BCA ACADEMY

Building Automation Concepts, Technologies and Practices for Green Buildings

School of Graduate Development and Management

The Education and Research arm of the Building and Construction Authority

Building Automation Concepts, Technologies and Practices for Green Buildings

Objective

Smart automation technologies can lower a building's operating and maintenance costs and create a safe, comfortable, healthy and productive environment for building occupants. After attending the course, participants will have a basic understanding on how building automation technologies can be leveraged to increase the environmental sustainability of buildings. On top of that, the course will cover sensors and field instruments, control basics, tracking of building performance and energy management strategies for lighting and HVAC.

Award of Certificate

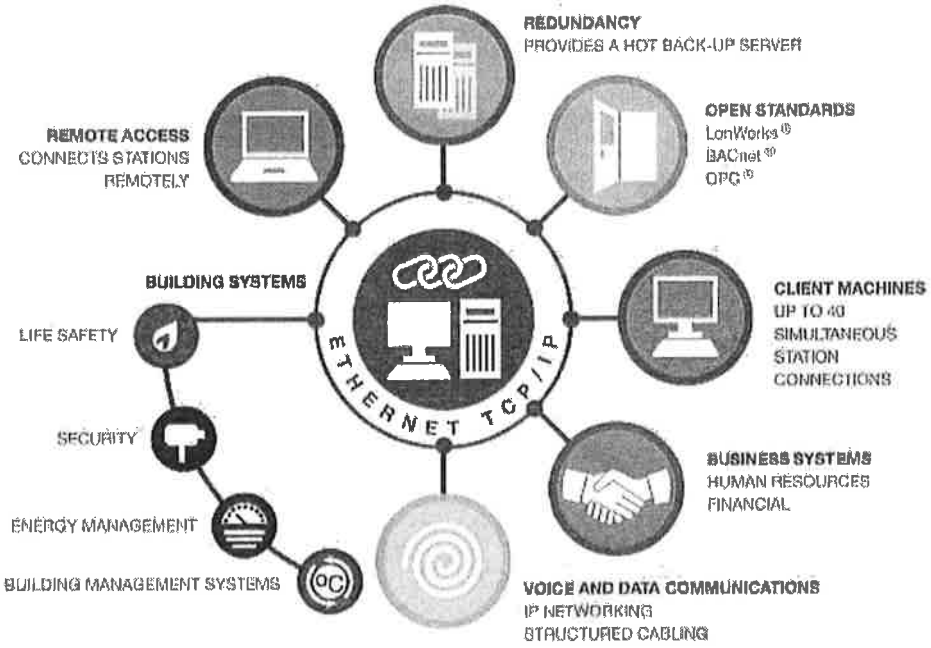
This course is assessment-based. To pass the course, a participant has to fulfil these requirements:

i. Achieved at least 75% class attendance; and
ii. Pass all the assessment(s) of the course.

A Certificate of Successful Completion (CSC) for the course will be issued to participants who have fulfilled the attendance and assessment requirements.

Building Automation Concepts, Technologies and Practices for Green Buildings

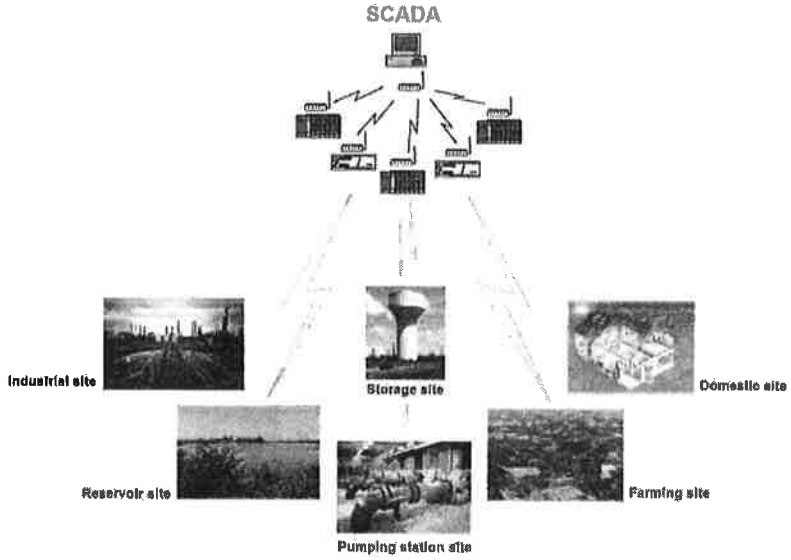


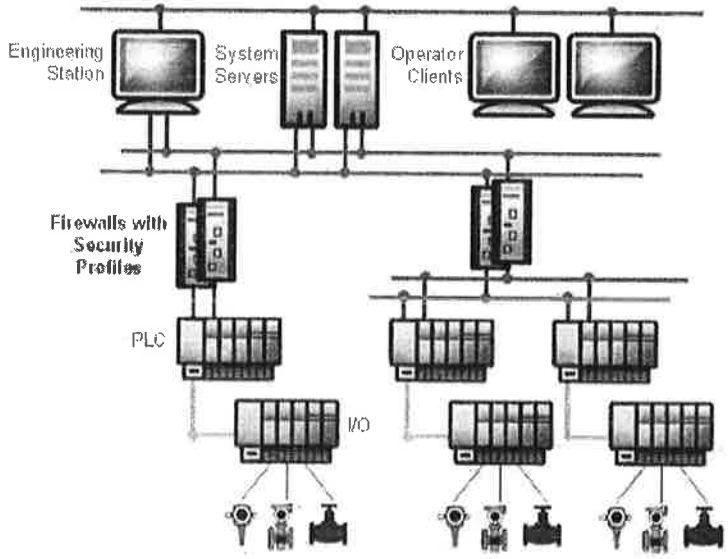




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6 Feb 2017

Industry Jargon, Terminology and Acronyms



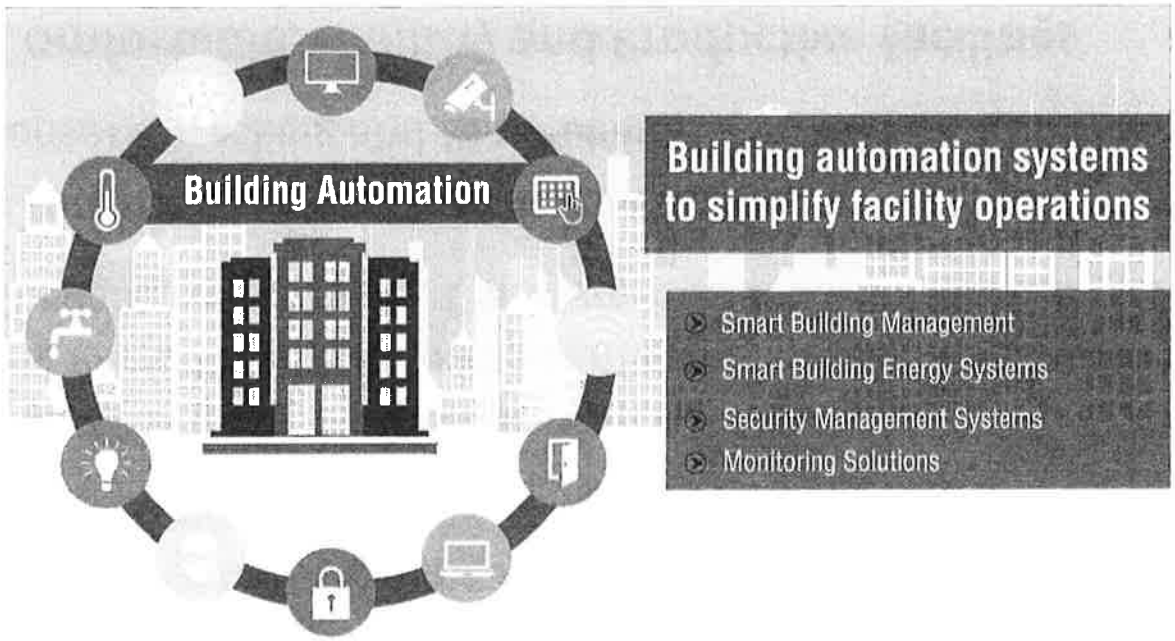


Building Automation Systems (**BAS**) also known as **Building Management Systems** (**BMS**), **Building Management and Control Systems** (**BMCS**), **Direct Digital Controls** (**DDC**) and **Building Controls.**

Other terms associated with Control Systems include:

- Supervisory, Control and Data Acquisition (**SCADA**)
- Programmable Logic Controllers (**PLC**)
- Energy Management System (**EMS**)
- **Modbus**, **Bacnet**, **Lonworks** – all refer to communications protocols
- '**Front End**' – legacy term used to refer to the BMS Operator Workstation

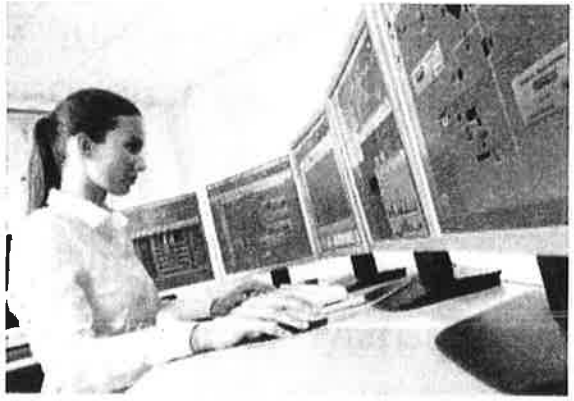
What is a Building Automation System?



- **Centralized**, **interlinked**, **networks of hardware** and **software** to monitor and control a building's technical systems and services such as air-conditioning, ventilation, lighting, vertical transportation systems and hydraulics.
- Latest systems are based on **open communications protocols** and are **web-enabled**, allowing integration of systems from **multiple-system vendors** and access from **anywhere in the world**.

Role of Building Automation System in Green Buildings

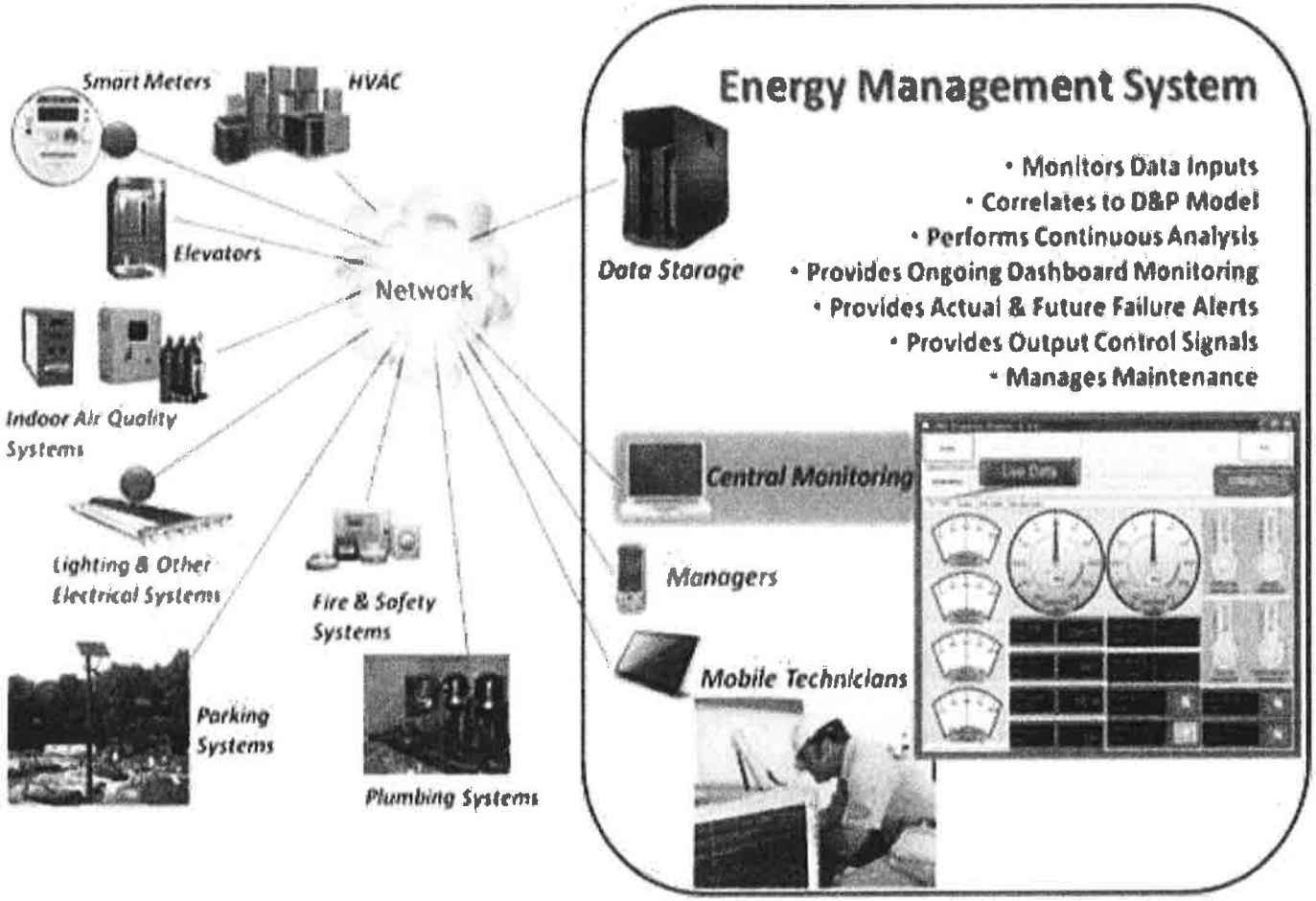






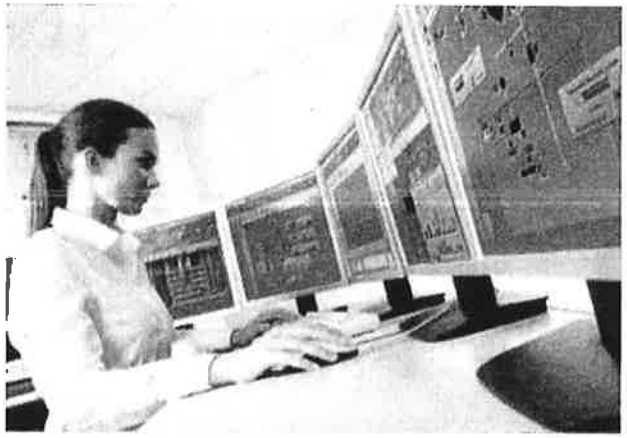
- **Higher Energy/Water Efficiency**
  - Occupancy Sensing, Lighting Automation, Dynamic Setpoints/Reset Strategies, Demand Response, Weather Programmes
- **Lower Operating and Maintenance Cost**
  - Building Performance Tracking, Automated Alerts, Performance Metrics, Trend Logging and Alarms, Computerized Facility Maintenance
- **Better Indoor Environmental Quality**
  - IAQ Sensors, Tracking and Maintaining Thermal Comfort
- **Safe, Comfortable, Healthy and Productive Facilities**
  - Enhanced Indoor Environmental Quality, Occupant-controlled Setpoints and Overrides

Energy Management



The correct operation of a BMS is essential for **optimal building performance** and offers the **most cost-effective option** to achieve **energy savings** in buildings.

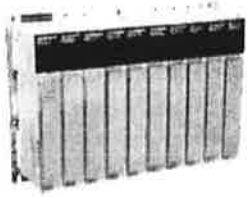
Basic Functions of a Buiding Management System



The four basic functions of a BMS are:

- **Controlling**
- **Monitoring**
- **Optimizing**
- **Reporting** on the building's facilities, mechanical and electrical systems for consistent comfort, safety and energy efficiency.





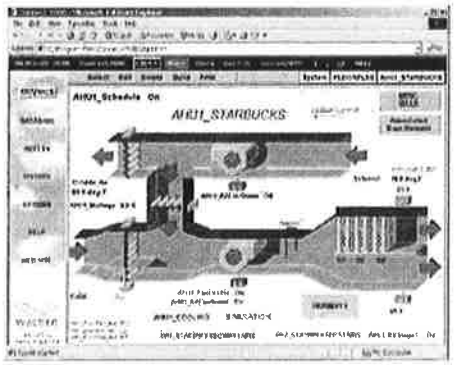




A BMS consists of the following elements:

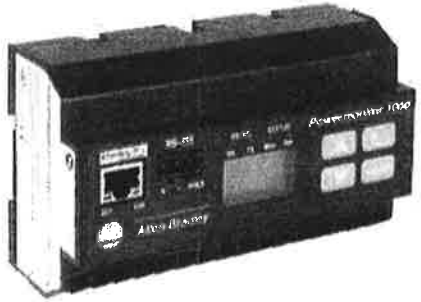
- **Hardware** – such as sensors, actuators and controllers
- **Software programmes** displaying and recording real-time information, programme to design control strategies
- **Networks** – including interfaces with other control systems

Major Components of a BMS



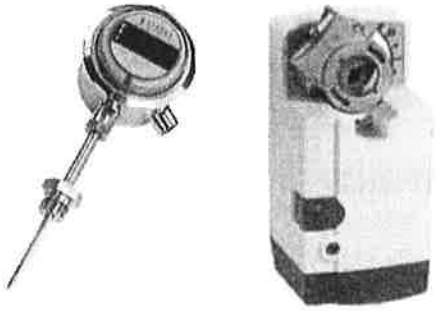
User Interface

- A **computer based graphical software application** that allows the user to **interface** with the system.
- Provides the user **full control** over the Building Management System.
- Interface may be via computer workstations, laptops, PDAs, smart phones or the internet.



Controllers

- **Electronic devices** that **monitor** and **change the operations of a specific system**.
- The operational conditions include **output variables** of the system which can be affected by adjusting **certain inputs**.

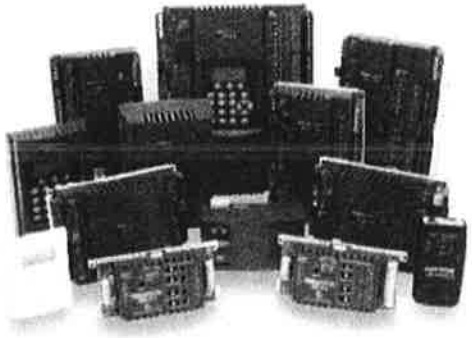


Input/Output Devices

- **Input devices** can range from **temperature sensors** to **pressure transmitters**.
- **Output devices** include **valve and damper actuators** and **variable speed drives**.

Typical System Components – BMS Hardware

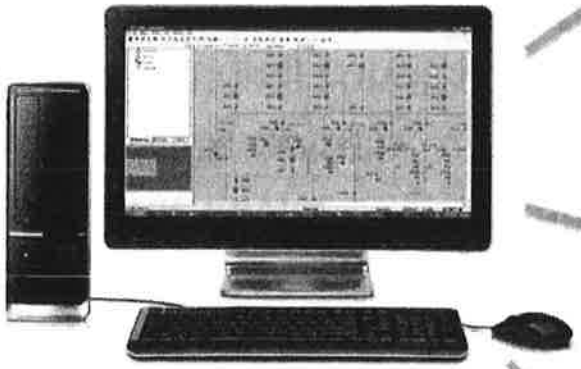
Range to Suit Applications



High Point Counts

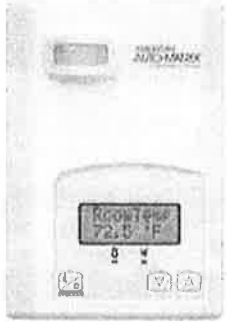


Operator Workstations



Built In Displays





Limited Features



Application Specific



Small Point Counts

Typical System Components – Field Devices

Damper Actuators



Variable Speed Drives (VSD)



Air Flows Pressures



Voltages Currents



Valve Actuators



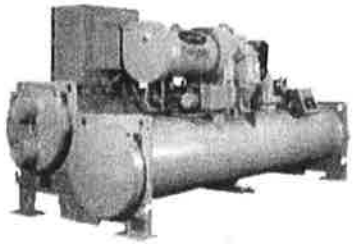
Pumps Fans Motors



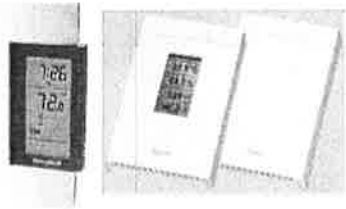
Water Flows Pressures



Chillers / Boilers Cooling Towers



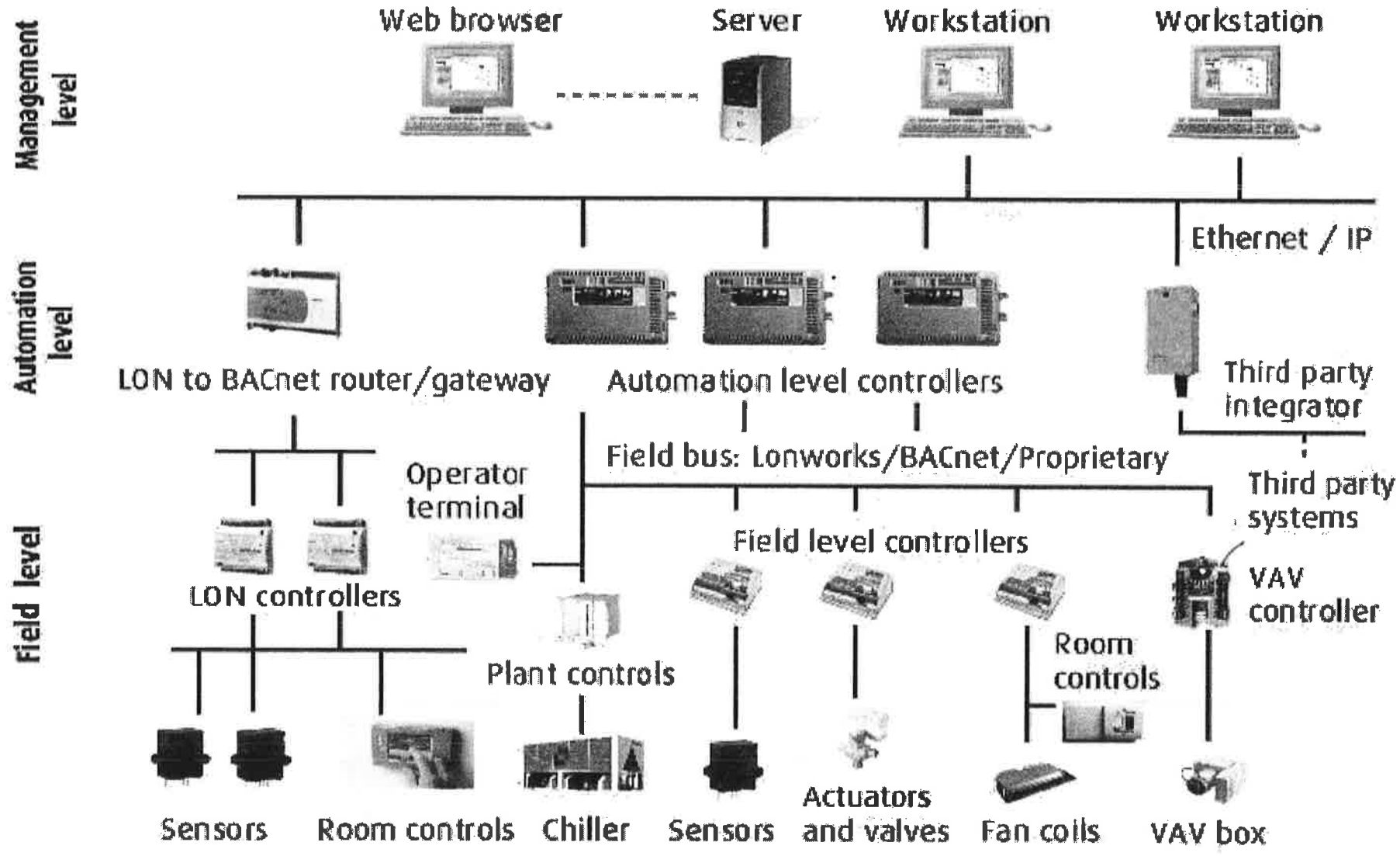
Temperature Relative Humidity CO2



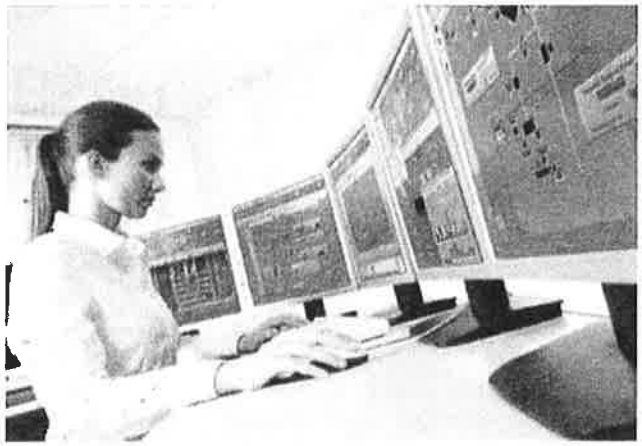
Low Level and High Level (HLI) Connections



Typical System Components – Networks



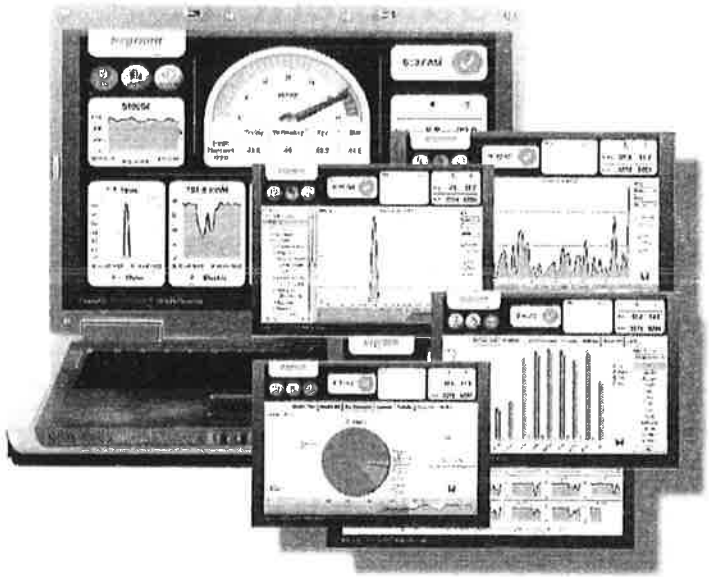
Management Level of BMS



The top or management level of a BMS is an **operator administration workstation** that can **communicate with, interrogate**, and **control** any of the **controllers** and **devices** on the network.

A BAS **monitors, supervises, controls,** and **reports on building control systems**. These systems may include access control, video surveillance, fire alarm, HVAC control, programmable lighting, and electric power management.

Enhancement of Energy Performance and Building Operation

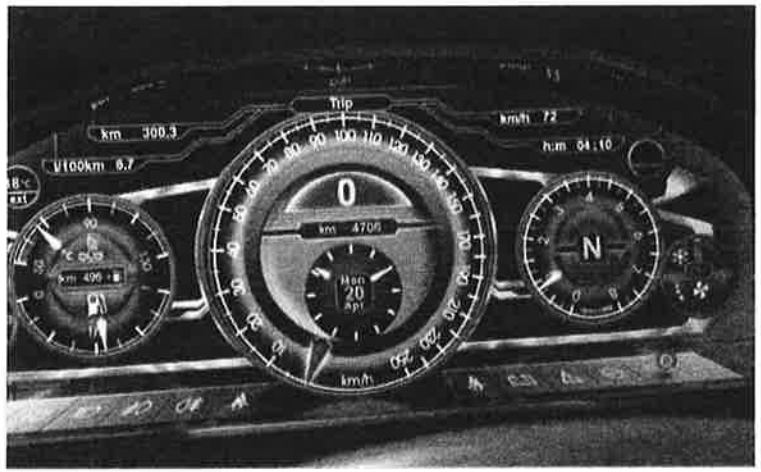


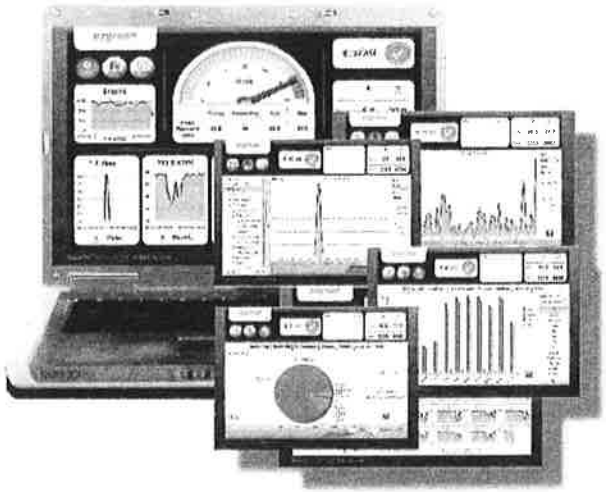
Dashboard view of building data to visualize **energy, environmental** and **portfolio performance metrics.**

Collect energy and operational metrics into a **central repository** for **enterprise-wide analytical** and **optimization capability**.

Improve facility operations by **analyzing real-time equipment alerts** and **automated service requests** to **service key building equipment** more efficiently.

Customized System Dashboards



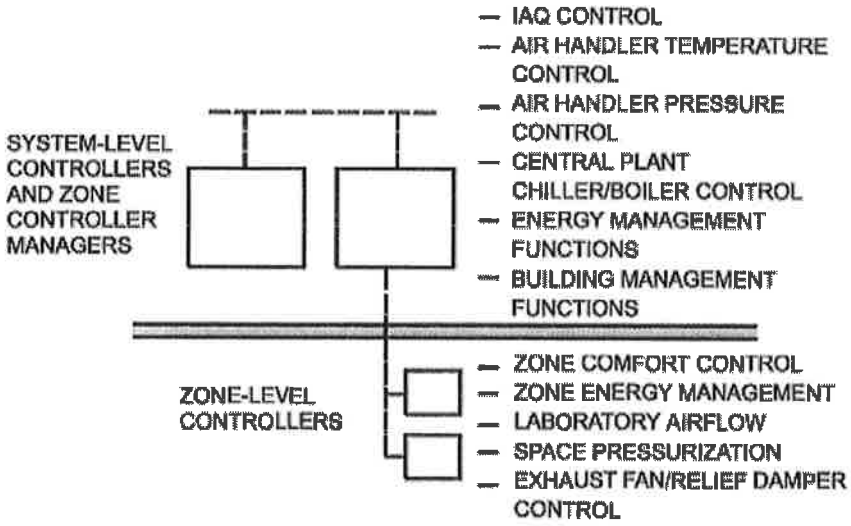


Like a car dashboard, a system dashboard provides a summary of **critical building alarms**, **energy information** and **key maintenance items** at a glance.

The dashboard summarizes all of the critical building information and present it in the **proper format** for **different members** of the **facility management team**.

An **operating engineer** requires detailed information about **specific mechanical systems**, while the **property manager** needs a summary of **energy and operating expenses** over the last 4 weeks.

System Level and Field Level Controllers



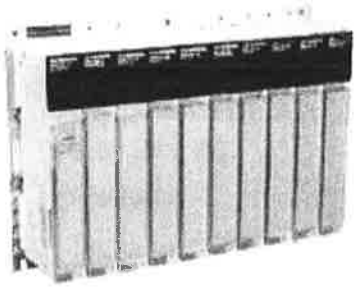
System Level or **Building Level Controllers**

- **Networked back** to the **management level**.
- Manage **HVAC equipment directly** (typically, major components such as air handling units) or **indirectly through lower-level controllers** that are networked downstream.
- Handle the **operations** of **all downstream field level controllers**, **collect and maintain data**, and can **operate** as **stand-alone units** if communication is lost to the management level.
- Have a **peer-to-peer relationship** with other controllers.

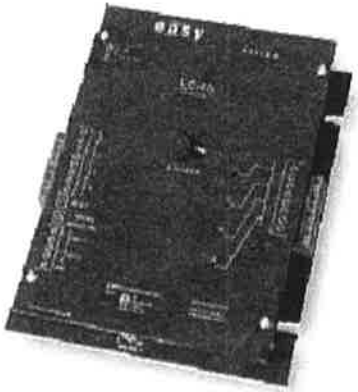
Field-level Controllers

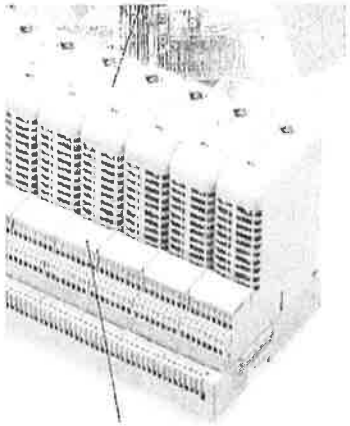
- Serve **building floors**, and **specific areas**, **applications**, and **devices**.
- Limited controllers, in terms of both functionality and connectivity.

Typical Controllers



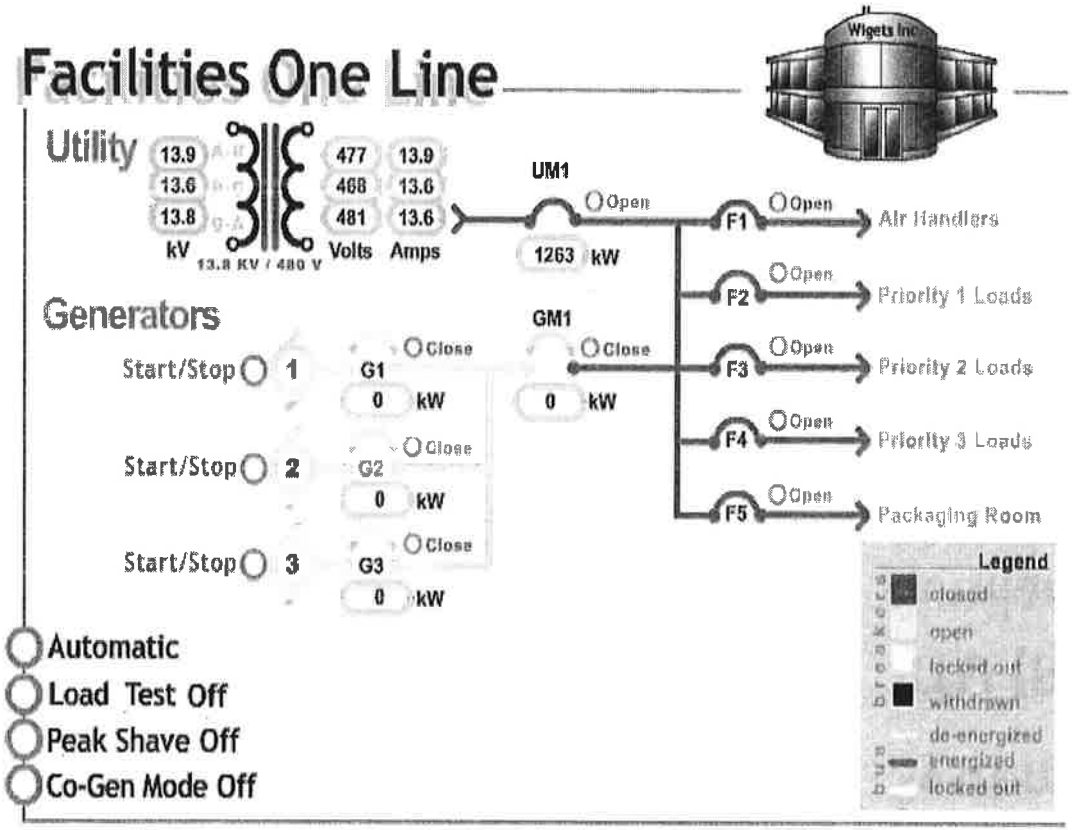






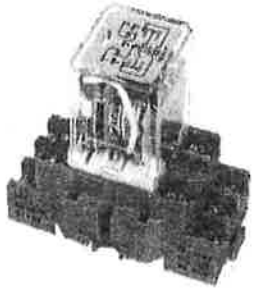
- **DDC (Direct Digital Controllers)**
  Mostly used in Building Management Systems.
- **RTU (Remote Terminal Units)**
  Similar to DDC but mostly used in remote sites for telemetry purposes.
- **PLC (Programmable Logic Controllers)**
  Mostly used in manufacturing plants and critical commercial facilities like hospitals, airports and mass rapid transit facilities.
- **DCS (Distributed Control System)**
  Mostly used in oil and gas plants.

Input and Output Devices

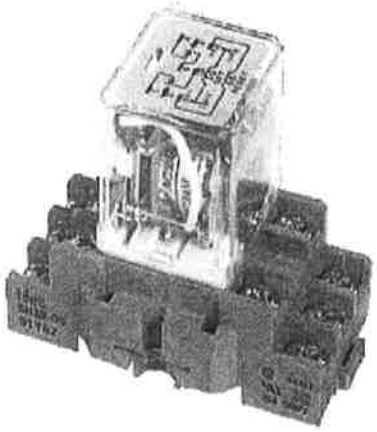


Basic Inputs and Outputs

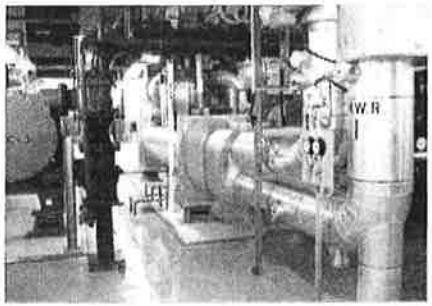
- **Digital Input or Analog Input**
- **Pulse Input or Pulse Width Modulation Output**
- **Digital Output or Analog Output**



Digital Input and Output







Chillers & Pumps



Lighting

Digital Inputs (DI)

Open or Closed Dry Contact

Signal “0” or “1” to the Controller

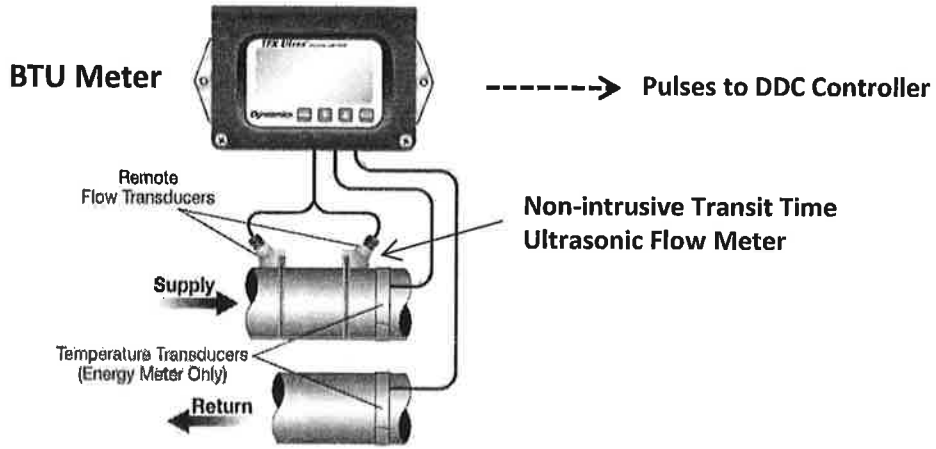
Examples:

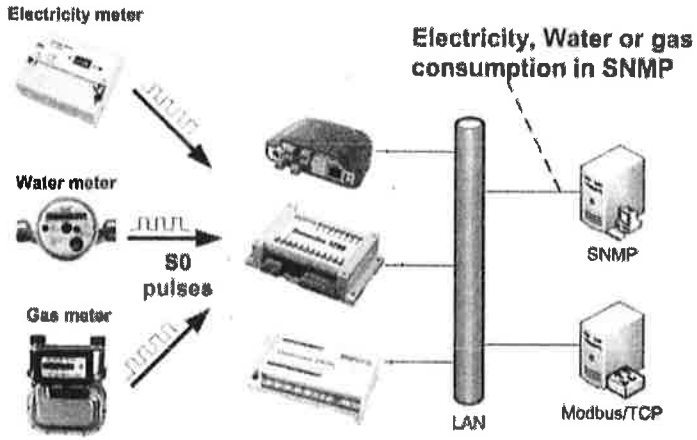
- **Lights On/Off**
- **Doors Open/Closed**
- **Fans Running/Not Running**
- **Motor Trip Alarm**
- **Filters Clean/Dirty**

Digital Outputs (DO)

- **Switch On/Off Lights**
- **Switch On/Off Pumps**

Pulse Input Sensors





Pulse Inputs

Signal **"0"** or **"1"** to the controllers

Examples are:

- **KWH Meters**
- **Flow Meters**
- **BTU Meters**
- **Push Buttons**

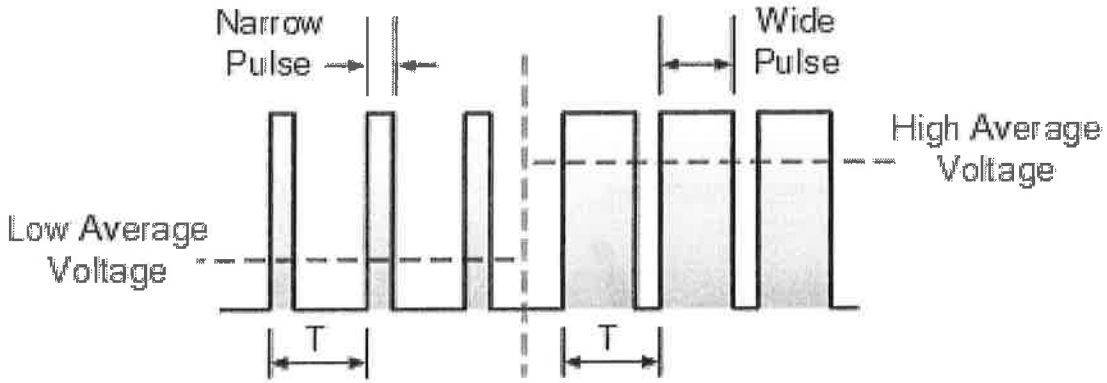
SNMP (Simple Network Management Protocol) is an Internet-standard protocol for collecting and organizing information about managed devices on IP networks. Devices that typically support SNMP include routers, switches, servers, workstations and printers.

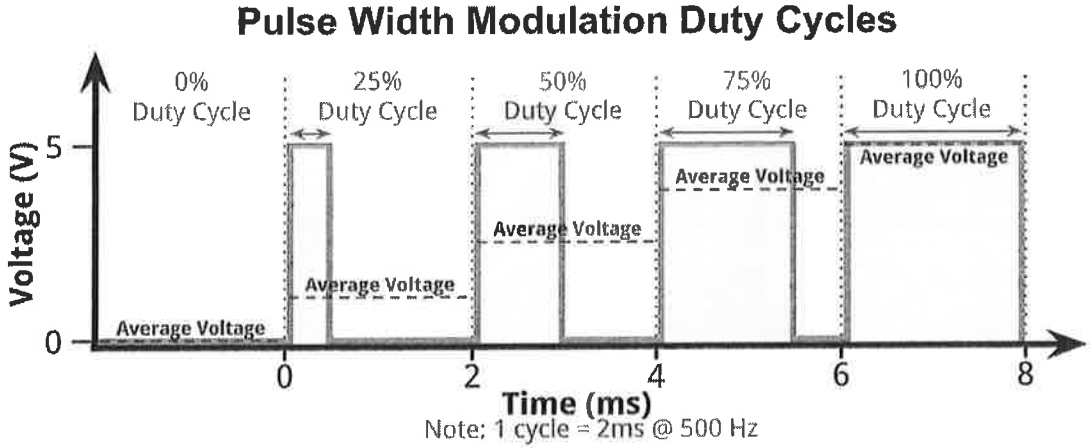
Modbus is a serial communications protocol originally developed for PLCs. It has become a de facto standard communication protocol commonly for connecting industrial electronic devices such as VSDs, power meters and water flow meters.

TCP/IP (Transmission Control Protocol/Internet Protocol) is the basic communication language or protocol of the Internet.

Modbus TCP/IP uses TCP/IP and Ethernet to carry data of the Modbus message structure between compatible devices.

Pulse Width Modulation



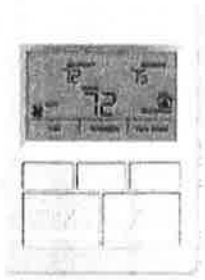


Note: 1 cycle = 2ms @ 500 Hz

PWM output is excellent for **time-proportional control** of **heaters.**

Analog Input Sensors

Temperature Sensors



Space



Air Duct



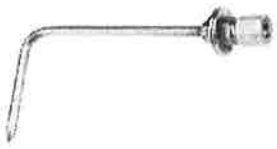
Immersion

Temp/RH Sensor with RS232 Output
Measured values are also converted to other humidity interpretation: dew point temperature, absolute humidity, specific humidity, mixing ratio, specific enthalpy.





Integrated Temp/ RH Transmitter



Static Pressure Sensor (Pitot Tube)



Differential Pressure Transmitter



Indicating Differential Pressure Transmitter

Analog Inputs (AI)

- **Analog sensors** or **transducers** issuing **current** , **voltage** or **resistance** readings to the controller.
- **Standard current sensors** providing output signals of **4 to 20mA** , **0 to 20mA** to the controller for processing.
- **Standard voltage sensors** providing output signals of **O-5 V, 1-5V, 2-10V** or **0 - 10V** signals to the controller.
- Examples
  - **Temperature sensors**
  - **Humidity sensors**
  - **Pressure sensors**
  - **Water/Air flow sensors**
  - **CO2 / CO sensors**
  - **Power meters (kW)**



Inline Electromagnetic Flow Meter

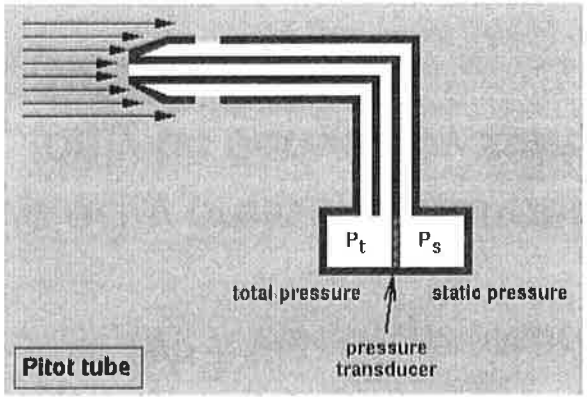


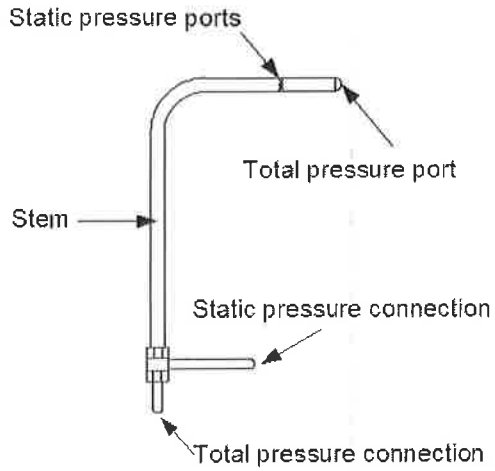
Power Meter

Basic Duct Hydraulics – Static Pressure



Magnehelic Gauge for Pressure Measurement

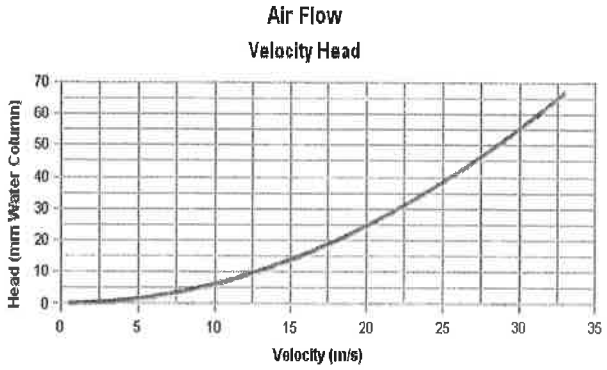


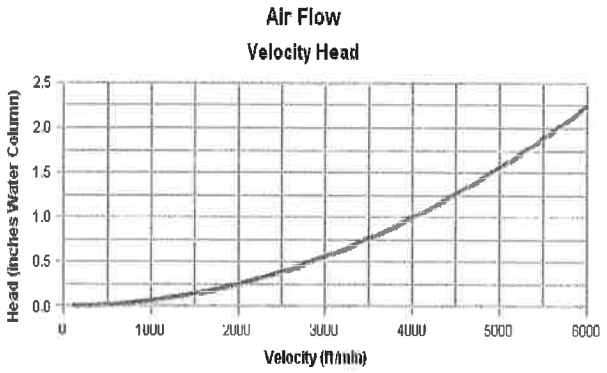


Static Pressure

- The pressure created by air (whether in motion or not) confined in an enclosed area such as a duct or building due to its **potential energy**.
- Static pressure, denoted **SP**, is exerted **perpendicularly** on **all interior walls of the enclosure** (duct or building) with respect to a **reference pressure outside the enclosure**.
- When static pressure is **above atmospheric pressure,** it is **positive** and when **below** atmospheric pressure, it is **negative**.

Basic Duct Hydraulics – Velocity Pressure





Velocity Pressure

The pressure created by air **moving at a velocity** due to its **kinetic energy**. Velocity pressure, denoted **VP**, is always **exerted in the direction of airflow** and is always **a positive value.** Velocity pressure and velocity are related by the equation:

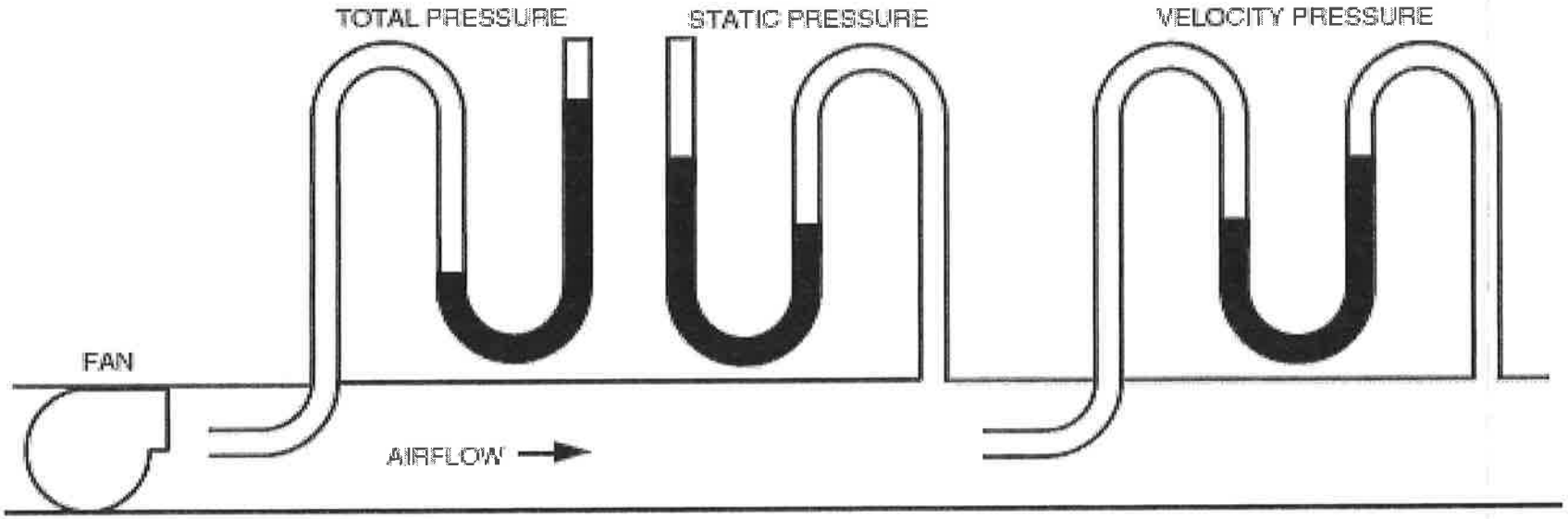
$$V = 1.3\ VP^{1/2}$$

Where V= Velocity in m/s

VP = Velocity pressure in pascals (Pa)

Velocity pressure cannot be measured directly. It can only be derived by **subtracting static pressure from total pressure**.

