INTERNATIONAL ENERGY AGENCY
energy conservation in buildings and community systems programme

ANNEX XIII - «ENERGY MANAGEMENT IN HOSPITALS»
A GUIDE FOR ENERGY MANAGEMENT IN HOSPITALS

BOOKLET II

HEAT GENERATION AND DISTRIBUTION
COLD GENERATION AND DISTRIBUTION

PFE
Via Nizza, 128
00198 Roma
Dicembre 1989

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TABLE OF CONTENTS

CONTENT OF THE SIX BOOKLETS

Booklet I

Introduction to the Booklets and the Management Perspective

Object of this Booklet is helping Institutions to identify the requirements, fund structures which support the initiatives, carry out certain procedures and ensure that the comfort of the facility is maintained, as well as the proper service, and energy with its associated cost is minimized.

Objectives of an Energy Management Program are reported, with indications for the development of such program.

Practical worked examples for Energy Conservation Opportunities are also included.

Content:

Booklet II

Heat Generation and Distribution
Cold Generation and Distribution

The main objectives of this Booklet are to provide a sound basis for the approach of thermal energy management, including both heat and cold generation; it is divided in three main parts: heat generation, heat distribution, cold generation and distribution.

The heating energy may be supplied by means of conventional boilers, heat pumps, or through a district heating system.

The cooling energy is usually provided by chillers equipped with compression or absorption cycles.

All systems are described, in order to understand their principles and mode of operation, pointing out how to act on them, in order to attain an energy efficient operation.

Energy Saving Opportunities are reported, mostly with minor changes on existing installations.

Content:

<u>Booklet III</u>

Heating, Ventilating, Air Conditioning
Domestic Hot Water

The Booklet focuses on the requirements of the various zones of a hospital, and how they can be met in an energy efficient way, by means of Heating, Ventilating, Air Conditioning systems (**HVAC**).

Detailed description of such systems is reported with indications of the Standards and special requirements specified for hospitals.

Examples of Energy Conservation Opportunities for the management and maintenance of systems are also included.

A chapter deals with Domestic Hot Water (**DHW**) production and distribution, referring to the hospital requirements, pointing out the problems related to an energy efficient operation of this systems.

Content:

Booklet IV

Electrical System

This booklet aims to give practical assistance to the technical hospital staff, with the intent to reduce electricity cost, describing possibilities for an efficient and cost-saving use of electrical energy in hospitals.

The electricity supply system from the public grid to the individual users or groups of users within the hospital is examined, specially relating to electricity consumption.

Examples of practical cases are also reported.

Lighting is treated in a separate chapter.

Content:

Booklet V

Services

In this Booklet are considered the auxiliary systems which are generally present in hospitals, such as: hospital medical equipment, laundry, kitchen, sterilization.

A description of all systems considered is reported, with indication of amount of energy required in each case.

For each system, Energy Conservation Opportunities are included, both in the purchasing phase and during operation, in order to reduce the energy cost.

Content:

Booklet VI

Building Envelope

This Booklet treats the problems related to the losses of energy occurring through the building envelope, which includes: walls, windows, roofs, floors, and fresh air intakes.

For hospital buildings, the following items have been considered: air infiltrations, walls, floors, roofs, windows.

Energy Conservation Opportunities are reported, with the aim to attain reductions in the energy required for the operation of HVAC systems in these buildings.

Content:

FOREWORD

Most of the energy flows in hospitals serve the heating and cooling systems. Generally, all this thermal energy (heat and cold) is transformed in the central heating and cooling plant.

The heating energy can be supplied to the thermal network by means of oil or gas fired boilers, gas, oil or electrical heatpumps or possibly cogeneration plants.

The cooling energy is usually supplied by chillers equipped with compression or absorption cycles.

This Booklet is meant to provide help in the management of the different heat and cold generation systems, and also partly the district heating and cooling systems inside hospitals.

It does not tackle the management of the end users. This subject is treated more in detail in Booklet III.

The main objectives of this Booklet is to provide a sound base for the approach of thermal energy management. All systems are described in order to be able to understand their functioning. Then one explains how to act on them, with the main objectives to achieve energy savings, mostly with minor changes of the existing installations only.

It is divided in three parts, namely: heat generation, heat distribution and cold generation.

CHAPTER 1. HEAT GENERATION

1. Introduction

The heat generation plant and the distribution network are the heart of the energy network in the hospital. More than 2/3 of the energy consumed in a hospital flows through them in those hospitals in northern climates.

It is therefore most important to improve the heat generation and distribution efficiencies because any gain in this building system results in large amounts of energy saved.

For example, if the boiler of a 400 beds hospital consumes 1 400 000 kg of oil per year, a gain of 5 % in the heat generation efficiency would save 96 000 kg of oil per year, without any change in the heating demand.

This chapter focuses mainly on the method to save energy without modification of the demand. This chapter deals with the subsystem heat generation and distribution. Subsystems consumers are treated in Booklet III.

Modification of the demand is treated more in detail in the chapter 2 (heat distribution) and in the Booklet III (end users).

For example, the insulation of an 100 millimeter diameter valve in a steam network may save as much as the energy consumed for heating several single rooms of the hospital.

1.1 Description

The thermal energy system is composed by three main categories of subsystems:

- Heat generation (boilers, heat pumps, and cogeneration)
- Heat distribution (district heating)
- Heat consumers (end users)

The heat generation plant converts the fossil energy into heat, and the distribution network supplies the different energy consumers as their requirements. An example of thermal energy network is shown below (Figure 1.1.A).

It shows well how complex the thermal energy network can be. At each district heating substation are connected different end users networks.

It is important to notice that the energy production must be adapted to the load pattern ; it must satisfy the energy needs, but it is not necessary to keep high temperature levels in the distribution network or boilers switched on when the load does not require it.

The time pattern of the heat generation plant is determined by the energy needs, in power and temperature.

The usual energy end users in a hospital are presented on Figure 1.1.B.

They may be supplied in energy in different ways. Therefore the kinds of networks may differ for each case. Some often seen configurations are presented in Figure 1.1.C.

There are many other possible configurations.

During the process of energy transfer from the heat generation plant to the end-users through the distribution network, some losses occur (see Fig. 1.1.D).

The structure of the heat generation plant is described in the Figure 1.1.E.

There are heat generators like boilers and heat pumps, which transform the fuel or electrical energy into heat energy, which is transferred to the district heating network. The energy is supplied following the control system commands to the heat generators.

For boilers, the production losses can be diminished by a heat recovery system on the stack gases, or on water blowdown, in the case of steam boilers.

The overall efficiency of the heat generation plant, which allows to qualify its performance, is defined as the ratio of the energy supplied to the distribution network divided by the fuel energy consumed.

The most important items in heat generation plants are the heat generators themselves.

<u>1.1.1 Heat generators</u>

The different kinds of heat generators are designed for different temperature levels. (see Fig. 1.1.F and Fig. 1.1.G).

Apart from direct electrical heating, where the plant efficiency is practically independent of the temperature

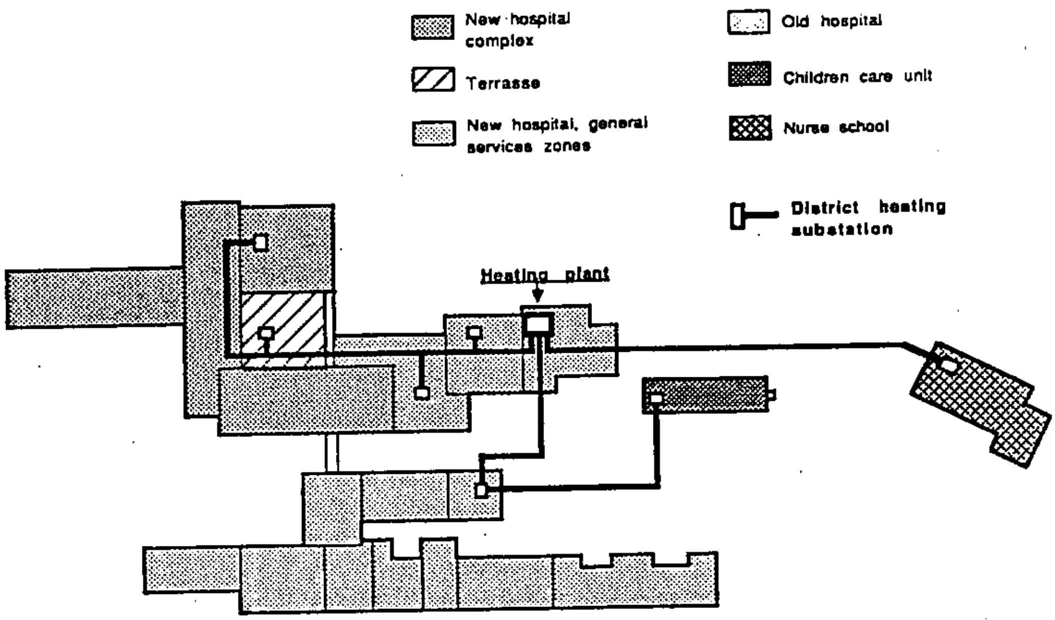


Figure 1.1.A - Thermal Energy network

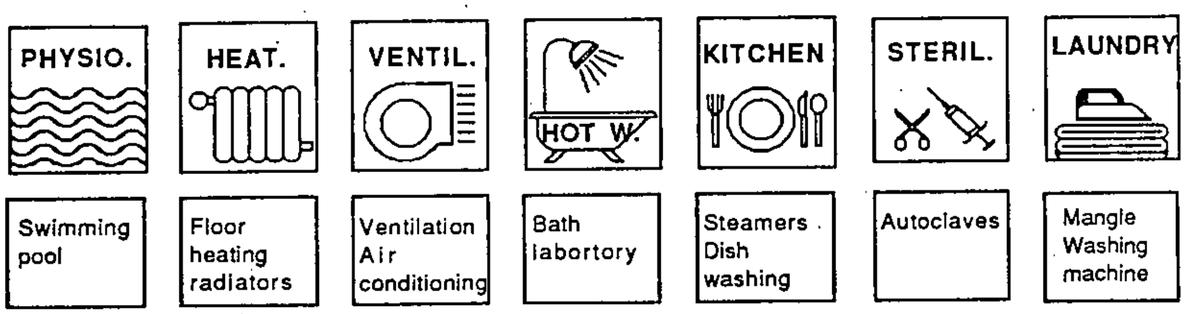
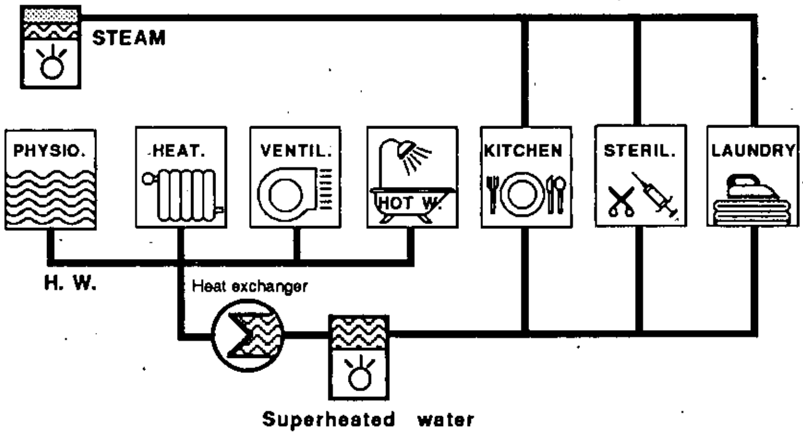
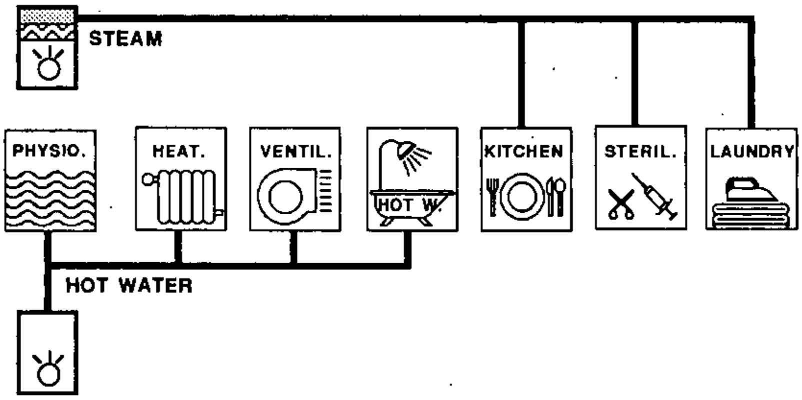


Figure 1.1.B - Usual Energy end users in a Hospital

1) A hot water and a separated steam network.



2) A separated water network, with a subnetwork of hot water, and a separated steam network, with the kitchen, laundry, sterilization, using superheated water and steam.



3) A main superheated water network, connected to hot water network and a steam network.

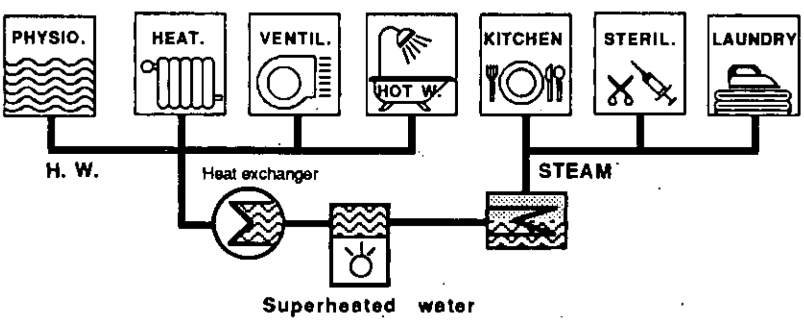


Figure 1.1.C - Configuration of network systems

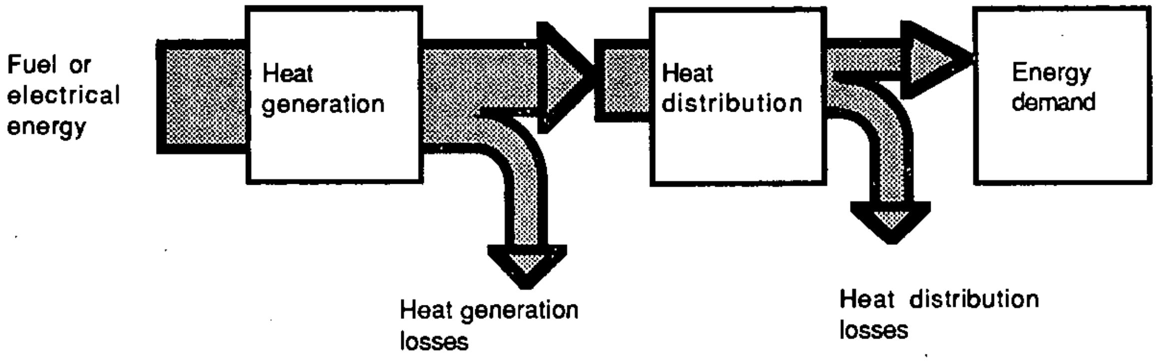


Figure 1.1.D - Heat losses

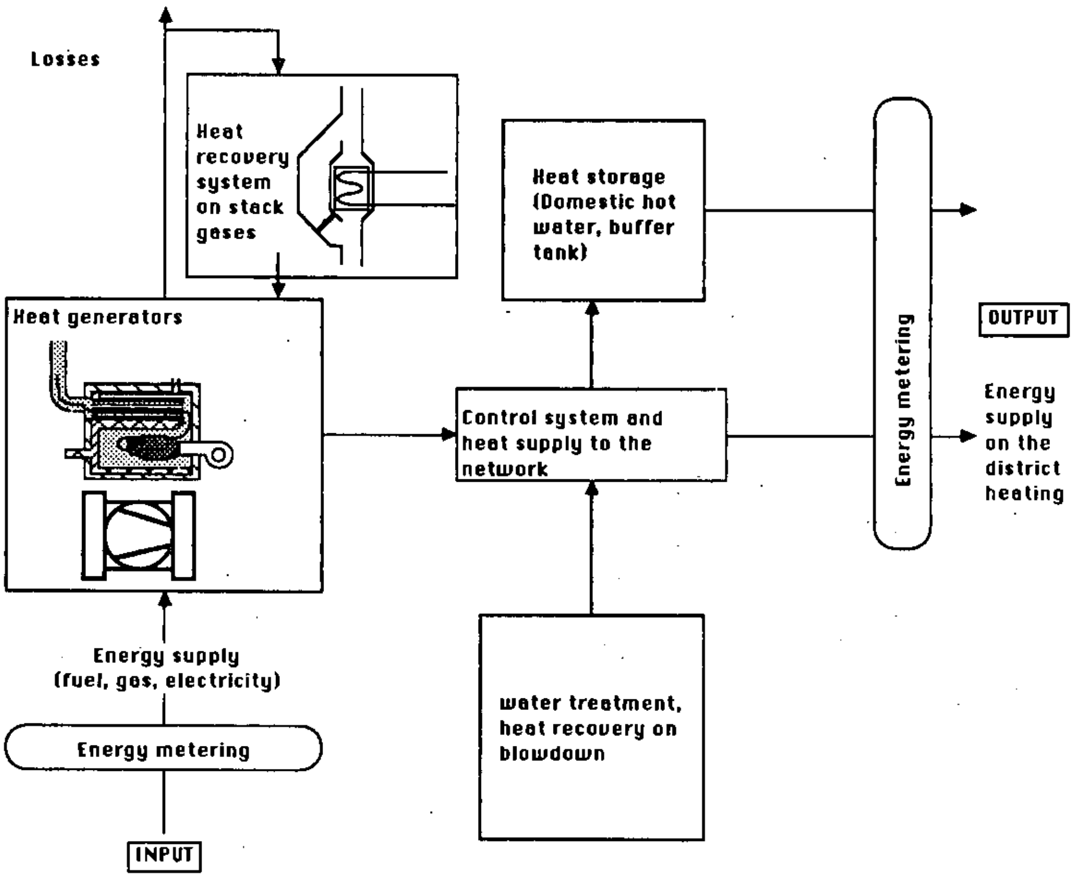


Figure 1.1.E - Structure of the heat generation plant

level, the temperature is an important factor for the energy production efficiency of all the heat generators.

Whenever as possible, one should not use high temperature heat generators to produce energy needs at a low temperature, like for example, steam boilers at high pressure producing heat for a low temperature space heating network.

The Figure 1.1.F shows an example of a middle temperature hot water system. The secondary loop (DHW, ventilation, radiators) needs water at 80 °C to be able to provide an indoor temperature of 22 °C at design conditions.

The Figure 1.1.G shows a steam system. There the mangle does need a temperature level of about 190 °C to operate. So, the steam pressure must be at 12 bar at least. During other periods, where the mangle does not operate, one could let pressure level come down to 150 °C.

One can see that the temperature levels required by each system are quite different.

Of course, quite often hospitals heat systems have not been separated in two different high and low temperature systems, for example, a superheated water network at 200 °C functioning around the clock, even if 200 °C is needed only few hours a day. By changes of the operational procedure energy can be saved.

Such a configuration is shown on the Figure 1.1.C., 3°. The addition of a heat recovery system on the exhaust of a boiler, lowering the exhaust temperature allows to increase significantly the boiler efficiency.

1.1.2 Cogeneration systems

Cogeneration, or CHP (Combined Heat and Power) production, may be described as a method by which electricity and heat are simultaneously produced in more efficient manner than if each were produced separately.

In a CHP plant, in fact, the heat released in power production is recovered and sent to the users, via a suitable carrier medium.

Hospitals are users with simultaneous and outstanding electricity and heat requirements; moreover, because obvious safety requirements and standard regulations, hospitals must be equipped with autonomous electric energy source, in order that no interruptions may occur in the essential power supplies, even in case of external grid black-out.

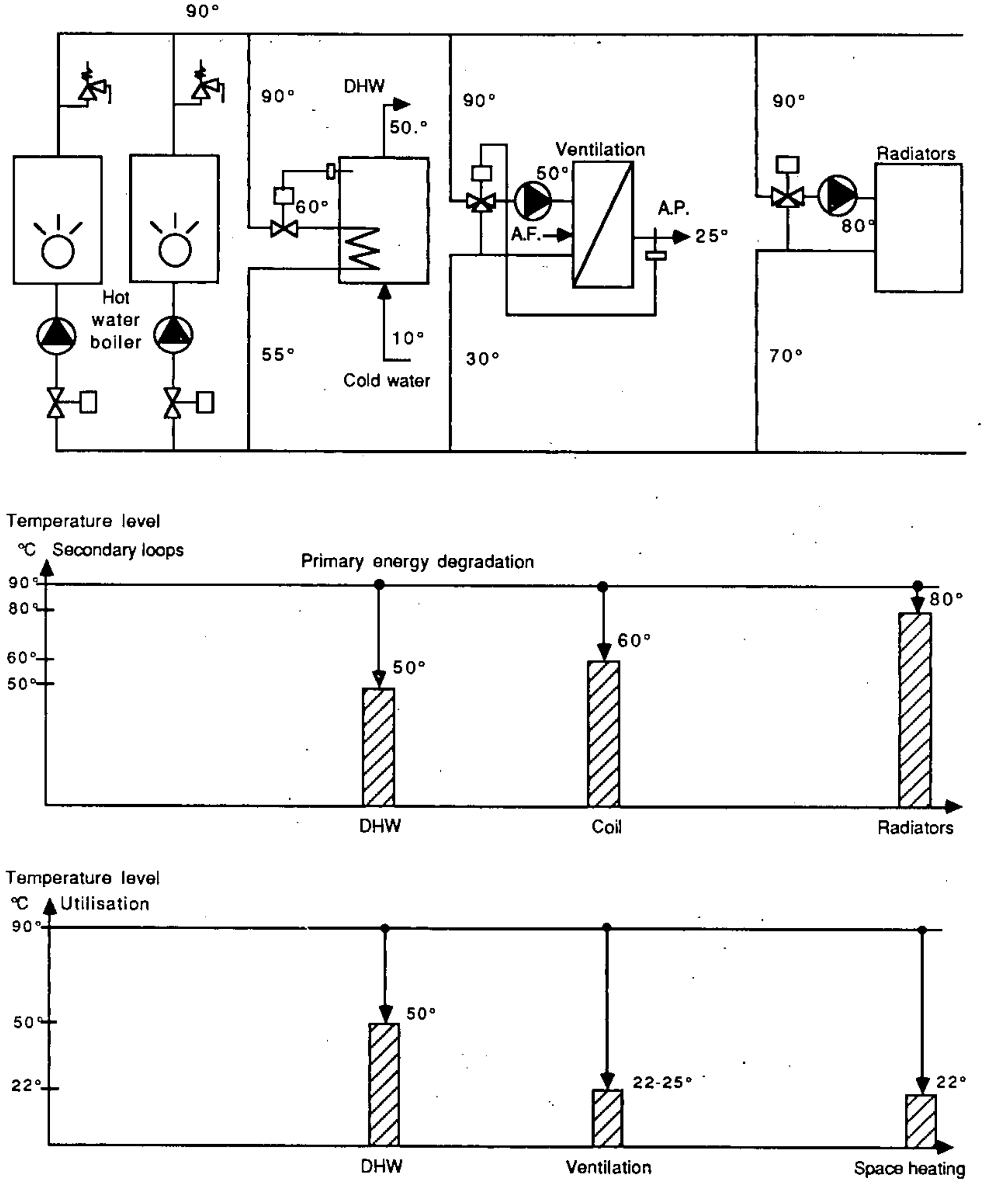


Figure 1.1.F - Heat production and distribution at middle temperature with hot water boiler

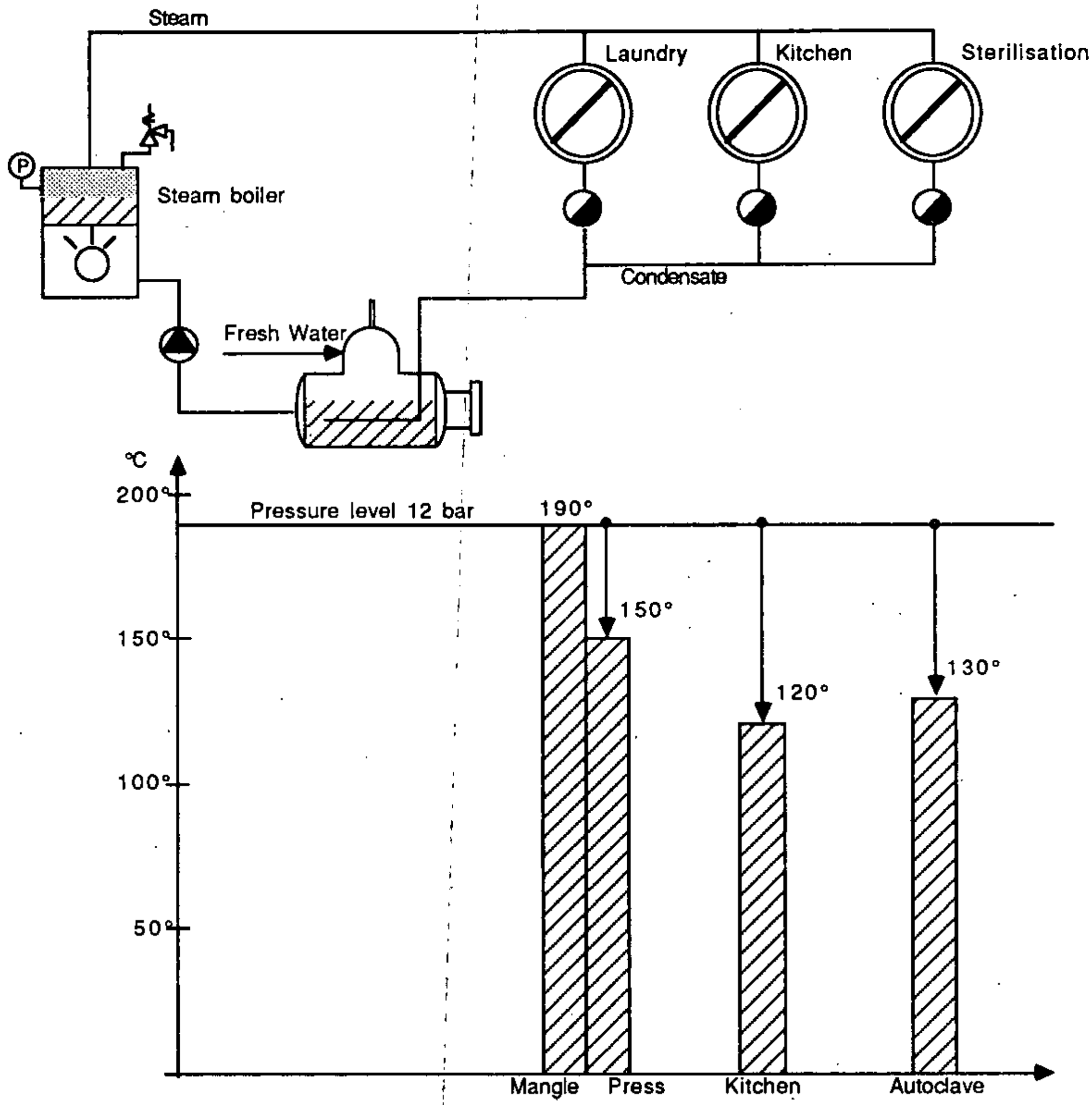


Figure 1.1.G - Steam production and distribution with steam boiler

From above considerations it follows, therefore, that a hospital is the typical case, where it could be convenient to make use of continuous autonomous power generation plants, with simultaneous recovery of discharged heat.

The study of cogeneration plants for hospitals is beyond the scope of this manual. Therefore, it will not be treated further. But one should keep in mind that hospitals are among the best suited users for such equipment. Therefore, when considering the replacement of old or inefficient heat generators, one should order a feasibility study for such possibility before taking any decision.

1.1.3 Control systems

These components are as important as the heat generators. The reason is that the control system must follow the actual energy demand in a hospital.

For example, the space heating and ventilation demands are primarily dependant on the outdoor temperature. The control system computes a proportional energy output based on the outdoor temperature. This computed energy output must be of the same magnitude as the actual energy demand. If it is higher, the energy supplied by the heat production system will be too high and will result in a higher temperature than required. In this Booklet, it is mainly the control of the heat generators system which is treated.

There are dedicated controls for the heat generators, which may or may not have a direct relationship to other portions of the control system. It insures a sufficient temperature or pressure level of the heating fluid to be distributed to the district heating network. Much energy can be saved with proper control because the standby losses can be reduced with the help of the right control strategy in varying the pressure or temperature time patterns.

For example, in Figure 1.1.F, a good control strategy would be that the boiler follows the temperature level required by the ventilation coils and the radiators. This would allow a reduction of the boiler losses, as it would be at a lower average temperature.

1.2 Strategy

1.2.1 Strategy at plant level

The goal of this section is to provide guidelines to reduce the energy consumption (fuels and electricity) of the heat generation plant.

The *energy consumed* by the heat generation plant is equal to the sum of heat furnished and of the heat generation losses.

To reduce the fuel energy consumption, one has to reduce the losses occurring during the heat production and/or to reduce the heat demand.

Emphasis is put on the reduction of the heat generation losses (Fig. 1.2.A), guidelines to reduce the heat demand by the heat are treated more in detail in the part heat distribution, and in Booklet III.

1.2.2 Efficiency, measurement, target values.

In the heat generation plant, before taking action, one has to determine its overall efficiency in order to be able to gratify its performance and compare it with target values.

