

Equipment  
for engineering  
education



Refrigeration  
and air conditioning  
technology



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## Welcome to GUNT

In this catalogue, we present a comprehensive overview of our innovative demonstration and experimental units.

GUNT units are used for:

- education in technical professions
- training and education of technical personnel in trade and industry
- studies in engineering disciplines

## Refrigeration and air conditioning technology

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### Imprint

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# Refrigeration and air conditioning technology at GUNT

**Refrigeration and air conditioning technology** is among the most important topics of the 21<sup>st</sup> century. The development of cooling techniques makes the preservation of perishable food possible in the first place. Likewise, the production of high-performance plastics would be inconceivable without the possibilities of process cooling.

And the air conditioning of buildings and vehicles has become indispensable due to the legitimate desire for comfort. Although air-conditioning technology and refrigeration are closely related, they are two independent sub-disciplines.

The methods and procedures used to generate cold are referred to as **refrigeration technology**. The theoretical knowledge used in refrigeration covers the entire field of natural sciences. In addition to sound knowledge of thermodynamics, further knowledge in the fields of mechanical engineering, heat transfer, chemistry, thermal process engineering, apparatus engineering, measurement and control engineering is required.

**Air conditioning technology**, which describes a sub-area of supply technology (HVAC), covers the regulation of room temperature, air humidity and air quality. An air conditioning system can heat, cool, humidify, dehumidify and filter. The central element of an air conditioning system is always a refrigerating plant.

GUNT has presented the subject of refrigeration and air conditioning technology briefly and compactly in its main catalogue **3 Thermal engineering**.

This important field of thermodynamics is examined in detail in this catalogue **3a Refrigeration and air conditioning technology**.



- Courses of study, all engineering sciences, e.g.**
- mechanical engineering
  - environmental engineering
  - applied natural sciences
  - industrial engineering
  - civil engineering and architecture
  - energy engineering
  - process engineering



- Training in the field of**
- refrigeration technology
  - mechatronics
  - air conditioning technology
- Courses of study**
- mechanical engineering
  - supply engineering
  - civil engineering
  - environmental engineering
  - refrigeration technology
  - building services engineering
  - facility management
  - climate engineering

## What can GUNT do for you?

In view of the growing demands in terms of the energy efficiency of refrigeration and air conditioning systems, the more complex regulations and new system concepts, it is essential that prospective engineers and skilled workers acquire in-depth knowledge. GUNT develops products and solutions to aid your teaching. Our range of educational products is characterised by a practical focus and high standards of quality.

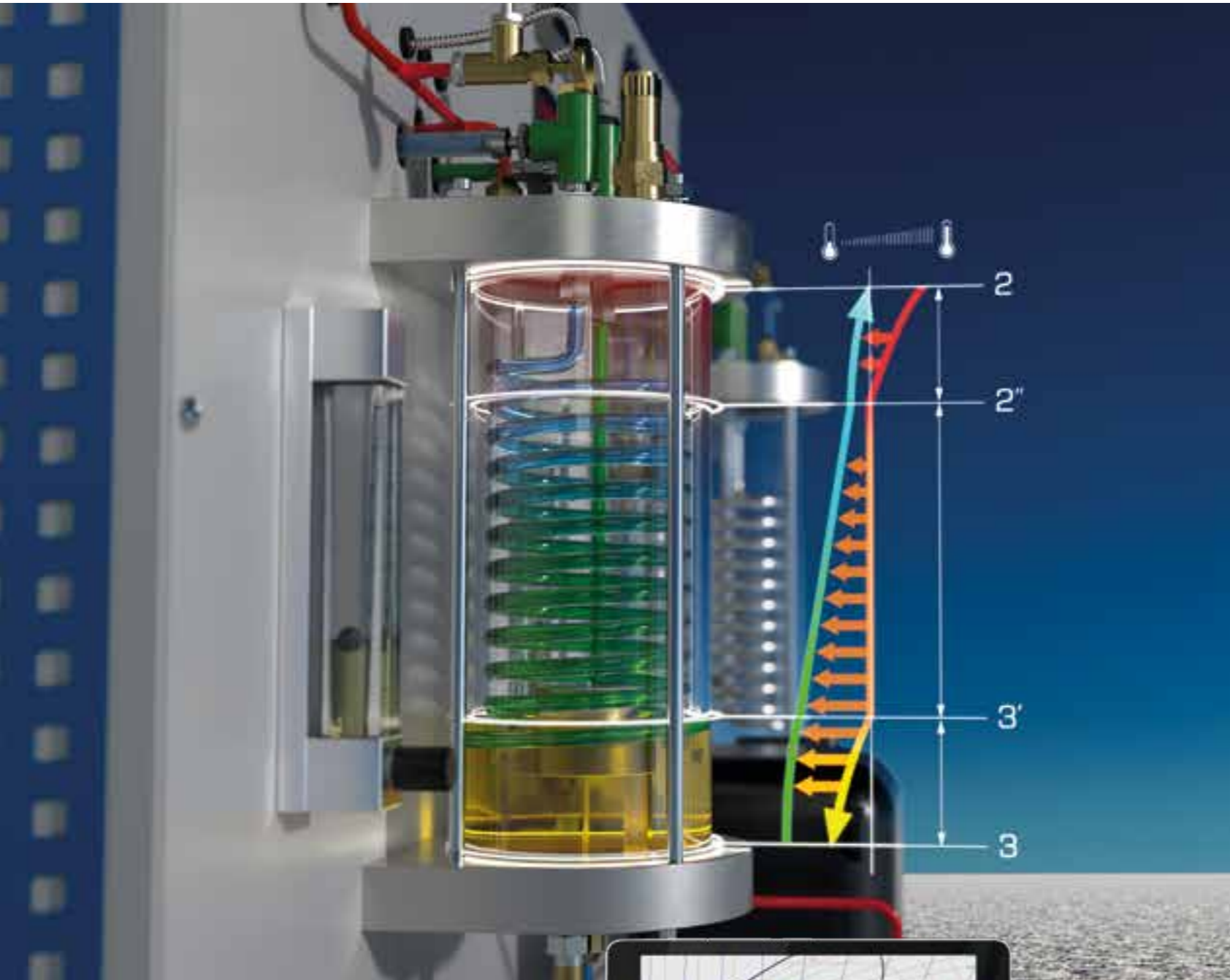
We offer 'Made in Germany' engineering education with over 40 years of experience. Our complete systems are perfectly matched to each other and can be used quickly and effectively in lessons or studies.



We plan, develop and manufacture stand-alone devices, modular training systems and complete specialist laboratories. We offer training on our products to users as well as experiment-based training sessions – at your site or at our Technical Academy. **Our knowledge takes you further!**



# GUNT training systems



GUNT offers a complete range of products for all aspects of refrigeration and air conditioning technology. The training systems are suitable both for vocational training as a refrigeration mechatronics technician and for engineering education.

Practical exercises	Scientific investigations
<ul style="list-style-type: none"> <li>■ assemble</li> <li>■ adjust</li> <li>■ test</li> <li>■ replace</li> </ul>	<ul style="list-style-type: none"> <li>■ thermodynamic inter-relationships</li> <li>■ observations in the cyclic process</li> <li>■ energy balances and energy efficiency</li> <li>■ efficiency</li> </ul>

The overall didactic concept from a single provider consists of:

- experimental unit
- measuring technology
- coordinated software
- instructional material
  - ▶ theoretical background
  - ▶ detailed experiment instructions
  - ▶ worksheets for trainees
  - ▶ solutions and hints for the teacher
  - ▶ educational software

See the outstanding quality of our devices for yourself. We look forward to welcoming you to our Technical Academy.

### Let's invest in the future together

European Regulation 517/2014 on fluorinated greenhouse gases has already come into force and sets high standards in terms of the responsible use of these refrigerants.

Refrigerants are evaluated on the basis of the relative global warming potential (GWP). This GWP value of a substance indicates the factor by which this substance contributes to global warming in comparison to CO<sub>2</sub>. Accordingly, CO<sub>2</sub> has a GWP of 1. The CO<sub>2</sub> equivalent is calculated as follows:

**CO<sub>2</sub> equivalent = GWP x refrigerant fill volume**

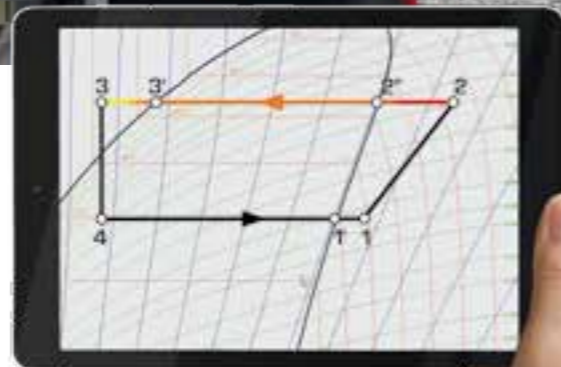
In the area of teaching especially, we see it as our duty to teach young people how to use resources responsibly. We are using the new regulations as an opportunity to contribute to combating global warming. The environmentally friendly concept behind our devices relieves you from various regulatory obligations incumbent upon operators.

All of our devices are designed so that they do not exceed a CO<sub>2</sub> equivalent of 5t. As such, our devices:

- are not affected by leak checks pursuant to article 4(1) of the Regulation,
- are exempt from the obligation to keep records pursuant to article 6(1) and
- do not require certificates for purchase and operation in almost all cases.

We make the complex changes of state in the otherwise closed piping systems of refrigeration and air conditioning systems visible and tangible. Operational changes are measured and displayed dynamically in the chart in real time.

Our devices combine the most effective methods of active and passive learning. The effective and long-lasting learning of thermodynamic formulas and their dependencies has never been so easy!





# Training in refrigeration and air conditioning technology with GUNT training systems

The skilled occupation of mechatronics technician for refrigeration is a particularly demanding profession due to the diversity of the scientific fundamentals required. Besides technical skills, it is also essential to be able to work with computers and evaluate and interpret measurement

data. The mechatronics engineer for refrigeration deals with the planning, calculation, installation, maintenance, repair and servicing of complex refrigerating plants as well as air conditioning systems and heat pumps. After installation, he checks the functionality of the system,

starts it up and instructs the customer how to use it.

## Subject areas for training as a mechatronics engineer for refrigeration

Refrigeration	Air conditioning technology	Electrical engineering in refrigeration and air conditioning technology
Functional interrelationships in the refrigeration circuit	Investigation of the states of the air	Principles of electrical engineering
Production of mechanical subsystems	Basic interrelationships in ventilation and room air conditioning	Consumers of single phase alternating current
Thermodynamics, log p-h diagram	Construction elements and function of the air conditioning system	Protection against electrical hazards
Refrigerants and lubrication oils	Air conditioning, h-x diagram	Simple refrigeration controls
Primary and secondary controllers	Air circuit in the ductwork	Consumers of three phase alternating current
Heat exchangers	Fire protection measures	Electrical drives and fault finding
Compressors	Energy saving	Control of refrigeration systems
Piping		Building automation
Troubleshooting, maintenance and disposal		

= covered by GUNT units

## Structure of the catalogue

The catalogue is divided into the three main areas of **refrigeration, air conditioning technology** and **electrical engineering in refrigeration and air conditioning technology**. Informative pages containing basic knowledge precede the sub-chapters

and explain the technical and physical context in an easy to comprehend manner. This allows for an easy introduction to the respective subject matter of the catalogue.

	<b>Refrigeration</b>	Principles of cold production
		Training systems
		Thermodynamics of the refrigeration cycle
		Components of refrigeration also assembly, troubleshooting, maintenance
		Heat pumps and ice store
		Solar cooling
	<b>Air conditioning technology</b>	States of the air
		Principles of air conditioning technology
		Practical air conditioning systems
		Ventilation technology
	<b>Electrical engineering in refrigeration and air conditioning technology</b>	Refrigeration controls
		Control of refrigeration systems
		Finding electrical faults

mainly with experimental orientation    mainly with technical orientation





# Principles of refrigeration

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## Introduction in the principles of refrigeration

### What is cold anyway?



Almost every child already has an idea of what cold is, because humans can feel cold. But what the term means from a physical perspective is not so easy to classify. Cold is neither a substance nor a form of energy. Simply put, "cold" is the absence of "heat". When we talk about "cold" we mean that the temperature at one point is lower than in the environment; there is a temperature difference.

From a thermodynamic point of view, "cold" is a state of imbalance. If there is a thermodynamic imbalance, nature always strives to level this imbalance out. In accordance with the second law of thermodynamics, this balancing out always occurs from a place of high temperature to a place of low temperature. Coming back to the child mentioned earlier, there is a temperature difference between the child's skin and the environment. Heat is transferred from the skin to the environment and the skin is cooled by the dissipation of heat.

The task of refrigeration is to develop technical solutions to produce temperatures below the ambient temperature. In other words, heat must be transported against its natural direction of flow. In order to generate and maintain this flow of energy, it is necessary to continuously supply energy to the refrigeration process.

Engineers have to deal with the issue of cooling in many areas. The removal of heat in manufacturing and production or air conditioning in buildings requires knowledge of refrigeration. Refrigeration offers a wide range of applications in machinery and plant manufacturing, as well as in many other specialist disciplines. Due to the wide range of applications, the requirements for technical implementation also vary.

GUNT offers a didactically structured product range based on the fundamentals of refrigeration. Experimental and demonstration units, optimally designed to accompany and support lessons, help teach complex topics.

### Principles of cold production

Introduction to the topic of cold production with experimental units that present the principles of cold production:



ET 101 as a simplified model of a compression refrigeration circuit



ET 120 as a functional model of a Peltier refrigeration system



ET 122 for demonstration of cold air generation using a vortex cooling device

### Compression refrigeration system

Investigation of compression refrigeration systems, the most frequently used system in refrigeration:



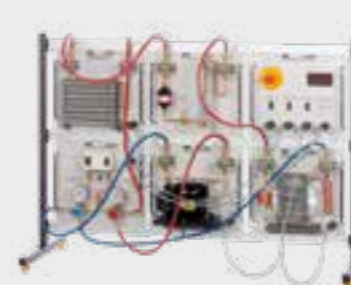
ET 411C represents a typical compression refrigeration circuit



ET 350 for demonstration of the processes in a refrigeration circuit

### Training systems

Training systems with a particularly strong focus on practical experience and that support the learning of manual work on refrigerating plants with an overall didactic concept:



ET 900 for introduction to refrigeration with simple, clear experiments



ET 910 for basic experiments and advanced experiments



ET 915 with the models refrigerator and refrigeration system to explain the function of refrigeration systems

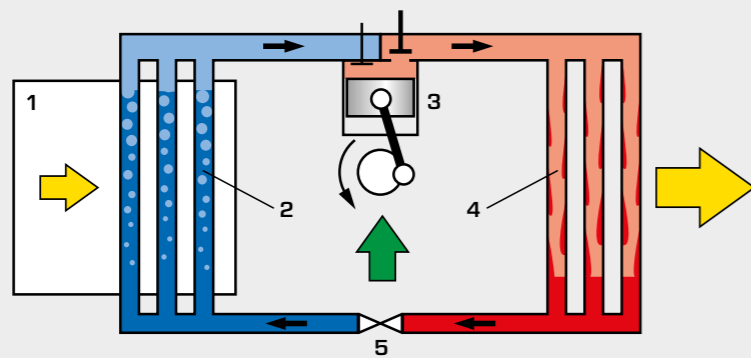
## Basic knowledge Principles of cold production

Refrigeration describes the removal of heat from a space which is to be cooled. Thermal energy is transferred from the warmer to the colder medium due to a temperature difference. There are various principles, presented here, on the technical implementation of heat transport.

**Compression refrigeration systems** are the most common cooling systems found in practice. In a compression refrigeration system a refrigerant flows through the refrigerant circuit and is subject to different changes of state. The compression refrigeration system is based on the physical effect that thermal energy is required during the transition from the liquid to the gaseous state. The evaporator **2** extracts thermal energy from the room **1** to be cooled. Different pres-

ures during evaporation and condensation allow the temperature levels to be set so that heat is transferred from the cold side to the warm side. The thermal energy is released again by condensation **4** of the refrigerant.

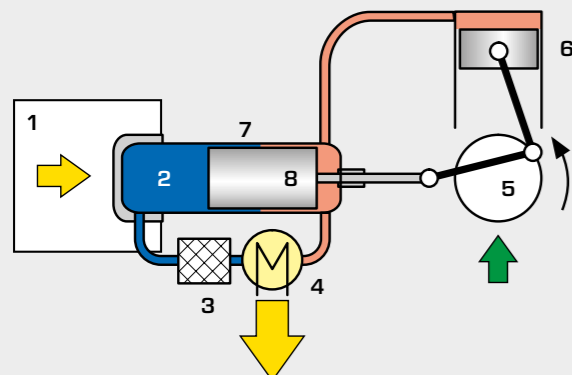
To increase the pressure, screw, scroll, turbo or vapour jet compressors can be used instead of the piston compressor **3** shown.



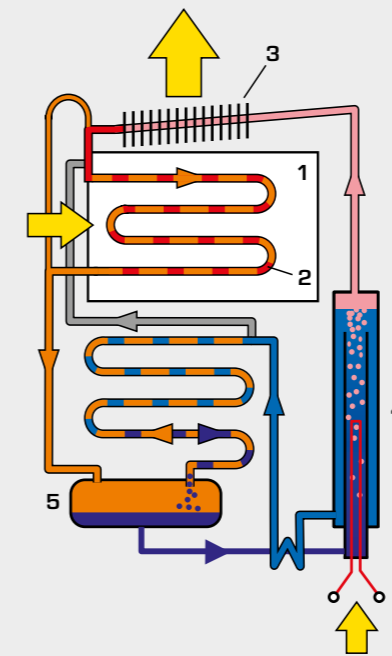
1 room to be cooled or process cooling, 2 evaporator, 3 compressor, 4 condenser, 5 expansion valve;  
 HP gaseous refrigerant, HP liquid refrigerant, LP liquid refrigerant, LP gaseous refrigerant, heat, mechanical work

The **Stirling refrigerator** is an absolute niche solution in practical application. It works according to the same principle as the Stirling engine, but with reverse direction of rotation. The Stirling refrigerator makes it possible to achieve very low temperatures, for example, to cool infrared cameras or to condense gases.

The Stirling refrigerator consists of a working cylinder **6** and a displacement cylinder **7**. A working gas is alternately compressed and expanded in the working cylinder. The compressed, hot gas releases its heat in the heat exchanger **4**. During expansion, the working gas cools down and absorbs heat on the cold side **2** of the displacement cylinder from the room **1** being cooled. Displacement piston **8** and working piston **6** are moved correspondingly phase-shifted via a crank mechanism **5**.



1 room being cooled or process cooling, 2 cold cylinder side, 3 recuperator, 4 heat exchanger, 5 crank mechanism, 6 working cylinder, 7 displacement cylinder, 8 displacement piston;  
 cold exhaust gas, hot exhaust gas, heat, mechanical work



In contrast to the compression refrigeration system, an **absorption refrigeration system** uses two working media, one refrigerant and one solvent. The two working media are separated from each other in the generator **4** where thermal energy is added. The expelled refrigerant vapour flows into condenser **3** and is condensed. The refrigerant then evaporates at low pressure in the evaporator **2** and dissipates heat. The resulting refrigerant vapour flows into the absorber **5**, where it is absorbed by the solvent. The solution of refrigerant and solvent is pumped back into the generator.

The use of absorption refrigeration systems makes sense if thermal energy, e.g. waste heat, is available. In this case, cooling can be achieved by using waste heat.

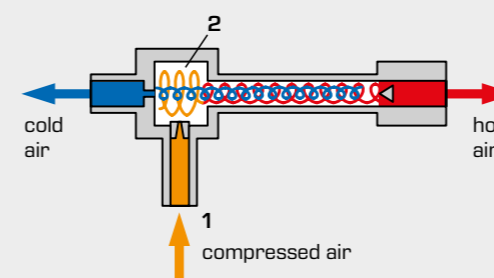
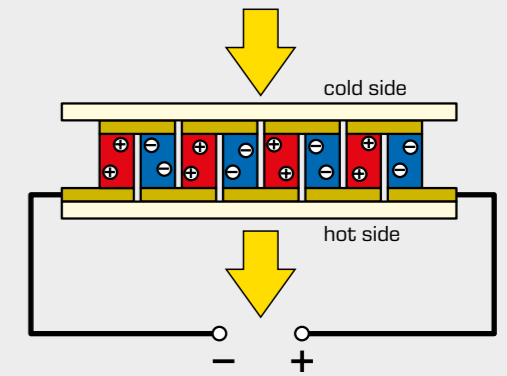
Illustration using the combination of ammonia and water as an example

1 room to be cooled or process cooling, 2 evaporator, 3 condenser, 4 generator, 5 absorber;  
 ammonia vapour, liquid ammonia, low ammonia solution, rich ammonia solution, hydrogen, hydrogen and ammonia vapour, heat

**Thermoelectric refrigeration plants** are based on the Peltier effect. A Peltier element generates a temperature difference in an electrical current flow and can be used for heating or cooling, depending on the direction of flow.

Current is conducted through a thermoelectric element. One electrical contact heats up and the other one cools down. In order to increase the power, several thermoelectric elements are connected in series, arranged in such a way that cooling and heating contacts are each connected to a cover plate. During current flow, one of the plates extracts heat and transfers it to the other. The cold plate corresponds to the useful side of the thermoelectric refrigeration plant.

Peltier elements can generate very low temperatures. However, the efficiency decreases as the temperature difference increases. Peltier elements are easy to adjust, have no moving parts and no toxic fuels.



1 inlet opening, 2 vortex chamber

The **vortex cold generator** has an exceptional operating principle. Compressed air is introduced into the inlet opening **1**. The compressed air is introduced tangentially into a vortex chamber **2** and is set in rotation. A cold air flow forms in the centre of this vortex, while the outer layer of the vortex heats up. The cold air flow is diverted from the centre of the vortex and used for cooling.

The advantage of a vortex cold generator is its particularly simple design, which has no moving components and does not require toxic fuels or power supply. The low efficiency is a disadvantage



## ET 101

### Simple compression refrigeration circuit



2E

#### Description

- introduction to refrigeration
- model of a compression refrigeration system / heat pump
- cooling and heating of the heat exchangers directly tangible

The purpose of a refrigeration system is the cooling of materials and products, e.g. to protect food from spoiling. Cooling can be described as a process in which heat is removed from the environment.

A commonly used refrigeration system is the so-called compression refrigeration system. In this system refrigerant flows through four main elements: compressor, condenser, expansion element and evaporator. The refrigeration system uses the fact that the refrigerant has a low boiling point at low pressure. This means that evaporation takes place on the low pressure side. During the evaporation of the refrigerant heat is removed from the environment and it is cooled. The condensation takes place on the high pressure side after the evaporator. Here the heat is discharged into the environment. If not the cooling effect but the discharged heat is used, this is called a heat pump.

The setup of ET 101 represents a simple compression refrigeration system. Evaporator and condenser have been designed as a pipe coil with each end immersed in a water-filled tank. The water simulates the environment. A thermostatic expansion valve serves as expansion element. Two manometers indicate the two system pressures on the high and low pressure sides. On an additional scale on the manometer the evaporation temperature of the refrigerant is indicated. Two thermometers measure the temperature of the water in the tanks.

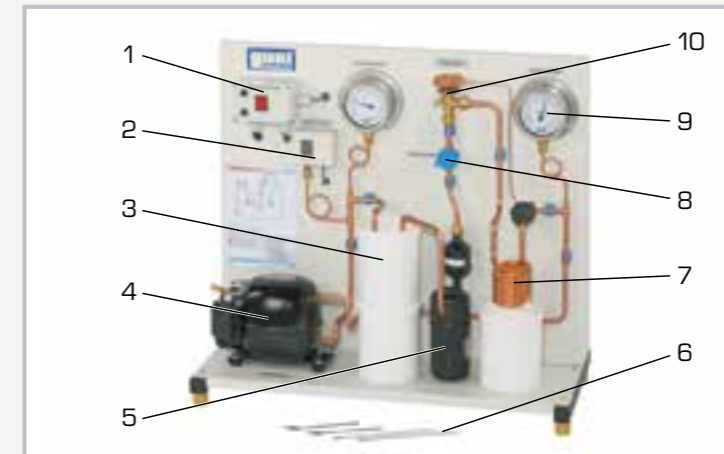
This allows for calculations of the amount of heat removed from the environment (evaporator, cold water) and added to the environment (condenser, hot water). A sight glass indicates the aggregate state of the refrigerant upstream of the expansion valve.

#### Learning objectives/experiments

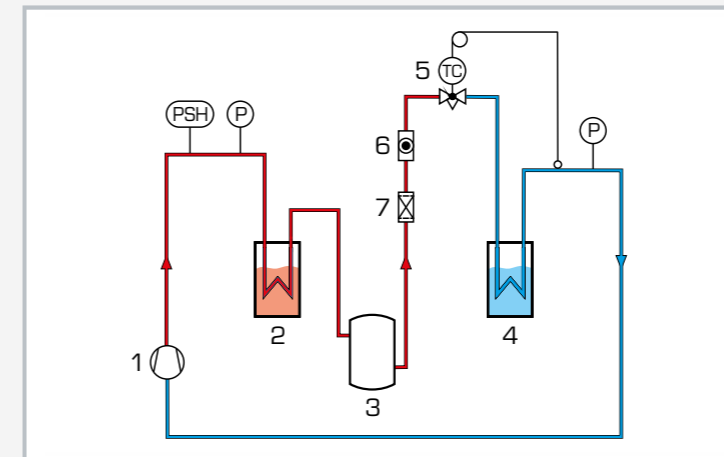
- fundamentals of a compression refrigeration circuit
- key components of a refrigeration system
  - ▶ compressor, evaporator, condenser, expansion element
- relationship between the pressure and boiling point of a liquid
- operation of a refrigeration system / heat pump
- developing a basic understanding of the thermodynamic cycle
- simple energy balance

## ET 101

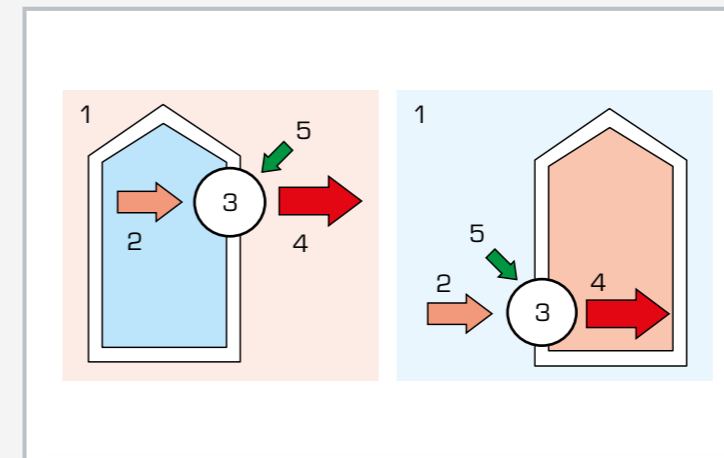
### Simple compression refrigeration circuit



1 main switch, 2 pressure switch, 3 condenser with water tank, 4 compressor, 5 receiver, 6 thermometer, 7 evaporator, 8 sight glass (refrigerant), 9 manometer, 10 expansion valve



Process schematic of the refrigeration circuit: 1 compressor, 2 condenser, 3 receiver, 4 evaporator, 5 expansion valve, 6 sight glass, 7 filter/drier; PSH pressure switch, P pressure



Cooling (left) and heating (right) using a heat pump  
1 environment, 2 absorbed heat, 3 heat pump, 4 discharged heat, 5 electric energy

#### Specification

- [1] fundamentals of refrigeration in a simplified model
- [2] typical compression refrigeration system with piston compressor, thermostatic expansion valve, evaporator and condenser (each in the shape of a pipe coil)
- [3] 2 manometers with temperature scale for the refrigerant show the values of the refrigerant on the high and low pressure sides
- [4] 2 water-filled tanks with thermometer to demonstrate the cooling and heating effect
- [5] pressure switch to protect the compressor
- [6] sight glass to monitor the aggregate state of the refrigerant
- [7] refrigerant R513A, GWP: 631

#### Technical data

##### Compressor

- power consumption: 104W at 5/40°C
- refrigeration capacity: 278W at 5/40°C
- displaced volume: 2,72cm<sup>3</sup>

##### Tank: 4x 1700mL

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 500g
- CO<sub>2</sub>-equivalent: 0,3t

##### Measuring ranges

- pressure: -1...12,5bar, -1...25bar
- temperature: -50...40°C, -40...80°C, 2x -10...50°C

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase  
120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 750x360x690mm  
Weight: approx. 30kg

#### Scope of delivery

- 1 experimental unit
- 4 water tanks
- 2 thermometers
- 2 spoons
- 1 set of instructional material

## ET 120

### Cooling using the Peltier effect



#### Description

- demonstration of the thermoelectric effect
- creation of energy balances

The experimental unit ET 120 demonstrates cooling using the Peltier effect. Peltier elements utilise the thermoelectric effect of some semiconductors. The thermoelectric effect is the reverse of the known thermopower effect which is e.g. used when measuring temperatures using thermocouples. If current flows through a Peltier element, one end of the semiconductor becomes hot and the other cold. By a suitable connection of p- and n-doped semiconductor materials the refrigeration capacity can be increased sufficiently to be usable.

