Heat recovery in the refrigeration cycle

Building Technologies

SIEMENS

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1. Introduction

1.1 General

Cooling generates considerable quantities of heat. If not utilized, this energy simply becomes waste heat. Siemens has developed modulating valves to control the direct utilization of waste heat. They provide for exact, demand-controlled heat recovery. The utilization of waste heat is profitable wherever heating and refrigeration are required at the same time, or where waste heat can be stored:

- In air conditioning systems to reheat dehumidified air
- In butcheries, dairies, hotels, etc., where, on the one hand, cold storage rooms are operated and where, on the other, there is always a great demand for domestic hot water
- In shops, where in addition to cooling foodstuff, heat demand also occurs, e.g. mall heating
- In cold storage facilities, for heating and domestic hot water
- In industrial processes (e.g. drying processes)

Fig. 1-1 Modulating magnetic valves for halogenated refrigerants
From left to right:
– Suction-throttling control valve (with manual adjustment)
– Modulating control valve for condenser control
– Bypass diverting control valve
– Electronic injection valve for safety refrigerants
– Pilot valve (also for ammonia)

Fig. 1-2 The new range of modulating magnetic valves MVL661… for halogenated refrigerants. One type of valve for three different applications:
– Modulating control valve for condenser control
– Bypass diverting control valve
– Electronic injection valve for safety refrigerants

2. Heat recovery

2.1 Heat supply of the condenser

The heat absorbed in the evaporator Q_o and the compressor work P in the form of heat must be released again in the condenser. Instead of dissipating this heat quantity Q_c to the environment, appropriate measures can be implemented in order to put this heat flow to meaningful use for heating purposes because of its temperature level.

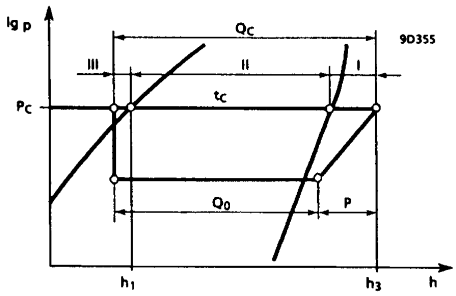


Fig. 2-1 Refrigeration cycle on the h-log p diagram

The condenser's output Q_c depends mainly on the refrigerant volume $\dot{m}$ circulated per unit of time and on the enthalpy difference $h_3 - h_1$ at a given pressure p_c. The liquefaction of the hot refrigerant vapor takes place in several stages. In the initial phase (I), heat is extracted from the hot compressed gas (e.g. 90 °C) from the compressor. The *extracted heat* amounts to 10…20 % of the total condenser output. Compared to the actual condensation temperature, this heat has a considerably higher level (up to 60 °C). It is particularly suitable for *heat recovery* if the required heating media temperature is higher than the condenser temperature, and the *extracted heat* alone can cover the heat demand.

The actual *condensation* then occurs in a second phase (II).

The temperature of the recoverable heat here corresponds to the condensation temperature t_c.

The final phase (III) in the condenser produces the *subcooling* of the now already condensed refrigerant. Due to the low temperature and energy content, this zone is hardly relevant for heat recovery.

The condensation temperature and pressure vary with changing ambient conditions, especially in the case of air-cooled condensers. Therefore, it is recommendable to limit the condenser pressure to a minimum.

It is also worth checking whether it is worthwhile raising the condensation temperature during the heating season.

2.2 Gas-side heat recovery

The condenser heat can be utilized in several ways.
Gas-side heat recovery methods are discussed here. They have several major advantages over other solutions. Direct use of the condensation heat usually provides a higher temperature and heat yield than conventional, indirect heat exchange methods.

Additionally, the three-port valve for gas-side control permits a simplification of the hydraulic circuit on the consumer side, especially in the case of reheating of the heating medium above the condensation temperature (e.g. hot water heating systems with electric water heaters). Three-port valves prevent the occurrence of undesirably high pressures in the condenser at high return temperatures, thus increasing operational safety at little expense.

Gas-side heat recovery takes place in auxiliary condensers. They can be connected to the main condenser via various circuits. Three basic configurations are explained in the following.

2.2.1 Condensers connected in series

If an auxiliary condenser is connected upstream of the main condenser for the purpose of heat recovery, the term series-connected condensers is used.

This configuration is selected especially if the auxiliary condenser is used for heating domestic hot water whose temperature is higher than the condenser temperature.

This is achieved by using the extracted heat. The achievable water temperature depends on the size of the auxiliary condenser and on the pressure prevailing in the condenser downstream from it:
- If the auxiliary condenser is used for reheating the air in an air conditioning system with dehumidification
- If the heat recovery condenser should have a higher condensation temperature than the main condenser with the aid of additional pressure control
- If an existing system with ON/OFF control is equipped with a reheater controlled in modulating mode as an auxiliary condenser in order to modulate the temperature progression in the supply air duct

In the case of series connection, the pressure losses in the condensers and refrigerant pipes accumulate. Therefore, the pressure loss between the compressor and the refrigerant collector must not be too great; otherwise the efficiency of the system suffers.

2.2.2 Condensers connected in parallel

If the auxiliary condenser is configured alongside the main condenser and supplied simultaneously with the same gas, this is a parallel connection of condensers. This is used where:
- Both condensers have a relatively large pressure drop, be it due to long pipe runs or due to a great pressure loss in the condenser itself
- Multiple condensers are used for heat recovery, e.g. for domestic hot water heating and air heating in the retail area and butchery

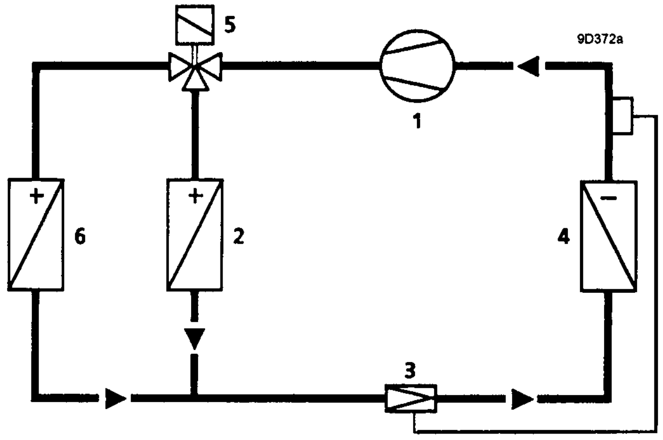


Fig. 2-2 Refrigeration system with hot-gas diversion (condensers connected in parallel)

1 Compressor	4 Evaporator
2 Main condenser	5 Hot-gas diverting valve M3FB…
3 Expansion valve	6 Auxiliary condenser

In the case of parallel connection, the pressure losses are divided among the condensers similar to electrical resistors that are connected in parallel. Therefore, such systems are especially efficient.

What series and parallel connection have in common is the fact that the condenser that is shut down in each case is partially or fully flooded with refrigerant, regardless of its supply control. This occurs until the condenser at the lower ambient temperature is flooded to such an extent that the pressure is equalized between the condensers.

This must be taken into account in the construction or conversion of the refrigeration system.
The quantity of refrigerant required to flood the heat recovery condenser must, therefore, be made available in a correspondingly larger refrigerant collector.

2.2.3 Combined circuits

If sufficient condenser output is centrally available, combinations of series and parallel connected condensers are also conceivable. Such combinations are especially used where several, often different heat consumers use the condenser heat.

2.3 Modulating control of several condensers

The modulating valve can basically be configured in two different ways, regardless of the condenser circuit:
a) Hot-gas side diverting control, or
b) Condensate side mixing control

Hot-gas side diverting control

In the case of hot gas distribution (Fig. 2-2), the control valve is located in the hot-gas flow. It proportions the gas flow according to the heat demand on the auxiliary condenser. The control system detects the heat demand on the heat recovery auxiliary condenser where it occurs (rooms, central air treatment plant, etc.) and converts it to the manipulated variable for the control valve. The output of the condensers is determined by the gas flow volume at the respective valve position.

The advantage of hot-gas diversion for control is that this control element configuration gives rise to a rapid reaction to control commands. Therefore, hot-gas diversion is recommended in cases where fast and particularly accurate control is needed.

