12.8 Electric Heating Systems

12.8.1 Types of Electric Heating Systems

The electric heating systems are classified as shown in Table 12.32. Their common features are as stated below.

(1) High temperature

It is possible to heat to the high temperature of 2,000 °C or more by arc heating and direct or by directly making a current flow through a heating unit.

(2) High heating efficiency

The heating efficiency is high because an object generates heat and there is no exhaust gas loss. However, it is necessary to make a general judgement of the power generation process including heat loss and input conversion efficiency.

(3) Quick heating

It is possible to change the direct electric power to heat in an object heated and conduct quick heating by raising the electric power density.

(4) Easy temperature control

As automatic control and remote control can be made easily, it is possible to control the temperature precisely.

(5) Easy atmospheric control

Atmospheric control can be made easily because no combustion is involved.

Table 12.32 Type and Main Applications of Electric Heating Systems

Heating method	System for converting electric energy to heat: Conversion system	System for converting electric energy to heat: Heating system	Main applications and examples of units
Utilization of Joule heat and arc heat	Resistance heating	Indirect resistance heating (50/60 Hz)	Various types of heat treatment furnaces using resistance heating method, sintering furnace, diffusion furnace, brazing furnace, salt bath, and fluid bed heating
		Direct resistance heating (50/60 Hz) (DC)	Direct energizing heating of metal, graphitizing furnace, glass melting furnace, and ESR furnace
	Infrared ray heating	Proximate infrared ray heating (0.76 - 2.5 μm)	Baking of painted surface, drying, and molding and processing of plastics
		Remote infrared ray heating (2.5 - 1000 μm)	Baking and drying of painting, resin hardening and processing, food baking
	Arc heating	Arc heating (50/60 Hz) (DC)	Steel making, melting of fire resisting materials
		Plasma arc heating (50/60 Hz) (DC)	Melting of heat resisting steel, Ni alloy steel, high melting point metal and alloy, melting of high melting point compound, production of single crystal, and high temperature thermochemical processing of other materials
Utilization of electro-magnetic induction	Induction heating	High frequency induction heating (50/60 Hz - 1MHz)	Melting of metal and alloy, heating for thermal processing, heat treatment of metal, welding, and brazing
		Low frequency induction heating (50/60 Hz)	Melting of cast steel and heating of large-sized steel
	Transverese flux heating		Heating of sheets such as non-ferrous metal and stainless steel
	Short-circuit heating	For metal melting	Channel furnace and heating of molten metal
		For metal heating	Shrinkage fitting of metal parts
Utilization of high frequency electric field	Dielectric heating (1 - 300 MHz)		Drying of lumber, drying and heat treatment of food, leather, textile, chemicals and synthetic resin, bonding of lumber, and welding of synthetic resin
Heat developed by the impact of electron and ion flow	Electron beam heating		Evaporation of metal, melting of high melting point metal, and fine processing of metal
	Ion beam heating and processing		Ion carburizing, heat treatment such as nitriding, surface coat treatment, etching of semiconductor, implantation, and other surface treatment
	Glow discharge heating		Surface heat treatment of metal and metal heating
Utilization of electro-magnetic wave	Laser heating and processing (1 - 11 μm)		Drilling processing of process-resistant material, welding, heat treatment and cutting of metal material, welding and processing of electronic parts, etc.
	Microwave heating (915, 2,450 MHz)		Preparation (electronic oven), drying and thawing of food, heating and vulcanization of rubber, and sterilization of food and chemicals
Utilization of electric mechanical power	Heat pump system	For household use	Air conditioning, hot water supply, and building air conditioning
		For industrial use	Drying of food, lumber and leather, effective utilization of exhaust heat, and others

12.8.2 Energy Conservation for Heating Systems

(1) Conversion of the heat source

When one considers the power generation in thermal power generation and atomic power generation, the energy efficiency is approximately 35 %, including the electricity loss during transmission and distribution, so heating method is extremely inferior as compared to other sources of heat. If there are no reasons for using electric heat as given above, other sources of heat (e.g. petroleum, coal, gas, and steam) should be used.

Even when the electric heat should be used, if it is possible to convert the heating method (e.g. indirect heating → direct heating), then the thermal efficiency might be raised.

(2) Correction of the capacity of equipment

In the electric heating systems, a continuous operation with a constant load would be desirable. Intermittent operation would repeat heating and cooling, resulting in the waste of power, so that the difference in the heat efficiency between the continuous and intermittent operations becomes enormous. It will therefore be necessary to restudy the production processes and work procedures and to select the capacity of equipment which would result in a continuous operation.

In particular, the electric heating systems tend to deteriorate by adopting easily the larger equipment when the smaller one is sufficient, so the power consumption per process becomes large, and therefore it will be necessary to compute sufficiently the power consumption and find a method which would enable operation at a minimum loss.

(3) Reinforced heat insulation

The electric heating systems generate various heat losses, as compared to the motors and transformers, so that the differences in heat efficiencies depends on the heat retaining property. Measuring the heat loss by the temperature sensors and heat flow meters attached to various parts of the equipment and strengthening the heat insulation in the parts of significant heat loss will be needed in order to raise the heat efficiency.

12.9 Heat Pump

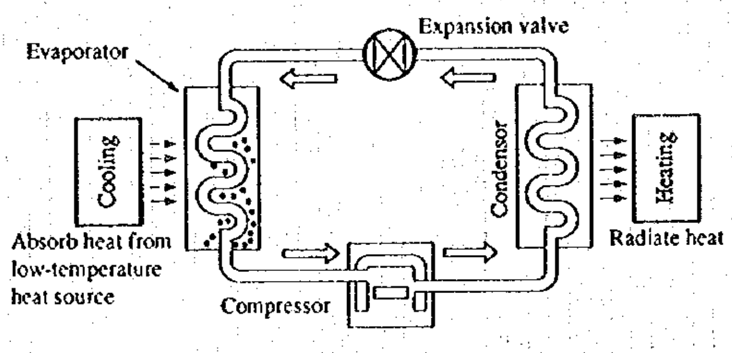
12.9.1 Heat Pump System

Electricity is not directly converted to heat but used as power source to convey heat in a heat pump system. Therefore, a heat source is always required.

Basically heat flows from a higher temperature place to a lower temperature place. The same is true for water; water flows from a higher level to a lower level. However, using a pump, water is allowed to flow from a lower level to a higher level. Because of functioning as a pump, a term "heat pump" was coined.

As shown in Figure 12.52, a vapor compression heat pump system needs a compressor, condensor, evaporator and expansion valve. The heat pump system performs heating operation by warming air or water through heat reaction in the condensor. On the other hand, by switching refrigerant circuits, the system can perform cooling operation by cooling air or water using cooling reaction in the evaporator. That is, the system can perform heating and cooling by alternating the heat radiation side and heat absorbing side.

Figure 12.52 Configuration of Heat Pump System



An absorption heat pump is driven by heat energy.

The mechanism is the same as in the vapor compression type in that it utilizes evaporation and condensation of operation media. However, it uses absorption liquid in order to pressure low-pressure vapor, which then abosorbs vapor and is transferred to a high pressure portion. By adding heat externally, the operation media is vaporized again. The absorption liquid is recycled by returned back from high-pressure side to low-pressure side. Hence, the basic configuration of an absorption heat pump includes an absorber, liquid pump and generator, instead of a compressor.

12.9.2 Features of Heat Pump System

(1) Features of heat pump system

a. One unit can perform heating and cooling.

b. Energy efficiency is excellent.

c. Ease of control and ease of operation can contribute to labor-saving.

d. Because no combustion accompanies, it is highly safe and clean.

e. Because it does not require any related facilities (chimney, oil reservoir, etc.) as in the case of boilers, installation space can be saved.

f. Electricity is the only required energy as utility.

(2) Coefficient of performance (COP)

The figure of Coefficient of Performance, or COP, is used to express the relationship between heat output from the heat pump and power required for the heat pump.

$$\text{Coefficient of performance } (\varepsilon) \text{ (COP)} = \frac{\text{Heat output (kcal/h)}}{\text{Power required (kWh/h)} \times 860 \text{ (kcal/kWh)}}$$

This equation is used to determine the efficiency of the heat pump and to obtain required power for necessary heat amount.

It may be meaningless if fuel consumption heat amount required to generate power for heat pump operation is larger than the direct combustion. In general the fuel consumption heat amount is 2,250 kcal for 1 kW power generation.

Heat output of a heat pump with COP (ε) is 860 ε (kcal/kWh) for required power of 1 kWh. The figure 860 is heat output from 1 kW electric heater.

To realize energy consrvation from a heat pump, at least the following equation needs to be satisfied.

$$860\,\varepsilon > 2{,}250$$
$$\varepsilon > 2.62$$

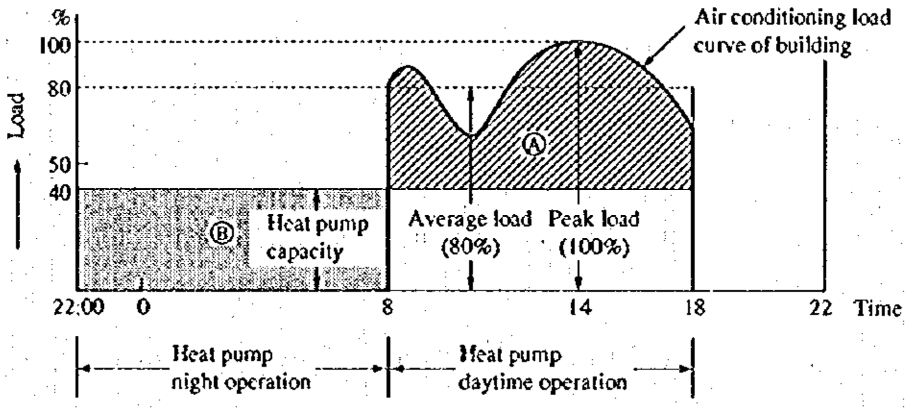
According to the heat pump operation fact research report for industry use (March, 1988) offered by the Heat Pump Technology Center of Japan, the COPs of actually operating heat pumps range from 3 to 20, all exceeding 2.62. This means contribution to energy conservation.

12.9.3 Application Range of Heat Pump

(1) Building airconditioning by regenerative heat pump

It is assumed that the load of air conditioning per day represents the area enclosed by thick line in Figure 12.53. The capacity of building air conditioning is conventionally determined based on the time period of maximum load (14:00 in the figure). In case of the regenerative system, however, about 50 % of the air conditioning load is reserved at night and utilized in the daytime. Thereby, the facility capacity can be lessened and the facility can be operated constantly at high load areas. As a result, high efficiency can be established.

Figure 12.53 Cooling Load Characteristics Curve



As shown in Figure 12.53, the heat pump is operated at night from 22:00 to 8:00 a.m. and warm and cool water equivalent to 50 % (portionⒶin the figure) of heat load is reserved in the heat storage tank. In the daytime, while the heat pump is operated, warm or cool water (portion Ⓑin the figure) in the heat storage tank is pumped up to the air conditioner. Then warm or cool air is fed for air conditioning.

Thus, the heat pump capacity can be reduced and the facility cost becomes less. This brings high facility operation rate and efficient operation. In addition, the following advantages can be expected:

a. As a result of reduction in facility capacity, the contract power amount can be graded down and then demand charge is reduced. Further, night-use incentive may reduce the operation cost.

b. The heat pump can be installed on the rooftop, resulting in efficient use of building areas.

c. Automatization is easy for energy conservation.

d. Combustion is not required; it is superior in safety and fireproof. It is also effective for environmental protection.

(2) District heating and cooling by a heat pump

Unutilized energy source in cities (urban waste heat) tends to increase year by year. This is because most of the energy supplied to cities is eventually wasted. The most of waste heat is of low temperature of less than 50 °C, generating sources of which are urban facilities such as subways, sewage treatment facilities, incinerators, power plants and substations, houses, factories, etc.

A number of advantages can be brought by using waste heat as heat source for the heat pump.

a. Advantages of district heating and cooling

1) Air pollution by combustion facilities and thermal pollution by waste heat can be reduced, resulting in envinronmental improvement.

2) Urban waste heat and heat in atmosphere, rivers and sea water can be recycled for the use of heat source to the heat pump. Thus, a system with high efficiency of energy conservation can be built. It will be also possible to effectively reduce the capacity of heat source facilities and lower the cost by introducing a heat storage system and combining heat load.

3) Handling and storing of dangerous items such as petroleum fuel can be eliminated, so that centralized control will promise safety of the facilities.

b. Method of district heating and cooling system

1) Centralized system

As shown in Figure 12.54 (a), the centralized system produces heat in a central plant at temperatures close to what is required by the demand site. Then it transfers heat to each local site. It is suited for city areas where load density is high and local piping length is relatively short.

2) Distributed system

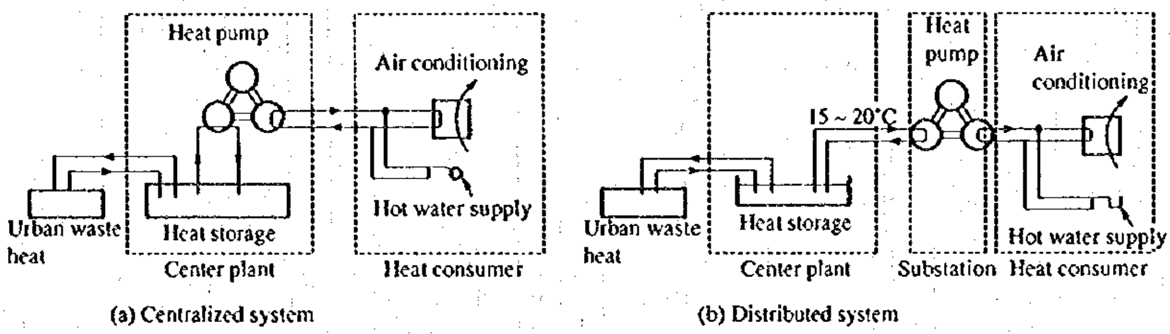
As shown in Figure 12.54 (b), heat pump temperature of heat source can be lowered (15 - 20 deg. C) and heat loss of the heat source water supplied can be reduced. Hence, cost of heat insulation work can be saved. This system is suited for areas where heat load is low and demanding sites expand widely.

3) Combined centralized and distributed system

In the case that a site in the centralized system area requires high temperature heat, heat source temperature is raised at the substation on the demand site. If the demand site is located nearby, heat is transferred through a dedicated line from the center plant.

The above-mentioned heat-pump-type district heating and cooling system will greatly contribute to waste heat recycling in city areas.

Figure 12.54 Heat-pump-type Local Air Conditioning System



(3) Heat pump application to the industry

The application effect expected from a process largely depends on the stance to introduce the system; e.g., where to apply the heat pump system in the existing production process, or whether to implement the multi-function heat pump system as an indispensable element in the planning and design of a process.

For home appliances, because temperatures for air conditioning and hot water supply are considered almost constant, the system configuration of a heat pump may be relatively simple. For industry use, on the other hand, the heat pump system is required to fit to various conditions of production processes. The planning and design of the heat pump system varies in a thousand different ways depending on sectors and production processes.

Therefore, it is important on one hand to know the trend of heat energy utilization in each sector of the industry. On the other hand, however, when introducing a heat pump system, it is also important to conduct a deliberate planning; finding applicable points in the production process, reviewing material balancing (economic distribution of utilities, etc.) in the process concerning energy and production, and obtaining advantages from quality-improved products through improved quality control accuracy of energy.

Figure 12.55 shows a flow of heat utilization mainly with a heat pump .

Heat pump usage covers a wide range of applications such as general air conditioning that mainly controls indoor temperature and humidity, a system that raises energy efficiency and economic effect by voparization separation of liquid, as is seen in the latent heat recycling heat pump for industry use, as well as a system that replaces combustion heating with heat pump heating and contributes to environmental improvement.

