International Energy Agency

A Guide to Sensors for BEMS

Energy Conservation in Buildings and Community Systems Programme. Annex XVI. Building and Energy Management Systems: User Guidance

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IEA ANNEX 16

A GUIDE TO SENSORS FOR BEMS

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Annex 16 Building Energy Management Systems • A User Guide

Building Energy Mangement Systems offer a large potential for improved energy performance of buildings. The realisation of this potential is critically dependent on the proper specification of the system, and effective use of the facilities by the operations staff. The IEA Executive Committe established Annex 16 in order to address these issues by pulling together information which could be of benefit to specifiers and users of BEMS systems.

This report is one in a series of publications produced by the Annex.
The publications are:-

a) Specifications and Standards for BEMS

b) Cost Benefit Assessment Methods for BEMS

c) Case Studies of BEMS Installations

d) A Guide to Sensors for BEMS

e) User Experiences with BEMS

Participants in the Annex are Finland, Germany, Japan, Netherlands and the United Kingdom.

Preface

International Energy Agnecy

The International Energy Agency (IEA) was established in 1974 within the flamework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-one IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD & D). This is achieved in part through a programme of collaborative FD & D consisting of forty-two Implementing Agreements, containing a total of over eight separate energy RD & D projects. This publication forms one element of this programme.

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy in one of these areas, energy conservation in buildings, the IEA sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy. Seventeen countries have elected to participate in this area and have designated contracting parties to the Implementing Agreement covering collaborative research in this area. The designation by governments of a number of private organisations, as well as universities and government laboratories, as contracting parties, has provided a broader range of expertise to tackle the projects in the different technology areas than would have been the case if participation was restricted to governments. The importance of associating industry with government sponsored energy research and development is recognized in the IEA, and every effort is made to encourage this trend.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial. The Executive Committee ensures that all projects fit into a pre-determined strategy, without unnecessary overlap or duplication but with effective liaison and communication. The Executive Committee has initiated the following projects to date (completed projects are identified by *):

I Load Energy Determination of Buildings * II Ekistics and Advanced Community Energy Systems * III Energy Conservation in Residential Buildings * IV Glasgow Commercial Building Monitoring * V Air Infiltration and Ventilation Centre VI Energy Systems and Design of Communities * VII Local Government Energy Planning * VIII Inhabitant Behaviour with Regard to Ventilation * IX Minimum Ventilation Rates * X Building HVAC Systems Simulation XI Energy Auditing * XII Windows and Fenestration * XIII Energy Management in Hospitals * XIV Condensation XV Energy Efficiency in Schools
XVI BEMS 1: Energy Management Procedures
XVII BEMS -2: Evaluation and Emulation Techniques
XVIII Demand Controlled Ventilation Systems XIX Low Slope Roof Systems
XX Air Flow Patterns within Buildings
XXI Energy Efficient Communities XXII Thermal Modelling

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A GUIDE TO SENSORS FOR BEMS

ABSTRACT

Right selection of sensors can be done only with correct knowledge on the performance not only of the sensors but of the control systems including the object systems to be controlled. Recent development in air-conditioning systems especially in relative to the control and management of the energy and environment is so rapid and highly technological that this guideline has the stance how to optimize the objective control systems through sensor selections. Therefore, a considerable amount of notes on control algorithms especially relating to air-conditioning are accompanied with selecting sensors.

Chapter 1 describes the purpose, scope and BEMS structure with which the authors' stance to direct the synthesized BEMS system with optimization functions are clearly presented. This chapter may seem not necessarily to be described as the sensor selection guideline. However, in the course of discussions on BEMS definition among the participants of Annex 16, authors thought it is necessary to make clear the standpoint of BEMS interpretation.

Chapter 2 describes the roles of sensors in relative to control system and their performance.

Chapter 3 is sort of directory of BEMS sensors included in this document and measuring object, type, principle, feature, example of uses are listed. It also demonstrates that this guideline includes not only these sensors connected to BEMS hardware but also those stand-alone control sensors and kinds of measuring devices which are closely concerned to building maintenance.

The main body of this guideline consists of five chapters for various kinds of building services as HVAC, plumbing and sanitation, electric utilities and lighting, security and fire prevention, and other miscellaneous control and management items in Chapter 4 to Chapter 8. For each service item, a selection guide table showing objective buildings, rooms and/or applications, control type, control action, control accuracy and applicable types of sensors is prepared first. Then, the sensor/control system, grade and manners of control in the second place, and applicable sensor candidates are shown for control and/or monitoring, reporting and analyses. For special items such as room temperature control, the description on an optimization phase are added in order to meet future demands.

Chapter 9 shows how suitable sensors can be selected for particular projects. This chapter is usable not only as the supplements of the main body of the document but as windows towards preparing software of building optimization.

Appendix consists of survey report, references on sensor applications, and regulations on building environment. The survey report, which is filed in a separate document in details, are based on participants' co-working. Though it is often very difficult to gather precise and newest data for this kind of survey, this will give a convenient overview on the actual status of sensor applications.

The object of listing regulations on building environment is to evaluate the importance of environmental control by which the roles of sensors are recognized.

This guideline has been prepared by the following working group members.

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Japan BEMS Committee

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CONTENTS

Abbreviation and Acronym

ANA	Analog
BOD	Biochemical Oxygen Demand
CAV	Constant Air Volume
CC	Cooling Coil
CCD	Charge Coupled Device
CCTV	Closed Circuit Television
CNC	Concentrated Nuclear Counter
CPU	Central Processing Unit
D	Derivative (action)
DDC	Direct Digital Control
DHC	District Heating and Cooling
DIG	Digital
EA	Exhaust Air
EH	Electric Heater
ET*	New Effective Temperature
FIN	Finland
FL	Floor / Floor Level
FRG	Federal Republic of Germany
FS	Full Scale
HC	Heating Coil
HDD	Heating Degree Days
HEPA	High Efficiency Particulate Air Filter
HVAC	Heating Ventilating and Air Conditioning
I	Integral (action)
IAQ	Indoor Air Quality
IC	Integrated Circuit
ICU	Intensive Care Unit
IR	Infrared
IS	Indicated Scale
JACA	Japan Air Cleaning Association
JIS	Japan Industrial Standard
JN	Japan
LPC	Laser Particle Counter
MRT	Mean Radiant Temperature
NL	The Netherlands
OA	Outdoor Air / Office Automation
OT	Operative Temperature

P	Proportional (action)
PI	Proportional + Integral (action)
PID	Proportional + Integral + Derivative (action)
PMV	Predicted Mean Vote
P-wave	Primary wave
2P	Two-Position (action)
RA	Recirculated Air
RC	Reinforced Concrete
RH	Relative Humidity
S	Steel (structure)
SA	Supply Air
SAT	Sol-Air Temperature
SCC	Supervisory Computer Control
SCR	Semiconductor Controlled Rectifier
SD	Standard Deviation
SEQ	Sequence
SET*	Standardized New Effective Temperature
SHF	Sensible Heat Factor
SRC	Steel Reinforced Concrete
S-wave	Secondary wave
UK	United Kingdom
UV	Ultra Violet
VAV	Variable Air Volume
VWV	Variable Water Volume

CHAPTER 1: Purpose, Scope and BEMS Structure

1.1 Purpose and Scope

This guide to sensors and detectors for building management deals primarily with their performance criteria and applicability. Matters relating to their installation are also discussed and in some cases guidance on appropriate control algorithms is included. Emphasis is given to input devices for environmental control. Treatment of sensors/detectors for certain utility services are included where they have relevance to good energy management.

The family of building and energy management systems (or BEMS) may be classified according to scale and/or scope. This guide deals almost exclusively with systems to be classified (see 1.2.2 below) as "Sophisticated", or Level III, BEMS. Note this guide makes no reference to "information" systems, eg telephone systems, management information control systems and others which operate without input from sensors or detectors.

1.2 Definition and Structure of BEMS

1.2.1 Definition of BEMS

BEMS is construed in a wide sense in this guideline as follows:

"BEMS is the system by which, under a reasonable and efficient utilization of energy, the building manager controls, manages, and maintains a safe, sanitary, comfortable and functional environment for living as well as for business for the sake of tenants."

1.2.2 Several Classes of BEMS

For convenience, BEMS may be classified as:

(1) LEVEL I (Fundamental BEMS)

The subject of management is mainly the automatic and/or remote control of HVAC, water and power supply. Typical functions are preplanned operation, monitoring of on/off status of plant and environmental conditions. The main objective for the use of this class of BEMS is a reduction of building management staff.

(2) LEVEL II (Expanded BEMS)

In this class of BEMS the scope for building management is expanded and control functions enhanced. For example facilities for fire prevention and detection, security and garage control. Preplanned controls develops to regulatory control as DDC and/or SCC, thus grading up the feedback control algorithm. For the management and maintenance program, the concept of efficiency and/or performance in energy usage are introduced. Thus, energy conservation, safety, and comfort become additional important purposes of BEMS.

(3) LEVEL III (Sophisticated BEMS)

A "sophisticated" BEMS extends further the facilities for management and automatic control; most important is the scope offered for the integration of all controls and hence for the OVERALL optimization of energy consumption and environmental condition. Also available are facilities for more advanced controls leading to improved fire prevention and detection, security etc as required by hotels, hospitals etc. Regulatory controls develop to include optimal controls with performance function for the effective use of energy and constraints to achieve comfort environment. Due to the development of machine interface and the structure of algorithm, users operation is also introduced. The concept of preventive maintenance, facility management, and tenant management are introduced in this class of BEMS to establish totalized building management concept. Therefore, several indices for comfort energy efficiency, and management become indispensable.

(4) LEVEL IV (Synthesized BEMS)

This system integrates fully all management and automatic control functions. A single "building database" is accessible to all management and control functions thereby allowing optimization against any operator-defined criterion/criteria, thus telephone communication system, office automation system and even cleaning maintenance and facility management may be combined with this class of BEMS.
The implementation of such a system is a long way off.

Figure 1.1 illustrates the various BEMS classes.

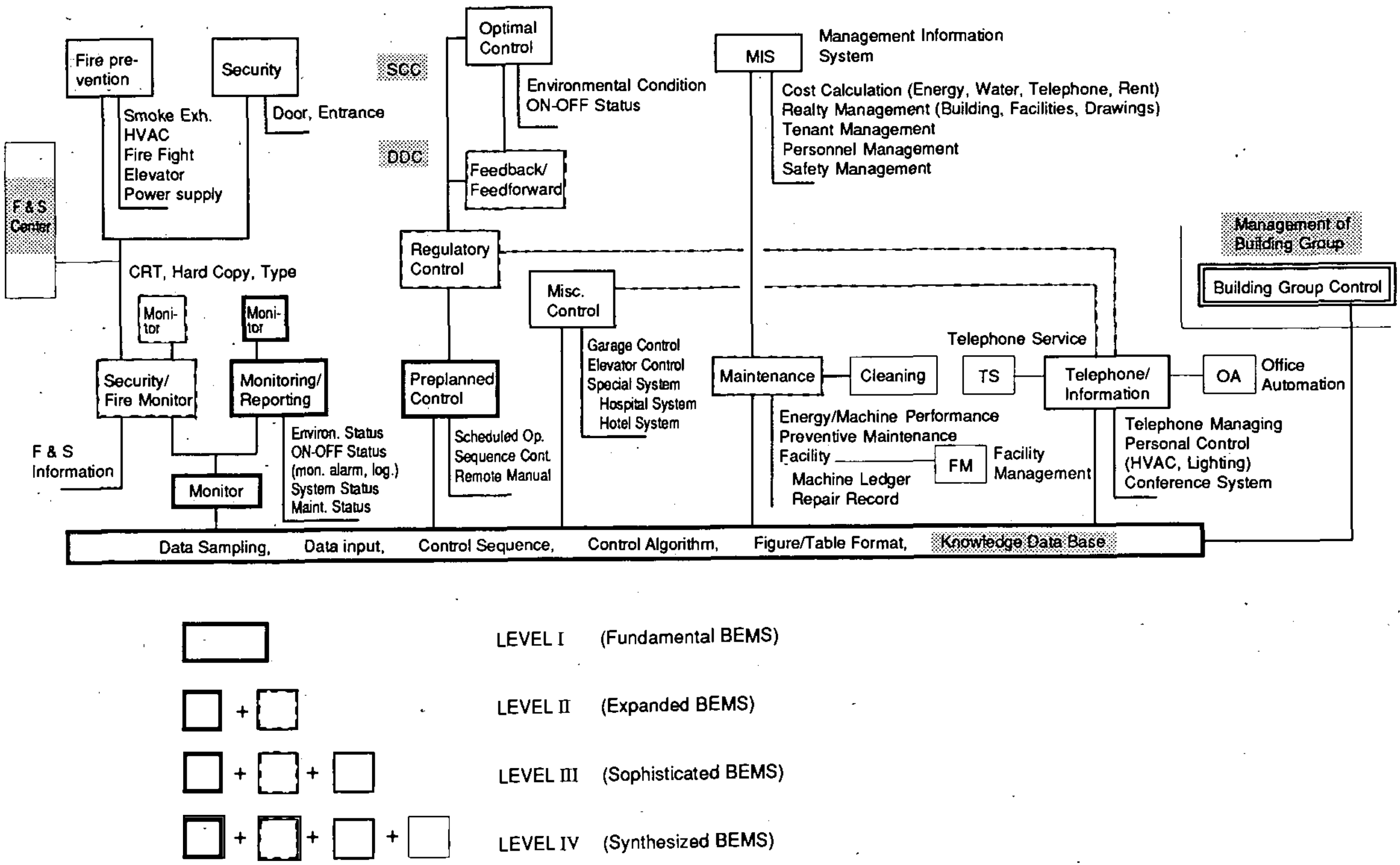


Figure 1-1 Development of a BEMS Hierarchy

CHAPTER 2: Roles of Sensors

2.1 Control Systems

Occupants of today's buildings expect an internal environment and utility services which match their needs. In an attempt to meet these expectations building managers are making increasing use of automatic controls and systems for data acquisition, processing and/or recording. The objectives of building management (used here in its generic sense so as to include "control") may be summarized as follows:

1) A healthy and comfortable environment
2) Safety and security of occupants and property
3) Economic operation of the building with respect to:
   a) maintenance staff and associated facilities, and
   b) energy related costs.

ANY control loop comprises the stages of
1) measurement, 2) comparison and 3) action; NB comparison and/or action can be effected either automatically or manually. The facility for manual and/or remote closure of a control loop and automatic change of set point is an especially important feature of the building management system. This form of control is sometimes referred to as "supervisory" control.

Security, protection and/or fire prevention are often effected by way of some form of supervisory control. Energy consumption, environmental variables are all examples of the subjects for measurement. Fundamental to all forms of control is the fact that the quality of measurement has a major influence on the quality of control OVERALL.

2.2 Sensor Application in BEMS

Sensors detect physical, chemical, biological, and other status information of the environment and the facilities as well as output signals and information corresponding to these quantities. Accordingly, their roles lie in correct and quick detection and output of these quantities.

Table 2.1 lists the features relating to the "performance/quality" of sensors. Also, Table 2.2 shows the relationship between the building management/control and sensors. The sensors must be carefully selected according to the their working purpose and place. Since sensors are often combined with converters for output processing, their adaptability to converters and their systematic performance must be examined carefully. Table 2.3 shows examples of characteristics of sensors and converters. The values given for the output range, accuracy and measuring range are tabulated based on the standard products used in Japan, therefore they may change in each countries due to difference of code etc. Care should be exercised in the selection of sensors; the following notes are included as a guide to the major issues:

① Select each sensor fully in accordance with its intended purpose.
② Assess whether or not a complete space can be satisfactorily represented by measurements made at a single point.
③ Take care of the influence of temperature, humidity, radiation, contamination, vibrations, electromagnetism, gravity, and other variables at the working places, because sensors are sensitive.
④ When sensors are used for integrating certain quantities for a long time, care should be taken for their long-term reliability, since errors are accumulated.
⑤ Care should be taken for the maintenance needs of certain kind of sensors.

The following chapters describe the application of various sensors. These sensors are always used for controlling, measuring, and monitoring building facilities. In addition to their application to the measurement of single variables sensor elements are often integrated with with switches or other mechanical devices, single converters etc to create a complete control device or subsytem.

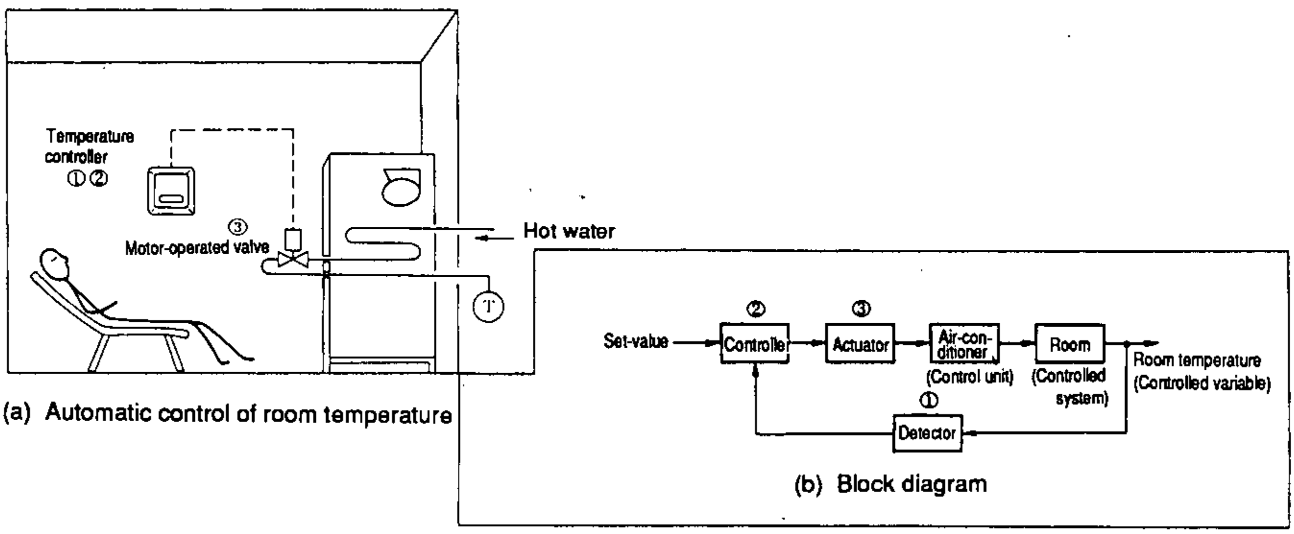


Fig. 2.1 An example of Control Systems (Feedback system) [JN 12)]

Table 2.1 Factors Relating to Sensor Performance and Use

Accuracy	Adaptability
Sensitivity Resolution Correctness Precision Linearity Hysteresis Reproducibility S/N ratio Dynamic range Response Frequency characteristic	Dimensions (A ratio to objects) Measuring range Easy handling Environmental resistance Security Coupling with other devices Composite functions Design
Reliability	**Economy**
Stability with time Thermal stability Noise resistance Environmental resistance Deterioration Life Fail-safe	Low prices Easy procurement Small size Energy-saving type Coupling with a computer Easy calibration Cost effect Maintenance ease

Table 2.2-2 Sensor Application

○: Applied sensor

Management, Control \ Sensed Variable		Tem-perature	Humid-ity	Pres-sure	Level	Flow-rate	Velocity	Gas	Smoke	Dust	Water Quality	Light, Solar	IR	UV	Sound, Noise	Vibra-tion	Force	Electric Quantity	Time
Environment	Living Space	○	○				○	○		○		○			○	○			○
	Production Space	○	○	○			○	○		○		○			○	○			○
	Outdoor	○	○	○			○	○		○		○			○				○
Equipment	Operation	○		○													○	○	○
	ON-OFF Status	○	○	○	○	○	○	○			○		○		○	○	○	○	○
	Malfunction	○		○		○	○	○			○		○		○	○	○	○	○
Safety	Security											○	○		○	○			○
	Disaster Prevention (Fire, Flood, Earthquake)	○	○					○	○			○	○	○	○	○			○
Building Usage	Energy Consumption	○	○	○	○	○	○											○	○
	Water Consumption			○	○	○	○				○								○
	Occupancy											○	○					○	○
	Usage of Equipment											○	○					○	○

2.3 Intelligent Sensors

Since this guideline is described on the assumption that the BEMS is constructed based on the conventional sensor technology, it does not cover any intelligent sensors (smart sensors) which are being discussed in recent years. However, they will be outlined for reviewing future BEMS sensors.

2.3.1 Outline

Intelligent sensors are provided with a built-in microprocessor to offer improved functions and also realize a communication function by introducing a field bus as a high-grade total system. It is, therefore, necessary for evaluating these intelligent sensors to evaluate transmitters, field buses, controllers, actuators, and total systems in addition to sensing elements themselves.

Temperature sensors, differential pressure/pressure transmitters, electromagnetic flowmeters, vortex flowmeters, and other devices are now available on the market as intelligent sensors.

These products are based on the conventional sensors shown in this guideline so long as their sensing elements are concerned. These sensors have been developed as industrial instruments, and they contain various problems including their costs, which still remain unsolved to apply them to BEMS.

2.3.2 Functions

Owing to microprocessors, sensing elements, A/D & D/A convertors, memory devices, controllers, digital communication units, and other components, these intelligent sensors offer characteristic functions introduced below.

① Exclusion of abnormal and exceptional values caused by sensors themselves
② Data processing by sensors themselves
③ Automatic calibration and compensating functions
④ Built-in algorithm and its change functions
⑤ A memory function
⑥ A communication function
⑦ Sensing of complex index based on multiple kinds of variables

These intelligent sensors will offer high precision, high performance, high reliability, long-term stabilization, excellent functions, operation ease, and remote operation in field instrumentation.

In BEMS, the development of high-grade normal operation systems will be expectable together with efficient maintenance, product quality trace control, maintenance control, and preventive maintenance.

2.3.3 Problems to be Solved

The cost performance, control systems including actuators, and total systems including a central monitoring system must be examined to apply intelligent sensors to BEMS as described above. It will also be important for introducing these intelligent sensors into BEMS to examine these problems together with composite sensors, expert systems, and other latest technical problems.

Table 2.2-3 Examples of Various Characteristics of Sensors and Converters [JN 4)]

Sensors				Converters		
Types	Measuring positions	Detection elements	Accuracy	Output	Measuring ranges	Accuracy
Temperature	Indoors	Pt (100Ω at 0°C)	Class A ~ B ±0.15 ~ ±0.3°C	0~100mV • 4~20mA	0 ~ 50°C	±0.3% F.S
	Indoors	Ni (508.4Ω at 0°C)	±0.3~ 0.5°C	0~100mV • 4~20mA	0 ~ 50°C	±0.3% F.S
	Pipeline	CC	±1.0°C	0~100mV • 4~20mA	0 ~ 100°C	±0.3% F.S
	Water tank	Ni (508.4Ω at 0°C)	±0.3 ~ 0.5°C	0~100mV • 4~20mA	0 ~ 100°C	±0.3% F.S
	Duct	Ni (508.4Ω at 0°C)	±0.3 ~ 0.5°C	0~100mV • 4~20mA	0 ~ 100°C	±0.3% F.S
Humidity	Indoors	LiCl	±1 ~ 3%	0 ~ 100mV	30 ~ 90% RH	±2% F.S
	Indoors/outdoors (Dry-bulb/wet-bulb)	Ni (508.4Ω at 0°C)	±0.3 ~ 0.5°C	0 ~ 100mV	20 ~ 100% RH	±0.3% F.S
	Indoors	High polymer		0~100mV • 4~20mA	30 ~ 70% RH	* ±3% RH
Atmospheric pressure	Indoors	Bellows		0~100mV • 4~20mA	940 ~ 1040mb	* ±0.2mb
Solar radiation quantity	Outdoors	Thermocouple		10 ~ 50mV	0 ~ 1.2kW/m²	* ±0.5% F.S
Flow	Pipeline	Turbine meter		Pulse 4 ~ 20mA	0 ~ 25m³/h	* ±0.5% F.S
	Pipeline	Electromagentic		Pulse 4 ~ 20mA	0 ~ 1000m³/h	* ±0.5% F.S
Liquid level	Water tank, Pipeline	Electrostatic		4 ~ 20mA	500 ~ 3000mm	* ±2% F.S
Pressure	Pipeline	Diaphragm		4 ~ 20mA	-1 ~ 700kgf/cm²G	* ±0.5% F.S
	Duct	Diaphragm		4 ~ 20mA	0 ~ 200mmH_2O	* ±0.5% F.S
CO_2	Indoors, Duct	Infrared-ray absorption		4 ~ 20mA	0 ~ 2000ppm	* ±1.5% F.S

* Accuracy including sensors, and converters

CHAPTER 3: Outline of Sensors for BEMS

This chapter sets out, in tabular form, a summary of the main characteristics and features relating to sensors for application to Building Management Systems viz 1) Principle of operation, 2) Significant features and 3) the main areas of their application to the management of buildings and their services.
Whenever the signal between the detector and controller or actuator differs each other signal converter are necessary. This table also include local sensors and measuring instruments, which are not directly connected to BEMS. Chapter 9 covers a case study for selecting sensors for easier understanding about the application.

Table 3.1 Outline of BEMS Sensors

Measuring object	Sensor type Measuring principle	Main Area of Application	Features and Remarks
Temperature	Bimetal A difference of the expansion and contraction due to a temperature of two kinds of metals having a different coefficient of linear expansion	• Room temperature control • Temperature control inside an airconditioning duct. • Temperature indicator	• Robust • Cheap • Not very accurate • Used for electronic and pneumatic temperature controllers. • Main Areas of Application: Simple ON/OFF control of heating/cooling elements/batteries for temperature regulation
	Liquid (gas) expansion A difference of the expansion and contraction of a temperature dependent volume liquid or gas	• Room temperature control • Temperature control inside an airconditioning duct. • Chilled/hot water temperature control	• Large power • Easy handling • Bellows, diaphragm, remote valve, etc. • Used for electronic and pneumatic temperature controllers.
	Resistance thermometer bulb (temperature dependent resistance) An electric resistance change	• Airconditioning heat flow measurement • Storage hot water bath temperature control • Boiler heat flow measurement • Room temperature measurement and control • Temperature measurement and control inside an airconditioning duct. • Thermal source heat exchanger temperature control • Regenerative bath temperature measurement and control • Outdoor temperature measurement	• High accuracy • Telemetering is possible. • A small change with time • Stability • Widely used for measuring and controlling Pt, Cu, Ni, Balco, FeNi, etc.
	Thermistor Temperature dependent resistor	• Room temperature control • Temperature control inside an airconditioning duct. • Chilled/hot water temperature control • Surface temperature measurement and control	• Small size • Cheap • Large temperature coefficient • Semiconductors

Table 3.1 Continued

Measuring object	Sensor type Measuring principle	Examples of uses	Features and Remarks
Temperature	Thermocouple Temperature dependent emf developed from the welding of two different metals (Seeback effect)	• Surface temperature measurement • Temperature measurement inside instrument • Fire detector	• Small size • Cheap • Wide measuring range
	(Crystal) Determines the (temperature dependent) frequency of an oscillator	• Room temperature measurement and control • Temperature measurement and control inside an airconditioning duct. • Chilled/hot water temperature control	• High accuracy • High reproducibility • Digital signal
	(IC) Temperature dependent of base-emitter voltage of a junction transistor	• Built inside units and devices	• Large output • Easy handling • Sensor and transmitter assembled into single device
	Rod tube A difference of the expansion and contraction due to a temperature difference of two kinds of metals having a different coefficient of linear expansion	• Temperature control inside an airconditioning duct • Chilled/hot water temperature control	• Rigid • Long life • Used for pneumatic temperature controllers
	(Temperature fuse) Physical melting point	• Overheat prevention • Smoke preventive/exhaust damper	• Cheap

Table 3.1 Continued

Measuring object	Sensor type Measuring principle	Examples of uses	Features and Remarks
Relative humidity	*Hair* Expansion and contraction due to moisture absorption	• *Room humidity control*	• Direct indication of relative humidity • Simple structure • Good reproducibility • Materials cannot be obtained easily. • Used for electric and pneumatic humidity controllers.
	Nylon film Expansion and contraction due to moisture absorption	• Room humidity control	• Direct indication of relative humidity • Simple structure • Cheap • *Used for electric and pneumatic humidity controllers.*
	Lithium chloride An electric resistance change due to moisture absorption	• Room humidity measurement and control	• High accuracy • Quick response • Affected by exposure to organic solvents • Change over lifetime • Widely used
	High polymer (resistance type) An electric resistance change due to moisture absorption	• Room humidity measurement and control	• Small size • Suitable for a medium humidity area (40 ~ 90% RH) • Not resistible against organic solvents
	High polymer (capacitance type) A capacitance change due to moisture absorption	• Room humidity measurement and control	• Small size • Suitable for a low humidity area (10 ~ 80% RH) • Not resistible against organic solvents • Shows an increasing trend.
	Ceramics An electric resistance change due to moisture absorption	• Room humidity measurement and control • Humidity measurement and con-trol inside an airconditioning duct.	• Small size • Suitable for a high humidity area (40 ~ 99% RH) • Sensors having a regenerative cleaning function show an excellent environmental resistance.

Table 3.1 Continued

Measuring object	Sensor type Measuring principle	Examples of uses	Features and Remarks
Dew point temperature (absolute humidity)	Lithium chloride + Ni Ceramics + Pt Measures the temperature at which the vapor becomes saturated (ie dew point), by utilizing the characteristic of lithium chloride.	• Supply air dew point control • Dew point temperature measurement	• High accuracy • Continuous remote measurement is possible. • Reproducible • The dew point temperature and absolute humidity represent the humidity conditions, although their units are different. • Inter relates with air temperature and RH.
Enthalpy	Ni or Pt + dew point temperature Measures the dry-bulb temperature and the humidity and calculates the dew point temperature and enthalpy of the air.	• Outdoor air intake control	• High accuracy • Continuous remote measurement is possible. • Widely employed
	Wet-bulb temperature (Ni or Pt) Approximates enthalpy from the wet-bulb temperature of the air.	• Outdoor air intake control	• Troublesome handling and maintenance of wet-bulb • Not used widely because of troublesome handling and maintenance of wet-bulb.
Relative humidity	Dry-bulb/wet-bulb temperature (Ni or Pt) Obtains the relative humidity by calculating a difference between the dry-bulb temperature and the wet-bulb temperature.	• Room humidity measurement and control • Humidity measurement and control inside an airconditioning duct	• Long life • Troublesome handling and maintenance • Excellent environmental resistance • Absolute measurement
Pressure	Bellows Bellows expansion/contraction measurement (An axial displacement is detected by a differential transformer or the like.)	• Pressure control of liquid and gas inside piping and tank • VAV airflow control • Filter operation control	• Relatively high pressure sensitivity • Small pressure resistance • Mainly used in a special atmosphere due to troublesome handling and maintenance of wet-bulb.
	Diaphragm Measures the pressure and displacement of a diaphragm by utilizing a capacitance change between electrodes mounted nearby	• Measurement of the liquid flow, liquid level, and pressure inside a tank	• Small size • Lightweight • High accuracy • Used for electric controllers. • Electrodes serve as secondary conversion elements.

