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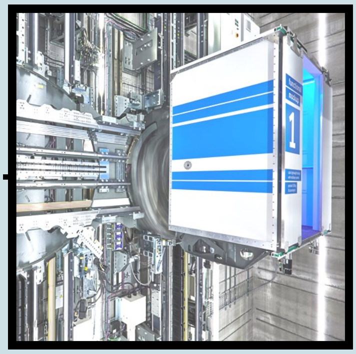
GUIDELINE FOR BUILDING AUTOMATION AND CONTROL SYSTEM (BACS) DESIGN



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ABBREVIATION

ACMV:	Air-Conditioning and Mechanical Ventilation
AHU:	Air Handling Unit
AI:	Analog Input
AO:	Analog Output
BACS:	Building Automation and Control System
BEMS:	Building Energy Management System
BI:	Binary Input
BMS:	Building Management System
BO:	Binary Output
BWL:	Bottom Water Level
CAV:	Constant Air Volume
CI:	Counter Input
DDC:	Direct Digital Controller
DI:	Digital Input
DO:	Digital Output
EnMS:	Energy Management System
EPU:	Economic Planning Unit
HLI:	High Level Interface
HTTP:	Hypertext Transfer Protocol
I/O:	Input / Output
MSTP:	Master-Slave Token Passing
MyCREST:	Malaysian Carbon Reduction & Environmental Sustainability Tool
NC:	Normally Closed
NO:	Normally Open
NCU:	Network Controller Unit
OEM:	Original Equipment Manufacturer
pH JKR:	Penarafan Hijau JKR
PLC:	Programmable Logic Controller
RH:	Relative Humidity
SAT:	Supply Air Temperature
TCP/IP:	Transmission Control Protocol/Internet Protocol
TWL:	Top Water Level
VAV:	Variable Air Volume

CONTENT

APPENDICES

1 INTRODUCTION

A Building Automation and Control System (BACS) is a centralised networked system of hardware and software that communicates with each other to monitor and control different mechanical services in a building, namely air-conditioning and mechanical ventilation system, fire protection system, lift system, cold water and sanitary system, building access and security and lighting system.

The aims of this guideline are as follows:

a) To provide easy-to-understand document for mechanical engineers in designing BACS correctly; and
b) To build up the expertise of mechanical engineers in BACS.

The scope of this guideline is limited to the BACS design for office buildings and the mechanical services in an office building. It excludes healthcare buildings such as hospitals and its specialised services such as medical gases pipeline system, and it does not include electrical services such as lighting, or security access.

1.1 Purpose of BACS

There are four (4) core functions of building automation:

a) To control the environment in the building, such as automatic switch on/off ventilation, air-conditioning and lighting;
b) To operate systems according to occupancy and energy demand, such as optimization of plant operation and services to minimize energy consumption and improve maintenance;
c) To monitor and correct system performance, and;
d) To alert or sound alarms when needed; for example, implementation of Uninterrupted Power Supplies (UPS) in the event of power failure, and so on, in critical environments, such as a hospital operating theatre.

1.2 Advantages of BACS

Having BACS in buildings holds several following advantages:

a) Automatic selection and scheduling against manual operator selection and start-stop of equipment;
b) Automatic logging and pre-determined call out messages against in-house monitoring and alarm response;
c) BACS can set up logs of comfort alarms and summary reports of energy used that can help operators, and;
d) BACS can help in managing a maintenance program in the form of run-time maintenance alarms, measured condition alarms such as filter pressure drop, or trend logs;
e) Cost benefit to the building owner.

1.3 Terms

The terms Building Automation System (BAS), Building Control System (BCS) Building Automation and Control System (BACS), Building Management System (BMS) are used interchangeably in the industry.

The BAS term is used by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), while the BACS term is adopted by the British Standards.

The following are several definitions of the terms:

Building Research Establishment (UK):

a) Building Management System (BMS) – a computer-based system which integrates building functions, such as ventilation and air conditioning, fire, security, power systems and lighting.
b) Building Energy Management System (BEMS) – controls and monitors plant, such as lighting or air conditioning in order to specifically address energy use. It does not integrate all control systems like BMS, that is control of security and fire protection systems is not included

The definition given by *Sinopoli* (2010) are as follows:
On Energy Management System: a system that generates information on energy usage and related costs for the purpose of reducing costs while still maintaining a comfortable and safe environment for building occupants.
Building Energy Management System (BEMS) is similar to the BAS but also capable of collecting and analyzing building energy-related data (such as electrical power and energy consumption, and solar power generation).

This guideline will use the term BACS throughout.

2 MECHANICAL SERVICES INTEGRATED WITH BACS

2.1 Air-Conditioning and Mechanical Ventilation System (ACMV)

The first step in design is to identify a suitable ACMV system for the building. It may be a chilled water system, or a direct expansion system (which, in turn, may be packaged, split, or a variable refrigerant flow type).

For chiller water system and variable refrigerant flow are required to have high-level interfacing via gateway from the control panel of equipment to the BACS.

Figure 2.1 shows a basic operation of a control loop of an ACMV system, which consists of the following four (4) components, namely a controller (e.g. thermostat), a controlled device (e.g. valve or damper), a controlled agent (e.g. chilled water), and a sensing device (e.g. transmitter).

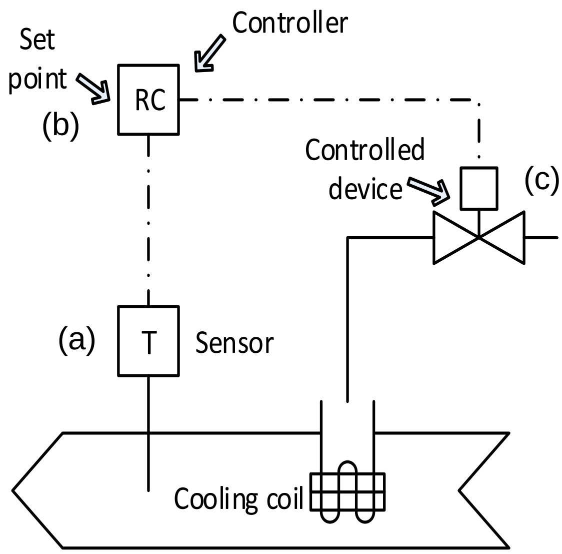

Figure 2.1: Conventional Control Loop

A duct temperature sensing device (a), such as a remote bulb, monitors the temperature of a supply air duct and sends a signal to the controller, (b). The controller monitors the signal as sent by the sensing device reacts either by opening or closing a controlled device, (c), such as a chilled water valve.

As a result of more or less of chilled water in cooling coil, the action of the controlled device creates a change in the air temperature of the duct and causes the sensing device to change the signal once again to the controller.

In **Figure 2.2** for DDC loop, the supply air temperature (SAT) sensor/transmitter will have one analog input (AI), and for the chilled water valve motor actuator there will be one analog output (AO), each wired to the DDC panel.

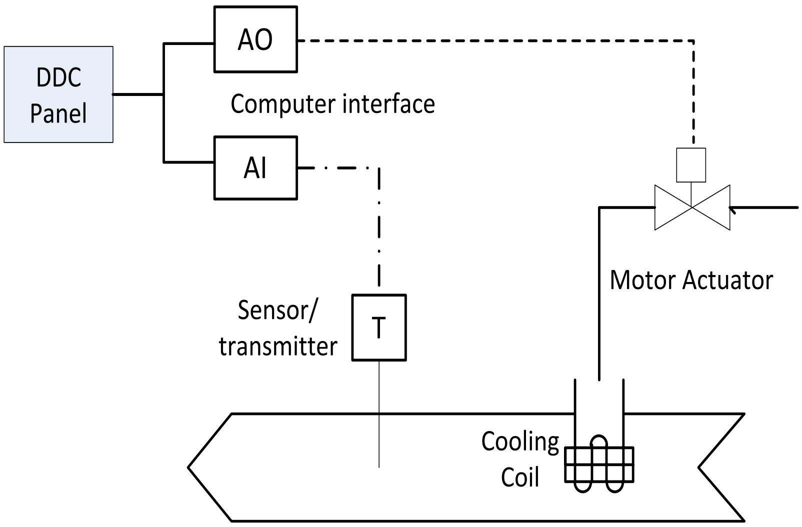

Figure 2.2: Direct Digital Control (DDC) Loop

The set-point of the SAT on the cooling coil is maintained by the DDC microprocessor, which continually monitors the SAT, compares the analog input sensor value to the set-point, and calculates an analog output to re-position the chilled water valve using the motor actuator to allow more, or less, chilled water flow such that the AI SAT sensor value comes into line with the set-point.

2.2 Fire Protection System

The Fire Protection System consists of Automatic Sprinkler System, Wet and Dry Riser System, Hose Reel System, Fire Alarm and Detection System and Fire Suppression System which only involve monitoring operation such as pump status (ON/OFF/TRIP), fire alarm detection, tank water levels (BWL/TWL) etc.

2.3 Vertical Transportation System

Lift system require high level interfacing via gateway with BACS to monitor lift operational status which duplicate information from lift supervisory panel and lift motor room temperature.

2.4 Cold Water System

The system involves monitoring the operation of pump status (ON/OFF/TRIP), tank water level (Bottom Water Level, BWL/Top Water Level, TWL) etc.

3 BACS COMPONENTS

This section gives a brief explanation on the components of the systems. A full description of the functions of BACS can be found in the BS EN ISO 16484 Part 3: Functions standards.

A BACS consists of:

a) Field devices
b) Controller
c) Communication protocol
d) User interface
e) System architecture

3.1 Field Devices

Based on the definition from BS EN ISO 16484 Part 2: Hardware, a field device is a physical connection from the input/output interface of a controller to an item of plant, thereby providing the necessary information or action to the conditions, states, and values of the process. Example: Sensors and actuators, operator panel, local monitoring and control device.

These sensors are connected to the controller via hard wire or wireless. Sensor provide signal/input via binary input (DI), pulse input and analogue input (AI).