Figure 12.55 Heat Flow Diagram Using a Heat Pump System

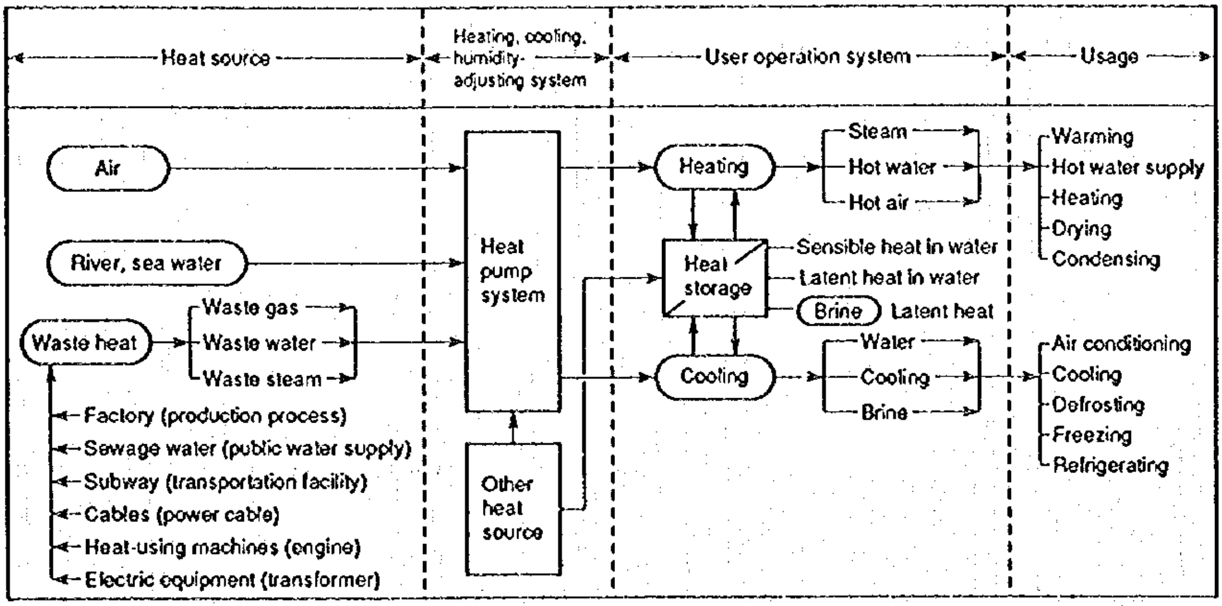


Table 12.33 shows the outline of the heat pump system performance. As for compressors, the main equipment of the system, rotary and reciprocating-types are employed for small size main equipment, and turbo and screw-types are employed for large size compressors.

Heat media is freon gas in general. However, freon gas, which has proved to cause depletion to the ozone layer, is currently being replaced by an alternative. Special materials (water, hydrocarbon family material) are used for high temperatures (more than 100 °C).

Table 12.33 Performance of Heat Pump

Type of heat pump	General-purpose heat pump			Latent heat recycling heat pump		Super-heat pump
				Direct	Indirect	
Heat source	Air (sensible heat)	Air (sensible heat)	Waste heat, etc.	Waste heat (latent heat)	Waste heat (latent heat)	Waste heat, etc.
Application	Air conditioning, hot water supply, etc.	Air conditioning, hot water supply, etc.	Warming, hot water supply, drying, heating	Food, chemical factory	Food, medicine, photos, plating factory	Various factories, local heat supply
Heat media	HFC	HFC	HFC	Water, etc.	Water, hydrocarbon, freon, etc.	Non-azerotropic mixture
Applied temperature	20 ~ 60°C	20 ~ 60°C	60 ~ 110°C	80 ~ 120°C	15 ~ 185°C	150 ~ 300°C
COP	About 3	About 4	About 4 - 5	About 10 - 20	About 2.5 - 6	About 6 - 8
Compressors	Rotary, reciprocating, screw, turbo, etc.	Reciprocating, screw, turbo, etc.	Reciprocating, screw, turbo, etc.	Turbo, roots, screw, etc.	Turbo, screw, reciprocating, etc.	Multi-stage turbo, etc.
Characteristics	For air conditioning use		For high temperature and heat recovery	High temperature, high efficiency, evaporation separation, concentration.	High temperature, high efficiency, heat recovery, low-temperature concentration, etc.	Under development

Table 12.34 shows major applications and installations by technology utilized.

Table 12.34 Application and Installation Fields

Technology	Application field
Air conditioning	Houses, buildings, housing complex (department store, school, hospital, public facilities), factories, clean room, public plantation, plant farming facility, etc.
Hot water supply	Pool, public bath, hotel, golf field, dying factory, ham factory, broiler factory, road heating, snow melting, etc.
Heating, cooling	Wine production, plantation facility, fish breeding, dairy farming, chemicals production, food, plating, etc.
Drying, humidity adjustment	Wood, fish, vegetables, fibers, gelatine, printed matters, peat, sewage, rubber products coating, etc.
Condensing, vaporization separation	Saccharated liquid, milk, glycerine, amino acid, antibiotic substance, agricultural chemicals, pulp, beat sugar, rayon fiber liquid, various waste liquid, etc.
Heat recycling	Organic solvent distillation, inorganic chemicals distillation, ethanol distillation, propylene, propane distillation

Waste heat utilization temperature distribution by sector is shown in Figure 12.56. Temperature of waste heat ranges 40 to 100 °C in a process. The shape of waste heat is vapor, hot water, air or gas (air containing solvent, dust), most of them including waste materials from the process.

Used temperature ranges 50 - 60 to 160 °C in a process. In the petrochemical industry and steel industry, waste heat source extends 500 to 1,500 °C high-temperature areas. Effective use of these waste heat is a subject for the future technological development.

Figure 12.56 Heat Utilization Temperature Distribution by Sector

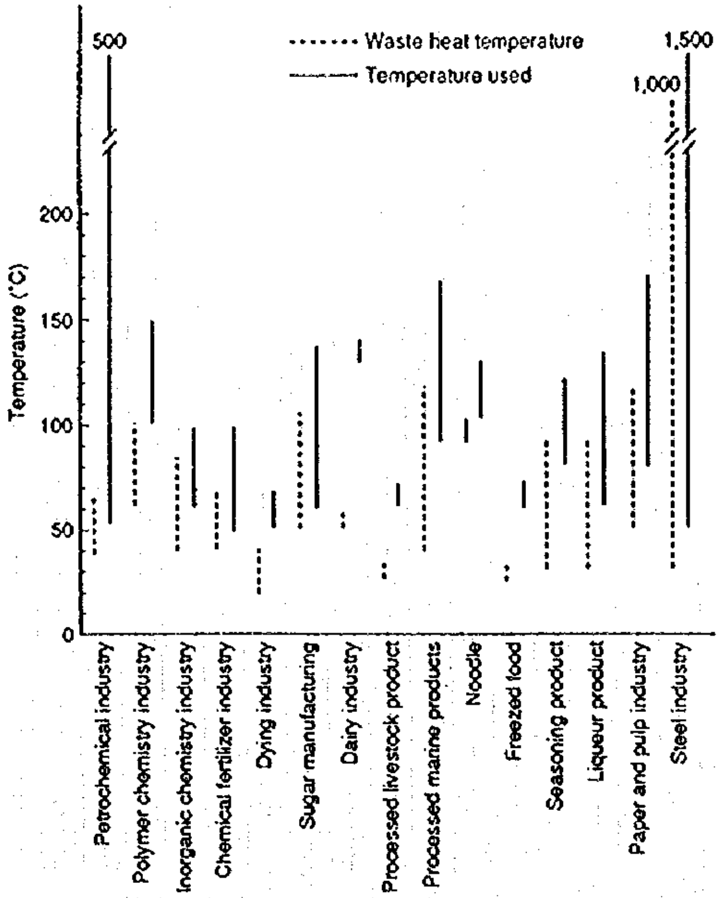


Table 12.35 shows each temperature level and heat demand rate of some industrial sectors. As is found in the table, sectors other than chemical industry and rubber manufacturing industry use heat level of 100 - 150 °C.

Table 12.35 Temperature Level Used by Sector (%)

Temperature / Sector	Less than 100°C	~ 150°C	~ 183°C	More than 183°C
Food, tabaco industry	2.5	62.3	16.6	18.6
Fiber industry	0.4	50.3	49.3	0
Wood, wooden product manufacturing	1.1	9.3	6.6	83.0
Pulb paper processing industry	0	85.9	4.1	0
Chemical industry	4.8	26.9	50.0	18.8
Rubber product manufacturing	0	26.3	53.4	20.4
Leather product	0	100.0	0	0
Ceramic and stone manufacturing	0	85.6	14.4	0

Table 12.36 shows application examples of heat pumps currently used, effect of energy conservation, COP of the system, applied places and used temperatures.

According to the table, VRC systems that use latent heat as heat source show high values of COP, 4.5 to 26. High efficiency of energy conservation is realized.

The heat pump system employed in a production process provides different cost performance largely depending on the cost of petroleum (Heavy oil, raw oil, naphtha, light oil) or gas (LPG, LNG) used as heat source. It is important to select investment timing to make the best use of the introduction of a heat pump system.

Heat pump systems for heating or cooling should be used systematically and comprehensively in combination with high temperature heat storage (hot water heat storage, hydrate heat storage) and low temperature heat storage (ice heat storage, inorganic salt and water). Thereby, energy efficiency is raised higher. It also provides reduction of initial cost and running cost, and other advantageous points such as labor-saving and space-saving. Further, larger effects than the aspect of energy utilization can be expected in other aspects such as improvement of product quality, improvement of yielding rate, speeding up of production, and environmental protection by recycling of waste heat and waste materials.

Table 12.36 Heat Pump System Application and Advantages of Energy Conservation Effect

	Applied place	Type	Temperature used (°C)	COP	Energy conservation effect	Comments
Drying and concentration	Drying of peat	VRC	130~180	4.5	About 75 % reduction	4-stage turbo: Water content 60 % → 10 %, 3 → 14 kg/cm²g
	Drying of gelatin	C	30~40	--	About 50 % reduction	Quality: Water content 67 % → 13 %
	Drying of laminated processed paper	C	40~50	About 4	About 50 % reduction	Improved controllability of capacity
	Drying of golf balls	C	H40 C15	6.24 (2.56 / 3.68)	About 50 % reduction	Quality
	Drying of fruits and vegetables	VRC	100		About 56 % reduction	Quality: Water content 90 % → 12 %
	Drying of seaweed	C	20~30		About 14 % reduction	Quality: Safety
	Calcination of beer malt	C	65~	4	About 58 % reduction	Quality
	Concentration of oil raw materials	VRC	100	15	About 93 % reduction	Density: 10 % → 50 %
	Concentration of pulp	VRC	100	21	About 90 % reduction	Density: 8 % → 40 % (3EF 40% → 70%)
	Concentration of wheat juice	VRC	100	7	About 50 % reduction	About 10% vaporized
	Concentration of waste whisky	VRC	100	20		Density: 3 % → 35 % 1 → 1.23 kg/cm³·g
	Concentration of amino acid	VRC	88~90	21~25	About 90 % reduction	Density: 35 %wt → 60 %wt
	Concentration of gelatin	VRC	60~70	19		
	Concentration of antibiotic substance	IVRC	25~30	18		Improvement of controllability and productivity
	Concentration of coarse phosphoric acid	IVRC	20	6	About 50 % reduction	Density: 25 % → 48 %
	Concentration of sugar liquid	VRC	93	21~26	About 66~75 % reduction	Density: 7 % → 48 %
Distillation	Ethyl alcohol purification	VRC	73~105	5.6	About 66 % reduction	
	Organic solvent purification	VRC	100	15	About 90 % reduction	
	BTX purification	VRC	145	6		Demonstration plant
Heating and cooling	Preprocess before coating	C	52	5	About 30 % reduction	Closing, quality
	Tofu production process	C	0			Ice heat storage, quality
	Eel breeding pond heating	C	3		About 33 % reduction	Use of nighttime power service
	Dying hot water supply	C	50		About 60 % reduction	Production speed: 4 times/day → 5 times/day
	Hot water supply for broiler	C	65	4.8	About 56 % reduction	Refrigerating waste heat recycling

Note: VRC: Vapour recompression C: compress-type IRVC: Indirect type
Quality: quality improvment 3EF: tripple effect can

12.10 Air Conditioning

12.10.1 Introduction

Air conditioning refers to control of air conditions of rooms or plants to their optimal states fit for its usage and purposes. As other indices for judging the quality of a room atmosphere, there are acoustic impression, visual impression and sense of freedom, but air conditioning has nothing to do with them unless the facility factors affect them adversely.

Air condition of rooms to be controlled include the following 4 factors.

(1) Temperature

The room air is either cooled or heated for control to the prescribed value of the dry-bulb thermometer.

(2) Humidity

The room air is controlled to the prescribed comfortable relative humidity.

(3) Cleanliness

The room air is removed of dusts below the allowable dust concentration, and at the same time it is maintained so that fume, CO_2, odor, toxic gases, etc. are kept below the allowable concentration.

(4) Distribution

To facilitate uniform distribution of conditioned air in the room, a proper air flow is produced and a constant temperature condition of the whole room is maintained.

Purposes of this air-conditioning can be classified largely into a. hygienic air-conditioning and b. process air-conditioning.

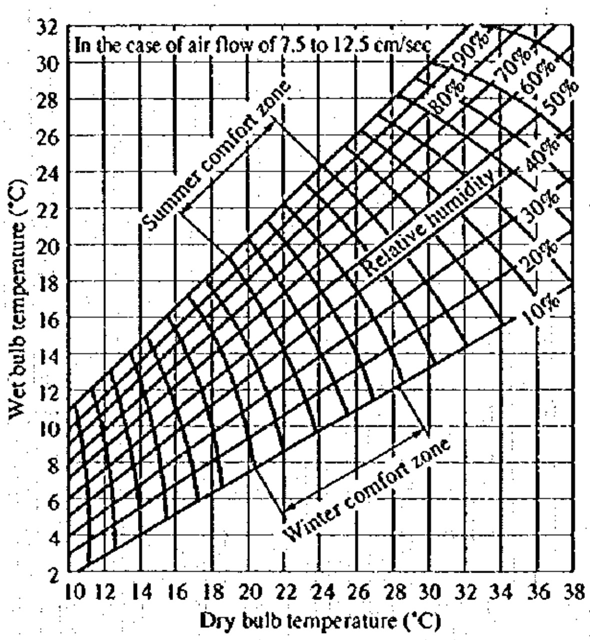
a. Hygienic air conditioning

Hygienic air-conditioning means to maintain the room air in a state which maintains the hygienic environment for the human body and gives a sense of comfort and amenity namely to maintain the room air to a state suited for people living or working there. The 2 major factors governing the optimal air condition are temperature and humidity. Figure 12.57 shows the comfortable zones during winter and summer in Japan.

Meanwhile, apart from this figure, it is considered desirable to keep the room temperature not so greatly different from the outdoor temperature and to keep the humidity at a minimum level. And, the difference between room and outdoor temperatures is considered most suitable when it is 5° ~ 7 °C.

For general office work, design conditions are set at 18° ~ 22 °C and 30 % ~ 50 % (R.H) during heating, and 25° ~ 28 °C and 50 % ~ 60 % (R.H) during cooling. When energy conservation is given priority, values near the lower limit of the given values, namely 18 °C and 40 % during winter, and 28 °C and 50 % during summer are adopted.

Figure 12.57 Comfort Zone



b. Process air conditioning

Of processes of industrial production, many including processes from raw materials to completion and storage of products require independent conditions for retaining the facility and quality. As processes often require coexistence of operators, workers there, process air conditioning should take factors of hygienic air conditioning into consideration. Generally, process air conditioning precedes, and for the human body hygienic performance is assured by local air conditioning and other means.

