates higher than necessary chiller energy consumption and maintenance costs due to:

- earlier than necessary engagement of higher cooling stage with additional energy consumption for chiller and associated CW and CHW pumps
- operation of some of the chillers in energy-inefficient (very low load) operating conditions
- longer than needed chiller operating hours (resulting in greater wear and tear)
- short-cycling of AC compressors of the next stage chillers (resulting in greater wear and tear).

The problem can become worse with uncalibrated CHW temperature sensors and/or energy-inefficient internal control settings of chillers.

Opportunity for optimisation

Several control-improvement steps can be undertaken to minimise the energy consumption of a CHW system having multiple chillers, including:

- add additional stage-up criteria to BMS to ensure that the next stage is not prematurely engaged, including:
  - percentage of current draw, in comparison to manufacturer's recommended maximum values
  - actual field cooling load (calculated by BMS, based on CHW supply and return temperature and flow rate)
  - Note: failure to meet CHW flow temperature set point is a good stage-up criterion and is more reliable than CHW return temperature.
- increase stage-up time as far as practical (up to 20 minutes)

- minimise stage-down time as far as practical (five minutes or less)
- minimise pre and post ‘cooling call’ operating time of CHW and CW pumps for the given type of chillers (one to five minutes typically) in line with the chiller manufacturer’s recommendations
- check and optimise internal chiller controls (minimum engaged power, CHW cut-in and cut-out temperature set points, sharing load control strategy, cooling trends, etc.). The integral chiller controllers should be optimised by the chiller manufacturer
- introduce a high level interface (HLI) into the HVAC control loop, so that the BMS can monitor internal chiller control parameters and assist building operators to diagnose inefficiency and non-performance of chiller controllers
- starting configuration of chillers should not be selected based on O/A temperature but rather a standard staging with minimised stage-up time.

Alternatively, chiller operating sequence could be seasonally adjusted with the initial starting stage determined by the building load at start-up. Matching the chiller capacity to the load at start-up will reduce the time for the plant to match the load and reduce optimal plant start times.

TIP: In the case of a low-load chiller associated with spaces where a sudden increase of cooling load is possible, stage-up time should be minimised (to around five minutes). A typical example is a shopping centre at opening time.

Chiller cooling call lock-outs

The inclusion of a chiller cooling call lock-out in the chiller control algorithm is a ‘belt and braces’ approach to preventing chillers operating wastefully due to spurious cooling calls. The control logic for chiller lock-outs may be time- and/or temperature-based. An example of a time-based lock-out is when cooling calls are disabled after-hours or during cooler months as scheduled on the BMS. An example of a temperature-based lock-out would be when cooling calls are disabled when ambient temperature is below 12–15°C.

Lock-outs should ideally be used after other optimisation measures have been adopted to prevent wasteful cooling calls and as an additional safety measure to prevent energy wastage due to component failures such as sensors drifting out of calibration and/or ad hoc changes by staff. Any cooling calls that occur while chillers have been locked out must be logged, investigated and rectified.

Energy-saving potential, costs, benefits and risks

Optimised staging of chillers and compressors can immediately improve the energy efficiency of the associated CHW systems and save up to 10 per cent of the energy consumed by chillers and associated components.

Application notes

The proposed HVAC optimisation strategy typically applies to larger centralised HVAC systems which incorporate multiple chillers and/or multiple compressors, and that are controlled by a BMS or central controller. The strategy provides the most benefit where there is a significant variable demand on the cooling system and the existing performance characteristics at part-loads are understood and can be reliably incorporated into the new control algorithm.

Getting started

Steps that should be taken to implement this optimisation strategy include:

- add additional stage-up criteria to the BMS to ensure that the next stage is not prematurely engaged
- minimise pre and post 'cooling call' operating time of CHW and CW pumps for the given type of chillers
- check and optimise internal chiller controls
- introduce a high level interface into the HVAC control loop
- start a configuration of chillers based on O/A temperature.

Plant control parameter optimisations

This section discusses the strategies that involve optimising control parameters used to control individual plant within the HVAC system. This section identifies five optimisation opportunities:

- **Opportunity 5** – Duct static pressure reset
- **Opportunity 6** – Temperature reset – resetting heating hot water delivery temperature
- **Opportunity 7** – Temperature reset – resetting chilled water delivery temperature
- **Opportunity 8** – Temperature reset – resetting condenser water delivery temperature
- **Opportunity 9** – Retrofit of electronic expansion valve.

Opportunity 5 — Duct static pressure reset

UP TO 30% ENERGY REDUCTION IN AIR HANDLING UNIT FANS

Strategy summary

Duct static pressure reset (DSPR) is an energy-saving strategy typically applied to variable air volume (VAV) air distribution systems controlled by direct digital control (DDC) or BMS. The objective for this strategy is to minimise the energy consumption of supply air (S/A) fans in air handling units (AHUs) and AC systems. The DSPR strategy uses variable speed drives (VSDs) to control S/A fans in AHUs to dynamically reset the duct static pressure set point when demand for S/A reduces at the VAV terminals during part-load conditions. This has the benefit of reducing AHU fan energy consumption.

The DSPR optimisation monitors the positions of volume control dampers of VAV boxes and adjusts the AHU fan speed (hence duct static pressure) to ensure that at least one VAV box (the most open VAV box) is kept nearly fully open (90–95 per cent) at any time. This strategy minimises duct static pressure by resetting its set point at regular time intervals, reducing the energy consumption of the associated AHUs (S/A fan). To prevent a faulty VAV box affecting the pressure optimisation, it is essential to obtain the DSPR feedback signal from a representative VAV box by using an appropriate sampling method similar to that described for Optimisation Opportunity 3.

The controls logic for DSPR may be based either on a proportional integral derivative (PID) control loop or an incremental loop with feedback.

With constant air volume (CAV) systems (AHUs or AC units), DSPR can be achieved simply by varying the pressure in relation to the deviation of space temperature from the set point. Care should be taken with direct expansion (DX) systems, as they are very sensitive to air flow reduction, resulting in possible freezing of coils if air flows are reduced excessively (due to reduced heat transfer between air and refrigerant in the cooling coils).

Duct static pressure reset will provide a reduction of energy consumption of AHU fans supplying VAV systems, when operating in part-load conditions.

Principle and equipment

DSPR is an energy conservation initiative that involves delivering S/A to air terminals at the lowest air static pressure possible without compromising air flow requirements. This arrangement is applicable for VAV air distribution systems with AHUs where supply air fans are controlled by VSD controllers. It can also be applied to a certain extent to CAV applications (both CHW and DX systems).

Minimum information

The minimum required information for a DSPR program (for VAV systems) includes:

- position of VAV dampers
- duct static pressure set point limits (maximum and minimum)
- adjustment of duct static set point in regular time intervals
- frequency limits for VSD fans (maximum and minimum).

Minimum equipment

The minimum required equipment for a DSPR program includes:

- static pressure field sensor (located on the index run, typically two-thirds along the total length of the index run, downstream of the fan)
- VSD controller for the fan
- DSPR controls logic (including a representative sampling method to enable detection of the most open VAV boxes).

It is important to not use the most open VAV box to drive a pressure reset as, almost inevitably, this box will have failed. It is prudent to use a strategy such as using the 15th or 20th percentile most open box to compensate for typical levels of failure that exist in most buildings.

Recommendation

When considering the implementation of DSPR control, several factors should be assessed:

- **type of application (variable or constant air volume, CHW or DX system)**
- **size of S/A fan, operating hours, typical duty cycle and potential benefits**
- **regulation of fan speed, suitability of motor for VSD control**
- **responsiveness of control loop.**

Ductwork distribution system in a commercial office building

Current practice

Many existing HVAC systems deliver S/A to air terminals at a fixed static pressure (maintained by VSD controllers) which is typically higher than necessary, hence energy is wasted. The main reason for these high static pressures is that systems are designed and set points are selected for extreme load conditions, including over-conservative margins set during commissioning. This is the case for both VAV and CAV systems.

There is also a lack of understanding of the operation of air-distribution systems and energy management strategies by HVAC operators. Building operators are also generally very risk-averse with regards to compromising occupant comfort and energy efficiency is often given a lower priority.

Insufficient operations and maintenance (O&M) practices, such as infrequent calibration of pressure sensors and ad hoc changes to pressure set points to remedy issues such as squashed flexible ductwork in index runs (caused during re-fits), can exacerbate the problem.

Opportunity for optimisation

Variable air volume systems

- Using the BMS trending functions, review existing static pressure set point and percentage opening of VAV dampers, with a view to dynamically reducing the static pressure.
- Reset static pressure set points at regular time intervals (e.g. at 300-second intervals) and adjust speed of S/A fans so that the most open VAV box (as determined through a representative sampling method) is around 90–95 per cent open at all times. This strategy ensures that spaces are not 'starved' for air and that S/A is delivered at the lowest static pressure possible, minimising the energy consumption and power demand of the fan.
- Check the air flow of VAV boxes that are frequently fully open for the correct operation of associated motorised volume control dampers, to ensure they do not limit the lowest possible static air pressure for delivering supply air to spaces.
- For similar reasons as above, ensure that there are no restrictions to air flow such as extensively long, squashed or kinked flexible ducting and/or open duct ends and/or other paths for excessive air leakage.
- Ensure the control strategies are appropriate and the loop responsiveness is set so that 'hunting' is avoided when the static pressure set point is reset and/or the position of the dampers in VAV boxes is changed.
- Review minimum design air flows for VAV boxes and their potential for reduction, considering issues including minimum O/A and the 'dumping' of cold air.

Did you know?

The term 'hunting' refers to instability within the control system when the system first overcorrects itself in one direction and then overcorrects itself in the opposite direction. Hunting within control systems results in unstable system control and premature wear of the affected components.

Figures 8 and 9 show the opportunity to implement the DSPR function – maintaining a lower static pressure in the duct by reducing the S/A fan speed. During mild weather conditions, the S/A fan can typically satisfy all cooling needs running at a lower speed than the design or maximum speed with a reduction in fan speed helping to save energy.

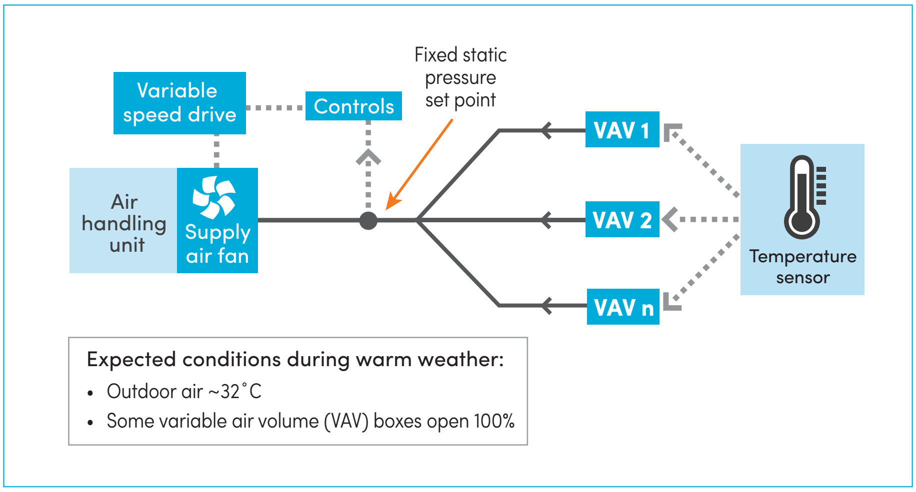


Figure 8: Variable air volume air distribution under full-load (typical summer peak) conditions

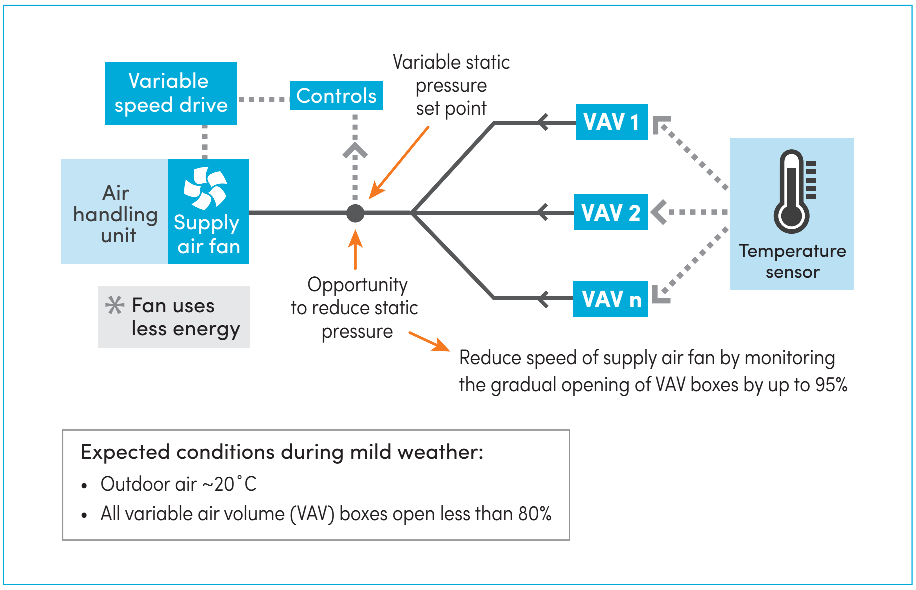


Figure 9: Variable air volume air distribution under part-load conditions

Tip: To maximise the benefits of DSPR, air flows must be tuned and balanced within the same zone to ensure that all VAV boxes modulate in a similar fashion.

Constant air volume air-distribution systems

The speed of the S/A fan can be reduced via the VSD controller in response to the deviation of actual space temperature from the space temperature set point. One option is to establish a linear dependency between the speed of the fan and the O/A temperature with a space temperature override function.

The following control strategy might be considered:

- In cooling mode, when the O/A temperature is lower than 25°C, the fan would be run at the minimum speed set point (e.g. 70 per cent).
- When the O/A temperature is over 30°C, the fan would be run at maximum speed set point (i.e. 100 per cent).
- When the O/A temperature is between 25–30°C the fan speed would modulate accordingly.
- If the actual space temperature deviated more than 1.5°C from the space temperature set point (excessive temperature), the fan speed would either ramp to full speed or increase incrementally.

Note that for CAV systems, the flow cannot be turned down too far without interfering with the air balancing; 60 per cent is a reasonable maximum turndown. If it is a single-zone system, balancing isn't that important and the flow can potentially drop further.

Energy-saving potential, costs, benefits and risks

Optimisation of duct static pressure through the BMS DSPR function reduces energy consumption in a very cost-effective way. Typically, there is no requirement for any equipment upgrades (VAV boxes, VSD controllers and motorised dampers being already installed) and only modifications to the control software and settings are required. This strategy can save up to 30 per cent of the energy consumed by fans serving AHUs.

Potential risks include unstable control loops and uncalibrated pressure sensors. Inaccuracy in pressure sensor readings will result in an unstable control system. These risks are mitigated by careful programming and the correct location, installation and ongoing maintenance of the duct pressure sensors.

Application notes

DSPR typically applies to VAV air-distribution systems, which consist of AHUs and VAV boxes. It can also apply to DX and CAV air-distribution systems, however, with limited success due to several factors including:

- DX AC systems being sensitive to air flow reductions
- CAV systems normally do not change air flow in the air-distribution system at a local level.

BMS graphics screens should display the actual and current floating duct static pressure set point for each AHU. The speed of fans, percentage of opening of VAV boxes and duct static pressures should be logged to enable monitoring of the performance of this control feature.

The control system should also provide the operator with the ability to exclude problem zones from affecting the operation of the system.

The turndown ability of motors to reduce speed using variable frequency drives (VFDs) needs to be checked as some older motors cannot be reduced below 30 hertz (Hz).

One of the biggest issues with this optimisation strategy is the accuracy or lack of calibration of the VAV box air flow pitot tube. Often the true performance of the VAV box is masked by this fault, making it appear as if the zone is receiving the wrong air flow. VAV box maintenance is critical to the success of a variable pressure control for a VAV system in order to improve performance and reduce system faults.

Getting started

Prior to implementing this strategy all VAV boxes should be inspected and maintained. VAV box maintenance should include fixing dampers, sealing leaking hot water valves, addressing heaters that trip, cleaning and adjusting air flow sensors and correcting zone temperature sensors that are incorrectly located.

It is also important to check the recommended minimum inlet static pressure nominated by the manufacturer of the VAV boxes. If the static pressure is too low, this will cause unsatisfactory control and excessive wear on the damper actuator.

Once box operations have been verified the duct static pressure reset optimisation can be implemented.

Opportunity 6, 7 and 8 — Temperature reset

Opportunity 6

Temperature reset – resetting heating hot water delivery temperature

UP TO 5% HOT WATER ENERGY REDUCTION

Opportunity 7

Temperature reset – resetting chilled water delivery temperature

UP TO 15% CHILLER ENERGY REDUCTION

Opportunity 8

Temperature reset – resetting condenser water delivery temperature

UP TO 15% CHILLER ENERGY REDUCTION

Strategy summary

Variable or floating temperature set point of heating hot water (HHW), chilled water (CHW) and condenser water (CW) is a control strategy whereby the temperature (or grade) of thermal energy is dynamically adjusted (or reset) to minimise the energy consumption of the associated HVAC equipment.

In practical terms, this means that HVAC control algorithms attempt to provide:

- the coolest possible water for heating
- the warmest possible water for cooling
- the coolest possible CW for cooling of refrigeration equipment.

It should be noted that the optimisation strategies must take a holistic view of minimising total HVAC system energy consumption, as the singular optimisation of one piece of equipment in isolation may be to the detriment of another. The algorithms must take into account several different parameters, such as actual or field heat/cooling load, outdoor air (O/A) conditions, the efficiency, operational characteristics and limits of the installed HVAC equipment and the responsiveness of the HVAC control loop.

Chilled water pipe

Current practice

Currently, most HVAC systems have a:

a. fixed temperature set point for HHW, CHW and CW, or

b. manually regulated floating temperature set points for the heating/cooling fluids which are not optimised.

HVAC equipment is designed to consider the order of highest heat load that can be expected, in terms of both external and internal heat loads (peak summer and winter temperatures, maximum solar gain, maximum occupancy, maximum amount of equipment in use, etc.).

HVAC equipment sized using these design conditions actually operates at part-load conditions for the majority of the time. This means the heat load of HVAC systems can be satisfied, for most of the time, with control parameters that are not as stringent as those required under the design for operation at full-load conditions.

Temperature reset is a control optimisation approach in which the temperatures of the cooling or heating media are altered in order to minimise the overall energy consumption of the HVAC system. This mainly relates to HHW, CHW and CW. The reset of S/A temperature is covered in Optimisation Opportunity 2 and 3.

Temperature reset can allow for minimised energy consumption of HVAC equipment when operating in the part-load conditions that occur throughout most of the year.

Principle and equipment

Minimum required information

The minimum required information for the control of temperature reset strategies includes:

- current space temperature set point
- operational characteristics and limits of the HVAC equipment that is subject to temperature reset
- temperature reset limits

Hot water systems in building plant room

- an indication of actual heating or cooling load based on thermal energy metering, prevailing ambient conditions, the percentage opening of field modulating valves or flow/return temperatures
- supply and return temperature of HHW, CHW or CW.

Minimum required equipment

The minimum required equipment for temperature reset includes:

- field temperature sensors
- controllers and data processors
- temperature reset software
- control interface between HVAC equipment and HVAC controls.

Opportunities for optimisation

Optimisation of heating hot water

Reducing HHW temperatures will reduce distribution losses (the heat lost or gained through the pipes and pipeline components) and slightly improve the thermal efficiency of conventional boilers while significantly improving the efficiency of non-condensing boilers.

If the return temperature of a conventional (non-condensing type) boiler is reduced below 55°C, any small gains in efficiency will be negated due to boiler 'back end' corrosion, also known as fireside corrosion, which will cause premature failure of the boiler. This must be avoided.