The benefits of cold production using Peltier elements are: Peltier elements are wear and maintenance-free, noiseless, independent of position and easy to adjust in their refrigeration capacity via the supply voltage. In addition, no refrigerants are required. Peltier elements are used for small capacities in thermography as beverage chillers or in medical engineering. Their low efficiency is a disadvantage.

The experimental setup is clearly arranged on the front of the experimental unit. The central component of the system is a Peltier element. The heating and refrigeration capacity of the Peltier element are dissipated via water flows. Measuring the respective flow rate and the inlet and outlet temperatures allows for the heat flows to be determined. The supplied electrical power is determined using a current and voltage measurement.

Due to the closed water circuit the experimental unit can also be operated for short periods of time without being connected to the water mains.

#### Learning objectives/experiments

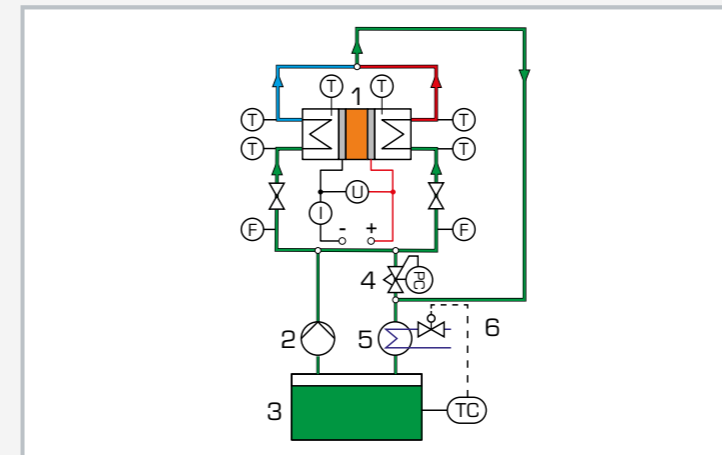
- function and operation of a Peltier element
  - ▶ for cooling
  - ▶ as heat pump
- determination of the refrigeration and heating capacity
- recording typical characteristics, such as refrigeration capacity, via temperature differences
- energy balance
- calculating the coefficient of performance

## ET 120

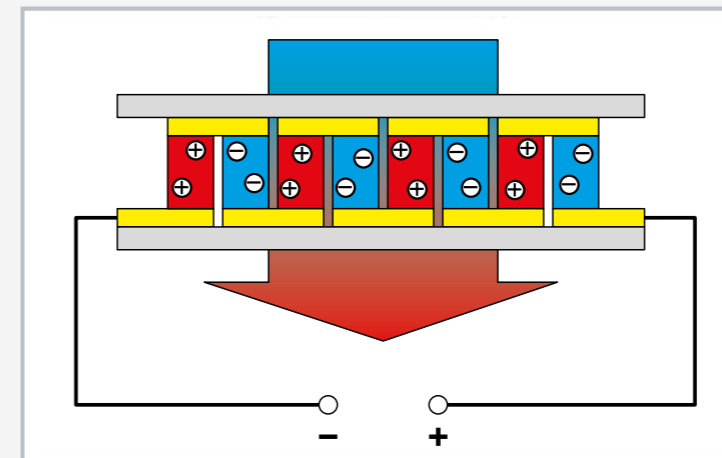
### Cooling using the Peltier effect



1 cold water flow meter, 2 temperature displays cold side, 3 water tank temperature controller, 4 voltage and current displays, 5 adjustment of the electrical power, 6 Peltier element with heat exchangers, 7 hot water flow meter, 8 temperature displays hot side, 9 water tank cover



1 Peltier element, 2 pump, 3 tank, 4 overflow valve, 5 heat exchanger, 6 solenoid valve; T temperature, F flow rate; U, I supply voltage and current measurement; blue: water cold side, red: water hot side, green: mixed water



Principle of operation: semiconductors connected electrically in series transport the heat from the cold side (blue) to the hot side (red)

#### Specification

- [1] functional model of a Peltier refrigeration system
- [2] experimental unit with clear design of all components at the front
- [3] water-cooled Peltier element
- [4] shared water circuit for heating and cooling with tank, pump and flow meters
- [5] electrical power freely adjustable via potentiometer
- [6] digital displays for temperature, current and voltage
- [7] flow meter measurement of the water flows via rotameters

#### Technical data

##### Peltier element

- max. refrigeration capacity: 191,4W
- max. current: 22,6A
- max. voltage: 16,9V
- max. temperature difference: 77,8K
- hot side temperature: 50°C

##### Pump

- power consumption: 120W
- max. flow rate: 1000L/h
- max. head: 30m

##### Water tank

- content: 7L

##### Measuring ranges

- current: 0...20A
- voltage: 0...200V
- temperature: 2x -30...80°C, 4x 0...100°C
- flow rate: 2...27L/h, 15...105L/h

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase  
120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1000x640x600mm  
Weight: approx. 60kg

#### Required for operation

water connection  
drain

#### Scope of delivery

- 1 experimental unit
- 1 set of instructional material



## ET 352

### Vapour jet compressor in refrigeration



#### Learning objectives/experiments

- understanding compression refrigeration systems based on the vapour jet method
- clockwise and anticlockwise Rankine cycle
- energy balances
- calculation of the coefficient of performance of the refrigeration circuit
- thermodynamic cycle in the log p-h diagram
- operating behaviour under load
- solar thermal vapour jet refrigeration

#### Description

- refrigeration system with vapour jet compressor
- cold production using heat
- transparent condenser and evaporator
- together with ET 352.01 and HL 313: using solar heat as drive energy for the vapour jet compressor

Unlike standard compression refrigeration systems, vapour jet refrigeration machines do not have a mechanical but a vapour jet compressor. This makes it possible to use different heat sources for cold production. Such sources could e.g. be solar energy or process waste heat.

The system includes two refrigerant circuits: one circuit is used for cold production (refrigeration cycle), the other circuit is used for the generation of motive vapour (vapour cycle).

The vapour jet compressor compresses the refrigerant vapour and transports it to the condenser. A transparent tank with a water-cooled pipe coil serves as condenser.

In the refrigeration cycle some of the condensed refrigerant flows into the transparent evaporator connected to the intake side of the vapour jet compressor. The evaporator is a so-called flooded evaporator where a float valve keeps the filling level constant. The refrigerant absorbs the ambient heat or the heat from the heater and evaporates. The refrigerant vapour is aspirated by the vapour jet compressor and compressed again.

In the vapour cycle a pump transports the other part of the condensate into a vapour generator. An electrically heated tank with water jacket evaporates the refrigerant. The generated refrigerant vapour drives the vapour jet compressor. Alternatively to the electric heater, solar heat can be used as drive energy by using ET 352.01 and the solar thermal collector HL 313.

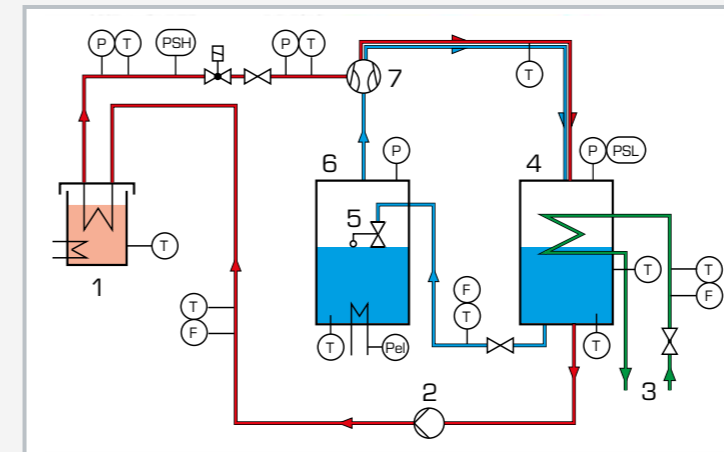
Relevant measured values are recorded by sensors, displayed and can be processed onto a PC. The heater power at the evaporator is adjustable. The cooling water flow rate at the condenser is adjusted using a valve.

## ET 352

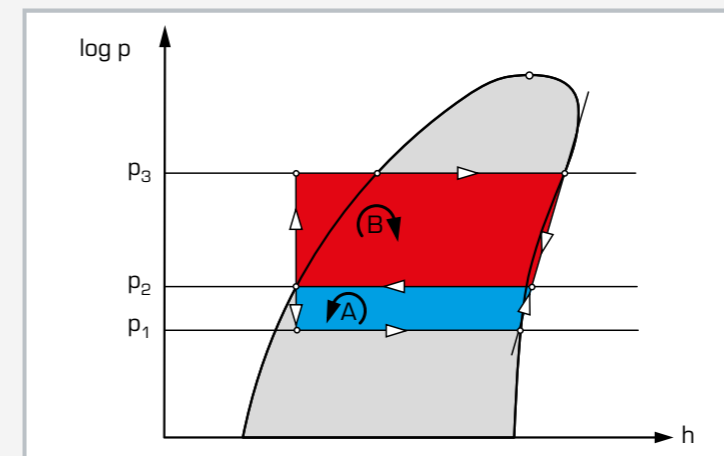
### Vapour jet compressor in refrigeration



1 manometer, 2 pressure switch, 3 displays and controls, 4 vapour generator, 5 evaporator, 6 pump, 7 cooling water connections, 8 flow meter, 9 condenser, 10 vapour jet compressor



1 vapour generator, 2 pump, 3 cooling water connections, 4 condenser, 5 float valve, 6 evaporator, 7 vapour jet compressor; T temperature, P pressure, PSL, PSH pressure switch, F flow rate, P<sub>a</sub> power; red: vapour cycle, blue: refrigeration cycle, green: cooling water



log p-h diagram: A refrigeration cycle, B vapour cycle,  $p_1$  pressure in the evaporator,  $p_2$  pressure in the condenser,  $p_3$  pressure in the vapour generator

#### Specification

- [1] investigation of a vapour jet compressor
- [2] refrigeration circuit with condenser, evaporator and vapour jet compressor for refrigerant
- [3] vapour circuit with pump and vapour generator for operating the vapour jet compressor
- [4] transparent tank with water-cooled pipe coil as condenser
- [5] transparent tank with adjustable heater as evaporator
- [6] flooded evaporator with float valve as expansion element
- [7] vapour generator with heated water jacket (electrically or solar thermally using ET 352.01, HL 313)
- [8] refrigerant R1233zd, GWP: 1
- [9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

Vapour jet compressor

- $d_{\min}$  convergent-divergent nozzle: approx. 1,7mm
- $d_{\min}$  mixing jet: approx. 7mm

Condenser

- tank: approx. 3,5L
- pipe coil area: approx. 0,17m<sup>2</sup>

Evaporator

- tank: approx. 3,5L
- heater power: 4x 125W

Vapour generator

- refrigerant tank: approx. 0,75L
- water jacket: approx. 9L
- heater power: 2kW

Pump

- max. flow rate: approx. 1,7L/min
- max. head: approx. 70mWS

Refrigerant

- R1233zd
- GWP: 1
- filling volume: 5kg
- CO<sub>2</sub>-equivalent: 0t

Measuring ranges

- temperature: 12x -20...100°C
- pressure: 2x 0...10bar; 2x -1...9bar
- flow rate: 3x 0...1,5L/min
- power: 1x 0...750W, 1x 0...3kW

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase, 230V, 60Hz, 3 phases

UL/CSA optional

LxWxH: 1460x790x1890mm

Weight: approx. 225kg

#### Required for operation

water connection, drain, PC with Windows recommended

#### Scope of delivery

- 1 trainer + 1 set of accessories
- 1 GUNT software CD + USB cable
- 1 set of instructional material

## ET 122

### Vortex cooling device



#### Description

- demonstration of the vortex principle
- cooling and heating using compressed air

The experimental unit ET 122 generates cold and hot air with the aid of ordinary compressed air. The central element of the experimental unit is a vortex cooling device also known as a vortex tube. In the vortex tube the tangentially incoming compressed air is moved in rapid rotation. This creates a cold and hot air flow in the vortex tube which leaves the vortex tube at opposite ends.

A vortex cooling device does not have any moving parts, is maintenance-free and immediately ready for operation.

The vortex cooling device is used for the convective cooling of high-speed tools, the air conditioning of protection suits and the cooling of switch cabinets. It is particularly suited for use in explosive environments. One benefit here is that the vortex cooling device does not require an electric power supply.

The inlet pressure is measured using a manometer. The compressed air volume and the outlet volume of the hot air flow are each measured using a rotameter. The inlet temperature of the compressed air and the outlet temperatures of the cold and hot air flows are displayed digitally.

#### Learning objectives/experiments

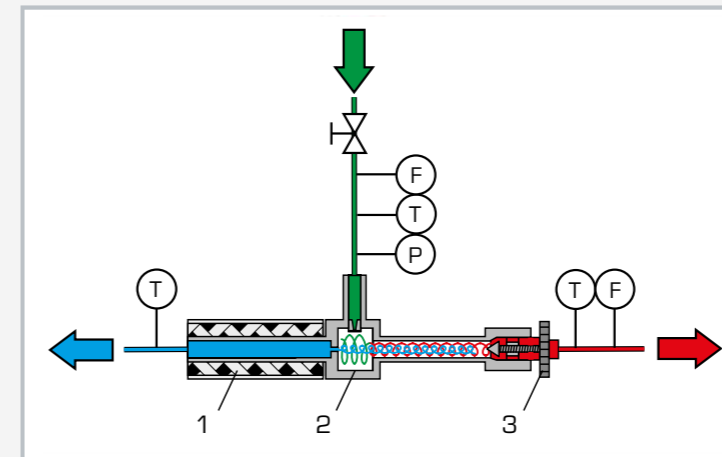
- function and operation of a vortex cooling device
- air flow distribution dependent on the temperature of the cold air flow
- effect of the inlet pressure on heating and refrigeration capacity

## ET 122

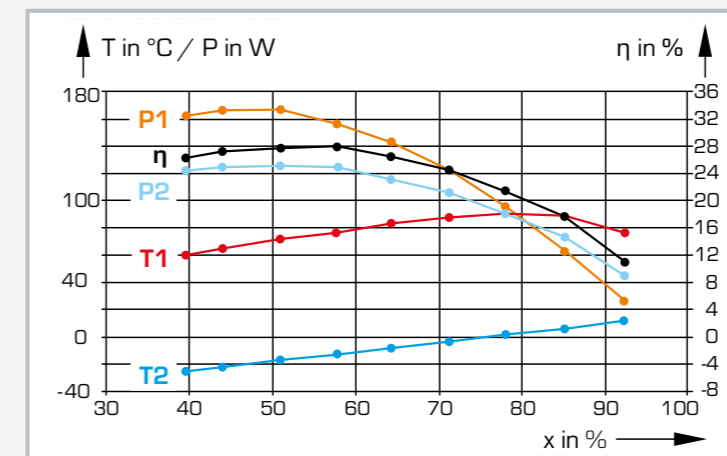
### Vortex cooling device



1 manometer, 2 vortex tube, 3 cold air outlet, 4 compressed air connection, 5 process schematic, 6 flow meter, 7 temperature displays, 8 hot air outlet



1 sound absorber, 2 vortex tube, 3 valve for adjusting the temperature of cold air; T temperature, P pressure, F flow rate; blue: cold air, red: hot air, green: compressed air



Temperature curve, capacity and efficiency depending on the cold air ratio; red T1: hot air, blue T2: cold air, orange P1: heat capacity, light blue P2: refrigeration capacity, black: cold air efficiency, x cold air ratio

#### Specification

- [1] functional model for cold air generation using a vortex cooling device (vortex tube) with the aid of compressed air
- [2] experimental unit with clear design of all components at the front
- [3] simple design, no moving components, wear-free
- [4] measuring of the compressed air inlet pressure by manometer
- [5] flow rate measurement of compressed air and exhaust hot air by rotameters
- [6] digital displays for inlet temperature and outlet temperature of cold and hot air

#### Technical data

##### Vortex cooling device

- inlet pressure: 5,5bar
- air consumption: max. 420L/min
- refrigeration capacity: max. 267W (230kcal/h)
- minimum temperature: -40°C
- maximum temperature: 110°C

##### Measuring ranges

- temperature: 3x -50...150°C
- pressure: 0...10bar
- flow rate: 2x 2...25m<sup>3</sup>/h

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase  
120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1000x600x710mm  
Weight: approx. 50kg

#### Required for operation

compressed air: min. 6bar, 25m<sup>3</sup>/h

#### Scope of delivery

- 1 experimental unit
- 1 set of accessories
- 1 set of instructional material



## ET 480

### Absorption refrigeration system



#### Description

- model of an absorption refrigeration system
- boiler operated alternatively by gas or electrically
- adjustable heating at the evaporator serves as cooling load

Refrigerating plants make use of the fact that a refrigerant evaporates at low pressure. In absorption refrigeration systems, the absorption of ammonia in the water produces this low pressure. The absorption process is driven by thermal energy, which can come for example from industrial waste heat or solar collectors to operate these systems.

This basic principle of an absorption refrigeration system is demonstrated in the ET 480 experimental unit taking the example of an ammonia-water solution with the ammonia acting as refrigerant. In the evaporator the liquid ammonia evaporates and withdraws heat from the environment. To keep the evaporation pressure low, the ammonia vapour in the absorber is absorbed by the water. In the next step, ammonia is permanently removed from the high concentration ammonia solution to prevent the absorption process from being halted. For this purpose, the high concentration ammonia solution is heated in a generator until the ammonia evaporates

again. In the final step, the ammonia vapour is cooled in the condenser to the base level, condenses and is returned to the evaporator. The low concentration ammonia solution flows back to the absorber. To maintain the pressure differences in the system, hydrogen is used as an auxiliary gas.

In process technology systems the resulting waste heat can be used for cooling. In small mobile systems, such as a camping refrigerator or minibar in a hotel, the required heat is generated electrically or by gas burner. Another benefit of absorption refrigeration systems is their silent operation.

ET 480 demonstrates the functional principle of an absorption refrigeration system with its main components: evaporator, absorber, boiler as generator with bubble pump, condenser. The boiler can alternatively be operated with gas or electrically. Another electric heater at the evaporator generates the cooling load.

Temperatures in the refrigeration circuit and the heating power at the boiler and at the evaporator are recorded and displayed digitally.

#### Learning objectives/experiments

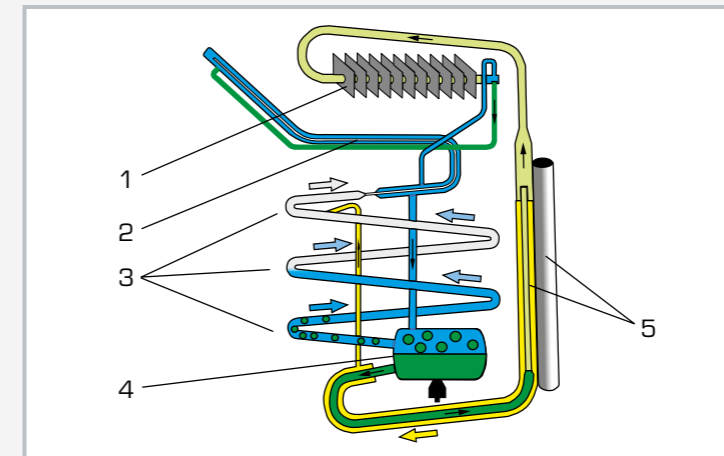
- demonstrate the basic principle of an absorption refrigeration system
- absorption refrigeration system and its main components
- operating behaviour under load

## ET 480

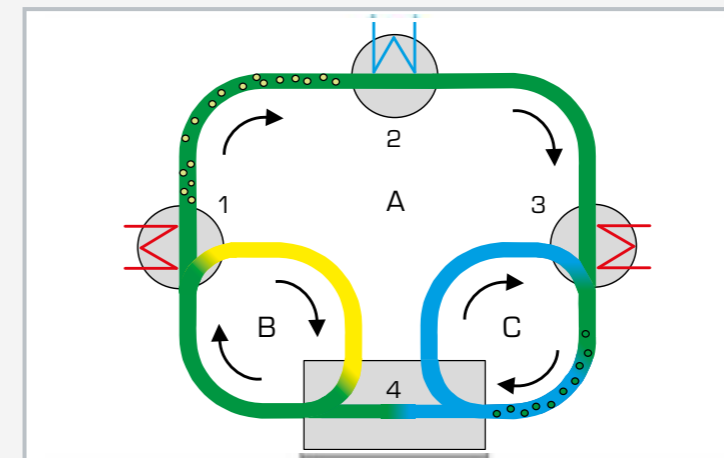
### Absorption refrigeration system



1 condenser, 2 evaporator with heater, 3 absorber, 4 tank, 5 gas burner, 6 pressure reducing valve for propane gas operation, 7 boiler with bubble pump to separate the ammonia, 8 displays and controls



1 condenser, 2 evaporator, 3 absorber, 4 tank, 5 boiler with bubble pump; green: high concentration ammonia solution, yellow: low concentration ammonia solution, blue: gas mixture ammonia-hydrogen



1 boiler with bubble pump, 2 condenser, 3 evaporator, 4 absorber; A: ammonia circuit, B: water circuit, C: hydrogen circuit

#### Specification

- [1] operation of an absorption refrigeration system
- [2] main system components: evaporator, absorber, boiler with bubble pump, condenser
- [3] ammonia-water solution as working medium, hydrogen as auxiliary gas
- [4] boiler to separate ammonia
- [5] bubble pump for transportation in the circuit
- [6] adjustable electrical heater at the evaporator serves as cooling load
- [7] boiler is alternatively heated by electrical heater or gas burner
- [8] piezoelectric igniter for gas operation
- [9] digital displays for temperature and power

#### Technical data

Working medium: ammonia-water solution  
Auxiliary gas: hydrogen  
Electric heater: 125W  
Gas burner, adjustable: propane gas  
Evaporator heater, adjustable: 50W

#### Measuring ranges

- temperature: 4x -80...180°C
- power: 0...150W

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase  
120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 750x450x750mm  
Weight: approx. 47kg

#### Required for operation

propane gas: 30...50mbar

#### Scope of delivery

- 1 experimental unit
- 1 hose
- 1 pressure reducer
- 1 set of instructional material

Basic knowledge

# Main elements of a compression refrigeration system

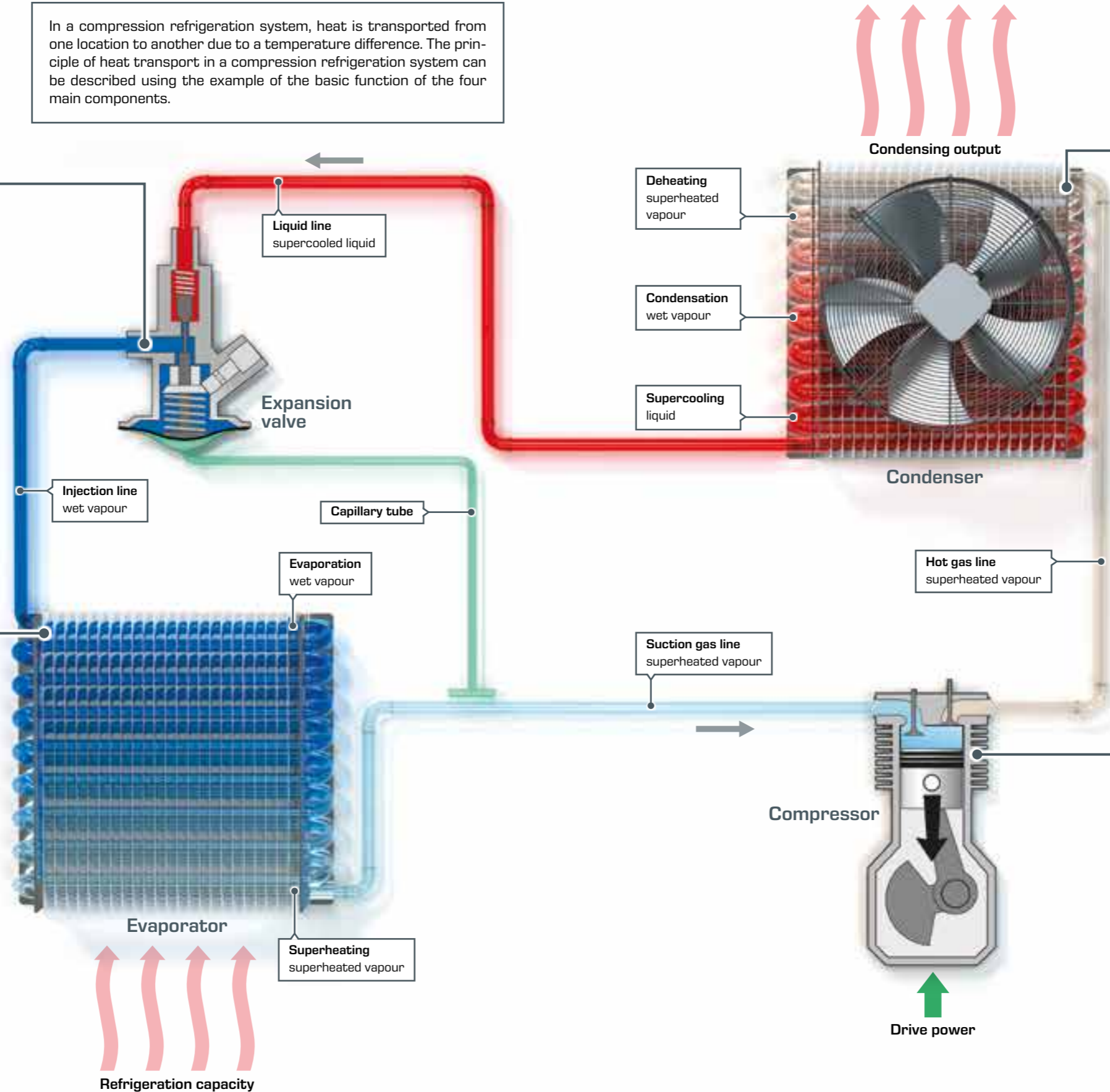


In a compression refrigeration system, heat is transported from one location to another due to a temperature difference. The principle of heat transport in a compression refrigeration system can be described using the example of the basic function of the four main components.

The **expansion valve** is located between the condenser and the evaporator. Its task is to expand the pressurised refrigerant. The expansion to a low pressure is necessary so that the refrigerant can evaporate again at low temperatures. A portion of the refrigerant evaporates due to the pressure reduction at the expansion valve, which results in a drop in temperature. In addition, the superheating of the refrigerant in the evaporator can be achieved by using the expansion valve. The superheating ensures complete evaporation of the refrigerant.



In the **evaporator**, heat is extracted from the environment or a fluid and transferred to the refrigerant. The refrigerant evaporates during this process. In this case, the useful side is located in a refrigeration plant. The temperature of the refrigerant remains constant during evaporation despite absorbing heat. The absorbed energy is used for the phase change. In order for evaporation to be able to take place, the temperature of the liquid refrigerant must be lower than the fluid being cooled. This required evaporation temperature is directly proportional to the pressure which is specifically achieved by the suction effect of the compressor and the contraction of the expansion valve.



In the **condenser**, the heat is released from the refrigerant and transferred to the environment. The refrigerant vapour condenses due to heat dissipation. The refrigerant vapour must have a higher temperature than the environment. This required condensing temperature is directly proportional to the pressure generated by the compressor. Condensation takes place at constant high pressure.



The **compressor** is the drive unit of a compression refrigeration system. It extracts the gaseous refrigerant from the evaporator, increases the pressure of the refrigerant vapour and conveys the gaseous refrigerant into the condenser. The compressor must raise the pressure of the refrigerant vapour to a sufficiently high pressure level so that the refrigerant can condense in the condenser by releasing heat.



## ET 411C

### Compression refrigeration system



#### Description

- compression refrigeration system with transparent evaporator and transparent condenser
- comparison of different expansion elements
- effect of under/overfilling of the system with refrigerant
- dynamic recording of the refrigerant mass flow rate

The setup of ET 411C represents a typical refrigeration circuit consisting of a hermetic compressor, condenser, evaporator and expansion element. Evaporator and condenser are designed as finned tube heat exchangers. The pipes of both heat exchangers are partially transparent to visualise the process of the phase transition during evaporation and condensing. Three capillary tubes of different lengths and a thermostatic expansion valve can be compared as expansion elements.

The trainer is equipped with a receiver for refrigerant. Using the receiver, refrigerant can be added to or removed from the refrigeration circuit. This allows for the effects of overfilling or underfilling of the system to be examined.