Table 12.37 shows typical design air conditioning states of various industrial processes. However, the table shows mere guidelines, and individual design should be determined by thorough study.

Table 12.37 Example of Process Air Conditioning

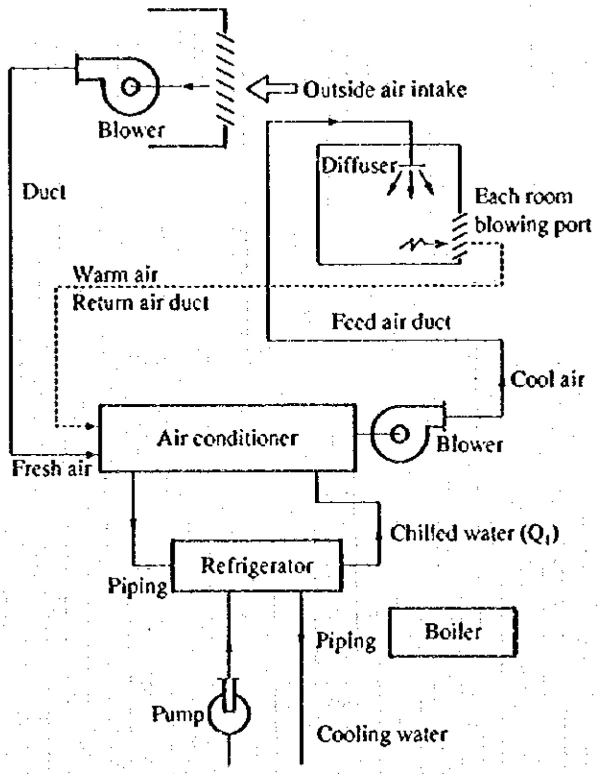
Classification	Process	Temperature (°C)	Relative humidity (%)
Color printing	Bronze plating room	24-27	45-50
	Plate preparation	24	45-50
	Printing room	24-27	45-50
Printing	Book binding	21-24	45
	Form	24-27	45-50
	Printing room	24-27	45-50
	Web press	24-27	50-55
	Paper storage	20-23	50-60
	Photographic printing	21-23	40-50
Optics	Melting room	24	45
	Abrading room	27	80
Plywood	Manufacture	–	55-60
	Gluing	–	55-60
Rubber	Storage	14-24	40-50
	Cementing	27	25-30
	Dipping	24-27	25-30
	Manufacture	32	–
	Sulfurization	26-28	25-30
Laboratory	Animal laboratory	24-27	40
	Central analysis room	23	50
Photograph	Manufacture of ordinary film	23-24	24-40
	Printing	23-24	65-70
	Finished product storage	16-27	45-50
	Developing	21-24	60
Bakery	Base mixing	24-27	45-55
	Base fermentation	27	70-80
	Bread cooling	21	70-80
	Bread wrapping	18-24	50-65
	Powder storage	21-27	50-60
	Cake freezing	21-27	45-50
Precision machinery	Gear cutting	24-27	45-55
	Precision parts	24	45-55
	Precision assembly	20-24	40-50
	Precision test room	24	45-50
Pharmacy	Capsuling	24-27	25-40
	Colloid	21	30-50
	Deliquescent salt	27-32	15-40
	Gelatin capsule	26	40-50
	Powder product	24-27	5-35
	Tablet forming	21-27	35-40
	Tablet furbish coating	24-27	35-40
	Serum	23-26	45-50
	Powder material drying	24-71	20
	General pharmacy room	21-27	10-50
Electricity	Manufacture of thermostat	24	50-55
	Manufacture of insulating material	24	65-70
	Assembly of electron tubes	20	40
	Cable insulation	40	5
	Transformer coil winding	16-24	15-35

Classification	Process	Temperature (°C)	Relative humidity (%)
Food	Manufacture of butter	16	60
	Coffee substitute	24-27	40-45
	Milling	–	60
	Macaroni	21-27	38
	Mayonnaise	24	40-50
	Mushroom prowing room	14-27	75
Brewing	Storage of grains	16	35-40
	General manufacture	16-24	45-65
	Aging room	18-22	50-60
	Beer fermentation room	3-4	50-70
	Beer malthouse	10-15	80-85
Confectionery	Chewing gum Cooling	22	50
	Drying	49-60	50
	Wrapping and storage	21-24	45-60
	Candy Manufacture	18-27	35-50
	Cooling	24-27	40-45
	Product storage	16-24	45-55
	Dry fruits storage	10-13	50
	Chocolate Bar manufacture	18	45-50
	Center cream manufacture	24-29	50
	Nougats	18	50
	Starch room	24-29	50
	Wrapping	18	50
	Product storage	16-24	40-50
Tobacco	Cigarette Raw material storage	27	75-78
	Cutting	24-27	80
	Cut tobacco storage	27-29	60-65
	Manufacturing room	21-27	55-65
	Wrapping room	27-29	50
	Truck removing room	27	70-75
	Sweating	49	80
Cotton spinning	Roving	21-24	50-55
	Spinning	21-24	55-65
	Drawing	21-24	55
	Picker	21-24	45-50
	Roving	21-24	50-60
	Warp spinning	24-27	50-65
	Weft spinning	24-27	50-65
	Cotton reel	24-27	60-70
	Twister	21-24	65
	Woven textile	24-27	70-85
	Fabric storage	24-27	65-75
Jute spinning	Fabric conditioning room	24-27	90-95
	Spinning	24-27	60
	Woven textile	26-27	80
	Preparation	18-20	80
	Roving and spinning	24-27	60
Match	Manufacture	22-27	45-50
	Storage	15	50

12.10.2 Composition of Air Conditioning System

The final means for performing air conditioning is the air, and generally air conditioning is performed by letting out the air with proper temperature, moisture and cleanliness from blowing outlets into rooms. And there are various devices for achieving this aim, of which a composition of a relatively large-scale air conditioning system is shown in Figure 12.58. Here descriptions are given mainly on cooling, based on this composition.

Figure 12.58 Composition Example of Large Scale Air Conditioning System (During Cooling)



During cooling, heat load flows from the outside into the room, which is transferred from air to cooling water within the air conditioner and carried to the heat source unit (refrigerator), and after pumped up by the refrigerator, is discharged through the cooling tower into the atmosphere.

During heating, oil or gas is burnt by boiler, and this heat, after transferred to warm water, is carried to the air conditioner, and supplied into the room by means of air conditioner.

(1) Heat source unit

The heat source unit supplies warm water (heating medium) or chilled water (coolant) to the air conditioner. Heat source units for heating the heating medium include boiler, regenerator tank, heat pump, etc., and that for cooling the coolant include the refrigerator. Besides them are heat exchangers, pumps, blowers and pipings as auxiliary equipment.

(2) Air conditioner

A unit for preparing the blow air to a temperature, moisture and cleanliness suited for the required room conditions. It therefore is equipped with various equipment within for purifying, cooling, temperature reducing, heating, humidifying, blowing, etc.

(3) Supply unit

A unit for supplying fluid and gas is composed of blower, pump, duct, piping, etc. That is, the air conditioned through the air conditioner is supplied through the duct to a room to be cooled. And, the warm room air is absorbed by negative pressure of the blower and sent into the air-conditioner.

(4) Diffuser

Installed at the outlet or inlet of the duct, composed of blowing outlet, suction port, muffler, damper, etc.

(5) Switch board, control panel, monitor panel

These are electric facilities for operating, controlling and monitoring the air conditioning system.

The above-mentioned units are not necessarily installed separately, and there are systems which combine several units in one or those in which all of them form a single unit, like a package-type air-conditioner, depending on the scale of air-conditioners.

12.10.3 Heat Load of Air Conditioning System and Its Calculation

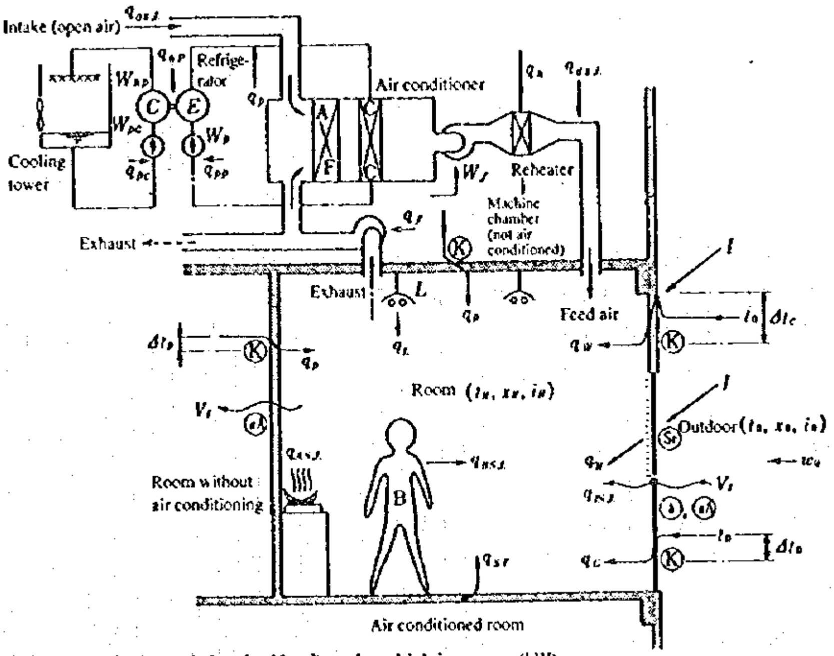
Figure 12.59 shows the inflow sections of heat load to a room.

Table 12.38 lists the type and composition of heat load, and calculation formulas corresponding to Figure 12.59. Additionally, accumulated heat load is generated during ordinary intermittent operation, which is accumulated in the building framework by invasion of external heat during the night when the air conditioner is stopped and is gradually flown away as load after resuming operation. Both heating load and cooling load are largely affected when operation is stopped during the night and during the day respectively by heat accumulation.

Figure 12.60 shows a cooling load example at a plant office. Construction of the building is as shown in Figure 12.61.

According to Figure 12.60, load due to heat transfer is the largest, followed by lighting, external air, solar radiation and human body in that order.

Figure 12.59 Type of Heat Load and Inflow Sections (Cooling)

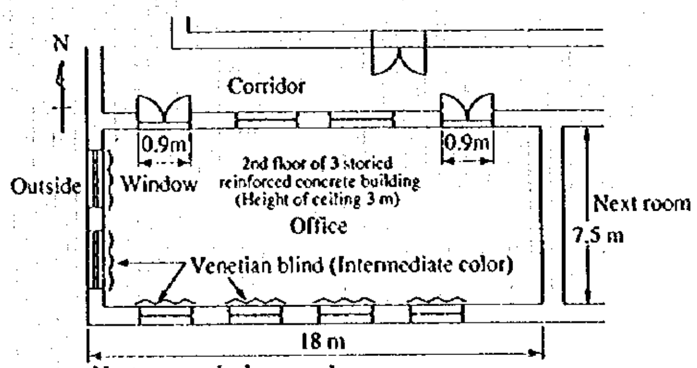


Note) I: Amount of solar radiation (kcal/h m²) L: Lighting power (kW)
W_O: Wind velocity (m/s) B: Number of persons in room
V_i: Volume of infiltration (m³/h) W: Drive power (kW)

Figure 12.60 Example of Air Conditioning Load in Factory Office (during Cooling)

Load due to human body	11%	
Load due to solar radiation	15%	
Load due to external air	15%	
Load due to lighting	16%	
Load due to heat transfer	43%	Total 17,045 kcal/h

Figure 12.61 Example of Office



Next rooms, the lower and upper floors have no cooling and heating system.

Table 12.38 Types and Composition of Air Conditioning Heat Loads, and Calculation Formulas

Load category	Type of load	Symbol	Calculation formula: Sensible heat load	Calculation formula: Latent heat load	Remarks
Heat source (oil, etc.) and heat sink (cooling tower-atmospheric air) load / Heat source unit (boiler, refrigerator, etc.) load HACL / Air conditioner load ACL / Room load RL / Outdoor load	Glass-transmitted solar radiation	q_R	$S_c \cdot A \cdot I$		S_c: Shield modulus, A: Area, I: Standard solar radiation gain
Outdoor load	Transfer through external wall and roof	q_W	$K \cdot A \cdot \Delta t_e$		K: Heat transfer coefficient $\frac{1}{K} = \frac{1}{\alpha_i} + \Sigma \frac{d_j}{\lambda_j} + \frac{1}{\alpha_o}$
Outdoor load	Transfer through external wall glass	q_G	$K \cdot A \cdot \Delta t_o$		α_i: Indoor heat transfer rate = 8 kcal/h·m²·°C; α_o: Outdoor heat transfer rate = 20 (summer), 30 (winter) [kcal/h·m²·°C]
Outdoor load	Infiltration	$q_{IS,L}$	$0.28 V_I \Delta t_o$	$715 V_I \cdot \Delta x_o$	d: Thickness of j-layer of component member, λ_j: Thermal conductivity [kcal/m·h·°C]; Δte: Effective temperature difference (°C)
Room load RL	Accumulated heat load	q_{ST}			For all-day air conditioning $q_{ST}=0$
Internal load	Lighting	q_L	$860 b \cdot L$		b: Ballast coefficient, incandescent lamp b=1.0, fluorescent lamp b=1.2, L: Lighting power [kW]
Internal load	Human body	$q_{BS,L}$	$h_s \cdot B$	$h_L \cdot B$	$h_s h_L$: Sensible heat and latent heat generated from a human body, B: Number of persons
Internal load	Equipment	$q_{AS,L}$	q_{AS}	q_{AL}	Use measured value (facility capacity ¥ load factor)
Air conditioner load ACL	External air load	$q_{OS,L}$	$0.28 V_o \cdot \Delta t_o$	$715 V_o \cdot \Delta x_o$	V_O: Amount of air intake $\Delta t_o = t_o - t_R$ $\Delta x_o = x_o - x_R$
System load / Duct system load	Duct heat reception and leakage	$q_{dS,L}$	$(K \cdot A \cdot \Delta t)$ $(0.28 V_D \cdot \Delta t_o)$	$(715 V_o \cdot \Delta x_o)$	V_D: Amount of leaked air; 5-20% of RL
Duct system load	Fan heat	q_f	$860 W_f$		Wf: Fan drive power [kW]; 5-20% of RL
Duct system load	Reheat load	q_h	q_h	-	Use measured value of reheat quantity
Piping system load	Piping heat reception	q_p	$(K \cdot A \cdot \Delta t)$		Δt: Difference between water temperature and ambient temperature; 2-5% of ACL
Piping system load	Pump heat	q_m	$860 W_p$		Wp: Pump drive power; 2-5% of ACL
Piping system load	Accumulator tank loss	q_{hs}	$(K \cdot A \cdot \Delta t)$		5-15% of HACL (Total 1-day value)
Heat source system load	Refrigerator drive power	q_{hp}	$860 W_{hp}$		For heat pump, it is included as part of heat source (during heating)
Heat source system load	Cooling water pump heat	q_{rc}	$860 W_{rc}$		Wp: Pump drive power [kW]
Heat source system load	Boiler waste heat	q_e	$\left(\frac{1}{\eta} - 1\right)$ HACL		h: Boiler efficiency

12.10.4 Energy Conservation of Air Conditioning Facility

For air conditioners, the load to be air conditioned is determined first, and secondly a suitable air conditioning system for this load is selected. Therefore, in considering energy conservation of an air conditioning facility, reducing the cooling load (1st step), and selecting an energy-saving air conditioner or system for the remaining cooling load (2nd step) are very important. Here, measures are considered mainly in relation to existing buildings.