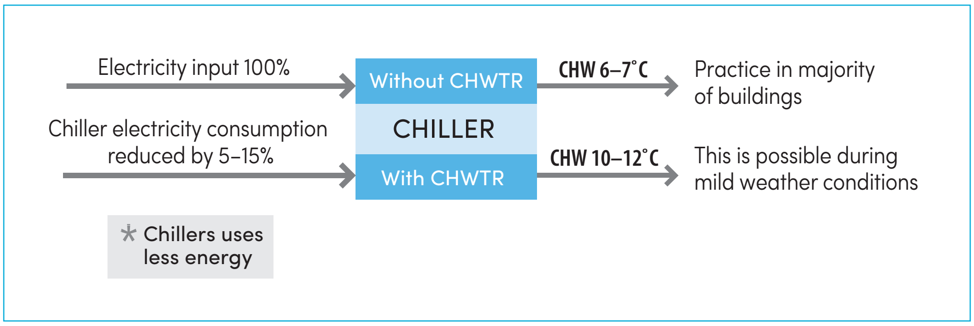


Figure 10: Benefits from higher chilled water temperature (chilled water temperature reset)

Where condensing boilers are installed, they are more efficient when the return temperature is maintained below 55°C – which is the typical dew point of flue gases for natural gas-fired boilers. As such, it is important to maintain the boilers at as low a HHW flow temperature as possible, except for the relatively short periods of the year when full heating system capacity is required; typically during extremely cold weather and/or during early morning warm-up periods. During periods of high heating demand, the HHW flow temperature should be reset to 80–85°C when condensing boilers have reached their maximum output. The HHW flow temperature should be reset to 80–85°C and the condensing boiler used as the lead boiler before additional (non-condensing type) boilers are brought online.

For additional information on optimising HHW boilers, refer to Optimising multiple boiler/water heater systems in Section 7.

Optimisation of chilled water

For every 1°C increase in chilled water temperature, chiller compressors consume 2–3 per cent less energy for fixed-speed compressors and 4–5 per cent for variable speed compressors.

Typically, CHW is supplied in most systems at temperatures between 6–7°C for most systems under design conditions; however, this temperature can be reset upwards to around 10–12°C during milder weather, providing there are no adverse effects such as the loss of de-humidification (humidity control). Increased CHW temperature will reduce chiller energy consumption; however, it could require additional pumping energy and/or increased S/A flow. These increases should be considered when calculating the overall benefits from this optimisation strategy.

For CHW systems that have long CHW circuits, the pumping power is significant. In these circumstances, variable CHW flow, on secondary circuits, may be a more appropriate strategy for energy saving than CHW temperature reset and should be assessed on a case-by-case basis. Generally, for short CHW circuits, CHW temperature reset is more energy efficient as savings in pumping power are smaller, relative to potential gains in chiller efficiency through CHW reset.

Variable speed chillers typically have a better response to increased CHW temperature than fixed-speed chillers. Similar behaviour occurs when CW temperature is reduced.

Figure 10 shows that, during mild weather conditions, warmer than standard CHW temperatures can satisfy the cooling load. Raising the CHW temperature will reduce the electricity consumption of chillers.

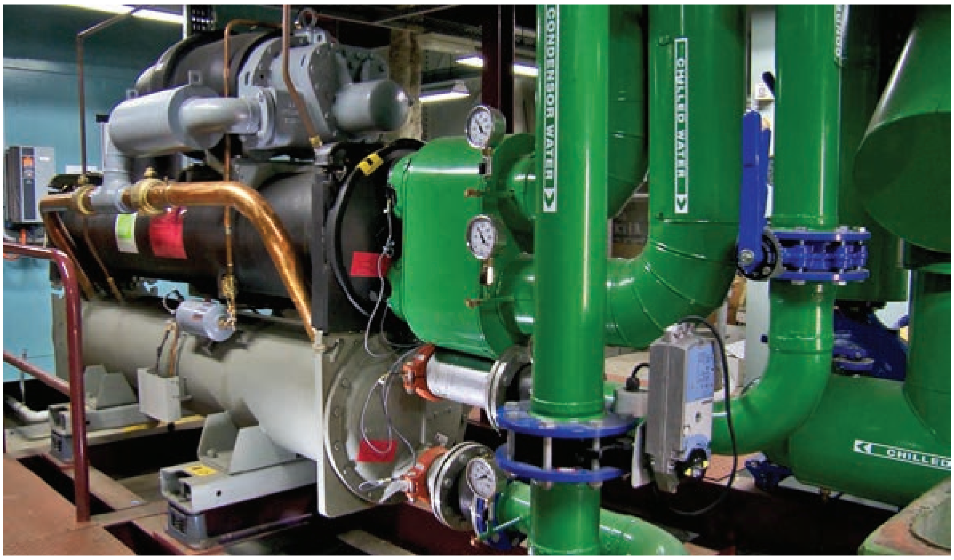
Tip: You can save energy by increasing the chilled water temperature during part-load conditions.

Optimisation of condenser water

For every 1°C decrease in CW, chiller compressors consume 2–3 per cent less energy for fixed-speed compressors and 4–5 per cent less for variable speed compressors.

Cooling towers are typically designed to produce CW at temperatures that are 3–4°C higher than the prevailing ambient wet bulb temperature. This temperature difference is called the cooling tower ‘approach’.

CW temperature reset is based on the modulation of the cooling tower fan speeds to track the ambient wet bulb temperature, which provides the lowest possible condensing conditions. Optimisation is essentially a balancing exercise between reduced chiller energy consumption (due



Temperature reset is a very cost-effective optimisation strategy, requiring minimal investment while providing immediate energy savings

to the lower condensing temperature) and higher fan energy consumption at the cooling towers. This optimisation should be assessed on a system-by-system basis, taking account of the following factors:

- Resetting CW temperature should take into account the minimum required CW temperature for the given type of refrigeration compressor, as nominated by the equipment manufacturer. CW that is too cold can create an excessively low pressure differential between the condensing and evaporating sides of a refrigeration cycle, causing difficulties with refrigerant flow through expansion devices and oil transfer to the compressor.
- For the majority of cooling towers, any attempt to get closer than within 3–4°C approach of the prevailing ambient wet bulb temperature (for example, wet bulb temperature plus 2°C) will result in a significant increase in energy consumption of the cooling tower fans, with little or no net benefits.
- For the successful application of the CW temperature reset control strategy, it is essential that the minimum approach temperature for a given brand and model of cooling tower is determined through seeking this information from the manufacturer.

Systems with multiple towers and towers with multiple fans should have all towers/fans controlled together. Running multiple fans together at part-load is more energy efficient than running individual fans at full speed, or cycling fans on/off.

Tip: **The most cost-effective option should be assessed on a case-by-case basis.**

Energy-saving potential, costs, benefits and risks

HHW, CHW, and CW temperature reset is typically a very cost-effective HVAC energy-efficiency improvement, as it requires minimal investment and immediately reduces the energy consumption of the HVAC system by reducing its load.

Resetting HHW delivery temperature can save up to 5 per cent of energy consumed by condensing boilers, while resetting CHW delivery temperature can save up to 15 per cent of energy consumed by chillers. Resetting CW delivery temperature can save up to 15 per cent of energy consumed by chillers.

Application notes

HHW temperature reset is typical for HHW boilers that provide space heating and re-heating. With conventional boilers, only limited savings are possible due to risks of fireside corrosion if the return temperature falls below 55°C. With condensing-type boilers, significant savings can be achieved. See also Section 7 on optimising boilers.

CHW temperature reset is applicable to both air-cooled and water-cooled chillers. Decent savings are available for most types of compressors and significant savings are possible with modern variable speed compressors.

CW temperature reset is applicable for water-cooled chillers and water-cooled DX equipment. Significant savings are possible with modern variable speed compressors.

Getting started

Current temperature set points should be determined along with the operational characteristics and limits of the HVAC equipment of the facility. Reset limits and modulation of the actual heating or cooling of the load based on energy metering, ambient conditions and field modulating valves will need to be determined to inform the implementation of the strategy.

Opportunity 9 — Retrofit of electronic expansion valves

UP TO 15% COMPRESSOR ENERGY REDUCTION

Strategy summary

This activity improves the energy efficiency of refrigeration systems. It involves the retrofitting of electronic expansion valves (EEVs) to replace thermostatic expansion valves (TXVs) in vapour compression refrigeration systems that operate with direct expansion (DX) type evaporators.

This opportunity is applicable to DX-type chillers and large packaged systems that have TXVs. Retrofitting EEVs will be more cost-effective when carried out for DX systems that have widely varying load conditions (as opposed to constant load) or are being upgraded for variable head pressure control, as described in Optimisation Opportunity 15.

Many existing AC systems are likely to have TXVs and there is often a significant energy-efficiency benefit from retrofitting systems with an EEV (see Figure 11). EEVs provide better control of the refrigerant flow into the evaporator, with less superheat requirements at the entry to the compressor for its safe operation without risk of damage from liquid refrigerant. This increases the efficiency of the evaporator and reduces the energy consumption of the compressor.

Since TXVs are more likely to exist in older systems that have R22 (HCFC-22) refrigerant, which is currently being phased out in Australia, it is important to assess the expected lifespan of the chiller or AC system when considering this optimisation for implementation. It is important to seek the advice of the manufacturer of the refrigeration system when carrying out this optimisation.

Retrofitting an electronic expansion valve in a refrigerant vapour compression circuit can result in reduced energy consumption of air conditioning compressors by 10–15 per cent and improved control and reliability of operation of refrigeration systems during part-load conditions.

Significant energy savings can be made from retrofitting direct expansion-type chillers like the one pictured

Principle and equipment

The function of TXVs in DX vapour compression refrigeration systems is to regulate the refrigerant flow through the system while maintaining a minimum level of superheat in the refrigerant gas leaving the evaporator. This ensures that there are no droplets of unevaporated refrigerant that could cause damage to the compressors. TXVs are mechanical devices and, as such, their degree of control is limited. EEVs are more sophisticated and can perform the task of regulating refrigerant flow more precisely and with a smaller margin of the superheat required for the protection of the compressor from 'liquid slugging'. This improves the efficiency of the compressor and reduces energy consumption.

Minimum required information

The minimum required information for retrofitting EEVs includes:

- age of equipment or system
- system refrigerant type and expected life
- system capacity
- system operating parameters – evaporating and condensing
- pressure drop across EEV
- whether the refrigeration system operates on a pump-down cycle
- interfacing EEV controls with BMS for monitoring.

Minimum required equipment

The minimum equipment includes:

- field sensors (temperature, pressure)
- controllers and data processors
- EEV.

Current practice

Most new AC systems have EEV devices, while many older systems (i.e. older than 5–10 years) typically have TXVs. Wear will degrade the operation of TXVs through control drift while superheat is often set conservatively, erring on safety; both of which will compromise the energy efficiency of the device.

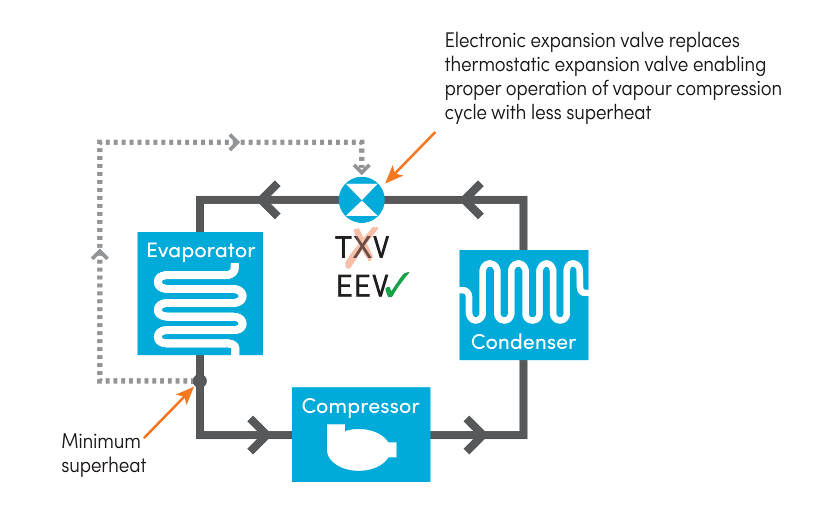


Figure 11: Thermostatic expansion valve is replaced with an electronic expansion valve

Opportunity for optimisation

The following control strategies and parameters are recommended in order to maximise the energy efficiency of refrigeration systems without compromising their performance:

- Retrofit EEV instead of TXV for larger refrigeration circuits controlling superheating in the region of 2–3°C, see Figure 11.
- Where it is not cost-effective to retrofit EEVs, adjust TXV to control superheating in the region of 5–7°C.

Energy-saving potential, costs, benefits and risks

Retrofit of EEVs can reduce energy consumption of AC compressors by up to 15 per cent. Cost-effectiveness can vary, with payback periods depending on the cost of the new valves.

Benefits arising from the use of EEVs include:

- more reliable operation of refrigeration systems
- reduced energy cost
- reduced GHG emissions
- reduced maintenance costs.

Risks arising from the use of EEVs include:

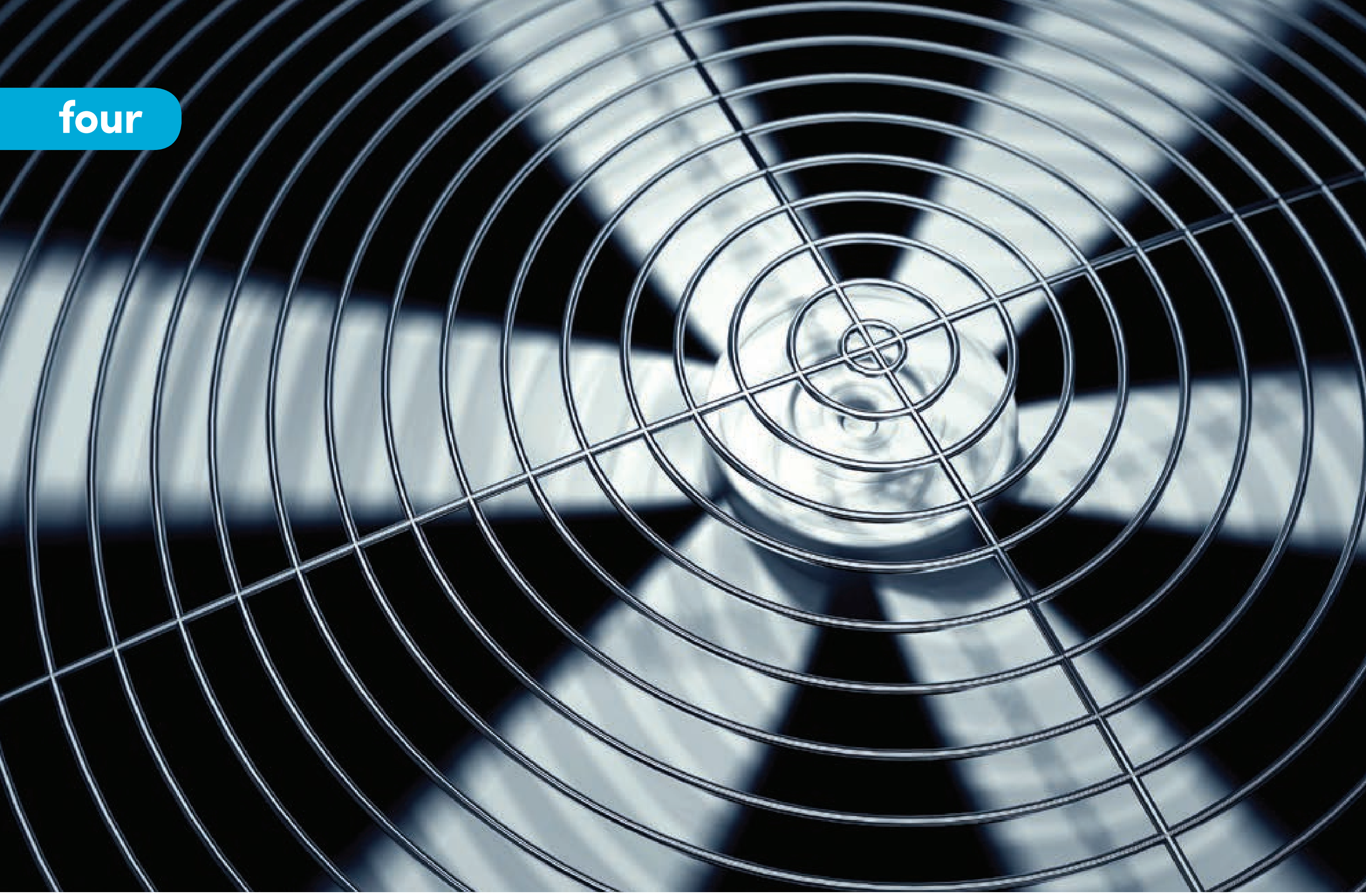
- incorrect sizing and set-up by inexperienced technicians.

Application notes

Typically, EEVs can be effectively retrofitted to vapour compression refrigeration circuits employed with larger AC units (typically reciprocating AC compressors).

Getting started

Facility managers or building owners/operators will need to establish the age of the current refrigeration equipment/systems, the refrigerant type, the remaining economic life of the equipment, and the system capacity, prior to the retrofit of an EEV. Interfacing with the current BMS or controller will also be required for monitoring of the EEV.



four

Ventilation and air flow optimisations

This section discusses the strategies that involve optimising air flows and ventilation systems to reduce energy consumption. This section identifies four optimisation opportunities:

- **Opportunity 10** – Economy cycle
- **Opportunity 11** – Night purge
- **Opportunity 12** – Demand control ventilation – carbon dioxide for occupied spaces
- **Opportunity 13** – Demand control ventilation – carbon monoxide for carparks and loading docks.

Opportunity 10 — Economy cycle

UP TO 20% COMPRESSOR ENERGY REDUCTION

Strategy summary

Economy cycle is a strategy that uses outdoor air (O/A) directly for space cooling, with the aim to reduce the energy consumption by reducing operation of AC equipment. This strategy provides the added benefit of improved indoor air quality (IAQ) by significantly increasing outdoor air ventilation rates during periods of mild weather.

> **Did you know?**
>
> **Economy cycle allows for a 15–20 per cent reduction of energy consumption of air conditioning compressors and improved indoor air quality.**

Principle and equipment

For most parts of Australia, the ambient outdoor air often has a lower enthalpy (total energy) than the air within conditioned spaces in buildings (except for the hot and humid northern regions). In such conditions, air returned from the occupied space can be exhausted (rather than being returned) and the lower enthalpy O/A can be used as supply air (S/A), reducing the operation of AC systems and reducing energy consumption, see Figure 12.

When an air handling unit (AHU) operates in cooling mode, it typically cools S/A to 12–13°C (for chilled water systems) or 8–9°C (for direct expansion systems). During mild weather conditions, cooling requirements can be satisfied with a higher temperature of S/A, sometimes even as high as 20°C. It should be noted that in such situations, the ability of AC systems to dehumidify is significantly diminished and this optimisation strategy will not be viable where humidity control is paramount. This is not the case for typical office type buildings where the space relative humidity can typically drift between 40–60 per cent (or even to 35–65 per cent for brief periods) without significant discomfort.

Taking into account the typical S/A temperatures noted above, as well as typical climate conditions for the southern part of Australia during the cooler months, O/A can be used to provide cooling for spaces, with or without the assistance of AC compressors, thereby reducing the system energy consumption.

When outdoor conditions are not suitable, typically due to high temperature and/or humidity, the economy cycle must be disabled and the AHU must revert to minimum O/A. The economy cycle must also be disabled during fire mode operation, which is an important consideration when retrofitting.

The economy cycle is one of the energy-saving control strategies normally included in HVAC direct digital control (DDC) system controllers or BMSs.

Often, existing economy cycles have been set up incorrectly and/or they have failed due to inadequate maintenance. When they fail, the HVAC system consumes more energy than necessary. Common reasons for failures of existing economy cycles include:

- malfunctioning sensors (especially humidity sensors)
- failed dampers or damper actuators resulting in discomfort
- building pressurisation issues
- disabled due to high energy consumption.

Significant energy savings can be realised by optimising existing settings, or retrofitting HVAC systems to incorporate economy cycles.

> **Often, existing economy cycles have been set up incorrectly and/or they have failed due to inadequate maintenance. When they fail, the HVAC system consumes more energy than necessary.**

Figure 12 shows the use of the O/A economy cycle as a first stage of cooling, when O/A conditions are favourable.

Minimum required information

The minimum information required for an economy cycle program includes:

- return air (R/A) temperature and enthalpy (based on temperature and humidity)
- O/A temperature and enthalpy (based on temperature and humidity)
- control strategy e.g. lock-out conditions
- control parameters e.g. O/A conditions
- conditions for activation
- economy cycle enabling time.

Minimum required equipment

The minimum equipment required for the economy cycle program includes:

- field sensors (outdoor and R/A temperature and humidity)
- DDC controllers
- economy-cycle software
- O/A and relief air dampers (of adequate size) and motorised modulating actuators (see Figure 11)
- O/A inlet, exhaust air outlet and ducts sized to accommodate 100 per cent O/A.