Examples:

- Process control of a drying plant
- Control of air side reheating
- Accurate and fast temperature control of domestic hot water heating systems

The valve installed on the hot-gas side gives rise to a residual pressure loss p_v in a pressure pipe. This must be compensated by a slightly greater compressor power. At p_v = 0.5 bar, it is approximately 1.7 %. Modulating control valves can control hot-gas side outputs of up to 80 kW.

Condensate side mixing control

The condensate side control valve mixes the condensate flows according to demand in the case of parallel-connected condensers.

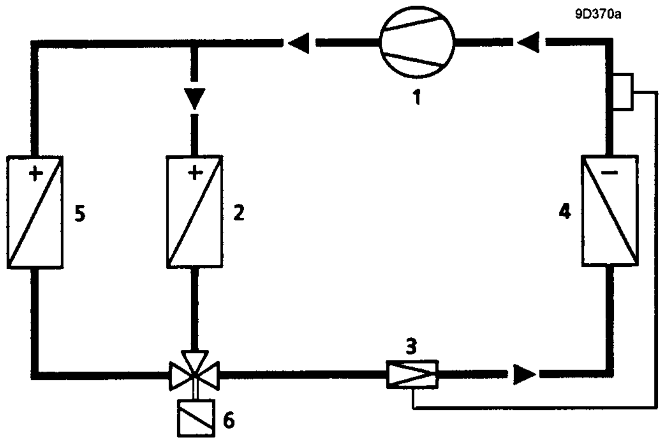


Fig. 2-3 Refrigeration system with condensate side control valve (condensers connected in parallel)

1 Compressor	4 Evaporator
2 Main condenser	5 Auxiliary condenser
3 Expansion valve	6 Condensate valve M3FK…

In case of heat demand, the three-port mixing valve opens the condensate pipe of the heat recovery condenser and simultaneously closes that of the main condenser. The heat recovery condenser is drained of condensate, and its output increases according to the heat transfer surface area that is exposed.

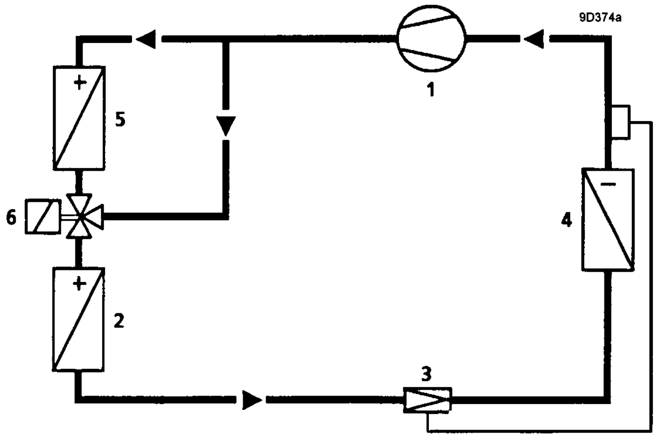


Fig. 2-4 Refrigeration system with condensate side control valve (condensers connected in series)

1 Compressor	4 Evaporator
2 Main condenser	5 Auxiliary condenser
3 Expansion valve	6 Condensate valve M3FK…

Auxiliary condensers controlled in modulating mode that are connected in series with the main condenser (Fig. 2-4) function in a similar manner. In this case, the condensate leaving the auxiliary condenser is controlled, and the remaining hot-gas passes through a bypass directly to the valve.

This is a frequently used application, especially in air conditioning systems with dehumidification and reheating. Both condensate side control methods (Fig. 2-3, Fig. 2-4) provide for precise, modulating, demand-controlled heat recovery systems.

Condensate side control is slightly slower than direct hot-gas control, so it is particularly suited for domestic hot water heating and for room heating purposes. In terms of the refrigeration machine energy balance, it is the slightly more efficient of the two solutions, all the more since no disadvantageous pressure losses (p_v) reduce the coefficient of performance, because the valve is installed between the condenser and the expansion valve.

On the condensate side, Siemens valves can control condenser outputs of up to 1,000 kW.

3. Examples of heat recovery

3.1 Preheating outside air

The air conditioning system of a shopping center operates with the four basic functions: heating, cooling, dehumidifying and humidifying. Before the cold outside air is ducted to the mixing chamber, it is preheated to a given, demand-dependent value. The preheater is supplied by the condensers of the refrigeration machine used for the cold storage and freezing rooms instead of by oil, gas or electricity.

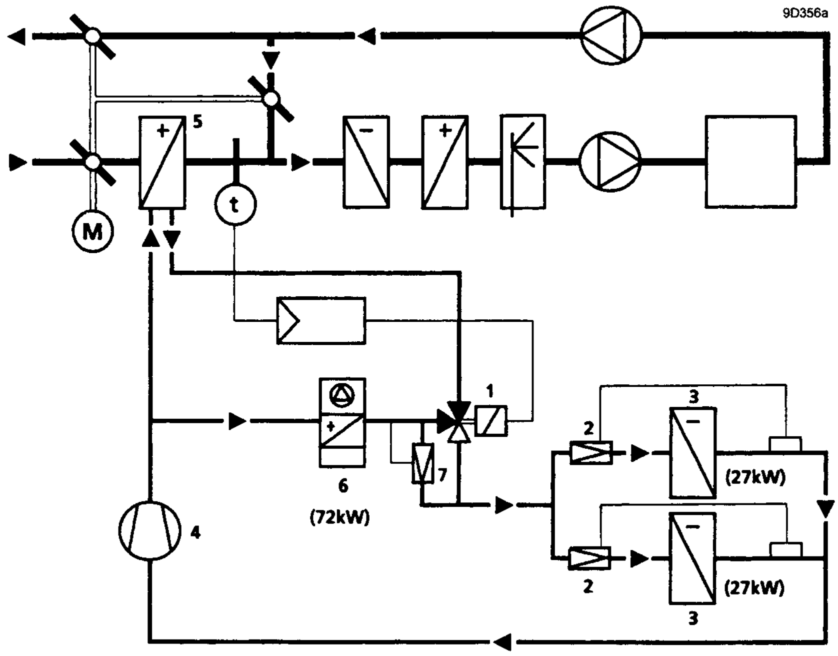


Fig. 3-1 Heat recovery system for preheating outside air

1 Control valve M3FK…
2 Expansion valve
3 Evaporator
4 Compressor
5 Auxiliary condenser
6 Main condenser
7 Overflow valve

Plant data

Location	Berlin
Winter design point	–15 °C
Operating time	Workdays 7:00 – 19:00

Air conditioning system

Preheater output	37 kW
Ventilation degree hours	48,168 K • h/a at 22 °C supply air temperature
Annual useful heat demand, preheater	approx. 55,000 kW/a
Min. air volume	0.9 m^3/s
Min. air mass	4,050 kg/h

Refrigeration systems

Year-round operation	
Evaporator output	2 x 27 kW
Air-cooled condenser	72 kW
Auxiliary condenser	37 kW
Refrigerant	R 22

Parallel connection of the condensers was selected because of the pressure losses in the piping between the refrigeration machine and the air conditioning system.

The necessary heat output is determined by the local ventilation degree hours. This is the product of the number of operating hours and the difference between the supply air temperature and the respective average outside air temperature. The number of ventilation degree hours for a system in Berlin that is operated between 7:00 and 19:00 with a supply air temperature of 22 °C is 48,168 K • h/a (degree hours per year). With an hourly air volume of 4,050 kg/h, the total annual heat demand is 55,000 kWh/a.

The refrigeration system must meet the following criteria:

- The operating time of the refrigeration machine must coincide with that of the heat consumer
- The refrigeration demand is almost continuous and depends little on the outside temperature
- The heat output of the auxiliary condenser covers the necessary heat demand

The *preheater* acts as the auxiliary condenser parallel to the air-cooled main condenser. The condensate flows are combined and passed on by a three-port mixing valve. Therefore, the condenser has modulating control on the condensate side.

In *heat recovery operation,* the control valve opens the condensate pipe of the auxiliary condenser according to the signal from the sensor in the outside air duct or according to a control signal, e.g. from the room. At the same time, the condensate pipe of the main condenser is closed. The flooded auxiliary condenser drains, and its heat transfer surface is exposed to the hot-gas that flows in from the compressor. The main condenser, on the other hand, floods with condensate and becomes ineffective.

3.1.1 Control

The heat recovery condenser must be controlled in such a way that it reduces the load on the supply air reheater but does not give rise to the unnecessary startup of the cooler. The control sequences of the respective devices must be matched.

