Experiment Instructions

ET 915 HSI Training System for Refrigeration and Air Conditioning Technology

Experiment Instructions

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This manual must be kept by the unit.

Before operating the unit:
- Read this manual.
- All participants must be instructed on handling of the unit and, where appropriate, on the necessary safety precautions.

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1 Introduction

The **HSI Training System for Refrigeration and Air Conditioning Technology** is a modular series of units which you can use to learn the basics of refrigeration and air conditioning. The main component of the series is the **base unit ET 915**. It includes condensers and compressors as basic elements of a compression refrigeration unit. The base unit can be quickly and easily linked to four different models depending on the specific learning goal:

- ET 915.01: Refrigerator model.
- ET 915.02: Refrigeration system model with refrigeration and freezing stage.
- ET 915.06: Single air conditioner model.
- ET 915.07: Climate control model.

The models include evaporators and expansion elements completing the refrigerant circuit. All components are clearly laid out on the base unit and on the models. This makes it easy to simulate the circuit and scan local temperature differences.

The **HSI Training System for Refrigeration and Air Conditioning Technology** is fully controlled by the supplied **software**. The software enables all measured values to be monitored online in a system diagram or in the state diagram of the refrigerant or humid air. For detailed evaluations, the measured values can be saved over a predetermined time span. The saved data can be easily imported into MS-Excel for further editing. The software is structured **like a teaching**

course. The following presents a listing of the subject areas covered, depending on the accessories you are using:

ET 915.01:

- Getting to know and understand the design and function of a simple refrigeration system
- Function of an evaporator
- Various expansion elements.
  - Operation with a capillary tube
  - Operation with an expansion valve
- Operating behaviour under load
- Refrigeration process in log *p, h* diagram
- Fault simulation

ET 915.02:

- Design and function of a refrigeration system with two evaporators
- Serial and parallel operation of evaporators
- Operating behaviour under load
- Refrigeration process in log *p, h* diagram
- Influence of evaporation pressure
- Fault simulation

ET 915.06

- Air conditioner for room cooling and its main components
- Mode of operation of an evaporator as an air cooler
- Fault simulation

ET 915.07

- Full air conditioning system and its main components
- Function of an evaporator for air cooling and dehumidification
- Function of an electric air heater
- Function of a vapour humidifier
- Heating and cooling in *h, x* diagram
- Fresh and recirculating air mode
- Fault simulation

1.1 Objectives of the system, target group and learning content

The HSI Training System for Refrigeration and Air Conditioning Technology, with its accompanying models, is a versatile unit for learning the basics of refrigeration and air conditioning. The system is particularly suitable for practical training of technicians, but it can also be usefully deployed in tertiary education.

1.2 Didactic information for the tutor

To support your teaching, we also provide these experimental instructions in PDF format on a CD.

The **ET 915** is part of our integrated range of teaching products for refrigeration and air conditioning technology, which can be found in **Catalogue 3b**. The training system can be used to teach content from the learning areas for refrigeration mechatronics engineers successfully and with practical relevance.

We very much hope you enjoy using this G.U.N.T. Training System ET 915, and we wish you success in your important task of providing students and apprentices with an introduction to the basic principles of the technology.

If you have any comments about this training system, please contact us.

2 Safety

2.1 Intended use

The unit is to be used only for teaching purposes.

2.2 Structure of the safety instructions

The signal words DANGER, WARNING or CAUTION indicate the probability and potential severity of injury.

An additional symbol indicates the nature of the hazard or a required action.

Signal word	Explanation
⚠ DANGER	Indicates a situation which, if not avoided, **will** result in **death or serious injury**.
⚠ WARNING	Indicates a situation which, if not avoided, **may** result in **death or serious injury**.
⚠ CAUTION	Indicates a situation which, if not avoided, may result in **minor or moderately serious injury**.
NOTICE	Indicates a situation which may result in **damage to equipment**, or provides instructions on **operation of the equipment**.

Symbol	Explanation
	Electrical voltage
	Hazard (general)
	Hot surfaces
	Cold
	Notice

2.3 Safety instructions

⚠ WARNING

When the rear panel is open, electrical connections are exposed – risk of electric shock.

- Prior to opening the back panel, unplug the mains connector.
- Work should only be performed by qualified electricians.
- Protect the system against moisture.

⚠ WARNING

Manipulation of the cooling circuit can result in severe injuries.

- Do not detach any of the pipework connections.
- The system is pressurised.

⚠ WARNING

Touching the refrigerant flowing out can result in frostbite to the hands and face.

- Do not detach any connections which are not intended to be detached.

⚠ WARNING

Touching the pressure pipes for the compressor can cause burns.

- Do not touch the compressor pressure pipes.

⚠ WARNING

Touching the air humidifier can cause burns.

- Do not touch the compressor pressure pipes.

NOTICE

The compressor may only be used in conjunction with the refrigerant specified in the appendix.

NOTICE

For the refrigerant to collect, the units must be left to stand for a time prior to initial commissioning. This applies particularly to the **base unit ET 915**, otherwise the refrigerant compressor may be damaged.

NOTICE

Before the compressor is switched on, all shut-off valves must first be opened.

NOTICE

If the thermal circuit breaker on the compressor is tripped, the system must be left to cool down before restarting. After switching on, the working pressures must be checked.

NOTICE

The refrigerant is an environmentally hazardous greenhouse gas which may leak out if the system is not correctly used.

NOTICE

The ball valves on the hoses must not be opened when the lines are connected. Close the ball valves before opening the connecting hoses.

3 Description and operation of the system

3.1 Commissioning the system

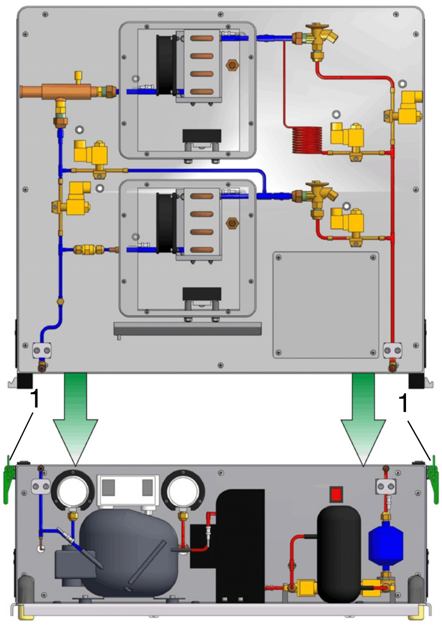


Fig. 3.1 Model assembly

As the base unit **ET 915** is not functional as a stand-alone unit, it must first be connected to a model. **ET 915** is fully controlled by the supplied software. Consequently, a connection to a PC is required in order to perform the experiment.

First make all the **mechanical connections**:

- Mount the desired accessories on the support stands of the base unit (see Fig. 3.1). You will find special carrying handles on the side of the model for the purpose.
- Then fix the model in place by the locking clamps (1).

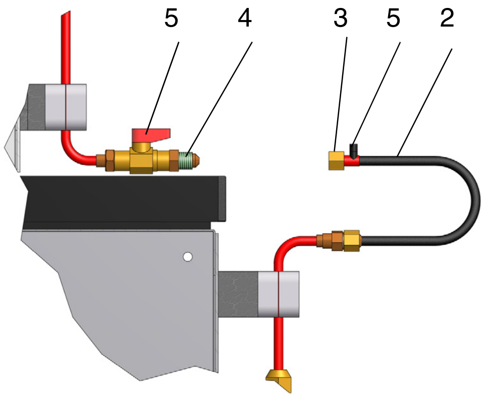


Fig. 3.2 Setting up the refrigerant circuit

- Set up the refrigerant circuit (see Fig. 3.2) by connecting the hoses (2) of the base unit to the model. Screw the union nut (3) onto the thread (4) to do so. Then the ball valves (5) can be opened.

NOTICE

The ball valves may only be opened once the refrigerant lines are securely interconnected. Otherwise the refrigerant will leak out.

To make the **data link** and connect the **power supply**:

- Connect the base unit ET 915 to the mains power socket by a cable.
- Connect the power supply by a connector between the base unit and the model.
- Make the data link by a USB cable between the base unit and PC and between the base unit and the model.
- Switch on the base unit at the main switch.

Fig. 3.3 presents an overview of the components to be interconnected by the data link and power supply cables.

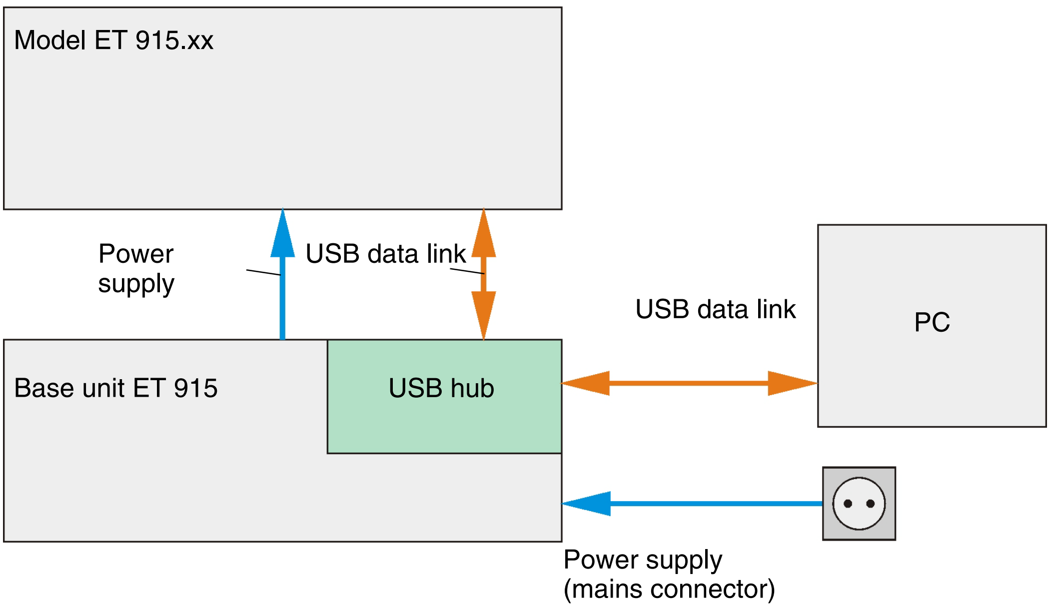


Fig. 3.3 Overview of data links and power supply

3.2 Maintenance

The mechanical system components are low-maintenance, though the humidifier of model **ET 915.07** should be decalcified occasionally.

In the event of malfunctions due to refrigerant loss, the system must be filled with new refrigerant (see Chapter 3.3).

3.3 Filling and draining refrigerant

The base unit and the associated models are factory-filled with refrigerant. However, frequent model changes and diffusion processes may lead to a shortage of refrigerant over time. Shortage of refrigerant is indicated, among other symptoms, by inadequate refrigeration performance and vapour bubbling which can be observed through the sight glass.

Consequently, each model is fitted with a filling valve by which refrigerant can be topped-up or drained off. The filling valve is fitted on the intake side.

NOTICE
Please comply with the legal requirements governing the use and storage of refrigerant.

3.4 Installing and starting the software

The following are needed for the installation:

- A fully operational PC with USB port (for minimum requirements see Chapter 8.1, Technical data).
- G.U.N.T. CD-ROM

  All components necessary to install and run the program are contained on the CD-ROM, supplied by G.U.N.T.

Installation routine

NOTICE

The trainer must not be connected to the USB port on the PC during installation of the program. The trainer can only be connected after the software has been installed successfully.

- Start the PC.
- Insert the G.U.N.T. CD-ROM.
- Launch the "**Start.bat**" installation software.
- Follow the installation procedure on-screen.
- After starting, the installation runs automatically. The following program components are installed on the PC:
  - Software for PC-data acquisition.
  - LabVIEW-Runtime and driver routines.
  - G.U.N.T. libraries
- When the installation program is finished, reboot the PC.

3.5 Using the software

- Select and launch the program using: **Start / All Programs / G.U.N.T. / ET 915**

  The language can subsequently be changed at any time on the "**Language**" menu.
- Various pull-down menus are provided for additional functions.
- For detailed instructions on use of the software refer to its Help function. This **Help function** is accessed by clicking the button **„?"**.

Saved measurement data can be imported into a spreadsheet application (such as Microsoft Excel) where it can be edited.

3.6 Layout of base unit ET 915

The base unit **ET 915** is the basic element of any experimental setup.

Fig. 3.4 presents the component layout of the base unit.

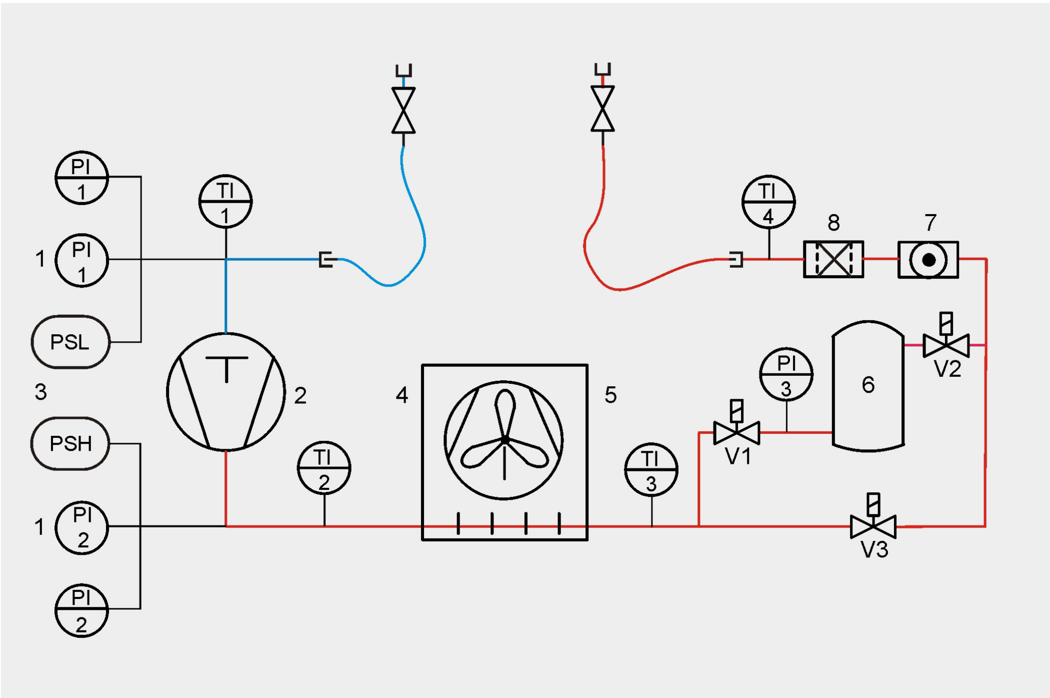
1	Compressor	7	Delivery side connecting line
2	Condenser, force-ventilated	8	Main switch
3	Refrigerant receiver	9	High pressure manometer
4	Solenoid valve	10	Pressure switch
5	Filter/dryer	11	Low pressure manometer
6	Locking clamp	12	Intake side connecting line

Fig. 3.4 Layout of components of base unit **ET 915**

3.7 Process schematic of ET 915

Process schematics are used to graphically represent refrigeration systems. They set out cycle processes in a simple way. The symbols used for the process schematics are standardised to **DIN 1861**. The process schematics are additionally affixed to the models.

Fig. 3.5 shows the process schematic for **ET 915**.



1	Manometer	8	Filter/dryer
2	Compressor	V1-V3	Solenoid valve
3	Pressure switch	p1...p3	Pressure measuring point
4	Condenser	T1...T4	Temperature measuring point
5	Condenser fan	PSH	High pressure switch
6	Refrigerant receiver	PSL	Low pressure switch
7	Sight glass		

Fig. 3.5 ET 915 process schematic

3.8 Refrigerant pump-down

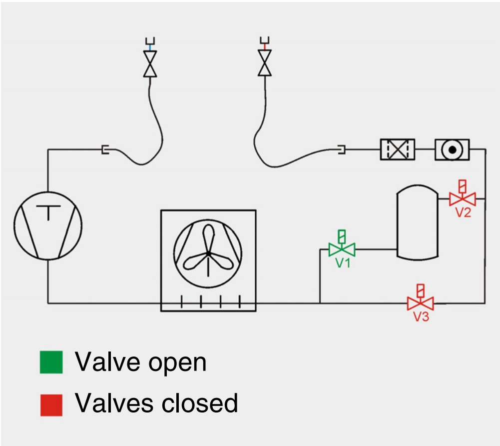


Fig. 3.6 Valve switching position for pump-down

Before mounting a different model on the base unit, the refrigerant should be routed into the receiver. This process is termed pump-down. To perform a pump-down, solenoid valves V2 and V3 must be close and V1 opened. Then the compressor is switched on. The compressor then draws in the refrigerant on the low pressure side and routes it into the receiver. The compressor keeps running until it is stopped by the low pressure switch. Then V1 is closed.

The advantage of this is that less refrigerant can leak out of the system on a subsequent model change.

It is also advisable to perform a pump-down **before** a lengthy system shutdown. If the system is left standing for a protracted period of time, refrigerant in the evaporator may condense. The refrigerant would be drawn in by the compressor the next time it is switched on and would damage it.

3.9 ET 915 system components and operation

The following describes the individual components of the base unit.

3.9.1 Hermetic piston compressor

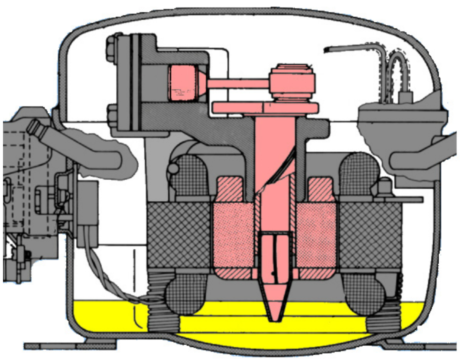


Fig. 3.7 Hermetic compressor

ET 915 is equipped with a hermetic piston compressor (Fig. 3.7). In this design, the motor and compressor are encapsulated in a gas-tight welded metal housing. The electric motor is cooled by the refrigerant vapour taken in. In this case, we refer to an intake vapour cooled compressor. The motor speed is theoretically 3000 min^{-1}. As the drive motor is an asynchronous machine, which exhibits low slip by design, a motor speed of approximately **2900 min^{-1}** can be assumed here. The compressor **capacity** V_H is 4,5 cm^3 and the **void ratio** is 2%.

In addition, the compressor used in **ET 915** has thermal overload protection. If the motor winding gets too hot, the circuit breaker shuts down the compressor.

NOTICE

The compressor may only be operated with the refrigerant specified by the manufacturer (see appendix).

3.9.2 Condenser

Fig. 3.8 Condenser

The task of the condenser (Fig. 3.8) is to discharge the heat flows absorbed during the cooling process to the environment. This is done by isobarically condensing the refrigerant vapour in it with extraction of the condensation heat.

The heat flows to be dissipated are divided as follows on the **ET 915**:

- The heat energy introduced into the system due to the compression process.
- The heat energy absorbed by the evaporators. The **number of evaporators** varies according to the **model** used.

The design used on the **ET 915** is a finned tube condenser to which air is applied. The condenser is additionally equipped with a fan to discharge the absorbed heat flows even when the system is under heavy load. The forced ventilation attained in this way increases the *k* value (coefficient of heat transfer) of the condenser.

The fan can be optionally switched on or off using the software. This means, for example, that a less efficient heat transfer such as due to dirt contamination on the condenser can be simulated.

3.9.3 Pressure switch

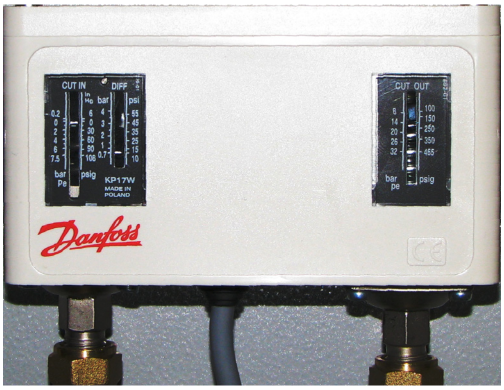


Fig. 3.9 Pressure switch

ET 915 is equipped with a double-action pressure switch which protects the system against excessively high and low pressures.

If the high pressure exceeds the maximum value set on the pressure switch, an electrical contact is operated and the compressor is shut down. This also happens if the pressure falls below the preset minimum.

The compression process is only restarted when the value is a certain amount above or below the maximum (hysteresis). The permissible maximum and minimum pressures and the hysteresis can be set on the pressure switch. For safety reasons, however, the factory default setting should be retained.

3.9.4 Sight glass

Fig. 3.10 Sight glass

The sight glass performs a dual function for the **ET 915**. Firstly, it enables vapour bubbling in the liquid line to be identified rapidly, thus preventing major damage to the system, particularly to the expansion valve. It is also equipped with a moisture indicator. The moisture indicator provides information about the water content in the system. The water content can be identified by the colour of the indicator. If it is unacceptably high, the filter/dryer and refrigerant in the system need to be replaced. On the **ET 915** the sight glass is located between the filter/dryer and the refrigeration receiver.

3.9.5 Filter/dryer

The task of the filter/dryer (see Fig. 3.11) is to filter dirt and water out of the refrigerant. On the **ET 915** it is located in the direction of flow of the refrigerant directly downstream of the sight glass.

Fig. 3.11 Filter/dryer

3.9.6 Solenoid valves

The task of the solenoid valves (see Fig. 3.12) is to enable and disable the refrigerant mass flow.

They are controlled by the supplied software.

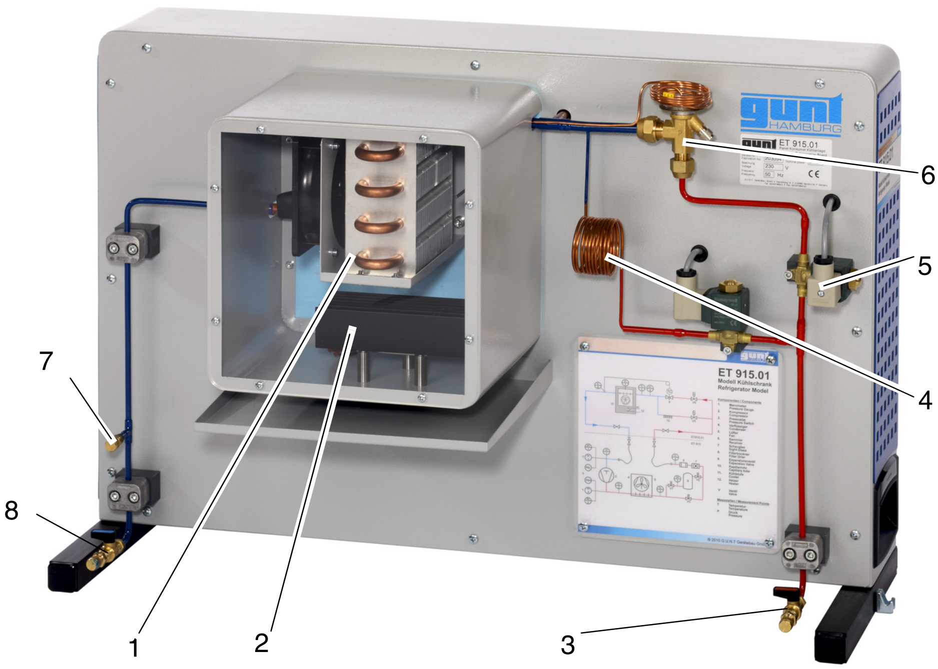
Fig. 3.12 Solenoid valve

3.9.7 Refrigerant receiver

Fig. 3.13 Refrigerant receiver

The task of the refrigerant receiver (see Fig. 3.13) on the **ET 915** is to receive all of the refrigerant when a pump-down is performed. It also provides something of a buffer in fluctuating operating conditions. The refrigerant receiver can also be used to simulate a shortage of refrigerant in the system. For this, part of the refrigerant must be pumped into the refrigerant receiver and stored there prior to performing the experiment. Then the solenoid valves V1 and V2 are closed. In the subsequent experiment the refrigerant receiver is bypassed via the open solenoid valve V3.

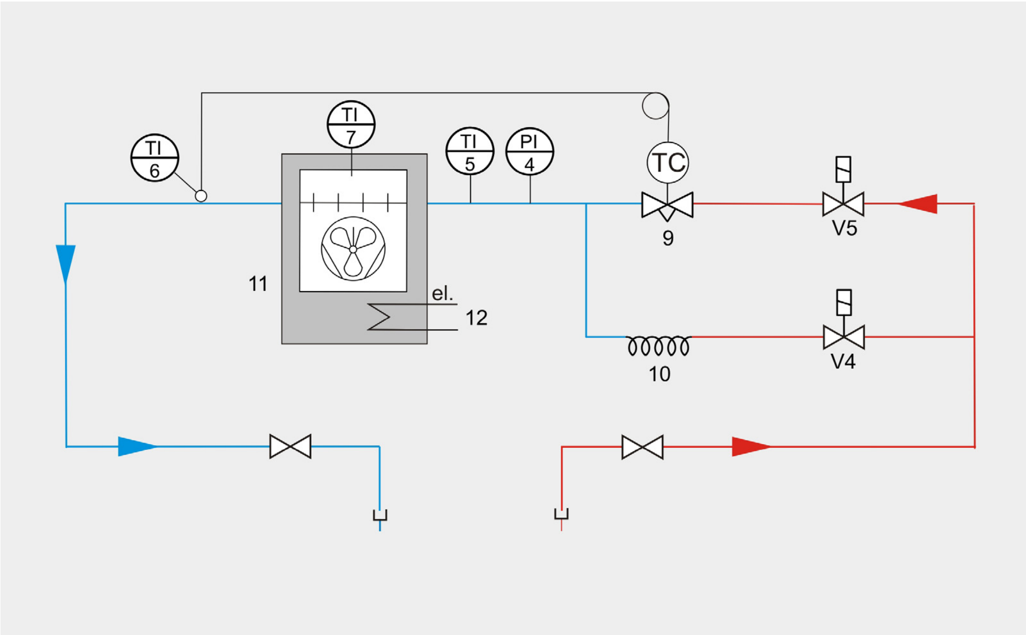
3.10 Design and components of ET 915.01



1	Evaporator	5	Solenoid valve
2	PTC heater	6	Thermostatic expansion valve
3	Refrigerant port, delivery side	7	Filling valve
4	Capillary tube	8	Refrigerant port, intake side

Fig. 3.14 ET 915.01 components

3.10.1 Process schematic of ET 915.01



9	Thermostatic expansion valve	V4-V5	Solenoid valve
10	Capillary tube	T5...T7	Temperature measuring point
11	Refrigeration chamber	p4	Pressure measuring point
12	PTC heater		

Fig. 3.15 ET915.01 process schematic

3.10.2 Evaporator

The evaporator is located in the refrigeration chamber, which has a Plexiglas screen on its front. This enables any frosting on the evaporator tubes to be observed and remedied by appropriate measures.

The evaporator is designed as a finned tube. To improve its heat transfer properties, there is additionally a fan on the evaporator which improves its *k* value. This improves the cooling capacity of the system.

The fan can be switched on and off using the software. This enables the cooling capacity with free and forced convection to be compared.

3.10.3 Restrictors

The **ET 915.01** employs two different restrictors. You can choose between a thermostatic expansion valve (TEV) and a capillary tube. Both restrictors lower the pressure of the liquid refrigerant. The key difference in this is between the loop control properties of the capillary tube and the thermostatic expansion valve:

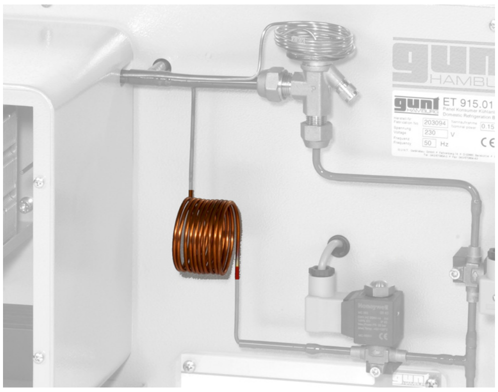


Fig. 3.16 Capillary tube

Capillary tube

Capillary tubes are **non-regulating** restrictors, though they do have a certain **self-regulating mechanism** which is illustrated by Fig. 3.17, Page 26. The diagram plots the mass flow rate as a function of the condensation temperature and evaporation pressure. The red lines indicate the respective compressor response. Here the mass flow rate rises as the evaporation pressures increase, because the density of the suction steam increases. Simultaneously, at a higher condensation temperature the mass flow rate on the compressor is reduced because the pressure trend rises and so the volumetric efficiency of the compressor decreases.