Temperature and pressure in the refrigeration circuit and the electrical power consumption of the compressor are recorded by sensors. The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included. The refrigerant mass flow rate is calculated in the software from the recorded measured values.

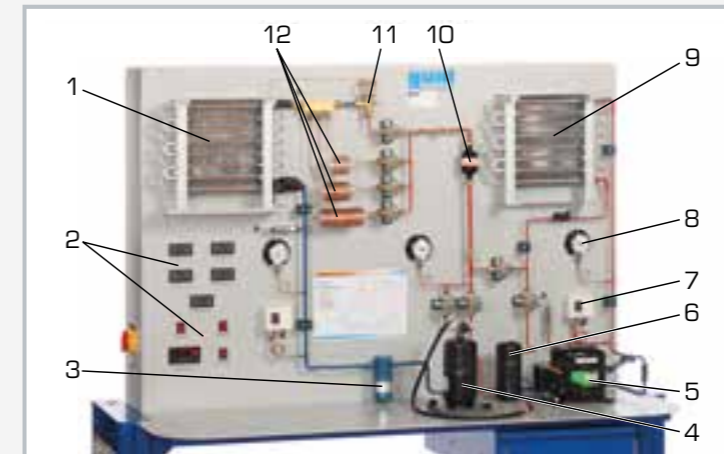
Parameter changes in the refrigeration circuit can be viewed dynamically in the software's log p-h diagram.

#### Learning objectives/experiments

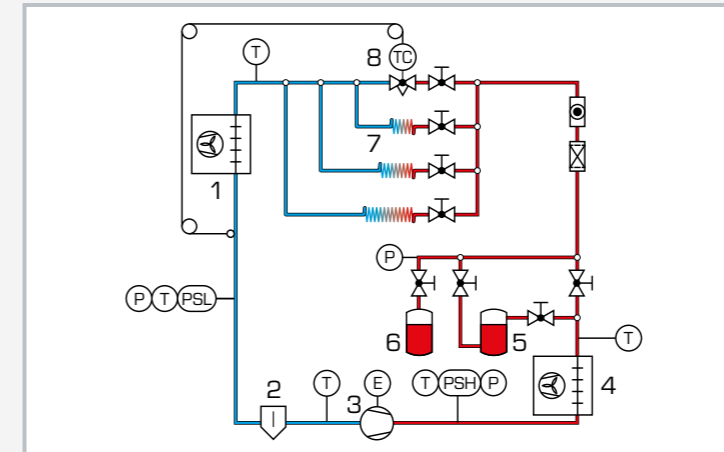
- function and operational behaviour of the refrigeration circuit components
- operation with expansion valve or with capillary tubes of different lengths
- underfilling or overfilling with refrigerant
- thermodynamic cycle in the log p-h diagram
- from the log p-h diagram and in comparison with the measured values
  - ▶ determination of the refrigeration capacity
  - ▶ determination of the coefficient of performance
  - ▶ determination of the efficiency of the compressor

## ET 411C

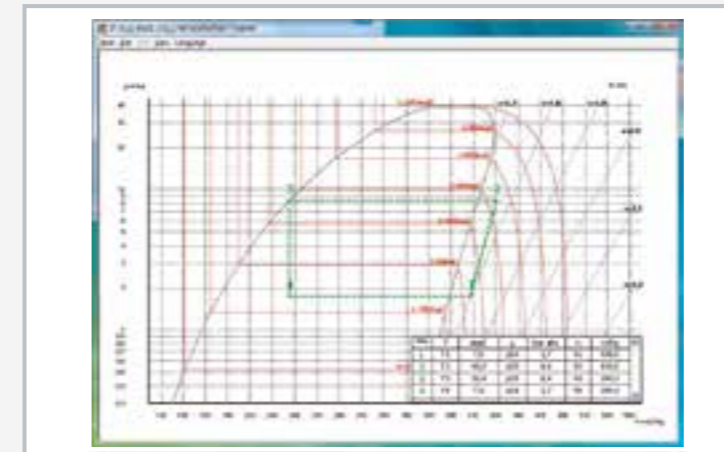
### Compression refrigeration system



1 evaporator, 2 displays and controls, 3 liquid separator, 4 reservoir, 5 compressor, 6 receiver, 7 compressor pressure switch, 8 manometer, 9 condenser, 10 filter/drier, 11 expansion valve, 12 capillary tube



1 evaporator, 2 liquid separator, 3 compressor, 4 condenser, 5 receiver, 6 reservoir, 7 capillary tube, 8 expansion valve; T temperature, P pressure, E power consumption, PSH, PSL pressure switch



Software screenshot: log p-h diagram

#### Specification

- [1] investigation of a refrigeration system with different expansion elements
- [2] refrigeration circuit consisting of a hermetic compressor, condenser, evaporator and expansion element
- [3] transparent finned tube heat exchangers as condenser and evaporator to observe the phase transitions of the refrigerant
- [4] expansion valve and capillary tubes of different lengths as expansion elements
- [5] receiver for underfilling/overfilling the system with refrigerant
- [6] sensors record pressure and temperature
- [7] refrigerant mass flow rate calculated in the software from recorded measured values
- [8] compressor equipped with two pressure switches
- [9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
- [10] refrigerant R513A, GWP: 631

#### Technical data

##### Compressor

- power consumption: 288W at 7,2°/54,4°C
- refrigeration capacity: 463W at 7,2/54,4°C

##### Condenser and evaporator with fan

- max. volumetric air flow rate condenser: 300m<sup>3</sup>/h
- max. volumetric air flow rate evaporator: 180m<sup>3</sup>/h

Capillary tubes: 1,5m, 3m, 6m  
Receiver for refrigerant: 1,3L

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 2,5kg
- CO<sub>2</sub>-equivalent: 1,6t

##### Measuring ranges

- pressure: -1...9bar / -1...24bar
- temperature: 4x -40...150°C, 1x -100...100°C
- flow rate: 2...19kg/h (refrigerant)
- power consumption: 0...1000W

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase  
120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1740x800x1780mm  
Weight: approx. 190kg

#### Required for operation

PC with Windows recommended

#### Scope of delivery

- 1 trainer
- 1 GUNT software CD + USB cable
- 1 set of instructional material

## ET 350

### Changes of state in the refrigeration circuit



#### Description

- refrigeration circuit demonstrated clearly
- transparent components offer insights into the changes of state
- energetic analyses of the refrigeration cycle
- value of Global Warming Potential GWP=1

In a compression refrigeration system a refrigerant flows through the refrigeration circuit and is subject to different changes of state. Here, the physical effect is used that during the transition of the refrigerant from a liquid to a gaseous state energy is required which is removed from the environment (evaporation enthalpy).

The experimental unit ET 350 represents a typical refrigeration circuit consisting of a hermetic piston compressor, condenser, expansion valve and evaporator. The evaporator and condenser are transparent to provide good monitoring of the phase transition process during evaporation and condensation. The operation of the float valve as expansion valve is also easy to observe. Before the entry into the evaporator the aggregate state of the refrigerant can be monitored at a sight glass. A water circuit cools the condenser or supplies the cooling load for the evaporator.

Cold and hot water and refrigerant flows are adjustable. The low pressure level of the refrigerant used permits the use of an evaporator and condenser out of glass.

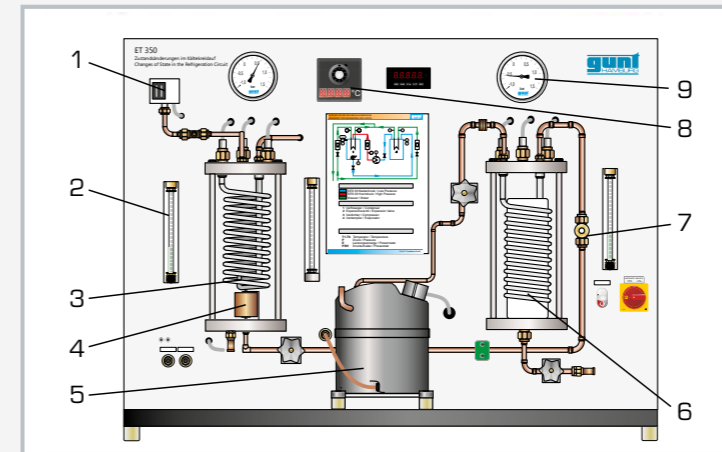
Temperatures and pressures are recorded and displayed. The key points of the cyclic process can be read and entered into a log p-h diagram. The power of the compressor and flow rates of the water flows and the refrigerant are also indicated.

#### Learning objectives/experiments

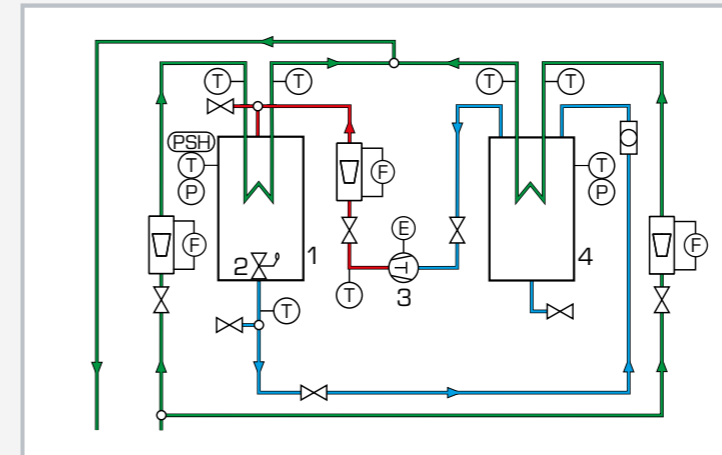
- design and operation of a compression refrigeration system
- observe the evaporation and condensation of the refrigerant
- represent and understand the refrigeration cycle in the log p-h diagram
- energy balances
- calculation of the coefficient of performance

## ET 350

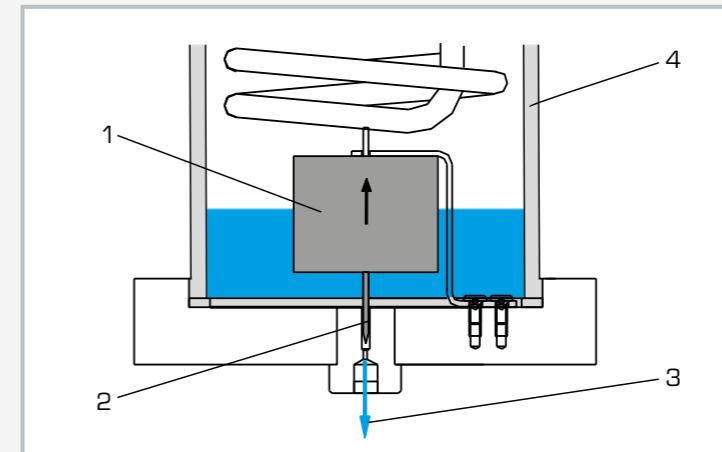
### Changes of state in the refrigeration circuit



1 pressure switch, 2 flow meter, 3 condenser, 4 expansion valve, 5 compressor, 6 evaporator, 7 sight glass, 8 temperature display, 9 manometer



1 condenser, 2 expansion valve, 3 compressor, 4 evaporator; T temperature, P pressure, E electrical power, F flow rate, PSH pressure switch; blue: low pressure, red: high pressure, green: water



Expansion valve in the shape of a float valve: 1 float lifts the needle from the valve seat, 2 needle, 3 refrigerant escapes, 4 tank

#### Specification

- [1] demonstration of the processes in a refrigeration circuit
- [2] for better process monitoring the evaporator and condenser are of transparent design
- [3] evaporator and condenser with pipe coil
- [4] expansion valve in the shape of a float valve
- [5] pressure switch to protect the compressor
- [6] temperature sensor, power meter, manometer in the refrigeration circuit, flow meter for hot and cold water and refrigerant
- [7] safety valves at the evaporator and condenser
- [8] refrigerant R1233zd, GWP: 1

#### Technical data

Hermetic piston compressor  
 ■ capacity: 18,3cm<sup>3</sup>

Evaporator capacity: approx. 2800mL  
 Condenser capacity: approx. 2800mL

Refrigerant  
 ■ R1233zd  
 ■ GWP: 1  
 ■ filling volume: 1,2kg  
 ■ CO<sub>2</sub>-equivalent: 0t

Measuring ranges  
 ■ temperature: 8x -20...200°C  
 ■ pressure: 2x -1...1,5bar  
 ■ flow rate:  
 ▶ 2x 0...48L/h (water)  
 ▶ 0...700L/h (refrigerant)  
 ■ power: 0...1200W

230V, 50Hz, 1 phase  
 230V, 60Hz, 1 phase  
 120V, 60Hz, 1 phase  
 UL/CSA optional  
 LxWxH: 1200x500x900mm  
 Weight: approx. 110kg

#### Required for operation

water connection, drain

#### Scope of delivery

- 1 experimental unit
- 1 set of hoses
- 1 set of instructional material



## ET 400

### Refrigeration circuit with variable load



#### Learning objectives/experiments

- design and components of a refrigeration system
  - ▶ compressor
  - ▶ condenser
  - ▶ thermostatic expansion valve
  - ▶ evaporator
  - ▶ pressure switch
- representation of the thermodynamic cycle in the log p-h diagram
- determination of important characteristic variables
  - ▶ coefficient of performance
  - ▶ refrigeration capacity
  - ▶ compressor work
- operating behaviour under load

#### Description

- refrigeration circuit with water circuit as load
- defined cooling load via controlled water temperature
- display of all relevant values
- dynamic recording of the refrigerant mass flow rate

ET 400 examines a refrigeration circuit under an adjustable load. The refrigeration circuit consists of a compressor, a condenser with fan, a thermostatic expansion valve and a coaxial coil heat exchanger as evaporator. A water circuit serves as load, consisting of a tank with a heater and a pump. The temperature in the tank is adjusted at a controller.

The purpose of this refrigeration circuit is the production of cold water. The water flows through the jacket of the coaxial coil heat exchanger, transfers heat to the refrigerant and thereby cools down.

All relevant measured values are recorded by sensors. The simultaneous transmission of the measured values to a data recording software enables easy analysis and the representation of the process in the log p-h diagram. The refrigerant mass flow rate is calculated in the software from the recorded measured values. The software also displays the key characteristic variables of the process, such as the compressor pressure ratio and the coefficient of performance.

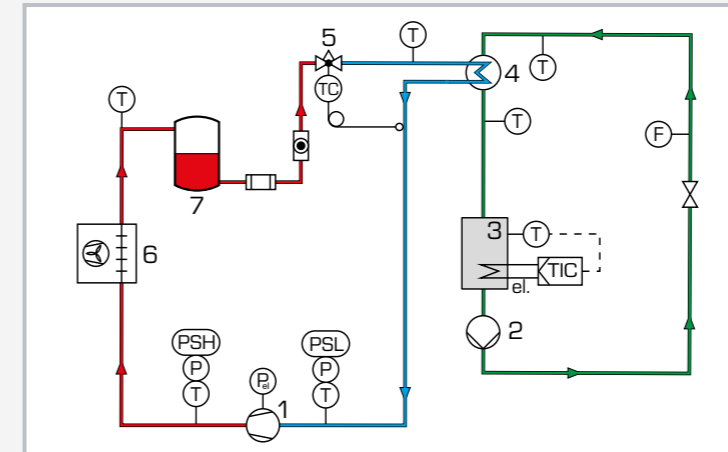
The clearly arranged components aid understanding.

## ET 400

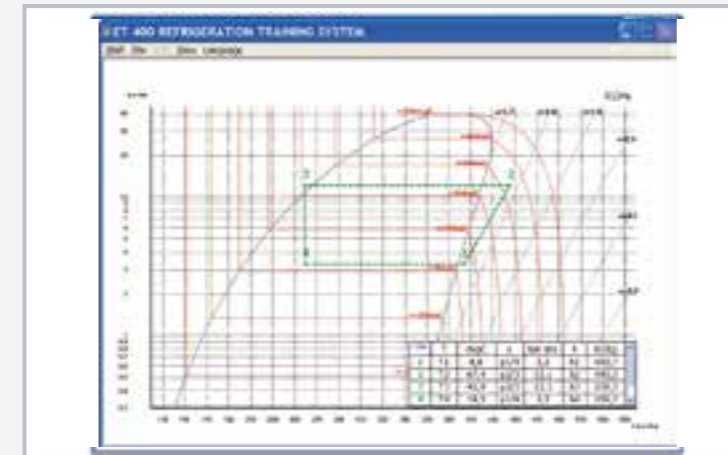
### Refrigeration circuit with variable load



1 condenser with fan, 2 receiver, 3 high pressure switch, 4 displays and controls, 5 heater controller, 6 compressor, 7 pump, 8 warm water tank with heater, 9 filter/drier, 10 sight glass, 11 expansion valve, 12 evaporator



1 compressor, 2 pump, 3 warm water tank with heater, 4 evaporator, 5 expansion valve, 6 condenser, 7 receiver; T temperature, P pressure, F flow rate, TIC temperature controller, PSH, PSL pressure switch; blue-red: refrigeration circuit, green: water circuit



Software screenshot: log p-h diagram

#### Specification

- [1] investigation of a refrigeration circuit with water circuit as load
- [2] refrigeration circuit with compressor, condenser with fan, thermostatic expansion valve and coaxial coil heat exchanger as evaporator
- [3] water circuit with pump, tank with heater as cooling load at the evaporator
- [4] heater with controller to adjust the tank temperature
- [5] refrigerant mass flow rate calculated in the software from recorded measured values
- [6] recording of all relevant measured values
- [7] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
- [8] refrigerant R513A, GWP: 631

#### Technical data

- Compressor
- refrigeration capacity: approx. 479W at 7,2/54,4°C
  - power consumption: 168W at 7,2/54,4°C
- Evaporator
- refrigerant volume: 0,4L
  - water volume: 0,8L
- Condenser
- transfer area: approx. 1,25m<sup>2</sup>
  - fan power consumption: 4x 12W
- Pump
- max. flow rate: 1,9m<sup>3</sup>/h
  - max. head: 1,4m
- Tank
- volume: approx. 4,5L
  - heater: approx. 450W
- Refrigerant: R513A, GWP: 631
- filling volume: 800g
  - CO<sub>2</sub>-equivalent: 0,5t

#### Measuring ranges

- pressure: 2x -1...15bar
- power: 0...750W
- temperature: 6x 0...100°C
- flow rate: 0,05...1,8L/min (water)
- flow rate: 0...17kg/h (refrigerant)

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase  
120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1620x790x1910mm  
Weight: approx. 192kg

#### Required for operation

PC with Windows recommended

#### Scope of delivery

- 1 trainer
- 1 GUNT software CD + USB cable
- 1 set of instructional material



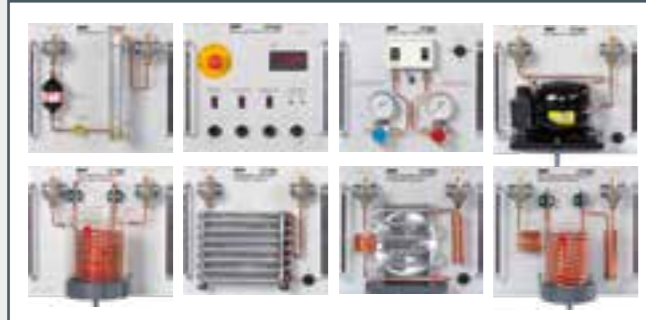
## ET 900 – ET 915 Training systems for experiments in the field of refrigeration

The systems deal with simply designed refrigeration circuits

- **ET 900** simple and clear basic experiments related to refrigeration systems and heat pumps
- **ET 915** basic experiments with software support; evaporator connected in series and parallel
- **ET 910** planning, design and testing of different refrigeration systems, primary and secondary controllers in the refrigeration circuit

### ET 900 Introduction to refrigeration with simple and clear experiments

- interchangeable components mounted on plates
- frame to arrange the components
- filling and evacuation of refrigerant



Components arranged in a frame and connected with refrigerant hoses

### ET 910 Base unit with components ET 910.10 and ET 910.11 for basic experiments and advanced experiments

- real components for the set-up of refrigeration circuits
- comparison of different capacity controllers
- assembly and maintenance of refrigeration systems



ET 910.10 Components for basic experiments



ET 910.11 Components for advanced experiments

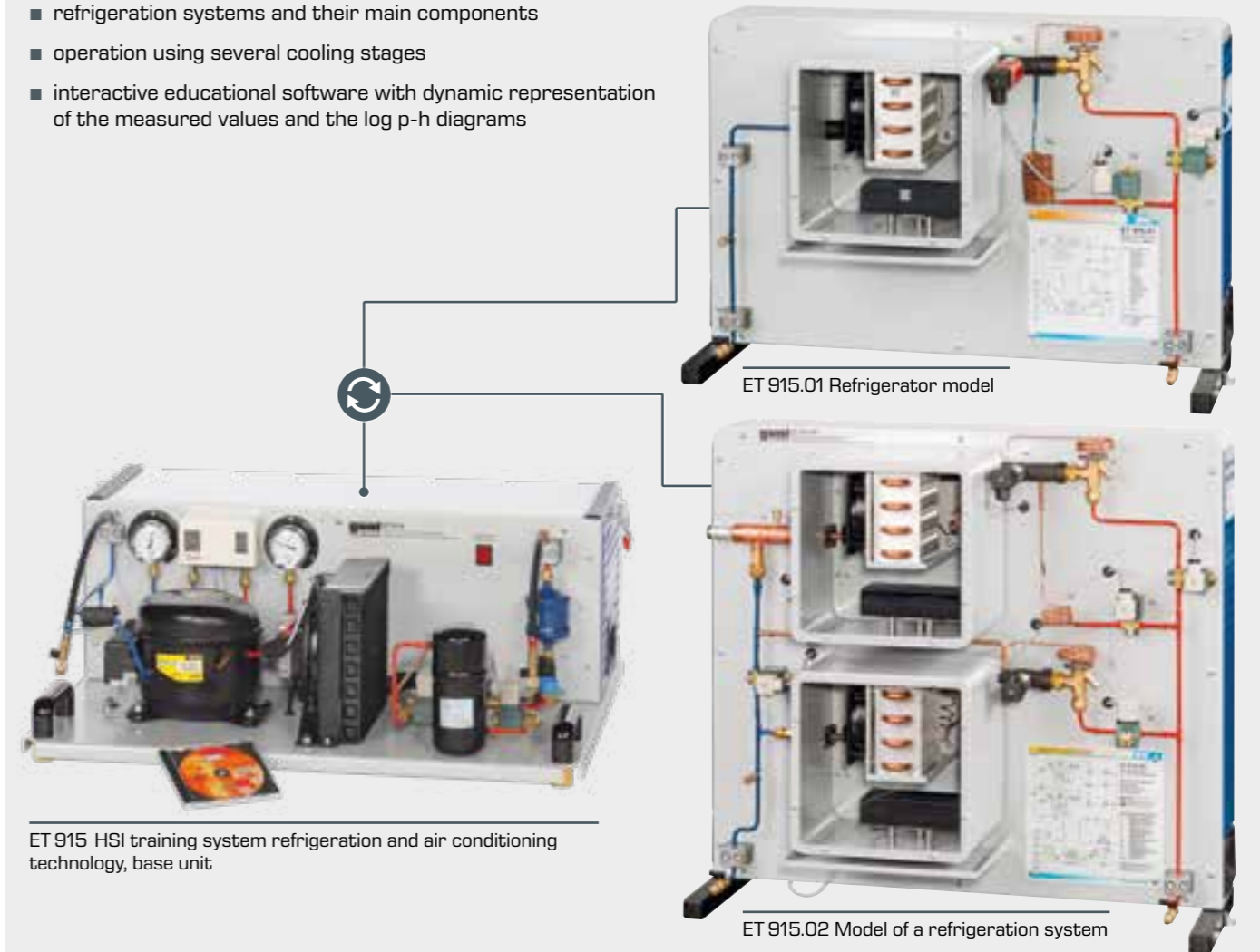


Experimental set-up

ET 910 with components from ET 910.10, laboratory workplace ET 910.05 and accessory set ET 910.12

### ET 915 HSI training system with the models refrigerator ET 915.01 and refrigeration system ET 915.02 explains the operation of refrigeration systems

- refrigeration systems and their main components
- operation using several cooling stages
- interactive educational software with dynamic representation of the measured values and the log p-h diagrams



ET 915.01 Refrigerator model

ET 915.02 Model of a refrigeration system

ET 915 HSI training system refrigeration and air conditioning technology, base unit

### Interactive educational software

- guides step by step through the basic learning objectives
- tracking of learning steps
- enables the control of the components and simulation of faults



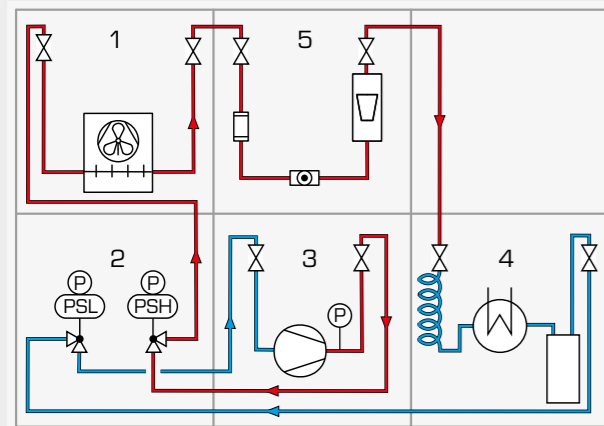


# ET 900 Introduction to refrigeration

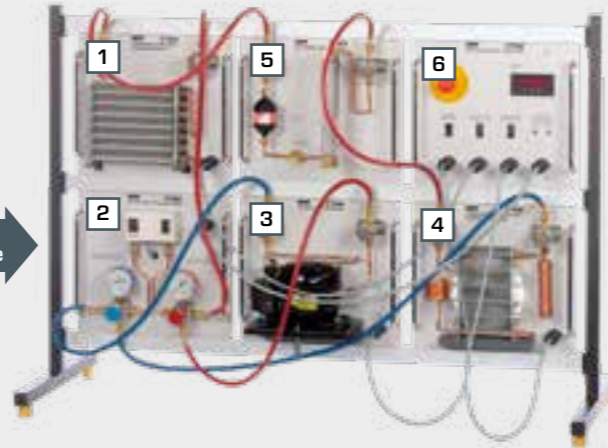
## Set-up of simple refrigeration circuits

With the training system ET 900 it is possible to familiarise yourself with the handling and principle of function of refrigeration systems. The training system includes all necessary components for operation, such as compressor, evaporator,

condenser and expansion element. Additional components, such as pressure switches, flow meter, sight glass and filter/drier complement the learning objectives.



on paper  
in practice



Refrigeration circuit with air-cooled condenser and air cooling evaporator

Process schematic: 1 condenser, 2 pressure switch, 3 compressor, 4 evaporator, 5 sight glass with filter/drier and flow meter, 6 display and control panel



Refrigeration circuit with water-cooled condenser and water cooling evaporator

1 water-cooled condenser, 2 pressure switch, 3 compressor, 4 water cooling evaporator with capillary tube, 5 sight glass with filter/drier and flow meter, 6 display and control panel

## Interchangeable modules

The interchangeable modules are mounted ready for installation on plates. The modules condenser and evaporator are available

in two designs each. This permits different combinations. A set of hoses and cables is included in the scope of delivery.