Table 3.1 Continued

Measuring object	Sensor type Measuring principle	Examples of uses	Features and Remarks
Pressure	Diaphragm A change of the electric resistance value of a strain gauge due to a pressure change	• Measurement and control of pressure inside piping and tank • Detection of differential pressure and flow of chilled/hot water, steam, etc.	• Long-term stabilization • Long life • Excellent reproducibility • Silicon and other semiconductors are used as a strain gauge of secondary conversion element.
	Diaphragm Detects the movement of the core directly connected to a diaphragm by an inductance change of two coils.	• Airflow and static pressure control inside duct and room	• Resistible against shocks and vibrations
	Bourdon tube Displacement due to an internal/external pressure difference of the Burdon tube	• Indication and control of the pressure inside piping and tank	• Easy
	Liquid column manometer (water and mercury) Static liquid pressure measurement	• Indication of the static water pressure inside tank	• Cheap • Rigid • Pressure measurement over a wide range • A ferrite core is used as a secondary conversion element
Level	Conductivity Detects the electric conduction between two electrodes by a relay.	• Water supply and drain operation control • Water level monitoring	• Electrodes must be corrosion-proof. • Accuracy is not so high. • Measuring objects are conductive liquids.
	Capacitance type Obtains a liquid level change from a capacitance change between two conductors.	• Water supply/drain tank liquid level control	• Electrodes must be corrosion-proof. • Be careful with a temperature change of objective liquid and the deposit of dirt to electrodes
	Pressure type Liquid level measurement by a diaphragm type pressure gauge, etc.	• Level monitoring and control of water supply/sewerage, oil, and almost all other liquids	• Relatively high accuracy • Not affected by floating substances.

Table 3.1 Continued

Measuring object	Sensor type Measuring principle	Examples of uses	Features and Remarks
Level	Float type Float liquid level measurement (Detects the float position electrically or pneumatically.)	• Applicable to almost all liquids.	• Simple structure • Direct indication
	Radiation type Measures the intensity of the detected radioactivity by utilizing a radiation sources.	• Applicable to liquids, slurry, pulverulent bodies, and adhesive substances.	• Applicable to tanks of less than 15m in diameter. • Not always applicable, if the radiation operation standard is strictly specified.
	Ultrasonic type Measures reflected signals by transmitting ultrasonic waves to the liquid surface. (Detects the turnaround time of ultrasonic waves to and from the level surface.)	• Applicable to liquids, slurry, pulverulent bodies, and adhesive substances.	• Measurement can be done without touching any storage substance. • Be careful since the propagation time of ultrasonic waves depends upon the temperature of substances.
Flow	Throttling type Bernoulli's theorem (Venturi, nozzle, orifice)	• Water supply/drainage flow measurement	• Low cost • Combination with a differential pressure gauge • Non-linear out put in the format a differential pressure
	Area type The flow is proportional to the sectional area of the passage	• Supply water and chilled/hot water (for experimental equipment in particular) measurement	• No straight pipe portion is required for installation. • Easy handling • Vertical mounting only
	Positive displacement type The flow is proportional to the unit volume.	• Fuel oil flow measurement • Supply water flow measurement	• Accurate in principle • Absolute measurement (ie requires no calibration) • Liquid measurement
	Turbine type The flow is proportional to the turbine revolutions (A type of the positive displacement type.)	• Supply water flow measurement • Gas flow measurement	• Suitable for liquids having small kinematic viscosity, since this type rotates the impeller. • Flow measurement of gas, water, gasoline, and kerosene • Not suitable for heavy oils or the like having large kinematic viscosity

Table 3.1 Continued

Measuring object	Sensor type Measuring principle	Examples of uses	Features and Remarks
Flow rate	Vortex type The flow rate is proportional to the Karman vortex frequency.	• Chilled/hot water flow measurement & steam flow measurement • Airflow measurement	• Wide rangeability • Cheaper than electromagnetic type • Gas, steam, and liquid measurement • VAV airflow control
	Electromagnetic type Farady's electromagnetic induction law	• Chilled/hot water piping (for heat source machine operation sequence control)	• No pressure loss exists in the passage. • High precision expensive • Easy maintenance • Applicable to conductive liquid measurement.
	Paddle type	• Chilled/hot water flow check	• Cheap • Prevention of chilled water from being frozen in refrigerators and other machines
	Pitot tube Bernoulli's theorem Output proportional to velocity head at a point	• Duct airflow and wind velocity distribution measurement	• Small size • Handy • Water flow velocity and wind velocity measurement • Applicable only to low velocity flows where compressibility and viscous dissipation effects are small.
	Ultrasonic type Measures the propagation time of ultrasonic waves in flowing water.	• Existing chilled/hot water piping flow measurement	• No pressure loss exists in the passage. • Measurement can be done without any need of pro-cessing the existing piping. • Appplicable to highly viscid and/or non-conductive liquids, too.
Velocity	Vortex flow type	• Chilled/hot water flow velocity measurement	• Wide rangeability • Gas, steam, and liquid measurement
	Hot-wire type Based on convection loss from a resistive element	• Airflow velocity measurement in an airconditioned room	• Applicable to gas flow velocity measurement. • Sorted into the constant current type, constant temperature type, resistance wire type, and semiconductor type. Best with element at constant temperature. • Pure metal or thermistor elements normally in a bridge network.

Table 3.1 Continued

Measuring object	Sensor type Measuring principle	Examples of uses	Features and Remarks
Velocity	Ultrasonic type Measures the propagation time of ultrasonic waves in flowing water.	• Existing chilled/hot water piping flow measurement	• No pressure loss exists in the passage. • Measurement can be done without any need of processing the existing piping. • Applicable to highly viscid and/or non-conductive liquids, too.
	Meteorological anemometer Generating voltage by wind velocity	• Meteorological data	• For wind direction/wind velocity measurement • Propeller type & cup type (ultrasonic type)
Gas	Infrared CO_2 sensor Infrared-ray absorption of CO_2 gas	• Parking area ventilation gas concentration monitoring • Boiler combustion monitoring	• Detector, sampler, light source, and indicator are combined as an assembly.
	CO Infrared ray absorption method	• CO in air • Enclosed car parks	• Detector, sampler, light source, and indicator are combined as an assembly. • Interfering gases are eliminated by a filter.
	O_2 Solid electrolytic ceramics, electric potential difference	• Combustion control	• Detector, sampler, light source, and indicator are combined as an assembly.
	NO_x Saltzman method, Color development degree of sample liquid	• NO and NO_2 in air	• Detector, sampler, light source, and indicator are combined as an assembly. • CO_2 correction is required.
	SO_x Solution conductivity method	• SO_2 in air	• High sensitivity • Be careful with interfering com-ponents being absorbed by solution.
	Gas leak Semiconductor gas sensor An electric resistance change due to gas absorption	• Gas leak alarm	• Suitable for low concentration in particular. Small size • Combustible gases • CFC (Chlorofluorocarbon) gases • Haloid gases

Table 3.1 Continued

Measuring object	Sensor type Measuring principle	Examples of uses	Features and Remarks
Smoke	Ionization type	• Hazardous substances storage facilities	• High sensitivity to fine particles • Effective for flaming and a fire No suitable at a place where a wind blows strongly.
	Photoelectric type	• Telephone machine room, mechanical electrical room control center	• Effective for a smoldering fire • Effective for a place where a smoke stays or a wind blows strongly.
pH	Glass electrode method Detects a pH difference on both sides of a glass film by a potential difference.	• Cooling water, chilled/hot water	• Good reproducibility
Hardness	EDTA method Titration with an indicator	• Boiler water, cooling water	• EDTA: Ethylene diamine tetra acetic acid
BOD	BOD method Oxygen quantity consumed by aerobic microorganisms in water	• Drainage	• Measuring period: 5 days • Dilution, pH adjustment, etc. are necessary. • Specified by JIS K0101 • Indicated as BOD_5.
	BOD sensor Microorganism film of trichosporon cutaneum	• Drainage	• Measuring time: 10 minutes • Linear to BOD_5 at BOD 3 ~ 60
Conductivity	Conductivity meter Measures a flowing current in a solution by applying a constant voltage across electrodes.	• Cooling water, drainage	• A measured value is obtained immediately. • Represented by a value at 25°C
Chromaticity	Platinum cobalt method Comparison of the transparency between the standard chromaticity liquid and tested water	• Drainage	• Visual inspection

Table 3.1 Continued

Measuring object	Sensor type Measuring principle	Examples of uses	Features and Remarks
Turbidity	Photoelectric turbidimeter Measures the scattering and attenuation quantity of 660μm light in turbid water.	• Drainage	• Standard turbidimeter is required. • The cell thickness is changed according to the turbidity.
Dust particles	Low flow weight method Obtains the gravimetric concentration by measuring an increase of the weight after filtering the air by the specified quantity through a filter paper.	• Indoor dust particle concentration measurement	• Less than 10μm • A long measuring time • Many attached units must be operated variously. • None of automatic, remote, and/for continuous measurement is possible. • Specified by the building management law. * (Japan)
	Digital dust meter Obtains the relative concentration from a counted current value after converting the light scattered by dust particles into a current.	• Indoor and outdoor dust particle concentration measurement	• Less than 10μm • Quick response • None of automatic, remote, and continuous measurement is possible.
	Filter paper dust meter Obtains the relative concentration of dust particles from the contamination degree of a filter paper after filtering air through the filter paper.	• Indoor dust particle concentration measurement	• Less than 10μm • Cigarette smoke ratio is also obtainable. • None of automatic, remote, and con-tinuous measurement is possible. • Light absorption system, colorimetric method
	Cascade impactor Counts the number of deposited dust particles and their sizes through a microscope by colliding air onto a glass plate.	• Indoor and outdoor dust particle concentration measurement	• 0.5 ~ 100μm • Particle sizes can be measured stepwise. • None of automatic, remote, and continuous measurement is possible.

* LAW REGARDING THE SECURITY OF SANITARY ENVIRONMENTS IN BUILDINGS

Table 3.1 Continued

Measuring object	Sensor type	Examples of uses	Features and Remarks
Dust particles	Laser particle counter Receives the scattered light by dust particles in the sample air by a photo diode, and converts it into electric pulses. Measures the particle sizes from the pulse height and the number of particles from the number of pulses.	• Full-time monitoring and measurement of clean rooms	• More than 0.5μm • Automatic continuous measurement is possible. • Data can be processed and displayed by a system where the laser particle counter is combined with a processor and a computer.
	Condensed nuclei measuring instrument Detects and measures dust particles optically by condensing alcohol vapor into particles in a sample air to increase the particle diameter.	• Full-time monitoring and measurement of clean rooms	• More than 0.05μm • Automatic continuous measurement is possible. • Data can be processed and displayed by a system where this measuring instrument is combined with a processor and a computer.
Ligh Solar irradiation	Photoelectric tube Generation of photoelectrons (current) in response to incident light	• Monitoring of the entrance or exit of persons	• Quick response • Sensible to weak light.
	Photoconductive devices Photoelectromotive force effect	• Elevator entrance control • Lighting control	• Quick response • Compact and lightweight
	Piezoelectric effect type optical sensor Pressure - emf relation	• Monitoring of the entrance and exit of persons	• Quick response • Wide range detection • Security sensor
	CCD sensor	• Safety and security monitoring	• Compact and lightweight • For image recognition
	Thermopile Thermoelectromotive force due to series of thermocouples	• Solar radiation measurement	• Large output
	Illuminancemeter	• Indoor/outdoor illumination measurement	• Handy

Table 3.1 Continued

Measuring object	Sensor type			Examples of uses	Features and Remarks
Electricity	Ammeter	Moving coil type:	Utilizes the torque generated between the magnetic field in a permanent magnet gap and a current flowing to the moving coil.	DC circuit meaurement	
		Moving-iron type:	Utilizes the torque generated when a moving iron in a fixed coil is attracted or repelled.	AC circuit measurement	
		Rectification type:	Combines a rectifier with a moving coil type meter.	AC circuit measurement	
		Electrothermal type:	Heats a thermocouple by flowing a measuring current to a resistance wire called thermal wire, and measures a current from the thermoelectromotive force generated at this time.	High-frequency current measurement	
	Voltmeter	Moving coil type:	Utilizes the electromagnetic force generated between the current and the magnetic field caused by the voltage when applying a measuring voltage to a high resistor connected in series with a moving coil after mounting the moving coil into the magnetic field of a fixed permanent magnet.	DC voltage measurement	Accurate and highly sensitive Linear scale
		Moving-iron type:	Utilizes the electromagnetic force generated in a soft iron in the magnetic field produced by flowing a current to a fixed coil at a measuring voltage.	AC voltage measurement	Rigid and low-priced
		Rectification type:	Measures a voltage by combining a moving coil type meter after rectifying AC.	AC voltage measurement	Accurate and highly sensitive
		Induction type:	Utilizes the electromagnetic induction torque acting to a circular copper piece which is put in the rotary magnetic field generated by flowing a current at a frequency measuring voltage.	Recorder Meters on switchboard	Poor accuracy
	Wattmeter	Electrodynamometer type wattmeter:	Utilizes the torque generator by applying a voltage to a moving coil via a high resistance by flowing a current to a fixed coil.		Used most frequently
		Single-phase wattmeter, Three-phase wattmeter, Induction type wattmeter:	Utilizes the force generated between the current and the magnetic flux by producing an eddy current on a moving metallic plate by means of electromagnetic induction.	AC watthourmeter	
	Power factor meter	Either electrodynamometer or moving-iron type power factor meter is often used.			
Others	Wind direction	Angle detection by a Selsyn motor		• Outdoor wind direction	• Combined with anemometer
	Switches			• Various safety and security monitoring	
	Water leak	Electrical resistance change		• Monitoring of water leak in wiring spaces of com-puter room and others • Monitoring of water leak in a water piping ass'y	• Easy handling • Cheap
	Radon	Scintillation counter Film sensitive to Alpha decay		• Monitoring and measurement of radon gas concentration	• Suitable for continuous measurement • Accumulative and convenient type • Measures actual Alpha decay from radon or dadon progeny

CHAPTER 4: Sensor Application to HVAC

General

"Complete" air conditioning implies the separate regulation of temperature, humidity, air flowrate and air quality/purity (propertional content of CO_2, odour, dust particles, and harmful bacteria etc). The desired value of each of the control parameters will be set according to the purposes intended for the conditioned sapce. For most spaces a subset only of the variables listed will be subjects for control.

This chapter deals with sensors and measurements related to air conditioning primarily in the context of offices and spaces for general use. Some treatment of dust and CO_2 monitoring is however set out in Section 4.6 and 4.7 respectively. Reference to the subject of air quality is to be found in Appendix C.

Air conditioning may be classified according to ---

- Airconditioning
  - Comfortable airconditioning for people
    - Commercial air conditioning: Offices, hospitals (excluding sick wards), hotels (excluding guest rooms), shops, schools, etc.
    - Residential air-conditioning: Residences, flats hospitals, hotels, etc.
  - Industrial airconditioning for products — Factories (manufacturing processes, etc.), laboratories, warehouses, etc.

Fig. 4.1 Classification of Airconditioning

Air-conditioning systems should provide for control of space temperature, of fresh air and of humidity as well, which is sometimes called as full air-conditioning. Desired values and methods used to achieve them are chosen with the following in mind: health, safety and comfort of the occupants, energy consumption and ease of control etc.
Fig. 4.2 shows the most basic airconditioning equipment configuration.

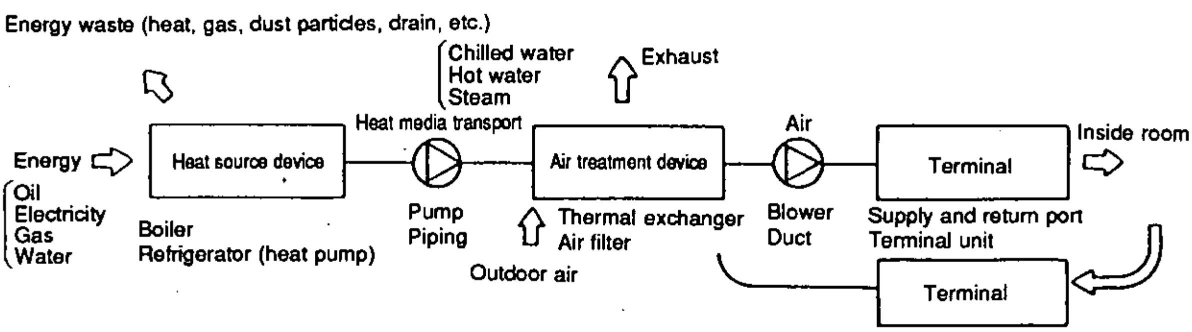


Fig. 4.2 Basic Airconditioning Equipment Configuration [JN 2)]

Typically there is no unique system configuration which is required to meet a specified air conditioning task. The sensor for each conditioned variable is chosen bearing in mind its compatibility with other system requirements, and factors such as a ease of maintenance, reliability, size, cost etc; see also Table 4.1.

The control action can be sorted from various points of view according to the functional relation of manipulated variables to control action signals. A necessary and sufficient system must be selected according to the objective control and controlled systems.
Table 4.2 shows the [Selection of Control Action] and Table 4.3 shows the [Application of Automatic Controllers]. For selecting sensors, refer to Fig. 4.3.

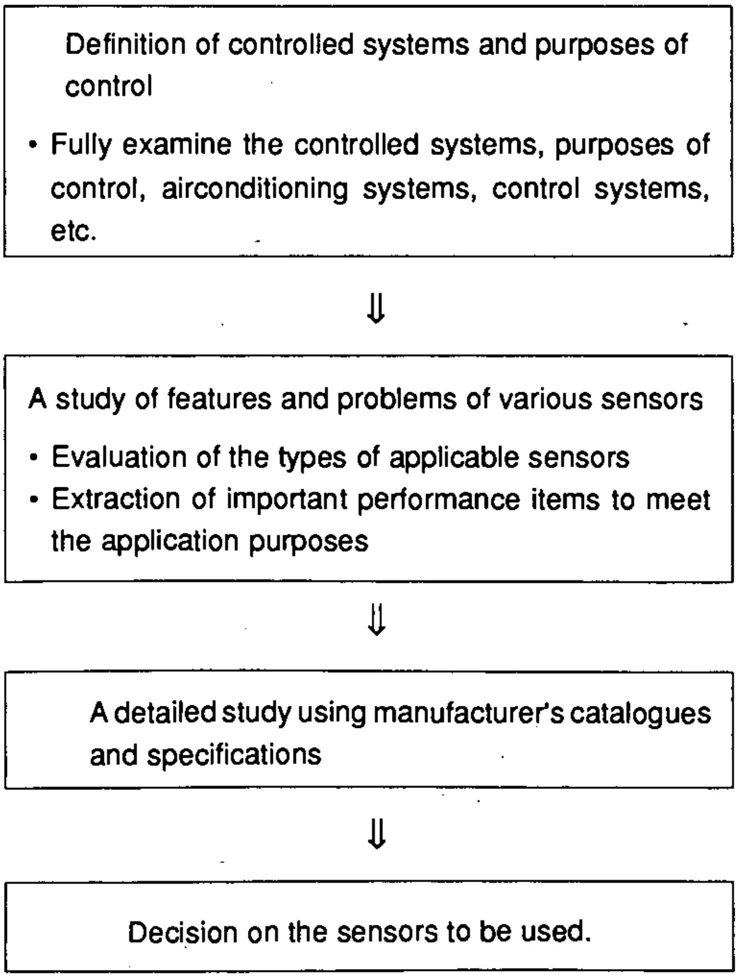


Fig. 4.3 Sensor Selection Procedure

Table 4-1 Classification and Features of Airconditioning Systems

Classification: Heat source	Classification: Thermal medium	No.	Typical airconditioning system	(a) Equipment cost	(b) Fan and pump power cost	(c) Energy mixing loss	(d) Machinery room space	(e) Duct, piping space	(f) Individual control	(g) Overtime operation	(h) Outdoor air cooling	(i) Design and execution technology	(j) Perimeter zone	(k) Interior zone	(l) Office building grade
Center system	Air system	(1)	Constant airflow single duct system	Low~Medium	Medium	Small~Medium	Medium~Large	Medium~Large	—	Possible	Possible	General	○	◎	—
		(2)	Variable airflow single duct system	Medium	Low~Medium	Small	Medium	Large	Possible	Possible	Possible	High grade	◎	◎	Medium~High
		(3)	(Constant airflow) double duct system	Medium~High	High	Large	Medium~Large	Large	Possible	Possible	Possible	High grade	○	◎	(High)
	Water / air system	(4)	Single duct reheating system	Medium~High	Medium	Medium	Large	Large	Possible	Possible	Possible	High grade	○	○	(High)
		(5)	Each floor zone unit system (Having a central system outdoor air treatment function)	Medium	Low	Small	Medium~Large	Large	—	Possible	—	General	○	○	Medium
		(6)	FC unit system with a duct (two-pipe system)	Low~Medium	Low	Medium	Small	Small	(Possible)	—	—	General	◎	○	Medium
		(7)	FC unit system with a duct (four-pipe system)	Medium~High	Low	Small	Small	Small	Possible	—	—	High grade	◎	○	High
		(8)	Indication unit system (two-pipe system)	Medium	Low-Medium	Medium	Medium	Small	Possible	—	—	General	○	○	Medium
		(9)	Indication unit system (three-pipe system)	Medium~High	Low-Medium	Small	Medium	Small	Possible	—	—	High grade	◎	○	High
		(10)	Radiation cooling/heating system with a duct (three-pipe system)	High	Low	Small	Medium	Medium	Possible	Possible	—	High grade	○	○	(High)
Individual system	Refrigerant system	(11)	Package unit system (small unit)	Low~Medium	Low	Small	Small	Small	Possible	Possible	—	Easy	○	○	Medium
		(12)	Package unit system with a duct	Low~Medium	Low	Small	Small	Medium	—	Possible	—	Eady	○	○	—

(Kiuchi, 1977)

(Notes)
1) A constant airflow single duct system which can be operated independently in each floor is frequently selected. Identify this system should be discriminated from the each floor zone unit system.
2) "High", "Medium", and "Low" in the cost of equipment are approximated as a reference.
3) "Individual control is possible" means that an automatic unit is mounted for individual control.
4) In the FC unit system with a duct, an FC unit is mounted in the perimeter zone and a duct is used in the interior zone. The possible combination of interior zone systems were abbreviated.
5) The "Overtime operation" means a run during the overtime duty service or nighttime other than the regular time from 08:30 hours to 17:30 hours in ordinary cases.
6) Mark ◎ is applicable more suitably as compared with mark ○.
7) 'Medium" and "High" indicate that corresponding systems are applicable to medium-grade and high-grade buildings, respectively.

Table 4.2 Selection of Control Action

Control action	Characteristics of controlled systems		Outside disturbance [3]		Application
	Time constant [1]	Dead time [2]	Magnitude	Speed	
2-position	Large	Short	Weak	Low	• Small scale units • Limit control • Terminal unit
Single speed (Floating)	Small	Short	Optional	Low	• Damper control (pressure) • Mixing valve control (water temperature)
Proportional	Large	Short	Weak	Low	• Small/medium-scale room temperature control
PI	Optional	Medium	Large	Low	• Large-scale room temperature control • Heat source unit control
PID	Optional	Medium	Strong	Optional	• High-precision control, such as constant temperature, etc. • Large-capacity heat source units

[Notes] 1) This quantity indicates the response speed. As the time constant becomes smaller, the response faster. The time constant of a temperature change is large when the thermal capacity is large, for example.
2) The time lag from a change of an input signal to the start of an output signal change.
3) The external action to disturb the control system status, such as outside air temperature, internal heat generation inside the room change, etc.

Table 4.3 Application of Automatic Controllers

Type	Accuracy	Detection delay	Operating speed	Price	Application
Electric type	Medium	Medium	Low [1]	Medium	Small/medium-scale units, terminal units
Electronic type	High	Small	Low [1]	High	Medium/large-scale units
Pneumatic type	Medium	Medium	High	Medium	Large-scale units having many actuators
Electropneumatic type	High	Small	High	High	Units requiring high accuracy
Self-actuated type	Low	Large [2]	Medium	Low	Radiator valve, float valve, etc.

[Notes] 1) The operating speed is low in case of a motor-operated valve, but it is high in case of a solenoid valve.
2) This is small with a float valve, etc.

4.1 Room Temperature Measurement

It is important to select a suitable airconditioning system and a control system according to use and purposes, and then, select a suitable sensor conforming to these systems.
In case of air-conditioning for people, for example, precise control accuracy is often treated as unimportant; where equipment and/or industrial processes are the main concern closer tolerances are usually specified.
Table 4.4 shows [Selection Guide for Room Temperature Sensors].

4.1.1 Feedback Control

Feedback control is mainly used for room temperature control. (cf. Fig. 2.1)
Out of various room temperature measuring methods, the room temperature and return air temperature measuring methods are generally used.

(1) Room temperature measurement

a) Related software

1) Room temperature control
2) Return air temperature control
3) Radiation temperature control

b) Control method

1) Feedback control

A change of room temperature due to indoor or outdoor nterferences is measured and compared with a set value to correct the value so as to keep the room temperature constant at the set value.
Control of supply air overcomes the effect of fluctuations in internal temperature.

c) Required performance of sensors

Sensors must satisfy the following performance.

1) High accuracy .... Note - 1), Note -2)
2) Good response
3) Good reproducibility
4) Small size
5) Aesthetic design (indoor mount type, in particular)

Sensors for air-temperature should be mounted at around 1.5m above floor-level and positioned on a wall out of direct sunlight and well away from any local influences such as heat sources, openable doors etc. The sensor housing should be designed so as to give a reading predominantly influenced by the temperature of the air and not that of the supporting structure.

Table 4.4 Selection Guide of Room Temperaure Sensors

	Buildings	Room space	Control type: Electric type	Control type: Electronic type ANA	Control type: Electronic type DIG	Control action: ON/OFF	Control action: P	Control action: PI	Control action: PID	Control accuracy Note 1) °C ±1.0	±1.5	±2.0	Types of sensors: Bimetal	Liquid (gas) expansion	Resistance thermometer bulb (Pt, Ni, Balco, etc.)	Thermistor	Quartz	Thermocouple
Comfort airconditioning	Residences	Living room	○			○					○	—	○	○				
		Bed room	○			○					○	—	○	○				
	Office	Popular office room	○			○	○				○	—	○	○				
		Intelligent office room		○	○		○	○		○	—				○	○	○	
		Computer room		○	○		○	○		○	—				○	○	○	
	Hotel	Popular guest room	○			○	○				○	—	○	○				
		Special guest room		○	○		○	○		○	—				○	○	○	
		Restaurant	○			○	○				○	—	○	○				
		Lobby	○			○	○				○	—	○	○				
	Department store	Sales counter	○			○	○				○	—	○	○				
	School	Classroom	○			○	○				○	—	○	○				
Industrial airconditioning	Warehouse	General	○			○	○			○	—		○	○				
		Special		○	○		○	○		○—					○	○	○	
	Factory	Semiconductor		○	○			○	○	○					○	○	○	
		Biotechnology		○	○			○	○	○					○	○	○	
		Clean room		○	○			○	○	○					○	○	○	
	Laboratory	Constant temperature/ constant humidity room		○	○				○	○					○	○	○	
	Art gallery	Showroom		○	○		○	○		○—					○	○	○	
	Hospital	General sick ward	○			○	○				○	—	○	○				
		ICU room		○	○			○	○	○					○	○	○	
Others	Measurement									○					○	○	○	○

Note 1) These figures show practical values including characteristics of building structures and facilities. If a control accuracy is demanded higher than specified above, systematical examination on the bulding structures and air conditioning system should be follow.

○— : ○ Accuracy of each sensor unit; — Accuracy of the entire system

Note -1) Since residential comfort airconditioning generally requires neither high accuracy nor fast response, either on/off action or proportional action is often employed as its control action. Accordingly, an electric thermostat is often used.

If high accuracy and response are demanded to suppress room temperature fluctuations in airconditioning for commercial use, a highly sensitive electronic sensor is employed in the same way as in industrial airconditioning.

Note -2) Since the industrial airconditioning and/or thermo/hygrostatic room control require high accuracy and high response, the PID action is often used as the control action, and electronic sensors are selected.

d) Applicable sensors

1) Sensors employed for residential airconditioning are typically
   - Bimetal, shield bellows, dual diaphragm, etc.
   - Remote bulb, rod tube, etc.
   - Wireless sensor

2) Sensors used for commercial airconditioning and industrial comfort airconditioning
   - Resistance thermometer bulb (Pt, Ni, Balco, etc.)
   - Thermistor
   - Quartz
   - Thermocouple

Select an indoor type or insertion type according to the mounting positions.
(This also applies to the following description, correspondingly.)

e) Supplementary items

1) Select the following mounting positions for measuring the room temperature correctly.

   (a) A position where a typical or average room temperature can be measured
   (b) A position which is not exposed to the direct sunlight
   (c) A position not subjected to irradiated heat
   (d) A position which is not subjected to any external thermal effect from the rear wall face, etc.
   (e) A position which is not directly exposed to the air stream from the supply grille
   (f) A place distant from the entrance
   (g) A place where air is not stagnant

2) If high sensitivity is demanded for the still-air temperature casing design must ensure that the influence of wall temperature is restricted.

3) Be careful with the insertion length to measure an average temperature when mounting sensors in an airconditioning duct.