1.2.2.1 Efficiencies

The overall efficiency of the heat generation plant is defined as the ratio of the heat furnished to the distribution network divided by the fuel + electrical energy consumed.

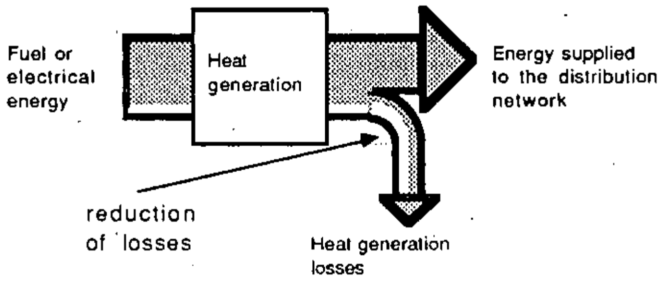
$$\eta_{pl} = \frac{Q_{pl}}{Q_f}$$

In a heat generation plant, the overall efficiency is dependant on few parameters like:

- Boilers efficiency, boiler group control system
- Efficiency of a possible heat recovery system
- Blow down losses (especially in steam systems).
- Losses of the primary network in the plant.

1.2.2.1.1 Boilers efficiency

The conversion of the fuel energy into useful heat is accomplished with some losses. For example out the 11.7 kWh of chemical energy contained in a kg of light oil, only part



Fugure 1.2.A - Heat generation losses

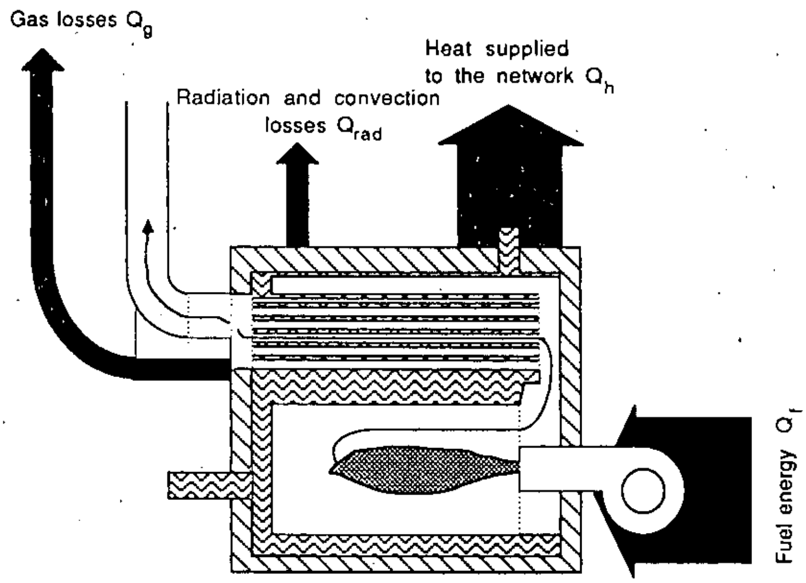


Figure 1.2.B - Energy flux in a boiler

of it will be actually transformed into useful heat (between 8 and 10.8 kWh), the rest of it being losses (Fig. 1.2.B).

The ratio of the useful heat delivered by the boiler to the chemical energy contained in the fuel is the overall boiler efficiency.

The yearly efficiency of the boiler is equal to the ratio of the useful energy delivered to the distribution network to the chemical energy consumed (fuel consumption):

$$\eta_{pyr} = \frac{Q_n}{Q_f}$$

This value is difficult to monitor directly because of the need of special instruments like energy meters if one wants to measure accurately the energy supplied. But one can calculate the efficiency with some indirect methods.

The value of the annual efficiency of a boiler is mainly dependant on four parameters:

- Excess air (CO_2 content): too much combustion air leads to higher stack gas losses.

- High stack temperatures, mean an increment of the stack gas losses. This temperature is dependant upon the fluid temperature and the area of the heat exchanger of the boiler and the air and fuel flow rate.

- Load factor: the higher the load factor, the higher the annual efficiency. This factor is dependant upon the power of the boiler, and on the power demand. The design approach is to match output with heating demand, avoiding oversized units.

  It can be changed through operational changes, or such techniques as derating of the boiler.

- Standby losses: can become dominant when the boiler is oversized. There, losses are also characteristic of the boiler type and cannot be changed without a modification of the boiler or of water or steam temperature level.

Calculation of the boiler efficiency

To determine boiler efficiency one has to measure first stack gas losses and radiation losses.

The combustion efficiency is equal to the ratio of the fuel energy consumed, minus the gas losses divided by the fuel energy consumed.

$$\eta_c = \frac{Q_f - Q_{st}}{Q_f} = 1 - q_{st}$$

where q_{st} is the ratio $\frac{Q_{st}}{Q_f}$

The steady state boiler efficiency is equal to:

$$\eta_b = \frac{Q_f - Q_{st} - Q_{rad}}{Q_f} = 1 - q_{st} - q_{rad}$$

where q_{rad} is the ratio $\frac{Q_{rad}}{Q_f}$

Efficiency of a boiler over a period of time is as follows:

a) One-stage boiler

For this kind of boiler the efficiency is equal to:

$$\eta = \eta_b \cdot \frac{1 - q_m/w}{1 - q_m}$$

where:

q_m = standby losses
w = load factor of the boiler

q_m and w have been measured

b) Two stage boiler

The efficiency of a two stage boiler is given by the following formula:

$$\eta = \frac{\dfrac{w_1 + w_2 - q_m}{1 - q_m} + w_2 \cdot (\eta_2/\eta_1 \cdot q - 1)}{w_1 + w_2 \cdot q}$$

where:

q = ratio of the oil consumption of the second stage to the first stage
η_1 = steady state boiler efficiency of first stage
η_2 = steady state boiler efficiency of second stage
w_1 = load factor on first stage
w_2 = load factor on second stage

c) Modulating boiler

There is no simple way to determine the boiler efficiency over a given period.

1.2.2.1.2 Heat recovery system

In case there is a heat recovery system, one has to check wether its operation is optimal. The efficiency of the plant depends on it.

1.2.2.1.3 Blowdown system

In steam generation plant, blowdown is an energy consumptive process. It is important to check wether the blowdown flowrate is not too high, and then if it is not possible to save energy by a recovery system, allowing to preheat the feed water, or the DHW system (see also Booklet III, Chapter 4).

1.2.2.2 Measurement and target values

In order to be able to analyze the plant quality one must proceed to some measurements.

There are different levels of measurements:

- Short duration measurements like stack gases temperature, unburnt gas content, liters of feed water consumed per fuel unit delivered.
  These measurements will allow to find out the boilers efficiency in steady state, and the quality of the steam feed water system.

- Longer duration measurements like load factor measurement, energy metering.
  These method will allow to understand more in detail and to estimate the overall heat generation plant efficiency over a given period of time.

Consequently, one has to differentiate two levels of target values:

Short measurement	Long measurement
Results	**Results**
steady state boiler efficiency	overall plant efficiency
radiation losses or standby losses of the primary system	

1.2.3 Analysis, levels of actions to be taken

To be able to assess the heat production efficiency and compare it with target values, one must begin by maintenance and tune-up of the heating plant and then compare the steady-state values of the efficiency of the heat generators with the target values in § 1.3.1.2.

This comparison gives a first indication of the extent of the losses due to the heat generation plant.

Once the efficiency has been determined, the next step is to take some measurements of the operating conditions, which will also provide a basis for a change in the operating conditions.

1.2.3.1 Maintenance and tune-up

It consists in simple actions such as checking and setting the CO_2 content in the stack gases of a boiler, setting of the stack gas temperature by adjusting the fuel flow rate, soot cleaning, checking proper functions of the control system, of the valves, etc.

By these kinds of actions, energy savings can be achieved without any long analysis, or any investment. It is the first priority of action before any other.

There is no use to take measurements if the various components of the heating plant are not in good operating condition. For example, it is useless to measure the load factor of a group of boilers, if they are all not in good operating condition.

Indeed an analysis based on the results from measuring a deficient system might be misleading.

If, in the above cited group of boilers, some valves are leaking, when the heat demand is low, a measurement would lead one to believe that all the boilers are always in operation even though they are not.

This approach is explained in detail in § 1.3.2.2. Action can be taken without any delay.

The next audit action is to see whether any operational change can help save energy.

1.2.3.2 Operational change

Once the checking, maintenance and tune-up are performed, the next step is to analyze whether the heat production is matching the demand. In other words, the approach consists of measurement of the heat demand, the temperature and the pressure required: then checking if the setpoints are correctly adjusted, and if the number of boilers in operation is not too high when compared with the power demand.

Before deciding any operational change, a careful analysis must be done. At this level detailed measurements of the load factor and of the heat generators analysis of the different operating conditions, will provide the information as to what operational changes, if any, can be realized.

1.2.4 Examples

1.2.4.1 Operational changes of superheated water boilers without modification of the heat demand

In 350 bed hospitals, with 4 superheated water 2 two-stage boilers, the heat demand has been recorded on an hourly basis.

The results are shown on the Figure 1.2.C.

On this Figure, one can see that peak heating power demand never exceeds 1 850 kW.

The total power of the four boilers is 5 400 kW.

That means that only two boilers should be in operation.

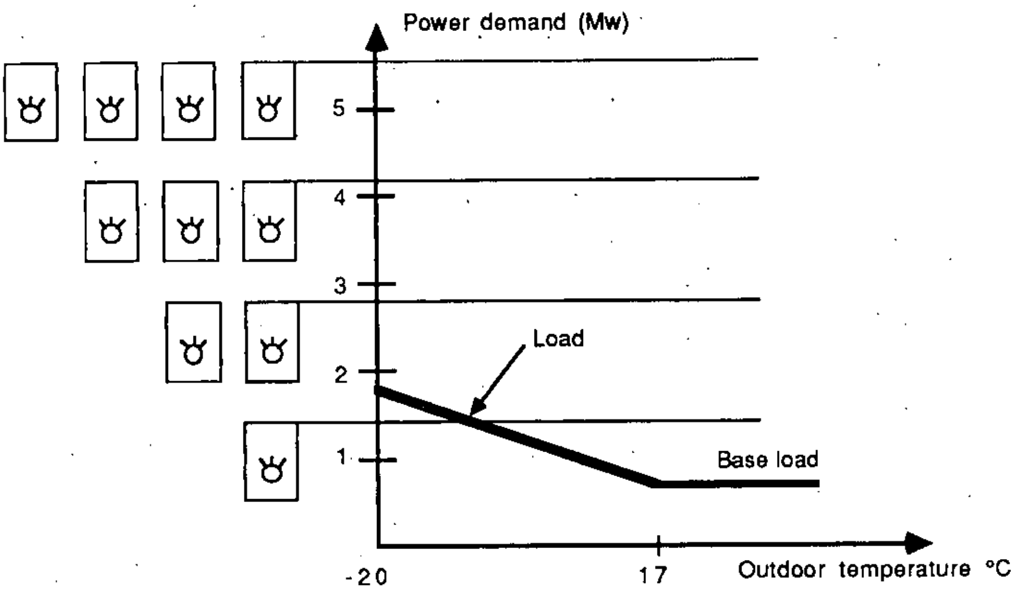


Figure 1.2.C - Seasonal adaptation to the load

How much energy savings can be achieved through such an operational change?

Depending on the boilers characteristics, a gain of 2 to 5 % can be achieved by this change.

In this case, the fuel gain represents 75 000 l per year.

The higher the standby losses, the higher the gain.

1.2.4.2 Energy saving in a steam generation plant

In a usual case, there are three kinds of steam consumers:
laundry, food preparation, sterilization. It is usual that the steam boiler is kept at the maximum pressure needed by only one of the consumers, i.e. laundry which usually requires 200 °C (see also Booklet V).

One can see immediately on Fig. 1.2.D that it is useless to keep the steam network at 12 bar when the laundry is not active, because the energy losses in piping, valves, boiler, and storage tanks are increased with temperature.

Example of a weekly steam consumption profile

In the case of this hospital, by measurement of the boiler load factor and by determine the steam pressure demand pattern, it could be shown that one could change the pressure set point during the period when the laundry was not in operation. This allowed one to keep the boiler pressure at a lower level most of time. In this way, the network losses were reduced, as well as the boiler losses (see Fig. 1.2.E).

The energy saving through such an operational change range between, 2 and 10 %.

That is possible without affecting the steam consumer habits.

All details about the method used to achieve these energy savings are explained in § 1.3 and § 1.4 of this chapter and partly in other chapters.

1.3 How to save energy with minor changes

1.3.1 Maintenance (Tune-up)

Very often, some components of the heat generation plant are not functioning properly.

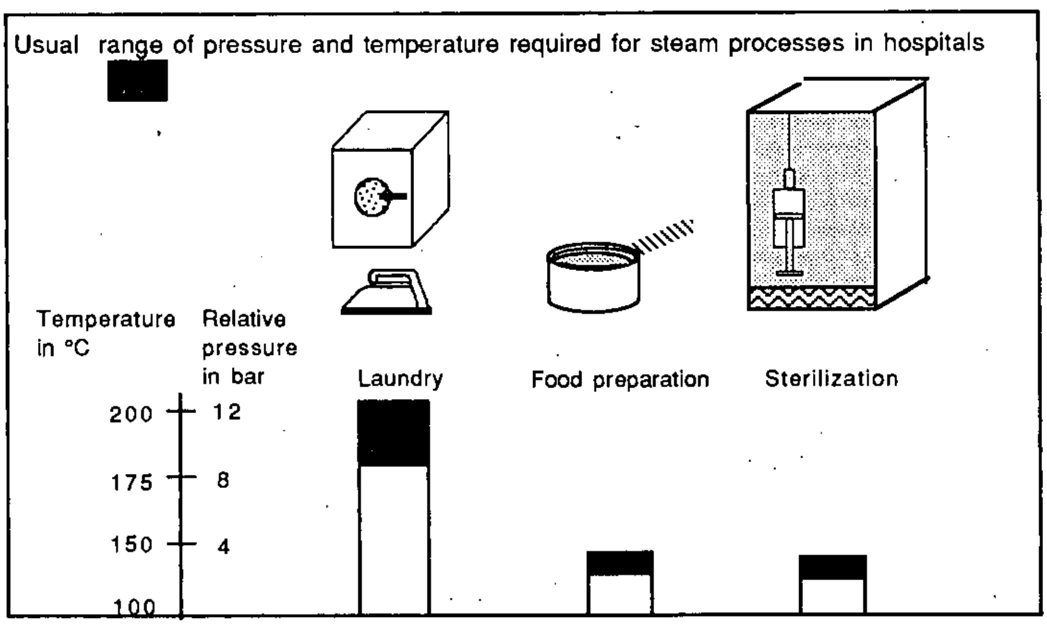


Figure 1.2.D - Usual range of pressure and temperature required for steam processes in the Hospitals

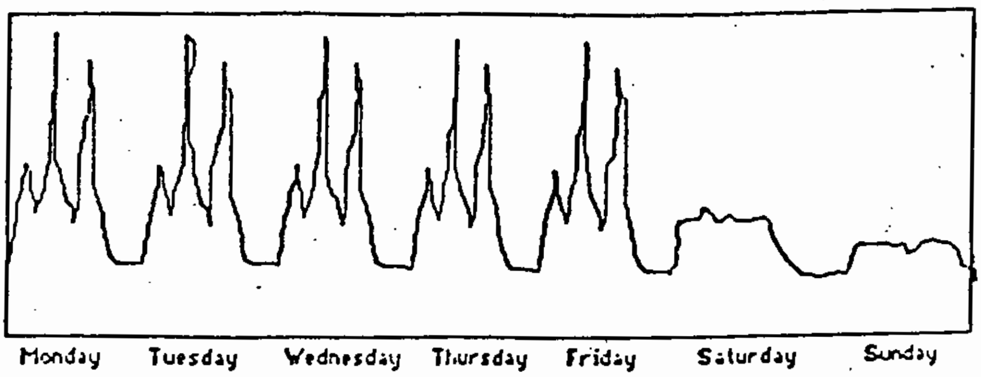


Figure : 1.2.E - Example of a weekly steam consumption profile

The reasons generally can be traced to:

- lack of maintenance
- poor tuning
- some other reasons like bad design, etc.

The following information is to provide help in the maintenance of the different components of the heat generation plant.

It is essential to follow the complete procedure, in order to avoid forgetting any important step.

After the completion of this part (§ 1.3.1) it is advisable to go on with § 1.3.2 and § 1.4.

1.3.1.1 Control system

1.3.1.1.1 What to do and how to do it

This part of the maintenance procedure is essential. It should be done carefully. If the control system does not function properly, you cannot get good efficiency from the heating plant. You must check carefully all the different operating conditions of the system, such as the first and second stage switches that control the boiler, and if the set temperatures and or pressures match the actual values observed, etc.

You must understand the different operational states that the control system should achieve. That knowledge will help you to analyze the results of the measurements (see part operational changes).

1. Switch points checking:
   Check the proper functions of the boiler control.

a) One-stage burner:

   Check the on and off switching temperature control for proper functioning.
   This must be done by an observation of the on-off cycles of the burner.

b) Multistage burner:

   Check if the different stages of the burner operation really take place as expected, and to make certain if is not simply locked on one stage.
   Try to make it work by changes in the set temperatures.

c) Modulating power:

Check the control of the modulating system. If you increase the set temperature, it should increase the fuel and air flow rate. If you decrease the set temperature, it must not switch off unless the power requirement goes down to the minimum adjustable power.

2. Set temperature:

Check if the set temperatures are not adjusted too high as compares to the set values of the distribution network.

1.3.1.2 Boilers

1.3.1.2.1 What to do and how to do it

This part applies to all kinds of boilers, and provides guidelines for:

- checking proper functions
- efficient tuning of the boilers, with a method to achieve a maximum efficiency without operational change or modification.

Even if the tuning of the boiler is often done under contract by servicing groups, this information provides arguments to convince the contractor to achieve higher efficiency.

Any improvement of performance at this stage is free of cost and may allow one to save several percent of the annual energy consumption.

The first step is to start with a general function checking;
the second step is to check the soot level;
the third step is to proceed to tune-up.

A) Proper function checking

Listed below is a checklist for oil and gas boiler maintenance.

It is recommended to install "on time" meters on each boiler for each stage (if there are more than one). In the case of variable flow rate, one has to install a fuel meter (see § 1.3.2.2.2).

Oil system

Jobs to be done on the oil burner:

- check burner motor and ventilator
  See if the motor is rotating properly and if the ventilator is clean. In case of dirt buildup on the ventilator the air flow rate would be too low, leading to a rich combustion mixture.
- check air setting adjustment of multistage or modulating burner
  Look to see if the command system for the air setting changes its position when the power demand changes. The air damper should give a larger aperture when the second stage is switched on, or when the modulating power increases.
- check burner nozzle position setting on multistage or modulating burner
  The nozzle and/or burner component must change its position while switching on another stage. Check whether this is still in an operating condition, otherwise, the combustion efficiency can not be at its optimum value.
- check ignition and ignition control
- check fuel pressure
  Pressure control valve and oil pump are important components. Check if the pressure is as per specification, and if it remains constant while switching from one stage to another.
- check and clean pump filter if needed

Jobs to be done on the boiler:

- check switching points, function of temperature controls and safety temperature limiters
- check function of pressure control valves
- check function of low water alarm
- check refractory lining (if any) for cracks and damage
- clean boiler inside and outside. (see effect of soot cleaning)

Electrical function test:

- check contacts and relays
- check function of warning lights
- check emergency stop for function.

Gas system

Jobs on the gas burner:

- check burner motor
- check ignition and ignition control
- check burner pipe and flame pattern.

Jobs to be done on the boilers:

- check switch points and function of temperature controls, and safety temperature limiters
- check pressure relief valves
- check function of low water alarm
- clean boiler inside and outside

Jobs to be done on the fittings:

- check burner and main valve
- check any other gas valves and pressure governors; adjust, if necessary.
- check the pressure before and after the pressure regulator, and see whether it remains constant when the gas flow rate increases.
- check pressure gauge and stopcock
- check fittings for leakage

Electrical function test:

- check contacts and relays
- check pick up time of the thermal trigger
- check warning lights lamps for function
- check emergency stop for function

B) Effect of soot cleaning on efficiency of oil-fired boilers

The cleaning of an oil-fired boiler is very important, because a clean boiler has a better efficiency. The cleaner the boiler, the lower the stack gas temperature (see Fig. 1.3.A). It should be done as often as possible.

Open the boiler when it is off and cold. Check the inner surface for soot thickness.

If the soot thickness is beyond 1 mm, then it is profitable to get it cleaned.

After cleaning the oil-fired boiler a decrease of 20 to 50 °C in the flue gas temperature occurs, leading to an

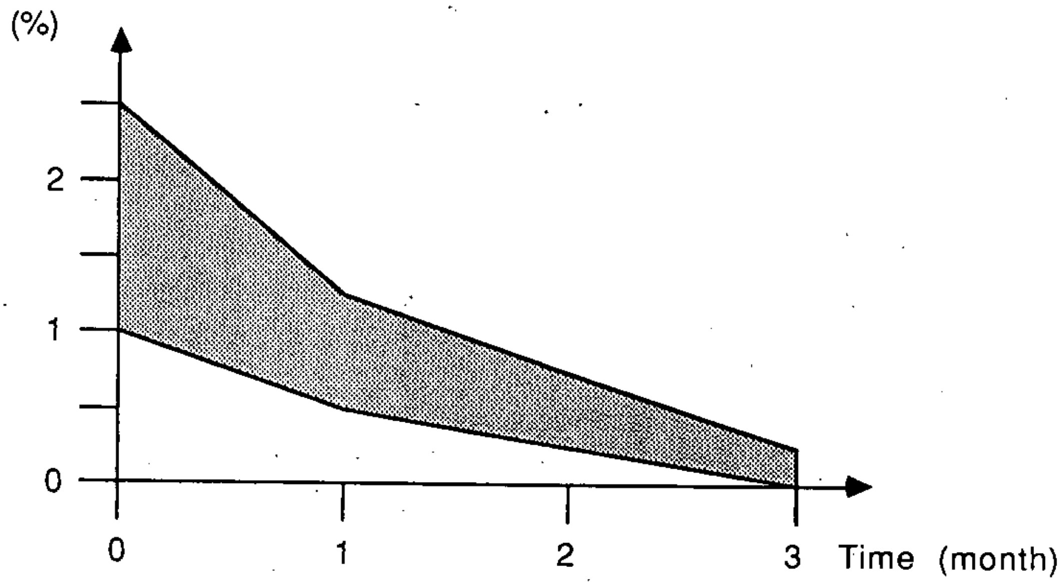


Figure 1.3.A - Gain in efficiency after boiler cleaning

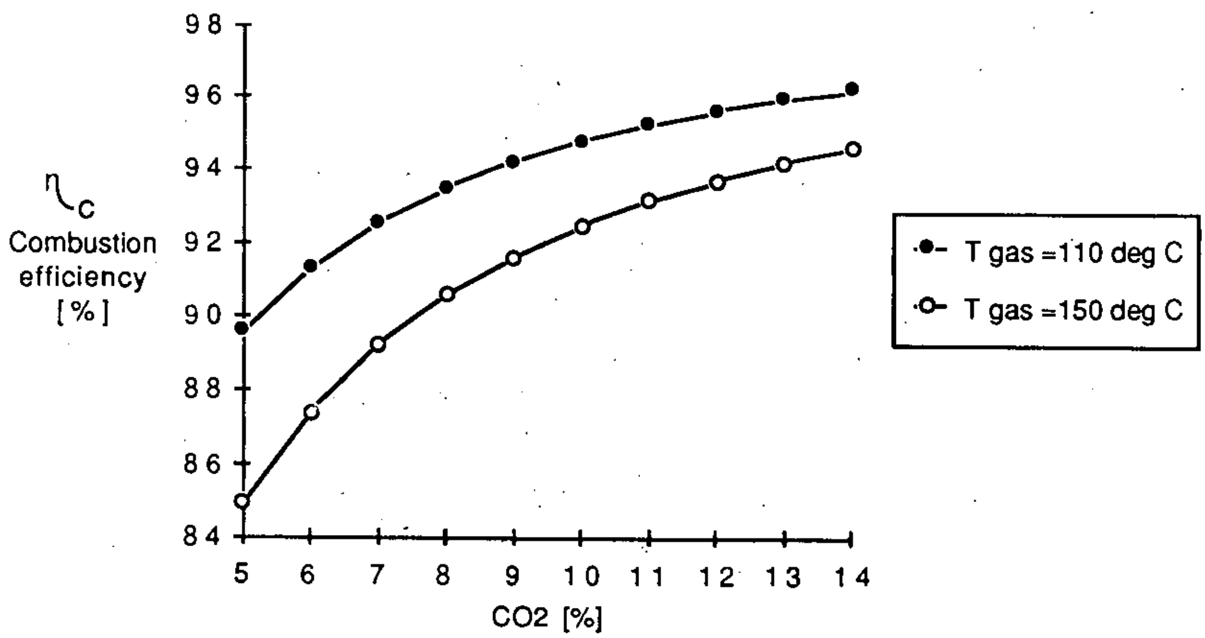


Figure 1.3.B - Combustion efficiency as a function of the CO_2 content

increase of 0.8 to 2.5 % in the boiler efficiency. Unfortunately the effect of boiler cleaning decreases with time, and after three months the gain in efficiency has been again lost. The more often the boiler is cleaned, the better will be the efficiency. For large oil-fired boilers, a cleaning every month is economically profitable.

C) Boiler Tune Up

Once you have gone through the maintenance and proper functions checklist, it is necessary to tune up the boilers in order to increase the combustion efficiency. It can be achieved by:

a) decrease the flue gas temperature (+ 1% for a 20°C decrease)

b) decrease the air excess (increase the CO_2 content of the flue gas without reaching the generation of unburnt gases)

For example, if the temperature of the flue gas is 200°C and the CO_2 content is 9 %, then etach = 88 %, by an increase from 8 to 13 % CO_2 one reaches almost 92 %, which is a 4% increase in efficiency of the boiler.
Any improvement at this level is free of cost except for the tune up labor.

As one can see in the Figure 1.3.B, the more the CO_2 content and the lower the stack temperature the higher will be the combustion efficiency. But the possible stack gas temperature are dependant of the characteristics of the system.

However, the stack gas temperature reached are dependant on:

a) the water or steam temperature in the boiler, determined by the temperature level required

b) the heat exchange coefficient between the combustion gas and the water or steam determined by the characteristic of the boiler

c) the air flow rate determined by the power level to produce

d) the fuel flow rate

Here one has to differentiate between one stage, multistage and variable flow rate burners.

Usually the difference between stack gas temperature and the water or steam temperature is 40 to 120 °C. If the difference is larger than 120 °C, then something must be done to decrease this difference.

There are mainly four kinds of heat generation systems using boilers.

For each configuration, the tune up method is different. The specifications for tune up are outlined in Fig. 1.3.C.

The reasons why the stack gas temperature are too high and when it is possible to decrease this temperature are outlined below.

There are basically four reasons why the combustion efficiency is reduced:

1. soot

   Soot cleaning is needed

2. scaling

   This problem may occur especially in steam boilers. Scaling affects the heat transfer through the boiler walls. This causes higher stack gas temperature and might lead to damage of the tubes or walls because of the high wall temperature.

   Unfortunately, scaling is almost impossible to detect before boiler disassembly, water impurities is an early warning sign.

3. air, fuel flow rate too high

   Air and fuel flow rates are too high (once points soot and scaling have been checked). In this case, one has to check whether the boiler has a high load factor.

   This can be done in winter during the early morning time when the demand is maximum or more extensively like explained in § 1.3.2.3.

   In the case of a group of boilers, with a switch on in sequence, one can reduce the fuel and air flow rate as low as possible so as to produce the temperature.