Sight glass with filter/drier and flow meter



Display and control panel



Pressure switch



Compressor



Water-cooled condenser



Air-cooled condenser



Air cooling evaporator with capillary tube (air cooler)



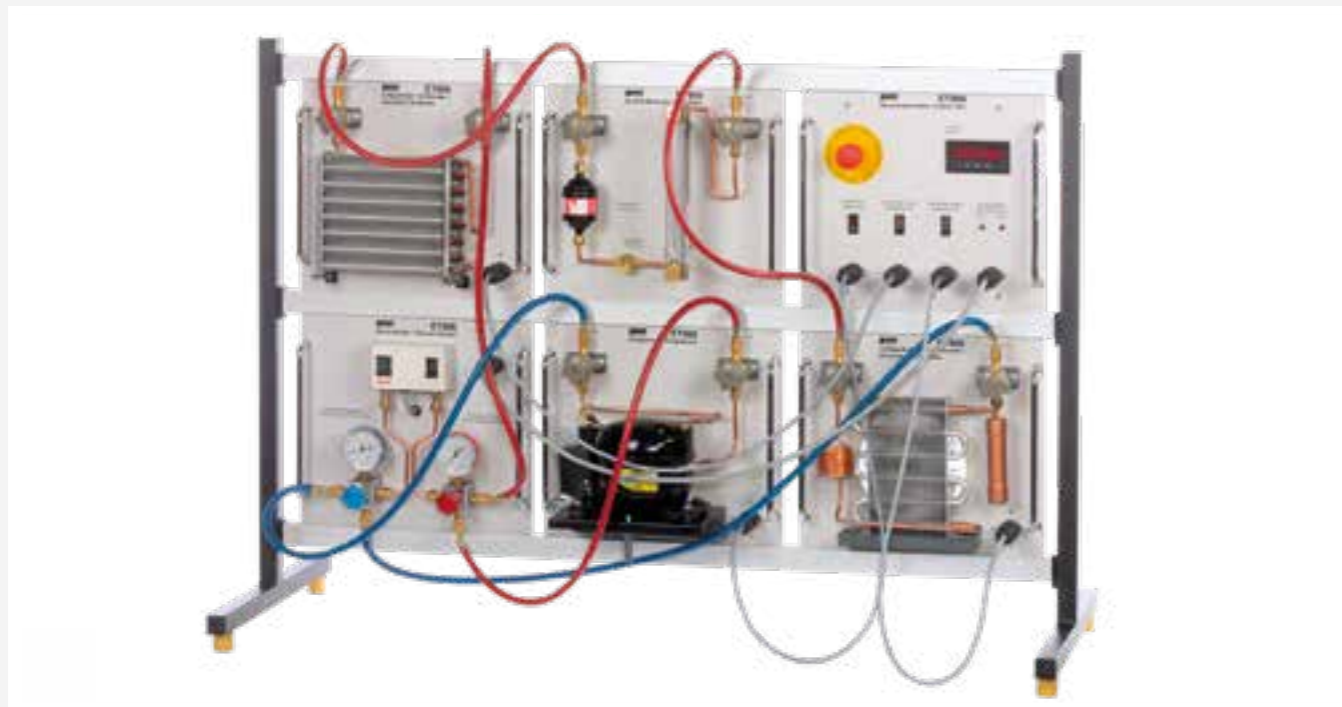
Water cooling evaporator with capillary tube (water cooler)

## Learning objectives

- stationary operation: air-cooled evaporator with an air cooling evaporator
- mobile operation: water-cooled condenser with a water cooling evaporator
- cold water generator: air-cooled condenser with a water cooling evaporator
- heat pump: air cooling evaporator with a water-cooled condenser (water heater)
- draining and filling a refrigeration system
- refrigeration system and main components
- basic principle of a thermodynamic cycle process
- simple energy balances
- fault finding

## ET 900

### Introduction to refrigeration



#### Description

- training system with interchangeable modules
- components mounted on plates
- rapid connection via hoses

With simple and clear experiments this equipment is intended mainly as a basic introduction to refrigeration.

ET 900 enables familiarisation with the operation and handling of a refrigeration system. The experimental unit includes all the necessary components for a fully operational refrigeration circuit, such as compressor, condenser, evaporator and a capillary tube as expansion element. Other components complement the scope of the equipment: display and control panel, pressure switches and pressure display to protect the compressor against excessive pressure and a flow meter and sight glass with filter/drier. Condenser and evaporator are each present twice: as air/refrigerant heat exchanger and as water/refrigerant heat exchanger. This allows for different component combinations.

The components are mounted on plates and form installation-ready modules. 6 of the 8 modules are positioned in the frame at any one time and connected via hoses and supply cables. This allows for the construction of different simple compression refrigeration systems. For filling the system the refrigerant filling and evacuation equipment ET 150.01 is recommended.

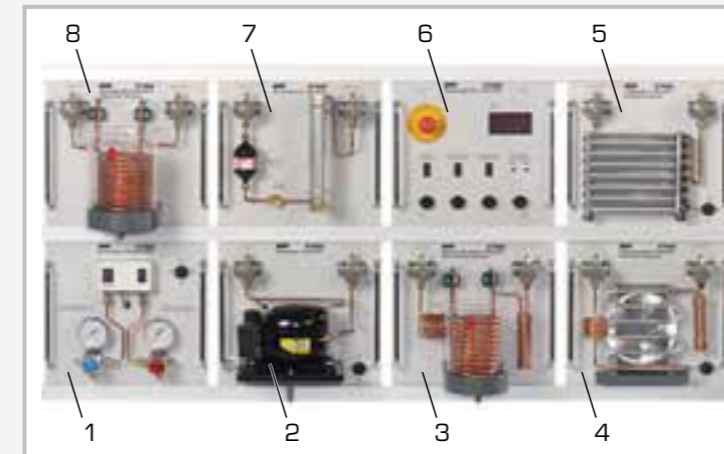
In experiments the processes in the equipment and the changes in the refrigerant state are initially demonstrated. Continued experiments allow the use of the equipment as a refrigeration system and as a heat pump. Pressures, flow rates power consumption of the compressor are displayed as important characteristic variables of refrigeration circuits. The temperature is measured by interlaboratory thermometers.

#### Learning objectives/experiments

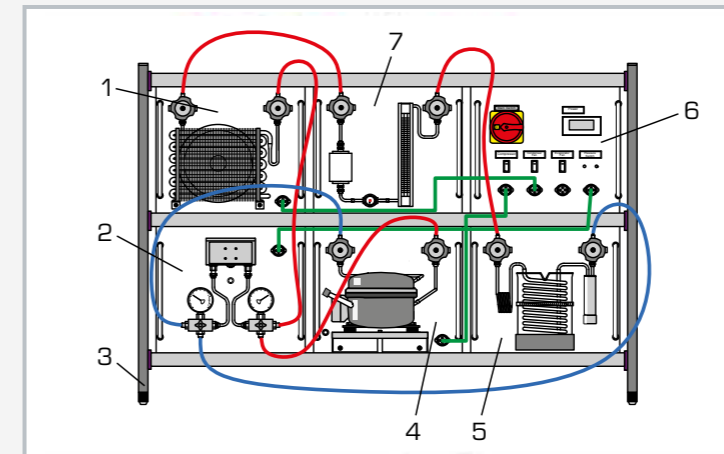
- fundamentals of a simple refrigeration circuit
  - ▶ detection and understanding of the cyclic process
  - ▶ changes of state of the refrigerant
  - ▶ representation the refrigeration circuit in the process schematic
  - ▶ representation of the cyclic process in the log p-h diagram
  - ▶ estimating key figures, refrigeration capacity and heat fluxes
- different operating modes
  - ▶ air cooling
  - ▶ generating cold water
  - ▶ heat pump (generate hot water)
- practical exercises
  - ▶ draining and filling the refrigeration system (with ET 150.01)
  - ▶ fault finding

## ET 900

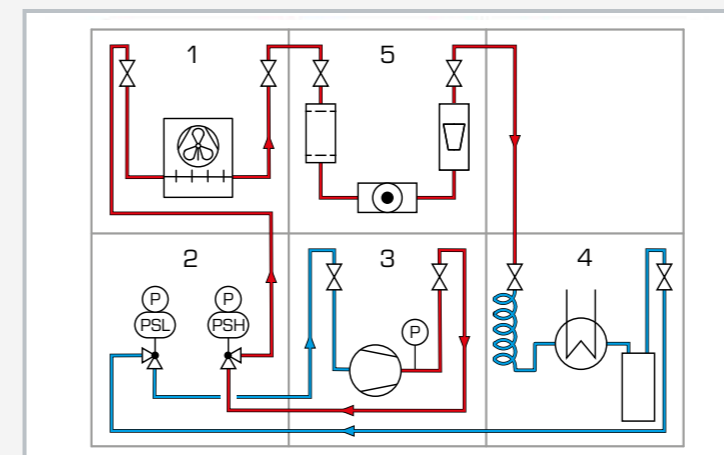
### Introduction to refrigeration



1 pressure switch, 2 compressor, 3 water cooling evaporator, 4 air cooling evaporator, 5 air-cooled condenser, 6 display and control panel, 7 sight glass with filter/drier and flow meter, 8 water-cooled condenser



Refrigeration circuit with air-cooled condenser and water cooling evaporator; 1 condenser, 2 pressure switch, 3 frame, 4 compressor, 5 evaporator, 6 displays and controls, 7 sight glass with filter/drier and flow meter; blue: refrigeration low pressure, red: refrigeration high pressure green: power supply cables



1 condenser, 2 pressure switch, 3 compressor, 4 evaporator, 5 sight glass with filter/drier and flow meter

#### Specification

- [1] setup of simple refrigeration circuits with different components
- [2] 8 self-contained operational modules mounted on a plate each
- [3] light-weight aluminium frame to arrange 6 modules
- [4] evaporator and condenser each available as air/refrigerant heat exchanger (finned tube heat exchanger) and as water/refrigerant heat exchanger (with pipe coil)
- [5] modules fitted with manual valves
- [6] components connected via hoses
- [7] refrigerant R513A, GWP: 631

#### Technical data

Hermetic refrigerant compressor  
 ■ power consumption: 67W at 5/40°C  
 ■ refrigeration capacity: 152W at 5/40°C

#### Tank content

- water tank, evaporator: 2L
- water tank, condenser: 3L

#### Pressure switch activation pressure

- LP: 1bar
- HP: 14bar

#### Manometer

- inlet side (low pressure): 1...10bar
- outlet side (high pressure): 1...30bar

Rotameter: 0...7,4L/h

#### Refrigerant

- R513A
- GWP: 631
- filling volume: 400g
- CO<sub>2</sub>-equivalent: 0,3t

230V, 50Hz, 1 phase  
 230V, 60Hz, 1 phase  
 120V, 60Hz, 1 phase  
 UL/CSA optional  
 LxWxH: 1300x700x900mm  
 WxH: 370x340mm (modules)  
 Weight: approx. 30kg

#### Scope of delivery

- 1 frame
- 8 modules
- 1 set of hoses
- 1 set of cables
- 1 set of instructional material



## ET 910

### Refrigeration training system, base unit



#### Learning objectives/experiments

- in conjunction with ET 910.10, ET 910.11, ET 910.13
- design of compression refrigeration circuit
- draining and filling of refrigeration systems
- operation of refrigeration components
- cyclic process of cold production
- fault finding
- different operating modes of the receiver
  - ▶ with and without receiver
  - ▶ pump-down
  - ▶ filling the refrigeration circuit
- compare different expansion elements
- a structured curriculum and a detailed representation of the range of experiments is available in our product brochure ET 910.

#### Description

- **setup of the most varied refrigeration circuits using modular component kits**
- **clear arrangement of components**

With this training system practical experiments relating to the operation of a refrigeration system can be implemented by dealing with differently configured compression refrigeration circuits. The components used are common in refrigeration and therefore closely related to practice.

The base unit ET 910 includes the main components of a refrigeration circuit: a condensing unit with compressor, condenser and receiver and a refrigeration chamber with integrated evaporator, fan for forced ventilation and an electric defrost heater.

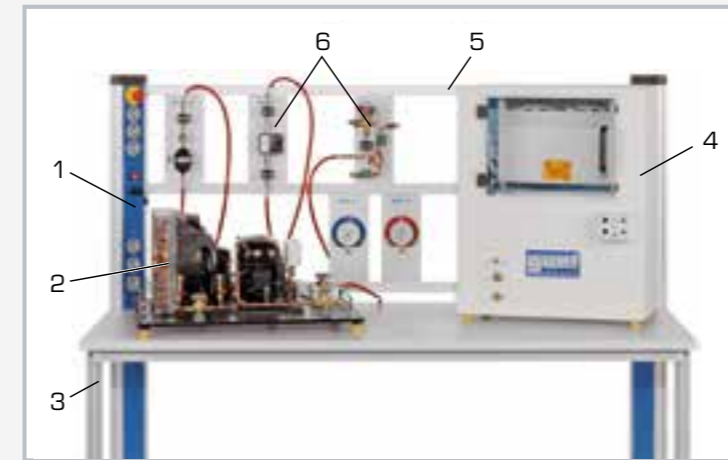
A pressure switch protects the compressor against excessive pressure. The refrigerant flow can be modified via shut-off valves.

Together with the components from ET 910.10, e.g. heat exchanger, flow meter or manometer, simple refrigeration circuits are realised. For continued experiments additional refrigeration components from ET 910.11 are used, e.g. post-injection valve, capacity controller or defrost timer. All components of the training system have ball valves at the connections. Using the required accessory kit ET 910.12 the components are connected into a complete refrigeration system. For the complete experimental setup, ET 910.05, laboratory workplace with frame for mounting the components and power supply, is required. The refrigerant R513A serves as working medium.

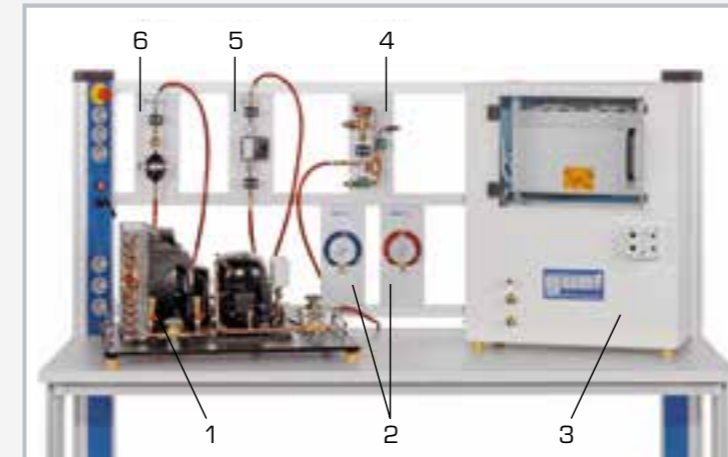
With the service set ET 910.13 additional exercises for the filling and evacuation of refrigeration systems are carried out.

## ET 910

### Refrigeration training system, base unit



1 power supply (ET 910.05), 2 condensing unit, 3 table (ET 910.05), 4 refrigeration chamber, 5 frame (ET 910.05), 6 components from ET 910.10



1 condensing unit with compressor, condenser and receiver, 2 manometer (ET 910.10), 3 refrigeration chamber with evaporator and electric defrost heater, 4 expansion valve (ET 910.10), 5 flow meter (ET 910.10), 6 sight glass with filter/drier (ET 910.10)



The illustration shows the accessory set ET 910.12

#### Specification

- [1] base unit for the refrigeration training system
- [2] extension with components from ET 910.10 for basic experiments using simple refrigeration circuits
- [3] extension with components from ET 910.11 for advanced experiments in refrigeration systems
- [4] condensing unit, consisting of hermetic compressor, condenser, receiver, pressure switches and shut-off valves
- [5] insulated refrigeration chamber with integrated evaporator, electric defrost heater and condensate drip tray
- [6] refrigeration chamber, condensing unit and power supply equipped with shock-proof lab jacks
- [7] refrigerant R513A, GWP: 631

#### Technical data

##### Air-cooled condensing unit

- refrigeration capacity: 1220W at 5/40°C
- max. volumetric air flow rate: 850m<sup>3</sup>/h
- receiver: 1,4L

##### Evaporator with fan

- cooling surface: 1,81m<sup>2</sup>
- max. volumetric air flow rate: 140m<sup>3</sup>/h
- electric defrost heater: 50W/m

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 1kg
- CO<sub>2</sub>-equivalent: 0,6t

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase

120V, 60Hz, 1 phase

UL/CSA optional

LxWxH: 600x300x700mm (refrigeration chamber)

LxWxH: 670x550x380mm (condensing unit)

Weight: approx. 45kg

#### Scope of delivery

- 1 condensing unit
- 1 refrigeration chamber
- 1 set of instructional material

**ET 910.10**

## Refrigeration components for basic experiments



The illustration shows the components in the frame of ET 910.05.

**Description**

- setup of simple refrigeration circuits
- practice-oriented basic experiments using real components from within the industry

ET 910.10 enables in conjunction with ET 910, ET 910.05 and the accessory set ET 910.12 the design and performance of various basic experiments related to refrigeration.

Commercial components are used in practical experiments. These components are mounted on plates ready to be connected and are arranged clearly in the frame of ET 910.05.

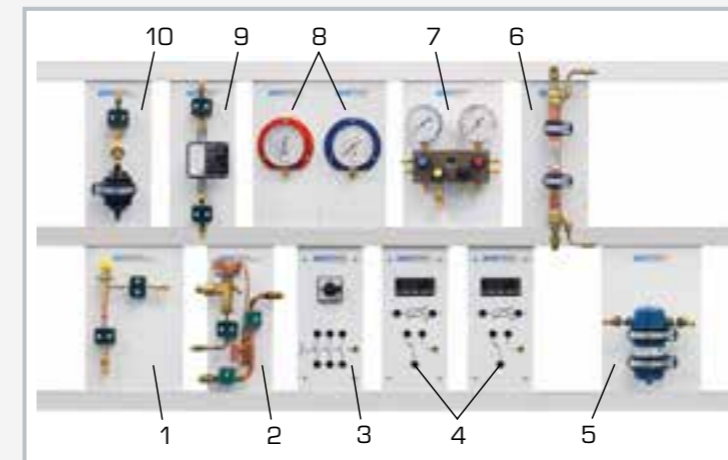
The set includes simple refrigeration components, such as expansion elements and filters, as well as electrical components, e.g. switches and thermostat. The superheater included in the set is a heat exchanger ensuring the complete evaporation of the refrigerant before entering the compressor whilst the liquid refrigerant is supercooled upstream of the expansion element. The control behaviour of the expansion element is monitored at the flow meter. Manometers provide an insight to the pressure ratios in the refrigeration circuit. Via pressure and temperature measurements the change of state of the refrigerant can be tracked and entered into the log p-h diagram. The temperature is measured by interlaboratory thermometers.

**Learning objectives/experiments**

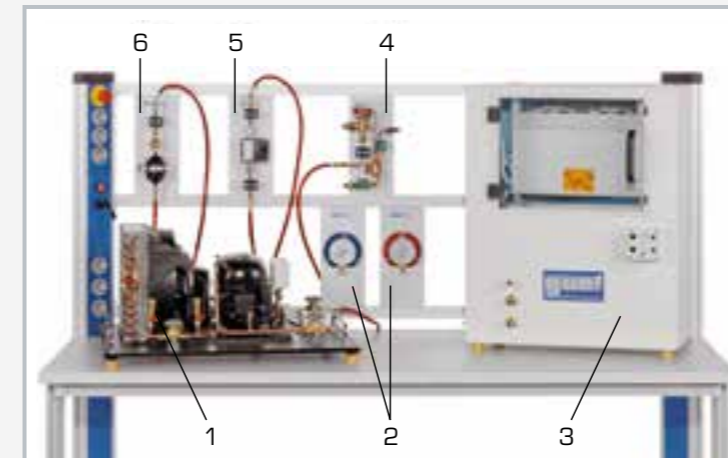
- design of different simple refrigeration circuits
- design, operation and adjustment of components
  - ▶ sight glass with filter/drier
  - ▶ flow meter
  - ▶ delivery and intake manometer
  - ▶ assembly aid
  - ▶ superheater
  - ▶ pressure-controlled expansion valve
  - ▶ thermostatic expansion valve
  - ▶ 3-pin circuit breaker
  - ▶ electric two-point thermostat with switch hysteresis
  - ▶ liquid separator
- read and understand technical drawings and operating instructions
- fault finding

**ET 910.10**

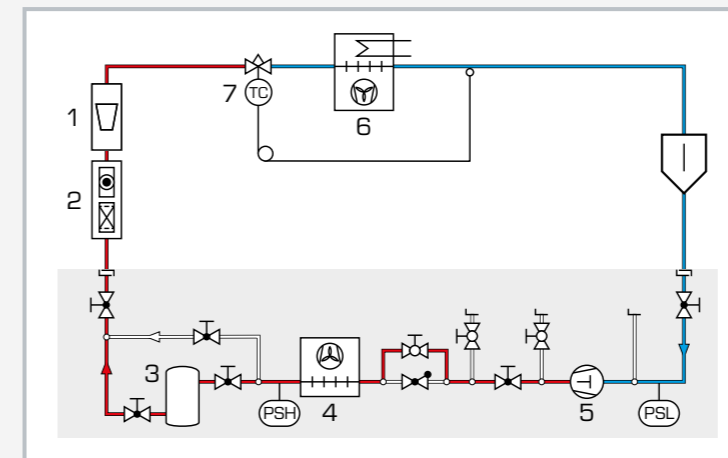
## Refrigeration components for basic experiments



1 pressure-controlled expansion valve, 2 thermostatic expansion valve, 3 circuit breaker, 4 electric thermostat, 5 liquid separator, 6 heat exchanger, 7 assembly aid, 8 manometer delivery side/intake side, 9 flow meter, 10 sight glass with filter/drier



1 condensing unit with condenser and receiver, 2 manometer (ET 910.10), 3 refrigeration chamber with evaporator and electric defrost heater, 4 expansion valve (ET 910.10), 5 flow meter (ET 910.10), 6 sight glass with filter/drier (ET 910.10)



1 flow meter, 2 sight glass with filter/drier, 3 receiver, 4 condenser, 5 compressor, 6 evaporator, 7 thermostatic expansion valve; PSL, PSH pressure switch; red: high pressure, blue: low pressure

**Specification**

- [1] components for the setup of simple refrigeration circuits in conjunction with ET 910
- [2] heat exchanger as superheater
- [3] 3-pin circuit breaker
- [4] assembly aid: 4-port directional valve with sight glass
- [5] sight glass with humidity indicator
- [6] pressure-controlled expansion valve
- [7] thermostatic expansion valve
- [8] 2 thermostats with different temperature ranges
- [9] components mounted on plates ready to connect
- [10] abrasion-proof symbols and labels on plates

**Technical data**

Pressure-controlled expansion valve

- pressure range: 1...7bar

Thermostatic expansion valve

- evaporation temperature: -45°...20°C

Circuit breaker, 3-pin: 3kW

2 electric thermostats

- -5...25°C
- -25...5°C

Heat exchanger

- capacity: approx. 2.5kW at -10°C evaporation temperature

Liquid separator: 0,3L, max. 28bar

Measuring ranges

- pressure: -1...9bar, -1...24bar
- flow rate: 3...41kg/h

Plate height: 297mm

Weight: approx. 20kg

**Scope of delivery**

- 12 components on plates:
  - 1 pressure-controlled expansion valve
  - 1 thermostatic expansion valve
  - 1 circuit breaker
  - 2 electric thermostats
  - 1 heat exchanger
  - 1 assembly aid
  - 2 manometers
  - 1 flow meter
  - 1 sight glass with filter/drier
  - 1 liquid separator



## ET 910.11

### Refrigeration components for advanced experiments



The illustration shows the components in the frame of ET 910.05

#### Description

- setup of complex refrigeration circuits
- sophisticated components for advanced experiments

ET 910.11 enables in conjunction with ET 910, ET 910.10, ET 910.05 and the accessory set ET 910.12 the performance of advanced experiments related to refrigeration.

Commercial components are used in practical experiments. These components are mounted on plates ready to be connected and are arranged clearly in the frame of ET 910.05.

The set includes complex refrigeration components, such as capacity controller, intake pressure controller, defrost timer, four-way reversing valve and refrigeration controller. The four-way reversing valve, for example, is used to reverse the circuit. This allows for the defrosting of an iced-up evaporator by operating it temporarily as condenser. Manometers provide an insight to the pressure ratios in the refrigeration circuit.

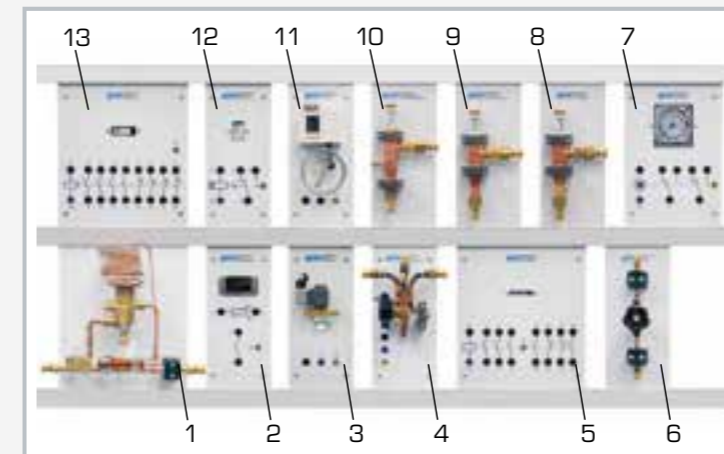
Via pressure and temperature measurements the changes of state of the refrigerant can be tracked and entered into the log p-h diagram. The temperature is measured by interlaboratory thermometers.

#### Learning objectives/experiments

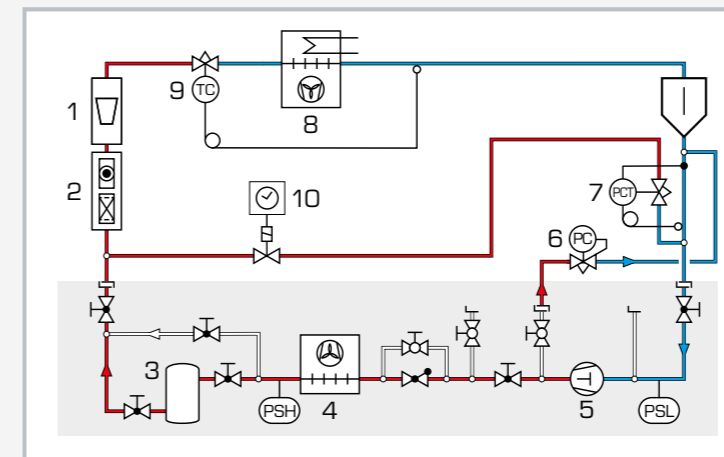
- setup of different refrigeration circuits
- design, operation and adjustment of components
  - ▶ evaporation pressure, intake pressure, capacity and refrigeration controllers
  - ▶ electric thermostat
  - ▶ manual valve as expansion element
  - ▶ post-injection valve
  - ▶ solenoid valve with coil
  - ▶ four-way reversing valve
  - ▶ power and auxiliary contactor
  - ▶ time relay
  - ▶ defrost timer
  - ▶ hot gas defrosting
- read and understand technical drawings and operating instructions
- fault finding

## ET 910.11

### Refrigeration components for advanced experiments



1 post-injection valve, 2 refrigeration controller, 3 solenoid valve, 4 four-way reversing valve, 5 main contactor, 6 valve, 7 defrost timer, 8 capacity controller, 9 intake pressure controller, 10 evaporation pressure controller, 11 thermostat, 12 time relay, 13 auxiliary contactor



Capacity control with post-injection: 1 flow meter, 2 sight glass with filter/drier, 3 circuit breaker, 4 post-injection valve, 5 condensing unit (ET 910), 6 manometer, 7 capacity controller, 8 valve, 9 expansion valve, 10 refrigeration chamber (ET 910)

#### Specification

- [1] components for the setup of complex refrigeration circuits in conjunction with ET 910 and ET 910.10
- [2] post-injection valve
- [3] refrigeration controller with PTC sensor
- [4] defrost timer, timing interval 30min
- [5] time relay
- [6] four-way reversing valve, solenoid valves
- [7] electric thermostat as temperature controller
- [8] power and auxiliary contactor

#### Technical data

Thermostat: -5...35°C

Refrigeration controller: -40...110°C

Post-injection valve: -45...35°C

Time relay

■ response delay: 0,05s...100h

Setting ranges

■ evaporation pressure controller: 0...5,5bar

■ intake pressure controller: 0,2...6bar

■ capacity controller: 0,2...6bar

Plate height: 297mm

Weight: approx. 25kg

#### Scope of delivery

- 14 components on plates:
  - 1 manual valve
  - 1 thermostat
  - 1 evaporation pressure controller
  - 1 intake pressure controller
  - 1 capacity controller
  - 1 four-way reversing valve
  - 1 post-injection valve
  - 1 refrigeration controller
  - 2 solenoid valves
  - 1 time relay
  - 1 power contactor
  - 1 auxiliary contactor
  - 1 defrost timer

## ET 910.05

### Refrigeration laboratory workplace



The illustration shows the table with supply strip and frame. Mobile cabinet and movable base frame not shown.

#### Specification

- [1] laboratory workplace for the modular training system refrigeration
- [2] table with supply strip
- [3] mobile cabinet with drawers
- [4] movable base frame with 4 steerable castors, brakeable

#### Technical data

##### Supply strip

- fault current protection switch: 25A
- motor protection switch: 10...16A
- key switch, sockets, lab jacks, emergency switch, main switch

230V, 50Hz, 1 phase  
 230V, 60Hz, 1 phase  
 120V, 60Hz, 1 phase  
 UL/CSA optional  
 LxWxH: 1800x810x1510mm (table)  
 LxWxH: 420x600x625mm (mobile cabinet)  
 LxWxH: 600x900x780mm (base frame)  
 Weight: approx. 80kg

#### Scope of delivery

- 1 table
- 1 mobile cabinet
- 1 movable base frame for the condensing unit

#### Description

##### ■ laboratory workplace with supply strip

This laboratory workplace enables in conjunction with the base unit ET 910 and the extension sets ET 910.10 and ET 910.11 and the accessory set ET 910.12 the setup of a complete trainer.