4.1.2 Optimal Control

This paragraph describes the requirements of the sensors for optimal control; in the context of temperature control the term optimization might mean operation so as to minimize energy consumption whilst maintaining specified conditions of comfort. It is to be expected that such controls will form part of any future higher-grade system.

(1) Trend measurement of room air temperature

a) Related software

1) Preheating load prediction (for optimal control of a preheating run time)
2) Daily thermal load prediction (for optimal control of thermal storage run)

b) Control method

The load prediction is executed by keeping track of fluctuating conditions of temperature hourly/daily.

c) Required performance of sensors

It is necessary for sensors to keep track of the relative movement, and high accuracy as an absolute value is not demanded. Negligible temperature fluctuations may be smoothed, but sensors must be stable. If a sensor concurrently serves as a control sensor for room temperature, it should have the performance according to the accuracy being demanded by rooms. cf. 4.1.1

d) Applicable sensors

- Resistance thermometer bulbs (Pt, Ni)
- Thermistors
- Thermocouples

e) Supplementary items

1) Mount the sensor at a typical position in the object space. It is recommended to mount a sensor at a place being free from any influence of the cold draft at the window, if a perimeter space is to be observed, for example.
Mount the sensor sufficiently away from the perimeter space, if an interior space is measured.
2) Measure the temperature at multiple points wherever possible and weight measurements by volume before combination if a single representative value is required.
3) Measure the structure temperature and solar radiation quantity concurrently according to the control software. (Refer to respective paragraphs.)

(2) Measurement of effective temperature

a) Related software

1) Room environmental optimal control according to the effective temperature
2) Outside air cooling optimal control (Under the constrains of relative humidity)
Due to the high grade of control, PI action may be necessary and also, effective temperature control finely affects the comfort in the vicinity of the boundary of the restricted comfort zone, therefore comparatively high accuracy is required.

b) Control method

Obtain the effective temperature (operating temperature OT, new effective temperature ET*, etc.) by measurement or calculation, and determine the set temperature/humidity to be actuatly controlled so as to minimize the energy consumption.

c) Required performance of sensors

Comparatively high accuracy is required, since PI control action is necessary due to the control mode, and also, the effective temperature finely affects the comfort conditions in the vicinity of the boundary of the restriction conditions.

d) Applicable sensors

1) For obtaining the mean radiant temperature (MRT) and operating temperature (OT);

Strictly, the MRT and OT are calculated using the globe temperature, dry-bulb temperature and air velocity. The air velocity may be negligible. Aensors have recently been developed to directly measure the operating temperature.

- Resistance thermometer bulbs (Pt)
- Thermistors
- A globe resistance thermometer bulb where a resistance thermometer bulb (Pt) and a thermistor are sealed
- An operating temperature resistance thermometer bulb where a resistance thermometer bulb (Pt) and a thermistor are sealed

2) For obtaining new effective temperature (ET*);

Strictly, new effective temperature is calculated from the operating temperature, dry-bulb temperature, and humidity (either of the relative humidity, absolute humidity, dew-point temperature, or wet-bulb temperature). It may be practical to use the dry-bulb temperature instead of the operating temperature.

Concept and definition of ET* is to be referred to ASHRAE Guide and Data Book Fundamental Volume.

Operating temperature	:	See the above item.
Dry-bulb temperature	:	• Resistance thermometer bulbs (Pt)
		• Thermistors
		• Thermocouples
Relative humidity	:	• Lithium chloride
		• High polymer
		• Ceramics

3) For obtaining the Predicted Mean Vote (PMV)

The PMV is calculated by the dry-bulb temperature, air velocity, mean radiant temperature, water vapour pressure, the clothing, and activity level of the room occupants. The comfort meter calculates/displays the PMV when inputting the above values. A composite sensor is used for measuring the dry-bulb temperature, air velocity, and mean radiant temperature.

e) Supplementary items

1) Many humidity sensors need recalibration once every 3 months or earlier, and also, the specified accuracy should be securely guaranteed even in the case of the maintenance interval of longer than 3 months. (cf. 4.5.1)
2) The operating temperature can be replaced with the dry-bulb temperature on condition that the radiation is not excessive. Accordingly, some form of compensation is needed at a place having a large window, or in the perimeter zone, in particular.

4.1.3 Monitoring, Reporting, and Analysis

(1) Monitoring

a) Related software

1) Equipment conditions monitoring
2) Various alarms monitoring
3) Measurement of analogue value
4) High-limit/low-limit monitoring of analogue value
5) Other monitoring

b) Required performance of sensors

The items related to the temperature or humidity out of the above related software are the measurement and high/low-limit monitoring of analogue values. High accuracy electronic sensors are frequently used.
The following functions are necessary, in particular.

1) High accuracy
2) Quick response
3) A reduced long term drift

If a computer is used, analog values are converted into digital values. However, it is recommendable for fully utilizing the computer to use digital output intellegent sensors.

c) Applicable sensors

- Resistance thermometer bulbs (Pt, Ni)
- Thermistors
- Quartz

d) Supplementary items

cf. 4.1.1, (1), e).
Digital sensors should show excellent noise resistance.

(2) Reporting

a) Related software

1) Alarm message
2) Operation message
3) Status change message
4) System message (System status, control information, etc.)
5) List recording (logging)
6) Trend log
7) Maintenance monitoring
8) Hard copy
9) Floppy disk data collection
10) Daily report/monthly report preparation
11) Alarm history display and printing
12) Others

For the [Required Performance of Sensors], [Applicable Sensors], and [Supplementary Items], refer to those in 4.1.3.

(3) Analysis

Analyze the system characteristics for optimization through the load calculation, energy simulation, etc. by off-line analysis of obtained data.

For the [Required Performance of Sensors], [Applicable Sensors], and [Supplementary Items], refer to those in 4.1.3.

4.2 Outdoor Air Temperature Measurement

4.2.1 Outdoor Air Temperature Compensation

The outdoor air compensation is done to change a set value of room temperature and/or supply air/water temperature according to a change of the outdoor air temperature, and it is also called schedule control.

a) Related software
  1) Summer compensation
  2) Winter compensation

b) Control method
  1) Schedule control

Summer compensation: The difference between the outdoor air temperature and the room temperature is depressed for the purpose of eliminating a cold shock which may cause a disease of the occupants and also reducing the cooling load (energy-saving).

Winter compensation: The room temperature is controlled to an optimum value according to the outdoor air temperature for the purpose of eliminating the discomfort caused by the radiation to outer walls and window glass faces.

Fig. 4.3 shows [Outdoor Air Temperature Compensation Schedule], Fig. 4.4 shows [Continuous Control], and Fig. 4.5 shows [An Instrumentation Example], respectively.

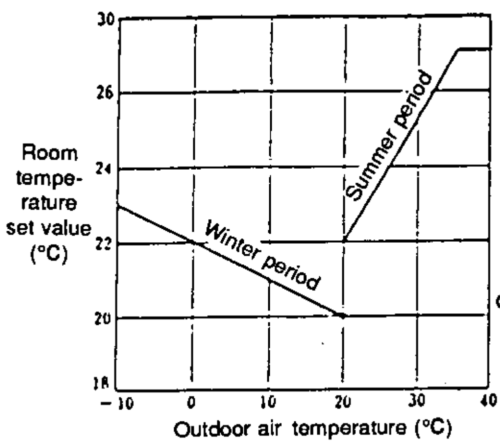
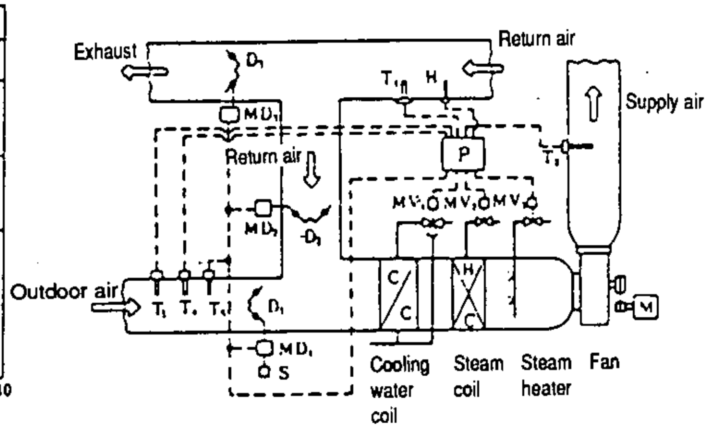
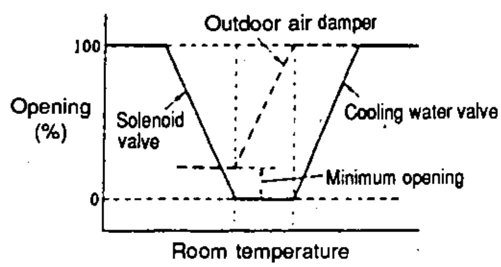


Fig. 4.3 Outdoor Air Temperature Compensation Schedule JN 32)



T_1 : Resistance thermometer bulb (return air or indoor)
T_2 : Resistance thermometer bulb (supply air)
T_3 : Resistance thermometer bulb (outdoor air)
T_4 : Thermostat (summer/winter selection)
T_5 : Thermostat (For fixing outdoor air damper)
H : Humidity detector
P : Temperature/humidity controller
D_1, D_2, D_3 : Damper
MD_1, MD_2, MD_3 : Damper motor
MV_1, MV_2, MV_3 : Motor-operated valve
S : Minimum opening adjusting potentiometer



Set the damper to the minimum opening in summer.

Fig. 4.4 Continuous Control JN 32)

Fig. 4.5 An Instrumentation Example JN 32)

c) Required performance of sensors

Electronic sensors are frequently used. The accuracy and response of these sensors should be the same as the corresponding values for their internal counterpart. Since the sensors for outdoor air temperature are sometimes subject to corrosive atmosphere and other pollutions, they should be packaged more securely as compared with other sensors and should have excellent environmental resistance.

d) Applicable sensors

- Resistance thermometer bulbs (Pt, Ni, Balco)
- Thermistors
- Quartz

e) Supplementary items

1) When the sensor is mounted in an outdoor air intake duct:

(i) Mount the sensor at the position near to the outdoor air intake.

(ii) The insertion type temperature sensor is generally used. If a protective tube is not used, the sensor must be prevented from being directly exposed to rain, water, etc.

(iii) When a protective tube is used, condensation may cause poor insulation or disconnection of sensors if the temperature drops. Accordingly, the sensor terminal connection must be fully sealed. In addition, the lead wire end must be sealed to prevent the penetration of water as shown in Fig. 4.6.

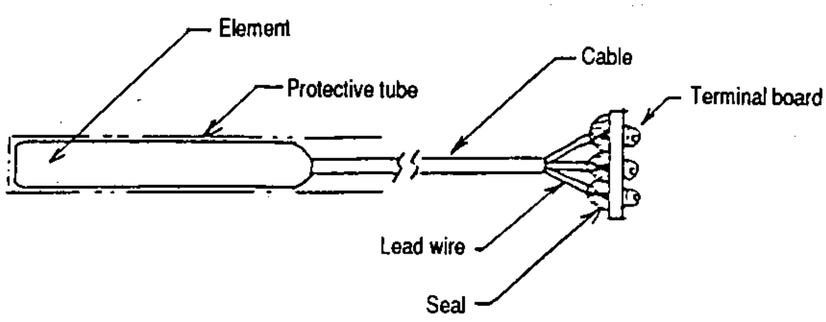


Fig. 4.6 Example of a Sealed Sensor Terminal Ass'y

(iv) Use of a protective tube results in a slower response to change. It is, therefore, recommended to fill the protective tube interior with conductive grease.

2) When the sensor is mounted outdoors (inside an instrument screen, etc.);

Similar attention as described in 1) is necessary. The sensor should be kept free of being exposed directly to rain water and direct sunlight, and also, it must be protected from being corrupted by exhaust gas, etc. Especial care should be taken with sensors having built-in electronic circuits.

4.2.2 Limiter

(1) Limit control according to the outdoor air temperature

a) Related software

1) Freezing prevention control

2) Summer/winter selection control

b) Control method

1) Outdoor air intake stop

Under the control of a sensor in the fresh air supply duct both the fresh-air and the exhaust-air dampers are closed and the recirculation damper fully open to prevent the hot water coils and steam coils from being damaged by freezing, when outdoor temperature drops below certain limit, eg., 1°C.

2) Minimum flow compensation

Under the control of a sensor in the fresh air supply duct,a motor-operated valve is controlled to obtain the minimum flow to protect hot water or steam system from freezing when outdoor temperature drops below certain limit, eg., 1°C.

3) Summer/winter selection

When the outdoor air temperature reaches a preset temperature, the entire system operation is automatically switched to either summer use or winter use.

The on-off control action is generally used.

c) Required performance of sensors

Since each sensor is used as a limiter, it is not required to be highly accurate, but it is required to be rigid.

d) Applicable sensors

- Remote valves, bimetals, etc.

e) Supplementary items

cf. 4.2.1, e).

4.2.3 Optimal Control

An airconditioning system provides a thermal function and a ventilation function as described in the beginning of this chapter. The outdoor air is an element related to both thermal function and ventilation function in airconditioning.

Thermal function .... • Outdoor air temperature compensation (cold shock prevention, radiation compensation, energy-saving)
• Outdoor air cooling or free cooling (energy-saving)
• Outdoor air intake control by enthalpy (energy-saving)
• Freezing prevention, summer/winter selection
• Others

Ventilation function ...... • Minimum outdoor air intake control according to the CO concentration and other indoor environmental conditions, etc.

The total air conditioning load consists of the room heating/cooling load and the outdoor air heating/cooling load for ventilation. Since the outdoor air load generally amounts to a considerable ratio of the entire air conditioning load, the reduction of the outdoor air load will be effective for energy-saving.

From the following equation, it is clearly understood that outdoor air load q_{oa} is proportional to quantity Q_F and the enthalpy difference between the outdoor air and the indoor air.

$$q_{oa} = (i_{oa} - i_r) \times Q_F \text{ (kcal/h)}$$

q_{oa} : Outdoor air load
i_{oa} : Enthalpy of outdoor air
i_r : Enthalpy of indoor air
Q_F : Outdoor air quantity

It will be useful for energy-saving to introduce an outdoor air having a low enthalpy so as to positively reduce the cooling coil load during in winter and the intermediate seasons. This condition can be realized by zones B and C in Fig. 4.7. In order for maximizing this effect it is necessary to keep the allowance of the relative humidity over a wide range.
Fig. 4.7 shows the outdoor air intake strategy in airconditioning.

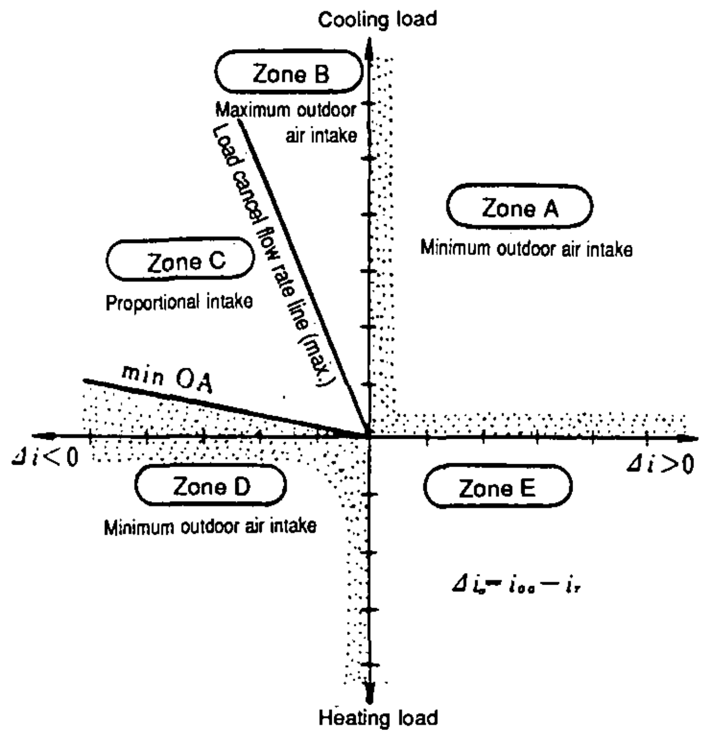
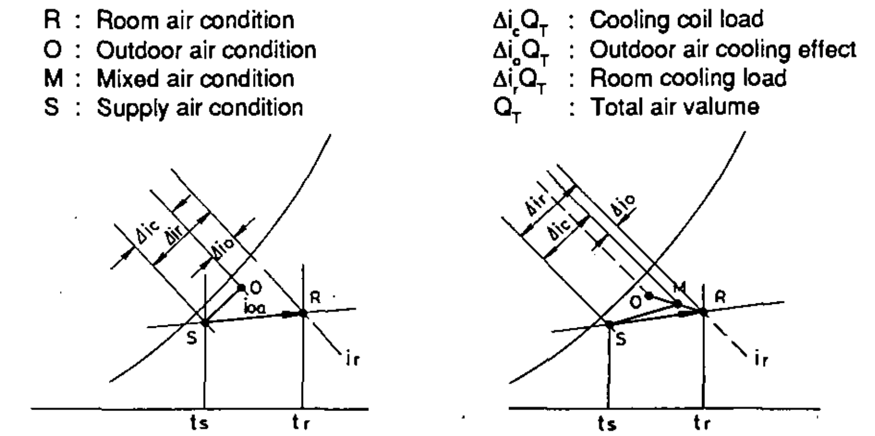


Fig. 4.7 Outdoor Air Intake Strategy in Airconditioning [JN 2)]

Zone A: The outdoor air enthalpy is higher than the indoor or return air enthalpy, and there is a cooling load, eg. in summer time. The minimum outdoor air intake as determined by the CO_2 concentration of the return air is effective to save energy.

Zone B: In this zone, when the outdoor air enthalpy is lower than the indoor air enthalpy, the outdoor air is fully introduced as shown in Fig. 4.8 (a).
If the outdoor air is limited to the minimum, the cooling coil load increase by Δi as shown in Fig. 4.8 (b).



(a) Total outdoor air introduction (b) Partial outdoor air introduction

Fig. 4.8 Zone B [JN 2)]

Zone C: The required temperature is reduced by mixing a sufficient quantity low temperature outdoor air with a part of the return air. Cooling can be achieved without the use of cooling coil.

Boundary condition with minimum outdoor air: The outdoor air should not be reduced any further.

Zone D: Minimum fresh air to limit heating load on the plant. Fresh air supply controlled by measurement of CO_2 concentration is effective for saving energy as in zone A.

Zone E: Enthalpy of inside air is low whilst building in a heating mode, that is, outside air temperature is lower than inside, which is an unusual condition. Whether system should supply minimum air or increased quantity more than minimum depends on the humidity control condition. If only the sensible heat is on the question, minimum fresh air should be supplied. If either humidification is necessary or some measures of dehumidification with equal enthalpy such as desiccant process, increased fresh air should be supplied to achieve minimum energy.

The outdoor air intake quantity serves as an optimal control performance criterion by the outdoor air utilization. The enthalpy, CO_2 concentration, temperature, humidity, effective temperature, etc. are restriction conditions.

a) Related software
   1) Outdoor air intake optimal control
   2) Enthalpy control
   3) CO_2 control
   4) Outdoor air cooling control

b) Control method

   The outdoor air quantity should be controlled to be optimized by measuring environmental valiables concerning about the above mentioned restrictive conditions, so as to minimize the energy consumption.

For the [Required Performanced of Sensors], [Applicable Sensors] and [Supplementary Items], refer to 4.2.1. For the enthalpy control, cf. 4.5.2. For the CO_2 control, cf. 4.6.

4.2.4 Monitoring, Reporting, and Analysis

cf. 4.1.3.

4.3 Temperature Measurement in Various Applications

4.3.1 Water Thermal Storage Tank
(Open type water thermal storage tank)

(1) Measurement of temperature inside the tank
The water thermal storage tank system is provided for the purpose of adjusting the thermal energy for airconditioning for fluctuating airconditioning loads. It may use the off-peak utilities, waste heat, and even unstable natural energy such as solar and/or wind energy.

a) Related software
1) Optimization of thermal storage temperature
2) Start-stop of thermal storage refrigerator

b) Control method
The thermal dynamic characteristic of a thermal storage tank is measured to execute the optimal control by taking the tank structure, thermal load fluctuations, and other factors into account. The PID control is used frequently.

c) Required performance of sensors
Since high accuracy is demanded, high-grade electronic sensors are used. The following functions are demanded, in particular.
1) Sensors shall have excellent water resistance, and be free of being affected by condensation. (cf. 4.2.1 e).)
2) Either insertion length shall be changeable flexibly, or various insertion sizes shall be prepared.

d) Applicable sensors
• Resistance thermometer bulbs (Pt, Ni, etc.)

e) Supplementary items
1) When the storage tank is mounted beneath the floor sensors are often mounted inside a manhole below the floor. Since water is often scattered for cleaning, they must be mounted as shown in Fig. 4.9 so that water can be discharged through the drain hole A even if water is introduced into the embedded box during cleaning.

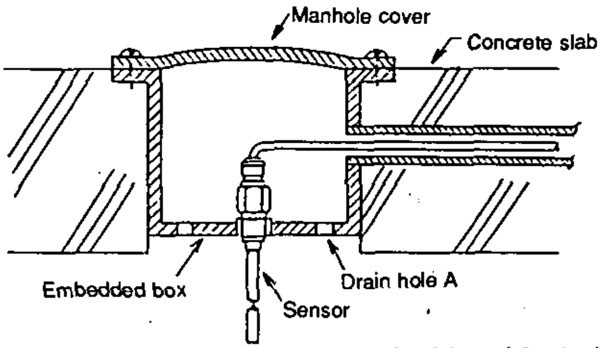


Fig. 4.9 A Mounting Example Inside a Manhole

2) Sensor connections should not be made inside manhole for the tank beneath the floor but outside manhole.
3) Select the insertion length to meet the depth at the places of measure.
4) Internal elements should be replaceable without the need of removing the protective tube.

4.3.2 Water Thermal Storage Tank (closed type water thermal storage tank mounted above floor) and Hot Water StorageTank Temperature Measurement

(1) Measurement of temperature inside the tank

a) Related software

1) Temperature control
2) High-limit temperature control

b) Control method

1) The optimal control of a thermal storage tank is conducted by measuring its thermal dynamic characteristic, while taking the tank structure, thermal load fluctuations, and other factors into account. The PID control is often used.
2) In case of a hot water storage tank, the temperature inside the tank is feedback controlled or limit-controlled. The on-off control is generally exployed.

c) Required performance of sensors

1) For the thermal storage tank, refer to 4.3.1, (1) c).
2) The sensors for hot storage tanks are not necessary to be highly accurate, but should be rigid and of low cost.

d) Applicable sensors

- Resistance thermometer bulbs (Pt, Ni)
- Thermocouples
- Thermistors
- Remote bulbs

These sensors are of an insertion type.

e) Supplementary items

1) If the sensing element is not inserted deeply enough, it will be affected by the temperature from the wall contacting the protective tube and the outside air temperature, thus producing faulty measurement. Accordingly, sensors require sufficient insertion length.
2) In case of an insertion type temperature controller using a liquid expansion temperature sensing element (remote valve), the controller unit and the temperature sensing element are connected to each other via capillary tube over a certain distance. Accordingly, an error may be produced depending upon the ambient temperature conditions. This error is often absorbed by the ambient temperature compensating mechanism consisting of mechanical parts. However, this compensation is not always sufficient. The ambient temperature compensation may sometimes be executed due to restricted working conditions, referring to makers' catalogues.
3) Be careful not to twist or bend any capillary tube sharply, to avoid the possibility of fracture and leakage of its volatile sealing liquid (gas).
4) The temperature sensing element is generally sealed with toluene or a similar volatile liquid or gas by a very small quantity. Use an exclusive protective tube for safety.

4.3.3 Ground and Structure Temperature Measurement

Temperature measurement of the ground earth and building structure are necessary when these are utilized as measures of thermal energy or when air conditioning heating and cooling load should be predicted for optimal control.

(1) Ground and structure temperature measurement

a) Related software

1) Ground temperature measurement
2) Structure temperature measurement
3) Preheating optimal control

b) Control method

The ground temperature or structure temperature is measured and controlled for the sake of energy conservation by utilizing the stored thermal energy in those materials.

c) Required performance of sensors

It is desirable that sensors are rigid and maintenance-free with excellent environmental resistance. If these requirement are not satisfied, then the sensors should be readily accessible for replacement when necessary.

1) Excellent environmental resistance (water-proof and corrosion resistance)
2) Small change in characteristics over element lifetime
3) Maintenance-free or easy maintenance

d) Applicable sensors

- Resistance thermometer bulbs (Pt, Ni, Balco)
- Thermocouples
- Thermistors

Fig. 4.10 shows an example of burying a sensor into the ground or a concrete slab.

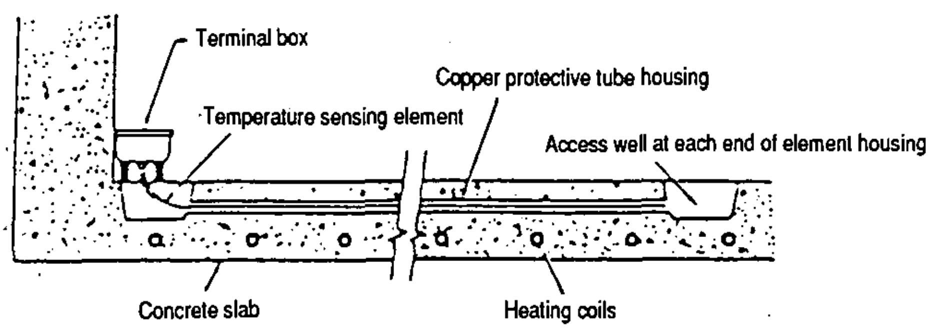


Fig. 4.10 An Example of Burying a Sensor into the Ground or a Concrete Slab

4.3.4 Surface Temperature Measurement

Thermal comfort depends on the operative temperature (OT) which include the radiant effect from the surface of structures. Surface temperatures should be measured to determine the mean radiant temperature (MRT) except that some specific sensors to directly measure the operative temperature. The radiant heating may also need the measurement of surface of radiant panel to control heat output.

(1) Surface temperature measurement

a) Related software

1) Radiation panel surface temperature control

b) Control method

The supply water temperature is generally feedback-controlled by an automatic three-way valve.

c) Required performance of sensors

High accuracy is not required, but it is desired that sensors are rigid and maintenance-free, because they are often embedded in the walls. If these requirements are not satisfied, then the sensors should be readily accessible for replacement when necessary.

d) Applicable sensors

- Resistance thermometer bulbs (Pt, Ni, Balco)
- Thermocouples
- Thermistors
- Others

4.3.5 Temperature Measurement in Airconditioners, Ducts, and Piping

(1) Temperature measurement in airconditioners and ducts

a) Related software

1) Temperature control
2) Temperature measurement

b) Control method

The temperature of the air flow in airconditioners and ducts is measured for the feedback control and monitoring.

c) Required performance of sensors

1) High accuracy
2) Good stability with time
3) Excellent environmental resistance
4) A rigid structure
5) Easy service & maintenance

d) Applicable sensors

- Resistance thermometer bulbs (Pt, Ni)
- Thermistors
- Remote bulbs
- Rod tubes (pneumatic)

e) Supplementary items

1) Sensors should be inserted to respond to conditions in the center of the duct; in some cases this will no doubt require some form of mechanical support.
2) When the size of the duct is large and the temperature distribution is expected as in the air handling apparatus, an average temperature should be measured as shown in Fig. 4.11.
3) Each sensor must be mechanically rigid when used in a high speed air stream or the like. It can often be reinforced by mounting a suitable mesh plate on the upstream side. However, the sensor should not affect the air stream noticeably.

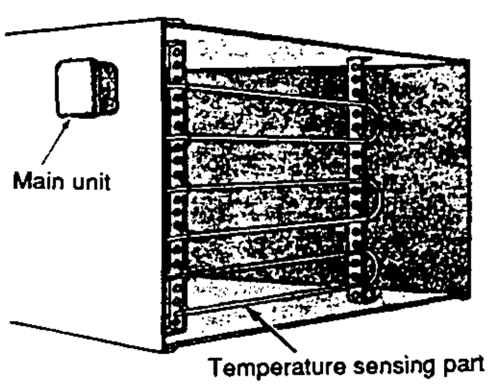


Fig. 4.11
An example of Average Temperature Measurement [JN 12)]

(2) Fluid temperature measurement inside piping

a) Related software

1) Temperature control
2) Temperature measurement

b) Control method

The temperature of a flowing fluid is measured inside piping. It is feedback-controlled and monitored.

c) Required performance of sensors

Sensors should have the accuracy according to purposes, and readily accessible for maintenance when necessary.

d) Applicable sensors

- Resistance thermometer bulbs (Pt, Ni)
- Remote bulbs

e) Related software

1) Select protective tube materials according to the kinds of fluids. Check the working pressure and temperature.
2) Use a sensor having a small thermal capacity so that the temperature distribution of the measured fluid does not change due to the installation of the temperature sensor.
3) Fill the air gap in the protective tube with special grease, if necessary.
4) It is desirable to mount the temperature sensing element at the piping center and insert the sensor to be against the flow.
   Fig. 4.12 shows [An Installation Example of a Resistance Thermometer Bulb to Piping]. Mount a sensor as shown in (b) if the piping diameter is comparatively large and the sensor can be inserted sufficiently deep. Mount it diagonally to be against the flow as shown in Fig. (b), if it cannot be inserted deep. Mount it by utilizing a bent portion as shown in Fig. (c), if piping is small in diameter.

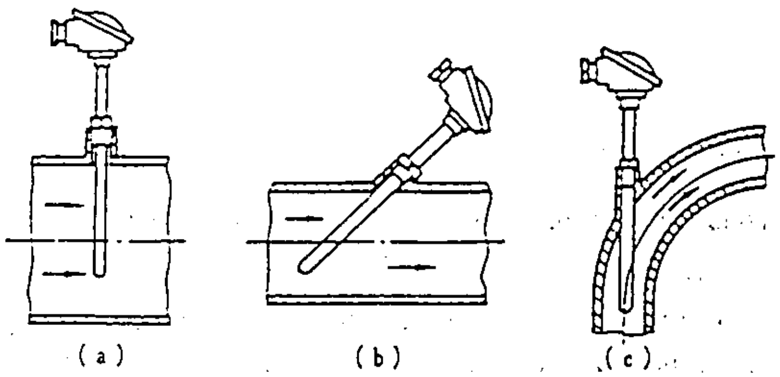


Fig. 4.12 An Installation Example of a Resistance Thermometer Bulb to Piping JN 3)

5) Where the measured temperatures are lower than those of the immediate surroundings care should be taken to ensure no condensation occurs within the sensor pocket.
6) Where the pipework is insulated ensure that the protective tube and sensor, when necessary also are insulated to the same standard.