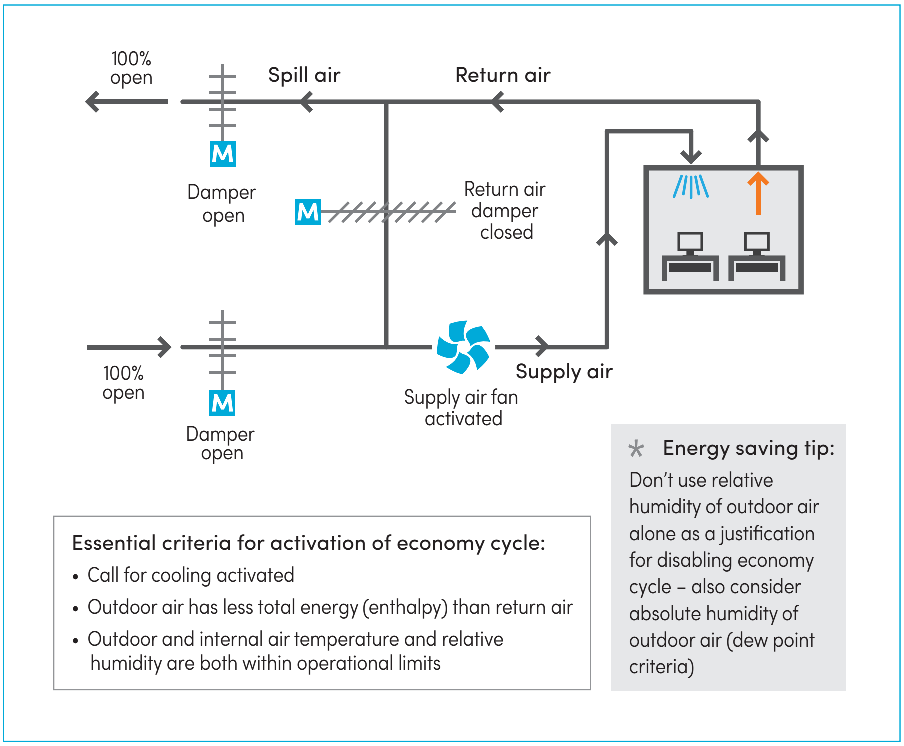


Figure 12: Activated economy cycle

Air plenum of an air handling unit showing motorised outdoor air and return air volume control dampers

A mixed air temperature sensor is very useful for this strategy. Modern BMSs can now also use weather data feeds from the internet for more accurate and reliable data.

Tips:

1. **In cooling mode, a higher space temperature set point increases the use of economy cycle.**
2. **Economy cycle often runs together with regular mechanical cooling, reducing the heat load on the mechanical HVAC equipment.**
3. **Don't use outdoor relative humidity (RH) as a control criterion for an economy cycle – it's irrelevant. Instead, use enthalpy, absolute humidity or dew point.**

Current practice

Many HVAC systems that are controlled by a DDC or BMS either do not have an economy cycle installed/enabled or it is underutilised due to an inefficient control strategy and/or inappropriate control parameters/limits.

Typical control strategies that lead to reduced opportunities for saving energy include:

- The economy cycle is used when O/A temperature is lower than the air temperature set point for the economy cycle (16–19°C), which is cooler air than the space temperatures. As such, the AC load is reduced. The disadvantage of this strategy is that it restricts the operation of the economy cycle at higher ambient temperatures. This represents a diminished opportunity for energy conservation, especially in systems where the enthalpy of the O/A is monitored and the O/A is only used when it has lower enthalpy than R/A.
- The economy cycle is only used when O/A temperature is close to S/A temperature (12–13°C). Such a strategy severely restricts the use of economy cycle (reduces its operating hours) as it only operates when O/A temperature is close to the off-coil S/A temperature.
- O/A temperature is lower than R/A temperature. This approach overlooks the fact that sometimes even warmer O/A, warmer than R/A (but much drier, lower humidity) can be utilised for the economy cycle.

A contributing factor to the under-utilisation of the economy cycle is inappropriate space temperature set points and ranges. Optimised control strategies and control parameters should take into account both the minimisation of the use of AC compressors and the comfort of occupants. Refer to Optimisation Opportunity 2.

Opportunity for optimisation

Typical control strategies (as described above) in place for economy cycles are not optimised. As such, they either operate within overly restrictive conditions or have excessive operation, both of which leads to energy wastage.

Economy cycles are typically beneficial in the following ambient conditions:

- Temperature: 10–20°C
- Enthalpy: < 52 kilojoules per kilogram (kJ/kg)
- Dew point: < 12°C.

In order to maximise the operating hours of the economy cycle, it should be enabled when the O/A temperature:

- is lower than the zone cooling set point temperature
- is below the R/A temperature
- has a dew point below 12°C or an enthalpy which is at least 10 kJ/kg below the R/A enthalpy.

This is the most efficient control strategy.

The source of O/A should be located away from polluted air (loading docks, traffic, etc.) and preferably on the southern or eastern side of the building to maximise economy-cycle operation potential.

Tips:

1. **In cooling mode, a higher space temperature set point increases the use of economy cycle.**
2. **Economy cycle often runs together with regular mechanical cooling, reducing the heat load on the mechanical HVAC equipment.**

Energy-saving potential, costs, benefits and risks

The economy cycle is typically a very cost-effective HVAC energy-efficiency improvement; however, it does require some investment in sensors, motorised dampers, filters and possibly ductwork modifications. The economy cycle immediately reduces the energy consumption of the HVAC system by reducing its load, as well as improving IAQ. This strategy can save up to 20 per cent of energy consumed by AC compressors.

If a building has smoke hazard management, most of the infrastructure is probably already in place and only new controls would be needed.

The total benefits arising from the use of economy cycle can include:

- reduced energy cost
- reduced CO_2 emissions
- improved IAQ (at times of increased O/A flows)
- reduced HVAC maintenance costs (less compressor run time)
- facilitation of other energy-saving initiatives (early morning warm-up/cool-down, demand control ventilation, night purge).

The potential risks arising from the use of economy cycle that should be considered include:

- increasing energy consumption by bringing in O/A that is too hot or too cold, due to faulty sensors or control settings. This risk is mitigated by implementing regular energy-efficiency maintenance inspections and using high-quality sensors

- IAQ impacts due to O/A pollution events
- HVAC hygiene impacts that may come with increased O/A (can be mitigated by filtration; however, filters can increase fan energy use)
- issues with O/A latent heat/moisture content if enthalpy sensors are not used.

Application notes

Economy cycle can be applied to centralised HVAC systems with chilled water (CHW), direct expansion (DX) AHUs and ducted packaged DX systems with motorised O/A dampers connected to a central (BMS) or local HVAC control system. AHUs facilitate this energy-conservation optimisation strategy as they are the source of O/A ventilation for buildings. When economy mode is enabled, the damper actuation should operate in sequence with the heating hot water (HHW) and CHW valve modulation.

It is important to use dampers with low leakage rates and to ensure that modulating dampers close when the AC or ventilation system is off to eliminate infiltration; this is also a requirement of Section J of the National Construction Code (NCC).

The economy cycle, or the use of O/A for AC, can also form part of a mixed-mode HVAC design (e.g. automated opening/closing of windows, dampers, or any other O/A provision).

For new installations, the use of economy cycles is mandated in Section J of the NCC.

The economy cycle is typically not suitable for applications where a narrow control band for both space temperature and RH is required (e.g. museums, art galleries, laboratories, clean rooms, etc.).

Getting started

The economy cycle is one of the energy-saving control strategies normally included in HVAC DDC system controllers or BMS packages. The control strategy has often been set up incorrectly and/or has failed due to inadequate maintenance. To implement a working strategy for an existing economy cycle the points to check include:

- malfunctioning sensors (especially humidity sensors)
- failed dampers or damper actuators resulting in incorrect airflows
- building pressurisation issues
- failure of the cycle to generate energy savings due to high fan energy consumption.

When implementing economy cycle or other HVAC optimisation strategies to existing systems, it is important to ensure that the original design intent for fire mode operation is not altered in any manner without consultation with the relevant authorities.

Opportunity 11 — Night purge

UP TO 20% COMPRESSOR START-UP ENERGY REDUCTION

Strategy summary

The aim of the night purge strategy is to reduce the use of mechanical cooling in buildings by automatically flushing the building with cool outdoor air (O/A) using natural ventilation at night time or for mechanical ventilation preferably just prior to start-up.

By ensuring that the air in the building is displaced by cooler outside air just before the HVAC system starts up, energy consumption is minimised. In mechanically ventilated buildings, as fan energy is consumed, night purge must only be enabled when the air handling unit (AHU) average zone temperature is more than 1.5°C above the cooling space temperature set point and only shortly prior to morning start-up. This is to ensure that the fan energy used will exceed the savings in cooling energy. This is not an issue where natural ventilation is used for night purge.

Night purge is effective in climates that have lower overnight temperatures and where the O/A is not humid; typically when the dew point is less than 12°C.

Night purge requires an effective automated control strategy with appropriate control parameters, which enable the effective flushing of a building with O/A that is typically at least 3–5°C cooler than the indoor air.

If not controlled properly, night purge can negate its purpose and consume more energy than that required for mechanical cooling to remove the heated air accumulated in a building at night.

Did you know?

Night purge can provide energy savings from a reduction in both operating hours and load of HVAC plant.

Principle and equipment

Night purge is an energy-saving strategy employed through DDC or BMS controls to use O/A to remove residual heat from the building. Heated air, accumulated during hot summer nights and through any residual equipment operating overnight while HVAC systems are shut down, is replaced with cooler O/A during the early morning hours shortly before start-up.

In the case of mechanically ventilated systems, the operating hours for night purge must be carefully selected to ensure the energy consumption of the fans used to provide night purge does not exceed the cooling energy saved.

Minimum required information

The minimum required information for a night purge program includes:

- space temperatures
- space temperature set points
- occupancy time 365-day schedule
- O/A temperature and humidity sensor (dew point or enthalpy sensing)
- night purge enabling time
- night purge enabling criteria.

Optionally, for natural-ventilation-based night purge systems, temperatures of the building materials can also be monitored if they are part of a control loop.

Minimum required equipment

The minimum required equipment for a night purge program includes:

- field temperature and humidity sensors
- controllers
- night purge software
- automated operation of outdoor, return and relief air provision.

Recommendation

When considering a night purge program, several factors should be checked. These include local weather data, potential energy consumption of the ventilation fans, the thermal characteristics of the building and any optimum start features already enabled.

Current practice

Many HVAC systems are controlled by a BMS with the existing night purge function either disabled or running longer than it should due to an inefficient control strategy or control parameters. There is also often conflict between night purge and the subsequent operation of central heating systems or re-heat, which leads to energy wastage.

Did you know?

If central heating is not disabled for a set period after night purge has occurred, it is possible that the benefits of night purge will be negated by the heating system.

Inadequate maintenance practices such as infrequent calibration of sensors and ad hoc changes made to control set points in response to complaints, can exacerbate the problem.

Opportunity for optimisation

Using mechanical ventilation to attempt to cool the building core is generally not an energy-efficient practice; however, replacing the hot indoor air of the building with cool O/A can reduce HVAC start-up energy use at certain times of the year.

For natural ventilation night purge applications, which use no fan power to provide the cool O/A, longer operation times and reduction of building core temperature may be cost-effective.

Options for the control strategy and control parameters include:

- For naturally ventilated buildings: activation of night purge (within a given enabling time) when the ambient temperature is at least 2°C below the cooling temperature set point of the conditioned space and the conditioned space is at least 1.5°C above the cooling temperature set point.
- For mechanically ventilated buildings: activation of night purge (within a given enabling time) when the ambient temperature is at least 5°C below the cooling temperature set point of the conditioned space and the conditioned space is at least 1.5°C above the cooling temperature set point. It is also important for the ambient humidity to be low, typically below 12°C dew point or the ambient enthalpy is 10 kJ/kg below indoor enthalpy levels.

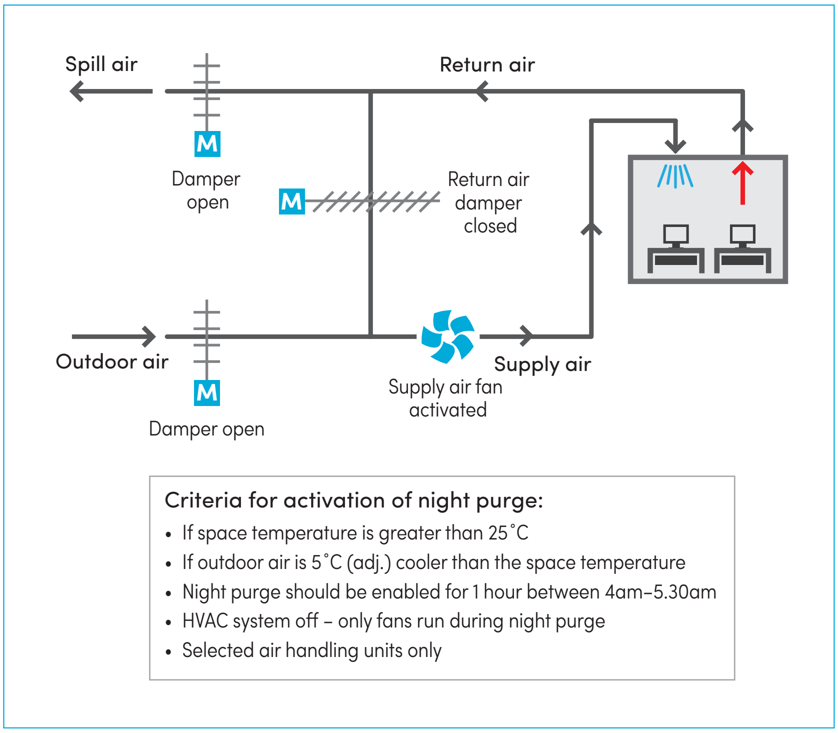


Figure 13: Activated night purge

Figure 13 shows an activated night purge function, recommended control strategies and control parameters. Hot air accumulated in the building during warm summer nights when the HVAC system is off (and space temperature is over 25°C) can be purged by cooler early morning air (around 20°C or lower).

Using natural ventilation for the night purge program

In the case of natural ventilation, the control parameters can be more flexible, including longer operating hours and smaller temperature difference between the outdoor and the indoor air temperature, as in this case, the energy consumption of night purge (fans) is zero.

When night purge is achieved without fans, full overnight operation could be considered, as it may help to reduce the building core temperature. Natural ventilation systems also need to consider weather and security issues. The installation of rain and wind sensors is recommended to override the system during inclement weather.

Using mechanical ventilation for the night purge program

The control strategy and parameters for the night purge program should be carefully selected, taking into account the thermal mass of the building fabric, the AC ventilation arrangements and zoning. Night purge should also be integrated with any OSS programming (refer to Optimisation Opportunity 1).

In the case of mechanical ventilation, to optimise an existing night purge program, the following should be taken into account:

- Any heating functions should be disabled during night purge and for a set period (at least one hour) after night purge has ceased.
- Enabling time for night purge (the time when the system can operate) should not be excessive, typically no more than one hour before occupancy.
- Night purge is only enabled when the O/A dew point is below 12°C or the outdoor enthalpy is below 50 kJ/kg.
- Running time should be limited to no more than 30–60 minutes.

- Only selected AHUs should operate in the night purge mode (typically centre zones, or other zones which have exceeded the night purge activation temperature) and possibly at lower speed (if fans are multi-speed or controlled by VSD controllers).

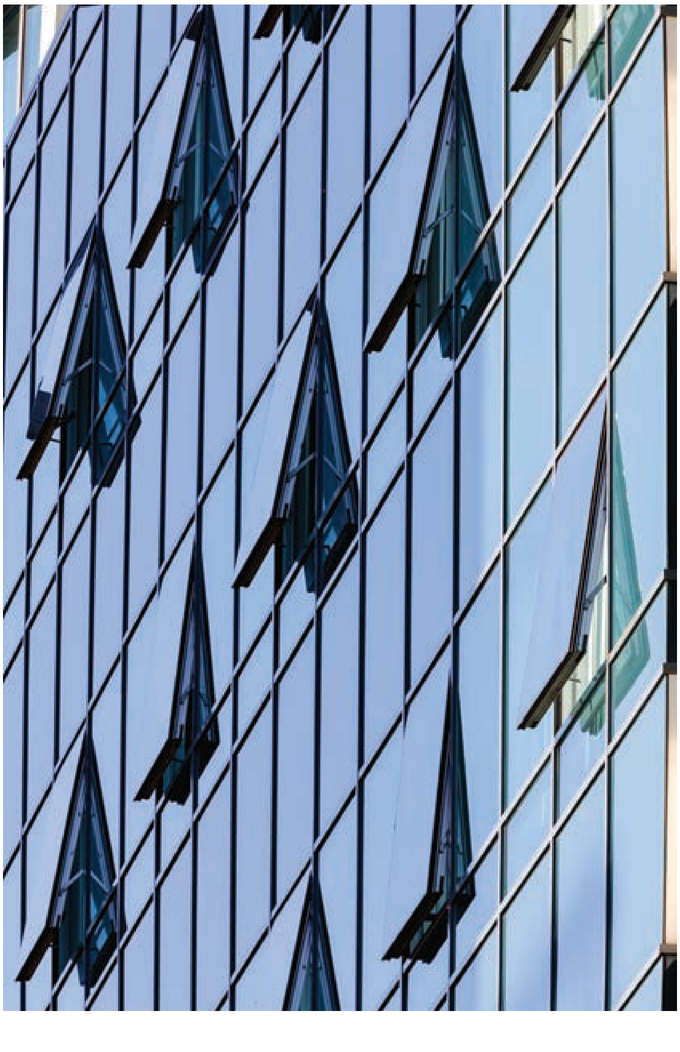
Increasing the temperature difference should be considered between the outdoor and indoor air temperature for the activation of night purge (4–5°C) in order to maximise its efficiency.

Regular review of the performance of night purge (length of operation, time of activation, number of AHUs and energy consumed for the given O/A temperature overnight) should be carried out and adjustments made as required.

Energy-saving potential, costs, benefits and risks

The reintroduction and optimisation of night purge via the BMS is typically a cost-effective HVAC energy-efficiency improvement. Where an economy cycle already exists, a new night purge strategy requires minimal investment (i.e. control software only, as other infrastructure and motorised dampers for R/A and relief air are already available from the economy cycle function). Night purge immediately reduces the energy consumption of the HVAC system by reducing the start-up load of HVAC plant. As such, this strategy can save up to 20 per cent of energy consumed by AC compressors during start-up time. Additional benefits include a morning flush of clean O/A to freshen the building and improve IAQ.

Where a well-optimised economy cycle is in operation, with O/A used as the first stage of cooling, the benefits of night purge are potentially small, except in naturally ventilated buildings.



Night purge aims to reduce the use of mechanical cooling in buildings by flushing the building with cool outdoor air using natural ventilation at night

The benefit of night purge varies based on climate. If not managed well, it can fill the building with moisture-laden air that requires more energy to condition when the system starts. The major risks associated with night purge include:

- air brought in is too hot or too humid to provide cooling
- energy used in ventilation fans exceeds energy saved by reduced morning cooling load
- security or weather impacts for natural ventilation systems.

These risks are mitigated by ensuring that the control parameters are regularly monitored and validated.

Application notes

Night purge typically applies to centralised HVAC systems with AHUs that have motorised O/A dampers connected to a central BMS or local HVAC DDC system. AHUs facilitate this energy conservation strategy as they are a source of mechanical ventilation for buildings.

Mechanical ventilation should only operate in the one-hour period immediately before normal plant operation. The intention is to flush the air, not reduce building core temperature; this usually occurs after three to five air changes have been completed. Care is required to not overcool the space.

Night purge after a long break or shut down should be considered differently, with longer cool-down periods allowed, ideally at low fan speeds, to enable the gradual cooling down of a building's thermal mass.

Getting started

The control strategy and parameters for the night purge program should be carefully selected, taking into account natural or mechanical ventilation opportunities. Facility managers/building owners will need to consider the following for implementation:

- whether there are opportunities for natural ventilation (consider security and weather issues)
- space temperatures and set points of the facility
- occupancy schedule of the facility
- O/A temperature and humidity sensor (dew point or enthalpy sensing)
- running time should be limited to no more than 30–60 minutes.
- only selected AHUs should operate in the night purge mode and at lower speed.
- any heating functions should be disabled during night purge.
- night purge is only enabled when the O/A dew point is below 12°C or the outdoor enthalpy is below 50 kJ/kg.

Opportunity 12 and 13 — Demand control ventilation (DCV)

Opportunity 12

DCV – based on controlling CO_2 for occupied spaces

UP TO 20% ENERGY REDUCTION ON OUTDOOR AIR PRE-HEATING & COOLING

Opportunity 13

DCV – based on controlling CO for carparks and loading docks

UP TO 80% ENERGY REDUCTION ON CARPARK VENTILATION FANS

Strategy summary

The objective of demand control ventilation (DCV) is to control ventilation systems to minimise the outdoor air (O/A) ventilation rates used to maintain an acceptable degree of indoor air quality (IAQ) at times when the O/A condition is not suitable for economy-cycle operation. For carparks and loading docks, ventilation rates can be reduced irrespective of ambient conditions, in order to reduce the energy consumption of fans.