Types of sensors include temperature sensor, humidity sensor, flow sensor, CO_2 sensor, valve and damper actuators.

3.2 Controllers

Controllers are small purpose-built computers, such as network controller units (NCUs) and DDC with input and output capabilities.

These controllers come in a range of sizes (depending on size of the system) and capabilities to integrate control, supervision, data logging, alarming, scheduling devices commonly found in buildings, and to control sub-networks of controllers.

Inputs allow a controller to read temperature, humidity, pressure, current flow, air flow, and other essential factors.

The outputs allow the controller to send command and control signals to field devices such as valve and damper actuator, and to other parts of the system.

Signal interchange between field devices and controller via inputs and outputs as follow:

3.2.1 Low Level Interface

a) **Binary (or Digital) Input, BI/DI** – a point that will accept only two states of information for the system, such as on-off or open-closed. DI devices include normally open and closed voltage free contact to sense relay status and fluid level sensors.

b) **Binary (or Digital) Output, BO/DO** – an output from controller in a form of two-state or two-position signal to command actuator (damper or motorized valve), to energise contactor for switching an electric motor (START/ STOP pump or fan), or to turn on lights,

c) **Analogue Input (AI)** – an input that reads a continuously variable signal, and used to measure the magnitude of a value; for example, active sensor for voltage (signal ranges from 1-5V, or 2-10V) and current (signal range from 4-20mA), passive sensor via resistance in ohm, change in room temperature and change in room CO_2 level. AI devices include temperature sensors, humidity sensors, pressure sensors, current and voltage sensing device,

d) **Analogue Output (AO)** – an output from the controller in the form of ‘proportional variable’ signal to control or adjust an actuator or external control device; for example, control valve for chilled water flow or damper position for fresh air intake.

e) **Counter Input (CI)** used to count pulse signal with certain duration; for example, water metering.

3.2.2 High Level Interface (HLI)

HLI allows monitoring and control of equipment directly *via* the BACS communications network. It provides real-time monitoring, parameter control, and scheduling for the operation of the whole system.

For example, a chiller can be controlled and monitored by connecting chiller microprocessor with to the BACS using communication protocol such as BACnet.

The device by an Original Equipment Manufacturer (OEM) can be "mapped", or configured, and connected directly to the network. The device will appear in the BACS as a typical controller.

3.3 Communications Protocols

BACS Protocols is the set of rules and formats regulating the information exchange between the elements of a system, including the specification of requirements for the application. Type of BACS protocols such us *BACnet*, *Modbus*, *KNX*, *Zigbee* and *Enocean*.

The protocol enables transmission data between field devices controller via supervisory workstation through hardwire (RS-485 and RS-232 cables) and wireless (radio frequency).

3.4 User Interface

Interaction with the BACS may take place at all levels of the system and at each level there may be different requirements for different classes of operator, such as programmer level, administration level and user level. The level of authorisation are controlled and identified by setting the user identification and password.

3.4.1 Programmer Level

Able to develop BAS system architecture such as programming control sequencing based on Input-Output point, as shown in **Figure 3.1**.

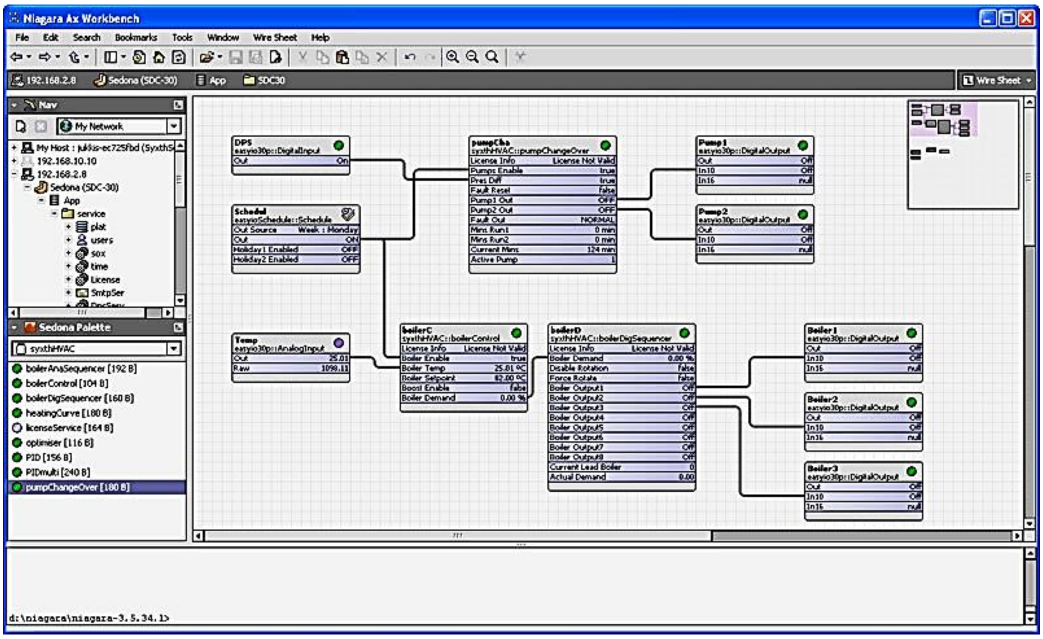

Figure 3.1: Programmer Level Interface

3.4.2 Administration Level

Able to analyse, trending, scheduling via high-level interfacing, as shown in **Figure 3.2**.

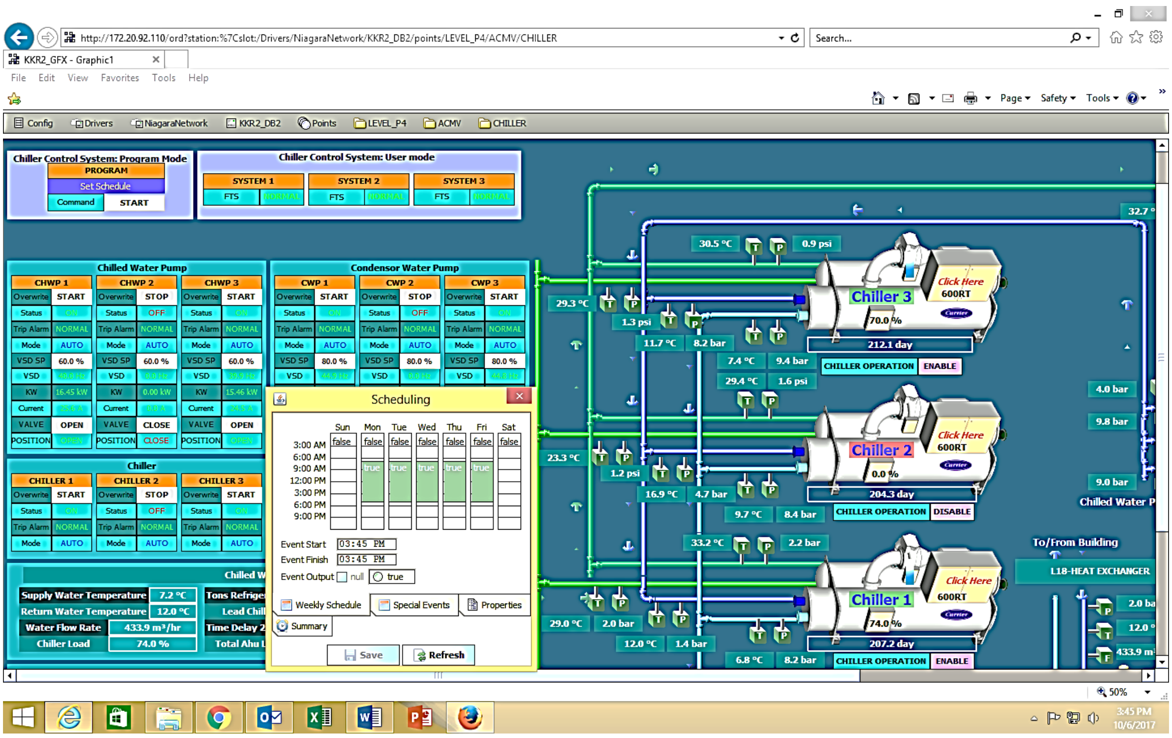

Figure 3.2: Administration Level Interface

3.4.3 User Level

Able to localise control and monitor BACS, such as START/STOP status for VRF system and adjust temperature setting, as shown in **Figure 3.3**.

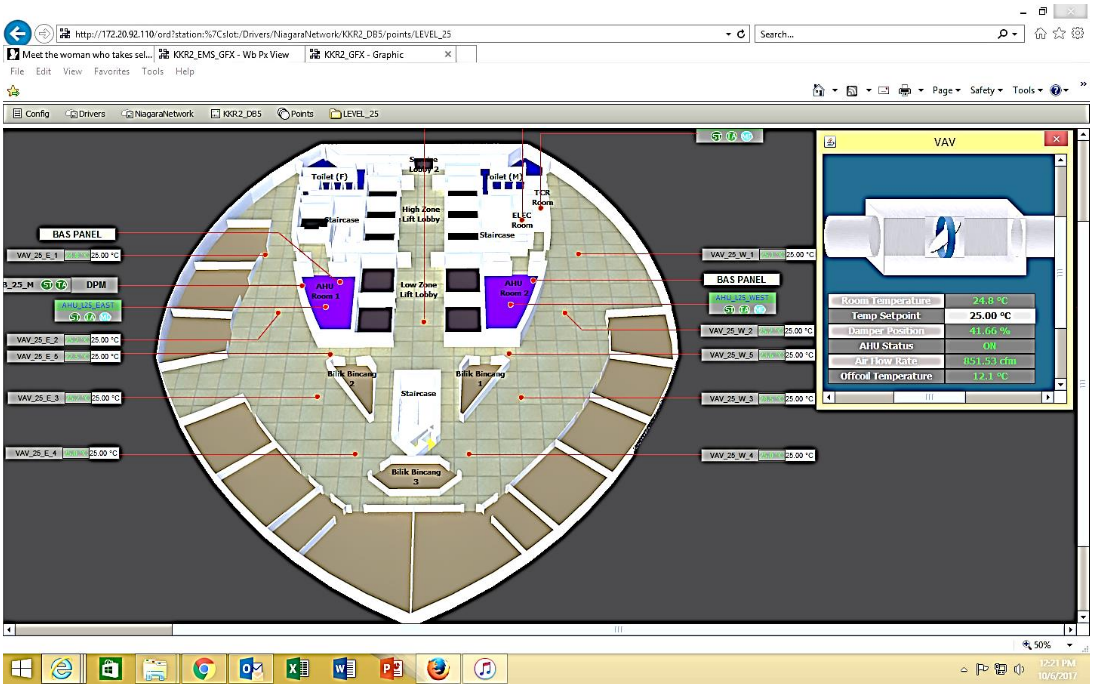

Figure 3.3: User Level Interface

3.5 System Architecture

System architecture is, basically, a communication network configuration for BACS. BACS network can be divided into three (3) management levels (BACS Workstation), automation level (Network Controller Unit, NCU) and field level (Direct Digital Controller, DDC and sensing device) via data transmission mode such as Ethernet, Transmission Control Protocol/Internet Protocol (TCP/IP), HTTP or MS/IP network.