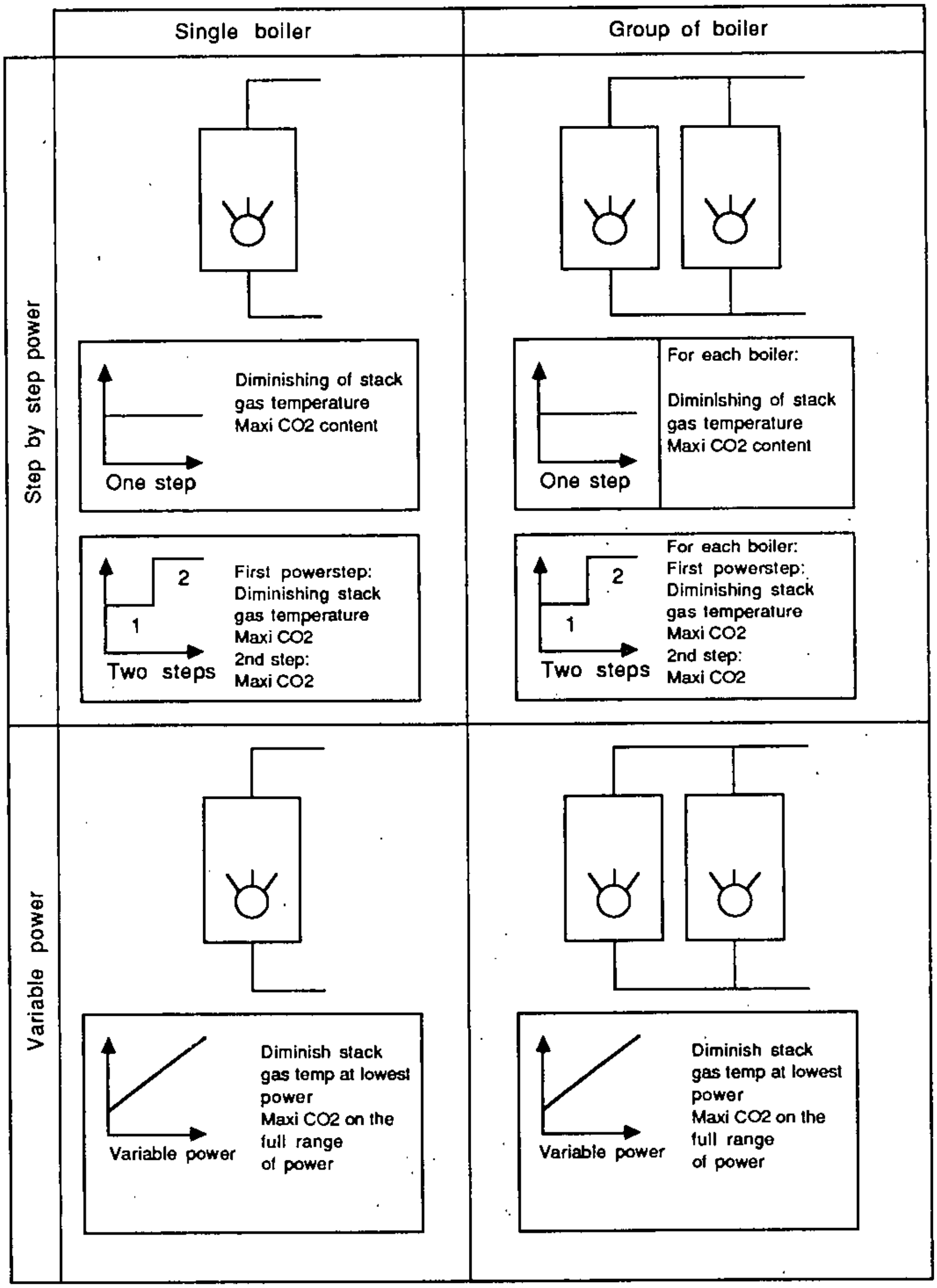


Figure 1.3.C - Heat production configuration

If the load factor is no more then 50% during this period, one can diminish the fuel flow rate and the air flow rate.

This will decrease the stack gas temperature and increase the load factor of the boiler leading to an increase of the boiler efficiency.

4. boiler characteristics do not allow a high efficiency

   If it is not possible to decrease fuel flow rate and still keep a low CO content, it is because the design it self does not allow a better efficiency.

   You have to keep in mind that it is not possible to reduce drastically the stack gas temperature. The characteristics of a boiler determines the heat exchange rate and accordingly, directly influence the stack gas temperature.

   The geometrical characteristics of a boiler restrains the minimum fuel flow rate below which combustion will be incomplete and the nozzle size restricts the minimum fuel flow rate where proper breakup of the fuel and mixing with the air can take place.

   If after a trial following the tune-up procedure, you can not reach the range of combustion efficiency in the diagrams (see Fig. 1.3.E and 1.3.F), then try to find out whether it is really due to the boiler characteristics.

   Technical data about the particular boiler will help to make rating evaluations.

   For example, if the stack gas in the technical data is beyond 200 °C for the fuel flow rate you have, you will not be able to derate the burner in order to get lower stack gas temperature. If you try to derate further, it is quite likely that there would be some unburnt gas produced.

   In order to reduce the stack gas temperature, two kinds of modifications are possible:

   a) to add baffles in the boilers itself, ask the manufacturer whether this can be achieved

   b) to add a heat recovery system (see modification section)

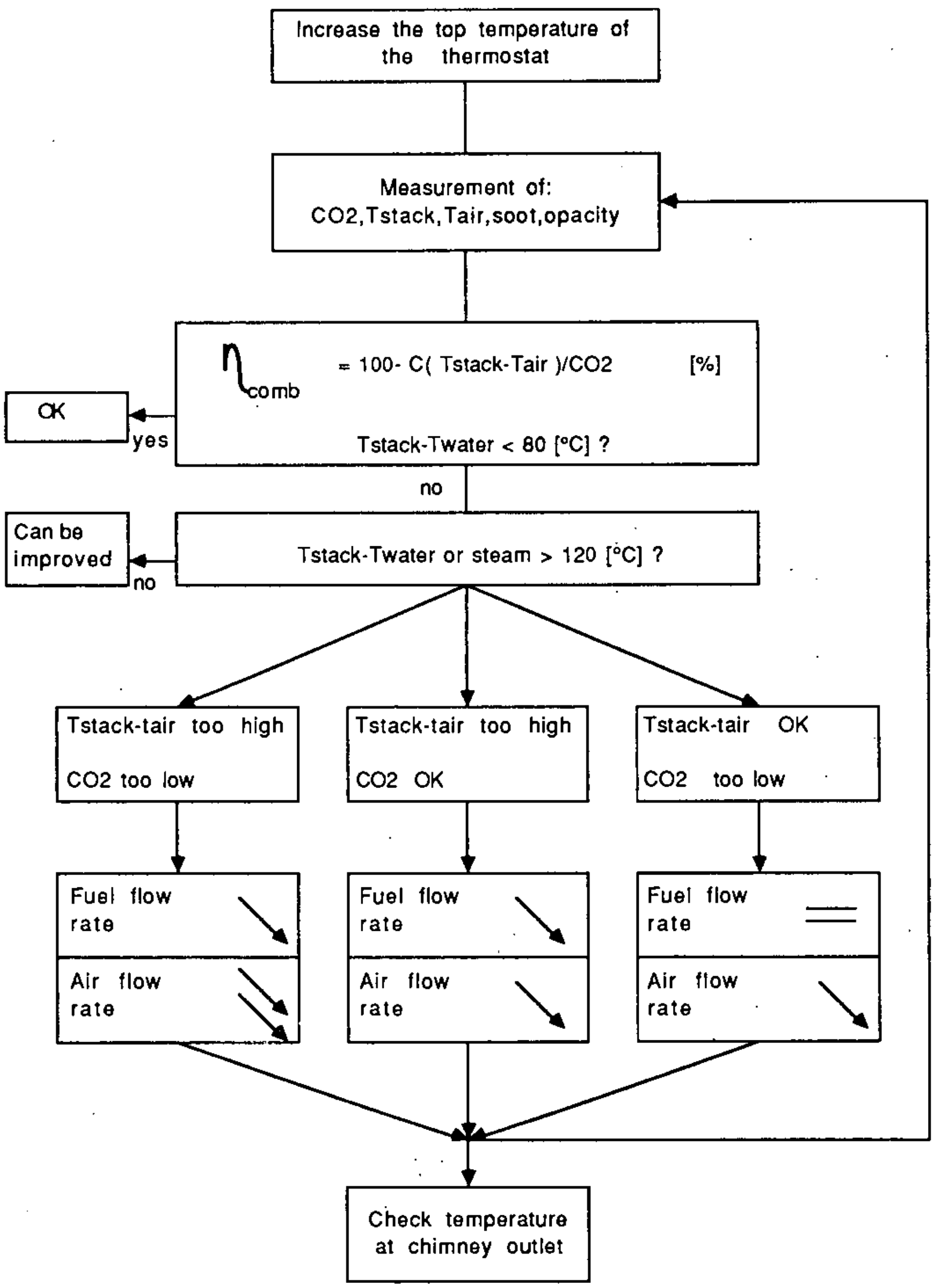


Figure 1.3.D - Tune-up procedure

Combustion efficiency of an oil boiler producing water at 80 ° C

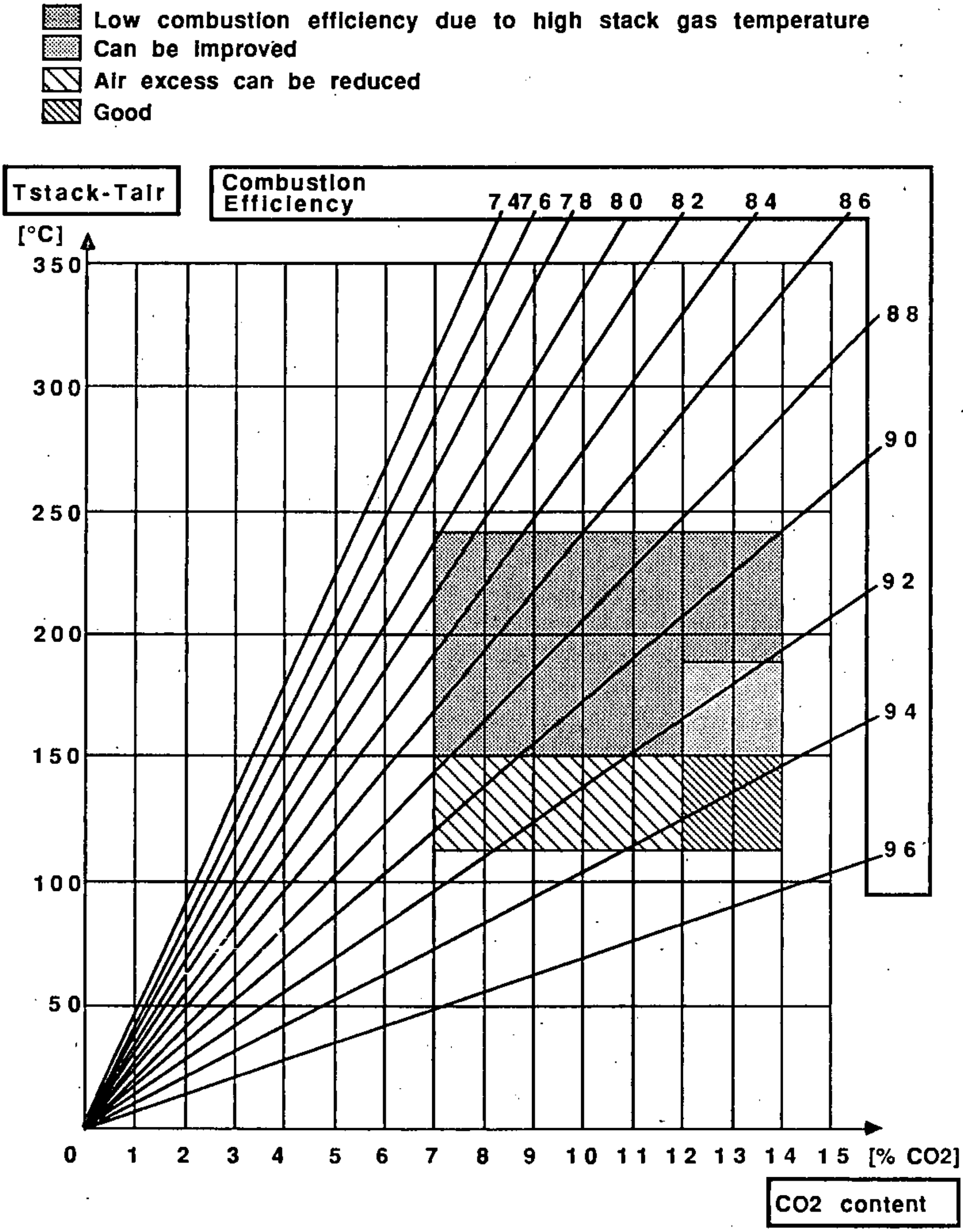


Figure 1.3.E - Combustion efficiency of an oil boiler producing hot water at 80 °C

Combustion efficiency of an oil boiler producing steam at 200 ° C

- Low combustion efficiency due to high stack gas temperature
- Can be improved
- Air excess can be reduced
- Good

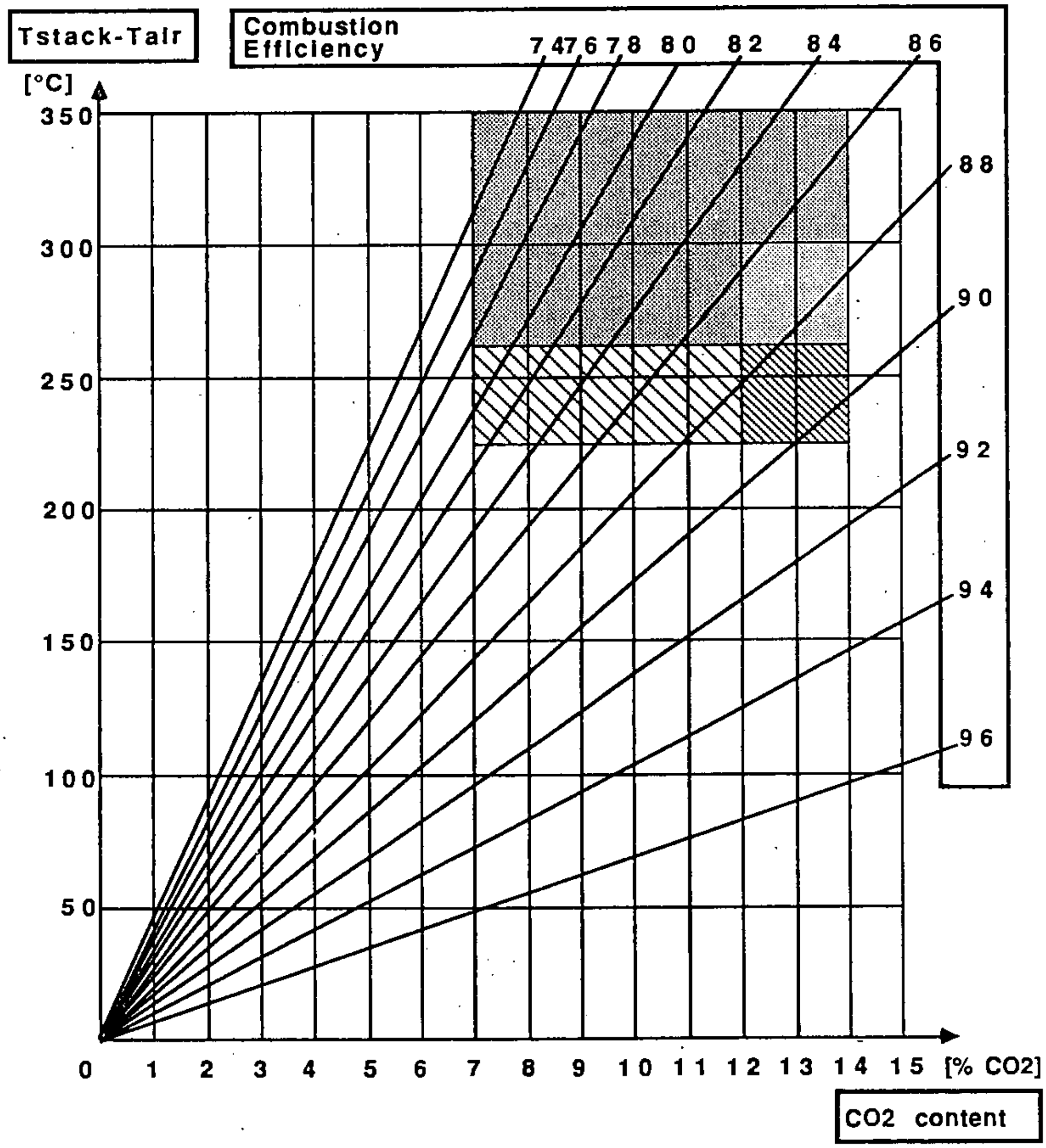


Figure 1.3.F - Combustion efficiency of an oil boiler producing steam at 200 °C

The Figure 1.3.D provided to guide the tune up procedure. Figures 1.3.E and 1.3.F give the combustion efficiency ranges for two categories of heat generators.

The first thing to do for the measurement of the stack gas temperature is to increase the difference between the switch off and on temperature if it is a one-stage burner. This is done to provide a longer measurement period. Let the boiler make a complete cycle and measure the on time.

Then proceed as per the flow sheet, but do not measure the CO_2 and temperature before half way through the burner cycle.

<u>1.3.1.3 Heat recovery</u>

<u>1.3.1.3.1 Stack gas heat exchanger</u>

Check to see that it is not dirty with soot.

<u>In case of variable flow rate</u>

Check the proper functioning of the control system for bypass. Does it really let the stack gas go through the bypass when there is no water flow in the heat exchange, and does it let the gas go through the heat exchanger when the water is flowing?

<u>1.3.1.3.2 Feed tank</u>

Check if there is any steam coming out of the feed tank exhaust pipe. If there is steam coming out in vast quantities, it means that the re-evaporated steam is not condensed in the feed tank (see § 1.4).

<u>1.3.2 Opserational changes</u>

There are two levels of action in a heat generation plant:

1^{st}) Actions centered on the plant efficiency independently of the demand

2^{nd}) Actions dependant upon the load pattern

The load patterns can be classified in two main categories: space heating, and technical heat.

1.3.2.1 Types of energy demand

1. Pure space heating
   In this case the energy demand is determined by the outdoor temperature. Knowing the thermal output of the different boilers in a group, it is possible to determine the number of boilers that have to be in operation at different periods of the year.

2. Pure technical heat
   In this case, the energy demand is not dependant upon the outdoor temperature. However, the demand varies following a definite time pattern. This data, once available, will help to improve the control strategy and the efficiency.

3. Mixed type load
   Some of the heat generation system produce for space heating as well as for technical heat. In this case both seasonal and daily variations must be taken into account.

1.3.2.2 Monitoring program and operational changes

One can divide the monitoring program into two levels.

The first level consists of a monitoring program for the boiler house and its components for each group of generators, with operational changes, and minor modifications. The different actions to be taken are the measurement of the standby losses which will allow you to determine afterwards the overall efficiency of the generators, the measurement of the water temperature in the heat generators that are not in operation and isolated by the control system , and the measurement of the preheating time and fuel consumed for it,which will allow you to determine if the boiler group losses are of importance.

The second level consists in a monitoring program of the heat demand at generators level. The actions to be taken are the measurement of the temperature and power demand, the operational changes that can be performed based on these measurements, and the monitoring after the operational changes (see also Booklet I).

1.3.2.2.1 What to do and how to do it

A) First level

Monitoring program for each group of generators, operational changes, and minor modifications.

Measurements of the boiler group characteristics.

1. Measurement of the standby losses

   This will allow you to determine afterwards the overall efficiency of the generators.

   The measurement of standby losses must be performed for each boiler at its lowest power and by isolating the boiler from the heating network. Be sure that there is enough water flowing through the boiler during the measurement period. There should always be enough recycled water circulated in order to avoid any damage to the boilers.

   a) One-stage or multistage boiler

   Leave the boiler operate in an isolated condition (not supplying energy to the network) and measure the fuel or gas consumed during this period (few hours).

   The burner on time will give you the value of standby losses.

   b) Modulation of the power

   Same as above, but you must measure the fuel flow rate.

2. Measurement of the water temperature of the heat generators that are not in operation, and isolated by the control system. Analysis, and possible modification.

   Very often the efficiency of a group of boilers is not as good as it could be, due to uncontrolled water flow through off boilers and poor control system.

   There are mainly three different kinds of boiler group arrangements :

   a) Parallel boilers without a flow control system (Figure 1.3.G).

   Water always flows through all the boilers even if only one is in operation. In this case, the losses are very high, and one should close the valves manually to isolate the boilers when their operation is not required.

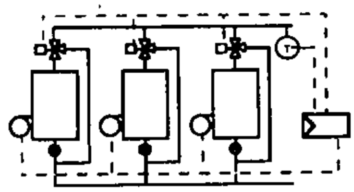


Figure 1.3.I - Parallel boilers with internal circulation pump

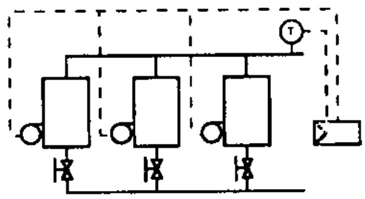


Figure 1.3.G - Parallel boilers without flow control

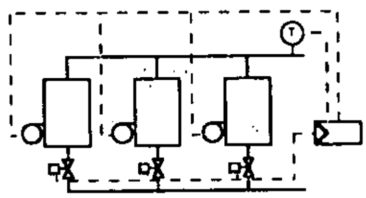


Figure 1.3.H - Parallel boilers with flow control

b) Group of boilers with one-way valves and a control system (Figure 1.3.H).

In this case, the water flows only through the boilers that are operating.
Unhappily, the check valves at the inlet of the boilers are very often leaking, leading to heat losses, and then losses in efficiency.

One has to check to see if these valves are really tight.

On the other hand one has to also check to see if the water flow rate is adjusted to coincide with the number of boilers in operation.

c) Group of boilers with internal circulation pump and three-way valves (Figure 1.3.I)

In the same spirit as in case b), one has to check whether the valves are really tight and if there is any uncontrolled water flow.

<u>Detection of uncontrolled water flow through the non operating boilers</u>

With the burner switched off and the control valves closed, measure the temperature after a long time in the boiler. If it is higher than the boiler room temperature it means that water is flowing through the boiler and is heating it.

If the boiler temperature is equal to the return temperature of the network, the losses caused by the leaks through the valve are equal to the radiation losses.

You can evaluate the losses due to the leakage following this procedure:

One can estimate the radiation losses:
radiation losses = X · standby losses, where
X varies between 1.00 (new boilers) and 1.5 (old boilers)

Uncontrolled leakage losses:

$$\text{leakage losses} = \frac{T_{bOFF} - T_{air}}{T_{bON} - T_{air}} \cdot \text{rad. losses}$$

where:

T_{bON} = boiler water temperature during a normal operation

T_{bOFF} = boiler water temperature when the boiler is switched off

T_{air} = boiler house indoor air temperature.

The first thing is to check whether or not the valves can be controlled in such a way that they really close properly.

For example, in case of a butterfly valve, the motor may not be adjusted to close the valve tightly.

Ask the control company to adjust the motor valve assembly in order to make the valve seal as designed.

If there is no progress, a second item to check is an estimate if it is economically viable to change the valves, and replace it by a poppet valve (see modification and substitution section).

3. Measurements of preheating time and fuel consumed for it

a) the boiler must be isolated from the network for a long time by manually closing the appropriate valve(s).

b) a measurement system for the fuel or gas flow rate must be in operation for this particular boiler (see measurement section).

c) you can preheat the boiler until it reaches the set temperature for

d) you have to compute the energy and time for the preheating

B) Second level

Measurement of the temperature and power demand.

Depending on the measurements techniques and on the kind of systems, different measurement methods must be used (Figure 1.3.J).

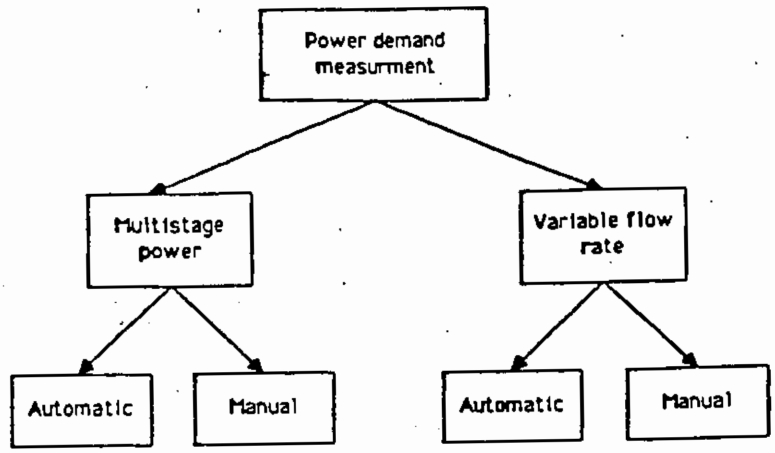


Figure: 1.3.J - Power demand Measurment

1. When should one measure?

   The measurement should take place during the coldest period of winter if it is for heating and ventilation. Other periods of the year are suitable for measuring the non heating energy demands (for example, steam for kitchen, laundry, etc.)

2. How long?

   To be relevant, the measurement should last at least two to three weeks.

3. Manual or automatic measurement?

   If it is possible to get automatic data acquisition, it is a better way for the measurement and its analysis.

   The reason is that electronic acquisition units allow one to measure every hour on a three weeks period, whereas a manual measurement can be done on a daily basis but not easily on an hour basis, because to write down every hour the readings of the energy demand personnel to be in the heating-room.

   In a general way, one can say that a daily measurement applies quite well to space heating systems, because the load variations on a daily basis are not too high and are proportional to the inside-outside temperatures difference, but nevertheless, very big variations of the demand do occur with ventilation systems, especially when the control system is adjusted for different day and night operation conditions.

   But for technical heat, like steam for laundry, food preparation, etc., the load variation based on a daily cycle are very high. It is most important to measure on an hourly basis in this case. Then the measurement by automatic data acquisition equipment is recommended.

   A manual measurement can be done on a daily basis with the help of on time meters.

   Automatic measurement involves the help of an engineering consultants but gives much more accurate results by providing hourly information. This allows one to know exactly the peak power demand, and to take action on a sound basis.

Stage-by-stage power boilers

In this case, the power demand can be determined by the load factor measurement of each power stage of each boiler.

The functioning time indicated by the on time meters or the electronic data acquisition devices differs from one burner to the other.

Some of the possible 2-stage burner configurations are shown in Figure 1.3.K.

There are some other configurations, but one has to check for each case what an on time meter or electronic device will actually measure. One should pay attention to the connection of the on time meter. They are sometime connected to the switch which gives the signal for the burner but includes also the preventilation time which should not be included in the measurements. So one has to check that the on time meter measures really the time during which fuel is injected into the boiler.

Manual measurement

In this case, the load factor will be determined on a daily basis.

Procedure:

- Install on time meters as shown in "step by step power".
- Install a min-max thermometers on the North side far away from the building. Take care that it is not insulated at any moment of the day and for the whole year.

Week load factor:

- Write down the hours every week at the same time for each on time meter.
  The best time is around 4 p.m.
- Calculate the load factor for each boiler and for each stage as per specifications in "stage-by-stage procedure".
- Read the min and max temperatures.
  The average temperature is equal to:

$$T_{day} = (T_{min} + T_{max})/2$$

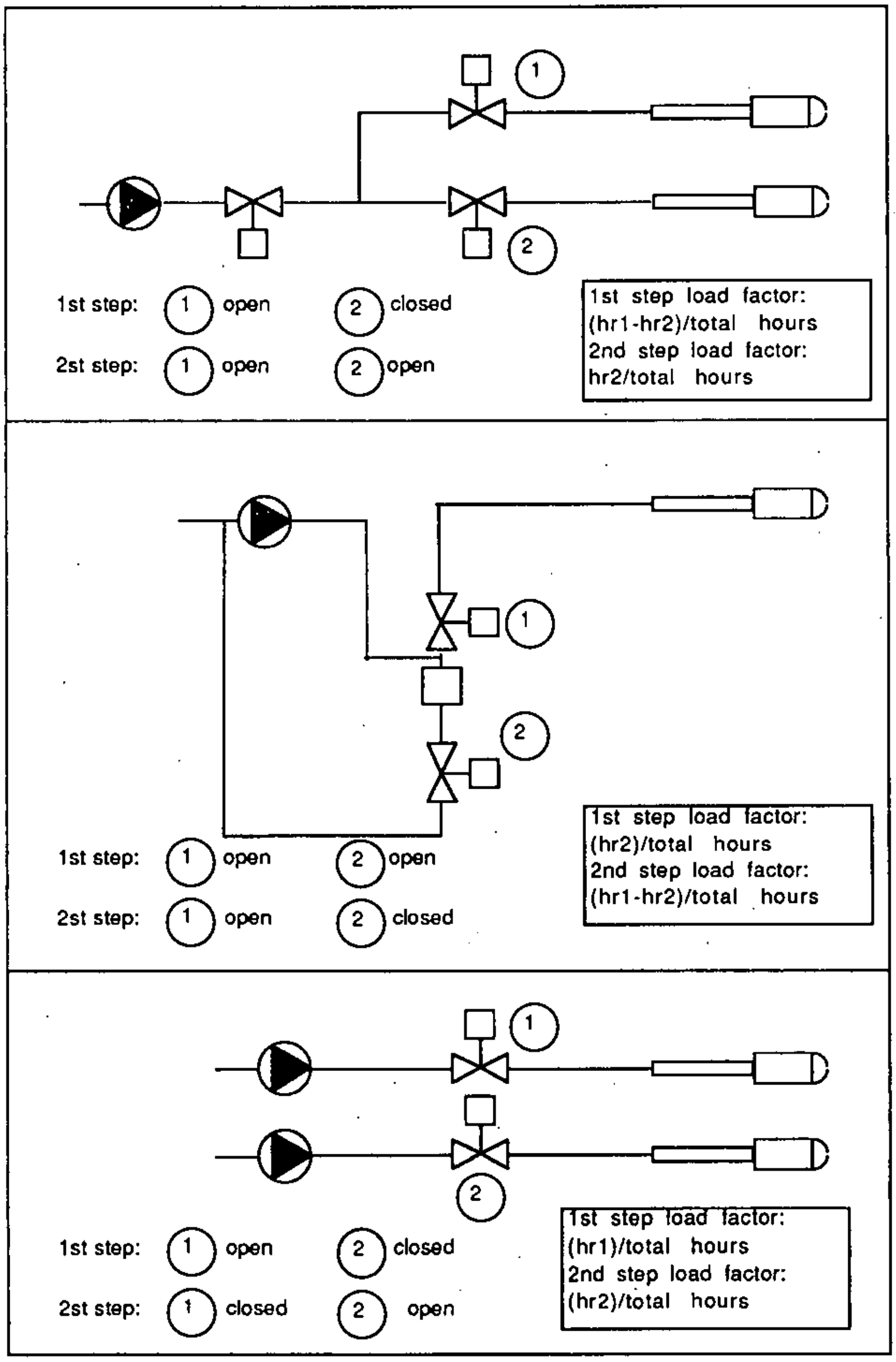


Figure 1.3.K - Two stage burner configurations

The average weekly temperature is the average value of the daily temperatures of the week.