The green lines indicate the mass flow rate through a capillary tube as a function of the condensation temperature and the evaporation pressure. In contrast to the compressor, here the refrigerant mass flow rises as the evaporation pressures fall and the condensation temperatures increase. The reason for this lies in the increasing pressure gradient between the inlet and outlet on the capillary tube.

But since the mass flow rate through the capillary tube and the compressor must be identical, under given operating conditions the compressor adjusts to a constant value, as illustrated by the red and green lines in Fig. 3.17. The mass flow rate cannot be influenced directly from the outside, however, so this is referred to as a non-regulating restrictor.

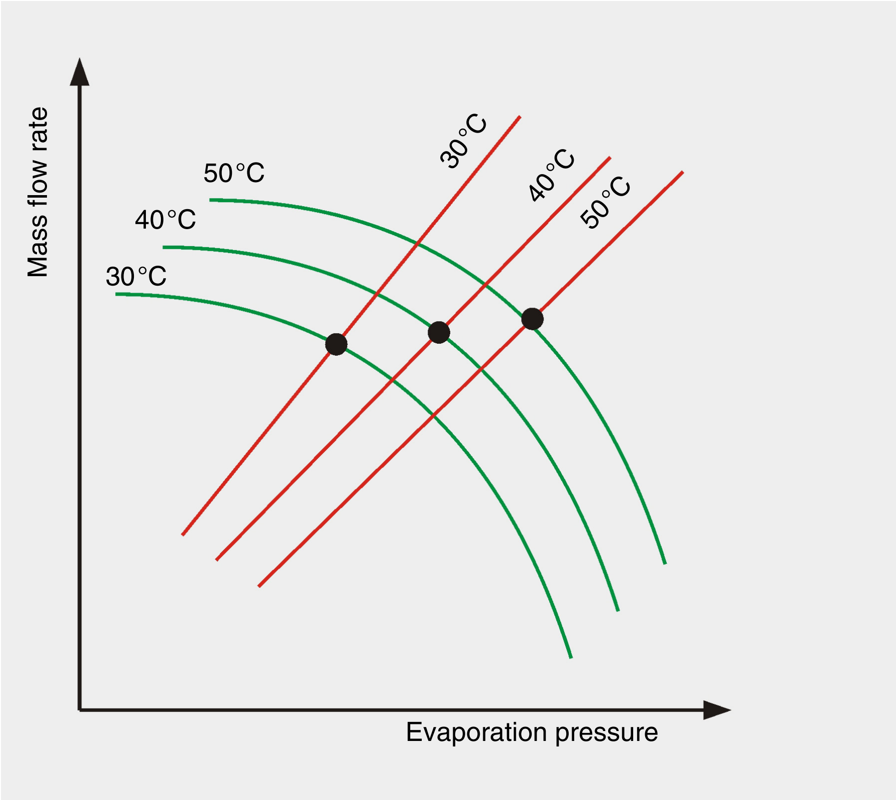
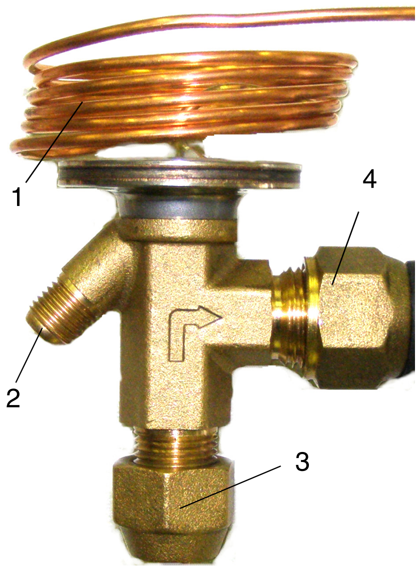


Fig. 3.17 Self-regulation of a capillary tube

On the **ET 915.01** the capillary tube is used to compare the operating behaviour of the capillary tube and thermostatic expansion valve.



1 Capillary tube
2 Adjusting screw
3 Inlet
4 Outlet

Fig. 3.18 Thermostatic expansion valve

Thermostatic expansion valve (TEV)

Thermostatic expansion valves are regulating restrictors which keep the superheating of the refrigerant at the evaporator outlet. To achieve this, there is a temperature sensor at the evaporator outlet, which is connected to the valve by a capillary tube (1). If the superheating rises above a set value, the pressure in the sensor increases and the valve is opened further. The refrigerant injection quantity is thus influenced by the superheating and therefore by the cooling load applied.

On the **ET 915.01** the desired superheating can be adjusted directly at the thermostatic expansion valve. For this, the cap must first be removed from the valve. Then the superheating can be adjusted by the adjusting screw (2) using a slotted screwdriver.

Adjusting the screw results in the following changes:

- Turning **clockwise** results in an **increase** in superheating.
- Turning **anti-clockwise** results in a **reduction** in superheating.

3.10.4 Chamber temperature control

For **ET 915.01** it is possible to control the cooling chamber temperature. A two-point controller is used for this. The functional principle of the controller is based on the fact that the heat flow is discharged discontinuously by opening and closing the refrigerant feed. This means that either the maximum possible refrigerant quantity or no refrigerant at all is conveyed. Fig. 3.19, Page 29 illustrates the function of a two-point control. In the upper diagram the chamber temperature is plotted over time, with its setpoint marked as t_R. If the setpoint value is then exceeded by a certain amount (hysteresis), the refrigerant feed is enabled. This causes the chamber temperature to fall until ultimately the lower hysteresis value is reached and the refrigerant feed is stopped again. The switching period and the temperature curve in the chamber are influenced primarily by the following factors:

- Pre-set chamber temperature value.
- Introduced thermal load.
- Chamber insulation.
- Evaporator refrigerating capacity.

The desired chamber temperature and the controller hysteresis can be adjusted in the software program.

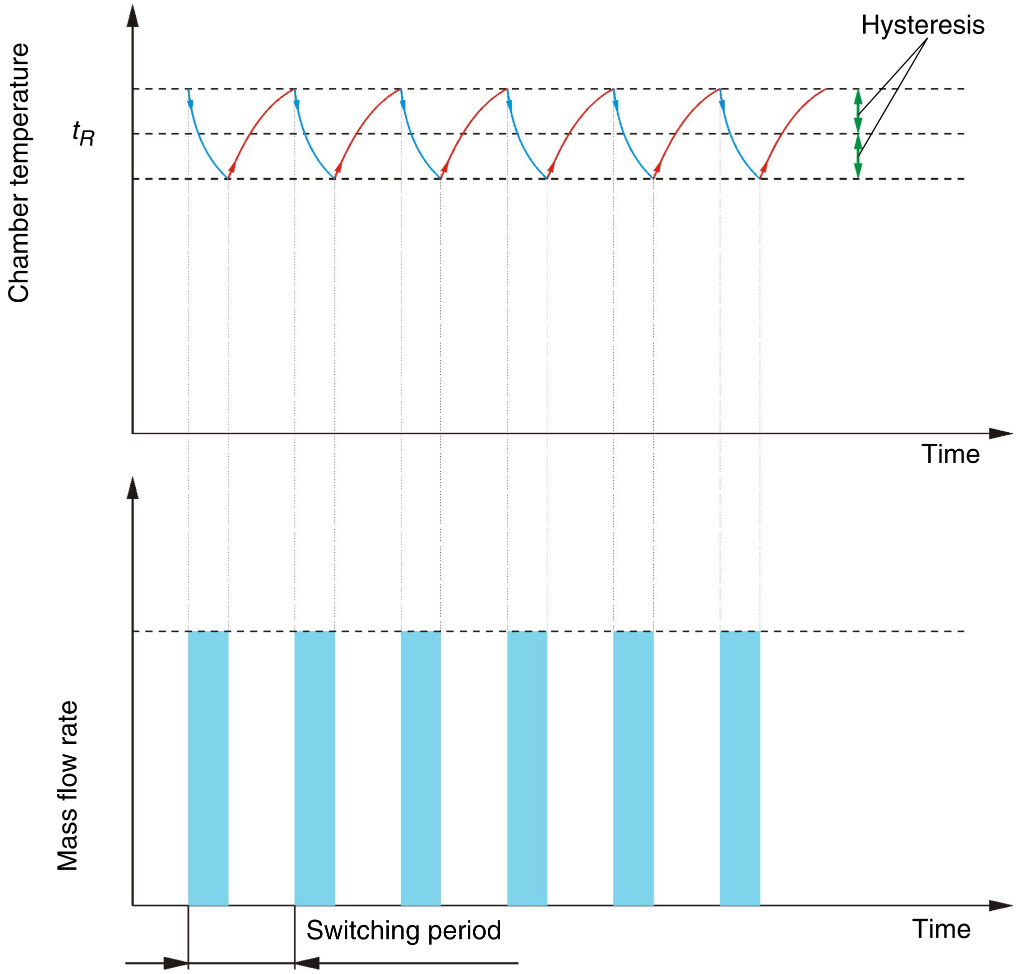


Fig. 3.19 Principle of a two-point control

3.10.5 Chamber heating

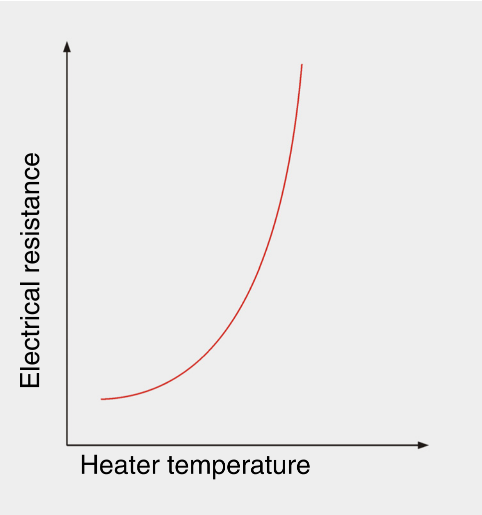


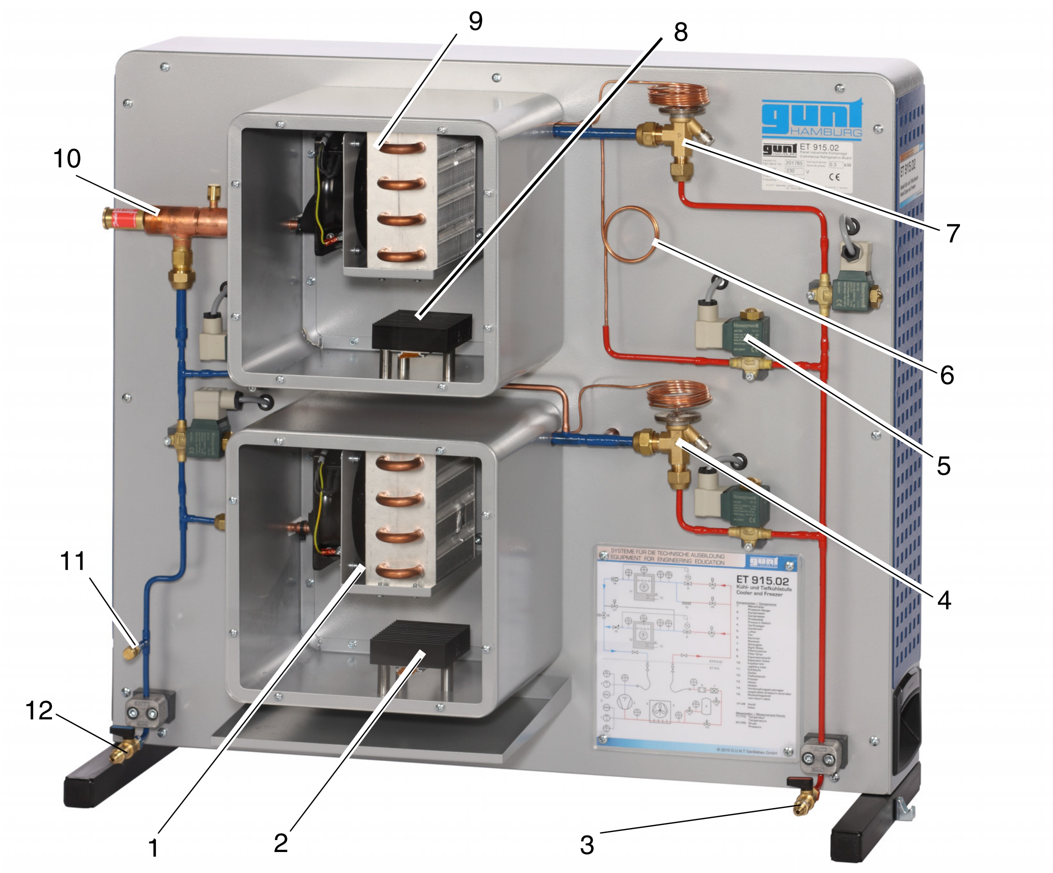
Fig. 3.20 PTC heating element characteristic curve

On the **ET 915.01** there is a heating element in the refrigeration chamber with which a cooling load can be simulated. The heater can be switched on and off using the software.

The heater used here is a PTC heating element with a non-linear resistance curve. Here the electrical resistance of the heating element rises as the temperature increases, thereby restricting the electric power consumption of the heater (see Fig. 3.20).

The advantage of PTC heating elements is that they have a self-regulating mechanism and so are protected against excessively high temperatures.

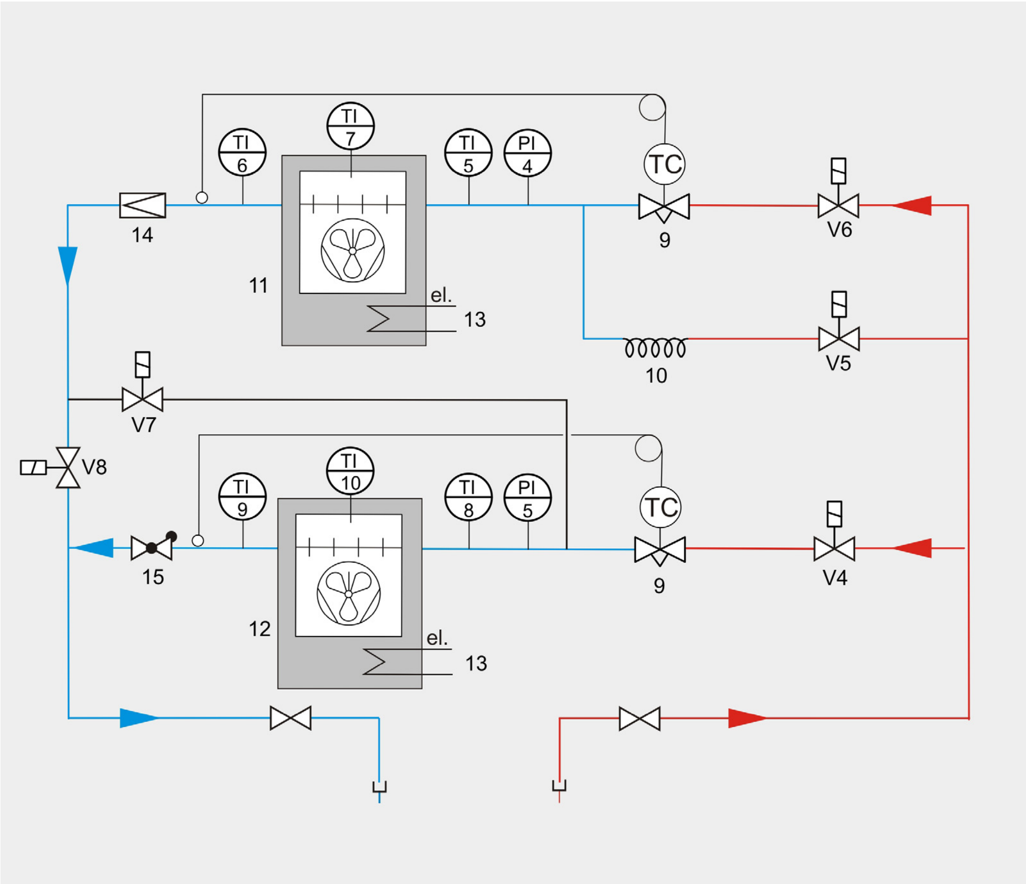
3.11 Design and components of ET 915.02



1	Evaporator, freezing chamber	7	TEV, refrigeration chamber
2	PTC heater, freezing chamber	8	PTC heater, refrigeration chamber
3	Refrigerant port, delivery side	9	Evaporator, refrigeration chamber
4	TEV, freezing chamber	10	Evaporation pressure controller
5	Solenoid valve	11	Filling valve
6	Capillary tube	12	Refrigerant port, intake side

Fig. 3.21 ET 915.02 components

3.11.1 Process schematic of ET 915.02



9	Thermostatic expansion valve	14	Evaporation pressure controller
10	Capillary tube	15	Non-return valve
11	Refrigeration chamber	V4-V8	Solenoid valve
12	Freezing chamber	T5...T10	Temperature measuring point
13	PTC heater	p4...p5	Pressure measuring point

Fig. 3.22 ET915.02 process schematic

3.11.2 Evaporator

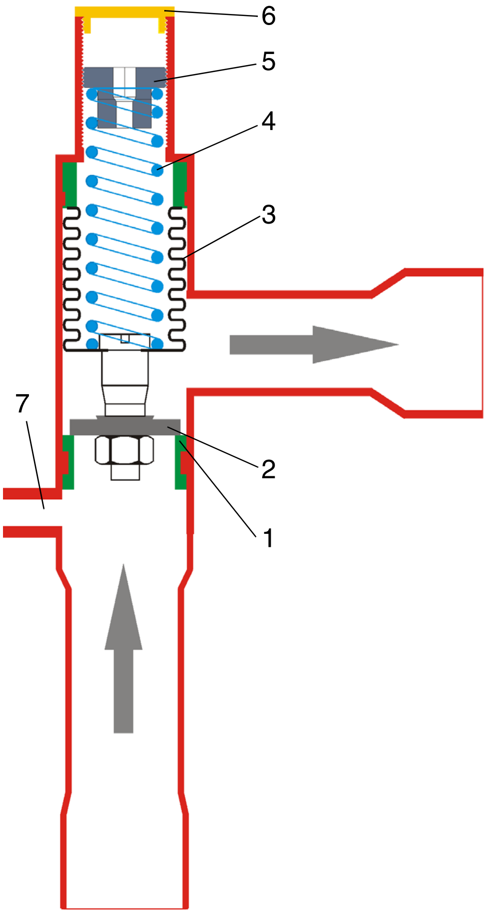
The **Model of a Refrigeration System with Refrigeration and Freezing Stage ET 915.02** has two evaporators which can be operated either in **parallel** or in **series**. The operating mode is defined by the setting of the solenoid valves.

The evaporators are located in the refrigeration chambers, which have a Plexiglas screen on the front. This enables any frosting on the evaporator tubes to be observed and remedied by appropriate measures.

Both evaporators are designed as finned tubes. To improve their heat transfer properties, there are additionally fans on each evaporator which improve their *k* values. This improves the cooling capacity of the system.

Both fans can be switched on and off using the software. This enables the cooling capacity with free and forced convection to be compared.

3.11.3 Evaporation pressure controller



1	Valve seat
2	Valve head
3	Corrugated compensating pipe
4	Spring
5	Adjusting screw
6	Cap
7	Manometer connection

Fig. 3.23 Schematic sectional diagram of an evaporation pressure controller

There is an additionally an evaporation pressure controller installed downstream of the evaporator in the upper refrigeration chamber. This enables the evaporation pressure in the upper evaporator to be kept at a constant value above the intake pressure of the compressor. It is normally used for two purposes in refrigeration engineering:

- On systems with only one evaporator, they are often used to prevent the evaporation pressure from falling below a certain value, as the value is correlated with the evaporation temperature. This is particularly important when sensitive material being cooled is in direct contact with the evaporator surface and would be damaged by low temperatures.
- In refrigeration systems with multiple evaporators, they are used to set different evaporation temperatures. This principle is applied by the **ET 915.02**.

The controller is located in the intake line directly downstream of the refrigeration chamber evaporator.

Controller setting and function:

When the cap (6) has been removed, the evaporation pressure can be adjusted by the adjusting screw (5). Turning the screw clockwise increases the evaporation pressure by raising the pre-tension of the spring (4). A higher spring tension results in the valve head (2) being pressed more strongly against the valve seat (1) and a higher evaporation pressure is then required to open the valve. The effective force in the opening direction is obtained by multiplying the evaporation pressure with the effective area of the valve head.

The initial pressure, i.e. in intake pressure of the compressor, has no influence on the control behaviour of the valve as the effective area of the corrugated compensating tube (3) corresponds to the area of the valve head. These identical areas mean that the forces cancel one another out in opening and closing direction.

It is also possible to connect a manometer to the controller via the connection port (7). The manometer can then be used for adjustment procedures.

3.11.4 Restrictors

The **ET 915.02** employs two different restrictors. The evaporator of the freezing chamber can only be operated with a thermostatic expansion valve (TEV) with internal pressure compensation, whereas for the refrigeration chamber evaporator either a thermostatic expansion valve or a capillary tube can be used. Both restrictors lower the pressure of the liquid refrigerant. The key difference in this is between the loop control properties of the capillary tube and the thermostatic expansion valve:

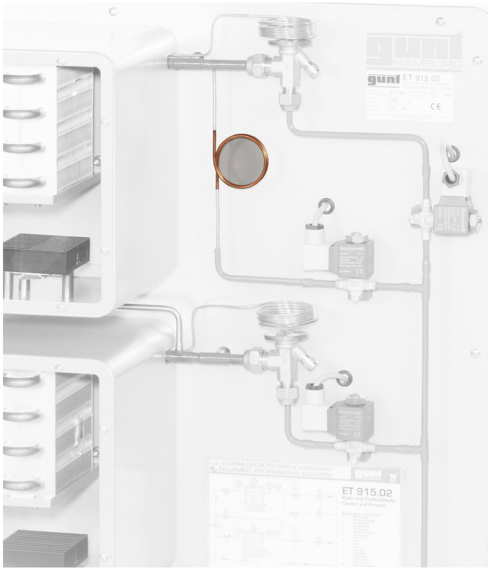


Fig. 3.24 Capillary tube

Capillary tube

Capillary tubes are **non-regulating** restrictors, though they do have a certain **self-regulating mechanism** which is illustrated by Fig. 3.25, Page 37. The diagram plots the mass flow rate as a function of the condensation temperature and evaporation pressure. The red lines indicate the respective compressor response. Here the mass flow rate rises as the evaporation pressures increase, because the density of the suction steam increases. Simultaneously, at a higher condensation temperature the mass flow rate on the compressor is reduced because the pressure trend rises and so the volumetric efficiency of the compressor decreases.

The green lines indicate the mass flow rate through a capillary tube as a function of the condensation temperature and the evaporation pressure. In contrast to the compressor, here the refrigerant mass flow rises as the evaporation pressures fall and the condensation temperatures increase. The reason for this lies in the increasing pressure gradient between the inlet and outlet on the capillary tube.

But since the mass flow rate through the capillary tube and the compressor must be identical, under given operating conditions the compressor adjusts to a constant value, as illustrated by the red and green lines in Fig. 3.25. The mass flow rate cannot be influenced directly from the outside, however, so this is referred to as a non-regulating restrictor.

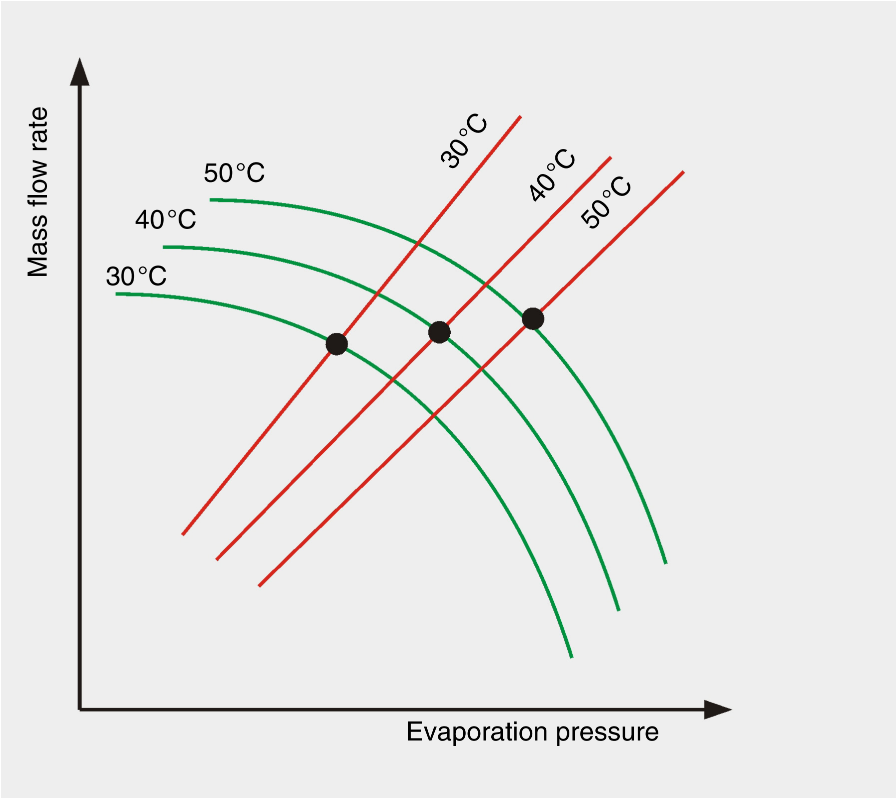
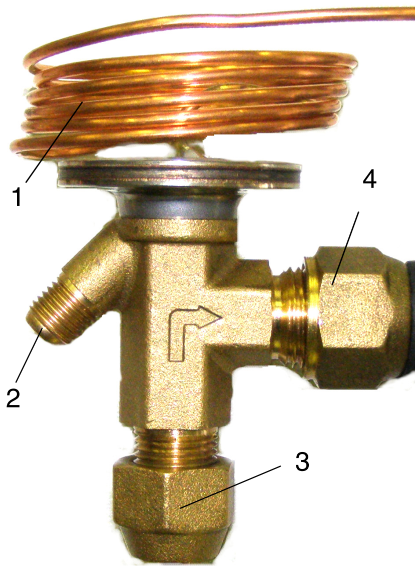


Fig. 3.25 Self-regulation of a capillary tube

On the **ET 915.02** the capillary tube is used to perform informative investigations with the evaporators in serial mode. Conducting investigations with a thermostatic expansion valve in serial mode is not advisable, as in this case only gaseous refrigerant is applied to the second evaporator.

ET 915.02 additionally permits comparison of the operating behaviour of the capillary tube with that of the thermostatic expansion valve.



1 Capillary tube
2 Adjusting screw
3 Inlet
4 Outlet

Fig. 3.26 Thermostatic expansion valve

Thermostatic expansion valve (TEV)

Thermostatic expansion valves are regulating restrictors which keep the superheating of the refrigerant at the evaporator outlet. To achieve this, there is a temperature sensor at the evaporator outlet, which is connected to the valve by a capillary tube (1). If the superheating rises above a set value, the pressure in the sensor increases and the valve is opened further. The refrigerant injection quantity is thus influenced by the superheating and therefore by the cooling load applied. If both evaporators are operated in parallel with both thermostatic expansion valves, note that the mass flow rate is not divided equally across the evaporators.