All input / output (I/O) modules are communicating with controller through interoperability protocols such as *BACnet*, *LonMark* and *Modbus*.

The number of level and controller depend on the complexity of the building, Mechanical and Electrical (M&E) systems and I/O points to be monitored and controlled as shown in **Figure 3.4.**

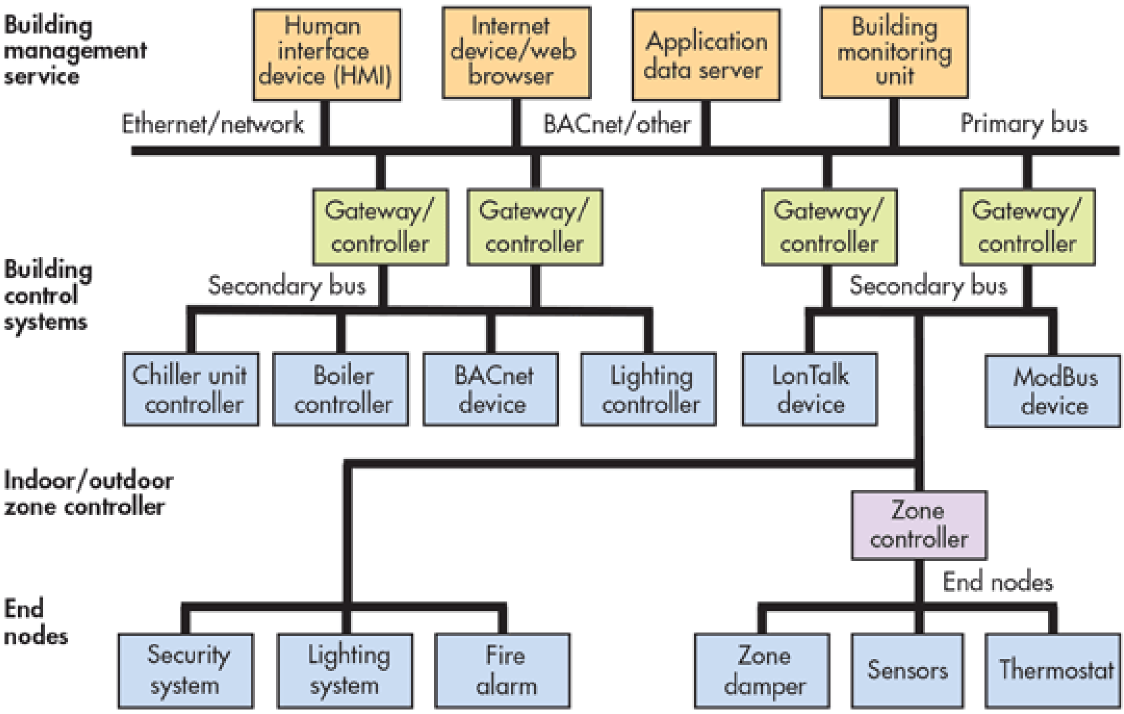

Figure 3.4: System Architecture Diagram (*courtesy of BASAM*)

Controllers used for BACS can be grouped into three (3) categories: programmable logic controllers (PLCs), system/network controllers, and terminal unit controllers.

An additional device/gateway is required to integrate or control third-party/proprietary systems (e.g. a stand-alone AC system/Lift).

These controllers are programmed to automate and optimise the mechanical and electrical system operation *via* monitor and control as per the user requirement.

4 DESIGNING BACS

4.1 Preliminary Design

It is important for the mechanical designers to refer to the latest Malaysian Code of Practice for Energy Efficient Design for Non-Residential Buildings (MS 1525), the available green rating schemes such as MyCREST and pH JKR, as well as *Garis Panduan dan Peraturan Bagi Perancangan Bangunan* by the Economic Planning Unit (EPU), Prime Minister Department Malaysia in addition to the project brief before starting to design.

The Guideline on Design Review and Verification by CKM JKR (2013) can also be used to check the design process of the BACS system. **Figure 4.1** shows the process flow for BACS design.

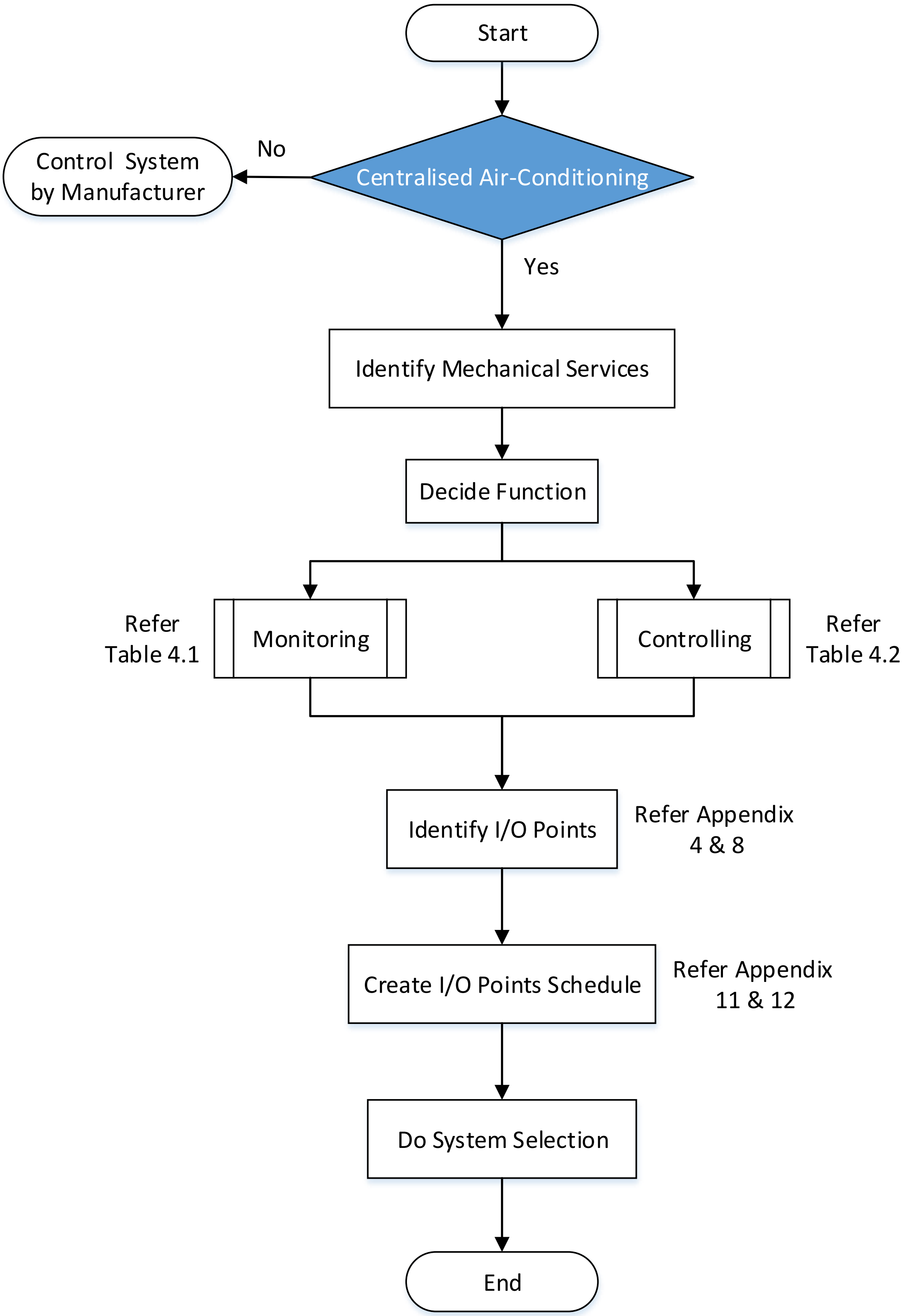

Figure 4.1: Process Flow for BACS Design

4.2 System Selection

In the system selection process as shown in **Figure 4.1**, it is important to consider the following (not in particular order):

a) Appropriate Type of Field Device (e.g. thermostat, CO_2 sensor);
b) Type of Medium (e.g. RS-485 cable, radio frequency);
c) Suitable digital controllers required;
d) Type of Monitoring Level (e.g. workstation level, web-based);
e) Type of Protocol (e.g. BACnet, Modbus, Zigbee for wireless);
f) Type of Data Transmission Mode (e.g. MSTP, TCP/IP, Ethernet);
g) Signal and communication cable route, or wireless devices, layout;
h) Locations for controllers and the BACS workstation.

