THE STUDY (AFTER-CARE)
ON THE ENERGY CONSERVATION PROJECT
IN THE KINGDOM OF THAILAND

TEXTBOOK FOR THE ENERGY AUDIT TECHNIQUES WORKSHOP

5. Measuring Methods for Factory Energy Audit

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Japan International Cooperation Agency (JICA)

The Energy Conservation Center, Japan (ECCJ)

1. Method for the Promotion of Energy Saving in a Plant

To promote the energy saving in a plant, it is, first of all, necessary to identify the present situation as shown in Fig. 1.

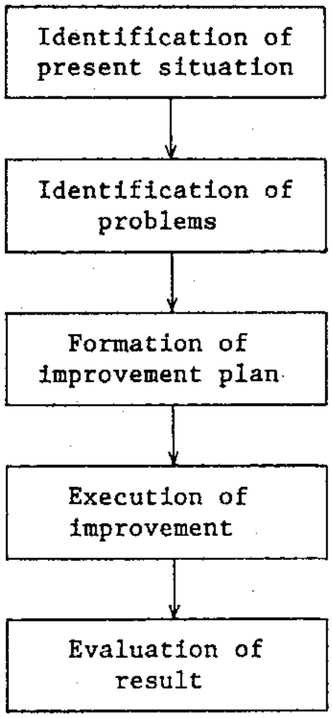


Fig. 1 Method for the Promotion of Energy Saving in a Plant

The identification of the present situation includes two cases; the identification for the plant as a whole and the identification for individual units of the plant. In either case, it is important to know how energy is used. For this purpose, it is required to carry out various kinds of measurement using general measuring instruments, and to calculate the input and output of energy.

2. Measurement in General

(1) Selection of Measuring Instruments

Measuring instruments for heat control include gas analyzers, thermometers, flow meters, pressure gauges, hygrometers, water quality testers, etc. In heat control, it is important to carry out measurement using such measuring instruments, and to express the results numerically for examination.

It is also important to select measuring instruments most suitable for respective purposes of measurement. For field operation, indicators can be used, but for the later examination of the operation, the use of recorders is recommended. The maximum scale, normal scale and minimum scale for the measuring range, and accuracy, etc. should be considered, and in addition, installation and subsequent maintenance should also be sufficiently taken into account. Meters with the same function have features respectively different from maker to maker, and those suitable for respective purposes should be purchased. The meters used in the field should be selected from those relatively inexpensive, simple in structure, easy to handle and sturdy. When many measuring instruments of one type are going to be adopted, one instrument higher in accuracy should be purchased, if possible, for comparative calibration of those used in the field.

(2) Place of Measurement

It is important to install an instrument at a proper measurement place. For a rational operation, it is required to sufficiently study what is to be measured at which portion of a unit. If a meter cannot be installed at a desirable place of measurement, or if a meter installed threatens to be remarkably consumed, installation at a different place or a different method for indirect measurement to know a relative trend should be thought out.

For heat balance, etc., efforts should be made to obtain average measured values for a certain period of time.

(3) Maintenance of Measuring Instruments

Measuring instruments for heat control are mostly used in places subject to temperature fluctuation, dust, vibration, etc. Therefore, the maintenance of meters must be sufficiently carried out. Furthermore, since they are generally expensive, they must be always maintained, to allow their effects to be exhibited for long time. Measuring instruments for heat control are often used in places subject to high temperatures. In general, an electric meter used at a high temperature causes the inside magnet to decrease in magnetism, the spring to decrease in controlling force, and the moving coil to increase in electric resistance, and as a result, an error is caused. Therefore, a meter without any temperature compensator must be moved to a place free from the effect of heat as far as possible, or any proper heat insulation method must be thought out. Furthermore, full recognition of meters is required. For example, it should be avoided that troubles of a CO_2 meter are mostly caused by the clogging of the primary filter and piping. Thus, the maintenance system must be established based on the knowledge and techniques not only for the meter itself but also for the attachments, piping, etc., and the adjustment, check, cleaning, oiling, consumable replacement, etc. of each meter must be periodically carried out.

(4) Measured Values

The indicated or recorded results of measurement must be expressed as graphs, or furthermore calculated, for the examination of the contribution to the improvement of production equipment and control techniques. However, measurement always accompanies an error. The difference between a measured value and a real value is called an error and is usually expressed in %. The error includes systematic error, individual error, mistake error and accidental error. The accidental error cannot be corrected even if the utmost care is exercised to lessen it, such methods as the averaging measured values and method of least square are used.

3. Methods for Analyzing Combustion Exhaust Gases

Combustion exhaust gases contain CO_2, O_2, CO, N_2, SO_2, NOx, etc. Analyzers of them can be roughly classified into chemical analyzers and physical analyzers, and further classified as shown in Table 1.

Chemical CO_2 meter uses the nature that CO_2 is very soluble in a strong alkali. Flue gas is introduced into an absorbing tank containing a strong alkali solution for absorbing CO_2, to know CO_2 concentration in % from the decrease of gas volume. Recently it is not commonly used in plants.

Physical analyzers use that respective gases are different in density, viscosity, thermal conductivity, magnetism, reactivity, infrared absorbability, etc. Kinds of gas analyzers used for combustion control are listed in Table 1.

Table 1 Classification of Gas Analyzers

	Method of measurement	Name of analyzer	Measured ingredients
Chemical gas analyzer	Absorption of solution	Hempel gas analyzer Orsat gas analyzer	CO_2, O_2, CO, N_2 CO_2, O_2, CO, N_2
Physical gas analyzer	Thermal conductivity method	Electric CO_2 meter Unburnt gas meter	CO_2 $CO+H_2$
	Specific gravity method	Specific gravity type CO_2 meter	CO_2
	Absorption of ultraviolet rays	Infrared gas analyzer	CO_2, CO, CH_4, SO_2, NO
	Electric conductivity	SO_2 automatic recorder	SO_2
	Electrochemical method	Zirconia type O_2 meter Galvanic cell type O_2 meter	O_2 O_2
	Magnetic method	Magnetic O_2 meter	O_2
	Gas chromatography	Gas chromatography	CO_2, N_2, H_2, O_2, CO, CH_4, SO_2, NO_2

(1) Exhaust Gas Sampling Methods

When gas samples for analyzing gas component are taken from a flue, care should be exercised to take the average samples, and the problems peculiar to the component to be measured must be taken into consideration.

1) Selection of gas sampling points

The measuring ports should be provided at positions where gas with the average properties can be taken, avoiding the positions where air leaks into the flue or where dust is deposited in the flue, and several measuring ports should be set, depending on the size and form of the flue. However, if the analytical results are little different among respective measuring points, and gas concentrations are almost the same at the cross sections of respective sampling positions, as in the flue for a boiler, then an optional one point can be selected for sampling.

2) Structure of gas sampler

A sampler is generally composed of a sampling tube, conduit, cooling dehumidifier, gas-liquid separating tube, condensed water trap, etc. The material of the sampling tube and conduit must not affect the analytical result of exhaust gas due to the chemical reaction or adsorption, etc. and must be resistant against corrosion. In case the water or gas component with high dew point in the exhaust gas should be condensed to clog the conduit, the sampling tube and conduit should be thermally insulated or heated as required.

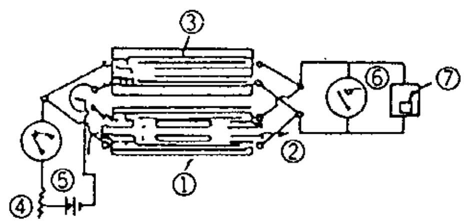
To prevent the ingress of dust, etc. into the sample gas, the sampling tube should contain a filter as required, and furthermore, a fine filter medium should be used downstream of the gas-liquid separating tube. To avoid indication errors due to the disturbance by the deposition of condensed water or water content in the tube inside the analyzer, a cooling dehumidifier for cooling and condensing water, gas-liquid separating tube, condensed water trap, desiccant, adsorbent, etc. should be used as required.

(2) Analysis of Carbon Dioxide

1) Thermal conductivity method

A meter using this method is also called electric CO_2 meter and this method is widely used. It applies that the thermal conductivity of CO_2 is very small compared with that of air.

As for the mechanism, as shown in Fig. 2, current is fed through the thin platinum wires stretched in the gas chamber ① and air chamber ③, and heated to about 100°C. Since the thermal conductivity of the flue gas, high in CO_2 content, which is fed into the gas chamber is smaller than that of air, the heat loss from the heated platinum wire is smaller in the gas chamber. Therefore, the temperature of the platinum wire in the sample gas chamber is higher than that in the reference gas chamber, to increase the electric resistance, and it is measured by a Wheatstone bridge and indicated by meter ⑥ or recorded by recorder ⑦.



① Sample gas chamber
② Gas passage
③ Reference gas chamber
④ Slide rheostat
⑤ Ammeter
⑥ Indicator
⑦ Recorder

Fig. 2 CO_2 Meter Using Thermal Conductivity

2) Specific gravity method

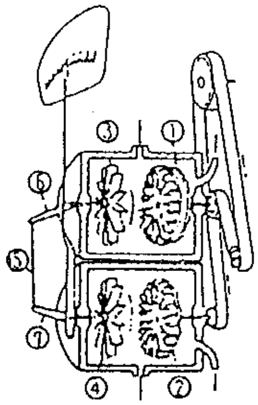
This is intended to measure the CO_2 content using the fact that the specific gravity of CO_2 is larger than that of air.

As shown in Fig. 3, two impellers of the same form and speed are used. One impeller is revolved in an air chamber and the other one is revolved in a chamber fed with the flue gas mutually in reverse directions. The wind pressures generated by them are received by passive impellers of the same form respectively facing the above mentioned impellers. If air current of the same condition is blown to both the impellers, to actuate both, the force for turning the air arm downward and the force for turning the gas arm upward are the same, and the connecting rod connecting both the arms does not move.

However, if flue gas is fed into the gas chamber, the revolving torque of the gas arm becomes larger than that of the air arm due to the difference of both in specific gravity, which raises the connecting rod by the gas arm. The movement of the air and gas arms and the connecting rod due to the torque difference is indicated by a needle or recording pen attached at the passive impeller shaft for air.

At the bottom of the meter, a water tank is provided to always give the same humidity to gas and air.

In the use of CO_2 meter for flue gas, if the composition of components other than CO_2 is different, it affects the specific gravity of the entire gas, which causes some error.

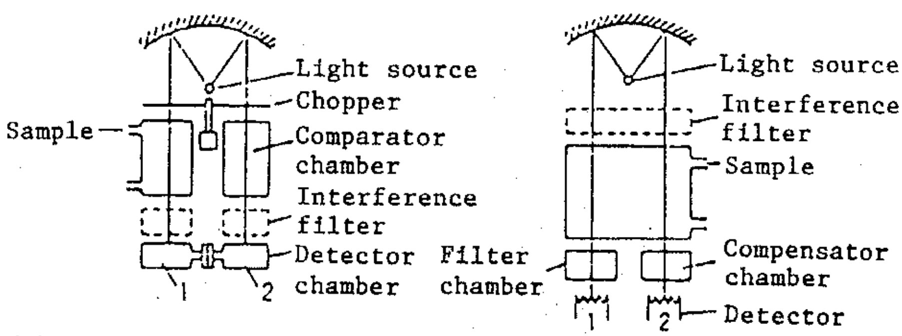


① Impeller for gas
② Impeller for air
③ Passive impeller for gas
④ Passive impeller for air
⑤ Connecting rod
⑥ Gas arm
⑦ Air arm

Fig. 3 Specific Gravity Type CO_2 Meter

3) Infrared gas analysis method

Most gases such as CO_2, CO and CH_4 except for gases in which one molecule consists of the same two atoms, such as H_2, N_2 and O_2 have respectively peculiar absorption wavelength bands against infrared rays. This is used in the method. An industrial infrared gas analyzer is either of a positive filter type or of negative filter type. A positive filter type analyzer usually uses a heated nichrome wire as the heat source and the heat is divided into two rays by a reflector. One ray goes through a sample tank into detector A, and the other goes through a comparator chamber (usually containing N_2) into detector B. Both the detector chambers 1 and 2 contain only the gas to be analyzed at a high concentration. The energy absorbed by detector chamber 2 remains the same, but the energy absorbed by detector chamber 1 depends on the concentration of the gas to be analyzed in the sample chamber. The difference of both the detector chambers 1 and 2 in the absorbed energy is taken out, for example, as the change in the capacity of the capacitor held between them, for indicating the concentration of the gas ingredient analyzed. A negative filter type analyzer uses non-selective detectors. The filter chamber contains 100% test gas, and the compensator chamber contains N_2, or the gas obtained by excluding the test gas from the gas of the sample chamber. The difference between the outputs of both the detectors such as bolometers is measured to know the concentration of the test gas.



(a) Positive filter type (b) Negative filter type

Fig. 4 Infrared Gas Analyzer

(3) Analysis of Oxygen

Automatic meters for continuously measuring the oxygen concentration in exhaust gas include the following:

1) Magnetic O_2 meter

The magnetic method continuously obtains oxygen concentration by using the attractive force generated when oxygen molecules, which are a paramagnetic material, are magnetized in a magnetic field, and includes a magnetic blow type and magnetic force type. The magnetic method can be used when the influence of the gas with high bulk susceptibility (nitrogen monoxide) is negligible.

a) Magnetic blow type O_2 meter

In this type, the intensity of the magnetic blow generated when the oxygen molecules attracted in the magnetic field are partially heated to lose magnetism, is detected by a hot wire element.

b) Magnetic force type O_2 meter

Dumbbell type: The displacement caused when a nonmagnetic dumbbell is extruded outside the manetic field by magnetized oxygen molecules is detected.

Pressure detector type: In a periodically intermittent manetic field, the intermittent attractive force acting on oxygen molecules is detected as the back pressure variation of auxiliary gas flowing into the magnetic field at a constant rate.

2) Electrochemical O_2 meter

The electrochemical method uses the electrochemical oxidation reduction reaction of oxygen, for continuously obtaining oxygen concentration, and includes zirconia type and electrode type.

Zirconia type: In this type, electrodes are provided at both ends of a zirconia element heated to a high temperature, and the sample gas is fed to one of them while air is fed to the other, in order to give an oxygen concentration difference, and for detecting the electromotive force generated between both the electrodes. Fig. 5 shows the structure.