The rate of ventilation is automatically adjusted in response to occupancy or usage levels to achieve IAQ set points. Automatic detection and measurement of air contaminants (typically CO and CO_2), is used as an indicator for usage rates.

The goal is to bring in only the required amount of O/A based on best engineering design practice and in accordance with the National Construction Code (NCC) and associated standards. DCV has two broad applications in buildings:

- occupied spaces with variable occupancy rates
- mechanically ventilated carparks.

Occupied space applications

DCV is particularly suited to spaces with variable occupancy, such as meeting rooms, foyers, food courts, cinemas and shopping malls where the amount of O/A introduced by the system can be adjusted through controls that monitor CO_2 levels, to suit the actual level of ventilation required by the space.

Carpark applications

DCV is also beneficial for carparks and loading docks and any areas which accommodate vehicles with internal combustion engines. In this application, the O/A ventilation rates are adjusted in response to monitored CO levels to offset the actual level of car exhaust pollutants in the air.

The NCC requires automatic control of carpark mechanical ventilation systems which serve more than 40 car parking spaces.

Note: **It is important not to confuse CO_2 (carbon dioxide) with CO (carbon monoxide). CO_2, while being an asphyxiant and harmful to health in high concentrations is nowhere near as dangerous as CO which can be fatal even in very small concentrations.**

Principle and equipment

DCV is an optimisation strategy whereby the level of ventilation is determined by the actual ventilation needs of the space measured in real-time. The dominant air contaminant is identified and measured in real-time with ventilation rates increased or reduced depending on the measured level of the contaminant. System set points and control parameters are configured to ensure that the concentration of contaminants is maintained within acceptable limits at all times.

Ventilation design parameters for mechanical ventilation are determined based on design conditions for maximum occupancy and maximum indoor pollutant generation rates. The design accounts for the highest usage that can be expected, in terms of both occupancy and the level of pollutants generated within a ventilated space.

For spaces with variable occupancy, ventilation systems sized using the above criteria nearly always provide a higher amount of outdoor ventilation air than is needed. This means that the minimum ventilation requirements for such spaces can be satisfied, for most of the time, with reduced O/A quantities than those required for the design conditions. Reducing O/A flows during HVAC system operation reduces heating and cooling loads and can also reduce fan energy consumption.

For carparks, usage patterns often vary throughout the operating period. Car densities are often lower than the design assumptions, meaning the space will be over-ventilated at all times the carpark is not full. Reducing O/A flows during system operation reduces ventilation fan energy consumption.

Demand control ventilation provides for minimised energy consumption of HVAC systems when the spaces served have less than their full design occupancy or usage level.

Occupied space applications

Typically, CO_2 sensors are installed to control the amount of O/A supplied by AHUs for spaces that have variable occupancy. The CO_2 level is used as an indicator of occupancy (IAQ) and, where CO_2 levels are lower than the set point, the volume of introduced O/A is reduced. Energy saving is achieved through reduced amounts of O/A, leading to a reduced need for cooling and heating. Variable amounts of O/A are achieved by modulation of O/A volume control dampers (or O/A fan speeds) in response to signals from the CO_2 sensors within monitored spaces.

Carpark applications

CO sensors are installed to control carpark ventilation fan speed via VSD controllers in response to CO concentration levels in carparks. AS 1668.2 prescribes system set points, control bands and maximum areas covered by a single CO sensor. Reduced speeds of ventilation fans correspond to energy savings that follow affinity laws for fans (see Appendix D) where the electrical power consumed by a fan is proportional to the power of three of the volume flow rate. In effect, if the volume flow is reduced by 50 per cent, the power consumption is reduced by up to 87 per cent.

The CO master signal is always of a ‘high select’ type, ie it uses the highest CO signal for controlling the fan speed or cycle time.

Minimum required information

The minimum required information for DCV includes:

- CO or CO_2 set point sensors
- actual CO or CO_2 concentration level as indicated by one or more CO or CO_2 sensors
- control strategy of staging of ventilation equipment or modulation of O/A quantities in response to the level of pollutants in the air (refer to AS 1668.2)
- ventilation enabling time.

Minimum required equipment

The minimum required equipment for DCV includes:

- field sensors (CO and CO_2)
- controllers and data processors
- DCV software
- ventilation staging control infrastructure (VSD controllers, multi-speed fans or switching).

Current practice

Occupied space applications

Indications that ventilation systems serving spaces with variable occupancy office buildings, shopping centres and public buildings need better O/A ventilation management include:

- oversupply of ventilation air for most of the time
- not run in response to actual ventilation requirements – they run longer and harder than they should
- run for a shorter time than they should, via time switches, contravening ventilation standards such as AS 1668.2
- have existing DCV capability which has not been optimised (e.g. incorrect set points or out-dated control strategies).

Carpark applications

As many enclosed carparks with mechanical ventilations systems are over-ventilated during periods of low usage, employing DCV strategies has the potential to save considerable fan power energy.

Many carpark ventilation systems are either running at full speed or are turned off. The first approach imposes a significant energy cost and the second can compromise occupant health and safety. DCV offers an energy efficient and safe solution to O/A ventilation.

Opportunity for optimisation

The following introduction and/or optimisation of the DCV control strategy is recommended in order to minimise the energy consumption of ventilation systems during part-load conditions (low occupancy or low level of air pollutants).

Occupied space applications

AS 1668.2 does not mandate a CO_2 control set point, but does state that typical set points are between 600–800 parts per million (ppm). Another standard, ASHRAE 62.1, suggests 1000 ppm as an appropriate IAQ target. For energy efficiency, the set point should be around the 800–1000 ppm level, otherwise the installation of CO_2-controlled DCV could actually achieve a perverse outcome and increase the energy consumption when compared to a conventional system which has minimum O/A supplied without CO_2 control.

Typically, the CO_2 concentration has to exceed 1500–2000 ppm before the effects of inadequate ventilation are detected. CO_2 set points may be set higher (typically 800–1000 ppm) providing other factors are favourable and include the degree of air filtration, the type of air distribution, the absence of materials that emit volatile organic compounds and the type of activity performed in the space (sedentary or active, transient or continuous).

Figure 14 shows the benefits of DCV where the amount of O/A is adjusted appropriate to the actual number of people in the conditioned space, in real-time.

Demand control ventilation is likely to be most beneficial for controlling the ventilation of spaces with variable occupancy – meeting rooms, entertainment centres, cinemas, foyers, shopping malls, food courts etc. are ideal candidates. Modulating dampers or variable speed fans are used to adjust the rate of O/A ventilation in response to detected levels of CO_2 and controller set points.

Carpark applications

AS 1668.2 mandates maximum CO levels of 30 ppm for a staffed carpark and 60 ppm for an unstaffed carpark. The Standard also mandates a series of ventilation control requirements depending on detected CO levels and system flow rates. Set points are often adjusted lower than the minimum requirements of the Standard (e.g. to ~ 20 or 50 ppm CO as applicable) recognising the significant potential adverse health impacts of excessive CO exposure. Another reason to exceed the minimum requirements of the Standard is that the AS 1668.2 DCV method does not take into account other factors, including the fumes given off by increasingly popular diesel vehicles, where the emissions of nitrogen oxide (NOx) is a concern. Variable speed supply or return fans (or both) provide a variable ventilation rate in response to detected levels and controller set points.

Figure 15 shows DCV operation where the performance of fans is adjusted to suit the actual level of pollution in the carpark, as sensed by the CO sensors.

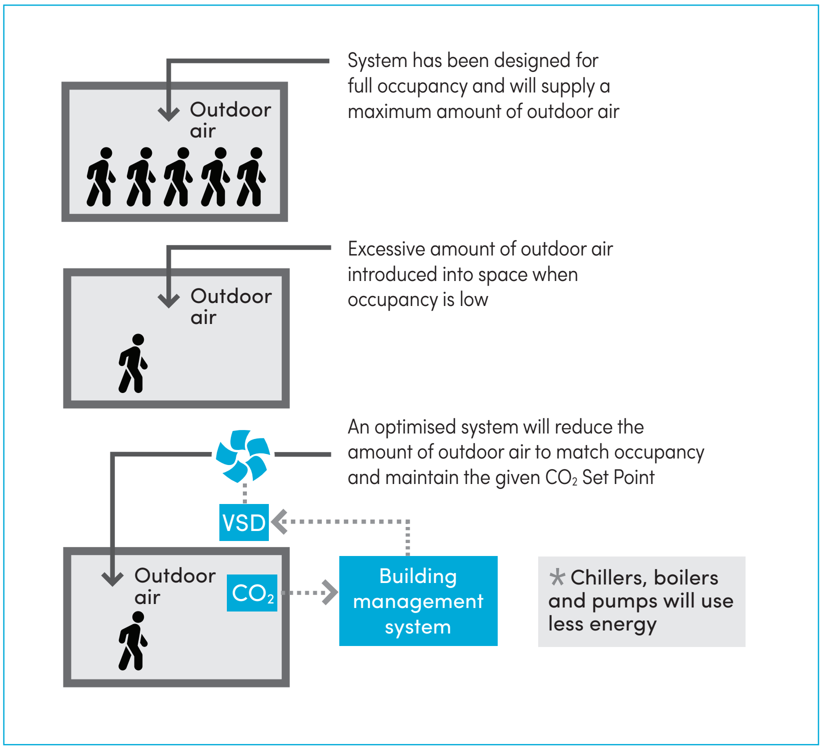


Figure 14: Demand control ventilation of spaces with variable occupancy

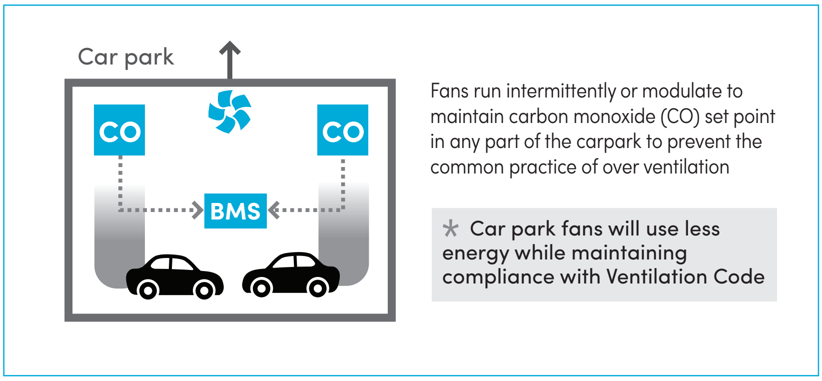


Figure 15: Demand control ventilation of a carpark

Energy-saving potential, costs, benefits and risks

DCV is typically a cost-effective HVAC energy-efficiency improvement over the longer term. It can be expensive to implement and often requires capital investment in controls, dampers and drives. DCV reduces the energy consumption of the ventilation fans by reducing their speed. DCV that minimise O/A flows in air conditioned environments considerably reduces heating and cooling loads on the system.

The application of DCV strategies can save:

- up to 20 per cent of the space cooling and heating energy, the energy used to condition O/A
- up to 80 per cent of energy consumed by carpark ventilation fans.

It should be ensured that turning down O/A quantities does not cause excessive infiltration.

Benefits arising from DCV include:

- reduced energy consumption and cost
- reduced greenhouse gas emissions
- reduced maintenance costs
- better knowledge regarding building IAQ
- reduced noise, typically overnight when occupancy is low.

Energy saving in a carpark can be achieved with demand control ventilation

The risks include:

- faulty sensors resulting in unsatisfactory IAQ. This risk is mitigated by implementing regular maintenance inspections. High-quality sensors should be used with self-calibrating features when available
- other contaminants may be present which are not detected by the system, e.g. nitrogen oxide (NOx) in carparks. This risk is mitigated by ensuring the system is responding to the dominant contaminant of concern
- other (non-occupancy related) CO_2 (or CO) absorbers or generators may affect the system potentially compromising energy or IAQ
- uncontrolled infiltration if O/A rates are lowered below exhaust air rates (e.g. in retail).

The potential for a severe energy penalty caused by a failed sensor is significant and this risk can be mitigated by sub metering and monitoring.

Application notes

Faulty sensors are notorious for taking control of the DCV system, often resulting in excessive energy use. Alarm features should be provided to alert operators in the event of fan failure, high limit and high deviation between sensors. The fan speed should default to full speed in the event of a sensor failure or if the VSD control fails.

Control strategies should use proportional (P) only control, to achieve maximum energy savings with stable operation.

Occupied space applications

DCV, using CO_2 as an occupancy indicator, can be employed in spaces with variable occupancy, including shopping malls, meeting rooms, lecture theatres, cinemas, theatres, sporting halls, entertainment centres, foyers and similar spaces.

Ventilation systems should not be turned off by DCV control systems as they are only detecting one potential air contaminant in the building, albeit the dominant one. The intention is to minimise ventilation rates but still provide a minimum background ventilation level to cater for other contaminants.

Typical levels of CO_2 in the air and potential effects on IAQ:

- **250–400 ppm – background (normal) O/A level**
- **350–1000 ppm – typical level found in occupied spaces with good air exchange**
- **1000–2000 ppm – acceptable for short-term exposure**
- **2000 ppm – IAQ issues including odour and unpleasant atmosphere for continuous occupancy.**

AS 1668.2 suggests that typical CO_2 set points are between 600–800 ppm; however, it recommends that factors including ambient CO_2 levels and the enclosure characteristics be considered.

Getting started

Facility managers/building operators will need to establish CO or CO_2 sensor set points and establish the actual concentration levels in the facility in order to implement DCV opportunities.

Optimisation scenario

A three-level underground carpark is ventilated by six exhaust and S/A ventilation fans with a total power of 60 kW. They run 24/7 as the carpark is available for public use at all times.

Annual electricity consumption is: 60 x 24 x 365 = 60 x 8760 = 525,600 kWh

At an average cost of electricity of $0.15/kWh the annual cost of ventilation is: $78,840 pa

This electricity consumption causes CO_2 emissions of: 1.06 x 525600/1000 = 557 t CO_2

After installation of carbon monoxide (CO) sensors and variable speed drive (VSD) controllers on the fans, the system energy consumption was reduced by 315,360 kWh in the first year, representing a 60 per cent saving.

Overall savings	
Electricity consumption	315,360 kWh pa
Cost savings	$47,304 pa
GHG emission reductions	334 tonnes CO_2 pa
Cost of installation of the new control system (CO sensors, wiring, control software, VSD controllers and maintenance)	$85,000
Simple payback period	1.8 years
Additional benefits	Less noise issues, less wear and tear and reduced maintenance costs

Variable speed based optimisations

This section discusses a series of optimisation opportunities based on the modification of plant and systems to use a variable speed control. A common way of changing a system to variable speed is the installation of variable speed drives to the fan, pump or compressor motors.

This section identifies three optimisation opportunities:

- **Opportunity 14** – Optimised secondary chilled water pumping
- **Opportunity 15** – Variable head pressure control (air-cooled)
- **Opportunity 16** – Variable head pressure control (water-cooled).

This section also discusses other potential variable speed applications for energy-saving potential within HVAC.

Opportunity 14 — Optimised secondary chilled water pumping (differential pressure reset)

UP TO 30% ENERGY REDUCTION ON SECONDARY CHILLED WATER PUMPS

Strategy summary

This strategy minimises the pumping energy required to distribute chilled water (CHW) by optimising the CHW distribution system using system differential pressure reset control. This strategy is applicable to secondary chilled water (SCHW) systems that have 2-port modulating valves and hence a variable flow.

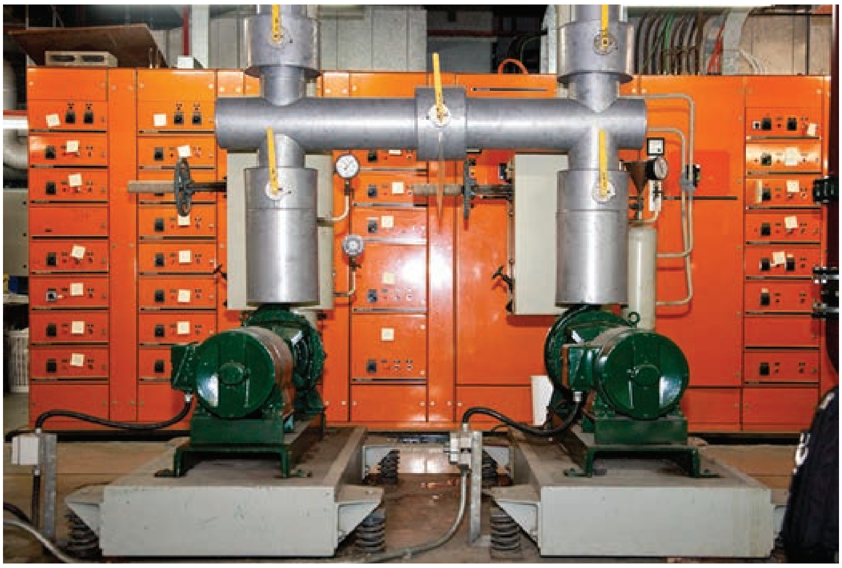
For systems that have 3-port modulating valves (constant flow), it is essential to convert the system to 2-port, either by modifying the existing valves through shutting down the bypass port (if this is acceptable for the type of valve) or replacing with 2-port valves.

The secondary chilled water pumping system distributes CHW from the CHW plant room to CHW users such as air handling units (AHUs) and fan coil units (FCUs). The SCHW distribution system does not pump CHW through chillers as this function is carried out by the primary CHW pumps. While this strategy mainly refers to the optimisation of existing SCHW pumping systems, the control logic would also be applicable to new SCHW systems.

Variable secondary chilled water pumping, using system differential pressure reset, allows for the minimisation of energy consumption required for pumping of chilled water to plant that uses chilled water, such as air handling units and fan coil units.

Principle and equipment

Space cooling for many buildings is achieved through the circulation of CHW through AHUs, which cools a mixture of return air (R/A) and outdoor air (O/A) when the air flows over CHW coils. The air mixture then becomes cooled supply air (S/A) that is ducted to conditioned spaces at a required rate to offset the external and internal heat load. The CHW generated by chillers in the plant room is circulated to remote CHW users (AHUs and FCUs) using CHW pumps that distribute CHW through pipework and control valves.



Secondary chilled water pumps

Primary chilled water pumping

When CHW is circulated to the CHW users by the same pumps that pump CHW through the chillers, this CHW distribution system is known as a primary-only CHW pumping system. Under part-load, less CHW is required by users; however, variable speed drive (VSD) control of primary CHW pumping is limited in its ability to reduce CHW flow, as the chillers require minimum CHW flow rates to operate satisfactorily, as specified by the manufacturer.

Note: primary CHW pumping can sometimes be variable and can be turned down to quite a low level, depending on the minimum chiller flow requirement.

Primary/secondary chilled water pumping

When CHW is distributed to CHW users via a separate CHW pump, in addition to the pump that pumps CHW through the chiller, this CHW distribution system is known as a primary/secondary CHW pumping system.

The concept of a variable SCHW flow is based on the fact that during part-load conditions or mild weather, the amount of CHW required for cooling is less than that required during summer peaks. The variable CHW flow reduces the amount of energy required for pumping.

In a primary/secondary CHW distribution system, the primary CHW loop is limited to the HVAC chiller plant room, recirculating CHW through the chillers using primary CHW pumps. These pumps are typically smaller as they only have to overcome the CHW pressure drop through chillers and the relatively small CHW pipework/loop.

SCHW pumping distributes CHW from the HVAC chiller plant room to CHW users, typically via long multi-branch SCHW pipework systems. SCHW pumps are usually much larger than primary CHW pumps.

A significant advantage of SCHW pumping is that there is no limit in its capacity to reduce CHW flow during part-load conditions, apart from satisfying the cooling needs of conditioned spaces. As such, significant energy savings are possible, especially in large buildings/systems. For this reason, primary/secondary variable CHW pumping can save much more CHW pumping energy than primary variable CHW pumping. An additional advantage is that SCHW pumps, which are typically centrifugal pumps, save more energy when flow rates are reduced.

Minimum required information

The minimum information required for optimising SCHW pumping using system differential pressure reset includes:

- cooling call signal to enable the SCHW pumps
- CHW pressure differential of index run – the run with the highest pressure drop
- position of CHW valves shown in order (via percentile function of BMS)
- software for automated adjustment of speed and number of CHW pumps, at regular time intervals.