Table 4.1: Minimum Parameters Required for Monitoring

No.	System	Equipment	Parameter Description
1.	Air Conditioning a) Chiller Water System b) Air / Water Cooled Package System	a) Chiller b) AHU c) Cooling Tower d) Chilled Water Pump e) Condenser Water Pump f) Make-up Water Tank g) Independent Split Units	a) Temperature b) Humidity c) Flowrate d) Pressure e) Tank Level (TWL/BWL) f) Equipment Status (ON/OFF/TRIP) g) Positions of valves & actuators (NC/NO)
2.	Mechanical Ventilation a) Smoke Spill System b) Pressurization System	a) Fan	a) Alarm Status Mode (NORMAL/FIRE) b) Equipment Status (ON/OFF/TRIP)
3.	Fire Protection	a) Fire Pump b) Fire Tank c) Fire Alarm Panel	a) Alarm Status Mode (NORMAL/FIRE) b) Tank Level (TWL/BWL) c) Equipment Status (ON/OFF/TRIP)
4.	Cold Water	a) Cold Water Pump Set b) Submersible Pump Set	a) Tank Level (TWL/BWL) b) Equipment Status (ON/OFF/TRIP)
5.	Vertical Transportation	a) Lift Motor	a) Supervisory Panel Status

Table 4.2: Minimum Parameters Required for Controlling

No.	System	Equipment	Parameter Description
1.	Air Conditioning a) Chiller Water System b) Air/Water Cooled Package System	a) Chiller b) AHU c) Cooling Tower d) Chilled Water Pump e) Condenser Water Pump f) Make-up Water Tank	a) Temperature b) Humidity c) Flowrate d) Pressure e) Start/Stop/Trip

5 MONITORING AND CONTROL STRATEGY

Generally, the BACS has three (3) main functions, stated in the latest Malaysian Standards MS 1525 Code of Practice, which consists of the following:

5.1 Control of Equipment

The primary purpose of the control of equipment is to ensure that the system functions as per design and optimised by:

a) Equipment scheduling and manual overriding;
b) Control of set points;
c) Status report and recording of operational alarms; and
d) Correct and safe sequencing of operation (for maximum demand limiting).

5.2 Monitoring of Equipment

The purpose of monitoring the equipment is to maintain the efficiency of operations by:

a) Providing centralised information of current equipment condition;
b) Providing information of equipment conditions through basic trending;
c) Providing a “management by exception” function to alert the operator of any abnormal equipment conditions
d) Providing analytical tools to aid the study and management of equipment operations and energy performance

5.3 Integration of Equipment Sub-systems

The purpose of integration is based on data input from monitoring and control to produce output program between equipment interfacing.

5.4 ACMV

The ACMV system is typically the largest energy consumer in a building and has the largest functional demand and energy savings potential.

The BACS must be able to monitor and control the functionality of ACMV system to ensure optimum and efficient operation. (**Note:** The full sequence of operation for the systems under this section can be referred to in the Appendices).

5.4.1 Central Plant

In buildings with chilled water system, the BACS should enable chiller optimization using, **at the minimum**, the following strategies:

a) Operation Control
   i. Based on pre-set time schedules to match occupancy patterns;
   ii. Chiller sequencing which involves selecting the most energy-efficient chiller configuration to satisfy building load;

b) Chilled Water Set-point Reset

c) The energy consumed by a chiller decreases as the set-point of the leaving chilled water is increased.

d) The BACS should automatically increase the set-point of the leaving chilled water temperature, whenever possible, to minimise energy consumption.

e) The BACS may adjust the set-point based on, but not limited to:
   i. time schedule;
   ii. outdoor air temperature/enthalpy;
   iii. maximum Air Handling Unit (AHU) valve position; and
   iv. indoor relative humidity.

Chillers are typically supplied with dedicated microprocessor-based control panels. Where possible, a high level data interface (HLI) between the chiller control panel and the BACS is recommended to avoid unnecessary additional sensors and transducers.

5.4.2 Air Handling Unit (AHU)

AHUs are typically the second largest energy consumer in air conditioning system beside central chiller plant.

The BACS must be able to optimise AHU energy consumption while maintaining acceptable room conditions and ventilation requirement.

These strategies should, **at the minimum**, include:

a) Start and stop functions; based on a time schedule.;
b) Temperature control, by manipulating chilled water control valves according to room set-point temperature;
c) Temperature and humidity control, by manipulating air heater power and chilled water control valve positions according to room humidity and temperature set-point;
d) For Variable Air Volume (VAV) AHU system, temperature control is achieved by manipulating supply air flow rate to the spaces based on duct static pressure. Off-coil temperature must be maintained by control valve operation. Series of VAV boxes must be in place to control individual zone temperature by adjusting zone air flow via VAV box dampers; and
e) Demand control ventilation, if required, by manipulating outside air damper based on pre-set room CO_2 level. Control of outdoor air supply to the AHU is recommended to be based on demand control ventilation to optimise energy consumption while maintaining indoor air quality, for example by incorporating CO_2 sensor in the room, or in the return air duct.
f) Overload protection shall must be provided and linked to the BACS for any current overload occurrence.
g) BACS local/auto switch must be provided at the AHU Starter Panel to allow for switch-over to local mode in the event of BACS failure.

5.4.3 Fan Coil Unit (FCU)

FCU operation must be controlled and monitored by the BACS using the following methods:

a) Individual-use FCU

Individual FCU is characterised by single user control over its operation and temperature setting. It is recommended that BACS interface be limited to **operational status feedback**.

b) Ducted FCU

Ducted FCU is characterised by multiple rooms or user served by a single FCU. It is recommended that their operation and temperature control be executed by the BACS based on **pre-set operation schedule and temperature set point**.

5.4.4 Mechanical Ventilation

Where appropriate, the BACS must start/stop mechanical ventilation equipment such as supply fans, or exhaust fans.

Some applications may require a number of fans to be grouped together at a common zone for start/stop control.

Control should be based, **at the minimum**, on:

a) time schedules;
b) carbon monoxide (CO) or carbon dioxide (CO_2) level in parking areas or large rooms with highly variable occupancy, and;
c) duty cycling algorithm.

The summary of BACS functions and capability is shown in **Table 5.1**.

Table 5.1: ACMV System: Summary of BACS Functions and Capability for Chilled Water Plant

Function Name	Objective	Control and Monitoring Strategy
Time schedules to match occupancy patterns	Energy reduction and avoidance of problems related to overcooling.	ACMV system components will be operated according to pre-set schedules. Temporary override of the time schedules to accommodate changes in usage (Manual overriding) and calendar functions (public holidays) features shall be made available.
Chiller plant sequencing	Energy efficiency	Selection of the most energy efficient chiller~~s~~ configurations to satisfy building load.
Chilled water temperature reset	Energy efficiency	Chiller energy consumption is directly proportional to temperature lift. Increasing chilled water set point will reduce chiller energy consumption but limited to chiller operational limit and maximum allowable space humidity. Leaving chilled water set point temperature shall be automatically adjusted to minimise energy consumption based on (but not limited to): a) time schedule; b) outdoor air temperature/enthalpy; c) maximum AHU valve position; and d) Indoor RH condition.
Demand Limiting	Maximum demand charge reduction	Chiller maximum power is limited as part of overall building maximum demand limiting program.

5.5 Fire Protection System

Basic monitoring for fire protection system operation is as follows:

a) Fire Pump Set

To indicate the ON/OFF/TRIP status

b) Fire Tank

To indicate the bottom water level (BWL), top water level (TWL) and the alarm status

c) Fire Alarm and Detection System

To indicate the alarm status

5.6 Smoke Spill System / Pressurization Fan

To indicate the ON/OFF/TRIP status

5.7 Vertical Transportation System

Basic monitoring for lift system operation is as follows:

a) To indicate the lift ON/OFF/FIRE mode status,

b) To indicate the lift motor room temperature

5.8 Cold Water System

Basic monitoring for Cold Water system operation is as follows:

a) Pump Set

To indicate status ON/OFF/TRIP

b) Cold Water Tank

To indicate status water level BWL/TWL and alarms

5.9 Application of Energy Management System (EnMS)

Buildings with air-conditioned space of **≥ 4,000 m^2** should be provided with EnMS (which is a subset of BACS) as specified in **MS 1525**.

The building should be equipped with utility consumption (utility refers to electricity, fuel, gas, water, compressed air, etc.) data logging facilities for the collation of data for energy auditing.

Suitable means or facilities for the monitoring of energy consumption (sub-metering) should be provided, **at the minimum,** for all incoming power supply to a building and the outgoing sub-circuits serving, the following services:

a) central air-conditioning system and/or external supplied cooling water;
b) lift and escalator system;
c) water pumping system;
d) general power supply; and
e) lighting supply.

5.10 EnMS Requirement

The EnMS should be supplied with, **at the minimum**, the following energy management features:

a) direct digital control algorithms;
b) equipment start and stop based on a time schedule and optimisation control logic;
c) temporary override of the time schedules to accommodate changes in usage;
d) chilled water leaving and/or entering temperature reset algorithm;
e) control loop set point reset algorithm;
f) chiller sequencing and optimisation algorithm;
g) demand limiting algorithm for minimizing energy demand for chillers, and
h) duty cycling algorithm for chiller operations.

The EnMS should come with an energy tracking and reporting system so that a historical record of energy usage is maintained for analysis and energy audit purposes.

EnMS monitoring should consist, **at the minimum**, the following categories of data collection;

a) energy consumption, for example, chiller kilowatt hour (kWh);
b) pattern identification/profiling; and
c) operation alarm notification.

The level of actual energy consumption is based on the collection of energy usage data from power meters, while pattern identification requires the mapping of building activities that are known to have specific energy consumption characteristics.

Where applicable, provision should also be made for automatic conversion of fuel energy use (for example, coal, oil and natural gas) into its electrical energy equivalent to enable building operators formulate energy-saving strategies using information from pattern identification (more than what would appear on a total utility bill)

EnMS software that monitors energy should be able to do (preferably real-time) the following:

a) data reporting;
b) data comparison between the recent and historical data;
c) help building operators track the energy consumption of very specific areas in a building;
d) analyse days while taking weather into consideration, and
e) identify energy consumption that is unexpected, or not in agreement with previous data, so the building energy usage can be streamlined.