On the **ET 915.02** both chambers can be operated with thermostatic expansion valves.

On the **ET 915.02** the desired superheating can be adjusted directly at the thermostatic expansion valve. For this, the cap must first be removed from the valve. Then the superheating can be adjusted by the adjusting screw (2) using a slotted screwdriver.

Adjusting the screw results in the following changes:

- Turning **clockwise** results in an **increase** in superheating.
- Turning **anti-clockwise** results in a **reduction** in superheating.

3.11.5 Chamber temperature control

For **ET 915.02** it is possible to control the cooling chamber temperature. A two-point controller is used for this. The functional principle of the controller is based on the fact that the heat flow is discharged discontinuously by opening and closing the refrigerant feed. This means that either the maximum possible refrigerant quantity or no refrigerant at all is conveyed. Fig. 3.27, Page 40 illustrates the function of a two-point control. In the upper diagram the chamber temperature is plotted over time, with its setpoint marked as t_R. If the setpoint value is then exceeded by a certain amount (hysteresis), the refrigerant feed is enabled. This causes the chamber temperature to fall until ultimately the lower hysteresis value is reached and the refrigerant feed is stopped again. The switching period and the temperature curve in the chamber are influenced primarily by the following factors:

- Pre-set chamber temperature value.
- Introduced thermal load.
- Chamber insulation.
- Evaporator refrigerating capacity.

The desired chamber temperature and the controller hysteresis can be adjusted in the software program.

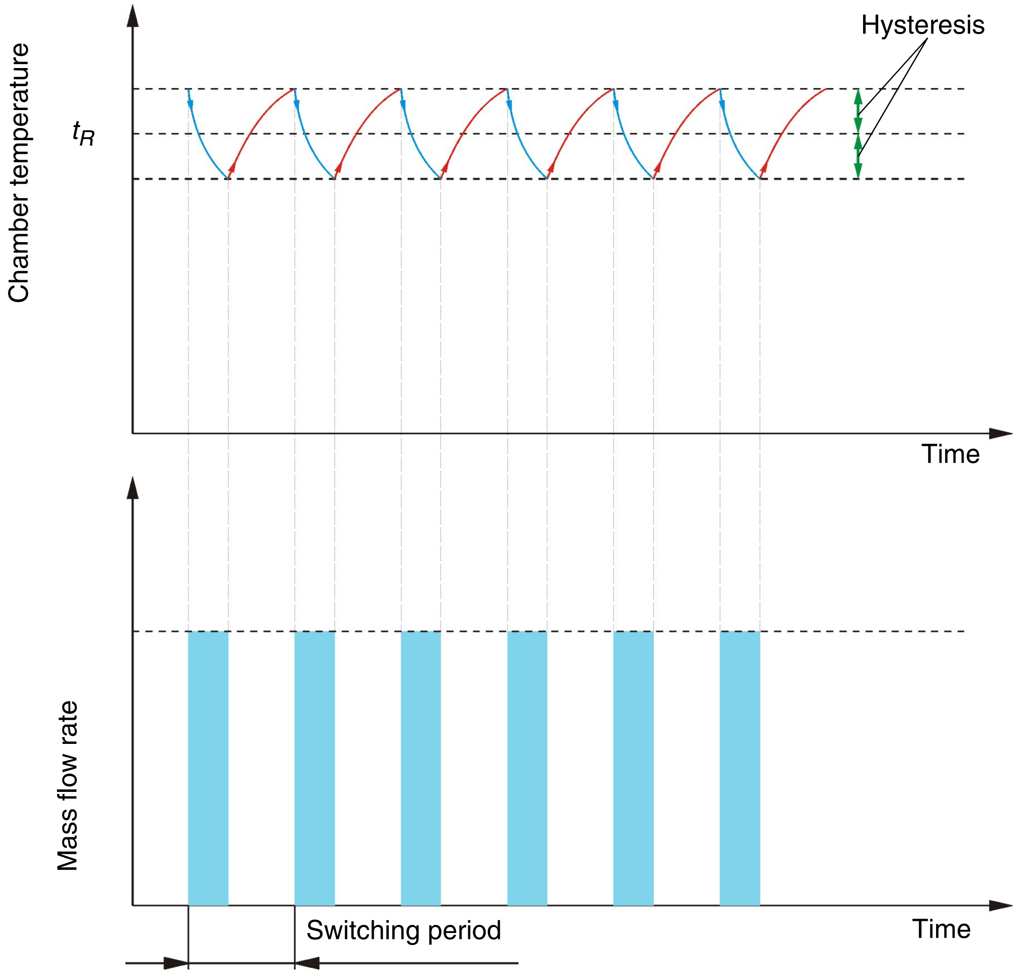


Fig. 3.27 Principle of a two-point control

3.11.6 Chamber heating

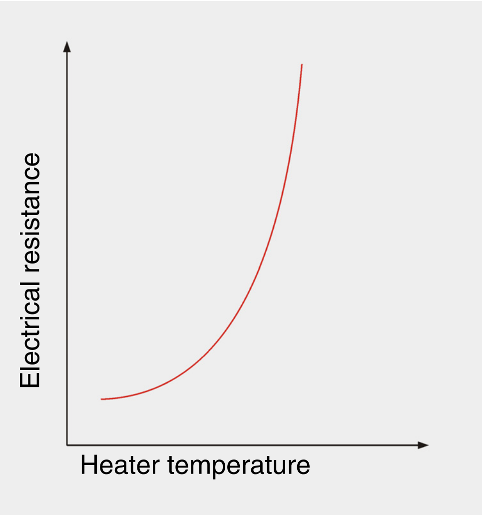


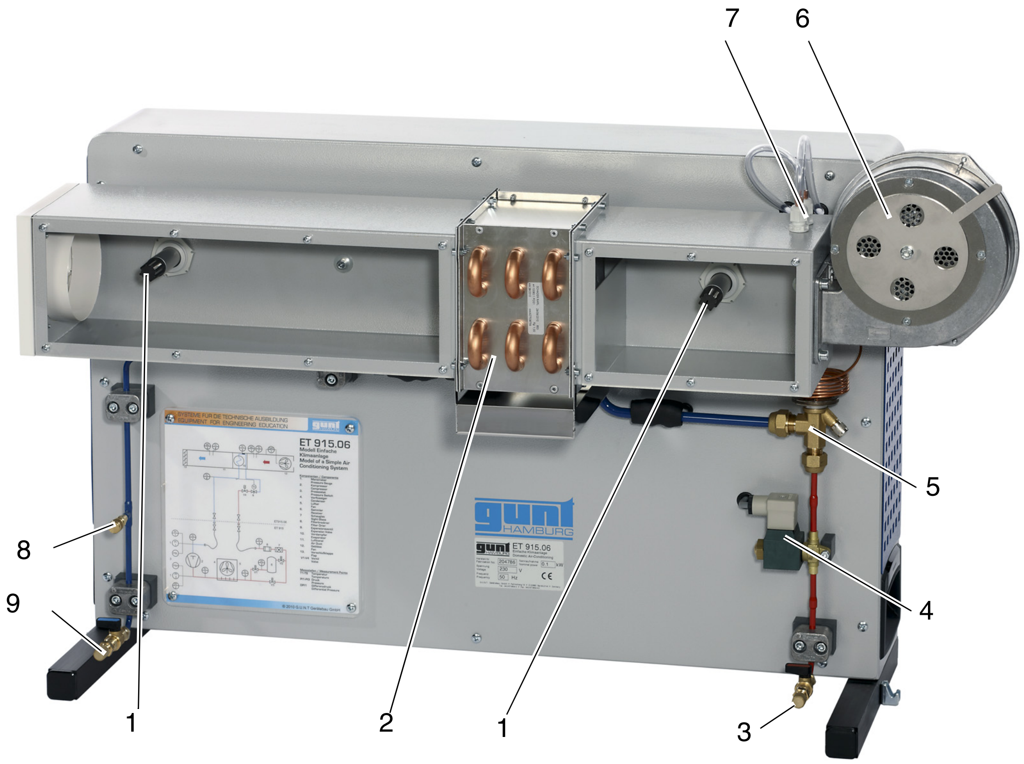
Fig. 3.28 PTC heating element characteristic curve

On the **ET 915.02** there are heating elements in the refrigeration chambers with which a cooling load can be simulated. The heaters can be switched on and off using the software.

The heaters used here are PTC heating elements with a non-linear resistance curve. Here the electrical resistance of the heating elements rises as the temperature increases, thereby restricting the electric power consumption of the heaters (see Fig. 3.28).

The advantage of PTC heating elements is that they have a self-regulating mechanism and so are protected against excessively high temperatures.

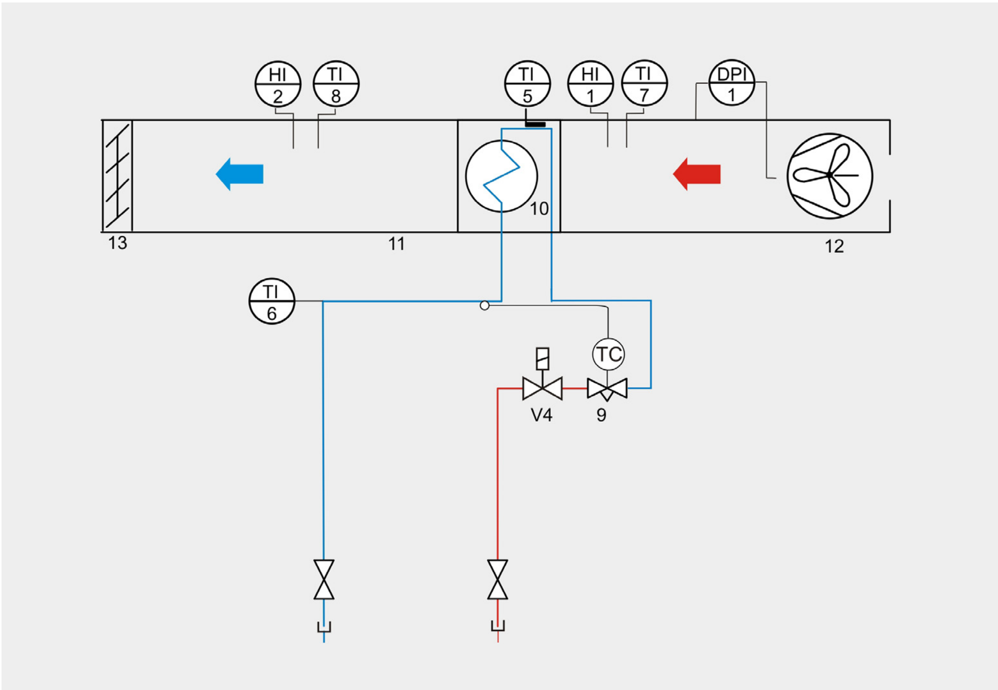
3.12 Design and components of ET 915.06



1	Humidity and temperature sensor	6	Fan
2	Cooler	7	Differential pressure probe
3	Connecting valve, delivery side	8	Filling valve
4	Solenoid valve	9	Connecting valve, intake side
5	Thermostatic expansion valve		

Fig. 3.29 ET 915.06 components

3.12.1 Process schematic of ET 915.06



9	Thermostatic expansion valve	V4	Solenoid valve
10	Cooler	T5...T8	Temperature measuring point
11	Air duct	H1...H2	Humidity measuring point
12	Fan	DP1	Differential pressure
13	Closing flap		

Fig. 3.30 ET 915.06 process schematic

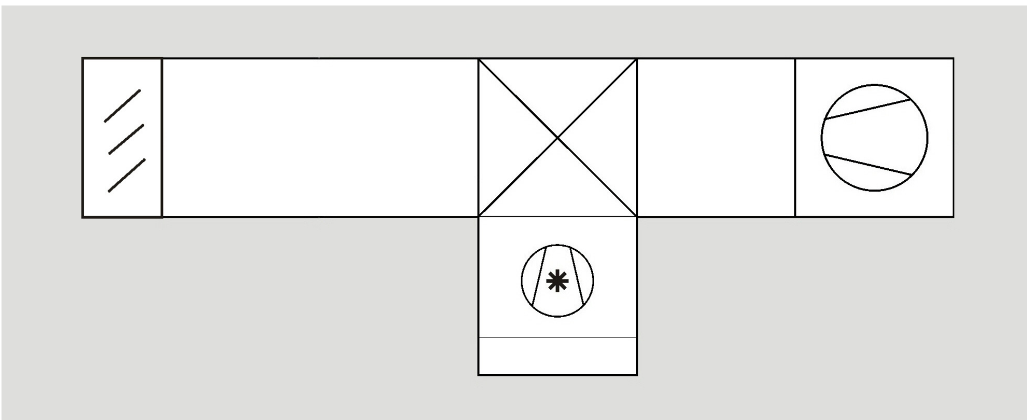


Fig. 3.31 ET 915.07 process schematic to DIN 1946-1

3.12.2 Measuring technique applied and measuring inaccuracies

To be able to interpret measurement results correctly, it is vitally important to obtain information on the tolerance of the measuring instruments used.

Humidity measurement

To measure the relative humidity the **ET 915.06** employs a capacitive humidity sensor. In this design there is a hygroscopic layer as a dielectric between the two electrodes of a capacitor. Depending on the relative humidity measured by the sensor, the hygroscopic layer adsorbs more or less water, as a result of which the electrical field constant and thus the capacity of the capacitor changes. This change is applied as a measure of the relative humidity.

The measuring inaccuracy of the humidity sensor used in **ET 915.06** is **±5% of the relative humidity**.

Temperature measurement

In all systems of the **ET 915 series** the temperature is measured with **Pt100** resistance thermometers and **calHT** measuring elements. In the temperature range under analysis the measuring inaccuracy of both methods is below **± 1 K**.

Differential pressure measurement

The differential pressure is measured by means of temperature-compensated ceramic bending bar technology. At 25°C the measuring inaccuracy is below **± 0,1 mbar**.

The cross-sectional area at the fan decisive for measurement of the differential pressure is 58 mm x 140 mm.

The cross-sectional area of the air duct is 140 mm x 140 mm.

3.12.3 Cooler

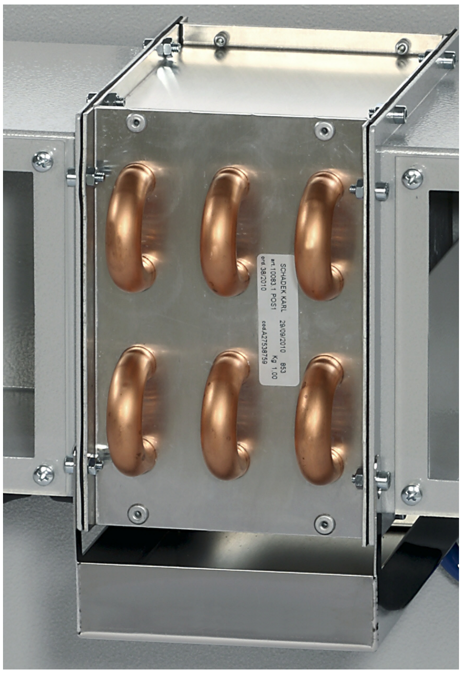


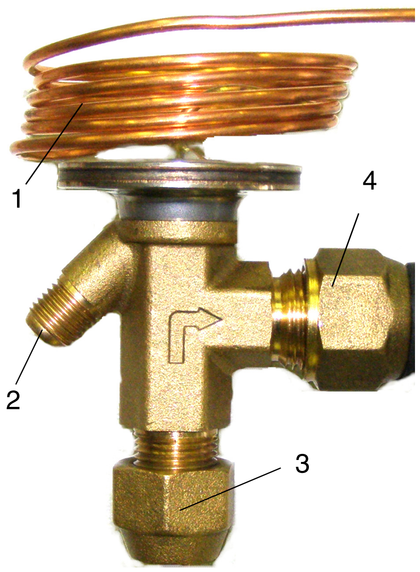
Fig. 3.32 Cooler

The model **ET 915.06** has an evaporator in the air duct which performs a dual role. Firstly, it cools the air and, secondly, it is used as a dehumidifier.

The cooler is downstream of the fan as seen in the direction of the air flow. The cooler is not insulated against the outside environment, so as not to impair the clear view of the system. In determining heat balances, therefore, it must be noted that a portion of the heat energy necessary for evaporation is drawn from the surrounding environment and not from the air in the air duct.

A tray is installed beneath the cooler to collect the condensation water.

3.12.4 Restrictors



1 Capillary tube
2 Adjusting screw
3 Inlet
4 Outlet

Fig. 3.33 Thermostatic expansion valve

The **ET 915.06** employs a thermostatic expansion valve.

Thermostatic expansion valves are regulating restrictors which keep the superheating of the refrigerant at the evaporator outlet. To achieve this, there is a temperature sensor at the evaporator outlet, which is connected to the valve by a capillary tube (1). If the superheating rises above a set value, the pressure in the sensor increases and the valve is opened further. The refrigerant injection quantity is thus influenced by the superheating and therefore by the cooling load applied.

On the **ET 915.06** the desired superheating can be adjusted directly at the thermostatic expansion valve. For this, the cap must first be removed from the valve. Then the superheating can be adjusted by the adjusting screw (2) using a slotted screwdriver.

Adjusting the screw results in the following changes:

- Turning **clockwise** results in an **increase** in superheating.
- Turning **anti-clockwise** results in a **reduction** in superheating.

3.12.5 Air duct temperature control

For **ET 915.06** it is possible to control the air duct temperature. A two-point controller is used for this. The functional principle of the controller is based on the fact that the heat flow is discharged discontinuously by opening and closing the refrigerant feed. This means that either the maximum possible refrigerant quantity or no refrigerant at all is conveyed. Fig. 3.27, Page 40 illustrates the function of a two-point control. In the upper diagram the air duct temperature is plotted over time, with its setpoint marked as t_D. If the setpoint value is then exceeded by a certain amount (hysteresis), the refrigerant feed is enabled. This causes the air duct temperature to fall until ultimately the lower hysteresis value is reached and the refrigerant feed is stopped again. The switching period and the temperature curve in the air duct are influenced primarily by the following factors:

- Pre-set air duct temperature value.
- Introduced thermal load.
- Air duct insulation.
- Cooler refrigerating capacity.

The desired air duct temperature and the controller hysteresis can be adjusted in the software program.

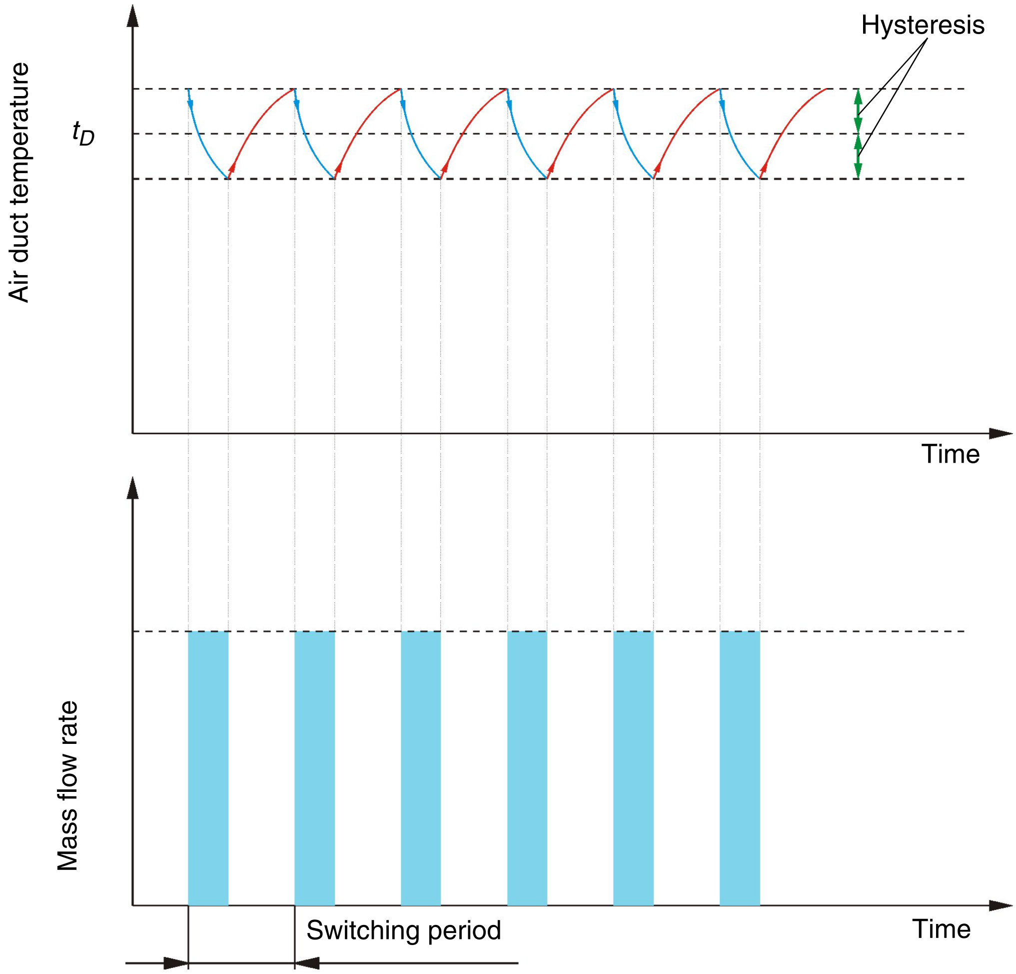
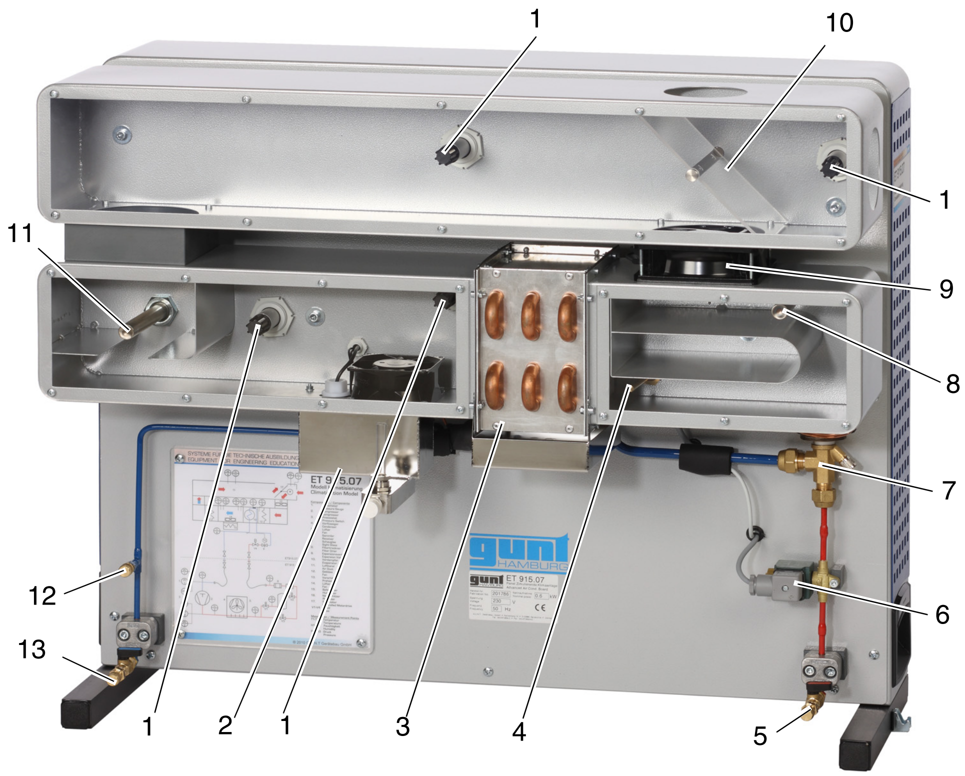


Fig. 3.34 Principle of a two-point control

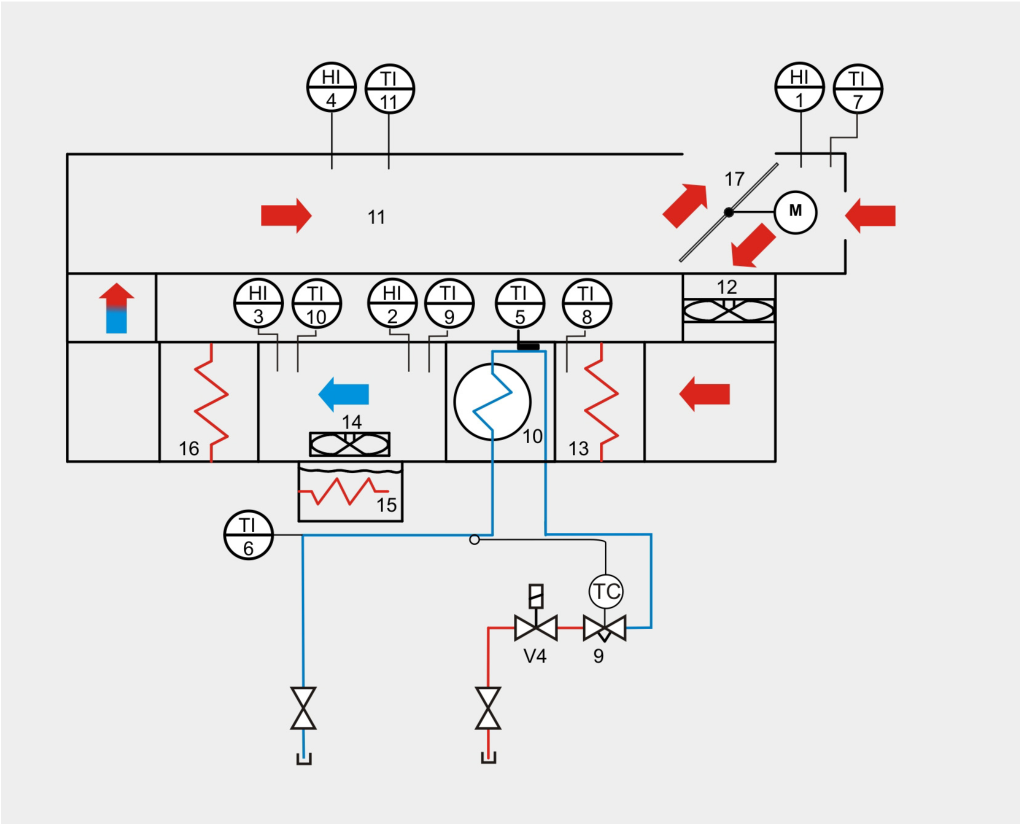
3.13 Design and components of ET 915.07



1	Humidity and temperature sensor	8	Preheater
2	Humidifier	9	Main fan
3	Cooler	10	Air guiding flap
4	Temperature sensor	11	Reheater
5	Connecting valve, delivery side	12	Filling valve
6	Solenoid valve	13	Connecting valve, intake side
7	Thermostatic expansion valve		

Fig. 3.35 ET 915.07 components

3.13.1 Process schematic of ET 915.07



9	Thermostatic expansion valve	15	Humidifier
10	Cooler	16	Reheater
11	Air duct	17	Air guiding flap
12	Main fan	V4	Solenoid valve
13	Preheater	T5...T11	Temperature measuring point
14	Humidifier fan	H1...H4	Humidity measuring point

Fig. 3.36 ET 915.07 process schematic

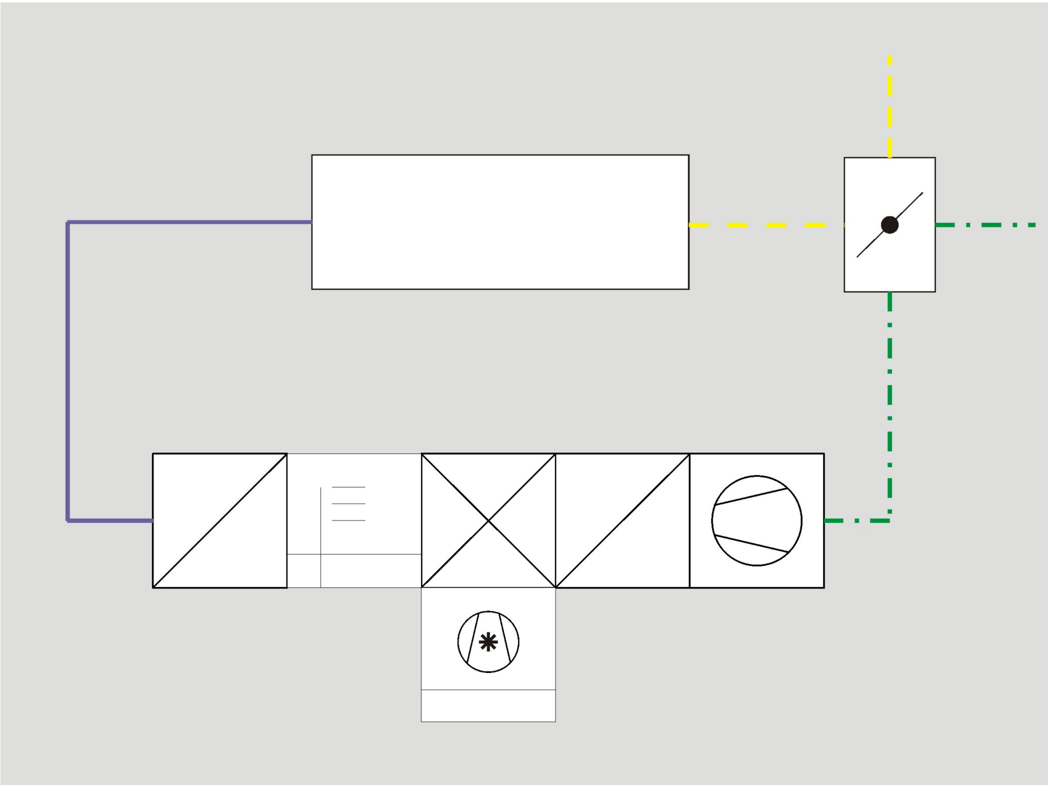


Fig. 3.37 ET 915.07 process schematic to DIN 1946-1

3.13.2 Measuring technique applied and measuring inaccuracies

To be able to interpret measurement results correctly, it is vitally important to obtain information on the tolerance of the measuring instruments used.