- Plot the point of the week in a chart (Figure 1.3.L).

Peak demand:

- On one week day, write down the load factors every hour.

- Then repeat the measurement every day for the two hours during which the load factor is maximum. Read the temperature at the same time and plot the point for each boiler and each stage, for the temperature at this time.

<u>Automatic measurement (to be done with the help of an external consulting company)</u>

- Connect a data acquisition units on each boiler and each power stage (see "stage-by-stage power").

- Take measurements for about three weeks, then perform the data analysis.
  Ask for daily as well as for peak demand load factor, and for overall load factor of the system.

Variable fuel flow rate boiler

In this case, one has to measure the fuel flow rate directly.

There are two kinds of burners :

a) Single oil pipe burner

   In this case one has to place one fuel meter in the oil supply line (Figure 1.3.M).

b) Double pipe burner (with by-pass)

   In this case two meters are required in oil supply and oil return (Figure 1.3.N).

   The fuel actually consumed is equal to the inlet flow minus by-pass flow.

<u>Manual measurement</u>

The same procedure as for step-by-step is used but the reading is in fuel volume instead of the on time.

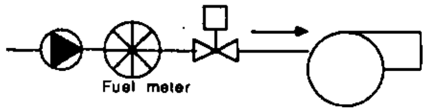


Figure 1.3.M - Single oil pipe burner

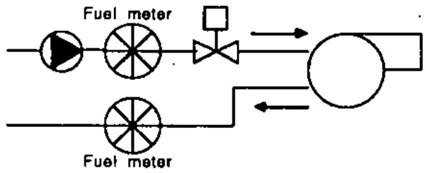


Figure 1.3.N - Double pipe burner

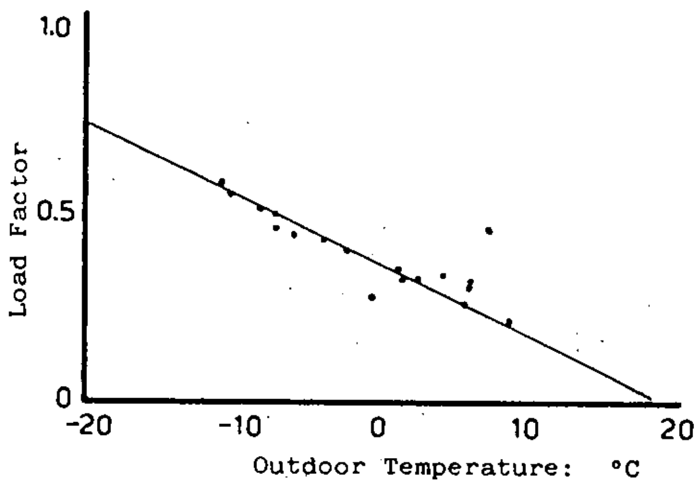


Figure 1.3.L - Chart of the load factor

Automatic measurement

The fuel meters must be equipped with an impulse generator, then one can connect an electronic data acquisition unit on each fuel meter.
Then follow the same procedure as for the stage-by-stage.

Operational changes in interrelationships with heat demand

Once the measurement of the boiler group characteristics, and of the energy demand has been done, it is most likely possible to save energy by a decrease, or a variation of the time pattern of the energy demand.

Before starting this job, one has to go through the main distribution system.

One can separate demand into two kinds of time patterns:

- Seasonal variation related to HVAC systems

- Daily and weekly variations related to technical processes.

We first look at the HVAC type load.

HVAC type load (seasonal variation, with morning peek)

One can divide the actions in three categories:

- First a better management of the boiler group on a season base

  If the power demand is strongly dependant upon the outdoor temperature like for HVAC, it is beneficial to switch off the boilers which are not needed for the heat production during some periods.
  To know approximately when one has to switch the units on or off, the diagram shown in Figure 1.3.0 must be plotted for each group of boilers.
  Once you know approximately when the switching time occurs, then you have a look on a min max thermometer and determine exactly the time when to do it.
  Keep a little bit of margin for safety reasons. Switch on a little bit earlier than the computed temperature.

- Secondly, a better management of the boiler group based on the fact that peak loads occur often at morning after the night set backs are switched off.

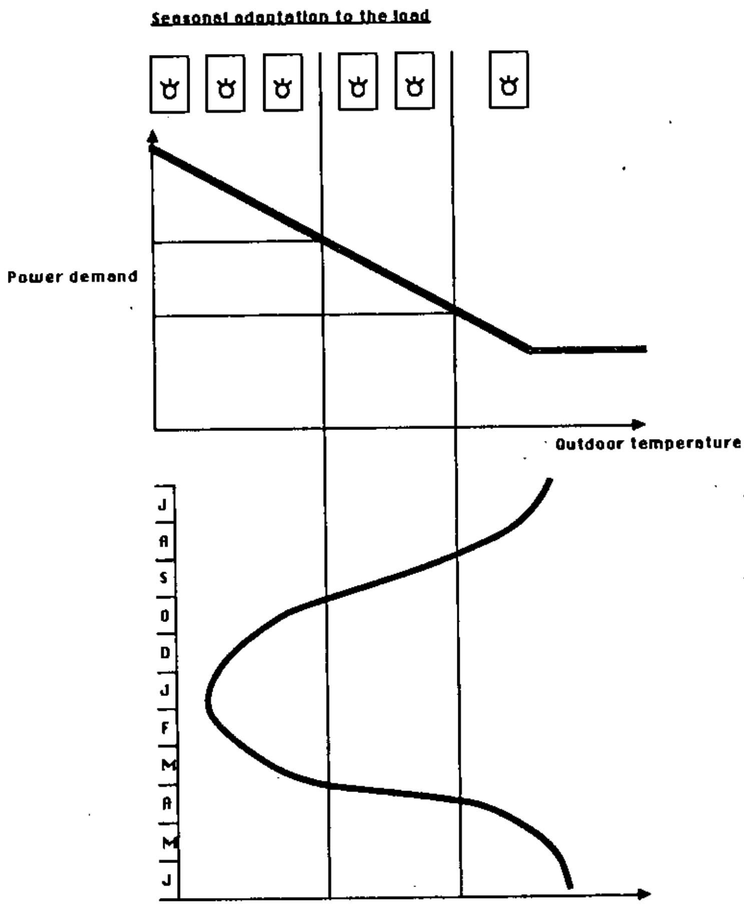


Figure 1.3.0 - Seasonal pattern at the power demand

The first hours of the hospital day normally provide peak power demand as shown in Fig. 1.3.P. If the measurement shows that only one additional boiler is switched on at this time, it can be sound strategy to try to lower the peak loads of the different heating loops in order to avoid this boiler being put into operation for only half an hour of so (see Figure 1.3.Q).
Try to moderate the demand peak by shifting individual peaks in order to avoid to switch on a boiler only for a short time.
This outphasing is energywise profitable especially in the mid seasons.

- Thirdly, one can decrease the energy demand by an adjustment of the set temperature curves of the HVAC systems

  In this case, an energy saving potential of 5 ÷ 7 % for each °C decrease on the heating curve can be achieved (see Fig. 1.3.P).
  One has to pay particular attention when changing the operating modes.
  The new problem is that a temperature or pressure reduction may not be possible due to the heating network characteristics.
  Indeed, if the flows in the network are not well balanced or if some heat exchangers are undersized, it might be possible that with a temperature and/or pressure reduction, the energy supplied becomes too low in certain areas of the hospital, and therefore the space temperature too low for comfort requirements.
  This must be checked with a trial:

  You apply the new control strategy, and measure the temperature of the fluid going to the space requiring heating or ventilation and compare it with the temperature before the reduction. Or in an easier way check the temperature level in the space where the energy is delivered with the help of a temperature and humidity recorder.

  If it is lower than before the change, then you should see whether it is possible to increase the water flow rate from the heating plant in this particular loop, or then modify the control on the space heating network.
  This is treated in Booklet III.

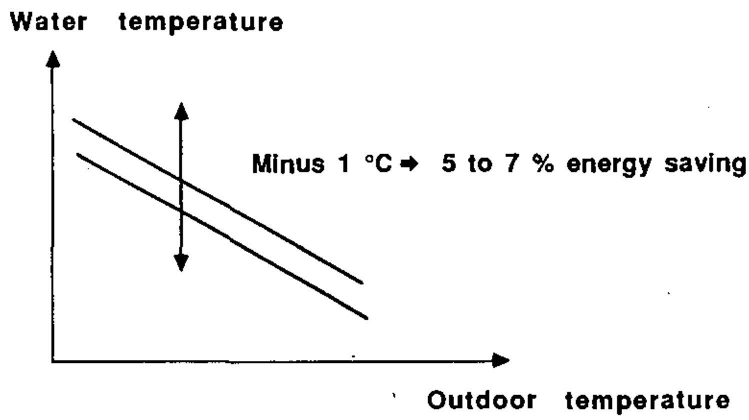


Figure 1.3.P - Heating curve

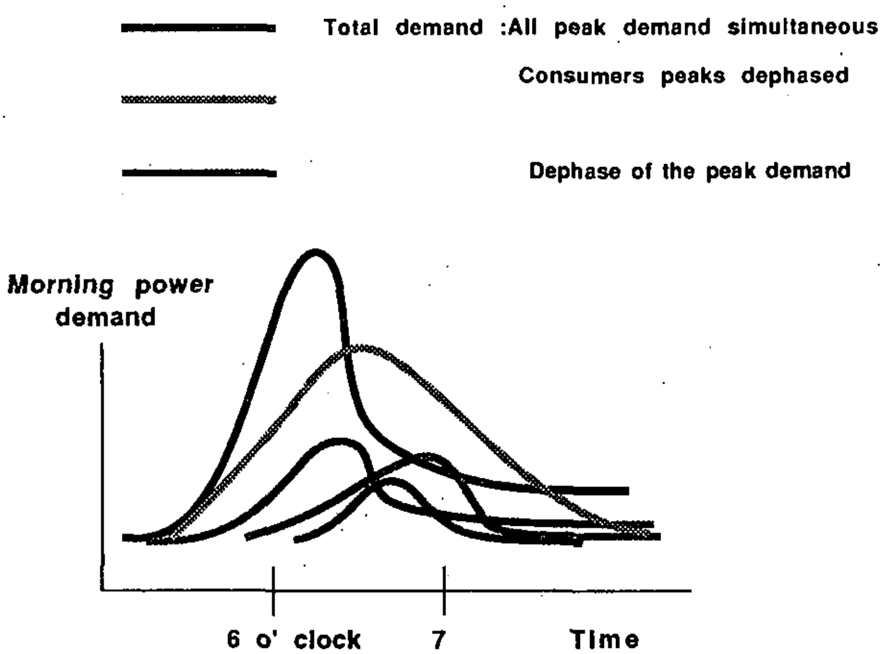


Figure 1.3.Q - Morning peak power demand

Process heat type load (laundry, kitchen, etc.)

See also Booklet V.

When the power demand varies following a regular pattern during the day, it is possible to adjust the power, and temperature or pressure on the energy production side.

During the measurement period you have to collect some other data:
operating hours of the laundry, kitchen and sterilization, and the pressure or temperature required for them.

Based on the power demand and the operating hours of the different technical heat consumers, you can adapt the power production to the demand.

This part applies particularly to the steam and superheated water systems.

1. Plot the power demand measured on an hourly basis as in the format.

2. Plot the load factor of each boiler of a group.

   This shows how the control system drives the boiler group.
   If one of the boilers has systematically a load factor below 20 %, you must compute its efficiency for the period of measurement, based on the measurement of the standby losses, following the formula given in § 1.2.2.1.1, and

3. Plot the operating hours of the consumers and measure and ask for their temperature requirements.

4. Plot the minimum pressure or temperature required for all the consumers during a week, and then adjust the heat production to the demand with a programmable clock.

   This curve must be standardized in 3 typical days: Week days, saturdays, sundays.

   If the group of boilers produces heat for space heating as well as for technical purposes, the daily variations are combined with seasonal variations.

1.4 How to save energy with modification

1.4.1 Boilers

Even after operational changes, if you do not get good boilers efficiency, some modifications could be done:

- If you have measured very high standby losses (>2 %) you should check the boiler insulation and increase the level to limit the losses.

- If the temperature of the boilers switched off by the control system have a temperature near that of the return temperature, it may be useful to and replace the valves with poppet valves which are really tight.

- It could be economically sound to consider installing a stack gas heat exchanger if the stack temperatures are always more than 150 °C higher than the fluid temperatures. This has to be evaluated with the help of an engineering consultant because the investment is high in this case.

1.4.2 Steam plant

The peculiarity of a steam plant is that it is equipped with a feed tank:

If there is steam coming of the exhaust pipe of the feed tank, you can modify the return pipe. Instead of a single pipe, it is much more efficient to introduce re-evaporated steam in the feed tank through small holes in a manifold type arrangement (see Fig. 1.4.A).

Here again, one has to ask the help of an energy consultant, because there are some design problems (like noise in the feed tank, pressure problems,...) to be solved.

1.4.3 Substitution

If the steady state efficiency of a boiler is after proper tuning in the range of low combustion efficiency (see Fig. 1.3.E and Fig. 1.3.F), then one has to consider the possible replacement of such a boiler. Some evaluation aspects are explained hereafter.

Based on the difference in steady state efficiency between the existing boiler and a new boiler, one can compute the energy savings that would occur during a year. Then one can compute the potential money savings and estimate the payback period of a new boiler. These calculations have to be done with the help of engineering consultants.

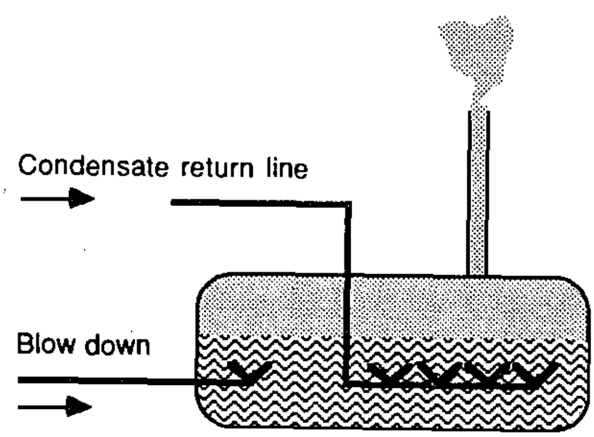


Figure 1.4.A - Condensate return arrangement

CHAPTER 2. HEAT DISTRIBUTION

2. Introduction

The energy produced by the heat generation plant is supplied to the consumers by the distribution network.The network must fulfill the requirements of the consumers in terms of flowrate and temperature.

The combination of these two problems makes design and control of the network a difficult task.

This part of the chapter deals with the distribution and its control system between the production and the consumption loads.

One can divide the actions in two categories:
with or without modification (see Figure 2.A).

2.1 Description

The main distribution network treated in this part is a system which does bring the energy from the heat generation plant to the different consumers. The different consumers have different time patterns, causing variation in the hydraulic and thermal conditions of the network.

In the lines some thermal losses occur. The more able the control system is to adapt the distribution network to the load, the more efficient it is (average line temperature reduced, resulting in a better energy efficiency).

The more insulated the lines, the less losses occur. The less duration of circulation the less pumping energy is consumed.

In this part, consideration is given to improve the distribution efficiency, as well as a discussion of the consumers effects on the heating plant performances, and the interactions between different energy consumers.

A detailed approach to the consumers efficiency is found in Booklets III and V.

2.1.1 Control system components

The most important items in the main distribution lines are the controller and their actuators. Valves moved by actuators under command of the control system makes the fluid in the network and the temperature vary as per the consumers requirements.

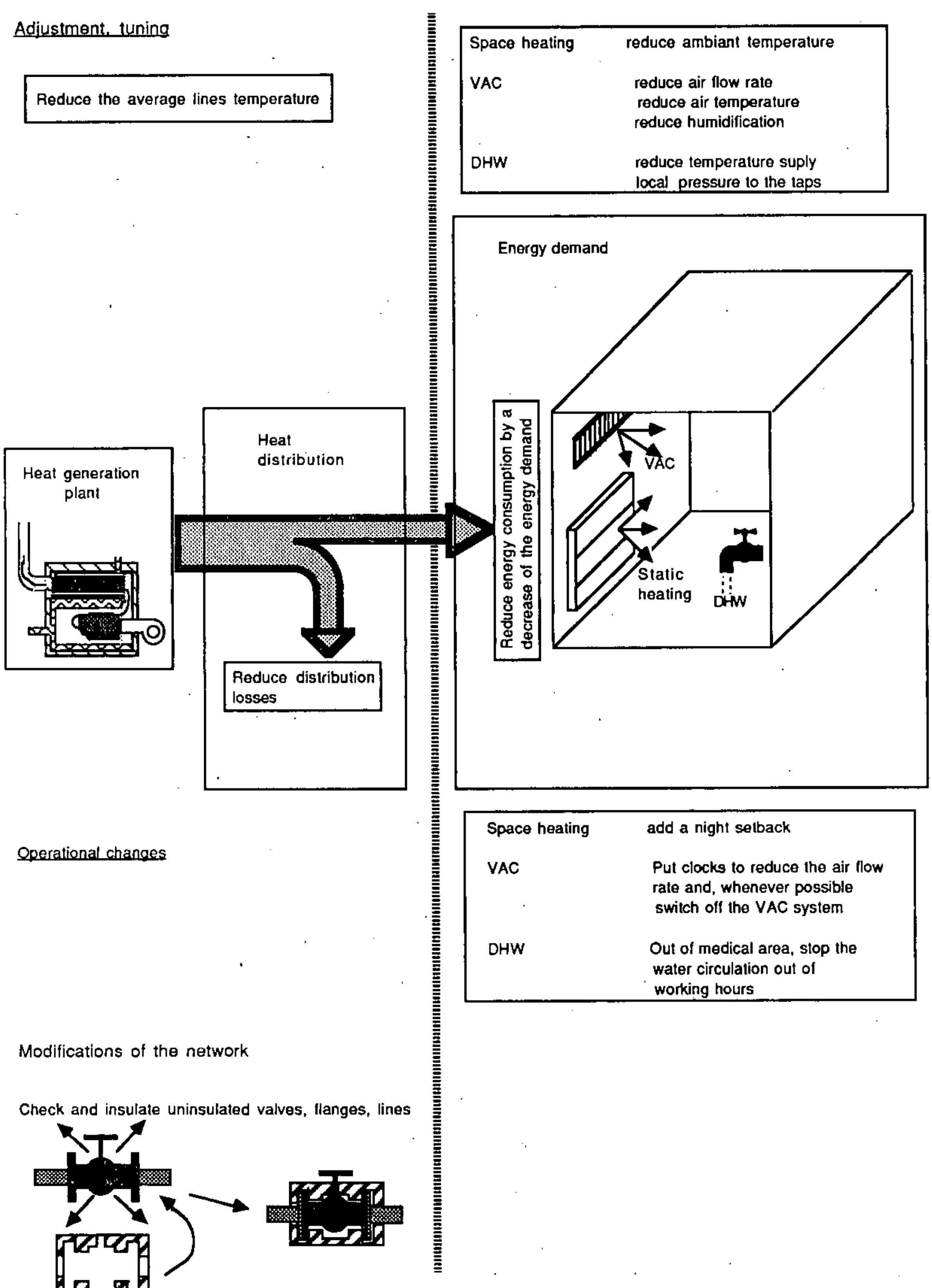


Figure 2.A - Energy savings without modification of the distribution network

We show here only some aspects linked with operational problems.

2.1.1.1 Automatic Control Systems (principles)

Control systems are meant for the automatic maintain without human intervention of a temperature pressure or humidity at a set point whatever is the variation in the demand of energy.

How does it work?

A regulator measures pressure or temperature (the controlled variable) with a sensor, and compares it with the set point (Fig. 2.1.B).

It acts then on the *control* variable with a *control* actuator.

There are mainly two categories of control strategy in the distribution networks:

a) Fixed setpoint control systems like

- DHW temperature (Figure 2.1.C)

- steam pressure in a steam network (Figure 2.1.D)

- fixed temperature in ventilation systems (Figure 2.1.E)

b) Outdoor temperature dependant setpoints like

- space heating (Figure 2.1.F)

For some of the heat consumers, the setpoints, dependant on the outdoor temperature or not, can be changed with clocks that allows to reduce the setpoints *during night time or week-end* , like for example night set back in space heating (Figure 2.1.G), or night, week-end set back in steam network (Figure 2.1.H).

It might be necessary to buy a clock and an additional controller for that.

The kind of valves used are not all equivalent for their quality (i.e their leak tightness).

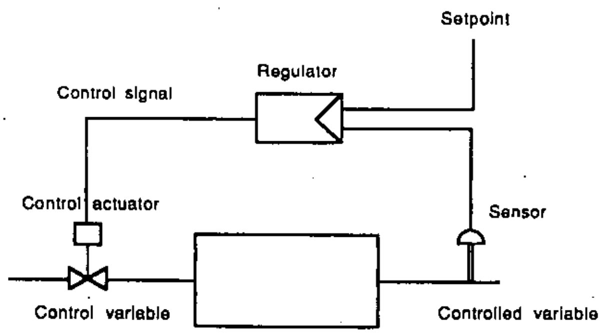


Figure 2.1.B - Control system diagram

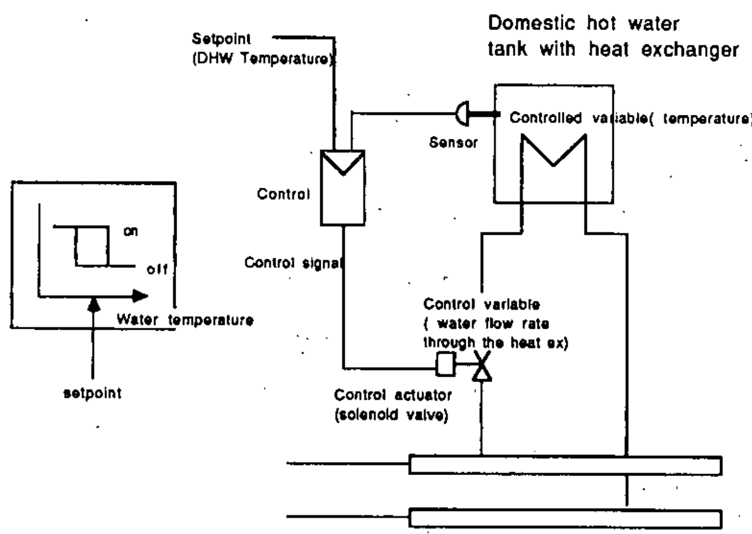


Figure 2.1.C - Fixed setpoint control system for Domestic Hot Water

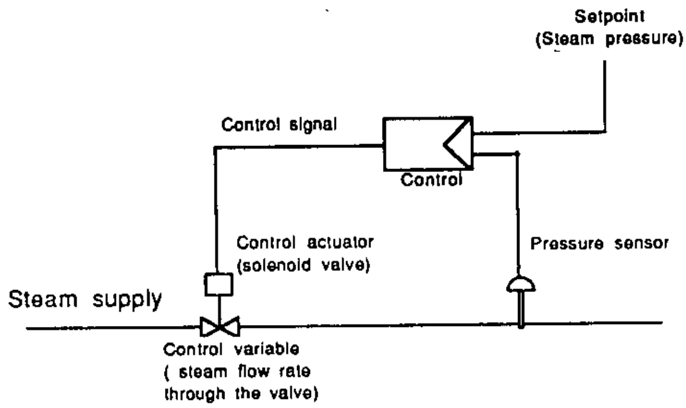


Figure 2.1.D - Steam pressure controll

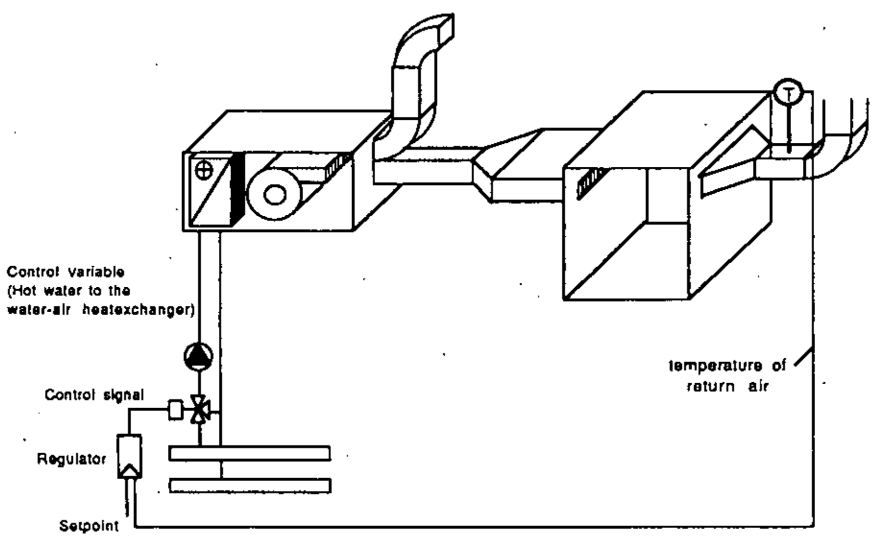


Figure 2.1.E - Fixed temperature

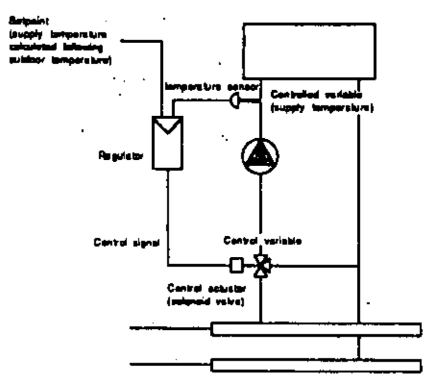


Figure 2.1.F - Supply temperature in function of outdoor temperature

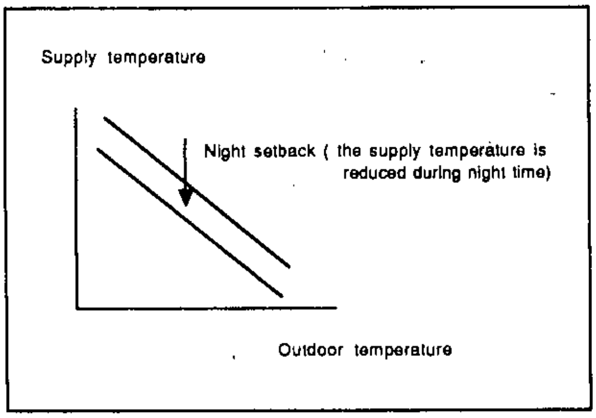


Figure 2.1.G - Night set back

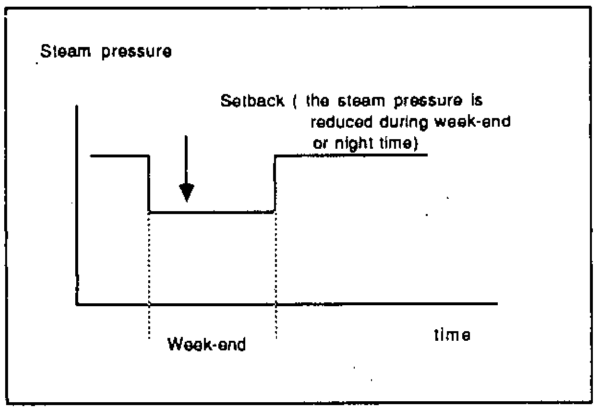


Figure 2.1.H - Night, week-end set back

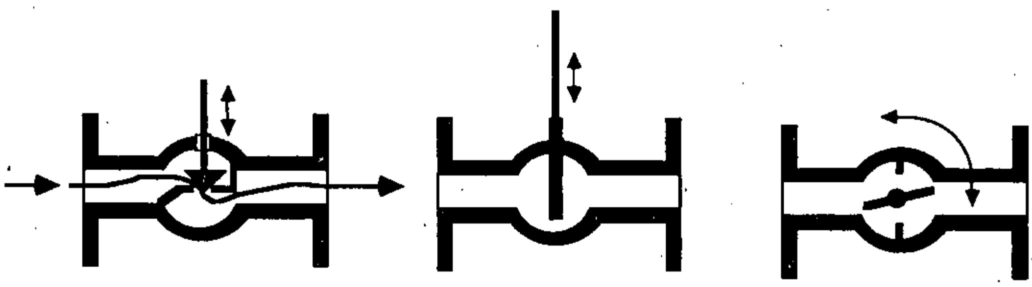


Figure 2.1.I - Kinds of valves

One can identify three distinct kinds of valves (Figure 2.1.I): Poppet valves, Sliding vane valves and Butterfly valves. Their tightness can be classified as shown below.

Poppet valves	Sliding vane valves	Butterfly valves
they are usually tight	slight leakage increasing with time	hard to seal tightly

Depending on the desired control quality, some of these valves are inadequate, and can cause parasitic flows in the hydraulic network even when they are closed.