(1) Heat insulation

The transfer heat load is expressed by $K \cdot A \cdot \Delta t_e$. The area A and effective temperature difference Δt_e are determined by the shape of building, weather condition and heat capacity, so when these cannot be changed, it is easiest to insulate the heat, that is, vary the heat transfer coefficient K. As methods of heat insulation, there are the following 3 methods.

a. Heat insulation of walls and windows

While external heat insulation has an advantage of being able to cut off heat without obstacles from the outside, internal heat insulation has disadvantages such as restrictions due to furniture or reduction of the room area.

b. Heat insulation of roofs and floors

c. Heat insulation of window glass

Heat insulation of window glass is done by doubling of window glass or doubling of window sashes. For the heat transfer coefficient, there is not so much difference as far as the number of window glasses is the same.

(2) Light shielding

The glass transmitted solar radiation load is expressed by $S_c \cdot A \cdot I$. The standard solar radiation gain is decided by weather condition and layout of the building, and methods are adopted for varying the shielding factor and window area.

a. Fitting blinds and curtains

It should be noted that the shielding effect is available only under the condition that sure open/close operations of blinds are carried out. Also, since the shield effect is connected with the use of day light, it is essential to obtain a method which makes the sum of cooling/heating energy and lighting energy at a minimum.

b. Fitting louvers and hoods

Provide fixed hoods, louvers, etc. outside windows with considerations made so as to shield solar radiation during the summer and not shield it during the winter.

c. Repairing window glass

Window glass is replaced with heat ray absorbing glass or reflecting glass, without having to change sashes, and the amount of transmitted solar radiation through window glass is reduced by bonding solar radiation adjusting film, to reduce cooling load.

(3) Preventing infiltration

Load q_t kcal/h due to infiltration is caused by entrance of external air through crevices of windows and doors and the open and close operations, and it is expressed by the following formula.

$$q_t = 0.28V_t \cdot \Delta t_0 + 715V_t \cdot \Delta x_0$$
$$= 0.28n \cdot V \cdot \Delta t_0 + 715n \cdot V \cdot \Delta x_0$$

where

n : Number of times for natural ventilation (see Table 12.39)

V: Room capacity (m^3)

Table 12.39 Number of Times for Natural Ventilation (n)

Class of room	n
1 wall surface facing outside air and having window or door	1
2 walls surface facing outside air and having window or door	1.5
3 walls surface facing outside air and having window or door	2
4 walls surface facing outside air and having window or door	2
Room without window facing the outside air or door	1/2 - 3/4

To reduce infiltration load, windows and doors may be sealed, and the number of (open/close) operations may be reduced, as practicable, much as possible by automatic doors. However, since Δt_0 will become negative when the outdoor temperature is below the room temperature during the nighttime, and it means more reduction of cooling load, and cooling effect is obtained by opening windows and doors to introduce external air.

(4) Producing heat values generated by equipment in the room

It is preferable not to place any equipment which generates heat inside the air-conditioned room. For lighting as well, adoption of local lighting and high-efficiency lamps and improvement of lighting appliances for more efficiency of lighting, or adoption of a ventilation system for disposing generated heat by lighting equipment separately, are desirable.

(5) External air load

The external air load q_o is produced by forced ventilation and is expressed by the following formula.

$$q_0 = 0.28 V_0 \cdot \Delta t_0 + 715 V_0 \cdot \Delta x_0$$

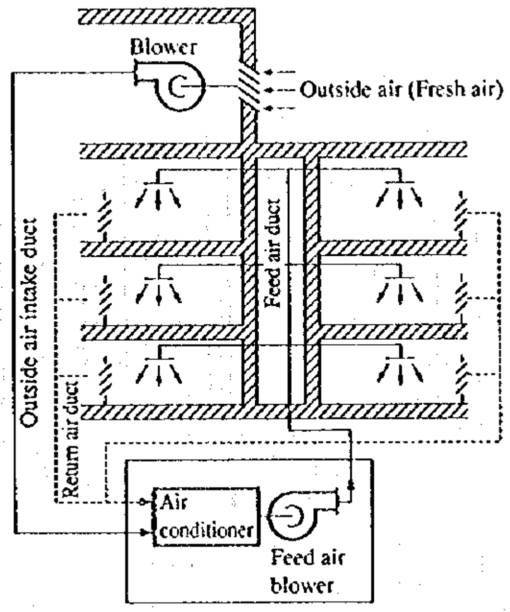
The ventilation volume V_0 is regulated mainly from the safety and hygiene for man. Suppose the allowable CO_2 concentration is 0.1 %, the required volume of external air is approx. 30 m^3/h/person.

At any rate, in order to reduce external air load, it is important to minimize the volume of ventilation within a range in which CO_2 concentration is below 0.1 %.

Where there is a circulation system as shown in Figure 12.62, introduction of external air should be reduced, as much as possible, by recirculating within the system. The damper opening of the circulation system is increased in size to increase return air, and at the same time opening of the damper at the external air intake system is reduced to cut down on the intake volume of external air.

What should be noted in the system (Figure 12.62) is that the room pressure becomes negative against the outdoors when return air is made excessive, resulting in a state which readily allows invasion of air and dusts from outside. Therefore, it is desirable to maintain the room pressure in the positive state at 0.1 mm Aq ~ 1 mmAq against the outdoors.

Figure 12.62 Air Conditioning System when Return Air is Available



(6) Alleviating the set room temperature

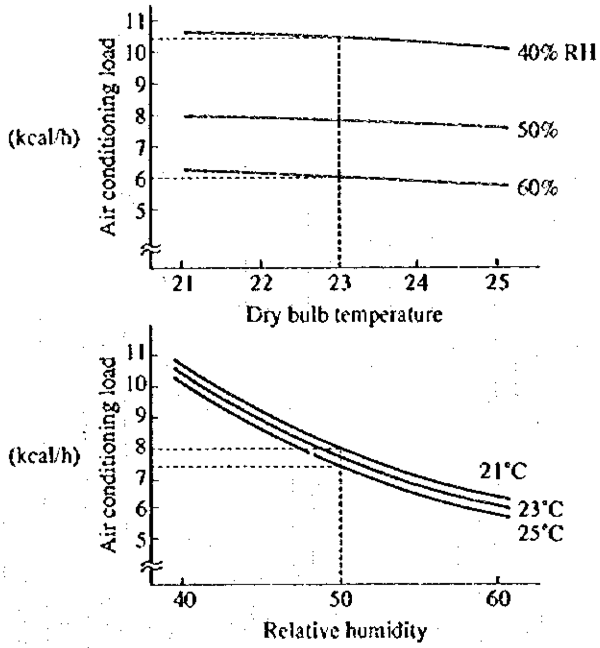
By raising the set temperature during cooling, cooling load by heat transfer from wall surfaces, which is proportionate to difference between temperatures inside and outside the room, is greatly reduced. In the case shown in Figure 12.60, for example, raising set temperature from 26 °C to 27 °C reduced cooling load by approx. 100 kcal/h.

(7) Review of room humidity

In the case of air conditioners having a dehumidifying function, alleviation of humidity condition is an effective measure toward energy conservation. According to the example calculations, variations of air conditioning load by varying humidity and by varying temperatures are as shown in Figure 12.63.

While approx. 4.2 kcal/h of load reduction can be attained when humidity is alleviated from 40 % RH to 60 % RH at 23 °C, load reduction is approx. 0.7 kcal/h only when temperature is alleviated from 21 °C to 25 °C at relative humidity 50 % RH - alleviation of humidity is about 6 times more effective as energy conservation. However, it should be noted that excessively high humidity would give uncomfortableness to man and affect on products quality adversely.

Figure 12.63 Energies Required for Temperature and Humidity Changes



(8) Improving control method

As mentioned before, control of heat load is available by method which varies flow rate, and by method which varies set temperature with flow rate set constant. Reduction effect of drive power for the fan and pump is larger in the former, and it results in energy conservation.

As control methods for flow rate, there are control of dampers and vanes, and various rotating speed controls. Power consumption is ranked as discharge damper control > inlet vane control > rotating speed control. As rotating speed control by VVVF is easily available for existing motor facilities with considerable effects, it should be studied first among other possibilities.

(9) Regular maintenance

a. Cooling water piping

Accumulation of scale and sludge in piping will increase resistance and require more pump output for the same flow rate. If the water quality is poor, it will naturally accelerate accumulation of scale and sludge. Therefore, control of water quality is necessary. Reference values for the control criterion are shown in Table 12.40.

Table 12.40 Quality Standard of Cooling Water (Japan Refrigeration and Air Conditioning Industrial Association Standard)

Item			Standard value for makeup water	Standard value for cooling water *1	Tendency *3	
					Corrosion	Scale
Standard item	PH (25 °C)		6.0 ~ 8.0	6.0 ~ 8.0	O	O
	Conductivity	(μs/cm)	200 or less	500 or less (1,000 or less)	O	
	Chlorine ion Cl	(ppm)	50 or less	200 or less	O	
	Sulfuric acid ion SO_4	(ppm)	50 or less	200 or less	O	
	Total iron Fe	(ppm)	0.3 or less	1.0 or less *2	O	O
	M Alkalinity $CaCO_3$	(ppm)	50 or less	100 or less		O
	Total hardness $CaCO_3$	(ppm)	50 or less	200 or less		O
Reference item	Sulfur ion S	(ppm)	Not be detected	Not be detected	O	
	Ammonium ion NH_4	(ppm)		Not be detected	O	
	Silicon oxide SiO_2	(ppm)		50 or less		O

*1 Cooling water means water passing through condenser for both transient and circulation systems.

*2 Standard value for plastic piping shall be 0.5 ppm or below.

*3 Mark O in "Tendency" column indicates a factor concerning either corrosion or scale tendency.

b. Heat exchanger

When scale, sludge and microbes are generated in the evaporator and condensor by cooling water, they will be accumulated to drop the efficiency of heat exchange, and increase power consumption per refrigeration ton. Therefore, periodical cleaning is necessary.

c. Air duct

When filters are used for cleaning the air, periodical cleaning is inevitable. Clogging of filters increases pressure loss and reduce air volume to degrade cooling capacity. As air conditioners are quickly contaminated when installed at places under poor atmospheric conditions, cleaning is required at least once a week.

d. Others

It is desirable to reduce air-conditioning load, as possible, by performing reviews of air-conditioning zones through studies on unbalanced supercooling/superheating of rooms, review of air-conditioning levels at corridors, etc. in each season.

Also, in installing any air conditioning systems, studies should be made carefully, including appropriateness of installing heat accumulation tanks, appropriateness of using waste heat, selection of the most efficient air conditioning duct system, etc., all of which are realized by placing emphasis on reduction of the running costs.

13. EXPLANATION ON HEAT CALCULATION WORKSHEET

13. EXPLANATION ON HEAT CALCULATION WORKSHEET

This document describes the content of the heat calculation worksheet and the method of using the worksheet which The Energy Conservation Center, Japan has already offered to our counterpart. This document is prepared on the assumption that it will be read as reference while the user has actually opened the calculation sheet on the PC. You will know more about the applications of the calculation sheet program if you thoroughly understand the contents of the worksheet.

(1) Compatibility

The heat calculation sheet software consists of several files that were developed in Japanese on the Japanese version of Lotus 123/DOS. The files we have offered are an English version which translated a part of these Japanese files. The Japanese Lotus 123/DOS calculation sheet can be read on Lotus 123/Windows and Excel/Windows, and also worked including macro instructions. The sheet can also be worked on the English version of Lotus 123/DOS. In order to use these files on the English Lotus 123/DOS, first open them using Japanese Lotus 123/DOS or Lotus 123/Windows and Excel/Windows and save the files with the extension ".wkl".

(2) Copyright

The Energy Conservation Center, Japan reserves the copyright to the heat calculation sheet software. Users cannot distribute this calculation sheet software to a third party. The Energy Conservation Center, Japan will not be responsible for any trouble whatsoever that might be encountered while using this calculation sheet software.

(3) Structure

The calculation sheet software includes the following files:

H_BL_GAS:	Gas fuel combustion calculation and boiler heat balance
H_BL_OIL:	Oil fuel combustion calculation and boiler heat balance
HBFC_GAS:	Gas fuel combustion calculation and heat balance of steel product continuous reheating furnace
SHIFTAVG:	Rearrangement of boiler continuous measuring data
E_INSU95:	Calculation of economical thickness of heat insulation
M_INSU95:	Calculation of heat release and temperature of multi-layer heat insulation
EMISSION:	Calculation of heat emission amount from surface for numerous cases
STEAM_14:	Approximation and application of steam table

Extensions have been omitted from the filenames above.

The extensions used and their associated application software are as follows:

wj2: Japanese version of Lotus 123/DOS
wkl: English version of Lotus 123/DOS
wk4: Lotus 123/Windows
xls: Excel/Windows

Since the ruled line function is not available in the English version of Lotus 123/DOS, the ruled lines and frames that appear on the Japanese version of the calculation sheet are not displayed on the English version. Therefore, it may be difficult to distinguish the input cell from other mathematical cells.

13.1 Combustion Calculation and Heat Balance of Boiler (or Furnace)

Files: H_BL_GAS: Gas fuel combustion calculation and boiler heat balance
H_BL_OIL: Oil fuel combustion calculation and boiler heat balance
HBFC_GAS: Gas fuel combustion calculation and heat balance of steel continuous reheating furnace

Combustion calculation forms the basis of heat calculation, as well as the calculations of heat transfer and heat insulation. The concept of this calculation is based on material balance and heat balance. Since the calculation involves only a simple equation and the four basic operations, you can perform the calculation even without a PC. It will be certainly more efficient and practical, however, to use the PC for the calculation. Using this software, the calculation sheet for each type of fuel (gaseous fuel, liquid fuel) is prepared and then the heat balance of the air preheater and that of the boiler are added.

13.1.1 Basic Calculation

The basic calculation is performed by setting the fuel composition, air conditions, and oxygen and carbon monoxide content in the exhaust gas. The cells in which you need to enter the setting values are displayed with frames to make it easier to identify these cells.

The fuel composition can be entered manually as well as by selecting it from a menu. The base temperature, ambient temperature, ambient humidity, air temperature (can be assumed as burner air temperature), and percentage of oxygen in the air are set for the air conditions. The ambient humidity is used for calculating the moisture content in combustion air. You can select the setting between relative humidity and wet bulb temperature. (The previous setting value will be retained even if you switch the setting, i.e it will remain effective.) This switching is performed by exchanging the formula using macro instructions, and the approximation formula of the steam table is used [Cell: v101..ae120].

Note: The information in square brackets ([ ]) indicates the relevant cell address.

The O_2 content and CO content contained in exhaust gas are set for the exhaust gas conditions. The settings of these exhaust gas compositions can be switched between wet base and dry base measured values in accordance with the analyzer characteristics. The previous setting value will be retained even if the setting is switched. However, you cannot select both wet base and dry base simultaneously. For example, you cannot select the wet base for measuring CO and dry base for measuring O_2. This switching is performed by exchanging the exhaust gas components and exhaust gas volume formulas using macro instructions [Cell: ap61..ax80]. The setting values that existed before you switched the wet base to dry base or vice versa are displayed as the new setting values after the values are converted into the new setting unit by macro instructions.

As a result of the calculation, the calorific value (net, gross) of fuel is displayed. Also, the wet base and dry base values of air volume, exhaust gas volume (for each component), and percentage of exhaust gas composition are displayed in the theoretical combustion column. The wet base and dry base values of each component of exhaust gas and its volume and exhaust gas volume are displayed in the actual combustion column. The air volume and air ratio are also displayed. Screen 13.1 and Screen 13.2 show examples of the calculation sheets [Cell: a21..i40].