Humidity measurement

To measure the relative humidity the **ET 915.07** employs a capacitive humidity sensor. In this design there is a hygroscopic layer as a dielectric between the two electrodes of a capacitor. Depending on the relative humidity measured by the sensor, the hygroscopic layer adsorbs more or less water, as a result of which the electrical field constant and thus the capacity of the capacitor changes. This change is applied as a measure of the relative humidity.

The measuring inaccuracy of the humidity sensor used in **ET 915.07** is **±5% of the relative humidity**.

Temperature measurement

In all systems of the **ET 915 series** the temperature is measured with **Pt100** resistance thermometers and **calHT** measuring elements. In the temperature range under analysis the measuring inaccuracy of both methods is below **± 1K**.

3.13.3 Cooler

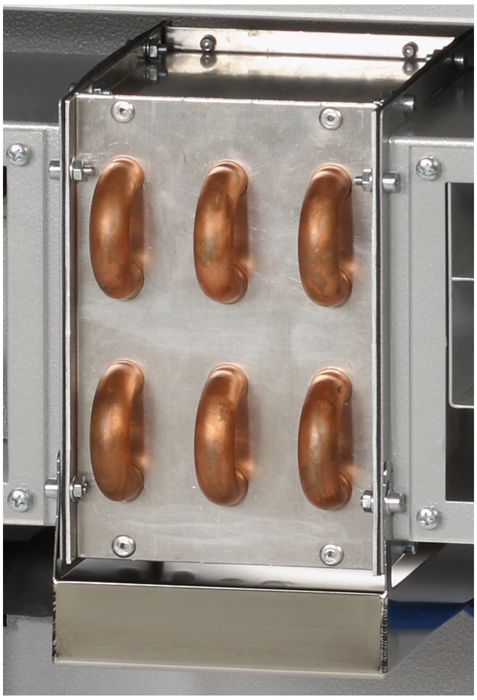


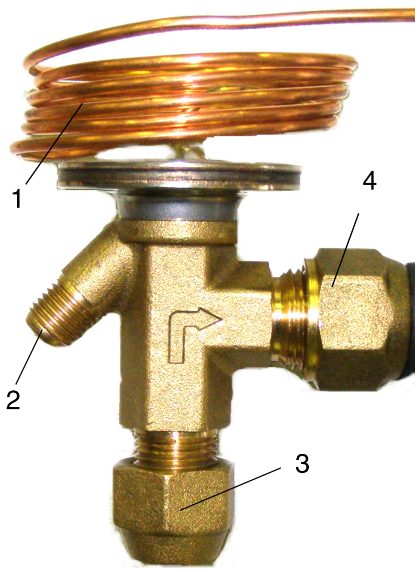
Fig. 3.38 cooler

The model **ET 915.07** has an evaporator in the air duct which performs a dual role. Firstly, it cools the air and, secondly, it is used as a dehumidifier.

The cooler is located between the preheater and the air humidifier as seen in the direction of the air flow. The cooler is not insulated against the outside environment, so as not to impair the clear view of the system. In determining heat balances, therefore, it must be noted that a portion of the heat energy necessary for evaporation is drawn from the surrounding environment and not from the air in the air duct.

A tray is installed beneath the cooler to collect the condensation water.

3.13.4 Restrictors



1 Capillary tube
2 Adjusting screw
3 Inlet
4 Outlet

Fig. 3.39 Thermostatic expansion valve

The **ET 915.07** employs a thermostatic expansion valve.

Thermostatic expansion valves are regulating restrictors which keep the superheating of the refrigerant at the evaporator outlet. To achieve this, there is a temperature sensor at the evaporator outlet, which is connected to the valve by a capillary tube (1). If the superheating rises above a set value, the pressure in the sensor increases and the valve is opened further. The refrigerant injection quantity is thus influenced by the superheating and therefore by the cooling load applied.

On the **ET 915.07** the desired superheating can be adjusted directly at the thermostatic expansion valve. For this, the cap must first be removed from the valve. Then the superheating can be adjusted by the adjusting screw (2) using a slotted screwdriver.

Adjusting the screw results in the following changes:

- Turning **clockwise** results in an **increase** in superheating.
- Turning **anti-clockwise** results in a **reduction** in superheating.

3.13.5 Air humidifier

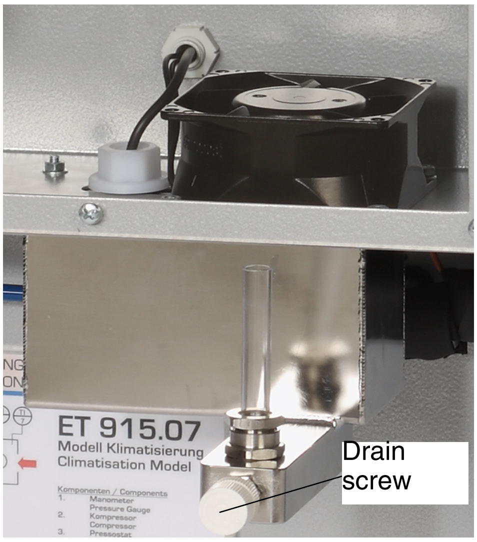


Fig. 3.40 Air humidifier with fan

The air humidifier installed in **ET 915.07** is a vapour humidifier. Consequently, the air conditioning is virtually isothermal. To generate steam, a resistance heater is used which brings the water in the storage tank to the boil. To protect the resistance heater against overheating, the storage tank is additionally fitted with a float control. This shuts the heater down as soon as the water falls below a certain level. The water level can also be viewed on the Plexiglas tube. To attain a homogeneous distribution of the steam, there is a fan directly over the humidifier which blows the steam into the air flow being conditioned.

The humidifier is filled by way of the Plexiglas tube. The humidifier can also be drained by way of the drain plug.

⚠ WARNING

Touching the air humidifier can cause burns.

- Do not touch the compressor pressure pipes.

NOTICE

As the float control shuts down the humidifier heater when the level falls below a certain minimum, an adequate water level in the humidifier must always be maintained.

3.13.6 Heating elements

Two heating elements are built into the **ET 915.07** - a preheater and a reheater. Both heaters are resistance heaters which deliver a constant output.

The task of the preheater is to preheat the air in humidifying mode, so reducing the relative humidity in the air. In the subsequent humidification, the air is more absorbent of the introduced water vapour.

The reheater is used in air dehumidification. It is used to reheat the air cooled by the dehumidification process.

If the air is only to be heated, both heating elements are active.

3.13.7 Air guiding flap

The task of the air guiding flap is to toggle between recirculating and outside air mode. The operating state is toggled directly in the software.

As the flap does not permit an intermediate position, **ET 915.07** does **not** permit mixed air mode.

4 Fundamental principles

The basic principles set out in the following make no claim to completeness. For further theoretical explanations, refer to the specialist literature.

Separate documents titled “Fundamentals of Refrigeration Engineering“ and “Fundamentals of Air Conditioning“ deal in detail with:

- Thermodynamic principles of the cyclic process.
- Function and components of a compression refrigeration system.
- Properties of the refrigerant.
- Thermodynamic principles of air conditioning.
- Mollier *h, x* diagram.
- Components of an air conditioning system.

We have included these documents to support you in your task of teaching the fundamentals of refrigeration engineering and air conditioning technology. Here we deal only with the system-specific principles not covered by the two accompanying documents.

4.1 Specific principles - ET 915.02

The document titled “Fundamentals of Refrigeration“ explains the fundamental principles of refrigeration engineering based on simple cycle processes. As **ET 915.02** has two evaporators which can be operated in either parallel or serial mode, the following deals with that special feature.

As differences in enthalpy have to be applied as a matter of principle when assessing the energy of refrigeration systems, we first indicate which measuring point is assigned which enthalpy value:

Log *p*, *h* diagram	Enthalpy	Calculated from measuring point
1	h_1	Temperature $T1$, pressure $p1$
2	h_2	Temperature $T2$, pressure $p2$
3	h_3	Temperature $T3$, pressure $p2$
—	h_4	Temperature $T4$, pressure $p2$
4	h_5	Temperature $T5$, pressure $p4$
5	h_6	Temperature $T6$, pressure $p4$
6	h_8	Temperature $T8$, pressure $p1$
7	h_9	Temperature $T9$, pressure $p1$

Tab. 4.1 Assignment of enthalpy values

4.1.1 Parallel operation of evaporators

Here both evaporators use a shared compressor, and have separate thermostatic expansion valves to expand the refrigerant. It should be noted, however, that in parallel mode the upper chamber should not be operated with the capillary tube, as it is fundamentally unsuitable for severely fluctuating operating conditions.

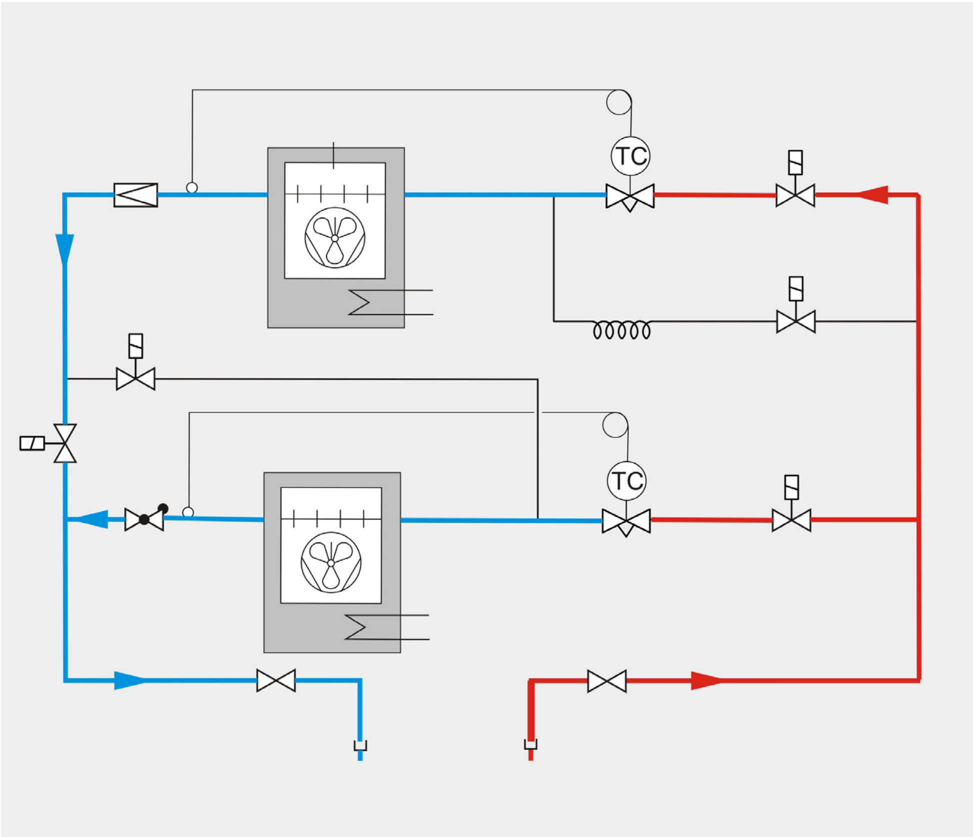


Fig. 4.1 Refrigerant flow in parallel mode

The key difference between operation in parallel mode and a simple cyclic process is that the refrigerant mass flow provided by the compressor is split between two evaporators. This split is not normally equal but depends on the control behaviour of the expansion valves. In addition, the pressure level in the upper evaporator can be adjusted using an evaporation pressure controller, as can be seen in the log *p, h* diagram for the process (see Fig. 4.2).

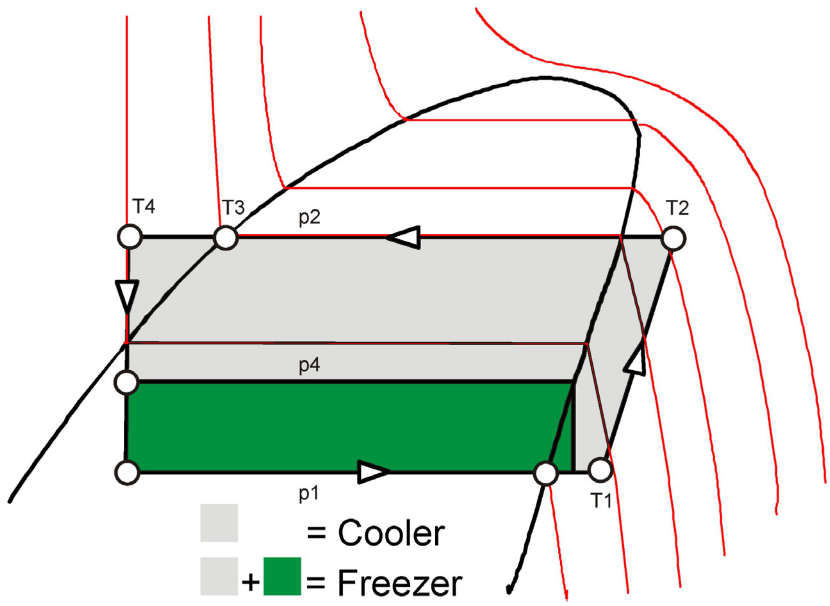


Fig. 4.2 Idealised cycle process in parallel mode

The pressure level of the upper evaporator is shown in Fig. 4.2 as *p4*.

Calculation of compressor output

The compressor output **transmitted to the refrigerant** can be calculated with the aid of the mass flow rate and the enthalpy difference of the compression process:

$$P_V = \dot{m} \cdot (h_2 - h_1) \qquad (4.1)$$

It is important to note here that the required drive output of the compressor can be significantly higher due to mechanical, volumetric and thermal losses. This is particularly the case at high pressures.

Calculation of condenser output

The output of the condenser can be calculated, like the compressor output, with the aid of the enthalpy difference and the mass flow rate.

Viewed in idealised form, the refrigerant enters the condenser at temperature *T2* and leaves it at *T3*. This enables the condenser output to be calculated as follows:

$$\dot{Q}_c = \dot{m} \cdot (h_2 - h_3) \tag{4.2}$$

Calculation of refrigerating capacity

As two evaporators are active in parallel mode, and it is not known how the refrigerant mass flow is split across the two heat exchangers, **ET 915.02** can only determine the total refrigerating capacity. This is the sum of the individual capacities:

$$\dot{Q}_0 = \dot{Q}_{0C} + \dot{Q}_{0F} \tag{4.3}$$

As they are unknown, the total refrigerating capacity can be determined by way of the following relationship:

$$\dot{Q}_0 = \dot{Q}_c - P_V \tag{4.4}$$

Applying Formula (4.1) and Formula (4.2) in Formula (4.4), the total refrigerating capacity is produced as:

$$\dot{Q}_0 = \dot{m} \cdot (h_1 - h_3) \tag{4.5}$$

4.1.2 Serial operation of evaporators

In serial mode, too, both evaporators use a shared compressor. In contrast to parallel mode, however, the refrigerant mass flow is not split. The refrigerant is expanded to a lower pressure level upstream of the upper chamber by means of the capillary tube. Then a portion of the refrigerant evaporates in the upper evaporator. It subsequently passes through the evaporation pressure controller and is fed into the lower chamber, where the residual liquid in the refrigerant can evaporate.

Since capillary tubes are unsuitable for severely fluctuating operating conditions, the refrigerant may already become overheated here if the upper evaporator is under heavy load. In this case the lower evaporator only functions as a superheater.

As in parallel mode, the pressure level in the upper evaporator can also be adjusted in serial mode.

Fig. 4.3 shows the refrigerant flow; Fig. 4.4 shows the idealised log *p, h* diagram in serial mode.

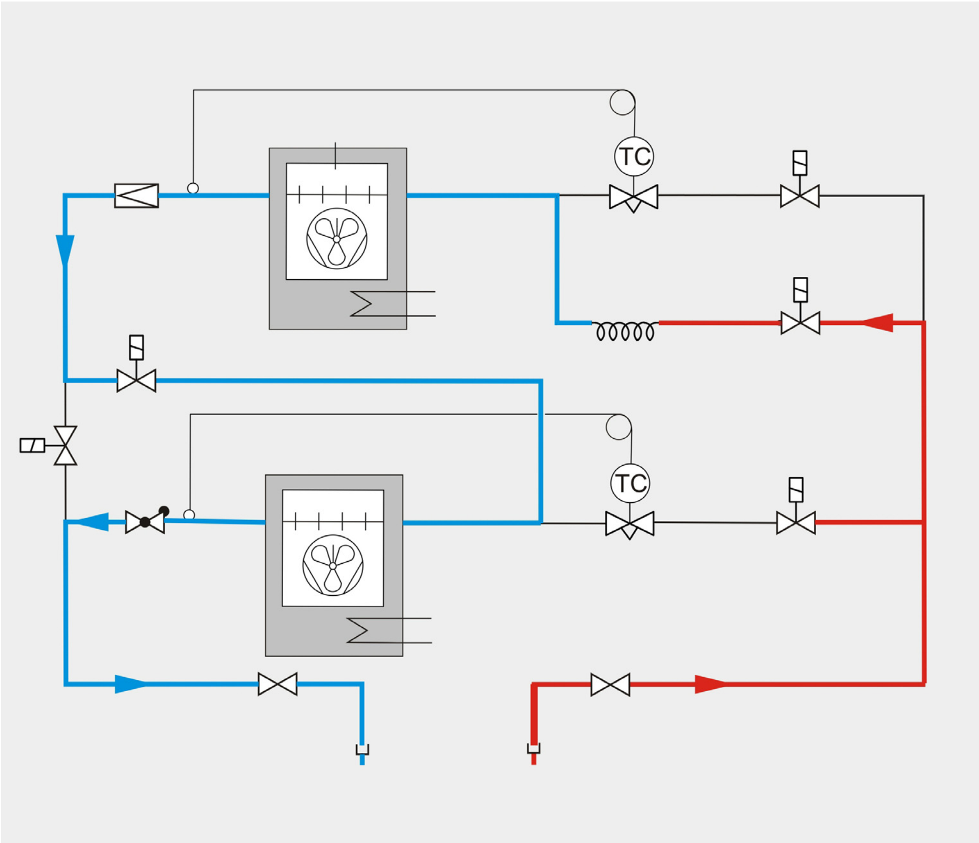


Fig. 4.3 Refrigerant flow in serial mode

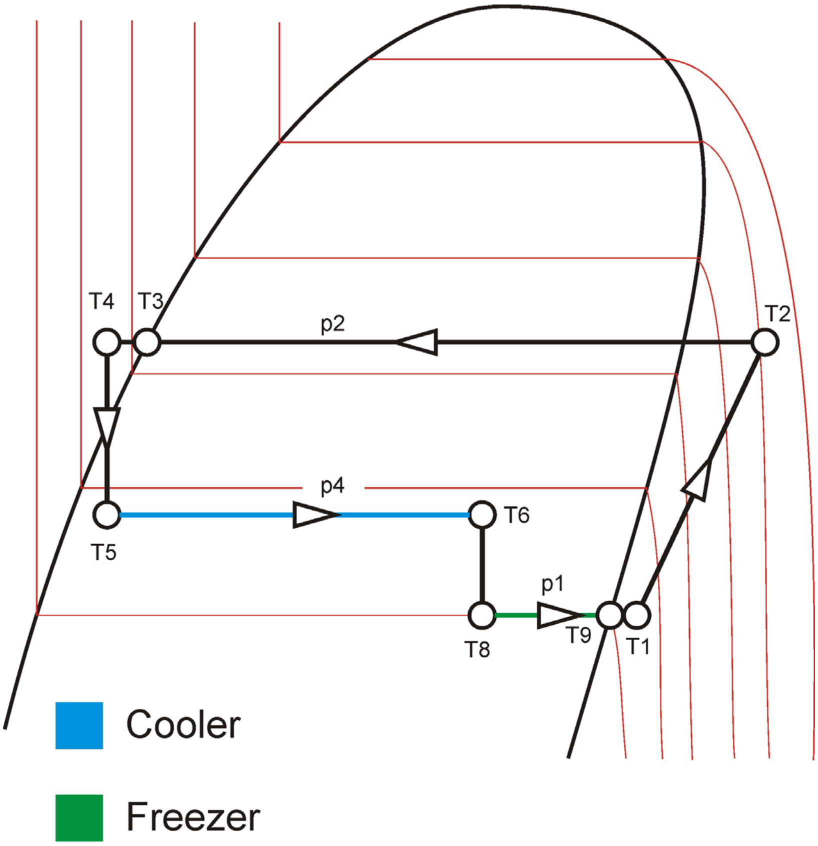


Fig. 4.4 Idealised cycle process in ET 915.02 serial mode

Calculation of compressor output

The compressor output in serial mode can be determined in the same way as in parallel mode:

$$P_V = \dot{m} \cdot (h_2 - h_1) \qquad (4.6)$$

Calculation of condenser output

The condenser output can also be determined in the same way as in parallel mode:

$$\dot{Q}_c = \dot{m} \cdot (h_2 - h_3) \qquad (4.7)$$

Calculation of refrigerating capacity

The total refrigerating capacity of the system is the sum of the refrigerating capacities of the upper and lower evaporators. As the refrigerant mass flow is not split, it can be simply determined based on the total enthalpy difference of the evaporation process and the mass flow rate:

$$\dot{Q}_0 = \dot{m} \cdot (h_9 - h_4) \qquad (4.8)$$

5 Worksheets - Tasks

The following worksheets provide an introductory guide to the field of refrigeration and air conditioning.

They contain exercises which can be performed with resources including the documents:

- Fundamental Principles of Refrigeration Engineering
- Fundamental Principles of Air Conditioning

We therefore recommend you work through those two documents before undertaking the exercises.

5.1 Worksheet 1: Construction of a refrigerating circuit

Page 1

Learning objectives:

- To construct a functional refrigerating circuit based on the fundamental elements of refrigeration engineering.

Exercise 1:

The table on page 3 contains symbolic representations of five refrigeration components.

a. Enter the names of the components next to the corresponding symbols on page 3.

b. Use the components to draw up a process schematic of a functional refrigerating circuit. The refrigerating circuit should meet the following conditions:

- The refrigerating circuit contains two evaporators.
- The evaporation pressure of one of the evaporators must be adjustable.
- The low-pressure lines should be marked in blue and the high-pressure lines in red.

NOTICE
Each component can be used multiply.

Worksheet 1, page 2

Exercise 2:

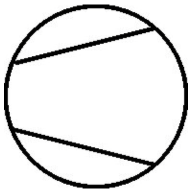
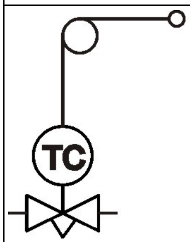
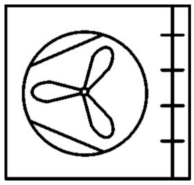
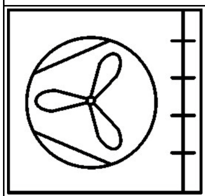
a. Plot the cyclic process of the refrigerating circuit in exercise 1 qualitatively into the log *p, h* diagram. Plot the approximate characteristic of the isotherms and isentropes.

b. Describe which quantities you need to measure, and at what positions, to plot the log *p, h* diagram of the process.

c. Where in the system is the lowest pressure?

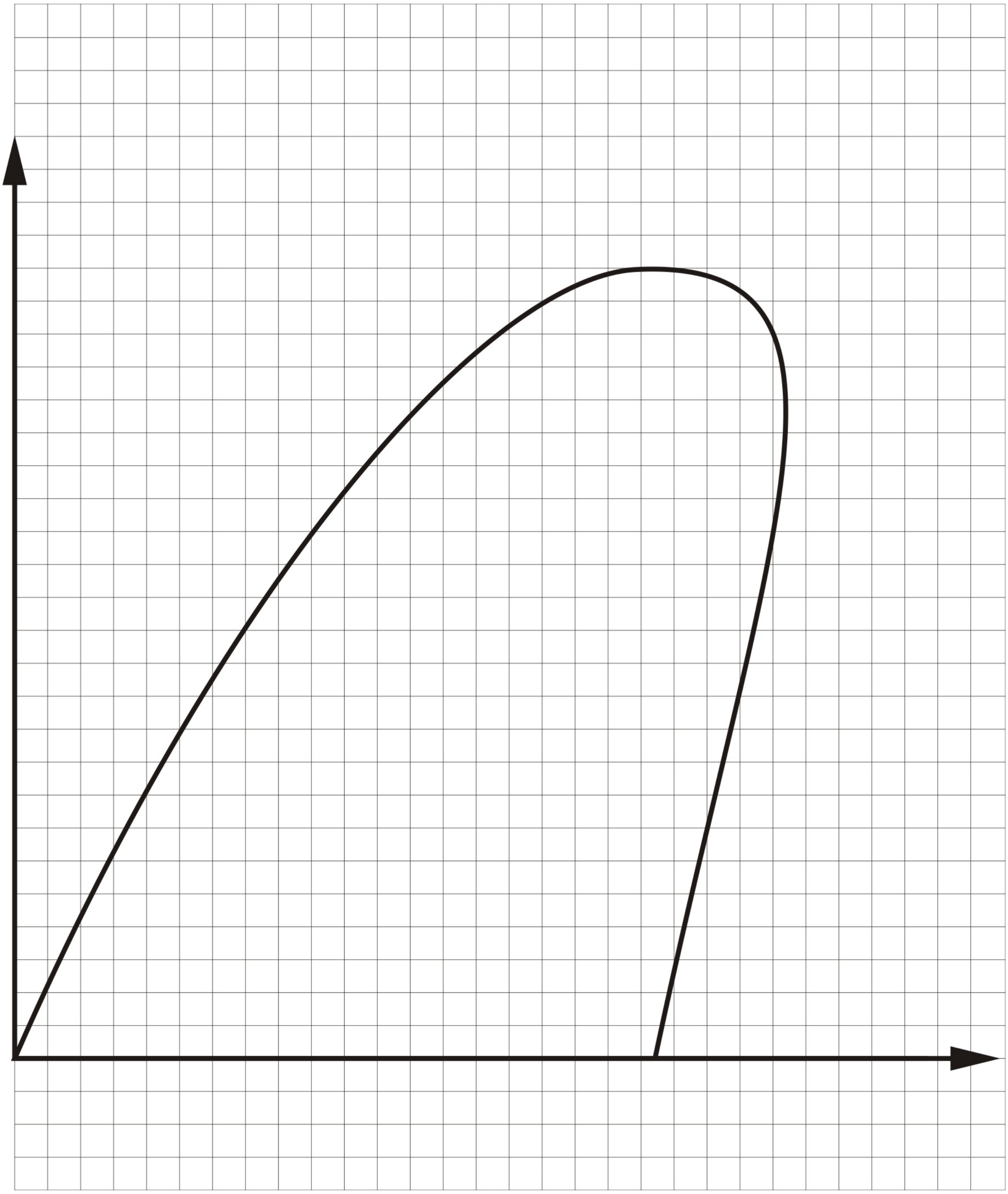
Worksheet 1, page 3

The following components are available for you to select from:

Symbol	Designation
	
	
	
	
 KVP	

Worksheet 1, page 4

Worksheet 1, page 5



Worksheet 1, page 6

Exercise 2b

Exercise 2c

5.2 Worksheet 2: Basic questions about the refrigerating circuit

Page 1

Learning objectives:

- To be able to describe the basic properties of a refrigerating circuit.
- To be able to describe the functions of key unit components.