Basic Duct Hydraulics – Pressure Measurement



A. PRESSURE IN THIS DUCT ABOVE ATMOSPHERIC PRESSURE

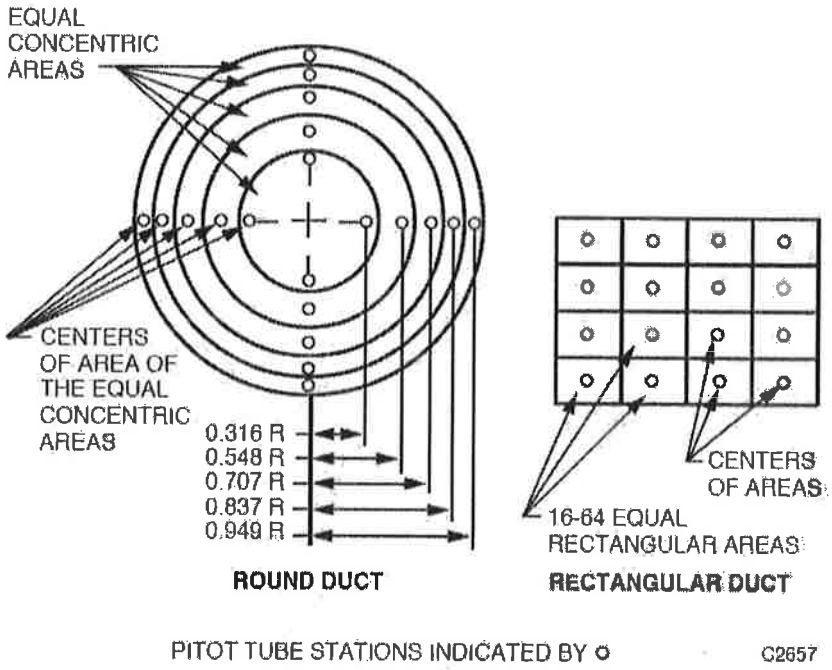
Total Pressure

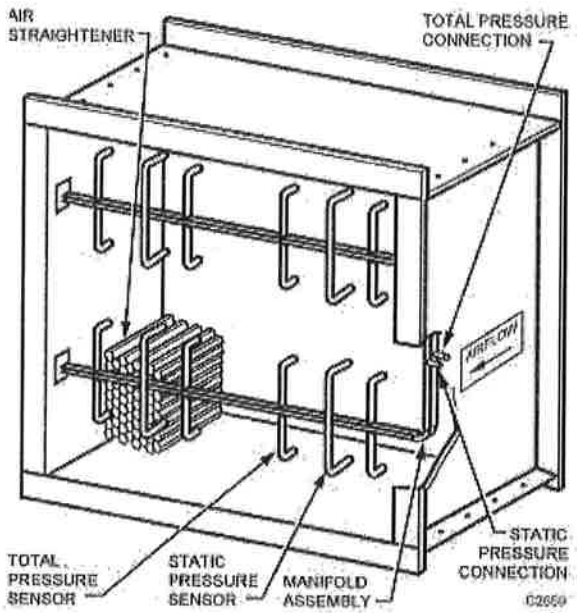
The algebraic sum of **Velocity Pressure (VP)** plus **Static Pressure**

Total pressure is derived:

TP = VP + SP

Air Flow Measurement with Air Flow Measuring Stations



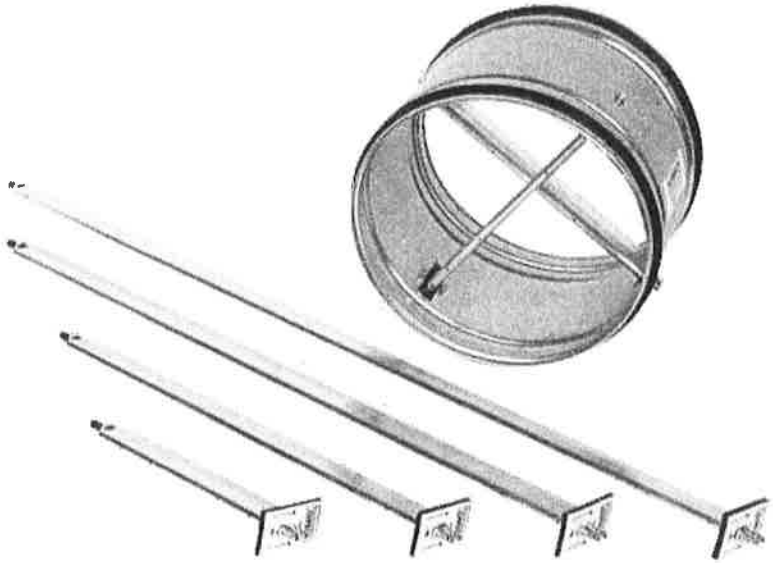


Averaging Flow Measuring Station

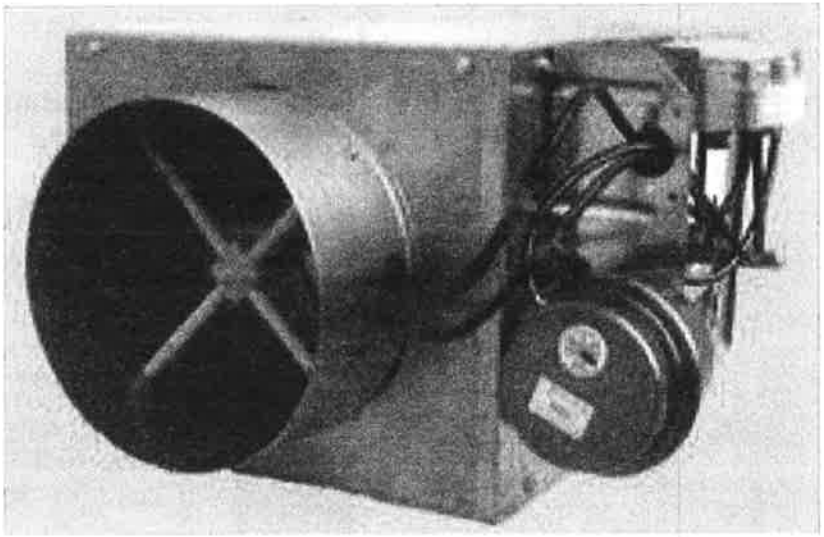
The **velocity** of the air stream is **not uniform** across the cross-section of a duct. **Friction slows the air moving close to the walls** so the velocity is greater away from the wall.

To determine the **average velocity**, a series of velocity pressure readings at **points of equal area** is found. These readings across the duct cross-section are known as **traverse readings**. Figure above shows recommended pitot tube locations for traversing round and rectangular ducts. In round ducts, velocity pressure readings at the centers of the areas of equal concentric areas are taken.

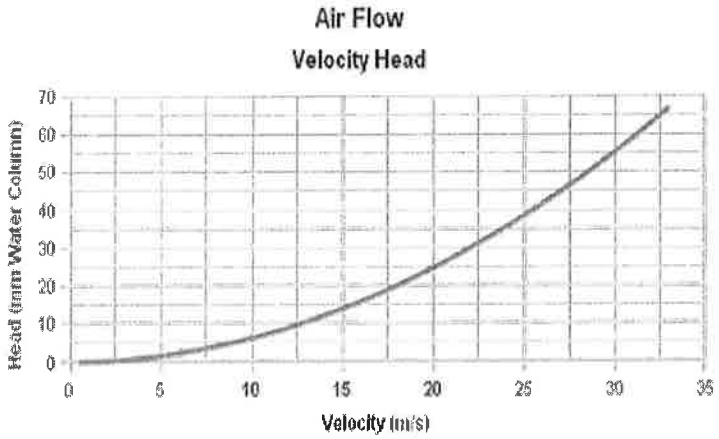
Air Flow Measurement with Probe Type Sensors



Air Flow Measurement Probes



VAV Box Cross-Flow Sensor



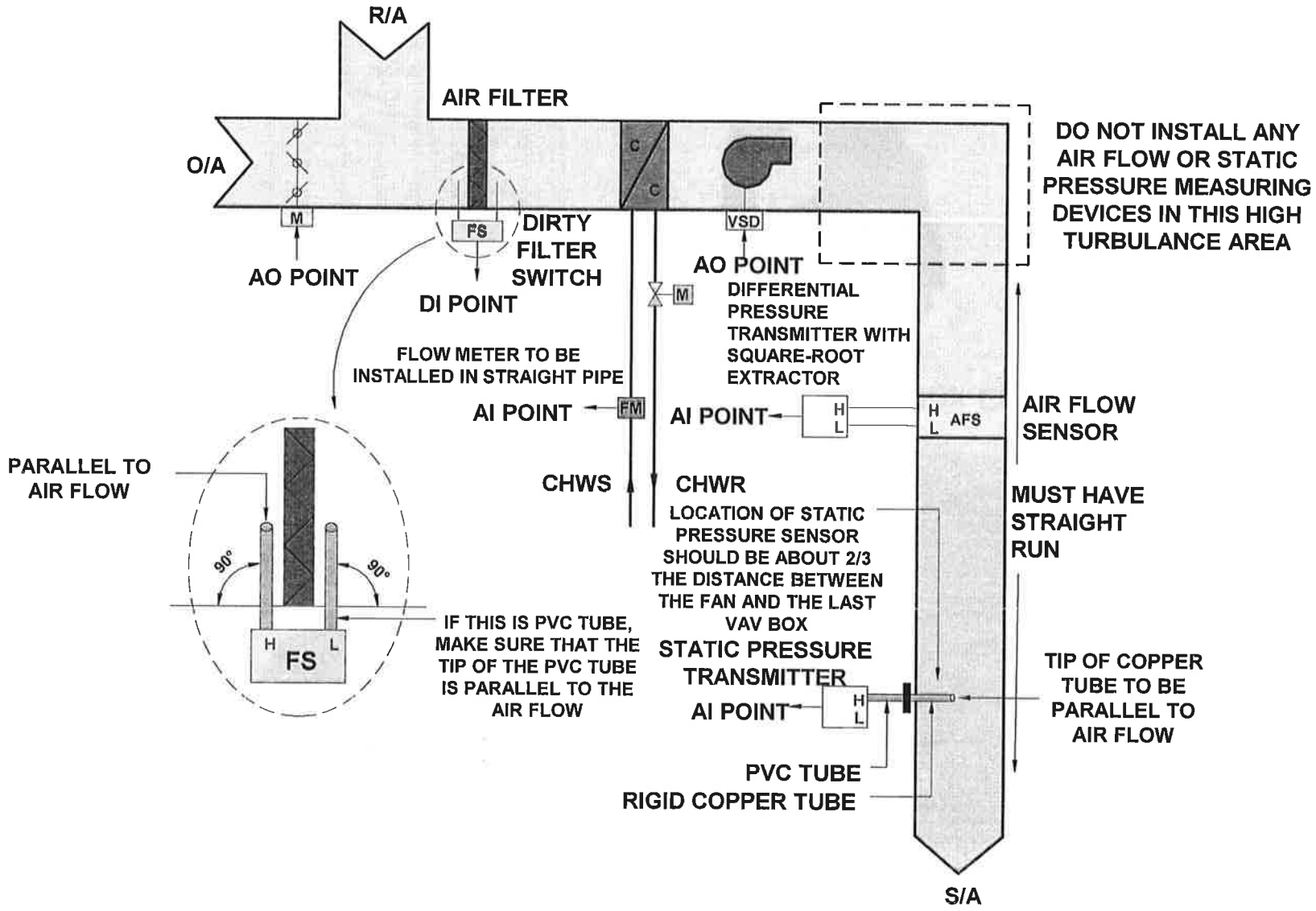


Differential Pressure Transmitter (Linear Output)



Differential Pressure Transmitter (Square Root Extraction Output)

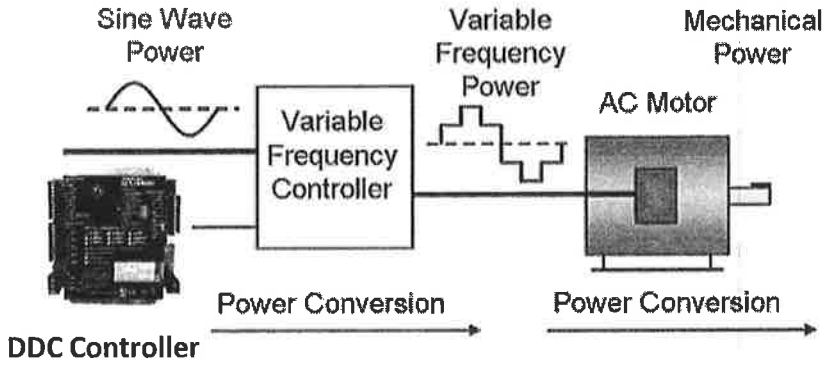
Correct Method of Installing Pressure and Flow Devices

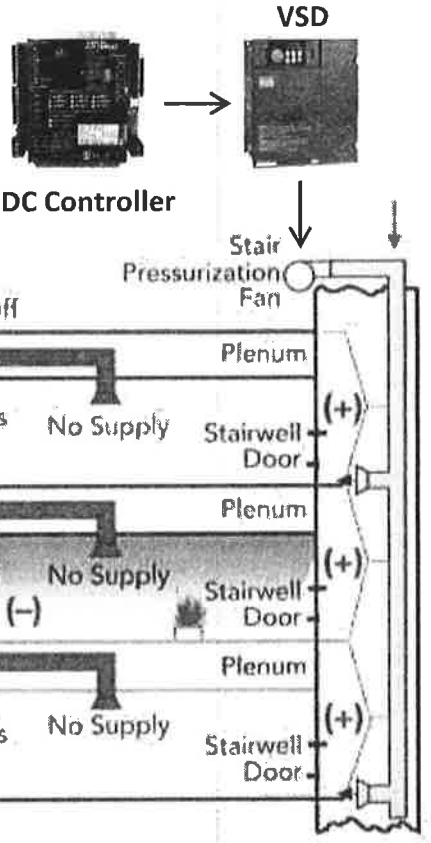


Analog Output

Analog Outputs (AO)

- Controller issues **current** or **voltage** to the field actuators
- **Standard current output :**
  4-20mA
  0-20mA
- **Standard voltage output:**
  0-5V
  1-5 V
  0-10V
  2-10V







FCU Valve Actuator



AHU Valve Actuator



Damper Actuator

Temperature Sensor Technologies

Temperature sensors technologies include: **RTD** (Resistive Temperature Device), **Thermistor**, **Thermocouple** and **IC** (Integrated Circuit).

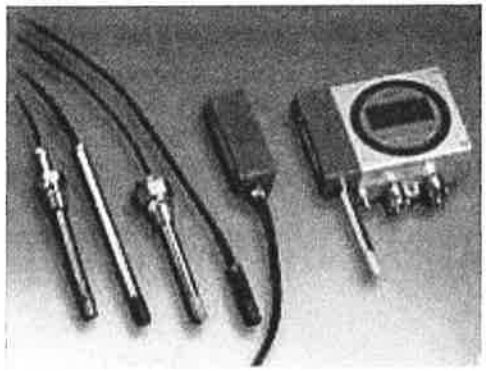
For HVAC applications, RTD and Thermistor are most appropriate.

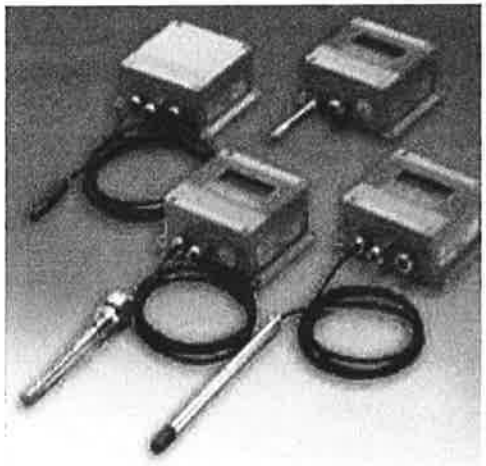
↓

	RTD	Thermistor	Remarks
Material Used	**Pure Metals e.g. Platinum, Nickel**	**Ceramic or Polymer Materials**	
Temperature Range °C	**(-200 to 800)**	**(-55 to 300)**	
Sensitivity	**Good**	**Excellent**	
Temperature Coefficient	**Positive**	**Negative**	
Typical Resistance Values Ω	**100; 1,000**	**10K; 20K; 100K**	
Typical Accuracy	**±0.15 °C, ±0.3 °C**	**±0.2 °C**	
Best Accuracy	**±0.03 °C**	**±0.02 °C**	**Green Mark for Chiller Plant: ±0.05 °C**
Maximum Cabling Distance for 2-Wire Circuit	**30 metres**	**1,000 metres**	**For RTDs, better to use PT 1,000 or use RTD transmitters**
Response Time	**Good**	**Excellent**	
Typical Temperature Stability	**<0.05 °C over 5 years**	**0.13 °C over 5 years**	

High accuracy temperature sensors should have NIST traceable calibration certificates with data points and a Resistance vs. Temperature (R/T) chart in 0.01°C increments

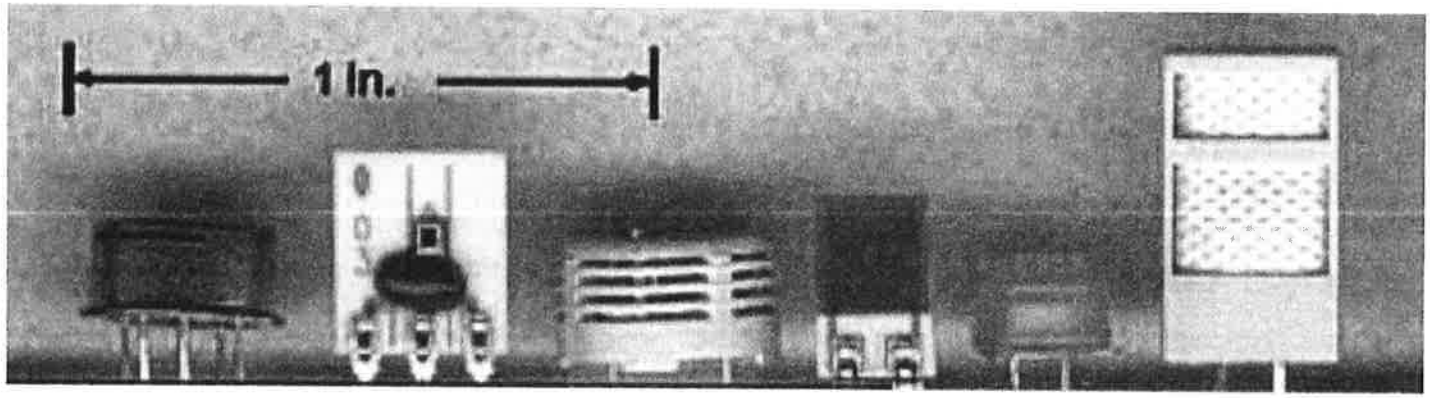
Humidity Sensor Technologies





- **Capacitive**
- **Resistive**
- **Thermal Conductivity**

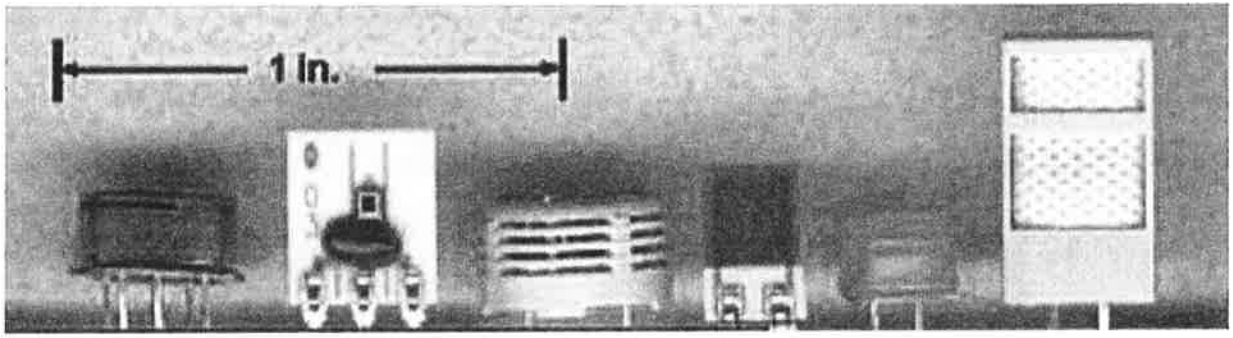
Capacitive Humidity Sensors



Widely used in **industrial, commercial** and **weather telemetry** applications.

Produced in a wide range of specifications, sizes and shapes including integrated monolithic electronics.

Capacitive Humidity Sensors



Change in capacitance is typically 0.2 – 0.5 PF for a 1% RH change, while the bulk capacitance is between 100 and 500 PF at 50% RH at 25°C.

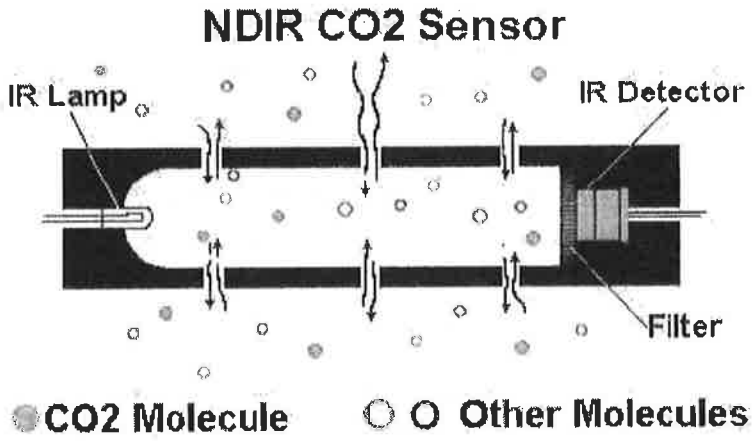
Capacitive sensors are characterized by **low temperature coefficient, ability to function at high temperatures** (up to 200 °C), **full recovery from condensation** and **reasonable resistance** to **chemical vapours.**

The response time ranges from 30 to 60 sec for a 63% RH step change.

CO_2 Sensor Technologies

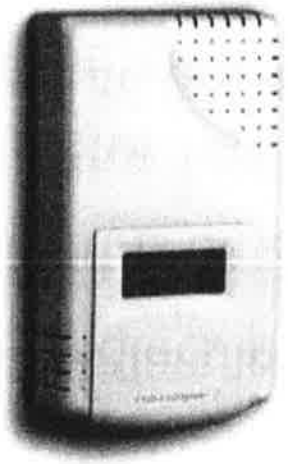
	Contact Type	Non-Contact Type
Types	▪ Electrochemical ▪ Solid Electrolyte ▪ Contact Combustion ▪ Semiconductor	▪ Non-Dispersive Infrared Radiation (NDIR) ▪ Photo Acoustic
Pros	▪ Possible to measure several kind of gases ▪ Fast response ▪ Low cost, light weight	▪ High accuracy of measurement ▪ Long life span ▪ Low power consumption
Cons	▪ Accuracy of measurement ▪ Short life span	▪ Impossible to measure monatomic molecular gases ▪ Comparatively higher cost

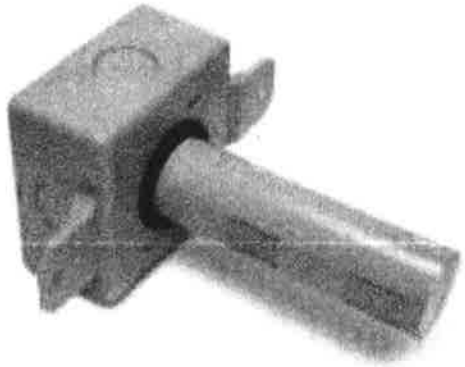
Non-Dispersive Infrared Radiation CO^2 Sensors



- **CO_2 molecules absorb light** at a specific wavelength of **4.46 µm (infrared range).**
- Gas molecules diffuse into sensing chamber.
- **IR light** is directed through sensing chamber towards detector.
- Detector has a **filter** in front of it which eliminates all light except the 4.46 µm wavelength that CO_2 molecules can absorb.
- **Intensity** of 4.46 µm light reaching the detector is **inversely proportional** to the **concentration of CO_2** in the sensing chamber.

Self-Calibrating CO_2 Transmitters/Monitors



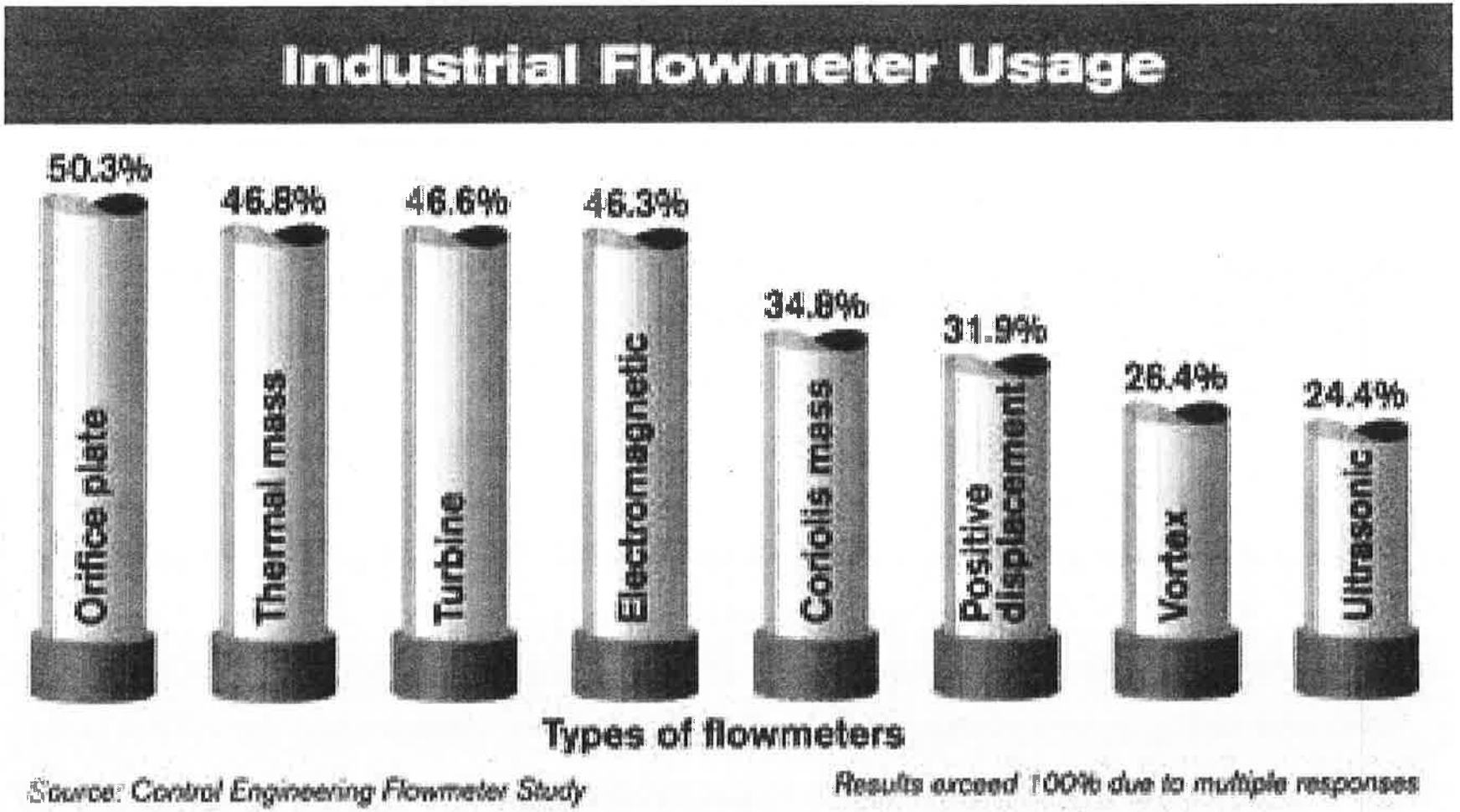




Self-calibrating CO_2 Transmitter/Monitor featuring **ABC feature (Automatic Background Calibration).** Device self-calibrates itself with its own **in-built micro-controller** based on **background CO^2 levels.**

The Self-calibrating CO_2 Transmitter / Monitor is totally **maintenance-free** with expected life of **15 years**. The sensing technology is based on Dual Beam Gold-Plated Infra-Red (NDIR) sensing technology, for high accuracy and stability.

Flow Meter Usage

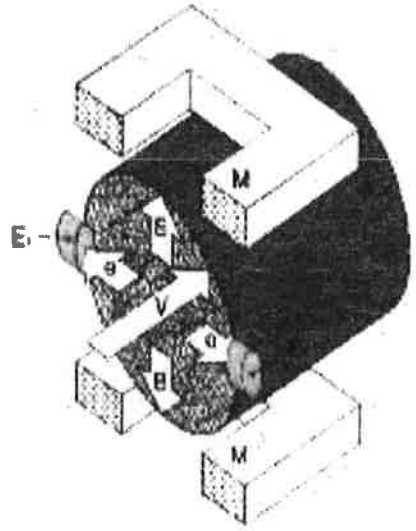


Electromagnetic Flow Meters

Magnetic flow meters are based on **Faraday's Law of Magnetic Induction**.

In a magnetic flow meter, the **liquid** acts as a **conductor** as it flows through the pipe. This **induces a voltage** which is **proportional to the average flow velocity** - the faster the flow rate, the higher the voltage.

This voltage is picked up by **sensing electrodes** mounted in the meter tube and sent to the **transmitter** which takes the voltage and calculates the flow rate based on the cross sectional area of the meter tube.



Faraday's Law :

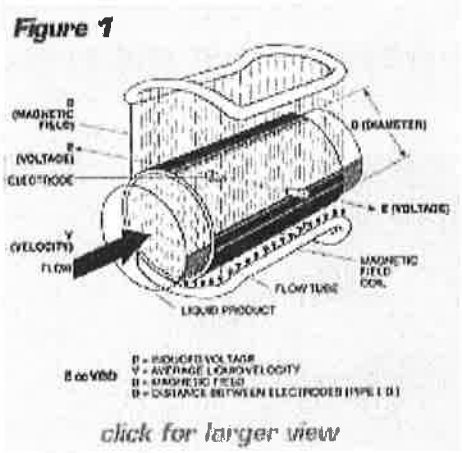
$E=kBDV$ where

E = Induced Voltage,
B = Strength of the magnetic field,
D = Conductor Width,
V = Velocity of the conductor.

Electromagnetic Flow Meters

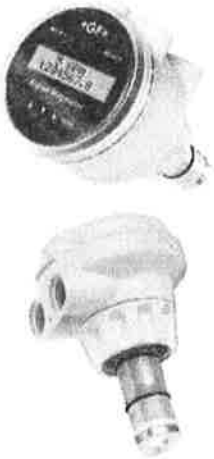
Inline Magnetic Flow Meter

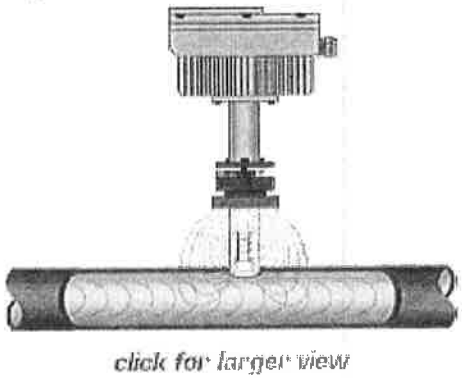




Typical accuracies: ±0.25% to 0.5% of flow rate

Insertion Magnetic Flow Meter





Typical accuracies: ±0.5% to 1% of flow rate

Turbine Flow Meters

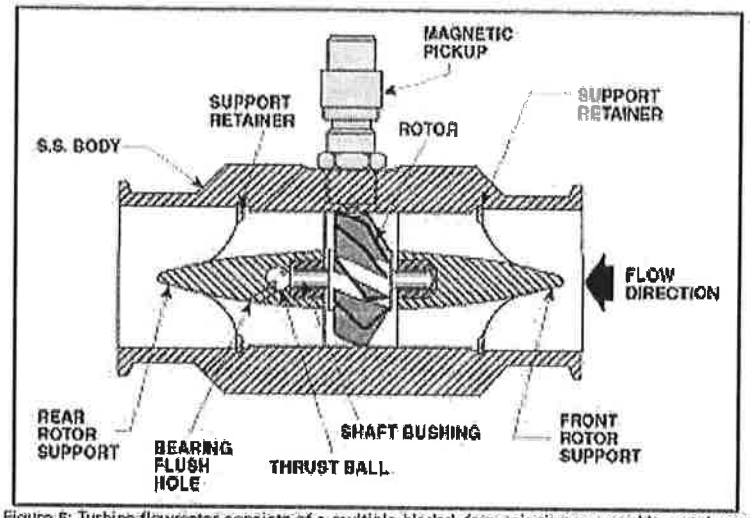


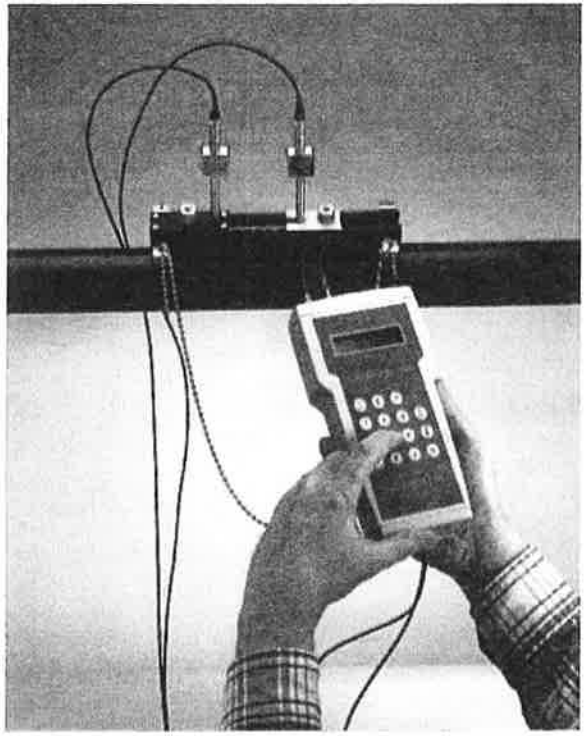
Figure 5: Turbine flowmeter consists of a multiple-bladed, free-spinning, permeable metal rotor housed in a non-magnetic stainless steel body. In operation, the rotating blades generate a frequency signal proportional to the liquid flow rate, which is sensed by the magnetic pickup and transferred to a read-out indicator

A **multiple-bladed rotor** is mounted with a pipe, perpendicular to the liquid flow. The **rotational speed** of the rotor is a direct function of **flow rate** and can be sensed by magnetic pick-up. **Electrical pulses** can be **counted** and **totalized**.

The **number of electrical pulses** counted for a given period of time is directly proportional to **flow volume**. A **tachometer** can be added to measure the turbine's rotational speed and to determine the liquid flow rate.

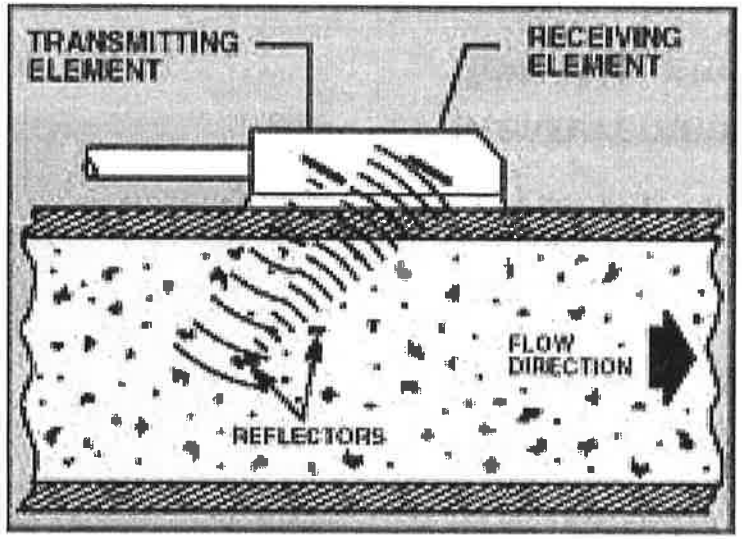
A major concern with **turbine meters** is **bearing wear**. A "bearingless" design has been developed to avoid this problem.

Ultrasonic Flow Meters



- Two types of Ultrasonic flow meters exist – **Doppler** and **Transit-time**.
- Both types feature clamp-on designs with transducer assemblies that detect flow rate from the outside.
- Installation entails neither breaks in the line nor interruptions of flow.
- **Clamp-on design simplifies** and **speeds up meter installation** and **minimizes maintenance**.
- Can be used to check the flow accuracy of existing flow meters.
- **Measurement accuracy** can be in the range of **1% of flow rate**, and speed of response can be as fast as 1 sec.

Ultrasonic Flow Meters (Doppler)

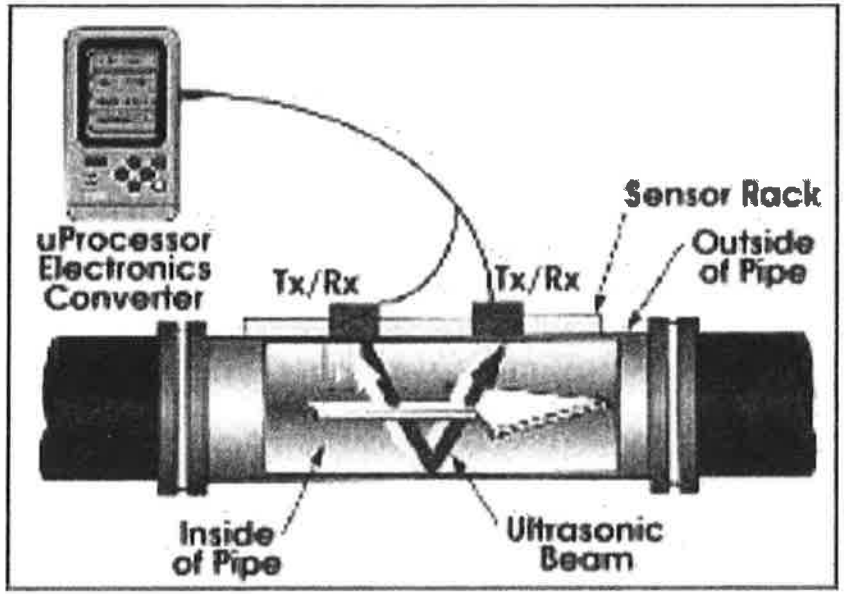


A **Doppler flow meter** is a **volumetric flow meter** which requires **particulates** or **bubbles** in the flow. Current technology requires that the liquid contain at least 100 parts per million (PPM) of 100 micron or larger suspended particles or bubbles.

The **Doppler Ultrasonic flow meter** measures the velocity of particles moving with the flowing fluid . **Acoustic signals** of known frequency are **transmitted, reflected** from particles, and are **picked up by a receiver.**

The received signals are analyzed for **frequency shifts** and the **resulting mean value of the frequency shifts** can be directly related to the **mean velocity** of the **particles moving with the fluid**.

Ultrasonic Flow Meters (Transit-Time)

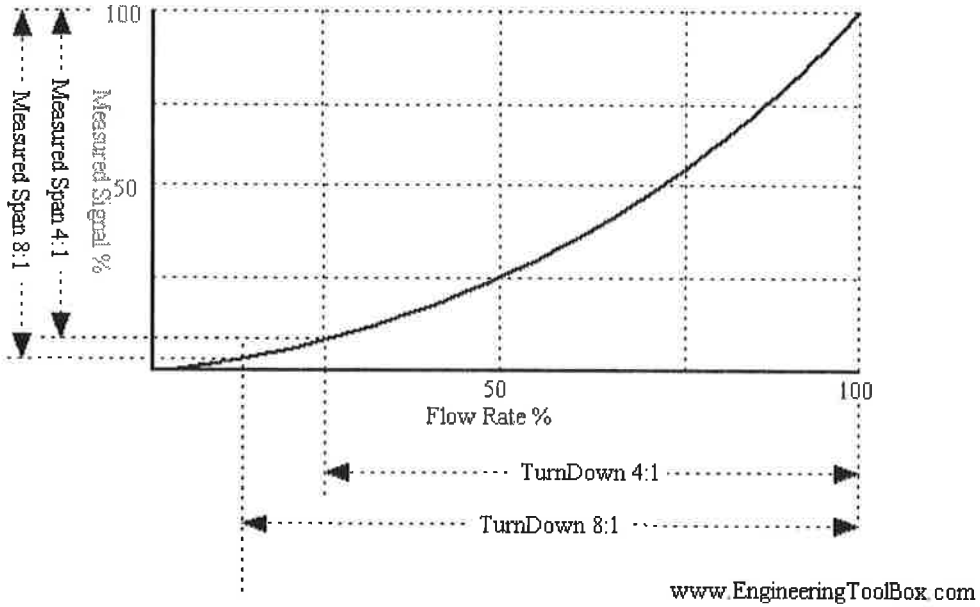


Transit-time Ultrasonic flow meters measure the **difference** in **travel time** between **pulses** transmitted in a **single path along** and **against the flow**.

Two **transducers** are used, one upstream of the other. Each acts as both a transmitter and receiver for the ultrasonic beam.

The **difference** in the **transit times** in the upstream vs. the downstream directions (TU - TD) measured over the same path can be used to **calculate the flow** through the pipe.

Flow Meters and Turndown Ratio



Turndown ratio can be expressed as:

TR = qmax / qmin *where*

TR = Turndown Ratio
qmax = maximum flow
qmin = minimum flow

Maximum and minimum flow is stated within a specified accuracy and repeatability for the device.

Most flow meters typically have a turndown ratio of **10:1**. The ratio for constant power thermal mass flow meters and constant temp mass flow meters is **100:1** and **1,000:1** respectively

How Much Straight Run is Required for Flowmeters?

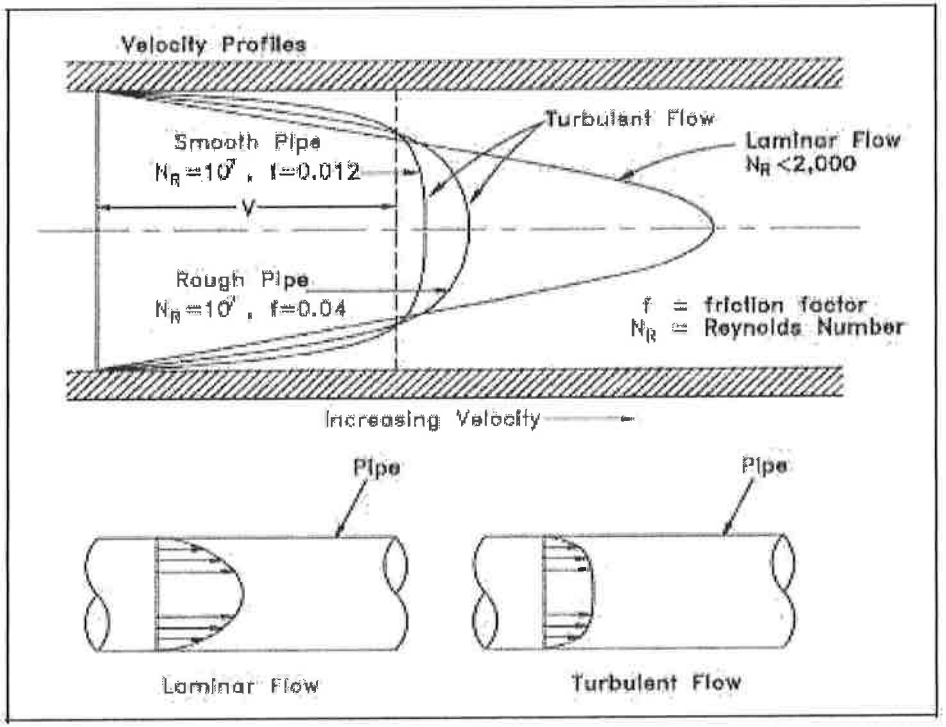


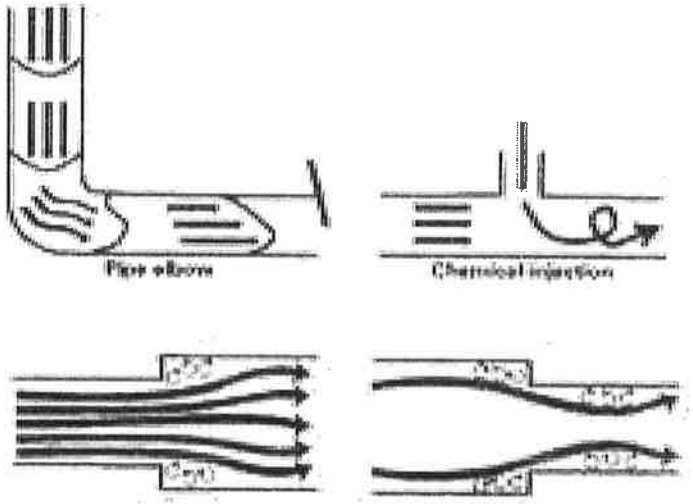
Figure 3 Laminar and Turbulent Flow Velocity Profiles

When a fluid flowing through a pipe assumes a **desirable flow profile**, it moves **uniformly** with the **greatest velocities** near the **center of the pipe.**

Improper flow meter installation can disturb this profile and degrade measurement accuracy.

Flow-profile distortion and **swirl** — the two most prominent types of fluid disturbance that affect a meter's flow coefficients — are typically the product of **improper piping configuration.**

How Much Straight Run is Required for Flow Meters?



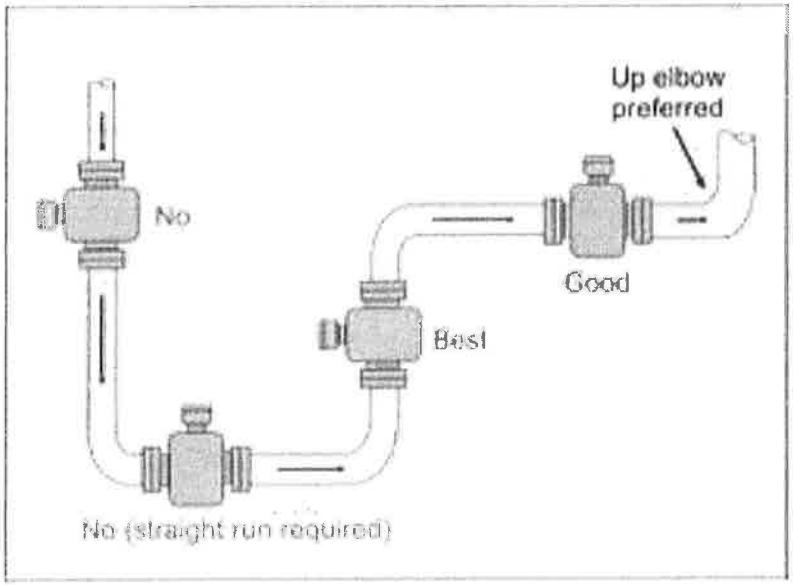
Flow-Profile Distortion Culprits

Fluid profile distortion occurs when an obstruction — such as a **partially open valve** or a **poorly mounted flange gasket** — partially blocks the pipe.

Swirl occurs when the fluid moves through **piping bends** in different planes. Swirl is far more difficult to correct than flow-profile distortion.

Obstructions upstream and **near** the flow meter can cause **errors ranging beyond 50 percent.**

Electromagnetic Flow Meter Piping Requirements



When installing electromagnetic flow meters, avoid downward flows. Horizontal configurations following an elbow require five pipe diameters of straight pipe upstream from the meter.

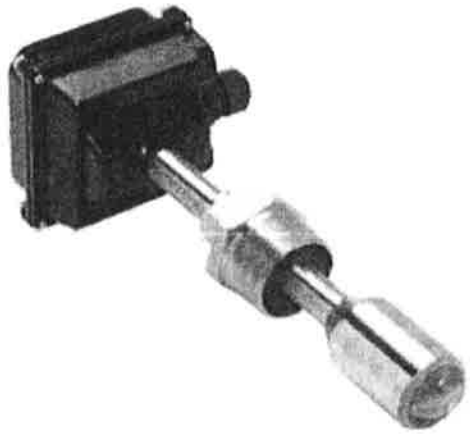
Electromagnetic flow meters are **relatively insensitive** to **errors** caused by **nonsymmetrical velocity patterns** or **swirl.**

The general rule of thumb for straight piping is a **five-diameter** length of piping **upstream** and **three diameters downstream** from the meter.

Independent testing has shown that electromagnetic flow meters may be **affected by piping effects** when the length of **upstream** straight pipe is **less than three pipe diameters**.

Errors from piping effects generally run between **0.1 % and 1.5 %**, depending on the exact configuration of piping and length of pipe run upstream of the meter.

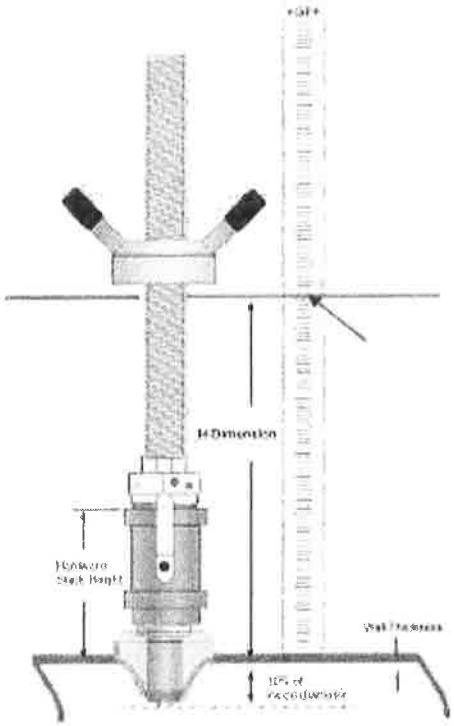
Insertion Electromagnetic Flow Meter Piping Requirements



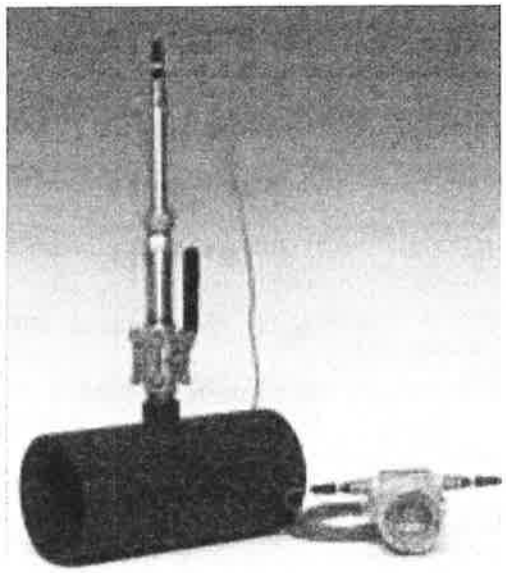
A minimum of **10 pipe diameters** of straight run upstream and **5 diameters** downstream is recommended.

For optimum operation, the pipe conditions upstream from the insertion electromagnetic flow meter must be good. ISO 7145, for example, calls for **25 to 50 diameters** of straight pipe upstream from the insertion meter.

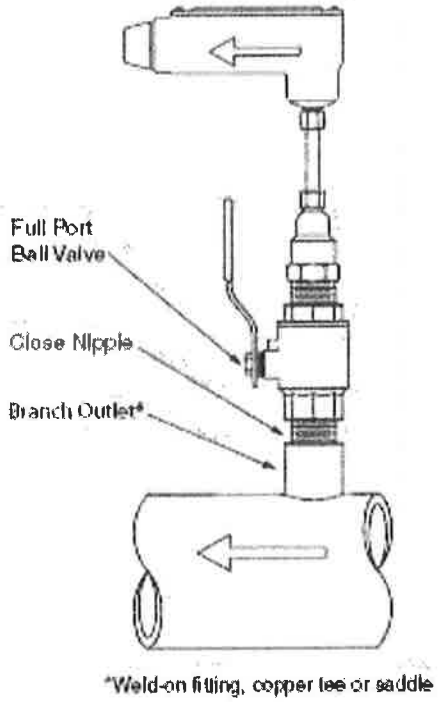
Hot Tap Insertion Flow Meters



Electromagnetic Flowmeter



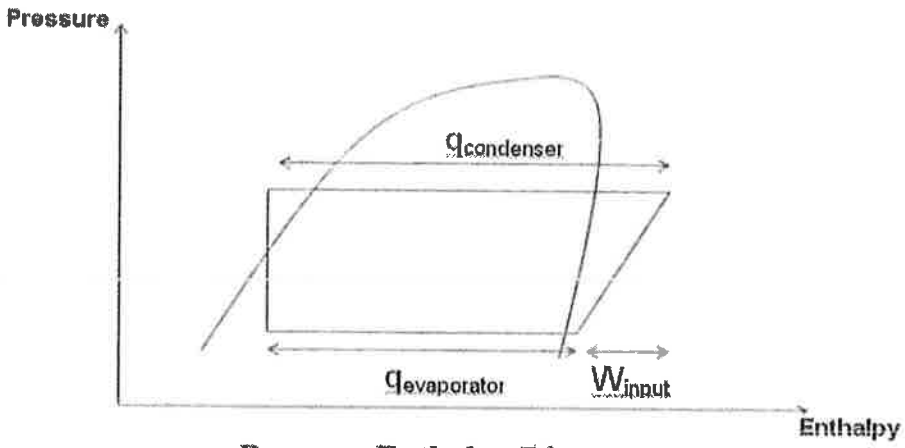
Vortex Flowmeter



Turbine Flowmeter

Hot tap flow meters may be **removed** and **reinstalled** while the pipe is **under pressure without process shut-down.**

Heat Balance



Pressure Enthalpy Diagram

The heat balance is represented by the following equation:

$$q_{condenser} = q_{evaporator} + W_{input}$$

where $q_{condenser}$ = heat rejected

$q_{evaporator}$ = cooling load

W_{input} = measured electrical power input to compressor

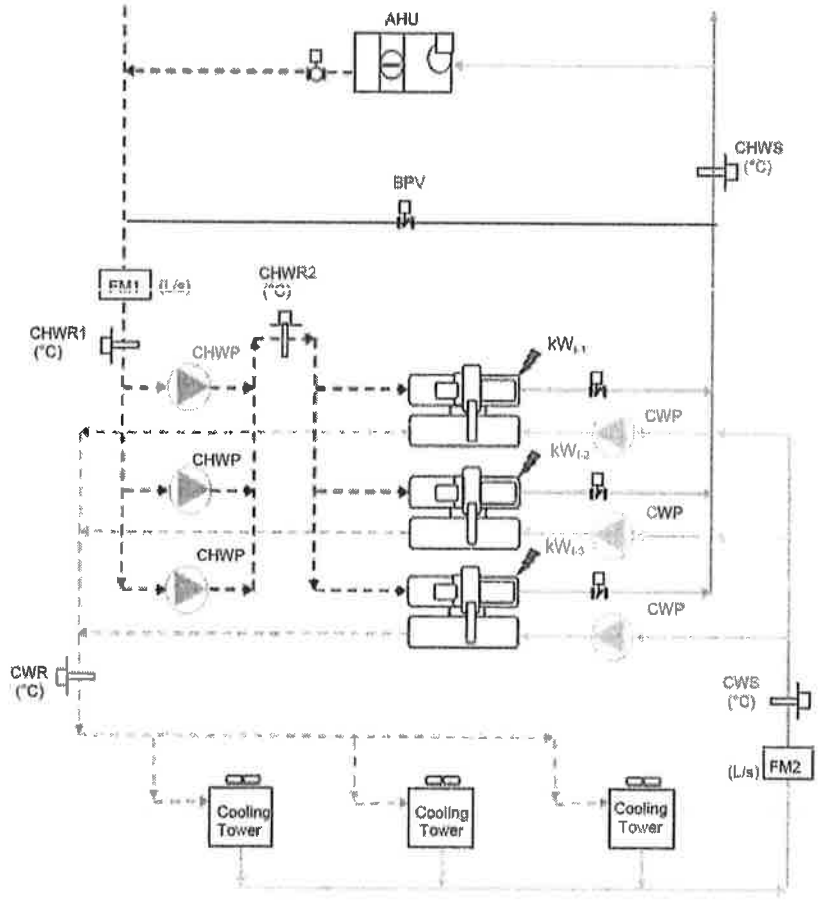
The computation of the percent heat balance (see formula below) that is the total heat gain and total heat rejected must be within ± 5% for 80% of the sampled points over the normal building operation hours.

$$\text{Percent Heat Balance} = \left| \frac{(q_{evaporator} + W_{input}) - q_{condenser}}{q_{condenser}} \right| \times 100\% \leq 5\%$$

Instrumentation Accuracy

Description	Measurement Error
Temperature Sensors - 10K/30K Thermistor - Platinum Resistance Thermometers	±0.03°C – 0.05°C @ 0°C
Flow Sensor / Meter - Ultrasonic - Full bore magnetic	±0.5 - 1% over entire measurement range
Power Meter	ANSI C12.1-2008, Class 1 ±1%

Variable Primary Chilled Water System



A: $q_{evaporator}$ = FM1 x Cp x (CHWR2 - CHWS)

B: $q_{condenser}$ = FM2 x Cp x (CWR - CWS)

C: W_{input} = $kW_{i-1} + kWi_{-2} + kWi_{-3}$

where Cp = 4.19 kJ/kg.°C and density of chilled water is assumed to be 1kg/l

Percent heat balance = [(A + C) – B] / B x 100%



Control Basics

Control Modes

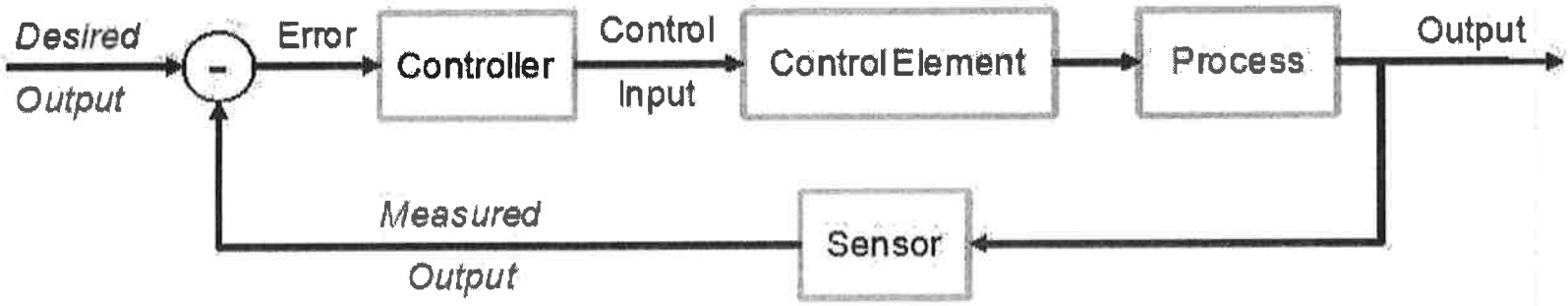
Control systems use different control modes to accomplish their purposes. Control modes in commercial applications include:

- **Two-Position Control**
- **Step Control**
- **Floating Control**
- **Proportional Control**
- **Proportional-Integral Control**
- **Proportional-Integral –Derivative Control**

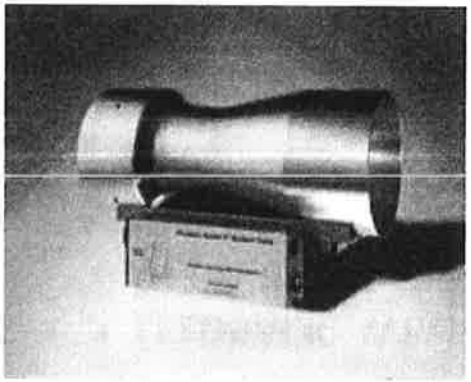
The Control Process

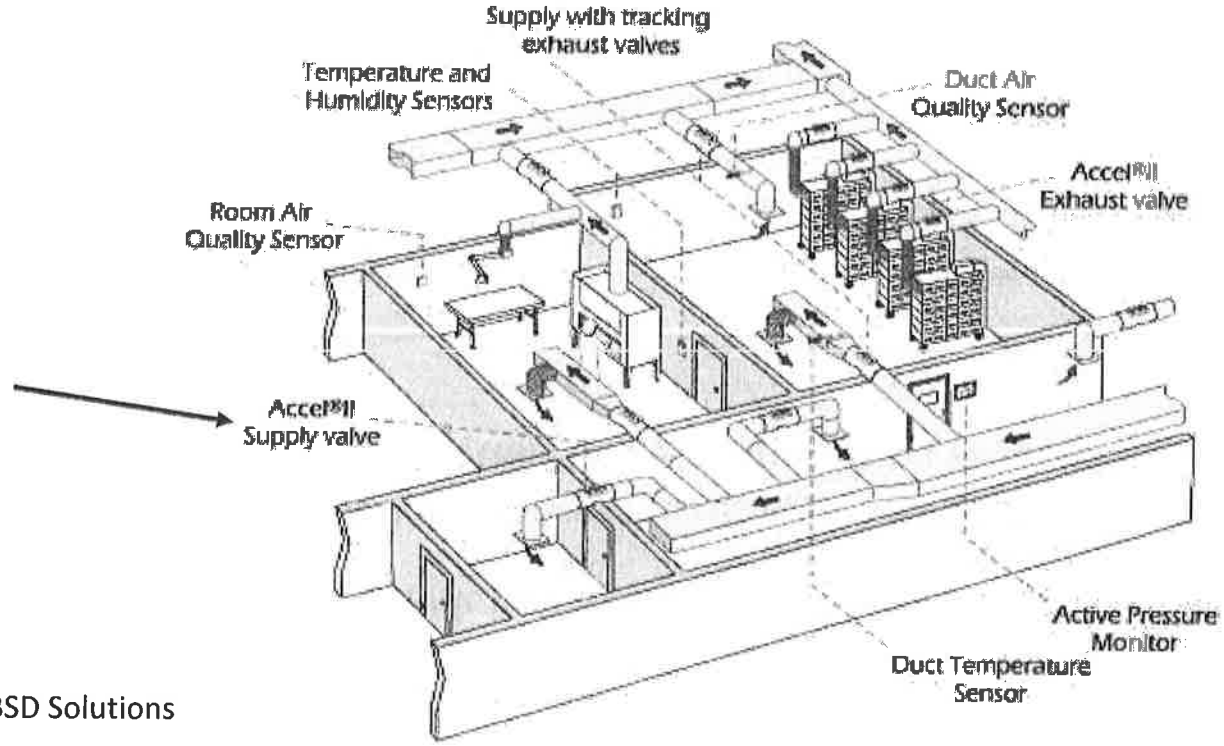
The control process requires:

- A **CONTROLLED VARIABLE** and **CONTROLLED MEDIUM**. In this case, the controlled variable is temperature. The controlled medium is, in most cases, air or water.
- **DISTURBANCE SENSING**. Deviations from normal temperature are the disturbance.
- A **SET POINT CONTROLLER**. This device is required to establish the normal temperature that the system is required to maintain.
- A **FINAL CONTROL ELEMENT**. This element is required to control the actual cooling device.
- **FEEDBACK**. When the system reacts to disturbance, the corrective action must be detected by the disturbance sensor, and it must signal the cooling to shut down when things are back to normal.