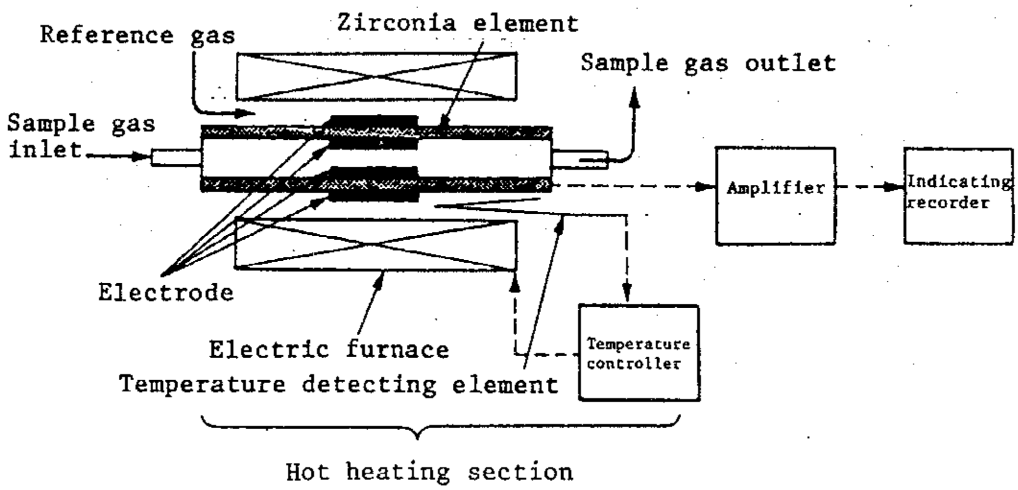


Fig. 5 Zirconia Analyzer

Electrode type: This type detects the electrolytic current generated when the oxygen diffused and absorbed in an electrolyzer cell through a gas permeable diaphragm is reduced on the surface of a solid electrode. This type can be further classified into a constant potential electrolysis type for giving reduction potential from outside, polarograph type, and galvanic cell type for forming galvanic cells.

(4) Analysis of Carbon Monoxide

Carbon monoxide in exhaust gas can be analyzed by the following methods:

1) Oxidation condensation method

Sample gas is cooled by liquid air to remove the condensable ingredients in the gas, and the remaining gas is fed through a gas oxidizing agent based on copper oxide, to oxidize carbon monoxide into carbon dioxide which is simultaneously condensed by liquefied air. In this case, the difference between gas pressures before and after oxidation condensation is measured (differential pressure method), or it is gasified once into a certain volume, and the pressure is measured (gasification pressure measurement method), for the determination of carbon monoxide.

2) Gas chromatography

A certain amount of sample gas is taken and introduced into a gas chromatograph with a thermal conductivity type detector, and carbon monoxide concentration is obtained from the height of the peak shown in the chromatogram obtained.

3) Infrared gas analysis method (non-dispersion method)

The light absorption of carbon monoxide in the infrared region is used, and the carbon monoxide concentration of the sample gas is measured using a non-dispersion type infrared gas analyzer.

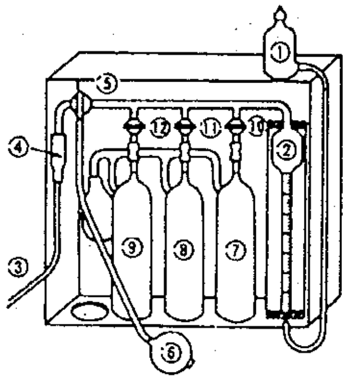
4) Detector tube method

Sample gas is fed through a carbon monoxide detector tube which is a thin glass tube packed with a certain amount of a detecting agent, and the coloring achieved is used to determine carbon monoxide. This is a simple method for knowing the approximate carbon monoxide concentration of exhaust gas.

(5) Other Analysis Methods

1) Orsat method

Carbon dioxide, oxygen, and carbon monoxide in exhaust gas are analyzed by the absorption method using an Orsat gas analyzer. As absorbants, potassium hydroxide solution (CO_2), alkaline pyrogallol solution (CO) are used. The instrument is small in size and light in weight, being convenient to carry and is simple in operation. However, skill is required.



① Leveling bulb
② Gas burette
③ Sample tube
④ Filter
⑤ Three-way cock
⑥ Suction pump
⑦ Carbon dioxide absorbing bottle
⑧ Oxygen absorbing bottle
⑨ Carbon monoxide absorbing bottle
⑩ - ⑫ Cock

Fig. 6 Orsat Gas Analyzer

2) Gas chromatography

Combustion gas can be analyzed also by using a gas chromatograph. Compared with the infrared gas analyzer, etc., this method is slow in the response speed and does not allow continuous analysis. However, if an automatic gas sampler is attached, automatic analysis can be made. Gas chromatography is suitable for analyzing a sample consisting of many ingredients, and especially allows trace analysis. Main component of combustion gas such as CO_2, O_2, CO, N_2, H_2, CH_4, SO_2, and NO_2 can be analyzed.

The gas chromatograph used has a thermal conductivity type detector, and a gas sample introducer or automatic gas sampler. The carrier gas used is either helium or nitrogen. Since the above ingredients cannot be isolated and eluted by single packing column, it is convenient to use two columns different in isolation capability, and to isolate and determine by the intermediate cell method in which one column is installed upstream of a detector and the other column downstream of the detector in one thermostatic oven as shown in Fig. 7. It is recommended to pack C1 column with silica gel or Porapak Q and C_2 column with Molecular Sieve 13X or 5A.

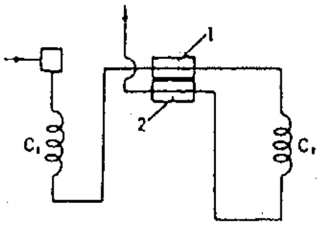


Fig. 7 Intermediate Cell Type Gas Chromatograph

4. Temperature Measurement Methods

(1) Kinds and Selection of Thermometers

Temperature measurement methods include the contact method in which an object to be measured is brought into a thermally close contact with the sensing element of a thermometer, to keep the same temperature for measurement, and non-contact method in which the radiation of the object, etc. is used for temperature measurement. The features and requirements of thermometers for respective methods are shown in Table 2. For selecting a thermometer, the following items should be examined, to select a thermometer suitable for the purpose of measurement.

1) The range of temperatures to be measured (working temperatures in principle).
2) Accuracy and error possibly occurring in measurement.
3) Material, form, size, etc. of sensing section.
4) Delay of indication.
5) Easiness to read the indication.
6) Necessity of telemetering, recording, alarm or automatic control.
7) Durability, corrosion resistance and reliability.
8) Easiness to handle.
9) Interchangeability.

Kinds and working ranges of various thermometers are shown in Table 3.

Table 2 Contact Method and Non-contact Method

	Contact method	Non-contact method
Requirements	(1) The object to be measured should be kept in close contact with the sensing element. (2) The temperature of the object to be measured should not be substantially changed even by the contact with the sensing element.	The radiation from the object to be measured should sufficiently reach the sensing element.
Features	(1) If the sensing element is brought into contact, the temperature to be measured tends to be changed. Therefore, it is difficult to measure the temperature of a small object. (2) The temperature of a moving object is difficult to measure. (3) The temperature at an optional point can be measured.	(1) Since the sensing element is not brought into contact, the temperature to be measured is not changed. (2) The temperature of a moving object can also be measured. (3) In general, surface temperature is measured.
Temperature range	Temperatures lower than 1000°C can be easily measured.	Suitable for measuring high temperatures.
Accuracy	In general, about 1% of scale span.	In general about 10 degrees.
Delay	Generally large	Generally small

Table 3 Kinds and Working Ranges of Various Thermometers (JIS Z 8710)

Kinds of thermometer		Serviceable temperature		Working temperature	
		Lower limit	Upper limit	Lower limit	Upper limit
Contact type	Liquid-in-glass thermometer				
	Mercury thermometer	-55	650	-35	350
	Organic liquid thermometer	-100	200	-100	100
	Bimetal thermometer	-50	500	-20	300
	Pressure thermometer				
	Liquid expansion pressure thermometer	-40	500	-40	400
	Vapor pressure thermometer	-20	200	40	180
	Resistance thermometer				
	Platinum resistance thermometer	-200	599	-180	500
	Nickel resistance thermometer	-20	150	-50	120
	Copper resistance thermometer	0	120	0	120
	Thermistor thermometer	-50	350	-50	200
	Thermoelectric thermometer				
	B thermoelectric thermometer	600	1,700	600	1,500
	R,S thermoelectric thermometer	0	1,600	200	1,400
	K thermoelectric thermometer	-200	1,200	0	1,000
	E thermoelectric thermometer	-200	800	-180	700
	J thermoelectric thermometer	-200	750	0	600
	T thermoelectric thermometer	-200	350	-180	300
Non-contact type	Optical pyrometer	700	2,000	900	2,000
	Radiation thermometer	50	2,000	100	2,000

(2) Liquid-in-glass Thermometer

Among various thermometers, this thermometer is simplest to handle and the most inexpensive. Generally used liquid-in-glass thermometers are either enclosed scale type thermometers or bar thermometers. An enclosed scale type thermometer has a capillary tube and a scale plate of milky white glass behind it enclosed in one glass tube, and mostly has fine graduations, to allow accurate reading for the indication. Therefore, it is generally used for precise measurements. A bar thermometer has graduations directly stamped on a thick-wall capillary tube, and is generally higher in mechanical strength than an enclosed scale type thermometer.

(3) Pressure Temperature

If mercury or any other liquid or gas enclosed in a sealed tube is heated, the pressure in the tube increases. The pressure is used to determine the temperature. As shown in Fig. 8, the main components are a heat sensor to be inserted into the temperature measuring point, a Bourdon tube in the meter, and a capillary tube connecting them.

Though not high in accuracy, it is structurally strong and allows easier reading compared with the glass thermometer. Since it is suitable for telemetry, it allows measurements at a place apart from a dangerous place. It can also be used for automatic control.

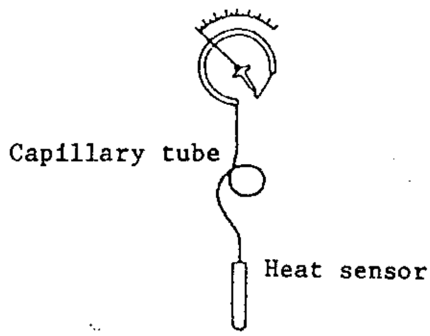


Fig. 8 Pressure Temperature

Table 4 shows the kinds and performance of pressure thermometers.

Table 4 Kinds and Performance of Pressure Thermometers

Kind	Liquid expansion type	Vapor pressure type
Enclosed material	Mercury	Volatile liquid
Scale range (°C)	-40~500	-40~200
Maximum length of capillary tube	8~20	50
Sensibility	Good	Rather poor
Influence of capillary tube on temperature	A little	Nil
Influence of atmospheric pressure	A little	A little at low pressure
Influence by the locations of heat sensor and meter	A little	Considerable at low pressure

(4) Resistance Thermometer

1) Resistance bulb

According to the rise of temperature, a metal wire changes in electric resistance, and there is a certain relation. Therefore, if a metal wire is brought into contact with an object to be measured, to be equal to the object in temperature, the electric resistance of the metal wire measured can be used for finding the temperature of the object.

The resistance bulb used should be desirably as large as possible in the change of resistance by temperature (temperature coefficient) and regular and stable in the change of value. To meet these requirements, a platinum wire is most excellent for precision measurement and has been used for a long time as a resistance bulb, but it is expensive which is a disadvantage.

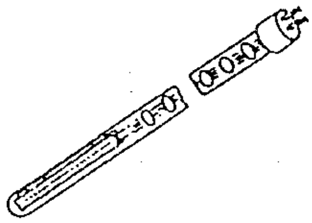


Fig. 9 Platinum Resistance Element

Fig. 9 shows the most general platinum resistance element for precision measurement. A platinum wire of about 0.01 to 0.2 mm in diameter is folded at the center into two parallel lines, and wound around a crossed frame of mica plate or ceramic plate, and usually three or four lead wires are attached to remove the error otherwise caused by lead wire resistance.

The resistance wire may be used as it is, but generally is put in a protective tube made of glass, quartz, porcelain or metal, etc., depending on the temperatures to be measured or the material to be measured.

A nickel resistance element is inexpensive, stable at room temperature and large in temperature coefficient, and therefore, it is often used next to platinum. However, it cannot be used higher than 150°C.

A thermistor is a semiconductor prepared by mixing and sintering a metal oxide of nickel, manganese or cobalt, etc., and the temperature coefficient of the thermistor changes, depending on the temperature. Therefore, it cannot be considered that the temperature coefficient is constant in a wide temperature range. However, the temperature coefficient of a thermistor at 25°C is as large as about -2 to 6%/°C, being about 10 times that of a platinum wire. For a measurement temperature range from about -50 to 300°C, a small temperature sensing element can be made, and therefore the time delay is also small.

2) Measuring instrument

a) Method by use of Wheatstone bridge: As shown in Fig. 10, the four sides of Wheatstone bridge are resistances P and Q, variable resistance R and platinum wire resistance X, and if R is adjusted to let ammeter G indicate zero,

$$x = R \frac{Q}{P}$$

usually P = Q, hence X = R.

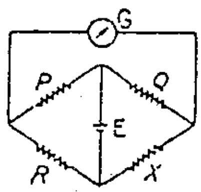


Fig. 10 Wheatstone Bridge

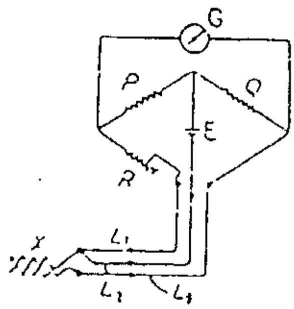


Fig. 11 Three Lead Wires

For precise resistance measurement, the resistance of lead wires connecting the resistance bulb with the measuring instrument cannot be neglected. To eliminate the influence, lead wires are variously contrived. Fig. 11 shows a case of three-wire connection.

That is, if two lead wires L1 and L2 are taken from one end of the platinum wire coil and a lead wire L3, from the other end (total 3 lead wires), and the respective resistances are L1, L2 and L3, then

$$X + L3 = R + L1$$

If L1 = L3, then we have X = R, and the value of R gives the resistance X of the coil.

b) Method by electronic automatic null balancing instrument: An electronic automatic null balancing mechanism is combined with a bridge circuit, to indicate or record the temperature by the zero method. The method includes AC bridge type and DC bridge type, depending on the measurement principle used. AC bridge type is prone to cause an error due to the AC noise voltage induced in the resistance element or lead wires, and DC bridge type is more practically used.

c) Method by moving coil type ratio meter: Fig. 12 shows a connection diagram for measuring the platinum wire resistance X, using a moving coil type ratio meter. Moving coils A and B are located between both the poles N and S of a permanent magnet, and the coil B contains resistance X of platinum wire.

If X is changed by a temperature change, the needle is deflected till the resultant magnetic field of both the coils A and B and the magnetic field of the permanent magnet reach a new equilibrium. This is widely used industrially.