One should know that even with 1 % of its nominal flow rate, a coil supplies approximately 10 % of its nominal power.
This can happen very easily with butterfly valves which may allow parasitic thermosyphon flows during summer in the radiators network.

2.2 Strategy

Even though the goal of this manual is to provide guidelines for energy savings, never forget that the most important thing in a hospital is to provide safety and comfort at any time to the patients and the working staff.

Nevertheless you must operate the heating system as efficiently as possible, in order to reduce the energy consumption (Figure 2.2.A).

2.2.1 Information about the distribution network

In order to be able to achieve energy savings without affecting the comfort and services in the hospital, you must have a good knowledge of the heat distribution network.
That will help you in the analyze of the energy problems.

The first step is to identify the different lines of each network (steam, water).

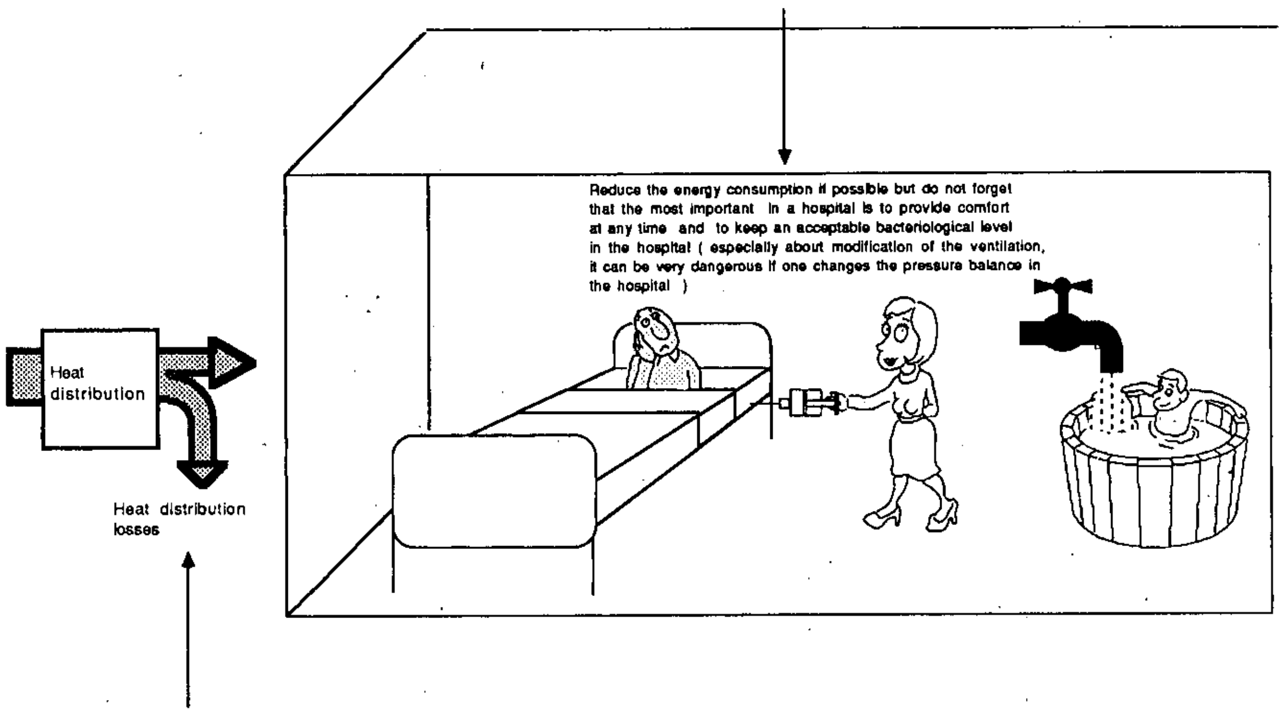


Figure 2.2.A - Strategy of energy saving

A schematic diagram will assist in the identification of the different lines. **Lacking a diagram, one should be constructed.**

An example of a schematic diagram is shown in Figure 2.2.B.

You must also identify the geographic area deserved by each subloop or substation.

Once you have identified the energy flows, you must understand how the these flows and temperatures are controlled.

You will add to the schematic diagram the control functions of the primary loops, and also of some important secondary loops, and describe how the regulators command the valves or command devices (Figure 2.2.B).

If you do not find the information on the control system, ask to the control supplier, the functions of each control device.

Once you have a schematic diagram with the main hydraulic control system characteristics, and that it has been carefully described, geographically and technically you can start the work on the heat distribution system.

2.2.2 Levels of intervention

There are two levels of intervention :

- Tuning, operational changes
- Modification, substitution

2.2.2.1 Tuning, operational changes

1. Reduction of the energy consumed by an adjustment of the control system of the end-users.

2. Reduction of the heat losses by a reduction of distribution temperature of the main distribution lines.

The part 2.3.1 gives guidelines for a reduction of the energy consumption by an adjustment of the control systems of the different heat consumers and the district heating.

The part 2.3.1.3 goes a little bit further and guides for operational changes of heat distribution. It has to be performed once the control functions have been checked and properly tuned.

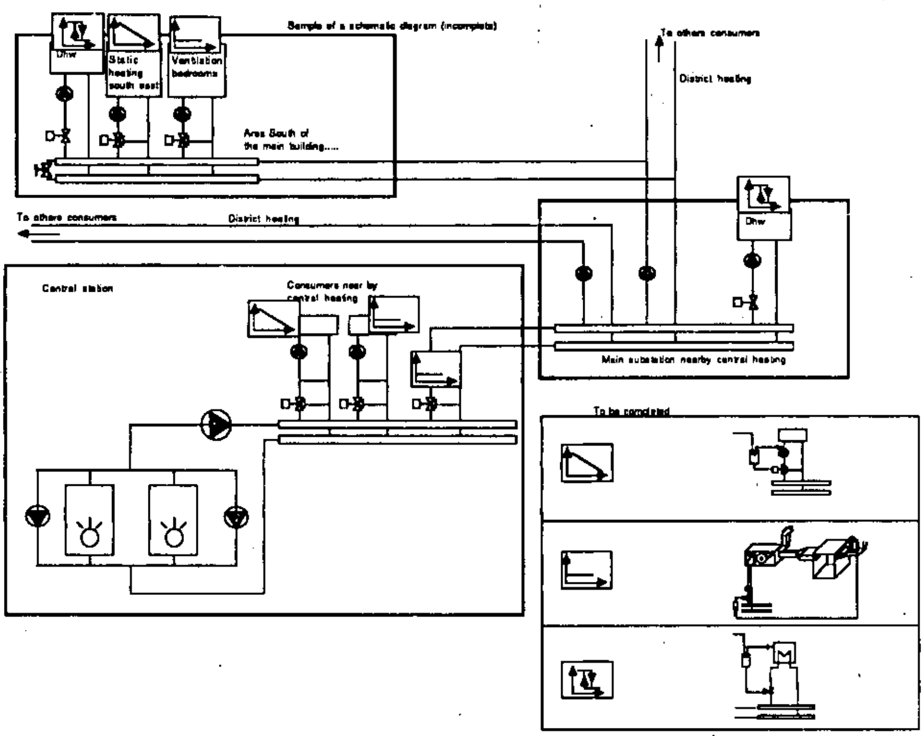


Figure 2.2.B - Schematic diagram of network

The part 2.3.1 and following require a good knowledge of the distribution network in its different functions.

Before any action, remember always that the patient comfort and security are the most important thing in a hospital and therefore be careful in your actions.

2.2.2.2 Modification, substitution

1. Reduction of the energy consumption by a reduction of the distribution losses (insulation or reinsulation of uninsulated parts).

2. Reduction of the energy consumption by a reduction of the lines length, by decentralizing some remote energy consumer.

Part 2.4.1 provides information for the improvement of the thermal properties of the network, that is to minimize the losses thanks to a better insulation.

2.2.3 Geographical approach

The best strategy is to decrease the energy consumption of each subsystem at its minimum by a fine tuning at the end-users level, then to reduce the temperature or pressure level at the primary level, taking into account the need of each consumer (Figure 2.2.C).

2.2.4 Kinds of consumers served by the distribution network

There are two different kinds of heat consumers:

- temperature dependant, like HVAC

- temperature independent, like DHW, processes (kitchen, laundry, sterilization)

2.2.4.1 Temperature dependant consumers

The power consumed is varying with the outdoor temperature (Figure 2.2.D).

For each substation you must correlate the outdoor temperature and the ambient temperature, there should not be any dependance between them, but in summer (Figure 2.2.E).

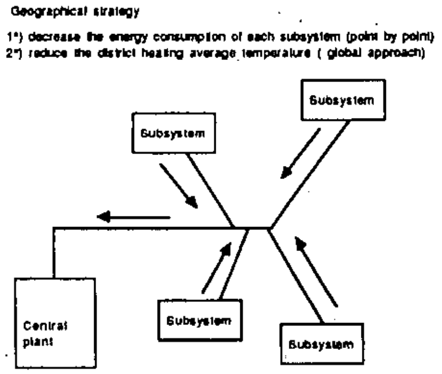


Figure 2.2.C - Geographical strategy

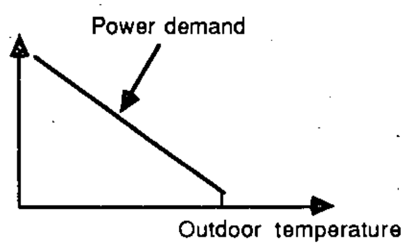


Figure 2.2.D - Power demand

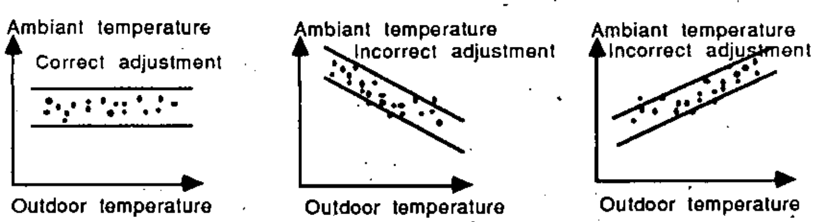


Figure 2.2.E - Correlation of outdoor and ambiant temperature

These figures represent three different cases:

a) Correct adjustment:

It shows that the indoor temperature at a given time of the day should be the same or less if the outdoor temperature remains below 12 °C

b) In that case the indoor temperature remains too high when the outdoor temperature is very low and to low when the outdoor temperature is around 8-12 °C. This is due to the fact that supply temperature is increasing too fast with a decrease of the outdoor temperature (see Fig. 2.2.F).

c) Similar as b) but in that case the supply temperature does not increase sufficiently with a decrease in outdoor temperature.

To measure that, you need a thermohygrograph that you keep in a room (always the same) to measure the ambient temperature.

In the case of a supply temperature dependant on the outdoor temperature, the measured supply temperature would be accordingly looking like that shown in Fig. 2.2.F.

By an action on the control you can adjust the supply temperature at its proper level for any outdoor temperature, keeping a constant ambient temperature.
(Detailed explanation is found in § 2.3.2).

In the case of an ambiance temperature control system, you must adjust the set temperature if it is too high.

2.2.5 Process consumers (laundry, kitchen, sterilization)

These consumers require a temperature or pressure level that is independent of the outdoor temperature, but changes during the day and the week.

You have to try to reduce the temperature and pressure level as much as possible and adapt the distribution network to it.

Once you have adjusted all these control systems, you can work on the primary loops.

Then one can reduce the primary loop temperature at its lower level to be able to still ensure that the process will work in good conditions (see also Booklet V).

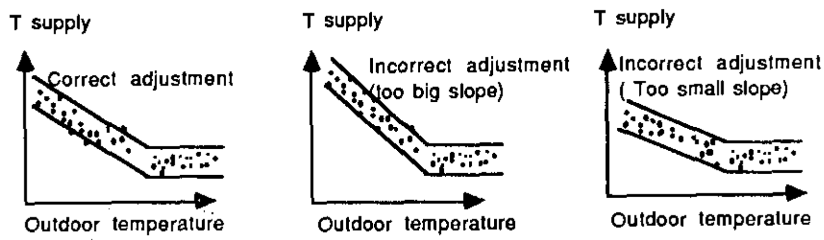


Figure 2.2.F. - correlation of outdoor and ambiant temperature

2.3 How to save energy with minor changes

How can one save energy without modification of the distribution network?

This part provides guidelines for proper function checking of the energy distribution system and then how to decrease the energy consumed as well as how to reduce distribution losses without modification of the distribution network.

It can be done with § 2.4.1.1, which treat the problem of insulation or reinsulation of the pipe network, and of the condensate recuperation (steam systems).

2.3.1 Limitations for energy savings by adjustment and/or modifications of the control system

2.3.1.1 Heating requirements in the hospital

The specific indoor climatic conditions required in hospitals make the energy saving a difficult task. The standards and recommended practice for indoor conditions in hospitals are briefly summarized in the Foreword of the Booklet III. Before taking any actions on the control system, one should pay attention to the national recommendations and standards.

2.3.1.2 Technical heat

Steam or superheated water supply used for technical processes can be switched off with the help of clocks controlling the valves.

2.3.1.3 Knowledge about the network

As explained in § 2.2.1, the Figure 2.2.B must delineate:

- each area heated by a specific loop, like for example the south-west group of heating, does cover a very well defined area in the building, and which control strategy is used (outdoor temperature dependant, ambient temperature, ...)

- each area deserved by a DHW network

- each area under ventilation, air conditioning

- each consumer of steam for technical process

You must identify, in the central plant and the substations, the different control systems and their functions for the loop they control (see Figure 2.2.B).

First we will see how to reduce the energy consumed by each consumer by an adjustment of the existing control systems.

Then we will see how to reduce the distribution network losses by a reduction of the average operating temperatures.

Before any action, one has to see the interactions with other areas or systems. For example, if the ambient temperature is too high in a given area, it can be due to different causes: poor adjustment of the control of heating and/or ventilation, too much internal heat sources, etc.

But *before doing any modification*, one has to see whether a change in set points will affect other areas, like for example HVAC systems covering different areas (see Figure 2.3.A) with static and ventilation heating.

In that case, we shall see some of the mistakes one should avoid, taking as an example the situation of the Figure 2.3.A.

Interactions between separate areas

1. Adjustment of the heating curves of static heating on a wrong basis.

   If one put a thermohygrograph in a place like the laundry, and that one measures too high ambient temperature, it does not mean that one can diminish the supply temperature, because if the network is common to some other users like for example bedrooms which are connected on the same loop might become too cold.

2. Night set back.

   For the same reason as above, if you apply a deep night set back for the kitchen and restaurant, without taking into account that it is connected to the same loop as the bedrooms above it, it will create problems in those rooms, because of temperature night setback that are too low.

   It means that in such a case one has to close the radiators manually when they are not needed in certain areas, instead of employing a night setback.

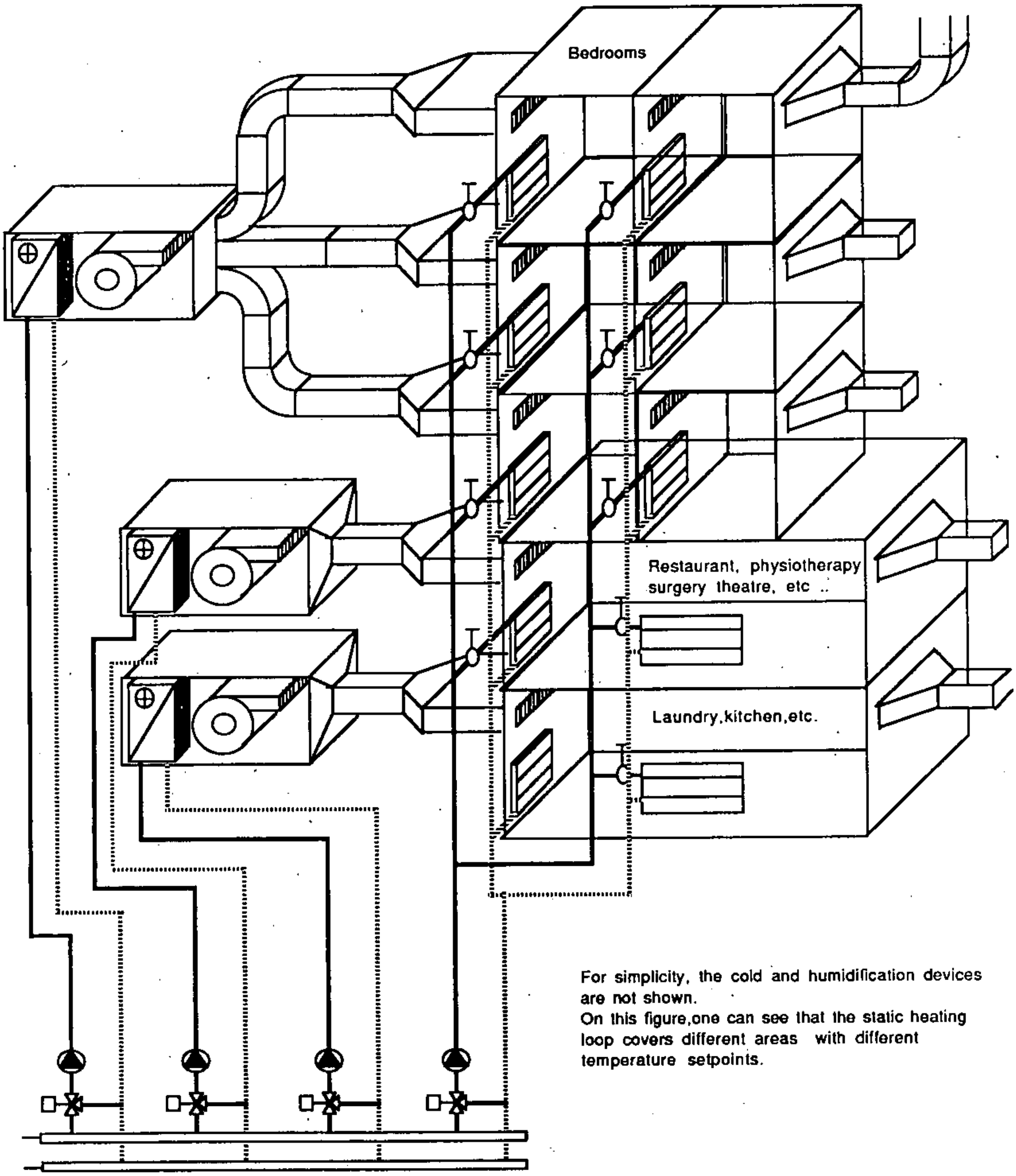


Figure 2.3.A - Different area covered by the vanne system

Systems interactions in HVAC

1. Adjustment of ambient temperature when static heating and ventilation are in operation without knowledge of the control system may lead to some discomfort.

   If one reduces the static heating supply temperature without thermostatic valve and that the ventilation control is based on the ambient temperature, there will not be any energy saving.

   One has to modify both in this case.

2. Do not vary or reduce air flow rate without the help of VAC specialists.

   Indeed some pressure differential is kept in some medical areas. By a modification it could be destroyed leading to risk of infection of other areas in the hospital.

2.3.2 Tune-up

Here is explained how to start with the work.

As explained in § 2.3.3 and following, one has to start with consumers, in order to be able afterwards to adjust the district heating control without affecting the good functioning of the whole system.

So first, we start with space heating then, ventilation, then process, then we tackle the problem of the district heating.

2.3.2.1 Space heating, ventilation

2.3.2.1.1 What to do and how to do it

Very often the temperature in an area of the hospital is too high.
This causes unnecessary energy losses that one can often reduce by adjustment of the control system of each consuming unit.

Let us consider first the problem of space heating alone.

A) Static space heating (alone)

If nobody complains for cold or heat during the year, you can assume that the control system is in operating condition.

But this does not mean that you cannot save energy. Most likely you can adjust the system in a better way in order to supply temperature for a lower energy consumption.

Remember that if you decrease the ambient temperature in a building by one (°C), the energy saving will be around 5-8 %. It can be done by an adjustment of the heating curve or of the set temperature. It will take time to adjust properly, you will have to do it step by step.

Remember that the occupants should not feel uncomfortable. Therefore you must adjust the control in such a way that the temperature are sufficient all the time for any area.

We do not mention here night setback; it is treated in § 2.3.3.1.

This monitoring program must be conducted for each heating loop which has got its own control system.

(The details about control systems are explained after)

First you need a thermohygrograph.

Select a room which is among the coldest of the group.

If some rooms are much colder than the others of the group, see chapter "Space heating" in Booklet III. You are certainly in presence of hydraulic imbalance.

Keep the device in the rooms for few days and plot the ambient temperature against the outdoor temperature during the day when sunshine and wind are not strong.

If the control is properly adjusted it should look like the example of Figure 2.3.B.

The ambient temperature must be held more or less constant what ever is the value of the outdoor temperature except during sunshine hours, and at night if there is a night set back.

You have seen the control system description in § 2.1.1 and following: the controller makes use of a heating curve which is provided or which is represented by its characteristics like slope and base temperature intercept. We will describe it afterwards.

You have to adjust the heating curve only in the range of the present outdoor temperature, and never more than 2 (°C) on the supply temperature at a time.

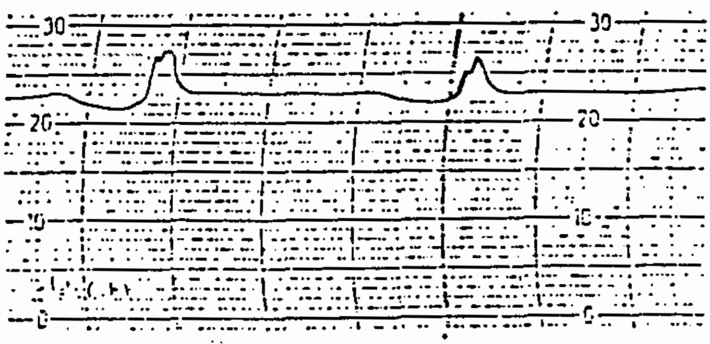


Figure: 2.3.B - Ambiant temperature during the day

Do not modify the entire range of curve unless you have already got measurement over the whole range of outdoor temperature.

Some typical operations to perform on control systems are shown on Figure 2.3.C.

B) Space heating and ventilation

In that case, on has to be much more careful, if one wants to save energy.

Indeed there are some interactions between both systems, and therefore one has to understand the whole process, in order to be able to act in a correct way.

Thereafter are shown two usual configuration for static space heating coupled with ventilation and the principles for adjustment of the control system.

In this case, if you decrease the static supply temperature, without decreasing the air exhaust set temp. you will not save energy.

Indeed the air intake temperature will be increased by the valve control system.

Therefore any adjustment of the static heating supply temperature must be done simultaneously with the exhaust set temperature in order to avoid any energy losses instead of energy savings. One more time it shows that you have to know the whole process very well if you want to be successful in energy savings.

Anyway, each time it is possible to switch off the ventilation do it (see § 2.3.2.1.1), but only after consultancies from VAC specialists.

The first usual configuration is (see Fig. 2.3.D):

- Static heating: no thermostatic valves, water supply temperature dependant upon the outdoor temperature
- Ventilation: fixed set temperature with measurement of the ambient or exhaust or ambient temperature.

  Static heating provides energy for a temperature 2-4 °C below the set value, the air is blown with a higher temperature in order to provide the desired temperature.

b) Maximum savings are obtained when cylinder unloading is in steps of one cylinder at a time. For multiple compressor applications, only one compressor should be unloaded at a time; all others should be used at full capacity or shutdown.

13. Use rivers, lakes and other natural water bodies for condenser cooling.
This approach is applicable to installations primarily with existing water cooled equipment close to natural water sources, and is most favorable in larger installations using this ECO. Cautions include:

a) Use of natural water source may cause fouling of heat transfer equipment resulting in loss of performance and requiring additional maintenance.

b) Increase of temperature, due to rejected heat,in small, non-flowing water bodies can upset water ECO system.

14. A desiccant for humidification, such as silica gel, can be used to reduce the moisture content of an air stream, thereby reducing the overall cooling load. The remaining sensible load can be taken care of in the normal way using a cooling coil and a cooling medium.
Because the latent load is handled by the desiccant, the cooling medium can be at a higher temperature than would be required if it were to handle the latent load; consequently "higher" temperature cooling mediums such as tower or well water can be considered. Especially useful in locations with long periods of high wet bulb temperatures, high internal latent loads and/or high fresh air loads.

15. Make use of exhaust steam from turbines to generate chilled water using absorption chiller(s). This ECO is applicable to buildup with steam-driven centrifugal chillers, or other steam-driven equipment particularly in the those buildings using purchased steam where the condensate is not returned to the supplier. This is a high-cost item although it can yield good paybacks (5 years or less in favorable situations).

16. Use water storage or ice making to store cooling. Storage may be short term, e.g., hourly/daily, or long term, e.g., seasonal. Seasonal storage systems are appropriate in locations with continental type climates where cooling storage can be generated

during winter months without mechanical refrigeration.
Short term systems are primarily applicable where electrical demand costs for cooling are significant.

Capital cost of providing short term storage with a small chiller can often be less than or comparable to the cost of larger machines without storage providing equivalent cooling. Consequently storage should generally be considered when evaluating the replacement of existing equipment.
Detailed hourly evaluations are almost always required in the decision process.

17. Replace old and inefficient equipment such as: condensers, cooling towers, compressors, etc. with new more efficient types. Prime targets are change of:

    a) air cooled condensers to cooling towers, (particularly in locations with fewer than 15 000 wet bulb degree hours),
    b) single unit to multiple unit systems,
    c) upgrade wood filled towers to ceramic towers, or replace fill,
    d) absorption to vapor compression systems,
    e) single stage absorption chillers to two stage systems,
    f) hermetic with open compressors (Ref. 1),
    g) high lift single stage compressors with two stage with flash intercooling.

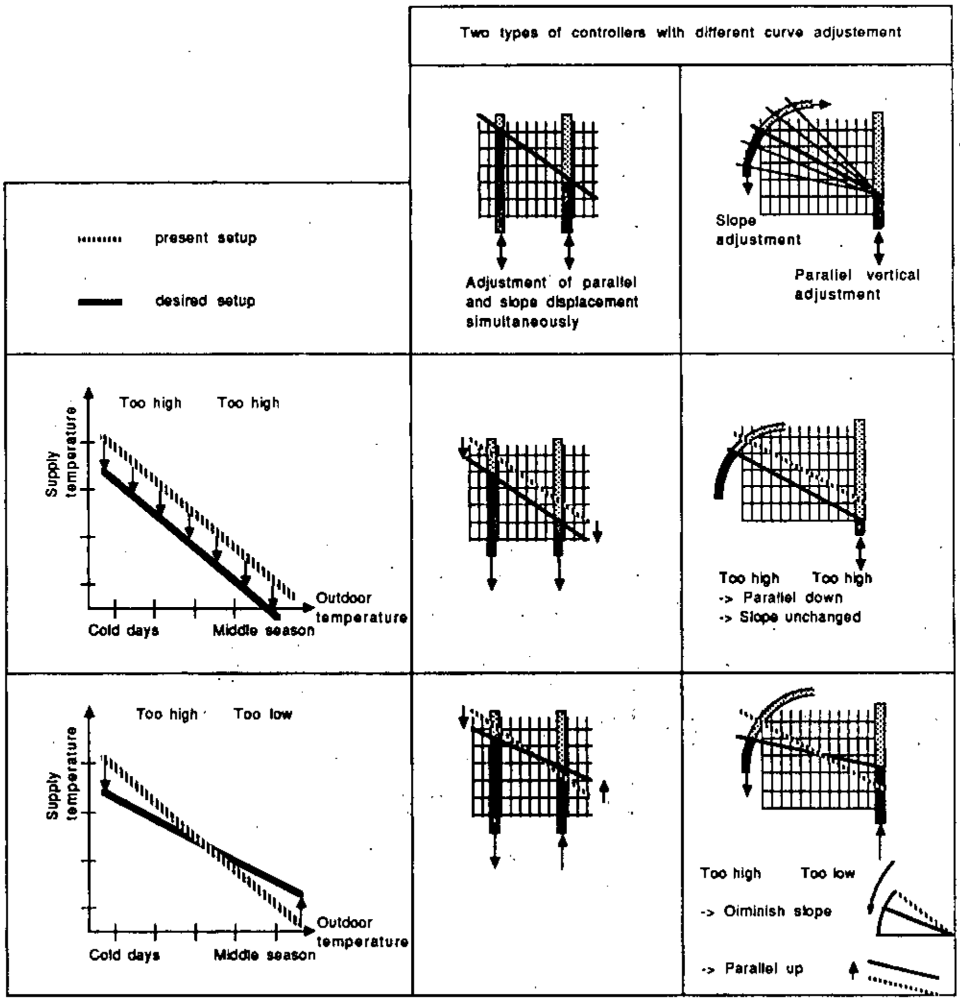


Figure 2.3.C - Typical operations on control systems

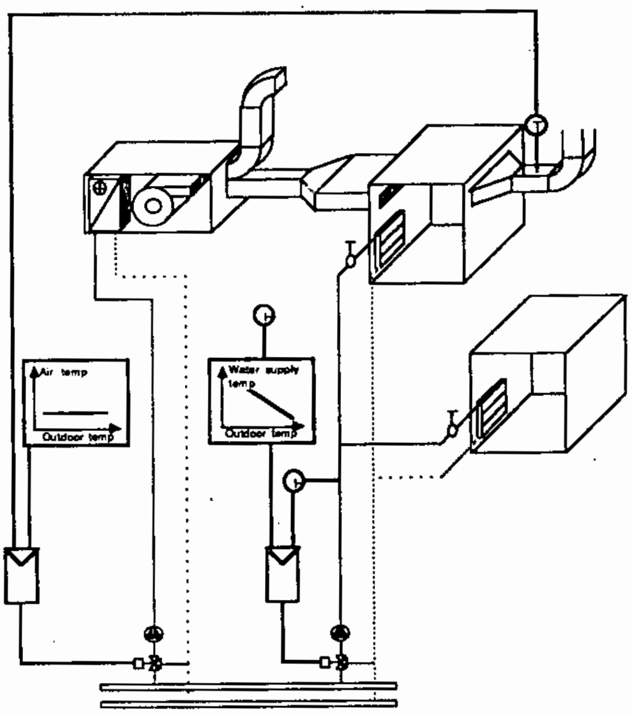


Figure 2.3.D - Usual configuration for stating heating and ventilation

In this case, if one switches off the ventilation, the ambient temperature will be too low.