Feed-Forward Control





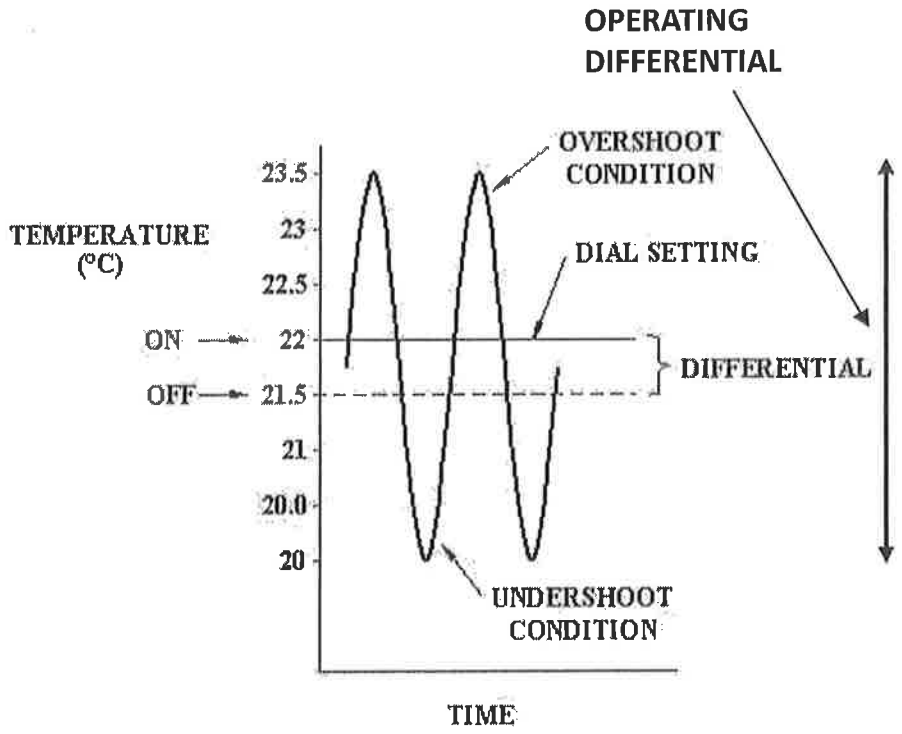
Picture Source: BSD Solutions

A feed-forward control system **does not rely on measuring the controlled variable**.

The **Venturi Valve** relies on a **characterization curve**. The Venturi Valve **adjusts** and **compensates** for **fluctuations of duct pressure** by using a **mechanical pressure-independent cone and spring assembly** that moves in and out of the venturi orifice, increasing and decreasing the airflow in a very **predictable manner** when exposed to pressure drops within a specified range.

Such feed-forward strategies provide **ultra-fast** and **accurate airflow control**.

Two-Position Control



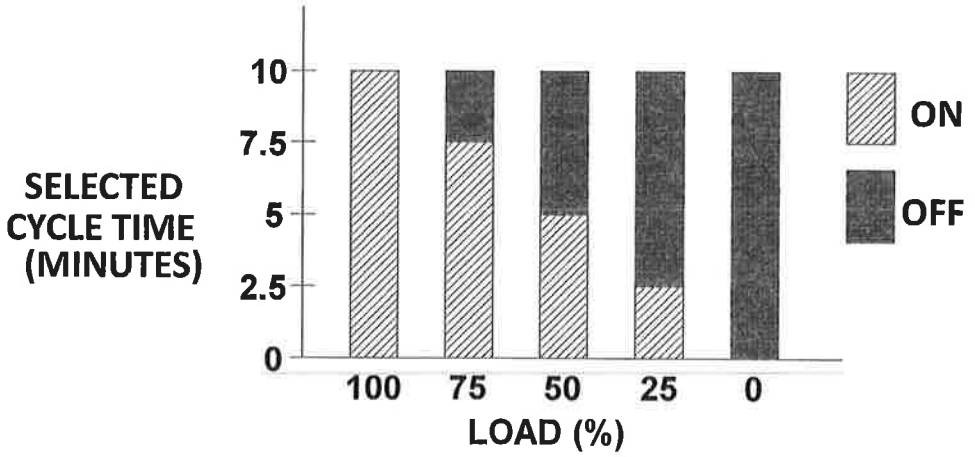
Two-Position Electric Control

- Typically used for FCU, DX coil and electric heater control.
- Two values of the control variable (usually equated with on and off) determine the position of the final control element. Between these values is a zone called the "**Controlled Differential**" or "**Differential**" in which the controller cannot initiate an action of the final control element.

Time Proportioning ✓

- Ideal for **proportional control of electric heaters** for reheat applications for humidity control, without need of adding expensive SCRs (Silicon Controlled Rectifiers).

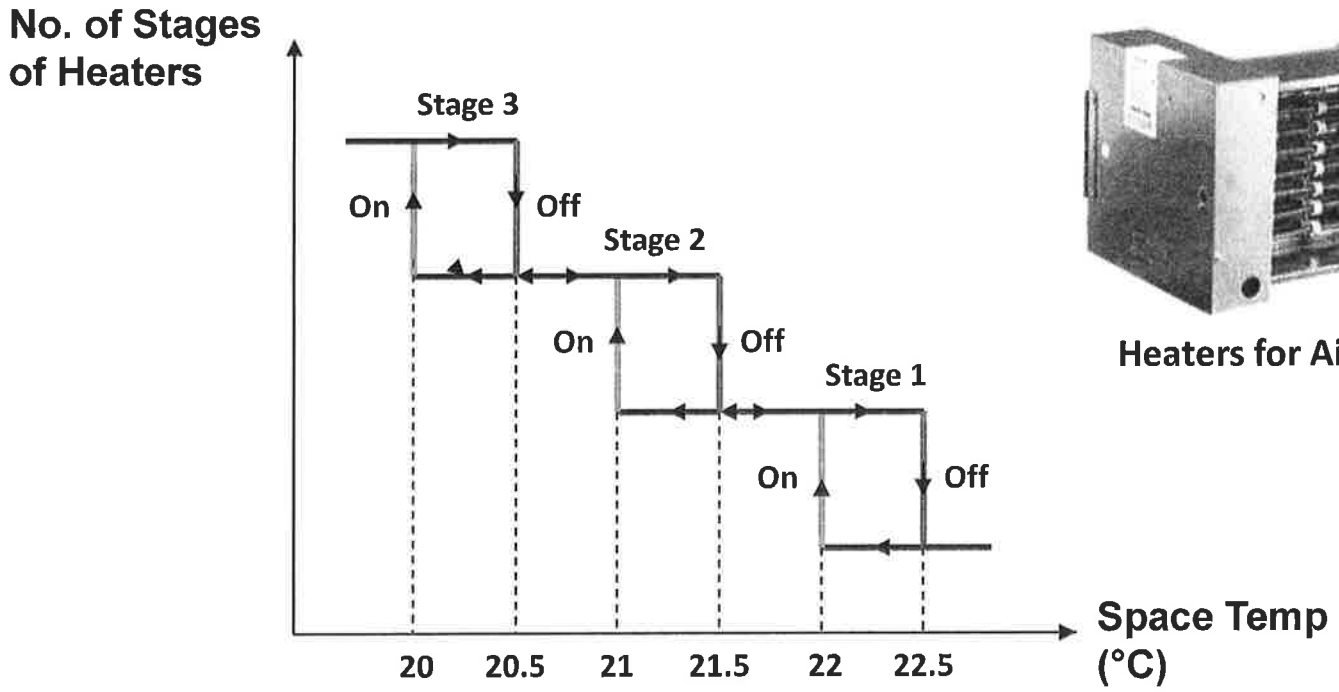
- Heat is introduced into the space using **on/off cycles** based on the actual load and programmable time cycle settings.



TIME PROPORTIONING CONTROL

Step Control

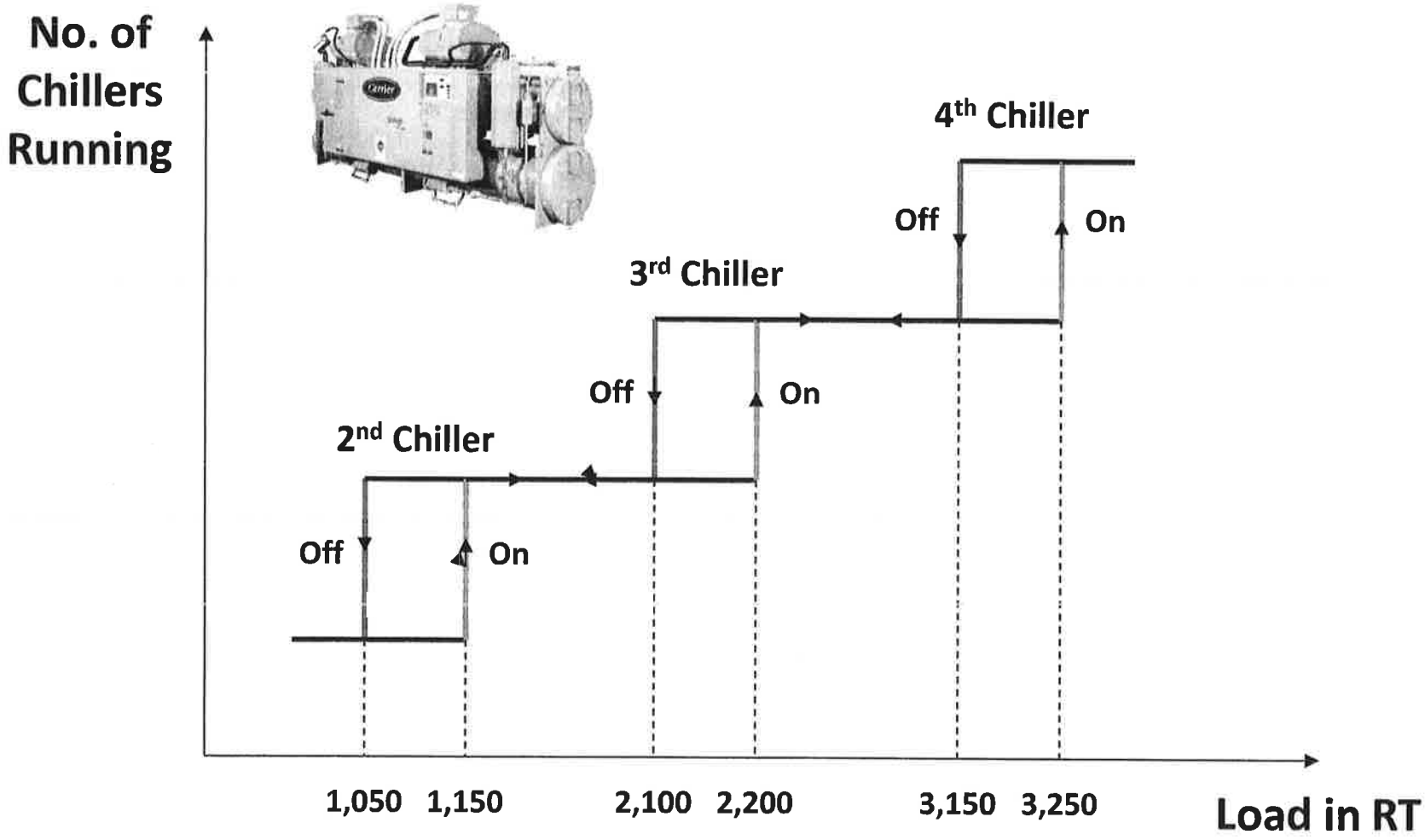
- Step control uses a proportional signal to attempt to obtain **proportional output** from equipment that is typically **on and off**.
- Step controllers operate switches or relays in sequence to enable or disable multiple outputs, or stages, of two-position devices such as **electric heaters** or **reciprocating refrigeration compressors**.



Heaters for Air Duct

Chiller Control

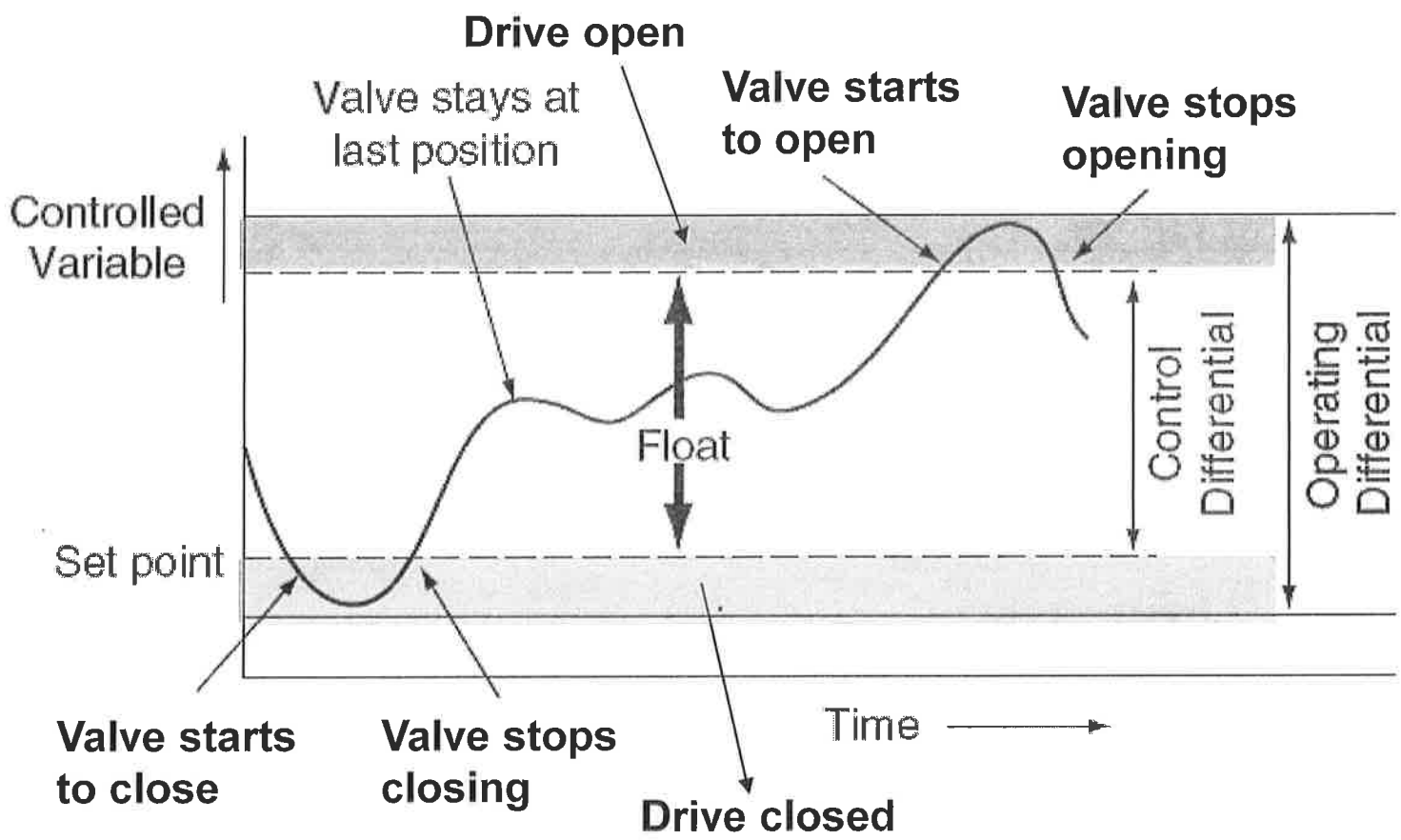
Chiller plant has 5 chillers, each of which is of 1,000 RT. Full building load requires 4 chillers. The fifth chiller is a standby chiller.



Floating Control

3 Stages

VAV



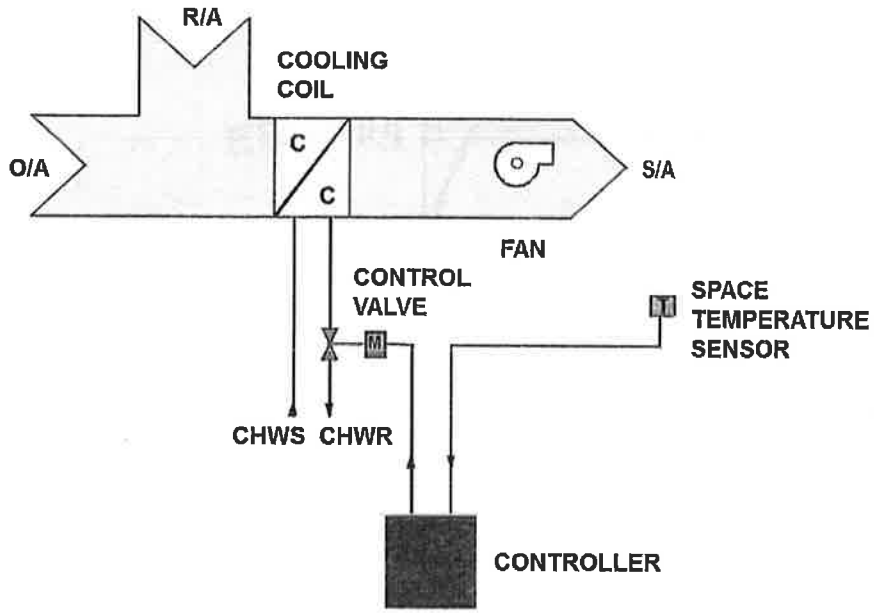
Floating control is a variation of two-position control and is often called **"tri-state"** or **"three-position" control**.

The controller has three modes: **drive open**, **idle (no movement)** or **drive closed**.

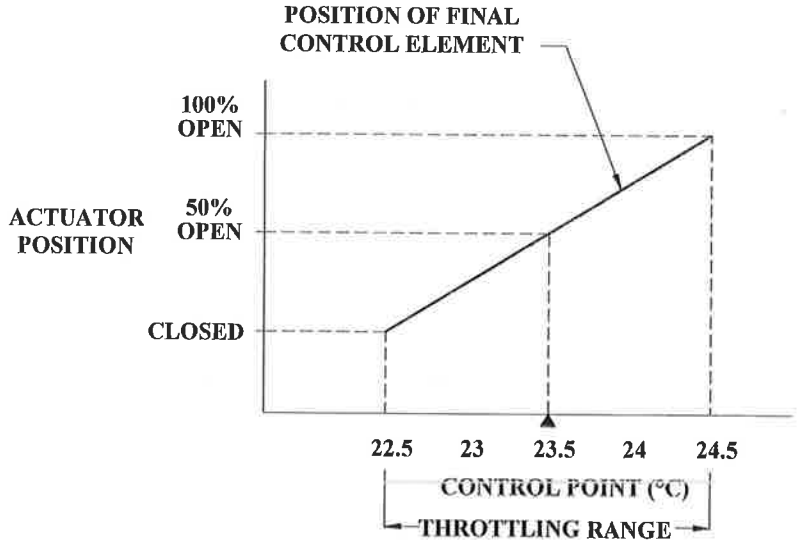
Proportional Control

Proportional control proportions the output capacity of the equipment (e.g. the percent a valve is open or closed) to match the heating or cooling load on the building.

For **direct acting controllers**, the **controller output increases** as the value of the **controlled variable increases**.



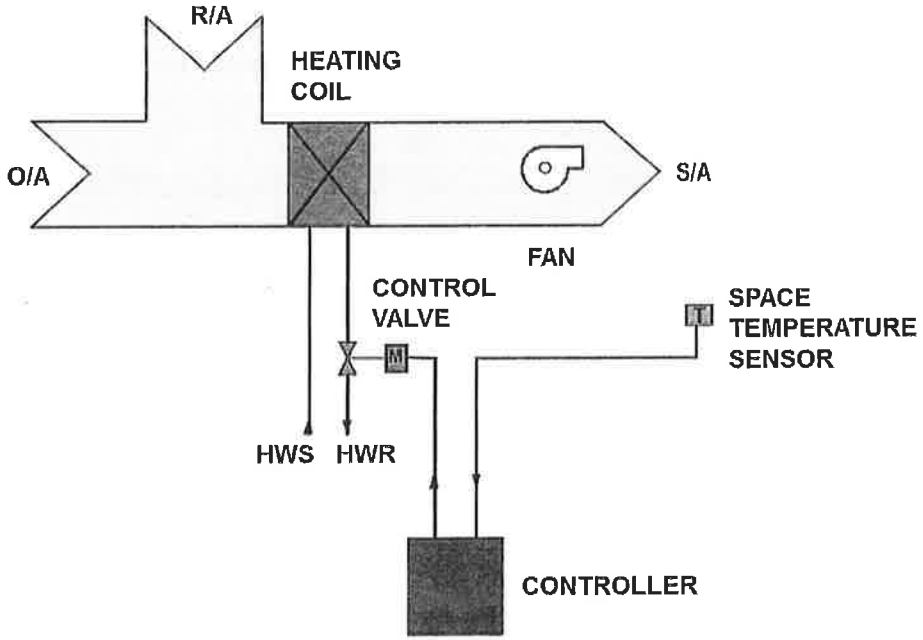
Proportional Control Loop



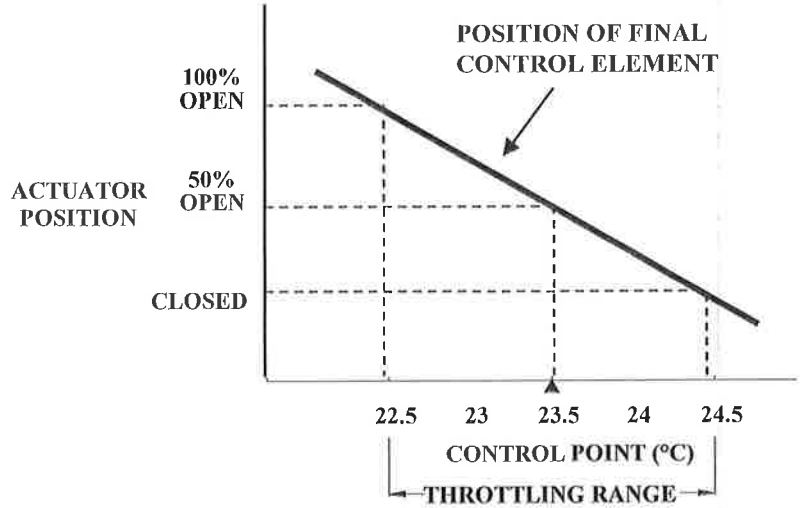
Final Control Element Position as a Function of the Control Point (Cooling System)

Reverse Acting Controller

For **reverse acting controllers**, the **controller output decreases** as the value of the **controlled variable increases.**



Proportional Control Loop



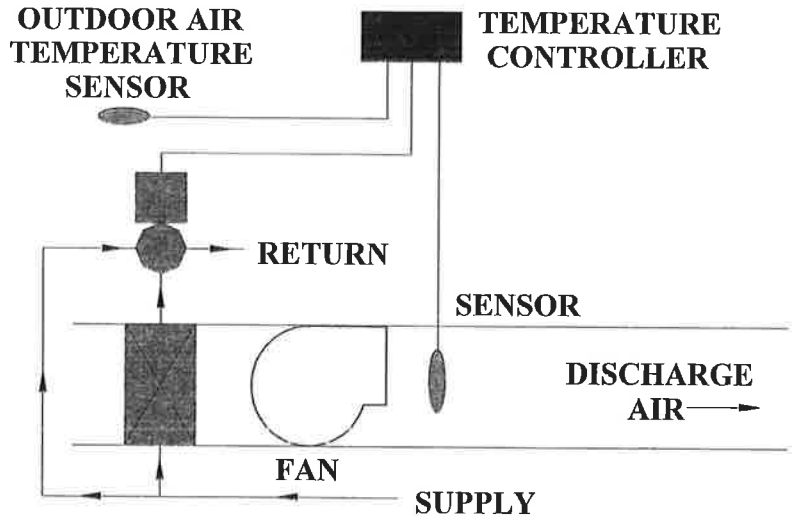
Final Control Element Position as a Function of the Control Point (Heating System)

Compensation Control

Compensation is a control technique available in proportional control in which a secondary, or compensation sensor **resets** the setpoint of the primary sensor.

An example of compensation would be the outdoor temperature resetting the discharge temperature of a fan system so that the discharge temperature increases as the outdoor temperature decreases.

	Normal Day	Rainy Day
Outdoor Air Temp	30°C	25°C
Discharge Air Temp	17°C	19°C



Discharge Air Control Loop with Compensation

Types of Compensation



Summer



Winter

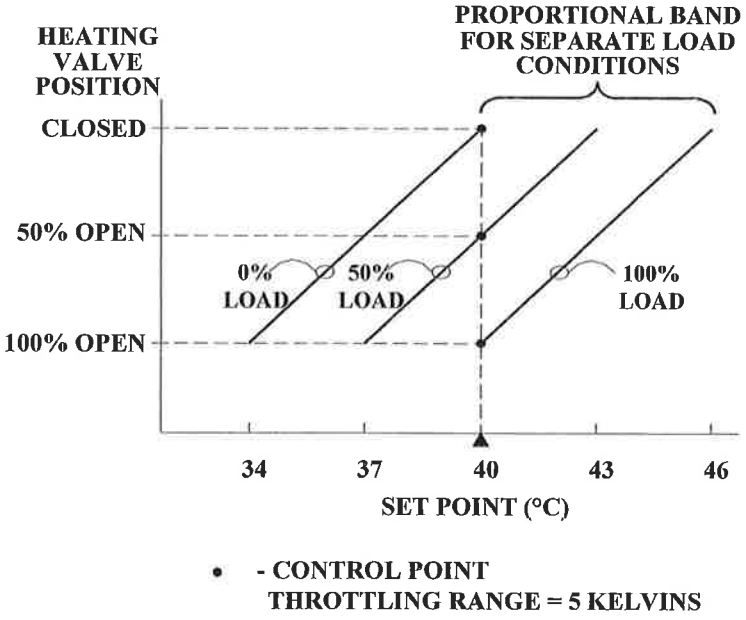
Compensation can either increase or decrease the setpoint as the compensation input increases.

Increasing the setpoint by adding reset on an **increase** in the compensation variable is often referred to as **positive** or **summer compensation**.

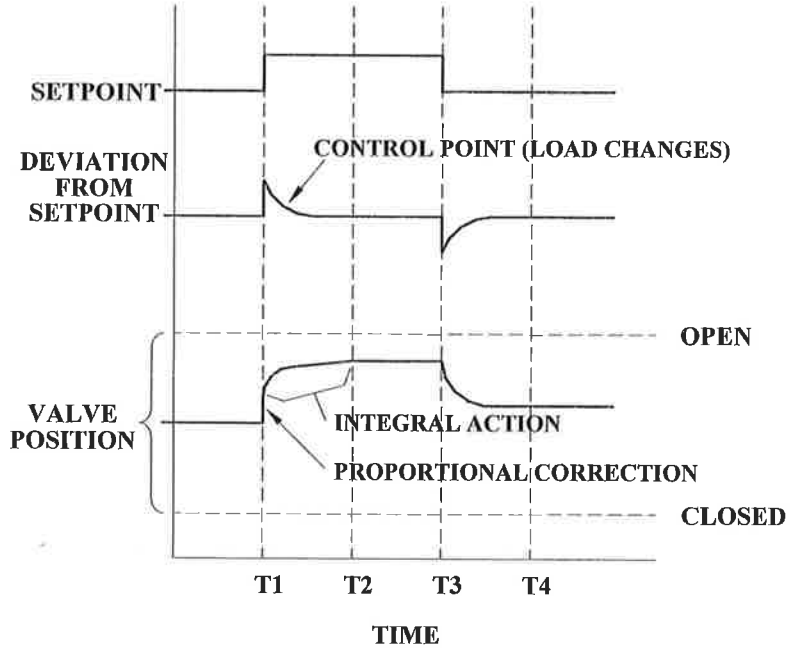
Increasing the setpoint by adding reset on a **decrease** in the compensation variable is often referred to as **negative** or **winter compensation**.

Proportional-Integral (PI) Control

Proportional-integral (PI) control mode provides **automatic reset** of the control point to virtually **eliminates offset**. As soon as the controlled variable deviates above and below the setpoint and offset develops, the proportional band gradually and automatically shifts and the variable is brought back to the setpoint.



Proportional Band Shift Due to Offset



Proportional-Integral Control Response to Load Changes

PI Mathematical Equation

With PI control, the position of the final control element depends not only upon the location of the controlled variable within the proportional band but also upon the **duration** and **magnitude** of the **deviation** of the controlled variable from the setpoint.

$$V = KE + K/T1 \int E\,dt + M$$

Where:

V = Output signal

K = Proportionally constant

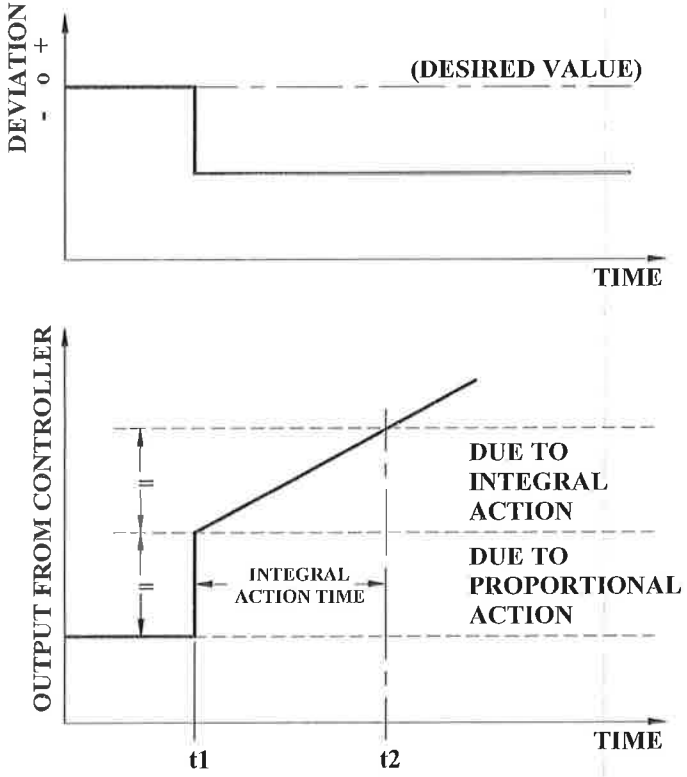
E = Deviation (control point-setpoint)

T1 = Reset time

K/T1 = Reset gain

dt = Differential of time (increment in time)

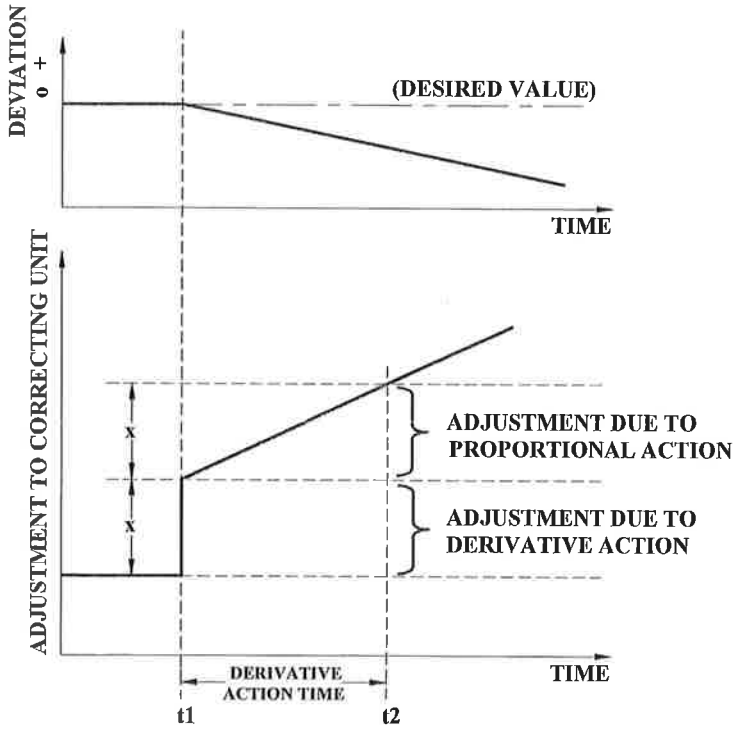
M = Value of output when deviation is zero



Illustrating Integral Action Time

Proportional-Integral-Derivative (PID) Control

Proportional-integral-derivative (PID) control adds the derivative function to PI control. The derivative function opposes any change and is proportional to the rate of change. The more quickly the control point changes, the more corrective action the PID system provides.



Illustrating Derivative Action Time

PID Mathematical Equation

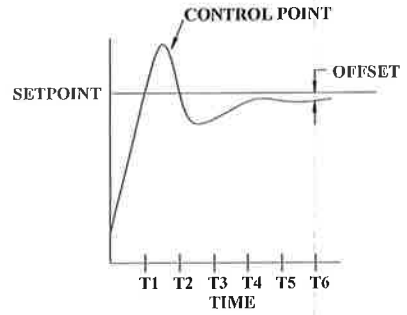
The complete mathematical expression for PID control can be expressed as:

$$V = KE + K/T1 \int E\,dt + KTd\,dE/dt + M$$

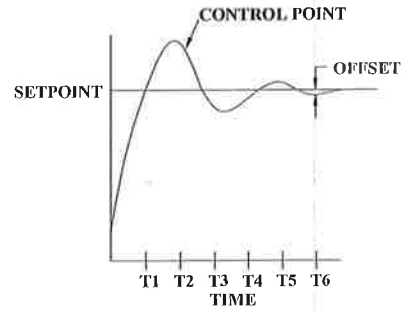
Proportional **Integral** Derivative

Where:

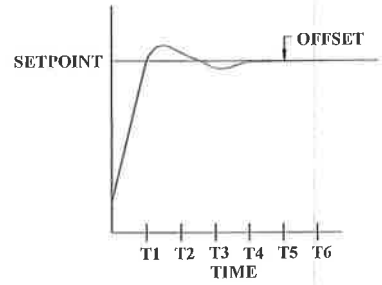
V = Output signal
K = Proportionally constant
E = Deviation (control point-setpoint)
T1 = Reset time
K/T1 = Reset gain
dt = Differential of time (increment in time)
Td = Derivative rate time
KTd = Rate gain constant
dE/dt = Derivative of the deviation with respect to time
M = Value of output when deviation is zero



PROPORTIONAL CONTROL



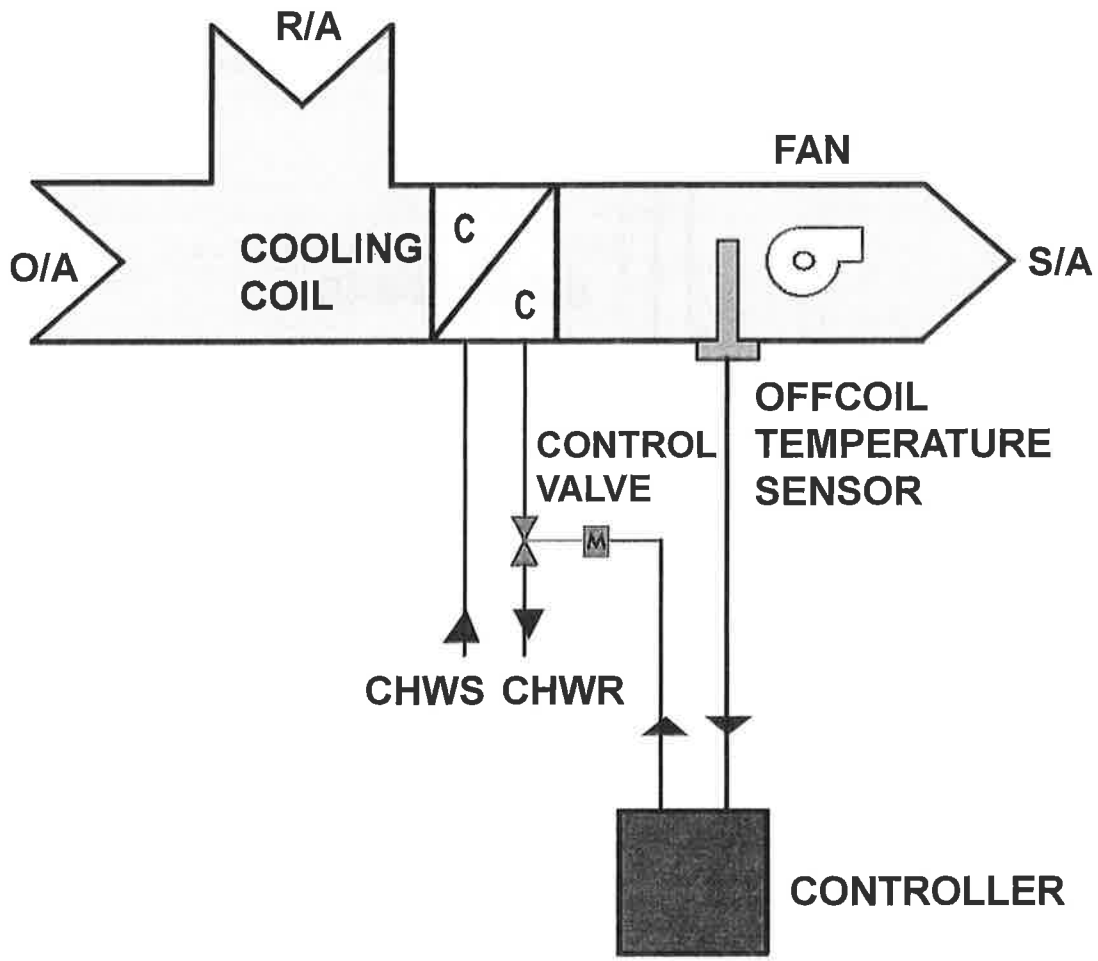
PROPORTIONAL-INTEGRAL CONTROL



PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROL

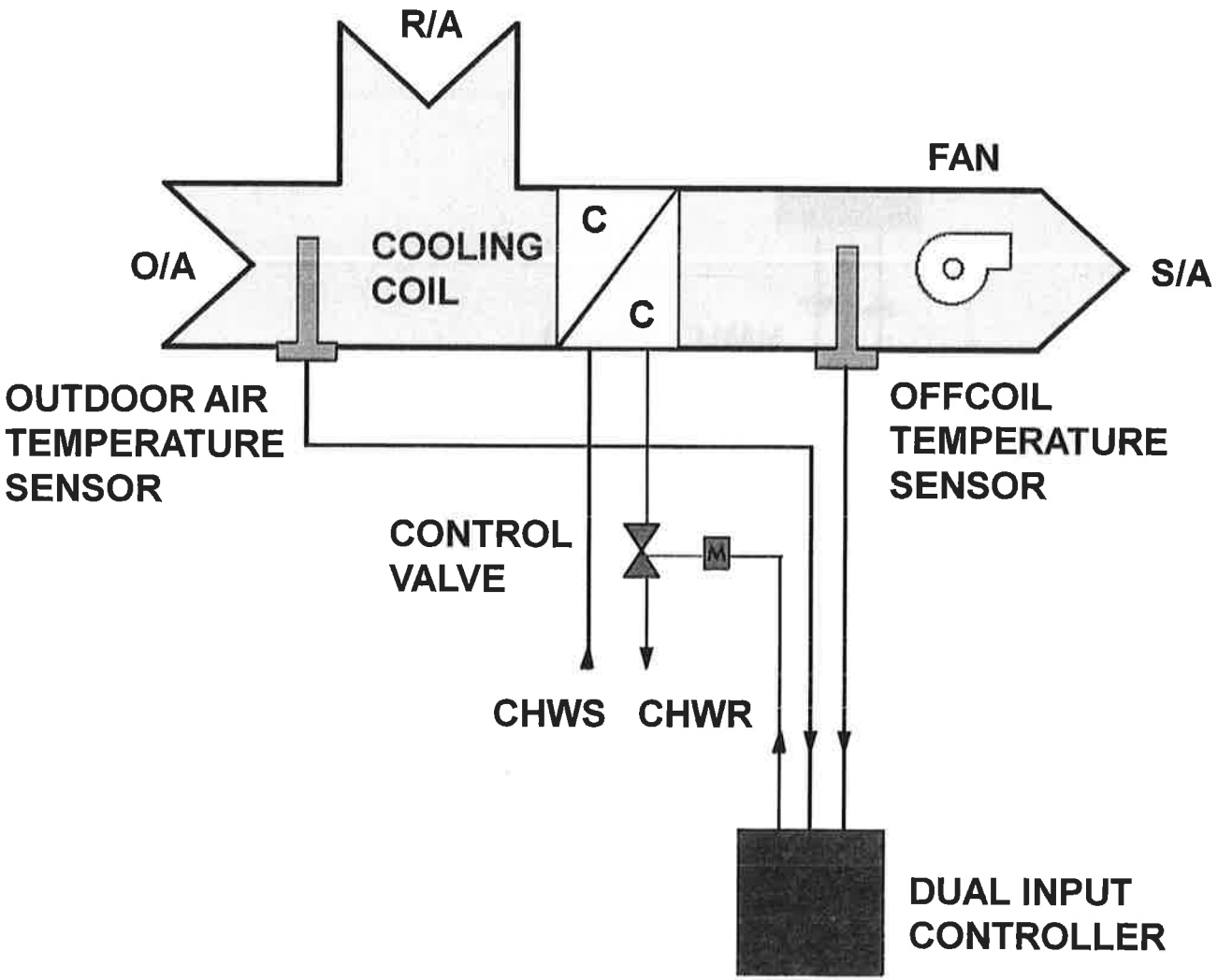


HVAC Control Systems



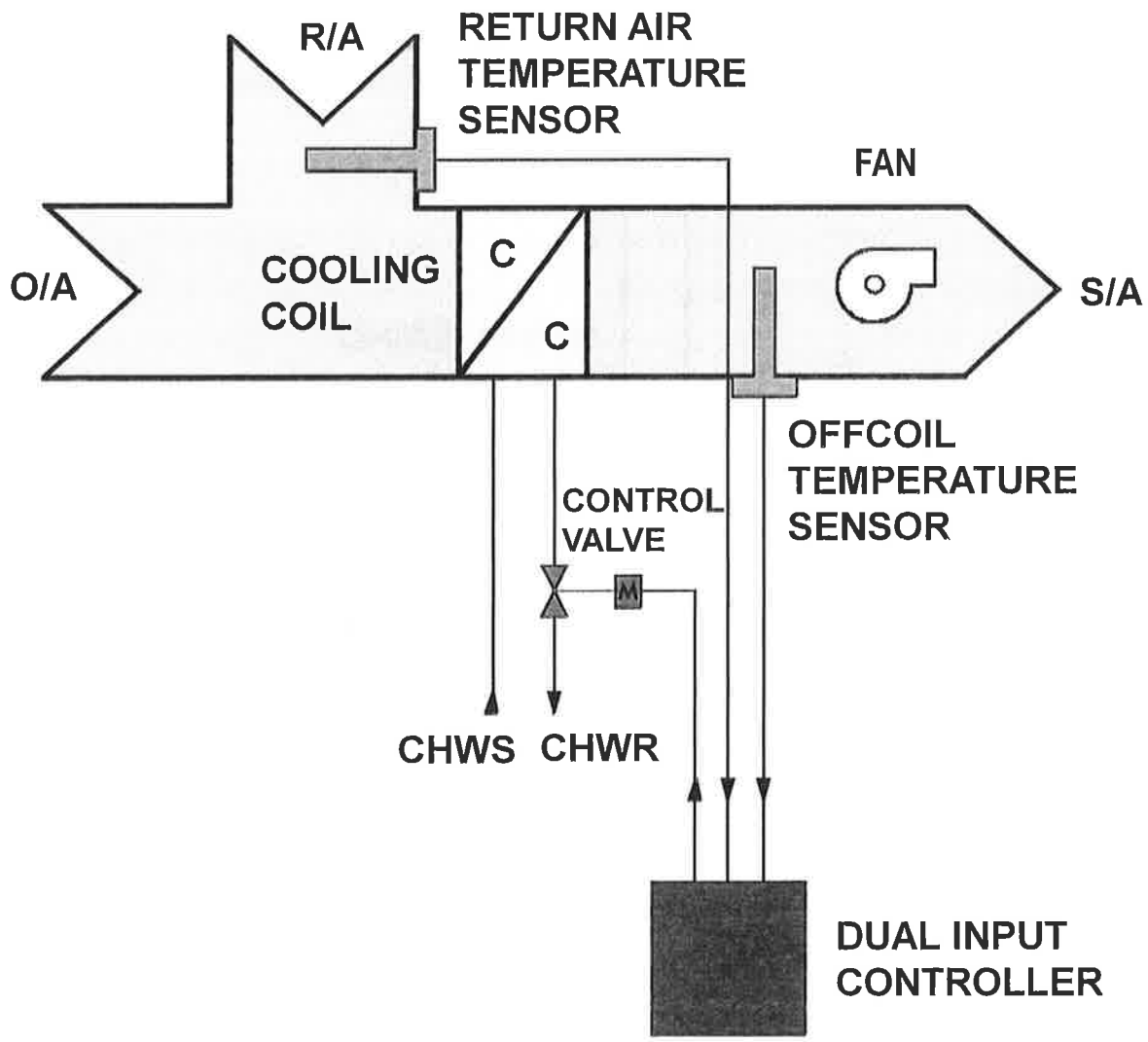
OFFCOIL TEMPERATURE CONTROL OF TWO-WAY VALVE

Constant Air Volume System – Old Approach



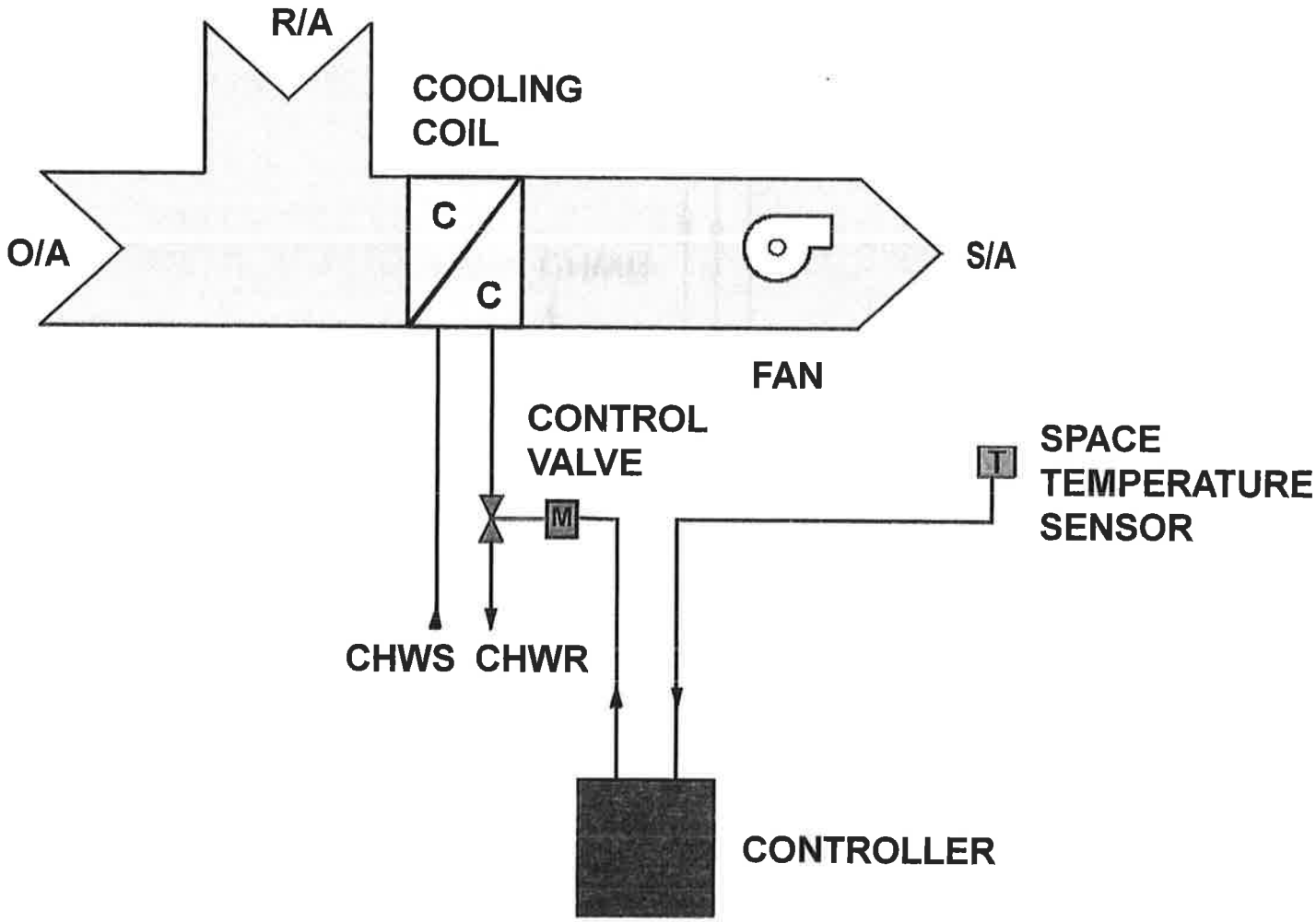
OUTSIDE AIR TEMPERATURE RESET OF OFFCOIL TEMPERATURE