4.4 Radiation and Solar Irradiation Measurement

Radiation is usually detected by one of the following methods: 1) indirectly, from the temperature rise due to energy received, or 2) by using a device which generates an output directly from energy in the infrared region. The former method typically entails the measurement of a temperature difference between that of either a) a pair of elements each with a different absorption coefficient or b) a blackened globe and still air.

Table 4.5 Radiation Detection Methods

Type		Accuracy	Response	Major uses
Photoelectric type			○	Solar radiation intensity
Temperature difference type	Surface material	○	○	Solar radiation
	Globe sphere		X	Indoor radiation

The solar radiation is characterized by a strong directivity, high intensity, and a broad wavelength range. According to the applications as shown in 4.4.4, various exclusive instruments are used for measuring the solar radiation according to applications.
A sol-air temperature (SAT) value is related to the solar radiation. This value is obtained by correcting the outside air temperature by the temperature rise equivalent to the solar radiation effect when the heat transfer on the wall face is taken into account. This value is calculated from the outside air temperature, solar radiation quantity, and night radiation.
The photoelectric type can also measure the illumination intensity to show the brightness on a plane.

4.4.1 Compensation Control

(1) Daily thermal load prediction (Optimal control for a thermal storage run)

a) Control method
This method is provided to keep track of a solar radiation change every hour and every day in daily thermal load prediction using the outside air temperature as a main index, and then, compensation can be made according to the solar radiation intensity together with the weather forecast information.

b) Required performance of sensors
High accuracy is not demanded as an absolute value, but sensors should be stable.

c) Applicable sensors
Pyranometer

4.4.2 Solar Collection Control

(1) Solar collection control

a) Control method

A pyranometer is mounted normal to the plane of panel to execute solar collection control so as to maximize the solar collection. Application may effect including refrigerators, heat exchangers, and other heat source devices. If the solar heat is utilized for multiple applications as heating, cooling, hot water supply, and other purposes, it should be selectively changeover depending on the usable temperature.

b) Required performance of sensors

The solar radiation quantity abruptly changes due to the movement of clouds. Accordingly, a suitable time lag is recommended for maintaining stable system operations.

c) Applicable sensors

Pyranometer

d) Supplementary items

The pyranometer surface is apt to be contaminated by the rainfall and snowfall as well as the solar collector surface. It is recommended to wash these surfaces frequently.

(2) Freezing prevention

a) Control method

The freezing prevention control of solar collection devices is often executed according to the outside air temperature. If SAT sensor is applied for this use as shown in Fig, 4.13, the set point temperature for starting a freezing prevention pump can be lowered to reduce an unnecessary operations and save energy.

b) Required performance of sensors

Sensors need not be precise.

c) Applicable sensors

SAT sensor

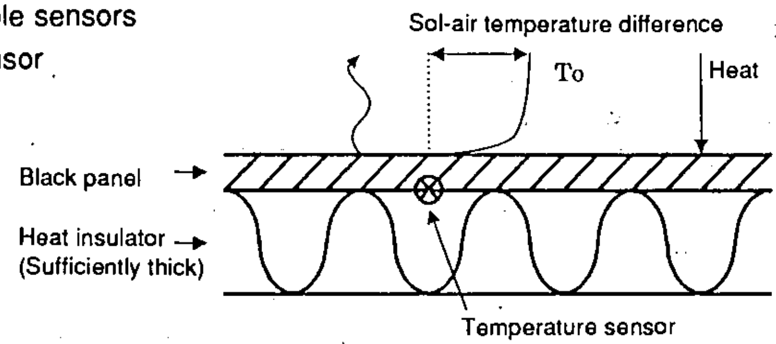


Fig. 4.13 An Outline of SAT Sensor

d) Supplementary items

It is recommended to wash the surfaces frequently to remove dirt caused by rainfall, snowfall, etc.

4.4.3 Optimal Control

(1) Refer to room temperature measurement / effective temperature measurement.
cf. [4.1.2 (2)]

(2) Illumination control

a) Control method
Illuminance sensors ie those sensitive to daylight may be situated in the window areas, to control artifical lighting on the basis of received daylight. Alternatively they may be installed within the rooms; additionally, either scheme may be used to control the operation of blinds.

b) Required performance of sensors
No particularly high control accuracy is required because of the characteristics of the daylight and controlled systems.

c) Applicable sensors
Illumination sensors

d) Supplementary items
When the heat recovery system is applied in winter heating and cooling, the cooling load depending on the lighting and solar insolation is important heat source for heating and sometimes for the domestic hot water. Therefore, the illumination control above mentioned should carefully take this into account in this case.

4.4.4 Monitoring, Recording, and Analysis

(1) Solar energy measurement

a) Pyranometer
This meter measures the total solar radiation, the sum of the direct solar radiation and diffuse radiation. The Eppley pyrheliometer is a typical example. A sky pyrheliometer is obtained by mounting a solar orbit shielding ring on to the pyranometer.

b) Pyrheliometer
This meter measures the direct solar radiation quantity. Accordingly, it automatically and sequentially tracks the sun. It is utilized for measuring the atmospheric transmittance and analyzing the performance of solar plants. The Ångström pyrhelio-meter and silver-disk pyrheliometer are available for example.

c) Spectro-pyranometer
This meter measures the solar radiation quantity in each selected band of solar irradiation; it is used mainly for assessing the performance of solar powered plant or equipment. This meter is realized by covering a pyranometer with a filter.

(2) Net radiation measurement

Net pyradiometer measures the radiation balance in the ground surfaces and buildings; it is effectively used in agricultural and architectural fields, in particular.

(3) Thermo-environment measurement

Thermo-environmental meter is used to evaluate the environments from the viewpoints of the comfort to the human body. It generally contains a radiation sensor, an air temperature sensor, and a wind velocity sensor based on the principle of the globe sphere to evalutate the comfort by SET* (Standardized Effective Temperature), PMV (Predicted Mean Vote), and other thermo-environmental indices. Refer to 4.1.2.

(4) Illuminance measurement

Illuminometer measures the illuminance intensity on a plane, and it is sometimes used for agricultural analysis, too.

4.5 Humidity Measurement

4.5.1 Feedback Control (relative humidity)

The control types, control accuracy, and applicable sensors.required for each system are as shown in Table 4.6 when the room humidity is controlled by detecting of the deviation from the set point.

(1) Room humidity measurement
Since the required accuracy differs between the comfortable airconditioning and the industrial airconditioning, sensors must be selected according to purposes and uses.

a) Related software
1) Room humidity control
2) Room humidity measurement

b) Control method
A room humidity change is detected and compared with a set point value. Corrective action is under taken so as to keep the room humidity at the set value.
1) The comfortable airconditioning requires no high accuracy and uses either on-off control or proportional control with broader differential or proportional band to save energy.
2) The industrial airconditioning requires both high accuracy and high response, and often uses the PID control.

c) Required performance of sensors
1) Internal conditions for occupants of commerical premises will typically be those which conform to the relevant locally applicable Code of practice, Health Regulations etc. The sensors should have the following properties.
   i) Small size
   ii) Excellent design (indoor mounting type)
   iii) Easy operation and handling
   iv) Good stability with time
   v) Low cost
2) Since working atmospheres of industrial airconditioning do not conform to the locally applicable Code of practice, it may be difficult to select a suitable sensor.
   i) Excellent environmental resistance
   ii) High accuracy
   iii) High response
   iv) Good stability with time
   v) Compatible

d) Applicable sensors
1) A nylon film sensor and a hair sensor are used for residences, general offices, shops, etc. where no particular accuracy is required in comfortable airconditioning. The hair sensor, however, is less used recently.

Table 4.6 Selection Guide of Room Humidity Sensors

	Buildings	Room space	Objective: Humidification	Objective: Dehumidification	Control type: Electric type	Control type: Electronic type ANA	Control type: Electronic type DIG	Control action: ON/OFF	Control action: P	Control action: PI	Control action: PID	Control accuracy Note 1) (% RH: ±5, ±10, ±15)	Types of sensors: Nylon film	Types of sensors: Hair	Types of sensors: Lithium chloride	Types of sensors: High ploymer	Types of sensors: Ceramics	Types of sensors: Dry-bulb/wet-bulb temp.	Types of sensors: Dew-point temp.
Comfort airconditioning	Residences	Living room	○	○	○			○				○ ±5 — ±15	○	○					
		Bed room	○	○	○			○				○ ±5 — ±15	○	○					
	Office	Popular office room	○		○			○	○			○ ±5 — ±15	○	○					
		Intelligent office room	○	○		○	○		○			○ <±5 — ±10			○	○	○		
		Computer room	○	○		○	○		○			○ <±5 — ±10			○	○	○		
	Hotel	Popular guest room	○		○			○				○ ±5 — ±15	○	○					
		Intelligent guest room	○	○		○	○		○			○ <±5 — ±10			○	○	○		
		Restaurant	○	○	○			○				○ ±5 — ±15	○	○					
		Lobby	○	○	○			○				○ ±5 — ±15	○	○					
	Department store	Sales counter	○	○	○			○				○ ±5 — ±15	○	○					
	School	Classroom	○		○			○				○ ±5 — ±15	○	○					
Industrial airconditioning	Warehouse	General	○	○	○			○				○ ±5 — ±15			○	○	○		
		Special	○	○		○	○		○	○		○ <±5 — ±10			○	○	○		
	Factory	Semiconductor	○	○		○	○			○	○	○ <±5 — ±5			○	○	○	○	○
		Biotechnology	○	○		○	○			○	○	○ <±5 — ±5			○	○	○	○	○
		Clean room	○	○		○	○			○	○	○ <±5 — ±5			○	○	○	○	○
	Laboratory	Constant temperature/ constant humidity room	○	○		○	○			○	○	○ <±5 — between ±5 and ±10			○	○	○	○	○
	Art gallery	Showroom	○	○		○	○		○	○		○ <±5 — between ±5 and ±10			○	○	○		
	Hospital	General sick ward	○		○			○				○ ±5 — ±15	○	○					
		ICU room	○	○		○	○			○	○	○ <±5 — between ±5 and ±10			○	○			
Others	Measurement											○ <±5			○	○	○	○	○

Note 1) These values show realistic values including those of building structures and facilities. If the control accuracy is demanded more than specified above, it is realized by systematically examining it with the building structures and facilities included.

○—┤ : ┤ Accuracy of the entire system; ○ Accuracy of each sensor unit

2) Lithium chloride, high polymer, ceramics, and other similar sensors are applied to commercial buildings, hospitals, galleries, etc. where industrial-like airconditions or comparatively high-accuracy are required. Also, a psychrometer (Pt, Ni) is used in an environment where other sensors are not applicable.

e) Supplementary items

The differences between temperature sensors and humidity sensors must be understood.

Temperature sensors can be enclosed with a protective tube or the like due to their structural principle. On the other hand, humidity sensors cannot be enclosed, and they are directly affected by their atmospheres. Humidity sensors often utilize a reaction with a gas as their principle. The influences of chemicals, for example, differ according to the temperature, humidity, and concentration. Accordingly where contamination of the sensor surface is to be expected consult the sensor manufacturer and/or your appropriate national code or standard. The manufacturer will of course need to be told the name of each contaminant and its expected level of concentration. Be careful with the following items for humidity sensors.

1) Nylon film and hair sensors:

i) A dust deposit causes poor sensitivity, and also, sensors deteriorat in the presence of sulfur oxide, unsaturated oxides, etc. in cities or the like. Remove dust particles by a lens brush or the like.

ii) The nylon film drifts, if an excessive tension is applied.

2) Lithium chloride sensors:

These sensors have conventionally been used frequently because of high accuracy. However, they must be handled with care.

i) Don't touch or scratch any sensor surfaces by fingers.

ii) If water is condensed on the surface, sensor characteristics are lost permanently. Accordingly, care should be taken to avoid moisture condensation caused by the use in a high humidity atmosphere or an abrupt temperature change.

iii) If a DC is applied from a circuit tester or the like, the characteristics change due to the polarization action. A current of lower than 100μA does not affect the characteristics when AC is higher than 10Hz.

iv) A dust deposit causes the deliquesence of lithium chloride due to its mositure content to shorten the life. The sensor must be protected with a permeable but non hygroscopic cover as required.

v) Remove the deposited dust particles by using a lens brush or the like. For oily deposits, dip the sensor into reagent benzine (where the content of benzene is less than the specified value), and waggle it and wait for a while until they are naturally dissolved in benzine.

iv) Since lithium chloride is electrolytic, it is affected by ionized substances. Accordingly, it must not be exposed to air containing acidic vapor, sulfurous acid gas, ammonia, alkaline vapor, and salt components.

Lithium chloride is also a hygroscopic substance. It is affected by glycerine, ethylene glycol, other glycol, sugar, and other hygroscopic substances, irrespective of whether these substances are gaseous, liquid, and solid. It is affected by the vapors of methyl alcohol, ethyl alcohol, and other alcohol. However, it is employable with vapors of gasoline, petroleum, dry cleaning solvent, and other hydrocarbon, or vapors of perchloroethylene, trichloroethylene, and other chlroine solvents. It is not affected by nitrogen, hydrogen, helium, and other inert gases.

3) High polymer sensor:
   Where contaminants are known to exist these should be identified before using such a sensor.
   i) Sensor performance is degraded in the presence of organic solvents in the same way as in lithium chloride sensors.
   ii) Avoid high humidities since the dew condensation affects the sensor life.
   iii) Read carefully the manufacturer's specification, especially when associated electronics are built into sensor head.

4) Ceramics sensor:
   A ceramics sensor having a regenerative cleaning function is characterized with comparatively excellent resistance against condensation and environmental influence. However, if this sensor is used in a special atmosphere (other than specified in the relevant locally applicable Code of practice, Health Regulations etc., the environment must be surveyed and confirmed in advance. Since this sensor is refreshed by automatically cleaning the sensor surface by means of heating, it can measure the humidity with high reliability for a long time. However, a signal output is held during cleaning, and thus, this sensor cannot execute continuous control or continuous measurement. In such a case, two humidity sensors must be alternatively used, switched by an external timer. Since this sensor is provided with a built-in far-infrared radiation ceramic heater, it cannot be used in a harzardous environment where a combustible gas, vapors, dust particles, etc. may reach the explosive limit.

5) Psychrometer detector:
   This sensor is used to obtain the relative humidity by calculating a difference between the dry-bulb temperature and the wet-bulb temperature.
   Its water and wet-bulb cotton cloth must be kept clean at all times, which is a disadvantage. However so long as cleanliness is observed and the water supply is maintained a consistent performance is ensured due to the absolute nature of the principle of measurement. This sensor displays its performance in a special atmosphere where other humidity sensors are not applicable.

6) For manual temperature-humidity measurement in airconditioned spaces, an Assmann psychrometer is used as a reference meter for calibrating various units and sensors frequently, because this meter can measure data with comparatively high accuracy at normal temperature by simple handling. However, if the wet-bulb is not properly covered with a wet cotton cloth, an error may results. So, this meter must be handled carefully.

(2) Humidity measurement inside airconditioners and ducts

a) Related software

1) Humidity control
2) Humidity measurement

b) Control method

The humidity of an air flow in a ducts is measured for the feedback control.

c) Required performance of sensors

1) High accuracy
2) Small long-term drift
3) Excellent environmental resistance
4) A rigid structure
5) Easy service & maintenance

d) Applicable sensors

- Hair
- Nylon film
- Lithium chloride
- Ceramics
- High polymer
- Dry-bulb/wet-bulb temperature detector (a special atmosphere, etc.)

e) Supplementary items

1) Since the characteristics of humidity sensors change due to the deposit of dust particles, a non hygroscopic dust-preventive measure is required.
2) It is recommended to mount a humidity sensor in a bypass duct with a filter or a sampling chamber and fan in a dusty atmosphere.
3) Since the characteristics of humidity sensors change due to the deposit of water drops, a water-drop preventive measure is required. This is particulary important when mounting a humidity sensor in an outdoor air intake duct or in the downstream of humidifier.
4) Humidity sensors must be mechanically rigid in a high-speed duct or the like. They can often be reinforced by mounting a suitable mesh plate on the upstream side, however, the air flow should not be affected hereby.
5) An electric humidity controller using hair or a nylon film is apt to be affected by an air flow, and a wind-shield is necessary.
6) Humidity sensors require periodical maintenance, and easy maintenance is an important requirement.

4.5.2 Wet-bulb Temperature (enthalpy approximation) Measurement

The use of outside air has important consequences for the energy consumed by an air handling unit, as described in 4.2. The fresh air component, when above its minimum acceptable level, is typically governed by the measured difference between its enthalpy, and that of the return air.

a) Related software
  1) Enthalpy control (outdoor air cooling control)

b) Control method
  The enthalpy of outdoor air and return air is measured to control the outdoor air intake quantity so as to minimize the energy consumption.

c) Required performance of sensors
  cf. 4.2.1, c).
  The maintenance required by psychrometers makes them unsuitable for this application. Enthalpy is often calculated by using resistance thermometer bulbs (Pt, Ni) and a dew point temperature detector.

d) Applicable sensors
  • Resistance thermometer bulbs (Pt, Ni)

e) Supplementary items
  Since this sensor may be seriously contaminated with the outdoor air, it can be used in this application only if cleaned regularly.

4.5.3 Dew-point Temperature (absolute humidity) Measurement

In general airconditioning, sensible heat load fluctuations are significant, whereas the fluctuation in the latent heat component of the internal load are typically small. It is therefore recommended that where a constant relative humidity is desired then control of supply-air dew-point is used in preference to control driven from humidity sensors in the conditioned space.
Such a control method is particularly convenient for hospitals or the like where the outdoor air is introduced in large quantities.

(1) Dew-point temperature (absolute humidity) measurement

a) Related software
  1) Dew-point temperature control

b) Control method
  The dew point temperature of the supply air is measured to keep its desirable absolute humidity.

c) Required performance of sensors
  1) Excellent environmental resistance (water-proof, drip-proof)
  2) High accuracy
  3) Quick response
  4) Small long-term drift
  5) Compatible
  6) Continuous measurement

d) Applicable sensors
  - Ni + lithium chloride sensor (dew probe)
  - Pt + ceramics sensor

e) Supplementary items
  1) The Ni + lithium chloride (dew probe) sensor utilizes the saturated vapor pressure of lithium chloride. For cautions, refer to 4.5.1, (1), e), 2) [Lithium Chloride] plus following cautions.
    i) For air speeds in excess of specified value, about 15m/s, errors may occur unless precautions are taken eg: Mount the attached ventilation hole shield cover with its opening facing the downstream side of fluid.
    ii) The bobbin can, and needs to, be regenerated periodically to retain consistent performance.
  2) Pt + ceramics sensor
    Refer to 4.5.1, (1), e), 4) ceramics sensor.
    This sensor is not greatly affected by air speed.

4.6 CO_2 Gas Concentration Measurement

4.6.1 CO_2 Gas Analyzer Used for BEMS

The CO_2 gas analyzers in BEMS are grouped roughly into those for airconditioning monitoring and control and those for boiler combustion monitoring (Table 4.7).
CO_2 gas is measured by the non-dispersive infrared absorption method.
Analyzers must be applied selectively by examining the necessity of sampling devices according to the properties of the gases to be analyzed.

Table 4.7 Objects of CO_2 Gas Measurement

Object	Sampling devices	Remarks
Environmental air	Not required.	A pump and a filter are provided as a built-in devices inside the analyzer.
Combustion exhaust gas	Required.	The analyzer contains a pump, a filter, a flow checker, and other devices.

4.6.2 CO_2 Gas Analyzer for Airconditioning Monitoring and Control

The CO_2 gas analyzers is applied for the maintenance of environmental conditions in plant cultivation, and comfort air conditioning in room.

(1) CO_2 control for plant cultivation
A plant produces hydrocarbon from CO_2 and water by means of photosynthesis, and the CO_2 concentration control is applied to the plant cultivation. Its control algorithm is simple feedback control (on-off) for outside air intake.

(2) CO_2 control for living environments
It is necessary for living comfort to limit the indoor CO_2 below some specified limit. This may, of course be achieved by increasing the supply of fresh air but unless carefully controlled this may incur a significant energy penalty. Accordingly, the outdoor air intake quantity should be limited to a necessary minimum from the viewpoints of energy-saving. Control of CO_2 concentration is applied to satisfy these mutually contradictory demands.

(3) Energy-saving by CO_2 concentration control
The outdoor air intake quantity must be controlled so that the CO_2 concentration of the indoor air is lower than specified (eg 1000 ppm in Japan), and the required outdoor air quantity is approximately determined by the number of persons in the room. However, the number of persons staying in hotels, department stores, chain stores, large meeting halls, etc. is highly variable.

Accordingly, if the minimum outdoor air intake quantity is held constant at the level determined by the maximum number of persons staying in these rooms, then at all other occupancies it would be excessive and result in an energy penalty.
Under these circumstances, energy consumption may be minimized by control of the fresh air supply in accordance with the concentration of CO_2 in the inside air, and then, by reducing the cooling/heating loads by means of limiting an excessive outdoor air intake to the minimum. In case of the year around airconditioning, free cooling can be accomplished by the outdoor air in the intermediate and winter periods as stated in 4.2.3. As a result, the indoor CO_2 concentration becomes sufficiently low (outdoor air CO_2 concentration) during these periods, and CO_2 concentration control should not be executed.

(4) CO_2 concentration control action
When attempting to control the fresh air supply both by temperature and by CO_2 concentration of the inside air, it should be noted that the same control devices, ie, dampers for fresh air, exhaust air and recirculated air, is available. Accordingly, the damper opening is controlled by comparing the two control signals.

(5) Maintenance of CO_2 concentration meter
In order to measure the CO_2 concentration, the following periodical maintenance and check are necessary.

a) Check and adjust the zero point and span periodically (once every month to once every 3 months) for securing the reliability of measured values.
b) Filters may became blocked, depending upon the properties of the indoor air. Check and replace them periodically, if required.
c) Check the sampling conditions of samples.

(6) Supplementary items

a) For measuring the CO_2 concentration, perform sampling from a return air duct where the mean concentration is detectable.
Linked control of exhaust-air and fresh-air flowrates may be necessary to keep the quantity of fresh air and exhaust air nearly equal and then to ensure that the pressure of air within the building is always positive with respect to the atmosphere.
b) Since the CO_2 concentration is detected at typical points only, it sometimes becomes difficult to measure or dilute the local high concentration spaces. It is therefore, necessary to secure the reinforcing method of local ventilation to the spaces as much as possible at the time of designing.
c) The CO_2 concentration is used as a reference for the air contamination in an underground parking area. In this case, fan energy (and related cost) is reduced by controlling the parking area supply air / exhaust fans by means of scroll dampers and fan speed.

4.6.3 CO_2 Gas Analyzer for Monitoring the Boiler Combustion

(1) CO_2 monitoring for monitoring the combustion conditions

In order to burn a fuel completely, air must be supplied at more than the theoretical minimum. An air supply in excess of this minimum incurs an increased energy loss via the exhaust gas; air supplied at less than this minimum results in incomplete combustion ie unburnt fuel - which appears as smoke. Accordingly, the CO_2 concentration in combustion exhaust gas is measured to obtain an excessive air ratio for monitoring the combustion conditions.

(2) Supplementary items

A combustion exhaust gas CO_2 analyzer is applied to the automatic combustion control of boilers. The heat loss and the generation of black smoke can be minimized by controlling the combustion airflow in accordance with same preset CO_2 level in the exhaust gas by measuring the CO_2 concentration in the flue gas.

4.7 Dust Particles

Dust particles in the air are also a subject for control. --- and they are measured at intervals. --- specified for certain buildings --- By definition dust particles are removed from clean rooms; typically they are monitored for operator intervention and not under automatic control. --- Dust particles and soot in exhaust gases are also subjects for monitoring and manual control.

Dust particle sensors are normally classified according to particle size and/or application; fine-particle sensors are required for clean rooms. In some cases hand-held instruments will be used for these measurements; these instruments require regular calibration.

4.7.1 Clean Room

In a clean room requiring high cleanliness in semiconductor factories, etc., neither air flowrate nor directions of the supply air is controlled by detecting the cleanliness, but the clean room is monitored to check if the cleanliness of the specified class is kept or not. For this monitoring, two kinds of meters are used.

1) laser particle counter (LPC)
2) concentrated nuclear counter (CNC).

These meters are designed by applying an optical principle to their detectors, and they are connectable to a computer to execute recording, display, and alarming by processing the sensors output signals. Increasing use of integrated circuits in meters has led to rapid development. Be careful with the reliability when selecting these meters. Check the meter accuracy daily. For monitoring measurement, it must be examined to increase the number of measuring counts and prolong the monitoring time for the purpose of improving the data reliability. In a clean room, soiling by workers and production devices must be taken into account. This also applies to any kind of meters. Exclusive robbot for the measurement has recently been developed and come to use.

4.7.2 General Living Room

For living rooms, the maximum permissible content of dust particle to be observed may be specified, eg: In Japan the Building Standard Law and the Building Environment Control Standards regurates that the dust quantity should be less than 0.15mg/m³ in living rooms having a centralized air conditioning system, and that an official agency measures and checks it at certain intervals. However, the dust quantity is not detected to control the airconditioning system in general buildings.

A meter now being employed according to the Building Environmental Control Standards is called low-volume air sampler. This device offers a simple and secure method to weigh the dust particles in an indoor air after catching them in a filter paper. Dust measurement requires a sampler, a suction pump, a balance, a filter paper holder, and other devices in addition to the labor and time. A digital dust monitor is a comparatively handy meter. It indicates the dust particles concentration by cpm (count per minute) by a kind of the light dispression system. The coefficient to convert "cpm" into the gravimetric concentration is given by a meter as 1cpm = 0.01mg/m³, for example. It is recommended to continue measuring dust particles for 5 to 10 minutes and then, obtain a mean value per minute. Since this meter can be handled easier than the low-volume air sampler, it is often used for the measurement specified by the Building Environnmental Control Standards instead of the low-volume are sampler.

Care should be taken not to soil the suction air since this meter is portable.

Smoke plumes comes into question frequently out of the dust particles in an indoor air. A spectro filter paper dust monitor is used for measuring indoor smoke plume particles and general dust particles.

4.7.3 Exhaust Gas

An optical transmittance type smoke concentration meter is used for the purpose of monitoring the combustion conditions of boilers, etc., which burn solid or liquid fuels. This meter receives the intensity of the light passing the exhaust gas in a stack by a photoelectric tube, and indicates the intensity as the concentration of smoke. An alarm may be installed. The optical source lamp and receiver should be protected from the contamination soiling and heat.

4.8 Flow Measurement

The controlled systems in buildings which entail flow measurements are the water flow (chilled/hot water, cooling water, drain, water supply, hot water supply, water discharge, etc.), airflow (duct, blow-out nozzle), vapor quantity, fuel oil quantity, gas quantity, etc. This paragraph describes the flow measurement for airconditioning only. The water supply and drainage as well as the fuel measurement are dealt with in Chapters 5 and 8.

Since a once installed in a commercial flowmeter may not be maintained frequently, as compared with industrial plant, it should be durable enough to keep its accuracy for a long time. In addition, important meters for transactions and control should be equipped with a bypass line or the like to be able to replace them as required.

The measuring principles, features, accuracy, required straight pipe length, prices, etc. variously differ depend on the types of the flowmeters. Accordingly, a suitable one should be selected to meet individual measuring purpose. Table 4.8 shows the types and features of flowmeters in buildings.

Table 4.8 Flow Rate Measurement for Airconditioning

Type		Differential pressure type		Area type	Hot-wire type	Electromagnetic type	Ultrasonic type	Vortex type	Vane-wheel type	Capacity type	Remarks
Measuring device		Orifice	Pitot tube	Rotor meter	Hot-wire type	Electromagnetic type	Ultrasonic type	Delta meter, etc.	Turbine meter Tap water meter	Oval meter Diaphragm type meter	
Measuring physical variables		Volume	Wind velocity	Volume	Wind velocity	Speed	Speed	Speed	Speed	Volume	
Rangeability		1 : 5		1 : 10	1 : 50	1 : 10	1 : 5	1 : 100	1 : 15	1 : 20	
Accuracy		±1.0% FS		±1.0% FS	±2.0~±5.0%FS	±1.0% FS	±1.0% FS	±0.5% IS	±0.5% IS (For transactions ±0.2% IS)	±0.5% IS (For transactions ±0.2% IS)	FS: Full Scale IS : Indicated Scale
Straight pipe length		Upstream 15D Downstream 5D	Upstream 15D Downstream 5D	Upstream Not provided Downstream 5D	Not provided	Upstream 5D Downstream 2D	Upstream 10D Downstream 5D	Upstream 15D Downstream 5D	Not provided	Not provided	D : Diameter of piping or duct
For liquid flow rate measurement	Heat source ass'y					① Variable flow rate control ② Calorie calculation	① Water flow rate measurement ② Header valve adjustment	① Variable flow rate control ② Calorie calculation			
	Chilled/hot water piping	① Water flow rate measurement ② Valve adjustment	① Water flow rate measurement ② Valve adjustment	① Water flow rate measurement		① Water flow rate measurement ② Calorie calculation	① Water flow rate measurement ② Valve adjustment				
	Other water supply and drainage, etc.			① Water flow rate measurement			① Large-diameter tap water flow rate measurement ② For control		Tap water meter ① Flow rate measurement ② Integrated water flow rate		
Airflow rate measurement	Airconditioner duct, etc.	Nozzle ① Airflow rate measurement ② For damper adjustment	① Airflow rate measurement ② For damper adjustment		① Airflow rate measurement ② For adjustment			① Airflow rate control ② For VAV	Turbine meter ① Airflow rate control ② For VAV	Oval meter ① Gas flow rate measurement ② For transactions Diaphragm type meter ① Gas flow rate measurement ② For transactions	
Steam measurement	Steam piping	① Flow rate measurement ② For control ③ For transactions						① Flow rate measurement ② For control ③ For transactions		Oval meter ① For drain quantity measurement ② For transactions	

4.8.1 Airflow Rate

In airflow rate measurement, the air velocity in a duct is measured and multiplied by a duct area. To calculate the heat flow, the air mass is multiplied by the air temperature and the specific heat. The heating/cooling power of an AHU of an air is in this way, for example. In the VAV system, control is sometimes carried out according to the airflow rate.

a) Related software
CAV control, VAV control

b) Control method
In CAV system, setting of air flowrate can be accomplished in the above-mentioned manner.
In VAV control, fan speed is controlled by an air velocity sensor signal inside a duct.

c) Required performance of sensors
Sensors should be durable and dust-proof for measuring the air velocity permanently. High accuracy sensors are particularly required for heat flow measurement and control, and they must be installed in a duct or at a place where the mean air velocity can be measured.

d) Applicable sensors
- Turbine type
- Vortex type

Measuring positions: Duct
Comments : Measuring results must be output as electric signals.

e) Supplementary items

1) The air velocity is often measured to obtain the flow rate. At the measuring point, air current should be turbulent where the fluid velocity is sensibly equal at all sectional points. In order to satisfy this requirement, a straight pipe is necessary before and behind the sensor. Since the required straight pipe length varies according to the types of sensors and measuring principles, sensors must be selected by taking the measuring conditions into account. These sensors must be mounted at representative points.