Preheating of the outside air must operate in a stable manner; otherwise it will have a negative effect on the subsequent control loops. This requires a precise modulating control valve.

An *overflow valve* between the main condenser and the refrigerant collector provides for reliable refrigerant circulation in all load cases. A valve of this kind is especially necessary in large condensers. In case of great heat demand on the heat recovery condenser, the control valve closes the liquid pipe of the main condenser. This causes increasing proportions of gas to flow into the heat recovery condenser. If it is not completely condensed there, the pressure rises and is transferred to the main condenser. If the adjustable opening pressure of the overflow valve is reached there, refrigerant drains from the main condenser. It then provides the residual condensation. The closer the opening pressure is to the maximum permissible operating pressure, the greater the heat yield becomes because of the higher condensation temperature. Without heat recovery, the refrigeration machine operates at the original, lower pressure level again. This provides an ideal way of minimizing operating costs for cooling and heat production.

3.2 Reheating dehumidified supply air

Dehumidification of air always involves cooling, which makes reheating necessary. The heat that occurs in the condenser can be used for this purpose.

Reheating using fuel or electricity is expensive in comparison.

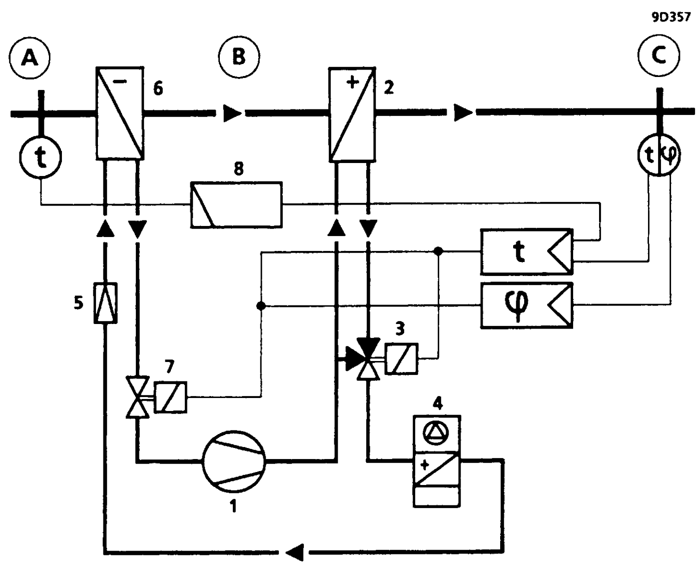


Fig. 3-2 Simplified schematic of the reheating of dehumidified supply air

1 Compressor	5 Expansion valve
2 Auxiliary condenser (reheater)	6 Evaporator
3 Heat recovery control valve M3FK…	7 Suction-throttling valve
4 Main condenser	8 Shift controller

Fig. 3-2 shows a system with a direct-expansion evaporator and a heat recovery auxiliary condenser as a reheater. The evaporator (6) cools the air down. The auxiliary condenser (2) provides reheating of the air after dehumidication. The auxiliary condenser and main condenser are connected in series.

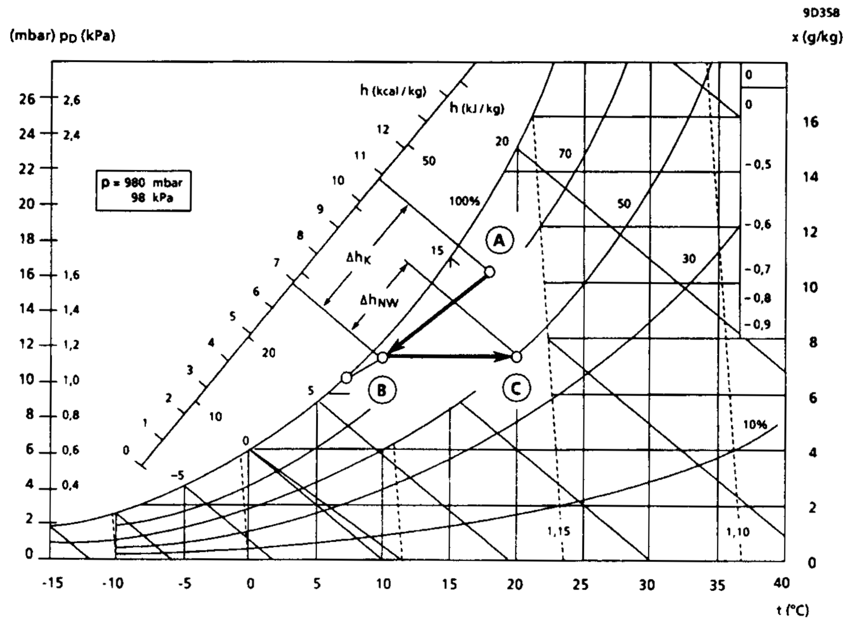


Fig. 3-3 Dehumidification process on the psychrometric chart

The dehumidification process takes place between points A and C (see psychrometric chart, Fig. 3-3):
Air at t_{AU} = 18 °C and φ = 75 % r.h. (point A) is dehumidified and reheated to t_{ZU} = 20 °C and φ = 50 % r.h. (point C).

Outside air conditions like these prevail frequently in moderate climate zones, e.g. on rainy days during intermediate seasons. The process passes through point B, where the air has the desired water content (x = 7.5 g/kg) but a temperature of only 10 °C. So it must still be heated by a further 10 K. This function is provided by the auxiliary condenser, in which a portion of the hot-gas condenses.

The three-port valve controls the amount flowing through the auxiliary condenser. It mixes the condensate with hot-gas. The remaining gas condenses in the main condenser. If the auxiliary condenser has no heat demand, all of the hot-gas flows via the main condenser, whereas the auxiliary condenser floods with condensate and becomes inactive.

The suction valve (7) downstream from the evaporator controls the refrigeration capacity according to the controller signals for temperature and dehumidification. If the dehumidification causes the supply air temperature to fall below the low limit, the heat recovery control valve (3) opens the condensate drain pipe, which starts the reheater according to demand. A shift controller (8) for summer and winter compensation influences the setpoint of the controlled temperature.

3.3 Heat recovery in drying plants

A *grain drying plant* (Fig. 3-4) has been selected as an example. The air cooling coil (1) is supplied by an indirect refrigeration cycle. Its primary task is air dehumidification. The dehumidified air is then heated to a given temperature that is appropriate for the grain. This is done by the reheater (2) using the waste heat from the refrigeration machine. The heat from the auxiliary condenser (3) is transported to the reheater via an intermediate circuit.
The auxiliary condenser is connected in series with the main condenser (4) and controlled on the hot-gas side. The bypass pipe (5) of the auxiliary condenser is pressure-controlled and serves as an overflow if the control valve is closed. The use of the waste heat is meaningful, because the heat available in the auxiliary condenser coincides with the heat demand in terms of time, temperature and quantity.

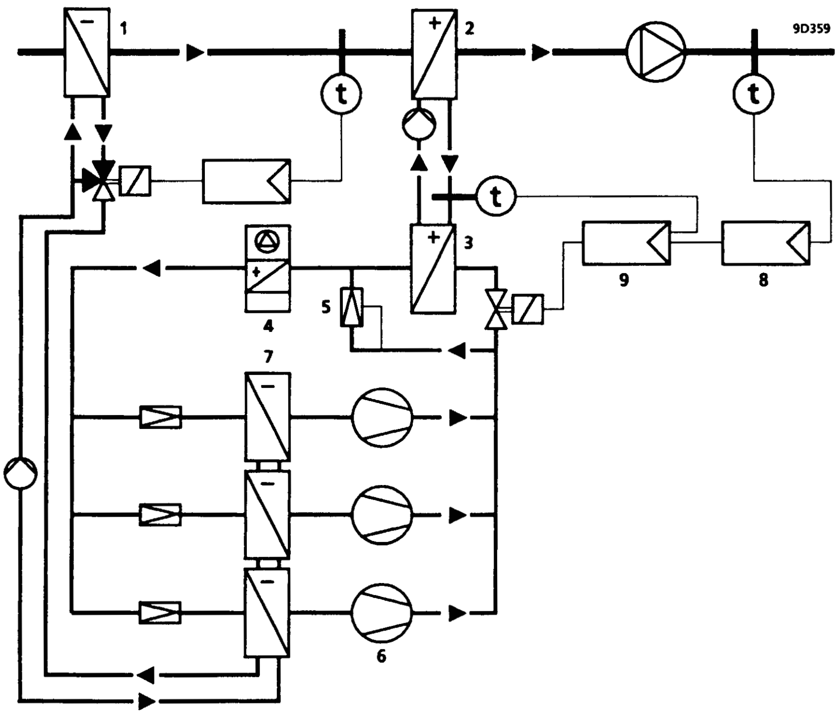


Fig. 3-4 Grain drying plant (simplified schematic)