Screen 13.1 Gaseous Fuel Combustion Calculation (File:H_BL_GAS, Cell:a21..i40)

Gas Combustion			<Dry>	Mixed		Base temperature	30	O_2/air
Gas composition	Mixed		Exhaust gas	Composition/wet	Exhaust volume	Composition/dry		21.0%
CO	25.8%		CO_2	20.6%	0.42	21.6%	Adiabatic temperature:	
CO_2	16.4%		N_2	70.5%	1.45	74.1%	(\D)	1261
H_2	7.6%		O_2	4.1%	0.08	4.3%	Input heat ratio:	
CH_4	0.1%		H_2O	4.8%	0.10	-	Fuel latent	100.00%
C_2H_4			CO	0.0%	0.00	0.0%	Fuel sensible	0.00%
C_2H_6			Total	100.0%	2.05	100.0%	Air sensible	0.00%
C_3H_8					Wet	Dry	Per fuel th.kcal	
C_4H_{10}			Excess air		0.41	0.40	Exhaust volume	2.089
N_2	50.0%		Air total		1.22	1.20	Exhaust gas weight	2.84
O_2	0.1%		Air ratio		1.50	1.50	Fuel option: \F	
H_2O			Invasion air ratio		0.0%		Burner air	1.22
Fuel temperature	30	Thoretical combution		Wet	Dry	CO_2 emission (C_eq)		
Air temperature	30	Oxygen	Gas volume	1.65	1.56	/fuel-Nm³		0.227
Ambient temperature	30	0.17	CO_2	25.7%	27.2%	/net_heat th.kcal		0.2305
Humidity	40%	Air_wet	N_2	68.7%	72.8%	Humidity option RH/WB:\W		
Fuel weight	1.28	0.81	O_2	0.0%	0.0%	Print : \P		Lock:\L
Net heat Hl	983	Air_dry	H_2O	5.6%	-	Wet/Dry option:\S		Free
Gross heat Hh	1020	0.80	Unit:m³,°C,kcal,kg			Adiabatic Calculatio	11/07	11:42

Screen 13.2 Liquid Fuel Combustion Calculation (File:H_BL_OIL, Cell:a21..i40)

Oil Combustion			<Dry>	A_fuel		Base temperature	5	O_2/air
Oil composition	Wt. %		Exhaust gas	Composition/wet	Exhaust volume	Compostion/dry		21.0%
C	84.6%		CO_2	10.2%	1.58	11.2%	Adiabatic temperature:	
H	11.8%		N_2	75.1%	11.64	82.7%	(\D)	1738
O	0.7%	HV adjust	O_2	5.4%	0.84	6.00%	Input heat ratio:	
N	0.5%	\U	H_2O	9.2%	1.43	-	Fuel latent	100.00%
S	2.0%		CO	0.0%	0.00	0	Fuel sensible	0.06%
H_2O	0.3%		SO_2	0.0903%	0.014	0.0994%	Air sensible	0.00%
Fuel temperature	20	Atomizing steam	Total	100.0%	15.51	100.0%	Per fuel th.kcal	
Air temperature	5	kg/kg	0		Wet	Dry	Exhaust volume	1.506
Ambient temperature	5	Pressure ata	8	Excess air	4.05	4.02	Exhaust gas weight	20.05
Wet bulb temperature	2.0	Invasion ratio		Air total	14.84	14.73	Fuel option: \F	
15/4 density	0.86	(to theoretical air)	0.0%	Air ratio	1.38	1.38	Burner air	14.84
Weight/volume	0.85675	Thoretical combustion		Wet	Dry	CO_2 emission (C_eq)		
Heat value/kg		Oxygen	Gas volume	11.46	10.06	/fuel-kg		0.846
Hl	10300	2.25	CO_2	13.8%	15.7%	/net_heat th.kcal		0.0959
Hh	10917	Air wet	N_2	73.9%	84.2%	Print:\P	Humidity set:\W	
Heat value/lit(Ref.)		10.79	O_2	0.0%	0.0%	Unit:kg,m³N,°C,kcal		
Hl	8825	Air dry	H_2O	12.2%	-	Wet/Dry option:\S		Free
Hh	9353	10.71	SO_2	0.1222%	0.1392%	Adiabatic Calculation	04/19	15:03

The calculation sheets have been designed and developed to meet general purpose applications as far as possible. For example, the base temperature is a setting value and is not always fixed at 0 °C. Moreover, if you change the setting of the oxygen content in air, the calculation sheet can be used for oxygen enrichment combustion. Also, you can set the intruding air into the furnace as the volume ratio to the theoretical air, and the volume excluding this setting amount is treated as the burner air ratio. The combustion air and exhaust gas calculations are performed by handling the air volume required by fuel components and generated exhaust gas volume in a matrix array instead of by approximation calculation. Furthermore, the moisture content in combustion air is included in the calculation.

13.1.2 Adiabatic Temperature of Combustion

The adiabatic temperature of combustion is calculated by macro instructions based on the setting conditions (including the fuel, air, and exhaust gas conditions). This method is used because the specific heat of the combustion gas is expressed by a quadratic of the gas temperature, and the relationship between the temperature and specific heat cannot be solved by a simple process. Therefore, repeated calculations have to be performed for convergence to obtain a closer result. However, the thermal decomposition of combustion generated gas at high temperature is not taken into consideration (needless to say that complete adiabatic combustion cannot exist in reality). This adiabatic combustion temperature therefore should be considered to be a reference value. The convergence method is simple and is done in the following manner. The postulated value is corrected and calculations are repeated over and over until the combustion temperature, which was obtained from the calculation based on a certain assumed temperature, becomes close to the postulated value [Cell: p81..s100]. You can set a convergence limit value for ending the repeated calculations.

13.1.3 Fuel Selection

The composition of each kind of fuel you can select from the menu is already written in the calculation sheet [Cell: a61..f73]. You can select your desired fuel composition from the menu, and by changing the composition already written, you can obtain the desired fuel composition. It is troublesome, however, to change the component instead of the fuel compositions. In that case, it is necessary to change the oxygen volume required by various combustion components and the exhaust gas generation volume [Cell: m61..aa80].

The fuel selection macro copies the name of the fuel selected on the calculation sheet. Therefore, it is necessary to change the name of the fuel if the fuel compositions are changed.

13.1.4 Exhaust Gas Oxygen and Various Properties

The changes in the various calculation results when the oxygen concentration in the exhaust gas is changed in calculations such as the above can be immediately obtained by entering the new numeric value in the oxygen cell. However, supposing you want to know the exhaust gas volume for several oxygen settings, it would be convenient if this result could be displayed in a summary table. The spread sheet is provided with a function to create such a table (called "What-if table"). Thus, this calculation sheet can calculate and display changes in the calculation results in accordance with various oxygen concentration levels as shown in Screen 13.3 [Cell: a41..i60]. Since this calculation is performed by several key operations instead of automatic execution, a macro instruction is used. The calculation is performed by CTRL+I (press and hold down the CTRL key and press the I key) after setting the assumed value. (At this time, "¥I" will appear next to the title at the top of the table.) After the calculation is completed, the time is written at the bottom of the screen under the table to prevent you from forgetting to perform the calculation.

The macro instruction may be executed by Alt+I on some systems (PC) or software. Also, the backslash "\" is displayed for the yen sign in the English version.

Screen 13.3 What-if Table for Combustion Calculation (File:H_BL_GAS, Cell:a41..i60)

What-if Study (\I) <Dry> Mixed

Tbl.1 Burner air etc.

O_2 dry	Air ratio	Air/wet	Exhaust/wet	CO_2 dry	Exhaust weight
0.0%	1.00	0.8	1.65	27.2%	2.32
2.5%	1.26	1.0	1.86	24.0%	2.59
5.0%	1.61	1.3	2.14	20.7%	2.95
7.5%	2.08	1.7	2.53	17.5%	3.44
10.0%	2.77	2.3	3.08	14.2%	4.16

(CO dry 0.00%) 11/07 11:41

Tbl.4 Adiabatic temperature (\T)

O_2 dry	CO 0.0%	CO 0.5%
0.0%	1495	1477
2.5%	1362	1343
5.0%	1221	1201
7.5%	1071	1051
10.0%	911	890

11/07 11:42

Tbl.2 Exhaust gas loss (to Hl)

O_2 dry	Exhaust gas temperature 150	200	250	300
0.0%	6.9%	9.9%	12.9%	15.9%
2.5%	7.7%	11.0%	14.4%	17.8%
5.0%	8.8%	12.5%	16.4%	20.2%
7.5%	10.2%	14.6%	19.1%	23.6%
10.0%	12.4%	17.7%	23.0%	28.4%

11/07 11:41

Tbl.3 Burner air heat (to Hl)

O_2 dry	Air temperature 100	150	200
0.0%	1.8%	3.1%	4.4%
2.5%	2.3%	3.9%	5.6%
5.0%	2.9%	5.0%	7.1%
7.5%	3.8%	6.5%	9.2%
10.0%	5.0%	8.6%	12.2%

11/07 11:41

The following study has been prepared as the What-if table besides the above.

13.1.5 Fuel Economy Ratio by Air Ratio Adjustment

This table is used for reading the fuel economy ratio from the percentages of O_2 before and after adjustment for each exhaust gas temperature indicated in the exhaust gas dissipation coefficient table in Screen 13.3 above (ratio for the fuel volume before adjustment is performed). The heat amount excluding the exhaust gas dissipation is calculated as the required heat amount (no change of volume even if the air ratio is adjusted) [Cell: k21..u40]. Since the calculation for this table is executed using the macro instruction ¥I after the calculation of Screen 13.3 above, there is no need for a separate calculation. Screen 13.4 shows an example of this table.

Screen 13.4 Air Ratio Adjustment (File:H_BL_GAS, Cell:k21..u40)

Table ** Fuel economy by air ratio adjust (%G) (to before adjustment fuel) **Mixed**

Invasion air ratio 0.0%

Exhaust temperature = 150

Before adjustment O_2 dry	O_2 dry after adjustment 0.0%	2.5%	5.0%	7.5%
0.0%	0.0%	-	-	-
2.5%	0.9%	0.0%	-	-
5.0%	2.0%	1.2%	0.0%	-
7.5%	3.6%	2.8%	1.6%	0.0%
10.0%	5.9%	5.1%	4.0%	2.4%

Exhaust temperature = 200

Before adjustment O_2 dry	O_2 dry after adjustment 0.0%	2.5%	5.0%	7.5%
0.0%	0.0%	-	-	-
2.5%	1.3%	0.0%	-	-
5.0%	3.0%	1.7%	0.0%	-
7.5%	5.3%	4.1%	2.4%	0.0%
10.0%	8.7%	7.5%	5.9%	3.6%

Exhaust temperature = 250

Before adjustment O_2 dry	O_2 dry after adjustment 0.0%	2.5%	5.0%	7.5%
0.0%	0.0%	-	-	-
2.5%	1.7%	0.0%	-	-
5.0%	4.0%	2.3%	0.0%	-
7.5%	7.1%	5.5%	3.2%	0.0%
10.0%	11.7%	10.1%	8.0%	4.9%

Exhaust temperature = 300

Before adjustment O_2 dry	O_2 dry after adjustment 0.0%	2.5%	5.0%	7.5%
0.0%	0.0%	-	-	-
2.5%	2.2%	0.0%	-	-
5.0%	5.1%	3.0%	0.0%	-
7.5%	9.1%	7.0%	4.2%	0.0%
10.0%	14.9%	13.0%	10.3%	6.4%

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For example, if the percentage of O_2 before adjustment in the exhaust gas temperature of 250 °C is 10 %, and if it is adjusted to 5 %, the fuel economy will be 8.0 % in terms of the heat balance.

In the calculation, the heat amount excluding the exhaust gas dissipation is calculated first as the required heat amount for each case. Then, the fuel economy volume is calculated based on this calculated heat amount value.

13.1.6 Fuel Economy Ratio by Air Preheating

In the same manner as in the previous section, the fuel economy ratio by air preheating is also calculated using the macro instruction ¥I as shown in Screen 13.5 [Cell: w 21..ak40]. The cells with a dash (-) in the table indicate cases which cannot exist since the air preheating temperature set is higher than the exhaust gas temperature. For example, if the air is preheated to 150 °C in conditions where the exhaust gas temperature is 250 °C and the exhaust gas oxygen is 5 %, the fuel is cut down to 5.6 % in terms of heat balance.

Screen 13.5 Air Preheating with Exhaust Gas Heat (File:H_BL_GAS, Cell:w21..ae40)

Table ** Fuel economy by air preheat (%) (to before adjustment preheat)

	Mixed
Air invasion=	0.0%

Exhaust temperature before preheating = 150

O_2 dry	Preheating temperature 100	150	200
0.0%	1.9%	-	-
2.5%	2.4%	-	-
5.0%	3.1%	-	-
7.5%	4.0%	-	-
10.0%	5.4%	-	-

Exhaust temperature before preheating = 200

O_2 dry	Preheating temperature 100	150	200
0.0%	2.0%	3.3%	-
2.5%	2.5%	4.2%	-
5.0%	3.2%	5.4%	-
7.5%	4.2%	7.0%	-
10.0%	5.7%	9.5%	-

Exhaust temperature before preheating = 250

O_2 dry	Preheating temperature 100	150	200
0.0%	2.0%	3.4%	4.8%
2.5%	2.6%	4.4%	6.1%
5.0%	3.4%	5.6%	7.8%
7.5%	4.4%	7.4%	10.2%
10.0%	6.1%	10.0%	13.7%

Exhaust temperature before preheating = 300

O_2 dry	Preheating temperature 100	150	200
0.0%	2.1%	3.6%	5.0%
2.5%	2.7%	4.6%	6.4%
5.0%	3.5%	5.9%	8.2%
7.5%	4.7%	7.8%	10.7%
10.0%	6.5%	10.7%	14.6%

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This calculation sheet is used to calculate the gas temperature of the air preheater outlet from the heat balance of the air preheater using the macro instruction ¥E [Cell: ag21..an40]. You can use this temperature as a reference for studying low-temperature corrosion of the air preheater. The calculation sheet also displays the exchanged heat amount [Cell: w41..ae60] and logarithmic average temperature difference [Cell: ag101..ao120]. In these calculations, the heat emission from the surface of the air preheater can be set as the ratio to the holding heat amount of exhaust gas at the air preheater inlet (the heat balance is calculated by excluding this heat emission volume from the exhaust gas heat amount at the air preheater inlet [Cell: ai22]).

Also, the air leakage in the air preheater (assuming that preheated air has entered the exhaust gas side from the air side at the gas side inlet of the air preheater) can be set by the ratio to the theoretical combustion air [Cell: al22]. (Be sure to enter these setting values before performing the calculation using the macro instruction ¥I.) When these setting values are set to zero, the calculations are made by assuming that there is no heat emission and no air leakage.

13.1.7 Boiler Heat Balance

The heat balance of the steam boiler is included in the combustion calculation worksheet. This calculation sheet allows you to calculate the boiler heat balance by setting the fuel volume, volume of feed water, exhaust gas temperature, and steam conditions according to the JIS land boiler heat balance (JIS B 8222), and to display the result of the calculation [Cell: bi21..bq40]. (Be sure to complete combustion calculations such as fuel selection before calculating the boiler heat balance.) The approximation formula of the steam table is used for calculating the steam enthalpy and compressed water enthalpy [Cell: az61..bg110]. You can select either of the following methods for the radiation heat from the furnace wall: (a) setting method by the ratio from the boiler capacity as indicated in JIS; (b) calculation method based on the furnace wall temperature. Screen 13.6 shows the basic numeric data for the boiler heat balance calculation and Screen 13.7 shows an example of the boiler heat balance table.