Minimum required equipment

The minimum equipment required for optimising SCHW pumping using system differential pressure reset includes:

- field sensors (CHW pressure differential across an index CHW user)
- DDC controllers

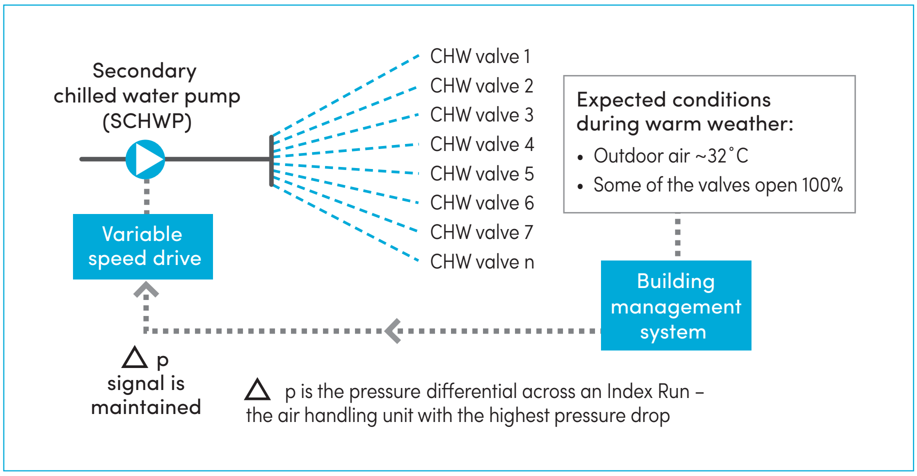


Figure 16: Minimised pumping energy at secondary chilled water loop – operation of HVAC system under full-load (typical summer peak) conditions

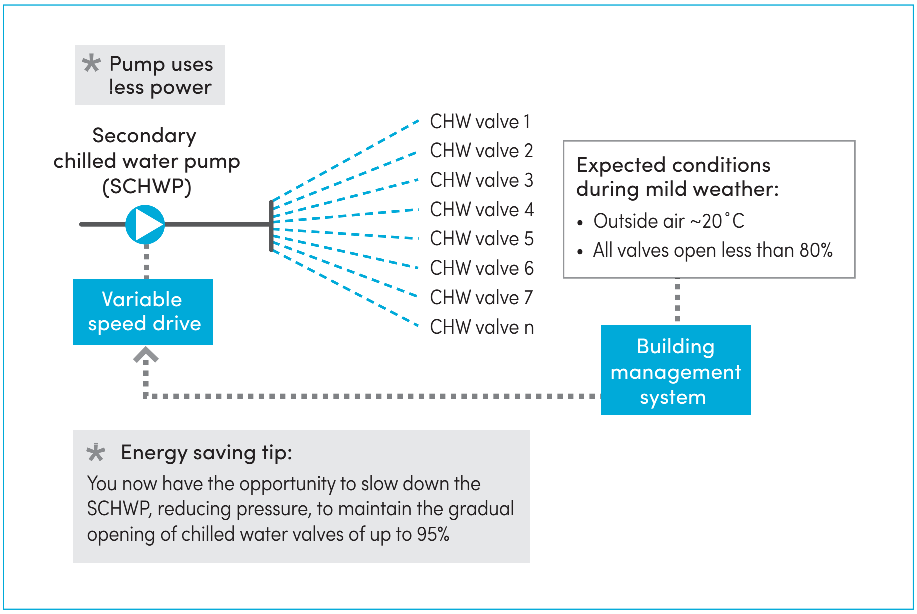


Figure 17: Minimised pumping energy at SCHW loop - Operation of HVAC system under part-load conditions

- SCHW control software
- SCHW pumps
- VSDs for pumps.

Current practice

Currently, most CHW-based HVAC systems distribute CHW by:

- using a primary-only CHW distribution system with constant flow. In this case, to achieve the full benefits through system differential pressure reset, the system has to be modified for primary/ secondary with variable secondary flow achieved through the modification of the 3-port control valves by shutting the bypass port (if the valve is suitable for this) or the replacement of the 3-port control valves with 2-port valves and the installation of a VSD
- using a primary-only CHW distribution system with limited variable secondary flow, which uses an arrangement of a bypass valve in combination with a VSD. There is limited scope for optimisation of this system
- using a primary/secondary CHW distribution system in which the SCHW pump is controlled by a set CHW pressure differential signal. The optimisation of this type of system is covered later in this section.

Opportunity for optimisation

The typical strategy used for the control of CHW secondary pumps in variable flow distribution circuits is to set the pump to maintain a constant pressure set point, which is typically selected for the peak design CHW flow. This results in the pump maintaining too high a static pressure most of the time and as such, energy is wasted.

For such systems, the following optimisation strategy for the SCHW pumping system is recommended in order to minimise the energy consumption during part-load conditions:

- When all CHW valves are less than 95 per cent open, SCHW pumps provide higher than needed CHW pressure. In such situations, the speed of the SCHW pump can be reduced on an incremental basis (CHW pressure set point reset) to maintain an opening of 95 per cent of the most open CHW valve. CHW is thereby delivered at the lowest possible pressure while still satisfying the CHW needs of all CHW users.

Figures 16 and 17 show that there is an opportunity to achieve further savings with SCHW pumps during mild weather conditions when the pump can slow its speed to allow for more frequent opening of semi-closed CHW valves.

Tip: Check CHW balancing/operation for the valves that are 100 per cent open more often than the other CHW valves.

Energy-saving potential, costs, benefits and risks

Optimised SCHW pumping is typically a cost-effective HVAC energy-efficiency improvement as it requires minimal investment and immediately reduces the energy consumption of the HVAC system by reducing its load. Costs significantly increase if 2-port valves need to be retrofitted. This strategy can save up to up to 30 per cent of energy consumed by SCHW pumps.

Benefits arising from SCHW pumping include:

- reduced energy cost of CHW pumping
- reduced GHG emissions
- reduced HVAC maintenance costs.

Application notes

Optimised SCHW pumping applies to SCHW pumps in centralised CHW HVAC systems, which include remote AHUs and/or FCUs.

Getting started

Implementation for the SCHW strategy will involve setting up compatible software to automate the adjustment of speeds of the CHW pumps at regular intervals. The type of CHW valves and their pressure characteristics will also need to be investigated to determine compatibility with this control strategy.

Opportunity 15 — Variable head pressure control (air-cooled condensers)

UP TO 30% ENERGY REDUCTION ON CONDENSER FANS

Strategy summary

Condenser fans use a lot of energy in an air conditioned system. Using variable speed drives (VSDs) on condenser fans to control the head pressure of air-cooled condensers and other HVAC applications improves the energy efficiency of air conditioning systems in part-load conditions.

Appropriate head pressure or condensing pressure is of vital importance for the proper operation of AC and refrigeration systems and can be maintained in several ways. The most energy efficient is via VSD controllers on the condenser fan (either with a constant or floating head pressure set point), which varies the amount of heat rejection.

This measure will deliver more savings when carried out in conjunction with the strategy of retrofitting electronic expansion valves (EEVs) as described in Optimisation Opportunity 9.

It is important to seek the advice of the manufacturer of the refrigeration system before embarking on this optimisation measure as failure to consult the manufacturer may void any warranty.

Retrofitting VSDs can result in reduced energy consumption of condenser fans by 10–30 per cent and improved control and reliability of the operation of air conditioning systems during part-load conditions.

Principle and equipment

During lower ambient air temperatures, the AC load typically decreases, while the capacity of condensers increases. As such, there is the possibility of saving energy by reducing the condensing pressure of the refrigeration cycle. This pressure can be maintained by VSD-controlled fans, which would save energy, compared to a scenario whereby the fan is simply cycled on and off. A recent alternative to VSD-controlled fans is the availability of fans with electronically commutated (EC) motors.

Air cooled condensers on the roof of a commercial building

During mild weather conditions, the cooler air can extract more heat from the condenser, thereby over-cooling or over-condensing an AC system. Over-condensing reduces the condensing temperature and condensing pressure, to an extent where it affects the performance of the system, especially if thermostatic expansion valves (TXVs) are installed.

AC systems should maintain adequate condensing (or head) pressure in order to enable the proper operation of the TXV. Appropriate head pressure is particularly important for:

- the prevention of premature flashing of refrigerant in the refrigerant liquid line (reduced refrigeration capacity)
- the proper operation of expansion devices (reduced refrigerant flow into evaporators)
- satisfactory oil return to the compressor.

Minimum required information

The minimum required information for maintaining head pressure includes:

- head pressure set point
- control strategy for modulation of the amount of heat rejection
- outside temperature (desirable)
- type of refrigerant.

Minimum required equipment

The minimum required equipment includes:

- field sensors (temperature, pressure)
- controllers and data processors
- condenser fans with VSD-controlled motors or EC motors.

Current practice

Most air-cooled condensers employ one of the following commonly encountered control strategies to maintain head pressure:

- single condenser fan switching on/off
- multi-speed or multiple condenser fan(s) staging and switching on/off.

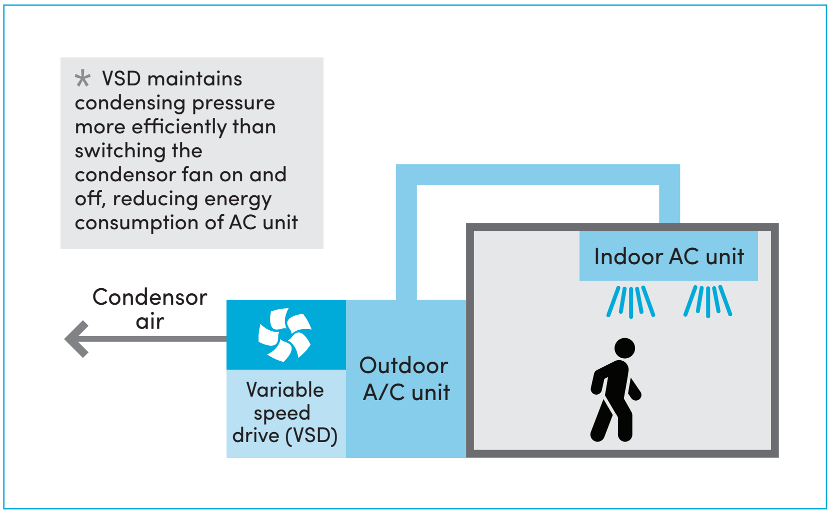


Figure 18: Condensing pressure of a split air conditioning unit maintained by a variable speed drive controller

Opportunity for optimisation

The following control strategy and control parameters are recommended in order to maximise the energy efficiency of refrigeration systems while not compromising their performance:

- Determine the optimal head pressure or calculate for a floating head pressure. Typically, air-cooled condensing units have the condensing temperature 8–12°C above the ambient dry bulb temperature.
- Maintain the optimal head pressure using VSD-controlled motors (or EC motors) on condenser fans to control the amount of heat rejection by controlling the speed of the fans.

Figure 18 outlines the maintenance of optimal condensing pressure via a VSD controller, which minimises energy consumption of an AC unit.

Energy-saving potential, costs, benefits and risks

Variable head pressure control is typically a cost-effective HVAC energy-efficiency improvement. It does require some investment in new drives and/or motors; however, it can immediately reduce the energy consumption of the system by reducing the fan power.

This strategy can save up to 30 per cent of energy consumed by condenser fans.

Benefits arising from controlling the head pressure of air-cooled condensers include:

- reduced energy costs
- reduced GHG emissions
- quiet operation, especially during night time when ambient temperature and heat rejection is low
- improved reliability of refrigeration systems
- reduced maintenance costs.

Problems that can be caused by inappropriate head pressure include:

- reduced capacity of AC system
- automated switching off of AC compressors for safety reasons
- insufficient lubricating oil transfer to AC compressors through the AC system
- damage to AC compressors.

Application notes

Maintenance of head pressure using condenser fan speed control can be successfully applied to any air-cooled AC system that operates on the vapour compression refrigeration cycle principle.

Getting started

Variable head pressure control strategy optimisation for air-cooled condensers can be implemented by establishing the head pressure set point for the equipment and refrigerant used, selecting and applying a fan control strategy for modulation of the amount of heat rejection, and determining and monitoring the head pressure and outdoor air temperature.

Opportunity 16 — Variable head pressure control (water-cooled condensers)

UP TO 30% ENERGY REDUCTION ON CHILLED WATER PUMPS

Strategy summary

Controlling the head pressure of water-cooled condensers improves the energy efficiency of air conditioning systems in part-load conditions. This optimisation strategy involves applying variable speed drive (VSD) controllers to pumps for head pressure control of single water-cooled direct expansion (DX) units. It also involves applying condenser water (CW) modulating head pressure valves for head pressure control of multiple water-cooled, AC DX units supplied by CW from one CW pump.

Implementation of this optimisation strategy could result in reduced energy consumption of CW pumps by 10–30 per cent and improved control and reliability of the operation of AC systems during part-load conditions.

Principle and equipment

During lower ambient air temperatures, the AC load typically decreases while the capacity of condensers increases. Energy savings are therefore possible by reducing the condensing pressure of the refrigeration cycle. This reduced pressure can then be maintained by VSD-controlled pumps, which would save additional energy compared to a control scenario where the pump is running at fixed speed.

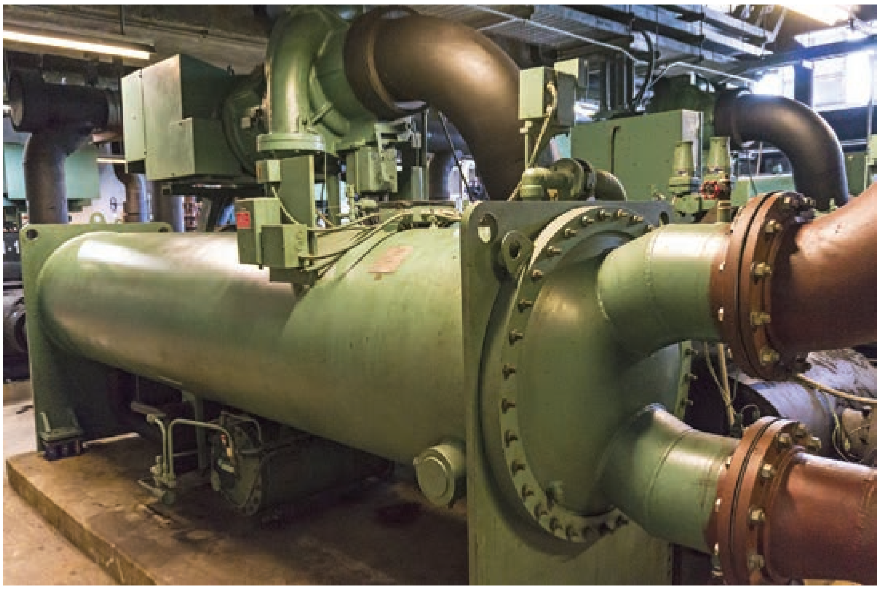
Appropriate head pressure or condensing pressure is important for the proper operation of AC and refrigeration systems with head pressure maintained in several ways. The most energy efficient way of maintaining condensing pressure (constant or, even better, floating set point) of water-cooled condensers is to adjust the amount of heat rejection in condensers:

- by VSD controllers for single AC units
- via CW-modulating head pressure valves (for multiple AC units, that are supplied CW from one CW pump).

For multiple AC units that are supplied CW from a pump controlled by a VSD (such as supplementary tenant AC systems), it is also important to automatically shut off the water supply to the condenser when the AC unit is not operating. This will significantly reduce the energy consumption of the CW pump.

Caution:

AC systems should maintain adequate condensing (or head) pressure in order to enable the proper operation of the vapour compression refrigeration cycle. Supplying more CW than required will extract more heat from the condenser, thereby causing over-cooling or over-condensing of an AC system. Over-condensing reduces the condensing temperature and condensing pressure, compromising the performance of the vapour-compression refrigeration cycle of the system.



Water cooled condenser/chiller

Minimum required information

The minimum required information for maintaining head pressure includes:

- head pressure set point
- control strategy for modulation of the amount of heat rejection
- type of refrigerant.

Minimum required equipment

The minimum required equipment includes:

- field sensors (temperature, pressure)
- controllers and data processors
- CW pump
- if the CW pump supplies CW to multiple DX AC units, a head pressure control is required
- VSD controllers.

Current practice

Most water-cooled condensers employ one of the following common control strategies to maintain head pressure:

- constant CW flow as per manufacturer's requirement
- constant CW flow as per HVAC system designer's requirements.

Both control strategies ensure sufficient heat rejection during the hottest O/A conditions; however, they potentially compromise part-load performance of associated AC DX units due to the risk from over-condensing. The additional CW flow also results in wasted energy at the CW pump.

In many buildings, CW continues to circulate through the AC units even when they are not in operation, thereby wasting energy at the CW pump.

Opportunity for optimisation

The following control strategy and parameters are recommended in order to maximise the energy efficiency of refrigeration systems while not compromising their performance:

- Determine optimal head pressure or calculations for a floating head pressure.
- Maintain optimal head pressure:
  1. **for single AC units:** using VSD controllers to control the amount of heat rejection by controlling the speed of condenser pump
  2. **for multiple AC units fed by a single CW pump:** using CW modulating head pressure valves to control the amount of heat rejection by controlling the amount of CW entering the condenser.
- When AC units are not in operation, ensure that CW to these units is isolated through a 2-port valve.

Energy-saving potential, costs, benefits and risks

Variable head pressure control is typically a cost-effective HVAC energy-efficiency improvement. It does require some investment in new drives, valves and controls; however, it can immediately reduce the energy consumption of the HVAC system by reducing system pump power.

This strategy can save up to 30 per cent of energy consumed by CW pumps.

Benefits arising from controlling the amount of heat rejection for water-cooled condensers include:

- more reliable operation of refrigeration systems
- reduced energy costs
- reduced GHG emissions
- reduced pump maintenance costs.

Potential risks include:

- inadequate set-up of the head pressure control valves with units either over-condensing (unsatisfactory performance and energy wastage at CW pump) or under-condensing (unsatisfactory performance, energy wastage at AC unit and risk of units tripping on protection devices)
- in open circuit systems, if the CW flow is shut down when the AC unit is not in operation, this creates a dead le.g. with the associated risks of corrosion and microbial growth
- supplementary AC units are typically owned and installed by tenants. Failure to seek their cooperation before carrying out modifications (such as shutting down CW flow when AC units are not in operation) and failure to execute this measure satisfactorily can damage relationships.

Application notes

Maintenance of head pressure using VSD controllers to control the speed of the CW pump is applicable for any single water-cooled AC system that operates on a vapour compression refrigeration cycle principle.

Maintenance of head pressure using CW head pressure valves to control CW flow of multiple AC units fed from one CW pump is applicable for water-cooled AC systems, which operate on a vapour compression refrigeration cycle principle.

The installation of 2-port valves to shut off CW supply to AC units when not in operation is best carried out during manufacturing when the unit is specified. When retrofitting, it is essential that the manufacturer's advice is sought to prevent nuisance tripping of the units or affecting the warranty of the units.

Getting started

Variable head pressure control strategy optimisation for water-cooled condensers is implemented through similar strategies to those of air-cooled condensers.

Other variable speed applications for HVAC

Strategy summary

Apart from the uses of VSDs for motors discussed so far, there are many other HVAC applications in which VSDs are employed. Some of these are applied to achieve energy savings, while the main role of other applications could be to serve as soft-starters i.e. as electrical devices to optimise the starting current of motors. As these applications are not essential for major energy savings in HVAC systems, but are still important, their basic characteristics are briefly explained below.

Appendix D outlines the relationship between flow rate, pressure and the energy consumed by a fan or pump. These affinity laws can be used to estimate energy savings.

Principle and equipment

When retrofitting VSDs, motors should always be checked for their ability to run at reduced speeds. Older motors, typically more than 20 years old, may also have insulation that is brittle and the installation of VSDs could lead to premature failure. However, in most cases, the cost of a new motor will be small in comparison to the potential energy savings and other benefits.

Throttled (choked) distribution system

The photo (previous page) shows two partially throttled valves that are being used to regulate the water flow through a CW system. The same water flow can be maintained by opening the valves and reducing the speed of the pump by using a VSD. This optimisation strategy will save system energy as reducing pump speeds reduces pump power consumption (see Section 7 on optimising distribution systems).

Opportunity for optimisation

Supply air fans (constant air volume applications) in air handling units

During mild weather conditions, the amount of S/A can often be reduced without compromising comfort while saving up to 50 per cent of fan energy.