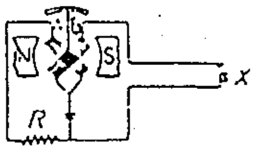


Fig. 12 Moving Coil Type Ratio Meter

d) Method by potentiometer: Resistance, i.e., temperature can be measured very accurately. This method is mainly used for precision measurement and calibration.

3) Error by self-heating

In a resistance thermometer, since current flows in a resistance element, Joule heat is generated to raise the temperature. The magnitude is usually less than 0.2°C, though depending on the resistance wire, and is mostly negligible.

(5) Thermoelectric Thermometer

1) Thermocouple

If metal wires of different kinds are bonded at both their ends as shown in Fig. 13 and both the junctions are kept at different temperatures, an electromotive force is generated by a Seebeck effect. The electromotive force is measured using a DC millivolt meter or potentiometer, to know the temperature. Such a combination of metals is called a thermocouple. The cold junction is kept at 0°C in an ice bath for reference, but in case of general plants, it is put in water, underground or atmosphere, to be kept at a constant temperature, and the other end (hot junction) is inserted into the measuring point.

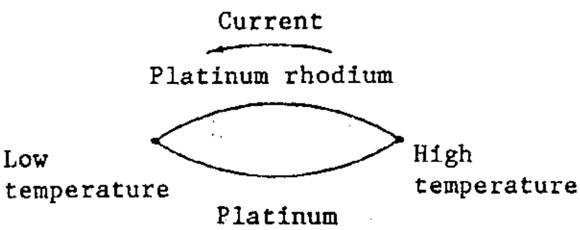


Fig. 13 Principle of Thermocouple

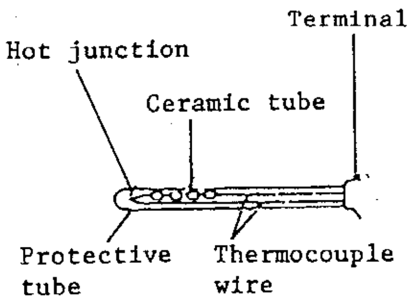


Fig. 14 Thermocouple

2) Requirements for thermocouple material

a) To be large in thermoelectromotive force which should rise continuously according to the rise of temperature.
b) To be stable in thermoelectromotive force, withstand long-term use and be free from hysteresis.
c) To be resistant against heat, mechanically strong even at high temperature, and resistant against corrosion in high temperature air and gas.
d) To be easily manufactured with constant characteristics and processed.
e) To be as small as possible in electric resistance and temperature coefficient, and also to be small in thermal conductivity.

f) To be smoothly available at low cost.

As materials satisfying these requirements, platinum-platinum-rhodium (B.R.S.), chromel-constantan (E), chromel-alumel (K), iron-constantan (J), copper-constantan (T), etc. are used.

Fig. 15 shows a thermoelectromotive force diagram of thermocouples.

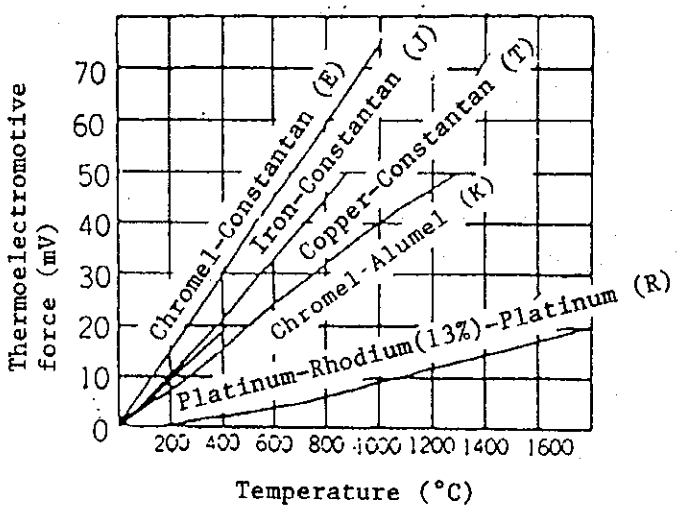


Fig. 15 Thermoelectromotive Forces of Thermocouples Specified in JIS

Thermocouples for high temperature measurement include Ir-Ir Rh (40%) 2000°C, W-Ir 2100°C, W-W Re (26%) 2980°C, etc.

Platinum-platinum-rhodium thermocouple is smaller than chromel-alumel thermocouple (K) in the thermoelectromotive force, but high in heat resistance and good in accuracy. It is resistant in oxidizing atmosphere but weak in the reducing atmosphere and metal vapor.

3) Compensating lead wire

As thermocouples are generally expensive, the part from the terminal of protective tube to the cold junction is substituted by a compensating lead wire.

A compensating lead wire is an electric wire which has the same characteristic as the electromotive force characteristic of the thermocouple at about the terminal temperature, and is mainly a combination of copper wire and copper nickel alloy wire. The electromotive characteristic is properly decided by nickel content.

4) Correction for cold junction temperature

The cold junction is kept at 0°C in principle, but when it is difficult, the temperature is corrected as follows. That is, if an electromotive force of E (mV) is generated between the cold junction t_c kept at any other temperature than 0°C and the hot junction t_H, the thermoelectromotive force e between 0°C and t_c is obtained from the temperature vs. thermoelectromotive force curve or electromotive force table of the thermocouple used, and the temperature corresponding to E + e is obtained from the diagram or electromotive force table.

The thermocouple, compensating lead wire, copper lead wire and indicator can be connected by various methods as shown in Fig. 16. The temperature at the cold junction in the respective connection methods is the correction temperature for the cold junction temperature.

There is also a meter which allows the cold junction correction to be automatically carried out using a resistance wire or bimetal, etc. large in temperature coefficient.

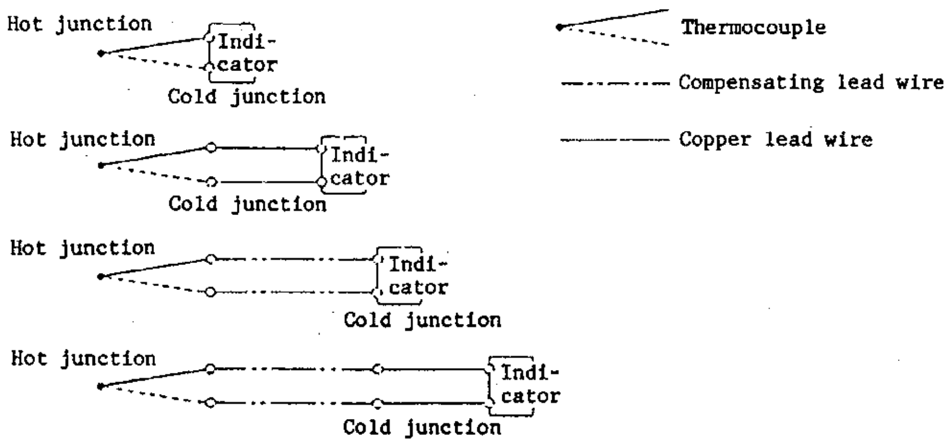


Fig. 16 Various Connection Methods and Cold Junction

5) Measuring instrument

When the thermoelectromotive force is measured by an ordinary potentiometer, as shown in Fig. 17, the electromotive force generated from the thermocouple M is compared with a known constant current supplied from the dry battery B, and the position of the contact F on the slide rheostat C-D is adjusted to let the needle of the galvanometer G indicate zero. The position at that time indicates the temperature corresponding to the electromotive force of the thermocouple. The potentiometer uses a mechanical method for balancing the specified current and the thermoelectromotive force, and requires a relatively delicate galvanometer for detecting the unbalance. The detection is intermittent.

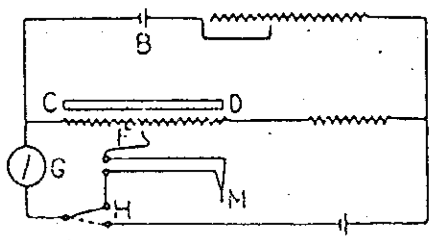


Fig. 17 Potentiometer

Electronic type uses an electronic continuous balancer instead of the galvanometer, and the related mechanism is the same as the electronic balancer used for the resistance wire.

The electronic type is large in the torque for moving the needle, to allow expression on a large scale and thus allowing observation from a remote place, and the indication is reliable and highly accurate. Automatic recording is also easy, and a meter with a scale narrow in temperature range can also be manufactured. However, the structure is complicated.

6) Error of thermoelectric thermometer

The electric error includes the error caused by the combination of a thermocouple and a meter, and the general error of an electric meter affected by temperature, magnetic field, etc. It also includes the secular change of the meter, and the error caused by the deterioration of the thermocouple.

What must be noted during use is thermal error. If a thermocouple is brought into contact with an object to be measured, the thermocouple may take away heat from the object, to lower the temperature of the measured object. In another case, when a thermocouple is inserted into the measuring point, heat is transmitted through the thermocouple and the protective tube. Fig. 18 shows a case of such error.

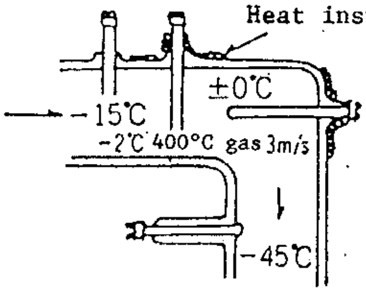


Fig. 18 Caution for Use of Thermometer

Furthermore, since a thermocouple which senses the temperature of the measuring point may be subject to the radiant heat from a nearby object with a higher temperature or may give heat to an object with a lower temperature by radiation, an error is caused especially in the temperature measurement of gas.

Fig. 19 shows a suction-pyrometer for preventing it. In the suction-pyrometer, the thermocouple is provided as a double tube for preventing the influence of thermal radiation, and gas is sucked at a high velocity toward the circumference of the thermocouple, for a better heat transfer to the thermocouple, and to know the temperature of the gas itself.

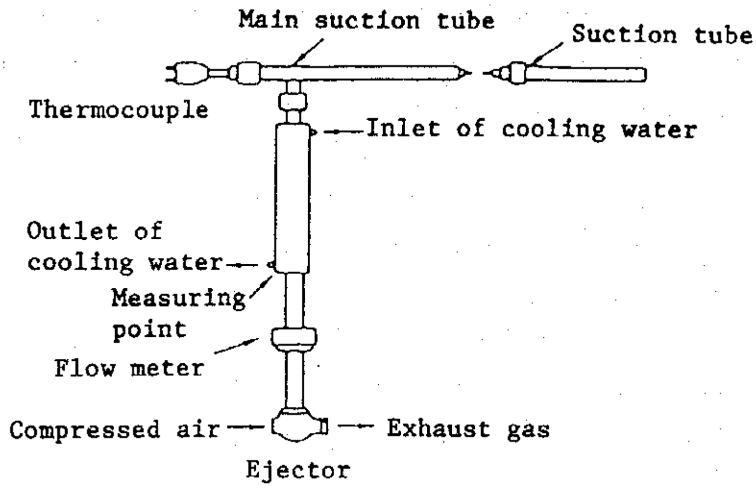


Fig. 19 Suction Pyrometer

7) Sheathed thermocouple

A sheathed thermocouple, as shown in Fig. 20, has magnesia (MgO) or alumina (Al_2O_3) kept and solidified in the protective tube of the thermocouple and is made very thin in order to be flexible. Sheathed thermocouples of about 0.25 to 12 mm in diameter are also manufactured, and the radius of possible bending is 1 to 5 times the diameter. Since they are thin, they are suitable for local temperature measurement and small in time delay of indication. Furthermore, they do not disturb the temperature of the measured object.

Fig. 20 Sheathed Thermocouple

Fig. 21 Surface Thermometer

8) Surface thermometer

As shown in Fig. 21, the cold junction of the thermocouple is grasped by hand and the hot junction is brought into contact with the surface of an object, for surface measurement.

There is also a surface thermometer which is heated internally to prevent the temperature drop of the measured object otherwise caused by contact with the thermometer.

(6) Radiation Thermometer

An object higher in temperature radiates stronger heat. The radiant heat Q emitted from a unit area of an object with emissivity ε and absolute temperature T (K) into a space with an absolute temperature θ (K) during a unit time is expressed by

$$Q = 4.88 \times \varepsilon \times \left(\frac{T}{100} \right)^4 \quad [\mathrm{kcal/m^2 \cdot h}]$$

The radiant energy is measured, to know the temperature.

Since the meter indicates the emissivity (blackness) of the black body as $\varepsilon = 1$, the real temperature of the measured object which is not a black body can be obtained by knowing ε of the measured object and dividing by $\sqrt[4]{\varepsilon}$.

Table 5 shows emissivities of some materials, which vary to some extent, depending on the temperature, state, etc. of each material.

Table 5 Surface Emissivities ε of Some Materials

Surface	Temperature range(°C)	Emissivity ε
Iron oxide	500 ~ 1200	0.87 ~ 0.89
Silica brick	1000	0.80
Rough aluminium surface	25	0.055
Rolled steel sheet	21	0.675
Limestone	63 ~ 193	0.36 ~ 0.40

A radiation thermometer collects radiant energy by a lens or reflector, as shown in Fig. 22. The former type is mainly used.

A lens radiation thermometer uses a lens transparent for the visible and infrared range of radiation. For the measurement of radiant energy, a thermocouple, a thermopile with many thermocouples assembled or bimetal, etc. is used. In this arrangement, consumable parts such as battery are not required, and a considerably large output is available. Therefore, the output voltage allows direct recording and can also be used for temperature control.

Notes for use:

1) If smoke, water vapor or carbon dioxide, etc. exists between the thermometer and the measured object, an error is caused.

2) If the temperature of the thermometer rises, an error is caused. Therefore, any proper air- or water-cooling device should be used.

3) It must be noted that each meter has its distance coefficient. As shown in Fig. 23, if the distance from the measured object to the lens of the transmitter is L, the effective diameter of the measured object is D, the distance from the lens to the thermal sensitive material is l, and the size of the thermal sensitive material is d, then l/d is called the distance coefficient. It is usually 10 to 30. In this case, L and D must be selected to satisfy the relation of L/D < l/d.