The laboratory workplace consists of a table with supply strip, a frame to arrange the components, a mobile cabinet and a movable base frame for the condensing unit.



## ET 910

### Training in refrigeration

Vocational training in refrigeration:  
 planning, design and testing of different refrigeration system configurations

The ideal training system for practice-oriented teaching



## Instructional design and subject areas

The modular training system can be used to construct various refrigerant circuits thanks to a comprehensive selection of refrigeration components. Refrigeration solutions and real-world problems are worked out didactically in experiments.

The training system offers practical experiments to accompany the areas of learning relevant to training as a mechatronics technician for refrigeration. The scope of experiments can be extended by using temperature measurements. Consequently, the device offers various qualitative experiments and can therefore also be used to great success in university level education for practical course experiments in the field of energy engineering/refrigeration technology.

By combining the components, it is possible to simulate many industrial refrigeration circuits. By incorporating bypasses, the system behaviour with or without the use of a specific component can be demonstrated directly. The result is lasting understanding of how the components work together.

The training system is ideal for independent group work with two to three trainees or students. In contrast to experimental setups with fixed piping, changes in the refrigeration circuit can

be made quickly and easily and their effects experienced directly. This immediate feedback ensures lasting learning success. By independently converting the system diagram into a real, functioning system, the trainees/students quickly achieve success.

The ET 910 training system uses standard industrial components from refrigeration technology. This ensures the necessary practical relevance making knowledge easier to recall. When selecting the components, care has been taken to ensure that as many training topics as possible can be covered.

Module plates mean the experiments can be designed flexibly and clearly. Using hoses that can be shut off minimises refrigerant losses when modifying experiments.

Even today, ET 910 alumni tell us that they apply the knowledge they learned – even many years later – when it comes to understanding complex systems.

### Covering subject areas in the training as a mechatronics engineer for refrigeration by experimental work with the training system ET 910

Refrigeration	Air conditioning technology	Electrical engineering in refrigeration and air conditioning technology
Functional interrelationships in the refrigeration circuit	Investigation of the states of the air	Principles of electrical engineering
Production of mechanical subsystems	Basic interrelationships in ventilation and room air conditioning	Consumers of single phase alternating current
Thermodynamics, log p-h diagram	Construction elements and function of the air conditioning system	Protection against electrical hazards
Refrigerants and lubrication oils	Air conditioning, h-x diagram	Simple refrigeration controls
Primary and secondary controllers	Air circuit in the duct system	Consumers of three phase alternating current
Heat exchangers	Fire protection measures	Electrical drives and fault finding
Compressors	Energy saving	Control of refrigeration systems
Piping		Building automation
Troubleshooting, maintenance and disposal		

■ applications for the ET 910 training system

#### Experimental range

##### Different expansion elements – function and properties

- manually operated expansion valve
- pressure-controlled expansion valve
- capillary tube
- thermostatic expansion valve with internal pressure compensation

##### Different temperature controllers – function and properties

- control of the evaporation temperature via evaporation pressure controller KVP (normal cooling stage)
- control of the cold storage temperature via thermostatic switch with compressor control
- control of the cold storage temperature via electric temperature controller with compressor control

##### Different capacity controllers – function and properties

- capacity controller KVC
- capacity controller KVC with post-injection
- electrical refrigeration controller with solenoid valve and pump-down control

##### Different defrost circuits in the freezing stage – function and properties

- shut-down of the compressor via defrost timer
- shut-down of the compressor via evaporator thermostat
- electric defrost heater via defrost timer
- hot gas defrosting via reversing valve and defrost timer

##### Different extensions of the refrigeration circuit – function and properties

- influence of a heat exchanger - supercooling and superheating
- pressure-compensated compressor start via time-delayed bypass valve
- intake pressure control via start-up controller KVL
- liquid separator in the intake pipe
- operation with and without collector

##### Different extensions of the refrigeration circuit – troubleshooting and maintenance

- opening of the refrigeration circuit with refrigerant displacement
- opening of the refrigeration circuit by extraction off the refrigerant
- evacuation of the refrigeration circuit
- filling of the refrigeration circuit
- leak detection
- setting of thermostats and controllers
- check electrical function

## ET 910 – ET 910.13 Design of the training system

### Modular design of the device

The ET 910 Refrigeration training system, base unit used in conjunction with the additional units:

- ET 910.05 Refrigeration laboratory workplace
- ET 910.10 Refrigeration components for basic experiments
- ET 910.11 Refrigeration components for advanced experiments
- ET 910.12 Set of accessories, and
- ET 910.13 Maintenance set

represents a modular compression refrigeration system.

The basic configuration alone fulfils many tasks. The system can be extended with ET 910.11 and ET 910.13 for a more in-depth treatment of the topic.

The modular aspect of the system allows trainees/students to independently construct refrigeration circuits of varying degrees of difficulty. The individual components are connected to each other with flexible hoses. The modularity means multi-user systems can also be designed at low cost.

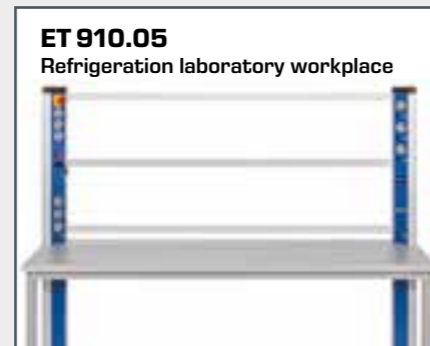
### Basic configuration ET 910.10

#### Fundamentals of the refrigeration circuit

- simple refrigeration circuit, consisting of compressor, condenser, receiver, filter/drier, expansion valve, evaporator
- function of the individual components
- pressures and temperatures in the cyclic process
- behaviour under different cooling loads
- behaviour under different cold storage room temperatures
- behaviour with different mass flow rates

#### Advanced considerations of the refrigeration circuit

- function of the evaporator (evaporation pressure, superheating)
- difference between vented/unvented evaporator, frosting in the evaporator
- function of condenser and receiver (condensing pressure)
- function of heat exchanger, supercooler/superheater
- function of liquid separator
- effect of pressure losses in the piping system, simulation via manual valve
- effect of overfilling/underfilling
- function of filter/drier and sight glass
- electrical connection of a consumer



Minimum configuration for a functional workstation, consisting of **ET 910** Base unit, **ET 910.10** Refrigeration components for basic experiment, **ET 910.05** Refrigeration laboratory workplace and **ET 910.12** Set of accessories.

### Extension set ET 910.11

#### Primary and secondary controllers in the refrigeration circuit

- various expansion elements: manually operated flow control valve, capillary tube, pressure-controlled expansion valve, thermostatic expansion valve
- various capacity controllers: KVP evaporation pressure controller, KVL start-up controller, KVC capacity controller with post-injection, electric thermostat with solenoid valve, refrigeration controller with solenoid valve
- compressor pump-down control system
- compressor start-up relieved via time-delayed bypass valve
- electric defrost heater with defrost timer
- hot gas defrosting with 4-way reversing valve and defrost timer

#### Simple electrical control systems from refrigeration technology

- proficiency in the fundamentals of control engineering
- complete tasks relating to refrigeration technology: thermostatic control, self-holding, alternating operation, delay circuit, electronic refrigeration controller

#### ET 910.11 Refrigeration components for advanced experiments



Further experiments with primary and secondary controllers in the refrigeration circuit. Electrical components can also be used to study tasks in the field of electrical engineering.

### Maintenance set ET 910.13

#### Troubleshooting and maintenance

- emptying and evacuating a system
- filling a system and checking for leaks
- opening a system with refrigerant displacement/pump-down
- adjusting expansion valves, thermostats, pressure controllers

The maintenance set essentially consists of

- selected tools
- leak detection device
- multimeter
- filling and evacuating device

#### ET 910.13 Maintenance set



For filling and emptying the system. An ET 910.13 maintenance set can be used for several workstations. This can also be used to complete maintenance and troubleshooting tasks.

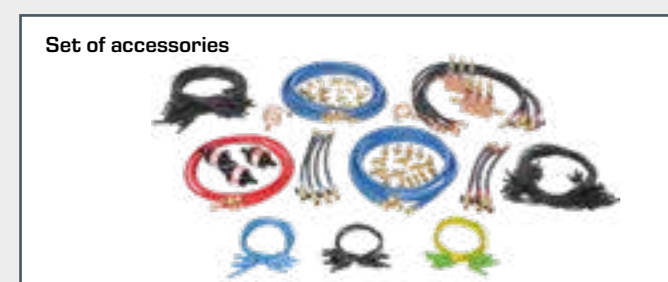


# Overview of the modular components

## ET 910.10 Refrigeration components for basic experiments

<p><b>Sight glass with filter/drier</b></p>	<p><b>Flow meter</b></p>	<p><b>Manometer delivery side/intake side</b></p>	<p><b>Assembly aid</b></p>
<p><b>Heat exchanger</b></p>	<p><b>Pressure-controlled expansion valve</b></p>	<p><b>Thermostatic expansion valve</b></p>	<p><b>Circuit breaker, 3 pins</b></p>
<p><b>Electric thermostat 1</b></p>	<p><b>Electric thermostat 2</b></p>	<p><b>Liquid separator</b></p>	

## ET 910.12 Set of accessories



The ET 910.12 Set of accessories is required to establish the hydraulic and electrical connection from the components to each other and to the base unit. It contains refrigerant hoses in different lengths and diameters (some with shut-off valves), refrigerant filter/drier as an alternative, T-sections, couplings and laboratory cables. Two capillary tubes of different lengths, two distributors and a sufficient length of insulating tube are also included.

## ET 910.11 Refrigeration components for advanced experiments

<p><b>Manually operated valve</b></p>	<p><b>Temperature controller</b></p>	<p><b>Evaporation pressure controller</b></p>	<p><b>Intake pressure controller</b></p>
<p><b>Capacity controller</b></p>	<p><b>4-way reversing valve</b></p>	<p><b>Post-injection valve</b></p>	<p><b>Defrost timer</b></p>
<p><b>Refrigeration controller</b></p>	<p><b>Solenoid valve 1</b></p>	<p><b>Solenoid valve 2</b></p>	<p><b>Time relay</b></p>
<p><b>Main contactor</b></p>	<p><b>Auxiliary contactor</b></p>		

## Example experimental setups

Some of the experimental setups that can be created with the training system are presented below as examples:

- simple refrigeration circuit with compressor, condenser, thermostatic expansion valve and evaporator
- understanding the function of a suction pressure controller in the refrigerant circuit
- hot gas defrosting process with a 4-way reversing valve

Before undertaking any practical work with the training system, the trainees/students first learn to read and understand refrigeration system diagrams or process schematics and simple electrical circuit diagrams.

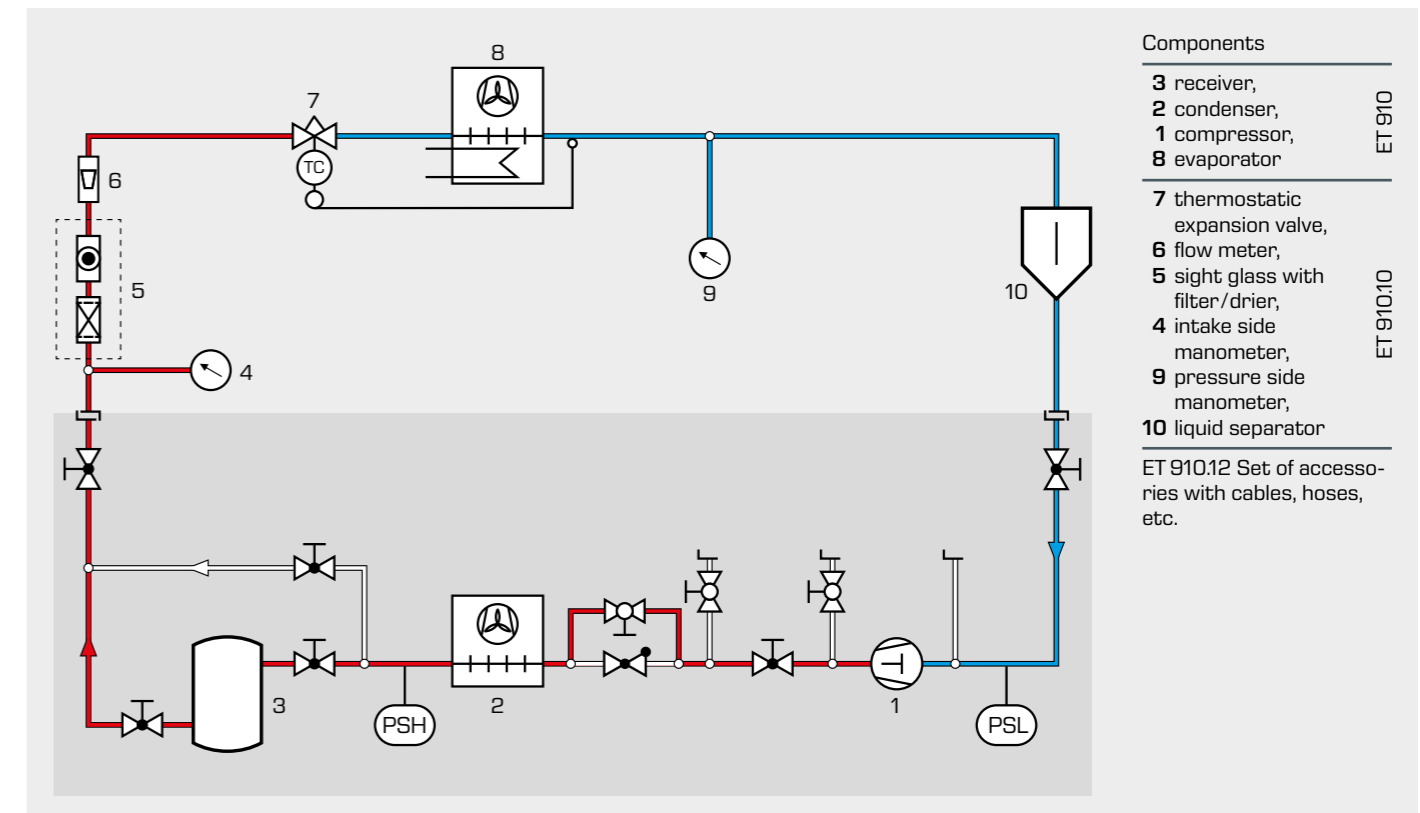
When compiling the required experiment components, students can familiarise themselves with real refrigeration components used in the system diagrams.

During commissioning, practical activities such as evacuation, filling and leak testing are carried out. The relevant rules and regulations can be reviewed. In the subsequent experiment, students can get to grips with the function of the system in the truest sense of the word. The function is optimised by adjusting the controllers and expansion elements. The effects of external influences can be demonstrated, such as the change in the thermal load on the evaporator.



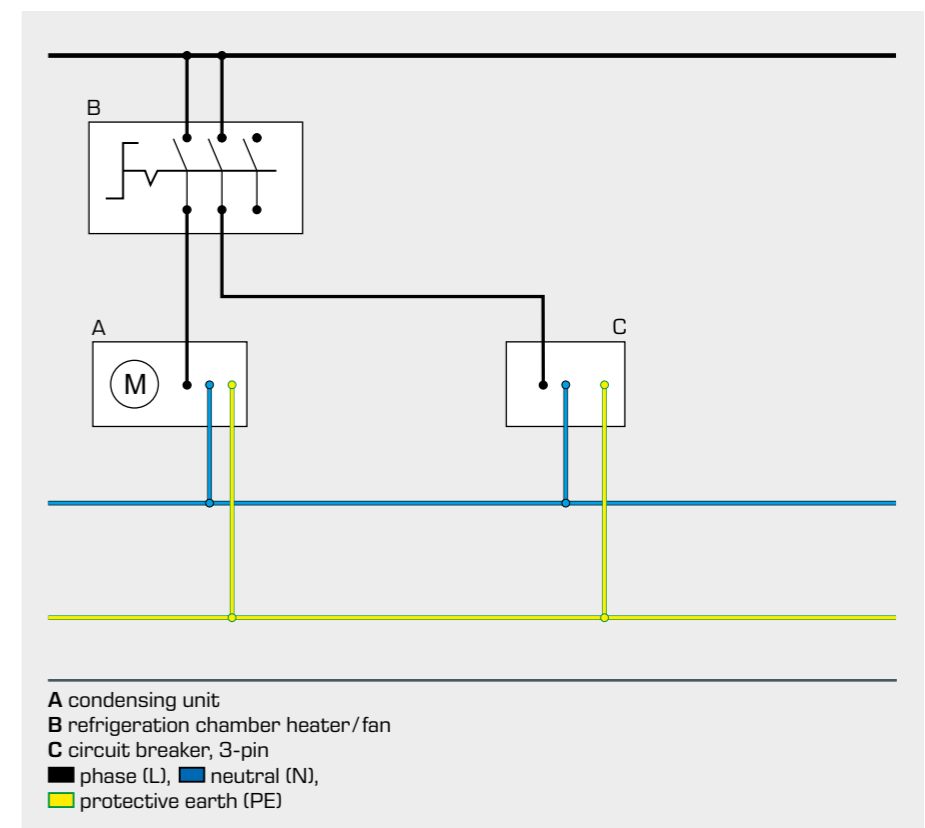
Laboratory workstation with base unit and components for experiment in the fundamentals

### Example: simple refrigeration circuit with thermostatic expansion valve



In this introductory experiment, a simple refrigeration circuit is set up, consisting of a condensing unit (compressor 1, condenser 2, receiver 3), refrigeration chamber with evaporator 8, thermostatic expansion valve 7 and sight glass with filter/drier 5.

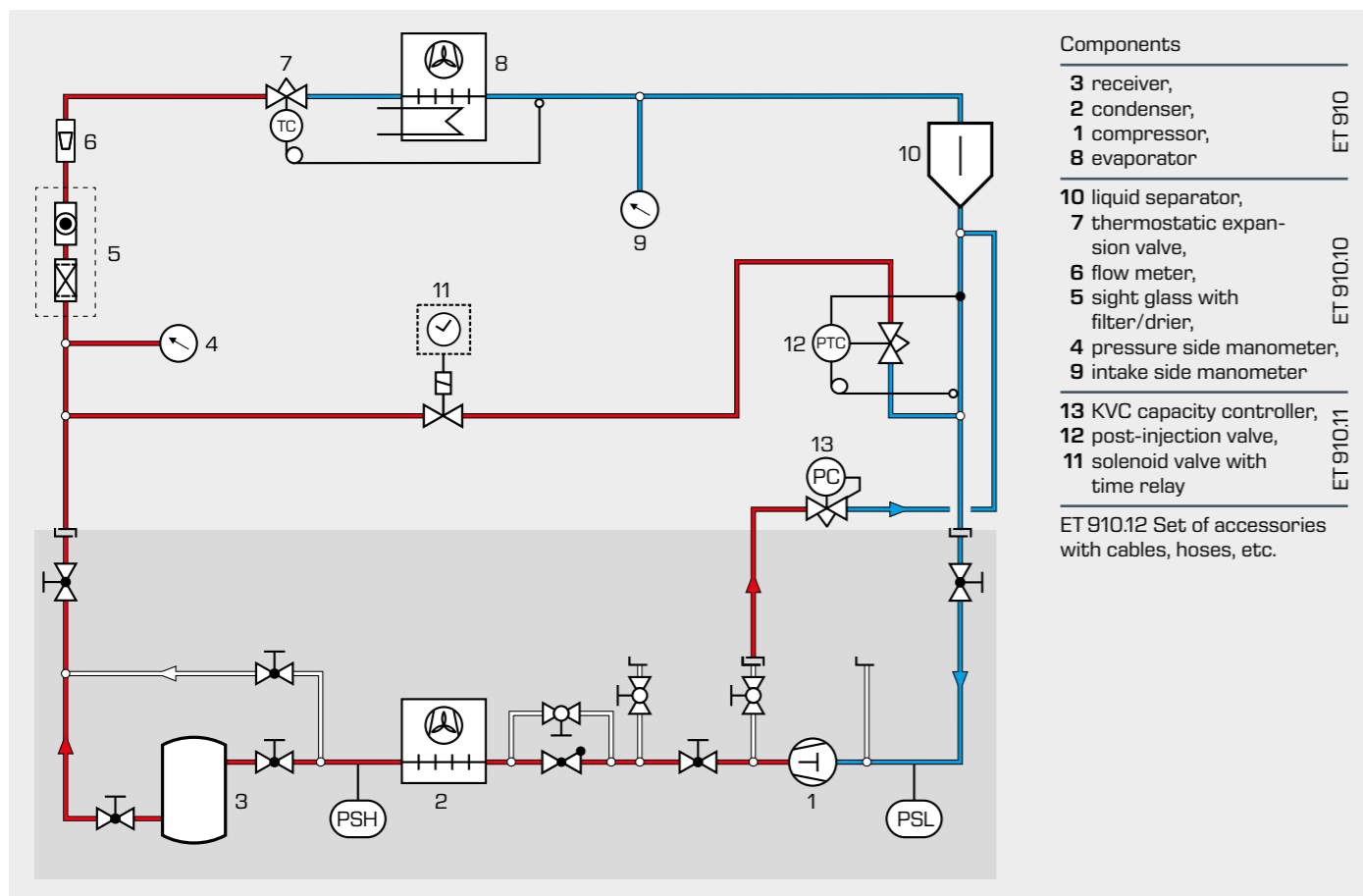
The control response of the expansion valve can be observed at the flow meter 6. Manometers 4, 9 provide an insight to the pressure ratios in the circuit. The trainees/students learn about the elements and functions in the refrigeration circuit. The change of state of the refrigerant can be tracked and entered into the log p-h diagram using pressure and temperature measurements. A deeper understanding of the processes is gained by measuring the temperatures manually.



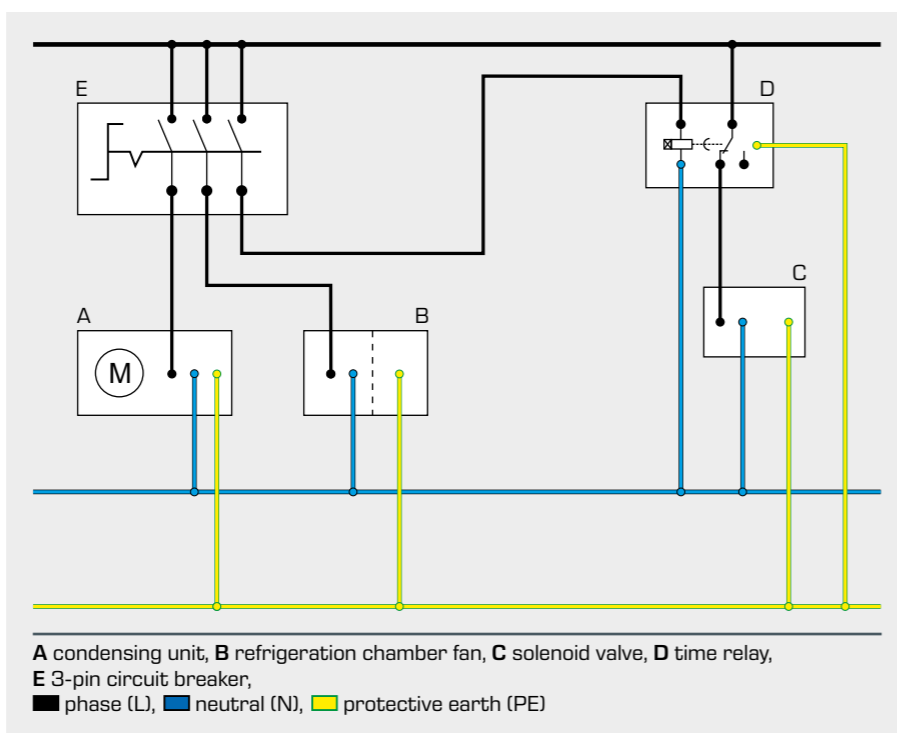


## Example experimental setups

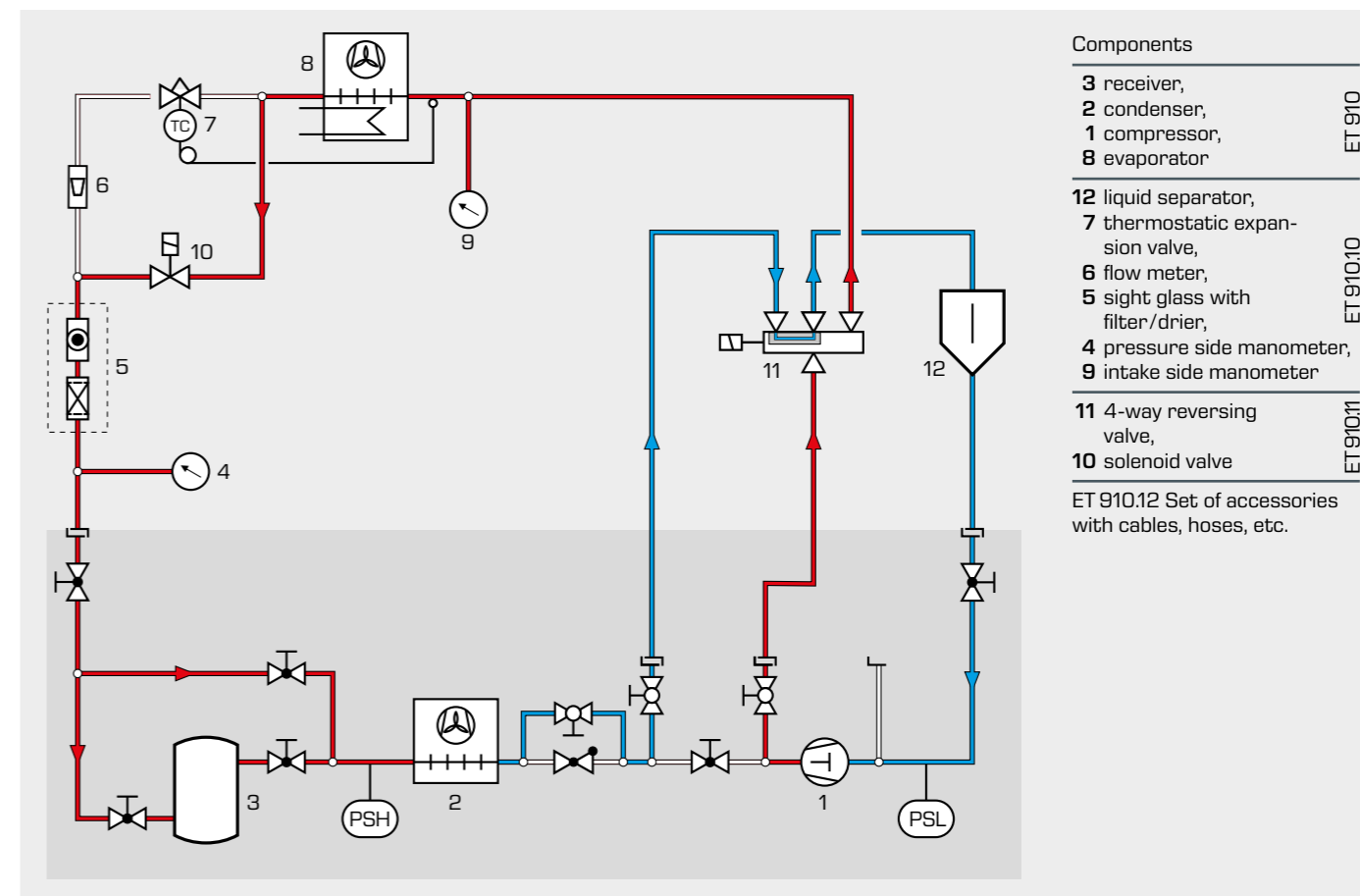
### Example: capacity control with post-injection



This experiment demonstrates one type of capacity control for larger plants. Whereas in small systems the power output is usually controlled by the compressor switching on and off, in larger systems a KVC capacity controller **13** is used. If the pressure difference between the pressure side and the intake side of the compressor is too high, the KVC allows a partial flow of the compressed gas to flow back to the intake side. This reduces the effective mass flow of refrigerant. To prevent the compressor from overheating, a small amount of liquid refrigerant is injected directly into the intake line via the post-injection valve **12**. The refrigerant evaporates immediately, thereby cooling the intake gas. The post-injection can be intentionally deactivated via the solenoid valve **11** so that the effect can be observed immediately.