Screen 13.6 Assumptions for Boiler Heat Balance (File:H_BL_GAS, Cell:az21..bh40)

Data for Boiler Heat Balance Calculation (combustion calculation to be completed) — Mixed

Time, begin	1100	(set in	Emission option	d
Time, close	1200	four digits)	d:JIS formula	0.52%
Time, hour	1		c:Calculated	0.10%
Boiler capacity, t/h	100	(Rated)	m:Manually	1.4%
Base temperature	30		Adopted	0.52%

Item	Unit	Amount	/hour	Pressure abs	Temperature	Unit heat
Fuel latent heat	m^3_N	32,750	32,750	-	-	983
Fuel sensible heat	kcal	32,750	32,750	-	30	0.00
Burner air	m^3_N wet	39,982	39,982	-	160	40.69
Invasion air	m^3_N wet	0	0	-	30	0.00
Exhaust gas	m^3_N wet	67,263	67,263	-	200.0	57.76
CO loss	m^3_N wet	0	0	-	-	3018
Eco inlet feed	kg	-	-	79.033	100	101.4
Boiler-in feed	kg	43,000	43,000		100	100.7
Drum blow	kg	0	0	8.033	-	171.5
Outlet steam	kg	43,000	43,000	35.53	416	778.8
	Dryness, %	98%	Superheated			

Screen 13.7 Boiler Heat Balance Table (File:H_BL_GAS, Cell:bi21..bq40)

Boiler Heat Balance (net heat value based)

Mixed

Heat -in	kcal/m³N	kcal/h	%	Heat -out	kcal/m³N	kcal/h	%
Fuel calorie	983	32,199,898	95.2%	Steam generated	889	29,128,269	86.1%
Fuel sensible heat	0	0	0.0%	Exhaust gas loss	119	3,884,920	11.5%
Air sensible heat	50	1,626,703	4.8%	CO loss	0	0	0.0%
	0		0.0%	Emission loss	5	167,000	0.5%
Total	1,033	33,826,601	100.0%				
				Sub total	1,013	33,180,189	98.1%
				Miscellaneous	20	646,413	1.9%
				Total	1,033	33,826,601	100.0%

Boiler efficiency		Utilized heat detail	kcal/m³N	kcal/h	%
In/out method	86.1%	Main body of boiler	747	24,453,413	72.3%
Heat loss method	88.0%	Economizer	0	-	0.0%
		Superheater	144	4,706,217	13.9%
		Total	890	29,159,630	86.2%

If the setting value of the steam temperature in the setting of steam conditions is lower than the saturation temperature of the setting pressure, it is treated as the saturated steam equivalent to the pressure. If the setting temperature exceeds the saturation temperature, it is treated as the super heat steam, and the setting value for dryness is ignored.

13.1.8 Successive Heat Balance Calculation for Boiler

When the measurement value to be applied as the assumption of heat balance such as the exhaust gas components is obtained by a time-oriented numeric data string (for example, when the values measured for each minute is obtained by a recording card of the continuous measuring instrument), this calculation sheet allows you to calculate the boiler heat balance successively by loading this numeric data group into the combustion calculation. In this manner, you can understand the operating characteristics such as boiler efficiency in the time series.

The combustion calculation sheet is provided with macro instructions which can input measured values from other Lotus 123 files, put these values successively into the setting values of the boiler heat balance in a chronological order, calculate the heat balance, and display the result [Cell: ca1..cs14]. The measured values must be stored in the designated array in order to achieve this calculation. Moreover, the name of the file must be "Shiftavg" (Uppercase and lower case characters are not distinguished). The array of the measured values are stored in the data file Shiftavg.

13.1.9 Measurement Data File

File: Shiftavg

The successive heat balance calculation macro loads the measured values from the file Shiftavg [Cell: ca21..ci21 and cells below] and uses this numeric data group to perform the successive heat balance calculation [Cell: cj21..cu21 and cells below]. Screen 13.8 shows a part of the result table of the heat balance calculation.

Screen 13.8 Successive Heat Balance Calculation (File:H_BL_GAS, Cell:cj21..cu)**

Time	HI	Fuel sensible heat	Air sensible	Total	Steam generated	Exhaust gas loss	CO loss	Emission loss	Miscellaneous	In-out method	H loss method
14:19:59	9,881	6.6	63.3	9,950.9	7,879.1	932.5	5.5	46.7	1,087.2	79.2%	90.1%
14:21:01	9,881	6.6	63.7	9,951.3	7,837.1	937.3	5.7	46.2	1,124.9	78.8%	90.1%
14:22:01	9,881	6.6	62.9	9,950.5	7,841.6	926.7	5.8	46.0	1,130.4	78.8%	90.2%
14:23:01	9,881	6.6	62.3	9,949.9	7,793.2	921.3	6.0	46.6	1,182.7	78.3%	90.2%
14:24:01	9,881	6.6	62.5	9,950.1	7,576.5	926.0	6.2	46.1	1,395.2	76.1%	90.2%
14:25:01	9,881	6.6	62.7	9,950.3	7,573.5	929.9	6.1	45.9	1,394.9	76.1%	90.1%
14:26:01	9,881	6.6	62.6	9,950.2	7,625.3	930.6	6.0	46.1	1,342.2	76.6%	90.1%
14:27:01	9,881	6.6	62.8	9,950.4	7,659.3	935.1	6.0	46.7	1,303.3	77.0%	90.1%
14:28:01	9,881	6.6	63.0	9,950.6	7,653.9	938.6	6.9	46.5	1,304.8	76.9%	90.0%
14:29.01	9,881	6.6	62.9	9,950.5	7,693.8	937.1	6.7	46.4	1,266.5	77.3%	90.0%
14:30.01	9,881	6.6	62.0	9,949.6	7,517.9	924.9	6.4	45.8	1,454.6	75.6%	90.2%
14:31:01	9,881	6.6	62.5	9,950.1	7,484.4	929.9	6.6	45.8	1,483.4	75.2%	90.1%
14:32:01	9,881	6.6	62.5	9,950.1	7,618.2	909.1	7.0	46.6	1,369.1	76.6%	90.3%
14:33:01	9,881	6.6	62.4	9,950.0	7,693.4	907.2	7.2	46.9	1,295.3	77.3%	90.3%

You can get the moving average for the measured values on the calculation sheet of the file Shiftavg. You can set the desired number of data for calculating the average once and the desired number of lines to be skipped for the moving average [Cell: r2..t3].

Example:

Calculate the average of successive 30 numeric values.
Next, move 15 lines down.
Calculate the average of successive 30 numeric values from this point.
Repeat the above.

Moving averages such as mentioned above are enabled. In the above example, the number of data for calculating the average is set to 30 and the number of lines to be moved is set to 15.

Furthermore, adjustment of the measured values is performed on the file Shiftavg. The adjustment of the measured values, for example, is performed on the assumption of temperature and pressure compensation for the flow rate measured values and conversion of the gauge pressure into absolute pressure. Compensation is performed for all measured items and the compensation formula is expressed by a simple equation [Cell: a14..i20]. Therefore, if compensation is not required, set the constant item of the equation of the first degree to 0 and set the coefficient of the simple equation to 1. Compensation is performed for all records in the same manner. In other words, you cannot change the coefficient of compensation for each record.

Since the file Shiftavg has no function for loading the measured values, it is necessary to copy the measured data manually to this file.

13.1.10 Heat Balance Calculation of Reheating Furnace

File: HBFC_GAS

This file provides the heat balance calculation function of the continuous reheating furnace for the steel product in addition to the gas combustion calculation sheet. This, however, copes with gas combustion alone, but not the oil combustion. Since the amount of materials charged and the discharged weight cannot be expressed by the continuous measured values for the continuous reheating furnace, the successive heat balance calculation function such as for boiler example is not attached. Only the static heat balance calculation is performed.

The heat content of a steel product is given by the approximation formula [Cell: az61..bkl15]. The heat content changes according to the temperature, and it changes irregularly near the transition temperature. Therefore, the approximation formulas are provided each for the zone near the transition point, and for the temperature zones before and after this transition zone, thus connecting these three formulas. The heat amount content varies depending on the steel type. Therefore, formulas such as these are prepared for each steel type, and the necessary numeric value is selected using the Lookup function with the selection code of the steel type as a key [Cell: bd23]. You can select from 11 types of steel including rimmed steel and stainless steel.

An air preheater is, in many cases, installed in a reheating furnace. The air leakage rate in the air preheater can be calculated by measuring the oxygen in the exhaust gas before and after the air preheater. Air leakage here means leakage of air to the exhaust gas side from the air side in the air preheater. In this calculation sheet, combustion calculation sections are provided at two locations [Cell: a21..i40, al21..il40], and the different exhaust gas oxygen concentrations can be set separately. The air leakage rate is calculated based on these settings [Cell: bi51..bl54]. This calculation finds the air leakage between two points at which the exhaust gas oxygen was measured. Therefore, it is not limited to before and after the air preheater. For example, if you set the exhaust gas oxygen in the inside furnace and at the air preheater inlet, you can find the volume of air which invades from the material charging door on the furnace inlet between the furnace inside and the air preheater inlet.

The heat balance of the reheating furnace is calculated under the conditions when the air preheater is included in the system as well as when it is not included in the system. In either case, you only need to set the boundary condition values (air temperature and exhaust gas oxygen) of the target system. Note, however, that the percentage indication values of the heat balance table assumes the overall heat-input, including fuel heat and air heat, to be 100 %. Screen 13.9 shows an example of the heat balance table of the reheating furnace [Cell: bi21..bq47].

Screen 13.9 Heat Balance Table for Reheating Furnace (File:HBFC_GAS, Cell:bi21..bq40)

Heat balance of continuous reheating furnace (includes AH)

Heat-in	(10^3 kcal/t)		Heat-out	(10^3 kcal/t)	
Fuel combustion heat	602.8	95.6%	Billet discharged	187.1	29.7%
Fuel sensible heat	0.0	0.0%	Scale sensible heat	6.6	1.0%
Billet heat content	1.1	0.2%	Exhaust gas sensible heat	196.2	31.1%
Scale formation	26.7	4.2%	Cooling water	9.8	1.6%
Total	630.6	100.0%	Emission and miscellaneous	230.9	36.6%
Recovered in AH	0.0	0.0%	Total	630.6	100.0%

Heat balance of continuous reheating furnace (furnace only)

Heat-in	(10^3 kcal/t)		Heat-out	(10^3 kcal/t)	
Fuel combustion heat	602.8	81.6%	Billet discharged	187.1	25.3%
Fuel sensible heat	0.0	0.0%	Scale sensible heat	6.6	0.9%
Air sensible heat	108.5	14.7%	Exhaust gas sensible heat	302.2	40.9%
Billet heat content	1.1	0.2%	Cooling water	9.8	1.3%
Scale formation	26.7	3.6%	Emission and miscellaneous	233.5	31.6%
Total	739.2	100.0%	Total	739.2	100.0%

13.1.11 Heat Value Adjustment of Liquid Fuel

File: H_BL_OIL

In the case of liquid combustion, the calorific value may sometimes be given as a precondition besides the fuel composition values. In this calculation sheet, however, the calorific value is calculated from the fuel composition values. Therefore, this calculated result does not always match with the given calorific value. In this calculation sheet, the unit calorific values of carbon and hydrogen among all fuel compositions are changed in proportion in order to provide a choice so that the given fuel calorific value is obtained (¥U) [Cell: a85..g100]. When this heat amount adjustment is performed, it is displayed on the screen [Cell: c22..c24]. Also, the adjusted value can be returned again to the original value using the same macro instruction.

13.2 Multi-Layer Heat Insulation

File: M_INSU95

For the heat insulation calculation, the heat conductivity coefficient of a heat insulation material changes depending on the temperature of the material It is expressed by a quadratic equation of material temperature by JIS [Cell: crl..eo40]. The heat transfer coefficient, which is a coefficient of heat loss from the outside surface of the heat insulation, is also given by the function of a surface temperature, making the heat insulation calculation become complex. Therefore, it is necessary to perform convergence by repeating the calculation. When you only wish to obtain an approximated result, it is accepted even if the heat conductivity coefficient and heat transfer coefficient do not rely on temperature. This calculation sheet can be used in these both cases.

13.2.1 Setting the Conditions

This calculation sheet allows you to calculate the surface temperature and heat emission volume when 2-layer or 3-layer heat insulation is provided for pipes, towers, and tanks. The inside and outside fluid temperature, the heat transfer coefficient of inside surface, and thickness of each layer must be set first as a precondition [Cell: a21..h40, i21..p40]. Then the heat insulation materials of each layer, outside surface heat transfer formula, wind velocity (only when there is forced convection), and emissivity of outside surface must either be selected or set from the menu of ¥A. The coefficient of the heat conductivity formula and heat transfer coefficient formula of the material is selected using a Lookup function by selecting the specific heat insulation material and heat transfer coefficient formula. There are no restrictions regarding the order of these selections and settings. Therefore, if you want to change the selection or setting you made, simply select or set the item again. You can also exit or return from/to the menu anytime, and need not to bother about setting omissions.

The heat insulation material must be selected for each layer. If, however, there is no target layer (for example, a 3rd layer when the heat insulation is performed for only 2 layers), you can simply set the thickness of the layer to zero. (In this case, even if the material of this layer is not selected, it will not affect the calculation results.) Normally, the materials (metal) of pipes, towers, and tanks are selected for the 1st layer. Since the heat conductivity coefficient of metal is large, you can ignore this and may start from the 1st layer of heat insulation. In this case, you will be able to calculate the heat insulation for up to 3rd layer.

13.2.2 Executing the Calculation

After completing the above settings and selections, you can perform the convergence calculation using the set conditions and formulas by selecting the calculation execution from the menu. Since the conditions (setting values and formulas) used for the previous calculation is retained, it is not necessary to set conditions when the same conditions are used next time. For example, this applies when you want to change the heat insulation material thickness and use other conditions same as the previous time.

The calculation sheet consists of the pipe and plane heat insulation pages, including the calculations for five cases. Therefore, you can see on the same display the calculation of a different portion or a trial calculation by changing the heat insulation material thickness and material. There are no mutual relationships between these five cases, and each case is independent. You can copy the setting conditions of another case to the currently selected case using the duplicate function in the menu. You can use the menu for selecting the pipe/plane and the case used for calculation. Screen 13.10 shows the setting page of the pipe case [Cell: a21..h40].

Screen 13.10 Multi-layer Insulation, Settings (File:M_INSU95, Cell:a21..h40)

Multi-layer heat conduction -- pipe				Box	Setting	Selected:	5
Case No.			1	2	3	4	5
Pipe line name							
I/O temp	Fluid, inside		180	180	180	180	180
	Ambient		20	20	20	20	20
Heat transfer	Inside		10000	10000	10000	10000	10000
coefficient	Outside	Convection	2.659	2.659	2.659	2.659	2.659
		Radiation	2.569	2.569	2.569	2.569	2.569
1st layer	Material		Steel 0.5C	Steel 0.5C	Steel 0.5C	Steel 0.5C	Steel 0.5C
	Heat transfer coefficient		46.0000	46.0000	46.0000	46.0000	46.0000
	Outside diameter		0.1143	0.1143	0.1143	0.1143	0.1143
	Thickness		0.006	0.006	0.006	0.006	0.006
2nd layer	Material		R.W.felt	R.W.felt	R.W.felt	R.W.felt	R.W.felt
	Heat transfer coefficient		0.0516	0.0516	0.0516	0.0516	0.0516
	Thickness		0.075	0.075	0.075	0.075	0.075
3rd layer	Material		G.W.cylinder	G.W.cylinder	G.W.cylinder	G.W.cylinder	G.W.cylinder
	Heat transfer coefficient		0.0330	0.0330	0.0330	0.0330	0.0330
	Thickness		0.025	0.025	0.025	0.025	0.025
Heat transfered	per length (kcal/m)		44.29	44.29	44.29	44.29	44.29
Temperature	Outside surface		28.58	28.58	28.58	28.58	28.58

The JIS related to heat insulation material was updated in 1995. The part "95" of the filename indicates that this file conforms with this new JIS.

13.3 Economical Thickness of Heat Insulation

File: E_INSU95

For steam pipes, the wall surface of heating tanks, and other portions, when the thickness of the heat insulation layer increases, the heat emission volume decreases, resulting in energy conservation and reduction of the fuel cost. However, the thick heat insulation requires a corresponding construction cost. JIS-9501 (1995) defines as "Economical thickness of heat insulation" the heat insulation thickness which can achieve minimum annual expense (sum of enery cost and the equipment/facility charge such as depreciation) by maintaining a balance between fuel cost reduction through heat insulation and equipment/facility cost (heat insulation construction cost), and provides the concept of this formula and specific calculated examples.