2) Air flow rates may be measured continuously as required by automatic controls, or at intervals when samples are obtained using hand-held instruments. Examples of the latter are air velocities near radiators, supply outlet, return grilles, draft to occupants, etc. These sensors containing a converter and a display should be lightweight to be portable.

Applicable sensors

- Hot-wire type wind velocity sensor
- Differential pressure type (Venturi tube, Pitot tube)
- Vane-wheel type (turbine type)
- Others

Measurements made at sites such as supply/exhaust grilles will typically be recorded manually. Accordingly, it is not necessary to output them as electrical signals, while there are devices which can be connected to a data logger.

4.8.2 Liquid Flow Rate

Liquid flow rate measurement in HVAC is mainly the chilled/hot water, the water supply of a boiler, a cooling tower, etc. The liquid flow rate control using a flowmeter comprises pump sequence control, pump inverter control, bypass valve control, etc. as the variable flow rate control (VWV) of the chilled/hot water system.
The sequence control of heat generators is linked to that used for control of the associated pumps.

a) Related software
- Chilled/hot water pump sequence control
- Pump inverter control
- Bypass valve control

b) Control method

Chilled/hot water pump sequence control :

Chilled/hot water flow rate change typically in response to valve operations, which in turn, are controlled by room temperature sensors. Where multiple water pumps are provided, the chilled/hot water flow rate is measured, and the necessary number of pump to be operated is determined according to the water flow rate.

Pump inverter control :

The chilled/hot water flow rate is measured at the final-stage pump in the pump sequence control, and the pump speed is controlled by an inverter according to the water flow rate. Also, a bypass valve and other valves may be controlled concurrently. The discharge pressure control should be concurrently applied as required together with the inverter control.

c) Required performance of sensors

Sensors are placed in the main (sometimes large) pipe of a chilled/hot water system. Since flowrate may change abruptly sensors with a short response time are required; these sensors must also be robust. Measurements should be insensitive to each of the many sources of local interference and readily convertible to provide a signal acceptable for control purposes.

Where flowrate is measured for the purposes of control, and especially for registration or accounting, high accuracy is required. High accuracy is particulary demanded when the heat flow is calculated based on the measured values of flow rate and temperature difference, as the error may be doubled by the two measurement.

d) Applicable sensors

Sensors for management and maintenance

- Vane-wheel type (turbine flowmeter, etc.)
- Area flowmeter
- Electromagnetic flowmeter
- Ultrasonic flowmeter
- Vortex flowmeter

Measuring positions : Boiler water supply, fuel oil

Control sensors

- Electromagnetic flowmeter
- Vortex flowmeter

Measuring positions : Chilled/hot water piping

e) Supplementary items

1) Electromagnetic flowmeters are most commonly chosen for automatic controls in building services; whilst they appear initially to be expensive they offer substantial advantages.
2) Unlike many other types of flowmeter the electromagnetic flowmeter has few restrictions regarding its position eg with respect to the lengths of straight unobstructed pipe upstream and downstream of the meter.
3) If accuracy is needed and a broad rangeability cannot be served by one meter, two sensors one having a large and the other small range may be installed and used selectively.

4.8.3 Steam Flow Rate

Steam is generally used for heating and humidification in buildings. The steam consumption for the heating and humidification is determined by the supplied water quantity. In most cases, the steam flow rate is not measured. In district heating and cooling, steam is consumed in large quantity. The steam flow rate is measured for heat rate transactions weighing and DHC operation. In this case, the steam consumption for airconditioning is measured by the condensate. However, the steam diffusion and other direct uses are measured by obtaining the steam flow rate. Steam mass flow rate, is obtained by measuring the pressure simultaneously.

a) Related software

Since the automatic control of the steam heating is done via the steam pressure, the flow rate is scarcely applied to the control.

b) Required performance of sensors

Since steam is often used at high pressure, a sensor having a high pressure resistance without any moving part is recommendable. See also 4.11.4.

Since steam piping ranges from large to small, various sensor diameters are required according to the pipe diameters. In the measurement ass'y, a sensor and a signal converter are often separated from each other for reason of heat insulation.

c) Applicable sensors

- Vortex flowmeter
- Ultrasonic flowmeter
- Differential pressure type
- Gear type flowmeter

4.8.4 Flow Detection

Flow detection is classified initially according to whether the fluid is air or liquid. The flow rate is detected by detecting a differential pressure movement at an orifice or by detecting the movement at a paddle.
The airflow detection is used for checking the inlet of fresh air in gas absorption chilled/hot water machines and combustion systems of the boiler. It is also used for preventing the overheating of electric heaters in air handling units.
On the other hand, the water flow detection is used for checking the chilled water flow for the purpose of preventing the chilling units from being broken due to freezing.

a) Related software
A common example of the detection of water flow may be found in chiller circuits where flow detectors serve to prevent damage due to freezing.

b) Required performance of sensors
The fluid should flow stably in a sensor ass'y, and also a straight pipe is required before and behind the sensor, so that the bellows or paddle does not oscillate. This straight pipe length should be as short as possible.
The operating flow rate for checking the flow must be optionally settable at site.

c) Applicable sensors
- Paddle (Pressure switch)
- Orifice (Pressure switch)

d) Supplementary items
Since the flow rate detection often serves as a start condition and a trip condition of devices and systems, sensors having moving parts like a paddle should be robust and reliable.

4.8.5 Limiters

Limiters are classified into a self-actuated type and power-driven types. They may be classified also by kind of fluid into a constant flow rate and a CAV (Constant Air Volume) unit to limit the airflow in an air duct. The constant flow rate valve supplies a constant flow to the radiator when the differential pressure is within a set value, even if the primary pressure fluctuates. The CAV unit utilizing the coil spring characteristic keeps the passing airflow constant even if the differential pressure changes before or behind the unit.

a) Required performance of sensors/regulators

Sensors must keep the flow rate constant over wide ranges of both upstream and downstream pressures; it is recommended that the desired flowrate be adjustable on-site.

Since the flow path area is always changed by a spring as the pressure fluctuates, moving parts should be durable.

b) Applicable sensors/regulators

- Constant flow rate valve
- CAV unit

4.9 Heat Flow Measurement

Heat flow measuring sensors in BEMS

The heat flow measurement control is divided roughly into the water system control and air (gas) system control. However, high-accuracy measurement has not been established yet for the air system because of difficulties in measurement.

4.9.1 Component Elements of Calorimeters

Calorimeters, or heatmeters are designed to give the heat flow by measuring the volume or mass flow of a medium, and the temperature difference between the supply and return. They are also classified into an assembly and a separate type according to their structures (Table 4.9). The assembly type is constructed by assembling its flow measuring ass'y, temperature detectors, and computing ass'y, while the separate type can separate these components from each other. There are some fully electronic gadget, too, eg for radiators.

- For the flowmeters, see the [Flowmeters].
- For the thermometers, see the [Thermometers].

Table 4.9 A configuration Example of Calorimeters

Sensor configuration	Application
Resistance thermometer bulb 2 units (Pt100 Ω) Flowmeter 1 unit, Turbine, Electromagnetic flowmeter Vortex flowmeter, Vane-wheel flowmeter Pitot tube Arithmetic unit 1 unit	Sequence control of heat sources

4.9.2 Required Performance of Sensors

a) An assembly type is frequently used when a low-priced sensor is needed eg for housing in district cooling and heating.

b) A composite sensor consisting of a vane-wheel type flowmeter, a resistance thermometer bulbs (Pt 100Ω), and an arithmetic unit is frequently used as an assembly type.

c) High accuracy is demanded for transactions, which meets reguration on measuring instrument, if necessary.

d) A separate type is frequently used for high-precision measurement.

e) A separate type is superior from the viewpoint of the selection of the mounting position, easy work, easy check, and easy maintenance.

4.9.3 Control Examples

Heat generators and other units of the HVAC equipment are designed with reference to the maximum load. However, these equipments actually operate in partial load almost all time. Accordingly, it is useful to split the heat generators to meet partial loads. As energy consumed by heat generators represent a large part of total energy consumption of a building, the other forms of optimization are highly desiable.
The sequence control of refrigerators is an example: it includs the sequence compensation control according to the supply water temperature and, initial start control in addition to control by heat flow, which must be examined systematically.

4.9.4 Enthalpy of Air

The energy-saving effect can be obtained by controlling an outside air intake damper for the outside air and return air after calculating their enthalpies by using temperature sensors and humidity sensors.

4.9.5 Calorie Transactions

It is desirable for central heating-cooling system in multi-tenant buildings to use a calorimeter or heatmeter, every tenant zone for the purpose of managing calorie. According to some actual results, energy-saving of more than 20% may be expected from the use of such meters. Either water meter or run-time meter can be used as simple alternatives in supplies to houses.

(1) Energy measuring objects

Methods for defining the basis for apportioning heating/cooling charges may be separated into the following two methods. One is to measure all kinds of energy consumption relating to the heat generating installation, the other is to measure only heat consumption in each buildings and zones.

a) Elements composing of energy costs in generating heat/cool
   1) Electricity
   2) Gas
   3) Steam
   4) Various fuels and others

b) Media for measuring the generated or consumed heat (or consumed heat)
   1) Liquids
   2) Gases (air, steam)

c) Approximate measurement of heat supplied
   1) Run-time meter
   2) Flowmeter
      This measurement applies to fan coil units or the like.

(2) Charging methods
The charging methods according to the above energy costs or consumed heat are shown below.
   a) Individual measurement of the consumption
      Charging is done by measuring the energy consumption of every tenant.
   b) Measurement of the consumption at the central station
      After measuring the energy consumption quantity or generated calorie at the central station, charging is apportioned every tenant as shown below:
      1) According to the occupation areas of tenants
      2) According to the working time (including the over-time) of tenants.

(Fixed amount transactions for housing are also available without any energy measurement.)

(3) Supplement
If the energy supplied to each tenant can be measured this information may be used both for charging and for energy management. However, due to some conflict of requirements, a combined measurements and charging system, with the necessary accuracy, is difficult to obtain.
Difficulties on the calorimetry with a calorimeter are as shown below.
   a) Heat flow measurement through air as a madia is not included.
   b) A temperature difference is about 7°C in cooling, so that the accuracy demands cannot be satisfied easily due to problems of accuracy in the measurement of the temperature difference and in the conversion.
      When there is no temperature difference in intermediate periods, it should be taken into account not to charge for any errouneous measurement.

4.9.6 Energy Analysis and Management

Many analysis procedures exist whereby we can:

a) determine the energy performance characteristics of items of plant and of distribution systems,
b) identify ways of reducing energy consumption, and
c) expose defects of an installed system

The analysis and management of energy is an important element in building management.

(1) Energy measuring divisions

1) The energy consumed is measured for whole buildings and for uses, and zones by the kinds of energy, such as electric power, fuels, district heat sources (heat media), and others.
2) Electric power should be measured by dividing into three divisions shown below.
   - Airconditioning, sanitation, and heat generation
   - Ilumination and receptacles
   - Others

   It is desirable to measure the electric power for airconditioning and illumination independently of each other and of other uses. It is also desirable to measure any individual loads when they are either important components or of noticeable unit capacity.
3) It is recommended that measured energy for air conditioning, sanitation and other uses is identifiable by type of fuel type.
4) If submetering is to be installed it should be supported, at least, by a check meter giving the total of submetered values.

(2) Energy management

By analyzing measured energy quantities, these data are applicable to the management. eg

1) Need of storage fuel in long and/or short term
2) Detect faults in system components and system operation,
3) Give the operator and user of the building an idea of the main heat consumers,
4) Prepare energy reports and
5) Produce a correct heating cost apportioning
6) Optimize the illmuniation zoning
7) Optimize the night power shift

4.10 Water Quality

cf. 5.3

4.11 Pressure

The pressure control applies to an air pressure in rooms, duct, and others, a water pressure in chilled/hot water and water supply piping, and a boiler steam pressure, for example. Table 4.10 shows a selection guide for these pressure sensors.

Table 4.10 Pressure Sensors Selection Guide

Object		Alarm	Control action				Applicable pressure range Note 1)						Types of sensors Note 2)			
							(1mmAq) 10	(100mmAq) 10^3	(1kgf/cm²) 10^5	(10kgf/cm²) 10^7	(100kgf/cm²) 10^9 Pa					
		ON/OFF	Floating	P	PI	PID		Very low	Low	Medium	High		Diaphragm	Pitot tube	Bellows	Bourdon-tube
Facilities	Boiler	O		O	O				—	—	—				O	O
	Refrigerator	O						—	—	—					O	O
	Air conditioner (filter, etc.)	O		O			—	—					O	O		
Conveyance system	Piping (pump, etc.)	O		O	O			—	—	—	—		O		O	O
	Duct	O	O	O	O		—	—					O	O		
System	Clean room	O				O	—	—					O			
	ICU room	O				O	—	—					O			

Note 1) The definition of pressure ranges changes more or less according to the controlled systems (coolant, cooling water, chilled water, chilled/hot water, hot water, high-temperature water, steam, air, gas, etc.).

Note 2) Materials depend upon the measuring objects.
- For high pressure ---------------------------------- Phosphor bronze, SUS316, etc.
- For low pressure and very low pressure ----- Teflon, synthetic rubber, etc.

Note 3) For the accuracy, select sensors according to the purposes and uses.

4.11.1 Indoor Pressure Control

The purposes of the indoor pressure control are to prevent the introduction or leak of air, contaminants, smoke, etc., and also to maintain the frames which are supported by means of an excess of internal air pressure, under the control of a combined compression/ decompression and air supply system.

a) Related software

1) Differential pressure control in a clean room
2) Differential pressure control in hospital wards and other various rooms
3) Smoke exhaust control in case of fire or other emergencies
4) Pressure control in an air-supported structures

b) Control method

1) In a clean room, spaces, each having different requirement for cleanliness are provided to be adjacent to each other, so that the air should flow from the room having higher cleanliness to the room having lower cleanliness. In this case, a differential pressure between both spaces is detected to control the intake outdoor air using a damper.
   In order to prevent ingress of external contaminants, the rooms are kept to be a positive pressure of about 1mmAq (10Pa). For this purpose, the differential pressure between the supply air and the return air is detected to operate the damper and fan inlet vane.
   Hospital wards are a kind of bioclean room, and these rooms are controlled by the same method which also applies to hospital rooms where organisms, radioactivity, odor, poisonous gases, and other contaminants are produced. If a temperature difference exists between adjacent rooms, the differential pressure established must be sufficient to overcome any pressure difference due to the natural ventilation.
2) The smoke exhaust control is executed to prevent the introduction of smoke by pressurizing passageways and annexed rooms, and also to absorb the indoor air by means of fans for the purpose of securing easy refuge in case of a fire. In this case, the smoke exhaust system is operated by a smoke sensor.
3) In an air-supported structure, the indoor pressure is normally kept at 30mmAq (about 300 Pa). This pressure must be increased according to additional loads in case of a snowfall or a strong wind. This control is carried out by resetting a preset pressure and adjusting the pressure fan dampers or VVVF (Variable Voltage Variable Frequency) fans after detecting a differential pressure between indoor and outdoor positions and also detecting the snowfall conditions and wind velocity.

c) Performance required for sensors

Since the control pressure range is small and a very low differential pressure is detected in clean rooms, high accuracy and rigidity are required for sensors.

d) Applicable sensors

- Bellows
- Diaphragms

e) Supplement

The limit control and redundancy should be taken into account for the purpose of securing the safety to pressure control in hospitals, shops, etc.

4.11.2 Static Pressure Control for Ducts

The discharge pressure of ducts is controlled to ensure correct airflow and air velocity in air-conditioning and ventilation.

a) Related software

1) CAV control
2) VAV control

b) Control method

When supplying air to many zones in centralized airconditioning, the operating conditions of fans are controlled to guarantee the minimum pressure by detecting the duct pressure so as to restrain changes of flowrate in other zones due to closed outlets.

When VAV control is executed by a throttling type unit, the operating conditions of fans are controlled by detecting the static pressure inside ducts for the purpose of regulating static pressure fluctuations caused by the damper operation.

c) Performance required for sensors

Sensors must be stable against vibrations and abrupt pressure changes.

d) Applicable sensors

- Pitot tube
- Bellows
- Diaphragms

4.11.3 Water Pressure Control

Piping for airconditioners, radiators, thermal storage tanks, humidifiers, cooling towers, and inside tank are the objects of detection in the water pressure control of heating cooling and airconditioning system. A differential pressure is also used for flow measurement.

a) Related software

1) Chilled/hot water pump discharge pressure control
2) VWV control of chilled/hot water control
3) Thermal storage tank return water pressure control

b) Control method

1) When the room temperature is controlled according to the thermal loads in chilled/hot water discharge pressure control, a pressure regulating valve is mounted to keep the discharge pressure constant.
2) In VWV control, a variable speed pump is used for efficient pumping operation when supplying chilled/hot water according to loads. A load inlet/outlet differential pressure signal is generative to control the pump speed. Pressure control is also executed in an open piping system to ensure the required minimum pressure.
3) In the thermal storage tank return water pressure control, a pressure at the lower part of the piping is detected, and then, controlled by changing the opening of a regulating valve for the purpose of preventing noises and vibrations due to the drop of water through a return pipe, pumping cavitation due to a negative pressure, and other failures. (Fig. 4.14)

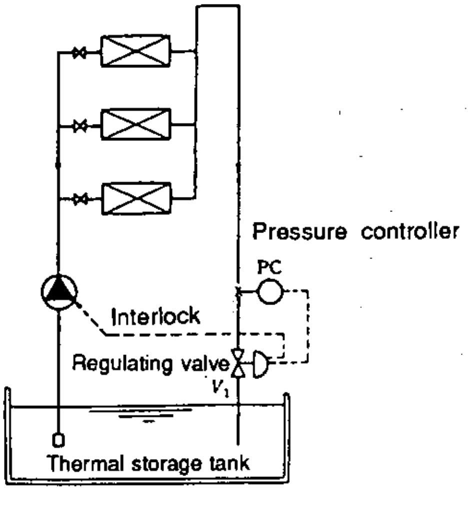


Fig. 4.14 Return Water Pressure Control [JN 20)]

c) Performance required for sensors

Select suitable sensors for 1), since the regulating valve pressure fluctuates noticeably. For 2), comparatively high accuracy is demanded. A vibration-resistant sensor is recommended for 3).

d) Applicable sensors

- Diaphragms
- Bellows
- Bourdon-tube
- Semiconductor pressure sensor

e) Supplement

The pressure measuring range, working temperature, etc. must, of course, be taken into consideration when selecting sensors. When a bellows is used as a sensor, care should be taken to the linearity and hysteresis, if the displacement increases.

Care also should be taken to the leak of water around the sensing element, too.

4.11.4 Steam Pressure Control

The steam pressure control applies to the steam generation in boilers for the use in radiators, heat exchanger, humidifiers, etc.

a) Related software

1) Feed steam pressure control
2) Limit control

b) Control method

1) The capacity control of a steam heating radiator and a steam/water heat exchanger is executed according to the steam flow or temperature to keep the supply steam constant at a specified pressure.

   Thus fuels are controlled by steam pressure.
2) The boiler steam pressure is detected to start or stop the boiler.

c) Applicable sensors

- Bourdon-tube
- Diaphragm
- Bellows
- Semiconductor pressure sensor

d) Supplement

A siphon tube is used for protecting sensors from steam.

4.11.5 Draught Control

The stack effect (draft) occurs due to a differential pressure and a wind pressure caused by an internal/external temperature difference in atria, stairwells, stairway rooms, shafts, etc. Accordingly, the draft should be prevented to eliminate uncomfortable feeling and heat loss/ gain in an airconditioned buildings.

On the other hand, the draft may be utilized effectively, since it serves as the ventilation driving force of ventilation in a naturally ventilated building. To date, there are known examples of controlling the draft by detecting a differential pressure between positions inside and outside a building, however, the door curtain, the anteroom for wind breaking at the entrance, movable ventilator driven by wind pressure and etc. are provided for controlling draught around building.

For draft control systems, sensors should be characterized with quick response, resistance against abrupt pressure fluctuations, etc.

CHAPTER 5: Sensor Application to Plumbing and Sanitation

5.1 Water Flow Rate

5.1.1 Cold and Hot Water Consumption

The consumption of cold water, hot water or resued water are all subjects for measurement and/or control. Typically each supply is pressurized; typically also control of flowrate is of no concern. Storage tanks or reservoirs are normally fed by pumps, in response to level and/pressure sensitive devices or switches.

(a) Applicable sensors

- Inferential water meter
- Positive displacement water meter
- Hot water meter
- Electromagnetic flowmeter

(b) Supplement

1) Some water meters permit flow to be read only locally, others have, either by original design or by adaptation, a transmitter for remote reading; The latter is widely used -- - --- The hot water meter is often simply a heat-resistant derivative of the cold water design.
2) Water meters typically do not register low flowrates accurately; it is necessary therefore that the flowrate range for any meter is carefully chosen.
3) When installing a water meter careful consideration should be given to factors such as ease of inspection and maintenance, susceptibility to freezing, pressure fluctuations etc.
4) A calorimeter is constructed by assembling a temperature sensor and an arithmetic function into a hot water meter.

5.1.2 Drainage Quantity

Drainage is rarely measured. However reused water is sometimes measured for the adjustment of flowrate, at the water treating facility, or when processed water is reclaimed.

(a) Applicable sensors

- Electromagnetic flowmeter
- Area flowmeter
- Weir

5.1.3 Rainfall (rain, snow)

Rainfall and/or snowfall are observed and recorded meteorologically as the precipitation. In case of buildings, the rainfall is measured when utilizing it as water source. In case of a membrane structure building, the internal pressure is controlled by detecting the snowfall on the membrane roof. The following sensors are available.

(1) Rain sensor

This sensor is used to detect the rainfall as an electrical resistance change between its rain sensing electrodes at the beginning and the end of rainfall. This resistance is infinite in dry condition. When these electrodes are moistened, the resistance amounts to several hundreds ohms to two kilo ohms to detect a rainfall. These sensors are also provided with a heater to melt snow and/or ice.

(2) Tipping-bucket rain gauge

This guage receives the rain, or snow in a cylinder of 20 cm of diameter and drops the water into a "measure" which functions as a "see-saw" moving device, and generates a pulse every 0.5mm of rainfall. It is provided with a heater for melting snow and preventing freezing to keep water at about 5°C.

(3) Rainfall intensity meter

The rainfall received by a cylinder is led a light beam through a fine tube, and the water drops are counted by triggering a photoelectric switch. One water drop corresponds to 0.0083 mm.

These sensors should be mounted at places far apart from trees, building and other noticeable disturbances of an airstream, in conformance with the guidelines for the meteorological observation.

5.1.4 Snowfall

Snowfall is visually inspected by a scale which is vertically erected on the ground, and recorded in meteorological observations. Snow lying on a membrane roof generates an excess pressure which may be countered by a controlled increase in internal air pressure. The build up of snow on such a roof can be minimized by the supply of hot air to warm the roof membrane and thereby induce melting.

5.2 Water Level

The water level is detected in a water receiving tank, a height tank, a pressure tank, a drain tank, etc. in water supply/drainage and sanitation facilities. Pumps are started or stopped, and valves are opened or closed according to a water level change.

(a) Applicable sensors

- Electrode type sensor
- Float type sensor
- Pressure sensor

(b) Supplement

When an electrode type sensor is used for drainage, detector electrodes may be contaminated with waste water. The insulation material on the electrode surface by taking the properties of the water into consideration.

5.3 Water Quality

The quality of the water employed in buildings is securely kept to be proper for the following purposes.

(1) Equipment plumbing, long-life of devices, corrosion resistance
(2) Resource and energy saving
(3) Keeping amenities of residential and productive environments

Table 5.1 shows sources of control problems and other factors relating to quality for various uses of water in buildings. Maintenance of the quality of cooling water is especially demanding as illustrated in Figure 5.1. The sensors detect the electrical conductivity of cooling water in a cooling tower, and automatically drains soiled water and feed water when it exceeds the predetermined value. They are mounted at a place where cooling water is mixed sufficiently and easily controlled without any sludge deposit.

The water quality of chilled/hot water, cold water, domestic hot water, and humidification water is not controlled in general, but it is often checked periodically by a maintenance engineer. Since chemical and biological methods are applied, reagents, standard solutions and tools should be handled or treated with due care.

Table 5.1 Water Usage and Corresponding Problem in Water Quality

Use	Problem	pH	Hardness	Electric conductivity	BOD	Chromaticity	Turbidity
Cooling water	Scale		O Less than 200	O Less than 800			
	Corrosion	O 6.5 ~ 8					
	Slime						O
Chilled/hot water	Corrosion	O					
	Scale		O	O			
Cold water Domestic hot-water Drain	Corrosion	O				O	
	Pollution				O	O	O
Humidifying water	Lime, germs etc.		O	O			

[Note] Numerics show the quality control standards specified by the Japan Airconditioning and Refrigeration Industry Association.

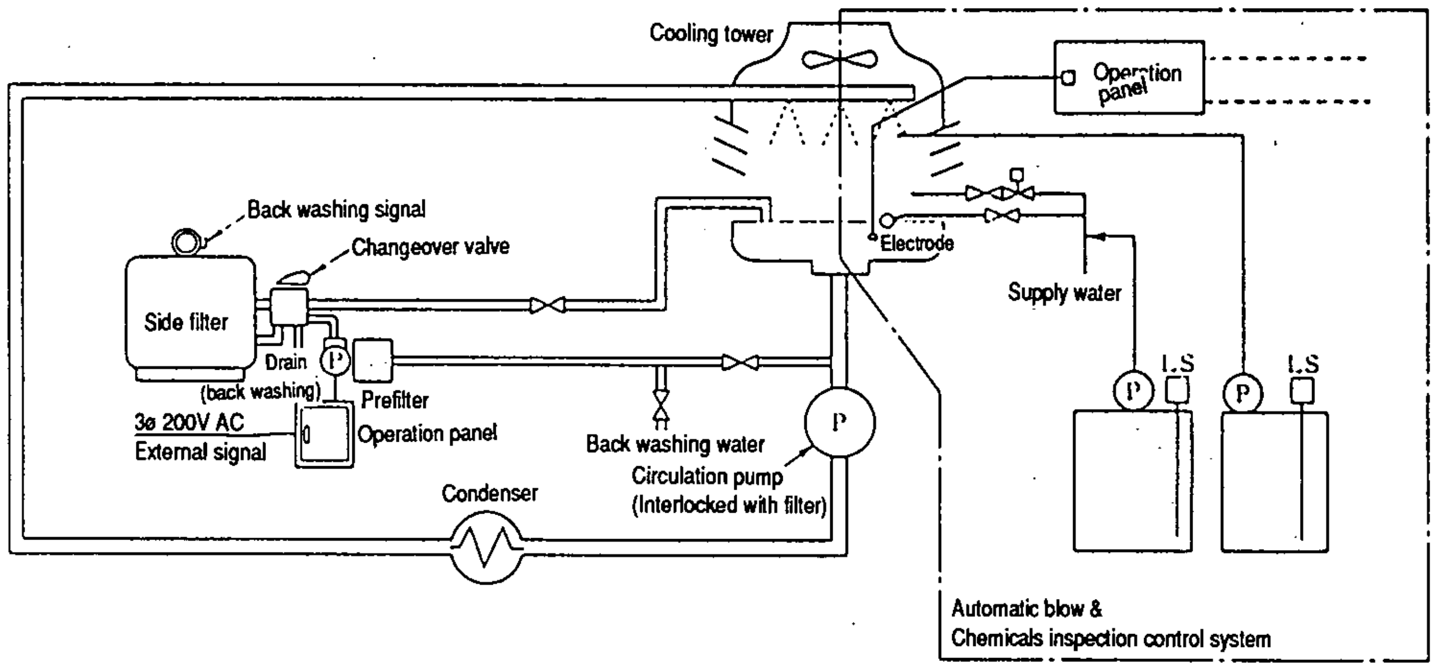


Fig. 5.1 An Example of Automatic Cooling Water Control System

5.4 Temperatures

cf. 4.1

5.5 Heat Flow

cf. 4.9

5.6 Pressure

cf. 4.11

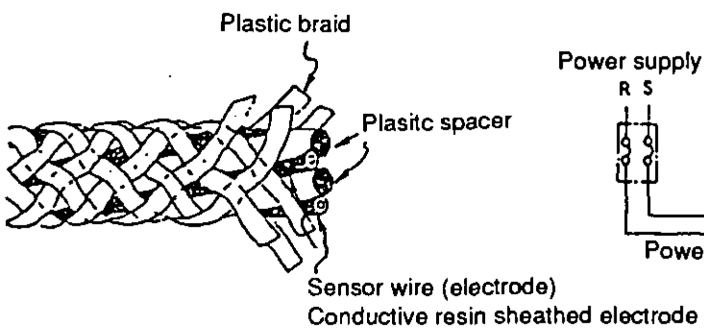
5.7 Others

5.7.1 Urination Detection (for automatic flushing)

Automatic flushing is used from the viewpoints of economizing flushing water, users' convenience, and sanitation. A pyroelectric sensor and an infrared sensor are available. The former can serve a number of urinals if correctly positioned and suitably chosen - so as to take account of its limited range and angle of view. However, be careful with its mounting position, since its detecting directions, range, and distance are limited. The latter is mounted at every toilet stool. A system is composed of a controller and a flushing valve in any case.