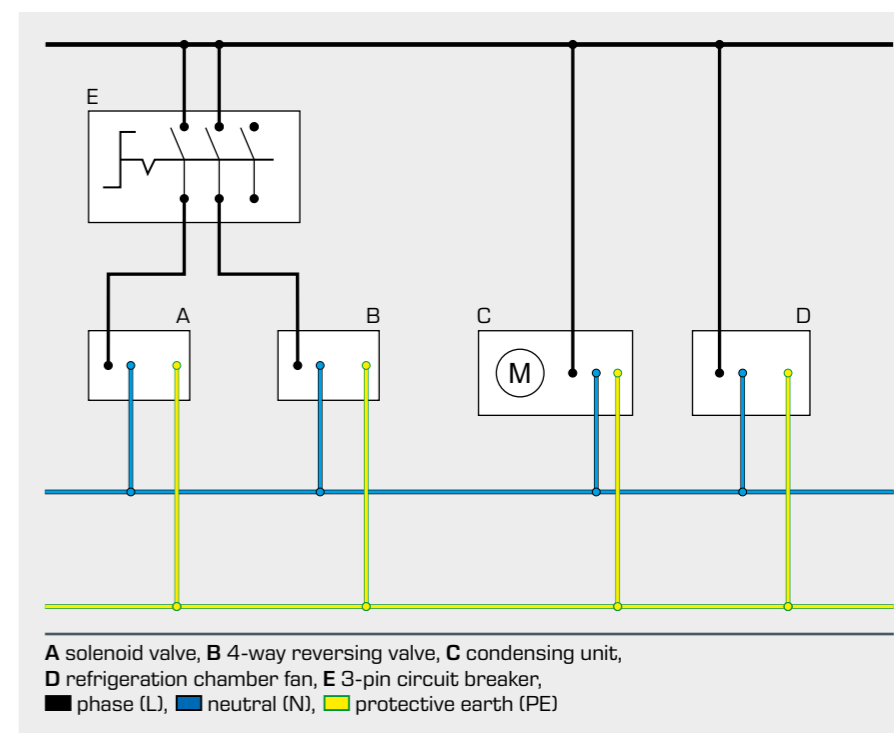


### Example: hot gas defrosting process with 4-way reversing valve



At evaporation temperatures of less than 0°C, e.g. in deep-freeze systems, the air is cooled below its dew point temperature, causing condensate to escape and freeze on the surface of the evaporator. This layer of ice hinders convective heat transfer and reduces the heat transfer surface. In addition to the option of using a time-controlled defrost heater, ET 910 also offers hot gas defrosting.

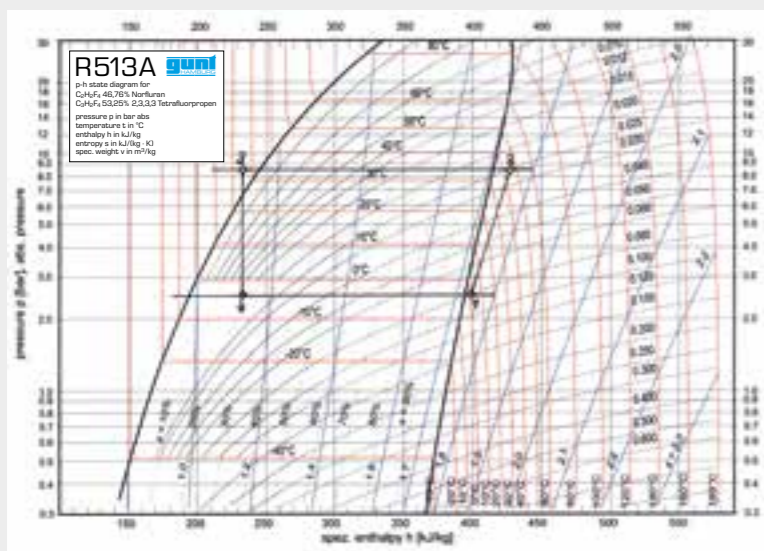
The function of evaporator **8** and condenser **2** is exchanged via a 4-way reversing valve **11**, thus reversing the flow direction of the refrigerant. The frozen evaporator now receives the hot gas directly from the compressor outlet and defrosts very effectively.



## Findings from the experiments

Measured Values Experiment 2			
Test run	1	2	3
Observation			
Evaporation Pressure $p_{\text{ev}}$ in bar	1.5	1.9	2.1
Evaporation Pressure, absolute $p_{\text{ev}}$ in bar	2.5	2.9	3.1
Evaporation Temperature in °C (Reading at the manometer)	-4.0	0.0	2.0
Condensation Pressure $p_{\text{co}}$ in bar	7.5	7.2	6.7
Condensation Pressure, absolute $p_{\text{co}}$ in bar	8.5	8.2	7.7
Condensation Temperature in °C (Reading at the manometer)	33.5	32.0	30.0
Temperature $T_1$ in °C at compressor outlet	45.6	42.3	43.0
Temperature $T_2$ in °C before expansion valve	24.8	24.0	22.5
Temperature $T_3$ in °C at evaporator inlet	-2.5	0.5	1.0
Temperature $T_4$ in °C at evaporator outlet	-1.2	2.5	5.0
Temperature $T_5$ in °C at compressor inlet	0.4	6.0	8.8
Refrigerant mass flow in kg/h	23	28	30

Recording measured values in a refrigerating plant



Enter measured values in log p-h diagram and plot cyclic process

By measuring pressures and temperatures, it is possible to study the function of the individual components in the refrigeration circuit in detail.

Understanding the changes in state caused by placing the components themselves, students gain lasting knowledge of how refrigeration components work. In addition to practising the real-world ability to measure temperature correctly (correct measuring position and good contact between the sensor and the tube) or read a manometer properly, this unit also considers the matter of the steady state of the system.

The cyclic process can be displayed graphically by plotting the measured values in the log p-h diagram. The log p-h diagram is very important for refrigeration since it clearly shows how the main components work, allowing this to be discussed in detail.

The abstract concept of enthalpy is demonstrated by a balance of the exchanged energy flows. Basic properties of phase mixtures, condensation and evaporation can also be explained using the log p-h diagram.

Calculations Experiment 2			
Test run	1	2	3
<b>Enthalpies (Readings of the log p-h diagram)</b>			
$h_1$ in kJ/kg	398	402	405
$h_2$ in kJ/kg	428	426	428
$h_3$ in kJ/kg	233	229	228
$h_4$ in kJ/kg	233	229	228
<b>Enthalpy differences</b>			
$h_2 - h_1$ in kJ/kg	165	173	176
$h_3 - h_4$ in kJ/kg	195	197	200
Mass flow in kg/h	23	28	30
<b>Calculation of Capacity</b>			
Evaporator capacity $P_e = \frac{m \cdot (h_1 - h_4)}{3600}$ in kW	1.054	1.345	1.466
Condenser capacity $P_c = \frac{m \cdot (h_2 - h_3)}{3600}$ in kW	1.245	1.532	1.666
<b>Theoretical coefficient of performance (COP)</b>			
$\frac{h_3 - h_4}{h_2 - h_1}$	5.49	7.18	7.33

Calculate energy flows and determine coefficient of performance

Energy flows can be determined using simple thermodynamic calculations. Calculating the coefficient of performance allows statements to be made about the efficiency of the system; the calculation can be altered in a targeted manner by using different components. In addition, the influence of thermal loads or the pressure ratio on the coefficient of performance is effectively illustrated.

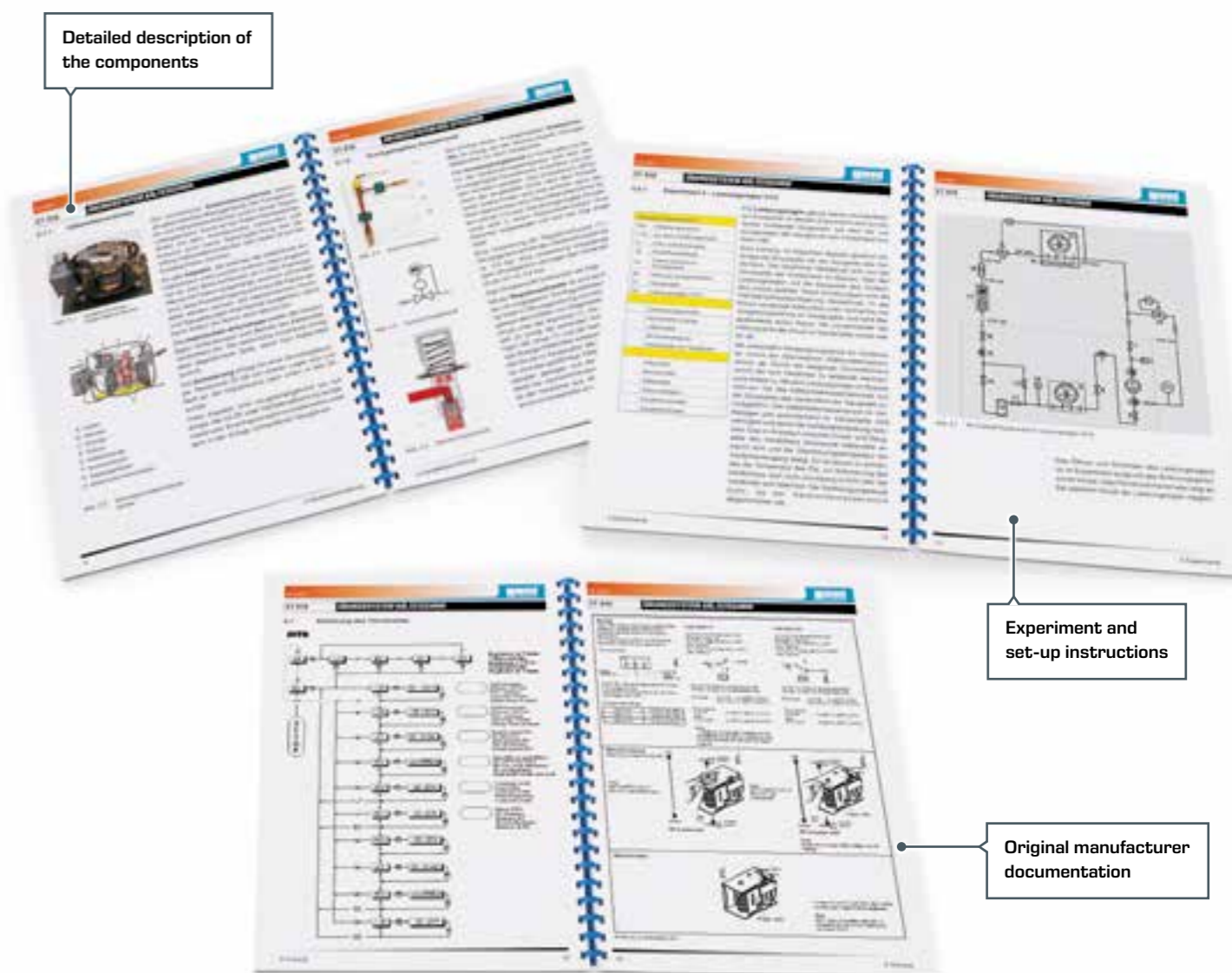
## The instructional material

We have developed extensive instructional material for the training system ET 910. This makes the use of the system during your lessons easier.

The instructional materials consists in detail of:

- comprehensive system description ET 910
- extensive operating instructions
- detailed description of the design and function of the components used
- design instructions with system flow chart, electric circuit diagram and item list
- worksheets with instructions for the experiments for trainees
- original manufacturer documentation and assembly instructions for the most important components

Materials as printouts and additionally also as PDF files.



Detailed description of the components

Experiment and set-up instructions

Original manufacturer documentation

With the purchase of the training system ET 910 you receive a first class documentation and teaching aid



# ET 915 HSI training system refrigeration and air conditioning technology

The ET 915 HSI Training system refrigeration and air conditioning technology, base unit provides basic experiments for the different areas of refrigeration and air conditioning technology.

The term HSI refers to our overall didactic concept:  
Hardware – Software – Integrated.

## Refrigeration

**ET 915.01**  
Refrigerator  
model



**ET 915.02**  
Model of a refrigeration system with refrigeration and freezing stage



## Air conditioning

**ET 915.06**  
Model of a simple air conditioning system



**ET 915.07**  
Air conditioning model



All attachments contain expansion elements and evaporators

The ET 915 base unit contains the main compressor and condenser components



**Modular system with extensive teaching possibilities**

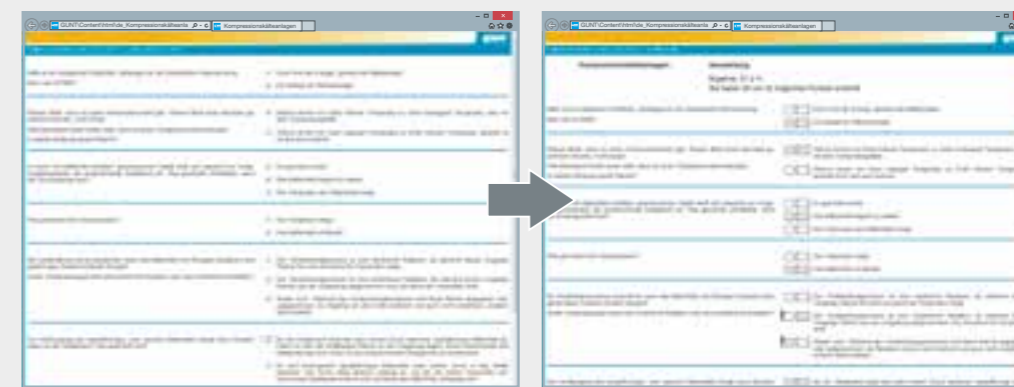
## Educational software

...with didactically valuable course of studies

- use the educational software on the students' own PCs
- complete course of studies for refrigeration and air-conditioning technology including quiz
- very flexible thanks to the structure of own learning modules and tests
- intuitive user interface



E-Learning



Quiz with detailed evaluation

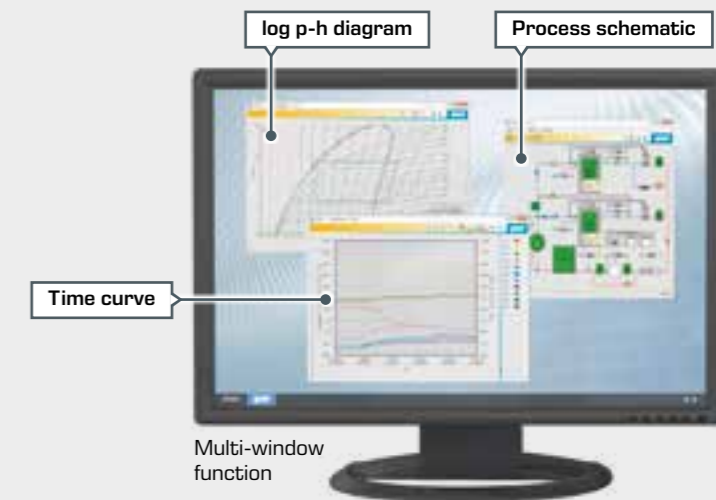
**Targeted review of the learning content**

- learning progress can be monitored discretely and automatically
- detect weaknesses and provide targeted support

## Data acquisition

...with unlimited networking capability

- interactive experiments for students via network connection
- real-time display of the processes in the log p-h diagram and h-x diagram
- plug & play system via USB connection



Multi-window function

## ET 915

### HSI training system refrigeration and air conditioning technology, base unit



#### Description

- base unit for the setup of basic experiments in refrigeration and air conditioning technology
- modern learning environment through hardware/software integration (HSI)
- four models on refrigeration and air conditioning technology
- dynamic recording of the refrigerant mass flow rate

The base unit ET 915 is, dependent on the objective of the experiment, extended into complete refrigeration circuit with one of the models available as accessories (ET 915.01 refrigerator, ET 915.02 refrigeration system with refrigeration and freezing stage, ET 915.06 simple air conditioning system, ET 915.07 air conditioning).

The main components of ET 915 are compressor, condenser and receiver plus electrical and communications systems. The models are plugged onto the base unit and connected hydraulically with refrigerant hoses and electrically with cables. Self-sealing couplings reduce the refrigerant loss to a minimum. All components are arranged well visible to allow their operation to be monitored.

The modern and powerful software is an integral part of the training system in the form of hardware/software integration (HSI). It enables the comfortable execution and analysis of the experiments. The experimental unit is connected to the PC via a USB interface.

The GUNT software consists of a software for system operation and for data acquisition and an educational software. With explanatory texts and illustrations the educational software significantly aids the understanding of the theoretical principles. Each model has its own GUNT software matching the learning objectives. With the aid of an authoring system, the teacher can create further exercises.

Temperatures and pressures in the system are recorded by sensors and displayed dynamically in the software for system operation and data acquisition. The refrigerant mass flow rate is calculated in the software from the recorded measured values. The effect of parameter changes can be tracked in log p-h and h-x diagrams. The system is also operated via the software.

#### Learning objectives/experiments

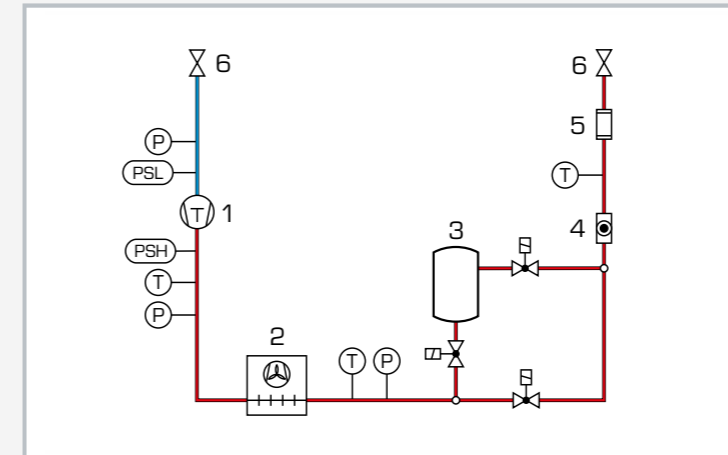
- in conjunction with ET 915.01, ET 915.02, ET 915.06 and ET 915.07
  - ▶ fundamentals of the refrigeration cycle
  - ▶ fundamentals of air conditioning
  - ▶ components in a refrigeration system/air conditioning system
  - ▶ system operation
  - ▶ fault finding

## ET 915

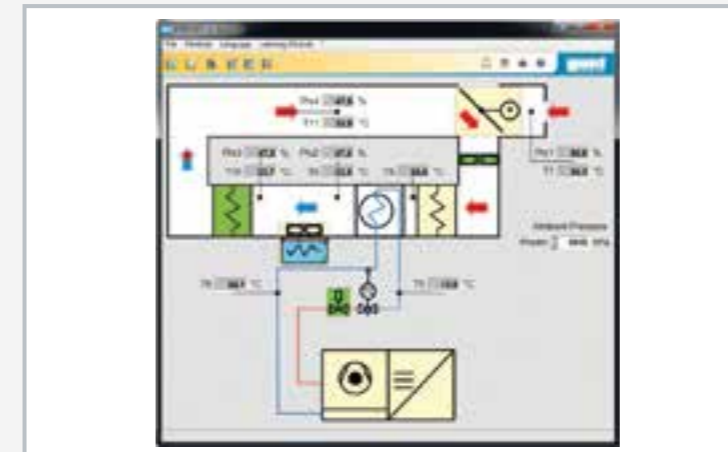
### HSI training system refrigeration and air conditioning technology, base unit



1 compressor, 2 condenser with add-on fan, 3 receiver, 4 solenoid valve, 5 frame to mount the models, 6 filter/drier, 7 manometer, 8 pressure switch, 9 refrigerant hose



1 compressor, 2 condenser, 3 receiver, 4 sight glass, 5 filter/drier, 6 refrigerant hose for the models; PSH, PSL pressure switch; T temperature, P pressure; blue: low pressure, red: high pressure



Software screenshot: process schematic of the model ET 915.07. Measured values are displayed „online“.

#### Specification

- [1] basic experiments on the operation of refrigeration and air conditioning systems by combining the base unit and models
- [2] GUNT training system with HSI technology
- [3] condensing unit consisting of compressor, condenser and receiver
- [4] connection between condensing unit and model via refrigerant hoses
- [5] model attached securely on ET 915 with fasteners
- [6] manometer for refrigerant with temperature scale
- [7] refrigerant mass flow rate calculated in the software from recorded measured values
- [8] refrigerant R513A, GWP: 631
- [9] system control via solenoid valves and software
- [10] functions of the GUNT software: educational software, data acquisition, system operation

#### Technical data

Compressor  
 ■ refrigeration capacity: 463W at 7,2/54,4°C  
 ■ power consumption: 288W at 7,2/54,4°C

Receiver: 0,7L

Refrigerant  
 ■ R513A  
 ■ GWP: 631  
 ■ filling volume: 700g  
 ■ CO<sub>2</sub>-equivalent: 0,4t

Measuring ranges  
 ■ temperature: 1x -50...50°C, 3x 0...100°C  
 ■ pressure:  
 ▶ 1x intake side: -1...9bar  
 ▶ 2x delivery side: -1...15bar  
 ■ flow rate: 0...19kg/h (refrigerant)

230V, 50Hz, 1 phase  
 230V, 60Hz, 1 phase  
 120V, 60Hz, 1 phase  
 UL/CSA optional  
 LxWxH: 830x650x320mm  
 Weight: approx. 60kg

#### Required for operation

PC with Windows

#### Scope of delivery

- 1 condensing unit, filled with refrigerant
- 1 CD with authoring system for GUNT educational software
- 1 set of instructional material



## ET 915.01 Refrigerator model



### Description

- simple model of a domestic refrigerator for connection to the ET 915
- component operation and fault simulation via the GUNT software

ET 915.01 is part of the HSI training system for refrigeration and air conditioning technology. In combination with the base unit ET 915 the operational model of a domestic refrigerator is created. The model is plugged onto the base unit, secured using fasteners and connected with refrigerant hoses to become a complete refrigeration circuit.

ET 915.01 consists of a refrigeration chamber with a heater as cooling load, evaporator, fan and various expansion elements. The fan supports the achievement of an even temperature distribution in the chamber. A cooling load can additionally be simulated with the heater. Solenoid valves enable the operation of the system with capillary tube or with expansion valve. All components are clearly arranged on a panel.

The operation of individual system components, here the temperature control, fan, heater, compressor and solenoid valves, takes place via the software. The software offers the option to simulate faults.

Temperatures and pressures in the system are recorded by sensors and displayed dynamically in the software. The effect of parameter changes can be tracked online in the log p-h diagram. Fundamentals and individual components are represented in the educational software for ET 915.01. Performance assessments check the learning progress. With the aid of the authoring system further exercises and performance assessments can be created.

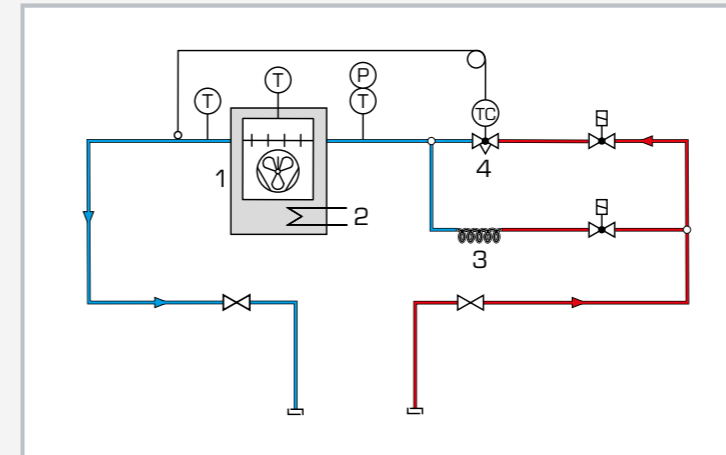
### Learning objectives/experiments

- design and operation of a simple refrigeration system
- different expansion elements
  - ▶ operation with capillary tube
  - ▶ operation with expansion valve
- operating behaviour under load
- refrigeration cycle in the log p-h diagram
- fault simulation

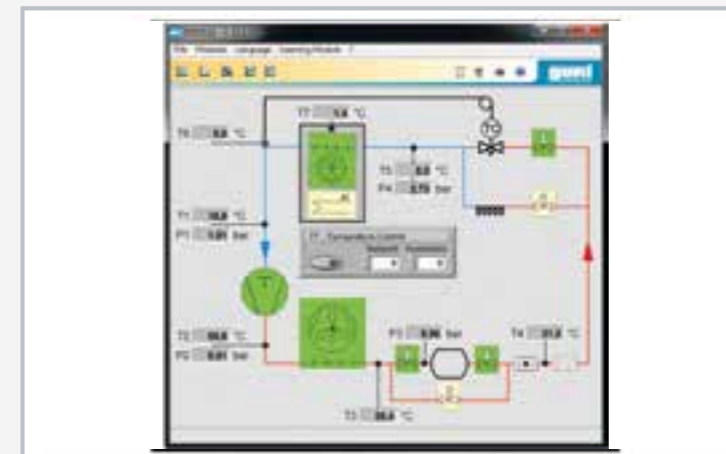
## ET 915.01 Refrigerator model



1 evaporator, 2 fan, 3 refrigeration chamber, 4 heater, 5 connections to ET 915, 6 process schematic, 7 solenoid valve, 8 capillary tube, 9 expansion valve



Process schematic of the refrigerator model: 1 evaporator, 2 heater, 3 capillary tube, 4 expansion valve; T temperature, P pressure; blue: low pressure, red: high pressure



Software screenshot: process schematic

### Specification

- [1] model of a refrigerator to plug onto the base unit ET 915
- [2] GUNT training system with HSI technology
- [3] refrigeration chamber with evaporator, fan and cooling load
- [4] chamber with transparent front
- [5] electric heater to generate the cooling load
- [6] expansion elements selectable via solenoid valves: expansion valve or capillary tube
- [7] sensors to record temperature and pressure
- [8] operation of solenoid valves, fan, heater and fault simulation via software
- [9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
- [10] GUNT software: educational software, data acquisition, system operation

### Technical data

Refrigeration chamber, LxWxH: 270x270x220mm

Electric PTC heater as cooling load: 210W

Capillary tube: length 2m

Measuring ranges

- temperature: 3x -50...50°C
- pressure: -1...9bar

LxWxH: 850x380x550mm

Weight: approx. 30kg

### Scope of delivery

- 1 refrigerator model, filled with refrigerant
- 1 GUNT software CD + USB cable

## ET 915.02

### Model of a refrigeration system with refrigeration and freezing stage



The illustration shows a similar unit

#### Description

- series and parallel connection of evaporators
- component operation and fault simulation via the GUNT software

ET 915.02 is part of the HSI training system for refrigeration and air conditioning technology. In combination with the base unit ET 915 the operational model of a refrigeration system with refrigeration and freezing stage results. The model is plugged onto the base unit, secured using fasteners and connected with refrigerant hoses to become a complete refrigeration circuit.

In refrigeration and freezing combinations evaporators are preferably connected in parallel. To increase the refrigeration capacity, evaporators are operated connected in series. Here different pressure levels in the evaporators can be used to obtain different temperature ranges for refrigeration or freezing.

ET 915.02 includes two separate refrigeration chambers with evaporator and expansion elements. The evaporators can be optionally operated connected in series or in parallel. Two fans in the refrigeration chambers support the achievement of an even temperature distribution. With heaters cooling loads can additionally be simulated.

One of the refrigeration chambers can optionally be operated with an expansion valve or a capillary tube as expansion element. The various operation modes are set via solenoid valves. An evaporation pressure controller permits in parallel operation the independent adjustment of the temperature level in the upper chamber. All components are clearly arranged on a panel.

The operation of individual system components, here temperature control, fan, heater, compressor and solenoid valves, takes place via the software.

The software offers the option to simulate faults. Temperatures and pressures in the system are recorded by sensors and displayed dynamically in the software. The effect of parameter changes can be tracked online in the log p-h diagram.

Fundamentals and individual components are represented in the educational software for ET 915.02. Performance assessments check the learning progress. With the aid of the authoring system further exercises and performance assessments can be created.