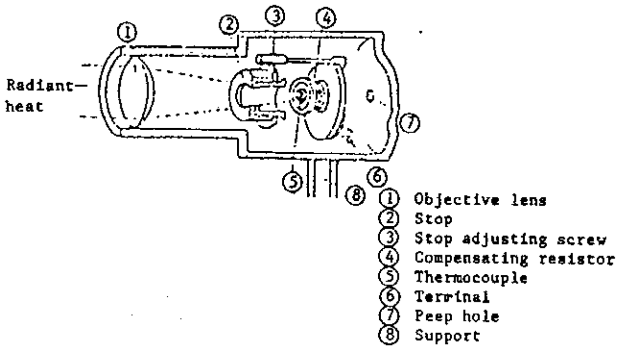


Fig. 22 Radiation Thermometer

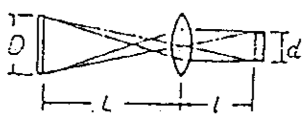
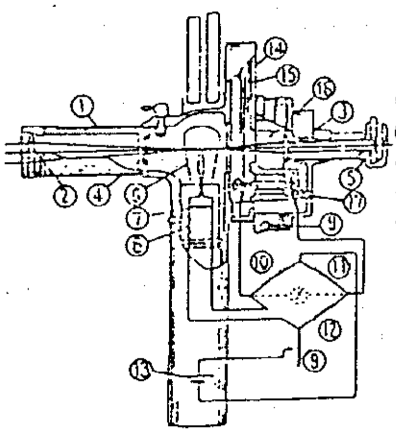


Fig. 23 Distance Coefficient

(7) Optical Pyrometer

An optical pyrometer is a kind of radiation temperature. The radiant energy of a specific wavelength (usually 0.65μ red) in the radiation from a hot object is compared in luminance with that of a hot material (lamp filament) with reference temperature in the pyrometer, to know the temperature.

Fig. 24 shows the internal structure of a filament dissipation type optical pyrometer most widely used.



① Telescope
② Objective lens
③ Eyepiece
④ Dark color filter glass
⑤ Red filter glass
⑥ Reference lamp
⑦ Parallel resistance for lamp characteristic adjustment
⑧ Series resistance for lamp characteristic adjustment
⑨ Variable resistor for lamp luminance adjustment
⑩ / 11 / 12 Fixed resistance for bridge balance
⑬ Battery
⑭ Scale plate
⑮ Needle
⑯ Permanent magnet
⑰ Moving coil

Fig. 24 Structure of Optical Pyrometer

The entire structure is one telescope, and a reference lamp for comparison is located at the center. The telescope is turned toward the hot object to be measured, and the lens barrel is visually adjusted to superimpose the image of the object on the plane of the filament. Visually comparing the luminance of the object image with that of the filament vertex through the red filter glass plate, and the filament current is adjusted by the resistance to make both the luminances equal. Since the relation between the filament temperature and filament current of the reference lamp is known beforehand, the temperature corresponding to the filament current can be obtained by reading the current flowing in the filament of the lamp using an ammeter. The temperature is indicated on the scale.

There is also another measuring method, in which with the luminance of the reference light source kept always constant by a constant current, the light from the hot object to be measured is made to pass obscure glass with a certain thickness or a polariscope, to weaken the luminance, for the adjustment to be equal to the luminance of the reference light source.

When the temperature of an object other than a black body is measured by an optical pyrometer, correction must be made to know the real temperature, by knowing the emissivity ε_λ of the object to wavelength 0.65μ (red). Fig. 25 is a correction table for it.

An optical pyrometer using a photoelectric cell or photoelectric tube to substitute human eyes is called a photocell pyrometer or phototube pyrometer.

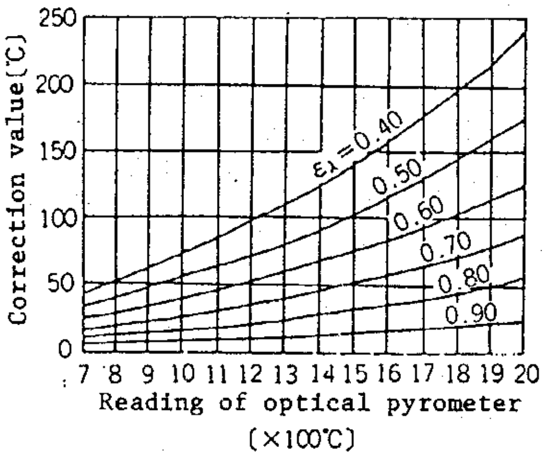


Fig. 25 Correction by Emissivity

(8) Color Thermometer

In general, a material begins to emit light at a temperature higher than 700°C, and changes from red to reddish yellow and further to bluish according to the rise in temperature. The reason is that according to the rise in temperature, the short wavelength (blue) component contained in light increases, while on the contrary, the long wavelength (red) component decreases. To use a color temperature while a hot object is observed through a color filter, the filter is adjusted to weaken one of the radiant energies of two wavelengths until it is visually confirmed that the color of the hot object becomes the same as the reference color. This is in order to obtain the temperature of the hot object from the weakened degree of the radiant energy of one wavelength.

This principle is used by the color filter thermometer and bioptics thermometer. There is also a two-color thermometer which measures the ratio of radiant energies of two wavelengths using photoelectric tubes, etc. and automatically indicates and records the thermometer. A color thermometer is little affected by emissivity and the measured value is close to the real temperature.

(9) Other Temperature Measuring Methods

1) Seger cone

This is a triangular pyramid prepared by mixing clay, various silicates, and metal oxides. If it is heated, each specific ingredient is softened and deformed at a specific temperature. It is used, for example, to know the internal temperature of a furnace. It is affected by the heating rate, gas atmosphere in the furnace, gas flow velocity, temperatures of surrounding furnace walls, etc. It can be more convenient than ordinary thermometers, depending on the place of use. It is used in the ceramic industry, etc.

2) Thermal paint

A thermal paint is applied to the measured portion, to know the temperature by using that the color changes at a predetermined temperature. Both reversible and irreversible paints are available.

3) Bimetal thermometer

Two kinds of metals which are different in the thermal expansion coefficient are stuck together. and their bending cused by temperature change is transmitted to a needle. It can also be used for temperature control.

5. Flow Rate Measurement

(1) Kinds and Features of Flow Meters

Major methods for measuring the flow rate of a liquid or gas include volume method for measuring a volume or mass, differential pressure method using an orifice plate or nozzle throttle mechanism, area method for knowing the flow rate by changing the throttle area with the differential pressure kept constant, flow velocity method for knowing the flow rate from the revolution of a propeller, etc. in a liquid, method using a Pitot tube, method using vortexes of a fluid, hot wire method for measuring the absorbed heat of a fluid, etc. Kinds, features and accuracies of main flow meters used for heat control are listed in Table 6.

In the selection of a flow meter, the following should be considered.

1) Temperature, pressure and density of fluid
2) Magnitude and variation range of flow rate
3) Solid content and pressure loss
4) Corrosivity, harmfulness and flammability
5) Integrated value or momentary value
6) Recorded value or indicated value
7) Direct reading measurement or telemetry

(2) Volume Method

A fluid is introduced into a container with a certain volume, for integration of the flow rate. Fig. 26 shows a wet gas meter, in which a rotary drum with four chambers A, B, C and D is installed in a horizontal cylinder filled with water up to a half. The gas entering from inlet G into the respective chambers sequentially rotates the measuring cylinder in an arrow direction and is replaced by water again, being discharged from outlet F. From the number of revolutions of the drum, the flow rate of gas can be known. As far as the water level is constant, accurate measurement can be achieved.

Table 6 Kinds, Features and Accuracies of Flow Meters

Measuring method	Flow meter	Features	Accuracy
Volume method	Wet gas meter	. Gas only can be measured. . Measuring range: 1 m/min to large flow rates	±0.5%
	Dry gas meter	. There is no fear of freezing since water is not used. . Handling is simpler than with wet type.	±0.5%
	Rotary piston type	. Measuring accuracy depends on the flow rate range and the nature of fluid. . Pressure loss is small.	Approx. ±0.5%
	Oval flow meter Roots flow meter	. Volume flow rate can be measured irrespective of kind, viscosity and density of liquid. . Mainly for liquid.	±0.1 ~ 2%
Flow velocity method (impeller method)	Tangential flow type	. In general, used for measuring the flow rate of city water.	Approx. ±4%
	Venturi tube diversion	. Can measure large flow rates of water. . Apparatus is simple.	
	Rotameter	. Small and can measure large flow rates.	0.2 ~ 1%
Area method	Rotameter	. Effective measuring range is wide. . Flow rate at low Reynolds number can be measured. . Scale keeps almost linearity.	Approx. ±2%
	Piston type flow meter	. Used for measuring fuel oil with high viscosity. . Allows telemetry.	
Measurement of velocity head	Pitot tube	. Simple and inexpensive.	
Throttle method (differential pressure method)	Orifice Flow nozzle	. Mechanism is simple. . Liquid, gas, vapor, etc. can be measured.	Approx. ±1%
	Venturi tube	. Pressure loss is small.	
Vortex	Swirl meter	. For gas	
	Delta flow meter	. Measuring range is wide.	
Hot wire method	Thomas gas meter	. For gas	
Electromagnetic method	Electromagnetic flow meter	. No pressure loss. . Quick response.	Approx. ±2%
Ultrasonic method	Ultrasonic flow meter	. No pressure loss.	

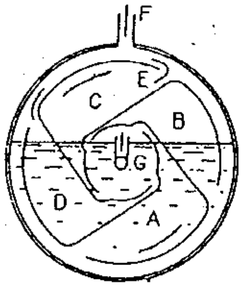


Fig. 26 Wet Gas Meter

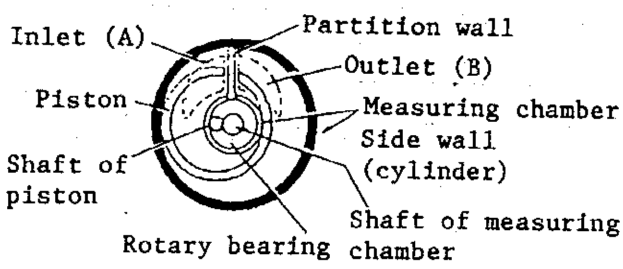


Fig. 27 Rotary Piston Type Flow Meter

A dry gas meter usually has two drums made of synthetic rubber, and if one drum is filled with a gas, valve action occurs, to change the gas passage in the other way. The expansion and contraction of the synthetic rubber drums moves a metering mechanism. The dry type has advantages over the wet type so that freezing does not occur and that moisture does not go into the gas.

Fig. 27 shows a rotary piston type flow meter. In the radial direction of a cylinder, one partition wall is provided, and the cutout of a rotary piston slides on it for eccentric motion with one point on the circumference of the piston kept always in contact with inner wall of the cylinder. The action is caused by the fluid pressure applied to the inside and outside of the piston, and the fluid is measured by the volumes inside and outside the piston.

Fig. 28 shows an oval flow meter. Two oval gear rotors are rotated by the difference between inlet and outlet pressures of a fluid, and from the number of revolutions, the flow rate is obtained. Various types and various flow rates transfer and indication methods are available.

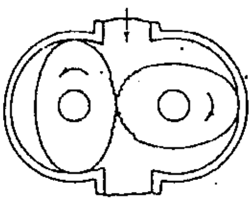


Fig. 28 Oval Flow Meter

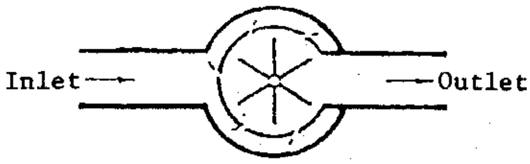


Fig. 29 Impeller Type Flow Meter

(3) Flow Velocity Method

In this method, from a propeller, etc. rotated in a fluid by flow velocity, the flow rate is obtained. Fig. 29 shows an impeller type flow meter, and it is available as a single box type or double box type. Axial flow type flow meters are used for measuring large flow rates of city water, etc. For industrial use, turbine flow meters are generally used which belong to axial flow type.

(4) Area Method

In this method, with differential pressure kept constant, the throttle area is changed to know the flow rate. Fig. 30 shows a rotameter. When a fluid to be measured flows through a vertical tube with a bottom bore slightly smaller than the top bore, the buoy in the tube is pushed up to a height corresponding to the flow rate of the fluid and comes to a standstill. Graduations are given to indicate the momentary flow rate from the stationary position. When this flow meter is used, it must be noted that the measured value depends on the density, pressure, viscosity, etc. of the fluid. Various kinds are available for various conditions. If properly used, it is simple and convenient, and widely used in many fields.

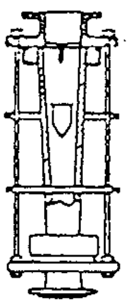


Fig. 30 Rotameter

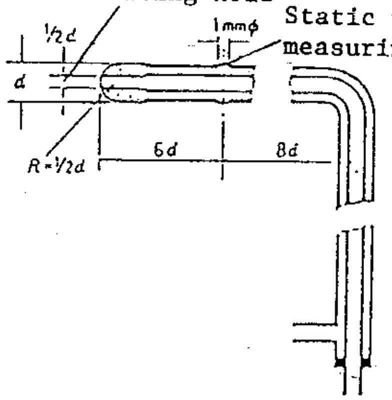


Fig. 31 Pitot Tube

(5) Method for Measuring Velocity Head

Fig. 31 shows a Pitot tube. It has a hole in front, and if the hole is turned toward the flow of fluid, a pressure corresponding to the sum of the static pressure of the fluid at the point and the dynamic pressure for the velocity is generated. In this case, since only the static pressure of the fluid acts on a side opening, the difference h is measured by a proper pressure gauge, to know the flow velocity of the fluid, for obtaining flow rate Q.

$$Q = A \cdot c\sqrt{2g \cdot h/\gamma} \quad [m^3/s]$$

A: Sectional area of tube (m^2)
$g = 9.8$ (m/s^2)
h: Pressure difference (kg/m^2) (mm H_2O)
γ: Specific gravity of fluid (kg/m^3)
c: Coefficient of discharge

The measurement by a Pitot tube is simple, but if it is wrongly used, a large error is caused. That is, the Pitot tube must be set to straightly face the flow direction. The sectional area of the Pitot tube must be smaller than 1% of the sectional area of the pipe line. Upstream of the Pitot tube, a straight tube portion as long as more than 20 times the tube diameter is required. When there is much dust, a double head Westone type Pitot tube is used, but it requires the coefficient of discharge to be noted.

(6) Throttle Mechanism Method

An orifice is a flow rate sensing element generally used for this method.