5.7.2 Leak Water Detection

This sensor is mounted below a raised floor of a computer room, at certain piping and/or air-conditioning plant, telephone exchanges, electric power receiving & distribution facilities, which may be seriously damaged if subjected to a water leak. This sensor detects a water leak point quickly, and issues an alarm and/or cuts off the water supply. If the sensor cable is moistened, the resistance between the electrodes is reduced to be lower than specified. Examples are shown in Fig. 5.2 and Fig. 5.3.



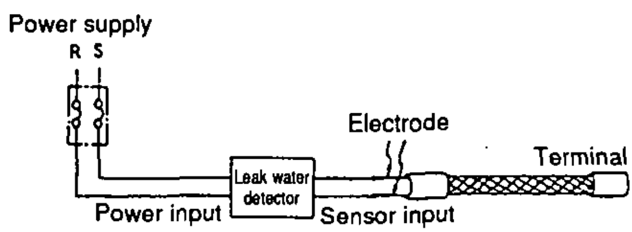


Fig. 5.2 An Example of Sensor Cables

Fig. 5.3 An Example Use

(a) Related software

1) Alarm in case of a water leak

2) Supply water interruption in case of a water leak

(b) Performance required for sensors

1) Sensors should be located at appropreate position to detect the water leak accuracy.

2) High reliability

3) Rigid structure and easy mounting

4) High sensitivity, clear indication of fault

5) Easy extension, modifications, and repair

6) No electric leak occurs when water leaks.

7) Quick resetting

(c) Applicable sensors

- A moistened position changes its color.
- Cable type sensors play a leading role in general.

However, electrode type sensors are also used according to application purposes.

(d) Supplementary items

The [Electronic Computer System Safety Measure Standards] specify the safety standards for electronic computers in Japan.

6.1 Electric Power System

6.1.1 Power Factor Improvement Control (Reactive power control)

The power factor is improved by reducing the lag side reactive power due to an inductive load by means of turning on a capacitors in step, thus, reducing the energy loss.

(1) Related software

Power factor improvement control

(2) Control method

Capacitors for power factor improvement are turned on or off according to the main secondary reactive power of the transformers, to keep the power factor at the utiliy's metering point as near unity as practicable.

In order to prevent hunting due to turn-on and off of capacitors, a reactive power lag or lead set point must be set as a dead band. The capacitors are turned on and off by a cyclic method to average their switching operation in most cases, and the control is executed when the power value is higher than specified.

(3) Performance required for sensors

Sensors should mainly satisfy the following performance.

a) Compact : Sensors should be small-sized for mounting them on a transducer panels and also saving a limited space in an electrical room.

b) High performance

c) High reliability

(4) Applicable sensors

a) Reactive power transducer

b) Active power transducer

c) Power factor transducer

d) Combined active/reactive power transducer

(5) Supplement

Since the high-limits of the voltage and current inputs of a transducer are limited to several hundreds volts and several amperes, an instrument potential transformer (PT) and a current transformer (CT) must be installed.

6.1.2 Power Demand Control

This system executes predictive monitoring of received power, so that the received power should not exceed the contracted demand with an electric power company at working conditions, and it controls to reduce loads if the power is presumable to exceed or has exceeded the contracted demand.

(1) Related software

a) Demand monitoring

b) Demand control

(2) Control method

When the actual power is found to exceed the contracted demand by the demand monitoring function, this system shuts off interruptible loads according to their priority to reduce overall demand within the contract power, and also turns on the interrupted loads when the above excessive condition has been eliminated.

(3) Performance required for sensors

Sensors should mainly satisfy the following performance.

a) Compact : Sensors should be small-sized for mounting them on a transducer panels thus saving limited space in an electrical room.

b) High performance

c) High reliability

d) Fastness

(Remote control switches must match the current of switched devices.)

(4) Applicable sensors

a) Active power transducer

b) Combined active/reactive power transducer

c) Wattmeter with a transmitter

6.2 Lighting System

Sensors are used in a "lighting management system" or "lighting control system" for automatically controlling the lighting at the perimeter zone buildings in the daytime or turning on and off the outdoor lighting..

6.2.1 Perimeter Lighting Control

Where artificial lighting is switched in banks parallel to a window it is possible to achieve significant savings in lighting energy by means of a control driven either from a light level sensor positioned externally or internally.

(1) Measurement in perimeter lighting control

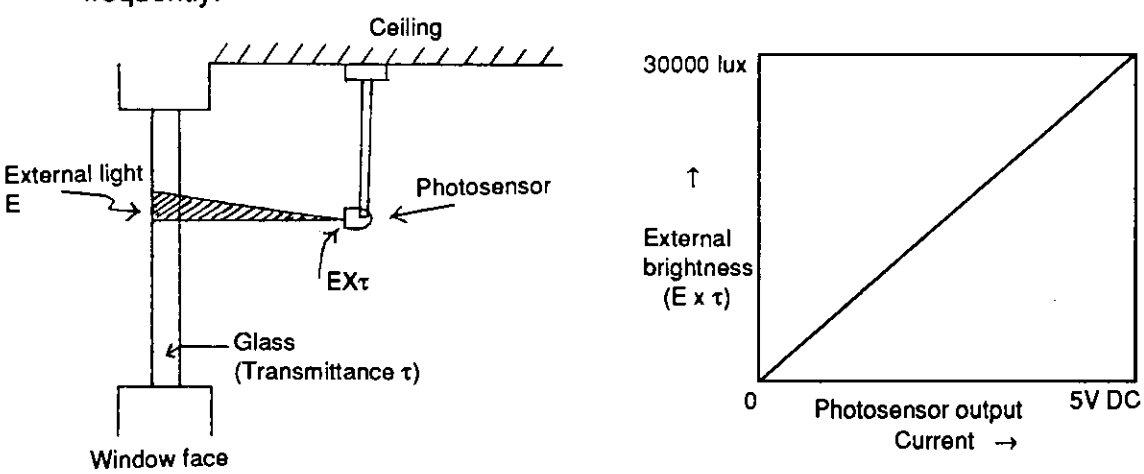
a) Related software

1) Perimeter lighting on-off control

2) Perimeter lighting multistage dimmer control

b) Control method

This system activates by measuring the change of the quantity of the external light coming through the window by using a photosensor mounted at the perimeter zone, and compares the measured values with preset values. Then, it automatically turns on and off the perimeter lighting or executes multistage dimmer control so as to keep the indoor lighting intensity constant at the window. An installation example is shown in Fig. 6.1. It is recommendable for the perimeter lighting control to execute continuously variable by using either rheostat or multistage dimmer control so as not to give any discomfort to occupants. It is also necessary to provide a time lag of several minutes to more than ten minutes against an abrupt change of the external light quantity due to clouds, showers, and other meteorological changes so as not to turn on or off the lighting frequently.



* Light is converted into a current through an internal photocoupler of the photosensor.

Fig. 6.1 An Installation and Output Example of a Photosensor

c) Performance required for sensors

Sensors should satisfy mainly the following performance. A sensor is generally suspended from the ceiling inside the window for sensing the incident light through the window. In this case, the sensor must be mounted to correctly measure the incident diffuse day light through the window. It should have good appearance.

1) An adequate luminance range (0 ~ several ten thousand lux)
2) Negligible long-term drift
3) Lightweight
4) Excellent design
5) Having the lag against an abrupt change of brightness

d) Applicable sensor

- Silicon photocell (with the visibility compensation)

e) Supplement

Mount the photosensor selectively at the following mounting positions for correctly measuring the incident light throught the window.

1) Select a window position where the lighting intensity can be measured as a mean and representative value in case of the same azimuth window face.
2) Mount the sensor inside a blind when windows are faced in the azimuth direction exposed to the direct sunlight (east and southwest faces).
3) Mount the sensor at a place where the surrounding environment outside the window (trees and buildings) changes little.
4) Mount the photosensor as close to the window face as possible for the purpose of eliminating the influences of lighting devices inside.

6.2.2 Blind Open/Close Control

This system detects sunlight transmitted through a window so as to open/close a blind and/or adjust its blade angle as required. It may also execute a multi-stage dimmer control of the indoor lighting intensity by means of a photosensor according to the blind conditions.

(1) Measurement for the blind open/close control

a) Related software

1) Multistage dimmer control of perimeter zone lighting
2) Blind open/close control

b) Control method

This system calculates the annual trajectory of the sun and automatically open or close the blinds and change the blade angle according to the direct incident light quantity through the window. It also executes the multistage dimmer control of the indoor window lighting automatically according to the blind angle.

c) Performance required for sensors

Sensors should satisfy the following requirements. The interrelationship among the measured direct sunlight intensity, calculated blade angle of the blinds and control of perimeter zone lighting should be fully taken into consideration in each directions of the building.

1) Captures the direct incident sunlight on the window of surface precisely.

2) Captures the incident light through on to the blind blade at each angle precisely.

d) Applicable sensors

- Silicon photocell (with visibility compensation)
- Luminance meter
- Pyrheliometer

e) Supplement

The control system should be carefully examined, because the incident light quantity through the window differs according to the blind materials and blade profiles.

6.2.3 Outdoor Lighting Control

For outdoor lighting facilities, the lighting is automatically turned on and off by means of sensor control throughout the year.

(1) Measurement in outdoor lighting control

a) Related software

1) Outdoor lighting on-off control

2) Outdoor lighting time schedule control

b) Control method

The outdoor lighting facilities are automatically lit at about 150 lux in the evening, and turned off about 300 lux next morning.

c) Performance required for sensors

Sensors should satisfy mainly the following criterion. These sensors are often mounted on outer walls of buildings or poles for sensing the external light.

Sensors are required to be weatherproof and have a range appropriate to whether they sense horizontal or vertical plane illuminace. Care must be taken to minimize the influence of the direct component of sunlight and that of any reflected light.

1) The brightness range should be detectable in units of 100 lux.
2) Small long-term drift
3) Lightweight
4) Not easily stained
5) Easy maintenance and servicing

d) Applicable sensor

Silicon photocell (with the visibility compensation)

e) Supplement

Fine lighting control can be established by combining sensors with timers:
All lamps are on during the evening, half are on at midnight and all are off by morning.

6.3 Monitoring, Recording, and Analysis

6.3.1 Monitoring

(1) Related software

a) Monitoring of the high-limit/low-limit of measured values

b) Monitoring of analog values and count values

c) Various alarms monitoring

d) Equipment status monitoring

e) Power demand monitoring

f) Analog measurement

g) Pulse counting, etc.

(2) Performance required for sensors

cf. 6.1.1, 6.1.2. and 6.2.

(3) Applicable sensors

These sensors serve as control sensors. In addition, these sensors are used to monitor the transformer temperature (resistance thermometer bulb Pt), a ground fault, circuit breaker conditions, and other status.

6.3.2 Recording

(1) Related software

a) Alarm messages

b) Operation messages

c) Status change messages

d) Daily report, monthly report, and other reports

e) Data storage on floppies, hard discs etc

f) Trend recording

g) Hard copy of CRT display screen and others

6.3.3 Analysis

Load fluctuation prediction, system analysis, simulation and other processes such as optimization are executed off-line (batch processing); all these processes required recorded data as input.

For the performance required for sensors and applicable sensors, see those in para. 6.

CHAPTER 7: Sensor Application to Security and Fire Prevention

7.1 Fire Detection

A fire sensor automatically detects the occurrence of a fire by detecting the heat, a combustion product (smoke), or a flame generated by a fire. Sensors may be classified as set out in Table 7.1.

This classification is according to Japanese practice; adjustments may be necessary for other countries. Each sensors should be installed so as make best use of its particular characteristics for the detection or prevention of a fire.

7.1.1 Mounting position of fire detector

(1) A fire detector may be installed anywhere except:

1) A position where the mounting face of the sensor is higher than 20 meters above floor.
2) A top roof or other places where an external air current circulates and the occurrence of a fire cannot be detected by the sensor.
3) Within a ceiling void with a height of less than 0.5m

(2) Places where a smoke sensor must be mounted

1) Stairs and ramps
2) Corridors and passage ways (excluding certain portions)
3) Elevator shafts, linen chutes, pipe ducts, and other similar places
4) Places where the mounting face of the sensor is higher than 15 meters but lower than 20 meters above floor
5) Base floor, windowless floors, and floors higher than the 11th floor other than those specified above (excluding certain portions)

(3) Places where the installation of a smoke sensor is prohibited

1) Places where dust, fine particles, or steam stay in large quantities
2) Places where a corrosive gas may be generated
3) Kitchens and other places where smoke stays usually
4) Very hot places
5) Places where maintenance is difficult.

(4) The fire alarming areas are determined according to the types and sensitivity of sensors.

7.1.2. Flame sensors

Flame sensors are utilized for fire prevention.

(1) Fire prevention in tunnels
(2) Outdoor fire detection
(3) Large-space buildings

Table 7.1 Classification of Fire Detector [JN 30)]

Types				Sensitivity	Operating principle
Heat detector	Diffused type (Rate of temperature rise)	Spot type		Class 1, Class 2	This is triggered by means of a heat effect at a local position when the ambient temperature has reached a certain rate of temperature rise.
		Line type	Pneumatic type	Class 1, Class 2, Class 3	This is triggered by means of an accumulated heat effect over a wide range when the operating temperature has reached a certain rate of temperature rise. (The thermal expansion of air is utilized.)
			Thermocouple type	Class 1, Class 2, Class 3	The operation mode is the same as specified in the pneumatic type. This detector utilizes the heat electromotive force of a thermocouple.
			Heat semiconductor type	Class 1, Class 2, Class 3	This detector uses a heat semiconductor in the heat sensing element.
	Fixed temperature type	Spot type		Special class, Class 1, Class 2	This detector is triggered when the ambient temperature exceeds a certain temperature at a local position. It uses a bimetal, a semiconductor, or a fusible insulator (a non-reuse type).
		Detected line type		Special class, Class 1, Class 2	This detector is triggered in the same way as in the spot type. It is of a wire type in appearance, and not reusable.
	Combined type	Spot type		Class 1, Class 2	The sensitivity of this detector changes as the ambient temperature changes at a local position. This detector is classified into the differential type and a fixed temperature type according to its performance.
Smoke detector	Ionization spot type	Delay type Time delay type		Class 1, Class 2, Class 3	The time delay type does not send any fire signal until smoke (a combustion product) at a certain concentration is collected in the sensing element for a certain period. It is suitable for a smoking room, a meeting room, or other rooms where smoke is apt to be produced under normal condition.
	Photoelectric spot type	Delay type Time delay type		Class 1, Class 2, Class 3	
	Photoelectric separate type	Delay type Time delay type		Class 1, Class 2	The light emitter and receiver are separately mounted to totally sense the smoke diffused in a certain space.
		Combined spot type			A combination of the performance of ionization spot type and the performance of photoelectric spot type.
Combined detector	Heat and smoke combined spot type				A combination of heat spot type and smoke spot type.
	Multiple point detector				A combination of different sensitivity and operating temperature signals.
Flame detector	Ultraviolet detector				This detector utilizes the principle of detecting the wavelengths in the ultraviolet range generated by a fire.
	Infrared detector	Radiation type			This detector recognizes as a fire when the radiation intensity level exceeds a certain level.
		Radaition filter type	Single radiation filter type		This system detects only a flickering component of flame by a frequency amplifier.
			Multiple radiation filter type		This detector detects the radiation levels of two separate wavelengths, and determines a real fire according to the output ratio.

Table 7.2 Selection Guide of Fire Detector

Mounting position		Applicable heat detector				Applicable smoke detector						Control action	Remarks
Environmetnal condition	Definite examples	Differential type		Combined type	Fixed temperature type	Ionization spot type		Photoelectric spot type		Photoelectric separate type			
		Spot type	Line type			Delay type	Time delay type	Delay type	Time delay type	Delay type	Time delay type		
Places other than specified in the following columns	Places where are free of the possibility of a fire	○	○	○	○	○	○	○	○	○	○	2P	
Places where a smoke sensor must be mounted	• Stairs and slope ways • Corridors and passage ways • Elevator shafts, linen chutes, pipe ducts, or similar ones • Places where a smoke sensor is mounted at higher than 15m but lower than 20m • Underground floor, windowless floor, and floors higher than the 11th floor					○	○	○	○	○	○	2P	
Places where dust and fine particles stay in large quantities	Dumping grounds, packages handling places, painting rooms, stonepits, etc.		○	○	○							2P	
Places where steam stays in large quantities	Steam washing rooms, hot-water heating rooms, dressing rooms, sterilizing rooms, etc.		○	○	○							2P	
Places where corrosive gases may be generated	Plating shops, battery rooms, sewage disposal plants, etc.		○	○	○							2P	
Kitchens or other places where smoke emits under a normal condition	Kitchens, cooking room, welding work rooms, etc.				○							2P	
Very hot places	Drying rooms, sterilizing rooms, boiler rooms, casting rooms, projector rooms, studios, etc.				○							2P	
Places where an exhaust gases arize in large quantities	Parking areas, garages, package handling places, ramps, generator rooms, truck yards, engine test rooms, etc.	○	○	○								2P	
Places where smoke may be produced in large quantities	Service rooms, front rooms of kitchen, food refrigerators in kitchen, dumbwaiters, corridors and passage ways around a kitchen, dining rooms, etc.	○	○	○	○							2P	

Table 7.2 Continued

Mounting position		Applicable heat detector				Applicable smoke detector						Control action	Remarks
Environmetnal condition	Definite examples	Differential type		Com-bined type	Fixed tem-perature type	Ionization spot type		Photoelectric spot type		Photoelectric separate type			
		Spot type	Line type			Delay type	Time delay type	Delay type	Time delay type	Delay type	Time delay type		
Places where the condensa-tion occurs	Warehouses or factories, each having a roof covered with a slate or an iron plate, exclusive accommodation compart-ments of package type refrigerators, enclosed underground warehouses, peripheries of freezers, etc.		○	○	○							2P	
Places where a smok stays to cause poor ventilation due to cigarette smoking	Meeting rooms, reception rooms, waiting rooms, dressing rooms, amuse-ment halls, tea rooms, restaurants, cabarets, and other collection rooms, banquet halls, etc.	○	○	○					○	○	○	2P	
Places used for sleeping facilities	Guest rooms of hotels, bed rooms, nap rooms, etc.						○		○	○	○	2P	
Places where fine particles other than smoke are floating	Underground passage ways, etc.						○		○	○	○	2P	
Positions ex-posed to wind	Lobbies, chapels, viewing stands, machinery rooms in tower buildings, etc.	○	○						○	○	○	2P	
Places where smoke reaches a sensor after moving over a long distance	Corridors, stairs, roads slope ways, clevator shafts, etc.							○		○	○	2P	
Places where a fire may occur due to smoul-dering	Telephone machinery rooms, communication machinery rooms, com-puter rooms, mechanical control rooms, etc.							○	○	○	○	2P	
Large spaces or high-ceiling places where heat and smoke are diffused	Gymnasiums, aeroplane hangers, high-ceiling factories, and upper part of viewing stands where the mounting place is higher than 8 meters	○	○							○	○	2P	
Others and special fire prevention	Tunnels, outdoor fire sensing, large-space structures											2P	Flame detec-tor

7.2 Security Detection Against Trespassers

An increased need for security has led to an increased range of person-detectors: also high precision security alarms, using infrared, ultrasonic, --- units permit detection systems which are spot, linear, --- or three-dimensionally sensitive.

Table 7.3 lists security sensors, their operation principles and likelihood of use. Sensors are grouped according to whether or not they are for inside or for outdoor use, for the detection of explosions, presence of metals, access control, CCTV or other specific applications.

Table 7.3 Security Detection Against Trespassers [JN 31)]

◎ Often
O Normal
Δ Not often

Major sort	Medium sort	Detector	Signal	Operation principle	Utilization frequency
Indoors	Spatial alarm (Facial alarm)	Passive infrared type	ON/OFF	Detects 7 to 10 μm infrared rays radiated from the human body.	◎
		Ultrasonic type	ON/OFF	Radiates ultrasonic waves into a monitoring area, and detects a Doppler effect frequency produced when an object moves in the area.	◎
		Electromagnetic wave type	ON/OFF	Utilizes the Doppler effect in the same way as in the ultrasonic type.	◎
	Linear alarm	Infrared type	ON/OFF	A projector is mounted on one side, while a receiver is mounted on the other side. The receiver gets modulated infrared rays always radiated from the projector, and detects a trespasser when infrared beam is shut off by the trespasser.	◎
		Trap sensor	ON/OFF	This sensor is a simple linear alarm device having a laid cable.	O
		Electromagnetic wave (micro-wave)	ON/OFF	This sensor is used for linear alarming over a long distance. Due to a long wavelength, the alarm range becomes wider as compared with the cable laying type, causing difficulty of the jumping over.	◎
	Point alarm	Magnetic type	ON/OFF	This sensor consists of an independent magnet ass'y and a switch to open or close the contacts when two components approach each other or separate from each other.	◎
		Vibration type	ON/OFF	This sensor detects specified frequencies generated by vibrations and shocks.	◎
		Piezoelectric type	ON/OFF	This sensor utilizes the Piezoelectric effect which transforms vibration or a pressure into a voltage.	◎
		Limit switch	ON/OFF	This is utilized for detecting the open and closed conditions of windows, doors, etc.	O
Outdoors	Linear alarm	Infrared type	ON/OFF	A projector is mounted on one side, while a receiver is mounted on the other side. The receiver receives modulated infrared rays alway radiated from the projector, and detects a trespasser when infrared beams are shut off by the trespasser.	◎
		Visible light	ON/OFF	See above, except for the 'infrared' to exchanged with 'visible' light.	◎
		Electromagnetic wave type	ON/OFF	This sensor is used for linear alarming over a long distance. Due to a long wavelength, the alarm range becomes wide as compared with the cable laying type, causing the jumping, and other trespassing to be difficult. This sensor is not noticeably affected by trees, leaves, etc.	◎
	Fence mounting type	Wire-breaking type	ON/OFF	This sensor is a simple linear alarm device having a laid cable.	◎

◎ Often
O Normal
Δ Not often

Table 7.3 Continued

Major sort	Medium sort	Detector	Signal	Operation principle	Utilization frequency
Outdoors	Fence mounting type	Tension type	ON/OFF	Detects a trespasser when a stretched wire is charge with a load more than a specified value or when the wire was cut.	◎
		Vibration type	ON/OFF	This sensor detects specified frequencies generated by vibrations and shocks.	◎
	Embedded type	Vibration type	ON/OFF	See above	O
		Piezoelectric type	ON/OFF	See the same type for indoors	O
Detector	Wire tapping detector	Electric wave type	ON/OFF	Detects an electric wave emitted from a concealed microphone.	Δ
	Metal detector	X-ray type	ON/OFF	This sensor detects metals by radiating X-rays which are projected on a polaroid film or a CRT.	Δ
	Explosive detector	Gas chromatography type	ON/OFF	This sensor detects explosives by means of gas chromatography.	Δ
Entrance control unit	Entrance control gate	Magnetic card type	ON/OFF	Controls the entrance by checking coded magnetic cards.	◎
		Magnetic tag type	ON/OFF	An activated magnetic substance generates higher harmonics by means of magnetism.	◎
		Photo read type (face print)	ON/OFF	An individual checker utilizing the image information of faces.	Δ
		Hand print identification type (Palm print, finger print)	ON/OFF	This sensor stores hand prints of persons into memory in advance and checks these hand prints when persons enter or leave the gate.	Δ
		Speach print read type (*1)	ON/OFF	This system collates words (voices) and codes with pre-assigned ones at the time of entrances. It discriminates them by wave amplitude and frequencies.	Δ
		Electric wave type	ON/OFF	This system mainly uses the inductive communication method by utilizing medium wave bands.	O
		Metal film type	ON/OFF	Individual checker utilizing an electromagnetic no-contact card.	Δ
		Ten keys (push-buttons) type	ON/OFF	This sensor collates pre-assigned numbers with the numbers entered by pressing ten keys.	◎
		Retina (eye) type	ON/OFF	This sensor stores retina patterns into memory by means of infrared rays, and checks them.	Δ
CCTV system				This system projects an image of a specified person or unspecified persons on a screen, automatically detects an abnormal condition of the image by visual check or by a motion detector or the like, and then, checks, records, and alarms it.	◎
Others		Shoplifting preventive device	ON/OFF	Detects a commodity having a special tag sticker when it passes a sensor gate.	Δ
		Burglar alarm mirror	None (Visual check)	Widens the monitoring range by increasing the visible range by means of a wide angle mirror.	Δ
		Automatic guest information device		This sensor detects the infrared rays being radiated from a human body or a Doppler effect frequency produced by radiating ultrasonic waves.	Δ

(*1): Speach print read type (Speach recognition device)

7.3 Gas Leak Sensor

This sensor detects a leak of city gas or LP gas employed in buildings and gives an alarm when the concentration exceeds a safety limit.

a) Gas leak detection: ON/OFF

b) Control method

City gas detector: Detection concentration; 1/200 ~ 1/4 of the lower-limit of explosive concentration
Alarm delay time; 20 ~ 60sec

c) Features of city gas leak sensor (Table 7.4)

Table 7.4 Gas Leak Sensor

Type / Item	Detection type		
	Semiconductor type	Contact combustion type	Gas thermal conduction type
Material	Heater electrode Indium, palladium alloy Semiconductor: SnO_2	Detection element } Compensating element } Platinum wire	Detection element } Compensating element } Platinum wire Semiconductor: SnO_2, etc.
Detection principle	The resistance value of a semiconductor changes according to the gas concentration.	The resistance value of a platinum wire changes due to the heat produced when the gas is oxidized on the surface of the coiled platinum wire.	This sensor utilizes a difference of the thermal conduction of semiconductors coated to a coiled platinum wire according to the gas conditions. The resistance value changes reversely as compared with the contact combustion type.
Features	• A resistance value change to a gas is comparatively stable. • A large output is obtainable. • Stable for a long time	• Various characteristics are excellent owing to a combined use with the compensating element.	• Almost the same as in the contact combustion type

● Semiconductor type sensors are employed in almost all cases.

d) Required features of sensors

1) Sensors should not be affected noticeably by environmental conditions and by coexisting substances in the air.
2) Fast response speed and excellent reproducibility
3) Stable operation for a long time
4) A long maintenance/check period and easy maintenance and calibration (Maintenance-free is desirable)
5) Inexpensive and readily available

e) Supplementary items

- The mounting positions of gas leak detectors are specified by the Fire Fighting Law, Gas Enterprise Law, and Liquefied Petroleum Gas Law in Japan.
- Household gas leak detectors are replaced once every 5 years, while those for industrial uses are replaced once every 4 years (in case of Tokyo Gas Co.).

7.4 Seismic Sensors

Seismic sensors are employed in buildings for preventing secondary diasters. They serve as an elevator control device emergency shut off of city gas and a seismic recorder in underground shopping center and a like in case of earthquake.

a) Control software

Elevator output : ON/OFF
Gas shut-off : ON/OFF
Oil stove : ON/OFF
Seismic recording : Continuous variables measurement

b) Control method

1) Set values of seismic sensors employed in seismic control operation devices of elevators are specified as shown in Table 7.5, in principle.

Table 7.5 Set Values of Seismic Sensors

Building height	Specially low set value (gal)	Low set value (gal)	High set value (gal)
Lower than 60m	80m or P-wave detector	120	150
Higher than 60m, but lower than 120m	30, 40, 60 or P-wave detector	60, 80 or 100	100, 120 or 150
Higher than 120m	25, 30 or P-wave detector	40, 60 or 80	80, 100 or 120

2) City gas shut-off
City gas shut-off set value in underground markets ------ 250 (gal)
3) Household city gas shut-off (MY-SAFE) ------------------- 200 (gal)
4) Household oil stove --------The sensor shall not function at lower than 150 (gal), but it shall function positively at higher than 250 (gal).

c) Sensor types and accuracy

Table 7.6 shows the types and accuracy of seismic sensors.

Table 7.6 Types and Accuracy of Seismic Sensors

Type	Principle	Reproducibility	Time response	Failure rate (10^{-6}) *
Weight tilting drop ball type	This sensor measures the seismic intensity according to whether the spherical body on a pipe drops or not due to the horizontal acceleration which is applied by the terrestrial movement.	1 ~ 5Hz About 5%	About 0.2 ~ 2s	13.7
Mechanical pendulum type	This sensor utilizes the principle that a pressure difference produced during an earthquake is proportional to the acceleration. It converts a microscopic change into an electrical resistance or inductance.	Less than 1%	About 10 ~ 30sec	6.3
Electric output type	This sensor measures the acceleration by converting it into a current.	Less than 1%	About 10 ~ 30ms	53.7

* Typical value

d) Required performance of sensors

1) Shall consist of parts each having a small failure rate.
2) Excellent environmental resistance
3) Short delay
4) Easy and secure maintenance check
5) Cheap and long durable

e) Applicable sensors

1) Elevator ---------------------- Pendulum type
2) Seismic shut-off device --- Drop ball type
3) Heaters ---------------------- Drop ball type

7.5 Water Flooding Detection

cf. 5.7.2

CHAPTER 8: Sensor Application to Miscellaneous Installations and Energy/ Environmental Management

8.1 Fuels Control and Measurement

Gases and fuel oil serve as major fuels. A boiler converts them into energy. This paragraph does not deal with any built-in sensors of boilers.
A gas supply line may comprises a gas pressure detection sensor for safety and a seismic sensor. For measuring the gas flow, various gas meters are provided for controlling the consumption.

a) Control software
Gas pressure detection : ON/OFF action
Seismic detector : With the functions of analizing as well as valuating of vibration mode
Gas flow : Counting function

b) Control method
Shutt-off control under an abnormal condition
: Shuts off the gas supply when the gas supply pressure becomes lower than 300 Pa.
: Shuts off the gas supply when detecting quake acceleration of more than about 200 gal.
Gas consumption counter
: No control function is provided. An automatic meter inspection system will transmit data to a gas supply company through a telephone line in the future.

c) Required performance of sensors
Compact design : A gas pressure detector, a seismic sensor, and a gas meter are assembled into a box, and these sensors are demanded to be smaller due to building circumstances. Therefore, these detectors will adopt circuits uses semiconductors technologies.
High accuracy : Since seismic sensors operate on the principle of the ball action due to vibrations, the mechanical accuracy is highly demanded.

d) Applicable sensors
Pressure switch : Diaphragm type (Built inside a gas meter for gas pressure detection.)
Seismic sensor : Pendulum type, Earthquake detection, Built inside a gas meter.
Gas meter : Diaphragm type : For general users
Wet type : For a reference use
Root type : For large users

e) Supplementary items
These sensors depend largely upon the device development concepts of big gas suppliers.