Exercises:

- Answer the following questions.

Exercise 1

How does the refrigerating capacity respond to falling evaporation pressures?

Exercise 2

Which component safeguards the system against unacceptable pressures?

Worksheet 2, page 2

Exercise 3

How does the intake pressure of the compressor respond when a load is applied to the evaporator?

Exercise 4

How does the condensation pressure respond as the refrigerating capacity increases?

Exercise 5

What is the effect of an evaporation pressure regulator integrated into the system?

Exercise 6

You must select a suitable evaporator for a refrigeration system in which frost is expected to form on the evaporator. For such a system do you use an evaporator with a small or large fin pitch? Give reasons for your answer.

5.3 Worksheet 3: Calculation of the capacity of a vapour humidifier

Page 1

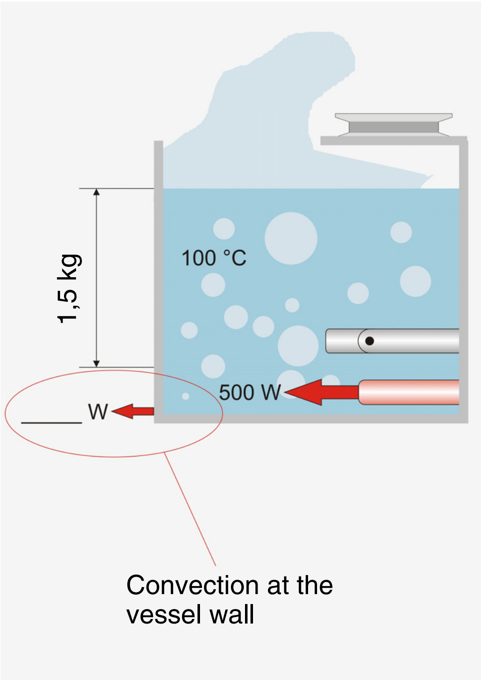


Fig. 5.1 Vapour humidifier

Learning objectives:

- To be able to estimate the steam generating capacity of a vapour humidifier.

Description of the exercise:

A vapour humidifier (500 W) is filled with 2 litres of water. A further 1,5 L of water can be evaporated until the float switch switches off the humidifier. Additionally, the water boils at 100 °C and the temperature on the outside of the stainless steel vessel is 98 °C. The ambient temperature during humidification is a constant 20 °C.

- What output is lost by the humidification process to the environment due to heat discharge. The surface area of the humidifier is 1000 cm^2. The heat transfer mechanism is assumed to be free convection (8 W/(m^2*K)).
- What is the steam generating capacity per second?
- How long, in seconds, can you humidify with the filled quantity until the float switch switches off the humidifier?

Worksheet 3, page 2

Calculation:

Worksheet 3, page 3

5.4 Worksheet 4: Moist air

Page 1

Learning objectives:

- To learn the basic properties of moist air.

Exercises:

- Answer the following questions.
- Enter the wet bulb temperature and the dew point temperature of moist air at a temperature of 16°C and a relative humidity of 50% in the *h, x* diagram provided.

Exercise 1

What is the dew point temperature?

Worksheet 4, page 2

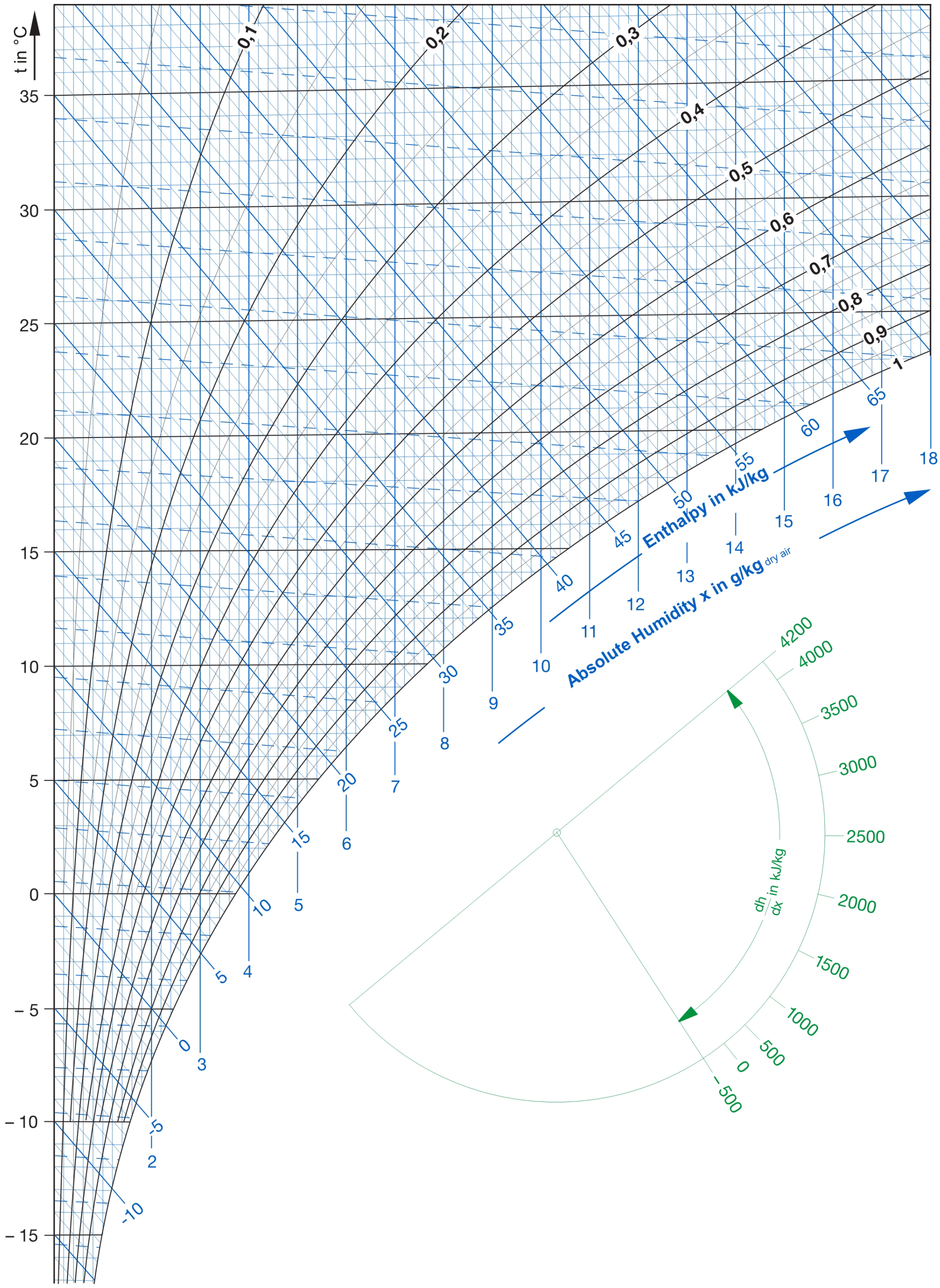
Exercise 2

What is the wet bulb temperature?

Exercise 3

How does the temperature of air respond when humidified with steam?

Worksheet 4, page 3



5.5 Worksheet 5: Calculations in the *h, x* diagram

Page 1

Learning objectives:

- To be able to carry out simple calculations in the *h, x* diagram.

Description of the exercise:

An air conditioner has a throughput rate of 0,3 kg of dry air per second. The air enters the air conditioner at a temperature of T_1=25 °C and a relative humidity of φ_1=15 %. The air is first cooled to 15 °C in a cooler. The evaporation temperature of the refrigerant in this process is 5 °C. After cooling, the air is humidified to φ_2=60 % using a vapour humidifier.

In the final section of the air conditioner the air is heated back up by a heater with an output of 2,5 kW.

a. Plot the process into the *h, x* diagram provided.

b. What is the capacity of the cooler and of the humidifier.

c. At what temperature and relative humidity does the air emerge from the air conditioner?

d. Is condensation to be expected in the cooler?

e. How can the process be energetically optimised? Indicate the optimised process by a dotted line in the *h, x* diagram.

Fig. 5.2 shows the schematic of the system.

Worksheet 5, page 2

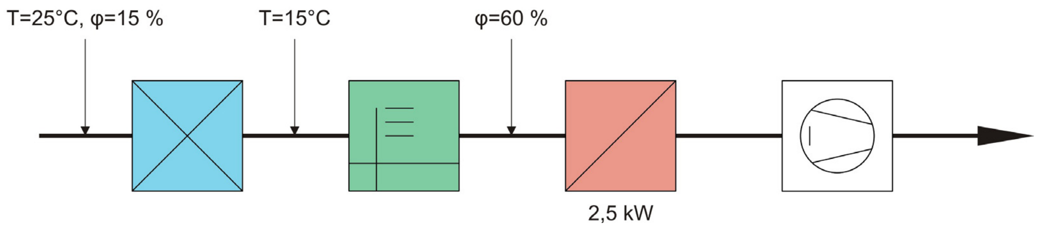


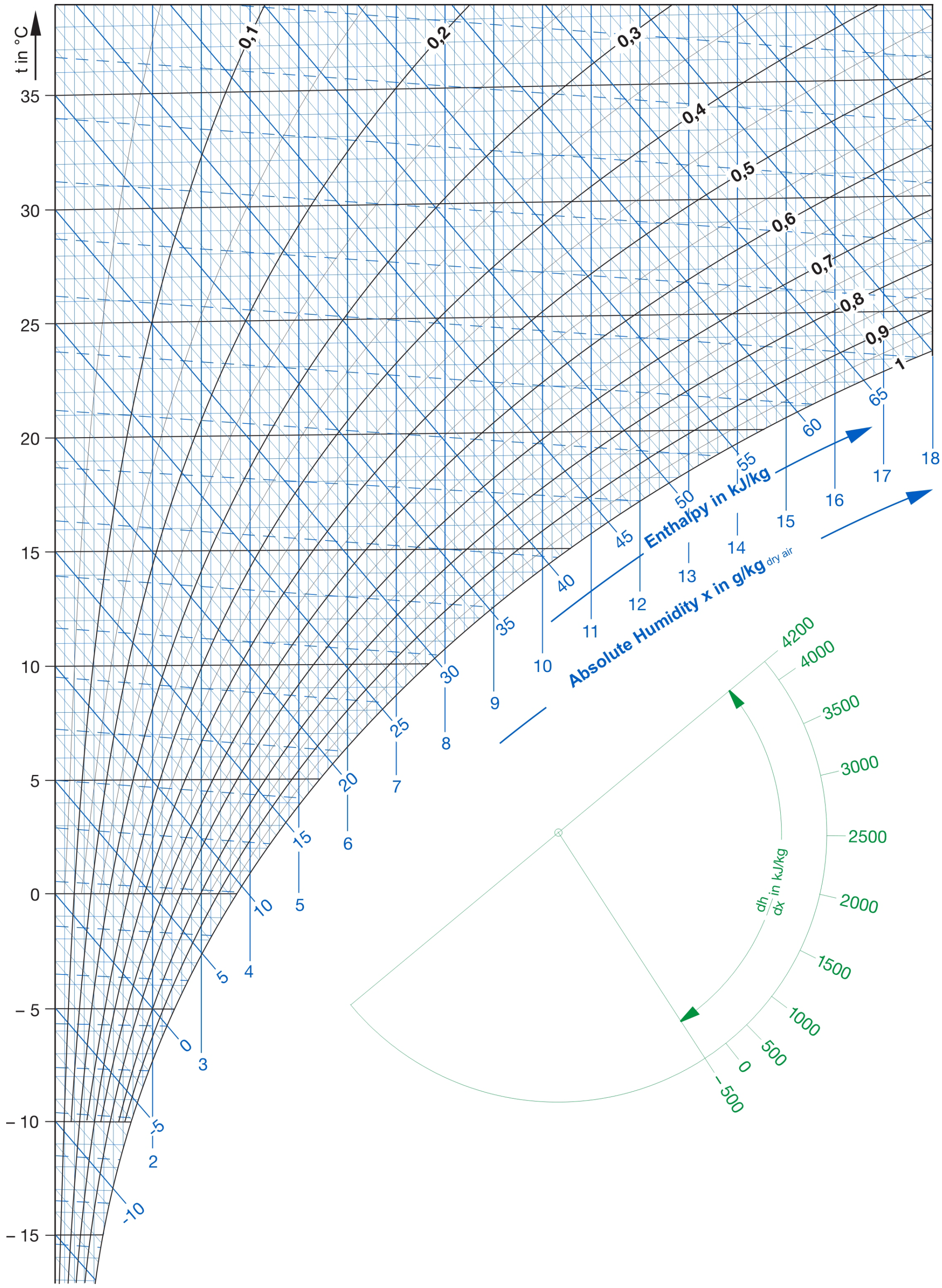
Fig. 5.2 Schematic diagram

NOTICE

This exercise represents a digression into the field of air conditioning engineering, and is intended to provide further tuition in use of the *h, x* diagram.

The numerical values have no direct link to the ET 915 system.

Worksheet 5, page 3



Worksheet 5, page 4

Worksheet 5, page 5

6 Worksheets - Solutions

The following worksheets provide an introductory guide to the field of refrigeration and air conditioning.

They contain exercises which can be performed with resources including the documents:

- Fundamental Principles of Refrigeration Engineering
- Fundamental Principles of Air Conditioning

We therefore recommend you work through those two documents before undertaking the exercises.

6.1 Worksheet 1: Construction of a refrigerating circuit

Page 1

Learning objectives:

- To construct a functional refrigerating circuit based on the fundamental elements of refrigeration engineering.

Exercise 1:

The table on page 3 contains symbolic representations of five refrigeration components.

a. Enter the names of the components next to the corresponding symbols on page 3.

b. Use the components to draw up a process schematic of a functional refrigerating circuit. The refrigerating circuit should meet the following conditions:

- The refrigerating circuit contains two evaporators.
- The evaporation pressure of one of the evaporators must be adjustable.
- The low-pressure lines should be marked in blue and the high-pressure lines in red.

NOTICE
Each component can be used multiply.

Worksheet 1, page 2

Exercise 2:

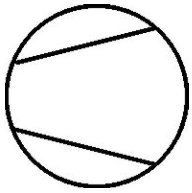
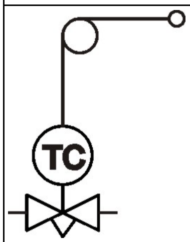
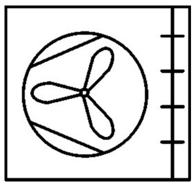
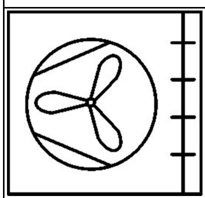
a. Plot the cyclic process of the refrigerating circuit in exercise 1 qualitatively into the log *p, h* diagram. Plot the approximate characteristic of the isotherms and isentropes.

b. Describe which quantities you need to measure, and at what positions, to plot the log *p, h* diagram of the process.

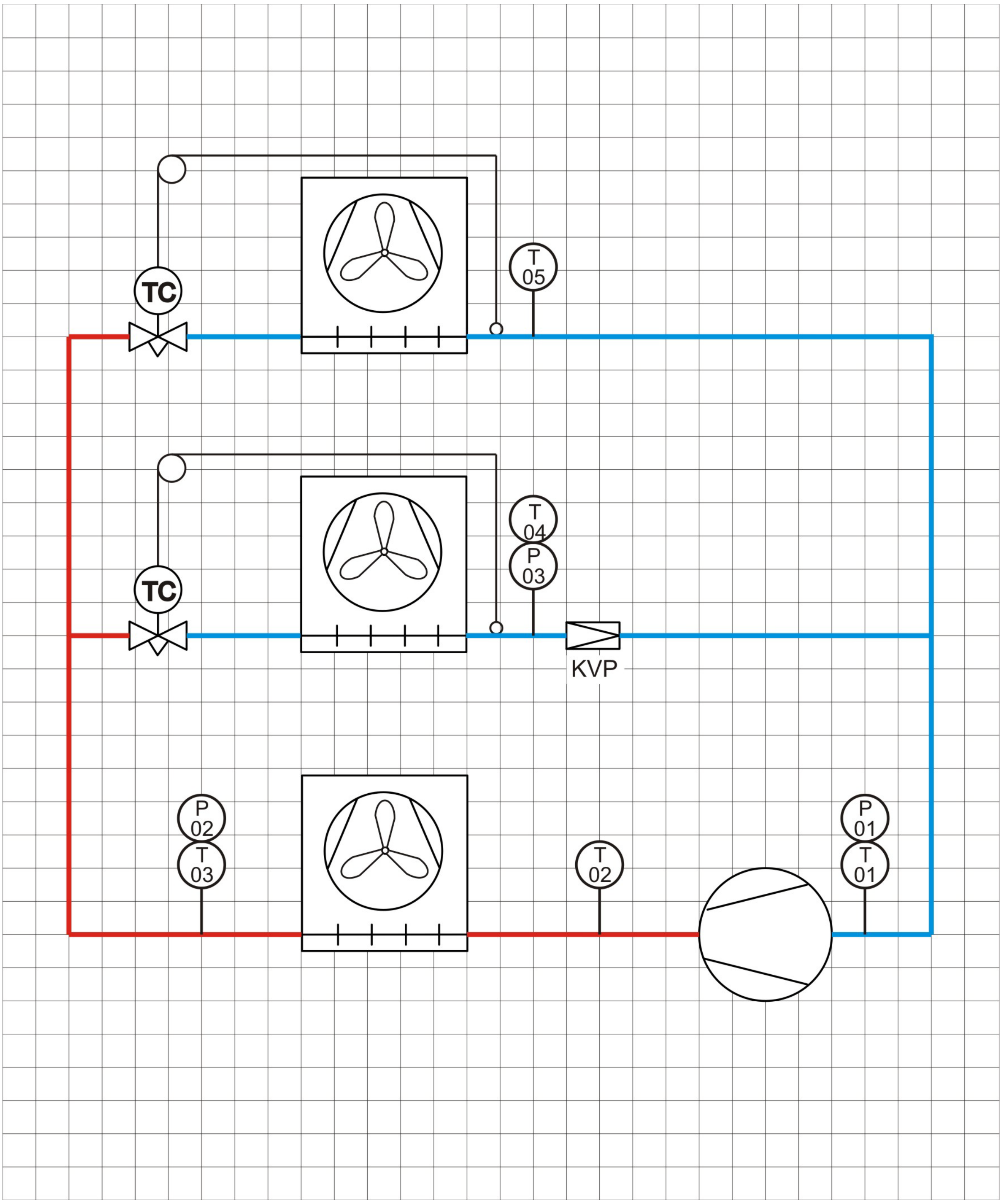
c. Where in the system is the lowest pressure?

Worksheet 1, page 3

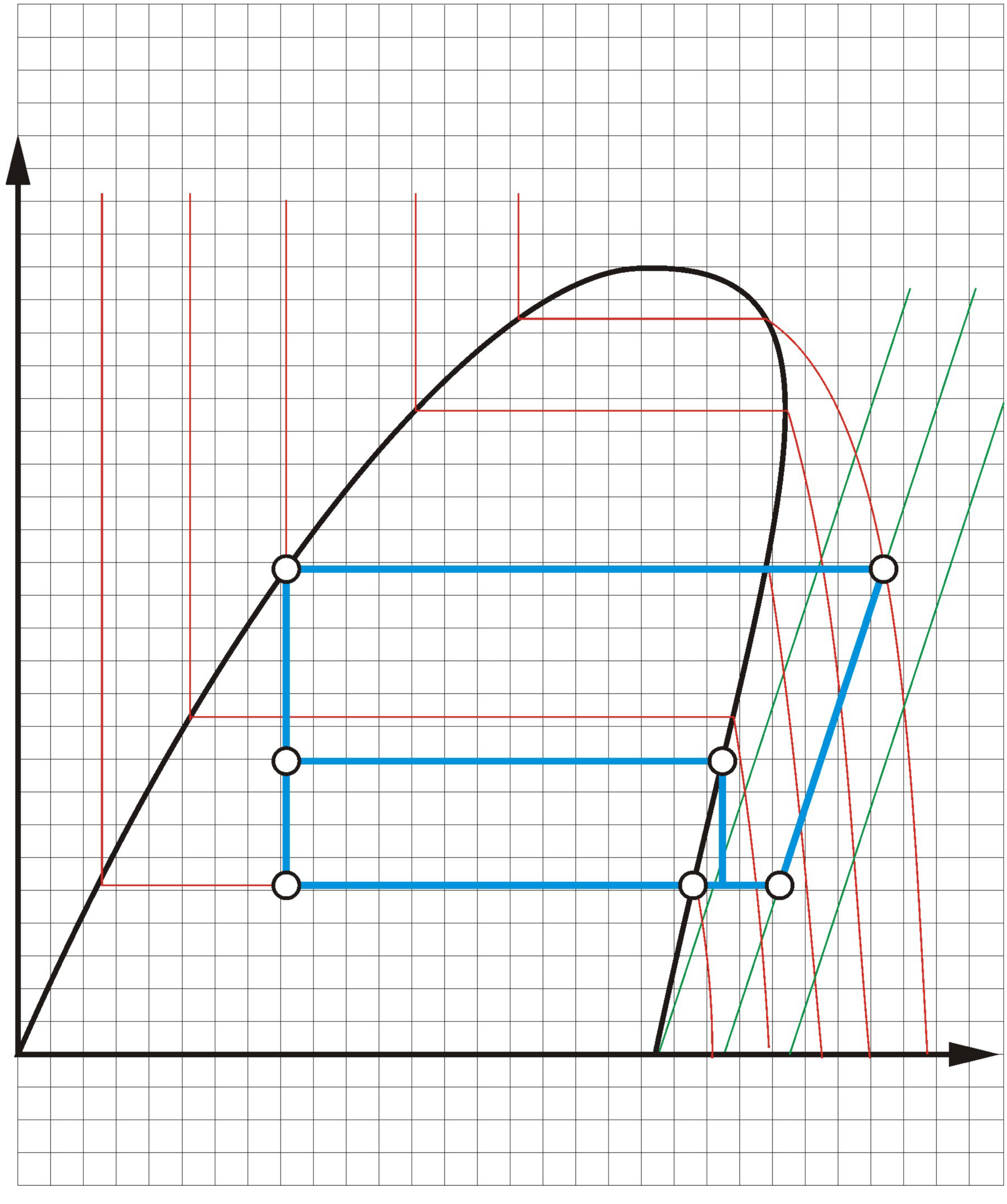
The following components are available for you to select from:

Symbol	Designation
	Compressor
	Expansion valve
	Condenser
	Evaporator
	Evaporation pressure regulator

Worksheet 1, page 4



Worksheet 1, page 5



Worksheet 1, page 6

Exercise 2b

To create the log *p, h* diagram of the process the following quantities must be determined:

– Compressor intake temperature.
– Compressor intake pressure.
– Final evaporation temperature.
– Condensation pressure.
– Temperature at condenser outlet.
– Evaporation pressure of evaporator fitted with evaporation pressure regulator.
– Outlet temperatures of both evaporators.

Exercise 2c

The lowest system pressure is at the condenser inlet. That pressure is also below the lowest evaporation pressure in the system. The reason for this is a pressure drop in the intake line and components and fittings in-between.

As the pressure drop in small systems such as ET915 is very low, it can be ignored here.

6.2 Worksheet 2: Basic questions about the refrigerating circuit

Page 1

Learning objectives:

- To be able to describe the basic properties of a refrigerating circuit.
- To be able to describe the functions of key unit components.

Exercises:

- Answer the following questions.

Exercise 1

How does the refrigerating capacity respond to falling evaporation pressures?

The refrigerating capacity of a system reduces as evaporation pressures fall. The specific volume of the refrigerant rises due to the lower pressure. Higher specific gas volumes result in a lower mass flow rate, as a result of which the system capacity decreases.

Exercise 2

Which component safeguards the system against unacceptable pressures?

The pressure switch safeguards the system against unacceptable pressures. The limit pressures are adjustable by the pressure switch, but for safety reasons should not be changed.

Worksheet 2, page 2

Exercise 3

How does the intake pressure of the compressor respond when a load is applied to the evaporator?

When a load is applied to the evaporator, the expansion valve must inject more refrigerant into the evaporator to maintain the superheating at the pre-set value.

As the compressor runs at a constant speed, the intake pressure must rise in order to transport the additional mass flow.

Exercise 4

How does the condensation pressure respond as the refrigerating capacity increases?

The condenser must discharge all the energy flows absorbed in the circle process to the surrounding environment. If the refrigerating capacity rises, the condenser output must also increase.

As the surface area and the coefficient of heat transfer can be assume to be constant, the additional output can only be discharged to the environment by increasing the condensation temperature. As the condensation temperature and pressure are correlated, the condensation pressure must accordingly also rise.

Exercise 5

What is the effect of an evaporation pressure regulator integrated into the system?

The evaporation pressure regulator limits the evaporation pressure to keep pressures low. This means that on systems with two parallel-running evaporators different evaporation pressures can be set, so a deep-freezing stage and a normal cooling stage can be implemented.

Exercise 6

You must select a suitable evaporator for a refrigeration system in which frost is expected to form on the evaporator. For such a system do you use an evaporator with a small or large fin pitch? Give reasons for your answer.

If frosting is expected, it is likely that an evaporator with a large fin pitch must be selected. The reason is that evaporators with a small fin pitch very quick freeze up, and the fan is no longer able to draw in air through the evaporator. This results in a significant loss of efficiency, and the evaporator has to be defrosted frequently. With a large fin pitch the defrosting intervals can be extended.

6.3 Worksheet 3: Calculation of the capacity of a vapour humidifier

Page 1

Learning objectives:

- To be able to estimate the steam generating capacity of a vapour humidifier.

Description of the exercise:

A vapour humidifier (500 W) is filled with 2 litres of water. A further 1,5 L of water can be evaporated until the float switch switches off the humidifier. Additionally, the water boils at 100 °C and the temperature on the outside of the stainless steel vessel is 98 °C. The ambient temperature during humidification is a constant 20 °C.

- What output is lost by the humidification process to the environment due to heat discharge. The surface area of the humidifier is 1000 cm^2. The heat transfer mechanism is assumed to be free convection (8 W/(m^2*K)).
- What is the steam generating capacity per second?
- How long, in seconds, can you humidify with the filled quantity until the float switch switches off the humidifier?