A throttling plate is inserted in a pipe line, and the pressure difference generated is measured, to obtain the flow rate according to Bernoulli's theorem. That is, as shown in Fig. 32, in a straight tube, a throttling plate (orifice plate or nozzle plate) with a hole smaller than the sectional area of the tube is inserted, to restrict the flow, and from the difference between the pressures upstream and downstream of it, the flow rate is measured. It can be used for either a gas or liquid. If F is the sectional area of the hole of the throttle plate (m^2), h is $P_1 - P_2$ = the difference between the pressures upstream and downstream of the throttle plate (kg/m^2), γ is the specific gravity of the fluid (kg/m^3), c is the coefficient of discharge, and ε is the expansion correction factor, then the weight G and the volume Q of the fluid passing through the tube per unit time can be obtained from the following:

$$G = c \cdot \varepsilon \cdot F\sqrt{2g \cdot \gamma(P_1 - P_2)} \quad [kg/s]$$

$$Q = c \cdot \varepsilon \cdot F\sqrt{2g(P_1 - P_2)/\gamma} \quad [m^3/s]$$

That is, they are proportional to the root of the differential pressure.

(7) Hot Wire Method

As one method, a heating wire or thermistor is placed in the fluid to be measured, and the temperature rise caused in the fluid is measured by the thermometers placed downstream and upstream of it, to know the flow rate. As another method, the cooling degree of the heating wire, i.e., the change in electric resistance is measured, in order to know the flow rate. As another method, the quantity of electricity required for raising the temperature of the fluid by electric heating by a certain temperature is measured to know the flow rate. An air meter, Thomas meter, etc. have been used, and as new meters for small and large diameters, thermal flow meters are being imported. The thermal flow meter keeps the hot wire away from direct contact with the fluid, and has a cylindrical probe with sufficient strength to assure industrial use, being said to be not so susceptible to the dust in air.

(8) Electromagnetic Method

If a magnetic field is generated at right angles to the flow direction of a conductive fluid flowing in a tube on both sides of the tube as shown in Fig. 33, an electromotive force E is generated in the direction perpendicular to the flow and magnetic field respectively.

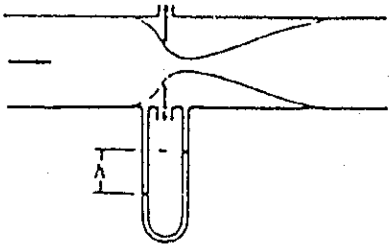


Fig. 32 Throttle Plate Flow Meter

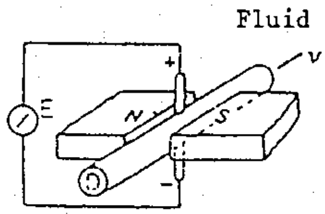


Fig. 33 Electromagnetic Flow Meter

If a conductive fluid flows in a tube of D in diameter at an average velocity v, and the intensity of the magnetic field is H, then the volume flow rate Q can be expressed by

$$Q = C \cdot D \cdot \frac{F}{H} \quad \text{(C: Constant)}$$

If the intensity of the magnetic field and the tube diameter are constant, the electromotive force is proportional to the volume flow rate.

The flow meter is characterized by a perfect freedom from pressure loss and a very quick response and usability inspite of ingress of some solid grains.

(9) Method by Fluid Vortexes

This method was developed with attention paid to the phenomenon that the frequency of vortexes generated in a fluid is proportional to the flow velocity. Fig. 34 shows a delta flow meter using the principle. Two thermal sensors are set in a triangular prism-like vortex generator, and the alternating change of von Karman's vortex street is taken as the change in the resistances of the sensors, for expressing as the flow rate.

Fig. 35 shows a vortex flow meter which uses the same principle as the delta flow meter. It uses a cylindrical sensor and one very thin platinum wire as the sensing element (the delta flow meter uses thermistors), and therefore, is different in electric circuit configuration. Both are small in pressure loss due to their structures, and can be easily installed and removed. A purge type vortex flow meter is also available for use for a fluid containing dust or corrosive fluid in a flue etc.

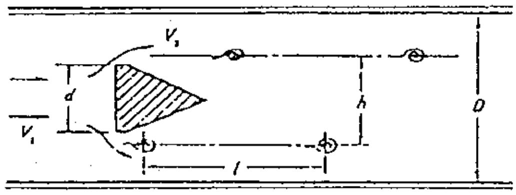


Fig. 34 Delta Flow Meter

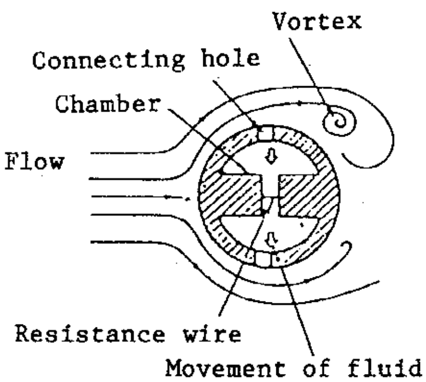


Fig. 35 Vortex Flow Meter

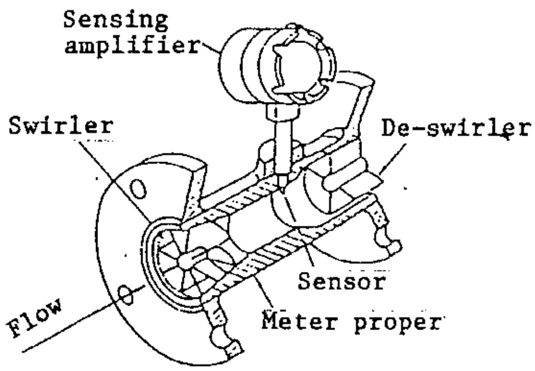


Fig. 36 Swirl Meter

Fig. 36 shows a swirl meter which is composed of a meter proper, swirler, de-swirler, sensor and sensing amplifier. The meter proper has internally Venturi tube structure. It was developed for gas. Each vortex generated by the swirler has a velocity distribution protruding at the axial portion and symmetrical around the axial center, and causes a braying motion at the neck portion of the Venturi tube. Since the number of revolutions at the velocity center (vortex center) is proportional to the actual volume of the gas, it is sensed by a thermistor, in order to indicate as the flow rate. The de-swirler is provided to remove the influence on the downstream side, and restores the original condition free from vortexes.

All the flow meters are wide in measuring a range as a common advantage, and their respective features are used to widen their applications.

(10) Other Flow Rate Measuring Methods

If an acoustic wave is generated in flow, the sound is propagated at a velocity equal to the vector of the sound velocity and the flow velocity. An ultrasonic flow meter uses this principle, to measure the propagation velocity, for measuring the flow velocity and flow rate. As for a laser flow meter, since a laser beam is monochromatic in wavelength and monodirectional with uniform wave front, the scattering in a fluid is used to measure the flow velocity. It has such features as non-contact measurement and a good response.

6. Measurement of Pressure

(1) Kinds and Features of Pressure Gauges

Pressures gauges include liquid column type, elastic type, inverted bell jar type, ring type, electric type, etc., and their features and accuracies are listed in Table 7.

In the selection of a pressure gauge, the following should be considered:

1) Measuring range: In the case of Bourdon gauge, etc., the measuring range should be 2/3 or less of the maximum graduation.
2) Direct reading measurement or telemetry.
3) Place of installation.
4) To have a safety device, in the case of high pressure.
5) Inspection should be carried out constantly to confirm that the indication is correct.

Table 7 Kinds, Features and Accuracies of Pressure Gauges

Measuring method	Pressure gauge	Features	Accuracy
Liquid column type	Mono-tube type	. Only once scale reading is required. . Influence of temperature is large.	Approx. 0.1mm
	U-tube type	. Higher in accuracy than mono-tube type. . Tube diameter and temperature affect error.	Approx. 0.1mm
	Mono-tube inclination type	. Straightness and inclination angle of tube exert large influence	Approx. $0.01mmH_2O$
Elastic type	Bourdon tube	. Simple in structure. So popularly used that it is a generally called pressure gauge which reminds people of Bourdon tube pressure gauge. . Measuring operation is simple and does not require skill. . Easy in handling and maintenance. . Telemetry and automatic recording are easy. . Allows measurement even in relatively severe conditions such as solid-containing fluid, corrosive fluid, etc. . Suitable for high pressure measurement and wide in measuring range. . Unsuitable for measuring slight pressure. . Since elasticity only is used, it is difficult to change the measuring pressure range. . Errors due to creep, hysteresis or secular change are liable to be caused.	Approx. ±0.5 to 2.5% of maximum pressure
	Diaphragm type	. Pressure receiving face is large. . Corrosion preventive measure can be easily taken. . Response is quick. . Maximum pressure is 2 kg/cm^2.	Approx. ±0.5 to 2.0%
	Bellows type	. Measuring range can be changed. . Displacement is large. . Pressure tightness and temperature compensation can be easily realized.	Approx. ±0.5 to 2%
	Capsular type	. Very sensitive to a slight pressure change. . Unsuitable for high pressure.	Approx. ±0.5 to 2%
Inverted bell jar type	Single bell type	. Mechanical friction is small. . Impact vibration can be measured.	Approx. ±1%
	Double bell type	. Higher in sensitivity and accuracy than single bell type.	Approx. ±0.5%
Ring type		. Turning torque is large. . Measuring range can be adjusted. . At end connection, elastic resistance is liable to occur.	±1% to 2%
Electric type	Strain gauge type	. Sudden change can be followed. . Suitable for telemetry and multi-point measurement.	Approx. ±1.5%
Piston type		. Measuring range can be adjusted.	Approx. ±1%
Weight type		. Measuring range is wide. . Accuracy is high.	1/200 of marked quantity

(2) Liquid Manometer

1) U-tube manometer

As shown in Fig. 37, a glass tube is bent like U shape, and one end connects to a measuring point. while the other end connects to another pressure measuring port or is usually open to the atmosphere. regarded as a 1-atmosphere constant pressure chamber.

The measuring liquid used is usually water. However, for large pressure difference, mercury is used, and for small pressure difference, any liquid lighter than water is used. However, in this case, calculation of multiplying the differential pressure by the specific gravity of the fluid used is required. The liquid used for the pressure measurement is required to have such properties as (1) small viscosity, (2) small thermal expansion coefficient, (3) small capillarity, (4) certain chemical ingredients, etc.

Therefore, if a precise measurement is required, correction of temperature, gravity and capillarity is required.

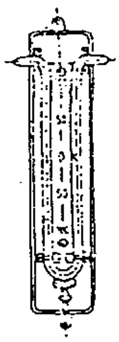


Fig. 37 U-tube Manometer

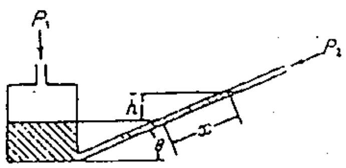


Fig. 38 Mono-tube Inclination Manometer

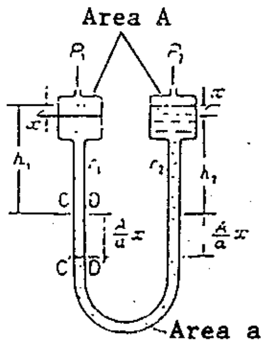


Fig. 39 Two-liquid Manometer

2) Mono-tube inclination manometer

As shown in Fig. 38, this is a modification of U-tube manometer. The sectional area of P_1 side is very large compared with that of P_2 side, and the change of the liquid level in the container large in sectional area corresponding to the change of the liquid level in the thin tube can be neglected. Therefore, the height of the liquid in the mono-tube is subtracted, and the length x corresponding to the pressure is enlarged by $1/\sin\theta$. Since x corresponds to $h/\sin\theta$ where θ is the inclination angle, pressure P_1 can be obtained from the following equation:

$$P_1 = P_2 + \gamma x \sin\theta$$

where γ is the specific gravity of the liquid. Both types constant and adjustable in the angle θ of the inclined tube are available.

3) U-tube manometer using two liquids

As shown in Fig. 39, two liquids are used, to enlarge the differential pressure. The pressure difference can be calculated from:

$$\Delta P = P_1 - P_2 = \frac{A}{a} x \{(\gamma_2 + \gamma_1)\frac{a}{A} + (\gamma_2 - \gamma_1)\}$$

where A: Sectional area of pressure receiving chamber

a: Sectional area of measuring tube

γ_1: Specific gravity of light liquid

γ_2: Specific gravity of heavy liquid

If a/A and $\gamma_2 - \gamma_1$ are smaller, even a slight pressure difference can be enlarged more. For example, if A/a = 1000, specific gravity of alcohol γ_1 = 800 kg/m^3, and specific gravity of petroleum γ_2 = 810 kg/m^3, then the enlarging factor becomes about 81 times.

(3) Elastic Pressure Gauge

1) Bourdon gauge

As shown in Fig. 40, a metallic pipe bent like a circular arc (or spiral, helix, any other form, etc.), and one end is fixed, while the other end is kept free. If an internal pressure is applied, the free end moves. The movement is enlarged by a lever or gear, to move the needle. Bourdon gauges are available in a wide accuracy range from superhigh accuracy to low accuracy. For various applications, various forms and sizes are available. Bourdon gauges are generally used in large quantities for industrial use.

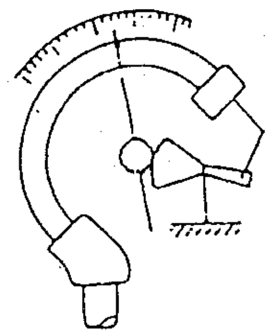


Fig. 40 Bourdon Gauge

2) Instrument pressure gauges

Instrument pressure gauges are offered for measurement and control sensing in large plants and industrial processes, and are applied for measuring static pressure, differential pressure and absolute pressure. Either current transmission (DC 4 to 20 mA) or pneumatic transmission (0.2 to 1 kg/cm^2) is used. The gauges are standardized for indication, recording and arithmetic input respectively.

The pressure receiving element is a diaphragm made of a special metal, and a liquid material is contained between it and the sensing element, for transfer of pressure. The diaphragm is available in various forms, sizes and materials, for various working conditions and pressure ranges. The measuring range available is generally from about 20 mm water column to hundreds of atmospheric pressure. Zero adjustment, span adjustment and damping adjustment can be made.

(5) Other Pressure Measuring Methods

1) Inverted bell jar type manometer

As shown in Fig. 41, this combines a beam with a bell. For industrial application, it is little used.

2) Strain gauge type pressure gauge

In general, a strain gauge is used as the sensing element. Strain gauge type pressure gauges are used mostly for special applications. The sensing means is characteristically small and quick in response rate. They are available for superhigh pressure to slight pressure. There are some using a semiconductor strain gauge or magneto-striction effect.

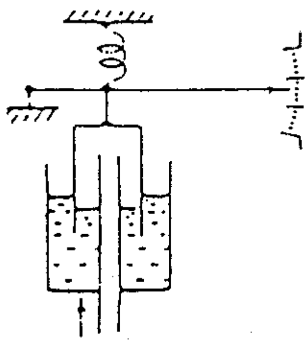


Fig. 41 Inverted Bell Jar Type Manometer

7. Measurement of Humidity

(1) Kinds of Features of Hygrometers

The humidity of a gas can be measured by using a psychrometer, dew point meter, electric hygrometer, hair hygrometer, etc.