Constant Air Volume System – Cold Approach



RETURN AIR TEMPERATURE RESET OF OFFCOIL TEMPERATURE

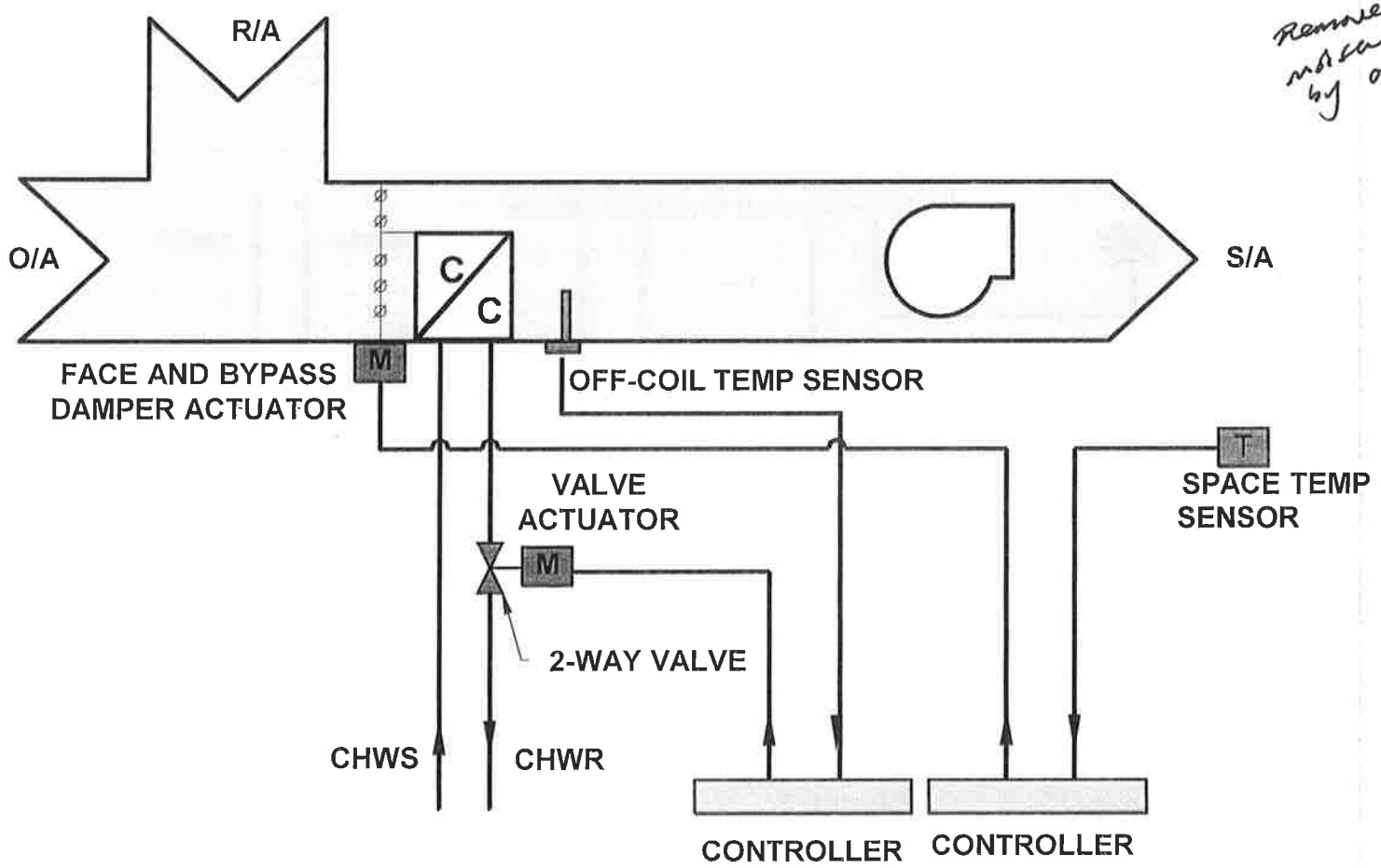
Constant Air Volume System – New Approach



SPACE TEMPERATURE CONTROL OF TWO-WAY VALVE

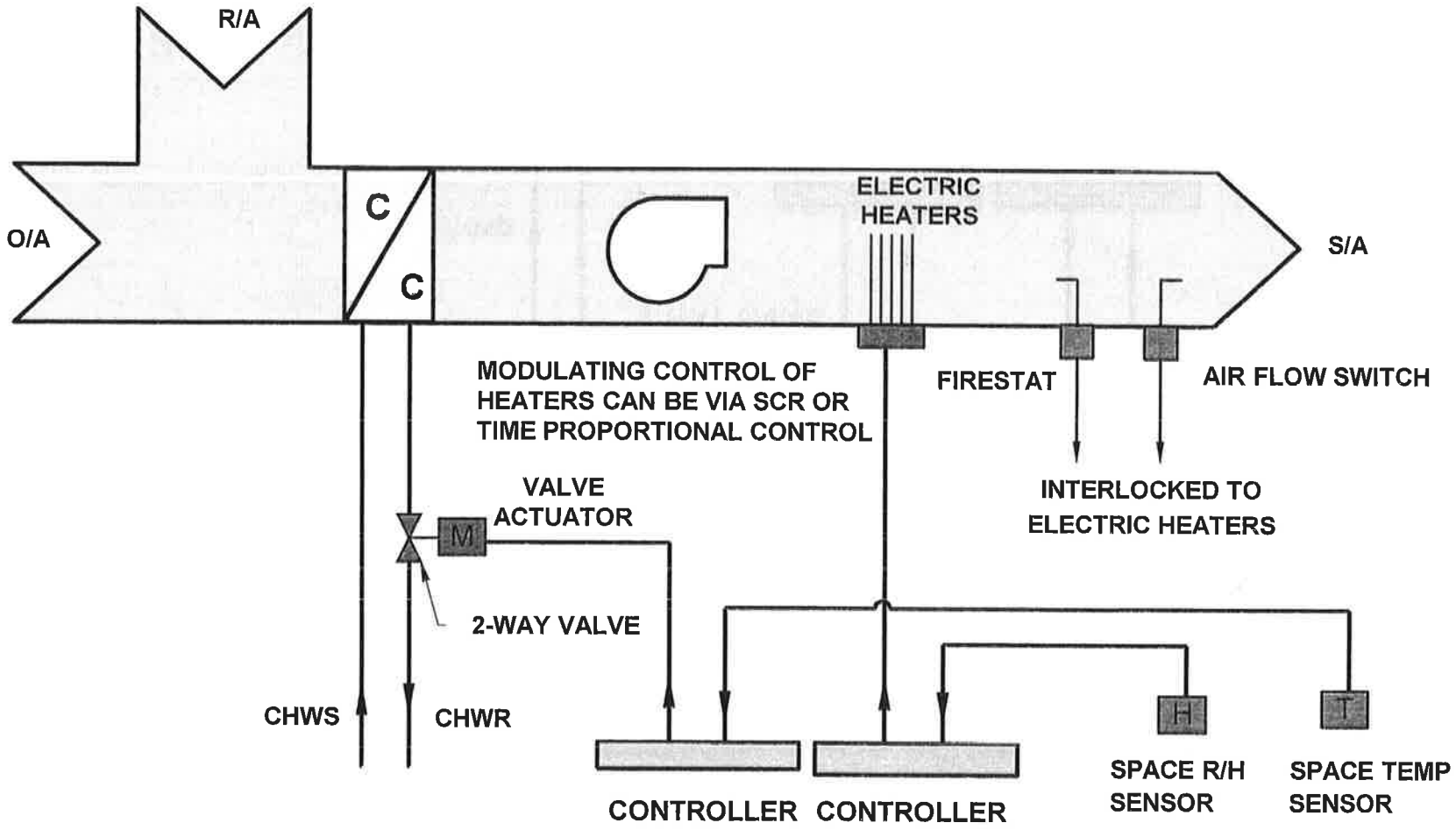
Temp ↓

Constant Air Volume System with Face & Bypass Damper

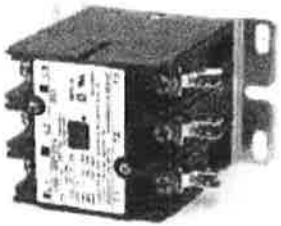


When **dehumidification** is needed, the **cooling coil temperature** is **lowered** to **increase moisture removal**. A portion of the entering air **bypasses** the cooling coil to hold the supply air temperature needed to maintain room temperature.

Constant Air Volume System with RH Control



Accessory Options



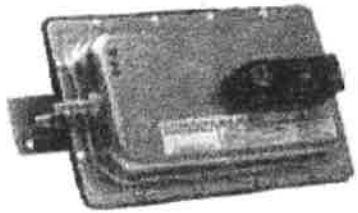
Magnetic Contactor



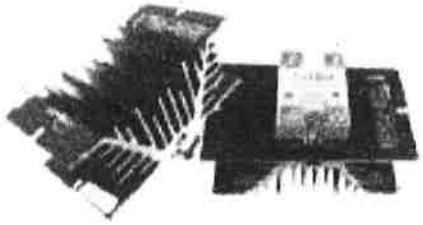
Thermal Safety Devices – Deenergizes heater element on overheating



Mercury Contactor - Silent operation and frequent cycling

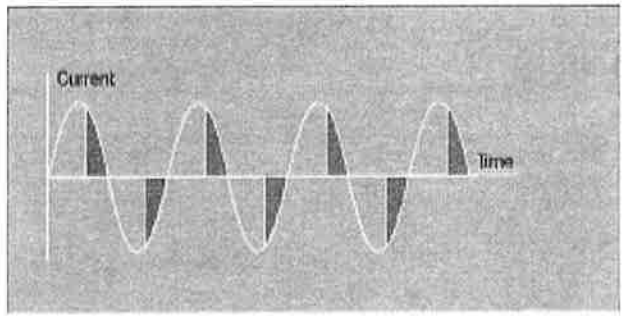


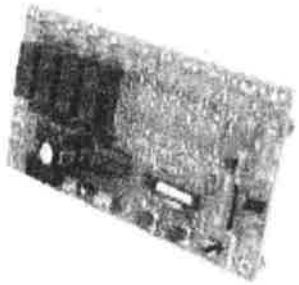
Air Flow Switch



- **SCR (Silicon-Controlled Rectifier)** - Provides continuous modulation from zero to the maximum

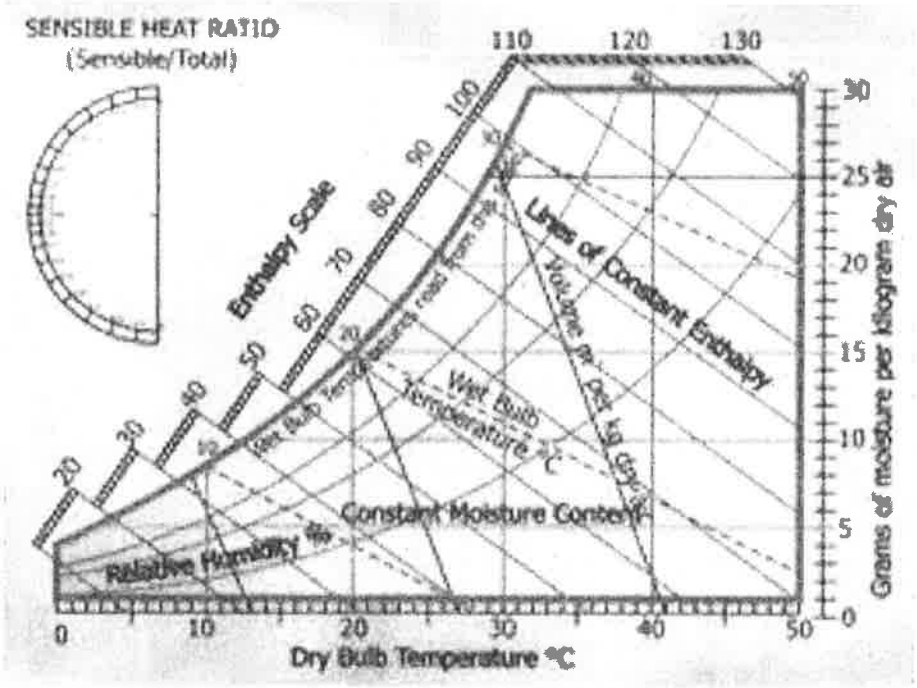
Partial Heating





Step Controller – Controls multiple heating stages

Understanding the Psychrometric Chart

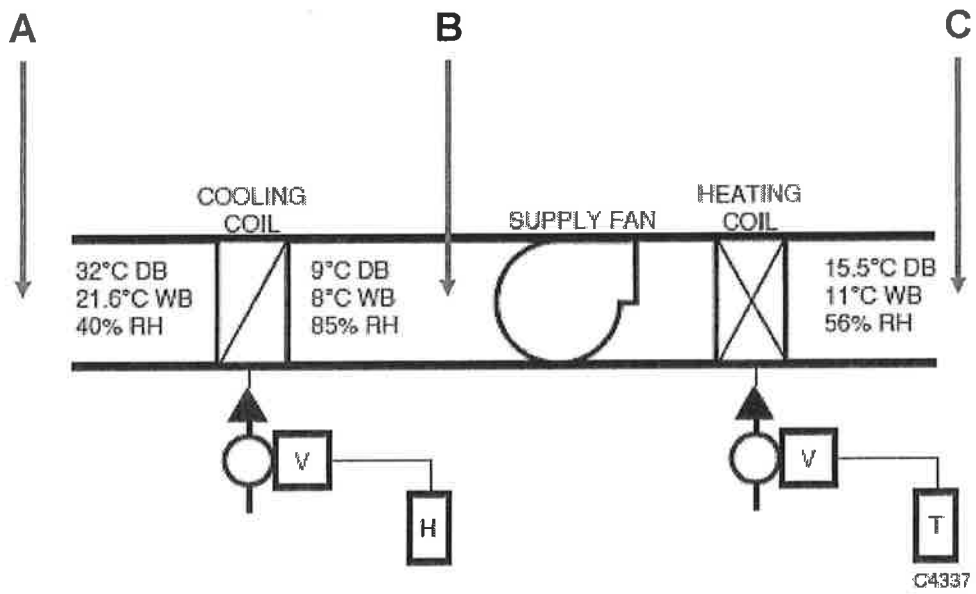


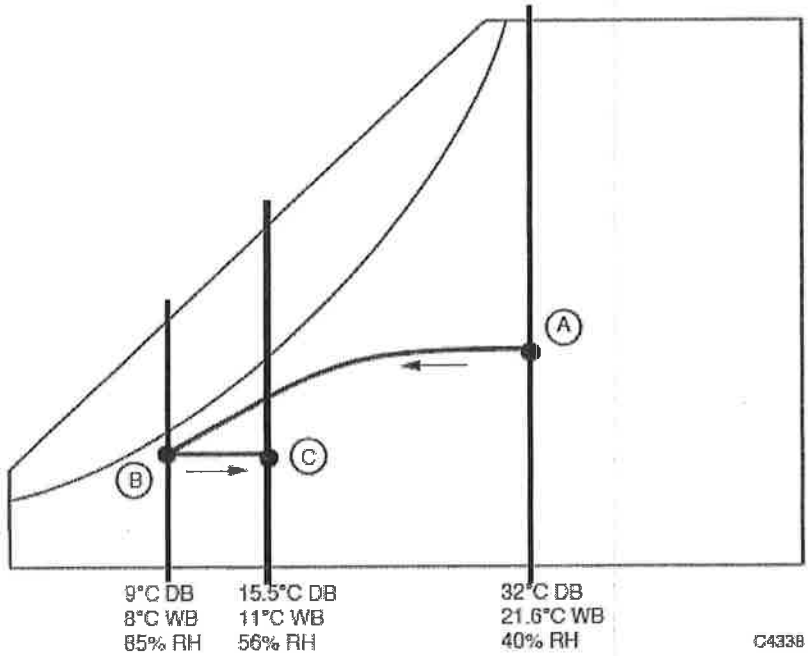
Picture Source: www.acr-news.com

The **Psychrometric Chart** provides a graphical representation of the properties of moist air including wet- and dry-bulb temperature, R/H, dew point, moisture content, enthalpy and air density.

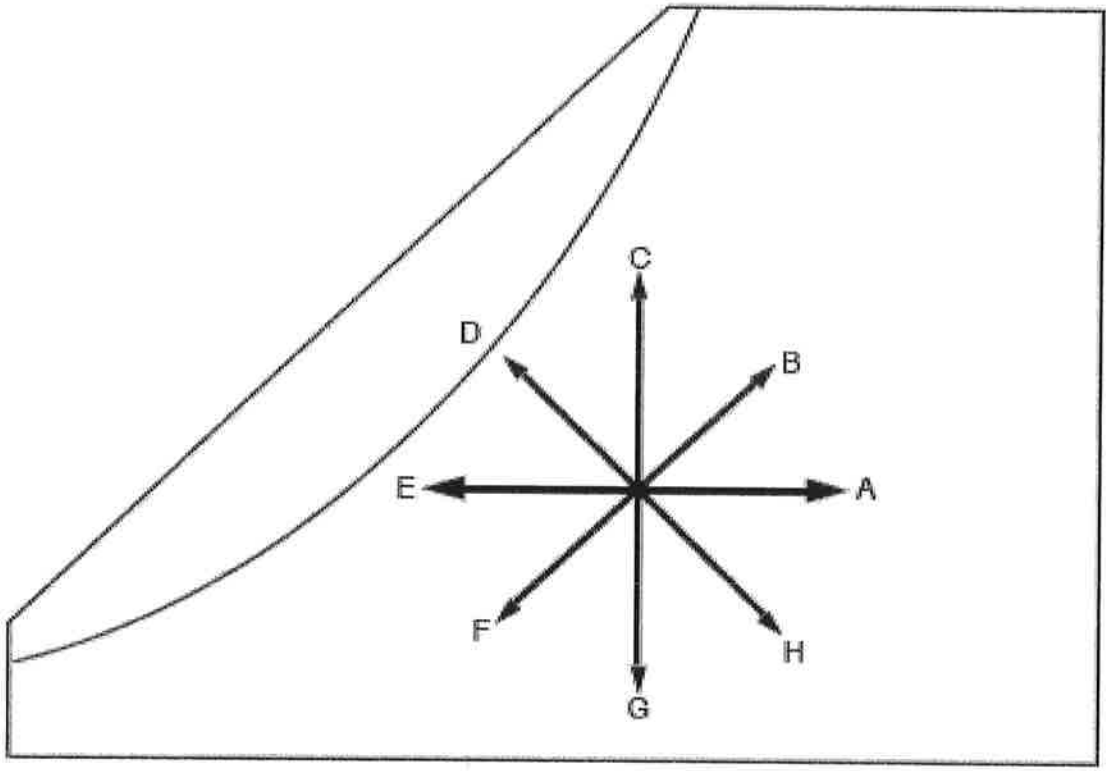
The chart is used to plot the **changes** that occur in the **air** as it **passes through** an **air handling system** and is particularly useful in **understanding these changes** in relation to the **performance** of HVAC control systems.

Fan System with Dehumidification and Reheat





Psychrometric Process Summary



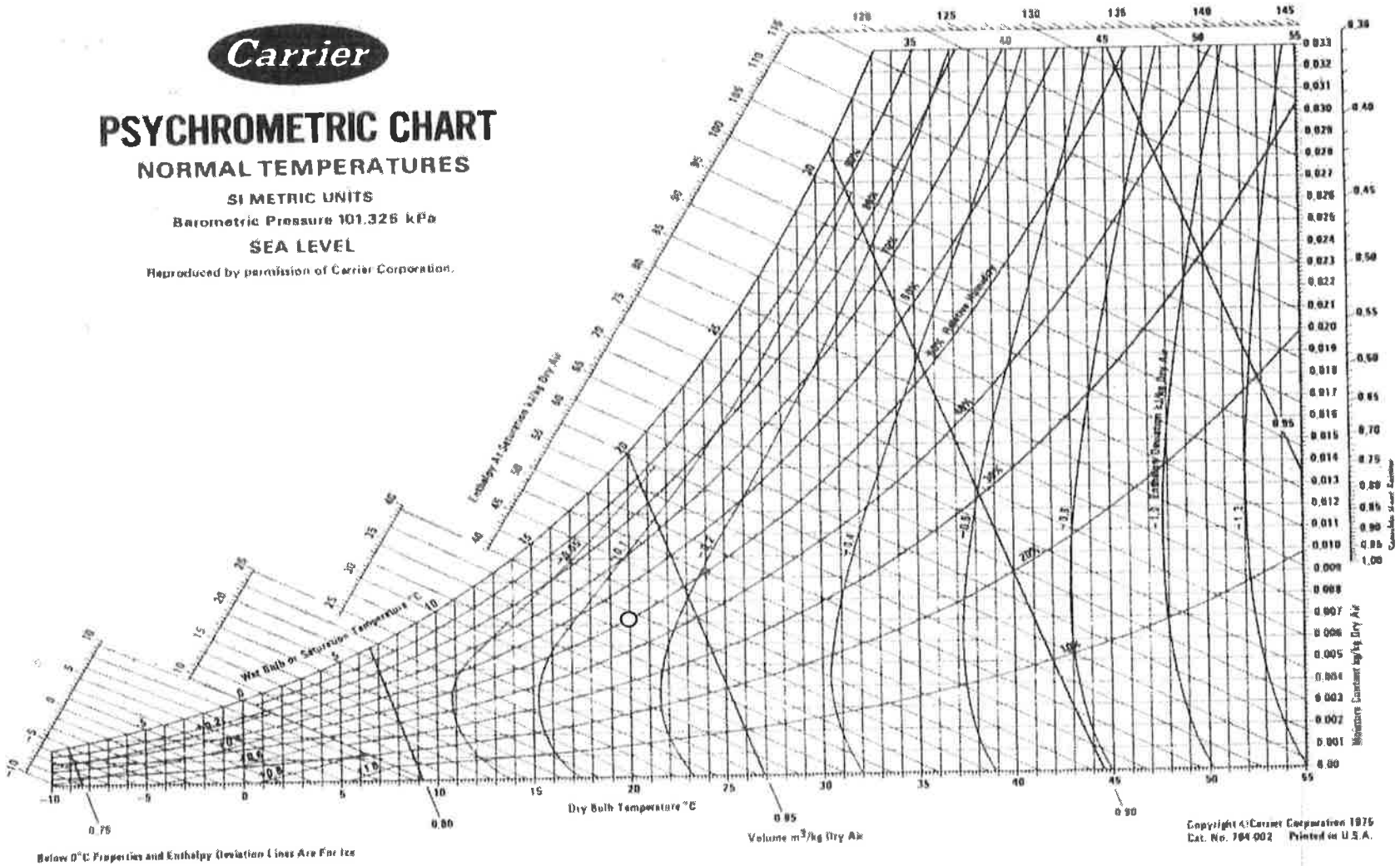
SUMMARY OF ALL PROCESSES CHARTABLE.
PROCESS MOVEMENT IN THE DIRECTION OF:

- A, HEATING ONLY - STEAM, HOT WATER OR ELECTRIC HEAT COIL
- B, HEATING AND HUMIDIFYING - STEAM HUMIDIFIER OR RECIRCULATED HOT WATER SPRAY
- C, HUMIDIFYING ONLY - AIR WASHER WITH HEATED WATER
- D, COOLING AND HUMIDIFYING - WASHER
- E, COOLING ONLY - COOLING COIL OR WASHER AT DEWPOINT TEMPERATURE
- F, COOLING AND DEHUMIDIFYING - CHILLED WATER WASHER
- G, DEHUMIDIFYING ONLY - NOT PRACTICAL
- H, DEHUMIDIFYING AND HEATING - CHEMICAL DEHUMIDIFIER

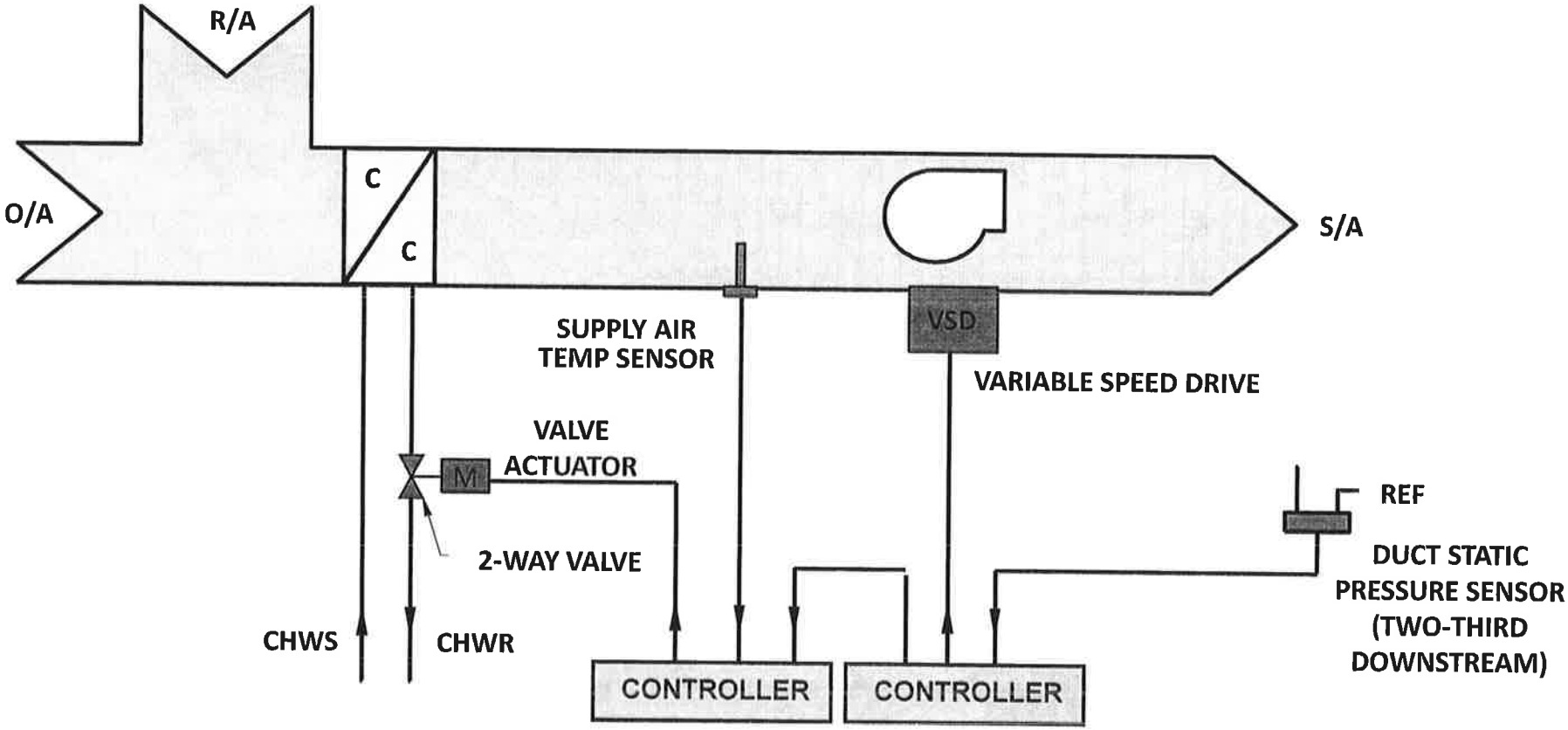
C1852

Psychrometric Chart Analysis

To Determine Whether Required Parameters Can Be Achieved



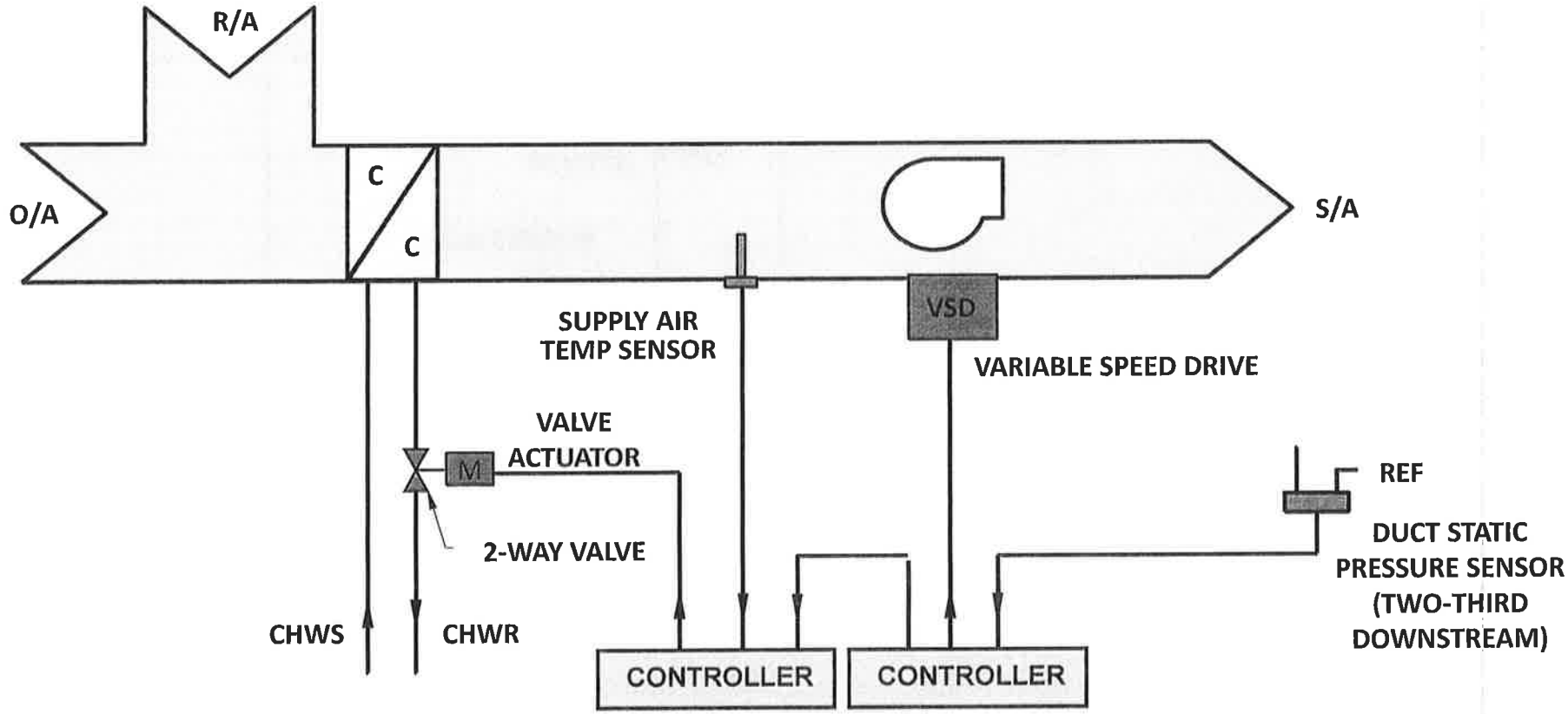
VAV AHU System



Variable Air Volume (VAV) is a technique for controlling the capacity of a HVAC system. The simplest VAV system incorporates one supply duct that, when in cooling mode, distributes approximately 13 to 17°C supply air.

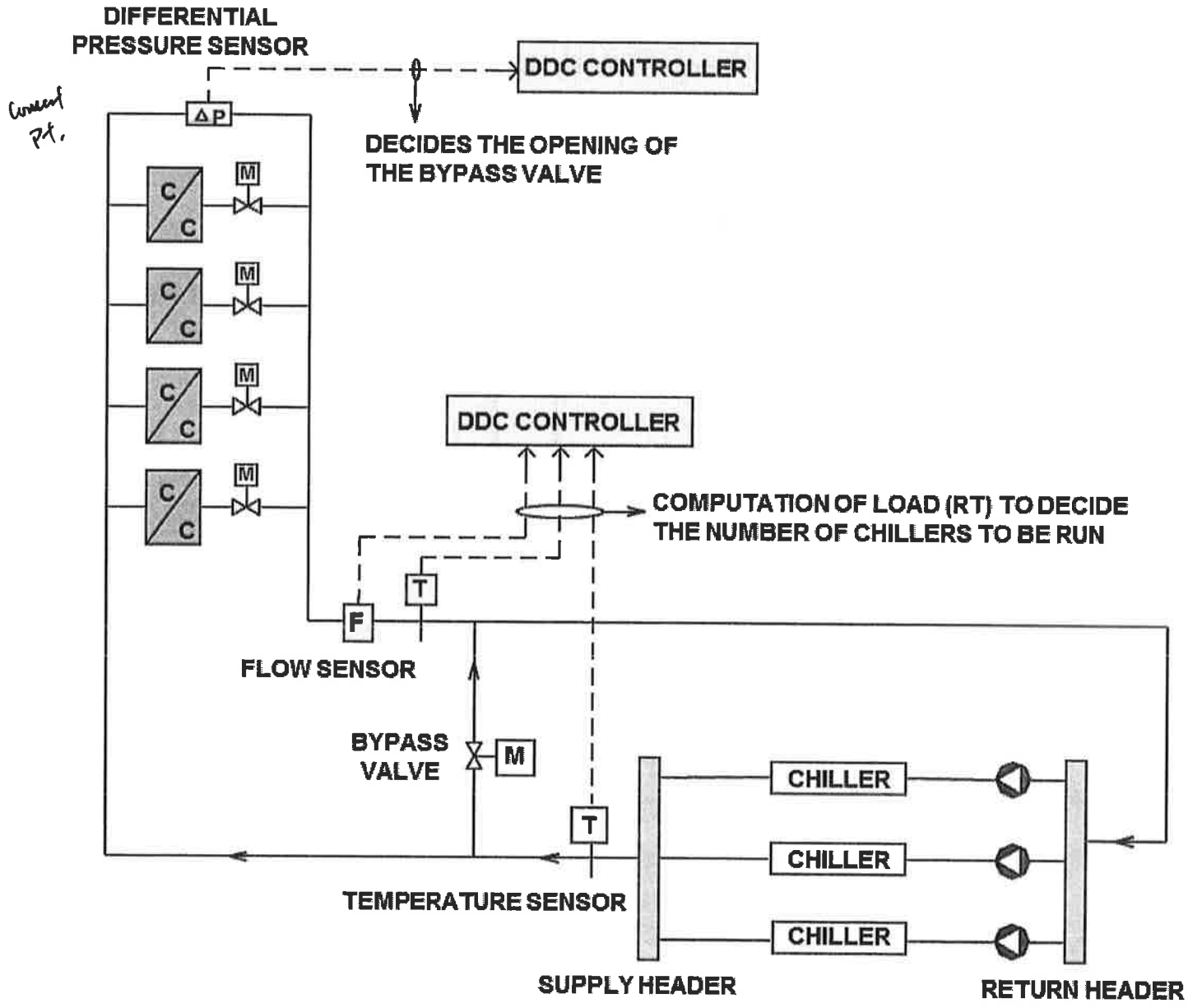
Because the **supply air temperature**, in this simplest of VAV systems, is **constant**, the **air flow rate must vary** to meet the rising and falling heat load within the thermal zone served.

VAV AHU System

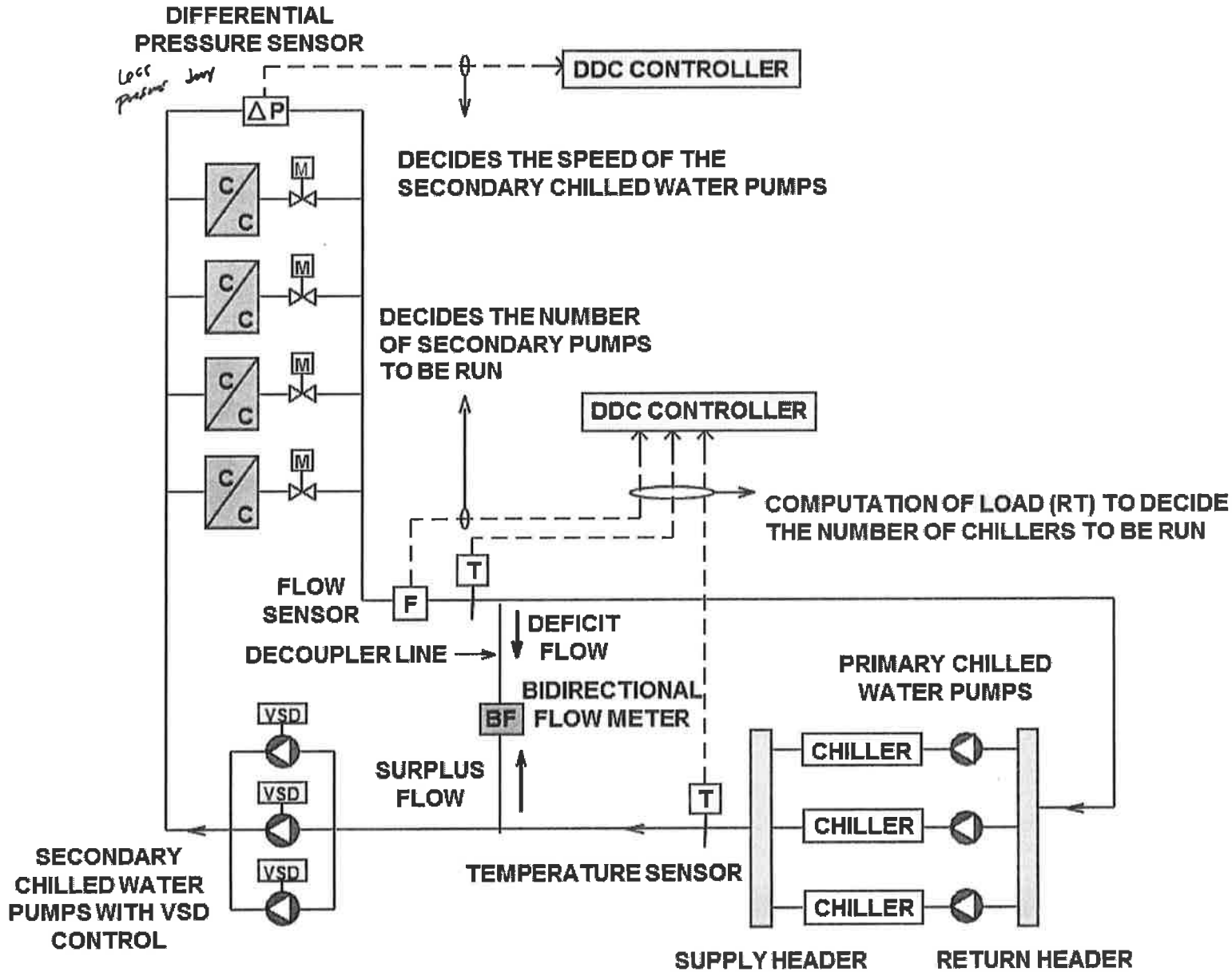


1. Where is the ideal location for static pressure sensor?
2. What should be the static pressure setpoint?
3. How to ensure sufficient ventilation on rainy days?

Chiller Plant Control System – Primary Pumps Only

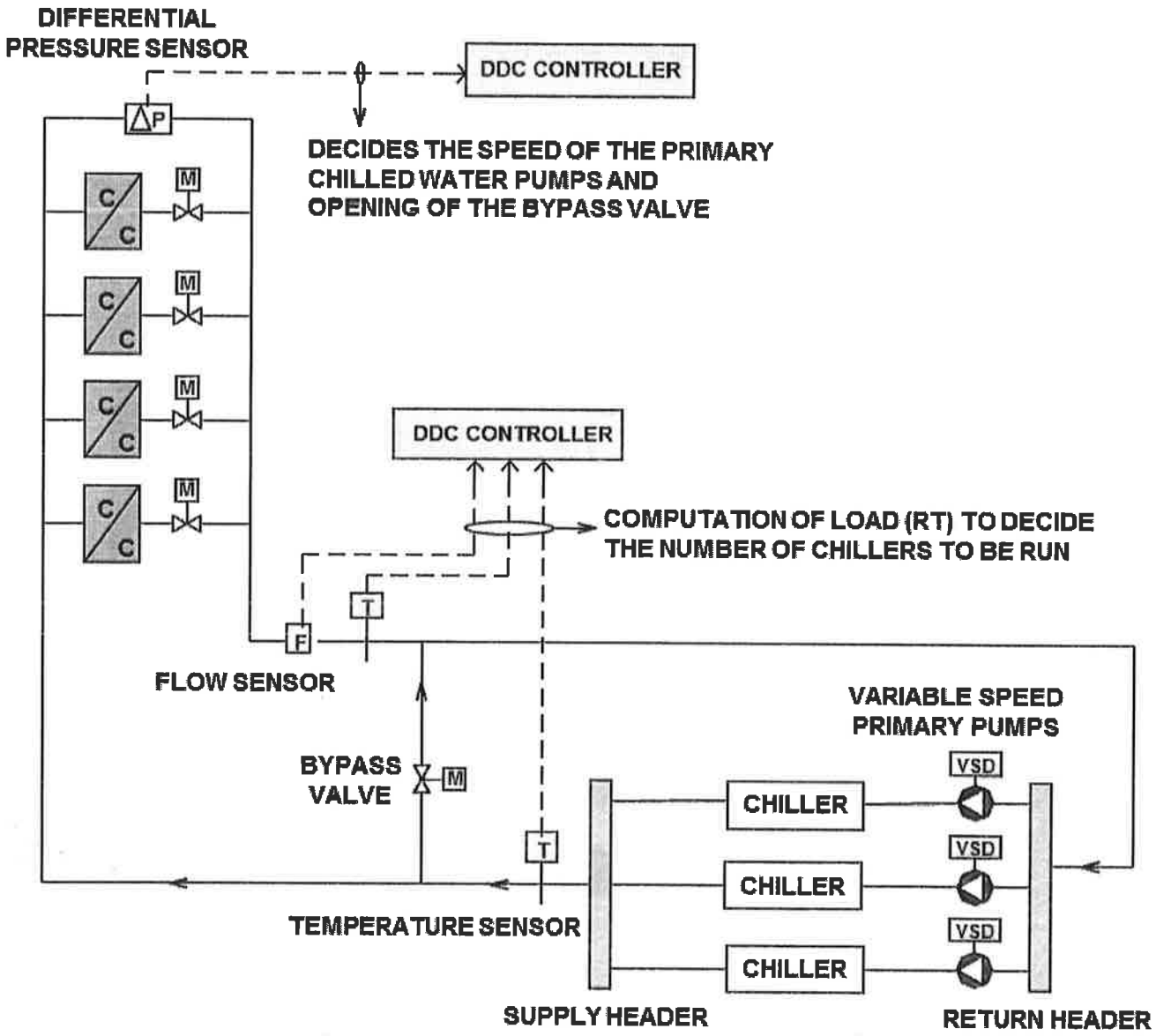


Chiller Plant Control System – Primary Secondary Pumps

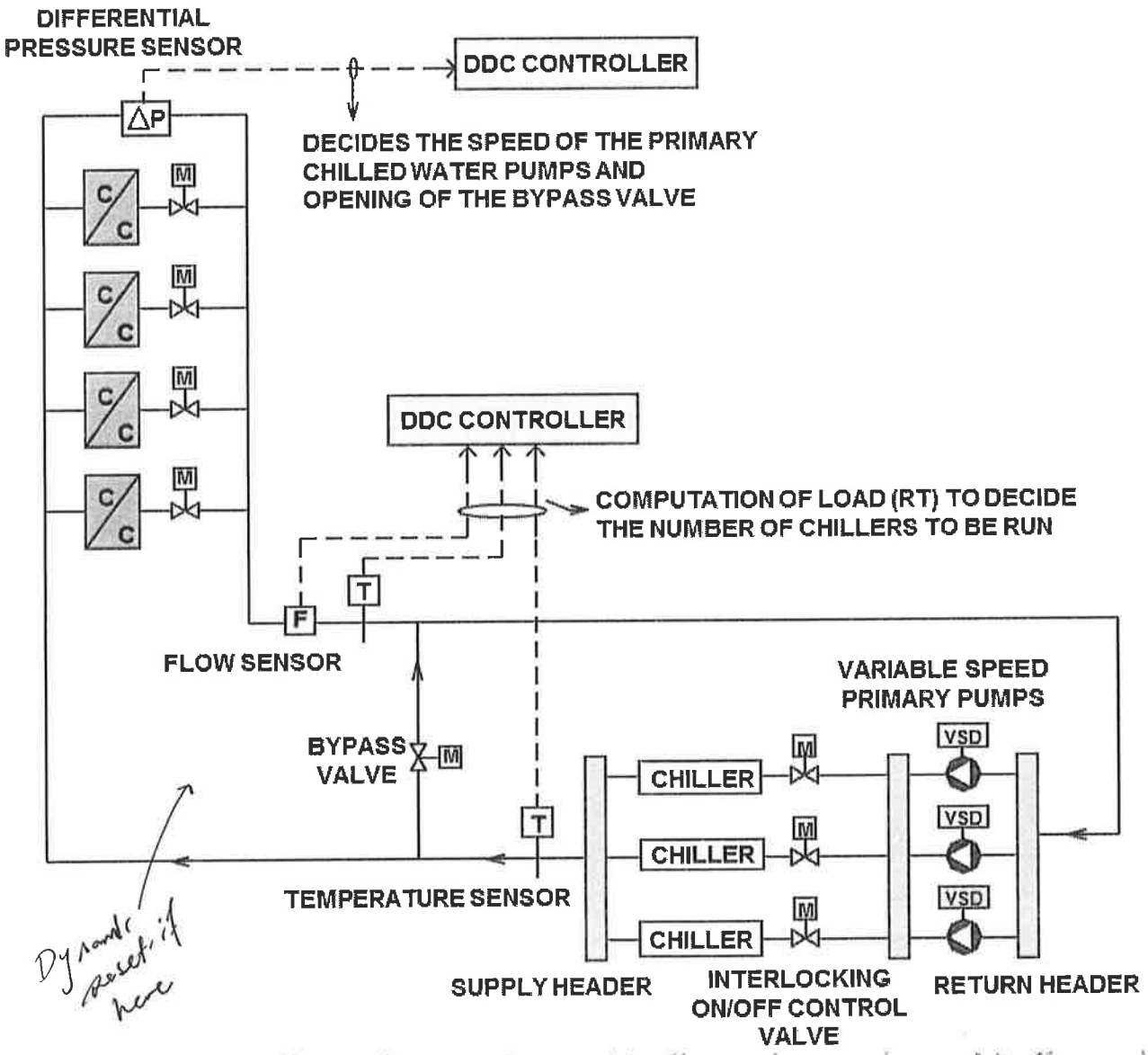


Chiller Plant Control System – Variable Primary Pumps

Pumps Connected in Dedicated Arrangement

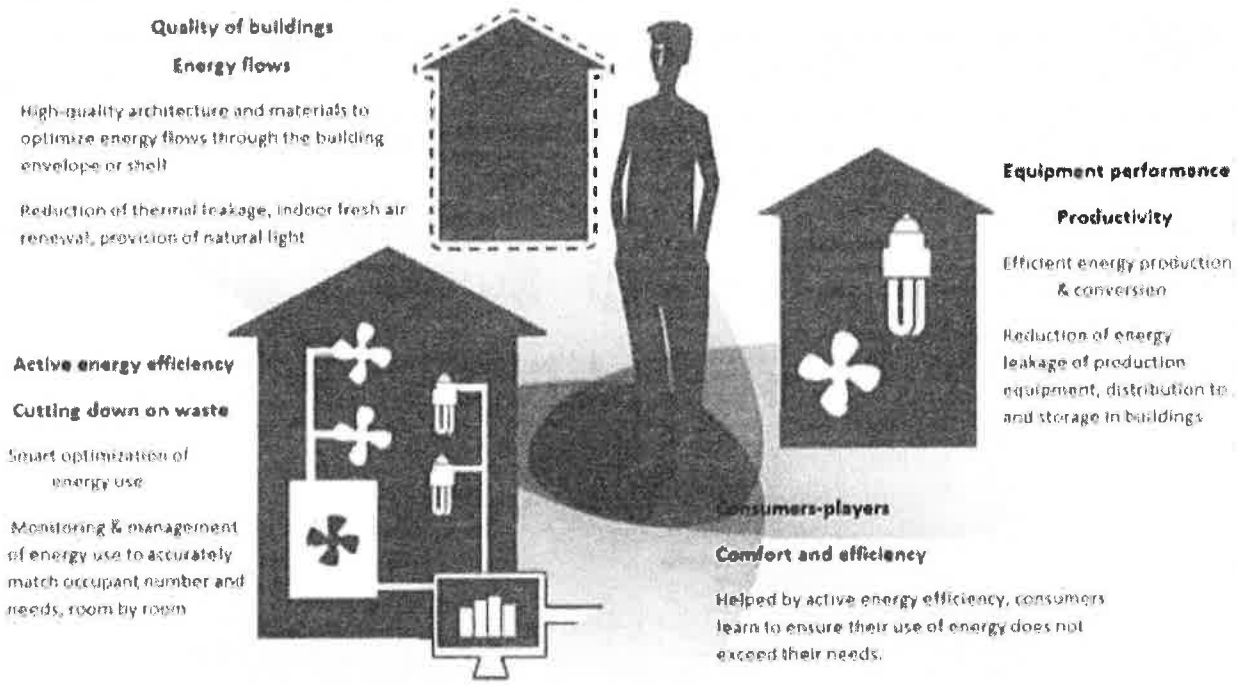


Pumps Connected in Manifold Arrangement



Tracking of Building Performance

Building Performance Tracking by BAS

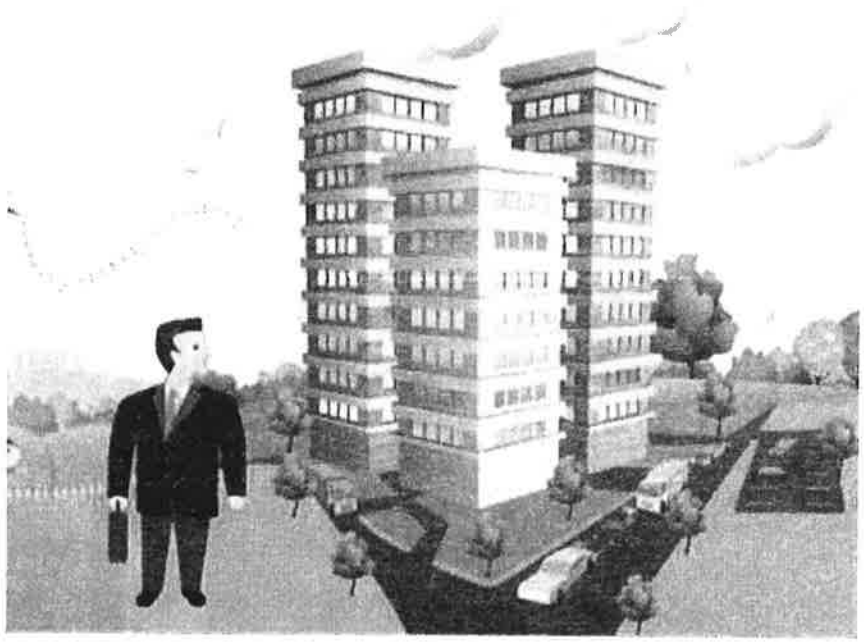


Modern building HVAC and lighting systems are interactive and complex. Over time, many building systems begin to **operate inefficiently** and may require **frequent attention** to ensure they are **optimized**.

For example, **sensors may drift out of calibration**, **building use could change**, and **adjustments in control sequences** might affect how well systems work together. This can result in **occupant complaints** and **increased energy costs**.

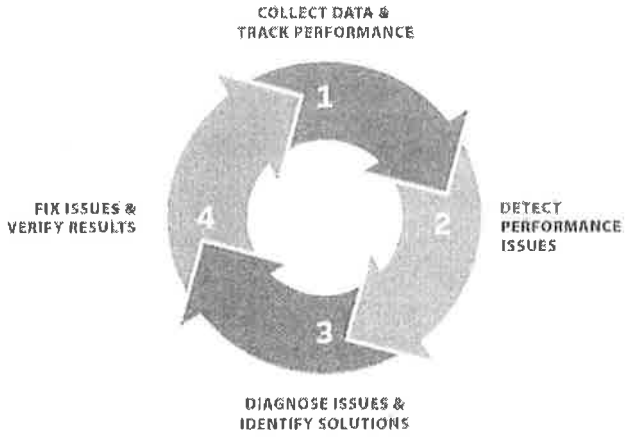
Building performance tracking is a **proactive strategy** for achieving **occupant comfort** without jeopardizing **energy performance**.

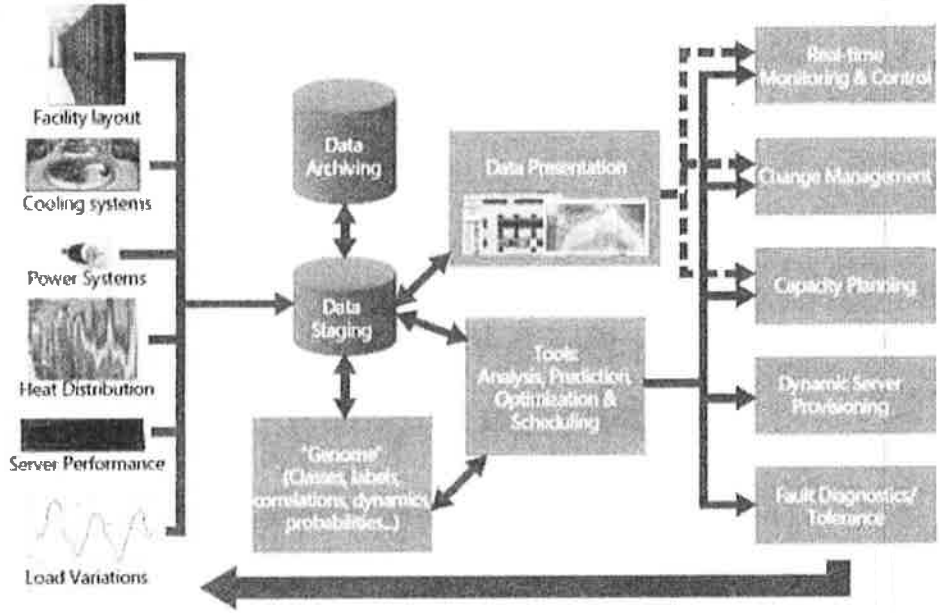
Continuous Improvement for Every Building



Buildings are investments with **significant profit potential**. In today's commercial building market, buildings need to be **comfortable** for occupants and must **operate efficiently** to **remain competitive**. Building owners who achieve this **balance** benefit from **deep cost savings** and **market leadership**.