1 Air cooling coil
2 Reheater
3 Auxiliary condenser
4 Main condenser
5 Bypass pipe
6 Compressor
7 Evaporator
8 P-controller
9 PID controller

Because grain quickly goes bad under unsuitable climatic conditions, the temperature and humidity control must work very precisely. Overheating of the supply air due to control overshoots must especially be avoided. In this system, three compressors, which are started or stopped according to refrigeration demand, give rise to major load variations in the auxiliary condenser and, therefore, in the reheater. The cascade control (8, 9) attenuates these variations and keeps the supply air to the heater at a constant temperature.
The primary controller (F) acquires the air temperature after the air heating coil via the sensor. It generates the input signal for the auxiliary controller (PID) from the difference between the setpoint and actual value. It is the auxiliary controller that acts on the control valve according to the difference between the value acquired in the water supply and its respective setpoint, which is assigned by the primary controller. Since the control valve is installed on the hot-gas side, the auxiliary control loop acts correspondingly fast.

3.4 Food shop with integrated heat recovery

In a relatively large food shop, very different heat sources and heat losses are active at the same time.
In the butchery department, the displays are cooled and are subject to relatively high humidity, whereas the retail area usually has to be heated at the same time. The same applies to all retail areas where cooled and frozen goods are sold. In the warehouse and retail areas, the external loads (conduction, ventilation losses, etc.) and internal loads (persons, lighting, etc.) vary greatly over time. Additionally, the consumption of hot water is continually high.

The ventilation system covers the main heating load in the retail area, butchery department and warehouse. Experience shows that heat recovery systems of this kind can cover up to 90 % of the total heating load.

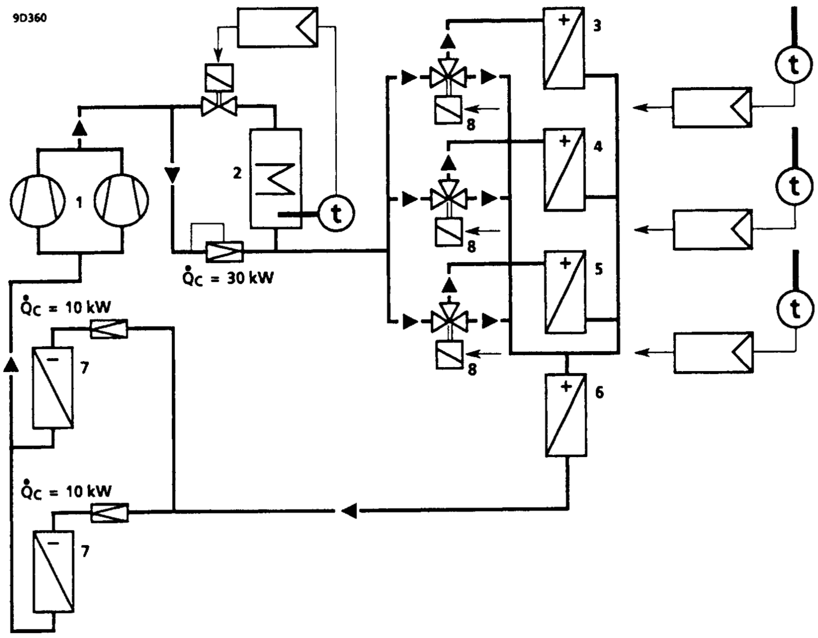


Fig. 3-5 Integrated heat recovery system: large food shop (simplified schematic)

1	Compressor	6	Main condenser
2	Storage tank	7	Evaporator
3 – 5	Auxiliary condenser	8	Heat recovery control valves M3FB…

3.4.1 Heat recovery system

The refrigeration machine supplies island-site refrigerated cases and refrigerated display cabinets. It is continually in operation. Therefore, heat is continually produced. Upstream of the main condenser, auxiliary condensers serving as air heating coils are connected in parallel and controlled on the hot-gas side. They are individually controllable by means of modulating, three-port valves.
The excess gas in each case is supplied to the main condenser via a manifold. In order to utilize the heat extraction from the hot-gas, a domestic hot water heat exchanger is connected upstream in series. If the control valve for domestic hot water heating is closed, the hot-gas flows directly to the heat recovery condensers via the bypass. If there is no heat demand at any of the consumers, the gas flows through the diverting control valve and manifold to the main condenser.

Condensate pressure controllers ensure that a minimum condensation pressure and temperature are maintained. They also prevent mutual interference of the condensate flow.

The bypass pipe between the compressor and collector provides the minimum necessary pressure in the refrigerant container during startup.

3.4.2 Control

Since the heat demand of each consumer varies, individual control loops for each heat recovery unit match the heat supply to the respective demand. This solution offers the advantage that the heat consumers are operated in conjunction with the refrigeration machine according to the criteria of comfort and economy.

3.5 Low-temperature heating via waste heat utilization

In the refrigeration system described in the following, the refrigerant that is heated by the refrigeration process is used to heat domestic hot water and to supply the low-temperature heating system. The system is installed in a butchery with a shop and an apartment above.

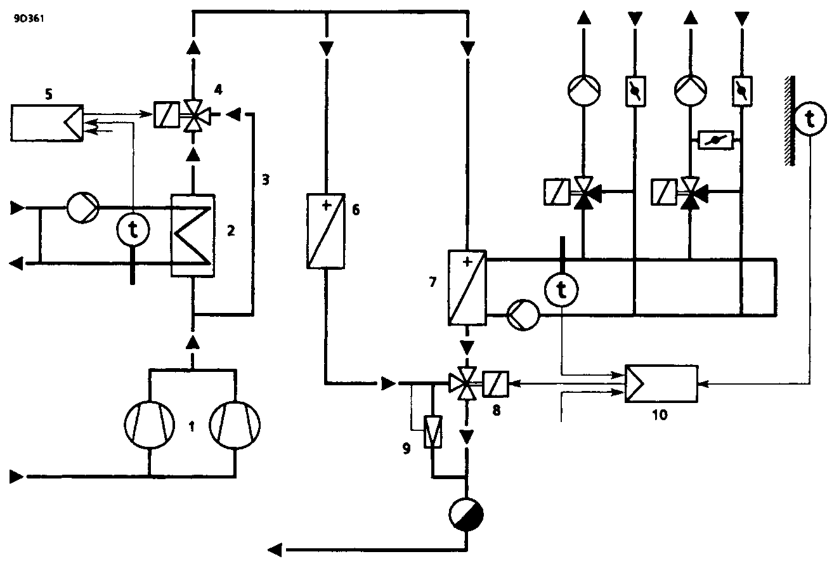


Fig. 3-6 Heat recovery for low-temperature heating

1 Compressor	6 Main condenser
2 Heat exchanger	7 Auxiliary condenser
3 Bypass pipe	8 Control valve M3FK…
4 Mixing valve M3FK…	9 Overflow valve
5 Temperature controller	10 Heating controller

Refrigeration system data

2 compressors	4.4 kW
Power consumption	8.8 kW
Refrigeration capacity	17.6 kW
Condenser power	26.4 kW

Heating system

Low-temperature heating system at $t_A = -11$ °C	$t_{VL} = 55$ °C
	$t_{RL} = 45$ °C
Heat output of the auxiliary condenser $t_c = 47$ °C	16.0 kW
Annual full operating hours at $t_A = 5$ °C	1,630 h/a

Domestic hot water heating

Demand 2,700 l/day	+60 °C
Heat output of the auxiliary condenser	10 kW
Heat demand per workday	125 kWh
Annual energy demand for d.h.w. heating	30,025 kWh/a

3.5.1 Operating principle

The hot-gas supplied by the compressors flows directly into a special heat exchanger for domestic hot water heating if required. The achievable domestic hot water temperature can be up to 60 °C, depending on the capacity of the auxiliary condenser, the degree of heat extraction and condensation and on the condensation pressure. If domestic hot water is required at temperatures higher than the condensation temperature, e.g. for cleaning, dishwashing, etc., the water is reheated in an auxiliary storage tank. The heat output of the exchanger is controlled by the mixing valve (4), which is used as a condensate bakkpressure valve in this case. At partial loads and in case of high return temperatures in the domestic hot water circuit, the hot-gas flows directly to the main and auxiliary condensers via the bypass (3) and mixing valve. This means that disturbances on the high-pressure side of the refrigeration machine cannot occur even in case of high return temperatures in the domestic hot water system.