8.2 Lifts (elevators) Control

In multi-storey buildings elevators play an important role as a vertical transportation system; they are required to be safe, reliable, to be comfortable for passengers and to have other technical features such as precise levelling at a floor, energy efficiency etc.
This paragraph describes the accuracy required for control to meet the operating performance requirement, the applicable sensors, the security and related aspects.

8.2.1 For Feedback Control

Table 8.1 shows the relationship among the accuracy required for each control of elevators, control algorithms, and control action.

Table 8.1 Elevator Control Sensors

Item	Building	Use	Control item	Control algorithm	Control action	Required accuracy	Applicable sensor
Running perform-ance	Residen-tial & Commer-cial buildings	For passen gers use & For freight use	Speed	Feedback	PI, PID	High	Pulse generator Speed generator
			Accel-eration	Feedback	PI, PID	High	Pulse generator Speed generator
			Weight	Setback control	2P	Normal	Microswitch
				Feedback	P	High	Differential trans-former
			Position	Setback control	2P	High	Reed relay
				Feedback	PI, PID	High	Pulse generator

8.2.2 For Optimal Control

Elevators are required to move smoothly between floors and to stop accurately at the desired floor irrespective of the number of persons in the car. This can only be achieved with accurate measurements and close control.

(1) Measurement of car load

The car load is measured to prevent an overweight failure for securing a safe run of an elevator. The elevator must not started running, if an overweight is detected. A microswitch is mainly used as a detection sensor.

The sensor also measures the load accurately to compensate for the control signal of the motor speed for ensuring a smooth run of the car.

In this case, a high-accuracy sensor is demanded to output a signal proportional to the loads without any noticeable hysteresis.

(2) Measurement of car position

The traveling distance and the absolute position of the car must be detected. The traveling distance of the car is mainly obtained by measuring the number of pulses from the pulse generator of the motor. This measuring signal serves as a data for decelerating the elevator to a desired floor.

A car position detection sensor is mounted near the floor level of each floor on the pit side to compensate the stop distance of the car for the purpose of accurately positioning the car to the desired floor level.

A reed switch mainly serves as a absolute car position sensor. It should not have any noticeable hysteresis when turning it on and off.

8.2.3 Security of Elevators

Elevators must be kept safe against earthquakes, fires, and power failure. These security systems must be prepared to meet the scales, uses, and control systems of buildings. The emergency control method differs more or less according to the magnitude of earthquakes. This paragraph describes seismic sensors and emergency control at the presence of earthquake.

(1) Seismic sensors

Seismic sensors are provided for enhanced safety to stop an elevator at the nearest floor quickly to save passengers when an earthquake has occurred. These sensors are classified into a P-wave sensor which detects P waves having a high propagation speed and an S-wave sensor which detects S waves having a low propagation speed with intense energy.

The P-wave sensor is generally called coil type vibrometer. It consists of a sensor to generate a current in proportion to the magnitude of seismic movement, and an amplifier. On the other hand, the S-wave sensor is generally called magnet type S-wave sensor. Its magnet being attracted to the main body drops when subjected to seismic vibrations to detect an earthquake. The pendulum type S-wave sensor, which is used widely, detects the oscillations of the built-in pendulum weight. The P-wave sensor is mainly mounted in the pit, while the S-wave sensor is mounted in the machinery room.

a) Required performance of sensors
   Seismic sensors should not respond to other than seismic vibrations. These sensors are classified into either a normal or a precise class according to their detection accuracy.
b) Applicable sensors (Regulations in Japan)
   Normal class ------- Motor room at less than 45m above ground.
   Precise class ------ Motor room at 45m or more above ground.

(2) Management operation control

a) When only the P-wave sensor was triggered (a small earthquake):
   The elevator stops at the nearest floor, and waits for about 30 seconds after opening its door. It is automatically reset to run, if the S-wave sensor does not respond during this time.
b) When the S-wave sensor was triggered:
   If the S-wave sensor has sensed an earthquake as a low grade (an earthquake having a medium seismic intensity), the elevator stops at the nearest floor. It is then taken out of service until cleared for use by a specialist. If it has sensed an earthquake as a high grade (an earthquake haivng a strong seismic intensity), the elevator stops running at once.

8.3 Door Movement

Doors are classified into auto doors, remote controlled manual doors, electric shutters, and other types. Sensors are used in their opening mechanisms for controlling the automatic opening or checking/monitoring the open or closed condition. Since the opening portions must be constructed to secure the airtightness of buildings, various sensors provide a secure opening control function and an opening/closing check function for the purpose of reducing the airconditioning loads.

a) Control type

Opening/closing control of auto doors

Control and monitoring of manual doors and emergency doors

b) Control action

Opening/closing control : Safety and minimum opening/closing time control through low-speed, high-speed, and timer operations of doors by detecting persons and articles

Control and monitoring : Remote monitoring of electronic keys and remote opening/closing control by detecting the open/closed conditions of doors

c) Required performance of sensors

Long life : Particularly required for sensors of auto doors which are opened and closed frequently.

High reliability : Required for human body detection and open/closed conditions detection of auto doors

d) Applicable sensors

Detection of moving persons and articles through an auto door (mounted at the entrance)

Rubber mat switch : A basic popular door sensor

Electromagnetic mat switch : A durable rubber mat switch

Doppler sensor : A typical non-contact sensor

Ultrasonic sensor : Not used widely because it is susceptible to interference.

Photoelectric sensor : Particularly used for safety.

Piezoelectric sensor : Used for detecting persons only.

Induction loop : A common type for automated vehicular door in the UK

Detection of moving position of automatic doors

Detection of open/closed conditions of manual or emergency doors

: An electronic key is built in.

Reed switch : Detection of moving position of automatic door mechanism

Microswitch : This switch is built inside an electronic key to check the open/closed conditions.

e) Supplementary items

Non-contact sensors, for the detection of passengers crossing the lift-landing threshold, are now preferred to the contact types for the purpose of improving their durability and water-proofing. The reliability of no-contact sensors is further demanded.

8.4 Meteorological and Environmental Sensors

Meteorological and environmental elements contain the wind direction, wind velocity, air pollution, odor, noises, vibrations, electromagnetic waves, radioactive rays (X-rays, radon) and others. These environmental sensors are scarcely applied to buildings in general at present, except for the meteorological observatories, some specified chemical plants, and other particular buildings. The environmental conditions may be measured by a portable sensor in general buildings for the purpose of periodical maintenance and inspections.

Since, environmental pollution problems have recently come into the focus in various fields, however, environmental sensors will be utilized increasingly for monitoring, control, and energy-saving in buildings in the future.

CHAPTER 9: CASE STUDIES FOR SELECTION OF SENSORS

Seven examples are described to illustrate the methods used in sensor selection. As shown in Table 9.1 below, a wide variety of situations is covered in these examples. Presentation of each example is in the form of a tutorial, starting with a description of the building and a specification of the criteria to be met.

Table 9.1 Examples for Selecting Sensors

No.	Kind of buildings	Object room	Airconditioning/ heat source system	Controlled Variables	Remarks
9.1	School	Classroom	Hot water heating, forced ventilation	Temperature, ventilation (CO_2)	Manual ventilation
9.2	Office	Office room	Hot air heating (airconditioning)	Optimal on-off of airconditioner	Adaptive control
9.3	Office	—	Airconditioning system in each floor	Flow, pressure, No. of pump units	
9.4	Industry	Measuring instrument room	Full airconditioning system	Temperature, humidity	Applicable to clean rooms, etc., too.
9.5	Any	—	Thermal storage system	Refrigerator number, capacity, thermal storage temperature.	
9.6	Office	Office room, Perimeter	Daylight + artificial lighting	Illumination	
9.7	Office	—	DHC heat source	Heat flow measurement	

9.1 Temperature and Ventilation Control in a School Classroom with Varying Occupancies (classroom)

9.1.1 Airconditioning System Conditions

- School classroom (accommodating 50 persons)
- Heating system: Hot water heating
- Ventilation system: Forced ventilation
- District: Sapporo (HDD = 4000) HDD; Heating degree/days
- Excessive ventilation should be avoided for energy-saving.
- Pupils should be kept healthy.

9.1.2 Control System (cf. Fig. 9.1)

1) Hot water panel heater system
2) A hot water valve is controlled for a hot water panel heater according to room temperature T_1.
3) The room temperature sensor should be tamper-proof, but adjustment by a teacher is to be permitted.
4) The hot water/supply water temperature is controlled according to T_2.
5) The hot water/supply water temperature is compensated for the outdoor temperature according to T_2 and T_3. (cf. Fig. 9.2)
6) A simultaneous supply/exhaust fan with a total heat exchanger is employed as the ventilation system for energy-saving.
7) This fan is interlocked with the indoor lighting switch, and operated by a teacher according to the number of indoor pupils. A speed changeover switch is mounted as required. Since the seating capacity is fixed as a condition of this case study, this system has a sufficient capacity.

<Supplementary items>

- If the seating capacity is variable in a classroom, it is recommended to select the variable airflow rate of the ventilation fan with a total heat exchanger.
  By operating this fan with a CO_2 sensor, the IAQ (indoor air quality) can be improved and energy can be saved. However, the balance between the application purposes and costs must be taken into consideration.

9.1.3 Selection of Sensors

1) Room temperature (cf. Table 2.3, Table 3.1, 4.1, Table 4.4)
   T_1:Bellows, diaphragm, electric temperature controller (indoor type)
2) Hot water supply temperature (cf. Table 2.3, Table 3.1, 4.3.5)
   T_2:Resistance thermometer bulb (Pt, Ni) (Insertion type with a protective tube)
3) Outdoor air temperature (cf. Table 2.3, Table 3.1, 4.2, 4.2.3)
   T_3:Resistance thermometer bulb (Pt, Ni) (Inside an instrument screen).

<Supplementary items>

- Since the seating capacity is fixed as a condition for this case study and the load fluctuations are not considerable, a simple electric control system is sufficient.
- An electronic control system is used when a system contains central monitoring facilities. In such a case, an indoor type resistance thermometer bulbs (Pt, Ni, Balco) and thermistors should be selected.

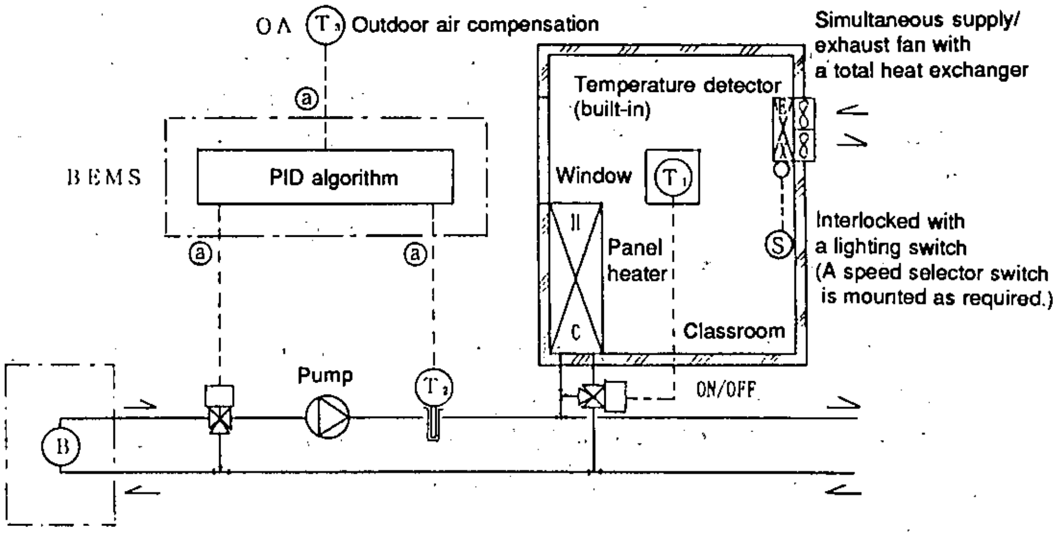


Fig. 9.1 Schema of Temperature and Ventilation Control

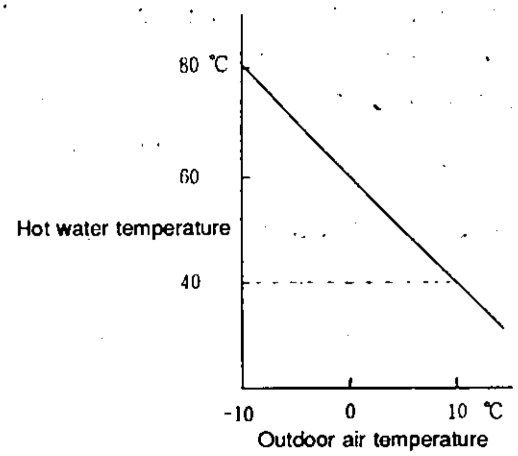


Fig. 9.2 Outdoor Air Temperature Compensation Example

9.2 Optimal Start-Stop Control in an Airconditioned Office

9.2.1 Building and Airconditioning System Parameters

- A mullistoried office building of a medium or large scale
- Zoned for each four directions.
- The perimeter uses a 4-pipe (individual or zone) fan-coil unit system.
- The airconditioning system for the interior is the all air VAV system corresponding to the cooling load only.
- Outdoor air is supplied by an interior HVAC system only.
- Preheating and precooling are supplied only by the fan coil unit in the perimeter.
- No airconditioner fan is on-off controlled during run time.

9.2.2 Control System (cf. Fig. 9.3, Fig. 9.4)

1) The trends of the outdoor air temperature are measured and typical floor room temperature, and the correlationship between the outdoor air temperature and a room temperature decay during plant shut down over night are obtained by learning.
2) The correlationship among a room temperature rise after starting the heating operation, the outdoor air temperature, the solar radiation, and the hot water supply temperature for each direction are obtained by learning every azimuth as study results.
3) The preheating operation start time for each direction are determined by inputting an allowable temperature deviation from the preset temperature at the start time of occupancy.
4) Keeps track of the actual temperature deviation from the set point temperature and adjusts parameters in the time decision formula in 2).
5) Determines the precooling time by the same logic as described above, since precooling is required for cooling in certain directions.

   <Supplementary items>

   i) Whether this control is required to be made for certain directions or not is determined by the airconditioning zoning which is affected by the thermal characteristics of buildings.
   ii) For the typical floor room in 1), a room having few partitions should be selected and the measuring position should be within 3 meters from the outer wall.
   iii) The floor temperature may be measured instead of the indoor temperature.

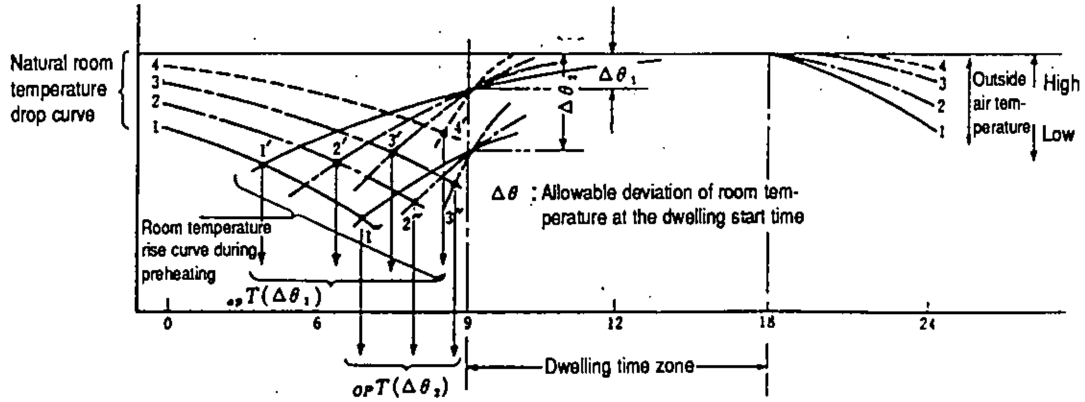
6) The interior airconditioner for the inner zone is controlled by a timer.

9.2.3 Selection of Sensors

1) Resistance thermometer bulb for trend observation
(cf. 4.1.2(1), Table 2.3, Table 3.1, Table 4.4)
T_O (Outdoor dry-bulb temperature)
Platinum resistance thermometer bulb (Instrument box mounted on the roof)
T_R (Indoor dry-bulb temperature)
Platinum resistance thermometer bulb (Indoor type)
T_F (Internal temperature beneath floor)
Platinum resistance thermometer bulb, Thermistor (Floor embedded type)

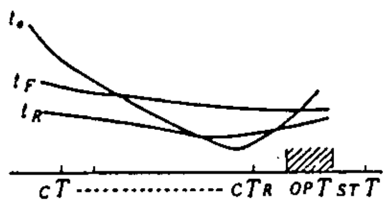
2) Hot water supply temperature
(cf. 4.3.5(2), Table 2.3, Table 3.1)
T_{WS} (Hot water supply temperature)
Platinum resistance thermometer bulb (Piping insertion type with a protective tube)

3) Solar radiation quantity (cf. 4.4.1(1), Table 2.3, Table 3.1)
I_T (Solarimetric quantity)
Thermopile type Eppley pyranometer
(Mounted on the roof unshaded)



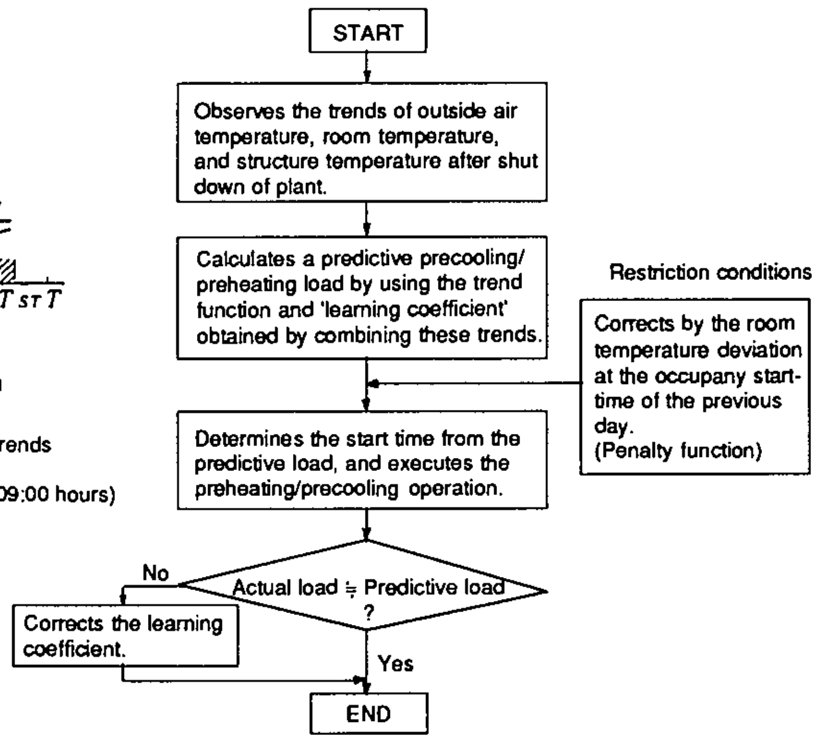
$_{OP}T\ (\Delta\theta)$: Optimal start-stop time when allowable deviation of room temperature is $\Delta\theta$.

Fig. 9.3 Concept of Preheating Control



(a) Trend observation

$_CT$: Observation start time of trends
$_{OP}T$: Optimal start time
$_{ST}T$: Building use start time (= 09:00 hours)



(b) Outlined optimization flow of preheating/precooling operation

Fig. 9.4 Optimal Airconditioner Start-stop Control Flow

9.3 Sequence Control of Chilled/Hot Water Pump

9.3.1 Building and Airconditioning System Conditions

- Secondary chilled/hot water pump
- Closed circuit pump
- A two-way valve is used as a control valve for airconditioners (variable volume system)
- About 3 to 5 pump units, each having the same performance, are required.

9.3.2 Control System and the Selection of Sensors

(1) Control system (Fig. 9.5, Fig. 9.6)

1) The number of pump units is in operation controlled according to the loads so as to save drive power.
2) The number of operating pump units is selectable by the flow detection method.
3) A minimum bypass valve is open during the operation of a pump unit for preventing the pumps from being heated (about 10% of the rated flow of pump).

<Supplementary items>

- In addition to the sequence control by the pumps each having the same performance, the pump speed control and switching operation of small and large pumps are effective for saving energy.

(2) Selection of sensors

1) Flowmeter for sequence control: A combined electromagnetic flowmeter (cf. 4.8.2) with
   a) Wide measuring range
   b) Comparatively short straight piping portion necessary
   c) High accuracy
   d) Easy maintenance

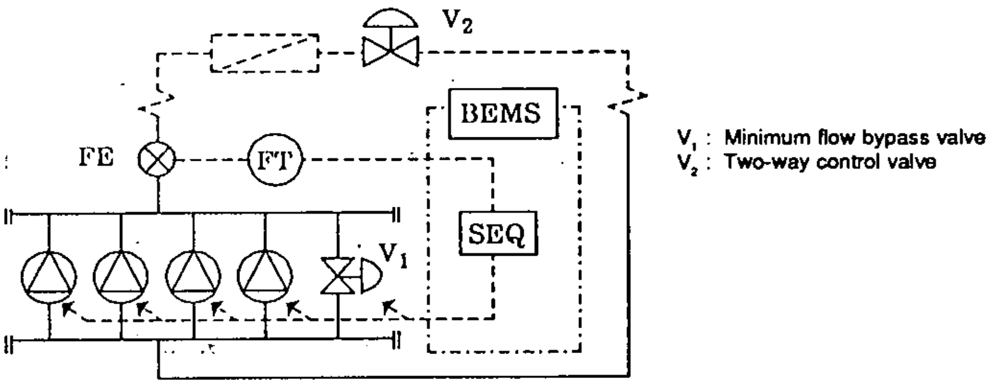


Fig. 9.5 Sequence Control Diagram

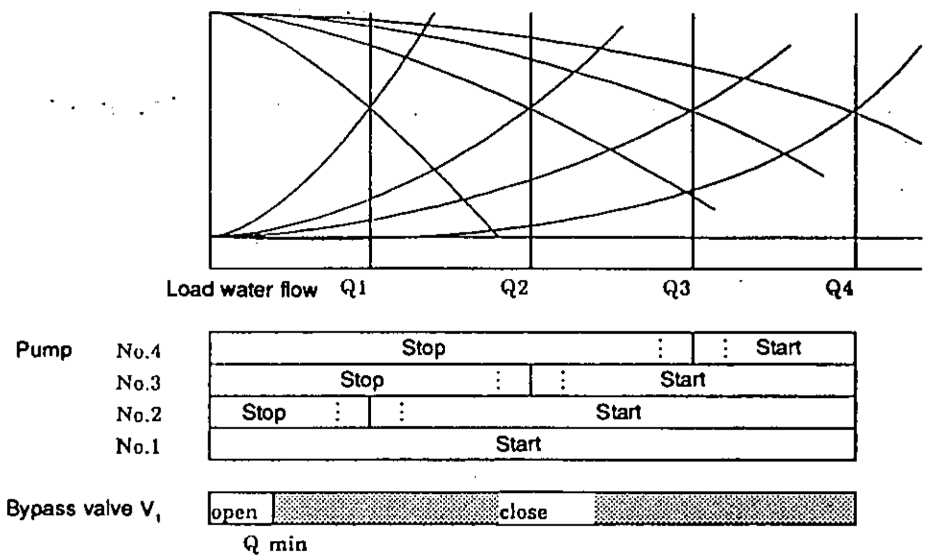


Fig. 9.6 Pump Characteristics and Sequence Control

9.4 Precisely Constant Temperature/Humidity Control for an Instrument Examination Room

9.4.1 Airconditioning System Conditions

- Measuring instrument room
- Control accuracy

  Temperature : ±0.1°C

  Humidity : ±5% RH
- Indoor controlled system space

  FL + 500 ~ FL + 1100mm

  300mm from the outer wall side

  150mm from the inner wall side
- The design conditions should be satisfied when no person is inside the room. However, the vicinities of measuring instruments which shows a transient phenomenon due to turning on/off of lighting as well as local heating by the instruments themselves.
- The target air cleanliness level is class 100. (ICR: US Federal Standards FS209B, BCR: US Aerospace Standards NH3340.2)

9.4.2 Control System Conditions (cf. Fig. 9.7)

1) The outdoor air is fed through an outdoor-air airconditioner filter, and lowered to the dew point temperature by the cooling coil. Then, the supply air temperature is PID-controlled by the heating coil.

   The supply air humidity is controlled by the dew point temperature of supply air.
2) The air treated in the primary outdoor-air airconditioner, and the return air from the measuring instrument room are mixed with each other, and processed again by the measuring instrument room airconditioner.
3) In the measuring instrument room airconditioner, a booster heater (electric heater) is PID-controlled by an SCR (thyristor unit), and also, the humidity is controlled by a steam humidifier.

   Air is supplied into the room through an HEPA filter for satisfying the design condition of cleanliness.

<Supplementary items>

- The room should be surrounded with a double wall.
- The air supply system should be designed to approximately produce an approximate laminar stream through the entire ceiling face made of a metallic perforated plate. (cf. Fig. 9.8)
- The air return system should be designed to exhaust the air at four circumferential faces of the room. (cf. Fig. 9.8)
- The ventilation rate should be 25 to 40 times/hour under the present design conditions.
- The controllability is noticeably affected by the ventilation rate. It is not profitable from the viewpoints of the equipment cost and running cost to increase the ventilation frequency more than necessary. Energy can be saved by improving the thermal insulation of the wall.

9.4.3 Selection of Sensors

1) Primary outdoor air processing airconditioner, cooling coil outlet temperature (cf. Table 2.3, Table 3.1, Table 4.4)

   T_1 : Platinum resistance thermometer bulb (Insertion type)

The following precautions should be observed when selecting sensors:

- The supply air temperature sensor should be securely mounted. (cf. Fig. 9.9 (a))
- The temperature sensor should not be affected by the radiation heat of heating coil. (cf. Fig. 9.9 (b))
- The cooling coil outlet temperature should be controlled by the dry-bulb temperature (not by the dew point temperature).

Reason: In case of the dew-point temperature control, either dehumidification or cooling may become insufficient, or it is possible that cooling is not done at all under certain outdoor air conditions. (cf. Fig. 9.10 (a), (b))

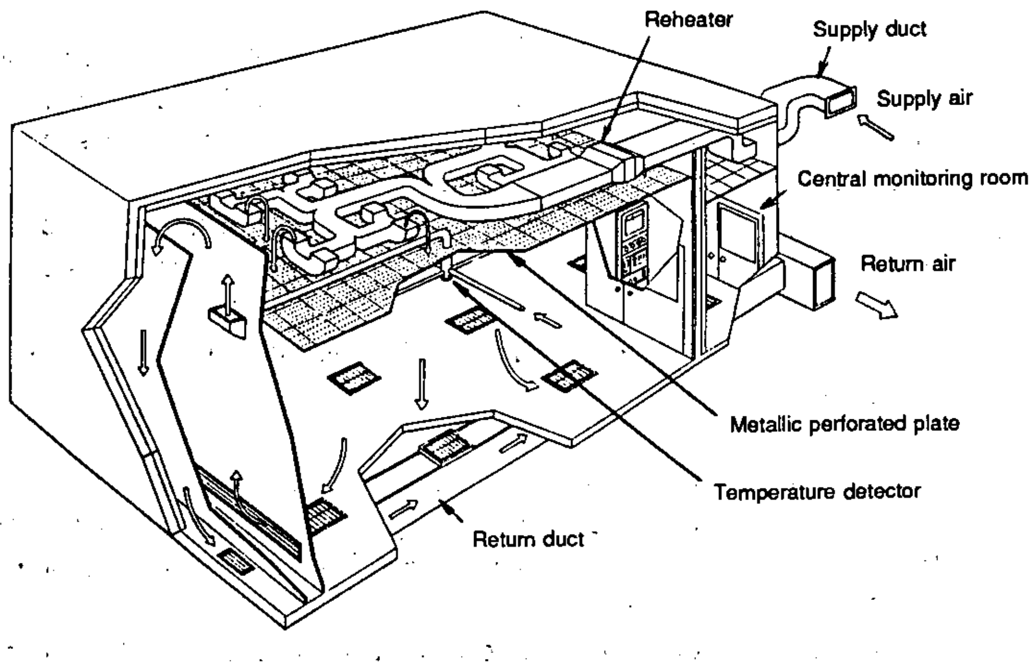
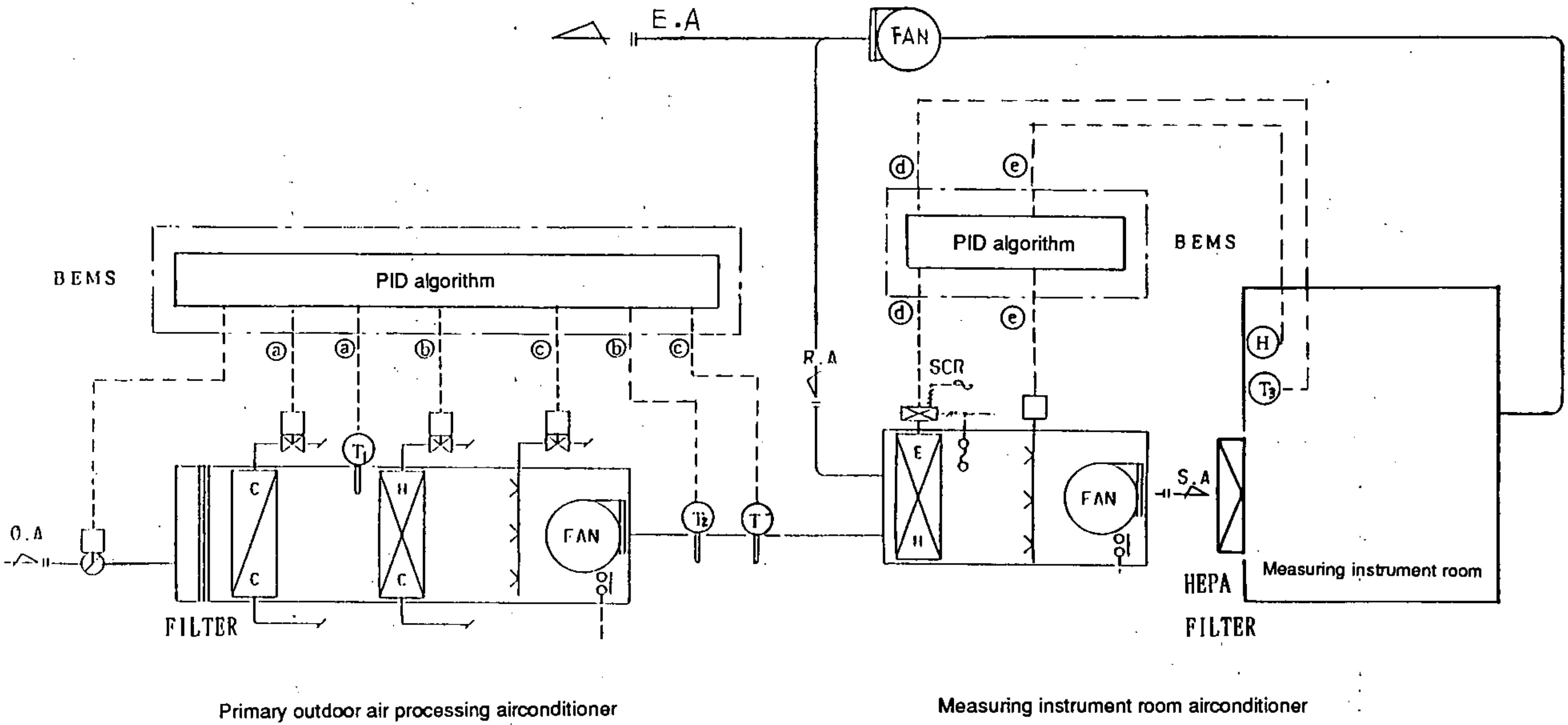


Fig. 9.8 Sectional Perspective Drawing of Thermostatic Room [JN 6)]



Note: ⓐ ----☐---- ⓐ indicates direct relationship of signal transfer for both sides.