The second usual configuration is (see Fig. 2.3.E):

- Static heating: thermostatic valves, water supply temperature dependant upon the outdoor temperature
- Ventilation: fixed blown air temperature

Space heating provides the energy to reach the desired ambient temperature and the air is blown just for air change. In that case when one switches off the ventilation, the ambient temperature is maintained.

In this case, if you decrease the supply temperature of the static heating, you will save energy because the blown air temperature remains constant, whatever the ambient room temperature is.

<u>2.3.2.2 Domestic hot water</u>

This part is treated in detail in Booklet III.

<u>2.3.2.3 Process heat</u>

<u>2.3.2.3.1 What to do and how to do it</u>

In the area where one uses process heat like laundry, kitchen, central sterilization, high temperature heat is used.

In the area where some of the consumers get temperatures that are too high as well as pressures that exceed their needs.

It is therefore very important to reduce the supply temperature or pressure to their minimum levels, while ensuring the required process is not compromised.

This will allow to reduce the average line temperature and thereby to reduce the piping losses.

The line losses in the supply and condensate return are dependant upon the temperature level and the quality of insulation (see § 2.4.1.1).

By an adjustment of the pressures in the different distribution lines, as per consumer requirement losses will be reduced.

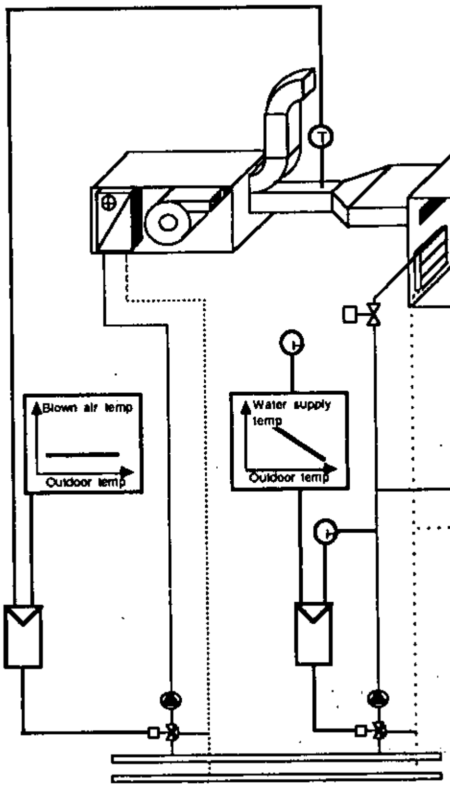


Figure 2.3.E - Usual configuration for the heating and ventilation constant temperature

For steam, for each separate supply line, one has to try to adapt the pressure reducer to the need.

Get in touch with the concerned peoples and try to find out the minimum level at which you can bring the temperature of pressure.

For that you have to adjust the pressure reducer to a lower value and check at the consumer level if it is still OK.

Do it when the consumer has its maximum demand, like that you are sure that it will be sufficient at any time.

2.3.3 Operational changes of the heat distribution

After that adjustment of the control system is completed, one can still go on further with changes in the operational patterns of the heat distribution.

That is for example:

- Closing the steam supply out of operating hours in kitchen, laundry, etc.

- Reduce the supply temperature of the static space heating.

- Reduce or switch off air flow rate in VAC systems (with the help of specialists).

- etc.

Before any operational change be sure that it will not create problem like too low temperature, or worse, inversion of the pressure balance in critical zones, where allow bacteriological level kept.

2.3.3.1 Space heating and ventilation

A) Space heating (alone)

In most cases it is possible to reduce the ambient temperature by night. This is done with the help of control systems with adjustable setpoints with a programmable clock.

With a night setback, the ambient temperature looks like in the Fig. 2.3.F.

This is done by a decrease in the water supply temperature night time, and a higher temperature early morning.

B) Space heating and ventilation

This part is not meant for guiding in VAC systems but only to show that if one put night setback on the static heating system, one has to be careful with the interaction between static heating and VAC system. While thinking that one is saving energy, one can loose energy if one does not really understand these interactions.

About the possibility to switch off or reduce air flow rates of VAC systems during nights, one has to see the chapter concerned with VAC.

If one can switch off the VAC system during night, it comes to the same as in § 2.3.3.1, A).

If the VAC system remains in operation round'clock, then one has to proceed as follows:

1. First see wether it is possible to reduce the air temperature (like in places where nobody stays).

2. Secondly remember that often a heating loop covers areas without VAC system, and then see if the non ventilated part are much bigger (see Fig. 2.3.A and imagine that the bedrooms are not ventilated).

If it is the case, it is advantageous to reduce the static heating temperature, even if there will not be any saving in the ventilated parts.

Because the energy saving in the non ventilated parts will be bigger than probable energy losses in the small ventilated parts.

If the control system is already equipped with a night setback, control if the night setback is OK or if it is too low. You can do that with a thermohygrograph.

Then control the morning reheating period duration.

It should not create an unnecessarily high ambient temperature, but should preheat fast enough (see Figure 2.3.G).

This has to be adjusted following the control system characteristics.

It is important to keep in mind that during the reheating period, the power demand to the central plant increases. One has to see wether it is possible to put reheating of the most important energy consumers stage by stage.

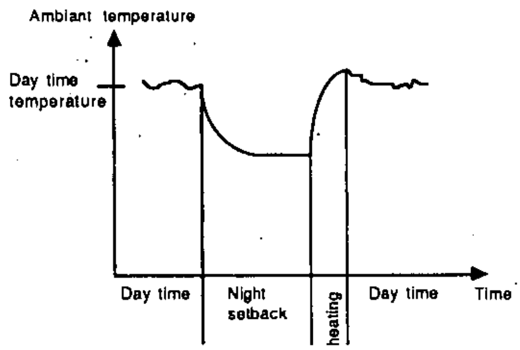


Figure 2.3.F - Night set back; ambiant temperature

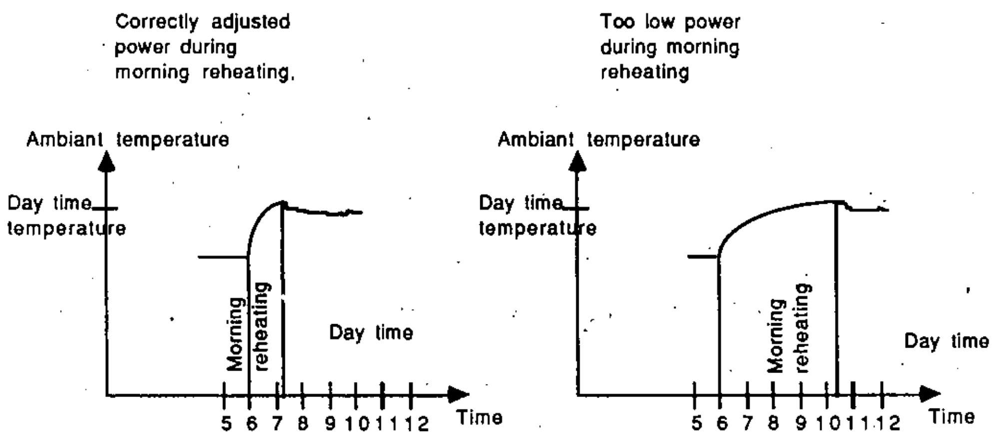


Figure 2.3.G - Morning reheating period

As shown in Fig. 2.3.A, one has to remember that some areas of different temperature level requirement are heated by the same loop. Therefore it is always necessary to see where the night setback is the most critical to do, before changing set points (that is see where the safety and comfort level is the highest required).

2.3.3.2 Process heat

Out of working hours, the energy supply for the technical processes like laundry, kitchen, sterilization can be switched off, but in the case of a steam sterilization unit in a surgery theatre where it should be operational at any time (see also Booklet V).

Like in the case of HVAC systems, it is important to open the supply in the morning stage by stage.

This will avoid overload of the central plant. It is very often believed that a steam boiler for example is undersized. But usually, it is a wrong statement because the preheating period of all the consumers occur at the same time. So, by installing programmable clocks and, putting the preheating periods one after the other stage by stage, one can avoid very often to switch on a steam boiler for few minutes only, which will not be in operation after because no more needed (see Figure 2.3.H).

2.4 How to save energy with modifications

2.4.1 Retrofit of the network

2.4.1.1 What to do and how to do it

Simultaneously to the work performed on the operational side of the distribution network, one can reduce the distribution losses by an improvement of the lines insulation.

According to calculation on a high temperature network, the annual energy saving obtained by the insulation of a DN 100 valve is equivalent to the annual energy consumption for the heating of several single bed rooms.

The priorities for reinsulation are:

- high temperature lines like steam supply.
- lines outside of the heated area, and/or in ventilated areas.

Outside of heated areas most of the energy released by the distribution lines is lost. In ventilated areas, the energy released by the distribution lines is taken away by

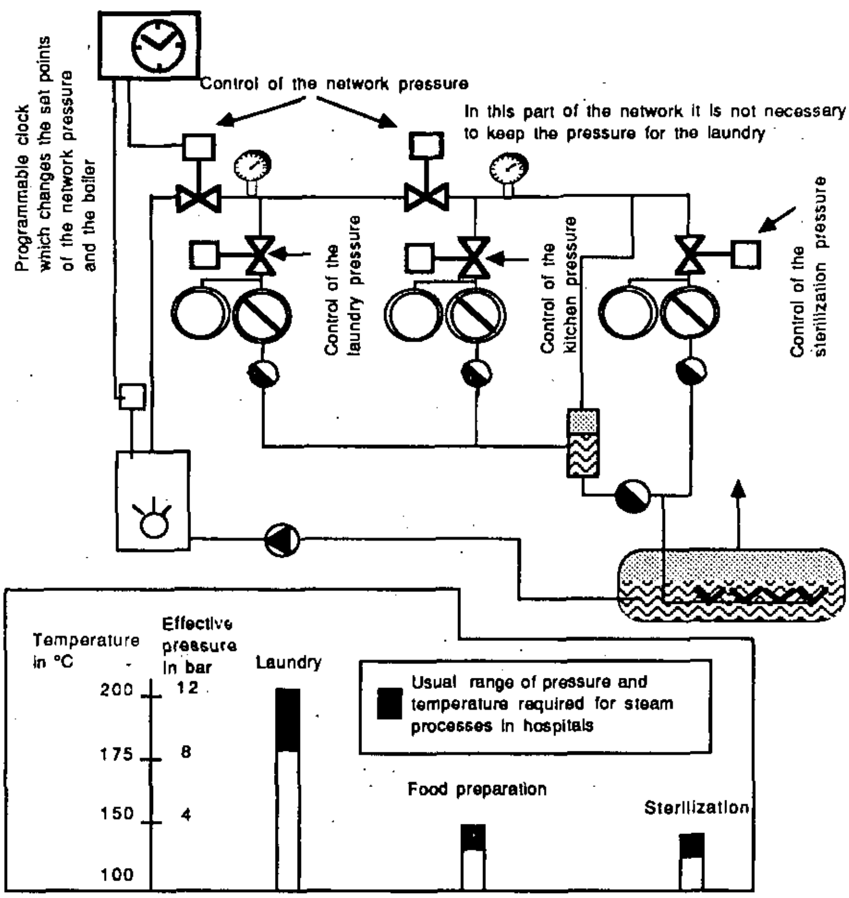


Figure 2.3.H - Programable cloack to change the set points of the network pressure and boiler

the VAC system, but if the control system takes into account internal sources.

Even if some parts of the distribution network are inside non ventilated areas, the network losses are partly recovered only. The reason is that, in Summer, the energy lost will be taken away through opened windows or increase the cold demand in case of cold air conditioning.

One has to assess the economic viability of the insulation to install.

But for any insulation job performed by the hospital staff, and if the insulation material (glass or mineral wool) is bought in bulk and then put in self made casing, the pay back period will be less than one year in any case.

The procedure to follow for economic viability is described below:

1. In order to be able to estimate the losses, determine for each sector of the network the average supply and return temperature of the lines during the year.

   Using the global schematic diagram, identify the sectors in which the temperature is the same at a given moment.

   There are three different kinds of temperature level in the lines:

   - Outdoor dependant temperature - Fig. 2.4.A
   - Outdoor dependant temperature with DHW - Fig. 2.4.B
   - Regular cycle temperature (process) - Fig. 2.4.C

   Determine the yearly heating duration in hours which corresponds to the period during which the lines are maintained at high temperature.

   This is true only if the circulating pumps are switched off during summer, and that consequently, the lines are at ambient temperature during this period.

   One has to calculate the average fluid temperature during the heating season.

   One can estimate it following this method:

   - Get meteorological data like the average outdoor temperature during the heating season. It can be

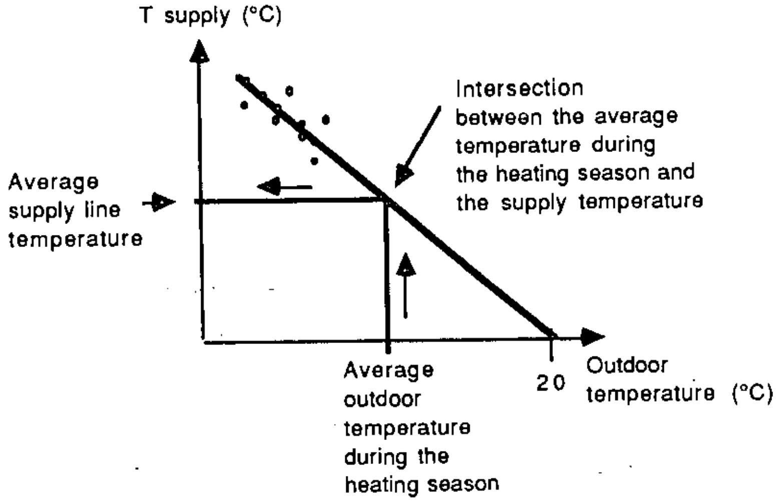


Figure 2.4.A - Average supply temperature

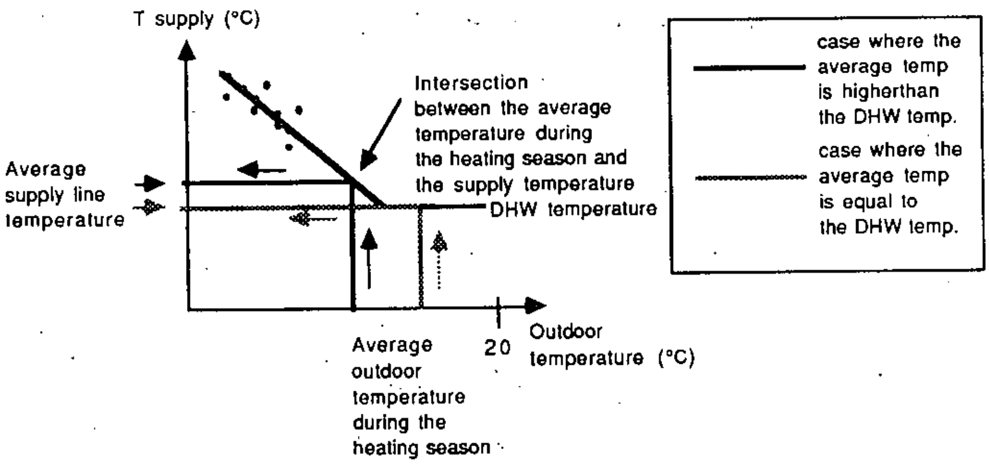
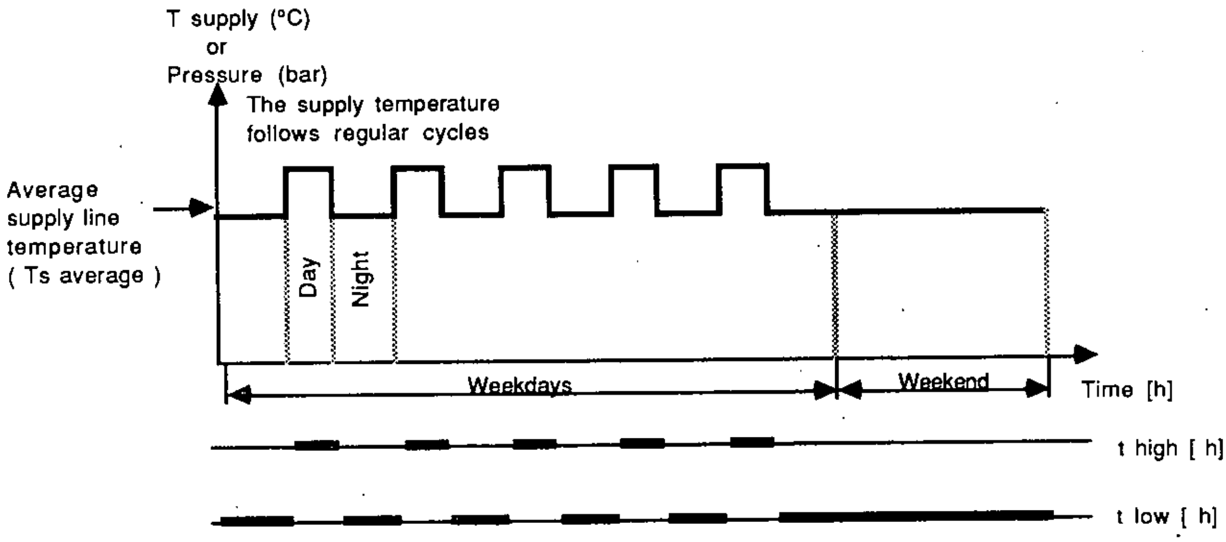


Figure 2.4.B - Average supply line temperature for heating and DHW



$$\text{Ts average} = \frac{\text{Ts high} * \text{t high} + \text{Ts low} * \text{t low}}{\text{t high} + \text{t low}}$$

Where :

t high is the time during which the supply temperature is high

t low is the time during which the supply temperature is low

Ts high is the high supply temperature

Ts low is the low supply temperature

Figure 2.4.C - Average supply line temperature regularly time dependant

obtained from the meteorological services.

- Get the maximum supply temperature for the cold days of the year.

If you do not know it, you have to measure it few times during very cold days day time.

Then plot it versus outdoor temperature, as shown in Figures 2.4.A, 2.4.B and 2.4.C.

In the scatter of point estimate a mean value.

Then draw a line from that point to 20°C Outdoor temperature.

Draw a vertical line from the average outdoor temperature during the heating season. The intersection gives the average line temperature.

In this case of process heat and variable set temperature like in a steam network for example, one can compute the average temperature following this method:

One must identify the different periods and their duration

The return can be estimated:

- steam: condensate temperature corresponding to the pressure.

- water: roughly 10 (°C) below the supply.

2. Determine the characteristics of the existing lines (insulation) and of the valves (leak), and check their quality.

Once you have determined an average temperature of the different network sector, you must analyze the quality of the insulation in different parts of the network and find all the places where there is no insulation are definitely to be insulated.

Quality of insulations and their characteristics

There are mainly two kinds of insulation materials:

- very old like cotton with plastic strips around or hemp
- recent like glass or mineral wool with a plastic or aluminium shell or polyurethane form

These values are valid only if the insulation is air tight, that is that if there is no air flowing between the lines and insulation.

3. Calculate the annual energy losses, and energy savings given by insulation.

First calculate the energy losses of the non insulated parts like pipes, valves, flanges, etc.

It is most likely very profitable to insulate any non insulated part, because the energy saving will be substantial.

Any insulation work on short distances can be made by yourself, it decreases very much the costs.

For valves, flanges, you can make the insulation yourself instead of buying special item for that.

If you do that the pay back period will be less than one year in any case.

For insulated pipes you can use the diagram of the Fig. 2.4.G.

For insulated valves, flanges, you can use the Figure 2.4.D giving an equivalent pipe length to each valve or flanges, and the diagram of the Figure 2.4.F.

For insulated parts compare it with the standard insulation thickness, which are near by the to day economic optimum (see Figure 2.4.E).

Unless the existing insulation be less than half of the standard thickness, it is not worth to calculate the energy savings with a new insulation, if the thickness is less than half of the optimum value, calculate the energy savings you could get with the diagram after.

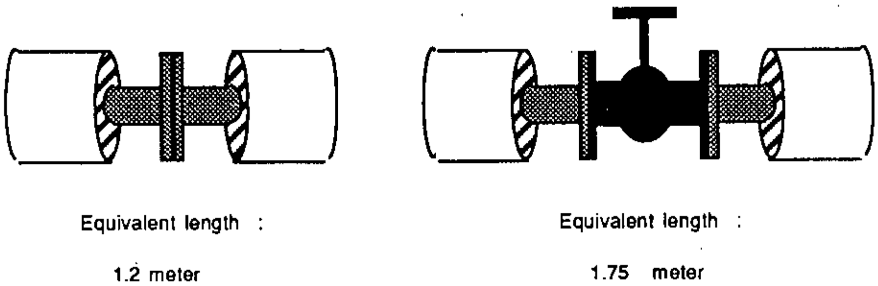


Figure 2.4.D - Equivalent length to an uninsulated pipe of the same nominal diameter

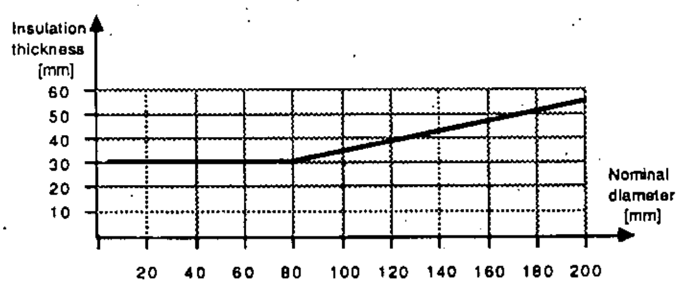


Figure 2.4.E - Near by optimum insulation thickness

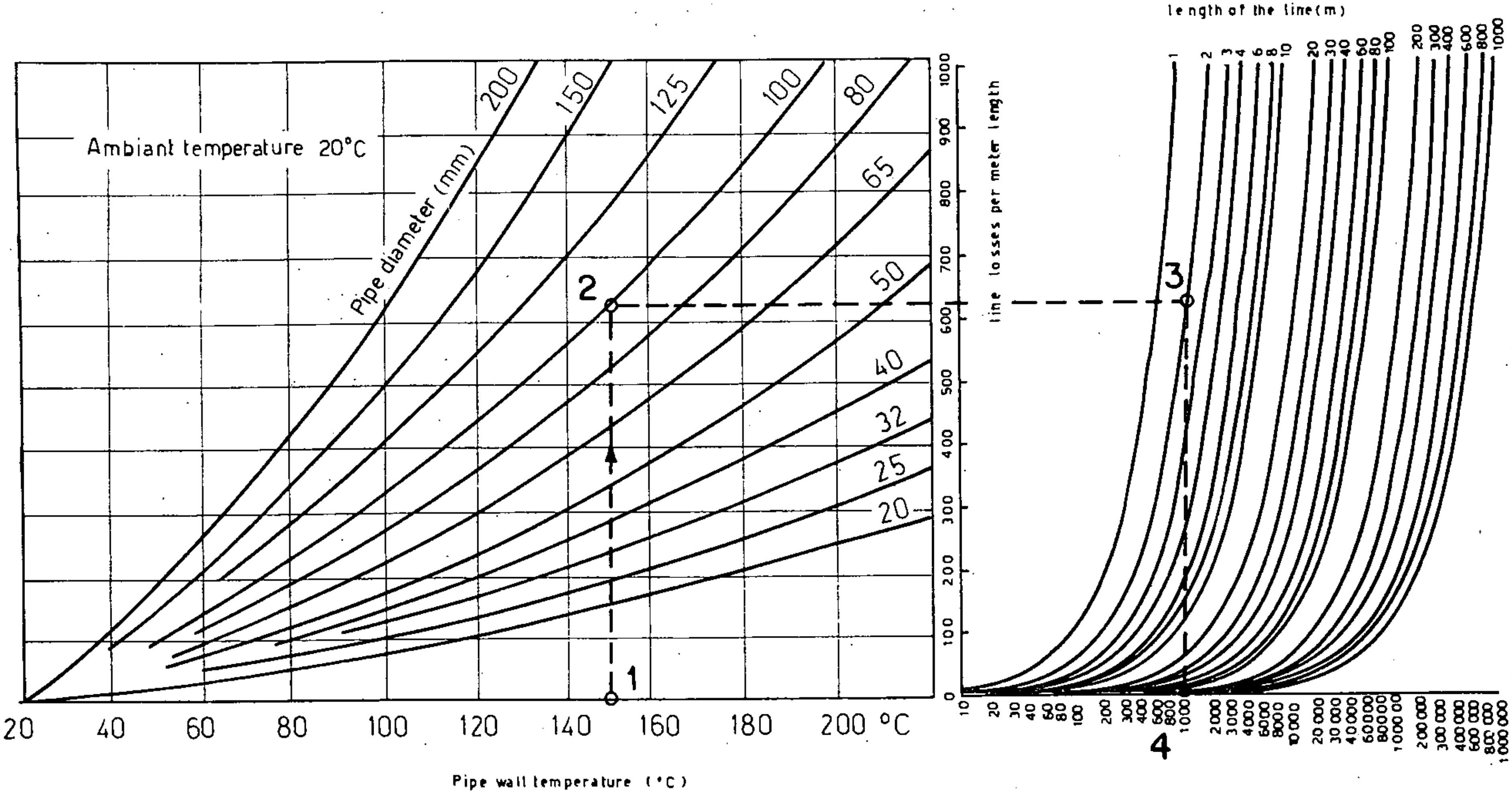


Figure 2.4.F - Energy losses of uninsulated pipes

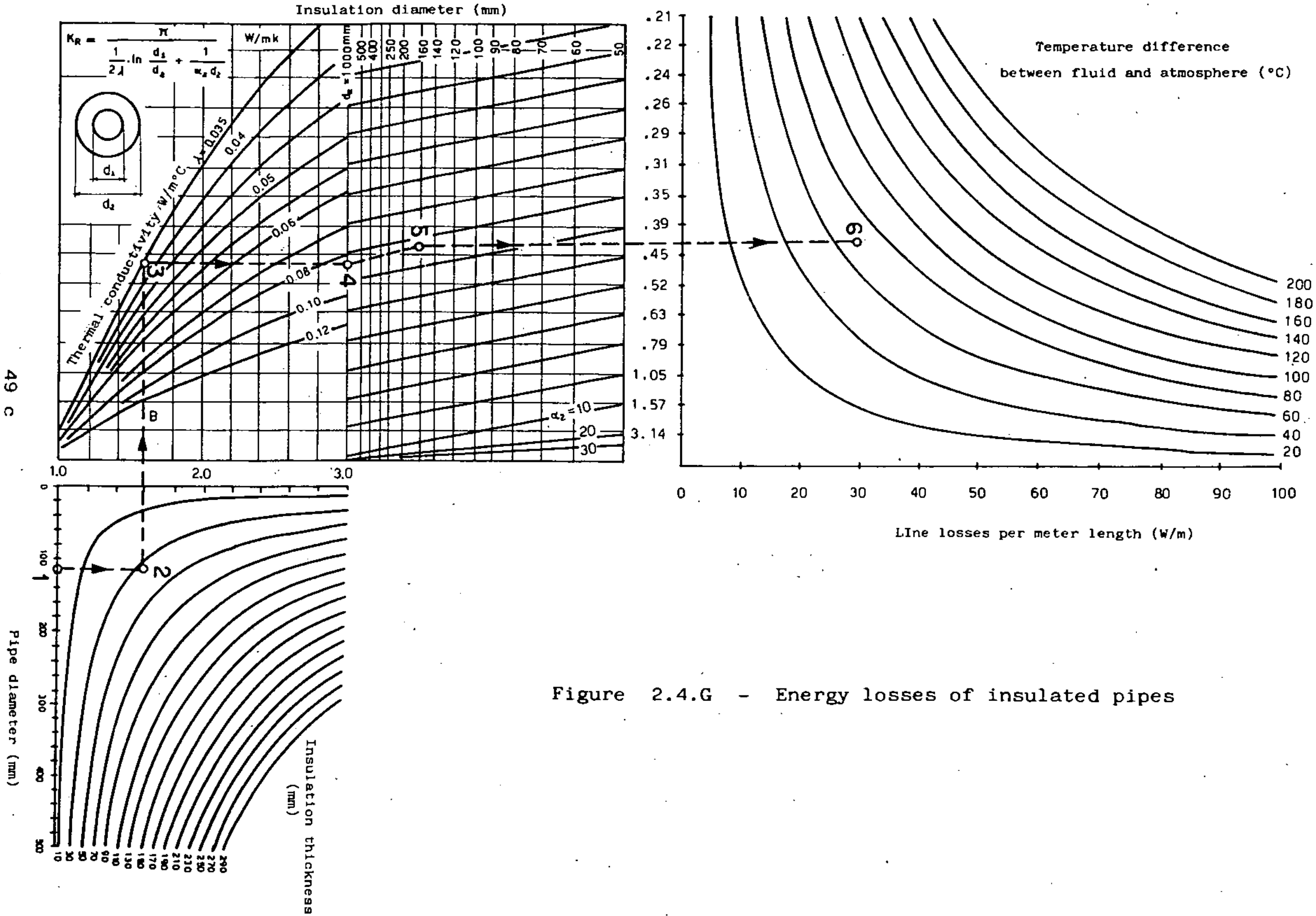


Figure 2.4.G - Energy losses of insulated pipes

In order to assess the energy saving potential, recalculate the energy losses with the insulation thickness for the pipe diameter in the diagram.