The refrigerant flows to the main condenser (6) and auxiliary condenser (7) in proportion to the position of the mixing valve (8). The latter is actuated by the controller (10), which controls the heating system supply temperature according to the outside temperature. The control action is achieved via the backing up of the condensate.

If no heat demand is detected, the mixing valve is closed to the heating condenser. The refrigerant condenses, completely flooding the auxiliary condenser. The condensate assumes the temperature of the heating medium. At the same time, the hot residual gas is supplied to the air-cooled main condenser via the manifold. Here, the heat is dissipated to the environment.

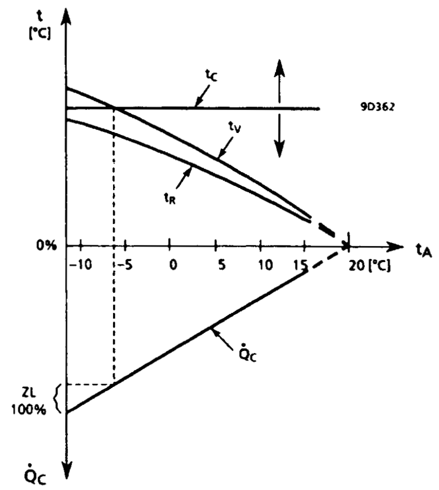


Fig. 3-7 Heating curve and heat output

As soon as heat demand occurs, the mixing valve reduces the flow of refrigerant to the main condenser. It floods and its output is continuously reduced. On the other hand, the valve opens the outlet of the heating condenser. The flooded heating condenser is drained according to the heat demand.

The *overflow valve* (9) controls the condensation pressure. In the example, the design temperature for the heating system was assumed to be t_A –11 °C. The radiators were sized such that the supply and return temperatures would then be +55 °C and 45 °C respectively (Fig. 3-7). With a condensation temperature of t_c = 47 °C, the waste heat of the refrigeration machine would cover the heating demand Q_c down to approx. t_A = –6 °C. For outside temperatures < –6 °C with the selected data, a modest auxiliary heating system with an output ZL = 17.5 % of Q_c would be necessary.

A comparative calculation made in chapter «Calculation of the economy of heat recovery systems» shows the potential annual energy cost savings when making a comparison with oil, gas and electric power.

Calculation of the economy of heat recovery systems

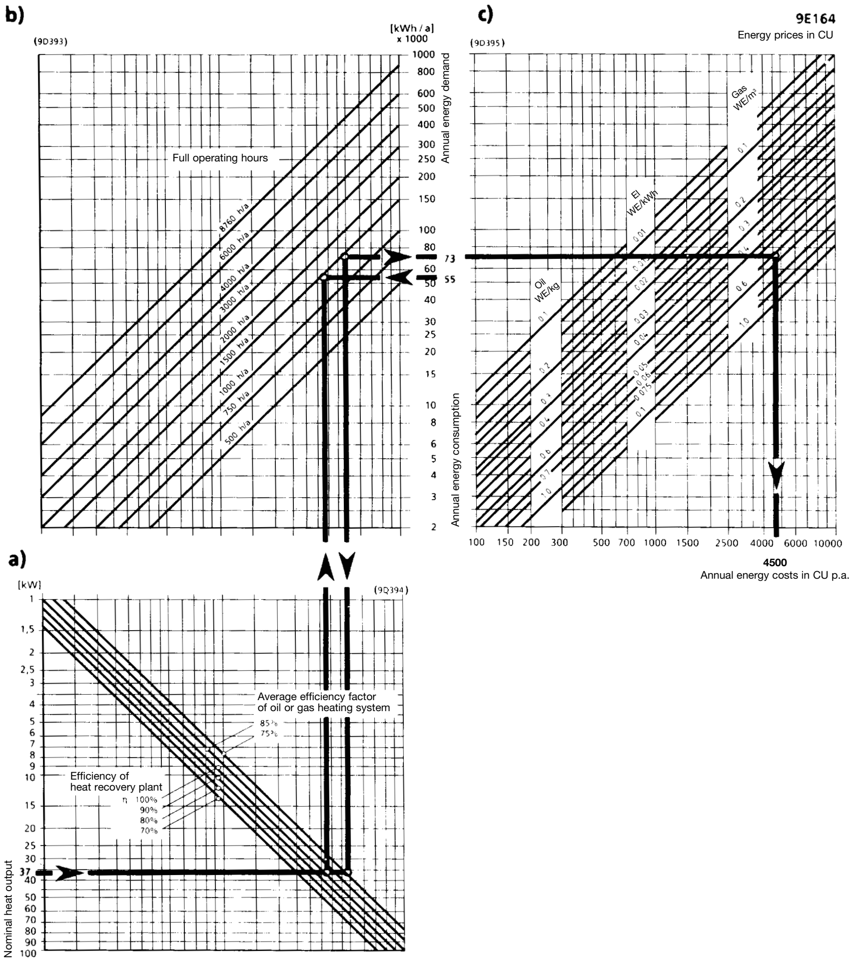


Fig. 3.8 Energy consumption and cost charts

Energy consumption and cost charts

To determine the annual savings achieved with the heat recovery equipment in terms of money in comparison with electric or fuel-based heating systems, the following data are required:

- Nominal heat output [kW]
- Annual energy consumption [kWh/a]
- Energy prices of electric power, fuel oil and natural gas
- Overall efficiency of the heating systems which are to be compared

The charts of Fig. 3.8 can be used to determine straightforwardly and rather accurately the annual savings or energy costs of conventional energy carriers (electric power, oil and gas). In place of national currencies (EUR, CHF or GBP), fictive currency units (CU) are used, making the charts universally applicable over a long period of time.

Reading example

Annual net energy consumption (b)	55,000 kWh/a
Nominal heat output (a)	37 kW
Efficiency of heat recovery	100 %
Mean efficiency factor of oil	75 %
Price of oil (c)	CU 0.7 per kg

First of all, these data are used to calculate the number of operating hours: start in chart «a» and draw a horizontal line at 37 kW until you reach the 100 % curve. From there, draw a vertical line up into chart «b», where you hit the curve (1,500 h/a) corresponding to a demand of 55,000 kWh/a. Hence, the result is 1,500 operating hours.

If oil with an efficiency factor of 75 % is used for heating, the annual energy consumption will rise. Chart «a» takes into account this efficiency factor of 75 %. It shifts the point of intersection on the 1,500 h/a curve and gives an actual energy consumption of 73,000 kWh/a. The associated energy costs, or the annual savings achieved with the heat recovery equipment, are shown in chart «c». At 73,000 kWh/a, draw a horizontal line into chart «c» until you reach the curve of CU 0.7 per kg (oil), then down where the result obtained is CU 4,500 p.a.

2. Calculation procedure for proof of economy

For proof of economy, a number of calculation methods can be applied. The static methods, which include the comparative cost calculation, the profitability and the payback calculation are based on the assumption that the savings in terms of money occurring at different points in time are equal. Investment «a» pays off if the annual savings over a number of years are greater.

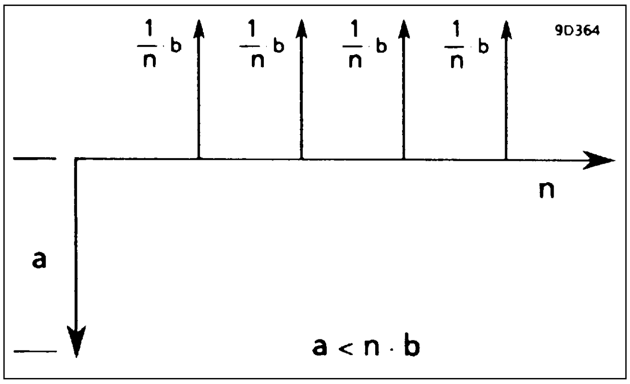


Fig. 3.9 Static method

Interests are not taken into consideration here. With the dynamic calculation methods, the investments (a) made at certain times and the resulting future savings are considered in terms of interests and compared with the *present* capital value.