The designers must ensure that the software enables the building operators to define his/her own energy usage levels (or baseline) and implement energy-saving measures.

If the baseline is exceeded, the software must be able to alert the building operators through e-mail and/or text messages.

Ideally, the EnMS should be able to provide, **at the minimum**, the following types of information **for trending purposes**:-

a) temperature;
b) pressure;
c) humidity;

d) damper and valve position commands, including variable frequency drive (VFD) control signals;
e) virtual points (internal calculations such as enthalpy or changing set-points and targets);
f) (ON/OFF) status or stage;
g) flow rate (water, air or fuel);
h) alarm state;
i) current;
j) power demand (kW);
k) energy consumption (kWh, therms, gallons, etc.);
l) revolutions per minute (RPM) of rotating equipment; and
m) power factor.

6 CONCLUSION

It is with fervent hope that the guideline will contribute, in the long term, to the increased expertise for mechanical engineers in designing the BACS. The correct design which fits the purpose of the building will result in more effective control and monitoring of mechanical services in buildings. The outcome of those will be higher overall building energy performance which reduces the government utilities cost. On the macro level, this will translate to contribution to the reduction of national carbon footprint.

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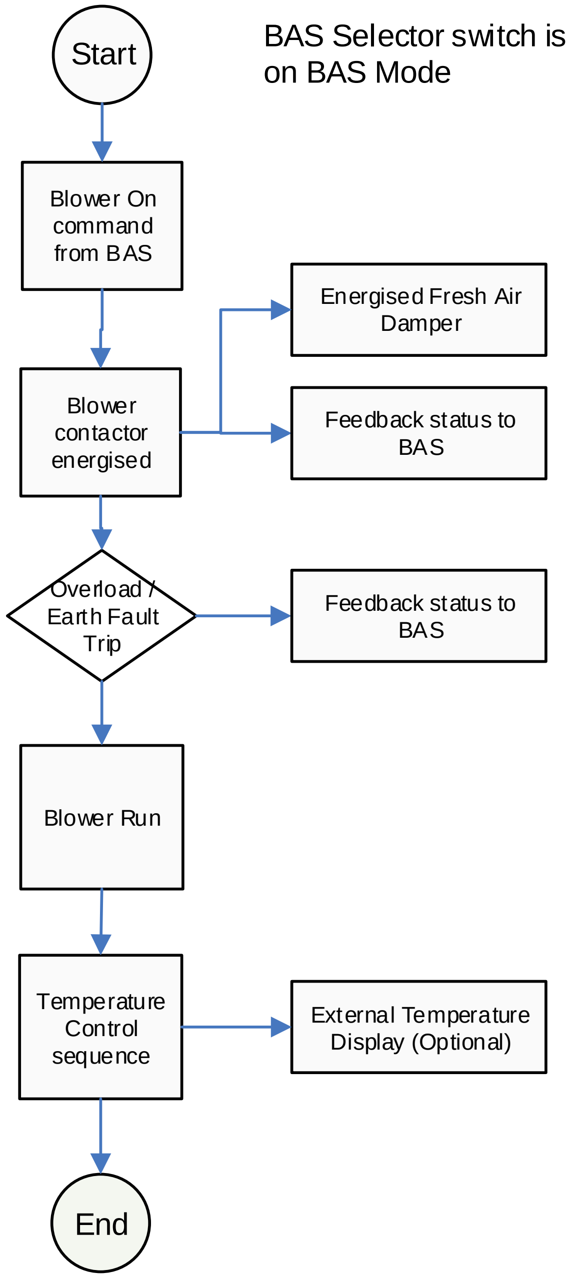
APPENDIX 1

TYPICAL TEMPERATURE CONTROL FOR CAV AHU

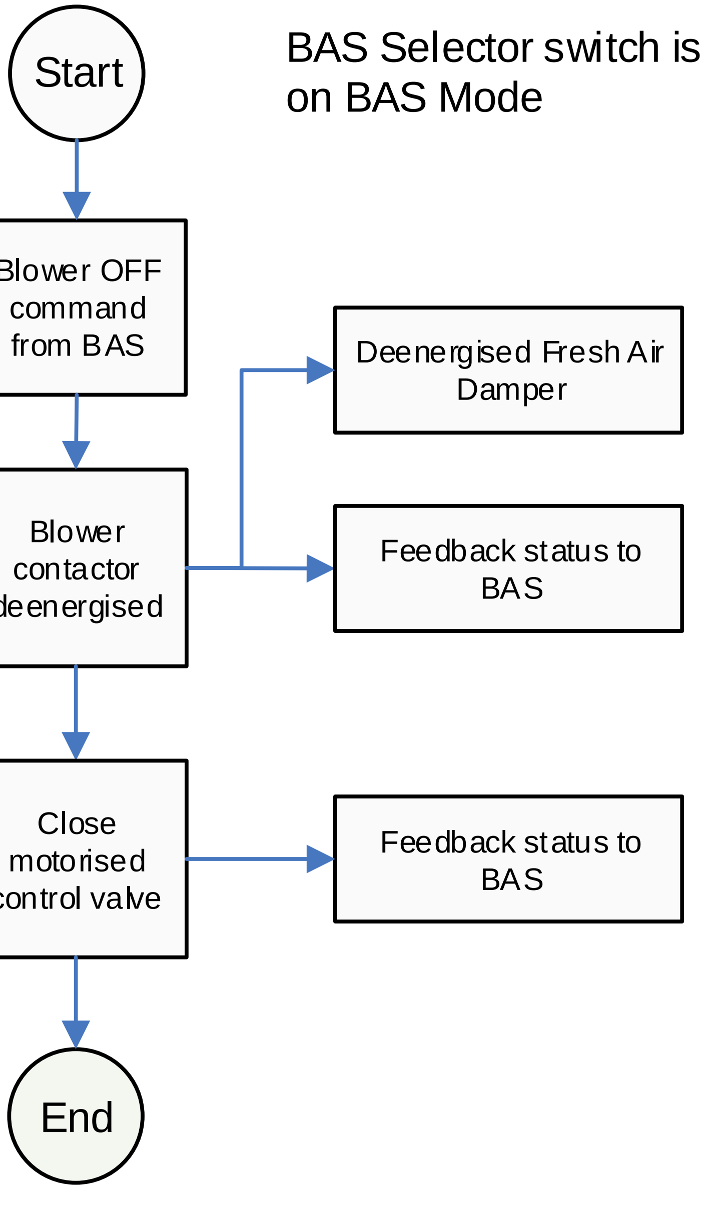
AHU ON SEQUENCE



APPENDIX 2

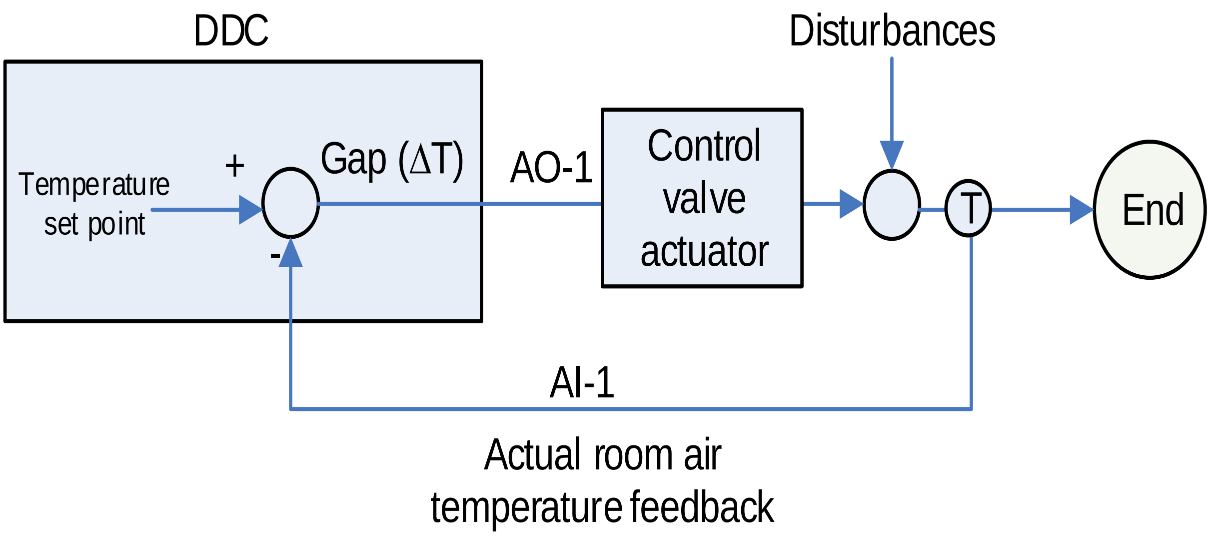
TYPICAL TEMPERATURE CONTROL FOR CAV AHU

AHU OFF SEQUENCE



APPENDIX 3

Typical Room Air Temperature Control Sequence



Legend:

AO: Analog Output

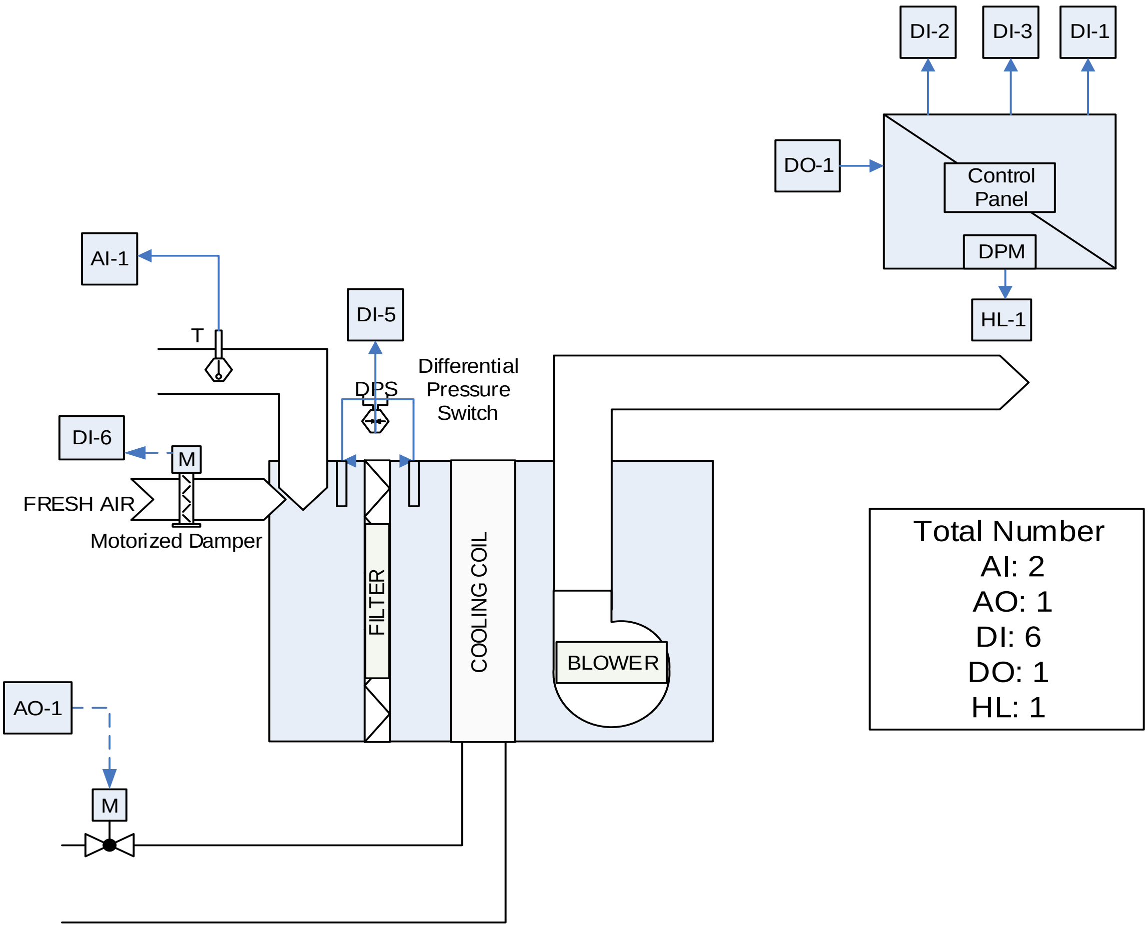
AI: Analog Input

DDC: Direct Digital Control

T: Thermostat

APPENDIX 4

Typical AHU I/O Points

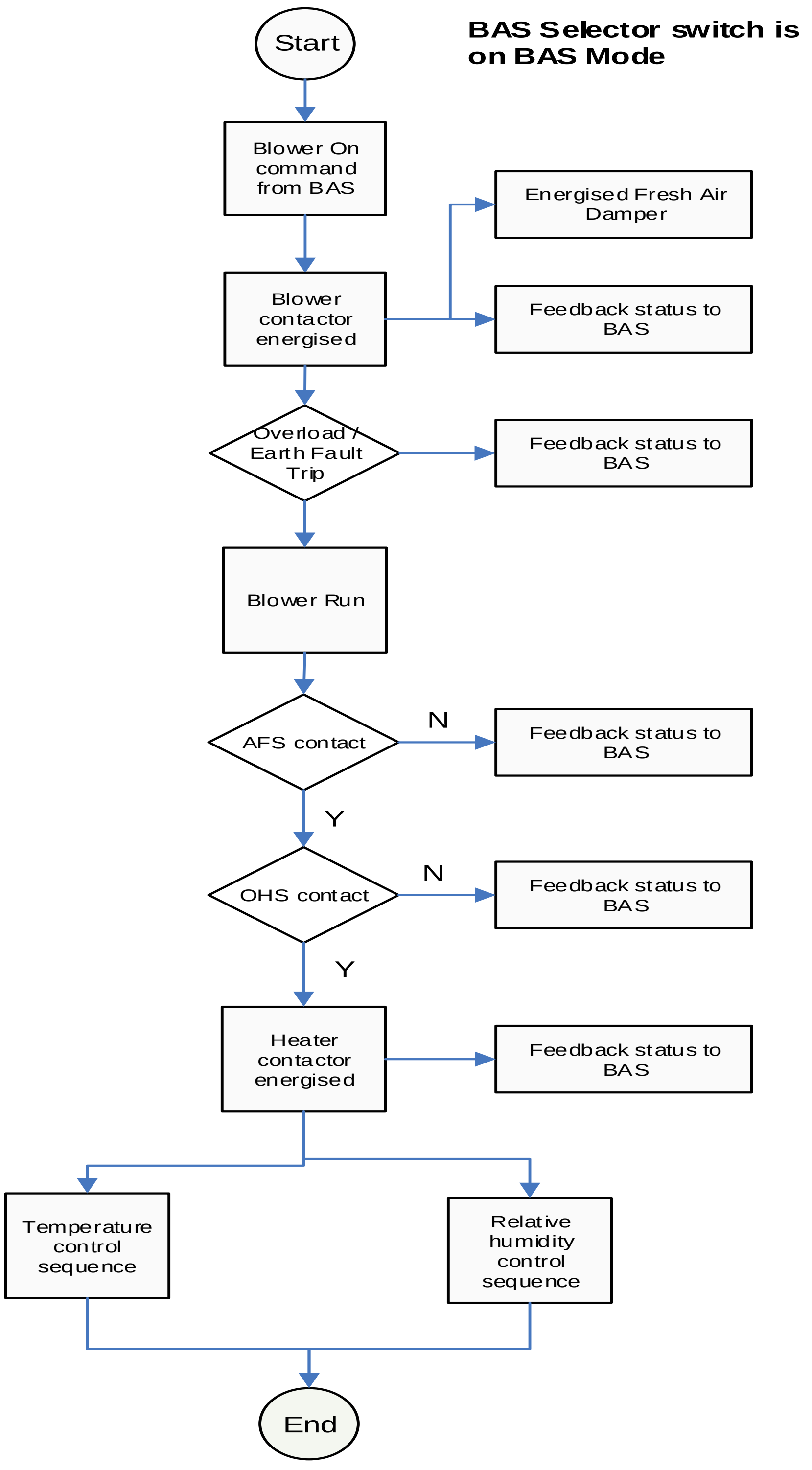


BAS INTERFACE														
DO	DI						AI		AO	HL1	SOFTWARE			
START/STOP CONTROL	BLOWER ON/OFF STATUS	OVERLOAD TRIP ALARM	EARTH FAULT TRIP	BMS/LOCAL SELECTOR	FILTER DIRTY ALARM	FRESH AIR DAMPER FEEDBACK	RETURN AIR TEMPERATURE	MODULATING CONTROL VALVE FEEDBACK	MODULATING CONTROL VALVE	DIGITAL POWER METER (DPM)	ROOM AIR TEMP CONTROL (PI LOOP)	SETPOINT ADJUSTMENT	SCHEDULING	ALARM GENERATION
/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
D0-1	DI-1	DI-2	DI-3	DI-4	DI-5	DI-6	AI-1	AI-2	AO-1	HL-1				

APPENDIX 5

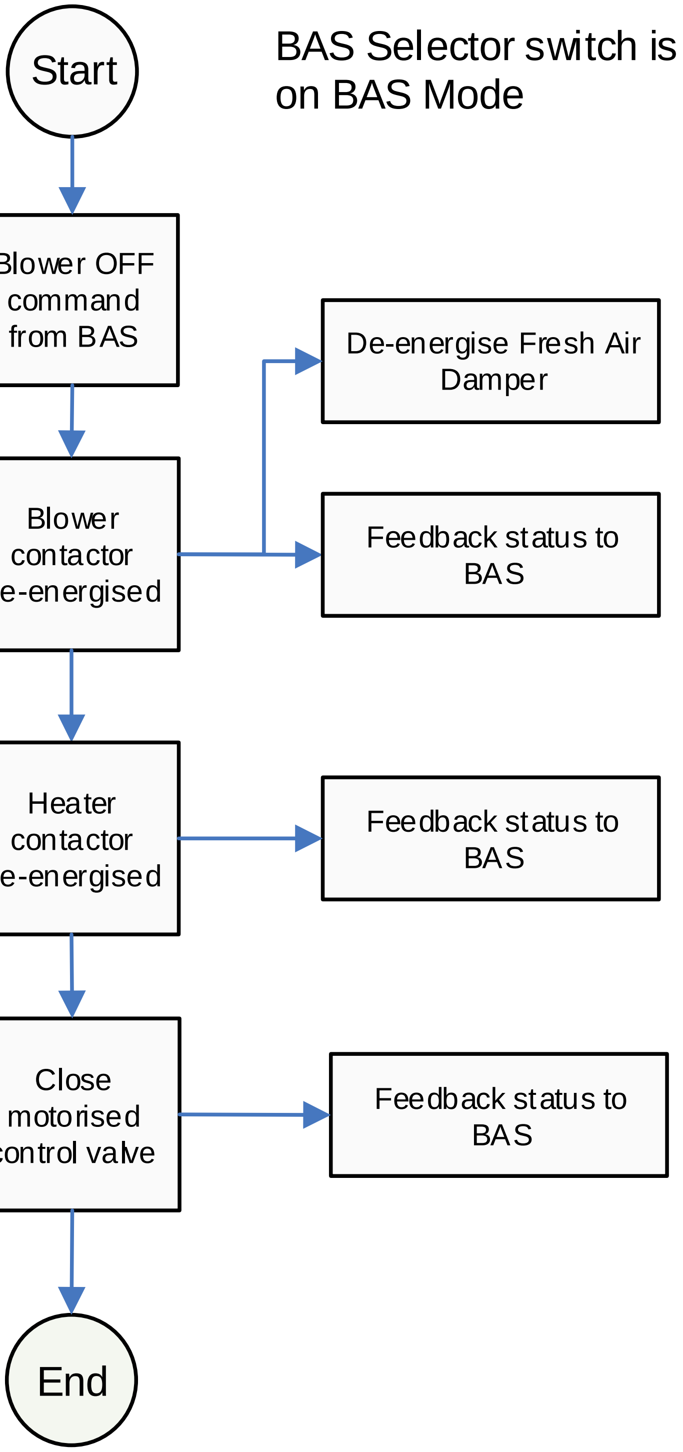
Typical Temperature and Relative Humidity Control for CAV AHU