Typical settings would be:

- speed changes between 70–100 per cent corresponding to O/A temperatures from 23–27°C (adjustable)
- the VSD controllers would run the S/A fan at 100 per cent speed if the O/A is higher than 27°C
- the VSD controllers would run the S/A fan at 70 per cent if the O/A is below 23°C
- if the O/A temperature is between 23–27°C, the speed would be adjusted based on a linear function between the O/A temperature and the speed of the S/A fan
- an override function would be available to increase the speed of the fan if space temperature increases at lower O/A temperatures.

Alternatively, the indoor temperature can be used to control the fan speed.

Minimum O/A flows for ventilation should be sufficient at all times, in line with AS 1668.2 requirements.

A minimum fan speed/air flow is required to maintain the air diffusion from the S/A registers; motors should be checked for allowable speed turndown.

Primary chilled water pumps

The amount of CHW pumped to the field and the energy consumed by CHW pumps can be reduced in response to the reduced cooling load during part-load conditions of HVAC systems.

This potential energy saving is limited by the minimum CHW flow required for associated chillers. Primary CHW flow controlled with a VSD varies between a minimum and maximum flow rate and is based on the type of chiller. Minimal value is typically set as 10–15 kilopascals (kPa) above CHW pressure differential settings for a chiller's flow switch, to ensure proper operation of the chiller during low CHW flow conditions.

With the introduction of a secondary CHW loop, this potential greatly increases, as explained in Optimisation Opportunity 14.

Outdoor air fans (risers)

In many buildings, O/A is provided to AHUs and spaces via masonry or ducted shafts and risers. Typically, the O/A fan is controlled by the VSD controller, which maintains a certain static pressure in the shaft or a duct (100–200 Pa typically).

As AHUs have their own fans, very often, there is an opportunity to reduce the static pressure set point of the O/A fans and their energy consumption. This should be carefully considered on a case-by-case basis and investigation should include air flow testing.

At very low part-occupancy, i.e. after-hours operation, O/A and spill fans can be shut down completely in some circumstances.

Kitchen hood exhaust and make-up fans

VSD controllers can be used to adjust the air flow of exhaust and make-up air fans in kitchen exhaust systems and the like to reflect actual usage rates.

Return air fans

In VAV applications where S/A fans are typically fitted with VSD controllers, R/A fans, if they exist, should also be fitted with VSD controllers.

Numerous strategies exist for satisfactory operation and optimisation of R/A fans including plenum pressure control and tracking S/A fans. Significant performance and efficiency gains can be made with strategies to match the duty of the R/A fan to the S/A fan.

Bathroom exhaust fans

Bathroom exhaust fans can be fitted with VSD controllers if they serve multiple compartments, e.g. in multi-story residential apartment buildings, so that they can reduce air flow during periods of low system usage (e.g. from 11pm to 5am).

Getting started

Check existing motors to ensure that they can run at reduced speeds, not all motors can. Check that the reduced system output (air flow, water flow or temperature) will not affect comfort or productivity.

Integrating multiple HVAC variable speed drive controllers

Large centralised HVAC systems frequently employ numerous VSD controllers for various HVAC services including:

- CHW (primary and sometimes secondary) and CW flows (water flows)
- HW flow (water flows)
- cooling towers (air flow)
- air-cooled chillers and DX systems (air flow)
- S/A and R/A (air flows)
- DCV (air flow).

The following issues could occur when developing control strategies and control parameters involving multiple VSD controllers and other control equipment:

- When deciding whether to reduce the speed of a S/A fan or the amount of CHW, the type of chiller, the control arrangement and infrastructure, length of CHW pipework, ductwork, size of S/A fan and size of CHW pump(s) should be considered.
- When deciding whether to reduce CHW temperature and thereby reduce CHW pumping costs, or to increase CHW temperature and reduce chiller's energy input, the control arrangement and infrastructure, relative humidity control requirements, efficiency of chillers, length of pipework and size of pumps should be considered.
- When deciding whether to increase the use of cooling tower fans and water consumption in order to reduce the chiller's energy consumption, the efficiency of chillers, the size of CW pumps, seasonal refrigeration load and the size of cooling tower fans should be considered (refer to Optimisation Opportunities 7 and 8).

six

Best practice HVAC operation and maintenance

The correct operation and maintenance of HVAC systems is extremely important for performance and energy efficiency. This section provides an overview of four important operation and maintenance strategies that can contribute to HVAC energy savings. These are:

- **Opportunity 17** – Energy management planning
- **Opportunity 18** – Energy management training and awareness
- **Opportunity 19** – Energy efficiency maintenance
- **Opportunity 20** – Management of system control software.

Opportunity 17 — Energy management planning

UP TO 50% TOTAL ENERGY REDUCTION

Strategy summary

Adopting an integrated and inclusive approach to energy management is essential in order to achieve an ongoing lasting success.

Energy management planning requires coordination among senior management, site operations and maintenance personnel, including electrical, mechanical and HVAC control/BMS contractors. The planning needs to be guided by a sustainability team and supported by relevant energy management policies, procedures, documentation and training. Transparency of objectives and the proactive involvement of all these parties are essential for optimal outcomes. Figure 19 shows the range of stakeholders that need to be involved in energy management planning.

To facilitate a clear understanding of activities and responsibilities, all energy management activity should be identified in a facility energy management plan.

Improved energy management seeks to systematically minimise energy consumption, power demand and site greenhouse gas emissions.

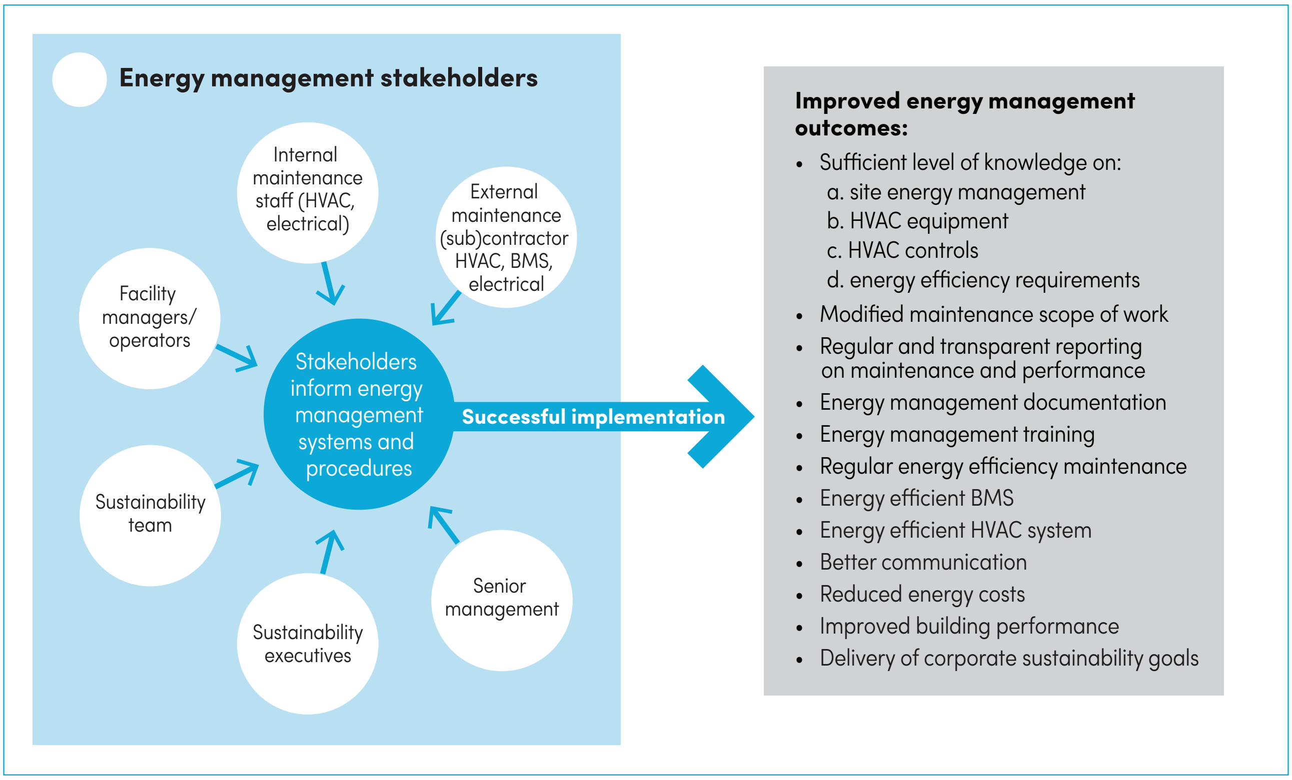


Figure 19: The influencing factors of energy management

Principle and equipment

For many facilities in Australia, there is often a lack of energy management documentation in place, which leaves significant opportunities for improvement in relation to the implementation of energy management planning.

Although energy management and optimisation is not only related to HVAC, due to the significant contribution of these systems to the overall building energy use, it is essential that HVAC is considered in all energy management plans.

Current practice

The current approach to energy management planning within buildings and facilities could be improved to leverage energy savings. At many sites, there is a lack of customised energy management planning and the establishment of site-specific energy management documentation.

Opportunity for optimisation

Energy management planning

The following aspects of energy management planning can be typically improved by:

- developing an energy management plan for the ongoing monitoring and supervision of site energy management, including the development of monthly energy targets and monitoring of the energy performance of the building using reporting/logging from BMS, utility bills, smart metering data and maintenance records
- fostering better understanding among all relevant parties (facility managers, internal and external maintenance personnel/contractors and the sustainability team) of energy supply arrangements, existing HVAC equipment and existing control strategies and parameters. This can easily be achieved through three- or six-monthly one-hour meetings with all relevant parties to ensure they are ‘on the same page’ concerning energy efficiency and that the energy management plan is progressing
- establishing site-specific energy management documentation and procedures, to make energy management of facilities transparent and accountable.

Strengthening energy conservation

It is important for building owners and senior management to set energy management objectives, allocate the necessary resources and to delegate key responsibilities to designated staff who

An energy management plan is a key part of optimising your HVAC systems

are capable to carry out the tasks. It is also important that objectives are SMART (specific, measurable, attainable, realistic and timely) and staff have awareness of the corporate objectives, access to training and resources, and ongoing support from senior management.

Measurement and verification

M&V is important for monitoring, recording and reporting on energy performance. M&V can:

- verify that actions are meeting the intended goals
- track costs and savings
- monitor stakeholder (including building occupants) satisfaction or dissatisfaction
- report on project successes or failures.

This feedback will help to inform the next steps in the energy management plan and prepare for the next project.

Communication with stakeholders

The success of HVAC optimisation depends not only on the implementation of appropriate strategies, but also on engagement and participation of building occupants. A strategy that reduces energy but compromises occupant comfort will often fail to achieve energy savings as occupants will act to override any optimisation measures that are perceived to cause discomfort. Success is easier when occupants are educated on the reasons for any changes (what are the goals and the benefits to occupants), trained on how to change current practices and are regularly informed on how progress is matching up to goals through progress reports.

Effectively communicating the need for energy management and providing training and guidance on how to implement specific strategies helps to achieve greater reductions and gain more support for initiatives.

Some ideas to keep in touch with your stakeholders:

- **regular newsletters**
- **regular reporting to management**
- **a ‘user guide’ for occupants regarding energy-efficient operation procedures for HVAC services.**

A simple way to begin the dialogue with your building occupants is through a night audit. A night audit – which basically entails checking an area after the occupants have left for the night – will reveal which equipment and systems are operating and why. The amount of energy that can be saved by switching equipment and systems off and the potential environmental benefits can be calculated and shared with building occupants. Empowering building occupants with real-time energy consumption data and energy efficiency or energy-saving data and information can reinforce the value of the energy-saving initiatives. This can be achieved in a variety of ways including interactive dashboard interfaces with the BMS or periodic energy reports from the energy management team as well as periodic energy awareness session/news updates for building occupants.

Other key stakeholders involved are the technical service providers who monitor and maintain the building HVAC systems. It is important to effectively communicate energy-efficiency goals and strategies with this stakeholder group and to incentivise energy-efficiency performance through contract renewals, positive references or bonus payments for meeting specified and agreed KPIs (e.g. improving a NABERS Energy rating).

Recognising individual and collective energy-saving efforts through awards or other recognition programs also provides opportunities to celebrate and communicate the valuable work being accomplished – success should never go unrecognised.

Energy-saving potential, costs, benefits and risks

The Warren Centre *Low Energy High Rise Building Research Study* showed that buildings perform better when all members of the building management chain feel they can influence building energy efficiency. Depending on the depth and level of commitment, energy savings of up to 50 per cent can be achieved.

Improved energy management planning can create a range of additional benefits including improved business productivity, improved corporate reputation, increased staff satisfaction and reduced future risks.

The risks involved in energy management planning are generally associated with sourcing the correct advice, the cost of expert advice and the ability of owners and managers to leverage that advice into real savings through project implementation using competent service providers.

Application notes

Improved energy management planning techniques can be applied to any HVAC system as well as any other energy-using service including lighting, domestic hot water (HW), information technology (IT) equipment, vertical transport and general power.

A typical energy management plan could incorporate the following:

- **Develop a site-specific list of the most important energy-efficiency initiatives.**
- **Extend the HVAC maintenance scope of work to incorporate energy-efficiency requirements into the maintenance regime.**
- **Modify a HVAC maintenance reporting template to ensure maintenance providers are accountable for energy efficiency and to provide more transparency for facility managers.**
- **Train external and internal maintenance providers on new energy-efficiency initiatives (including monitoring and reporting).**
- **Establish energy management documentation, including a training register and an updated 'functional description' of the BMS and mechanical services.**
- **Hold a workshop session with BMS, electrical and HVAC contractors/staff to seek feedback and to ensure that new energy-efficiency regimes, roles and responsibilities are clearly understood by all parties.**
- **Define requirements for regular monthly reporting on energy efficiency (including adding more trend logs to the BMS to enable better diagnostics of the performance of the HVAC system).**

Getting started

A first step to implement this strategy is to identify all energy management activity in a facility energy management plan. This plan should be consolidated with assistance from senior management, site operations and maintenance personnel.

Establishing a night audit will also reveal which equipment and systems are not operating at an optimum level, and can then be shared with building occupants and owners to provide energy-savings initiatives. Constant communication with applicable stakeholders needs to be maintained to implement energy management planning effectively.

Optimisation scenario

An office building in Sydney uses 2,500,000 kWh of electricity and 2,100,000 MJ of natural gas per annum (pa) for its base building services. The building occupancy hours are from 8.30am to 5.30pm, Monday to Friday.

The building does not have any energy management documentation – there is one consultant looking after energy efficiency but only to a limited extent. There is no checking of the building's after-hours load, there is no attempt to check and more appropriately match occupancy and HVAC system operating hours. After-hours use of AC is not monitored.

The adjustment of space temperature set points and control strategies and control parameters is left to the facility manager and BMS technicians. BMS technicians and the facility manager change the control strategies and parameters from time-to-time; however, there is no energy management training in place to prepare them for their HVAC energy management duties.

The BMS functional description is out-dated, as many of the changes that have been made to the BMS have not been documented. When tenants complain about AC, the facility manager and BMS technicians change temperature set points in an effort to try and satisfy them. The building's NABERS Office Base Building rating is 2 stars, which is below average and much lower than the expected 4 stars.

Behaviour changes included in this intervention

New building management has adopted a new approach to energy management, taking a more proactive approach to energy-efficiency maintenance and also providing energy management training and documentation. The proactive participation of facility managers, internal and external maintenance personnel, the facility's sustainability teams and the new energy management approach has resulted in a significant improvement in the energy performance of the building and results in a reduction of both electricity and gas consumption of 15 per cent.

Electricity saving calculations

2,500,000 x 0.15 = 375,000 kWh pa

Assuming an average electricity cost of 15 c/kWh, the electricity cost saving is $56,250 pa

Using the National Greenhouse Accounts (NGA) factor for NSW of 1.06 kg CO_2/kWh, this represents a reduction in CO_2 emissions of 397 t pa (electricity).

Gas saving calculation

2100 GJ x 0.15 = 315 GJ pa

Assuming an average cost of gas of $15/GJ, the natural gas cost saving is $4725 pa

Using the NGA factor for gas for NSW of 65.4 kg CO_2/GJ,

Emission reductions = 315 x 65.4 = 20,601 kg CO_2 pa

Therefore, this optimisation strategy results in an emission reduction from gas of approximately 21 t CO_2 equivalent pa.

Overall savings	
Cost savings	$60,975 pa
GHG emission reductions	418 t CO_2 pa
Typical cost of implementation	~$26,000 pa for ongoing optimisation
Simple payback period	Less than 0.5 years

Opportunity 18 — Energy management training and awareness

UP TO 10% TOTAL ENERGY REDUCTION

Strategy summary

Simply raising the awareness of facility managers, service providers and building occupants about energy consumption and HVAC energy efficiency, as well as the potential benefits of incorporating energy-saving practices into their day-to-day activities can help achieve significant savings.

Depending on the group, the objectives, training and education activities can be either:

1. formal, with specific learning objectives (compliance-related training)
2. informal, with educational materials provided via posters, newsletters, blogs and other media. Informed staff can be considered engaged and therefore more likely to actively contribute towards making a positive impact.

Principle and equipment

Ongoing training of building management staff and building occupants can help to ensure that systems are understood and operated correctly. This is particularly true of new staff. Original training materials should be made available to new staff when they join the team with specific training provided in relation to the building's HVAC system. Training should include the intended operation and the increased level of energy consumption that results from inefficient practices such as changing system set points, blocking vents and grilles, opening windows while the system is in operation and leaving systems in operation when not required.

Current practice

Knowledge gaps regarding HVAC system controls, operation and energy wastage can often lead to weak energy performance in many businesses. Currently, facility managers, HVAC operators and maintenance personnel are often not sufficiently educated in energy efficiency, particularly in training that refers to site-specific HVAC equipment and controls. At many sites, there is a strong case for customised energy-efficiency training and the establishment of site-specific energy management documentation to help operators and maintenance personnel optimise HVAC systems.

Opportunity for optimisation

Training in the area of HVAC energy efficiency is generally insufficient and few of those operating HVAC systems receive training dedicated to identifying energy-saving opportunities associated with the plant. A lot of saving opportunities fall into the category of no/low-cost opportunities which can typically be identified and corrected immediately by a sufficiently trained HVAC operator. The following aspects of energy management training and awareness can typically be improved in facilities/buildings:

- Encourage building operators and system maintenance staff to increase their skills and knowledge through available and relevant industry courses and training. Well-informed and trained staff are more likely to maintain a high level of system performance into the future. (See Appendix B for related resources.)
- Establish a simple 'live' energy management training document detailing the basic energy management training requirements customised for different groups, i.e. technical training for maintenance personnel and supervisory and procedural training for the sustainability team and facility manager.

Raising awareness about energy consumption and HVAC energy efficiency can help achieve significant savings

- Establish site-specific energy management training procedures to make energy management of facilities transparent and accountable.
- Document cultural and procedural changes arising from contemporary energy management requirements (wider temperature bands, seasonal clothing, recognition of inefficient equipment/ procedures, better monitoring and reporting, improved purchasing and procurement policies, improved maintenance procedures).

Energy-saving potential, costs, benefits and risks

The *Low Energy High Rise Building Research Study* showed that buildings, where the facility manager reports a higher level of energy-efficiency knowledge, perform better (by up to 1.3 NABERS Energy stars). Buildings where there is an energy-efficiency training program also reportedly perform better (by up to 0.5 NABERS Energy stars).

There are costs involved in delivering training and awareness-raising programs, including the cost of delivery and lost staff time. It has been shown, however, that training technical staff on energy efficiency and empowering building occupants with information on the correct operation of HVAC systems has the potential to significantly reduce HVAC-related energy costs.

As well as the energy savings achieved on the site through improved energy-efficiency awareness and training, additional benefits from increased training and awareness include:

- happier and more engaged building occupants
- happier and more empowered staff
- contribution to corporate or personal sustainability goals.

Risks associated with this strategy include the potential for better educated staff being headhunted by others who recognise the value of their enhanced skill set.

Application notes

The delivery of improved energy-efficiency training and awareness-raising information can be applied to a range of building and facility types. The more complex the system or its controls, the higher the potential for energy savings to be unlocked from this activity.

This strategy is best implemented after close consultation with key stakeholders, including the facilities management staff, service providers and building occupants.

Getting started

There are a number of options available for implementing energy management training and awareness programs. These range from specific formal and targeted energy-efficiency courses for individuals or groups to more informal approaches such as the creation of energy-awareness campaigns, development of an internal energy team with monthly energy meetings to take action on awareness issues and newsletters. A list of training course providers can be found in Appendix B.