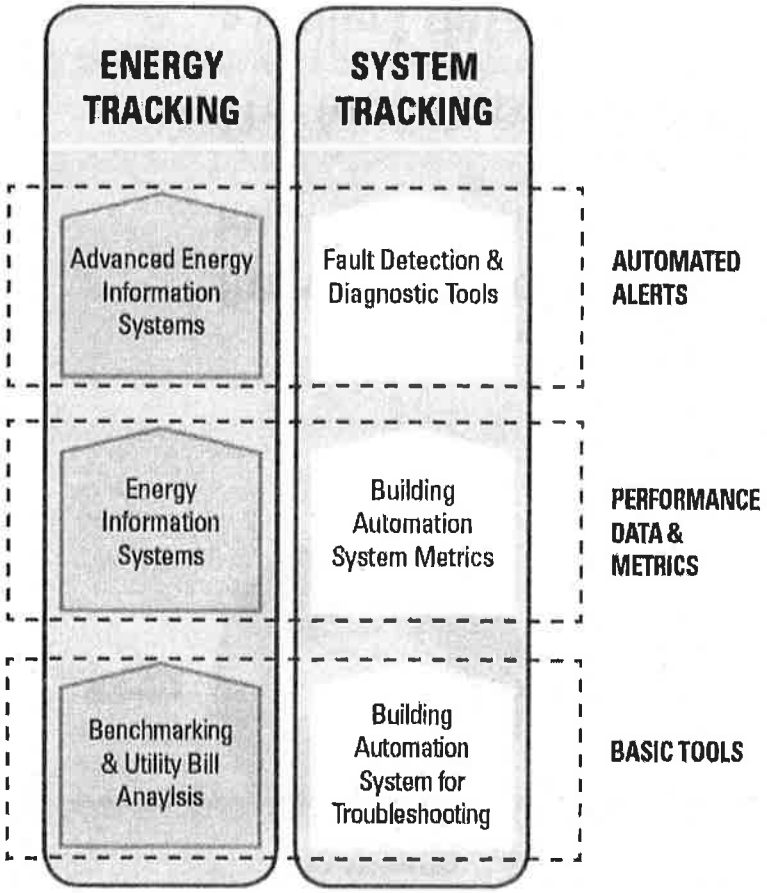
Building Performance Tracking - A Process of Continuous Improvement





- Building performance tracking is a process of continuous improvement.
- The four steps involved are:
  - Collect **data** and track **performance**
  - Detect and uncover **performance issues**
  - Analyse/diagnose issues and identify **solutions**
  - Resolve issues and verify **results**

Energy Tracking and System Tracking



Energy Performance Tracking

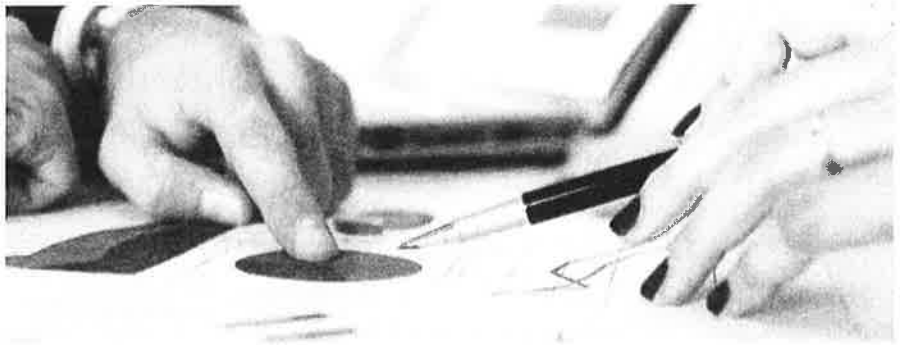
- Data accessed through **power meters** and **monthly utility bills**.
- Track **normalized energy use** with data normalization to factor in variables such as **weather**, **building operating hours** and **building type**.
- Track **Energy Efficiency Index** or **EEI** and compare to publicly available data.
- Benchmarking of **utility costs** against a **pre-defined budget** and benchmarking of **energy use** against **pre-defined savings targets** and a **portfolio**.

System Performance Tracking

- **Track parameters** such as supply air temperature and pressure, CO_2 level, variable frequency drive speed, zone temperatures and lighting level via BAS.
- **Trend logging** and **alarms** (e.g. equipment or system fault, data point outside of pre-determined threshold).
- **Diagnose** and **fix problems**.
- **Verify** that performance has improved by observing data at the operator workstation and reviewing trends.

BAS Metrics





What are Metrics?

Metrics are **parameters** or **measures of quantitative assessment** used for **measurement**, **comparison** or to **track performance**.

Metrics are **key performance indicators** which may be compared to **historical** or **expected values** to describe building performance.

A typical BAS has capabilities far beyond troubleshooting and simple alarms.

Using the BAS to track key performance metrics can be an **effective** and **inexpensive** way to reduce the **thousands of data points** that may be tracked into **digestible information**.

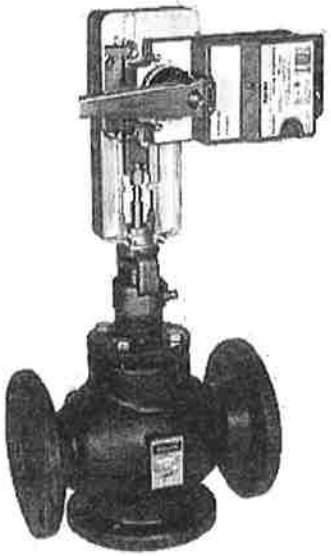
This **minimizes daily labour resources** required and provides a way to **track long term building performance improvements**.

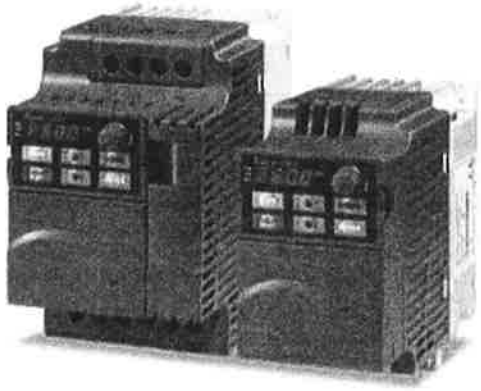
Examples of Useful Metrics

- Tracking the **kW** for a **chiller plant** gives some indication of performance, but this will vary considerably based on load and outside temperature.
- Tracking the **kW per ton of cooling** delivered provides a measure of how efficiently the plant is operating .
- Tracking **zone temperatures** is important for ensuring comfort, but reviewing temperatures in every zone is difficult to manage long-term.
- Tracking a metric such as the **percentage of time** when **zones are within setpoint** can be useful for assessing performance at a glance and for tracking improvement or degradation over time.
- Other useful metrics:

  - **kW/CMH** for fan system efficiency
  - **kW/ton** for total air-con system efficiency (chiller plant plus air distribution)
  - **CO_2 level** during occupancy and non-occupancy periods
  - No. of equipment **trips/faults** per day, per month and per year
  - **Litres of water** used per building occupant per year
  - **Cooling tower approach** versus original specification
  - **Cooling capacity of AHUs** versus original specification
  - **Chilled water ΔT** at AHUs and chiller plant header
  - **Chilled water ΔP** at furthest point of chilled water loop
  - **Control valve opening** of top 10% of AHUs with highest cooling load

Smart Alarms





Smart alarms can identify problems that would otherwise go undetected through simple alarms.

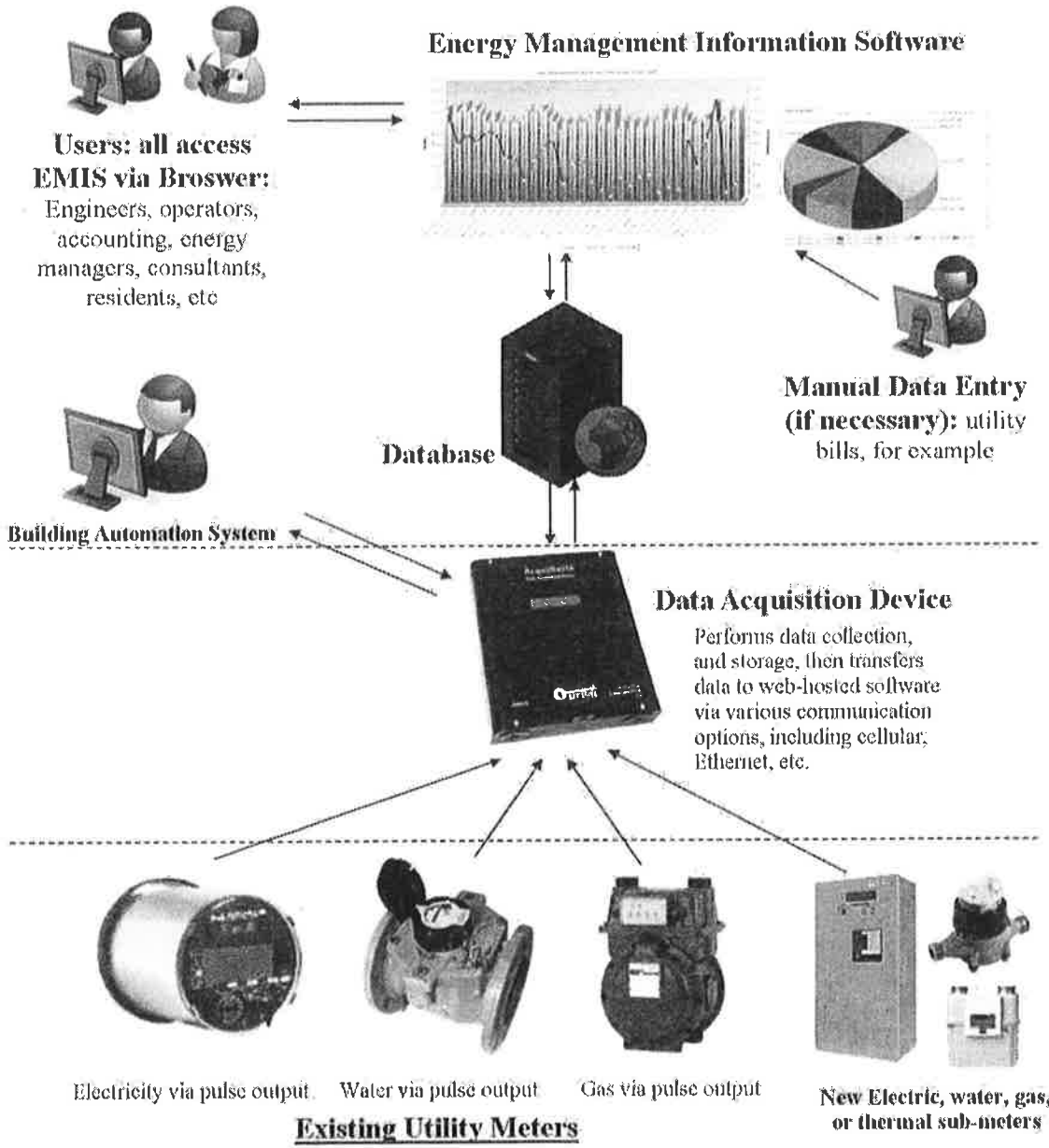
Examples of smart alarms:

- BAS to trigger alarm when water flow is detected by water flow meters at night when no water usage is expected – **water pipe leak**.
- Chilled water flow at AHU is detected by either water flow meters or ΔP sensors when AHU valves are commanded shut – **leaky valves or valves with poor close-off ratings**.
- VSDs at AHUs not throttling but remain constant – **wrong location of installation of static pressure sensors, faulty static pressure sensors** or **oversized fans.**
- Output devices such as control valves 'cycle' (opening and closing) too fast - control system unstable due to **inappropriate parameter settings** or other reasons.



Energy Tracking

Energy Management System



Energy Tracking System



- Electrical **usage** and **analysis** and **identification of peak demand levels**.
- Fair and equitable **cost allocation** for tenant billing and departments.
- **Measurement**, **verification** and **benchmarking** of kW/kWh for energy initiatives.
- **Profiling** and **efficiency tracking** of common loads (e.g. chiller plant)
- Threshold **alarming** and **notification**.
- Multi-site **load aggregation** and real-time historical monitoring of energy consumption patterns for negotiating lower energy rates.
- Online monitoring via **ethernet**, **web-browser**, **wireless RF link**.
- Power quality monitoring – **power factor**, **harmonics**.

Options for Tracking Energy Metrics

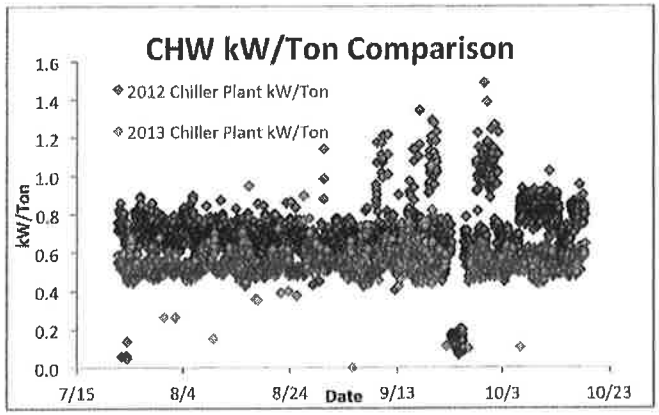
Example: Whole Building kWh / sq ft / year

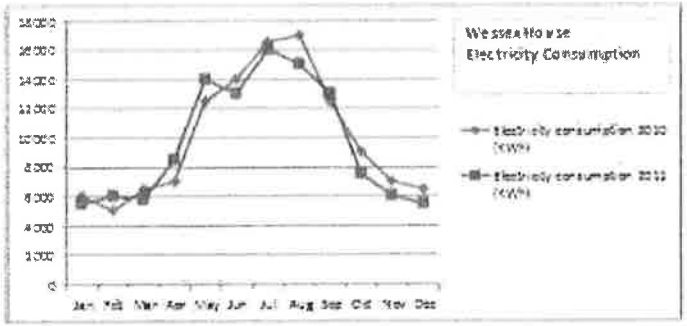
Metering Scope
- Whole building
- End use (HVAC, lighting, plug loads, etc.)
- Specific system (chilled water, air handlers, etc.)

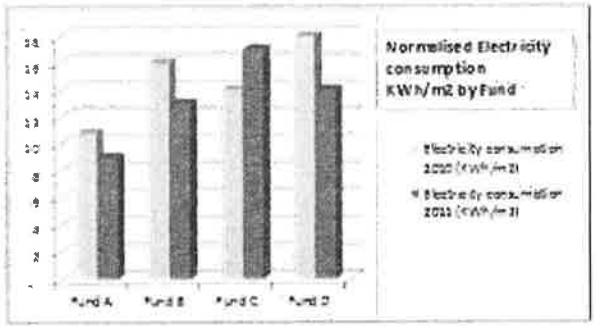
Units Tracked
- Electricity (kWh)
- Demand (kW)
- Gas (therms)
- Combined electric and gas (kBtu)
- Cost ($)

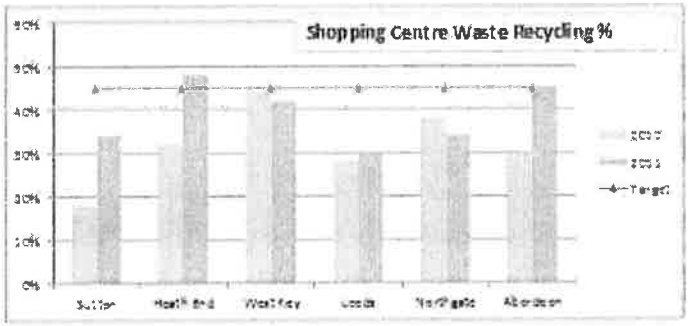
Normalization
- Square feet
- Cooling degree days
- Heating degree days
- Occupancy

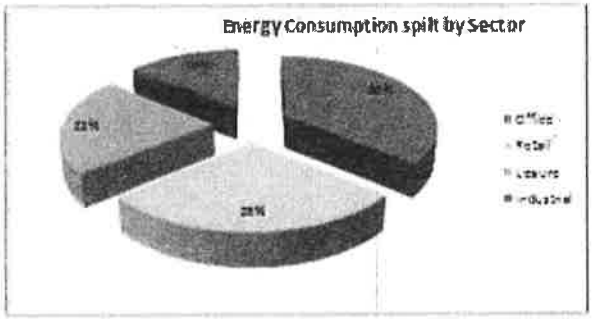
Time Frame
- Per year
- Per month
- Per day



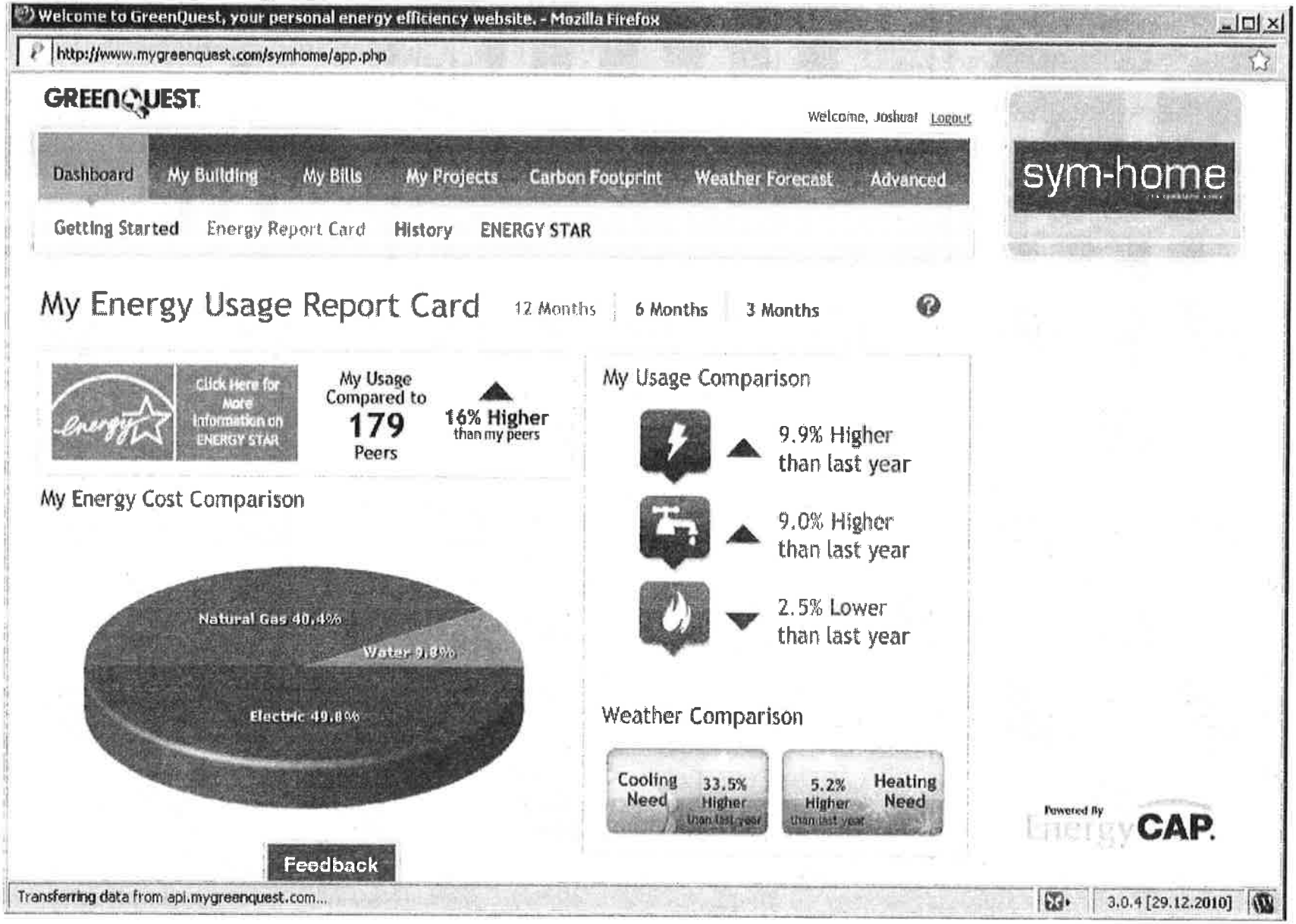






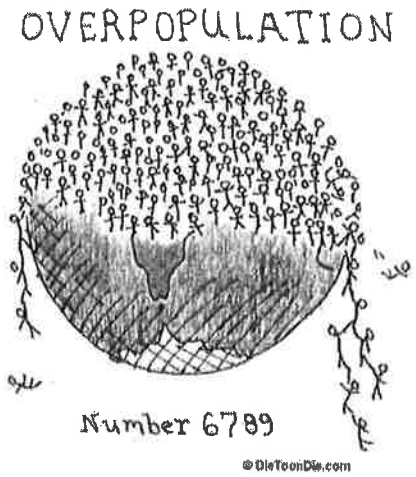


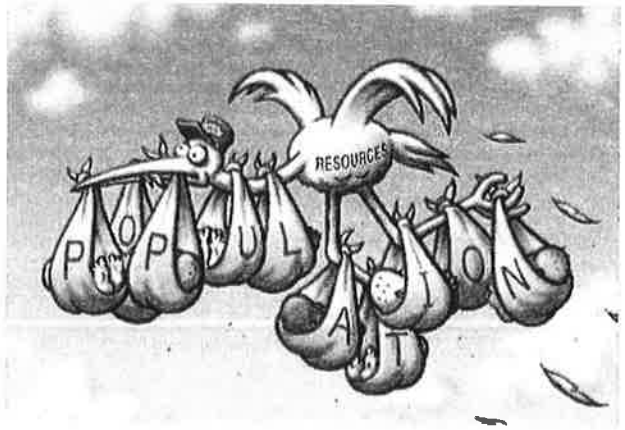
Energy Usage Report Card



Energy Management Strategies

Why Do We Need to Conserve Energy?





According to the U.S. Census Bureau, the world population is expanding at a **mind-boggling rate**.

The world reached **1 billion** people in 1800; **2 billion** by 1922; and over **6 billion** by 2000. It is estimated that the population will swell to over **9 billion** by 2050.

That means that if the world's **energy resources** were evenly distributed, people in **2050** will only have **¼** of the energy resources per capita that people in **1950** had.

Why Do We Need to Conserve Energy?

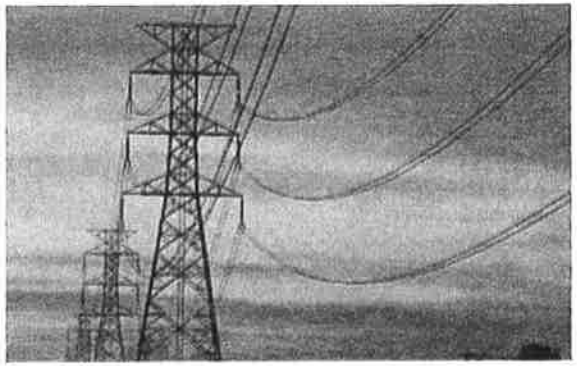
Energy Shortages / Power Outages

Electricity Crisis



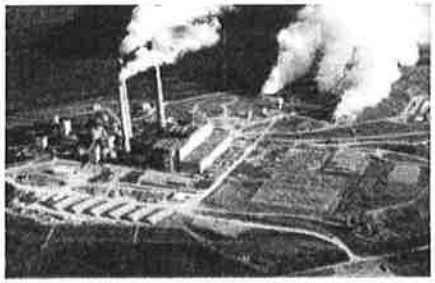
Pakistan has a serious electricity crisis with daily **18-hour of electricity outage**.

Energy Shortages

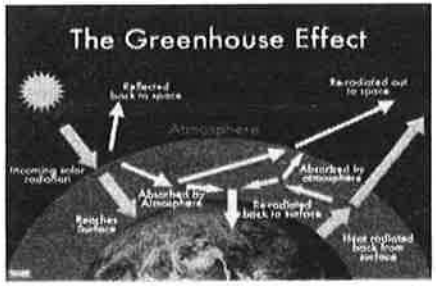


Despite **India** having an installed power capacity to rival the US and China's, the nation is failing to meet rapidly growing demand for electricity.

Global Warming & The Consequences



Greenhouse Gases from Power Plants



Greenhouse Effect

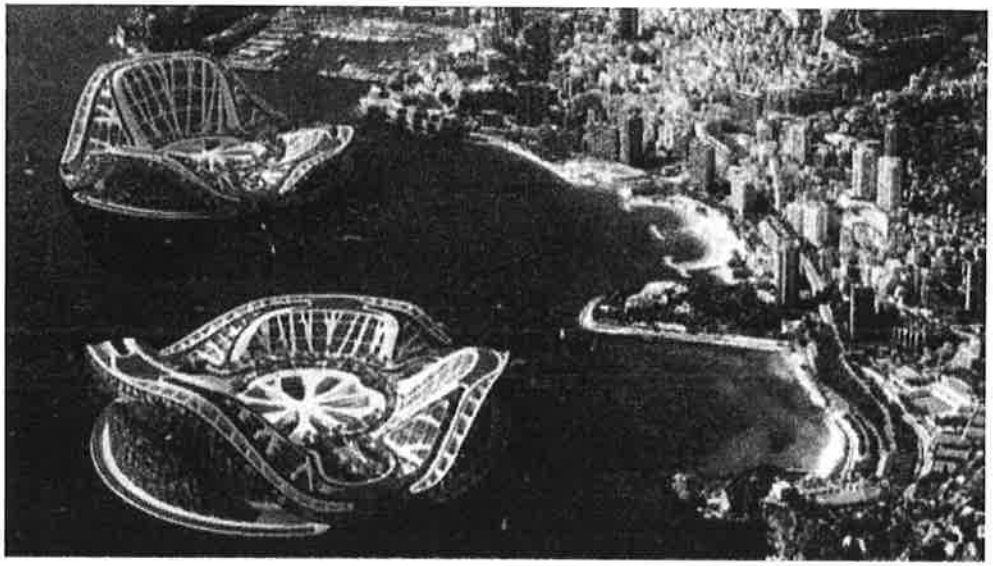


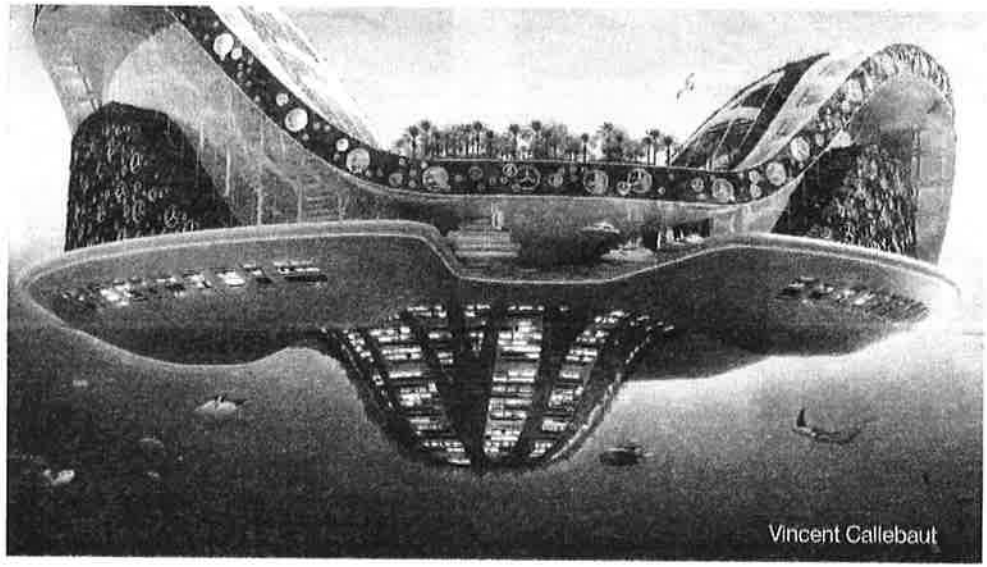
Cyclone



Queensland Flood 2011

LILYPAD – Floating City for Climate Change Refugees





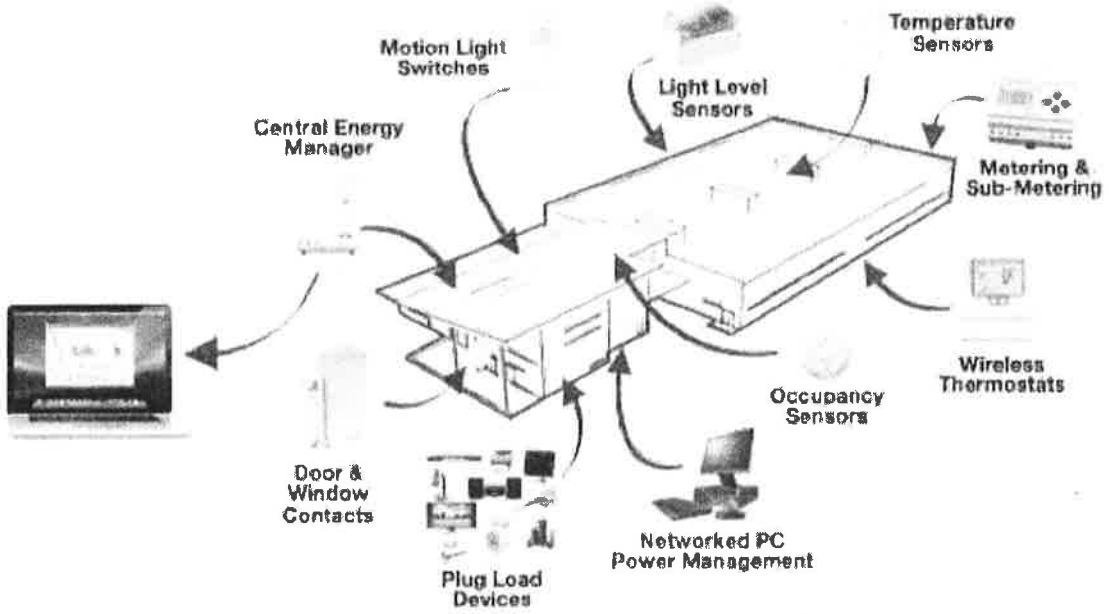
True amphibian – half aquatic, half terrestrial city housing 50,000 inhabitants.

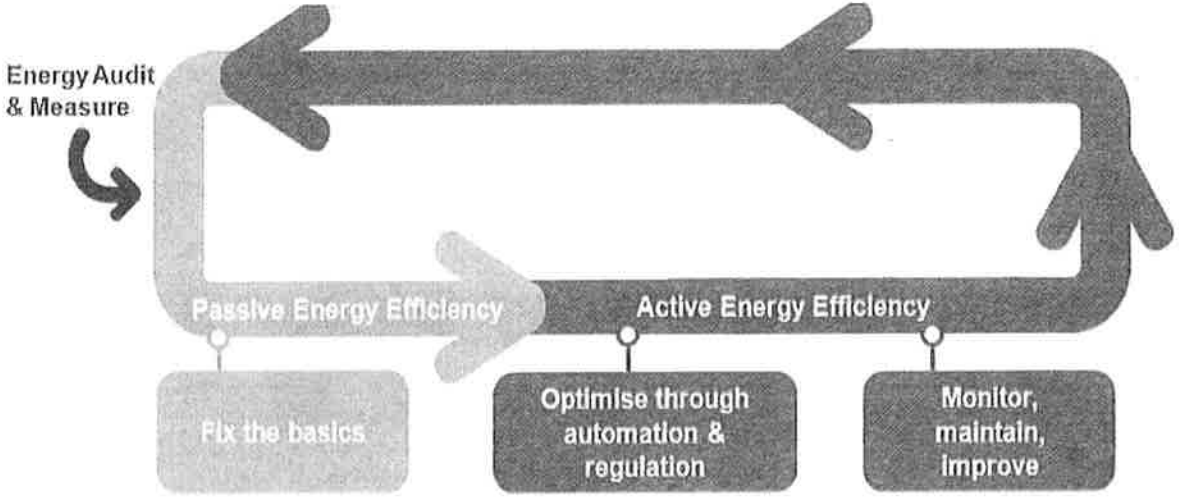
Great **biodiversity of fauna and flora** around a central lagoon of soft water, ballasting the floating city.

Whole set covered by a **stratum of planted housing** in suspended gardens and crossed by a network of streets and alleyways with organic outline.

Entirely auto-sufficient – solar, thermal and photovoltaic, wind, hydraulic, tidal and osmotic energies, phyto-purification, waste recycling and aquaculture fields for crop cultivation.

Saving Energy Through Building Automation and Controls



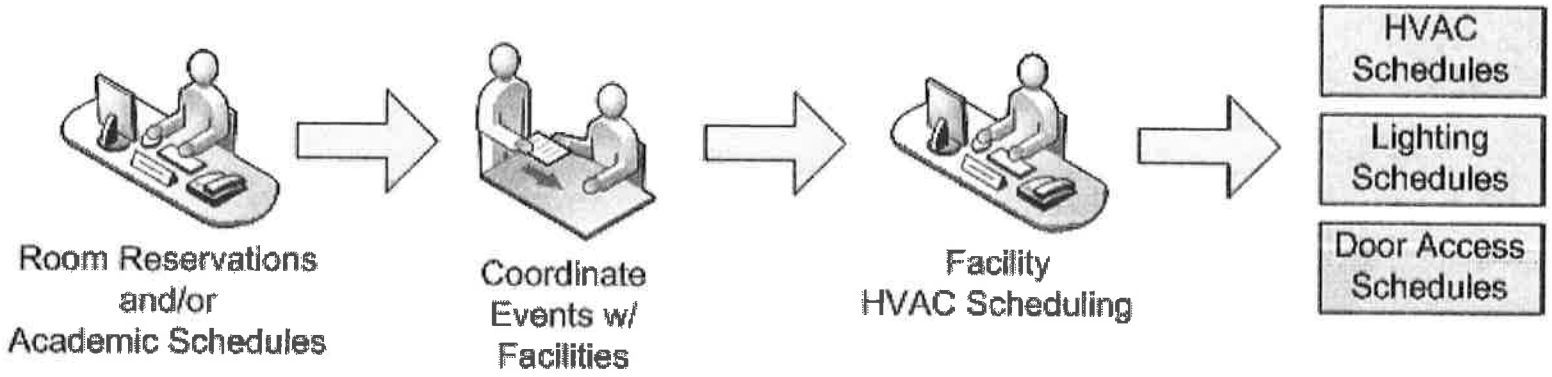


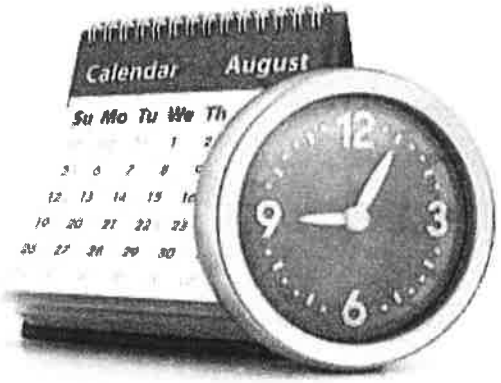
Switch to energy efficient materials and equipment.

Only use what you need, when you need it.

Use monitoring and maintenance services to continuously improve performance and control your savings.

Scheduling





- Scheduling defines not only **ON/OFF times**, but **setpoints** as well.
- The first step in smart scheduling is to **shut down unnecessary equipment** when it is **not needed**.
- Taking control of schedules may still be the **quickest** and **simplest way** to see an **immediate reduction in energy bills**.

Types Scheduling

- Daily Scheduling
- Calendar Scheduling
- Exception Scheduling
- Zonal Scheduling
- Override Control and Tenant Billing
- Night Setup/Setback
- Optimum Start
- Optimum Stop
- Morning Cool-Down

Daily Scheduling: Weekday and Weekend.

Calendar Scheduling: Public Holidays, School Term, Production Schedule, Sports Events, Parliamentary Sittings, Earth Day.

Exception Scheduling: For one-off type of events.

Zonal Scheduling: Shutting down of equipment in unoccupied areas/zones.

Override Control and Tenant Billing: For tenants who work outside of normal schedule.

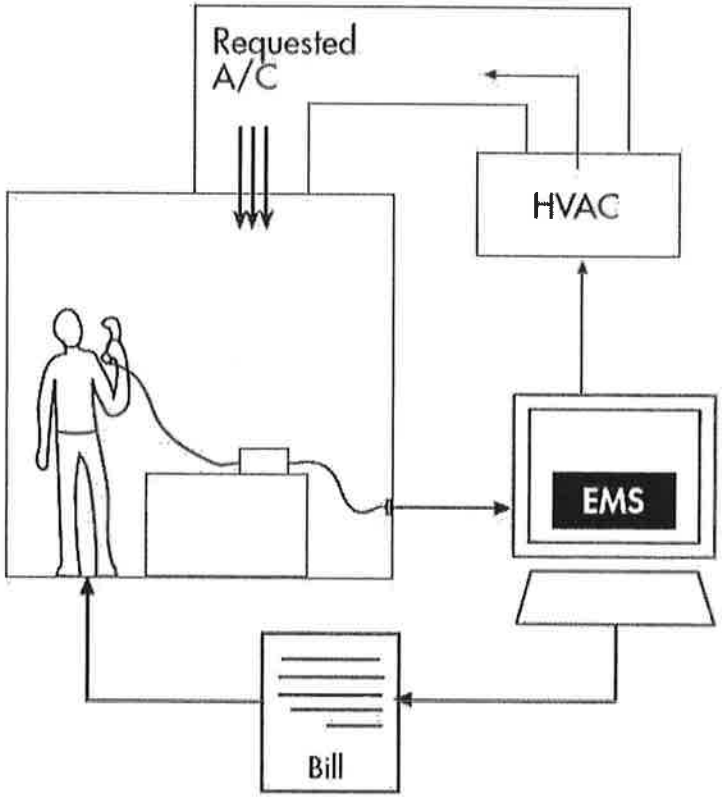
Night Setup/Setback: Setpoint changes during night time or period of less or no occupancy.

Optimum Start: Starting the equipment only as early as required to bring the building to setpoint at the occupied time. Adaptive Control.

Optimum Stop: Earliest possible time to turn off equipment before unoccupied periods and still maintain occupant comfort.

Override Control and Tenant Billing

Override Control





IP Phone

Override function to request for air-con or lighting extension can be achieved by **dialling into the system** or through a **web browser interface** or through a **smart IP phone**.

This feature is desirable when **occupant use** is **widely variable** and **difficult to program** as a schedule into the BAS or EMS.

Based on agreed cost per square foot, the BAS will **bill the tenants** for the off-schedule operational hours they request.

Lighting Energy Management Strategies

Lighting Control Strategies

Lighting Control Categories

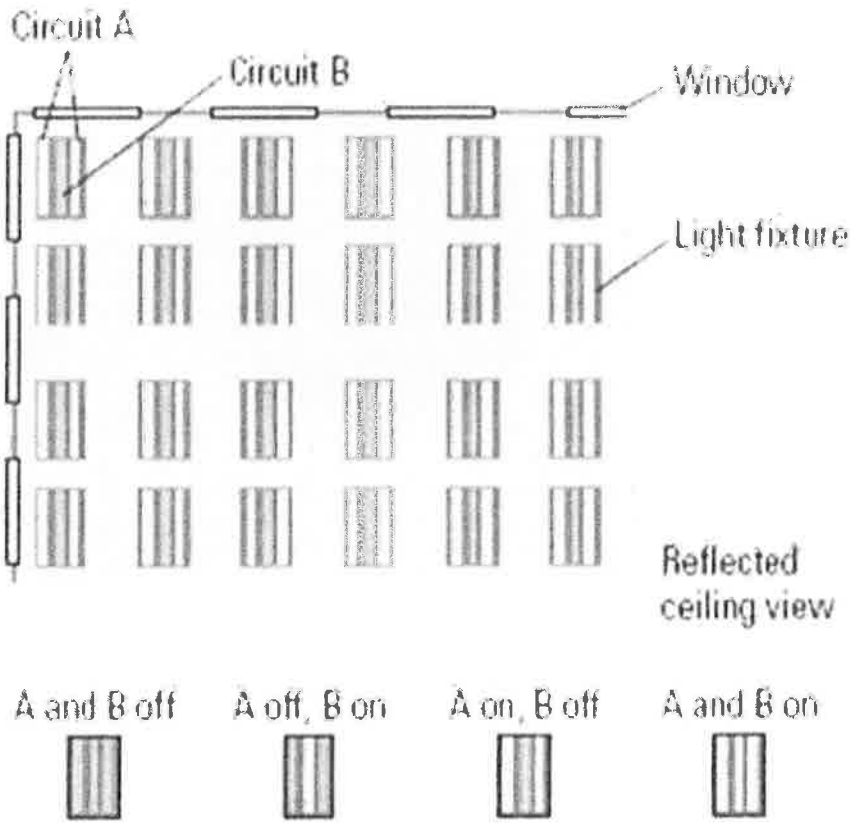
TYPICAL		ENHANCED AUTOMATION
Basic Controls	**Advanced Controls**	**Centralized Controls**
On/Off Controls Clock/timer controls Manual dimming controls	Light-level sensors Occupancy sensors Daylighting/hi-lo/dimming	Lighting sweep strategies Override strategies Demand limiting strategies Occupancy sensors Dimming capabilities

The most basic type of lighting control is **on/off control**.

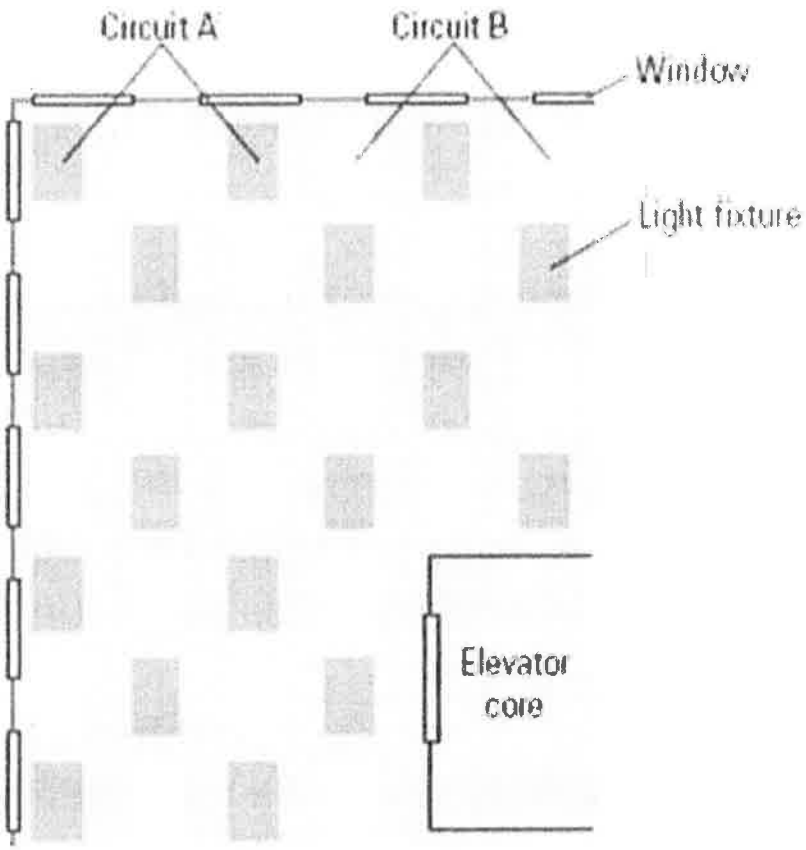
Fixtures can be wired to be controlled in **rows** or **some other pattern**, with a **hi-lo capability**, or in an **inboard/outboard configuration**, which allows some or all of the lamps in a multi-lamp fluorescent fixture to be turned off.

Common applications include reducing light levels after hours for **security and cleaning crews** or where there is a **significant contribution of daylight**, such as **near windows**.

Lighting Control Strategies



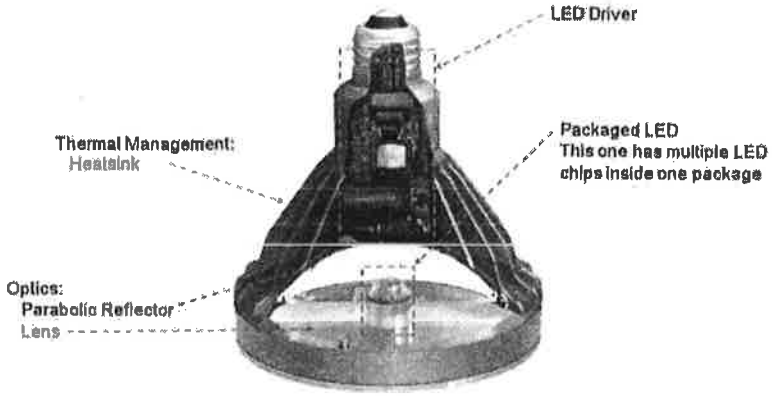
Lamp Patterning



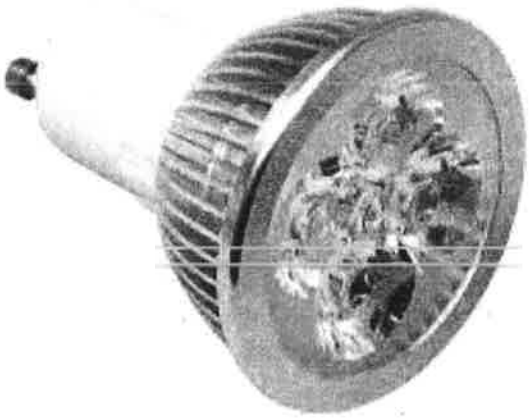
Fixture Patterning – Checkerboard Configuration

Even though **lamp patterning** can provide an **enhanced level of light distribution** compared to **fixture patterning** through the **elimination of dark spots**, the wiring requirements for lamp patterning are **more complicated** since each fixture is served by two circuits.

LED Lighting



Anatomy of an Integrated LED Lamp



LEDs are **low-voltage light sources**, requiring a **constant DC voltage** or **current** to operate optimally.

LEDs require a device called a **driver** that can convert incoming **AC power** to the **proper DC voltage**, and **regulate the current** flowing through the LED during operation.

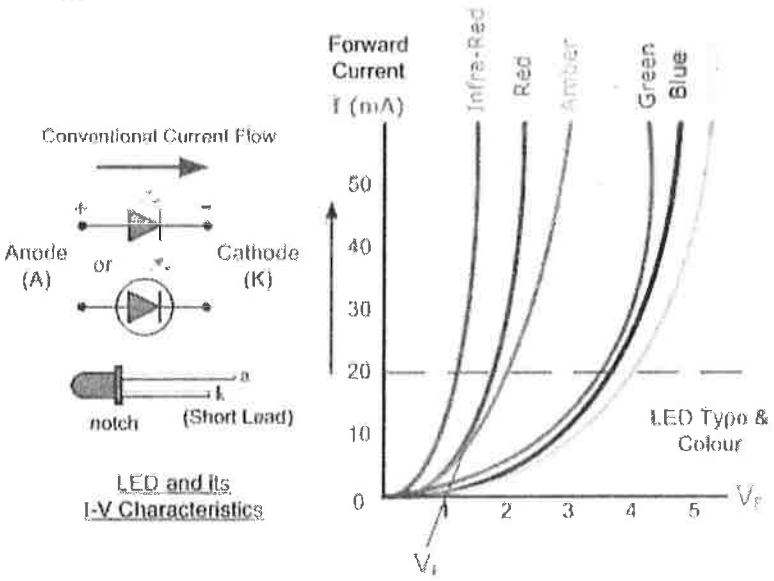
The driver converts **230V, 50Hz AC power** to **low-voltage DC power** required by the LEDs, and protects the LEDs from line-voltage fluctuations.

An LED driver is the **power supply** for an **LED system**, much like a **ballast** is to a **fluorescent** or **HID lighting system**.

LED drivers may be **constant voltage** types (usually 10V, 12V and 24V) or **constant current** types (350mA, 700mA and 1A).

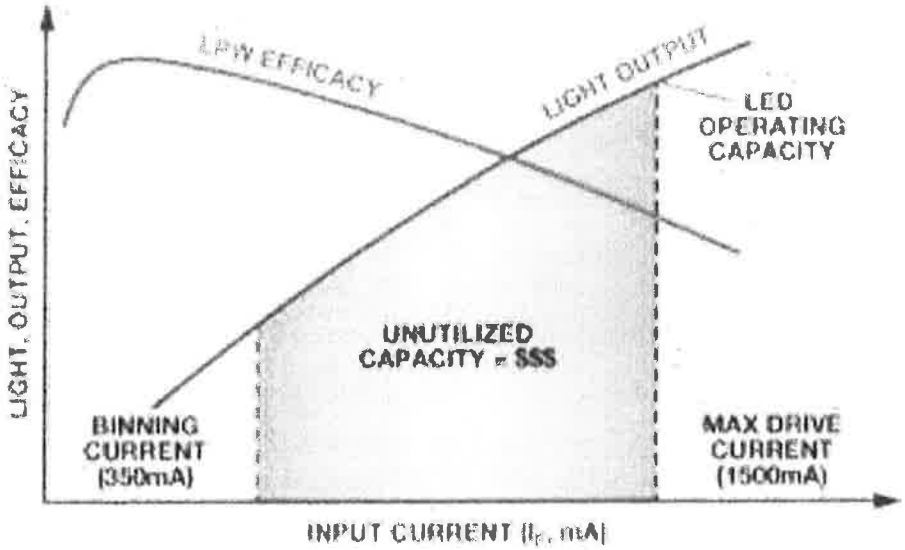
Working Principle of LED Lamps

Light Emitting Diodes I-V Characteristics.



Light Emitting Diode Colours

Typical LED Characteristics			
Semiconductor Material	Wavelength	Colour	V_f @ 20mA
GaAs	850-940nm	Infra-Red	1.2v
GaAsP	630-660nm	Red	1.8v
GaAsP	605-620nm	Amber	2.0v
GaAsP:N	585-595nm	Yellow	2.2v
AlGaP	550-570nm	Green	3.5v
SiC	430-505nm	Blue	3.6v
GaInN	450nm	White	4.0v

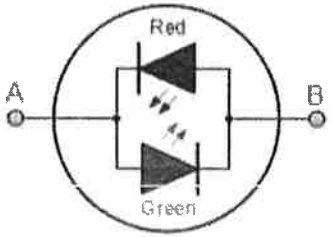


The **average forward LED current** determines the **brightness** of an LED. The relationship between **forward LED current** versus **lumens of optical output** for a given LED is remarkably **linear** over usable ranges of forward current (IF).

An LED's colour temperature metric describes the colour of the light emitted by the LED. The **colour temperature** of a given LED shifts with variances in **IF**, junction temperature, and the LED's age.

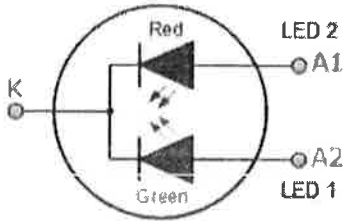
Working Principle of LED Lamps

A Bicolour LED



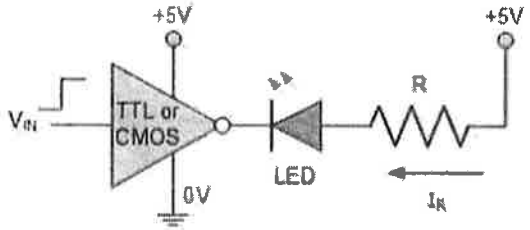
LED Selected	Terminal A		AC
	+	-	
LED 1	ON	OFF	ON
LED 2	OFF	ON	ON
Colour	**Green**	**Red**	

A Multi or Tricoloured LED

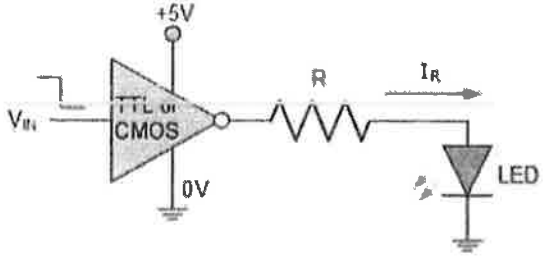


Output Colour	Red	Orange		Green
LED 1 Current	0	5mA	9.5mA	15mA
LED 2 Current	10mA	6.5mA	3.5mA	0

IC Driver Circuit



LED is "ON" when the output is LOW (current sink)

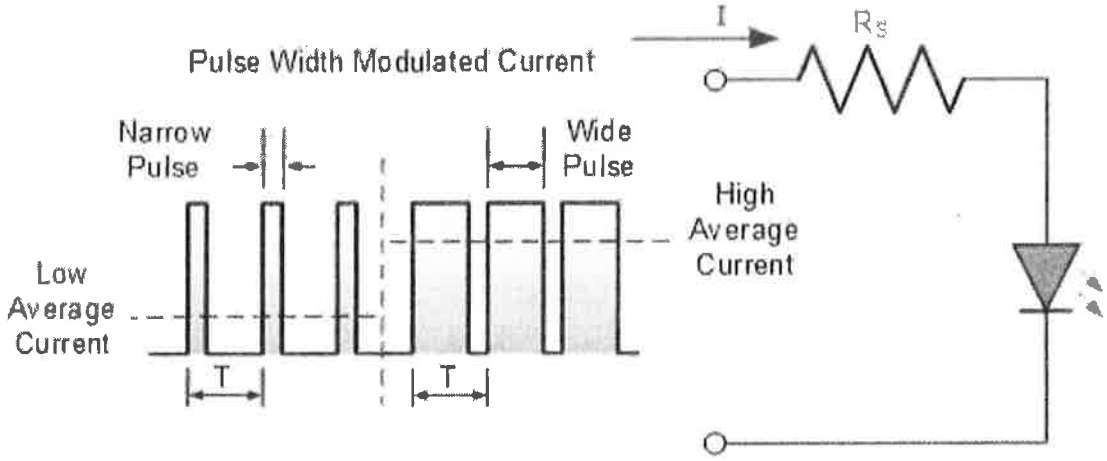


LED Driver Circuit using ICs

LED is "ON" when the output is HIGH (current source)

LED Dimming Control

LED Light Intensity using PWM



PWM Dimming

- **Greatly reduces colour changes** with varying brightness levels, as LED essentially runs at a **constant current** when it is on and at no current when it is off.
- **More expensive** due to **additional logic** to create the PWM waveforms.