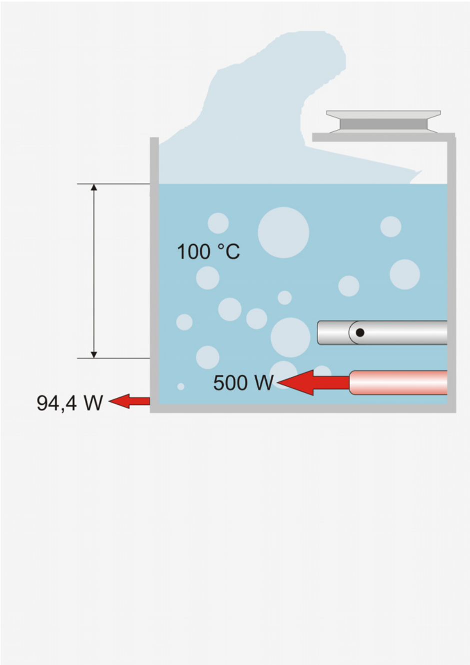


Fig. 6.1 Vapour humidifier

Worksheet 3, page 2

Calculation:

Sensitive heat load

$$\dot{Q}_K = A \cdot \alpha \cdot \Delta T$$

The applied temperature difference is the difference between the box temperature and the surface temperature.

The surface area of the humidifier and the coefficient of heat transfer are specified in the exercise:

$$\dot{Q}_K = 0{,}1\ \mathrm{m}^2 \cdot 8{,}0\ \frac{\mathrm{W}}{\mathrm{m}^2 \cdot \mathrm{K}} \cdot 118\ \mathrm{K}$$

$$\boldsymbol{\dot{Q}_K = 94{,}4\ \mathrm{W}}$$

Steam generating capacity

The humidifier has an output of 500 W, of which 94.4 W is discharged directly to the box by convection. The remaining output is consequently used for the phase transition of the water from the liquid to the vaporous state:

$$\dot{Q}_S = \dot{Q}_{tot} - \dot{Q}_K$$

$$\dot{Q}_S = 500\ \mathrm{W} - 94{,}4\ \mathrm{W}$$

$$\boldsymbol{\dot{Q}_S = 405{,}6\ \mathrm{W}}$$

The mass flow rate can then be determined based on the steam generating capacity and the evaporation enthalpy of the water.

$$\dot{m}_S = \frac{\dot{Q}_S}{h_S}$$

Worksheet 3, page 3

$$\dot{m}_S = \frac{405{,}6\ \frac{J}{s}}{2257000\ \frac{J}{kg}}$$

$$\boldsymbol{\dot{m}_S = 0{,}00018\ kg/s}$$

Humidification time

The humidification time can then be calculated based on the water mass which remains to be evaporated and the mass flow of the steam:

$$t = \frac{m_W}{\dot{m}_S}$$

$$t = \frac{1{,}5\ kg}{0{,}00018\ kg/s}$$

$$\boldsymbol{t = 8347\ s}$$

6.4 Worksheet 4: Moist air

Page 1

Learning objectives:

- To learn the basic properties of moist air.

Exercises:

- Answer the following questions.
- Enter the wet bulb temperature and the dew point temperature of moist air at a temperature of 16°C and a relative humidity of 50% in the *h, x* diagram provided.

Exercise 1

What is the dew point temperature?

The dew point temperature is the temperature at which the air is saturated with steam. When air is cooled or humidified further in the dew point state, condensation forms.

Worksheet 4, page 2

Exercise 2

What is the wet bulb temperature?

The wet bulb temperature is the lowest temperature which can be reached by evaporative cooling.

When liquid water is atomised in unsaturated air, the air temperature falls due to the evaporation enthalpy of the water. The temperature falls until the air is saturated with water. This distinct point corresponds to the wet bulb temperature.

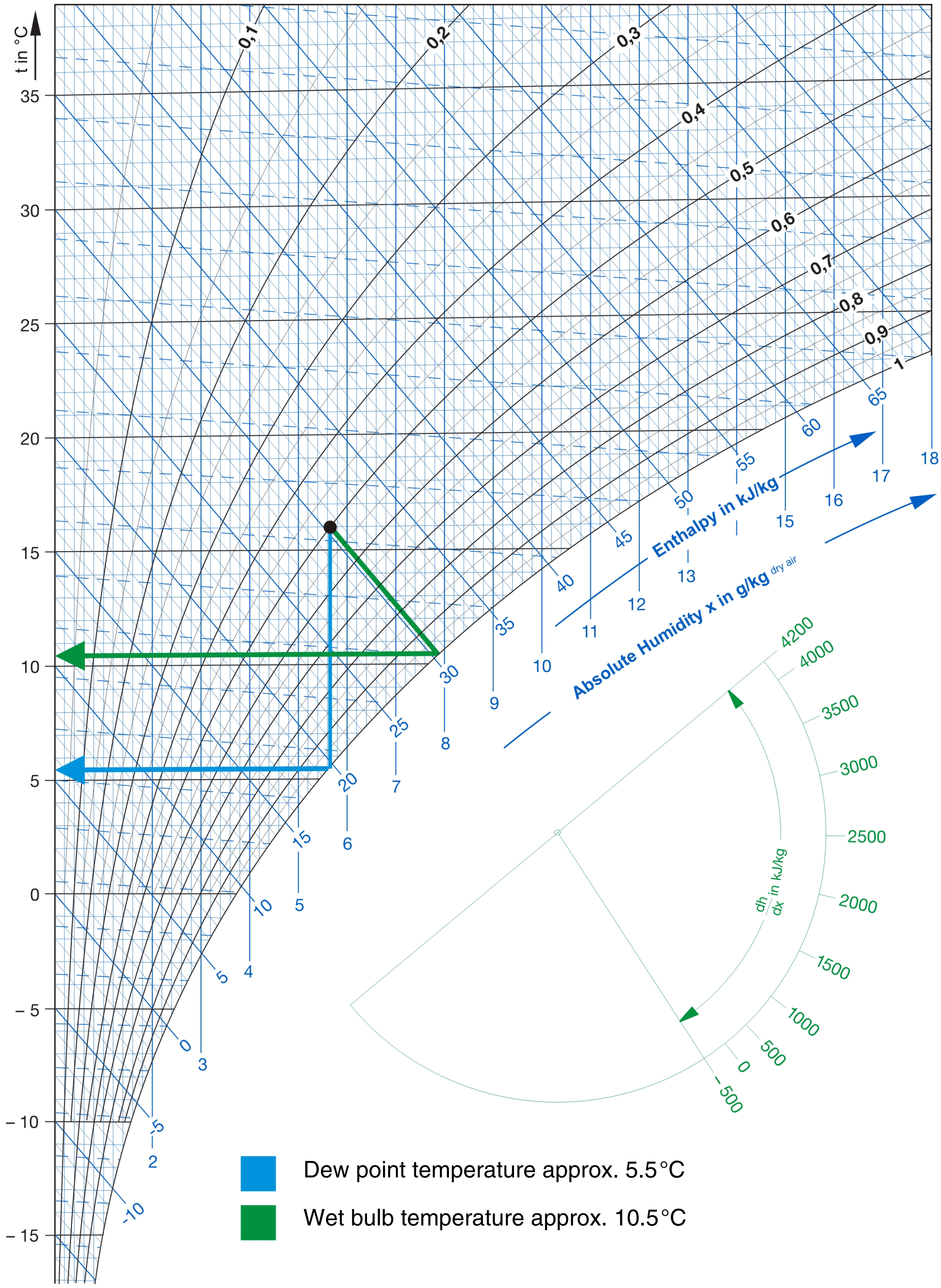
The *h, x* diagram can be used to determine the wet bulb temperature of air graphically, by rotating a straight line in the respective state point of the air until it is running parallel to a fog isotherm. The point of intersection of the straight lines with the saturation line then corresponds to the wet bulb temperature. As the fog isotherms run virtually parallel to the isenthalpies, and in many *h, x* diagrams the fog isotherms are not plotted, a straight line can also be rotated until running parallel to the isenthalpies.

Exercise 3

How does the temperature of air respond when humidified with steam?

When humidified with steam, the air temperature can be expected to rise slightly.

Worksheet 4, page 3



Dew point temperature approx. 5.5°C

Wet bulb temperature approx. 10.5°C

6.5 Worksheet 5: Calculations in the *h, x* diagram

Page 1

Learning objectives:

- To be able to carry out simple calculations in the *h, x* diagram.

Description of the exercise:

An air conditioner has a throughput rate of 0,3 kg of dry air per second. The air enters the air conditioner at a temperature of T_1=25 °C and a relative humidity of φ_1=15 %. The air is first cooled to 15 °C in a cooler. The evaporation temperature of the refrigerant in this process is 5 °C. After cooling, the air is humidified to φ_2=60 % using a vapour humidifier.

In the final section of the air conditioner the air is heated back up by a heater with an output of 2,5 kW.

a. Plot the process into the *h, x* diagram provided.

b. What is the capacity of the cooler and of the humidifier.

c. At what temperature and relative humidity does the air emerge from the air conditioner?

d. Is condensation to be expected in the cooler?

e. How can the process be energetically optimised? Indicate the optimised process by a dotted line in the *h, x* diagram.

Fig. 6.2 shows the schematic of the system.

Worksheet 5, page 2

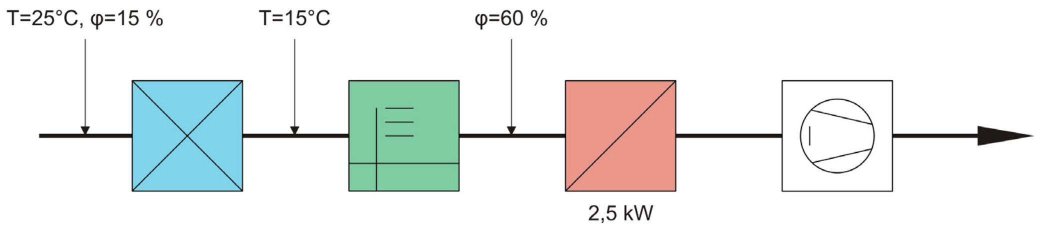


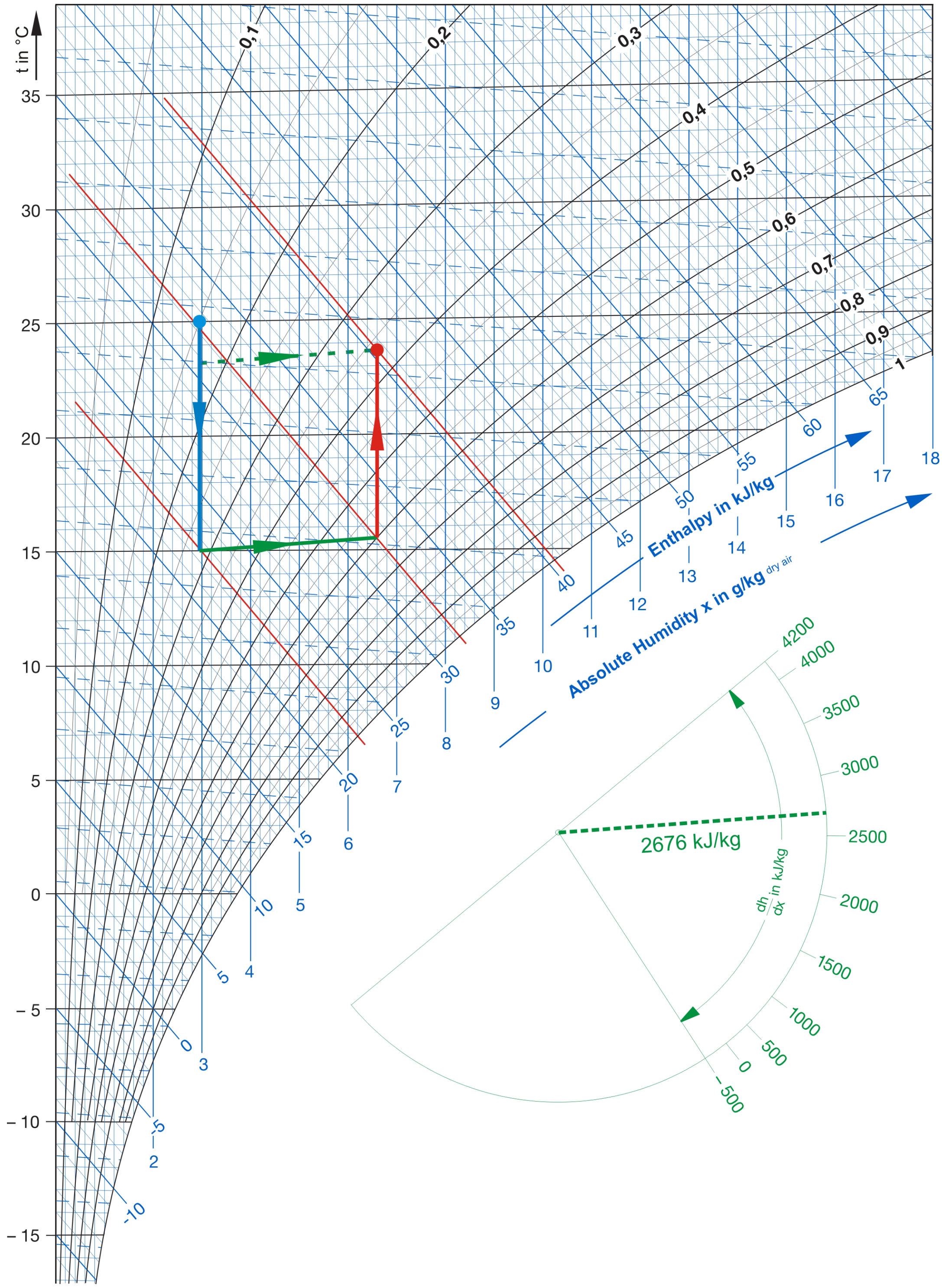
Fig. 6.2 Schematic diagram

NOTICE

This exercise represents a digression into the field of air conditioning engineering, and is intended to provide further tuition in use of the *h, x* diagram.

The numerical values have no direct link to the ET 915 system.

Worksheet 5, page 3



Worksheet 5, page 4

Capacity of the cooler

The capacity of the cooler can be determined based on the enthalpy difference and the mass flow rate. The enthalpy difference can be determined from the *h, x* diagram:

Cooler inlet enthalpy h_{0In}: 32000 J/kg

Cooler outlet enthalpy h_{0Out}: 22500 J/kg

$$\dot{Q}_0 = (h_{0In} - h_{0Out}) \cdot \dot{m}$$

$$\dot{Q}_0 = \left(32500 \ \frac{J}{kg} - 22500 \ \frac{J}{kg}\right) \cdot 0{,}3 \ \frac{kg}{s}$$

$$\boldsymbol{\dot{Q}_0 = 3000 \ W}$$

Capacity of the humidifier

The capacity of the humidifier can be determined in the same way as the cooler capacity:

$$\dot{Q}_h = (h_{hIn} - h_{hOut}) \cdot \dot{m}$$

$$\dot{Q}_h = \left(32000 \ \frac{J}{kg} - 22500 \ \frac{J}{kg}\right) \cdot 0{,}3 \ \frac{kg}{s}$$

$$\boldsymbol{\dot{Q}_h = 2850 \ W}$$

In this analysis it is assumed that a humidifier with a storage tank is used, and that the water is heated up to boiling point in the tank before the humidification process. This means no energy is required during humidification to heat cold water up to 100 °C.

Worksheet 5, page 5

Air outlet

The air exits the air conditioner at a temperature of 23,5°C and a relative humidity of 37%.

Condensation

No condensation will form on the cooler because the evaporation temperature of the refrigerant is above the dew point temperature of the inflowing air. The dew point is at approximately -3°C.

Optimised process

The process can be optimised by cooling the air in the cooler to only approximately 23°C and then humidifying it. In this case the cooler could be made smaller, and no heating would be required.

7 Experiments

The selection of experiments makes no claims of completeness but is intended to be used as a stimulus for your own experiments. The results shown are intended as a guide only. Depending on the construction of the individual components, experimental skills and ambient conditions, variations may occur in the experiments. Nevertheless, the laws can be clearly demonstrated.

7.1 ET 915.01

The following investigates how various expansion elements respond on application of a cooling load. To do so, the capillary tube is compared with the thermostatic expansion valve. The main focus here is on the differing behaviour of regulating and non-regulating expansion elements on application of a cooling load - that is to say, under a changed operating condition.

The experiment is first conducted with a thermostatic expansion valve under no load. The heater initially remains off. Once a steady state has been reached and the measured values have been recorded, the heater is switched on and again a steady system state is awaited.

This experiment is then repeated with the capillary tube.

Learning objectives:

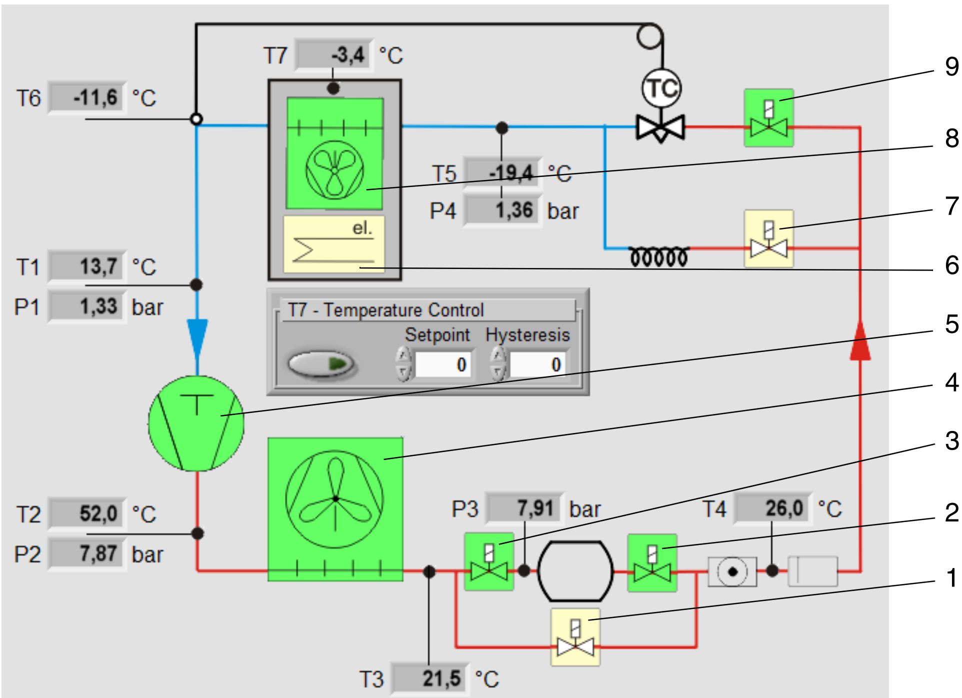
- To be able to plot the cyclic process of a refrigeration system into a log *p, h* diagram.
- To be able to describe the effects of a cooling load on the cyclic process.
- To be able to describe the differing behaviour of regulating and non-regulating expansion elements.

Exercises:

- Record all relevant measurement values to create the log *p, h* diagram.
- Plot the cyclic processes of the four steady states into a log *p, h* diagram.
- Describe the essential difference between the thermostatic expansion valve and capillary tube based on the measured values.
- Compare the refrigerating capacity of the four steady states.

7.1.1 Preparing the experiment

- Switch the system on at the main switch.
- Enable the refrigerating circuit by opening the relevant solenoid valve V5 (9).
- Switch on the fan of the evaporator (8) and of the condenser (4).
- Switch on the compressor (5).



1 Solenoid valve V3 collector bypass
2 Solenoid valve V2 downstream of collector
3 Solenoid valve V1 upstream of collector
4 Condenser fan
5 Compressor
6 PTC heater
7 Operation with capillary tube
8 Evaporator fan
9 Operation with TEV

Fig. 7.1 System diagram and buttons in unit software

7.1.2 Performing the experiment

- Set the system to the steady state with the settings detailed in the previous chapter.
- Record all relevant measurement values.
- Switch on the PTC heater.
- Wait for the steady state to be reached.
- Record all relevant measurement values.

Repeat the complete experiment using the capillary tube (selected via solenoid valve V4 (7)) as the expansion element.

7.1.3 Measured values

	TEV under no load	TEV under load	Capillary tube under no load	Capillary tube under load
T_1 in °C	13,7	14,1	9,2	17,2
T_2 in °C	52,0	60,2	59,1	59,3
T_3 in °C	21,5	22,8	21,7	21,4
T_4 in °C	26,0	26,8	26,4	6,4
T_5 in °C	-19,4	-15,2	-17,7	-17,8
T_6 in °C	-11,6	-7,7	-13,3	4,7
T_7 in °C	-3,4	4,4	-2,8	7,1
p_1 in bar abs	1,33	1,59	1,44	1,41
p_2 in bar abs	7,87	8,09	7,90	7,86
p_3 in bar abs	7,91	8,16	7,95	7,91
p_4 in bar abs	1,36	1,67	1,47	1,47

Tab. 7.1 Specimen measured values (dependent on ambient conditions)

7.1.4 Processes in the log *p, h* diagram

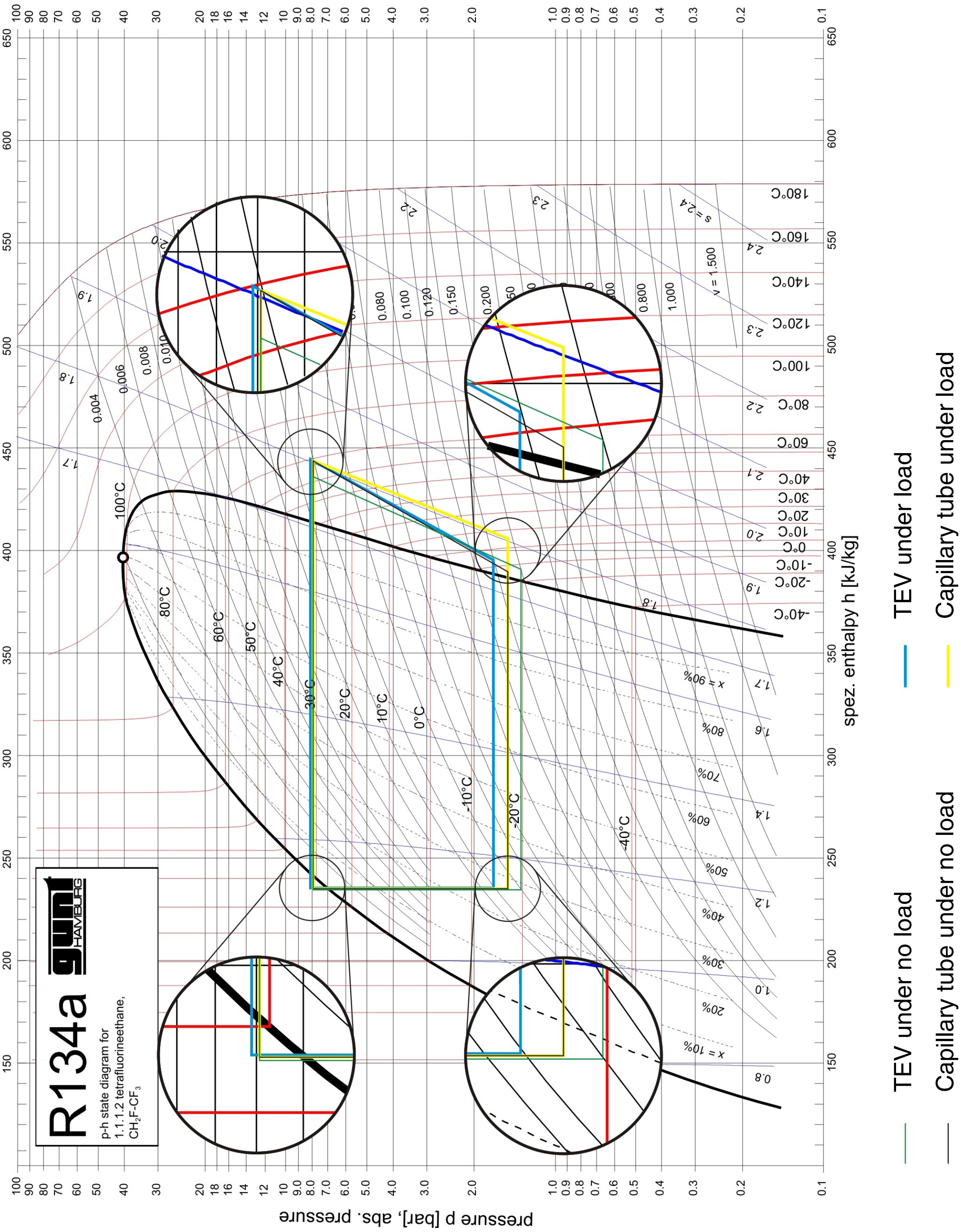


Fig. 7.2 TEV and capillary tube under load and no load

7.1.5 Evaluation

Behaviour of the thermostatic expansion valve under load

The thermostatic expansion valve attempts to maintain the superheating at the evaporator outlet at a constant value. Under no load the superheating is 7,8K; under load it is 7,5K, meaning it is virtually identical in both operating states.

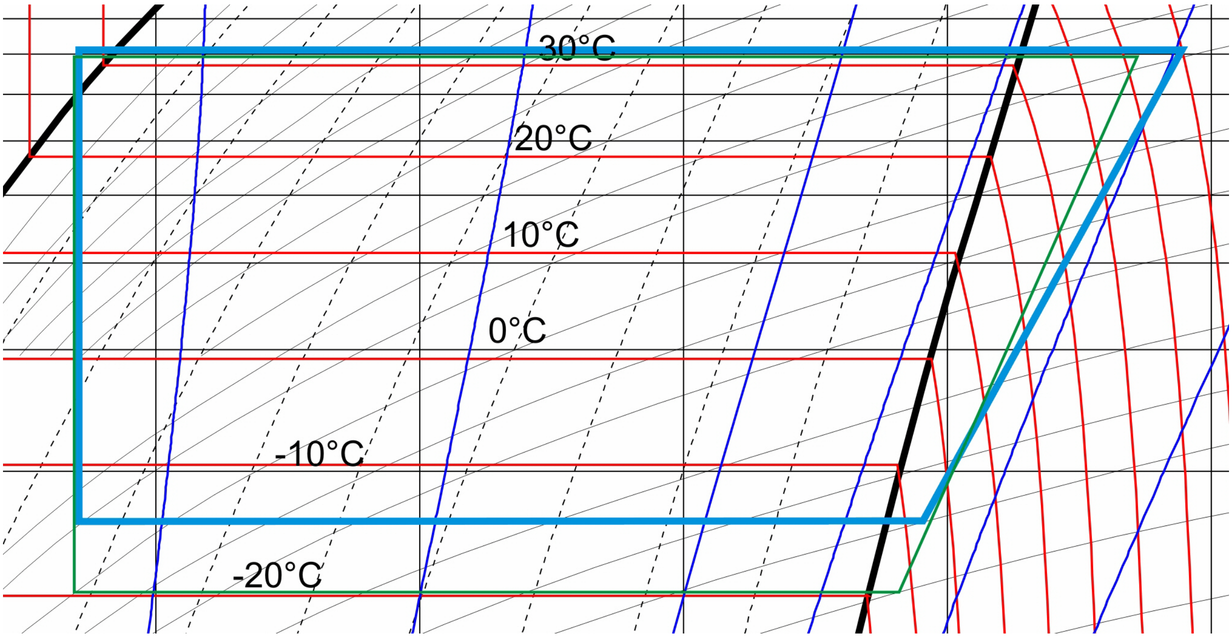


Fig. 7.3 TEV under cooling load and no cooling load
Blue: under cooling load
Green: under no cooling load

In order to then regulate the superheating of the refrigerant at the evaporator outlet to a constant value, the refrigerant flow through the expansion valve must be reduced. The expansion valve is closed further. As the refrigerant compressor always takes in the same geometric volume, however, the pressure of the refrigerant - and thus its density - must consequently decrease (condensation pressure. Δp = 0,24bar, evaporator pressure.

Δp = 0,29 bar). The decrease in density results in a reduction in mass flow rate and thus in the refrigerating capacity of the system.