#### Learning objectives/experiments

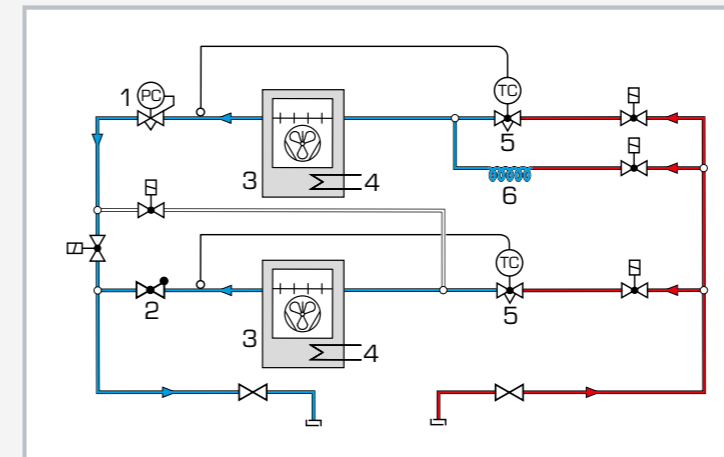
- design and operation of a refrigeration system with two evaporators
- series and parallel connection of two evaporators
- familiarisation with the different expansion elements
  - ▶ operation with capillary tube
  - ▶ operation with expansion valve
- operating behaviour under load
- refrigeration cycle in the log p-h diagram
- effect of the evaporation pressure
- fault simulation

## ET 915.02

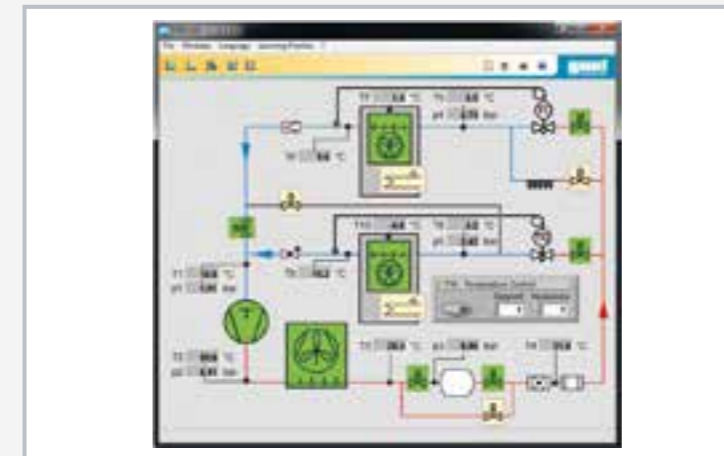
### Model of a refrigeration system with refrigeration and freezing stage



1 evaporation pressure controller, 2 evaporator, 3 fan, 4 heater, 5 connections to ET 915, 6 process schematic, 7 capillary tube, 8 solenoid valve, 9 expansion valve



Refrigeration system model, evaporators connected in parallel:  
1 evaporation pressure controller, 2 non-return valve, 3 evaporator, 4 heater, 5 expansion valve, 6 capillary tube; T temperature, P pressure; blue: low pressure, red: high pressure



Software screenshot: process schematic

#### Specification

- [1] model of a refrigeration system to plug onto the base unit ET 915
- [2] GUNT training system with HSI technology
- [3] each refrigeration chamber includes: evaporator with fan (to recirculate the air) and heater to generate the cooling load
- [4] refrigeration chambers with transparent front
- [5] adjustable evaporation pressure controller
- [6] selectable expansion elements: expansion valve or capillary tube
- [7] operating modes of the system configurable via 5 solenoid valves
- [8] sensors to record temperature and pressure
- [9] operation of solenoid valves, fan, heater and fault simulation via software
- [10] GUNT software with control functions and data acquisition via USB under Windows 7, 8.1, 10
- [11] GUNT software: educational software, data acquisition, system operation

#### Technical data

Refrigeration chamber:  
LxWxH: 270x270x220mm

Electric PTC heater as cooling load: 210W

Capillary tube: length 2m

Evaporation pressure controller: 0...5,5bar

Measuring ranges

- temperature: 6x ±50°C
- pressure: 2x -1...9bar

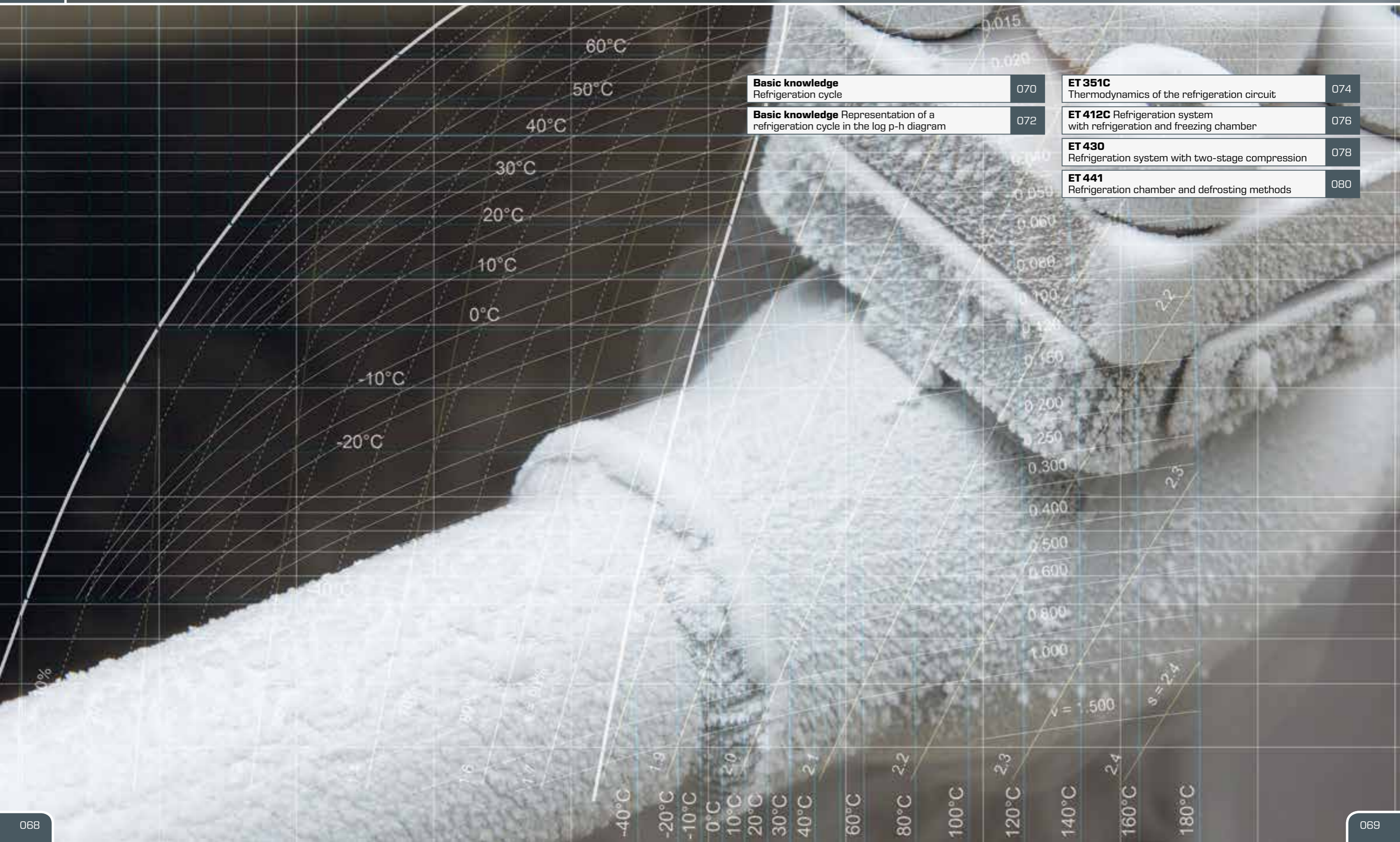
LxWxH: 850x380x750mm  
Weight: approx. 45kg

#### Scope of delivery

- 1 refrigeration system model, filled with refrigerant
- 1 GUNT software CD + USB cable



# 2 ❄️ Thermodynamics of the refrigeration cycle



**Basic knowledge** Refrigeration cycle 070

**Basic knowledge** Representation of a refrigeration cycle in the log p-h diagram 072

**ET 351C** Thermodynamics of the refrigeration circuit 074

**ET 412C** Refrigeration system with refrigeration and freezing chamber 076

**ET 430** Refrigeration system with two-stage compression 078

**ET 441** Refrigeration chamber and defrosting methods 080



## Basic knowledge Refrigeration cycle

The refrigeration cycle can be described by a sequence of state changes of a refrigerant. This sequence runs periodically and always achieves the initial state (cyclic process). In refrigeration, the state variables such as pressure, temperature and density are important as is the dependence of these state variables on each other.

The thermodynamic processes in the refrigeration cycle are complex. Calculation using formulae and tables requires a considerable amount of effort due to the three different states of the refrigerant from liquid, boiling and gaseous. Therefore, for reasons of simplification, the log p-h diagram was introduced.

Using a log p-h diagram, the various state variables can be represented graphically according to their dependencies. The thermodynamic state variables can be read directly at each state point and are available for further calculations. Heat quantities,

technical work or pressure differences of a change of state are shown as measurable lines. Using the log p-h diagram greatly simplifies thermodynamic calculations and is essential for understanding how refrigeration plants work.

On the basis of this knowledge, our software for refrigeration equipment displays the respective log p-h diagram in real time. Changes to operating parameters can be read directly in the diagram and allow a valuable insight into the formation of the thermodynamic states, which otherwise can only be appreciated statically.

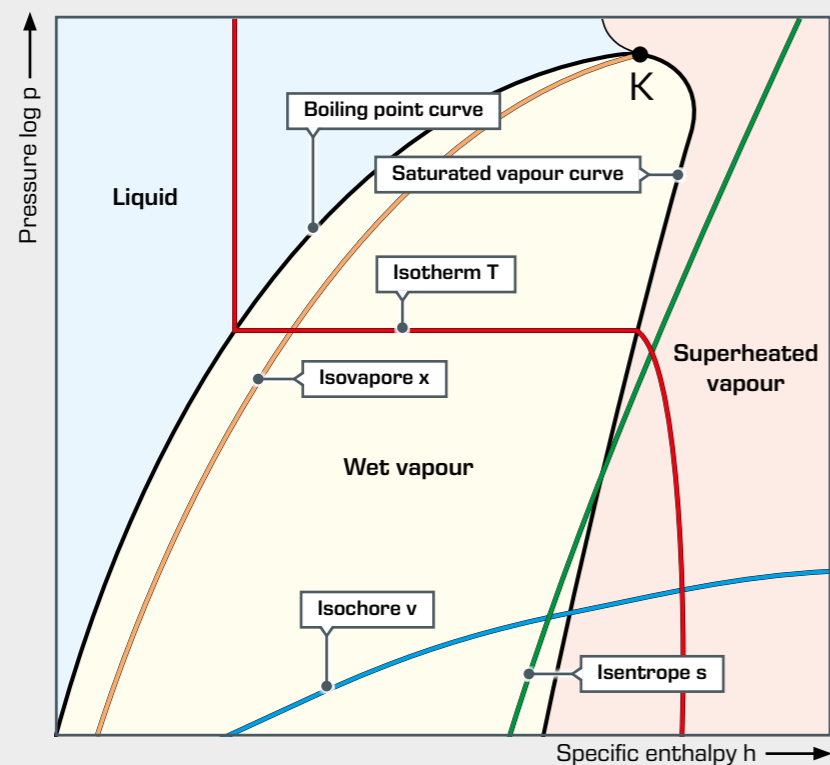
In general, a log p-h diagram shows the aggregate state of a substance, depending on pressure and heat. For refrigeration, the diagram is reduced to the relevant regions of **liquid** and **gaseous** as well as their **mixed form**.

The vertical axis shows the logarithmic pressure and the horizontal axis shows the specific enthalpy with linear scaling. Accordingly, the isobars are horizontal and the isenthalps are vertical. The logarithmic scaling makes it possible to represent processes with large pressure differences.

The saturated vapour curve and the boiling point curve meet at the critical point **K**.

The log p-h diagram shows the thermodynamic state variables in the respective phase.

- pressure **p**
- specific enthalpy **h**
- temperature **T**
- specific volume **v**
- specific entropy **s**
- gas content **x**

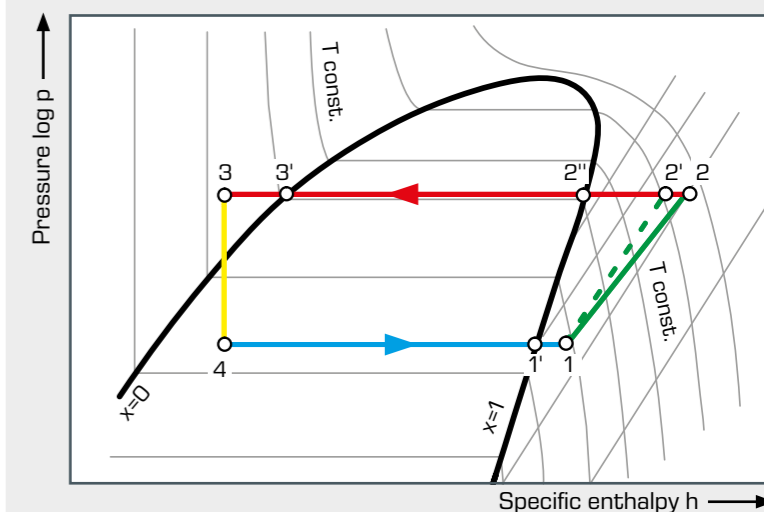


### The refrigeration cycle in the log p-h diagram

The distinctive feature of the refrigeration cycle is that it runs counter-clockwise, i.e. opposite to the joule or steam cycle. A change of state occurs when the refrigerant flows through

one of the four main components of the refrigeration plant. The actual refrigeration cycle consists of the following changes of state:

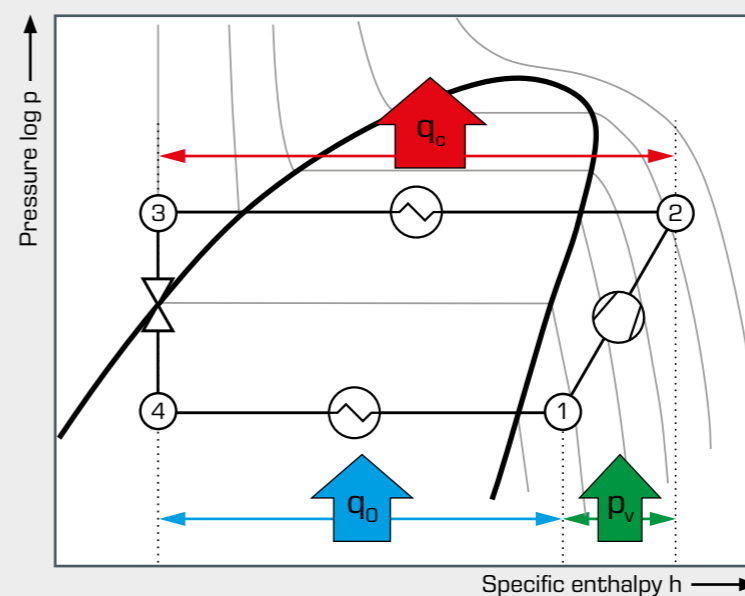
- 1 – 2 polytropic compression to the condensing pressure (for comparison 1 – 2' isentropic compression)
- 2 – 2'' isobaric cooling, deheating of the superheated vapour
- 2'' – 3' isobaric condensation
- 3' – 3 isobaric cooling, supercooling of the liquid
- 3 – 4 isenthalpic expansion to the evaporation pressure
- 4 – 1' isobaric evaporation
- 1' – 1 isobaric heating, superheating of the vapour



Refrigeration cycle in the log p-h diagram

■ compressor, ■ condenser, ■ expansion valve, ■ evaporator

In addition, pressure losses also occur in the actual refrigeration cycle, so that evaporation and condensation do not take place exactly horizontally (isobarically).



The **specific amounts of energy** that can be absorbed and released to reach the state points are marked as lines in the log p-h diagram. The specific enthalpy **h** can be read for each separate state point directly from the log p-h diagram.

If the mass flow rate of the refrigerant is known, the associated **thermal output** can be calculated by means of the specific enthalpy at the respective state point.

- the line  $h_1 - h_4 = q_0$  corresponds to the cooling and results in the **refrigeration capacity** by multiplication with the the mass flow rate.
- the line  $h_2 - h_1 = p_v$  corresponds to the technical work of the compressor, which is actually transferred to the refrigerant.
- the line  $h_2 - h_3 = q_c$  corresponds to the emitted heat and results in the **condenser capacity** by multiplication with the the mass flow rate. It is the waste heat from a refrigeration plant.



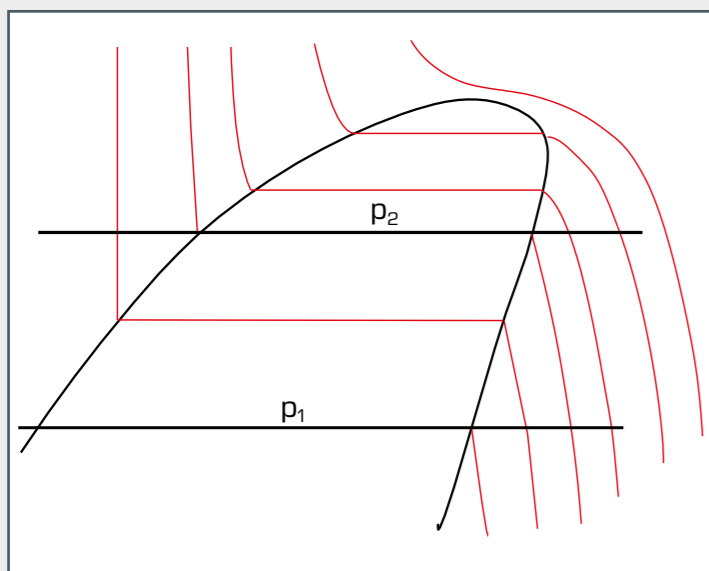
Basic knowledge

# Representation of a refrigeration cycle in the log p-h diagram

This digression is designed to help you understand the functional relationship between the components of the refrigeration plant and the thermodynamic processes. The following state variables are required to display a refrigeration cycle in the log p-h diagram:

- $p_1$  evaporation pressure
- $T_1$  temperature at the compressor inlet
- $p_2$  condensing pressure
- $T_2$  temperature at the condenser inlet
- $T_3$  temperature at the condenser outlet

### Step 1: plot limiting isobars

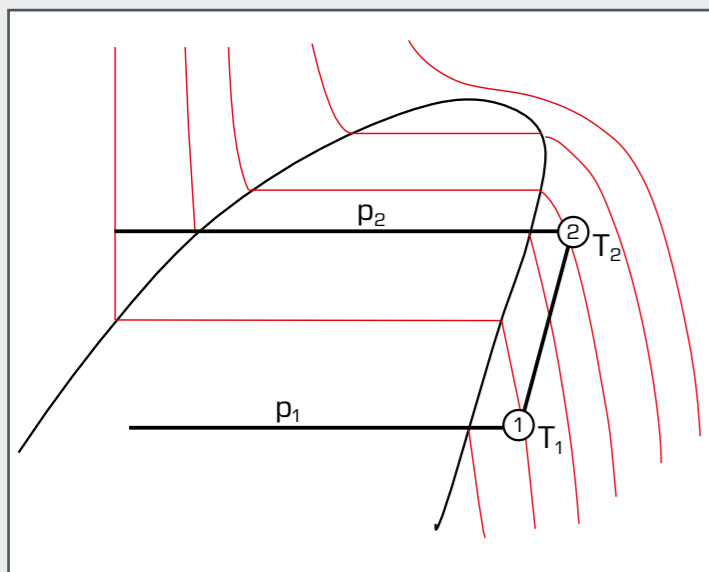


First of all the isobaric changes of state have to be plotted in the diagram.

- $p_1$  evaporation pressure
- $p_2$  condensing pressure

In doing so it is important that absolute pressures are plotted in the diagram.

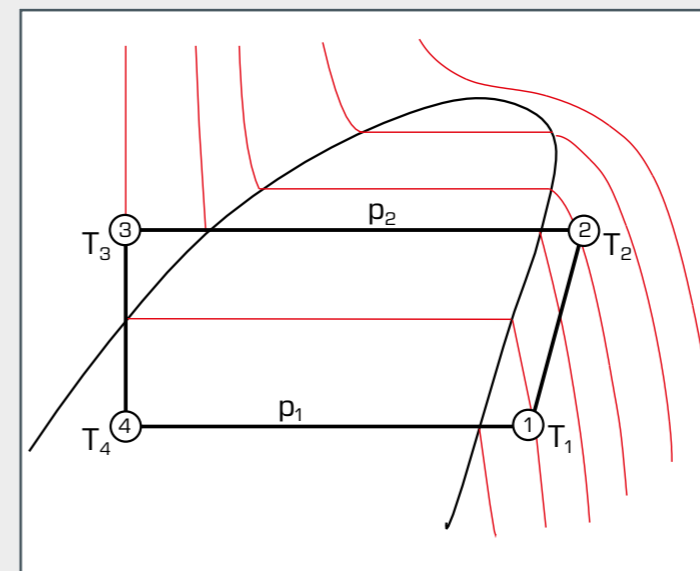
### Step 2: plot compression process



After the limiting isobars have been plotted in the diagram, the compression process can now be plotted.

- identifying the point of intersection of the isobars  $p_1$  with the temperature at the compressor inlet  $T_1$  gives the state point **1**.
- identifying the point of intersection of the isobars  $p_2$  with the temperature at the condenser inlet  $T_2$  gives the state point **2**.
- the connection between the two state points **1** and **2** describes the compression process.

### Step 3: plot the isenthalpic expansion

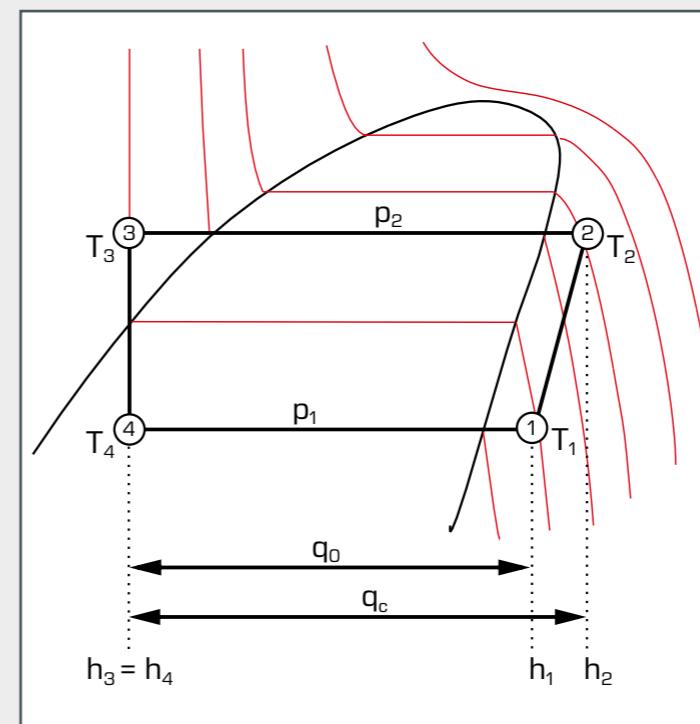


The expansion process is plotted in the diagram as follows:

- identifying the point of intersection of the isobars  $p_2$  with the temperature  $T_3$  at the condenser outlet gives the state point **3**.

The expansion is an isenthalpic process. Therefore, the previously marked intersection point can be connected to the isobars  $p_1$  by a vertical line. This results in the last state point **4** with the evaporation temperature  $T_4$ .

### Step 4: reveal the specific enthalpy values



When calculating operating states of a refrigeration plant, it is necessary to determine the specific enthalpies of the individual changes of state. The procedure is as follows:

The specific enthalpy can be read off using a vertical connection of the state points and the x-axis.

- $h_1$  spec. enthalpy after evaporator
- $h_2$  spec. enthalpy after compressor
- $h_3$  spec. enthalpy after condenser
- $h_4$  spec. enthalpy after expansion valve

The specific refrigeration capacity  $q_0$  and the specific condensation capacity  $q_c$  can be read directly from the log p-h diagram.

specific refrigeration capacity  $q_0 = h_1 - h_4$

specific condensation capacity  $q_c = h_2 - h_3$

**ET 351C**

## Thermodynamics of the refrigeration circuit



## Description

- **compression refrigeration system for thermodynamic investigations**
- **indirectly heated evaporator and water-cooled condenser**
- **open compressor with pendulum bearing drive motor for torque measurement**

In this trainer, great care was taken to make the thermodynamic processes in the refrigeration system as transparent as possible. The capacities of compressor, evaporator and condenser can be measured. Pressure and temperature measuring points are located at all the relevant locations to also allow for the pressure and heat losses in a refrigeration system to be investigated in detail.

The refrigeration circuit of ET 351C contains an open compressor with variable speed, a water-cooled condenser, a thermostatic expansion valve and an evaporator heated by a hot water circuit.

The compressor is driven via a pendulum bearing motor with frequency converter for speed adjustment. A force transducer permits the measuring of the drive torque. Using the speed the mechanical drive power of the compressor can thus be determined. The electrical heating power of the hot water circuit can be freely adjusted and is displayed. The condenser capacity is measured via the cooling water flow.

The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included. The software allows for the process to be represented in the log p-h diagram and displays the key characteristic variables of the process, e.g. compressor pressure ratio and coefficient of performance.

## Learning objectives/experiments

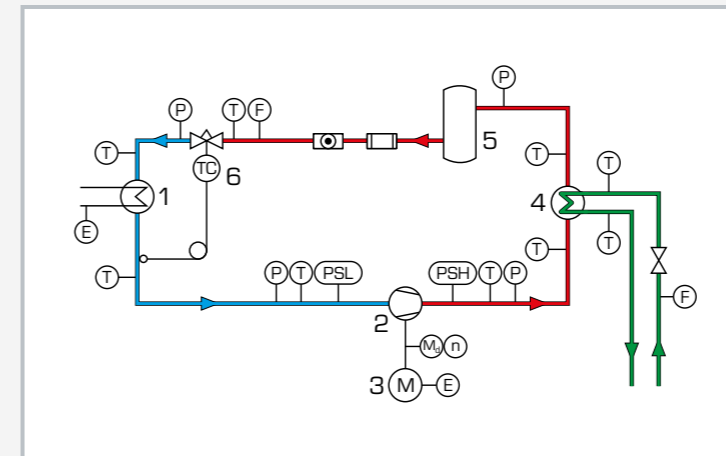
- cyclic process in the log p-h diagram
- comparison of the real cyclic process and the ideal cyclic process
- balances at the evaporator and condenser
- calculation of the motor power via speed and torque
- determination of losses
- calculation of the coefficient of performance
- operating behaviour under load
- non-steady-state operating behaviour

**ET 351C**

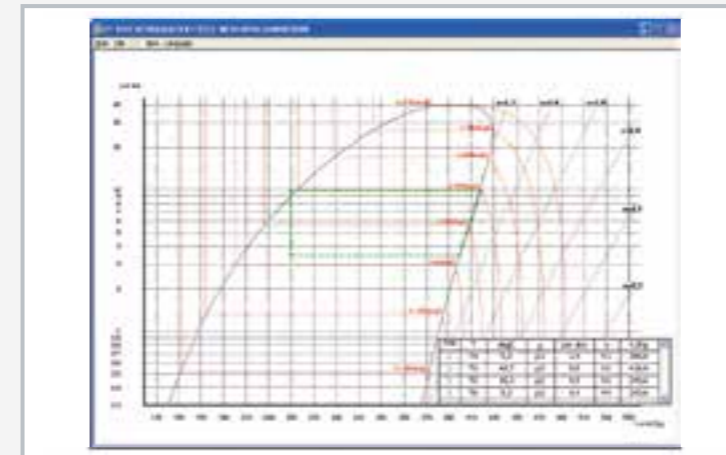
## Thermodynamics of the refrigeration circuit



1 expansion valve, 2 evaporator, 3 refrigerant flow meter, 4 pressure switch, 5 process schematic, 6 receiver, 7 hot water circuit of the evaporator, 8 drive motor, 9 compressor, 10 cooling water flow meter, 11 condenser, 12 displays and controls



1 evaporator, 2 compressor, 3 drive motor, 4 condenser, 5 receiver, 6 expansion valve; P pressure, T temperature, F flow rate,  $M_t$  torque, n speed, E electrical power; PSL, PSH pressure switch; blue: low pressure, red: high pressure, green: cooling water



Software screenshot: log p-h diagram

## Specification

- [1] thermodynamic investigation of a refrigeration circuit
- [2] refrigeration circuit with open compressor, water-cooled condenser, thermostatic expansion valve and indirectly heated evaporator
- [3] compressor drive with speed-controlled motor via V-belt
- [4] motor on pendulum bearing for torque measurement
- [5] tube evaporator with hot water circuit as cooling load
- [6] water-cooled coaxial coil heat exchanger as condenser
- [7] displays for temperature, pressure, flow rate, speed, torque and power at the equipment
- [8] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
- [9] refrigerant R513A, GWP: 631

## Technical data

Open compressor

- refrigeration capacity: approx. 965W (at a speed of  $1450\text{min}^{-1}$  and  $5/40^\circ\text{C}$ )

Heater: 1x 1000W

Condenser, capacity: 1300W

Refrigerant

- R513A, GWP: 631, filling volume: 2kg,  $\text{CO}_2$ -equivalent: 1,3t

Measuring ranges

- temperature: 9x  $-30\text{...}100^\circ\text{C}$ , 1x  $0\text{...}100^\circ\text{C}$
- pressure: 1x  $-1\text{...}9\text{bar}$ , 1x  $-1\text{...}24\text{bar}$ , 4x  $-1\text{...}15\text{bar}$
- torque: (compressor)  $0\text{...}10\text{Nm}$
- speed: (compressor)  $0\text{...}2500\text{min}^{-1}$
- power consumption: (compressor)  $0\text{...}1125\text{W}$
- power: (heater)  $0\text{...}1125\text{W}$
- flow rate: (water)  $5\text{...}70\text{g/s}$
- flow rate: (refrigerant)  $0\text{...}0,5\text{L/min}$

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase; 230V, 60Hz, 3 phases

UL/CSA optional

LxWxH: 1520x790x1760mm

Weight: approx. 120kg

## Required for operation

water connection, drain

PC with Windows recommended

## Scope of delivery

- 1 trainer
- 1 set of hoses, 1 manual pump
- 1 GUNT software CD + USB cable
- 1 set of instructional material



**ET 412C**

## Refrigeration system with refrigeration and freezing chamber

**Description**

- refrigeration system with two different evaporation pressures
- simulation of 18 faults

Identifying faults in refrigeration systems requires comprehensive knowledge. This includes knowledge of the structure and the task of the individual components. With ET 412C, the design and components of a refrigeration system can be examined. The simulation of typical errors extends the scope of the experiment.