Dynamic methods include the capital value calculation*, the internal interest rate calculation and the annuity calculation.*

* Both methods are recommended by VDI (VDI Richtlinie 2071).

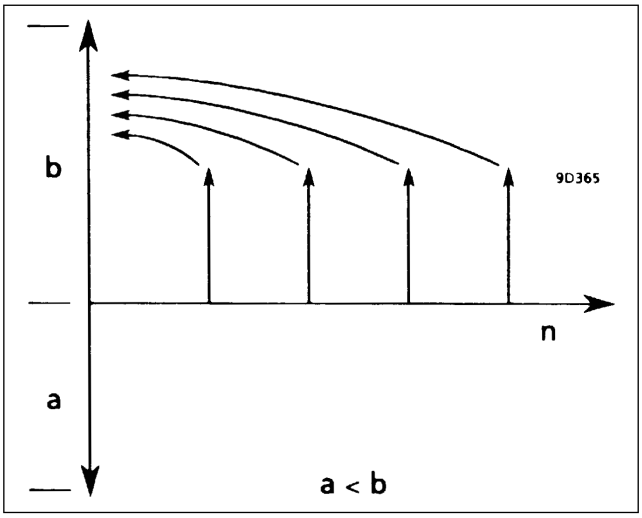


Fig. 3.10 Dynamic method

Two frequently applied methods shall briefly be discussed here:

a) The payback method

This method determines the period of time required for the energy cost savings to pay for the investment. The total amount of money invested is divided by the energy cost savings per year:

$$\frac{\text{Invested sum}}{\text{Annual energy cost savings}} = \text{payback time}$$

The payback time corresponds to the number of years required for the energy cost savings to equal the total investment made. General rule: the shorter the payback time, the more profitable the investment.

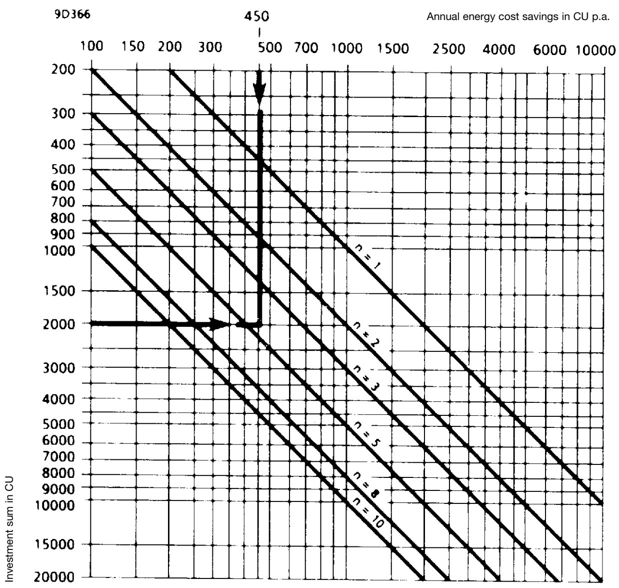


Fig. 3.11 Chart illustrating the payback method

Example:
With annual energy cost savings of CU 4,100 and an investment of CU 20,000, the payback time is nearly 5 years (on the chart above, both have been divided by a factor of 10).

b) The annuity method

With the annuity method, the costs (resulting from writeoffs and interest yield of investment) are determined in the form of equal annual contributions (annuities). Prerequisite for applying the annuity method are therefore equal costs in each payment period. This method is especially suited when comparing different alternatives. Here, a measure of the level of economy is the benefit-cost factor f_{NK}.

$$f_{NK} = \frac{\text{Annual energy cost savings}}{\text{Annual costs}}$$

Economy is reached when $f_{NK} > 1$. It is used primarily for comparing different types of heating systems.

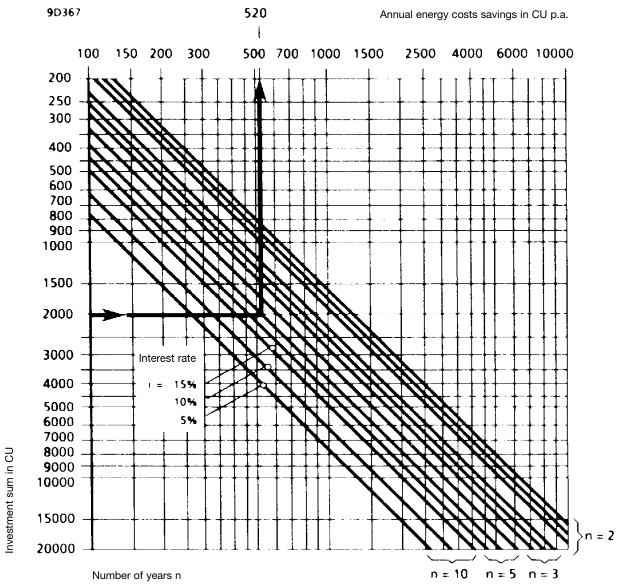


Fig. 3.12 Chart illustrating the annuity method

Reading example:

Invested sum	CU 200,000 (1/100 on the chart)
Writeoff period	n = 5 years
Interest rate	i = 10 %

The chart shows annual costs in the form of writeoff and interest yield amounting to about CU 52,000. This means that the investment pays off if the energy costs exceed CE 52,000 p.a.

1. Plant with «Preheating of outside air» (refer to page 10)

Examples

If the outside air is heated with *conventional energy carriers*, the annual *energy costs* will be as follows (according to the charts of Fig. 12):

Energy carrier	Energy price	Efficiency % factor	Annual energy consumption kWh/a	Annual energy costs CU/a
Oil	CU 0.70 per kg	75	73,000	4,500
Gas	CU 0.60 per m³	75	73,000	5,250
Electric power	CU 0.15 per kWh	100	55,000	8,250

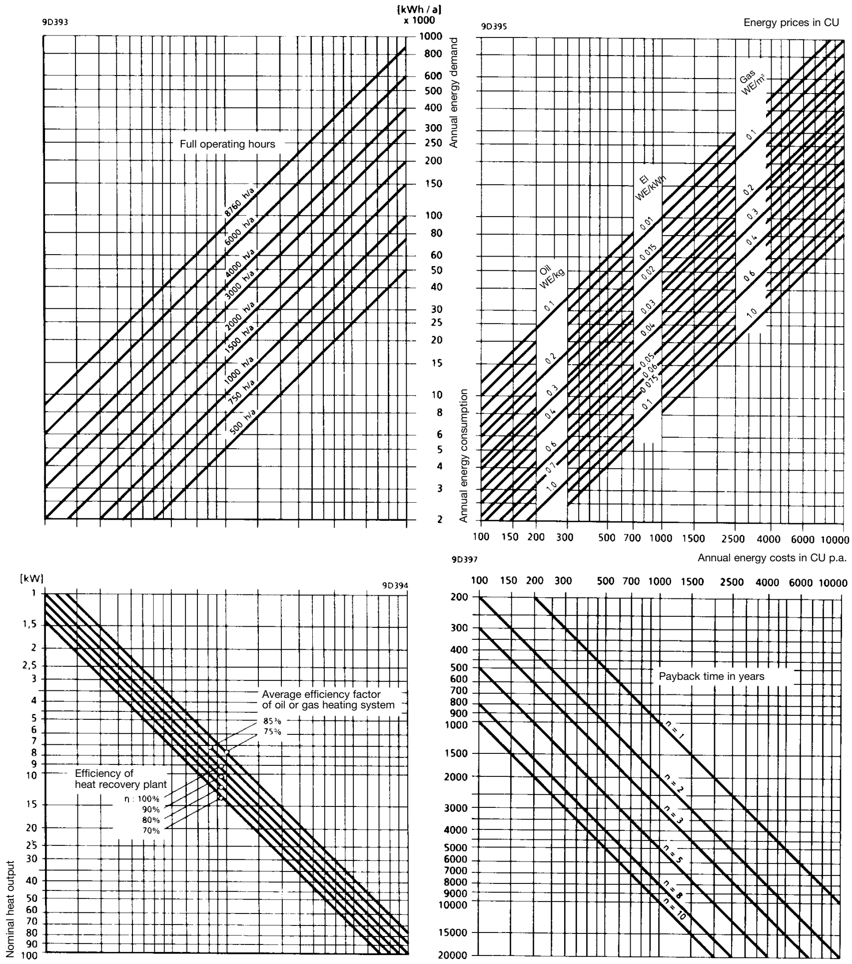


Fig. 3.13

With heat recovery, preheating is provided by the extra condenser at no cost. The resulting savings are made available for the heat recovery investment. The limit of the economically justifiable investment can be determined with the charts of Figs. 3.11 and 3.12. For that purpose, a payback time is chosen. In this example, it is assumed to be 5 years. For this comparison, the most favorably-priced conventional energy carrier (oil) is selected.