The thermostatic expansion valve adapts to the various operating conditions by opening and closing.

Behaviour of the capillary tube under load

The capillary tube is a non-regulating expansion element. This is shown in particular under **fluctuating operating conditions**. It must be configured specially for a specific refrigerating capacity, as this experiment is intended to illustrate.

When the system is run under no load, the measured evaporation temperature is T_4=-17,7°C and the temperature at the outlet of the evaporator is T_5=-13,3°C. So the refrigerant is slightly superheated on exiting the evaporator. The measured values show that the capillary tube is slightly too short for the given operating state and the ambient conditions prevailing at this point in time (T_{amb}=19,6°C). Slightly less refrigerant should be injected into the evaporator.

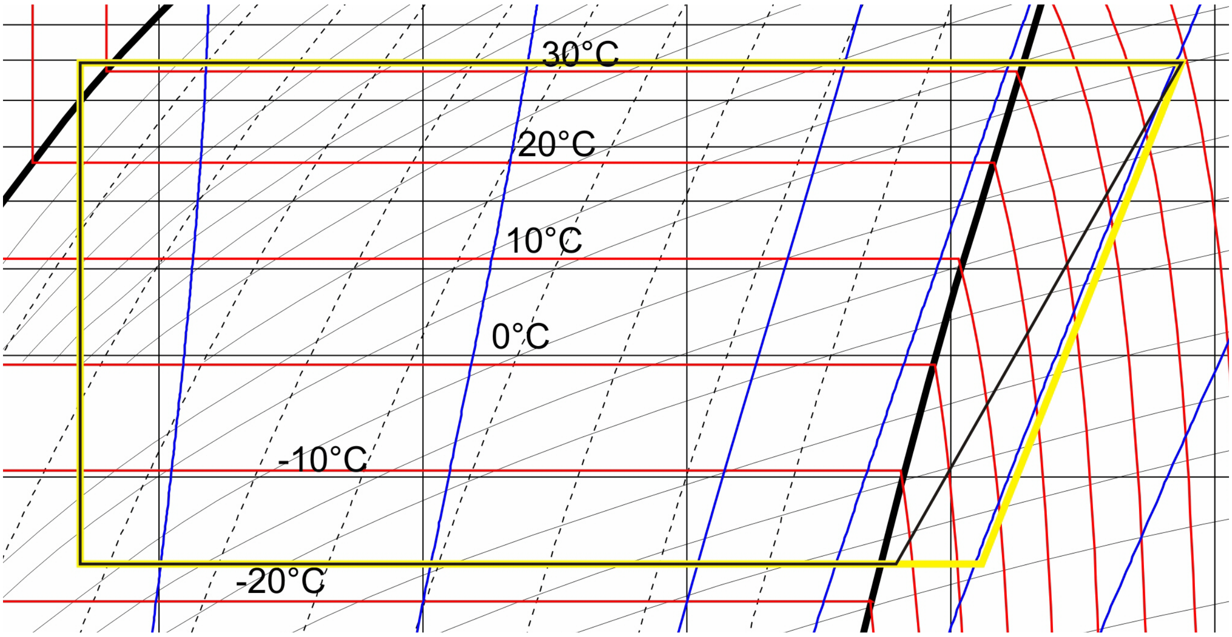


Fig. 7.4 Capillary tube under cooling load and no cooling load
Yellow: under cooling load
Black: under no cooling load

When the experiment is conducted under load, in operation with the capillary tube superheating of 22,5K is attained. This is an indicator that the evaporator is not being utilised efficiently. Too little refrigerant is being injected, and too much evaporator surface area is being used for superheating. For the system to work satisfactorily at this operating point, a shorter capillary should now be used.

It is also seen that the condensation pressure and the evaporator pressure remain unchanged in both cases. Thus the capillary tube does not adapt to the changed operating conditions.

7.2 ET 915.02 Experiment 1

This experiment investigates the behaviour of a refrigeration system under a cooling load. To do so, the refrigerant flow is adjusted so as to pass only through the lower box.

The system is first set to the steady state with the heater switched off - that is to say, under no cooling load - and the measurement values are recorded. Then the heater is switched on and the system is again set to the steady state.

Learning objectives:

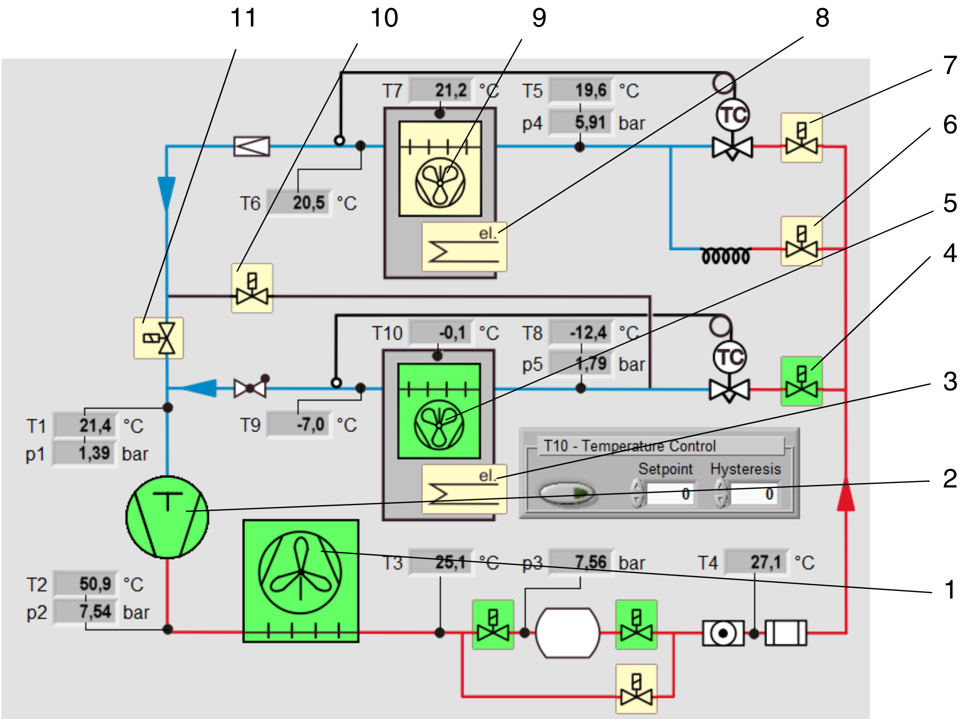
- To be able to plot the cyclic process of a refrigeration system into a log *p, h* diagram.
- To be able to describe the effects of a cooling load on the cyclic process.

Exercises:

- Record all relevant measurement values to create the log *p, h* diagram.
- Plot the processes under cooling load and under no cooling load into a log *p, h* diagram. When doing so, also take into account the pressure loss by way of the evaporator.

7.2.1 Preparing the experiment

- Switch the system on at the main switch.
- Enable the refrigerating circuit by opening the relevant solenoid valve (4).
- Switch on the fan of the lower evaporator and of the condenser.
- Switch on the compressor (5).



1 Condenser fan
2 Compressor
3 Heating lower box
4 Valve lower circuit
5 Fan lower evaporator
6 Capillary operation upper box
7 Operation with TEV upper box
8 Heating upper box
9 Fan upper evaporator
10 Evaporators in-line operation
11 Evaporators parallel operation
12

Fig. 7.5 System diagram and buttons in unit software

7.2.2 Performing the experiment

- Set the system to the steady state with the settings detailed in Chapter 7.2.1.
- Record all relevant measurement values.
- Switch on the heater of the lower box.
- Wait for the steady state to be reached.
- Record all relevant measurement values.

7.2.3 Measured values

Under no cooling load	T_1 in °C	T_2 in °C	T_4 in °C	T_9 in °C	p_1 in bar	p_2 in bar	p_5 in bar
	21,4	50,9	27,1	-7,0	1,4	7,6	1,8
Under cooling load	T_1 in °C	T_2 in °C	T_4 in °C	T_9 in °C	p_1 in bar	p_2 in bar	p_5 in bar
	20,5	52,2	27,4	-4,0	1,7	7,8	2,0

Tab. 7.2 Measured values under cooling load and no cooling load

7.2.4 Processes in the log *p, h* diagram

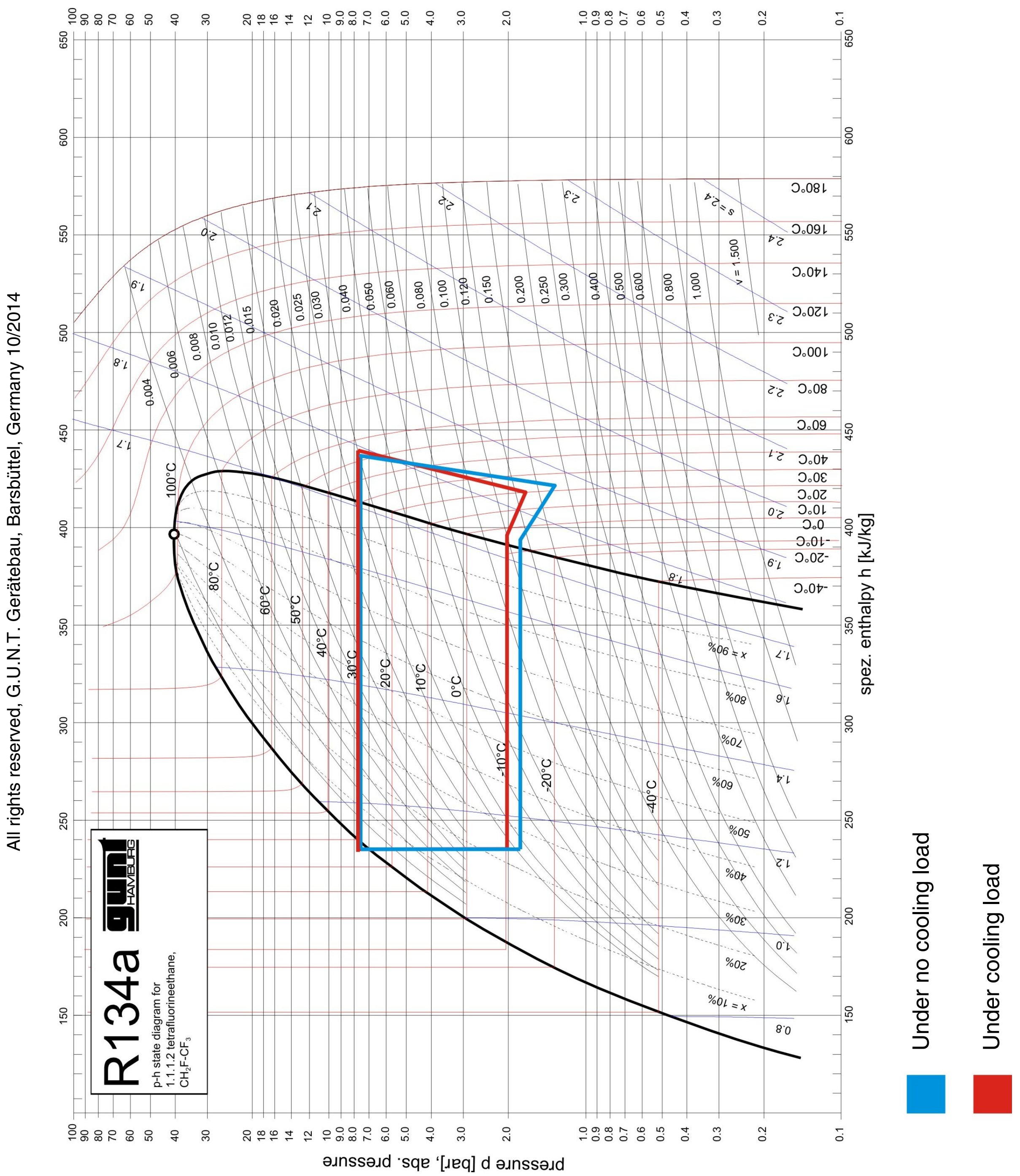


Fig. 7.6 Effect of cooling load in log *p, h* diagram

7.2.5 Summary

Comparing the cooling process under load and no load, it is noticeable that the evaporation pressure is higher when the cooling load is applied. The reason for the higher evaporation pressure is that under higher load the expansion valve injects more refrigerant into the evaporator in order to maintain the superheating at the value pre-set on the expansion valve. As the compressor runs at a constant speed, however, and so always takes in the same geometric volumetric flow, the pressure in the evaporator must consequently rise. A slight increase in condensation pressure is also seen. The reason for the higher pressure in the condenser is that under cooling load more energy has to be discharged by way of the condenser. In order to discharge the additional energy at the condenser, the condensation temperature - and thus the condensation pressure - must rise.

7.3 ET 915.02 Experiment 2

In this experiment both cooling boxes are run in parallel. Also, the evaporation pressure regulator is now used to set different evaporation pressures in the two evaporators. The system is run under no load in the experiment.

Learning objectives:

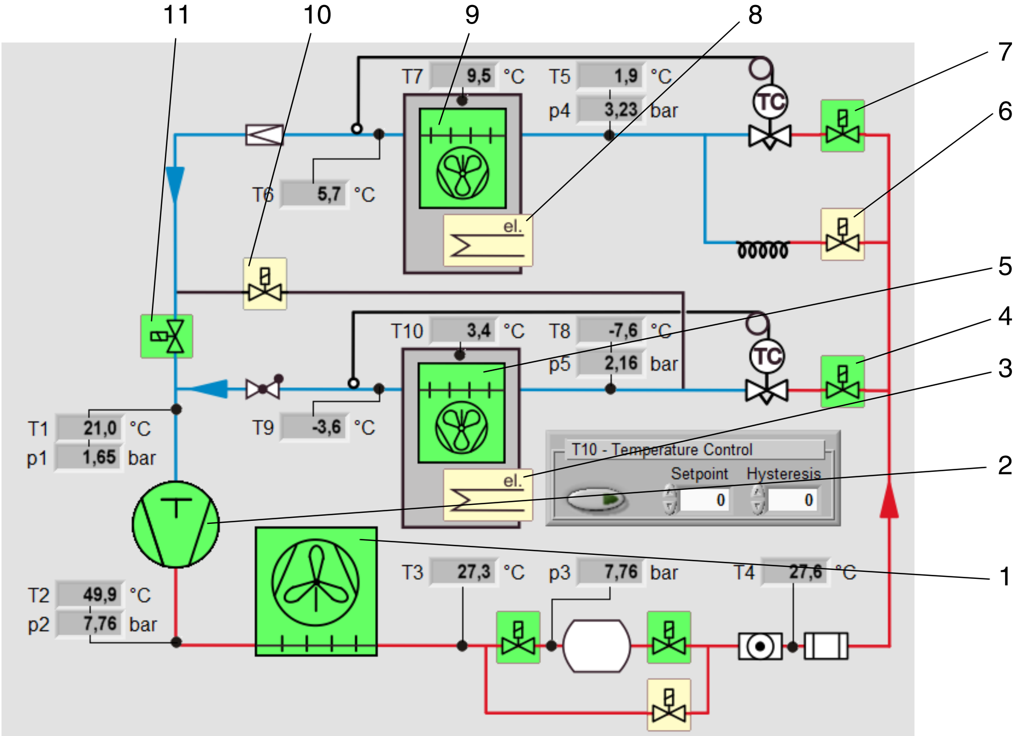
- To be able to create the log *p, h* diagram of the two-stage process from the measured values.
- To be able to describe the effect of the second evaporator on the overall process.

Exercises:

- Record all relevant measurement values.
- Plot the cyclic process into a log *p, h* diagram.
- Describe the effects of the second evaporator on the process. In doing so, also use the experimental results from Chapter 7.2.

7.3.1 Preparing the experiment

- Switch the system on at the main switch.
- Enable the refrigerating circuit by opening the relevant solenoid valves (4) and (7).
- Switch on the fan of the lower evaporator and of the condenser.
- Switch on the compressor (5).



1	Condenser fan	7	Operation with TEV upper box
2	Compressor	8	Heating upper box
3	Heating lower box	9	Fan upper evaporator
4	Valve lower circuit	10	Evaporators in-line operation
5	Fan lower evaporator	11	Evaporators parallel operation
6	Capillary operation upper box		

Fig. 7.7 System diagram and buttons in unit software

7.3.2 Performing the experiment

- Set the system to the steady state.
- On the evaporation pressure regulator set a pressure higher than the evaporation pressure of the lower evaporator.

The evaporation pressure can be adjusted using an 8mm hexagon socket wrench:

- Turning the adjuster screw **clockwise** increases the evaporation pressure.
- Turning the adjuster screw **anti-clockwise** reduce the evaporation pressure.
- A **half turn** varies the pressure by approximately 0,5bar.

- Set the system to the steady state with the new settings.
- Record all relevant measurement values.

7.3.3 Measured values

T_1 in °C	T_2 in °C	T_4 in °C	T_6 in °C	T_9 in °C	p_1 in bar	p_2 in bar	p_4 in bar	p_5 in bar
21,0	50,0	27,6	4,4	-1,9	1,7	7,8	3,2	2,2

Tab. 7.3 Measured values in parallel operation of the evaporators

7.3.4 log *p, h* diagram

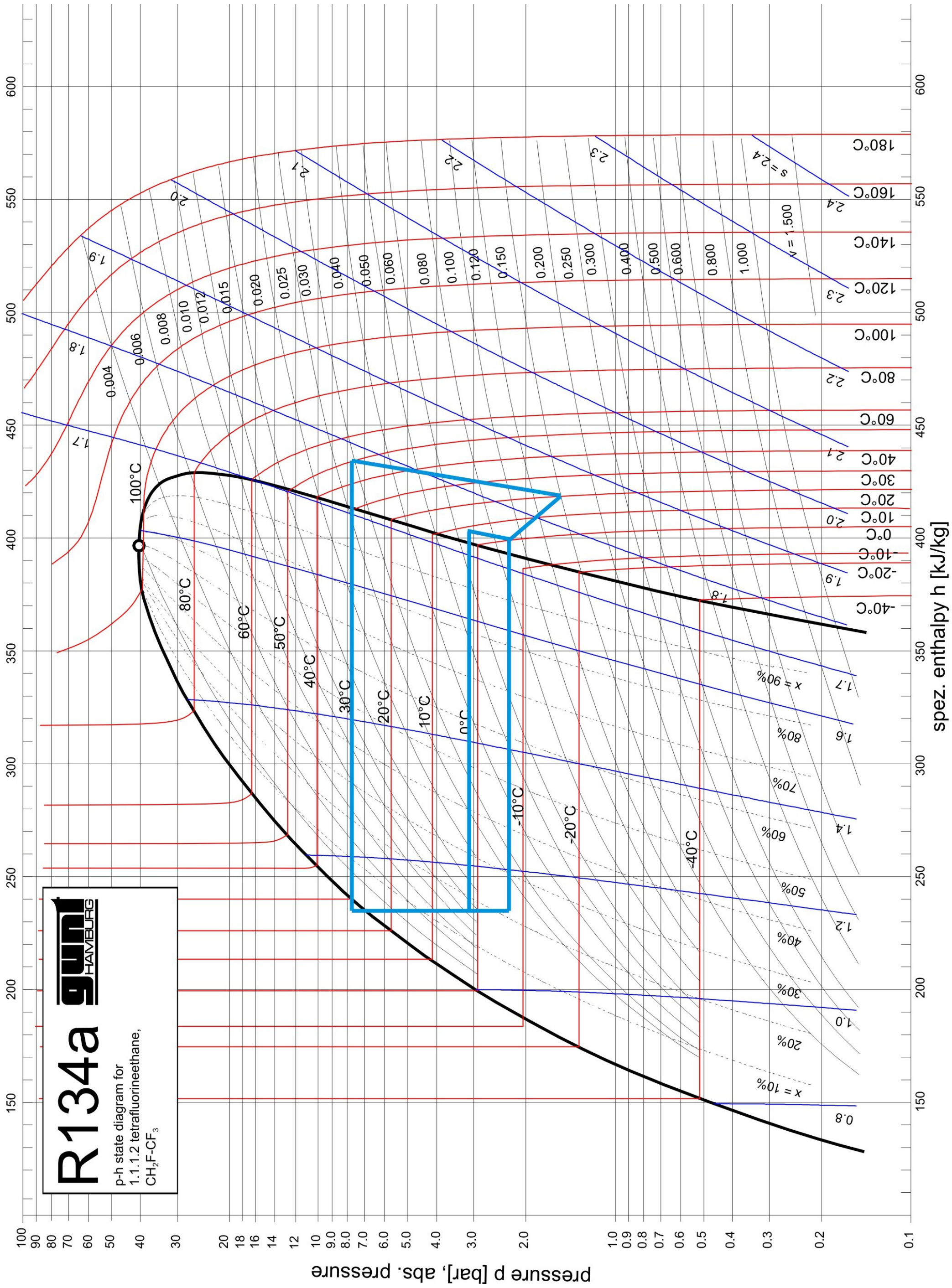


Fig. 7.8 log *p, h* diagram of process with parallel-working evaporators

7.3.5 Summary

If the system is operated with two parallel evaporators, the special feature lies firstly in the fact that the refrigerant mass flow delivered by the compressor is split across two evaporators.
Moreover, the evaporation pressure regulator integrated into ET 915.02 makes it possible to set different evaporation pressures - and thus different evaporation temperatures - in the evaporators. This means that a refrigeration system operating with a shared compressor can be equipped with a cooling stage and a deep-freeze stage. Less refrigerant is then fed to the evaporator with the higher evaporation pressure than to the one with the lower evaporation pressure. This is shown, among other ways, in the lower refrigerating capacity of the evaporator, as is demonstrated by the higher box temperature. In parallel mode, the intake pressure p_1 of the compressor rises relative to the process with only one evaporator. This is shown when comparing the measurement values from this experiment with those from Chapter 7.2 (the measurements under no cooling load). The reason for the rise is that in parallel mode the overall cooling load is greater and the two expansion valves inject more refrigerant into the evaporators than in stand-alone mode. The condensation pressure p_2 in the system also rises due to the higher cooling load.

7.4 ET 915.06

This experiment investigates the change of state when the air is cooled:

The change of state of the air is plotted into a *h, x* diagram for the purpose. Deviations from the theoretical change of state are also discussed.

And the cooling process - that is to say, the change of state of the refrigerant - is plotted into a log *p, h* diagram.

Learning objectives:

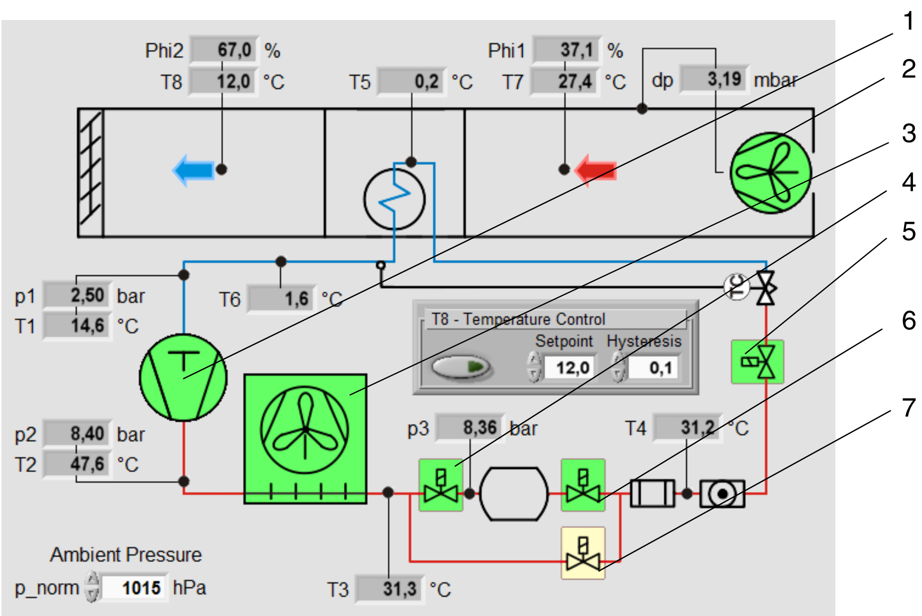
- To be able to plot the change of state of the air into a *h, x* diagram.
- To be able to explain variations between the theoretical and actual change of state of the air.
- To be able to plot the log *p, h* diagram of the refrigeration process.

Exercises:

- Record all relevant temperatures and relative humidities to plot the change of state of the air.
- Plot the change of state of the air into a *h, x* diagram.
- Plot the refrigeration process into a log *p, h* diagram.

7.4.1 Preparing the experiment

- Switch the system on at the main switch.
- Enable the refrigerating circuit by opening the relevant solenoid valve V4 (5).
- Switch on the fan (2).
  You can regulate the air throughput at the fan inlet with the baffle plate.
- Switch on the compressor (1).



1 Compressor
2 Fan
3 Condenser fan
4 Solenoid valve V1 upstream of collector
5 Solenoid valve V4 for cooling circuit
6 Solenoid valve V2 downstream of collector
7 Solenoid valve V3 collector bypass

Fig. 7.9 System diagram and buttons in unit software

7.4.2 Performing the experiment

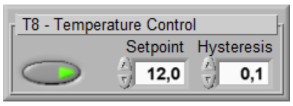


Abb. 7.10

- In the **Setpoint** field enter the desired temperature for T_8 (here 12°C).
  As this is a purely cooling process, the selected temperature for T_8 must be lower than the ambient temperature (T_7).
- In the **Hysteresis** field define the hysteresis range (here 0,1 K).
- Switch on the temperature control.
- Wait for the steady state to be reached. This is the case when the temperature T_8 and the relative humidity H_2 no longer change, or change only marginally, and ideally the temperature T_8 has reached the setpoint.
- Record the measurements necessary for evaluation of the experiment.