Opportunity 19 — Energy efficiency maintenance

UP TO 20% HVAC ENERGY REDUCTION

It may be feasible to cost-effectively implement many of the recommendations of this guide. This can begin with discussions with your maintenance service providers about saving energy and water.

Strategy summary

The provision of regular maintenance inspections and rectification work dedicated to the energy efficiency of the plant has the potential to keep the plant running at its optimal performance, reducing current and avoiding future operational costs.

Principle and equipment

The existing plant and equipment is surveyed from an energy-efficiency point of view and a series of schedules developed to outline the maintenance activities that need to be included within the program. Performance-based maintenance contracts are adopted, nominating system performance standards and KPIs and incentivising maintenance and service providers to achieve those standards.

Current practice

Most facilities in Australia have room for improvement in relation to the delivery of maintenance for energy-efficiency outcomes. A lack of appropriate incentives for maintaining the energy efficiency of HVAC systems significantly contributes to poor energy performance. At many sites, there is a strong case for the development and delivery of a customised energy efficiency maintenance program for HVAC systems.

The operations and maintenance (O&M) of HVAC systems in commercial buildings has traditionally been carried out with a focus on complying with statutory requirements for health and safety and providing comfortable conditions to avoid complaints from building occupants. The subject of setting up and managing maintenance contracts for HVAC compliance with mandatory requirements is already comprehensively covered in various publications. Mandatory requirements for maintenance varies between the different states and territories across Australia.

Best practice O&M shifts the focus to also include energy and water efficiency as well as safety and comfort. The importance of including energy efficiency within commercial building maintenance contracts has been increasing for the following reasons:

- enhanced occupant comfort and improved reliability of HVAC systems leading to productivity gains
- better retention of building asset value
- increasing costs for energy and water – reducing operating costs improves the bottom line
- an increasing need or desire to reduce the environmental footprint of commercial buildings
- government policy and commercial trends towards increased uptake of green leases
- the Commercial Building Disclosure scheme, incentivising increased energy efficiency in buildings
- commercial tenants now demanding sustainable buildings and corporate sustainability commitments to minimise environmental impact

- building performance rating systems such as Green Star and NABERS, driving buildings to actually perform efficiently rather than just having the potential to be efficient.

Opportunity for optimisation

The following aspects of energy-efficiency maintenance can typically be improved in facilities/buildings:

- HVAC systems and components should be checked regularly to make sure they are operating as intended to help prevent energy being used inefficiently and excessively. HVAC components should be kept free of dirt and other obstructions. The overall system should be inspected and serviced periodically.
- A site-specific energy-efficiency maintenance schedule should be developed for each system and major component.
- Maintenance personnel must be trained and properly resourced in order to contribute to energy management improvements. This includes in-house and contracted personnel.
- A comprehensive guide on best practice O&M for energy efficiency has been developed, the DCCEE *Guide to Best Practice Maintenance and Operation of HVAC Systems for Energy Efficiency*, which can be used to help upskill maintenance service providers. Maintenance personnel also need to be trained in site-specific energy-efficiency characteristics in order to be able to understand the purpose of the HVAC control strategies (particularly the related control parameters) and what needs to be done to ensure continued optimised operation.

Energy-saving potential, costs, benefits and risks

> **“Buildings that provide efficiency penalties/incentives to maintenance contractors perform better.”**

The Warren Centre *Low Energy High Rise Building Research Study* showed that buildings that provide efficiency penalties/incentives to maintenance contractors perform better. The primary benefit of delivering maintenance for improved energy outcomes is a reduction in energy use and associated utility costs. The potential additional or complementary benefits of energy efficiency maintenance include:

- better indoor air and environment quality
- reduced risk of plant failures
- reduced maintenance costs
- longer system service life
- reduced water use
- better system documentation.

Application notes

Maintenance for energy efficiency can be applied to any energy-using HVAC system and generally requires the modification of the scope of works for HVAC, BMS and electrical maintenance contracts.

The following points should be noted when implementing maintenance for energy-efficiency strategy:

- A proper maintenance specification for the building HVAC must be compiled as a site-specific document. All sites are different. Generic documents with cut-and-pasted clauses will not deliver positive results for energy and water efficiency, or HVAC system performance.

Incorporating energy efficiency into maintenance is an important strategy for optimisation

- AIRAH DA19 HVAC&R Maintenance provides comprehensive maintenance information, including maintenance schedules for typical HVAC equipment and information regarding the process for procuring and monitoring maintenance contracts. However, it should not be treated as a maintenance specification.
- For buildings that are covered by existing maintenance contracts that may not necessarily be geared for efficiency, the contents of the *Guide to Best Practice Maintenance and Operation of HVAC Systems for Energy Efficiency* will increase awareness of important issues such as setting up an asset register and monitoring systems.
- Comparing a building's performance with available benchmarks, identifying potential KPIs and the installation of electricity/gas/water sub metering are essential for gathering the necessary information for setting up future maintenance contracts which are focused on energy and water efficiencies.

Important factors that promote energy and water efficiency gains in HVAC O&M contracts are described in the *Guide to Best Practice Maintenance & Operation of HVAC Systems for Energy Efficiency*.

Getting started

Maintenance plans/schedules should be provided for each element of the HVAC system with each schedule including the steps required to optimise energy use.

In addition to optimising system energy efficiency, the application of routine maintenance will also help identify potential problems at an early stage, which lowers the risk of breakdown (refer to AIRAH DA19). HVAC&R maintenance strategies that should be adopted include:

- develop and document a formal maintenance policy or plan
- adopt performance-based maintenance contracts incorporating preventative maintenance and condition-based monitoring
- incentivise maintenance and service providers, linking incentives to system performance standards and KPIs
- include the re-tuning of systems as part of the ongoing maintenance contract
- enhance current maintenance strategies to ensure that systems are maintained at their optimum performance, including the adoption of advanced maintenance strategies.

Getting started ...

Energy efficiency maintenance plan

A site-specific energy efficiency maintenance plan should be developed to include HVAC controls in relation to the actual needs of the building. This plan must include a fully defined occupancy time for all tenancies and occupied areas.

To achieve long-term benefits from HVAC optimisation, the following actions should be added to the energy efficiency maintenance plan:

- Energy efficiency maintenance training needs to be delivered to site HVAC operators to assist in understanding the optimised HVAC control functions and performance requirements, as well as providing a troubleshooting ability to identify and rectify occurrences of energy inefficiency in relation to current control strategies.
- Systems should be configured to prevent unauthorised ad hoc changes to HVAC control parameters (BMS settings, temperature sensors in conditioned spaces, schedule times, KPIs etc.).
- BMS graphic screens need to be provided displaying all updated control strategies and control parameters including space or zone temperature set points, proportional and dead bands and actual space temperatures. A brief explanation of individual control strategies should be added to relevant BMS screens where required, including menus or submenus (AHUs, FCUs, VAV boxes, electric duct heaters (EDHs), conditioned spaces layout, chillers, boilers, etc.). Ensure that control set points are within the designed capabilities of the system, e.g. do not adjust the maximum S/A set point to 40°C if the heating coil is only capable of raising the air temperature to 35°C.
- Check the BMS log – the BMS needs to be set up to provide logging of O/A and space temperatures as well as other HVAC system control parameters or KPIs such as energy use, coefficient of performance, supply or return temperatures, actual duct static pressure, speed of fans, percentage of opening of VAV boxes or water valves and status of air dampers. BMS trend logs should generate exception reports and alarms when monitored parameters deviate beyond specified ranges.

For additional information on designing, specifying or installing and commissioning a BMS, refer to AIRAH DA28 *Building Management and Control Systems*.

In addition to standard maintenance for energy-efficiency activities, the following checks should be made – regular checking, at least every six months, on:

- calibration of O/A temperature or humidity sensors
- calibration of S/A temperature sensors
- calibration of CO and CO_2 sensors
- calibration of CHW and HW temperature sensors
- calibration of velocity and pressure sensors
- correct position, operation and sealing of motorised outdoor, supply, return and relief-air dampers
- correct operation of fans and their VSD controllers
- BMS logging to confirm that HVAC operation and control strategies operate satisfactorily.

All space temperature control strategies and parameters and actual space and zone temperatures (based on trend-logging data from BMS) should be checked and verified. Any deviations beyond the given space temperature limits must be investigated, explained and rectified.

Getting started ...

Periodically (at least annually) perform a calibration and installation check for:

- space temperature sensors
- flow sensors
- velocity sensors.

Incorrect sensor readings typically cause increased energy consumption and discomfort of occupants. For example, an improperly located (e.g. near a photocopier) or uncalibrated space temperature sensor might indicate a space temperature 1°C higher than it should. This would cause overcooling of the space and potentially re-heating in adjacent zones wasting significant amounts of cooling and heating energy. Sensors should be unobstructed, on an interior wall, away from heat sources and the influences of S/A and at a suitable height, typically 1.5–1.7 m above fixed floor level.

Control equipment should be checked to ensure it operates in line with the specified control strategies and control parameters such as:

- opening/closing/modulation of VAV boxes and chilled/hot water valves
- ensuring there is no leakage through CHW and HHW valve (re-stroking of modulating valves has to be carried out in the case of leaking into the coils)
- switching on and off or modulation of AC compressors
- switching and staging of EDHs
- operation of chillers and boilers – arrangement for cooling and heating calls, staging up and down, starting strategy
- CHW pressure differential control parameters (opening/closing/modulation of motorised CHW valves) and operation of all CHW valves (modulation, minimum and maximum opening).

The selected control strategy and control parameters should be checked to ensure they are still suitable for current applications and usage of the facility. Temperature compatibility should also be checked between control strategies, e.g. space temperatures controlling the opening and closing of VAV boxes of an AHU supplying multiple boxes serving one zone in a typical office building, should be compatible with space temperatures for opening and closing CHW and HW valves at that AHU.

Opportunity 20 — Management of system control software

UP TO 10% HVAC ENERGY REDUCTION

Strategy summary

A lack of energy efficiency within HVAC systems can often stem from management of the system controls. Difficulties can arise where the correct settings are lost, overridden or undermined.

Principle and equipment

Complex systems require a high level of management, particularly BMSs, but also system level and plant controllers. System access should be managed and restricted to secure the performance with each user having unique log-on privileges to identify when and what was being performed on the system and by whom. Generally, most systems have event logs that can be used to audit and track operator activity. Controls should be managed so that:

- schedules are validated – occupancy scheduling should be provided for each functional area or per floor in multi-storey office buildings
- software is backed up – preferably to a remote location off-site
- programming is kept up to date by authorised personnel only
- a change log is maintained to record all changes.

Current practice

Currently, many HVAC control systems are managed in an ad hoc and informal way. They can be the subject of software patches and quick-fixes which may involve the loss of all settings or a reversion to factory default settings.

Opportunity for optimisation

Systems that have the correct programming can be protected from degradation by limiting access to authorised personnel only and by documenting standard operating procedures for access, backup and virus protection.

A systematic approach to managing your building management system will ensure energy savings are maintained

Application notes

Systems that store large amounts of important data must be backed up to an external device or remote destination. Trend logs and alarm history can build up significantly and should be regularly archived for future reference.

The (energy-efficient) control settings should be documented and linked back to the energy-efficiency management plan which should outline what the HVAC control settings are and why they have been chosen so that they can be easily reprogrammed should the control system reset to default settings.

Getting started

Only specified authorised personnel should have access to control systems and key stakeholders must be consulted before system changes are made.

All activity should be recorded on a BMS log.

Antivirus software and firewalls should always be installed on operator workstations, especially when connected to the internet. The antivirus and operating software must be kept up-to-date with regular scans scheduled. Systems must be backed up in accordance with good IT practice.

Other HVAC optimisation opportunities

This section outlines a range of additional optimisation activities that can be undertaken to reduce the energy consumption and improve the performance of HVAC systems. These include:

- optimising existing fan/pump distribution systems
- re-balancing air and water distribution systems
- addressing duct sealing and leakage
- optimising multiple boiler/water heater systems
- demand response systems to reduce peak loads
- using occupancy controls to control HVAC
- free cooling or water-side economy cycles from cooling towers.

These optimisations tend to require more capital and/or labour investment that the HVAC optimisations outlined in Sections 2 to 6.

Optimising existing fan/pump distribution systems

Approach to optimisation

The first approach to optimisation should be to assess the current system for problems. The system pressure and flow rate requirements should then be established and the installed fan or pump capabilities quantified. Part of this process is to collect system performance data over time. Logging data such as flow rate, discharge pressure and energy consumption is essential for diagnosing optimum system performance.

Identifying sub optimal systems

Many existing fan and pumping systems in HVAC can improve their efficiency and performance. System problems arise from incorrect fan or pump selection and operation, the indicators of which can include:

- highly throttled air-balance dampers or control valves in use
- excessive flow regulation via bypass lines
- frequent on/off cycling of a fan or pump in a constant flow application
- presence of noise or vibration evidencing cavitation
- presence of defects or major corrosion on casing or mounting
- parallel pumping or multiple fan systems where all pumps/fans are continuously running
- no means for measuring system flow, pressure or pump power
- systems that have been modified or extended over time
- blocked filters/strainers and clogged or dirty heat exchangers
- evidence of neglect including corrosion and leaking seals
- over or under pressurisation of the building envelope due to S/A and R/A imbalance.

Analyse the system performance

By comparing the system pressure/flow requirements with the fan or pump performance curve, it is possible to determine if the fan or pump is the correct size for the application. In many cases, the fan or pump performance can be better tailored to the system requirements. Maximum efficiency and minimum power consumption will be achieved by ensuring that the flow and pressure at the fan or pump's most efficient point closely matches the system operating point.

A best practice approach to analysing existing HVAC fan and pumping systems includes the following steps:

- Fully document all plant and components in the system.
- Determine the flow rates required for each load/branch in the distribution system.
- Balance the distribution system to meet the flow rates determined.
- Minimise additional system resistances needed to balance flow rates.
- Change the fan or pump to minimise excessive pressure (head) in the balanced system.

Methods that can be used to analyse systems include both observation and measurement methods as well as calculation and analysis techniques. Modelling the system using analytical, computational fluid dynamics or hydraulic models is useful when designing and evaluating potential system improvements. Modelling can also help evaluate the impact of proposed changes to the fan or pump, distribution systems or controls on a common platform.

To evaluate an existing fan or pump system, you must be able to:

- audit the system installation for inappropriate flow and pressure characteristics
- understand the existing operation and control of the system or process
- identify potential system issues over a range of operating conditions
- use and interpret historical data available for the system or plant
- capture field data and analyse and interpret that data.

Improving system performance

Some of the solutions to sub optimal distribution systems include:

- **Replace** old fans/pumps with modern energy-efficient replacements.
- **Replace** constant volume systems with variable volume systems.
- **High pressure drop** – clean filters/strainers and heat exchangers to reduce pressure drops.
- **High pressure drop** – reduce system resistance by upsizing ducts/pipes and fittings, removing unnecessary fittings, removing throttling dampers/valves and installing low pressure-drop plant.
- **Oversized fan/pump** – trim/change impeller, smaller impeller, VSD, two-speed drive, lower rpm.
- **Undersized fan/pump** – replace fan/pump or reduce system resistance (optimise flows).
- **Multiple fans/pumps operating continuously** – Review and update the control system.
- **High maintenance costs** – match fan/pump capacity with system requirements; check materials compatibility (corrosive environment etc.).
- **High flow rates** – adjust system operating temperatures to maximise temperature differentials and reduce flow rates.
- **Over throttled system** – modify fan/pump performance to reduce the need for throttling.
- **High power use** – Rebalance the system to minimise flows and remove throttling.
- **High distribution losses** – review the quantity and quality of the insulation system installed on duct and pipework. Repair defects and upgrade insulation levels to meet contemporary energy standards.
- **Provide instrumentation** – to measure pressure, flow and power use.
- **Repair seals and packing** – to minimise losses.

Rebalancing distribution systems

Reasons for a rebalance

During the design of HVAC systems, various design assumptions are made before heat load calculations are performed to determine the size of required equipment and the water and air flows for each space. Often, the flows determined at design do not reflect the actual needs of air conditioned spaces due to the following factors:

- different actual heat load (number of people, equipment) than that assumed during the design process
- changes to the space or to the use of the space (for example, repartitioning of open plan office space; more internal heat load from people, equipment, lighting; different type of occupants, etc.)
- inadequate or incorrect testing, adjusting and balancing at commissioning stage
- additional ducts or fittings introduced, compromising the amount of air flow due to a greater drop in air pressure
- modifications of a building envelope (for example, increased percentage of glazing)

Air flow volume control damper

- deterioration of the building envelope (for example, air leakage through facade or deterioration around window frames).

At the commissioning stage for new HVAC, system dampers (see photo) and valves are set up to balance the system to provide the required air and water flows to ensure the system performs as designed.

The air balancing and distribution of most HVAC systems is rarely checked or calibrated after the original design and commissioning. Poor air distribution results in excessive re-heating (which hides the problem) and overcooling, and can compromise the comfort of building occupants.

Usually, the two most common operational responses to the issue of an imbalance between air flows and actual heating/cooling needs are either (1) no action or (2) a modification of space temperature set points, neither of which will optimise system operation.

A longer term holistic solution is to review and rebalance the distribution system.

How to rebalance

This optimisation involves the review of actual cooling and heating needs for air conditioned spaces to identify any discrepancy between the estimated (at design stage) and the actual heat load. Distribution systems can be adjusted and rebalanced to better reflect the current use and needs of the air conditioned space.

The photo shows how air flow is set manually by the positioning of the air flow volume control dampers. In this case, the damper is set to be fully open. Reviewing and optimising these damper settings to reflect actual facility loads can save energy and improve comfort.

Testing adjusting and balancing is a dynamic test where the system is measured and adjusted to deliver the specified measureable performance parameters, such as flow or temperature. System testing, adjusting and rebalancing is a specialised skill set and air and water distribution systems need to be reviewed and optimised as a complete system by a trained professional.

In order to rectify the issues with unbalanced air and water flows, the following optimisation initiatives are recommended:

- Check the original design heat load and air flow figures for S/A and O/A against the actual measured air-flow figures. Check this on a zone/AHU level and at a local level for the current usage of the facility.
- Monitor and adjust air flows in relation to actual space temperatures, occupancy and use.
- Check the original design heat load and water flow figures for heating and cooling coils.
- Monitor and adjust water flows in relation to actual space temperatures, occupancy and use.

Duct leakage

Ductwork air leakage is an important issue when assessing HVAC due to its potential energy wastage and impact on system performance. When a system has to compensate for ductwork leakage, it requires increased air flows and fan power consumption. Leakage into and out of ductwork increases system heating/cooling loads and can impact on IAQ.

Identifying and repairing ductwork leaks to ensure adequate sealing is an important step to optimise HVAC performance. A number of sealant types, such as liquid sealants, mastics, tapes or heat-applied materials can be used. Ducts can be manufactured to incorporate self-sealing factory-applied gaskets. Retrofitting sealant to fix leaking ductwork is difficult and, as such, all new duct work should be sealed and tested.

All new ductwork for air distribution systems greater than 3 m^3/s should be tested for leakage in accordance with AS 4254.2.

Optimising boilers

Although HW boilers are relatively simple technologies, they are often not controlled well and, as such, present opportunities for optimisation.

Designing hydronic heating stages by switching on/off boilers in systems with multiple boilers will save energy and limit potential wear and tear while retaining comfort. Using controls to obtain optimum performance from multiple boilers requires an understanding of staging control and the individual boiler characteristics. The benefits of multiple boiler staging controls includes:

- staging of boiler modules to meet load demand
- automatic rotation of boiler modules to ensure equal run time
- PID control logic for precise control of supply water temperature.

For non-condensing boiler systems, checks should be carried out to ensure the reset control strategy does not lower return water temperature to the point where flue gas condensation is triggered.

Using air-to-fuel ratio control equipment such as oxygen trim control ensures a more complete combustion to reduce energy consumption by up to 2 per cent. The stack gas temperature should be measured under normal operating conditions after servicing and cleaning and this optimal temperature regularly compared with the stack temperature. Major variations can indicate a drop in efficiency and a need to adjust air-to-fuel ratios. It is estimated that there is a 1 per cent efficiency loss with every 5°C increase in stack temperature above the optimal temperature.

Boiler efficiency can be improved by installing heat recovery equipment such as economisers or recuperators.

- An economiser is an air-to-liquid heat exchanger that recovers heat from the flue gases to pre-heat boiler feed water.
- A recuperator is an air-to-air heat exchanger that is used to recover heat from flue gases to pre-heat combustion air.

VSDs can be retrofitted to combustion air fans to continually match the load of the boiler.

Running more boilers at lower loads (i.e. the optimal load for the specific plant) can provide better efficiency for condensing boilers. Multiple boilers also provide an inherent backup in the event of a boiler failure.