(2) Psychrometer

This meter is usually used. Two ordinary mercury-in-glass thermometers are placed in the air to be measured, and the bulb of either of them is wrapped with cloth wetted by water.

From the dry bulb temperature and wet bulb temperature, the humidity is obtained in reference to the psychrometer diagram.

The wet bulb indication of a stationary psychrometer is generally too high, affected by radiant heat, and does coincide with the real wet bulb temperature. Therefore, there is also a device contrived to increase the velocity of the air around the wet bulb.

A sling psychrometer has the psychrometer mounted on one frame, and swung around the frame, to reach an equilibrium temperature.

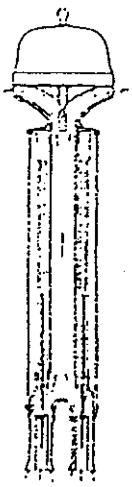


Fig. 42 Asmann Ventilated Psychrometer

An Asmann ventilated psychrometer has a small spring revolved like the works of a watch at the top of the psychrometer, and it is revolved to cause an air current of about 2.5 m/s in flow velocity on the surfaces of the dry and wet bulbs.

(3) Resistance Thermometer Type Hygrometer

As shown in Fig. 43, the principle is the same as that of a psychrometer. Instead of mercury thermometers, resistance thermometers are used. The cold junction is wrapped with wet cloth, and the hot junction is exposed to air, to generate an electromotive force corresponding to the difference between dry and wet bulb temperatures. Remote indication and recording can also be realized.

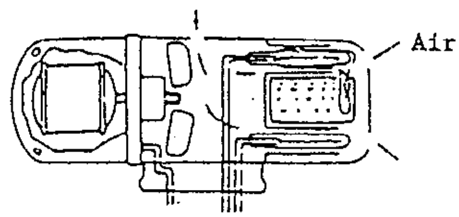


Fig. 43 Resistance Thermometer Type Hygrometer

(4) Dew Point Meter

A cooling dew point meter has a smoothly polished metallic face placed in the air to be measured, and the metallic face is gradually cooled by feeding water inside or using the heat of vaporized ether, etc. At a certain temperature, the glossy face becomes cloudy with a thin film of dew. On the contrary, if the temperature of the metallic face is cloudy with dew is gradually raised, the cloud disappears at almost the same temperature as before. The mean temperature of both is called a dew point. If the dew point is known, the humidity can be obtained from the water vapor table or humidity diagram.

The cloud by dew can be judged visually, or using a photoelectric tube or electric resistance.

A phototube dew point meter measures the cloud on the metallic specular gloss face using a phototube circuit, and allows recording.

(5) Electric Hygrometer

If a hygroscopic conductive thin film (e.g., containing lithium chloride) is spread between two electrodes insulated from each other, the moisture around it is absorbed according to the increase of the humidity of the air around it, in order to decrease electric resistance. This principle is used in this hygrometer.

8. Practice of Liquid Flow Rate Measurement

1) Flow rate measurement by an oval flow meter
2) Flow rate measurement by an orifice flow meter
3) Flow rate measurement by an ultrasonic flow meter
4) Electricity management measurement by an electricity management meter
5) Practice of water quality analysis (pH)
6) Practice of water quality analysis (electric conductivity)

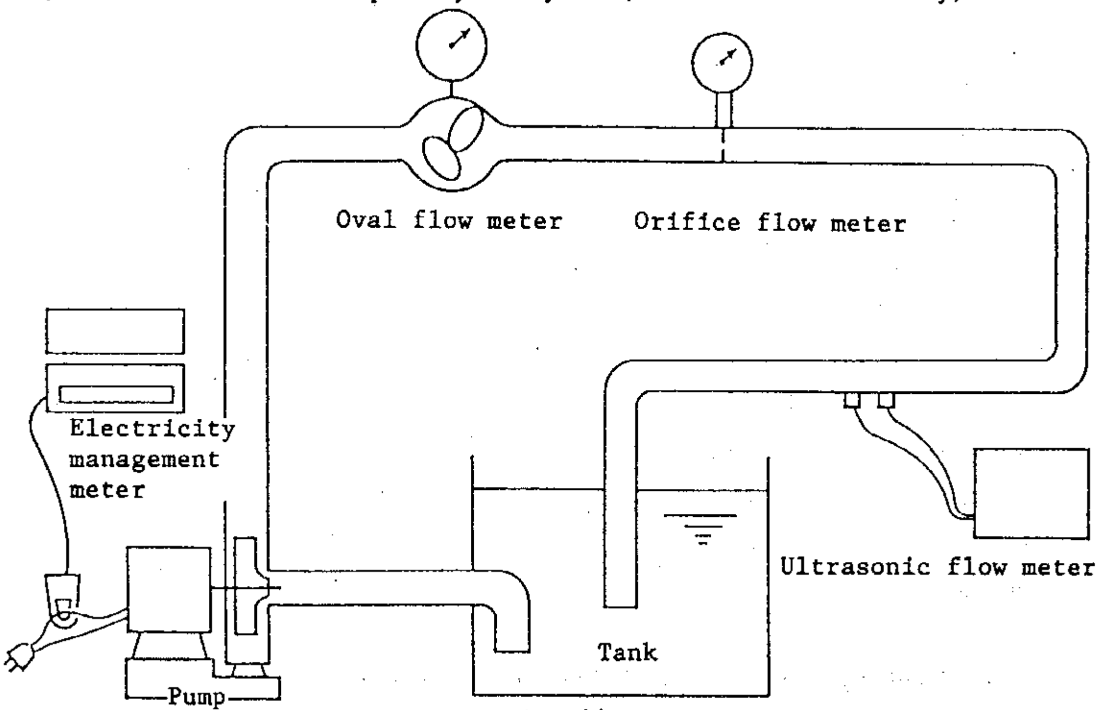


Fig. 44

9. Practice of Temperature Measurement

1) Surface temperature measurement by a thermocouple thermometer
2) Gas temperature measurement by a thermocouple thermometer
3) Surface temperature measurement by a radiation thermometer
4) Recording by a dot printing recorder
5) Electricity management measurement by an electricity management meter

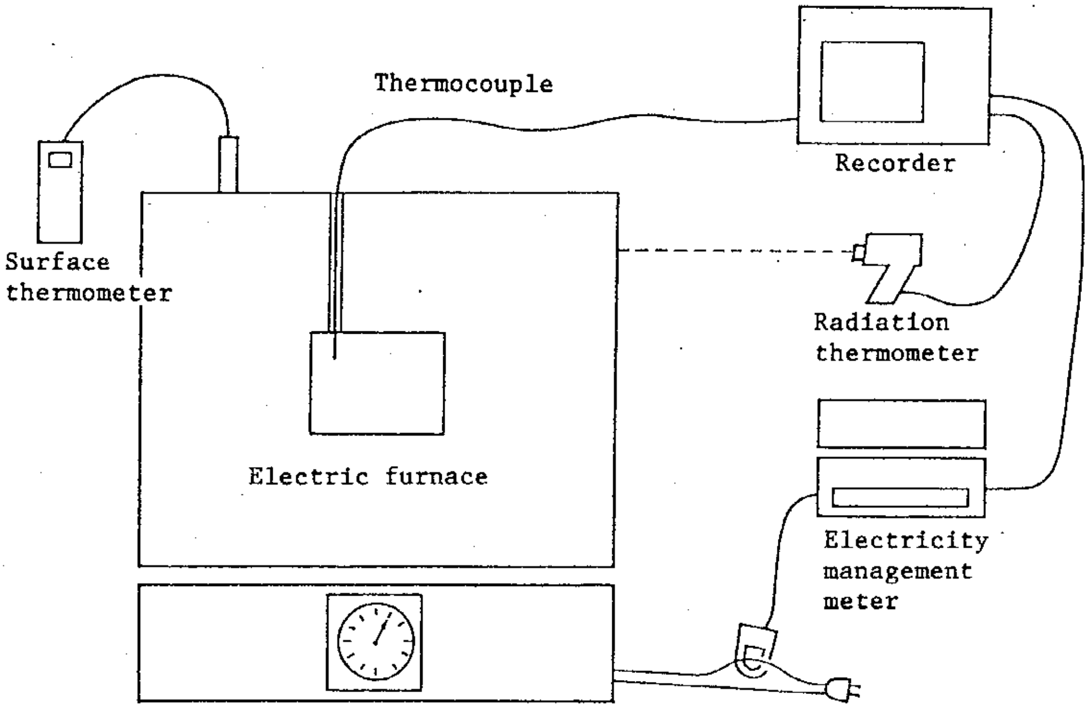


Fig. 45

10. Practice of Gas Flow Rate and Pressure Measurement

1) Pressure measurement by a diaphragm micro-pressure difference pressure gauge
2) Wind velocity measurement by a constant temperature type hot-wire anemometer
3) Recording by a dot printing recorder
4) Electricity management measurement by an electricity management meter

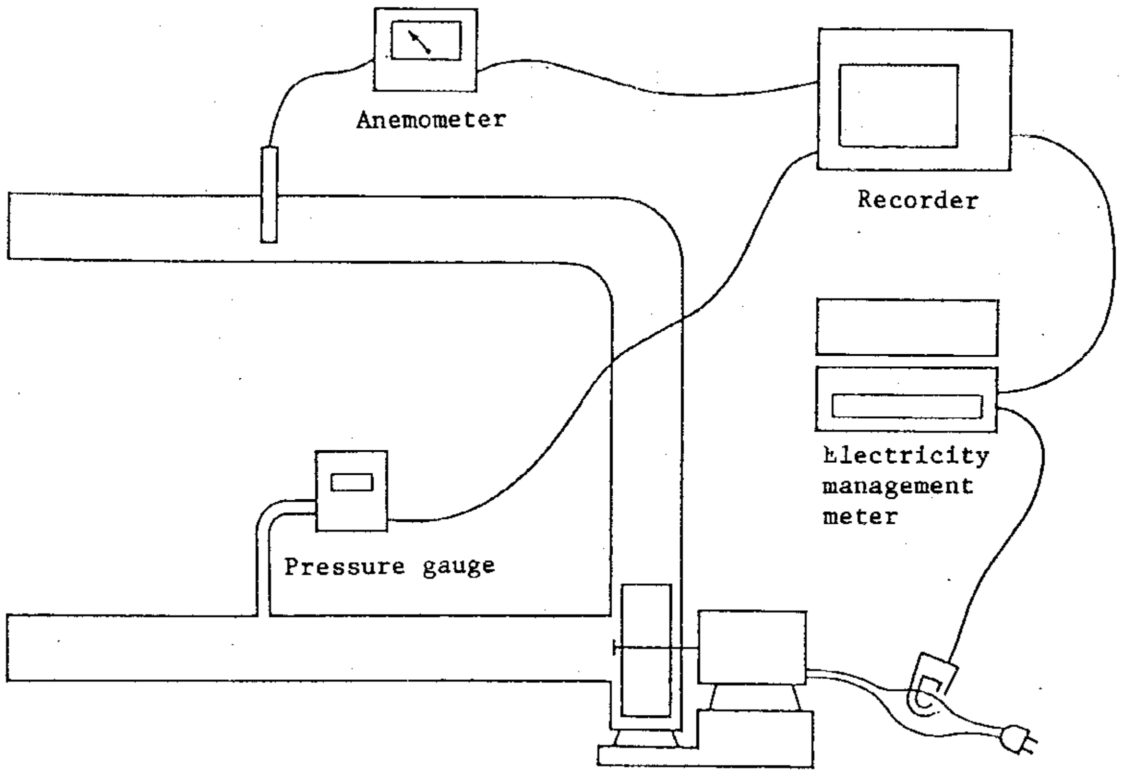


Fig. 46

Temperature Measurement

Date:______________ Room Temp ____°C

time		heating	inside	operating
start	measure	time	temp	temp

Position		Temperature °C						Heat rate	
		local value					Ave.	/m² h	/h
upper ____m²									
left ____m²									
right ____m²									
back ____m²									
front ____m²	door ____m²								
	wall ____m²								
Total Heat Loss [kcal/h]									

Liquid Flow Rate Measurement

Date:__________ Room Temp ____°C Water Temp ____°C

No.	Flow Rate				Power
	Orifice	Ultrasonic	Oval		
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

Water Quality Analysis

Date	Temp	pH	conductivity

Gas Flow Rate Measurement

Date:______________ Room Temp ____°C

No.	Pressure	Velocity				Flow Rate	Power
		①	②	③	Ave.		
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							

THE STUDY (AFTER-CARE)
ON THE ENERGY CONSERVATION PROJECT
IN THE KINGDOM OF THAILAND

TEXTBOOK FOR THE ENERGY AUDIT TECHNIQUES WORKSHOP

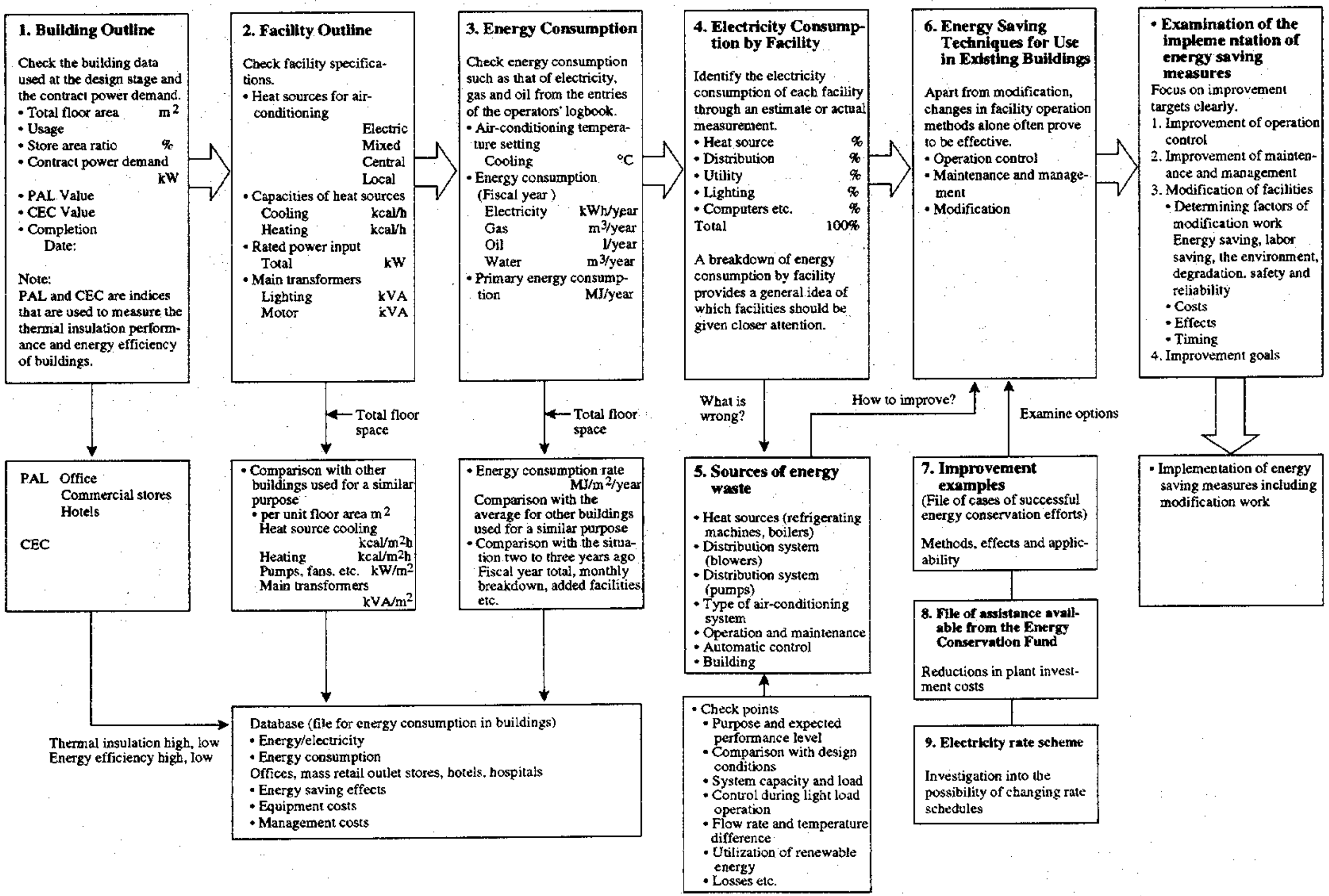
6. Energy Conservation Measures for Existing Buildings