The difference between before and after gives the energy saving.

(One can estimate that uninsulated parts loose ten times more than insulated parts in steam network).

To get an idea of the saving potential, compare it in the Figures 2.4.F and 2.4.G.

4. Get the costs of new insulation for the different parts. Never forget that any self made job is much cheaper than to buy ready made material.

5. Compare it with the energy savings and calculate the pay back period.
   Any pay back below 5 years must convince you and the administrative peoples to do the work.

This kind of procedure can be performed separately for different parts of the network.

Start with the highest temperature lines like steam, etc., and especially in places outside of the heated area, and where there are big valves, flanges uninsulated.

The return average temperature can be estimated at 10 (°C) below the supply temperature.

<u>Outdoor temperature with DHW</u>

Same procedure as before but the heating curve must be limited to the bottom by the DHW temperature (Fig. 2.4.B). See also Booklet III, Chapter 4.

<u>Constant supply temperature</u>

In that case the line temperature is constant all over the year.

<u>Regularly time dependant temperature</u>

See Figure 2.4.C.

CHAPTER 3. COLD GENERATION

3. Introduction

This section describes the hospital central cold generation system. The details of the operation of the key components of the central plant are outlined. Energy aspects of the various system choices are discussed followed by examples of operational or system changes that are possible. Energy conservation opportunities are then discussed with an initial emphasis on operation and maintenance ECOs progressing through system improvements and finally treating replacement of the system or installation of major new equipment.

Those features of the cold generation system that involve cooling individual zones and rooms of the hospital are treated in Booklet III, Heating, Ventilating and Air Conditioning. Distribution of chilled water will be discussed in that Booklet as well as in this section.

Although not consuming the same amount of hospital energy as the heat generation component, the removal of heat using the cold generating plant often finishes second in those climate zones that require cooling. In those hospitals, space cooling may consume up to 25 percent of the total energy.

Whether the hospital is designed to the latest energy codes or is of older design there is little influence on the cooling energy use component. The energy use in hospitals has been shown to be two and one-half times that of clinics or nursing homes, where these buildings are far more representative of typical building energy use. With this much energy expended, there are many zones within the hospital that must be cooled throughout the year. Operating rooms, medical equipment, intense lighting, food preparation are just a few of the reasons for the required cooling and the need for a central chilling facility. Central cooling systems are also justified because of special requirements for air cleanliness and isolation between zones so that it is often not possible to operate the hospital in the economizer mode, i.e., bringing in outside air to provide for all the cooling needs without complicating system design and attainment of local pressure requirements for the different zones in the hospital.

Versatility to meet local space temperature demands often requires ready access to a cooling source.The preferred approach is to make heating and cooling available to the majority of rooms and zones using a four pipe system.

This allows adjacent rooms to be heated and cooled simultaneously on demand.

Patient care can require this versatility, as well as the equipment activity in the various rooms. The cold media for these tasks is normally chilled water provided by a central chiller. The conditions provided in the rooms are discussed in Booklet III which includes Heating, Ventilating and Air Conditioning. The total cooling demand on the central chiller must be estimated accurately if the best performance is to be achieved. Intermittent operation or operation far from design for many of the individual components will lead to energy waste.

3.1 Description

The central cold generation facility may be designed on direct expansion of the refrigerant, chilled water or a combination of the two approaches. Key to all of these designs is the standard refrigeration or vapor compression cycle.

A diagram of this process with direct application to a central liquid chiller system is shown in Figure 3.1.A. In the ideal cycle a gas refrigerant, such as one of the Freon compounds, moves between the condenser and the cooler. Part of the cycle is at high pressure and part of the cycle is low pressure transforming the refrigerant from a gas to a liquid. The compressor and the expansion valve are two components in the cycle used to transform the refrigerant allowing the vapor compression cycle to provide the desired cooling.As shown in the figure, typical chilled water temperatures are approximately 7°C (44°F). Direct expansion, DX, is generally limited to smaller capacity systems (200 tons or less), and is based upon refrigerant piped directly to the site of the cooling load, or the design may use packaged units located at each site. Reciprocating compressors and air cooling are most common in DX designs. Economical 1 in first cost, the power demand is high due to high condensing temperatures and the compressor design. When DX systems use centrifugal or helical compressors with water-cooled condensing they are both energy efficient and low cost.

Chilled water systems are central units where refrigerant is used to chill the water which is then pumped to the individual sites. Certain features found in the hospital environment make the chilled water approach very desirable.

1. The systems are flexible and are easily adjusted to a new arrangement of loads;

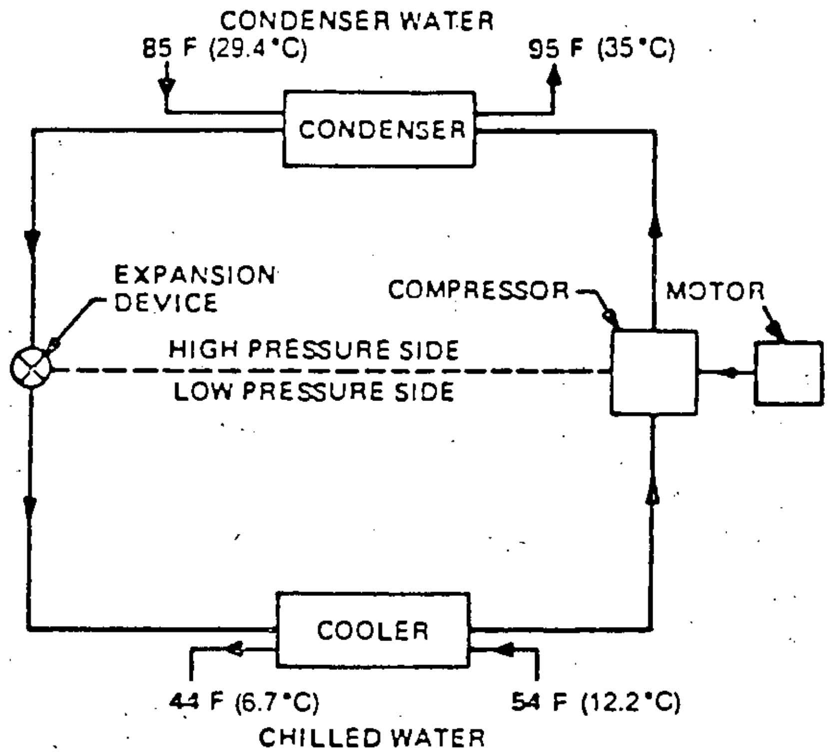


Figure 3.1A Equipment Diagram for Simple Liquid Chiller

2. Since they serve a large number of individual loads, the system can be designed for net demand, rather than accumulated peak loads. This load diversity can result in a 10 to 50% smaller total capacity to serve the same needs;

3. Since the units are centrally located, noise is removed from critical hospital areas;

4. Leaks of the refrigerant are easier to control (no lengthy piping runs) and are again removed from critical areas of the hospital;

5. Power demand costs are less due to item (2); and

6. Because of the central location, maintenance is easier and maintenance personnel intrusions into hospital activities are reduced.

Distributed placement of water chillers can also be used where loads are physically separated. This will reduce piping of chilled water but will reduce the capability to gain from load diversity. Use of a chilled water loop can regain the central chiller advantages.A medical center with a number of buildings can benefit from such an arrangement.With any loop design or chilled water circulation, adequate insulation on the piping runs is essential for good system performance.

Chillers based on the compression cycle may be designed in several ways:

- Positive displacement compressors of two or more cylinders: these tend to have higher friction, are more noisy, cost more to purchase and operate than rotary type units.

- Screw-type compressors are used in rotary helical chillers. These units are normally operated above atmospheric pressure, with direct expansion using refrigerant in the tube and water in the shell. There is good capacity control, and refrigerant can operate at high condensing temperatures (to 65 °C) making helical chillers well suited to heat recovery applications.

- Centrifugal chillers use turbo compressors with impellers that operate on a centrifugal principle. The flow of the refrigerant is continuous thereby increasing the capacity of this design over an equivalent sized reciprocating unit. There is very little noise or vibration with this equipment and its

versatility will make it the principal compressor discussed under components.
The chiller is illustrated in Figure 3.1.B which shows the compressor, condenser and evaporator.

- Absorption refrigeration is another approach to the design of a central chilling facility. The principle is that the refrigerant, in this case water, is vaporized.The cycle depends on operating under high vacuum conditions, and on the affinity of lithium bromide for water. This vacuum is provided in the sealed, factory-manufactured absorption equipment. A diagram of such an absorption water chiller is shown in Figure 3.1.C. These systems may be indirectly fired or directly fired. In the indirect firing version, steam at 10 atmospheres or water to 200 serves as the heat source to provide a chilling capacity to 2 000 tons. Direct firing system capacities go to 1 500 tons and the energy source is normally natural gas or process waste gas. The COP is much less than that of the vapor compression type chiller (i.e., 0.5-1.0 versus 2.7-6.2). The central cold generation facility consists of one or more chillers. Based upon consideration of redundancy, growth, and cost; decisions are made with regard to the number and size of the chillers in the central plant. Two half-size units will insure 50 % capacity in the case of failure of one unit. Flexibility in output allows modern large chillers to operate down to 15 percent load without shutting down, thus avoiding intermittent operation with resultant chilled water temperature variations.

Key components in such systems are described in the following.

3.1.1 Centrifugal Compressor

Typically a centrifugal compressor is used in the liquid chiller because it is not a constant displacement device, thereby offering a range of capacities to meet varying loads.Design features allow sizing of the centrifugal compressor for a variety of chilled liquid temperatures. The ability to continuously vary capacity to match a wide range of load conditions, in a manner that is nearly proportional to changes in power consumption, makes it a logical choice to achieve close temperature control and energy conservation in hospitals. Because of this flexible operation, the centrifugal chiller remains on for long periods with infrequent starts. This means longer equipment life due to reduced wear on bearings and other critical components.

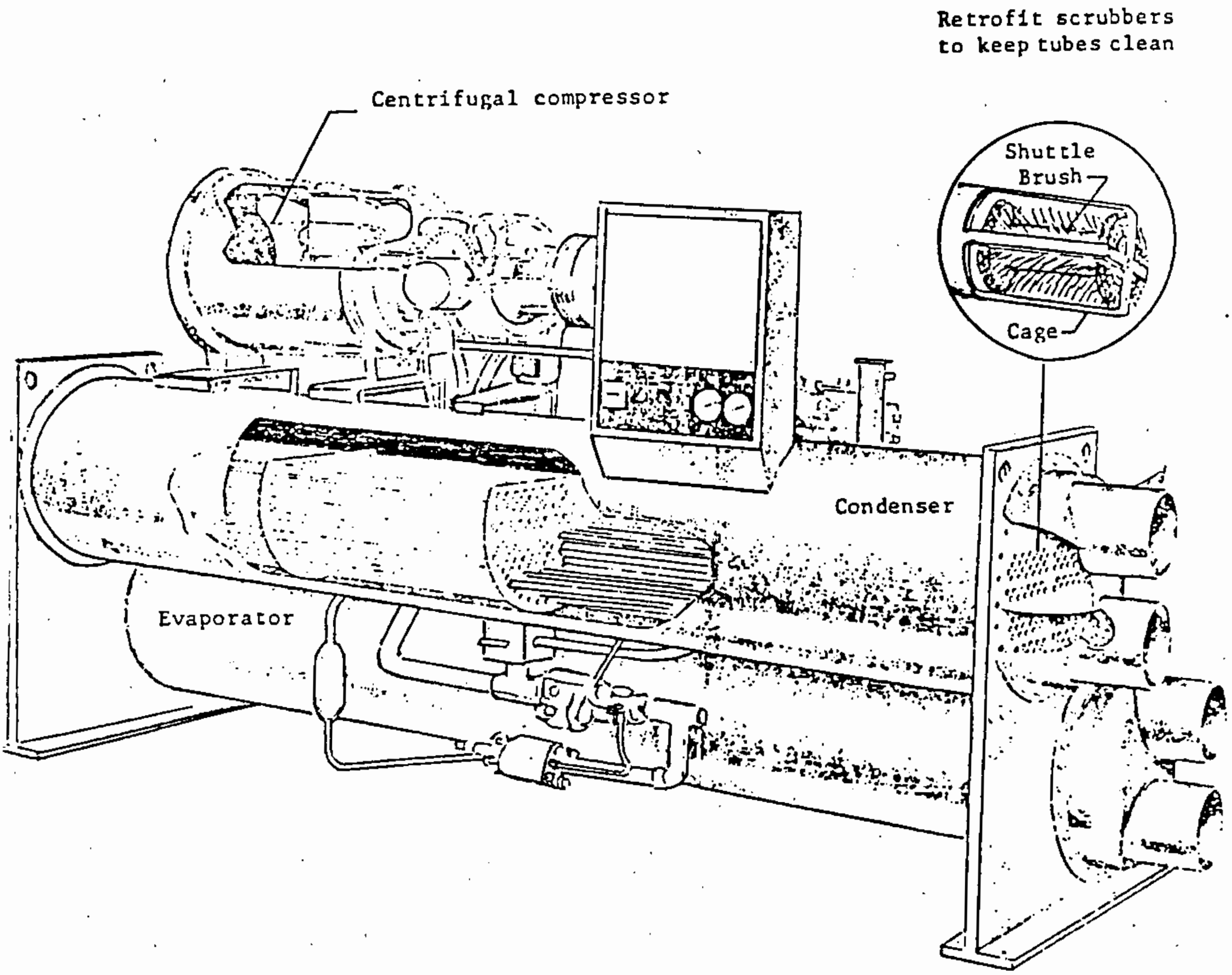


Figure 3.1B Electric motor driven centrifugal chiller showing details within the condenser.

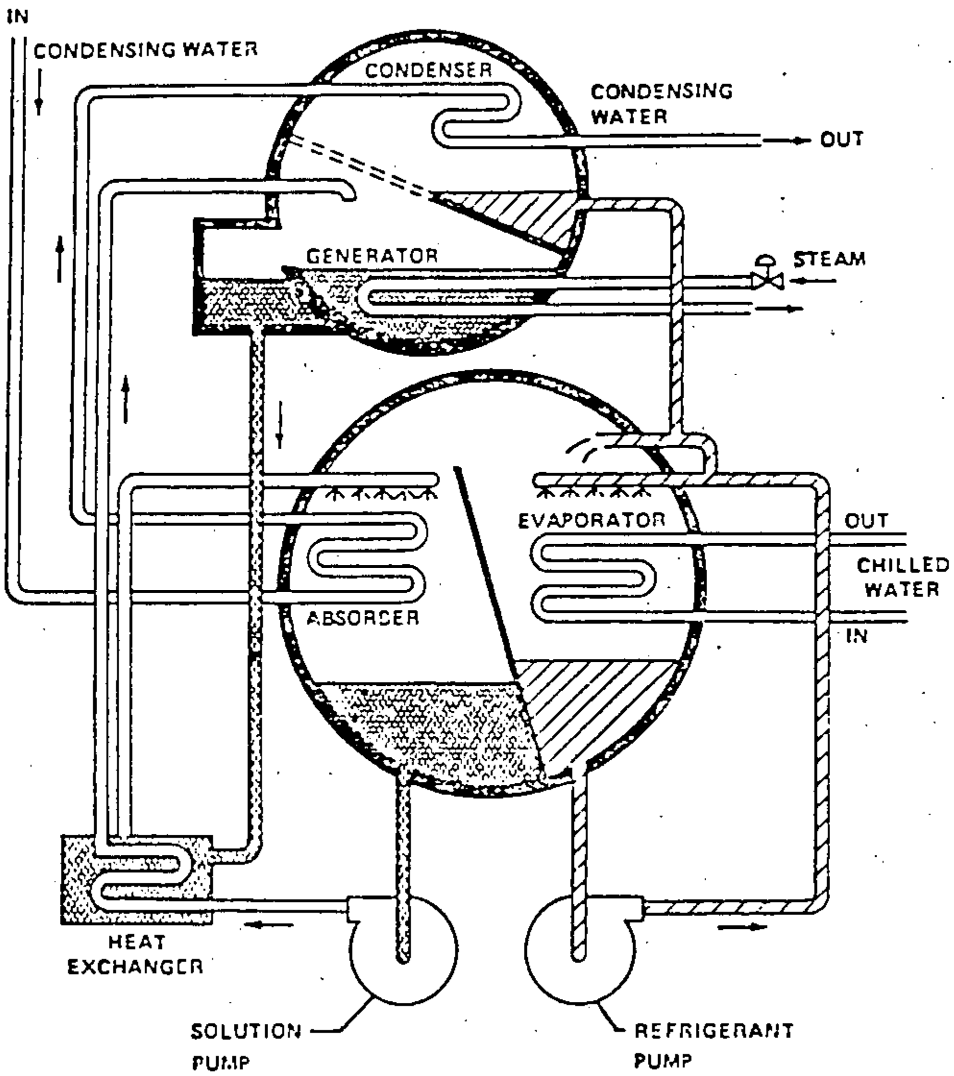


Figure 3.1C Diagram of Two-Shell Lithium Bromide Cycle Water Chiller

3.1.2 Condenser

The condenser is normally water cooled, with refrigerant condensing on the outside of copper tubes. Air-cooled units can also be used with high-pressure refrigerants but with a considerable increase in energy use. These operating costs must be balanced against water-cooled systems using cooling towers and condenser water circulating pumps. Details of the condenser cross-section with tube scrubber portion of the chilling equipment are found in Figure 3.1.A.

The cooling tubes normally form a bundle with water passing from one end of the manifold to the other. Because of buildup of deposits on the inside of the tubes the heat transfer and the performance of the condenser will normally decrease over time.To restore performance the manifolds must be removed and the tubes cleaned either mechanically or chemically. To postpone such cleaning procedures, treated water in a closed loop system may be used. Another solution is to alternate the water flow direction and scrub the internal tube surfaces with nylon brushes that shuttle back and forth with the water flow. Such a device is shown as an insert to Figure 3.1.A.

3.1.3 Evaporator

Outwardly resembling the condenser portion of the chiller (as seen in Figure 3.1.B) the chore of the evaporator is to transfer heat from the circulating water loop to and from the spaces in the building so that the water will be chilled to the proper temperature when it returns to those spaces. Depending on the system, the temperature of the chilled water may vary from 5 to 13 °C.

3.1.3.1 Cooling Towers

An important component of the central chilling plant is the cooling tower which is used to dissipate heat from water-cooled refrigeration and air conditioning systems. Typical cooling tower designs are shown in Figures 3.1.D and 3.1.E.

Heat and mass flow are used to cool water. The water to be cooled is exposed to the outside air by sprays splashing or running the water through heat transfer media (fill), where air and water are in intimate contact. The thermal performance of a cooling tower is affected by the relative humidity of the entering air.

The amount of cooling of the water equals the heat transferred to the atmosphere and is limited by the thermal capacity of the tower. Thus the cooling tower should be matched to the central chiller capacity, considering when

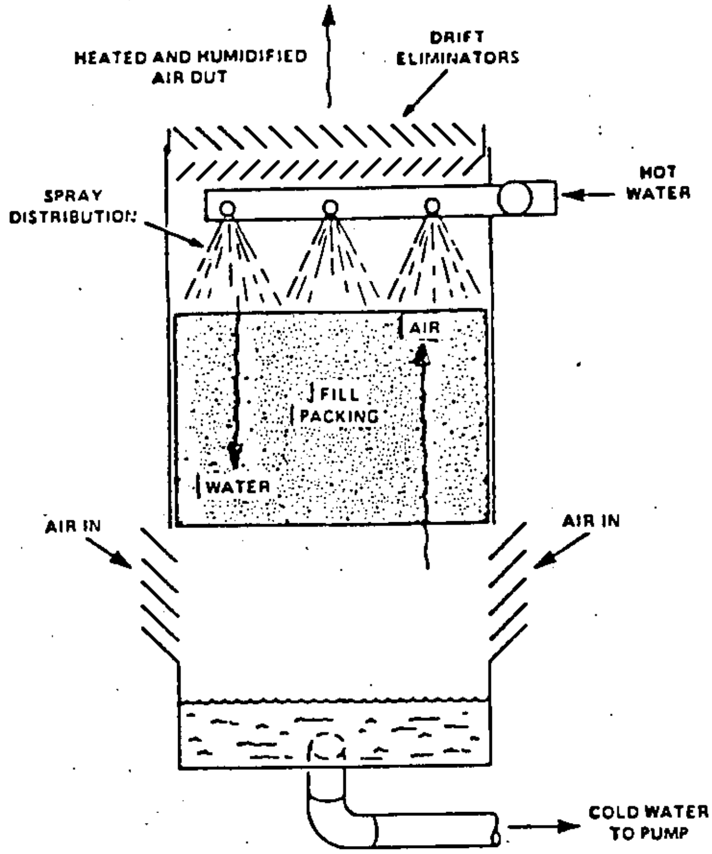


Figure 3.1.D - **Direct-Contact Evaporative Cooling Tower, Showing Counterflow Water-Air Relationship**

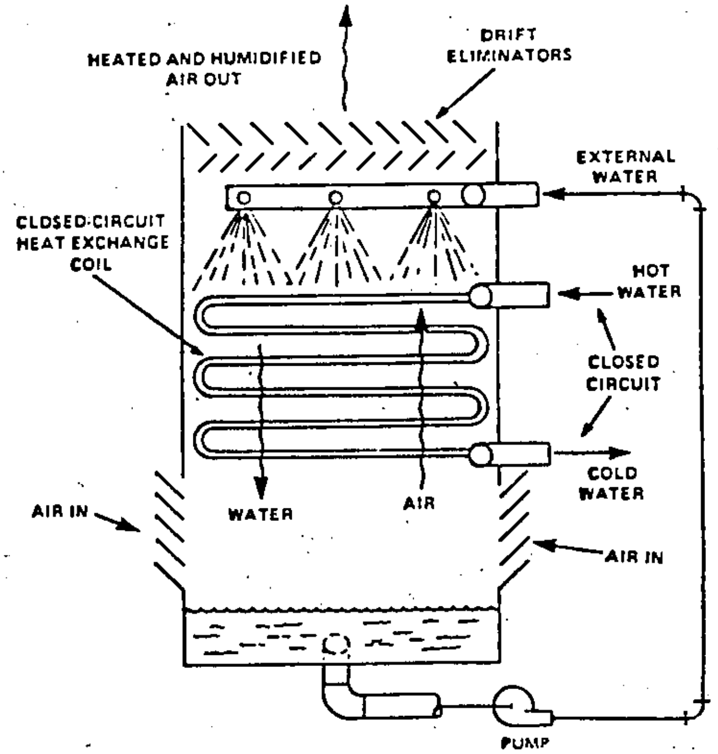


Figure: 3.1.E - **Indirect-Contact Evaporative Cooling Tower, Showing Counterflow Water-Air Relationship** peak loads are anticipated and under what weather conditions. The two types of cooling towers shown in the figures work on two different principles.

Figure 3.1.D shows the direct contact approach where the water is exposed to the cooling effect of the air resulting in heat transfer to that air. In contrast, Figure 3.1.E shows two separate fluid circuits in this type of cooling tower which is often referred to as a closed circuit fluid cooler.

Evaporative cooling of the spray that bathes the closed circuit heat exchange coil results in the heat being transferred to the air passing upward through the tower. The closed circuit coil allows for the best control of the conditioning of the water in that loop. The fill packing in the direct contact evaporative cooling tower (Figure 3.1.D) may be of the splash-type or film type as illustrated in Figure 3.1.F. Counter flow and cross flow paths are used in these designs.

These are by no means the only type of cooling tower but rather represent common design approaches normally augmented by fans to control and improve the air cooling process.A typical fan augmented design is shown in Figure 3.1.G.

3.1.4 System Efficiency

System efficiency in cooling systems is normally stated as a coefficient of performance, COP, which is defined as the energy out divided by the energy into the system. Limited by basic thermodynamic relationships, the COP of operating equipment can vary from the very inefficient COP, approaching 0, to very efficient with COP greater than five. Figure 3.1.H is a table of water chilling systems which points out these COP variations as well as indicating speeds of motor rotation, capacity, type of refrigerant, conditions in the evaporator and condenser, the condensing media and typical applications.

Hospital applications cover many of the units cited.

The actual layout for a chilled water distribution system with multiple chillers unit pumps, primary pumps and secondary pumps and coils is shown in Figure 3.1.I. The illustration points out the range of system complexity.