BLOWER ON SEQUENCE



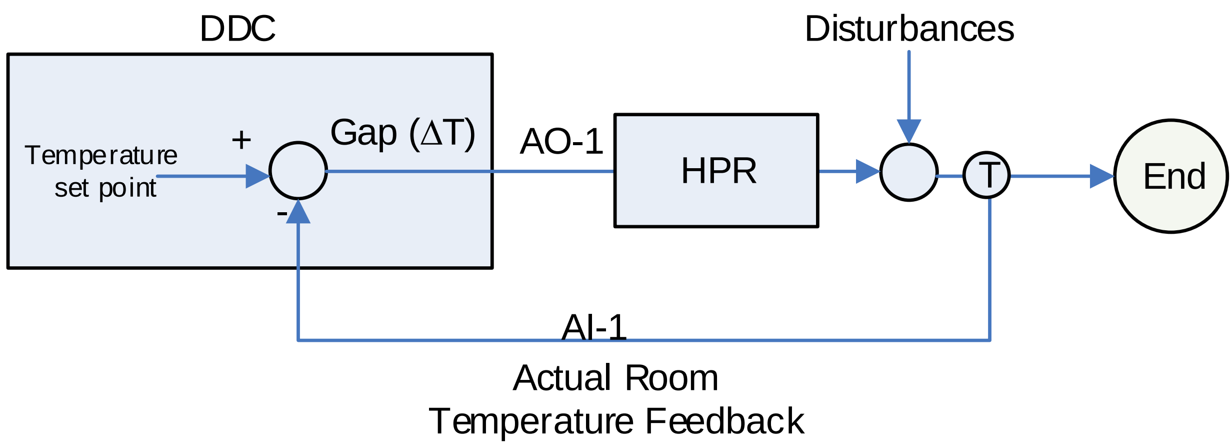
APPENDIX 6

TYPICAL BLOWER OFF SEQUENCE

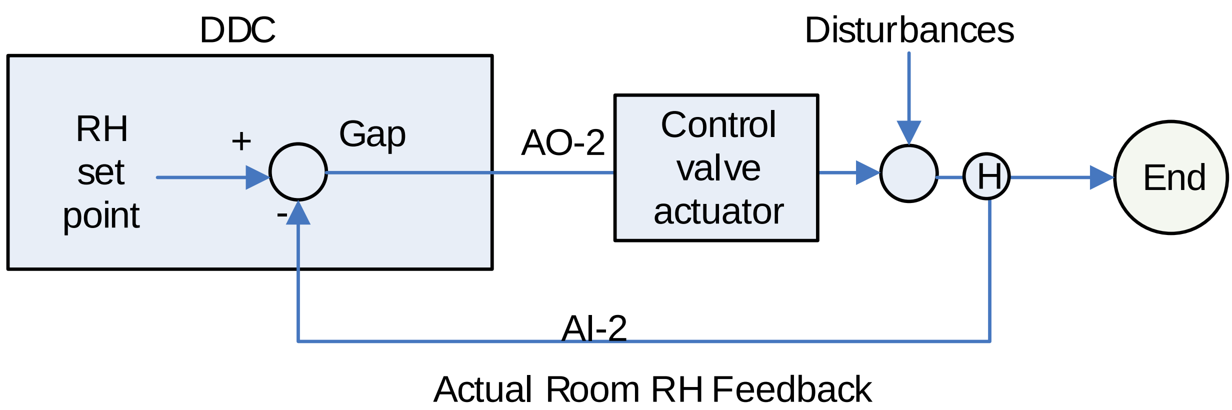


APPENDIX 7

Typical Temperature Control Sequence



Typical RH Control Sequence



Legend:

AO: Analog Output

AI: Analog Input

DDC: Direct Digital Controller

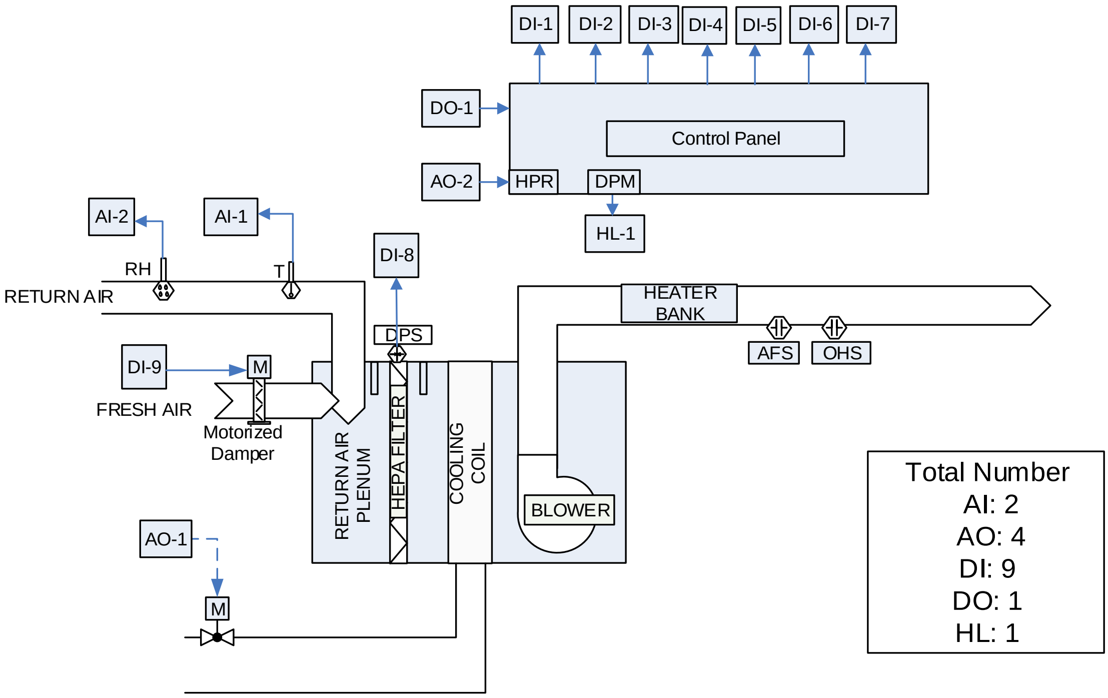
H: Humidistat

HPR: Heated Pressure Regulator

T: Thermostat

APPENDIX 8

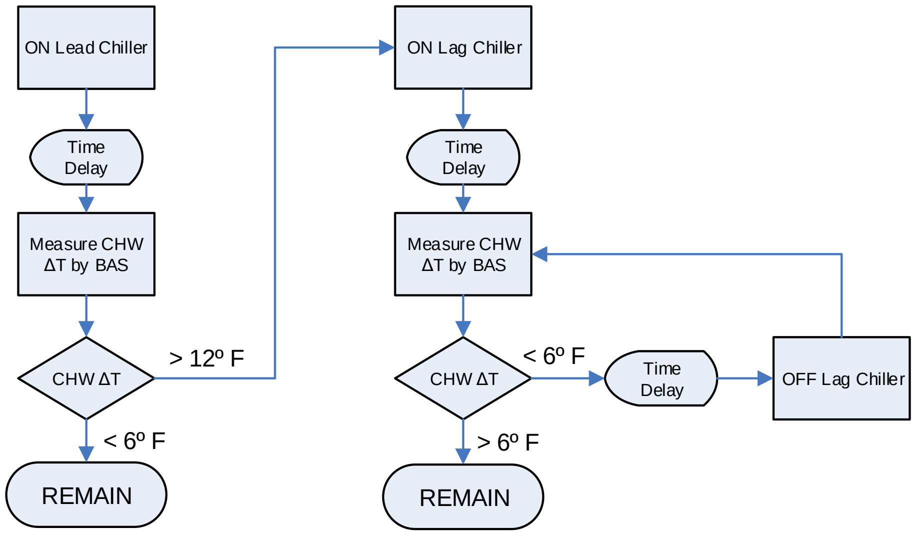
Typical AHU with Heater I/O Points (If RH Control Is Critical)



BAS INTERFACE																						
DO	DI									AI		AO				HL1	SOFTWARE					
START/STOP CONTROL	BLOWER ON/OFF STATUS	HEATER ON/OFF STATUS	OVERLOAD TRIP ALARM	EARTH FAULT TRIP	OVERHEATING SWITCH	AIR FLOW SWITCH	BMS/LOCAL SELECTOR	FILTER DIRTY ALARM	FRESH AIR DAMPER FEEDBACK	RETURN AIR TEMPERATURE	RETURN AIR HUMIDITY TEMPERATURE	MODULATING CONTROL VALVE	MODULATING HEATER	EXTERNAL DIGITAL TEMP DISPLAY	EXTERNAL DIGITAL HUMIDITY DISPLAY	DIGITAL POWER METER	ROOM AIR TEMP CONTROL (PI LOOP)	ROOM AIR RH CONTROL (PI LOOP)	SETPOINT ADJUSTMENT	SCHEDULING	ALARM GENERATION	TOTALISATION GENERATION
/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
D0-1	DI-1	DI-2	DI-3	DI-4	DI-5	DI-6	DI-7	DI-8	DI-9	AI-1	AI-2	AO-1	AO-2	AO-3	AO-4	HL-1						

APPENDIX 9

TYPICAL CHILLER SEQUENCING CONTROL LOGIC



Legend:
CHW ΔT: Chilled Water Temperature Difference (°F)