Fig. 9.7 Instrumentation Diagram

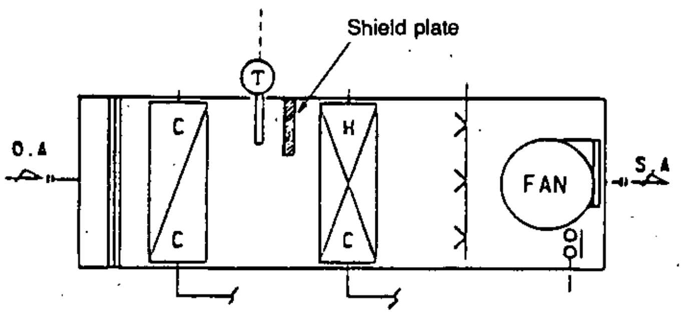


Fig. 9.9 (a)

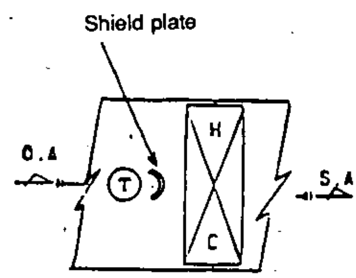
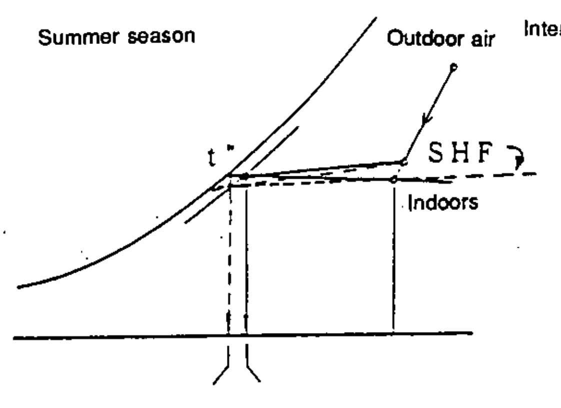


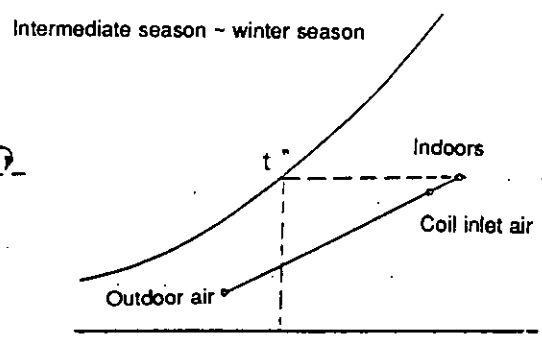
Fig. 9.9 (b) Top View



In case of dry-bulb temperature control

In case of dew-point temperature control

Fig. 9.10 (a)



No cooling signal is issued, if the dew-point temperature of the coil inlet air is lower than a set point variable.

Fig. 9.10 (b)

2) Primary outdoor air processing airconditioner, supply air temperature
   (cf. Table 2.3, Table 3.1, Table 4.4)
   T_2 : Platinum resistance thermometer bulb (Insertion type) for PID control
3) Primary outdoor air processing airconditioner, supply air humidity
   (cf. Table 2.3, Table 3.1, Table 4.6, 4.5.3)
   T" : Dew point temperature sensor (LiCl+Ni, ceramics+Pt) for PID control
4) Measuring instrument room temperature
   (cf. Table 2.3, Table 3.1, Table 4.4)
   T_3 : Platinum resistance thermometer bulb (Indoor type)

<Supplementary items>

- High accuracy and quick response are necessary.
- These sensors should be housed inside a sampling tube having a forced ventilation unit to detect the temperature at the center of the room for the purpose of preventing the radiation and obtaining an average temperature. (cf. Fig. 9.8)

5) Measuring instrument room humidity
   (cf. Table 2.3, Table 3.1, Table 4.6, 4.5)
   H : Humidity sensor (LiCl, ceramics, high polymer), indoor type
   High accuracy and quick response are necessary.
6) Cleanliness inside the measuring instrument room
   (cf. Table 3.1, 4.7)
   The cleanliness should be measured and monitored by a condensation nuclear measuring instrument or a laser particle counter.

<Supplementary items>

- This case study is applicable to operation rooms of hospital, ICU, bio-clean rooms, and other similar rooms.
- Since the control accuracy and cleanliness differ according to uses, sensors and filters should be selected according to purposes.

9.5 Sequence Control of Heat Pump Operation in Thermal Storage System

9.5.1 Heat Source System Conditions

- As the water storage tank, the multi-connected complete mixing type was used. It is divided into two in winter, each for hot water and chilled water respectively.
- Thermal storage operation is in a partial mode at the partial air conditioning load, the day time operation are reduced and fully utilized the night time electricity.
- A load prediction calculation is practiced in a separate routine.
- The capacity of the electrical centrifugal heat pump is controlled by current; ie in a full capacity.

9.5.2 Control System (cf. Fig. 9.11, Fig. 9.12)

(1) Sequence control of heat pumps

1) Calculates the residual thermal storage quantity from the temperature distribution inside the water thermal storage tank before entering the night power time zone (2200 hours usually).

2) Required heat pump unit to operate preferentially in the night time zone according to the compensation between predictive load and the residual thermal storage quantity.

3) Calculates and update the predictive load and residual thermal storage quantity at every hour.

4) Executes the operation control to add or reduce the number of operating units according to the heat balance conditions.

(2) Capacity control of heat pumps

1) Executes the vane control with the rated current for the maximum capacity operation at the rated power.

2) A built-in thermostat of the heat pump for normal outlet temperature control should be removed, or used as a protector for freezing at a low temperature.

3) An interrupter should be mounted to suppress the vane opening speed at the starting time.

(3) Thermal storage temperature control (three-way suction valve control)

1) The set point temperature for the thermal storage is determined by a separate routine.

2) The system controls a pump suction three-way valve to indirectly adjust the inlet temperature by the instruction of the outlet temperature of the evaporator (chilled water) or condenser (hot water) to keep constant inlet temperature to the tank.

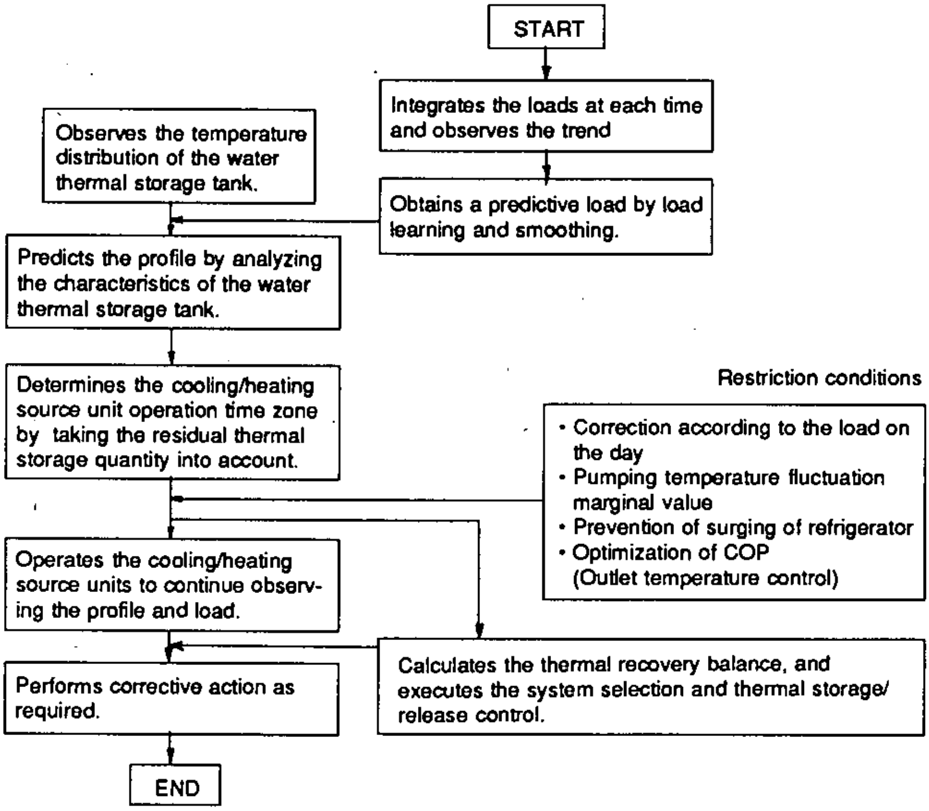
3) After stopping the heat pump, the three-way valve is bypassed to the pumping side (low temperature side for chilled water and high temperature side for hot water).

9.5.3 Selection of Sensors

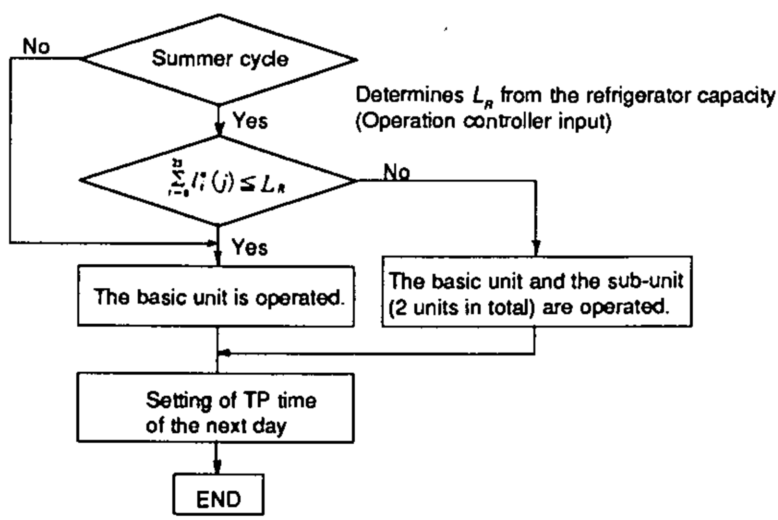
1) Resistance thermometer bulb for measuring the temperature inside the water thermal storage tank (for calculating the thermal storage quantity).
   (cf. 4.3.2, Table 2.3, Table 3.1)
   T_S (Water tank temperature)
   Platinum resistance thermometer bulb (suspension type inside the tank)
2) For thermal storage temperature control
   (cf. 4.3.5-1, Table 2.3, Table 3.1)
   T_O (Outlet temperature)
   Platinum resistance thermometer bulb (Piping insertion type)

   Caution: Three-way valve control should be done by PID control for minimizing a offset. The offset, if any, unfavorably affects the pumping temperature from the water thermal storage tank, to the airconditioners and also interferes action of built-in low temperature cutting control.
3) For heat pump stop (cf. 4.3.5(2), Table 3.1)
   T_O (Outlet temperature)
   As described above.
4) For chilled water low temperature cutting (cf. 4.3.5(2), Table 3.1)
   T_{LC} (Outlet temperature)
   Nickel resistance thermometer bulb, thermistor, remote valve type, etc.

There are several built-in sensors in a standard heat pump products, however, these sensors should be systematically combined with the outside sensors attached for optional control as shown in this example. Otherwise the sensor group in both sides often works viciously each other.

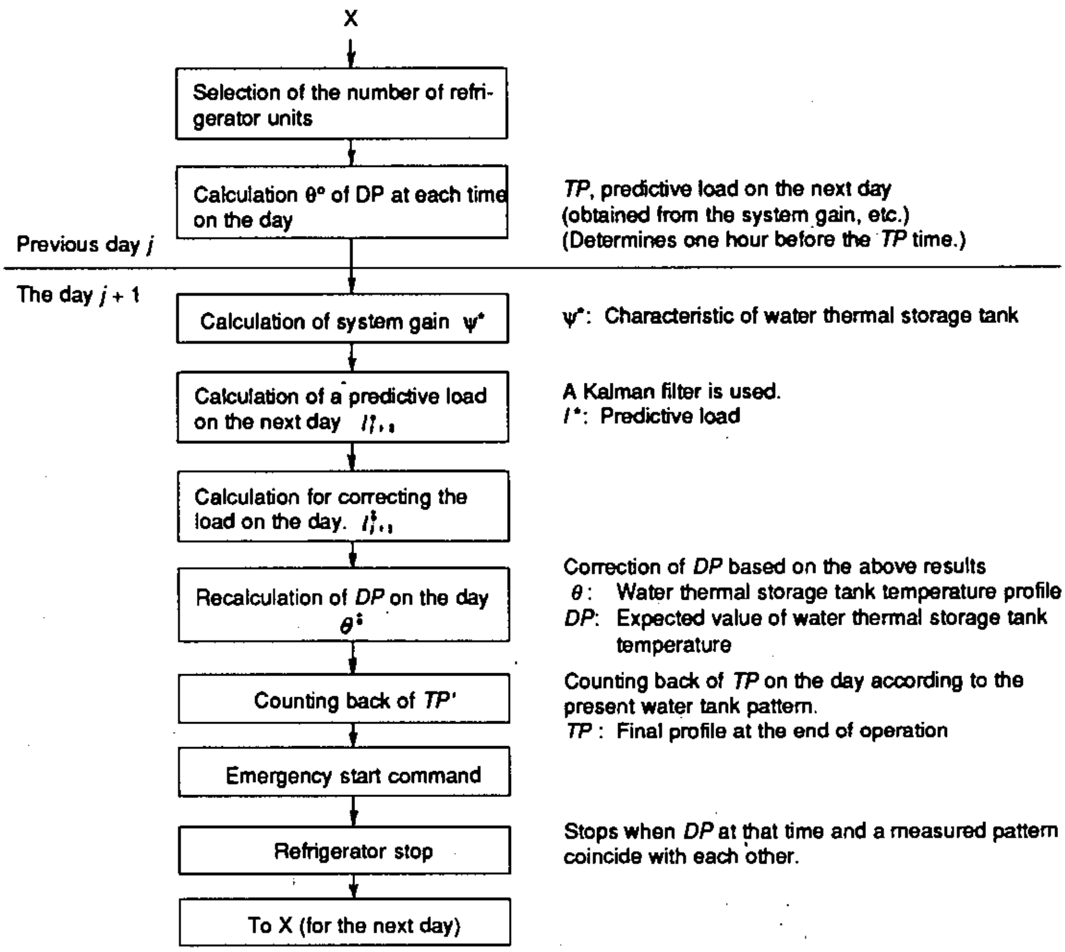


(a) Basic flow

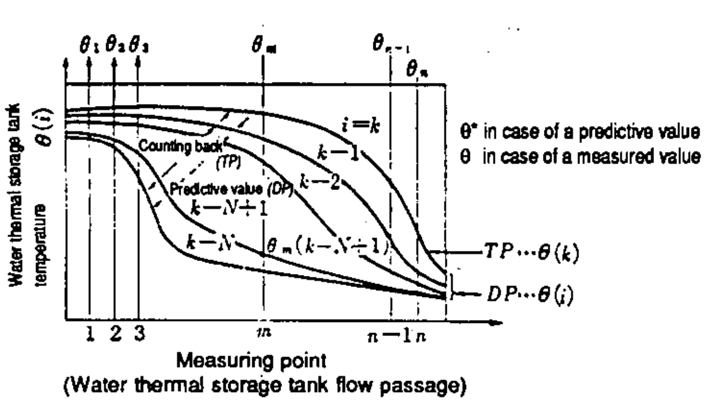


(b) Flow of selecting the number of refrigerator units

Fig. 9.11 Flow for Determing the Number of Heat Pump Units in Operation



(c) Refrigerator stop flow



(d) Water thermal storage tank temperature profile and its calculation

Fig. 9.11 Continued

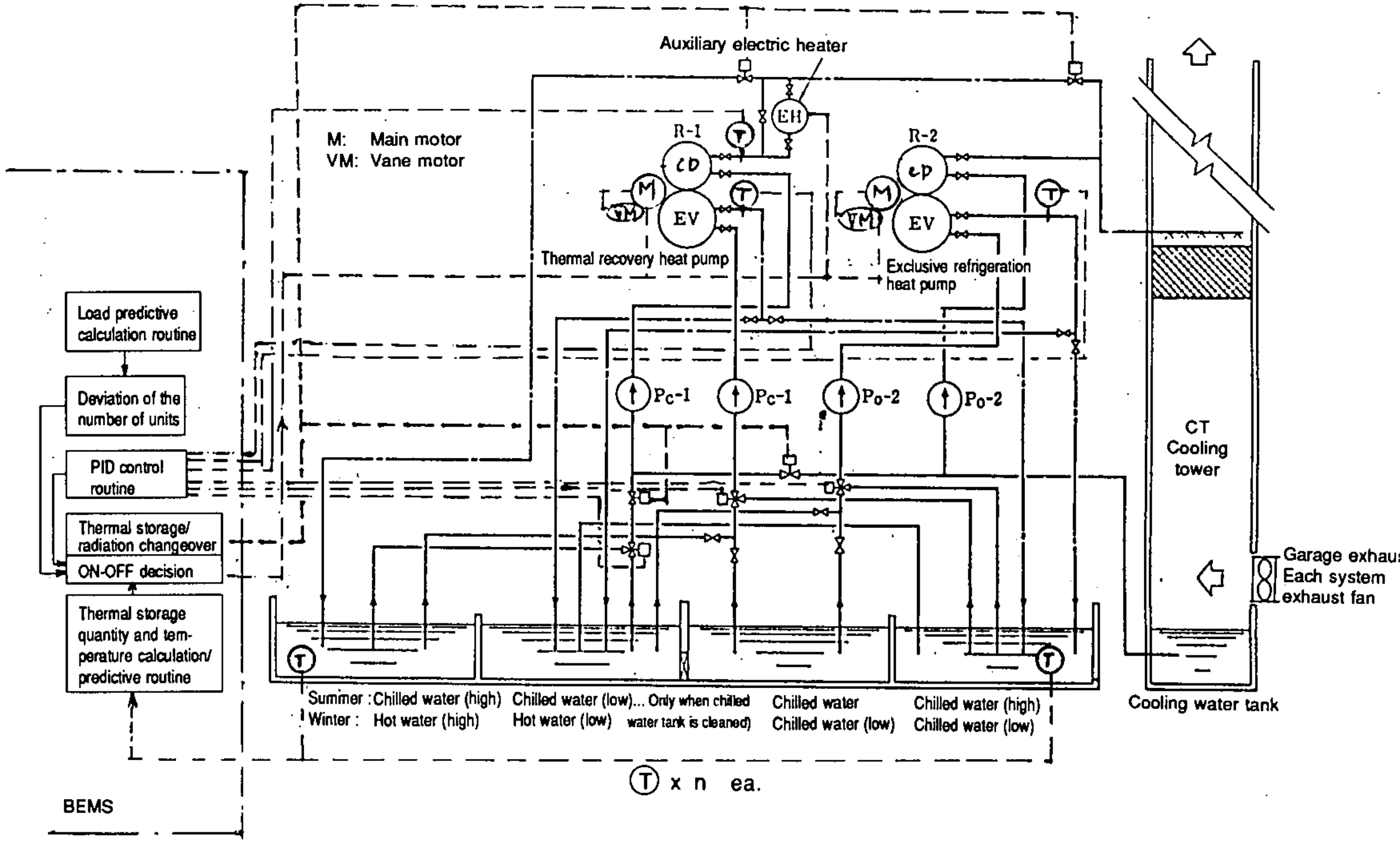


Fig. 9.12 Heat Pump Sequence Control Block Diagram

9.6 Lighting Control for an Office for Daylighting

9.6.1 Building and Lighting System Conditions

- Office building
- Perimeter zone, up to say 5m from any window which may receives significant daylight.
- A blind may be mounted optionally.
- The blind may be operated manually or electrically. An electric blind can be finely controlled, and it is effective for energy-saving.
- Luminaires should be individually switchable.

9.6.2 Control System and Selection of Sensors

(1) Control system (cf. Fig. 9.13)

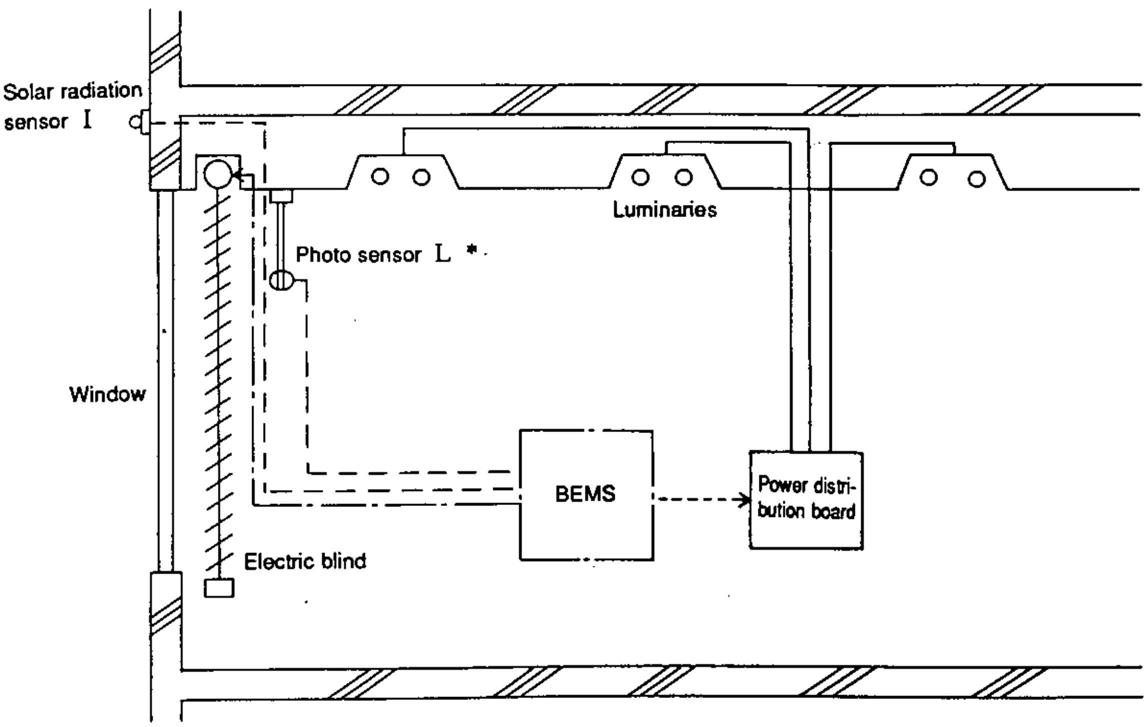


Fig. 9.13

1) Determines the relationship of the control action for luminaries on-off operation, blind open/close operation, blind slat angle, etc. according to the solar position determined by the seasons and time, various values of indoor lighting and sets their corresponding desired values for the purposes of control.
2) CPU processes measured values of solar radiation and lighting level and executes control of luminaires and of blinds.

* The sensor may be located otherwise eg on the desk when the room is for individually use.

3) Samples the illumination intensity several times at intervals of about several minutes, and judges the control action according to a change of the illumination intensity for the purpose of preventing frequent lighting on/off and/or blind open/close operation.

   Note: For the mounting position of the photo sensor,cf. 6.2.1 e).

9.6.3 Selection of Sensors

Solar radiation sensor I	Eppley pyrheliometer or silicon photo cell
Photo sensor L	Silicon photo cell

9.7 Energy Measurement in District Cooling/Heating Facility

9.7.1 Building and System Conditions

- Heat flow measurement of chilled/hot water in a district cooling/heating transfer facility (office building)
- Independent of the transfer control system

9.7.2 Monitoring System and Selection of Sensors

(1) Monitoring system (cf. Fig. 9.14)

1) Calorie transactions are done by the meter rate system, and a calorimeter is mounted.
2) Calorie is measured with high accuracy by a direct method which obtains a calorific value by calculating a medium flow and the supply/return temperature difference.
3) An electronic calorimeter is used for a direct measuring system.
Its thermal medium flow measuring part, supply/return temperature measuring part, and calorie calculation part are separated from each other.

Notes: 1) A flat sum system or mechanical measurement often applies to small scale users (houses, etc.)
2) A calorie computing function may sometimes be assembled as a function of the transfer station control system.

(2) Selection of sensors

1) Flowmeter: Electromagnetic flowmeter (cf. 4.8.2)
  a) High accuracy
  b) A wide measuring range
2) Temperature: Platinum resistance thermometer bulb (cf. 4.3.5)
  a) High accuracy

9.7.3 Supplementary Items

- In addition to hot water, steam may also be used as the energy carriers. In this case, accounting is based on the return water flow rate. Since return water is fed back intermittently from a hot well tank, the rangeability may be narrow.
An electromagnetic flowmeter or a vortex flowmeter is used.
- Steam flow measurement applies to the transactions, if steam is consumed in a humidification system, etc.
  Sensor: Vortex flowmeter

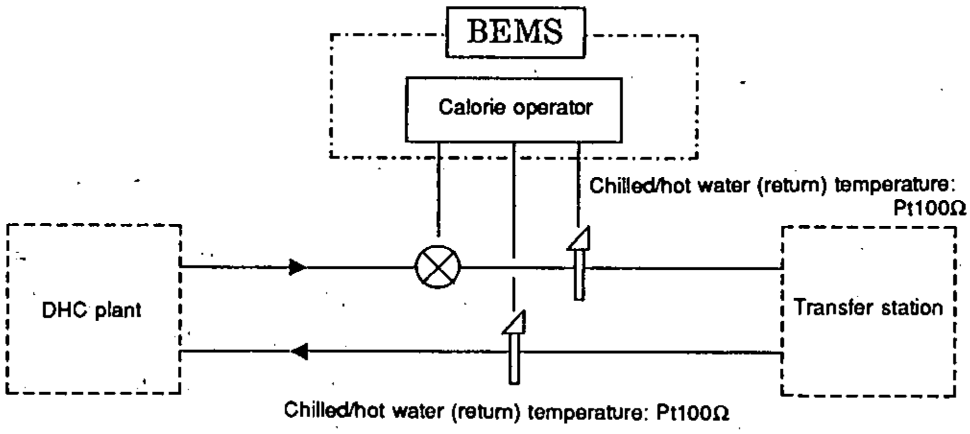


Fig. 9.14 Heat Flow Measurement in a District Cooling/Heating, Chilled/Hot Water Transfer Station Facility

It is recognized that various definitions for the BEMS have been proposed. For the purposes of this guide definitions have been given, in chapter 1, for the generalized BEMS, and for each of four classes of system. These latter are given so as to emphasize the development either in design or application of these systems. Unless specified otherwise this guide either explicitly or implicitly refers to a level 3 system.

This guide treats aspects of control where relevant to the application of sensors; the treatment of control is however not considered to include sufficient detail to warrant inclusion of the word "control" in the title.

Most sensors cited in this guide are commonly used in each of the participating countries of the Annex, however those relating to laws and regulations, especially of fire prevention, are not always applicable to all countries. In such cases the guide can offer only examples and illustrations of sensor use; these are clearly indicated in the text.

The importance of control software in selecting sensor is stressed throughout the text. Examples in the form of case studies are given to illustrate methodology for the selection of sensors for specific applications. Such information together with the chosen control algorithms point the way to system optimization and fault detection.

The survey report, which follows provides an indication of the differences amongst the five nations which participated fully in the Annex. It should be noted that, except for Japan, the systems referred to, in this survey, are not necessarily from the latest generation. Also, in view of the wide disparity in experience amongst the classes of respondents, entries in the evaluation columns should be interpreted with care.

Indoor environmental standards are under continuous review and revision in each country. In the future complex indicates may be expected for the control of the internal environment, including air quality. "Smart" and/or intelligent sensors for the purpose are expected in the near future. Another development to be expected is the control of the internal environment by means of a floating set-point, which is actually realized by static optimization, to minimize energy consumption with the environmental constraints, the boundary of which are regulated.

As the leading country of this topic, authors acknowledges Annex 16 delegates from each participating country listed in the following.

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