March 1994

Japan International Cooperation Agency (JICA)

The Energy Conservation Center, Japan (ECCJ)

Flowchart of Energy Saving Checks in Buildings



I. Building Outline

II. Facility Outline

1. Building outline

<table>
<tr><td colspan="2">Building name</td><td colspan="2"></td><td rowspan="3">Contact person</td><td rowspan="3">Name:

Tel:</td></tr>
<tr><td colspan="2">Owner</td><td colspan="2"></td></tr>
<tr><td colspan="2">Location</td><td colspan="2"></td></tr>
<tr><td colspan="2">Building data</td><td colspan="4">1. Site area m2
2. Number of stories below ground above ground
3. Structure RC, SRC, etc.
4. Building area m2 5. Total floor area m2
6. Air-conditioning area m2
7. Completion date
8. Number of employees persons (used by persons/day)</td></tr>
<tr><td rowspan="2">Building usage</td><td>Occupants</td><td colspan="2">1. Owner (company) 2. Tenants
3. Both (tenants %)</td><td colspan="2" rowspan="2">Store area m2
(Store area ratio %)
Computer room m2
Parking space m2</td></tr>
<tr><td>Usage category</td><td colspan="2">1. Office (private sector) 2. Apartment house
3. School/research laboratory
4. Hospital/clinic 5. Office (public service)
6. Department store/supermarket 7. Hotel
8. Public hall/meeting place
9. Entertainment facility
10. Other ( )</td></tr>
<tr><td rowspan="3">Design/ construction</td><td></td><td>Building</td><td>Air-conditioning system</td><td colspan="2">Electrical facilities</td></tr>
<tr><td>Design</td><td></td><td></td><td colspan="2"></td></tr>
<tr><td>Construction</td><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="2">Receiving voltage</td><td colspan="4">kV</td></tr>
<tr><td colspan="2">Type of air-conditioning system</td><td colspan="4">Central air-conditioning (i) Refrigerating machine (electric)
(ii) Heat pump chiller
(iii) Absorption refrigerating machine (gas, oil)
Local air-conditioning (iv) Package type
(v) Multi type for buildings
Combined</td></tr>
</table>

2. Refrigerating machines (turbo-refrigerating machines, refrigerating chillers, heat pump chillers, absorption refrigerating machines)

Classification	Rated capacity Cooling kcal/h	Compressor kW	Power consumption kW Gas Nm3/h	Maker installation date	Auxiliary equipment Cooling water pump	Auxiliary equipment Blower	Remarks
Subtotal							

per floor area	kcal/m2h	1 RT = 3,024 kcal/h	Flow meter for cold water	m3/min

3. Boilers (for hot-water supply)

Classification	Hot-water supply kg/h	Gas Nm^2/h	Maker installation date	Auxiliary equipment kW
per unit floor area	kcal/m2h			

4. Heat sources (local) (package type, multi type for buildings, heat recovery water cooled heat pumps, etc.)

Classification	Indoor machines			Outdoor machines			
	Cooling capacity kcal/h	Blower kW	Number of units	Compressor kW	Blower kW	Cooling water pump kW	Number of units
Subtotal							

per unit floor area	kcal/m2h	Total indoor and outdoor motor capacity kW

5. Heat storage tank

Classification	Water volume m^3	Ice volume m^3
Water/ice		
per unit floor area	m^3/m^2	m^3/m^2

6. Cold water pump for air-conditioning system

Classification	Water flow (m^3/min)	Motor kW	Number of units	Remarks
Cooling hours				
(24 hours)				

Water supply method: Variable water flow (via the number of pumps and rotational speed)
Fixed water flow

7. Air-conditioners/fan-coil units

Classification	Air supply rate	Air intake rate	Blowers	Number of units
Air-conditioner				
Outside air-conditioner				
Fan coil unit total				
Subtotal				

Air supply system: Variable air flow type (via the rotational speed and damper), fixed airflow
Cooling control with outside air: with/without Minimum outside air intake rate: with/without
Total enthalpy heat exchanger

8. Air supply and exhaust fans

Classification	Air flow m^2/h	Motors	Number of units
General total			
Parking space total			
Kitchen total			
Subtotal			

9. Sanitary pumps

Classification	Water flow m^3/min	Motors	Number of units
Water supply			
Subtotal			

10. Elevators

Classification		Motors	Number of units
Subtotal			

11. Lighting/wall sockets

Classification	General total	Shared total	Store total	Wall socket load
Fluorescent lamps Incandescent lamps				OA equipment Vending machines

Subtotal	Fluorescent lamp total kW	Incandescent lamps kW	per unit floor space W/m2	Subtotal	kW

12. Local

Computers Package air-conditioner for computers Show case

Total power input kW

13. Power receiving facility

Main transformers

Lighting	kVA ×	Power condenser for power factor improvement
Motor	kVA ×	
Total	kVA	
	per unit floor area	kVA/m2

III. Energy Consumption

1. Operation management

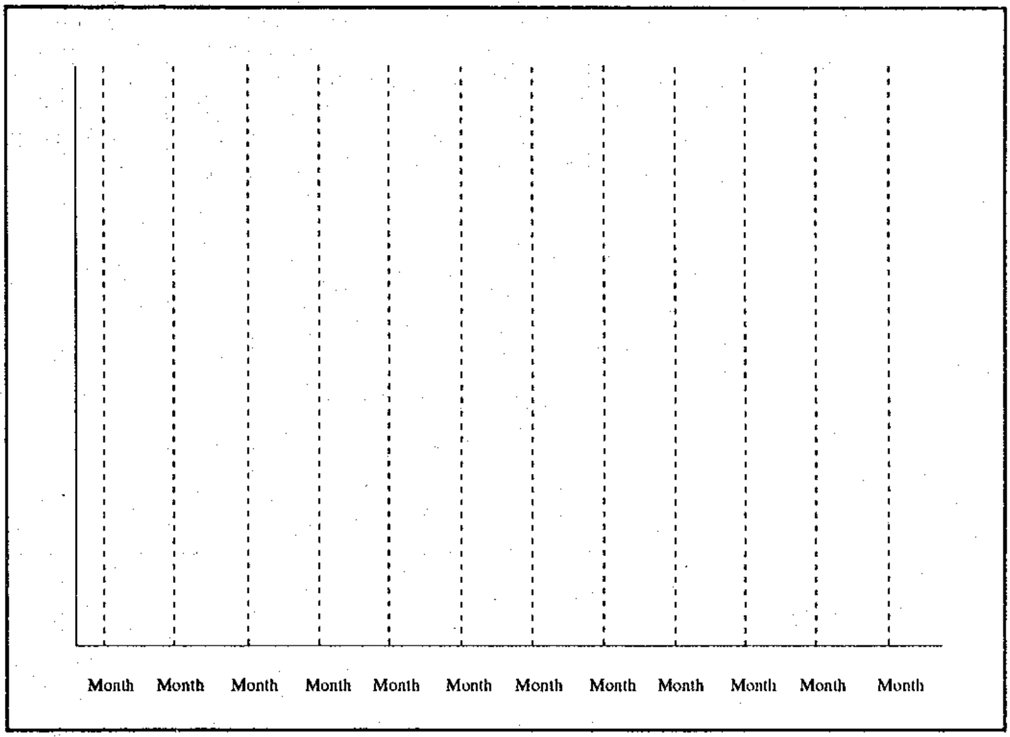
<table>
<tr><td>(1) Air-conditioning period</td><td colspan="6">Cooling from to</td><td rowspan="3">Remarks

Indoor environmental standards</td></tr>
<tr><td rowspan="2">(2) Air-conditioning hours
Temperature setting</td><td>A/C zone</td><td colspan="2"></td><td colspan="2"></td><td>Computer room</td></tr>
<tr><td>Cooling</td><td>from
to</td><td>℃</td><td>from
to</td><td>℃</td><td>from
to ℃</td></tr>
<tr><td>(3) Control system</td><td colspan="6">• Equipment control (auto/manual/mixed), (building management system with/without, heat storage controller with/without)
• Distribution system (controlled by changing the number of motors in operation/controlled by changing motor speed), (outside air intake with/without)</td><td></td></tr>
<tr><td>(4) Maintenance and management</td><td colspan="6">• Operation organization total staff persons
(day persons, night persons)</td><td>After-hours operation</td></tr>
</table>

2. Annual consumption of electricity, gas, etc. (from to)

Date	Electricity		Gas (units)	Fuel oil (units)	Water		Remarks
	Max power demand	Electricity consumption			Drinking water	Service water	(expansion etc.)
Fiscal year total							
Primary energy consumption							Total MJ/year
per unit floor area		kWh/m²/y	units/m²/y	units/m²/y	m3/m²/y		MJ/m²*year

3. Graphs of the monthly consumption of electricity, gas, etc.

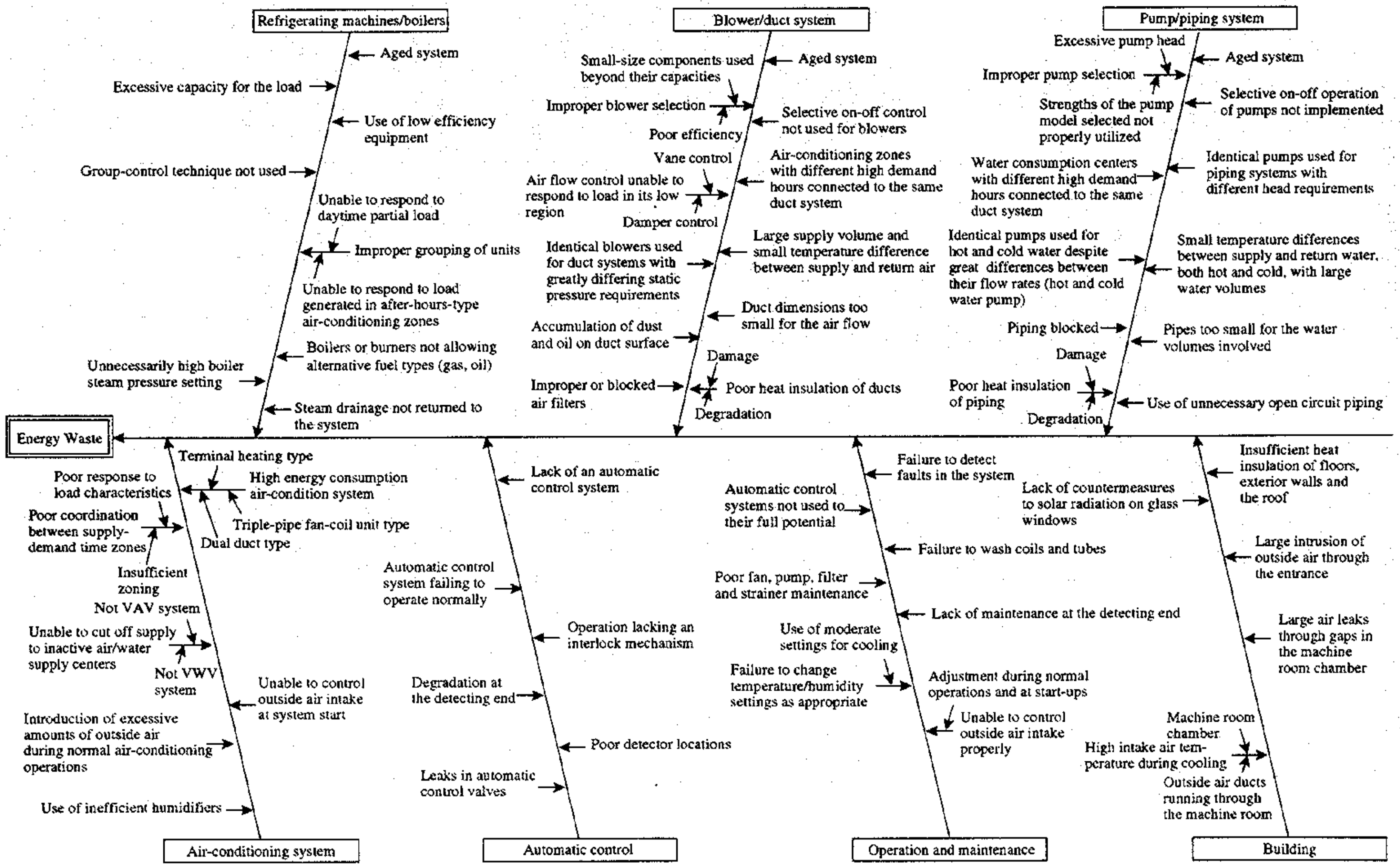


IV. Electricity Consumption per Facility

Facility	Capacity (rating plate)			Calculation of power consumption	Annual electricity consumption		Remarks
	Motor	Rated output kW	Power consumption kW	Rated output (power consumption) × operating hours/day × days/month × number of months × load factor	Calculated/ actual kWh	Ratio%	Efficiency, load factor, demand factor, operating hours, etc.
Central heat sources	Refrigerating machine	Cooling					
	Refrigerating machine auxiliary equipment						
	Boiler	Hot-water supply					
Local heat sources	Package air-conditioners						
Pump/Fan	Pump						
	Air-conditioner						
Utility	Air intake and exhaust fans	General Parking space Kitchen					
	Sanitary pump	Water supply					
	Elevator						
Lighting	Lights	General Common Store					Including ballast loss
	Wall sockets	OA Vending machines					
Computing equipment	Computers Package air-conditioner for computers						
Others	Showcase						
Transformer losses							
Total						100	

Notes: 1. Rated output kW, shaft output kW
Power consumption = Shaft output/Efficiency
It is assumed that rated output nearly = power consumption here.
2. In the case of fans, however, demand factor should be taken into account based on current readings, as they are frequently operated on light load.
Demand factor = Actual max power demand kW/Rated max power input kW
3. Load factor = Electricity consumption for a given period of time kWh/(rated maximum power input kW × full load operating hours h)
4. Calculation is not necessary where individual watt-hour meter readings are used.