A number of factors (pipe diameter and thickness, heat transfer coefficient of the outside surface, thermal conductivity coefficient of the material, heat price, heat insulation construction cost, interest rate, and the depreciation period) are involved in the calculation of the economical thickness of heat insulation. Thus, it is quite difficult to calculate this manually. Moreover, the calculation examples given in JIS assume the specific conditions for these factors. Therefore, if the conditions are changed, you need to make calculations again.

13.3.1 Setting the Conditions

In this calculation sheet, you have to set or select various preconditions such as temperature of each portion, economical conditions, and material selection. Then, the economical thickness, annual expense, and heat emission volume are calculated by executing the calculation using macro instructions. The macro instructions ¥R and ¥S are used for calculation of pipes and plane respectively. The setting cells for the setting values common for a pipe and plane are displayed on the left side portion of the screen, and the setting cells for the individual setting values are displayed on the right. Screen 13.11 shows the settings and calculation result screen [Cell: a21..h40].

Screen 13.11 Economical Thickness of Heat Insulation (File:E_INSU95, Cell:a21..h40)

Economically Optimum Insulation Thickness			Conventional (kcal unit)		Currency	\unit
			<Pipe> (\R:calc)		10/31	16:22
<Premises---Pipe/Surface>			Economical thickness	Xp	0.077	m
Inside temperature	th.0	200.0	Outer diameter of insulation	do	0.319	m
Room temperature	th.r	20	Inner diameter of insulation	di	0.1652	
Heat transfer *	alpha	10.32	Annual expense	Fp	6496	Vyear
Heat price *	b	5.813953	Heat loss / hour *	Qp	78.1	kcal/m/h
Annual interest	n	5.00%	Surface temperature	th.pe	27.5	°C
Insulation life, year	m	15	Heat conductivity (avg)*	ramda p	0.0475	
Working hour	hr	8000	Insulation work price	ap	506	th.V/m³
Annual depreciation	dep	9.6%	Insulation material	Ca-Si cylinder 1-13		
*: careful on unit			Bare tube heat loss		964.0779	kcal/m/h
Work price coefficient	I	12	<Plane surface> (\S:calc)		10/31	16:22
Artificial fiber	La	200	Economical thickness	Xs	0.113	m
Inorganic porous	Lb	300	Annual expense	Fs	7804	Vyear
Exchange rate	V$	100	Heat loss / hour *	Qs	72.9	kcal/m²/h
Macros:	\U:Unit option		Surface temperature	th.sc	27.1	°C
\A:Menu	\P:Print		Heat conductivity (avg)*	ramda s	0.0475	
\G:Call graph	\X:Boxes		Insulation work price	as	406	th.V/m³
\L:Cell protect	Free		Insulation material	Ca-Si board 1-13		

You can switch the unit of heat amount between kcal and Wh in this sheet (because the unit Wh is used in JIS), and the currency unit can be switched between yen and dollar [Cell: r1..z16]. It should be, however, noted that the unit of length m and ft is not switched even if you change the currency unit. Therefore, it is necessary to be careful about the unit when you check heat conductivity coefficient, and heat emission volume value. When the unit is switched, the values set before the switching takes place are retained as the converted value.

13.3.2 Calculation

The heat conductivity coefficient of the heat insulation material is given by function of a temperature. The coefficient of the heat conductivity formula is selected in the related calculated cells by a Lookup function in accordance with the material selection. The construction cost of heat insulation is set by a formula and the different coefficient is selected by a Lookup function depending on the category of the material [Cell: i32..l40, r32..s40].

In this calculation sheet, a differential value is calculated by differentiating the above-mentioned formula representing the annual expense with respect to the value for the insulation thickness. The convergence calculation macro repeats this calculation to find out the thickness so that the differential value will become zero [Cell: i21..o30, r21..x30]. The convergence limit is the setting value.

Also, "Pipe size/heat price vs economical thickness," "Heat insulation thickness and heat emission loss/equipment charge," and "Change of construction unit price and economical thickness" are provided as the What-if tables. The data in these tables is calculated using the macros indicated on each page of the table [Cell: r41..z120]. Screen 13.12 and Screen 13.13 show some of the examples of the tables.

Screen 13.12 Insulation Thickness & Annual Expense (File:E_INSU95, Cell:r51..z60)

Table 2 Economical Thickness vs Annual Expense (Pipe) (\J) 04/24 05:46

Insulation thickness		Surface temperature	Loss heat	Loss expense	Fixed cost	Annual expense	Insulation price
70%	0.054	31.3	116.5	4662	2171	6832	606.8
80%	0.062	29.8	106.0	4242	2389	6631	564.5
90%	0.069	28.5	97.7	3907	2619	6527	532.1
100%	0.077	27.5	90.9	3635	2861	6496	506.5
110%	0.085	26.8	85.2	3408	3115	6522	485.7
120%	0.092	26.1	80.4	3216	3379	6595	468.6
130%	0.100	25.5	76.3	3051	3655	6706	454.3

Screen 13.13 Heat Price & Economical Thickness (File:E_INSU95, Cell:r41..z49)

Table.1 Pipe size / Heat price vs Economical thickness (\H) 04/24 05:46

	25A	50A	100A	150A	200A	250A	300A	Plane
Heat price	0.034	0.0605	0.1143	0.1652	0.2163	0.2674	0.3185	
4	0.045	0.054	0.065	0.070	0.074	0.076	0.079	0.100
6	0.054	0.065	0.077	0.083	0.088	0.092	0.095	0.124
8	0.062	0.073	0.087	0.094	0.100	0.104	0.107	0.144
10	0.068	0.081	0.095	0.104	0.110	0.115	0.119	0.161
12	0.074	0.087	0.103	0.112	0.119	0.124	0.128	0.177
14	0.079	0.093	0.110	0.119	0.127	0.132	0.137	0.191

If you manually enter another value in the "economical thickness" cells [Cell: g23.g34] after calculating the economical thickness using the macro in this calculation sheet, the annual expense and heat emission volume are automatically calculated. In this case, the heat conductivity of the heat insulation material is calculated using the economical thickness (i.e., the thermal conductivity value under the heat insulation temperature in terms of the economical thickness). When the surface temperature changes are small, this would be a sufficient approximation (the What-if table is created in this manner).

13.4 Surface Heat Emission Calculation

File: EMISSION

For a pipe and plane, when the heat emission volume is calculated by setting the surface temperature, the heat transfer coefficient value of the surface directly affects the heat emission volume. On the convection heat transfer coefficient from the surface, several formulas have been suggested as functions of the surface temperature and ambient temperature based on the orientation of the surface (vertical orientation, horizontal orientation, etc.) and wind velocity. Using this calculation sheet, you will set the relevant preconditions of the calculation such as surface temperature, ambient temperature, emissivity, wind velocity, and surface area or pipe length; select the relevant formula for multiple surfaces (multiple calculation cases); and calculate the heat emission from the surface using macros. You can select the formula by setting the code (numeric value) associated with the formula [Cell: a3..o9]. The calculation macro writes the calculation results using the respective formula in the list. Screen 13.14 shows a calculation example.

Screen 13.14 Heat Emission Calculation (File:EMISSION, Cell:al..q18)

Heat Emission from Surface (calculation after setting with \C)
Factory name:

Code:

111 Surf-Nat-Up-JIS	117 Surf-Nat-Up-Hirata	211 Pipe-Nat-Horizontal-Takamura
112 Surf-Nat-Down-JIS	118 Surf-Nat-Down-Hirata	212 Pipe-Nat-Horizontal-Hirata
113 Surf-Nat-Vert-JIS	119 Surf-Nat-Vertical-Hirata	213 Pipe-Nat-Vertical-Hirata
114 Surf-Nat-Up-Takamura	121 Surf-Forced-Smooth-JIS	221 Pipe-Forced-Takamura
115 Surf-Nat-Down-Takamura	122 Surf-Forced-Rough-JIS	
116 Surf-Nat-Vertical-Takamura	123 Surf-Forced-Takamura	Unit: m, °C, hr, kcal

No.	Ambient temperature	Surface temperature	Formula Code	W.Velocity m/s	Radiation rate	S_typical length	P_typical length	Pipe diameter	Area Length	Convection coefficient	Radiation coefficient	Unit heat	Total heat
1	30	100	211		0.9			0.3185	11.4	4.49	6.87	796	9,096
2	30	110	211		0.9			0.2674	35.3	4.64	7.20	796	28,045
3	30	130	211		0.9			0.2163	100.8	4.90	7.89	870	87,653
4	30	130	211		0.9			0.1652	90.0	4.90	7.89	664	59,773
5	30	110	211		0.9			0.1143	50.8	4.64	7.20	340	17,276
6	30	110	211		0.9			0.0891	125.0	4.64	7.20	265	33,137

When you calculate the heat emission volume from the inside based on the condition where the heat is emitted from the heat insulated surface, the heat resistance of the heat insulation material acts as a dominant factor in the heat transfer. Therefore, the heat transfer coefficient of the surface does not directly affect the heat emission volume, which may not be taken into much consideration. On the other hand, when the heat emission is calculated based on the surface temperature as it is in this calculation sheet, the heat transfer coefficient of the surface directly affects the heat emission volume. In an actual situation, the heat transfer coefficient is always changing due to wind velocity and sunlight, and the heat emission volume varies even depending on the selection of the formula used for calculation. Due to these reasons, the calculation result should not be regarded as absolute.

13.5 Approximation of Steam Table [Cell: a21..j140]

File: STEAM_14

For example, to find the pressure loss of a steam pipe, it is necessary at first to find the specific volume of the steam equivalent to the applied pressure and temperature on the steam table. Since the steam table is a list of numeric data and not formulas, you need to refer to the steam table every time the pressure and/or temperature changes. Also, an interpolation may be sometimes required depending on the pressure and temperature from the data obtained from the steam table.

The approximation formula of the steam table immediately gives the characteristic value when the steam conditions are set. Using this feature, you can easily perform simulations of various steam application problems on the work sheet. In this sheet, a formula is independent for each recorded item, and a macro is not used for the approximation itself. Therefore, you can utilize the portion you need by copying it to another sheet.

13.5.1 Pressure Based Saturated Steam and Super Heat State Steam Table

There is one variable for the saturation steam table, one variable for pressure and one variable for temperature of super heat steam in the steam table. When there is one variable in this approximation formula, approximation is performed by polynomial expression. When there are two variables, the approximation is performed in the following manner. For example, the enthalpy under specific pressure is approximated by the polynomial expression of temperature, and this approximation is calculated for several levels of pressure beforehand. The enthalpy equivalent to the temperature under the pressures, which are before and after the level of the applied pressure, is calculated from the polynomial expression of temperature. The enthalpy under the applied conditions is then obtained by an interpolation based on the pressure.

The relative accuracy of the approximation formula for the enthalpy calculated using the above method is 0.1 % or less. Supposing that a pressure of 42 kg/cm^2 abs and a temperature of 480 °C are applied, the approximation result H = 811.5 is obtained by the interpolation (linear interpolation) based on the pressure using the following expression of temperature: 40 abs/480 °C, H = 812.04 (equation of the 5th degree of temperature) and 50/480, H = 809.21. The value displayed in the steam table is 811.6. Since the accuracy of approximation tends to be poorer near the lower limit of the applicable range, the steam characteristics for a pressure of 2 ata or less is calculated using another formula. Screen 13.15 shows an example of the steam table screen [Cell: a21..i40].

Screen 13.15 Pressure Based Steam Table (File:STEAM_14, Cell:a21..J40)

(Press.base) Sat,SH steam			Box	:Set value
Applied: Pr 1.5 - 140 abs under			\U:Pressure unit conversion	
Temperature upto 500 °C			Actual unit:	kg/cm² abs
Pressure kg/cm² abs	130.00			
Pressure kg/cm² gauge	128.97		When set temperature is less than saturation temperature,	
Pressure MPa	12.75		calculation is on saturation steam.	
Temperature °C	340			

<Saturation steam, pressure base>	(kcal)	(kJ)	<Super heat steam>	(kcal)	(kJ)
Saturation temperature	329.3		Super heat degree	10.7	
Saturated water volume	0.001538		Volume m³/kg	0.0142	
Saturated steam volume	0.013		SH steam enthalpy	655.7	2745
Saturated water enthalpy	363.7	1522	SH heat amount	17.7	74.0
Saturated steam enthalpy	638.0	2671	Average specific heat	1.652	6.914
Latent heat	274.3	1148	SH steam entropy	1.331	73.99
Saturated water entropy	0.847	3.546			
Saturated steam entropy	1.303	5.452			

Heat: kcal or kJ/kg, Specific volume: m³/kg　　　Conversion=> 4186

Approximation formula & accuracy on below

The applicable range of this sheet is up to a pressure of 140kg/cm² and temperature of 500 °C. Since the approximation formula approximates the physical characteristic value of steam without any connection to the physical properties, it is not recommendable to perform extrapolation exceeding the applicable range.

This file contains the following approximation formula besides the above screen.

13.5.2 Temperature-Based Saturated Steam Table [Cell: k21..r60]

Setting value: Temperature

Approximated values: Saturation pressure (kg/cm² abs, kg/cm² gauge, MPa), Saturated water specific volume, Saturated steam specific volume, Saturated water enthalpy, Saturated steam enthalpy, Saturated steam latent heat, Saturated water entropy, Saturated steam entropy

13.5.3 Low-Pressure Saturated Steam Table (0.01 to 2.0 kg/cm²)

Setting value: Pressure

Approximated values: Saturation temperature, Steam specific volume, Saturated water enthalpy, Saturated steam enthalpy, Saturated water entropy, Saturated steam entropy

This file also contains a table which calculates the saturation pressure from the setting values of the temperature, enthalpy, and entropy besides the above.

13.5.4 Compressed Water (0.1 ≤ P) [Cell: a21..aa8]

Setting value: Pressure, temperature

Approximated values: Enthalpy, Entropy

13.5.5 Mutual Approximation of Quantity of Steam State

The following approximation formulas on pressure P, temperature T, entropy H, and enthalpy S are provided for super heat steam:

P,H to T, P,S to T, P,S to H, and P,H to S

On saturated steam: S to H
On saturated water: S to H

The following examples are provided in the same file as the application examples of the approximation formulas.

13.5.6 Steam Accumulator Calculation [Cell: ad21..ah40]

In this calculation, the initial pressure and final pressure of the steam accumulator and the hot water capacity in the vessel are set to calculate the steam volume generated between these two pressures. Generally, the steam volume of the accumulator is given by a graph using these data as parameters. If you use this approximation, the steam volume of the accumulator is given as numeric value on the worksheet. Therefore, it is easy to perform the simulation using the initial pressure and/or final pressure as parameters. Screen 13.16 shows an example of the calculation.

Screen 13.16 Steam Accumulator (File:STEAM_14, Cell:ad21..ah40)

Steam Accumulator & Self Evaporation of Hot Water   [Box] :set value

Applicable: 1.5 - 140 kg/cm² abs under

	Initial	Final	
Pressure kg/cm² abs	120.00	10.00	
Pressure kg/cm² gauge	118.97	8.97	
Pressure MPa	11.77	0.98	
Saturated temperature	323	179	°C
Saturated water enthalpy	354.3	181.3	kcal/kg
Saturated water volume	0.00150	0.00112	m³/kg
Latent heat	288.5	481.6	kcal/kg
Saturated steam enthalpy	642.8	662.8	kcal/kg
Saturated steam volume	0.0146	0.1979	m³/kg
Unit evaporation		0.2	kg/m³-initial w.vol
Saturated water amount	80.0	51.2	ton
Saturated water ttl volume	120.0	57.6	m³
Evaporation	0	28.7	ton
Steam volume	0.00	5687	m³

What-if table on right page

13.5.7 Pressure Loss of Steam Pipe [Cell: ax21..bd100]

Since the specific volume of steam is represented by the approximation formula, you can easily calculate the pressure loss of the pipeline. In this calculation, the inside diameter of the pipe is read by entering the pipe code (such as Sch40, Sch60, Sch80) and nominal size A value (for example, "150" by the unit of mm). The flow velocity is calculated from the specific volume by setting the steam pressure, temperature, flow rate, and the pipe length, and then the pressure loss is calculated. The formula specified in the latest version of "How to Utilize Steam, Application edition" (issued by the Energy Conservation Center, Japan, in 1984) is used for the calculations. However, the gradual decline of pressure in the direction of pipe length due to pressure loss and the changes of specific volume are not taken into consideration. If such considerations are necessary, you can perform the calculation by dividing the length of entire pipe into some portions lengthwise.