The *payback calculation* reveals that based on CU 4,500 p.a. energy costs for oil, heat recovery equipment operates economically up to an investment of CU 22,500 (refer to Fig. 3.13).

Using the same data and an (assumed) interest rate of 10 %, the annuity calculation produces an upper limit of the investment of about CE 17,000 (refer to Fig. 3.14).

2. Plant with «Low-temperature heating via waste heat utilization» (refer to page 16)

To make a comparison with a plant with no heat recovery, the following assumptions are made:
- The building is heated with oil, efficiency factor 75 %, oil price CU 0.60 per kg
- D.h.w. heating is electric, price of electricity CU 0.10 per kWh

Using the plant data of page 16, the energy costs will be as follows (refer to Figs. 3.13 and 3.14):

Energy carrier	Energy price	Efficiency % factor	Annual energy consumption kWh/a	Annual energy costs CU/a
Oil	CU 0.60 per kg	75	35,000	1,830
Electric power	CU 0.10 per kWh	100	30,000	3,000

Economically justifiable investment for heat recovery (payback time 10 years):

Payback calculation:	Heating	approx. CU 18,300
	D.h.w.	approx. CU 30,000
Annuity calculation: (interest rate 10 %)	Heating	approx. CU 11,250
	D.h.w.	approx. CU 18,500

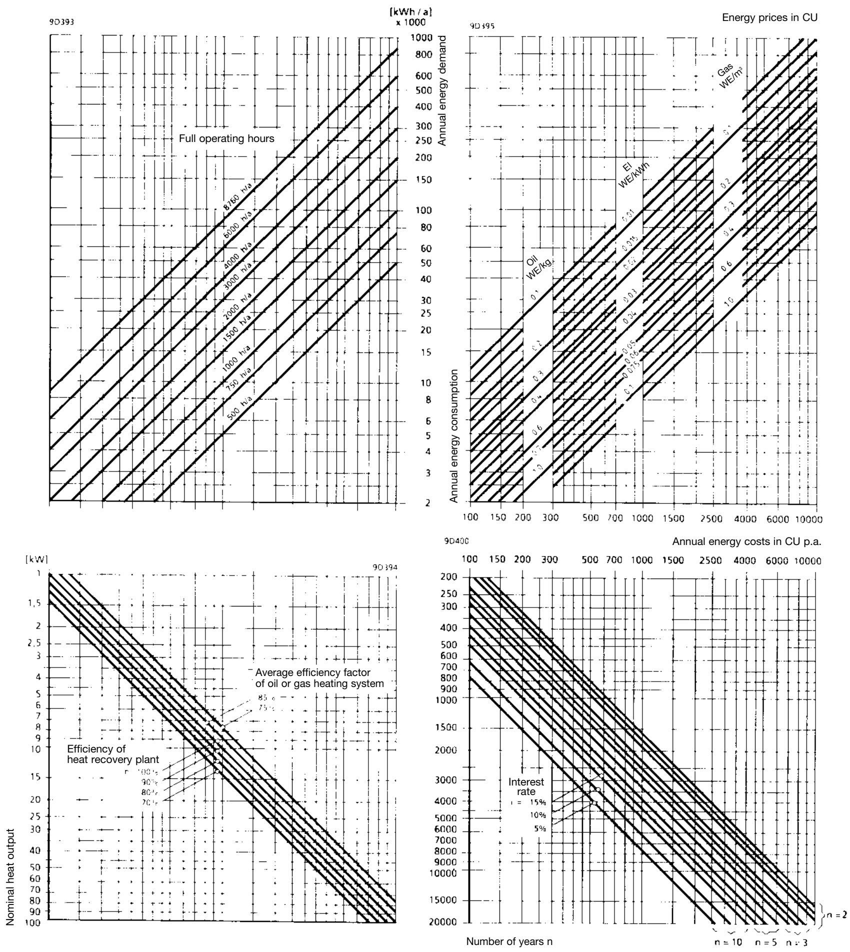


Fig. 3.14

Overview of heat recovery options (simplified plant diagrams)

1. Condensers connected in parallel

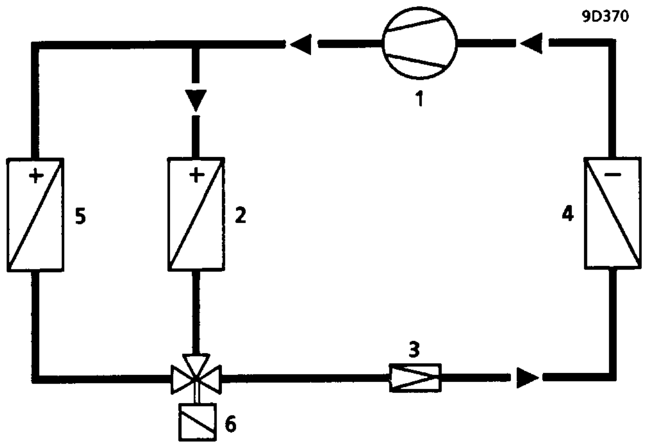
Condensate control of an auxiliary condenser

The condensate valve allows refrigerant to pass through the auxiliary condenser when there is demand for heat. The condensate collects in the main condenser which becomes inactive.

Benefits:
- Straightforward
- Modulating heating control 0…100 %
- Control valve does not call for a higher compressor output since it is installed on the liquid side
- Especially suited for use in plants with high pressure losses in the condensers
- Extensive controllable capacity range: up to 1,000 kW per valve

For consideration:
- Relatively slow response to control commands, therefore suited primarily for preheaters, d.h.w. heating or low-temperature heating systems

Examples of plant in the text:
«Preheating outside air» (page 10)
«Low-temperature heating via waste heat utilization» (page 16)



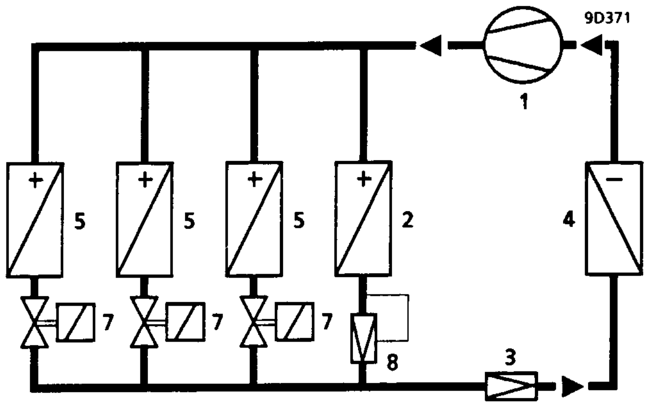
1 Compressor
2 Main condenser
3 Expansion valve
4 Evaporator
5 Auxiliary condenser
6 Condensate valve M3FK…

Condensate or hot-gas control of several auxiliary condensers

Auxiliary condensers are controlled individually using two-port valves on the condensate or hot-gas side.

Pressure holding valve opens when the auxiliary condensers do not call for heat and the pressure exceeds the set value.

Maximum controllable capacity of each MVL661… valve approx. 400 kW



1 Compressor
2 Main condenser
3 Expansion valve
4 Evaporator
5 Auxiliary condenser
6 Automatic pressure holding valve
7 Two-port valve MVL661…
8 Pressure holding valve (overflow valve)

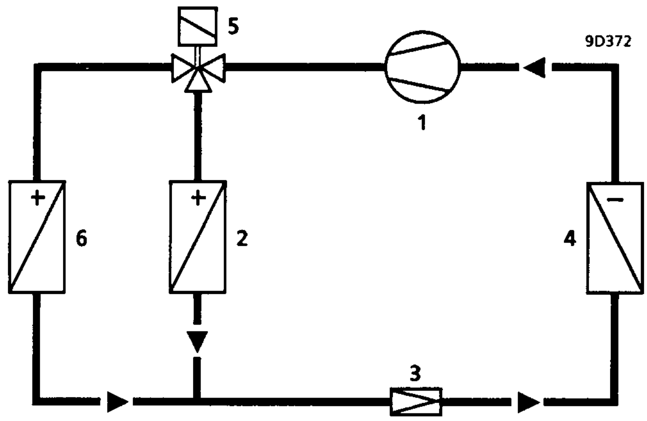
Hot-gas diversion control with three-port valve

Hot-gas diverting valve M3FB… opens the path to the auxiliary condenser when there is demand for heat.