Variable primary pumping should be supplied when possible as it provides lower initial and operating costs. This should also include two-way, two-position control valves at each boiler to prevent flow to a boiler when not in use.

Where condensing boilers are installed, it is important to ensure that the HHW return is below 55°C as often as possible to ensure that optimum efficiency is achieved.

Where condensing boilers are used with conventional boilers, it is important to configure the condensing boiler as the lead boiler and to ensure that when conventional boilers are used for back up and/or additional capacity, the HHW return temperature is greater than 55°C to prevent boiler back-end corrosion. Also refer to Optimisation Opportunity 6.

Boiler heating calls can also be 'locked out' to provide additional savings.

Demand response

By installing submeters, the electrical use and demand for the facility can be monitored in real-time. As the overall building electrical demand approaches a pre-set level, the BMS can be programmed to turn off (or load shed) specified electrical loads for short periods of time. This reduces the peak demand for electricity and therefore reduces that billing period's peak demand charge. With an established process for limiting electrical demand, facilities can participate in demand response programs. These programs allow energy retailers to notify participants when they need to reduce the demand for electricity on the grid system. The facility then must reduce their electrical demand to a predetermined level. The payoff for this is reduced rates for electricity; however, there is a penalty if the facility fails to meet the agreed demand reduction.

Occupancy control

Occupancy control of a HVAC system allows for the automatic switching of a ventilation system if the presence of occupants in an area is detected. This ensures a ventilation system is only operational when required. The most common form of occupancy detection is passive infrared sensors. This type of control strategy is suitable for areas that are occupied intermittently.

Similarly, temperature set points can be relaxed or set back when occupancy is not detected and reinstated when occupants return.

It is possible to use three modes – occupied, unoccupied and set back – for terminal units and to integrate their operation with motion sensors used for lighting control.

Free cooling

When exterior ambient air conditions permit, cooling towers can produce enough cold water to provide the required cooling at coils without engaging the system chillers. The provision of CHW without the energy penalty of engaging chiller compressors is called 'free cooling' or 'water-side economy cycle'.

Refer to AIRAH Application Manual DA17 *Cooling Towers* for more information on energy and water efficiency in cooling tower systems.

Maintaining your HVAC optimisation

This section outlines the approach to maintenance that will ensure the benefits of any adopted HVAC optimisation strategy are retained for the long term.

Maintaining the benefits of your optimisation

> **HVAC optimisation is not a set-and-forget activity.**

HVAC optimisation is not a set-and-forget activity – the system requires regular monitoring and fine-tuning to ensure it continues to operate optimally. The operations and maintenance team is integral when implementing strategies to ensure the continued performance of the systems, with initiatives supported by experienced, knowledgeable, interested and available staff more likely to be cost-effective and have long-lasting results.

HVAC maintenance

Most HVAC systems are invisible to owners and occupants until a problem occurs, at which point it is often too late for maintenance to be performed efficiently as it becomes an urgent and reactive issue. The nature of many HVAC systems is such that when faults occur, the system automatically self-compensates to maintain comfort conditions, thereby compromising energy performance.

> **Reducing the levels of planned preventative maintenance might reduce maintenance costs in the short-term; however, it leads to higher lifecycle costs associated with reduced system efficiency and higher costs associated with reactive maintenance. In the long-term, reactive maintenance is the most costly way to maintain building HVAC systems.**

In a well-maintained building, a reduction in the level of maintenance takes time to manifest. Once issues materialise, it typically requires more resources and expenditure to recover. Many buildings have fallen into this 'poorly maintained' category, with reactive maintenance presented as the norm.

Facility managers need to make the case that investing money in HVAC maintenance will provide the organisation with a rate of return that is equal to or even greater than other investment options. This requires a cost–benefit analysis and a robust business case to be developed.

It is important to employ qualified technicians to perform the work. Skilled HVAC technicians are likely to identify signs of impending issues even in parts of the system they're not working on.

Refer to AIRAH Application Manual DA19 *HVAC&R Maintenance* and the DCCEE *Guide to Best Practice Maintenance & Operation of HVAC Systems for Energy Efficiency*, for further information on maintenance. Links to these documents can be found in Appendix B.

Maintaining accurate and reliable documentation on how the HVAC systems should function will assist in benchmarking and identifying/diagnosing problems that may contribute to unsatisfactory operating performance. Clear, complete, up-to-date as-installed drawings, operating manuals, functional descriptions, maintenance procedures, checklists and logbooks expedite the optimisation process.

Indoor air quality impacts

Building owners appreciate both low energy use and a comfortable indoor environment that enhances the value of their buildings and the satisfaction of the occupants. Building performance certification systems include energy use and the quality of the indoor environment in their evaluation criteria. As such, it is important to implement HVAC optimisation solutions that reduce energy consumption while maintaining acceptable IAQ.

IAQ and HVAC energy reduction can have competing priorities and it is easy to reduce energy when IAQ is not being maintained. HVAC optimisation must be addressed in terms of using the least amount of energy to deliver a fit-for-purpose HVAC solution.

One of the most important factors affecting the IAQ of a building is the O/A ventilation rate. Increased ventilation rates usually mean higher IAQ and higher energy consumption; however, ventilation strategies are important for the energy efficiency of buildings and careful design of systems and the use of optimised control strategies will minimise this impact.

The requirements for optimal IAQ and energy efficiency do not have to conflict with each other. Many strategies and technologies are available that improve IAQ while at the same time having a minimal impact on system energy consumption. These include economy cycles, purge cycles, demand control ventilation, fan speed control, filtering, heat recovery and localised control of the indoor environment.

IAQ is also an important issue when considering HVAC maintenance and the operating condition of the equipment. A well-maintained system will not only enhance the working environment through better IAQ, but will also protect an organisation from adverse publicity associated with potential failures of ‘duty of care’ under Work Health and Safety regulation. The cost of HVAC system maintenance is very small in comparison to the potential costs related to inadequate IAQ.

Periodic testing of IAQ is often a helpful system diagnostic strategy and testing indoor air can often uncover broken outdoor air dampers and linkages as well as fan and air distribution issues. A NABERS Indoor Environment rating can be used as an effective measure of IAQ.

Submetering

The most effective way of gathering hard data on system performance parameters is through submetering. Many existing buildings are unlikely to include this feature. The installation of electricity and gas submetering for new buildings greater than 2500 m² floor area is covered in the National Construction Code.

Submeters measure the electricity and gas consumption and demand from individual electrical or gas circuits and can be applied to a range of HVAC equipment including chillers, boilers, pumps, air handlers, lighting systems, air conditioners and refrigeration systems. Submeter data can be used to compare load profiles for a particular piece of equipment, e.g. the chillers, to previously measured profiles to identify developing equipment problems or operational inefficiencies.

Submeters are relatively simple and inexpensive to install; however, they are often found installed incorrectly or do not work. A typical electrical installation involves monitoring the current transformers and voltage sensors placed around the supply cable to the equipment. The meter or data logger can send collected data via cable or modem, or wirelessly to a BMS.

Submeters for monitoring water consumption should also be considered for cooling tower make-up, water and bleed.

Appendix A: Main areas of energy waste

Area	Causes of energy waste
Design/ installation	• Oversized plant and equipment with poor part-load efficiency and operational ability • Wrongly located and/or installed sensors • Inadequately specified and programmed BMS hardware and controls algorithms • Thermal bridging or duct/pipe insulation, equipment insulation, window frames, building fabric • Excessive air infiltration due to building pressure, facade integrity, zoning • Excessive minimum O/A ventilation flow rates • Motor use or missed VSD opportunities • Inappropriate zoning and to serve areas that have long or unscheduled hours of operation • Missed energy recovery opportunities e.g. exhaust air, heat recovery from plant • Air leakage in ducts, connections and access panels • Balancing and commissioning.
Operational	• Excessive operating hours due to over-conservative time schedules that include public holidays • Control sequences and systems integration e.g. systems not integrated – working against other ventilation and smoke control systems • Incorrect control set points, i.e. temperature/pressure set points • Simultaneous heating and cooling, i.e. cooling and heating systems working against each other • Excessive use of re-heat, which can mask control and operation problems • Pressure control in AHUs (VAV systems) and in variable-flow pumping systems • Incorrect economy cycle operation including failure to use O/A for free cooling and/or using excessive amounts of O/A during high/low outdoor temperatures • Ineffective mechanical night purge in buildings with high thermal mass • Pre-heating/pre-cooling schedules, i.e. using fixed time start/stop rather than optimum start/stop (OSS) • Absence of temperature lock-outs for economy or purge cycles • Lack of temperature lock-outs for boilers and chillers • Manual intervention and ad hoc changes to control set points and poor change management protocols for the BMS • Wasteful operation after-hours, rather than operating on demand • Lack of awareness of BMS functionality and graphical user interface by building operators, e.g. diagnostic screens, alarms, trend logs.
Maintenance issues	• Focus on compliance issues and reactive maintenance rather than on performance, energy efficiency and preventative activities • Unskilled staff carrying out maintenance • False or repeatedly ignored alarms • Incorrectly calibrated temperature, pressure, velocity, flow and humidity sensors • Dirty or blocked heat exchange surfaces of chillers, boilers, cooling towers and coils • Clogged or blocked filters, both air and water • Overridden VSDs • Overridden economy cycle • Incorrect refrigerant charge in chillers and DX systems • Water leaks and excessive water use due to cooling tower bleed and pressure relief valves • Excessive throttling using dampers or valves, particularly on index circuits • Equipment left in manual mode on switchboards, VSD drives and or BMS • Leakage from bypass valves and dampers.

Appendix B: Documents and resources

Referenced documents

- AS 1668.2 – *The use of ventilation and air conditioning in buildings – Part 2: Mechanical ventilation in buildings*, Standards Australia
- AS 4254.2 – *Ductwork for air-handling systems in buildings – Part 2: Rigid duct*, Standards Australia
- ANSI/ASHRAE 55 – *Thermal Environmental Conditions for Human Occupancy*, American Society of Heating Refrigeration and Air conditioning Engineers – www.ashrae.org/resources--publications/bookstore/standard-55
- ANSI/ASHRAE 62.1 – *Ventilation for acceptable indoor air quality,* American Society of Heating Refrigeration and Air conditioning Engineers – www.ashrae.org/resources--publications/bookstore/standards-62-1--62-2
- *National Construction Code*, Australian Building Codes Board – https://services.abcb.gov.au/NCCOnline/Publications/2015
- *Guide to Best Practice Maintenance & Operation of HVAC Systems for Energy Efficiency*, Department of Climate Change and Energy Efficiency (DCCEE), ISBN 978-1-922003-16-4 (2012) by Lasath Lecamwasam, John Wilson and David Chokolich (GHD), Commonwealth of Australia 2012, www.industry.gov.au/Energy/EnergyEfficiency/Non-residentialBuildings/HVAC/Pages/GuideBestPractice.aspx
- *Managing the work environment and facilities – Code of Practice*, Safe Work Australia – www.safeworkaustralia.gov.au/sites/swa/about/publications/pages/environment-facilities-cop
- *Air-conditioning and thermal comfort in Australian public service offices: an information booklet for health and safety representatives*, Comcare Australia
- *Low Energy High Rise Building Research Study: Final Research Survey Report*, The Warren Centre – http://thewarrencentre.org.au/wp-content/uploads/2011/11/LEHR-Research-Survery-Report-Ver-5.2.pdf

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- DA17 *Cooling Towers*
- DA19 *HVAC&R Maintenance*
- DA27 *Building Commissioning*
- DA28 *Building Management and Control Systems*

Office of Environment and Heritage NSW

- *Measurement and Verification Operational Guide*: http://www.environment.nsw.gov.au/resources/energyefficiencyindustry/120990bestpractice.pdf
- *Project Impact Assessment with Measurement and Verification tool*: www.environment.nsw.gov.au/business/piamv-tool.htm
- *Energy efficiency and Renewables Finance Guide*: www.environment.nsw.gov.au/publications/business/140746eefingde.htm
- *Accredited Certificate Provider Directory*: acpdirectory.environment.nsw.gov.au

Energy Savings Scheme

NSW Energy Savings Scheme: www.ess.nsw.gov.au/Home

Additional resources

Energy efficiency for HVAC

- The Energy Efficiency Exchange: eex.gov.au/technologies/HVAC
- The UK Carbon Trust: www.carbontrust.com/resources/guides/energy efficiency (hvac)
- AIRAH useful technical resources: www.airah.org.au/Technical_Resources
- AIRAH useful technical publications: www.airah.org.au/Technical_Publications

AIRAH training

AIRAH provides training in a range of formats on a range of topics and that are relevant to HVAC optimisation. These include Sustainability and HVAC Design, Sustainable Building Operations, Energy Auditing, and Building Tuning. For further information contact AIRAH Training at www.airah.org.au/Professional_Development/Training_Courses.

OEH training

OEH runs a practical and interactive training course on energy-efficient HVAC for business. Course attendance provides access to a half-day one-on-one site visit, as well as post-training support to help implement HVAC optimisation opportunities specific to the site. For more information, visit www.environment.nsw.gov.au/business/hvac-training.htm.

Appendix C:
HVAC optimisation and the NSW Energy Savings Scheme

Introduction

Energy savings unlocked by HVAC optimisation activities can potentially generate revenue using the NSW Energy Savings Scheme (ESS). By undertaking measurement and verification, savings can be demonstrated and Energy Saving Certificates (ESCs) can be generated and sold to offset the costs of the optimisation or to facilitate future energy-efficiency interventions.

Overview

The NSW ESS establishes legislated annual energy-savings targets for scheme participants (electricity retailers and generators) that must be met through the creation and surrender of ESCs.

The scheme is administered by the Independent Pricing and Regulatory Tribunal (IPART).

Accredited Certificate Providers (ACPs) can create ESCs by carrying out Recognised Energy Savings Activities (RESA) as defined in the *Energy Savings Scheme Rule of 2014*. These activities can include the optimisation of HVAC or an improvement in the NABERS Energy rating of a building, based on changes in HVAC electricity consumption measured against an established baseline.

Each ESC is the equivalent of one tonne of CO_2 (equals approximately 1 MWh of electricity). Since the ESS began in 2009, reported prices of a single ESC have ranged from under $10 to over $30. Figure A shows the spot price and quantity of ESCs generated between August 2009 and February2015.

The scheme is estimated to have saved 8.5 million megawatt-hours of electricity in its first four years of operation, which is equivalent to around 8.5 million t CO_2-e.

ESS rules

The *Energy Savings Scheme Rule of 2014* states that energy savings should be achieved by installing, removing or modifying usage of electrical end-use equipment without any loss in end-use service. When businesses invest in using HVAC systems more efficiently – including through the optimisation strategies in this guide – ESCs can be created by ACPs providing savings have been calculated according to the methodologies detailed in the Rule.

Technical methods for quantifying savings

There are a number of methods for quantifying energy savings under the ESS. The two that are particularly applicable to HVAC optimisation projects are the Metered Baseline Method (MBM) and Project Impact Assessment with Measurement & Verification (PIAM&V) method.

Figure A: NSW Energy Savings Certificate (ESC) Spot Prices – from August 2009. Greenroom Feb 2015

Metered Baseline Method

The MBM is typically used for energy-saving activities where:

- energy savings result in significant reductions in site electricity consumption
- representative historical site electricity consumption data is available.

In general, MBM calculations involve measuring the baseline (before) and project (after) electricity consumption, adjusting for changes that are unrelated to the energy-savings measure (where relevant - both explained and unexplained). The key steps are:

- Select a measurement period.
- Calculate the baseline electricity consumption over the selected measurement periods.
- Determine the level of unexplained baseline variability to account for the unexplained variance in the baseline for each measurement period.
- Calculate electricity savings.
- Apply a confidence factor, based on baseline variability.

The NABERS MBM makes use of the NABERS performance rating for commercial offices, business hotels, large shopping and data centres. The improvement in the NABERS rating is used to quantify the energy savings. The certified NABERS rating must be conducted by an accredited NABERS assessor in compliance with the rules of the scheme.

Project Impact Assessment Method with Measurement and Verification

The Project Impact Assessment and Verification Method (PIAM&V) allows the creation of multiple years (up to 10) of energy savings certificates upfront through the use of best practice measurement and verification techniques. This increases the initial incentive that the ESS scheme can provide with HVAC optimisations projects.

Forward creation of certificates using PIAM&V requires the development of pre- (baseline) and post- (operating) energy usage models that identify and measure specific variables that impact on energy use. The baseline model is used to predict what the level of consumption would have been in the absence of the energy-savings activity and the operating model can be ‘normalised’ to allow the prediction of energy savings over 10 years.

Notable characteristics of the PIAM&V method:

a. Energy usage models for pre- and post-implementation energy use must be verified and signed off by an appropriate measurement and verification professional.

b. The RESA needs to be approved by IPART prior to the implementation of the energy-saving activity.

c. An accuracy factor is applied to the savings calculations that reflects among other things, the error associated with measurements and the accuracy of the model used to determine baseline and operating energy. The application of an accuracy factor provides an incentive for abatement providers to conduct a thorough measurement and verification processes in order to maximise ESC creation upfront.

d. Calculation methods are required to produce a result that is reasonably reflective, to the satisfaction of IPART, of actual energy savings.

e. There may be higher level of measurement and verification than required in the MBM method, however, you are able to claim up to 10 years’ worth of certificates upfront.

f. An added operational benefit is the energy models that are created can be used by the sites to monitor energy use ongoing and can highlight any major changes to their energy use.

For more information on the ESS, ACPs and measurement and verification visit www.ess.nsw.gov.au.

Appendix D: Explaining the fan (and pump) affinity laws

The fan (and pump) affinity laws are most often used to calculate changes in flow rate, pressure and power of a fan (or pump) when the size, rotational speed or gas/fluid density is changed. The following explanation is for fans but also applies to centrifugal pumps.

In the following laws, the suffix '1' has been used for initial known values and the suffix '2' for the changed values and the resulting calculated value:

$$q_2 = q_1 \times \left(\frac{n_2}{n_1}\right) \times \left(\frac{d_2}{d_1}\right)^3 \times \frac{\rho_2}{\rho_1}$$

$$p_2 = p_1 \times \left(\frac{n_2}{n_1}\right)^2 \times \left(\frac{d_2}{d_1}\right)^2 \times \frac{\rho_2}{\rho_1}$$

$$P_2 = P_1 \times \left(\frac{n_2}{n_1}\right)^3 \times \left(\frac{d_2}{d_1}\right)^5 \times \frac{\rho_2}{\rho_1}$$

q = volume flow of air, m^3/s

p = pressure developed by fan, Pa

ρ = density of air (or gas), kg/m^3

n = fan rotational speed, m/s

d = diameter of impeller, m

P = power absorbed by fan, kW

When a significant change of density occurs between the fan inlet and discharge, the arithmetic mean of the density and volume is used. For fans operating at pressures below 2.5 kPa the above fan laws may be taken to apply when using inlet volume and inlet density.

These laws are simplified when one or more of the variables remain unchanged. For example, when the gas density is constant, the ratio $\rho 2/\rho 1$ equals 1 and can be omitted from the equation.

Similarly, if the diameter is also constant as with an existing fan, d2/d1 is 1 and this too can be omitted. Only the speed variation laws then apply, as follows:

$$q_2 = q_1 \times \frac{(n_2)}{(n_1)}$$

$$p_2 = p_1 \times \frac{(n_2)^2}{(n_1)^2}$$

$$P_2 = P_1 \times \frac{(n_2)^3}{(n_1)^3}$$

It should be noted that the fan laws are a theoretical analysis and are derived from a specific set of assumptions, including a perfect and closed geometrically similar system with a constant motor efficiency. In reality, these assumptions do not always apply, so the laws can only be used to assess small changes in fan performance.

For example, the power required by a fan whose speed is controlled using voltage modulation, typically has a linear relationship to speed and not the cubed relationship defined within the fan laws. This is due to efficiency changes within the motor. Where the motor efficiency is retained, for example with electronically commutated motors, then the fan laws provide a more accurate analysis.

A common mistake made is to assume that the S/A fan power in VAV-type HVAC systems obey the cube law. This is not always true, as the VAV terminals shut down and reduce air flow in response to reduced demands, the system characteristics change and also the duct static pressure is typically maintained as a constant rather than allowed to float downwards.

Care is required in applying the fan laws in the duct static pressure reset situation, as the fixed pressure scenario is already achieving close to quadratic turndown in a VAV system. Moving to variable pressure in a VAV system increases this to around the power of 2.7, so the saving is the difference between the two. In these situations, the fan power changes nearer to a square law rather than a cube law.

Fan laws should always be used with caution when predicting fan performance.