V. Schematic Diagram showing Sources of Energy Waste



VI. Energy Saving Techniques for use in Existing Buildings

1. Techniques involving operation control

Item	Techniques to improve the effectiveness of energy saving efforts		Effects	Remarks
(1) Reducing the air intake volume	a. Reviewing the outside air intake requirements	• Find a minimum required outside air intake setting suitable for the building usage and number of people present.		Consideration should be given to malodor generation and an interior pressure balance, in addition to CO_2 concentration control. • Introduction of dampers for outside air intake control
	b. Controlling outside air intake	• Provide outside air intake control according to changes in the number of people in rooms. • Implement outside damper control using a CO_2 concentration detector or a timer based on forecast changes in the number of people present	Effective for buildings with large daily or hourly variations in the number of people present, e.g. department stores and theaters	
	c. Avoiding outside air intake during precooling	• Close dampers completely using a timer during time zones when there are few people present, e.g. at system start-ups	Reductions in air-conditioning load due to outside air and the required air-conditioning capacity	Attention should be given to achieving an interior pressure balance through outside air intake and exhaust operations.
(2) Changing temperature settings	a. Changing thermostat settings (rooms where people stay a long time)	• Generally adopt higher cooling temperature settings.	Summer room temperature: 26°C -> 28°C Reduction in cooling load by about 20%	Reductions in air-conditioning load due to outside air Consideration should be given to variations in the pleasant temperature level depending on each individual, as well as room-to-room temperature fluctuations.
	b. Changing thermostat settings (other rooms)	• Increase temperature settings for spaces where people do not stay long, e.g. corridors and entrance halls.		
	c. Changing temperature settings based on the outside air temperature	• Increase temperature settings as the outside temperature rises		
	d. Changing the temperature setting for the computer room	• Increase temperature settings as high as possible, provided it does not affect computer performance (consideration of 28°C).	Reduction in computer-related cooling load	Consultation with the computer maker; Reheating heaters
(3) Preventing overcooling	a. Checking thermostat settings	• Provide frequent manual control where the automatic control system is inadequate.	Interior environment improvements, as well as energy savings, will result.	• Provide dampers at necessary locations if there is no means of air flow control.
	b. Adjusting air supply volumes and flow rates	• Prevent the overcooling of rooms by adjusting branch dampers, etc. • Provide frequent unit air flow and water flow control.		

Item	Techniques to improve the effectiveness of energy saving efforts		Effects	Remarks
(4) Changing humidity setting and avoiding reheating	a. Changing humidistat setting	• Generally adopt higher humidity settings. • Increase the dew point temperature setting where dew point control is provided.	Energy saving effects achieved by changing the dew point temperature of primary air: Summer: 10°C -> 12°C Approx 17% reduction	Increasing humidity settings during cooling is effective for rooms with a small sensible-heat factor where people do not stay long, e.g. theaters, public halls and restaurants.
	b. Avoiding reheating for the purpose of dehumidifying, if there is no need for constant temperature.	• Stop using a reheating device.		
	c. Maintaining the room temperatures by reducing air supply volumes instead of providing reheating, in the case of a fall in sensible heat load during coolingChange from CAV to VAV	• Allow a rise in room humidity during low cooling load hours.		
(5) Adjusting system starting and stopping times and reducing operating hours	a. Optimizing the starting time b. Investigating the stopping time	• Adjust time schedules for starting and stopping according to days of the week and seasons. • Operate only minimum necessary equipment after hours (overtime hours).	Energy savings through the shortening of the duration of precooling Reductions in system operating hours	
	c. Shortening operating hours d. Reducing the size of the supply area	• Reduce the operating hours of ventilating fans for the machine room, parking space, etc. • Introduce local air-conditioning (concentrated air-conditioning within limited areas)	Reductions in blower operating hours Reductions in air-conditioner operating hours	
(6) Reducing air supply volumes	a. Adjusting air supply and exhaust volumes for the machine room, parking area, etc.	• Check the ventilation frequency, as well as the minimum air flow requirement according to the Parking Facilities Law, the Building Standards Law, etc. • Decrease air flow by modified the pulley instead of individually controlling duct system dampers, when dealing with excessive air supply by blowers.	Since blower power consumption increases proportionally with the cube of air flow rate, a 10% decrease in air flow rate will result in a 27% decrease in power consumption.	Investigation is necessary as to whether temperature and humidity conditions will deteriorate to such an extent as to be detrimental to office equipment, etc.

Item	Techniques to improve the effectiveness of energy saving efforts		Effects	Remarks
(7) Operating heat source equipment efficiently	a. Group-controlling boilers, refrigerating machines, etc.	• Reduce the number of active units during partial load operations.	Improvement in total efficiency Improvement in the coefficient of performance	Partial load operation characteristics and other data relating to equipment targeted for energy-saving efforts, including its associated equipment, must be thoroughly known. Care should be taken where there are strict temperature control requirements.
	b. Adjusting cold water outlet temperature settings for refrigerating machines			
	c. Adjusting the cooling water temperature setting	• Lower the cooling water temperature to the lowest tolerable level for refrigerating machines via cooling tower fan shutdown control. Apply the same technique to cooling tower by-pass valve.	Improvement in the coefficient of performance	The lower limit of cooling water temperature setting must be established. Turbo-refrigerating machines: 15°C Absorption refrigerating machines 25°C
(8) Heavy utilities	a. Operation and management of heavy utilities	• Reduce the number of elevators and escalators in operation. • Reduce the frequency of elevator stopping.	Reductions in power required to operate heavy utilities	Target a utilization factor of just below 50%.
(9) Hot-water supply and sanitary systems	a. Operation and management of hot-water supply system b. Sanitary system	• Reduce both hot-water supply hours and areas. • Lower hot-water supply temperatures depending on usage. • Provide flush valve fine adjustments.	Reduction in unnecessary energy consumption Reduction in heat losses relating to hot-water supply Reduction in boiler energy consumption Reduction in water consumption	
(10) Lighting facilities	a. On-off management of lights	• Keep illumination level to the allowable minimum • Turn off some lights in over-illuminated working spaces • Reduce lighting time before working hours begin. Illuminate floor by floor during early morning cleaning, etc., depending on actual work progress. • Turn off lights in rooms which are not in use. • Turn off lights near windows.	Reduction in lighting hours Reduction in cooling load	
(11) Electrical facilities	a. Operation and management of the electrical facilities	• Connect loads in such a way as to balance the phases of three-phase power feeders.		Check on the low load operation of electrical facilities.

2. Techniques involving maintenance and management

Item	Techniques to improve the effectiveness of energy saving efforts	Effects	Remarks
(1) Maintenance and cleaning of equipment	(a) Clean air-conditioning fan-coil units and filters. (b) Inspect and repair duct leaks. (c) Clean condensers and evaporators.	Improvements in heat exchange efficiency Reductions in energy consumption associated with heat distribution	Cleaning of interior air inlets and outlets
(2) Repair and replacement of equipment	(a) Repair equipment and devices exhibiting performance degradation due to corrosion, wear, tear, etc. (b) Carry out replacement in cases where performance degradation cannot be rectified even if repairs are provided.	Improvements in equipment and heat exchange efficiencies	
(3) Inspection of automatic control equipment	(a) Check the precision of sensors. (b) Check operation of valves, dampers, etc. (c) Above all, inspect the heat source control system.	Improvements in the interior environment, as well as energy saving effects	Air leaks from air piping
(4) Strengthening the supervision of equipment	(a) Increase meters and other measuring instruments to help monitor energy consumption and interior environment conditions, etc. (b) Check management items.	Labor saving as well as energy saving effects	
Others	(a) Place OA equipment with the same temperature and humidity condition in the same space. (b) Remove objects near air outlets, etc. that interfere with air flow, such as other equipment and decorations. (c) Keep shut doors leading to the outside or rooms without air-conditioning, providing "Do not open" signs on them. (d) Provide ventilation in toilets only when they are used by linking its operation to that of lighting. (e) Place a wind cover at outside air inlets so as to prevent excessive outside air intake. (f) Keep blinds shut if there is solar radiation while cooling is being provided. (g) Do not wear too many clothes while cooling is provided. (h) Broadcast messages appealing for energy saving efforts at the beginning and end of working hours within the building. (i) Create an energy conservation promotion organization.		Blinds should be drawn down at the end of work (to avoid morning solar radiation).

3. Techniques involving modifications to equipment

Item	Techniques to improve the effectiveness of energy saving efforts		Effects	Remarks
(1) Building	a. Increasing the thermal insulation of external walls	• Modify walls and windows to improve their thermal insulation. • Modify the roof and floors to improve their thermal insulation. • Thermally insulate window panes.	Reductions in air-conditioning load due to heat transmission through the building structure	• Exterior thermally insulating construction method (aluminum panels etc.) • Wooden frames can be used in the interior of existing buildings.
	b. Avoiding solar radiation	• Provide blinds and curtains • Provide louvers and eaves • Modify window panes • Sprinkle the roof with water and provide water tank on it.	Reductions in air-conditioning load due to solar radiation	• Solar radiation control film • Use blow water for cooling etc.
	c. Preventing drafts	• Modify the entrance and provide a revolving door, an enclosed buffer area, etc.	Reductions in air-conditioning load due to intrusion of outside air	Automatic doors allow considerable drafts from outside.
	d. Improving lighting	• Provide reflective louvers and eaves. • Paint room interiors in light colors. • Finish walls with a surface coating.	Reflecting effects Maintenance of brightness	
	e. Improving ventilation	• Modify window frames and provide windows that can be opened.		
(2) Type of heat source	a. Heat recovery and reuse	• Use total enthalpy heat exchangers • Use heat recovery heat pumps • Recover heat from exhausts and drainages (boiler flue gas, drainage from the hot-water system, steam drainage, etc.) • Recover heat from refrigerating machine cooling water • Recover heat from air-conditioning system return air	Reduction in air-conditioning load due to outside air (approx 70% recovered) Improvements in the coefficient of performance of heat pumps as a result of heat recovery For hot air supply and reheating during cooling Reductions in air supply and exhaust fan power consumption	• Installation of exhaust ducts and exhaust fans Ventilation of polluted rooms
	b. Modification of the heat source system	• Convert the system to a heat storage type. • Modify the heat storage tank and heat storage system. • Modify the heat source to convert it to a high efficiency one. • Change the type of heat source operation control system.	Reduction in contract power demand Improvement in the efficiency of the heat source	• Heat pumps etc.

Item	Techniques to improve the effectiveness of energy saving efforts		Effects	Remarks
(3) Distribution system	a. Modification of hot and cold water piping systems	• Change to variable water flow type. • Increase differences between water utilization temperatures. • Reduce piping resistance and water velocity. • Change to selective on-off control. (VWV system) • Increase the heat insulation of piping.	Reductions in power consumption by pumps [Three-way valve control -> Two-way valve control Changes in the size of elbows, tees and pipes Dividing pumps into groups (collective pump capacity control)]	• Selective on-off control It is necessary to check the number of coil rows in connection with change in water volume.
	b. Modification of duct systems	• Change to a variable air flow duct system. • Increase differences between air outlet and room temperatures. • Reduce air velocity inside the duct. • Increase the heat insulation of ducts.	Reductions in power consumption by fans [CAV -> VAV High velocity ducts -> Low velocity ducts]	Necessary check points include ventilation frequency in connection with change in air flow rates and air flow distribution in connection with change in air outlet temperatures.
	c. Modification of the type of air-conditioning system	• Review the air-conditioning zoning strategy and control each zone individually after increasing the number of zones. • Introduce an outside air intake control system. • Change the type of air conditioning system: from all-air to water-air type; from constant air flow to variable air flow type. • Switch from reheating to VAV type. Change the air supply volume according to changes in sensible heat load.	Energy savings and improvements in the interior environment Reductions in energy consumption accompanying heat distribution and outside air cooling Single duct system -> FCU system CAV system -> VAV system	Zoning and control equipment locations • Introduction of new exhaust fans Carbon dioxide concentration control
	d. Others	• Introduction of air curtains • Introduction of local exhaust outlets	Load reduction as a result of preventing outside air from leaking in Reduction of heat generation in the rooms	
(4) Heavy utilities	a. Heavy utilities	• Implement group-control for elevators.		

Item	Techniques to improve the effectiveness of energy saving efforts		Effects	Remarks
(5) Hot-water supply and sanitary systems	a. Hot-water supply system	• Strengthen the thermal insulation of the hot-water supply system • Improve the hot-water supply system. Through a change from the central to local type	Reductions in heat losses	• Utilization of running steel pipes (to reduce head loss)
	b. Sanitary system	• Introduce water saving devices. • Wash urinals using a sensor. • Finish floors with coating. • Utilize rain water.	Savings in water consumption No more need for washing with a brush	
(6) Lighting facilities	a. Limiting lighting areas	• Split the power distribution circuit for lighting. • Provide an individual switch for every lighting fixture. • Implement the automatic control of lighting using timer switches. • Implement local lighting. • Introduce outdoor lighting timers and automatic on-off switches.		• Canopy switches • Timers and photoelectric sensors
	b. Increasing lighting efficiency	• Change to high efficiency lamps. • Modify or replace lighting fixtures.	Improvements in lighting efficiency	• Electronic ballast type high frequency lamps • Bulb-shaped fluorescent lamps
(7) Power receiving facilities		• Introduce power condensers to improve power factor. • Introduce demand supervisory control. • Improve the power factor of transformer secondary circuits.	Power factor improvements Reductions in the maximum power demand	• Automatic power factor control device • Power demand controller • Placement of power condensers on the load side of transformers