Benefits:
- Quick response to control commands permits quick compensation of disturbance values, e.g. with reheaters and where a high level of control accuracy is required
- Forced control by three-port valve eliminates the need for auxiliary valves
- Especially suited for plants with high pressure losses in the condensers

For consideration:
- Extra work of compressor resulting from permanent pressure loss caused by control valve
- Large control valves required

Example of plant in the text:
«Food shop with integrated heat recovery» (page 15)



1 Compressor
2 Main condenser
3 Expansion valve
4 Evaporator
5 Hot-gas diverting valve M3FB…
6 Auxiliary condenser

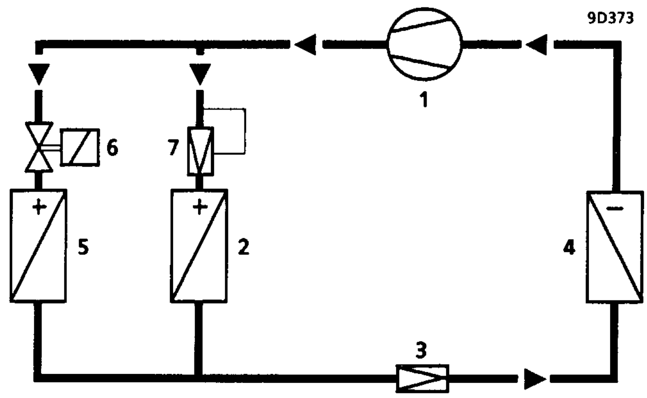
Hot-gas diversion control with two-port valves

Two-port valves in place of three-port diverting valves when their capacity is no longer sufficient. Also suited for plants with several condensers.

Pressure holding valve maintains pressure in the main condenser at the same level as in the auxiliary condenser.

Controllable capacity per valve:
- MVL661… 100 kW
- M3FK… 180 kW

Example of plant in the text:
«Heat recovery in drying plants» (page 14)



1 Compressor
2 Main condenser
3 Expansion valve
4 Evaporator
5 Auxiliary condenser
6 Two-port valve
7 Automatic pressure holding valve

2. Condensers connected in series

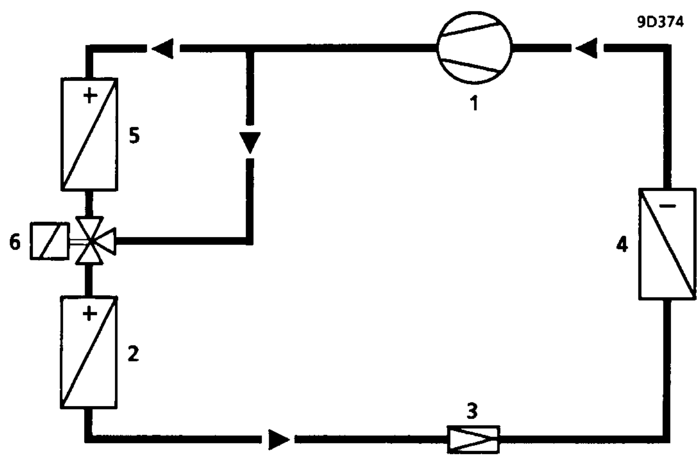
Control on the condensate side

When there is demand for heat: condensate pipe of the auxiliary condenser is open, bypass to the main condenser is closed or throttled.

Benefits:
- Especially suited for the conversion of existing plant (because of the condensers' series connection)
- Suited for use with air reheaters

For consideration:
- Constant pressure loss of valve in the pressure pipe (< 0.5 bar)
- Control valve to be sized like a hot-gas valve
- Maximum controllable capacity of each valve (M3FK…) 180 kW

Example of plant in the text:
«Reheating dehumidified supply air» (page 12)



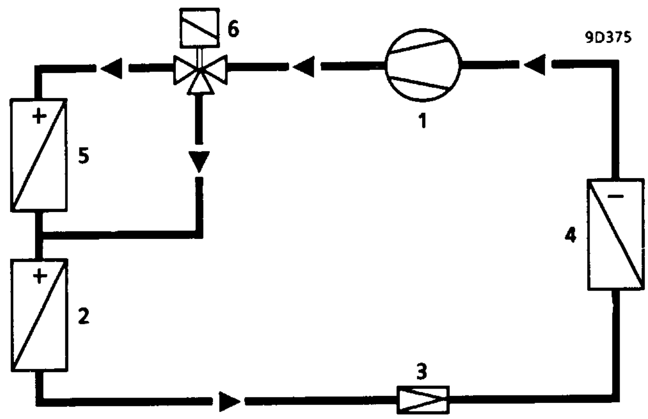
1 Compressor
2 Main condenser
3 Expansion valve
4 Evaporator
5 Auxiliary condenser
6 Condensate valve

Control on the hot-gas side

When there is demand for heat: pipe to the auxiliary condenser is open, bypass to the main condenser is closed or throttled.

Benefits:
- Very quick response to control commands
- Especially suited for use in small plants (up to 15 kW cooling capacity)
- Suited for use with air reheaters

For consideration:
- Constant pressure loss of valve in the pressure pipe (< 0.5 bar)



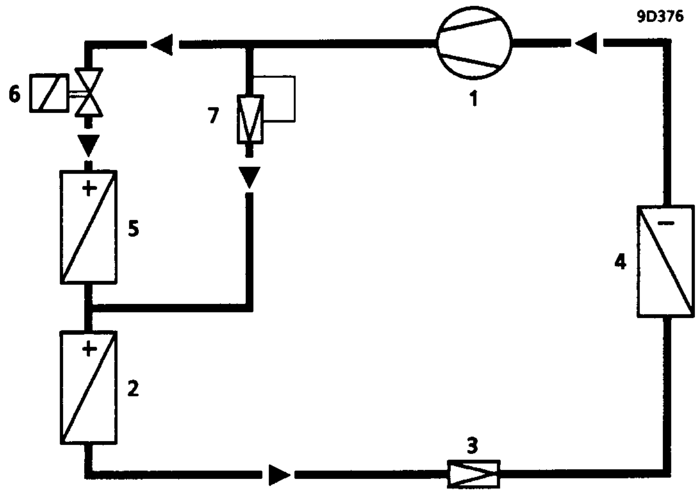
1 Compressor	4 Evaporator
2 Main condenser	5 Auxiliary condenser
3 Expansion valve	6 Hot-gas diverting valve

Control on the hot-gas side with two-port valves

For capacities >15 kW

Siemens two-port valves:
- MVL661…
- M3FK… L (port 2 closed off)

Controllable capacity per valve: max. 80 kW



1 Compressor	5 Auxiliary condenser
2 Main condenser	6 Two-port valve
3 Expansion valve	7 Automatic pressure holding valve
4 Evaporator	

4. Economy

4.1 General

In principle, heat recovery becomes increasingly economical the longer the daily operating time of the heat recovery system. Whether it is worthwhile providing a reheater for conditioning dehumidified air depends not only on the energy prices of the respective alternative energy sources but also on:

- the operating times of the oil- or gas-fired heating system; in particular the high standstill losses in summer must be taken into account
- the plant size, which plays a decisive role:
  at approximately the same heat recovery investment costs, the savings increase considerably with increasing plant size.

References

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Siemens Building Technologies
Building Automation
Sales and Application Training
Gubelstrasse 22
CH-6301 Zug

Siemens Switzerland Ltd
Building Technologies Group
International Headquarters
Gubelstrasse 22
CH-6301 Zug
Tel +41 41 724 24 24
Fax +41 41 724 35 22

Siemens Building Technologies Ltd
Hawthorne Road
Staines
Middlesex TW18 3AY
United Kingdom
Tel +44 1784 46 16 16
Fax +44 1784 46 46 46

Siemens Ltd
Building Technologies
Units 1006-10
10/F, China Resources Building
26 Harbour Road
HK-Wanchai
Tel +852 2870 7888
Fax +852 2870 7880

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