Analog Dimming

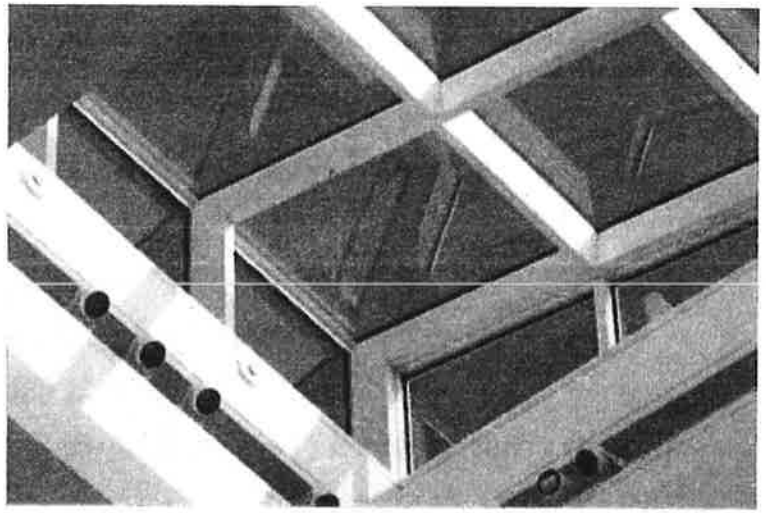
- **Variable current** supplied to the LED means that the regulator supplying the current to the LED must soak up any power not supplied to the LED.
- This **additional power** (wasted as **heat**) arises from the difference between the raw supply voltage powering the LED/regulator subsystem and the voltage across the LED.
- **Colour change** due to variable current driven through the device.

Light Level Sensors / Photocells





Photocell



Light-level sensors or **photocells** can initiate **on/off**, **multi-level**, or **dimming strategies** according to **actual light levels** in the space, based on user-defined requirements.

Building spaces with **significant contributions of daylight**, such as offices and work areas with windows, may often be **grossly overlit** when undimmed lighting is turned on.

Using the signal from **photocells** to **adjust artificial lighting** to supplement natural lighting in these areas can result in significant electricity savings—20 to 70 % of an undimmed system.

Daylighting Control Types



Open Loop

- Definition: The photocell **views the daylight directly** and does not respond to the electric light that it controls.
- Exterior or interior lighting.
- On/off or dimming.

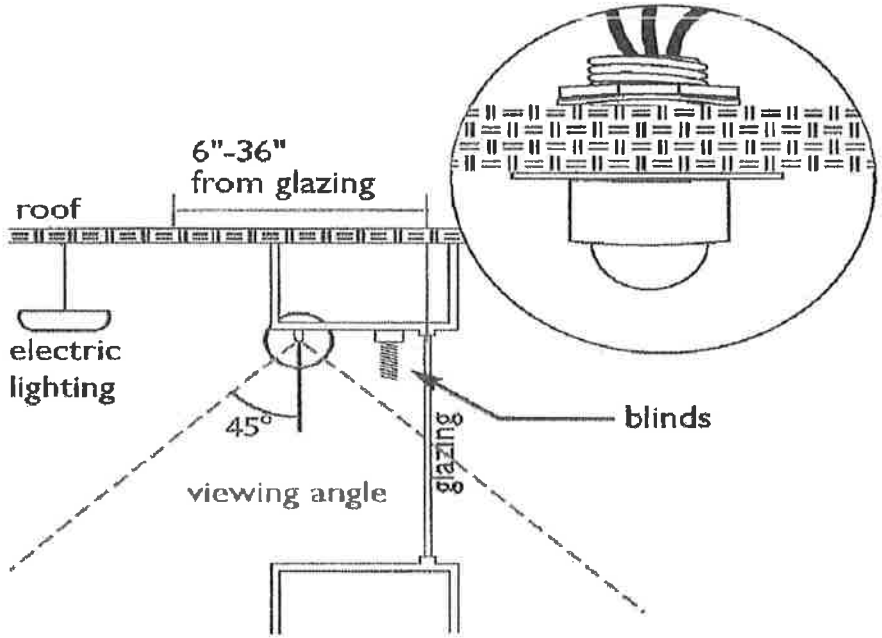
Closed Loop

- Definition: The photo sensor is **exposed** to an area **representing the brightness of the room,** including contribution from daylight.
- Never for exterior lighting.
- Usually for dimming.

Open Loop Photocell Location

For Side Lighting

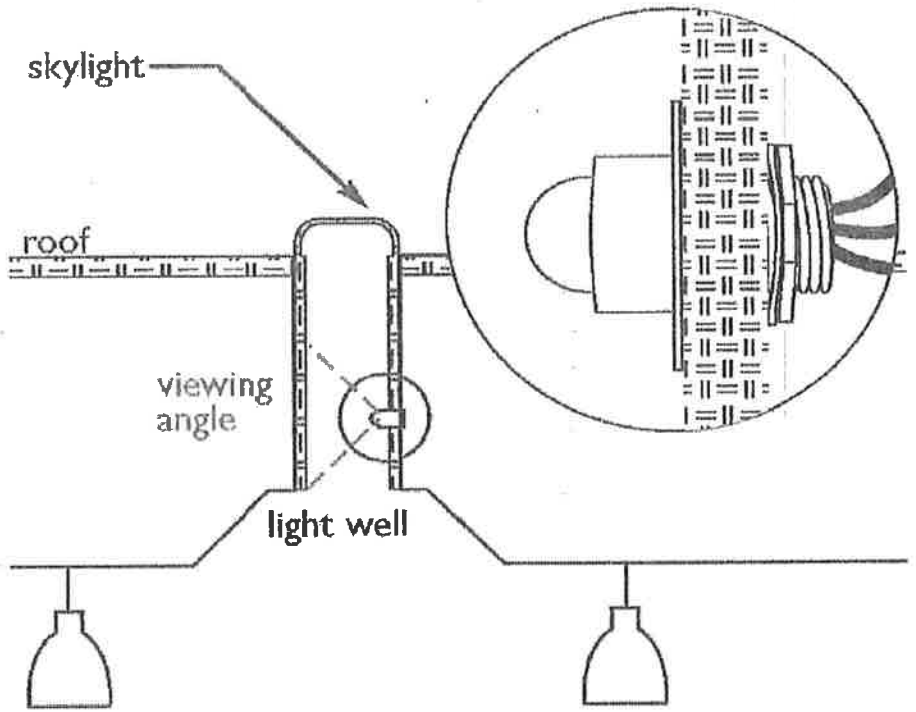
- Place photocell as close as possible to vertical glazing
- Photocell function affected by window shade
- All lights must have the same daylight exposure



Open Loop Photocell Location

For Top Lighting

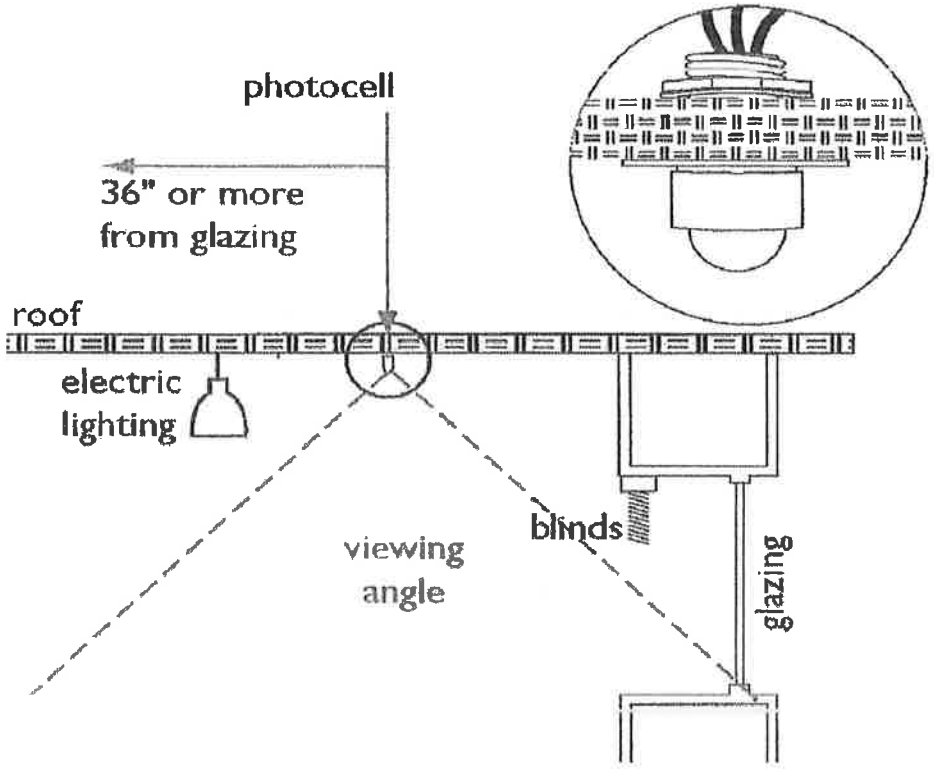
- Avoid direct exposure to sunlight
- Place photocell in light well
- Avoid direct exposure to electric light
- Zone lights with same daylight exposure



Closed loop Photo Sensor Location

For Side Lighting

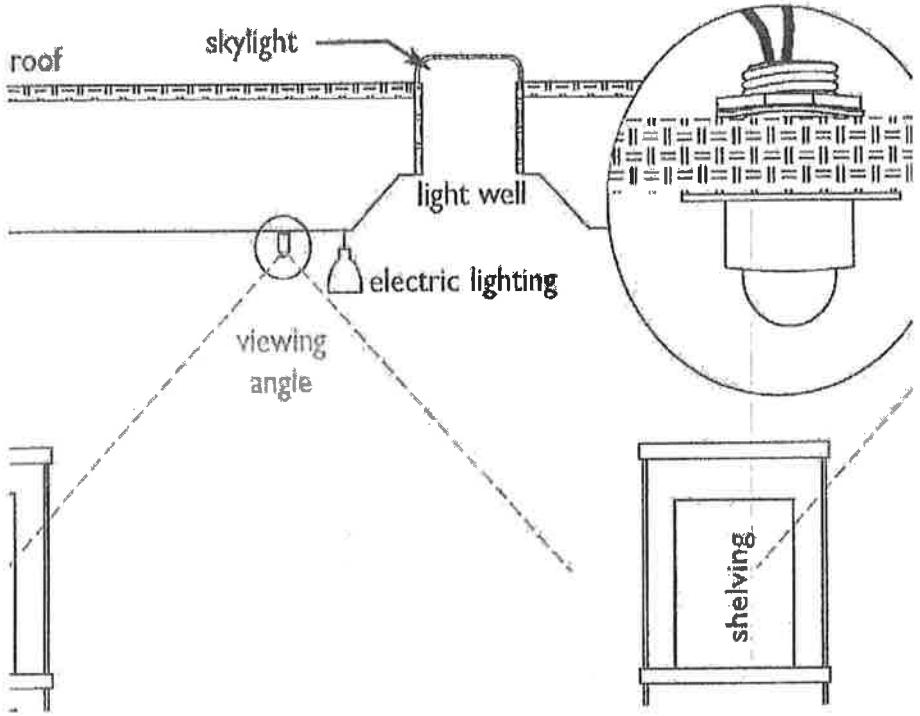
- Mount between windows and first row of lights
- Avoid placement in direct line of sight of indirect electric lighting or direct outdoor view



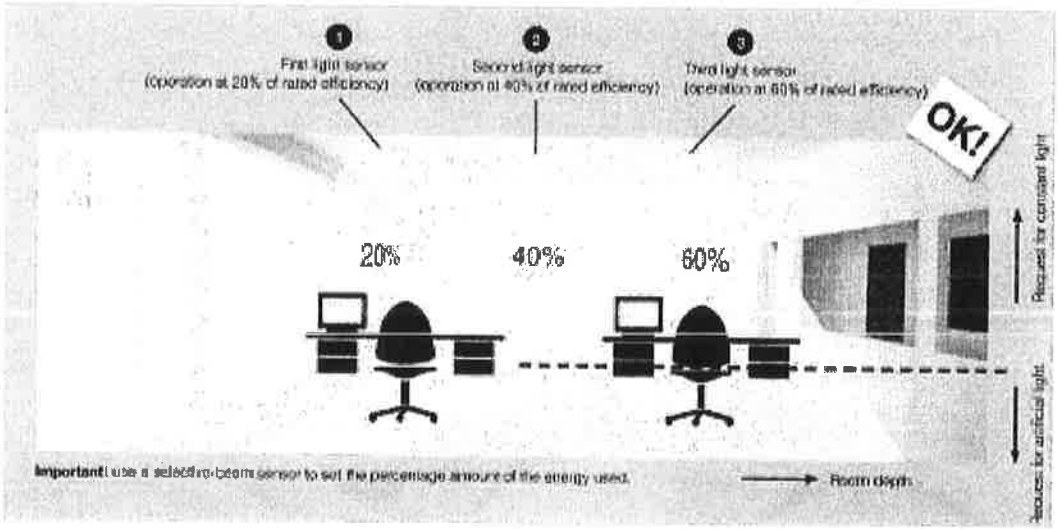
Closed Loop Photo Sensor Location

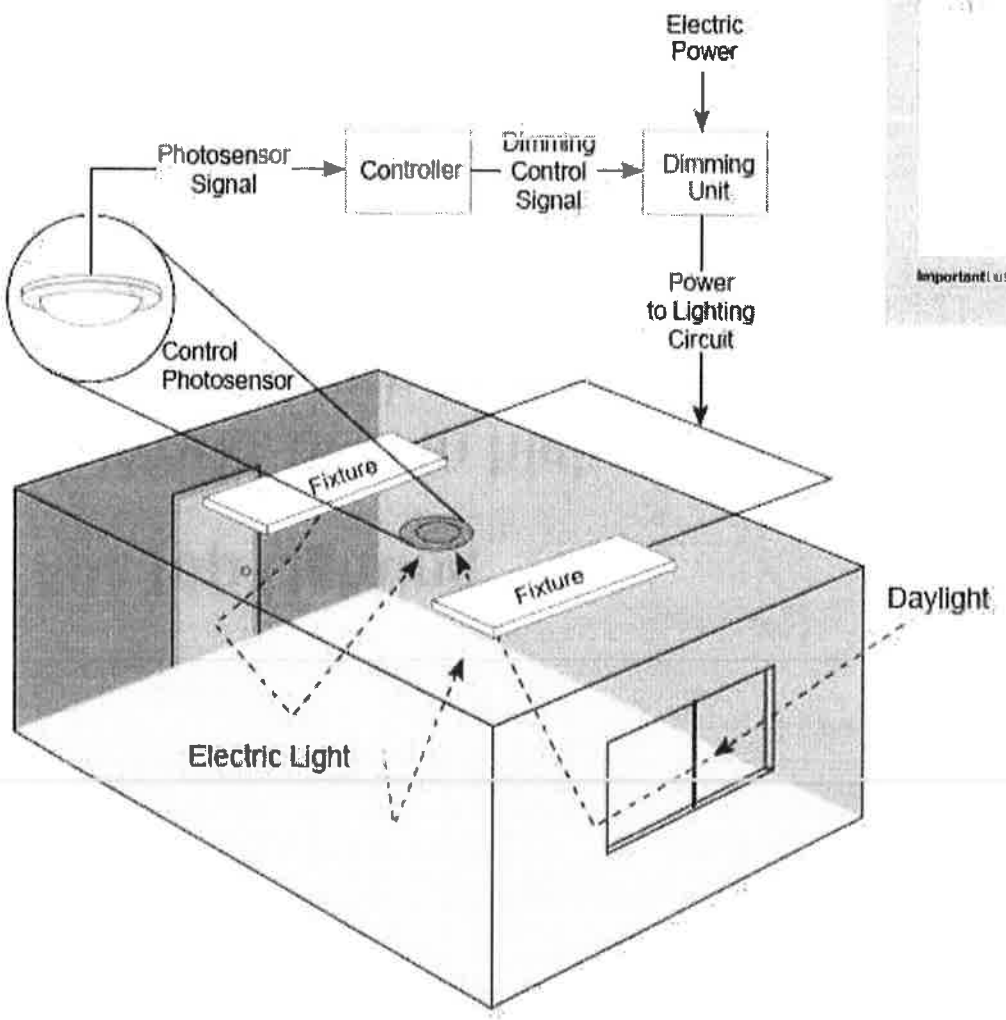
For Top Lighting

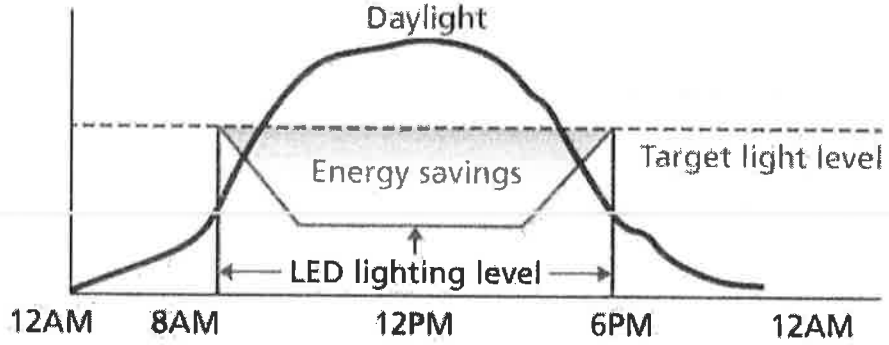
- Works best in high-ceiling spaces with grid of diffuse skylights
- Avoid direct line of sight of indirect electric lighting



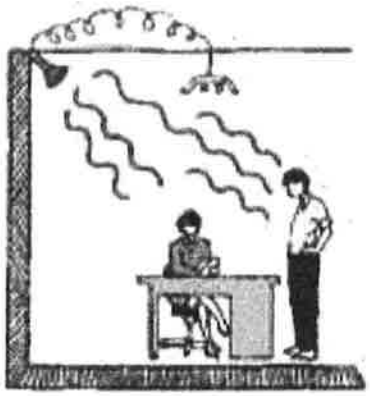
Variable Lighting Control via Light Sensors



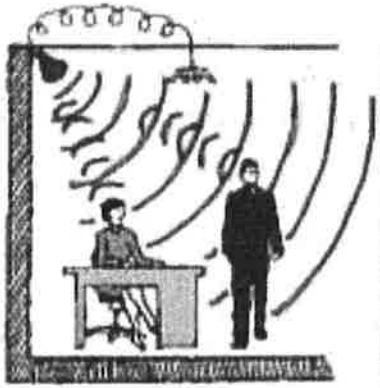




Occupancy Sensor Technologies



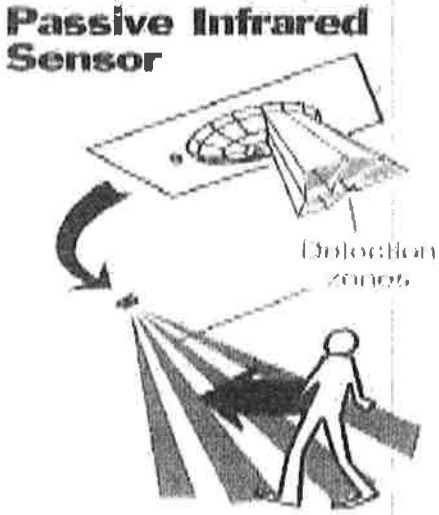
Infrared Detector



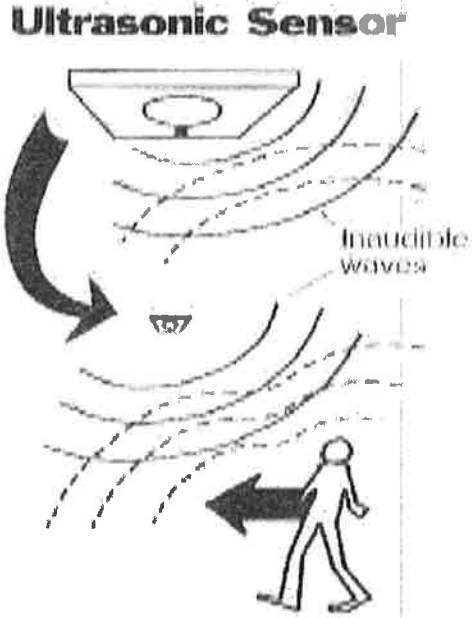
Ultrasonic System



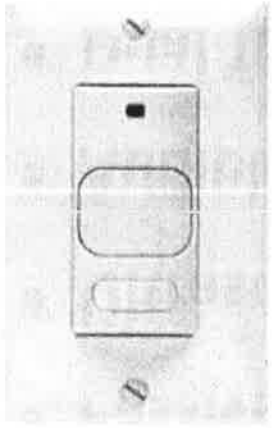
Acoustic Sensor



- **Passive Infrared** – PIR
- **Ultrasonic** – ULT
- **Audible** – Microphonic
- **Dual Technology** – PIR/ULT
- **Manual On Wall Sensor**



Occupancy Sensor Technologies

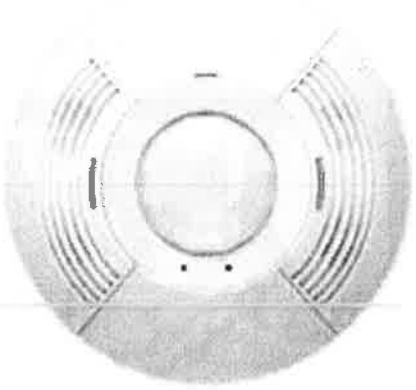


Two technologies dominate.

Infrared

Triggered by the **movement of a heat-emitting body** through their field of view. Occupants must be in **direct line-of-sight** of the sensor.

Limited Range



Ultrasonic

Emit an **inaudible sound pattern** that is **disrupted** by **any moving object** altering the signal returning to the sensor (Doppler shift). Same working principle used by bats. Detects **very minor motion** better than most infrared sensors and is often used in restrooms since the hard surfaces will reflect the sound pattern.

Dual-technology Sensors

Use both methods, **increasing accuracy and flexibility**, but at a higher price.

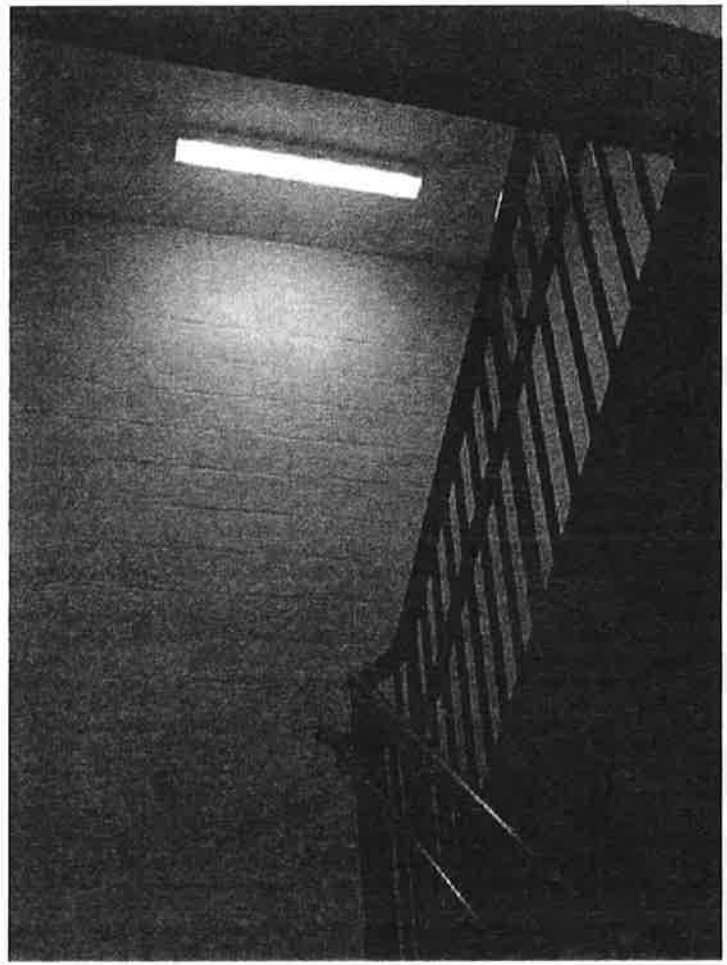
Occupancy Sensing



Locker Room



Toilet



Staircase

Lighting Sweep Strategies



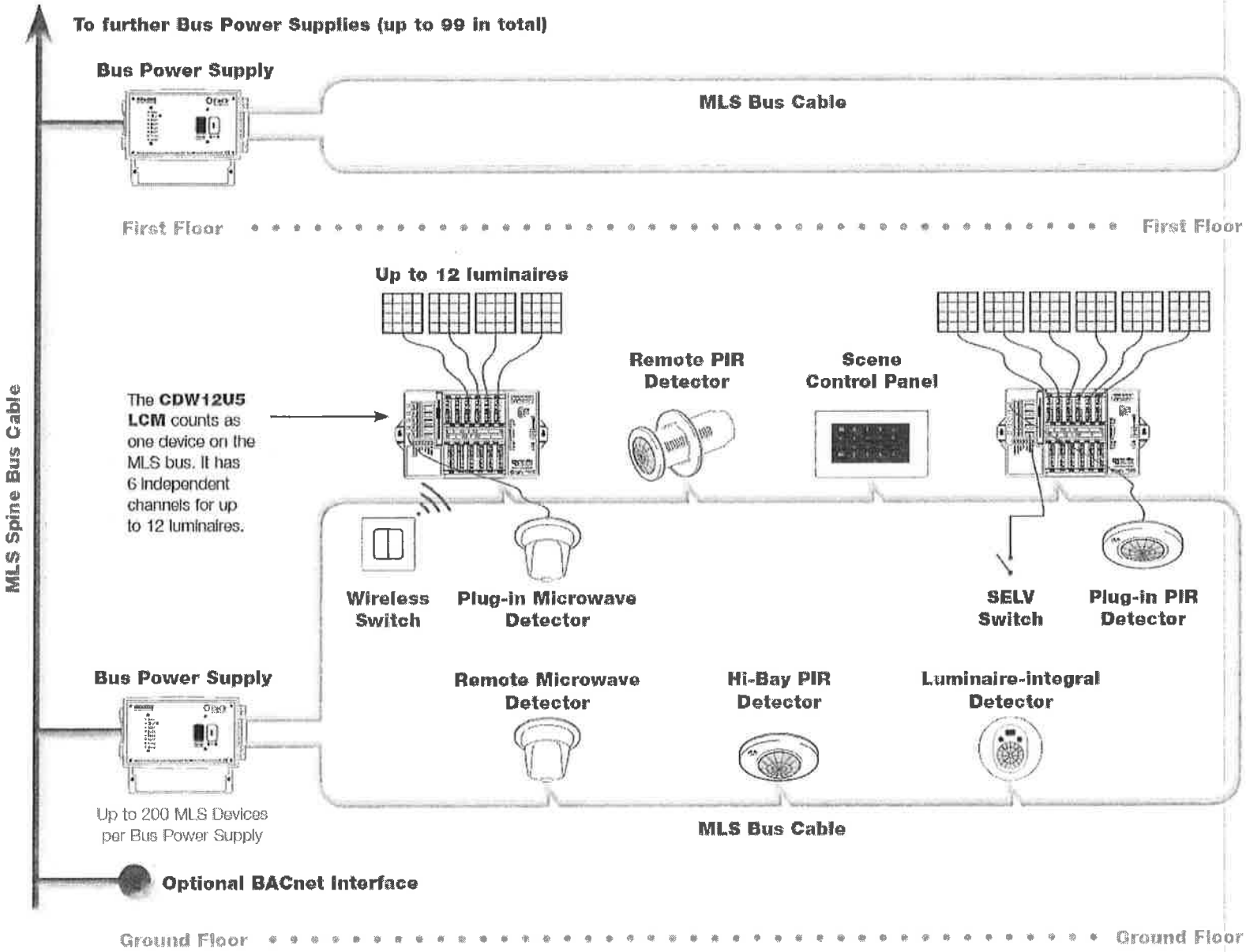


- Modern lighting control systems in large office complexes or multi-building facilities use **'sweep' controls** that turn certain lamps or fixtures at **preset times**.
- **Periodic**, **programmed** and **sequential sweeps** ensure that fixtures are turned off as soon as the activity in an area **diminishes**.
- Some level of **local warning** and **override control** so occupants will not be **'caught in the dark'**.
- Local override (on zone basis)

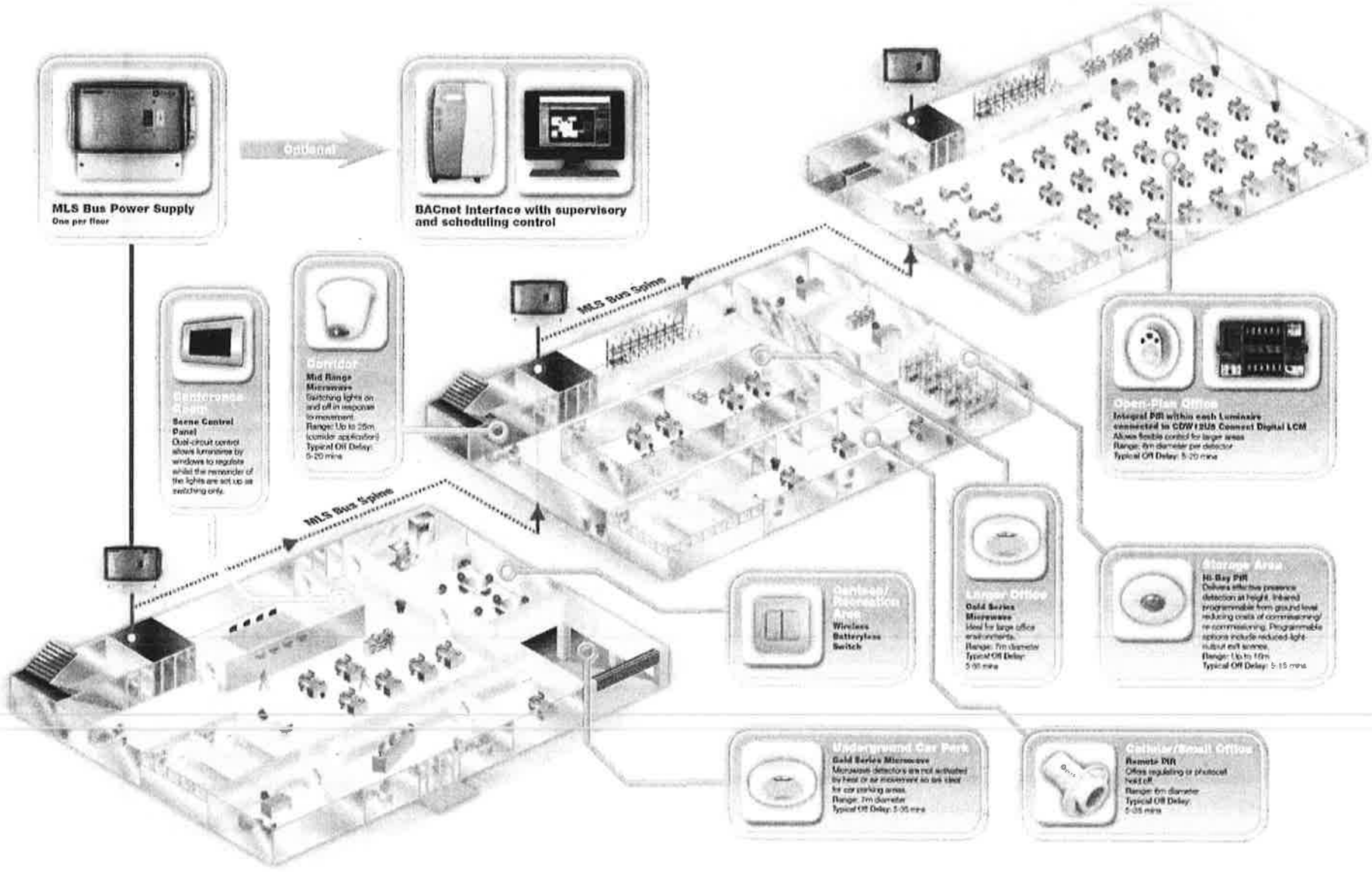
  - Wall switches

  - **IP Phones**

Networked Managed Lighting System

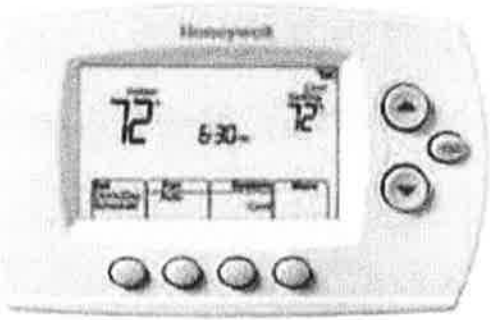


Networked Managed Lighting System



HVAC Energy Management Strategies

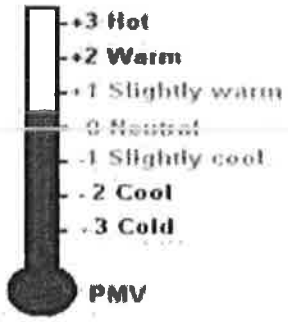
Setpoints



More than anything else, **setpoints** have far-reaching impact on **energy savings**, **building occupant comfort** and **safety**.

Setpoints range from those inside equipment logic to space temperature setpoints on standalone thermostats.

Some setpoints are **defined by the operator** and associated with a schedule. Others may be **adjusted by internal calculations** of the programme (e.g. reset temperatures or pressures).



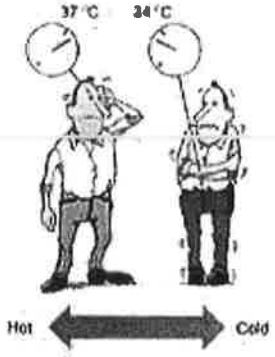
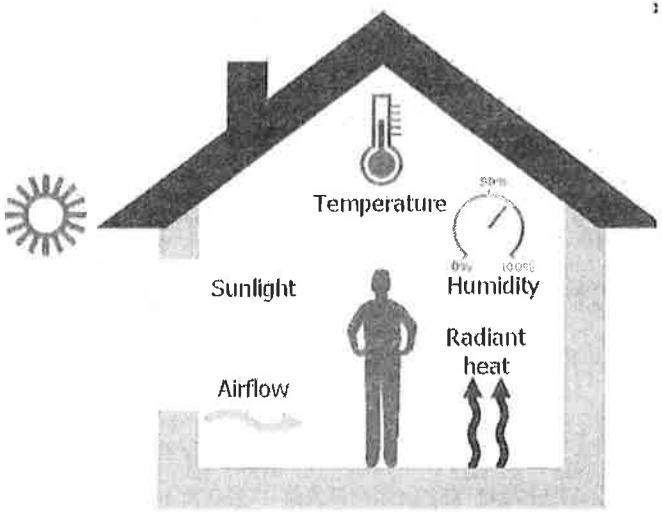


Figure1. The PMV Scale

Space Temperature Setpoint Considerations



The following information should be reviewed when considering space temperature setpoint changes:

- Time of day
- Number and fluctuation of occupants in zone
- Humidity conditions
- Types of activities in zone
- Location of zone
- Zone exposure (perimeter or core, south or north, etc.)
- Impact on pumping, fan, or plant efficiency
- Equipment in zone (e.g., computers or laboratory equipment).

Comfort is a function not only of **space temperature** but also of **radiant temperature** (direct sunlight), **airflow**, and **humidity**.

Duty Cycling

Duty cycling is defined as the shutting down of equipment for predetermined short periods of time during operating hours

Why Duty Cycle?

- HVAC systems seldom operate at peak design conditions.
- When a system is shut off for a short period of time when not at full design load, there is enough '**thermal inertial**' to overcome temperature drift during the shut down period.
- It does **reduce energy inputs** to auxiliary loads such as **fans** and **pumps**.

How to Duty Cycle?

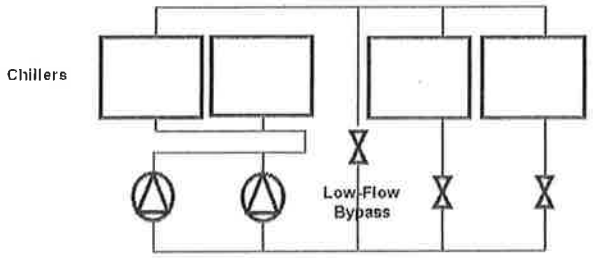
- AHUs/FCUs may be cycled "off" for some maximum period of say **15 min** per hour of operation.
- The "off"-time period and frequency must be **programme-adjustable** so that the "off" times are **decreased** when **space temperature conditions are not satisfied** or **increased** when **space temperature conditions remain satisfied – 'Temperature-Compensated Duty Cycling'**.
- Suitable for use during **lunch time, rainy days** or **at night**.

Variable-Capacity Control

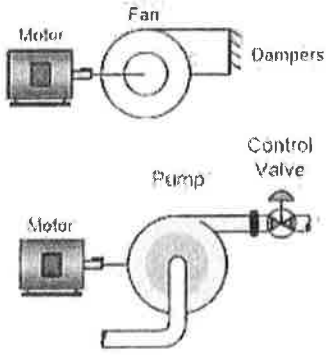
HVAC systems respond to varying loads in several ways. Common design techniques include:

- **Bypass or recirculation of chilled water** around the cooling coil or at chiller plant.
- **Throttling valves** or **dampers**.
- **Variable pitch** for vane axial fans.
- **Variable-inlet vanes** for fans or centrifugal cooling compressors.
- **Variable-speed drives** for fans or pumps.

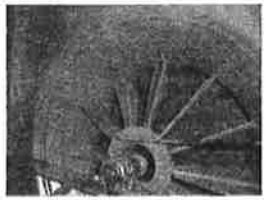
Bypass and **throttling strategies waste energy** and should be avoided if possible. Variable-pitch vane axial fans and inlet vanes save some energy but do not improve efficiency as effectively as **variable speed drives**.



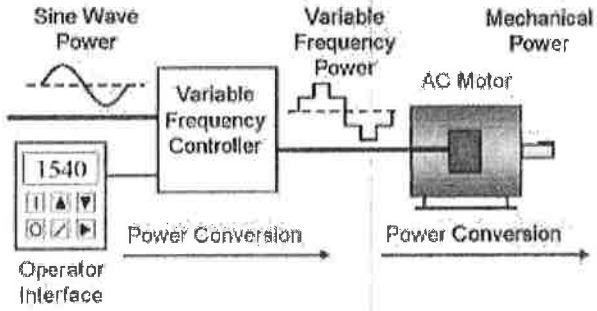
Chiller Plant Bypass Valve



Throttling Valve/Damper



Fan Inlet Guide Vanes

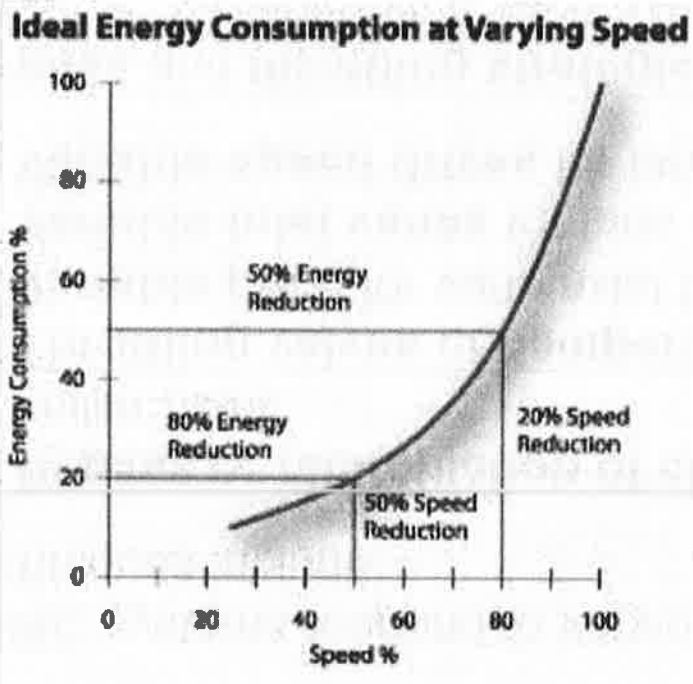


VSD

Variable Speed Drives

- Power supply equipment that change the **rotation speed** of the HVAC equipment in response to a **control signal** that indicates **demand for flow**.

- VSD control strategies save energy by **closely matching the power input** of a motor to the **output requirements**, maximizing the efficiency of the system.



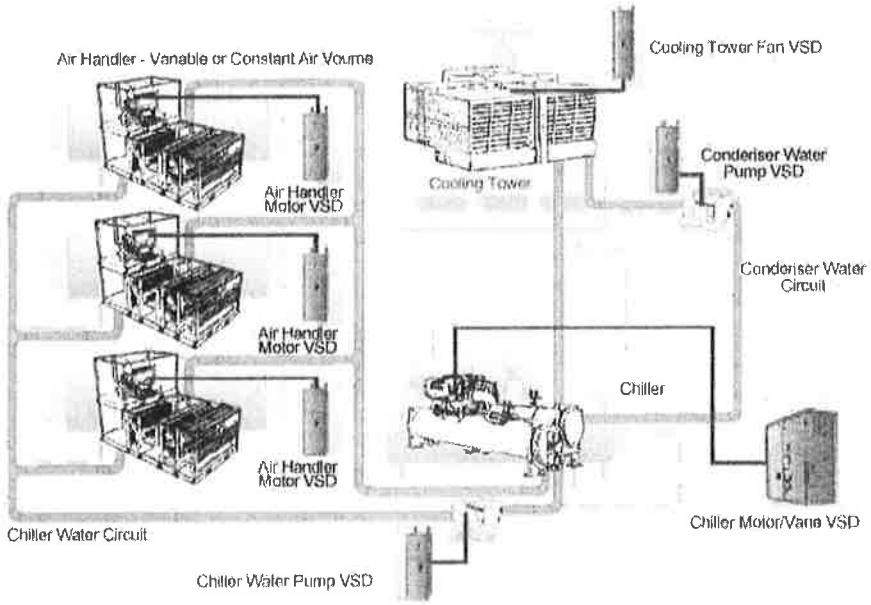
$$\frac{Flow_2}{Flow_1} = \frac{RPM_2}{RPM_1}$$

$$\frac{Pres_2}{Pres_1} = \frac{(RPM_2)^2}{(RPM_1)^2}$$

$$\frac{HP_2}{HP_1} = \frac{(RPM_2)^3}{(RPM_1)^3}$$

Where:
Pres = Pressure
RPM = Revolutions per minute

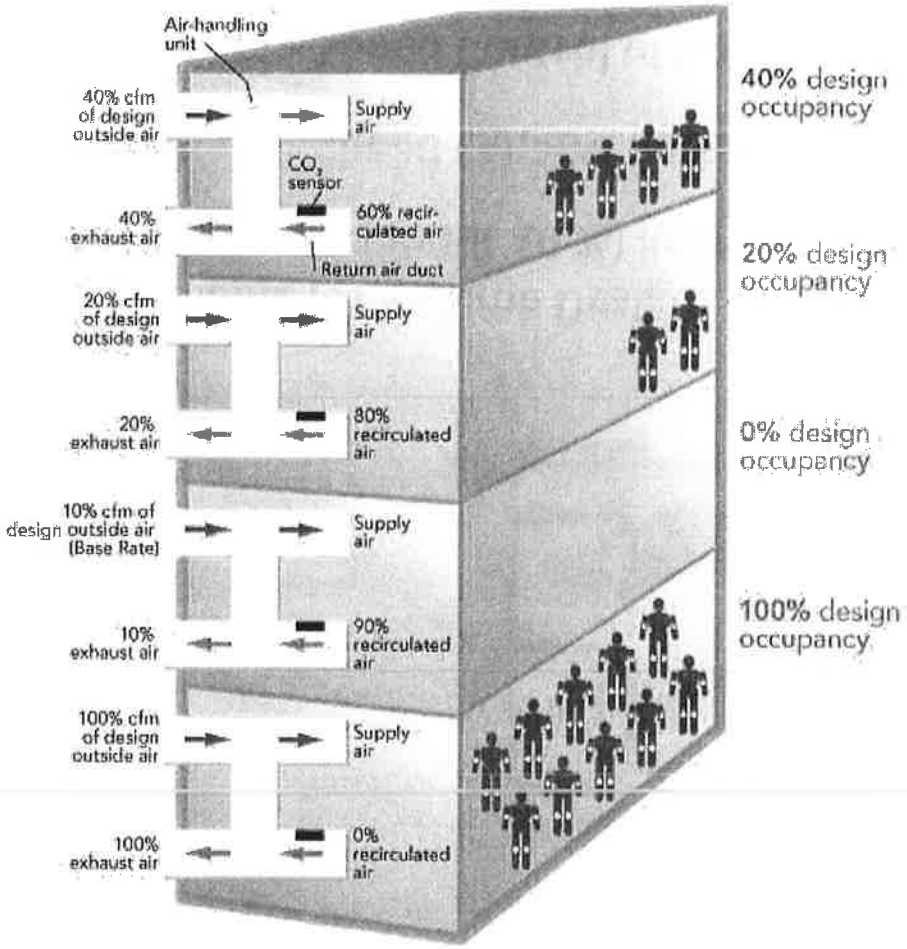
Applications of Variable Speed Drives



- **Variable Air Volume Designs** - Air distribution fan energy is a significant fraction of energy use (about **10 %**) in any conditioned building.
- **Variable-Speed Exhaust Systems** - Particularly in large exhaust systems in hospitals.
- **Variable-Speed Control of Cooling Towers** – Saves energy by operating multiple cooling towers with fans operating at lower speed.
- **Variable-Speed Drives for Chillers** – Enhanced chiller efficiency at part load.
- **Variable-Speed Pumps for Condenser Water or Chilled Water** - Decoupled primary/secondary systems and variable primary pump systems are now common.

Demand-Response Ventilation

Carbon Dioxide Sensing Systems



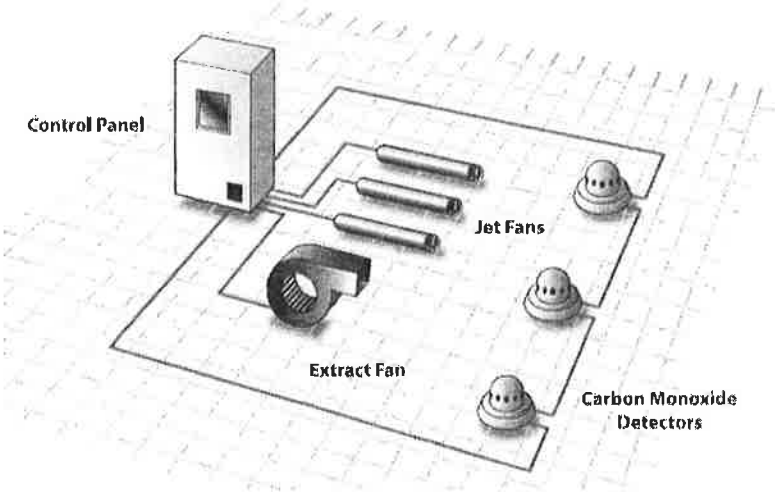
This is an effective energy-saving strategy and is particularly applicable to spaces with **highly variable occupancy** like auditoriums, gymnasiums, classrooms, meeting rooms, public and even private offices, restaurants, cafeterias, and retail stores.

Typical CO2 setpoint is 700 ppm above outdoor level (350 to 450 ppm) or between **1,000 to 1,100 ppm**. This setpoint is typically maintained by modulating an **outside air damper**.

Carbon Monoxide Sensing Systems for Car Parks

- Carbon monoxide (CO) is an indicator of other gases of automotive exhaust.
- Indoor car parks have high volumes of exhaust and require supply ventilation to remove exhaust-contaminated air.
- Car park ventilation systems are required under code to **operate continuously** during the **operating hours** of the building. Where permitted by code, a system of **CO sensors** tied to the supply and exhaust fans via the BMS will allow **significantly reduced fan operation**.
- In Singapore, the maximum allowable level of CO over an 8-hr period is **25 ppm**.
- Some car park systems have **CO/Temp** control to improve thermal comfort.







Occupancy-Sensing Systems

Occupancy sensors similar to those used for lighting systems can be installed in rooms to minimize or **turn off supply air and/or exhaust** to the rooms entirely when unoccupied.

This strategy may be beneficial in buildings with rooms which are **sporadically-occupied** e.g., **training rooms**, **conference rooms**, **lecture theatres**, **wash rooms**, **changing/locker rooms, staircases** and **corridors**.

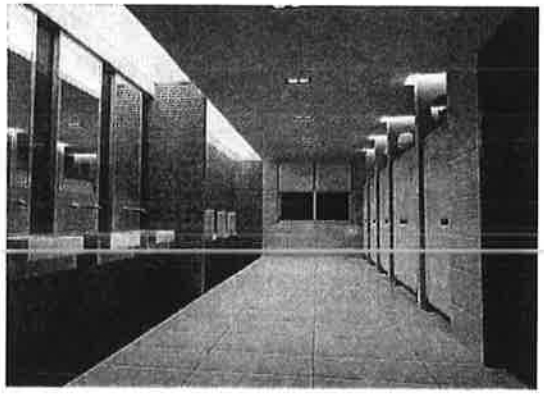
Occupancy-sensor or key-activated equipment is prevalent in hotel rooms. These systems can also be wired to turn off the **lights**, **TV**, **exhaust fan**, and to **set back** the **cooling temperature**.



Ultrasonic / Passive Infrared Motion Sensors



Hotel Guest Room



Wash Room

IMSC (Interactive Multi-System Control)

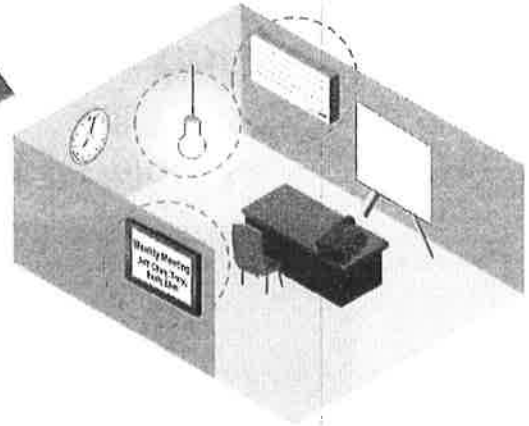
Computerized Facility Booking System



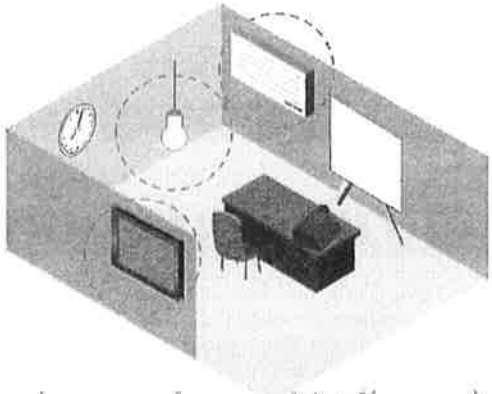
Users require after-hours meeting



Meeting facilitator uses MS Outlook to book meeting



Meeting room lights activated, A/C turned on 15mins before meeting. Digital signage outside room shows meeting name & participants

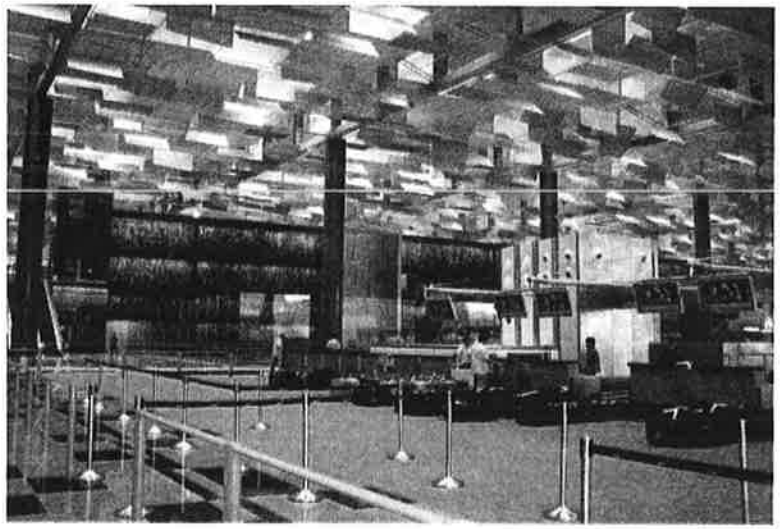


Motion detectors sense end of meeting and turn of lights, a/c and signage

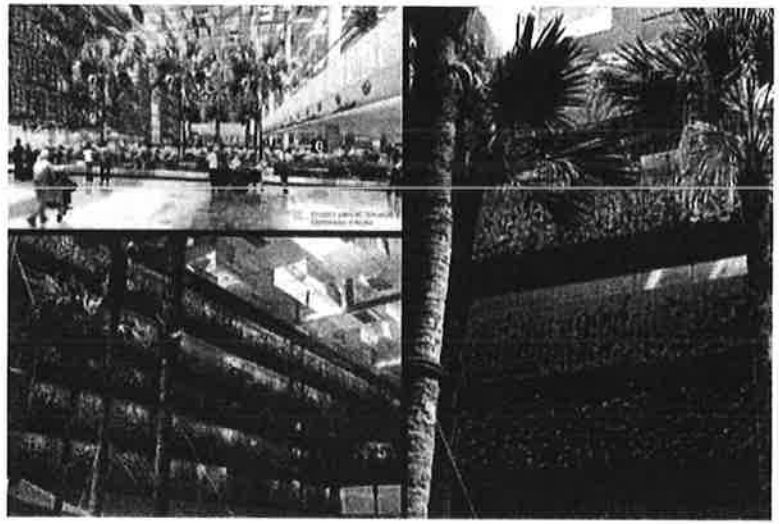


Property Management System tracks usage and bills user / dept for after hours usage

Integration with Airport FIDS



Changi Airport Terminal 3

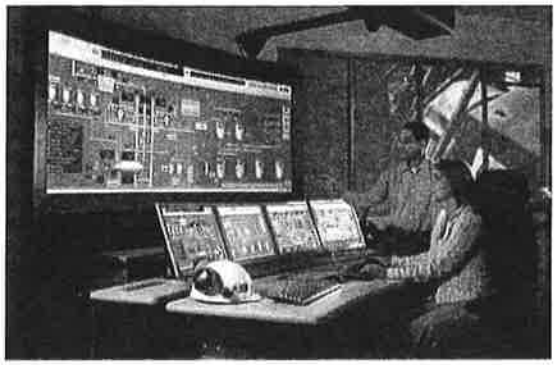


Changi Airport Terminal 3

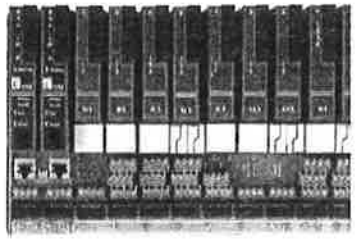
IBMS receives up-to-date arrival and departure information including **flight numbers, scheduled date and time, actual time of departure, current and actual gates**.

IBMS optimizes the turning on and off of **air-conditioning** and **lighting** based on **gate allocation** and **scheduled date and time** provided by the FIDS system.