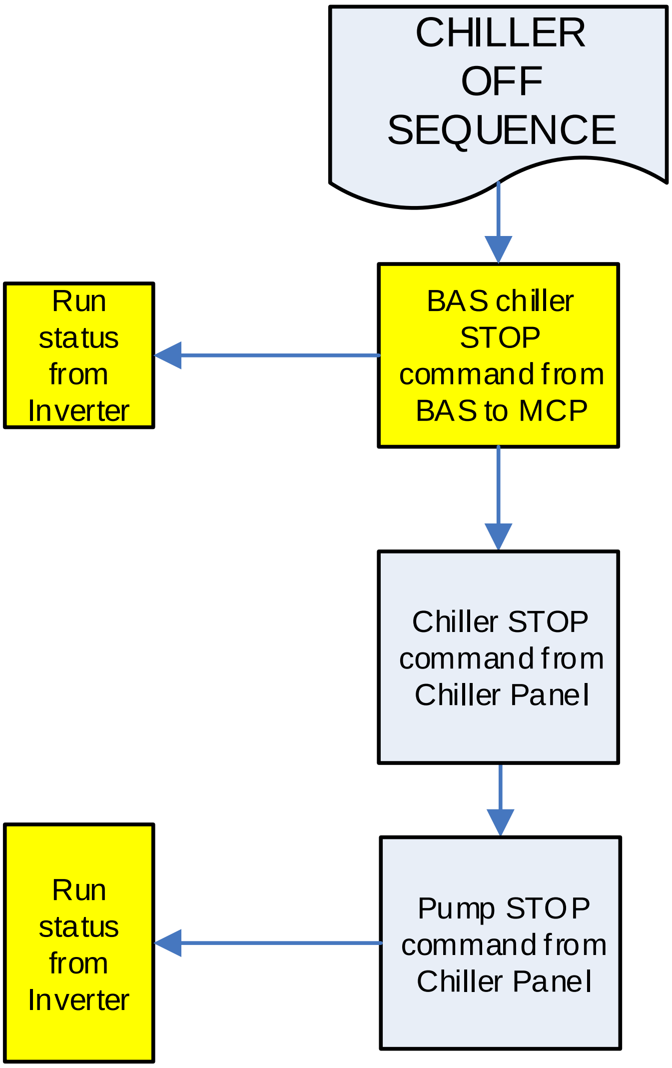
Chiller Scheduling

		Lead Chiller	Lag Chiller
WEEK 1	MONDAY	CH-1	CH-2
	TUESDAY	CH-3	CH-2
	WEDNESDAY	CH-1	CH-2
	THURSDAY	CH-3	CH-2
	FRIDAY	CH-1	CH-2
	SATURDAY	CH-3	CH-2
	SUNDAY	CH-1	CH-2
WEEK 2	MONDAY	CH-2	CH-1
	TUESDAY	CH-3	CH-1
	WEDNESDAY	CH-2	CH-1
	THURSDAY	CH-3	CH-1
	FRIDAY	CH-2	CH-1
	SATURDAY	CH-3	CH-1
	SUNDAY	CH-2	CH-1
WEEK 3	MONDAY	CH-2	CH-3
	TUESDAY	CH-1	CH-3
	WEDNESDAY	CH-2	CH-3
	THURSDAY	CH-1	CH-3
	FRIDAY	CH-2	CH-3
	SATURDAY	CH-1	CH-3
	SUNDAY	CH-2	CH-3

Repeat Schedule

APPENDIX 10

TYPICAL CHILLER STOP SEQUENCE



Legend:

MCP: Main Control Panel

APPENDIX 11

TYPICAL I/O POINTS FOR ACMV SYSTEM

EQUIPMENT			BAS INTERFACE																																							
			DO		DI									AI								AO					HLI				SOFTWARE						TOTAL NUMBER					
NO	EQUIPMENT DESCRIPTION	QUANTITY	START/STOP CONTROL	CONTROL VALVE	CONTACTOR ON/OFF STATUS	HEATER ON/OFF STATUS	OVERLOAD TRIP ALARM	EARTH FAULT TRIP / RCCB	BMS/LOCAL SELECTOR	FILTER DIRTY ALARM (HEPA ONLY)	STEP HEATER FEEDBACK (IF APPLICABLE)	CONTROL VALVE FEEDBACK (SWITCH)	FRESH AIR DAMPER FEEDBACK	RETURN AIR TEMPERATURE TRANSMITTER	CONTROL VALVE FEEDBACK (POTENTIOMETER)	RETURN AIR HUMIDITY TEMPERATURE TRANSMITTER	PRESSURE TRANSMITTER/DIFFERENTIAL PRESSURE TRANSMITTER	WATER TEMPERATURE TRANSMITTER	AMBIENT AIR TEMPERATURE SENSOR	AMBIENT AIR HUMIDITY SENSOR	DUCT STATIC PRESSURE	MODULATING CONTROL VALVE	MODULATING HEATER (IF APPLICABLE)	EXTERNAL DIGITAL TEMP DISPLAY (IF APPLICABLE)	EXTERNAL DIGITAL HUMIDITY DISPLAY	VARIABLE SPEED DRIVE	VARIABLE SPEED DRIVE (IF APPLICABLE)	VAV CONTROLLER	BTU METER/FLOWMETER	DIGITAL POWER METER (ABOVE 2.0 kWe ONLY)	ROOM AIR TEMP CONTROL (PI /ONN-OFF LOOP)	ROOM AIR RH CONTROL (PI LOOP)	SETPOINT ADJUSTMENT	SCHEDULING	ALARM GENERATION	TOTALISATION GENERATION	DIGITAL OUTPUT	DIGITAL INPUT	ANALOG INPUT	ANALOG OUTPUT	HLI	SOFTWARE
A	**ACMV SERVICES**																																									
I	**Chilled Water Plants (Water Cooler Chiller)**																																									
1	Main Air Cond Board - Incomer				/		/	/																						/					/	/						
2	Chillers		/		/		/	/	/																								/	/	/	/						
3	Chilled Water Pumps				/		/	/																																		
4	Condenser Water Pumps				/		/	/																																		
5	Cooling Tower				/		/	/																																		
6	Chiller isolation Valve (Common pipe ony)				/																																					
7	Cooling Tower isolation Valve (Common pipe only)				/																																					
8	Energy meter / Flowmeter																												/													
9	Supply & Return Chilled Water Header																/	/																								
10	Chilled water bypass														/							/																				
11	Ambient Condition																		/	/																						
II	**Chilled Water Plants (Air Cooler Chiller)**																																									
1	Main Air Cond Board - Incomer				/		/	/																						/					/	/						
2	Chillers		/		/		/	/	/																								/	/	/	/						
3	Chilled Water Pumps				/		/	/																																		
4	Chiller isolation Valve (Common pipe ony)				/																																					
5	Energy meter / Flowmeter																												/													
6	S & R Chilled Water Header																/	/																								
7	Chilled water bypass														/							/																				
8	Ambient Condition																		/	/																						
III	**Chilled Water Air Side**																																									
1	Temperature Control CAV AHU		/		/		/	/	/	/			/	/	/							/		/			/			/	/		/	/	/	/						
2	Temperature Control CAV FCU (MULTIUSER COMMON ZONE)		/	/	/		/	/	/	/		/	/	/								/		/			/			/	/		/	/	/	/						
3	Temperature Control CAV FCU (INDIVIDUAL USER CONTROLLED ZONE)				/		/	/	/	/		/	/											/			/			/	/											
4	Temperature & Humidity Control CAV AHU/FCU		/		/	/	/	/	/	/	/		/	/	/	/						/	/	/	/		/			/	/	/	/	/	/	/						
5	Temperature Control VAV AHU		/		/		/	/	/	/			/	/	/						/	/		/		/	/			/	/		/	/	/	/						
6	Heat Recovery Wheel / Enthalpy Wheel				/																																					
7	VAV Box																											/					/	/								
IV	**Unitary Package (Water Cooled/Air Cooled DX)**																																									
1	Temperature Control CAV WCP/ACP DX		/	/	/		/	/	/	/			/	/										/						/	/		/	/	/	/						
V	**Other System (ACMV)**																																									
1	ACSU				/																																					
2	All type of Ventilation Fans				/																																					
	TOTAL		0	0	0	0	0		0				0	0							0	0								0												

Note

1. For humidity controlled AHU with reheater, heater safety protections i.e flow switch, overheating switch shall be interlocked with blower fan contactor. No connection to DDC required.
2. Operation of on/off fresh air damper, inline booster fan, heat recovery wheel shall be interlocked directly with blower fan contactor. Only feedback status shall be relayed back to DDC controller.
3. VAV bos controller shall be connected to high level interface of BCS network. BCS shall be able to adjust room temperature set point and operation scheduling.
4. Chilled water pump, condenser water pump, cooling tower and associated isolation valve (for common pipe only) shall be interlocked directly with chiller switchboard complete with neccesary timers and relays. Operation of these ancillary equipments shall commence from chiller panel output signal. Only feedback status shall be relayed back DDC controller.

APPENDIX 12

TYPICAL I/O POINTS FOR COLD WATER, LIFT AND FIRE PROTECTION

			DI					SOFTWARE		
NO	EQUIPMENT DESCRIPTION	QUANTITY	ON/OFF STATUS	TRIP ALARM (OVER LOAD)	(BAS/AUTO)/MANUAL MODE-SELECTOR	LOW WATER LEVEL ALARM	HIGHT WATER LEVEL ALARM	ALARM GENERATION	TOTALISATION GENERATION	MAINTENANCE TIME REMINDER
B	**COLD WATER**									
I	**Pump Room**									
1	Water Transfer Pump		/	/	/			/	/	/
2	Suction Tank					/	/	/		
II	**Roof Tank Room**									
1	Hydropneumatic Pump		/	/	/			/	/	/
2	Water Storage Tank					/	/	/		
C	**LIFT**									
1	Lift			/				/	/	/
D	**FIRE PROTECTION**									
1	Main Fire Alarm Panel		/	/				/		
2	Hose Reel Pump		/	/				/		
3	Sprinkler Pump		/	/				/		
	TOTAL									