At the same time, the heat expansion of the pipe and the steam volume required for heating up the pipe at the initial stage are calculated. (This calculation is made by assuming that the heat amount required for increasing the temperature of pipe material is supplied by the latent heat of the steam equivalent to the pressure, and does not include the heat emission.) The calculations are made for steel, copper, and aluminum as pipe materials. Screen 13.17 shows an example of the calculation.

Screen 13.17 Pressure Drop & Heat Up Steam in Steam Pipe (File:STEAM_14, Cell:ax..bd40)

Pressure loss, heat expansion & heat up steam of steam pipe [Box] :set value

Applicable: 1.5 - 140 abs under

(Set nominal size A, then check nominal size B)

<Setting>					
JIS pipe code		[2]	<Calculated>		
1:SGP 2:Sch40 3:Sch80			Flow velocity	m/s	26.0
Nominal size A (mm)		[200]	Pressure loss	kg/cm²	0.483
Nominal size B (inch)		8	Heat expansioı	m	
Inside diameter:Di	m	0.2	Carbon steel		0.400
Pipe weight	kg/m	42.1	SUS 18-8		0.547
Steam flow:G	t/h	[20]	Aluminum		0.806
Pressure abs	kg/cm²	[15]	Copper		0.560
Temperature	°C	[230]	Heating steam	kg	356.4
Latent heat	kcal/kg	465	(as saturated steam / steel pipe)		
Unit vol:v	m³/kg	0.1467			
Saturation temperature	°C	197	If set temperature is less than sat		
Pipe length:L	m	[200]	temperature of steam, the sheet		
Initial temp	°C	[20]	assumes it as saturated steam.		

Pressure loss formula: $10.5/10^4*v*G^2/((Di/1000)^5*(\pi/4)^2)/3.6^2*L$

(Quoted from "Intelligent steam use"(ECC) p.72 Equivalent length on right

13.5.8 Steam Turbine Calculation [Cell: by21..cg180]

In this calculation sheet, the enthalpy difference in the steam turbine is calculated by a simple method by using a square and ruler on the i-s chart attached to the steam table. If you, however, use the approximation formula of the steam table and the mutual approximation of the steam characteristic value, you can perform the steam turbine simulation on the worksheet. On this worksheet, for the simple extraction condensing turbine (without re-heating), the output of high & low pressure parts and overall efficiency are calculated by setting data such as the steam conditions of inlet steam and extraction steam, expansion efficiency, and condenser vacuum (switchable between vacuum and saturation temperature). (The extraction steam is set by the ratio to the inlet steam flow). The overall efficiency is calculated by assuming that all heat amount which the extraction steam is retaining is effective. Screen 13.18 shows an example of the steam turbine calculation.

Screen 13.18 Steam Turbine Simulation (File:STEAM_14, Cell:by21..cg40)

Steam Turbine

Box :set value

<H-P turbine> (Back-pressure turbine)		<L-P turbine> (Condensing turbine)		<Condenser>	
Pressure	40	Extraction pressure	20	Pressure	0.20
Temperature	500	Temperature	407.1	Vacuum Hg	612.9
Enthalpy	823.0	Enthalpy	779.9	Saturation temperature	59.66
Entropy	1.695	Entropy	1.711	Dryness	95.1%
Expansion efficiency	80.0%	Expansion efficiency	85.0%	Enthalpy	595.8
Power out (kWh/kg-steam)	0.0501	Power out (kWh/kg-steam)	0.2141	Entropy	1.809
Steam kg	1	Extraction kg	0.4	Condense kg	0.6
		Extraction ratio	40.0%	Overall efficiency (Overall efficiency)	56.6%
Output(kWh)	0.05005 (kWh)	Output(kWh)	0.12846 (kWh)	Total out	0.17852 (kWh)

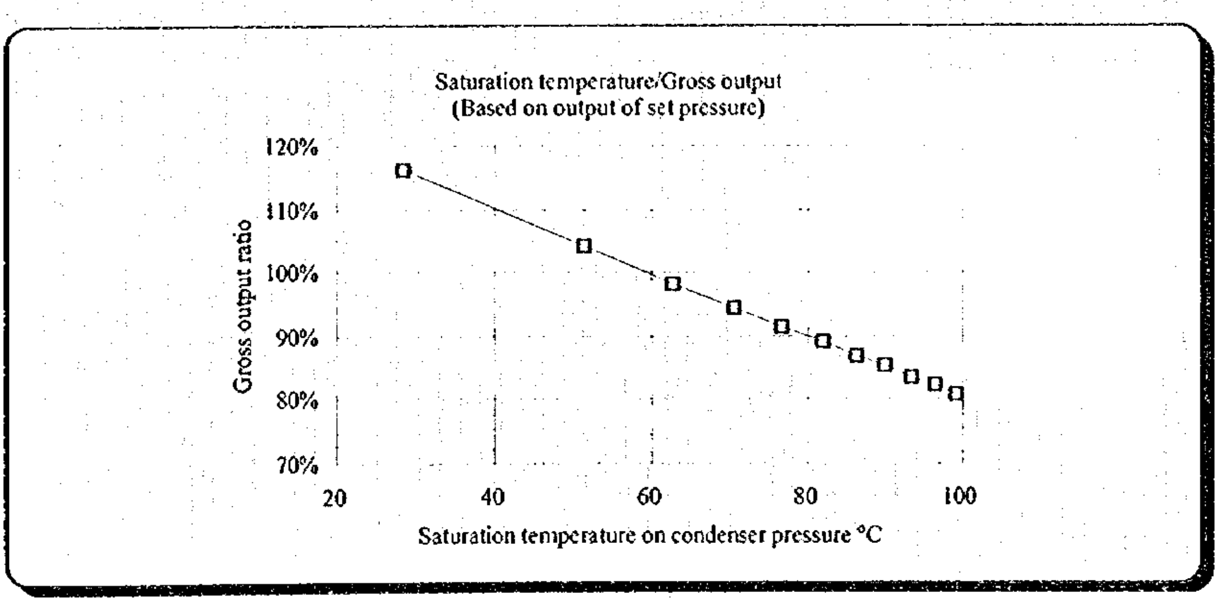
\F: Condenser pressure option (pressure/saturated temperature)

Extraction: Steam extraction for process use

Expansion efficiency: Adiabatic expansion efficiency inside turbine

You can easily simulate the effect (sensitivity) of all presumed values for the turbine output using this calculation sheet. The study using extraction steam pressure and condenser vacuum as parameters is displayed in a graph as an example on the sheet. Screen 13.19 shows the saturation temperature equivalent to condenser vacuum and turbine output.

Screen 13.19 Sensibility of Condenser Saturation Temperature on Turbine Output (File:STEAM_14)



If you set the efficiency to zero, this sheet can be used for the calculation of simple pressure reduction (adiabatic expansion of enthalpy constant).

13.5.9 Pressure and Temperature Reducing Device [Cell: ci21..cn85]

When the back-pressure turbine is used for generating electric power and supplying the process steam, a pressure and temperature reducing device by water injection for high-pressure super heat steam is sometimes installed as the turbine bypass to cope with turbine shutdown time and load fluctuation. In this calculation, you will set the primary side and secondary side steam conditions and water injection conditions to calculate the necessary water injection volume. Screen 13.20 shows an example of this calculation.

Screen 13.20 Pressure & Temperature Reduction (File:STEAM_14, Cell:ci21..cn36)

Temperature, pressure reducing device (by water injection)

Box :set value

			Primary	Secondary
Steam				
	Pressure	kg/cm² abs	60	16
	Temperature	°C	300	230
	Enthalpy	kcal/kg	689.7	685.4
	Amount	t/h	25	25.19
Water				
	Pressure	kg/cm² abs	69	
	Temperature	°C	120	
	Enthalpy	kcal/kg	121.4	
	Injection	t/h	0.191	

13.6 Using the Calculation Disk

(The information in this section is given based on Lotus 123/DOS. The spread sheet on Windows may be slightly different in the display format and selection method.)

13.6.1 Menu

This disk is a data disk of Lotus 123. When you boot up your existing Lotus 123 (or the compatible spread sheet) on your PC and load the necessary files from this disk, the private menu will appear on the screen in most cases (it is not a command menu of Lotus 123). When you use the cursor key to move the cursor on this menu, the outline of each menu will be displayed on the message line above the menu line. To enter data in the setting value cell, you need to exit this menu using Exit. However, we recommend you to use this menu to look through the pages of the sheet screens before exiting the menu. (Press the Return key at the desired menu item to jump to the relevant page.) Since the private menu can hold only 8 items, sometimes a sub-menu is provided under the specific item. A selection is provided so that you can return to the original menu after moving to the sub-menu and you can also quit the menu.

The screen display area is fixed on the DOS version. On the other hand, the screen display area can be adjusted for the Windows version, and thus the operation of moving between screens using macros may not be effective in some cases. It will not affect the calculation, however. Since the layout on the worksheet is displayed as a table in most of the files, you can grasp most of the worksheet structure by moving to the "Location map on the menu". If you make a print-out of this map page, you can keep it with you for reference whenever you need to. Screen 13.21 shows a location map of the gas combustion sheet.

Screen 13.21 Location Map on Combustion Calculation Sheet (File:H_BL_GAS, Cell:aq2..ax20)

Location map

(H_BL_GAS.wj2)

	A	J	V	AF	AP	AZ	BI
1	Instruction	What-if remarks	W/D option remarks	Air Heat remarks	Map	Heat balance remarks	Macro list
21	Setting Basic calculation	AR adjust effect	Air heating effect	AH outgas temperature	Cp arrange (Heat balance)	Heat balance setting	Heat balance table
41	What-if table	Utilized heat Saturated water	AH calc	AH outgas macro	AH heat balance	Surface emission	AR,AH effect
61	Fuel composition	Heat value Air required	Combustion calculation	Fuel selection	O2/CO W/O option	Steam Hs appximation	Heat balance English
81	Gas Cp coefficients	Adiabatic temperature calculation	Cp arrange	AR W-ifs macro	Adiabatic W-if macro	FW_Hw approximation	Heat balance JIS style
101	Menu macros	Control macros	Humidity option RH/WB	AH logarithmic mean temperature difference	AH inlet gas temperature	Hw/T approximation	·
121	·	·	·	AH temperature efficiency	AH exchanged heat	AH effect	·

ca1.. Heat balance macro
ca21.. Heat balance data
cj1.. Heat balance macro
caj1.. Heat balance data

You can enter this private menu anytime using macro instruction ¥A from normal input status (Press and hold down Ctrl (or Alt) key and press the A key).

13.6.2 Input and Calculation

When you enter a value in a cell on the spread sheet, the calculation is automatically performed and the displayed values of the related cells will change. You need to enter a decimal for the numeric value input in the cells that indicate a percentage (you may enter a percentage value directly in some Windows version). For example, to set 24 % in the fuel gas composition data cell, enter 0.24. The cells that you can set are enclosed in a thick frame (the frame line type may not be distinguishable or the frame line may not be displayed on some PC and/or some software types). In addition, the cell unlock state is set and thus the characters are displayed in white on a color screen (123/DOS).

If you accidentally enter data in the cell in which a formula is written, the formula may be destroyed and you could be obtaining a wrong calculation result if you did not notice this mistake. Even if you notice such a mistake, it is difficult to recover many of the formulas after the file has been saved and has replaced the original file. If you lock the cell using macro instruction ¥L (cell protect/free), you can avoid the destruction of formulas by accidental inputs. It is best, however, to make a backup copy of the disk (files) in the beginning to prevent these troubles.

13.6.3 Macro

A part of the calculations (such as a calculation to be repeatedly performed for convergence) and What-if table must be recalculated by executing macros. In such cases, indications such as ¥C is displayed on the relevant calculation pages. You simply need to execute this indicated macro (press and hold down the Ctrl (or Alt) key while pressing the C key in the same manner as mentioned earlier). Lotus 123/Windows or Excel/Windows can read the macros as they are and execute them without rewriting the macros of Lotus 123/DOS.

Besides the ¥L (cell protect/free) mentioned above, the common macros set for all files are ¥P (print), ¥X (ruled line display disabled/enabled), and ¥A (initial menu). ¥L and ¥X are so-called toggle switches. Each time you press the switch, the operation is reversed. For example, after setting the cell protect by pressing ¥L, press ¥L again to cancel the protect status and enable input in the cell.

The print macro ¥P is used for printing the worksheet screen using the printer. (You can also print the screen using the Lotus menu.) You can adjust the character pitch and line pitch of the print finish by changing the numeric values such as C1 and L2 using the F2 key (Edit key). The print-out may not be successful using the print macro indicated on the sheet on some printer models. In that case, you can either print from the Lotus menu or change the indication of the print macro. (The part related to print is exclusive to Lotus 123/DOS. On Windows, you can print using the Windows function.)

A macro consists of a series of written procedures to be performed by keyboard input on Lotus 123 as they are according to an input sequence along with the indications of the dedicated macro instructions. Since the types and use methods of the dedicated macro command can be displayed by the Help of Lotus 123 (you can read this information from the worksheet any time using Help key), you can easily understand the dedicated macro command (used for a branch of operation according to the conditional judgment and menu screen display control in many cases) used in this sheet and change them according to your needs. To execute a macro, simply hold down the Ctrl key (or Alt key for some PC) and press the relevant alphabet key. Lotus 123 starts reading and executing the procedures one after another from the cell in which the macro was indicated to the lower cells, and the operation is stopped (ended) if there is a blank cell. Therefore, the cell immediately below the macro end cell must either be left blank, or "{quit}" must be indicated in the last of the macro instructions (this is more secure) to declare the end. Moreover, if you assign the name "¥0" (zero) to the macro, this macro is executed immediately after reading the file. The macros of the private menu of this calculation sheet are processed in this manner.

13.6.4 Operation Table

The What-if table is also called the operation table. It is used for checking how the calculated numeric values change when 1 or 2 setting values are changed in the process of a series of calculations. This table is one of the convenient functions of the spread sheet. You can create an operation table by selecting the desired variables and calculated result values. However, some procedures (key operations using Lotus menus) are necessary. In this calculation sheet, several What-if tables are provided on the screen and the macros for calculation key operations have been prepared. Therefore, you can look at the simulation result by simply executing the macro name (such as ¥T) indicated at the title portion of each operation table, and also check the calculation result of some tables in a graph.

13.7 Japanese Version Enecalc.wj2

The following calculation sheets have been developed for the Japanese version, besides the calculation sheets explained above.

Combustion calculation of solid fuel

Heat calculation A, B — Heat transfer formulas, heat exchange, and heat transfer coefficient examples

Various gas specific heat, evaporation out of hot water surface, air invasion from furnace openings, and ambient diffusion formulas

Pressure loss of gas and liquid tree structure pipes

Pressure loss of gas and liquid loop structure pipes

Economical study of the co-generation system

Among the English version calculation sheets we have offered this time, the successive heat balance of boiler, heat balance of reheating furnace, Shiftavg, and EMISSION functions and/or files are not included in the Japanese version.

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