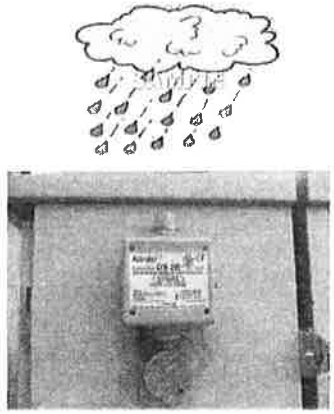
Weather Responsive Control Strategies



IBMS



PLC Controller



Rain Sensor

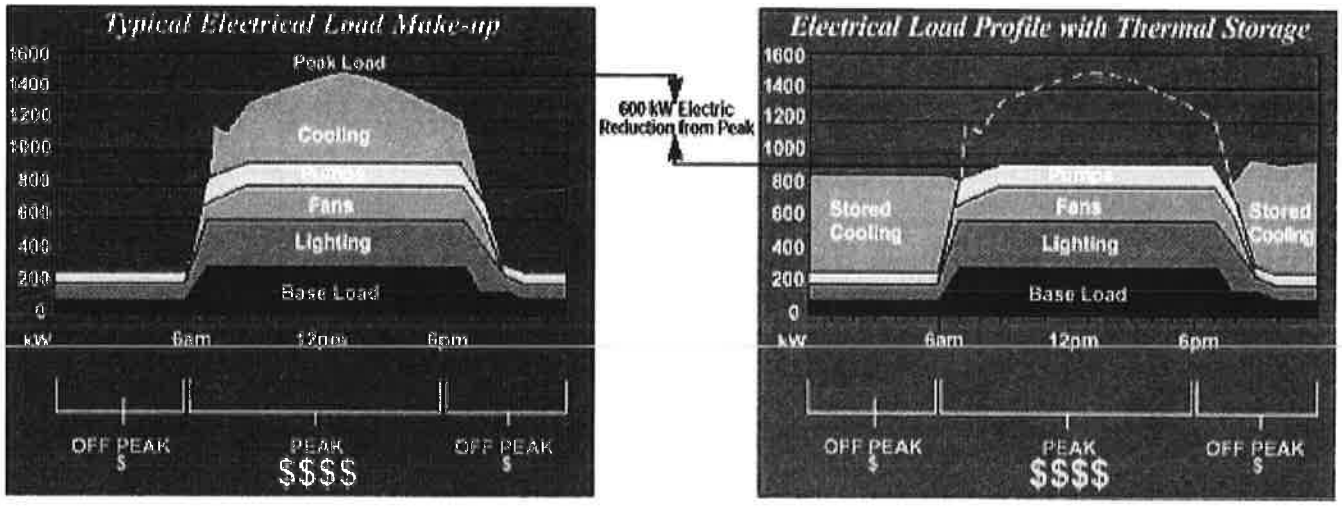


Photocell

Rain sensor and **weather programme** will enable the building save energy on rainy days via space temperature reset. A **1°C temperature raise** will save approximately **4% to 5 % energy**.

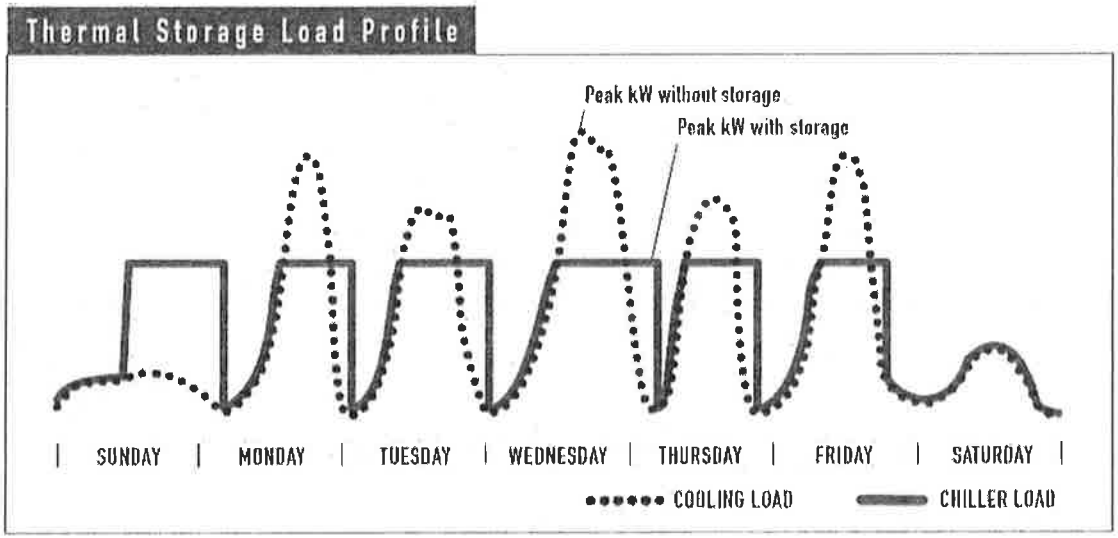
Photocells will be installed at various strategic locations around the building for **'daylight harvesting'.** Lights along corridors, glass-clad building perimeter areas, external lighting will be controlled via photocells to conserve energy.

Peak Load Shifting Strategy



- **Thermal storage** for HVAC is a **peak-load shifting strategy** in which refrigeration equipment makes **cold water** or **ice** during **non-peak hours**.
- The water or ice can be used to cool the building during peak hours, **minimizing or turning off chiller(s)** during **peak hours**.
- The **energy use (kWh)** of a system designed for thermal storage is often **slightly greater** than a system without storage. The chiller operates at a lower efficiency to make **lower temperature chilled water.**
- The **lower electric tariffs** (off-peak rates) at night more than compensate for the slightly lower chiller plant efficiency.

Peak Load Shifting Strategy



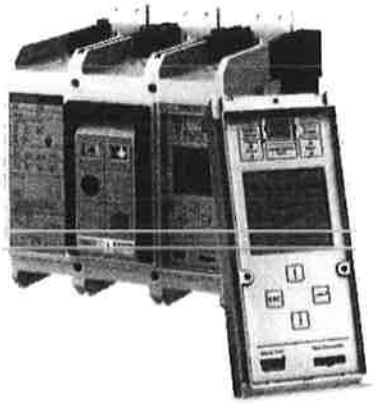
The existing (or projected) cooling load profile should be reviewed by an engineer to determine the **technical and financial viability** of thermal storage as an energy cost-saving option.

The following elements must be considered:

- The **cooling system characteristics**
- The **electricity rate structure**
- The **duration** of the time-of-use periods
- **Prices** of energy
- **Demand** during each time-of-use period
- **Space** for installation of storage tanks

Cost of Energy

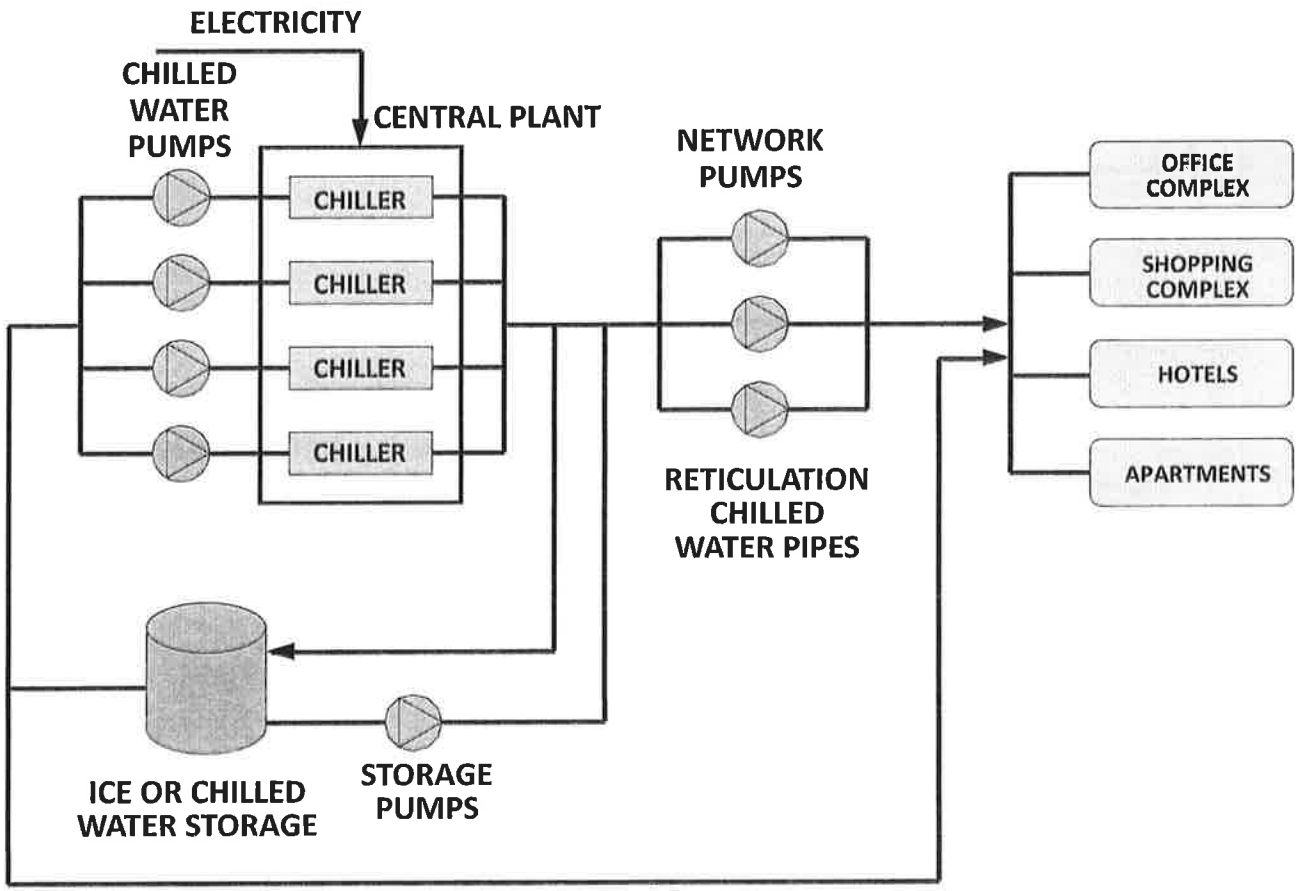
	May 98	Jan-00	Feb-01	Jan-02	Jan-03	Apr-04	Jan-05	Oct-06	Apr-08	Jul-10	Apr-12	Oct-16
Peak (S$ per KWh)	$0.0834	$0.094	$0.1458	$0.1133	$0.1196	$0.1257	$0.1354	$0.1923	$0.2166	$0. 2195	$0. 2721	$0. 1585
Off Peak (S$ per KWh)	$0.0734	$0.0711	$0.1169	$0.0704	$0.0647	$0.0704	$0.0787	$0.1150	$0.1299	$0.1399	$0.1670	$0.0983
% Difference	13.6%	32.2%	24.7%	60.9%	84.9%	78.5%	72%	67.2%	66.7%	57.9%	62.9%	61.2%



Electricity Tariffs based on High Tension Large (HTL) Supplies.
Prices excludes GST.

Contracted Capacity Charge : **S$8.36/KW/month**
Uncontracted Capacity Charge : **S$12.54/KW/month**
Reactive Power Charge : **0.59¢/KVARh**
(for amount exceeding 62% of KWh consumption)

Schematic of Chilled Water Storage



A district cooling system with thermal storage is really a simple variation of a **decoupled chiller system**.

- Separation of production and distribution of chilled water.
- Decoupler bypasses chilled water when production exceeds distribution and borrows return water when distribution exceeds supply.

Control System for Chilled Water Storage System

Full Charging Cycle

1 All secondary pumps are shut-off.

2 Motorized valves V_3 are fully closed.

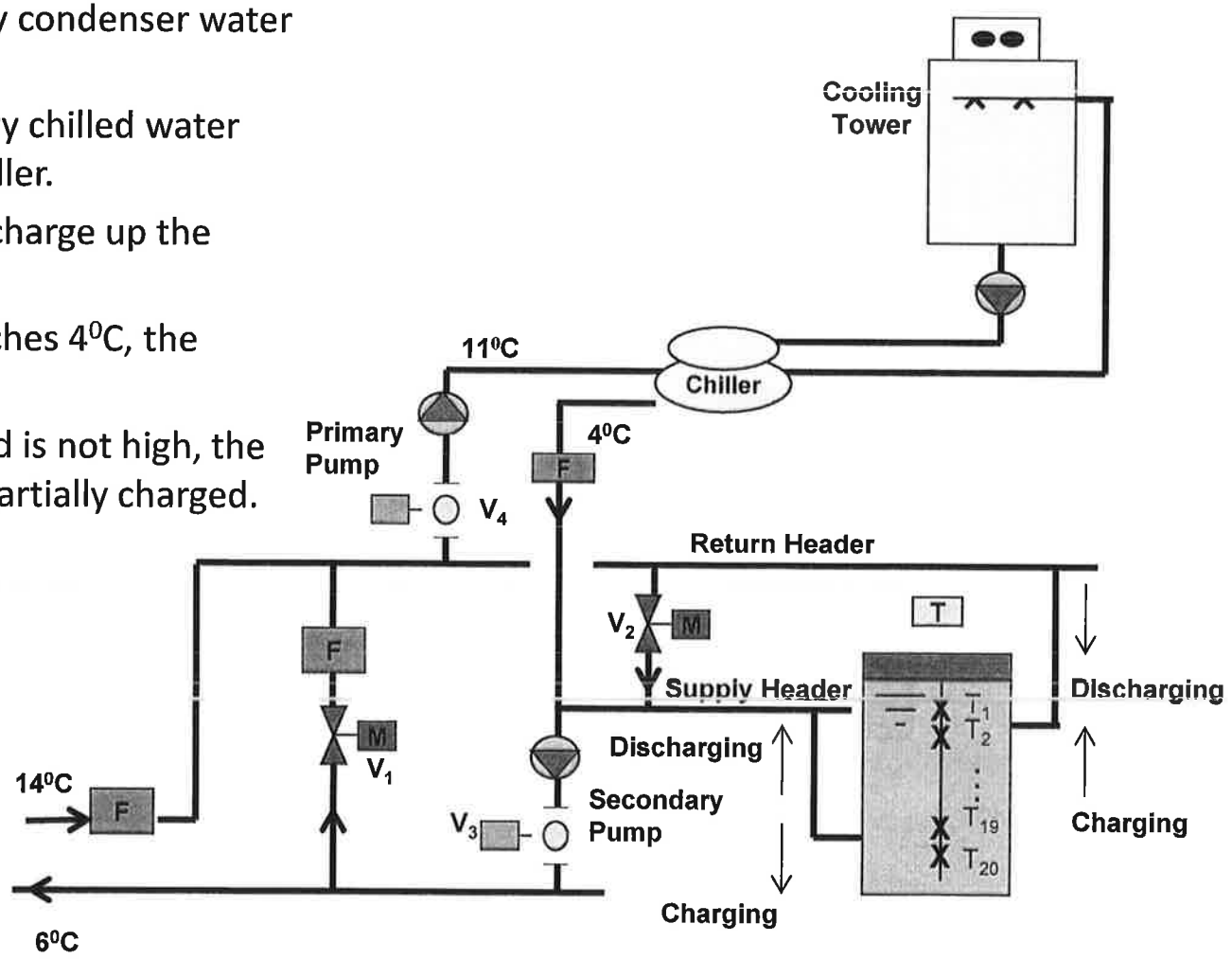
3 Cooling tower is started followed by condenser water pump.

4 Butterfly valve V_4 opens and primary chilled water pump is started followed by the chiller.

5 Chilled water from chiller starts to charge up the thermal storage tank.

6 When the average of T1 to T20 reaches 4^0C, the charging cycle stops.

7 If next day's anticipated cooling load is not high, the thermal storage tank may only be partially charged.



Full Discharging Cycle

1 All chillers, primary chilled water pumps, cooling towers and condenser water pumps are shut-off.

2 Valves V_4 is closed.

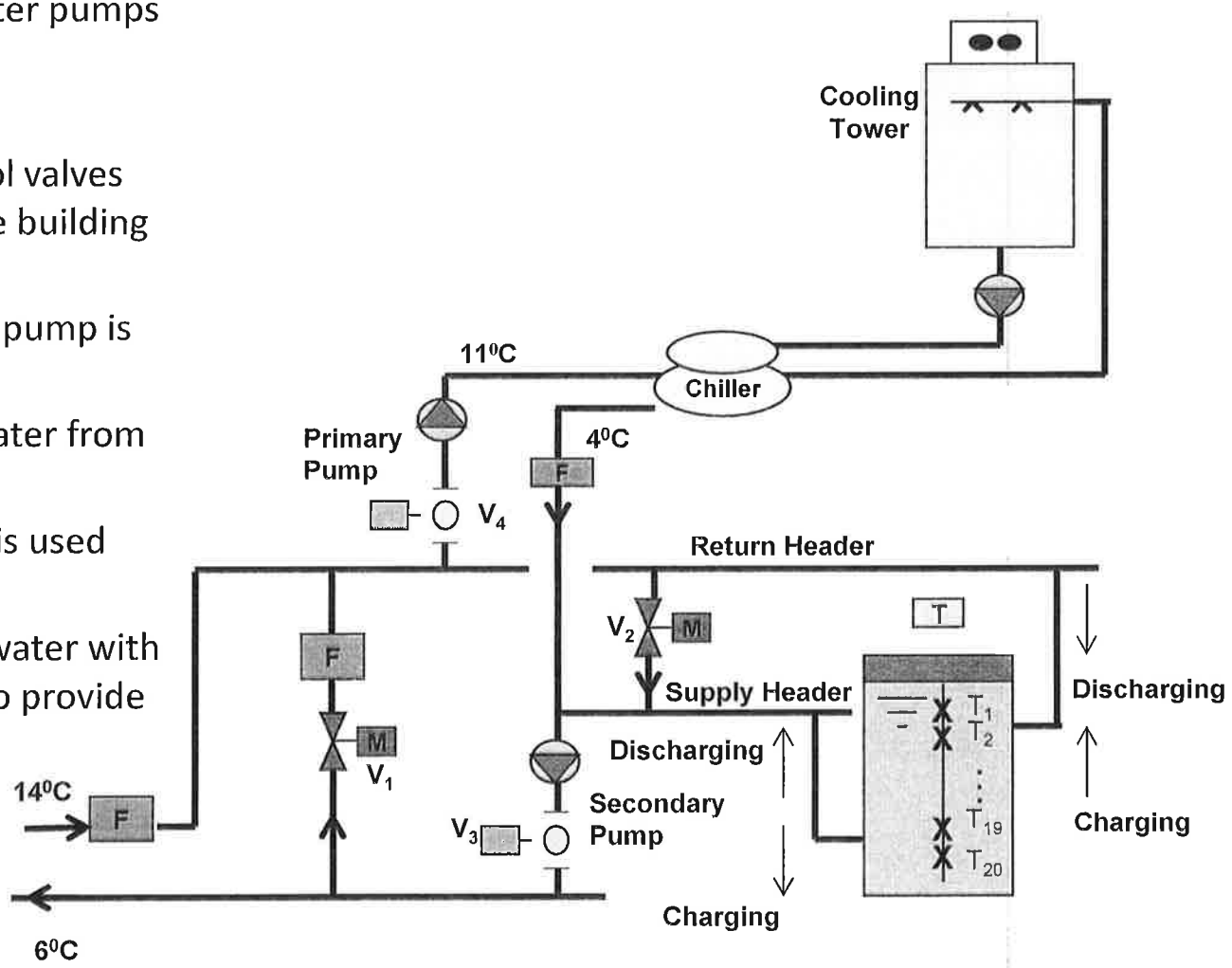
3 Sub-station heat exchanger control valves are activated based on the remote building occupancy time.

4 Valve V_3 is opened and secondary pump is started.

5 Secondary pump starts to draw water from the thermal storage tank.

6 Lowest temperature water at 4^0C is used first.

7 Valve V_1 is modulated to mix 4^0C water with the warmer return chilled water to provide 6^0C water to customer.



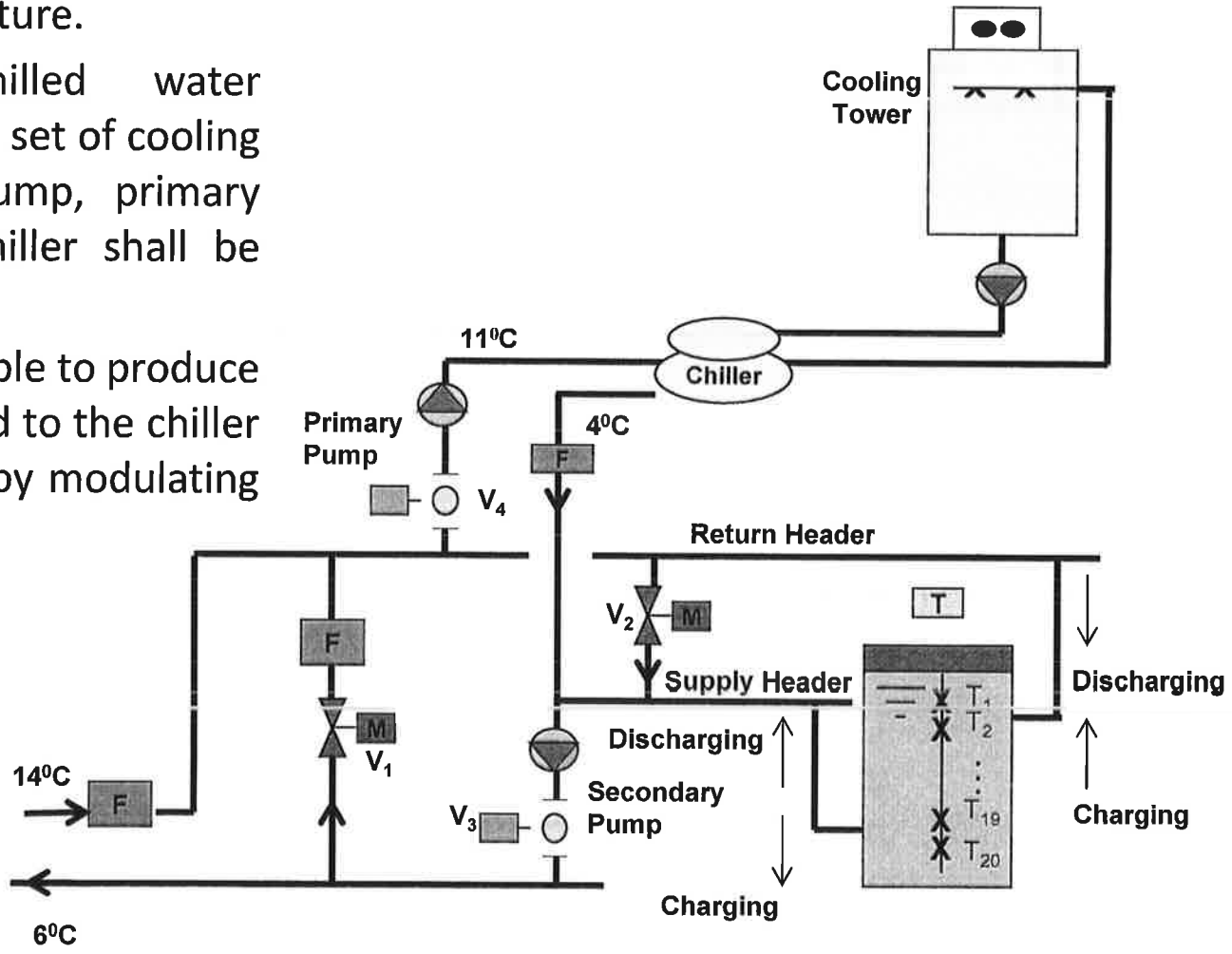
Control System for Chilled Water Storage System

Charging Plus Instantaneous Cooling Cycle

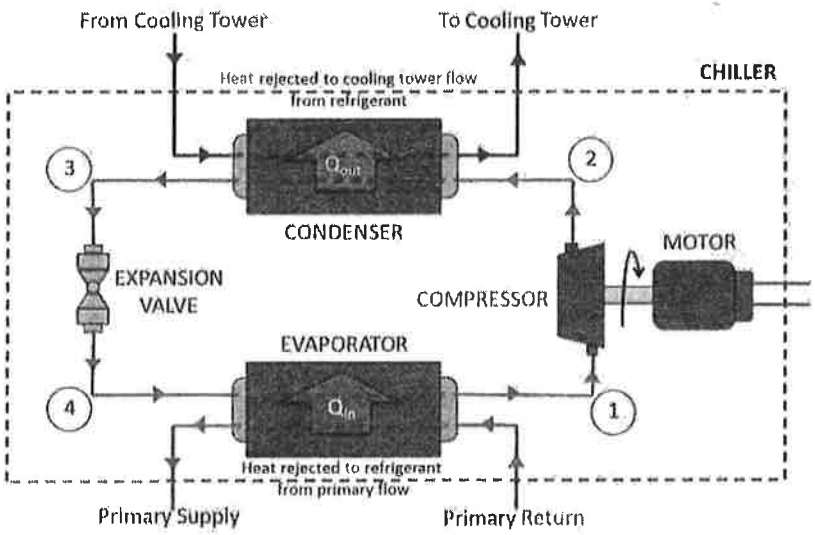
1 Control system shall continuously monitor supply chilled water temperature.

2 Should the supply chilled water temperature exceed 6^0C, one set of cooling tower, condenser water pump, primary chilled water pump and chiller shall be started in sequence.

3 To ensure that the chiller is able to produce 4^0C water, the water returned to the chiller shall be maintained at 11^0C by modulating valve V_1.



Condenser-Water Temperature Control



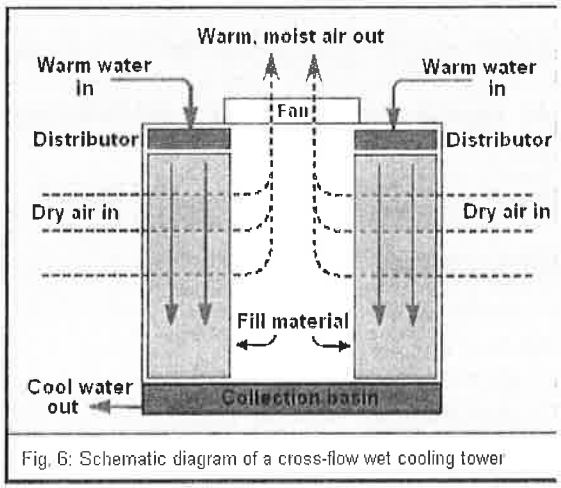
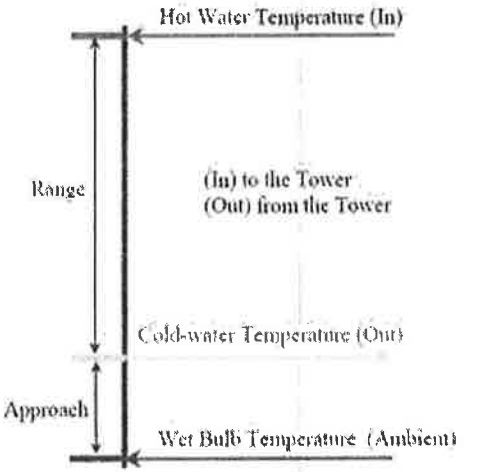


Fig. 6: Schematic diagram of a cross-flow wet cooling tower



Range and approach of cooling towers

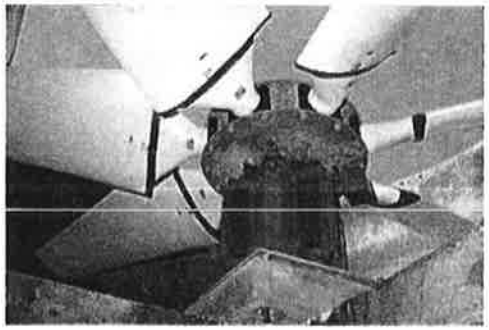
The condenser water temperature is also an important factor in determining the efficiency of the chiller.

Allowing the condenser water temp setpoint to float about **2 °C** above the ambient wet-bulb temp should minimize the total chiller input power for a given cooling load.

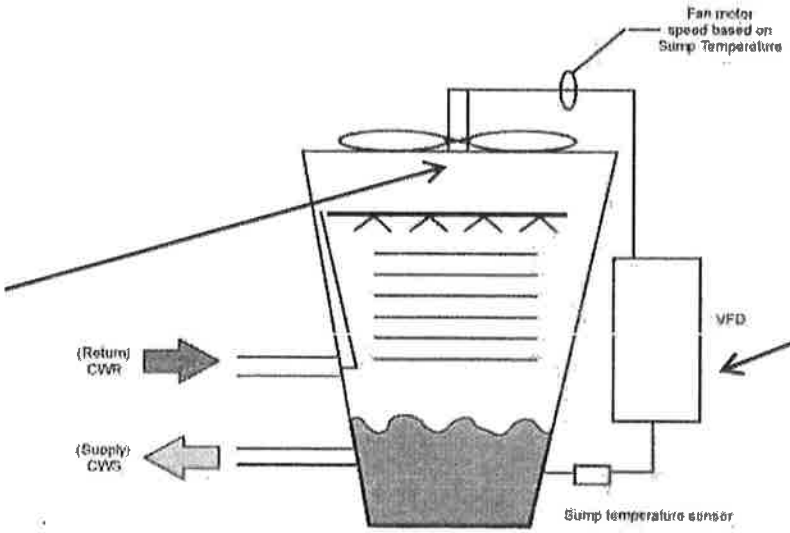
Every °C lowering of the condenser water temp helps the chiller to improve its efficiency by **3 to 4%.**

The **cooling tower approach** is the **difference in temperature** between the **cooled condenser water temperature** and the **entering-air wet bulb temperature.**

Cooling Tower Fan Control



Cooling Tower Fan





Variable Speed Drive

For most cooling towers, about **10% of the heat-rejection capacity** can be achieved by the **evaporative effect** of water flow **without any forced air flow** (i.e. with the fans off).

From that point, for a given ambient condition, the **heat-rejection capacity** of a cooling tower **increases linearly** with the **air flow** through the tower.

The optimal control strategy for a multiple cell tower with VSD fan speed control is to **operate all of the fans at low speed** and allow the **speed** of all fans to **increase together** until the **condenser water temperature setpoint is reached**.

Reset Strategies

What are Resets?

Reset is the strategy of **changing a control parameter setpoint** based on a **change in related conditions**. Temperature and pressure are the most common reset parameters.

The intent of a reset strategy is to **identify changes in demand** (cooling, heating, pressure, flow rate) and **reset delivery of air or water** to meet that demand.

This is accomplished by **monitoring the control point** in question (e.g. supply air temperature) and several other parameters that impact that point (e.g. return air temperature, outside air temperature).

When these parameters indicate that **load** is **decreasing** or **increasing**, the **control point can be reset** to better fit the current demand.

Common Reset Strategies

Supply Air Temperature - Based on load indicators such as **return air/ supply air temperature difference** and **VSD fan speed**.

VAV Fan Duct Pressure and Flow - Resetting VAV airflow or static pressure down during periods of **low cooling load** reduces unnecessary fan energy.

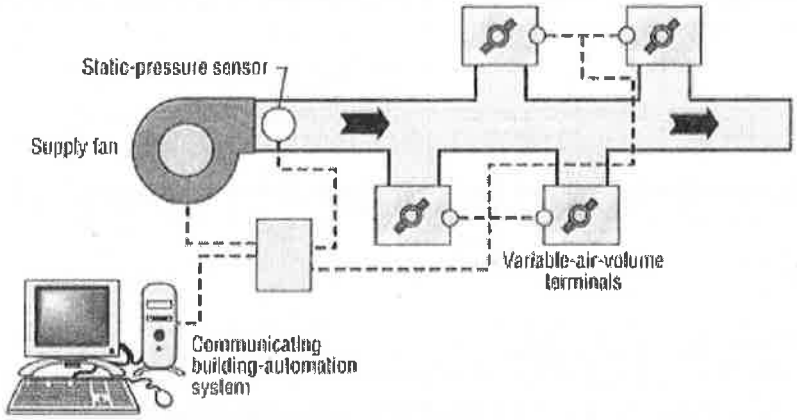
Entering Condenser Water Temperature - Resetting the chiller entering condenser water to a lower value will save energy by increasing chiller efficiency.

Chilled Water Supply Temperature - For chilled water systems, the chilled water loop temperature can be raised as the cooling requirements for the building are reduced, increasing chiller efficiency.

Chilled Water Secondary Loop Pressure - Instead of controlling the secondary chilled water loop to a fixed differential pressure setpoint under all conditions, this strategy **resets the pressure down** as the **load decreases** (the chilled water valves close) to always have one cooling coil valve 100% open This keeps the pumps operating at the very lowest pressure and speed possible.

Weather Programme – Reset space temperature higher during cool weather.

Fan Pressure Optimization for VAV Systems



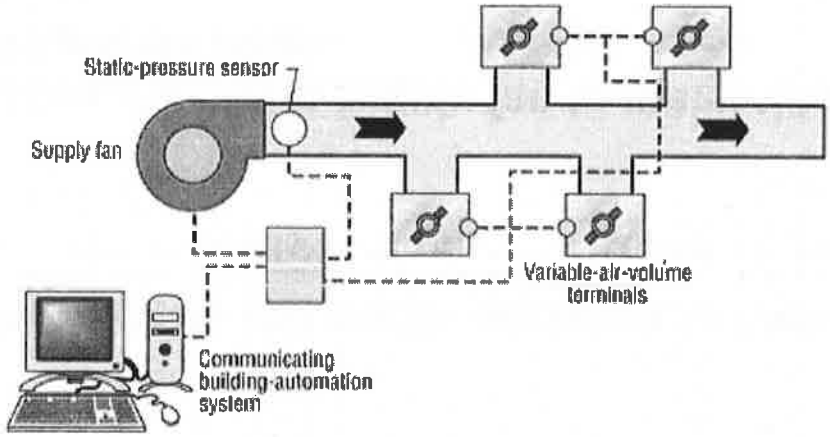
As **cooling loads change**, VAV terminals modulate to **vary airflow** supplied to the zones.

This causes the **pressure** inside the supply ductwork to **change**. In many systems, a pressure sensor is located approximately two-thirds of the distance along the main supply duct.

The AHU **varies** the **capacity** of the **supply fan** to **maintain the static pressure** in this location at a **constant set point**.

With this approach, however, the system usually **generates more static pressure** at **part load than necessary**.

Fan Pressurization Optimization for VAV Systems

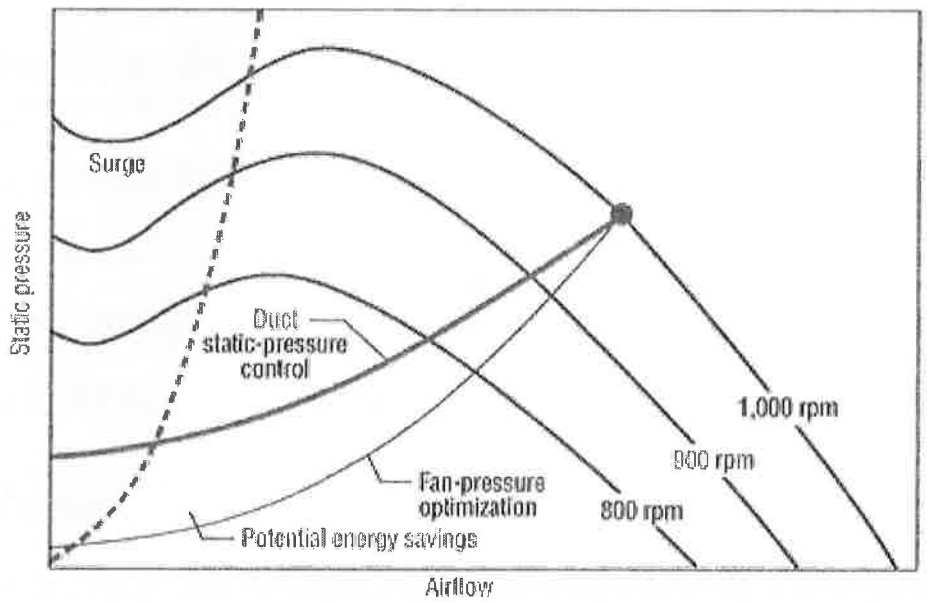


When **communicating controllers** are used on VAV boxes, it is possible to **optimize** this **static-pressure control function** to **minimize duct pressure** and **save fan energy**.

Each VAV-unit controller **knows the current position** of its **air-modulation damper**. The BMS continually **polls** these individual controllers, looking for the VAV terminal with the damper that is **open the widest**.

The **supply fan's set point** then is **reset** to provide **just enough pressure** so that at least **one damper** is **nearly wide open**. This results in the supply fan generating **only enough static pressure** to push the required quantity of air through this **"critical"** VAV-terminal unit.

Fan Pressurization Optimization for VAV Systems

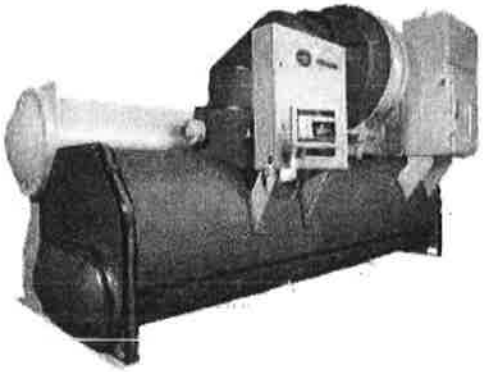


Reduced supply-fan energy use. At part-load conditions, the supply fan is able to operate at a **lower static pressure** and **consume less energy**.

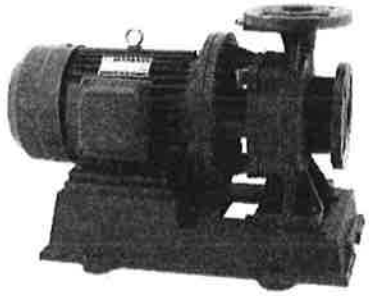
Lower sound levels. The supply fan **does not generate as much static pressure** and typically generates **less noise**. In addition, with lower pressures in the supply duct, the **dampers** in the VAV boxes **open wider**, resulting in **less regenerated noise**.

Reduced risk of fan surge. With the fan operating at a lower pressure when delivering reduced airflow, the fan operating point is kept **farther away from the surge region**.

Implication of Resetting Chilled Water Supply Temperature



Chiller – Big Energy Consumer



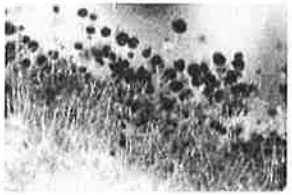
Chilled Water Pump – Small Energy Consumer

When the **chilled water supply temperature** is **reset up**, the **chiller efficiency is improved**.

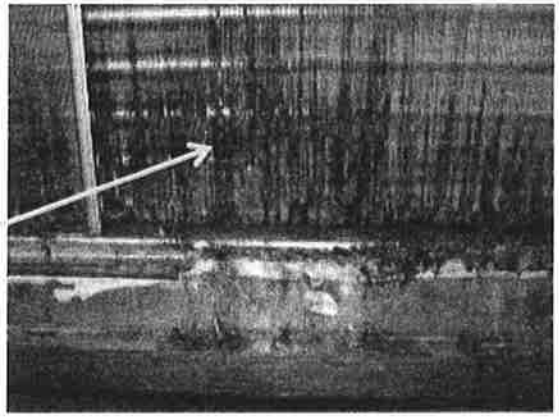
But where warmer water is sent to the cooling coils, the cooling coil valves open further and call for more water, thus increasing the pumping speed and energy. In this case, **saving chiller energy** is done at the expense of **increasing pump energy**.

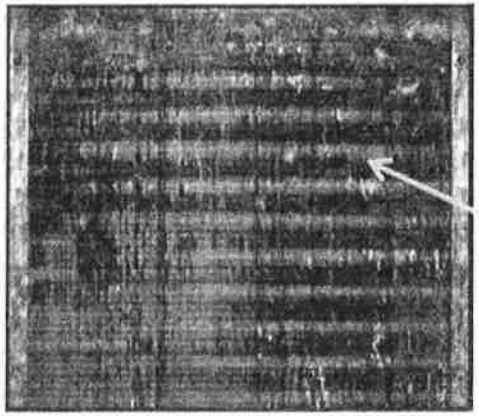
Chilled water reset is most effective when the **chiller horsepower** is **more than three or four times** the **horsepower of the chilled water pump.**

Creating the Condition to Allow Raising of Chilled Water Temperature



Mould



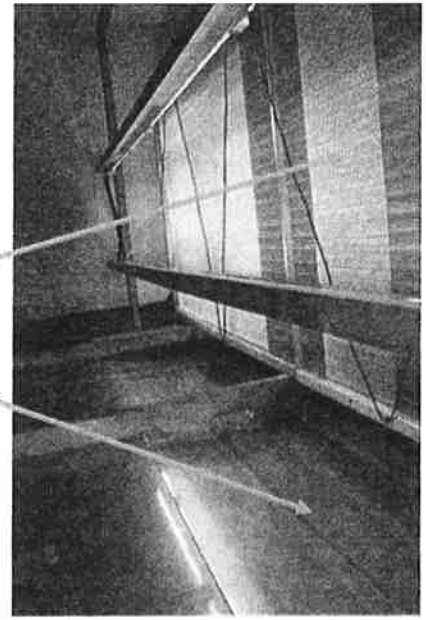


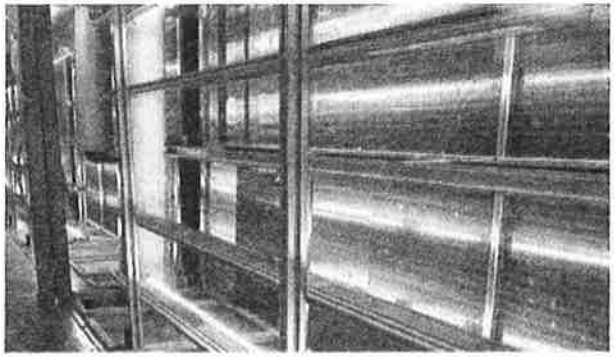


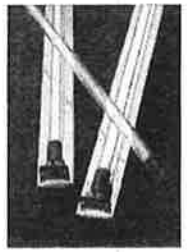
Mould

Fungal Growth Insulates Cooling Coil and Reduces Heat Transfer

UVC Irradiation Keeps Cooling Coil and Drain Pan Clean Without Washing since 2008



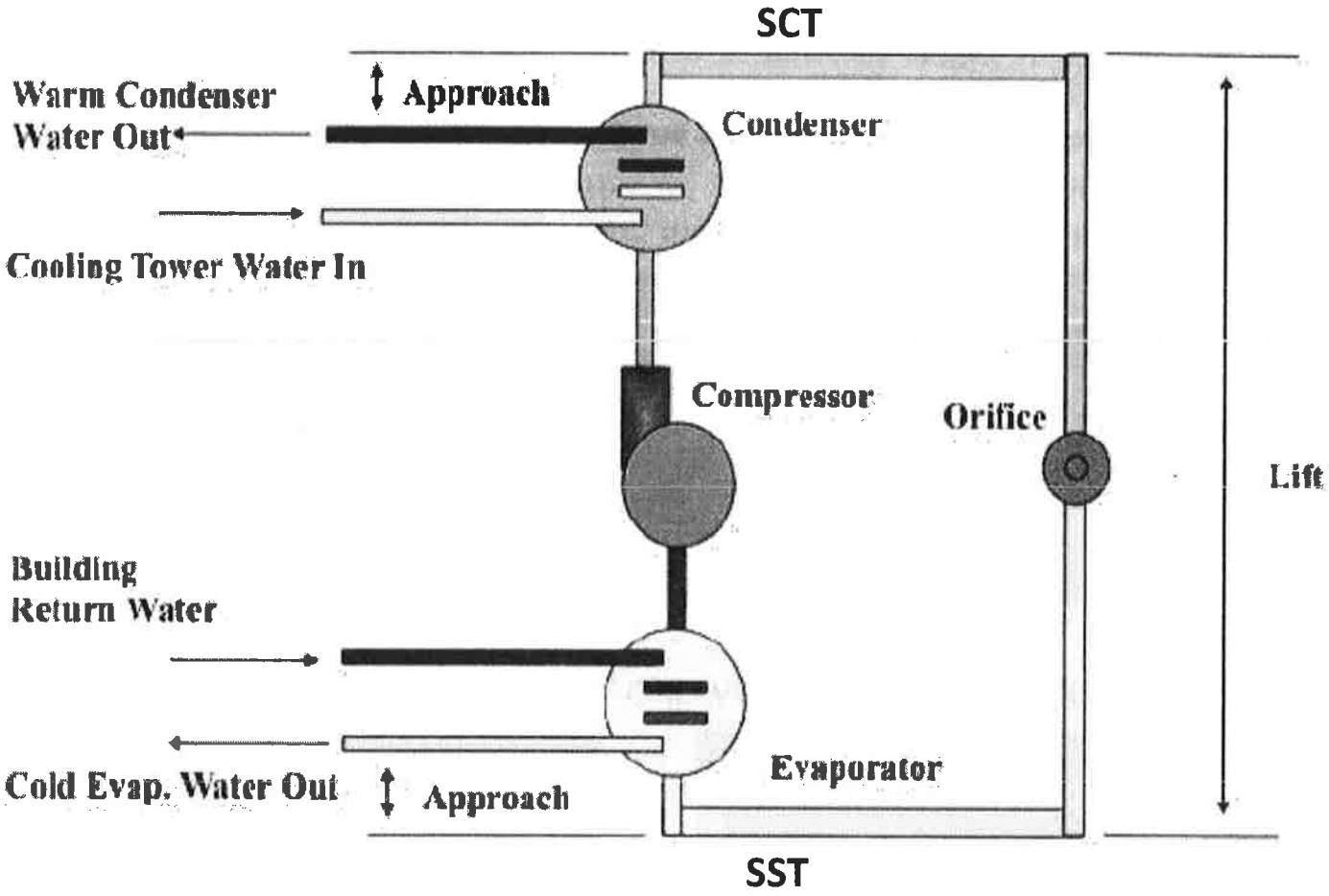




UVC irradiation creates 'self-cleaning' cooling coils free of bio-films / fungal growth. This maximizes cooling coil heat-transfer efficiency, resulting in high chilled water ΔT and the raising of chilled water temp setpoint to improve chiller plant energy efficiency.

Make-up Air Unit at Seagate W3

What Influences Chiller Efficiency?



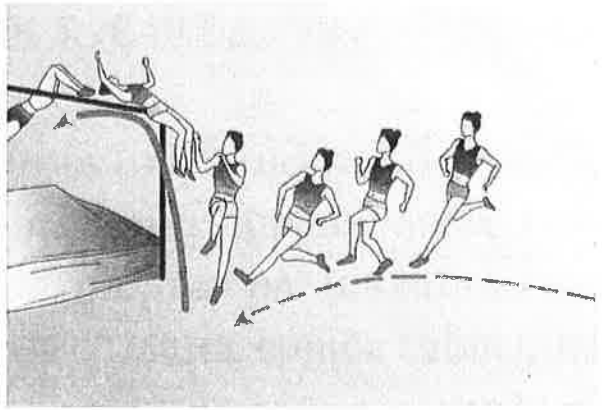
Temperature Lift = SCT – SST

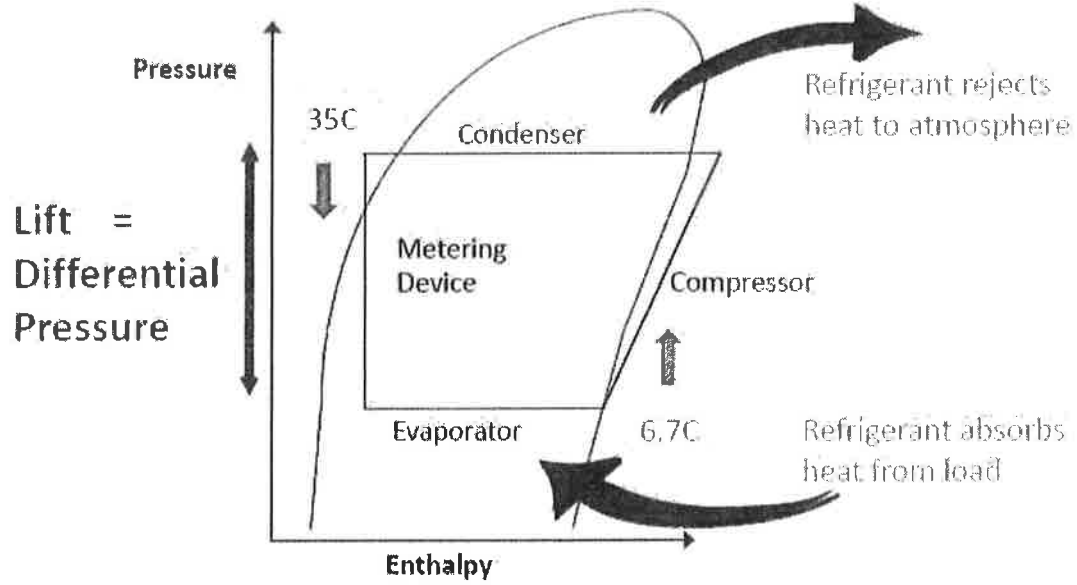
Saturated Condensing Temperature (SCT) is dependent on **LEAVING condenser water temperature**

Saturated Suction Temperature (SST) is dependent on **LEAVING chilled water temperature**

Reducing Compressor Lift Saves Energy







Just like in high jumping, **reducing compressor lift** helps to **improve chiller efficiency** and **save energy**.

Maximizing High Chilled Water ΔTs

Tonnage = Constant x Water Flow x Temperature Differential

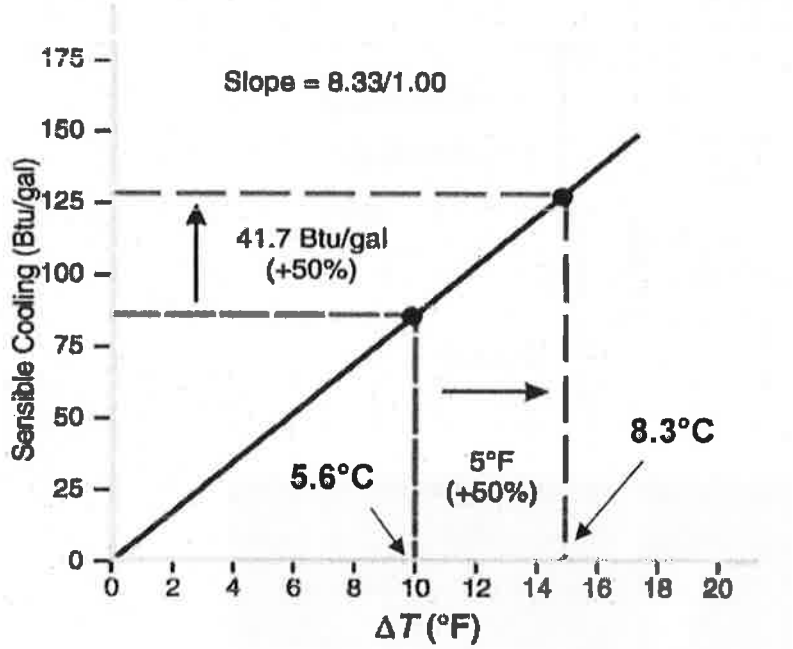
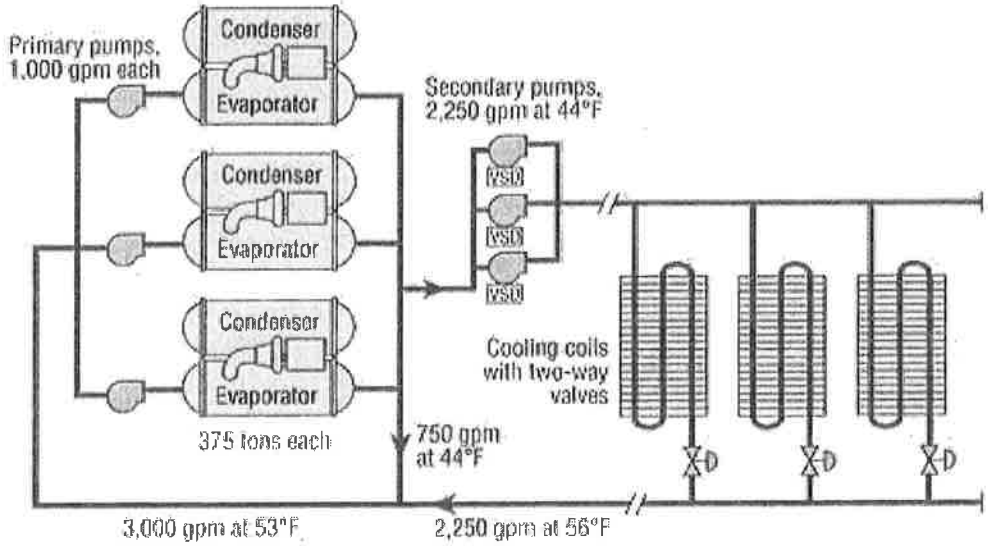


Figure 1 : Hydronic cooling leverage

- Once high chilled-water ΔTs are realized, **more tonnage** of cooling will be accomplished **per m³ of chilled-water** distributed.
- **Pressure losses** and **pumping energy** will **decline** considerably in existing hydronic cooling systems and smaller pumps and piping may be installed in new hydronic cooling systems.
- Also, water chiller capacities will no longer be limited by maximum evaporator flow rates and chilled water storage tanks will store many more ton-hours of cooling.

Since typical ΔT is about 5 °C, an increase of 1 °C in ΔT will help to reduce chilled water flow by 20 %. This will reduce chilled water pumping energy by 49%.