7.4.3 Measured values

T_7 in °C	H_1 in %	T_8 in °C	H_2 in %	DP_1 in mbar
27,4	37,1	12,0	67	3,19

Tab. 7.4 Measured values on the air side

T_1 in °C	T_2 in °C	T_3 in °C	T_4 in °C	T_5 in °C	T_6 in °C	p_1 in bar	$p3$ in bar
14,6	47,6	31,3	31,2	0,2	1,6	2,50	8,36

Tab. 7.5 Measured values on the refrigerant side

7.4.4 Changes of state in the *h, x* diagram

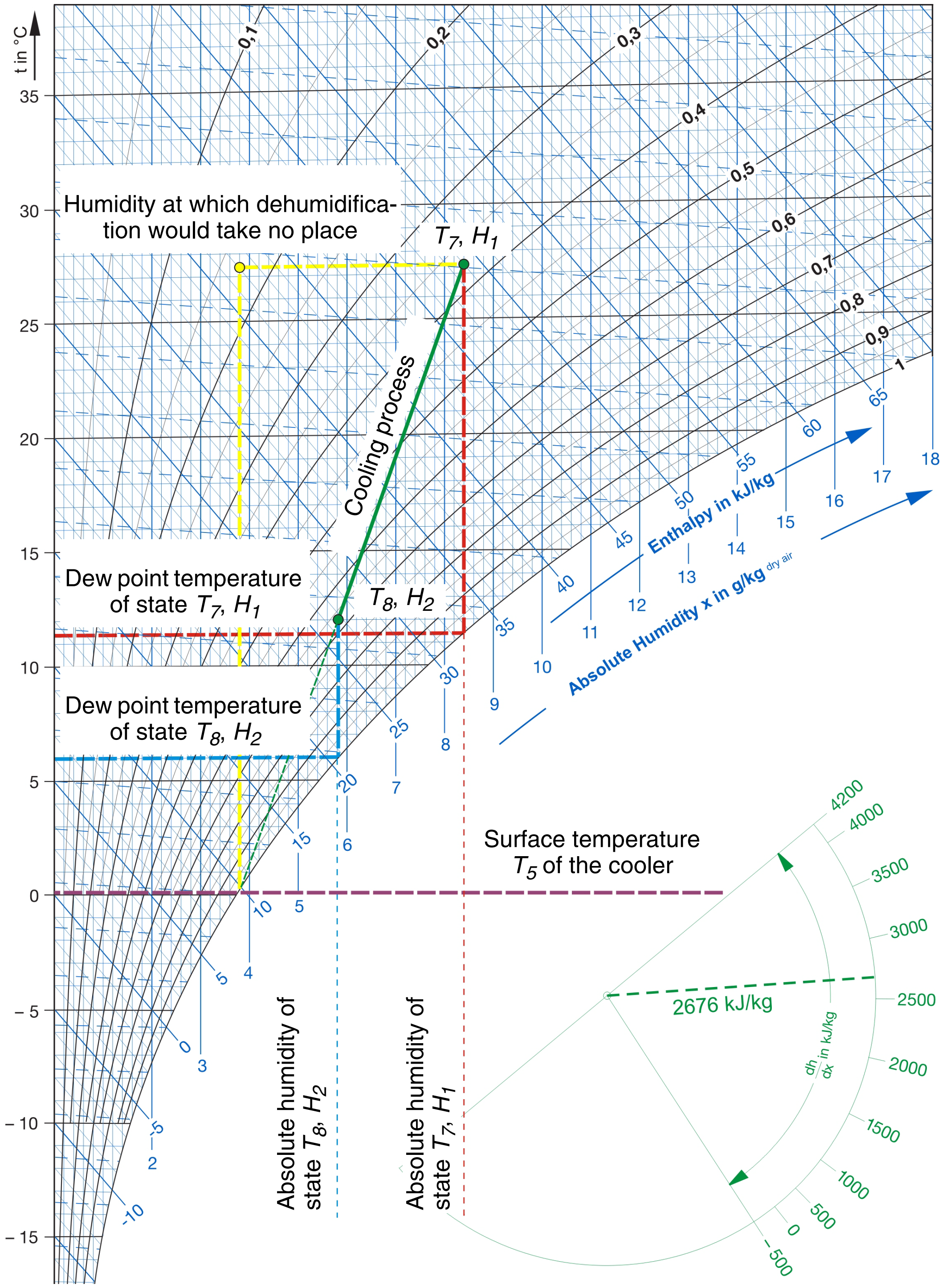


Fig. 7.11 Change of state under cooling in the *h, x* diagram

7.4.5 Cooling process in the log *p, h* diagram

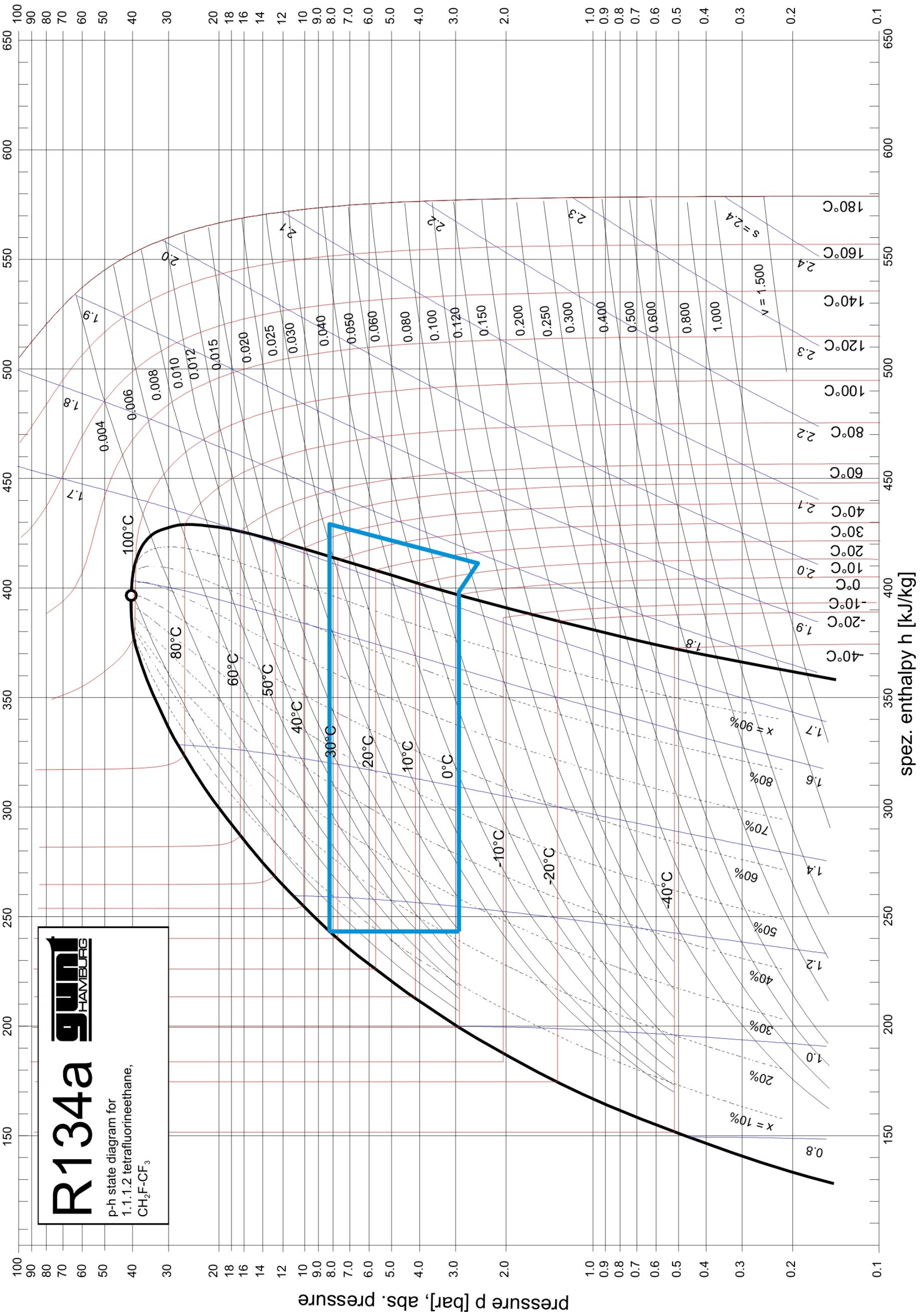


Fig. 7.12 Cooling process in the log *p, h* diagram

7.4.6 Summary

The air is cooled from 27,4°C to 12,0°C. It is also dehumidified in the process. The reason for the dehumidification is that the surface temperature of the cooler is below the dew point temperature of the air, so condensation forms on the cooler surface. The dew point temperature of the inflowing air is approximately 11,5°C, while the evaporation temperature of the refrigerant - and thus the surface temperature of the cooler - is approximately 0,2°C (corresponding to the evaporation temperature at a pressure of 3,0bar). Dehumidification can only be avoided if the evaporation temperature is above the dew point temperature.

7.5 ET 915.07 Experiment 1

This experiment investigates the individual changes of state of the air in fresh air operating mode:

- Cooling
- Heating
- Humidifying
- Dehumidifying

The respective changes of state of the air are plotted into a *h, x* diagram for the purpose. Deviations from the theoretical changes of state are also discussed.

Learning objectives:

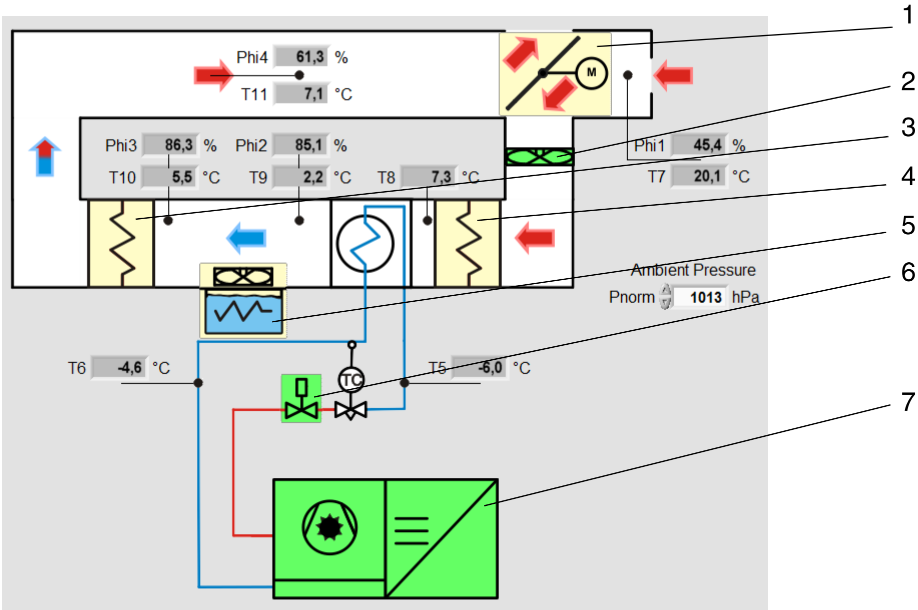
- To be able to plot the individual changes of state of the air into a *h, x* diagram.
- To be able to explain variations between the theoretical and actual change of state of the air.

Exercises:

- Record all relevant temperatures and relative humidities to plot the four changes of state of the air.
- Plot the four changes of state of the air into a *h, x* diagram.
- Plot the refrigeration process into a log *p, h* diagram.

7.5.1 Preparing the experiment

- Switch the system on at the main switch.
- Enable the refrigerating circuit by opening the relevant solenoid valve (6).
- Set the system to fresh air mode (1).
- Switch on the fan (2).
- Switch on the compressor with condenser (7).



1 Air guiding flap
2 Fan
3 Reheater
4 Preheater
5 Humidifier
6 Solenoid valve for cooling circuit
7 Compressor with condenser

Fig. 7.13 System diagram and buttons in unit software (here cooling)

7.5.2 Performing the experiment

- Conduct a total of four subsidiary experiments:
  - Cooling
  - Dehumidifying
  - Heating
  - Humidifying

and start with the Cooling experiment as described in Chapter 7.5.1.

- Wait for the steady state to be reached before conducting each experiment. This is the case when the temperature T_{11} and the relative humidity H_4 no longer change, or change only marginally.
- Record the measurements necessary for evaluation of the experiment.

Activate the following elements for the individual experiments (see Fig. 7.13):

Cooling:

- Solenoid valve (6)
- Compressor with condenser (7)
- Fan (2)

Dehumidifying:

- Solenoid valve (6)
- Compressor with condenser (7)
- Fan (2)
- Reheater (3)

Heating:

- Fan (2)
- Preheater (6)
- Reheater (1)

Humidifying:

⚠ WARNING

Touching the air humidifier can cause burns.

- Do not touch the compressor pressure pipes.

- Fan (2)
- Humidifier (4)

7.5.3 Measured values

Cooling	T_7 in °C	H_1 in %	T_{11} in °C	H_4 in %
	22,7	48	14,3	63
Dehumidi-fying	T_7 in °C	H_1 in %	T_{11} in °C	H_4 in %
	21,5	44	18,1	48
Heating	T_7 in °C	H_1 in %	T_{11} in °C	H_4 in %
	23,5	44	37,1	21
Humidifying	T_7 in °C	H_1 in %	T_{11} in °C	H_4 in %
	21,8	47	23,9	65

Tab. 7.6 Measured values on the air side

Cooling	T_5 in °C	T_6 in °C
	0,7	5,4

Tab. 7.7 Measured values on the refrigerant side

7.5.4 Changes of state in the *h, x* diagram

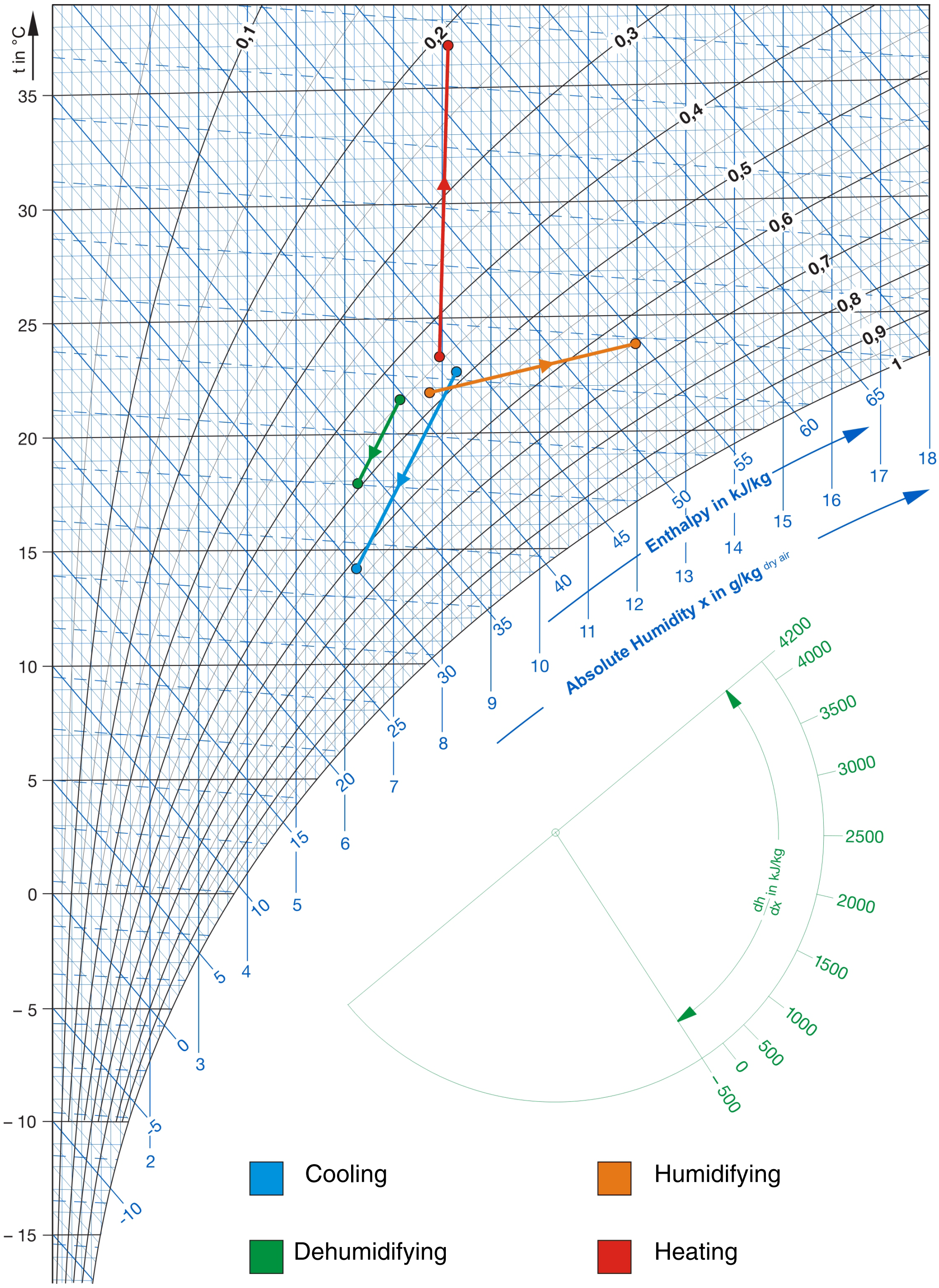


Fig. 7.14 Changes of state in the *h, x* diagram

7.5.5 Summary

Cooling

During cooling the air is cooled from 22,7°C to 14,3°C. It is also dehumidified in the process. The reason for the dehumidification is that the surface temperature of the cooler is below the dew point temperature of the air, so condensation forms on the cooler surface. The dew point temperature of the inflowing air is approximately 11,5°C, while the evaporation temperature of the refrigerant - and thus the surface temperature of the cooler - is approximately 0,7°C. Dehumidification can only be avoided if the evaporation temperature is above the dew point temperature.

Dehumidifying

The dehumidification process differs from the cooling process only in that the air is heated in the reheater after cooling. This becomes clear on comparing the temperature difference between the inlet and outlet in the cooling process (8,4K) with that in the dehumidification process (3,4K). It is further seen that the cooler has a greater capacity than the reheater, as demonstrated by the fact that the outlet temperature T_{11} is lower than the inlet temperature T_7.

Heating

The heating process is carried out with the pre-heater and reheater active.

According to the theory, the absolute humidity of the air must not change, as in the process water is neither fed in nor discharged. The experiment reveals a minor deviation from the theory however. This deviation results from uncertainties in measuring the relative humidity.

Humidifying

The humidification system used here is a vapour humidifier. This process is in theory virtually isothermic. But a temperature increase of 2,1 K does take place here. The temperature increase is caused primarily by the vapour humidifier heating the air duct. The air duct then acts additionally as a heater.

7.6 ET 915.07 Experiment 2

This experiment investigates the difference in energy terms between fresh air and circulated air mode. To do so, the ET 915.07 is set to the steady state once in fresh air mode and once in circulated air mode during cooling.

Both changes of state of the air are plotted into a *h, x* diagram.

Learning objectives:

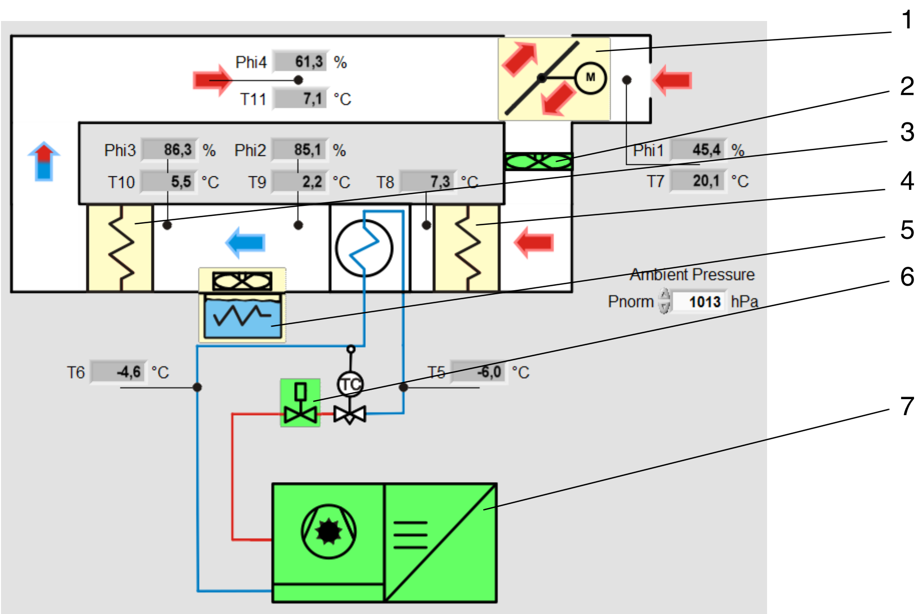
- To learn the difference in energy terms between fresh air and circulated air mode.

Exercises:

- Plot the cooling process in fresh air mode and in circulated air mode into a *h, x* diagram.
- Describe the difference between fresh air and circulated air mode based on the measured values.

7.6.1 Preparing the experiment

- Switch the system on at the main switch.
- Enable the refrigerating circuit by opening the relevant solenoid valve (6).
- Set the system to fresh air mode (1).
- Switch on the fan (2).
- Switch on the compressor with condenser (7).



1 Air guiding flap
2 Fan
3 Reheater
4 Preheater
5 Humidifier
6 Solenoid valve for cooling circuit
7 Compressor with condenser

Fig. 7.15 System diagram and buttons in unit software (here cooling)

7.6.2 Performing the experiment

First run the system in fresh air mode.

- Wait for the steady state to be reached. This is the case when the temperature T_{11} and the relative humidity H_4 no longer change, or change only marginally.
- Record all relevant measurement values.
- Switch the system to circulated air mode.
- Set the system to the steady state again.
- Record all relevant measurement values.

7.6.3 Measured values

Cooling - fresh air	T_7 in °C	H_1 in %	T_{11} in °C	H_4 in %
	22,7	48	14,3	63
Cooling - circulated air	T_7 in °C	H_1 in %	T_{11} in °C	H_4 in %
	20,2	44	4,1	59

Tab. 7.8 Measured values on the air side

Cooling Fresh air	T_5 in °C	T_6 in °C
	0,7	5,4
Cooling Circulated air	T_5 in °C	T_6 in °C
	-8,6	-3,8

Tab. 7.9 Measured values on the refrigerant side

7.6.4 Change of state in the *h, x* diagram

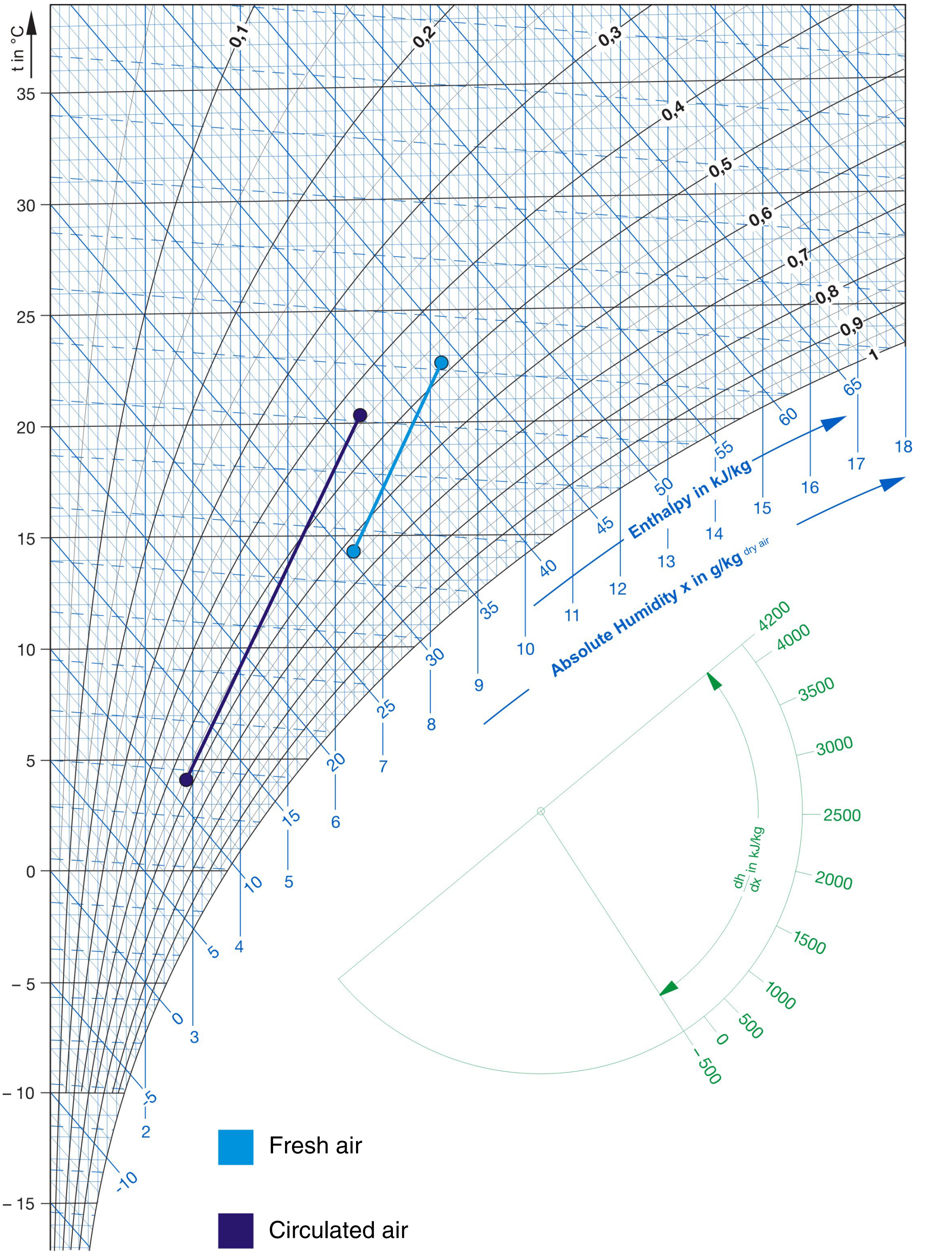


Fig. 7.16 Changes of state in the *h, x* diagram

7.6.5 Summary

When the system is run in circulated air mode, much lower air temperatures can be attained than in fresh air mode. The reason is that in circulated air mode the air cooled by the cooler is fed back to the cooler and as a result the steady state is successively attained. From this it can be inferred that at an assumed setpoint temperature T_{11} (here the temperature of the air-conditioned room) of 15°C the refrigeration system has to work continuously in fresh air mode and in circulated air mode only intermittently (two-point control). This enables savings to be made on energy and ultimately on operating costs.

8 Appendix

8.1 Technical data

ET 915

Dimensions

Depth:	approx. 630 mm
Width	approx. 850 mm
Height	approx. 320 mm

Power supply

Single phase	230V,~50 Hz
Nominal consumption (output)	350 W

Optional alternatives, see rating plate

Compressor

Type: Hermetic piston compressor

Power consumption (at 5/40°C)	174 W
Refrigerating capacity (at 5/40°C)	443 W
Refrigerant	R134a

Analog manometers

HP range:	-1...24 bar
LP range:	-1...9 bar

Pressure transducer

HP range:	0...16 bar
LP range:	0...10 bar

Temperature measuring range

HP range:	0...100 °C
LP range:	-50...50 °C

Condenser (t_c=40°C, t_{amb}=25°C)

Area	0,75	m^2
Fan output	330	m^3/h
Power	665	W
Fan power consumption	30	W

Refrigerant receiver

Capacity	0,7	L

ET 915.01

Dimensions

Depth:	approx. 380	mm
Width	approx. 840	mm
Height:	approx. 550	mm
Nominal consumption (output)	250	W

ET 915.02

Dimensions

Depth:	approx. 380	mm
Width	approx. 840	mm
Height:	approx. 750	mm
Nominal consumption (output)	500	W

ET 915.06

Dimensions

Depth:	approx. 370	mm
Width	approx. 970	mm
Height:	approx. 600	mm
Nominal consumption (output)	120	W

Differential pressure sensor

Ceramic	0...10	mbar

Temperature measuring range

calHT	0...50	°C

ET 915.07

Dimensions	
Depth:	410 mm
Width	840 mm
Height:	670 mm
Nominal consumption (output)	800 W
Preheater, reheater	
Power consumption	250 W
Humidifier heating	
Power consumption	150 W
Temperature measuring range	
calHT	0...50 °C

Data acquisition

Program environment:

LabVIEW Runtime

System requirements:

PC with Pentium IV processor, 1 GHz
Minimum 2048 MB RAM
Minimum 1 GB available memory on hard disk
1 CD-ROM drive
1 USB port
Graphics card resolution min. 1024 x 768 pixels, TrueColor
Windows Vista / Windows 7 / Windows 8

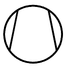
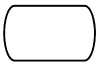
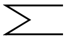
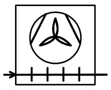
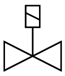
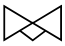
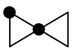
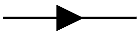
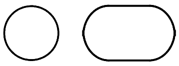
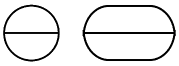
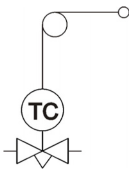
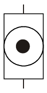
8.2 List of key symbols and indices

Symbol	Size	Unit
$\dot{m}$	Mass flow rate	kg/s
Q	Heat flow	W
A	Area	m^2
h	Specific enthalpy	J/kg
k	Coefficient of heat transmission	W/K
n	Speed	min^{-1}
p	Pressure	bar
P	Power	W
q	Specific thermal output power	J
T	Temperature	°C, K
t	Time	s

Indices

Index	Explanation
0	Evaporation
0_F	Evaporation in freezer
0_C	Evaporation in cooler
1...n	Measuring points 1...n
c	Condensation
C	Cooler (normal refrigeration chamber)
F	Freezer (freezing chamber)
V	Compressor

8.3 List of symbols for process schematic

Symbol	Name
	Compressor
	Tank, general
	Heating or cooling
	Finned tube heat exchanger with fan
	Fitting, general
	Fitting with magnetic actuation
	Fitting with continuous adjustment characteristics
	Non-return valve
	Flow line
	Function line
	Measuring point with local display
	Measuring point with remote evaluation
	Thermostatic expansion valve
	Sight glass with moisture indicator