In addition to the basic system there is also an ability for heat recovery and interaction with heat generation and the heating system as described in this Booklet and in Booklet III. Some of these possibilities are outlined in Figure 3.1.J. Thermal storage is one way to reduce the high demand period due to space cooling based upon outside

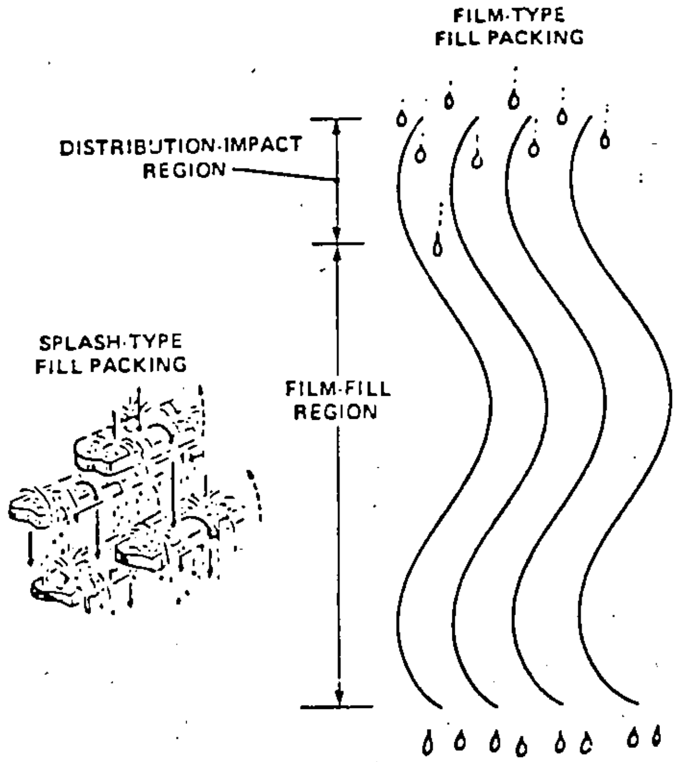


Figure: 3.1.F - Types of Fill

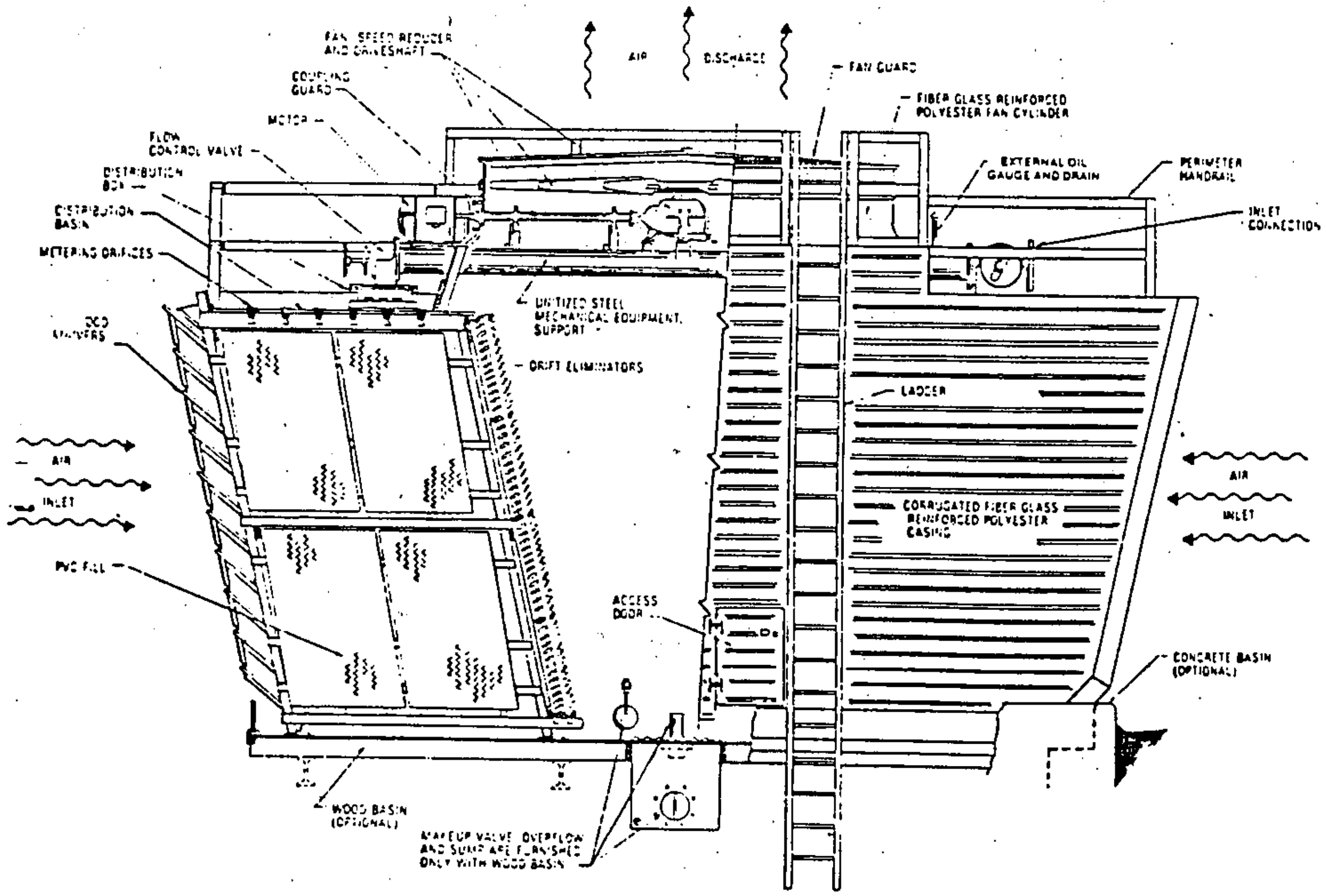


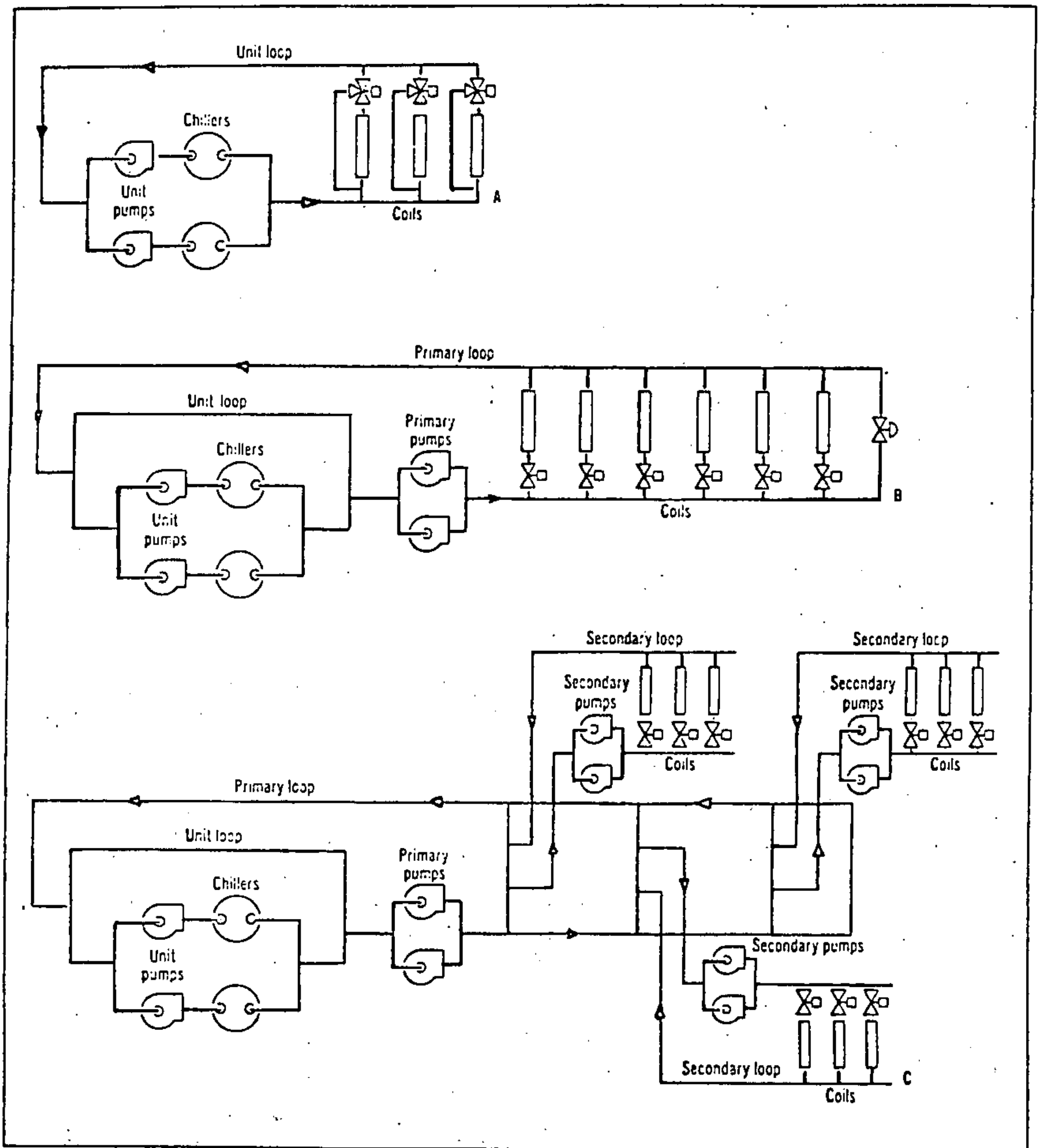
Figure: 3.1.G - Crossflow Mechanical Draft Tower

Characteristics of water chillers.

Type	Speed, rpm	Capacity range, tons	Typical refrigerant: Type	Operating pressures: Evaporator	Operating pressures: Condenser	Condensing media	Performance (COP)	Applications
Reciprocating								
Semihermetic	1750	20-200	R-22	65-75 psi	200-230 psi	Water	3.2-3.8	Commercial/industrial
Open	1750	20-150	R-22	65-75 psi	200-230 psi	Water	3.5-4.2	Cooling systems up to 200 tons with water or air
Semihermetic	1750	20-200	R-22	65-75 psi	235-300 psi	Air	2.7-3.0	Cooled condensers
Open	1750	20-100	R-12	35-42 psi	150-180 psi	Air	2.9-3.2	
Rotary								
Helical screw								
Hermetic	3500	50-480	R-22	65-75 psi	200-230 psi	Water	4.5-6.0	Commercial cooling systems
Open	3500	120-750	R-22	65-75 psi	200-230 psi	Water	5.0-6.0	Industrial cooling systems
Centrifugal								
Direct drive hermetic	3500	100-2000	R-11	14-16 in. Hg vac	8-14 psi	Water	4.5-6.0	Commercial/industrial cooling systems over 150 tons
Open gear drive	5000 to 7500	150-8000	R-11 (1) R-12 (2) R-500 (2) R-22 (2)	14-16 in. Hg vac 35-42 psi 45-50 psi 65-75 psi	8-16 psi 117-145 psi 140-175 psi 200-230 psi	Water	4.6-6.2	Commercial/industrial cooling systems over 150 tons
Hermetic gear drive	6000 to 20,000	100-2000	R-11 (3) R-12 (4) R-500 (4)	14-16 in. Hg vac. 35-42 psi 45-50 psi	8-16 psi 117-145 psi 140-175 psi	Water	4.8-5.6	Commercial/industrial cooling systems over 150 tons
Absorption								
Direct fired	—	100-1500	Water	6 mm Hg abs	50mm Hg abs.	Water	1.0	Commercial/industrial cooling some units can be equipped with heat exchangers for generating heating hot water
Indirect fired (Steam, hot water)	—	75-2000	Water	7 mm Hg abs	7.5mm Hg abs.	Water	0.5-0.8	Commercial/industrial cooling where waste heat or steam is available

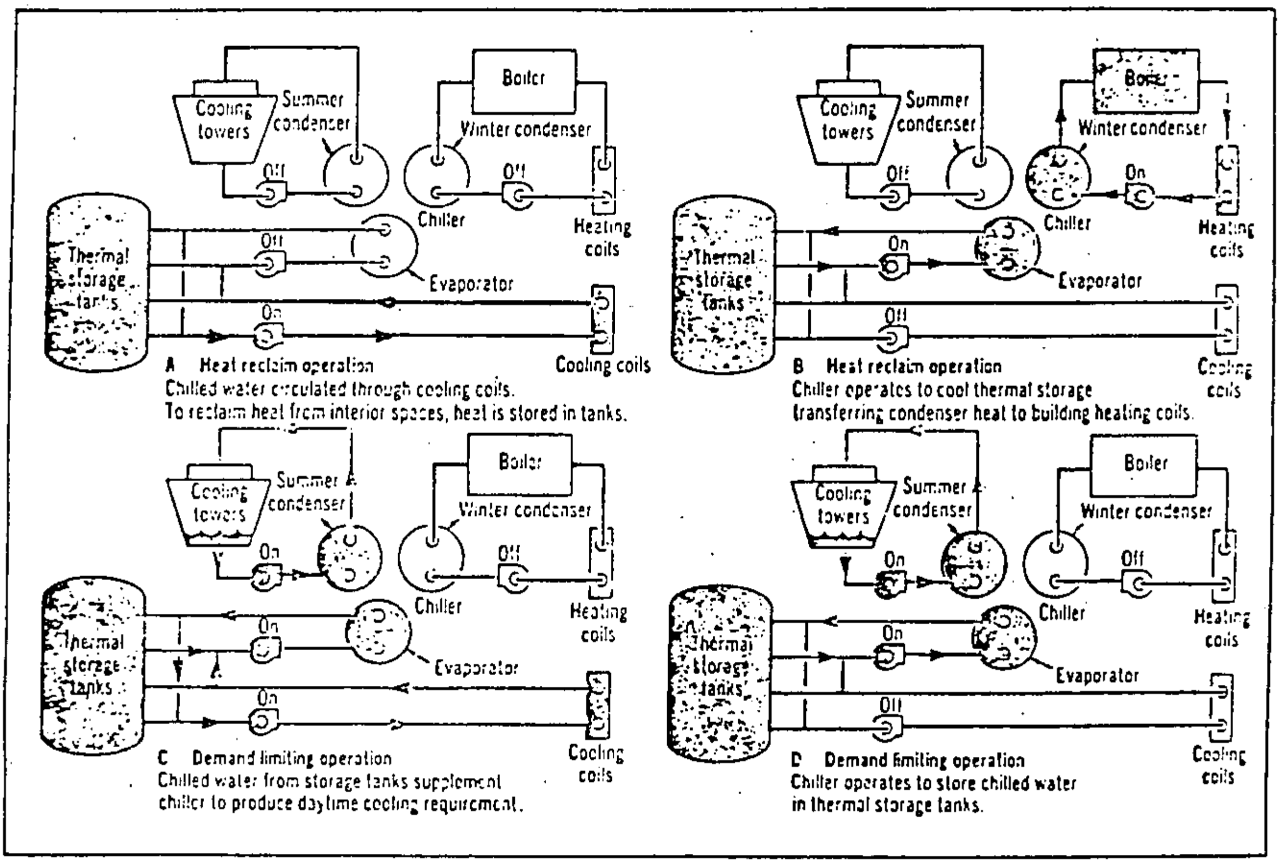
Notes (1) Up to 750 tons (2) Up to 2000 tons (3) Up to 1000 tons (4) 750-2000 tons

Figure: 3.1.H - Performance of Water Chillers



Chilled water distribution systems. The figures illustrate alternative hydronic configuration. A: Unit loop distribution for small systems; B: Unit loop with primary distribution for large single buildings; C: Unit loop with primary/secondary distribution most often used for groups of buildings such as college campuses.

Figure: 3.1.I - Chilled Water Distribution Systems



Figures illustrate the flow of chilled, hot, and condensing water of a combination heat reclaim and thermal storage system.

Figure: 3.1.J - Thermal Storage Used to Assit Cold Generation influences of weather, time of day and such important interior loads as the use of operating rooms and food preparation.

Since the centrifugal chiller is so versatile in load management it can provide extra cooling sent to storage in off peak periods to limit late afternoon demand.Demand charges amount to 40 % or more of typical electrical consumption charges in many U.S. cities, and although energy is not saved in the off peak cold storage, costs can be greatly affected. Ice storage is much more compact than water storage (approximately one-tenth the volume but requires ice making equipment that uses 30 to 80 % more energy.

Also important in the evaluation of the system efficiency is the heat rejection equipment using air or water-cooled cooling towers. Figure 3.1.K is a listing of the characteristics of this component looking at: capacity, air flow, electrical consumption and applications.

3.2 Strategy. Case studies

In the previous sections the key components of the central cold generation facility have been discussed. Now the discussion will concentrate on ways in which to gain the maximum efficiency from the system. Those items dealing with the air conditioning in individual zones will be discussed in Booklet III, although it should be recognized that the loads are closely linked to how one can best operate the cold generation system.

First, the general remark should be made that the central facility should allow excellent access to all equipment so that equipment can be properly serviced. This is a key factor in achieving a well operated facility. A second, and equally important feature, is that all key locations should be properly instrumented.The instruments must be accurate if controlled energy efficient operation is to be achieved.

Chilled water temperature is normally in the 5.5-7 °C range (although the range can extend from 5-13 °C). Moving to lower temperatures for a few local load requirements in the building can penalize the performance of the entire system. Adding local DX systems for special needs should be considered. If the normal operating temperature of the chilled water can be raised, system performance improvements can be achieved. If reheat systems are used, this delivered chilled water temperature should be as high as possible in keeping with local humidity requirements to minimize reheat.

Table —Characteristics of heat rejection equipment.

Type	Capacity range, tons	Air flow, cfm per ton	KW input per MMBtuh	Applications
Air cooled				
Air cooled condensers (propeller fans)	3-150 (1)	500-700	9.0-12.0	Commercial cooling systems where towers are not practical and for year-round systems where freezing of cooling towers is difficult to control as in extreme climates.
Dry coolers (propeller fans)	3-65 (2)	1000-1400	10.0-13.0	Can be used to cool condenser water or to directly cool chilled water in northern climates, not economical in southern climates
Water cooled				
Cooling towers				
Packaged induced draft (propeller fan)	5-1000 (3)	200-250	2.0-3.0	Ideal for small and medium size cooling plants. Somewhat less expensive than built-up towers but usually has a shorter life span.
Packaged forced draft (centrifugal fan)	10-400 (3)	200-250	4.0-6.0	Applicable to commercial/industrial cooling systems, especially adapted to indoor and restricted outdoor installations; very compact units, relatively quiet.
Field erected induced draft (propeller fans)	200-1500 (3)	200-250	1.5-2.0	For use with large water cooled systems. Towers can be built-up to 20,000 tons per cell; however, the most commonly used pre-engineered sizes range from 200-1500 tons.
Water spray type fluid coolers (centrifugal fans)	5-150 (3)	500-700	14-18	Minimizes water treatment requirements. Eliminates condenser freeze protection when used with water glycol solution. Can be used for direct chilled water cooling during cold weather.

Notes: (1) Larger units available when factory coupled to air cooled chillers. Data based on 95 F ambient, 115 F condensing temperature. (2) Data based on cooling condenser containing water glycol solution from 100 to 110 F at 95 F ambient. (3) Based on one cell; multiple cells available. Data based on cooling from 95 to 85 F at 78 F wb.

Figure: 3.1.K - Heat Rejection Equipment Characteristics

Condensing temperatures are normally specified at 25°C entering and 35°C leaving condensing water, with absorption chillers operating in the 25-40°C range. As the load or outside relative humidity decreases, cooling towers will be able to provide colder condensing water resulting in less energy use at the chiller. These temperature decreases are limited by possible compressor surging in centrifugal chillers and lithium bromide crystallization in absorption systems. Cycling of tower fans or varying fan speed is used to control the temperature.In colder weather, circulating the water through the fill with the fan off may prove sufficient. Temperature control may be achieved with a mixing valve.

Maintaining adequate water flow through the tower fill can prevent ice buildup in winter.With more than one tower this may mean shutting towers down to provide adequate flow to the operating tower.

Chilled water flow control in the primary and secondary loops can save pumping energy. The simplest method is to allow the primary pump to move upward on the pump curve causing pump head to increase as flow is reduced. A bypass is used to prevent overpressure. Another approach is variable speed drives which are becoming more common.

Energy optimization depends on many factors in the operation of the central cold generation facility.These factors are outlined in Figure 3.2.A which lists the components and what can be modulated.

Factors affecting energy optimization of a chilled water plant

System Components	Control Factors		
		Modulation	
	On/Off	Flow	Temperature
Compressors	x		
Refrigerant		x	
Condenser water			x
Chilled water		x	x
Unit pumps	x		
Condensing water pumps	x		
Primary pumps	x	x	
Secondary pumps	x	x	
Heat rejection fans	x	x	
Cooling air		x	x

Fig. 3.2.A - Energy Optimization of a Chilled Water Plant

Major changes in the central plant may also be worthwhile. Two examples are given.

Evaporative chilling may be used in those areas which have the right combination of temperature and humidity.As an example, once a new cooling tower was installed it was possible to substitute evaporatively-chilled for mechanically-chilled water. This should not be confused with replacing mechanically-refrigerated with evaporatively-cooled air. Electrical use was reduced by 21 percent.

Supply a Plate Heat Exchanger in parallel with the chillers. During winter operation, the cooling towers are connected to the plate heat exchanger with the chillers turned off. Control of the cooling towers is used to supply 7 °C condenser water. Termed "hydronic free cooling" this approach has provided three-year pay-back in a number of systems where it has been applied. The heat exchanger is shown in Figure 3.2.B.

Consider the use of ground water as a heat rejection medium. Many locations offer an easy access to ground water supplies when using closed systems. These ground water temperatures are often in the 12-16 range making this a very attractive way to achieve high performance COPs > 5. Local

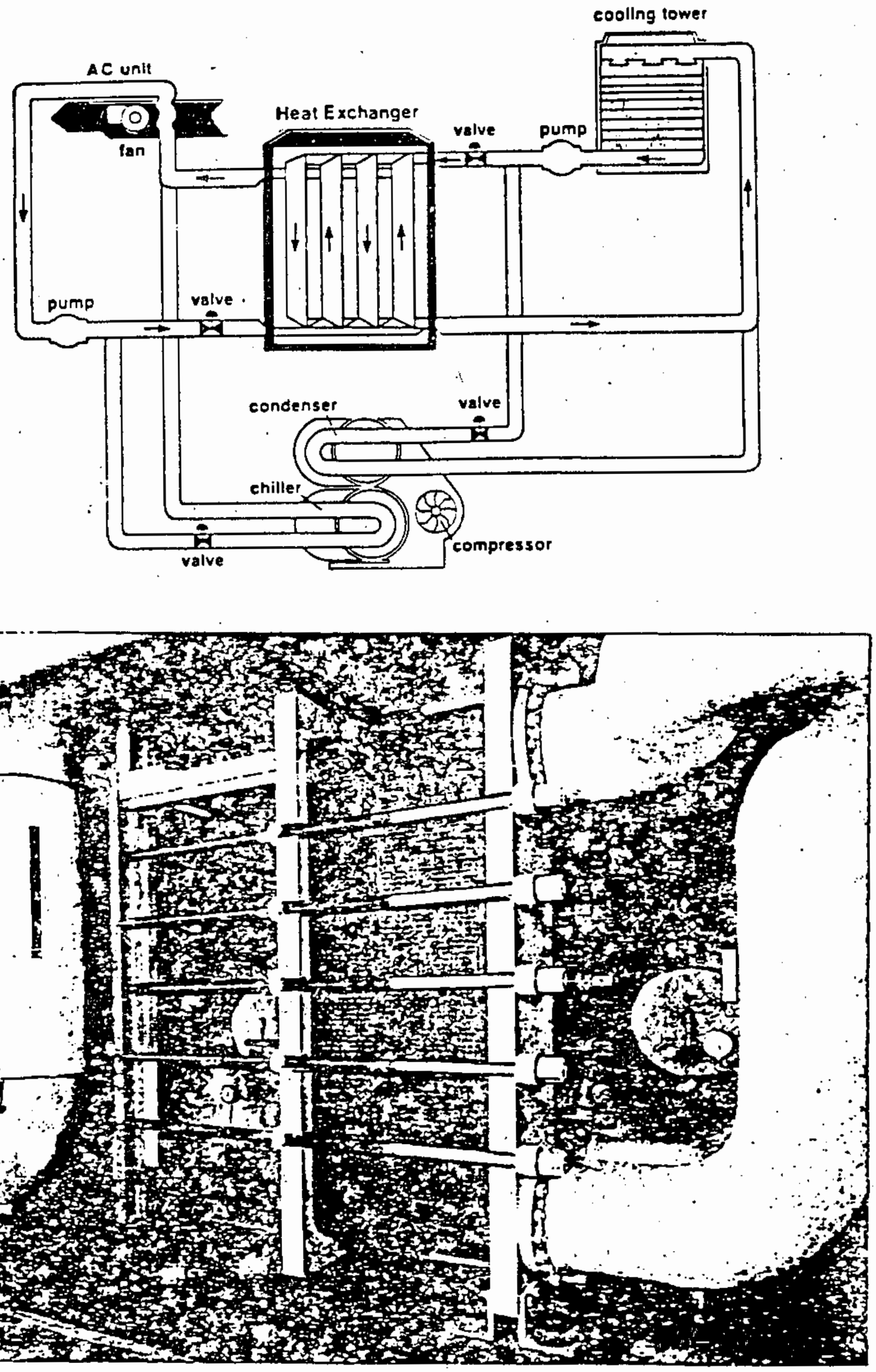


Figure 3.2B Heat exchanger in parallel with chillers used for winter cooling.

authorities may restrict such use of ground water or aquifers.

3.3 How to save energy with minor changes

The following is a listing of ways in which to save energy associated with the cold generation system making use of procedural changes or minor alterations to the system.

1. Consider operating chillers from outdoor relative humidity/temperature conditions (instead of dry bulb temperature alone). This approach is suggested as one way to optimize chiller operation in conjunction with scheduling the chilled water supply temperature to the cooling load demand.

2. Lower condensing cooling water setpoint (chillers) and head pressures (DX equipment) consistent with the cooling capabilities of the heat rejection equipment. Consider changing setpoint manually or automatically as load and outside air conditions vary.
   Lower temperatures can be achieved by:

   a) increasing tower or air cooled condenser fan volumes;
   b) increasing tower water flow rate;
   c) where installation operates at constant condenser water temperature, modify controls for more continuous tower/condenser operation;
   d) move condenser closer to the compressor to minimize pumping energy;

   This approach is not applicable when condenser heat is reclaimed unless lower "heating fluid" can be tolerated. Increased compressor life (operates at lower load and pressures may be anticipated. Increased overall energy may occur if increased tower energy is higher than COP improvements.

3. Raise chilled water temperature setpoint (chillers and suction gas pressure (DX equipment to highest value consistent with satisfying cooling and dehumidifying requirements.Consider changing setpoint manually or automatically as load varies. Reduced pressure lift on compressors tends to prolong their service life.Raising chilled water temperature lowers capacity for latent cooling causing space humidity levels to rise. Too high an evaporator temperature may compromise proper functioning of expansion devices.

4. Sequence operation of multiple chillers and refrigerator compressors with load variations to achieve optimum overall plant performance. Isolate off line chillers when not required and reduce water flow rate and pumping costs. The sequencing should be verified through field measurements and/or monitoring since catalogue data are not always valid or applicable at part loads.

   Isolation of off line chillers is a low cost method if carried out manually using existing valves; more expensive if automatically operated valves are required to be installed. Control of water flow rate may be expensive if multiple pumps are not installed.

5. Shut off all auxiliaries where chilling/refrigerant plant is not required. Equipment would include chilled and condenser cooling water pumps, oil heaters and cooling tower pan heaters and trace heating (to cooling tower). This action will involve no cost if carried out manually but is most effective if automated.

6. Evaluate present instrumentation to determine whether additional thermometers, pressure gauges and flow meters are required to obtain adequate information on system performance. Make a list of instruments, indicating how frequently each should be read.Make certain instrumentation is well labeled to aid operations personnel.

7. Operate only the necessary hot water, chilled water and condenser water pumps. If multiple cooling towers or tower fans exist, cycle only as many as required.

8. Inspect and repair insulation on chilled water lines, chilled water storage tanks or other chilled water distribution components.

9. Use a leak detector to check for refrigerant and oil leaks around shaft seal, sight glasses, valve bonnets, flanges, flare connections, the relief valve on the condenser assembly, and at pipe joints to equipment, valves, and instrumentation.

10. Maintain full charge of refrigerant by locating and correcting leaks and adding refrigerant as necessary. Improved service life of the compressor and maintenance of full machine capacity will result, in addition to higher efficiency. Loss of refrigerant has potentially adverse environmental

effects. Overcharging can cause liquid refrigerant to enter compressor which can damage centrifugal compressors and affect performance of all compressor types. Elimination of leaks will lower future cost of refrigerant recharging, although repairing leaks can be costly.

11. Check the liquid line where it leaves the strainer on electric chillers and DX equipment. If this line feels cooler than the liquid line entering the strainer, it is clogged. If it is very badly clogged, sweat or frost may be visible at the strainer outlet. Clean as required.

12. Periodically perform tests on the condenser water to determine whether solids buildup is maintained at an acceptable level. Flush system when appropriate. Water additives may be necessary to limit solids buildup.

13. Remember that a chiller will operate more efficiently at a higher chilled water temperature. Experiment by raising the temperatures a few degrees and observing if air systems serving critical areas in the hospital can still maintain required space temperatures and humidities. This can be done progressively for different outdoor conditions. A table illustrating maximum chilled water temperature at various combinations of outside temperature and humidity can be prepared and prominently displayed near the controls.

14. Establish normal operating pressures and temperatures for each refrigeration system. Check all gauges frequently to ensure that those conditions are being met. Increased system pressure may be caused by dirty condensers, which will decrease system efficiency. High discharge temperatures are often caused by defective or broken compressor valves.

3.4 How to save energy with modification

The following is a listing of ways in which to save energy associated with the cold generation system employing modifications.

1. Increase condenser heat exchanger surface areas for lower condensing temperatures; e.g., larger cooling tower or condenser or additional unit(s).

2. Clean water-cooled condenser tubes (annually or install automatic tube cleaning system (as shown in Figure 3.1.B). This action will reduce dependence on chemical water treatment which lessens corrosive and ecologically undesirable side effects.

3. Clean and repair cooling tower fill and heat exchanger surfaces in closed circuit towers, clean pans and air louvres and provide water treatment to maintain water quality and limit algae growth. This ECO has direct health impact since algae and fungi growth in these locations has been directly linked to "Legionaire disease". The ECO will provide lower condensing water temperatures.

4. Minimize adverse external influences on cooling tower and air cooled condenser performance by providing shading from solar and adverse wind, eliminate the recirculation of hot damp discharge air, remove any air flow restrictions.

5. Install heat exchangers on condenser cooling water or hot refrigerant lines or install double bundle condenser to reclaim heat.
   Applied to facilities with air conditioning or process cooling, this ECO is particularly attractive where there is year round cooling plant operation and a need for space or domestic water heating. A trade off is required between high grade reclaimed heat and its impact on lowering refrigeration COP (COP falls with increasing condensing temperature).

6. Heat storage can increase savings. Centrifugal machines permit heat to be recovered only up to 40 ÷ 52 °C (105 ÷ 125 °F).

7. Obtain free chilled water by cooling with outside air using the existing cooling tower, an auxiliary heat exchanger located outside or using an existing air handling unit coil. See previous discussion in § 3.1.
   This ECO is of interest for installations requiring year round cooling, with cold (cool) winters where it is not practical to use outdoor air directly (i.e., economizer cycle). Can be a relatively low cost item compared with other means of generating winter chilled water.

8. Reduce compressor capacity where equipment is oversized by reducing speed of motor, fitting a smaller compressor or reducing the size of the impeller in centrifugal machines. Reduce motor size to match reduced load and retain the (now oversized)

heat exchangers. This approach is applicable where existing equipment is oversized, particularly where energy intensive capacity controls are used, and where it is possible to replace the compressor only.

9. Exhaust cool conditioned air over condensers and through cooling towers by modifying exhaust ductwork so that when exhaust air has a lower temperature or energy content than outside air, it can be used to provide more efficient cooling of the heat rejection equipment. Useful where exhaust is close to cooling tower or condenser. Most benefit is where outside air temperatures are consistently much higher than maintained internal conditions.

10. Install cooling coil using city water to provide "free cooling". This can be applied to hospitals with large and consistent cold water demand such laundries. Heat gain to water can be of benefit since the laundry water requires heating. It must be evaluated for economic benefits, and in many instances may not be permitted by water supply agencies, city water for cooling unless it is being used for some other purpose.

11. Install a central controller to optimize the operation of all cooling system components including compressor sequencing, condenser and chilled water reset, and auxiliaries operation. It is most suitable for large installations where unattended operation allows the existing staff to be used elsewhere. Operators must be appropriately instructed. Hardware used to provide feedback information to the central controller are essential and can be expensive.

12. Improve capacity control:Improve the efficiency of capacity control by using:

    a) variable speed control,
    b) cylinder unloading,
    c) solution control.

    The ECO may be applied to: a) all compressor driven compressors, b) reciprocating compressor and c) absorption chillers. This ECO results in prolonged equipment life. Some of the options can be expensive. It should be remembered that:

    a) Centrifugal machines normally operate most efficiently between 40 and 70 % loaded.