Analogy between a Chilled Water Pump & a Truck





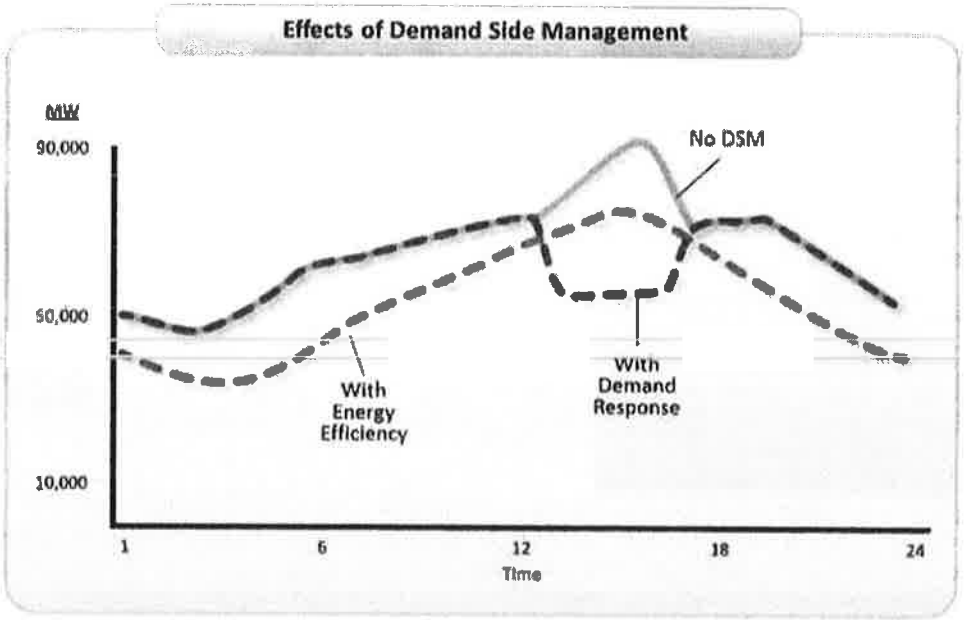
- **Fouled** cooling coils results in **poor cooling coil heat transfer**.
- Chilled water pumps have to work harder by **pumping more chilled water** to remove heat from partially insulated cooling coils.
- This is analogous to filling a truck partially full.
- Partially-filled trucks have to **make more trips** and **waste more energy** compared to fully-loaded trucks.

Demand Response Programmes

What is Demand Response?

Demand response (DR) refers to a mechanism that encourages customers to **reduce** or **shift their electric power usages** under certain conditions to help utilities to overcome temporary constraints in the electricity supply.

DR includes **time-of-use rates** and other means of **passing on power costs to end users**, with the objective of **reducing electrical load** during **high demand periods**.



Why is Demand Response Important in Many Countries?

- **Power plant generating capacity** generally cannot keep pace with **growth of utility load**.

- Utilities have two primary strategies to meet the growth in demand:
  - **Build expensive power plants** and **transmission** and **distribution** systems to provide energy on days with high peak demand .
  - **Manage** the **growth in demand for electricity**.

- **Energy security** is a critical benefit of demand response.

- **Blackouts** imposed tremendous **economic and social costs**, including **equipment damage, lost revenue** from damaged or spoilt products, **lost wages and reduced productivity.**

Demand Response Strategies

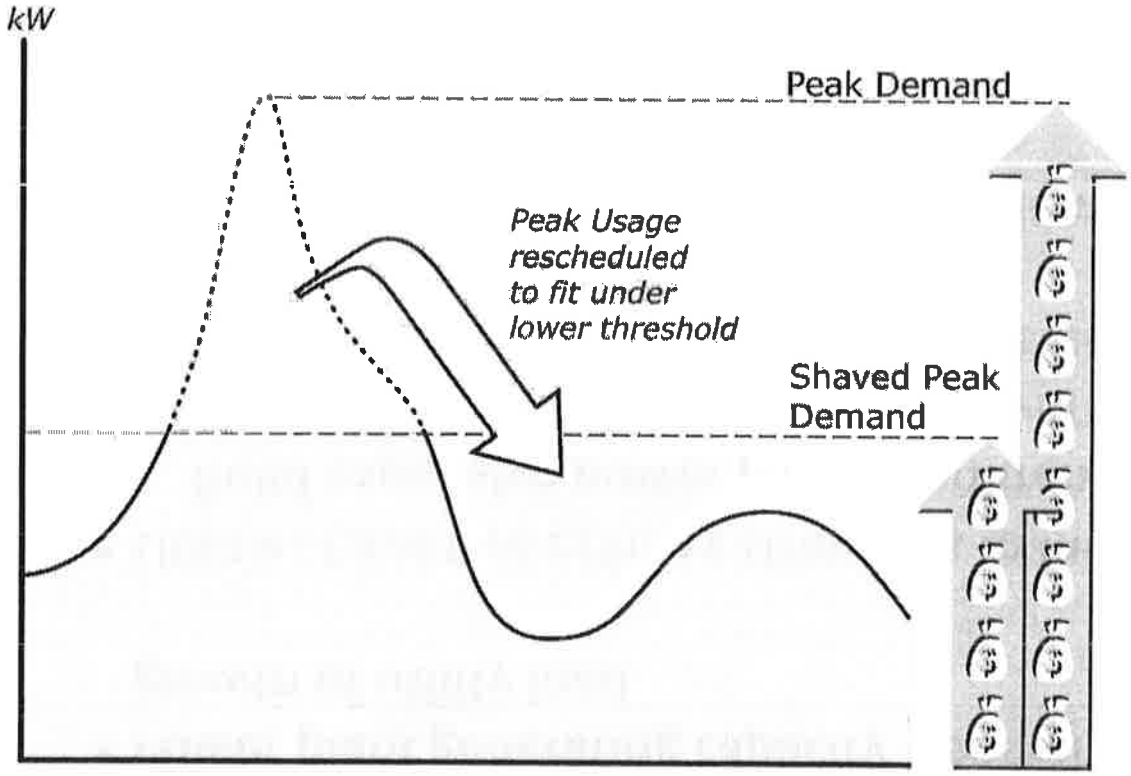
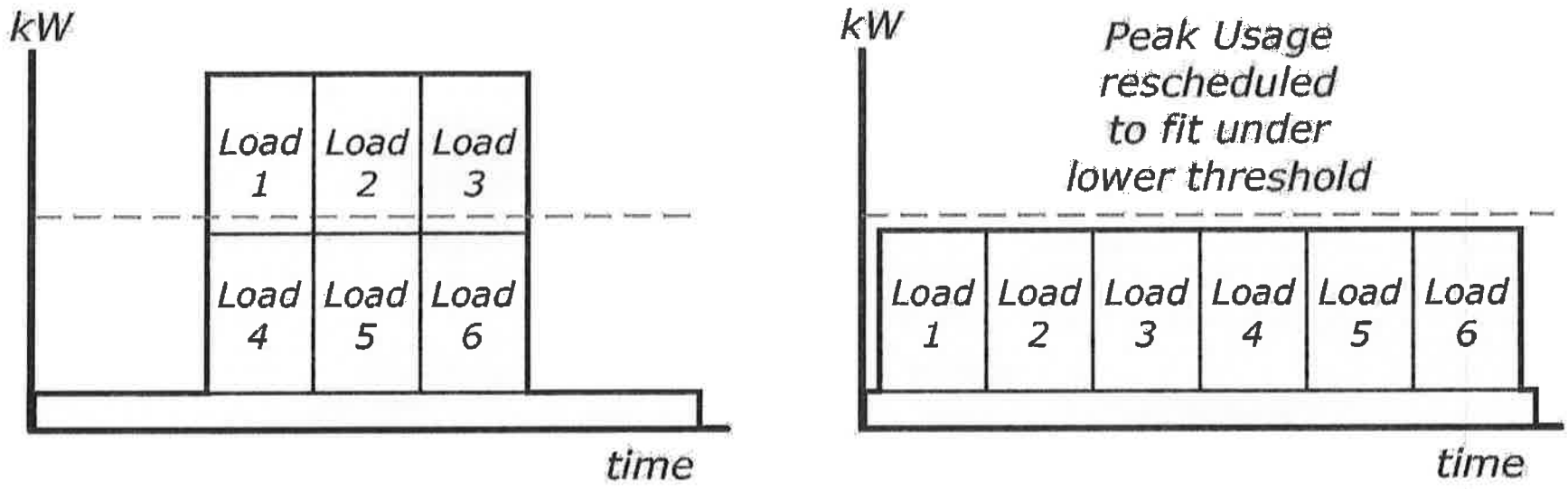


illustration of peak shaving, demonstrating how re-allocating tasks from peak usage time to lower-usage time can decrease overall capacity charges

Peak Shaving Methods:

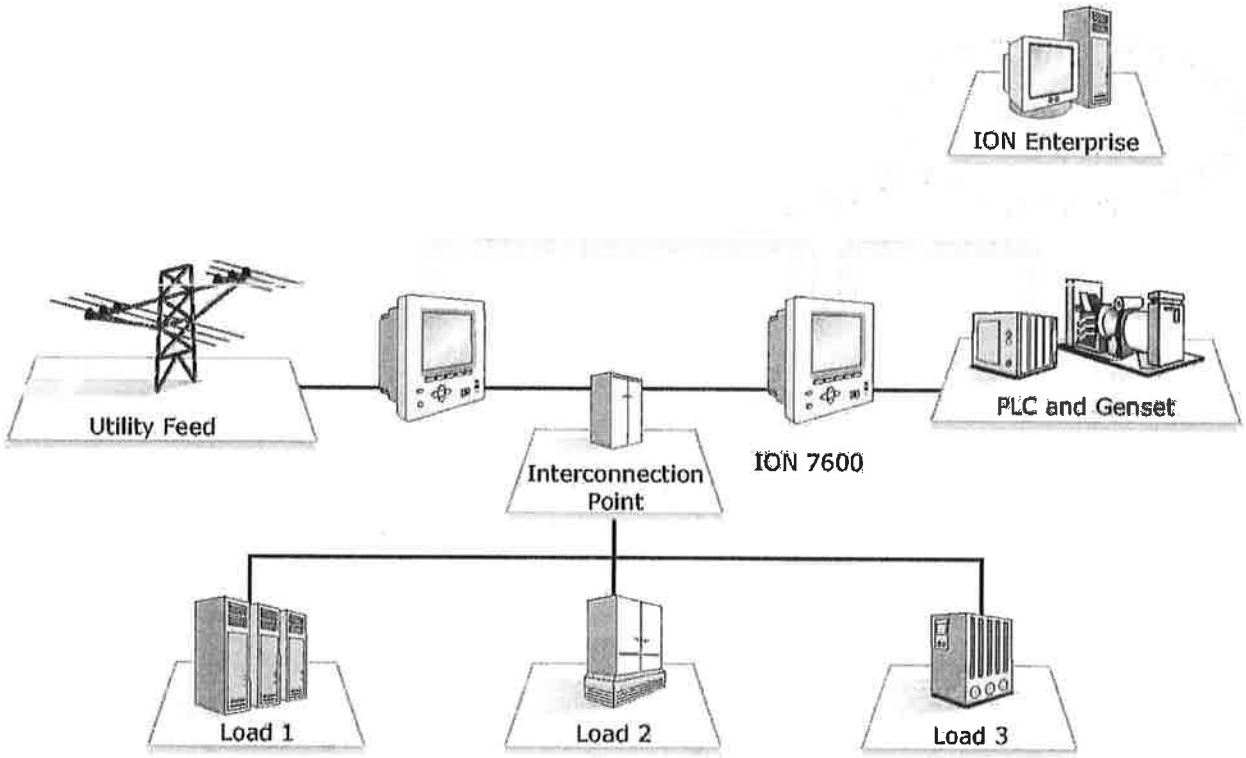
- **Load scheduling**
- **Generation**
- **Load shedding**

Load Scheduling



Load scheduling. By scheduling **non-time-sensitive loads** to run **sequentially** rather than **concurrently**, capacity at any time can be reduced, which in turn **reduces demand penalties.**

Generation for Demand Control

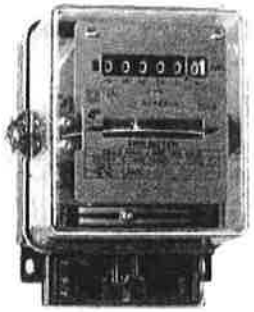


Simple system of generation for **demand control**. By turning on the generator when demand reaches a certain level, consumers can reduce their **demand penalties** by keeping their usage under a certain limit. Thin black lines represent power flow. Thicker gray lines show communications.

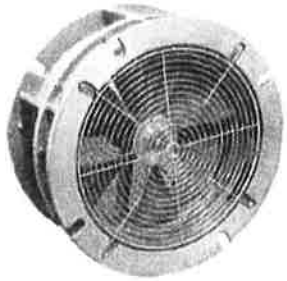
Load Shedding Programme

What can you afford to shut down without making people uncomfortable and angry? Unfortunately, some comfort will be sacrificed to achieve load shedding. Some ideas for load shedding without sacrificing too much comfort are:

- Reduce **VSD speeds**
- Turn off **outside air fans**
- Turn off **toilet exhaust fans**
- Reduce **static pressure setpoints**
- **Increase space temperature setpoints** in non-critical areas
  Examples: Admin areas in hospitals and production plants, back-of-house areas in hotels.
- **Turn off lights or reduce lighting level** in non-critical areas
  Examples: Corridor lighting, accent lighting, decorative lights
- Design bigger water tanks and **keep pumps off** during peak demand periods.



Power Meter

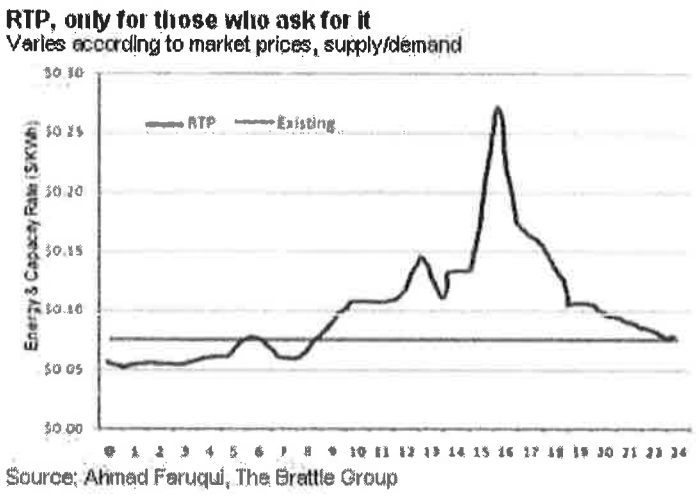


Outside Air Fan



Office Lighting

Real Time Pricing (RTP)





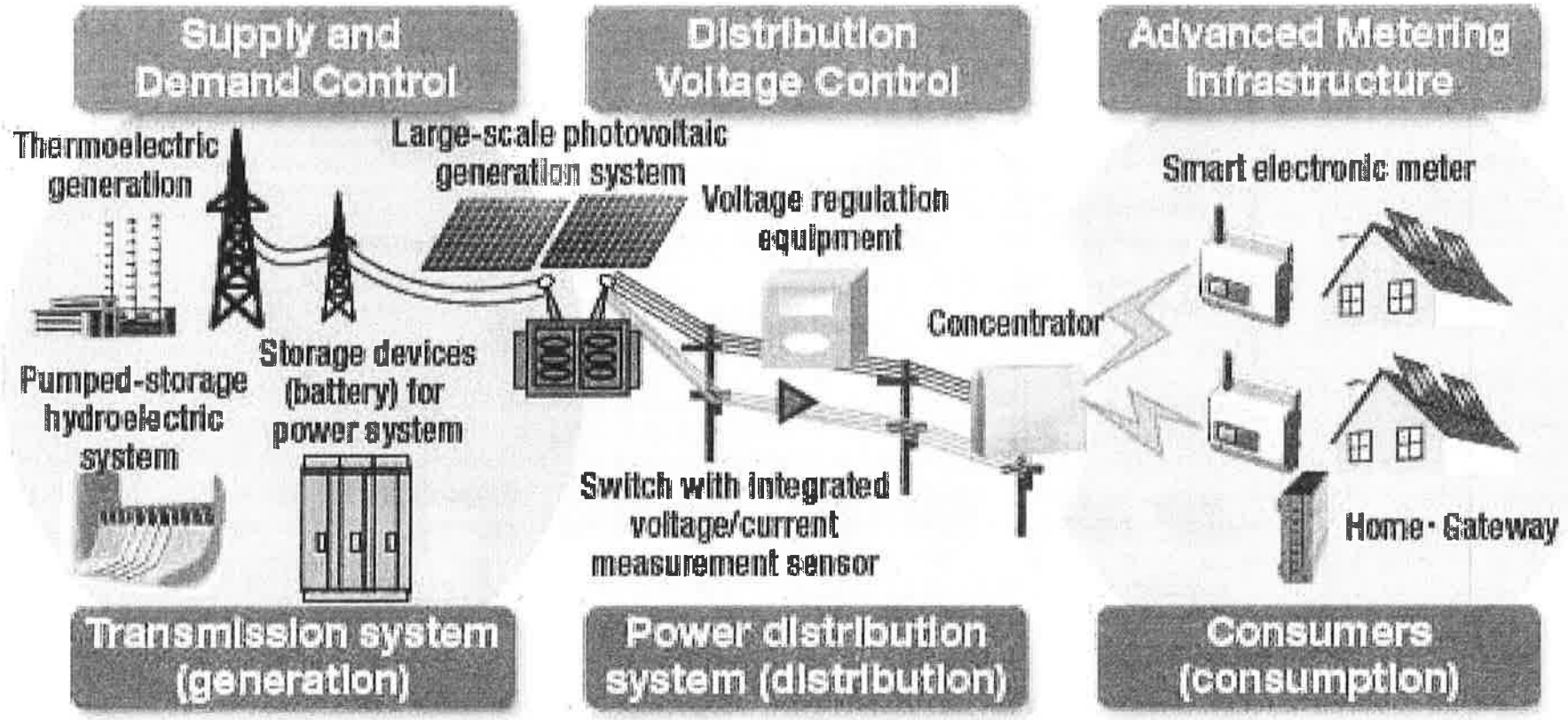
What is real-time electricity pricing?

- Used in more sophisticated energy market like the United States.
- Gives consumers information about the **actual cost of electricity at any given time**.
- Electricity prices change from hour to hour.
- Let consumers **adjust their electricity usage accordingly** - for example, **scheduling usage** during **periods of low demand** to pay cheaper rates.

How does it work?

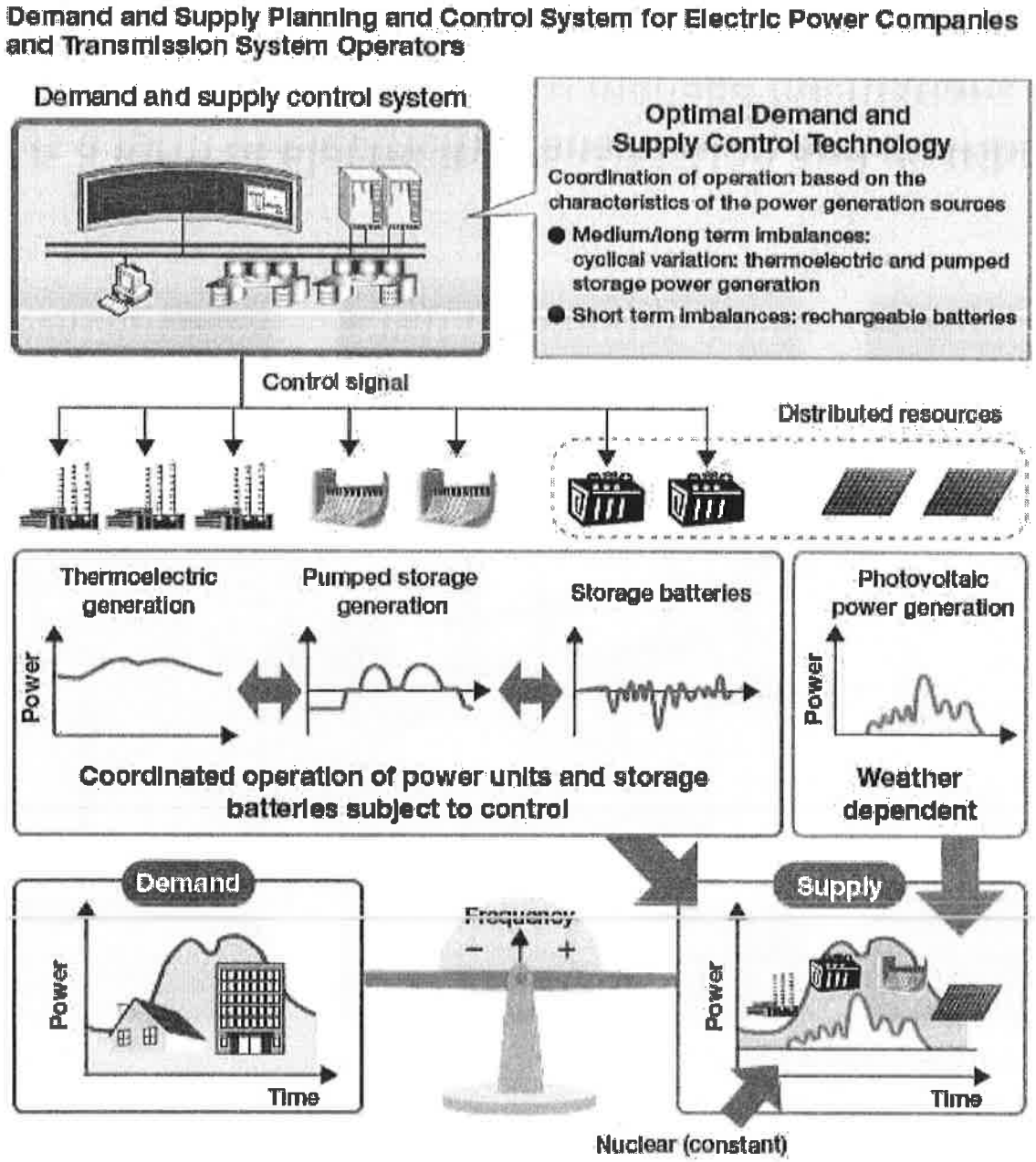
- Requires installation of an **electricity smart meter** that can send and receive information about **electricity costs** and give consumers more information about their own usage.
- The information can be received, including **online**, via **e-mail**, **text message**, or **telephone**.

What is a Smart Grid



A **smart grid** is a form of **electricity transmission and distribution network** that utilizes **information technology** to manage fluctuations in both supply and demand to create **stable flow of electricity**.

Smart Grid – Balancing Power Generation, Transmission and Consumption



Benefits of Smart Grids

A smart grid is an electricity grid that uses **ICT** (Information and Communications Technology) to gather and act on **information** from suppliers and consumers in an **automated way**.

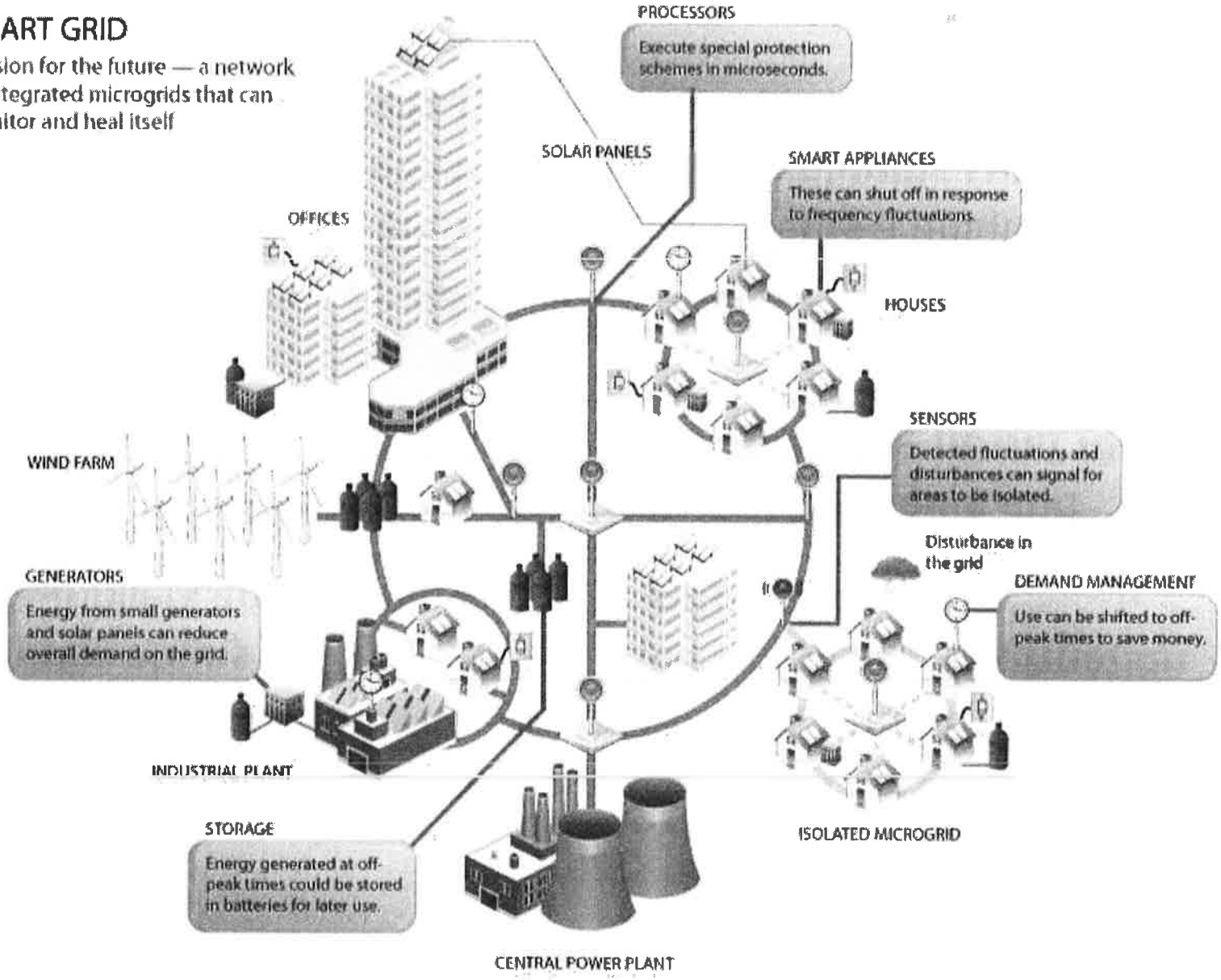
This allows it to **integrate energy** from **unpredictable and intermittent renewable sources** and to **distribute power much more efficiently**.

A smart grid will deliver electricity **more cost-effectively** and with **lower greenhouse gas emissions**. It represents a unique opportunity to enable **electrification of developing countries** where access to electricity is still very limited.

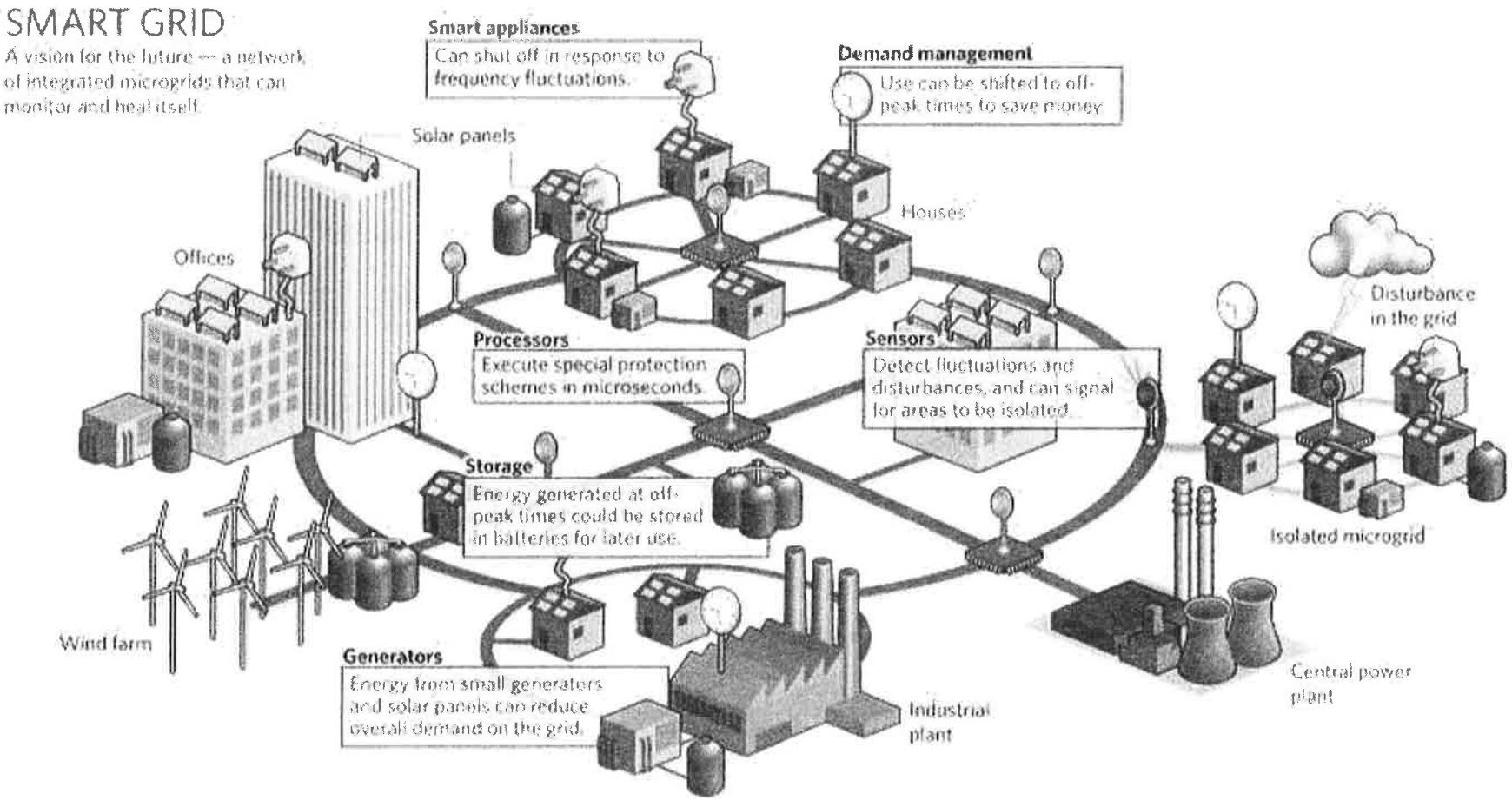
Smart Grid – A Vision for the Future

SMART GRID

A vision for the future — a network of integrated microgrids that can monitor and heal itself



Smart Grids



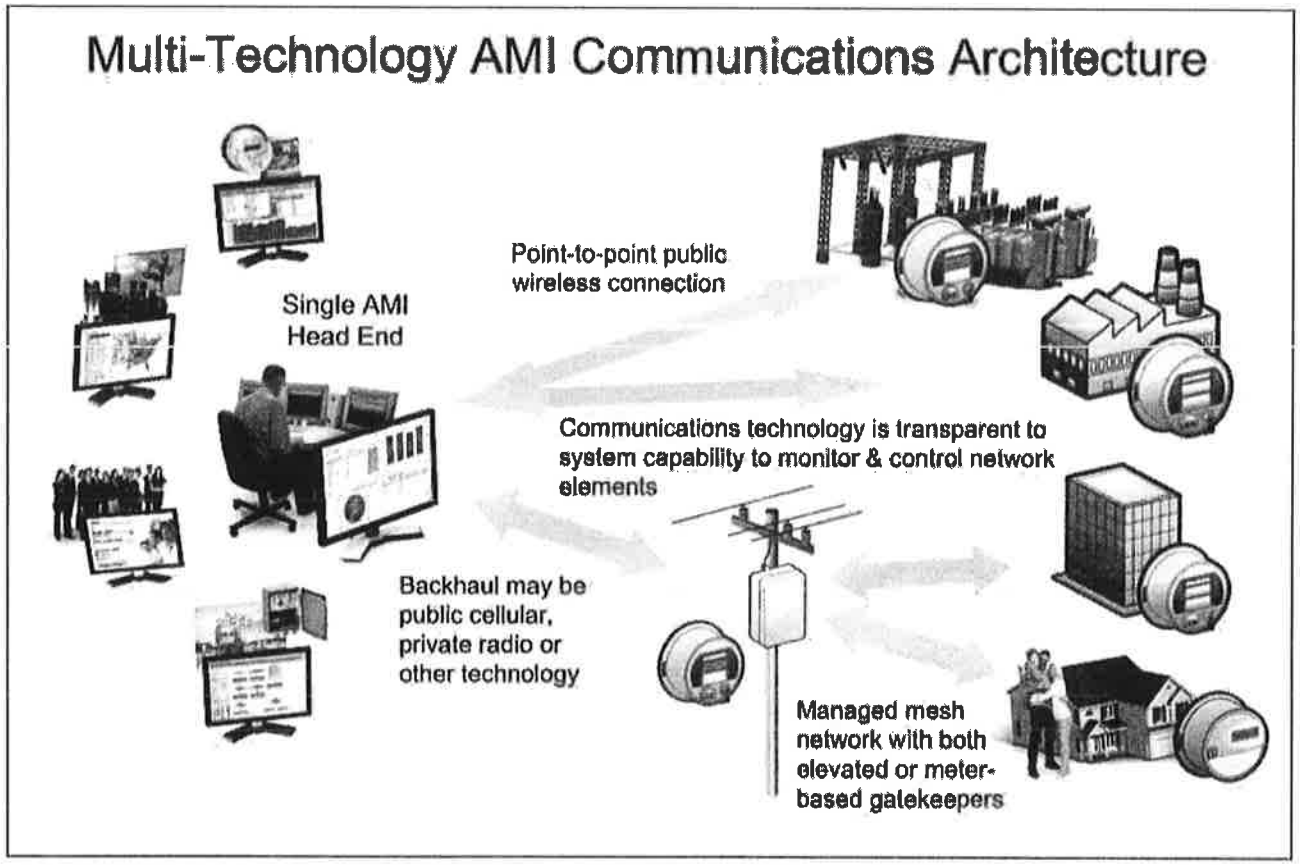
Use of **digital information** and **controls technology** to improve **reliability**, **security**, and **efficiency** of the electric grid.

Integration of **distributed resources** and **generation** including **renewable resources.**

Use of **smart technologies - metering** and **communications** concerning grid operations and status and distribution automation.

Advanced electricity storage and **peak-shaving technologies - plug-in electric** and **hybrid electric vehicles**, and **thermal-storage air conditioning**.

Advanced Metering Infrastructure



Smart electric meters that are capable of collecting fine grained **consumer electrical usage data** and transmitting the data securely over GPRS or WIFI Mesh.

Incorporates **data collection**, **analytics**, system planning, engineering, operations, **energy management**, **asset management**, and **value-added customer services**.

Smart Meters serve as **information gateways** to customers. They provide **periodic meter reads** to support **dynamic pricing programs**, improve **revenue management**, **proactive customer communications** to **educate about energy efficiency**.

Water Conservation

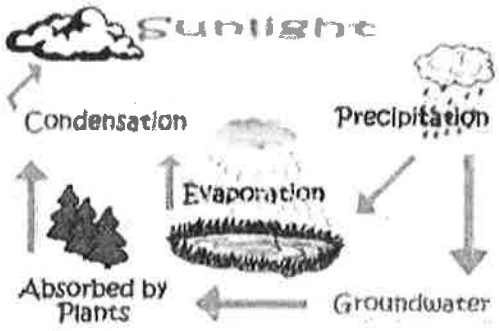
Rain Water Harvesting and Intelligent Irrigation





Rain Sensor

Irrigation system is inactivated when it rains



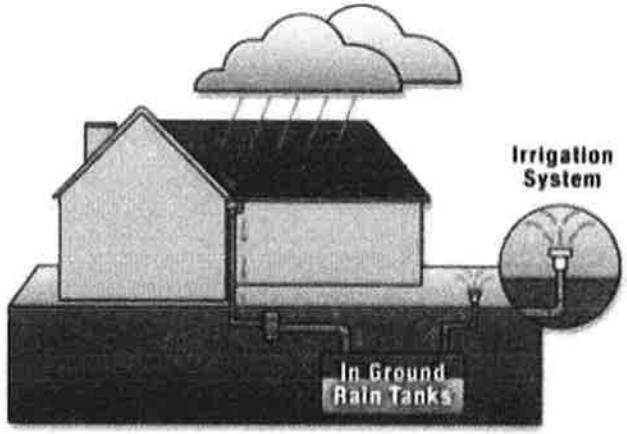
Nature's Water Cycle



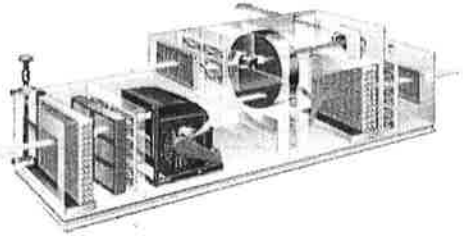
Soil Moisture Sensor



NeWater



Rain Water Harvesting System



Recovery of AHU Condensate

Rain water harvesting system to collect rain water for plant irrigation. Use of **soil moisture sensor** to initiate watering. Mimics nature's **'water cycle'**.

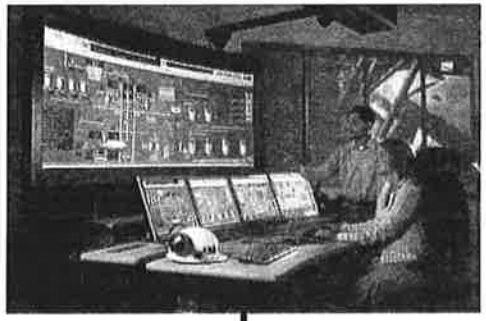
Non-Portable Water for Cooling Tower Make-up and Irrigation





Rain Sensor

Building Automation System



DI

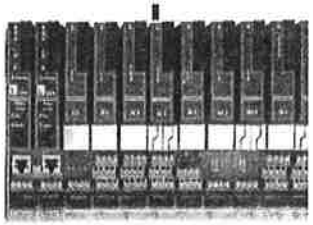
DI



Soil Moisture Sensor



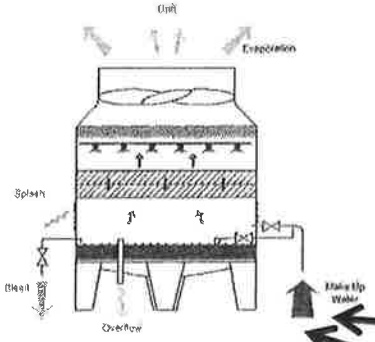
Vegetation



DDC Controller

DO

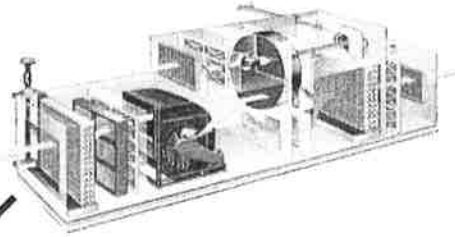
DO



Cooling Tower



Rain



Recovery of AHU Condensate



Water Pumps

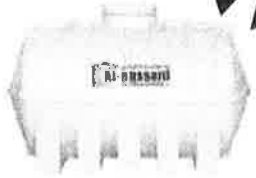




NeWater

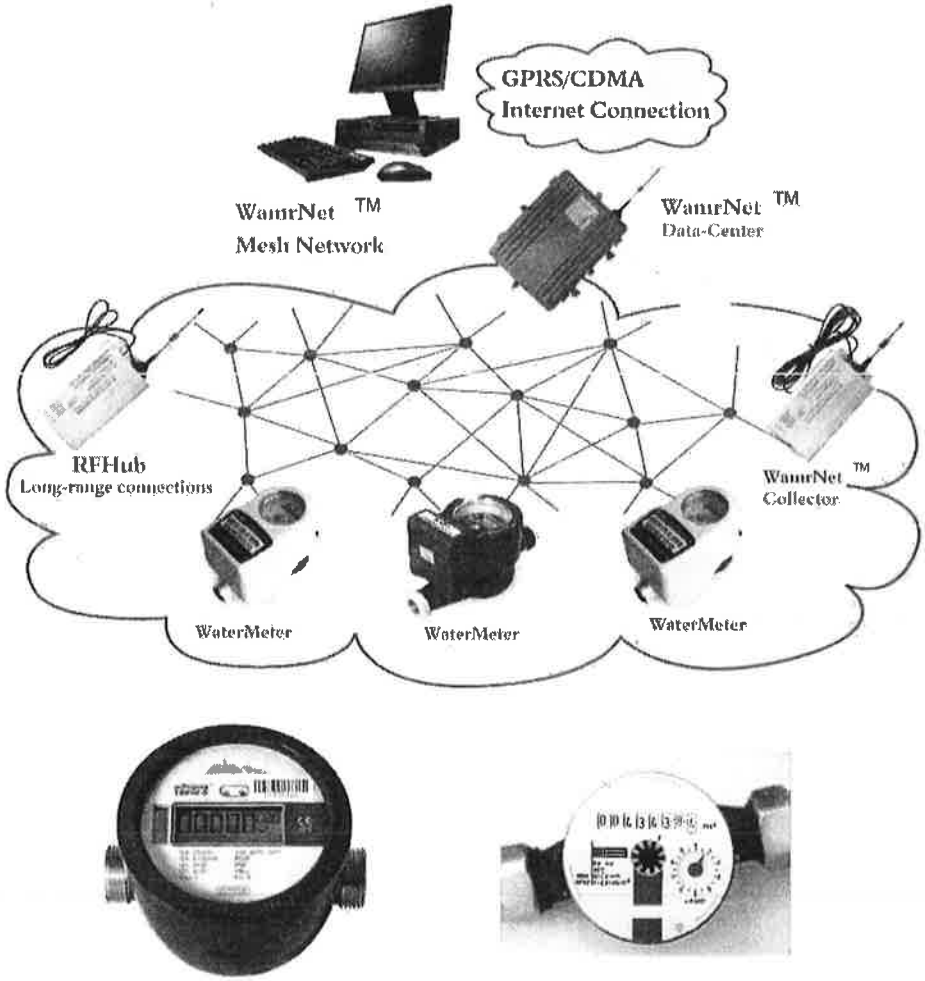


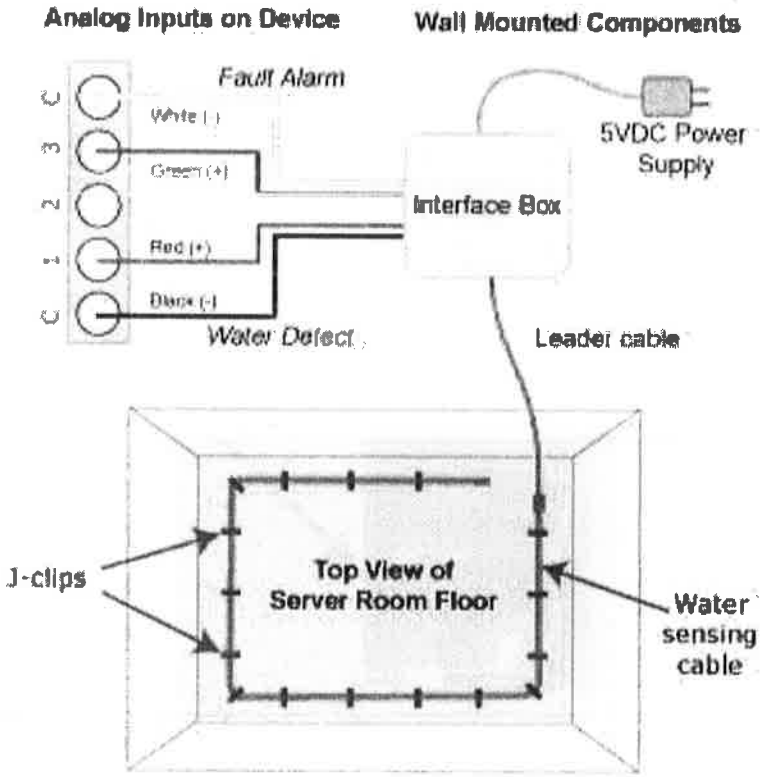
Water Tank



Water Tank

Water Usage Metering and Water Leak Detection





Water Usage Tracking by BAS

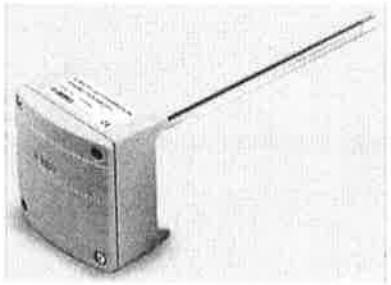
Water Leak Detection

Round-the-clock water consumption tracking by BAS can detect water leaks if water flow is indicated during periods of low or zero usage.



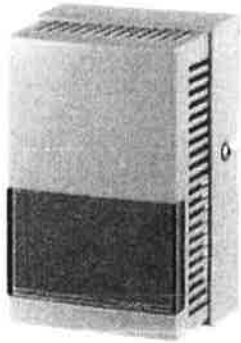
Enhancement of Indoor Environmental Quality

IAQ Tracking/Monitoring by BAS





Temperature Sensor / Transmitter



RH Sensor



Carbon Dioxide Sensor



Carbon Monoxide Sensor



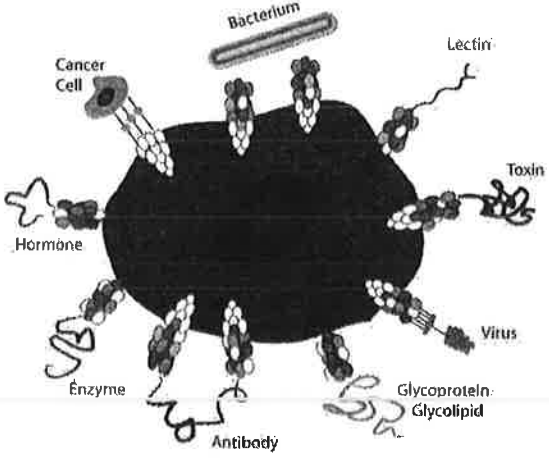
TVOC Transmitter



Ozone Gas Transmitter



Nuclear Radiation Sensor



Biological Sensors



Refrigerant Gas Detector

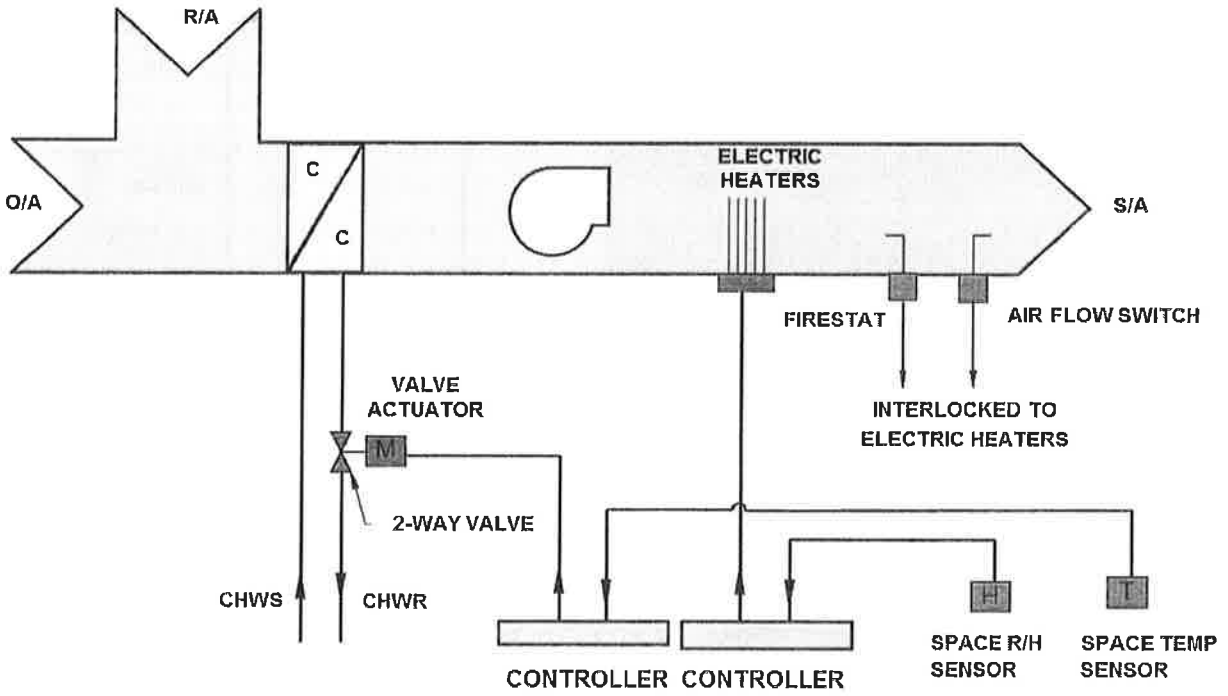


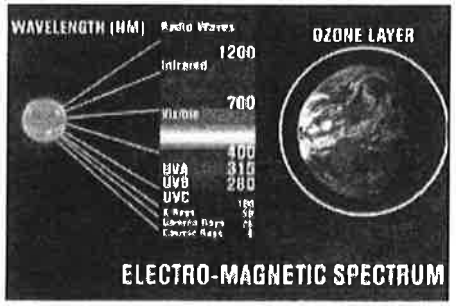
Oxygen Gas Transmitter



Radiant/Operative Temperature Sensor

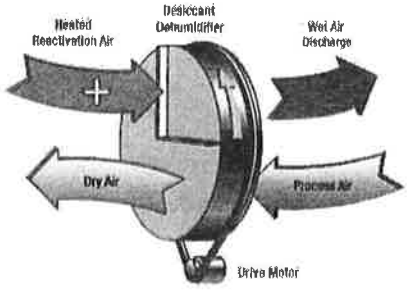
RH Control – Key to Control of Fungal Bacterial Growth



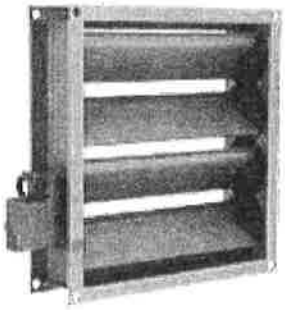


UVC approaches the Intensity of X-Ray

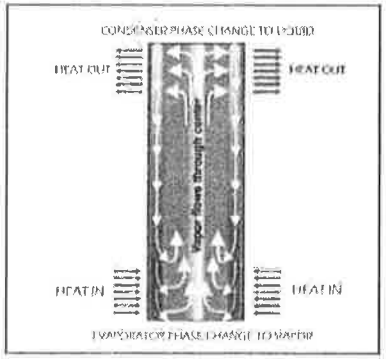
UVC emitters installed at cooling coils eliminates bio-film and enhances moisture removal from the air .



Desiccant Wheel

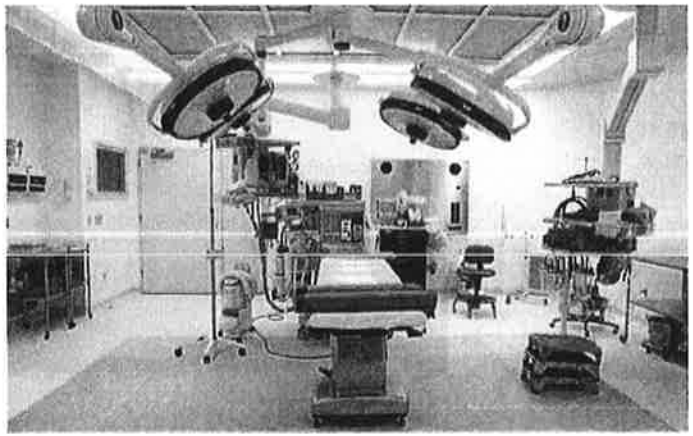


Face and Bypass Damper

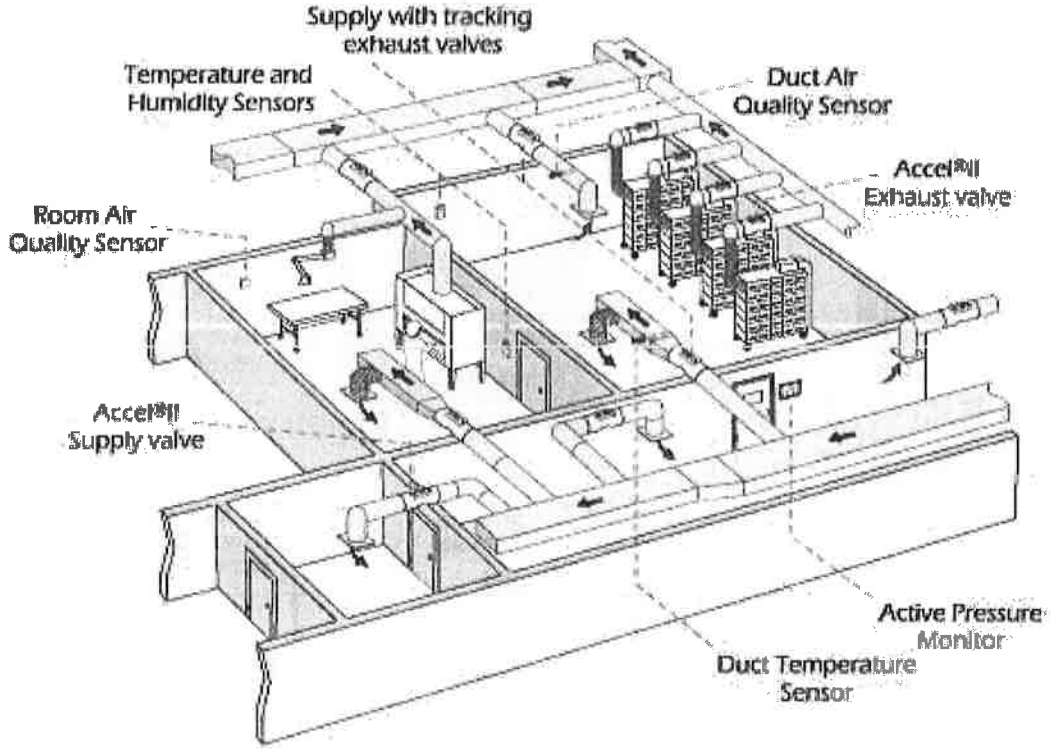


Wrap-around Heat Pipe

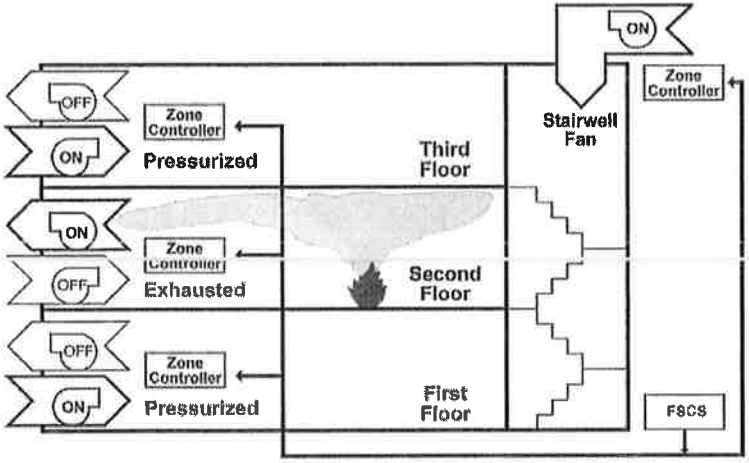
Use of Pressurization to Control Flow of Contaminants



Operating Theatre



Laboratory



Smoke and Fire Containment



Cleanroom in Semicon Manufacturing Plant