The components of a refrigeration circuit with refrigeration and freezing chambers are arranged clearly in the trainer. Solenoid valves enable the individual or parallel operation of the evaporators in the two chambers. The circuit is equipped with a combined pressure switch for the delivery and intake side of the compressor. The refrigeration chamber features an evaporation pressure controller. The effect of the evaporation pressure controller on the overall process is being examined. An inner heat exchanger in the inlet of the two evaporators is used for supercooling the refrigerant to increase the efficiency of the process. At the same time the intake gas is superheated.

An electric defrost heater is available to defrost the freezing chamber. The simulation of 18 different faults, e.g. faulty solenoid valves or faulty relays, is provided for.

The process schematic at the trainer offers a quick overview. Signal lamps in the process schematic indicate the operating state of selected components.

Relevant measured values are recorded by sensors. The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included. The refrigerant mass flow rate is calculated in the software from the recorded measured values.

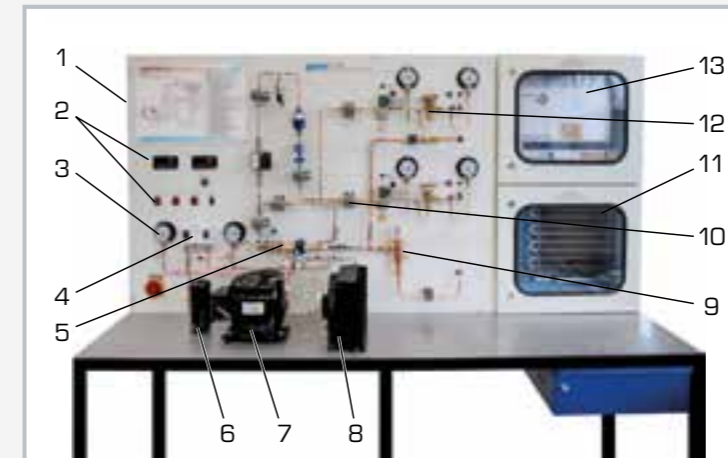
The most important pressures are additionally indicated with manometers directly at the trainer. The software enables the representation of the cyclic process in the log p-h diagram.

**Learning objectives/experiments**

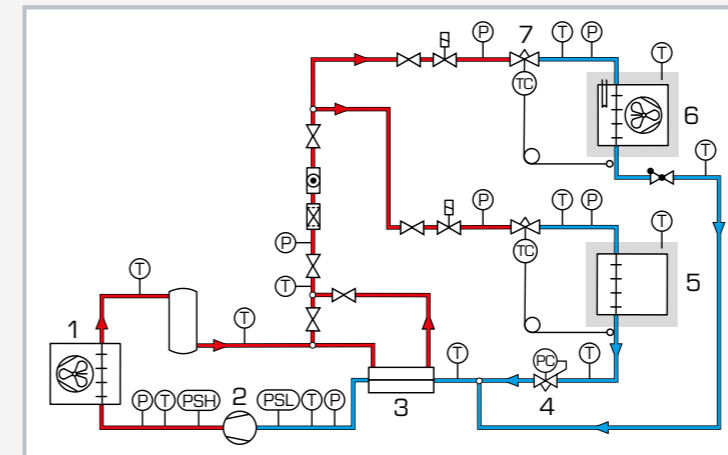
- design and components of a refrigeration system with 2 evaporators
- components and their functions
  - ▶ compressor, condenser, evaporator
  - ▶ thermostatic expansion valve
  - ▶ evaporation pressure controller
  - ▶ pressure switch
  - ▶ electric defrost heater
- thermodynamics of the refrigeration cycle
  - ▶ effect of refrigerant supercooling
  - ▶ representation of the thermodynamic cycle in the log p-h diagram
  - ▶ determination of important characteristic variables: coefficient of performance, refrigeration capacity, compressor work
- fault finding in refrigeration system components

**ET 412C**

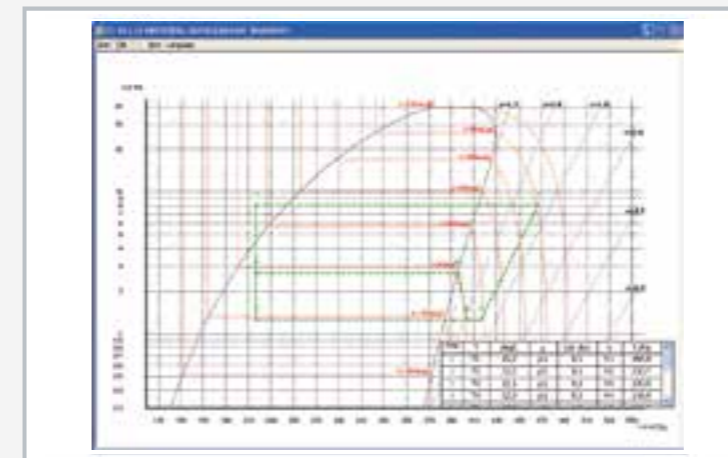
## Refrigeration system with refrigeration and freezing chamber



1 fault button, 2 displays and controls with process schematic, 3 manometer, 4 pressure switch, 5 heat exchanger, 6 receiver, 7 compressor, 8 condenser with fan, 9 evaporation pressure controller, 10 valve, 11 refrigeration chamber, 12 expansion valve, 13 freezing chamber



1 condenser, 2 compressor, 3 heat exchanger, 4 evaporation pressure controller, 5 refrigeration chamber, 6 freezing chamber with defrost heater, 7 expansion valve; T temperature, P pressure, F flow rate, PSH, PSL pressure switch



Software screenshot: log p-h diagram with 2 different evaporation pressures

**Specification**

- [1] investigation of a refrigeration system with refrigeration and freezing chambers
- [2] refrigeration circuit with compressor, condenser and 2 evaporators with thermostatic expansion valve and evaporation pressure controller
- [3] insulated freezing chamber with fan and electric defrost heater
- [4] insulated refrigeration chamber with evaporation pressure controller
- [5] heat exchanger for refrigerant supercooling
- [6] individual or parallel operation of the chambers via solenoid valves
- [7] sensors record pressure and temperature
- [8] refrigerant mass flow rate calculated in the software from recorded measured values
- [9] simulation of 18 faults
- [10] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
- [11] refrigerant R513A, GWP: 631

**Technical data****Compressor**

- power consumption: 565W at 7,2/54,4°C
- refrigeration capacity: 1363W at 7,2/54,4°C

**Condenser with fan**

- volumetric air flow rate: 290m<sup>3</sup>/h
- transfer area: 1,5m<sup>2</sup>

**Refrigeration chamber**

- evaporator transfer area: 1,06m<sup>2</sup>

**Freezing chamber**

- evaporator transfer area: 2,42m<sup>2</sup>
- volumetric air flow rate, fan: 135m<sup>3</sup>/h
- electric defrost heater: approx. 150W

Evaporation pressure controller: 0...5,5bar

**Refrigerant: R513A, GWP: 631**

- filling volume: 1,5kg
- CO<sub>2</sub>-equivalent: 0,9t

**Measuring ranges**

- temperature: 12x -50...120°C
- pressure: 3x -1...15bar, 3x -1...9bar, 3x -1...24bar
- power: 0...1125W
- flow rate: 1...11,5L/h

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 2000x660x1900mm  
Weight: approx. 219kg

**Required for operation**

PC with Windows recommended

**Scope of delivery**

- 1 trainer
- 1 GUNT software CD + USB cable
- 1 set of instructional material

## ET 430

### Refrigeration system with two-stage compression



The illustration shows a similar unit

#### Description

- **compression refrigeration system with two-stage compression to achieve particularly low temperatures**
- **injection intercooling**
- **heat exchanger for additional refrigerant supercooling**
- **real-time representation of the process in the log p-h diagram of the software**

Refrigeration systems with two-stage compression are used for the generation of particularly low temperatures. At very low temperatures large pressure differences are required between the evaporator and condenser. In a compressor the volumetric efficiency drops significantly at high pressure ratios.

Therefore, two compressors are connected in series, with each compressor only having a relatively low pressure ratio. This makes a more favourable dimensioning of the low pressure stage compressor possible. Due to the large specific volume it requires a larger capacity at lower drive power.

In addition, intercooling between the low pressure compressor (LP) and the high pressure compressor (HP) reduces the

outlet temperature of the HP compressor to harmless values and improves the efficiency of the compression.

The trainer ET 430 uses injection intercooling. A small amount of liquid refrigerant is injected from the receiver into the outlet line of the LP compressor. The liquid refrigerant evaporates and thus cools the intake gas for the HP compressor. Via an add-on heat exchanger in the injection cooler the supercooling of the liquid refrigerant can be increased upstream of the expansion valve. This allows for an increase in the evaporator capacity.

Valves allow for the injection intercooling or the heat exchanger for refrigerant supercooling to be switched off. This can demonstrate their effect on the system.

All relevant measured values are recorded by sensors and displayed. The simultaneous transmission of the measurements to the GUNT software enables analysis and the representation of the process in the log p-h diagram in real time. Additionally, two flow meters indicate the total volumetric flow rate and the volumetric flow rate in the intercooling.

#### Learning objectives/experiments

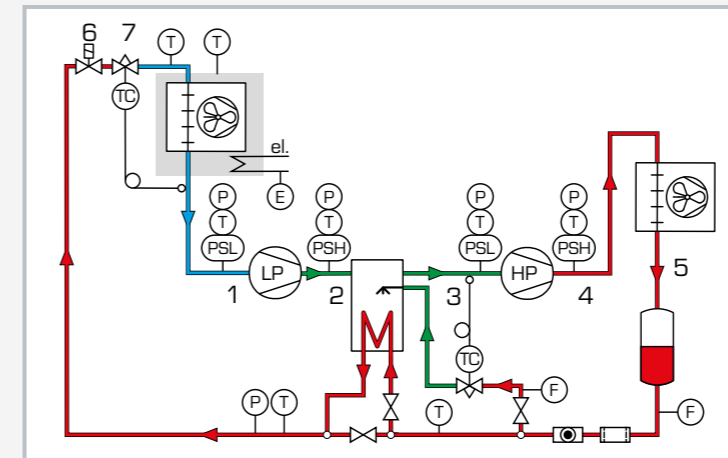
- design and function of a refrigeration system with two-stage compression and injection intercooling
- effect of the inlet temperature at the HP compressor on the efficiency of the compression
  - ▶ with intercooling
  - ▶ without intercooling
- effect of the additional refrigerant intercooling
- distribution of the compressor pressure ratios
- represent and understand the refrigeration cycle process in the log p-h diagram

## ET 430

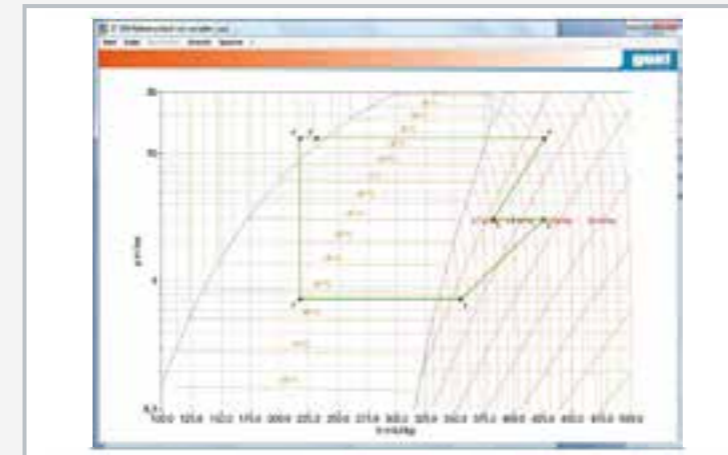
### Refrigeration system with two-stage compression



1 expansion valve, 2 refrigeration chamber, 3 displays and controls, 4 pressure switch, 5 injection valve, 6 injection cooler, 7 LP compressor, 8 HP compressor, 9 receiver, 10 flow meter, 11 heat exchanger, 12 condenser



1-2 LP compression, 2-3 intercooling, 3-4 HP compression, 4-5 condensation, 5-6 supercooling, 6-7 expansion, 7-1 evaporation;  
T temperature, P pressure, E electrical power, F flow rate, PSL, PSH pressure switch



Software screenshot of a real system process

#### Specification

- [1] refrigeration system with two-stage compression
- [2] hermetic low and high pressure compressors
- [3] adjustable intercooling via refrigerant injection
- [4] heat exchange for additional supercooling of the liquid refrigerant
- [5] closed refrigeration chamber contains evaporator with fan and adjustable electric heater as cooling load
- [6] digital display for temperatures, drive power of the compressors and cooling load power
- [7] real-time representation of the process in the log p-h diagram of the software
- [8] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
- [9] refrigerant R449A, GWP: 1397

#### Technical data

##### Low pressure compressor (LP)

- power consumption: 275W at -10/55°C
- refrigeration capacity: 583W at -10/55°C

##### High pressure compressor (HP)

- power consumption: approx. 841W at -25/55°C
- refrigeration capacity: 702W at -25/55°C

##### Refrigerant

- R449A
- GWP: 1397
- filling volume: 1,29kg
- CO<sub>2</sub>-equivalent: 1,8t

##### Measuring ranges

- flow rate: 2...29L/h, 4...40L/h
- pressure: 1x -1...15bar, 2x -1...24bar
- temperature: 8x -75...125°C
- power:
  - ▶ 0...562W (heater)
  - ▶ 0...750W (LP compressor)
  - ▶ 0...2250W (HP compressor)

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase  
230V, 60Hz, 3 phases  
UL/CSA optional  
LxWxH: 1900x790x1900mm  
Weight: approx. 283kg

#### Required for operation

PC with Windows recommended

#### Scope of delivery

- 1 trainer
- 1 GUNT software CD + USB cable
- 1 set of instructional material



## ET 441

### Refrigeration chamber and defrosting methods



#### Description

- combined refrigeration and freezing chamber with temperature and humidity measurement
- evaporators of different sizes
- different defrosting methods
- dynamic recording of the refrigerant mass flow rate

The climate in the cold storage room has a significant effect on the quality of the products stored there. This climate depends on different influences, such as the surface temperature of the evaporators, cold storage room temperature, degree of evaporator icing, quantity and type of refrigerated goods etc.

The icing of the evaporators depends on the evaporator and room temperatures and the quantity of humidity introduced by the refrigerated goods. Icing of the evaporators significantly reduces the refrigeration capacity and must therefore be prevented as much as possible by periodic defrosting, i.e. heating the evaporator surfaces. In addition to the periodic defrosting at set times, there is defrosting performed as required by measuring the actual ice coating. The evaporator surface can be heated from the outside by electric heating or from the inside by hot gas directly from the refrigerant compressor.

The trainer features a large refrigeration chamber. Two evaporators allow for an investigation of the effect of different evaporator sizes on the cold storage room climate and the icing. An electric defrost heater and hot gas defrosting are available. The defrost process can be performed as required using a defrost controller or at set intervals using a defrost timer.

Two adjustable heat sources in the refrigeration chamber simulate the cooling load. One of these heat sources generates water steam to simulate the introduction of humidity into the refrigeration chamber.

The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB.

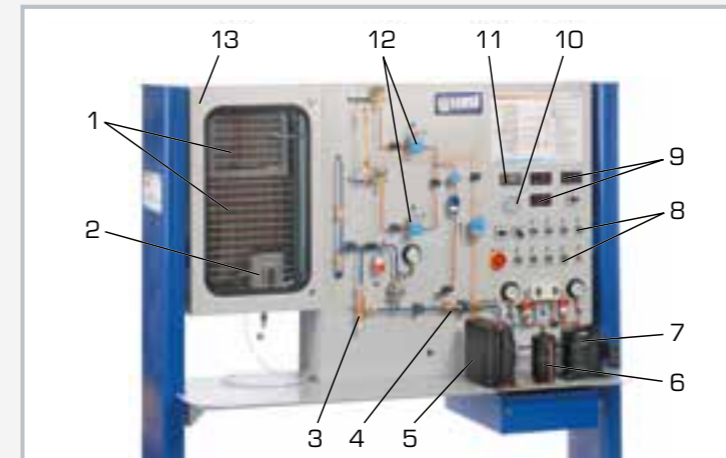
The data acquisition software is included. The data acquisition enables e.g. the recording of the defrosting process over time and the online representation of the climate in the refrigeration chamber in the h-x diagram. The refrigerant mass flow rate is calculated in the software from the recorded measured values.

#### Learning objectives/experiments

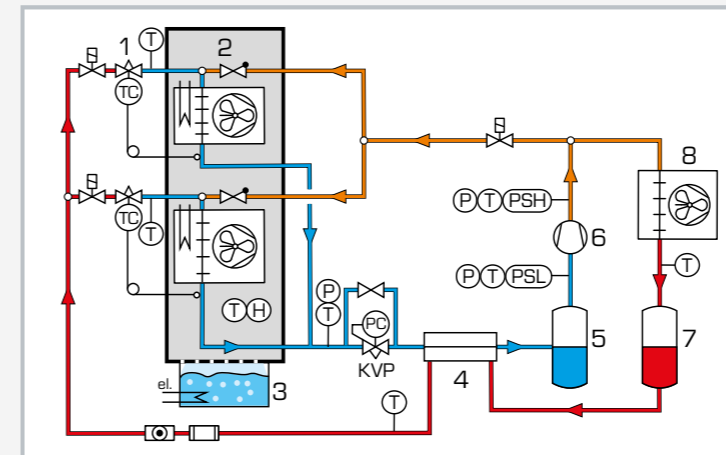
- effect of the evaporator size and temperature on the climate in the refrigeration chamber
- frosting and icing under different operating conditions
- difference between latent and sensitive cooling load
- different defrosting methods (electric heater, hot gas)
- configuration of defrost controls such as defrost timer or defrost controller

## ET 441

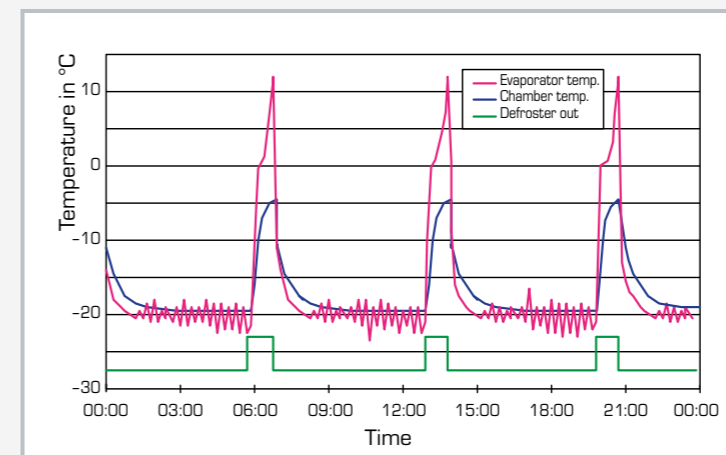
### Refrigeration chamber and defrosting methods



1 evaporator, 2 humidifier, 3 evaporation pressure controller, 4 heat exchanger, 5 condensing unit, 6 receiver, 7 compressor, 8 controls, 9 temperature and humidity displays, 10 defrost timer, 11 defrost controller, 12 solenoid valves to select the evaporators, 13 refrigeration chamber



Process schematic with hot gas defrosting (orange); 1 expansion valve, 2 refrigeration chamber with 2 heat exchangers of different size, 3 steam humidifier, 4 heat exchanger, 5 liquid separator, 6 condenser, 7 receiver, 8 condenser; T temperature, P pressure, H humidity, PSH, PSL pressure switch



Time progression of a defrost control (green) with temperature of evaporator (red) and refrigeration chamber (blue)

#### Specification

- [1] refrigeration system to investigate the climate in the refrigeration chamber and different defrosting methods
- [2] 2 evaporators, separately switchable via solenoid valves
- [3] electric defrost heater
- [4] hot gas defrosting
- [5] defrost controller and defrost timer
- [6] latent and sensitive cooling load
- [7] evaporation pressure and temperature adjustable
- [8] heat exchanger as superheater and for refrigerant supercooling
- [9] digital display for temperature and humidity in the refrigeration chamber
- [10] refrigerant mass flow rate calculated in the software from recorded measured values
- [11] GUNT software with online representation of the h-x diagram
- [12] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
- [13] refrigerant R513A, GWP: 631

#### Technical data

##### Compressor

- power consumption: 565W at 7,2/54,4°C
- refrigeration capacity: 1363W at 7,2/54,4°C

##### Latent cooling load: 2x 0...250W

Sensitive cooling load: 1x 0...200W, 1x 0...250W  
Receiver: 1,3L

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 1,3kg
- CO<sub>2</sub>-equivalent: 0,8t

##### Measuring ranges

- pressure: 2x 0...16bar, 1x 0...25bar
- temperature: 7x -50...150°C; 1x -25...125°C
- rel. humidity: 0...100%
- flow rate: 0...39kg/h (refrigerant)

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase; 230V, 60Hz, 3 phases

UL/CSA optional

LxWxH: 2000x790x1900mm

Weight: approx. 250kg

#### Required for operation

PC with Windows recommended

#### Scope of delivery

- 1 trainer
- 1 GUNT software CD + USB cable
- 1 set of instructional material

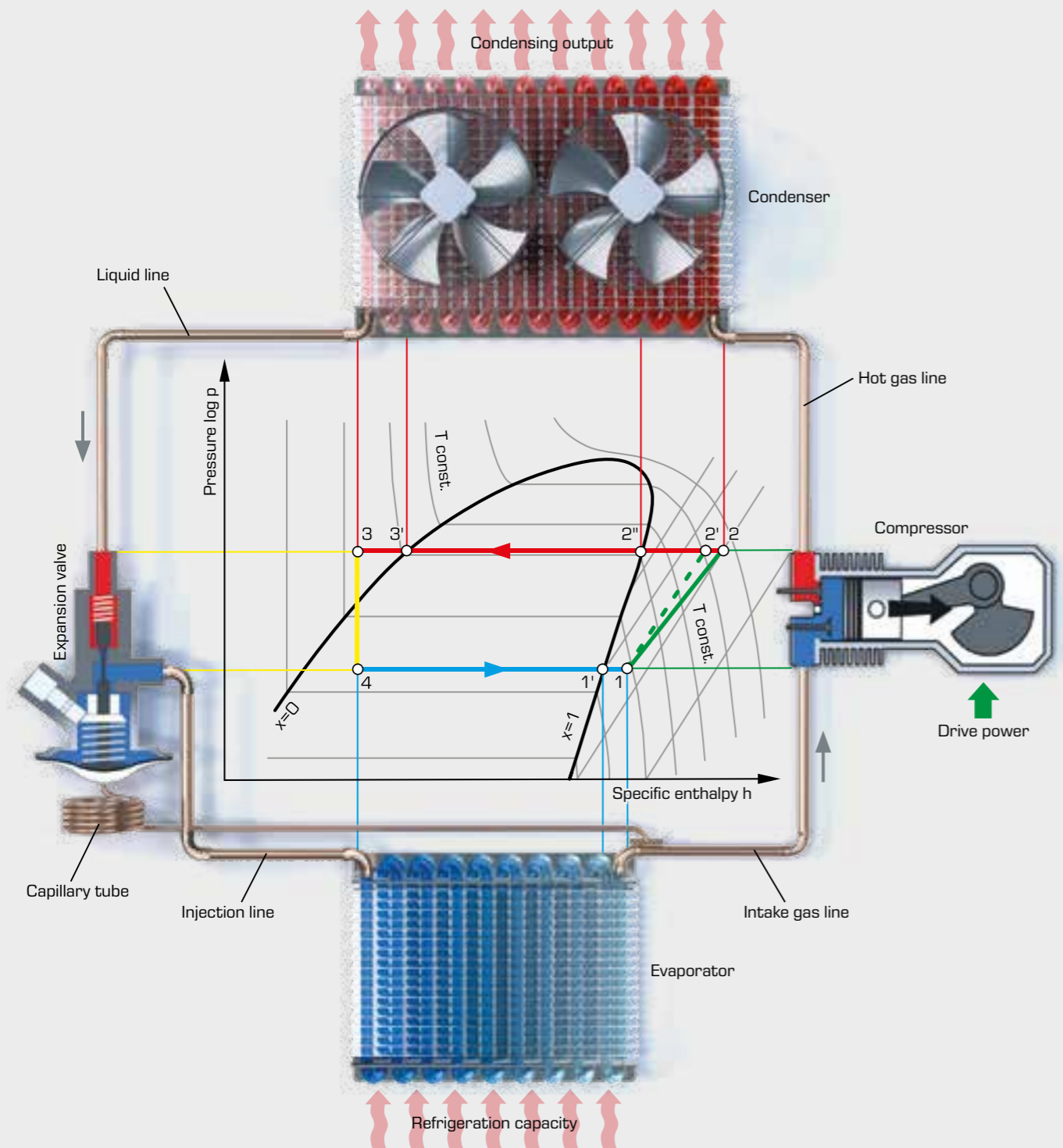
# Components of refrigeration

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<b>ET 180</b> Pressure switches in refrigeration	108	<b>ET 499.21</b> Cutaway model: sight glass with humidity indicator	122		
<b>ET 181</b> Adjustment and operation of expansion valves	110	<b>ET 499.25</b> Cutaway model: 4-way reversing valve	122		
<b>ET 182</b> Secondary controllers in refrigeration systems	112	<b>ET 499.26</b> Cutaway model: condensation pressure control valve	122		



# Components of refrigeration

## Components in the refrigerant circuit



1 – 2 polytropic compression to the condensing pressure (for comparison 1 – 2' isentropic compression)	2 – 2'' isobaric cooling, deheating of the superheated vapour	2'' – 3' isobaric condensation	3' – 3 isobaric cooling, supercooling of the liquid	3 – 4 isenthalpic expansion to the evaporation pressure	4 – 1' isobaric evaporation	1' – 1 isobaric heating, superheating of the vapour
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Experimental units from GUNT show the function of components in the refrigerant circuit and their interaction with each other. Different types of main components such as compressors, evaporators and condensers, as well as primary and secondary controllers are investigated and typical characteristic variables are determined. The functioning of tubes conveying lubricant as well as gaseous and liquid refrigerant is also investigated.

**ET 180**  
Pressure switches in refrigeration

**ET 460**  
Oil return in refrigeration systems

**ET 432**  
Behaviour of a piston compressor

Engineering animations such as **cutaway models** are ideally suited for representing processes and functions. GUNT uses up-to-date original parts for its cutaway models. Movement and switching functions are maintained. The cuts are made in such a way that the design details are clearly visible. The scope of delivery includes a short description and a sectional drawing. This allows the didactic use of the models to be extended to exercises on engineering drawing.

The larger models are clearly mounted on a base plate. Two handles make them easier to transport.

**ET 499.01**  
Cutaway model: hermetic refrigerant compressor

**ET 499.03**  
Cutaway model: open refrigerant compressor, 2-cylinder

**ET 499.18**  
Cutaway model: thermostatic expansion valve

**Assembly exercises, troubleshooting and maintenance** provide students with a particularly high level of real-world relevance and support them with an overall didactic concept in learning manual work on refrigerating plants. This involves the planning, implementation and checking of processes.

**ET 192**  
Replacement of refrigeration components

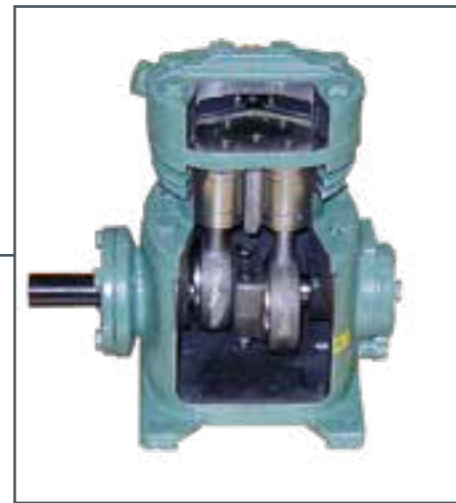
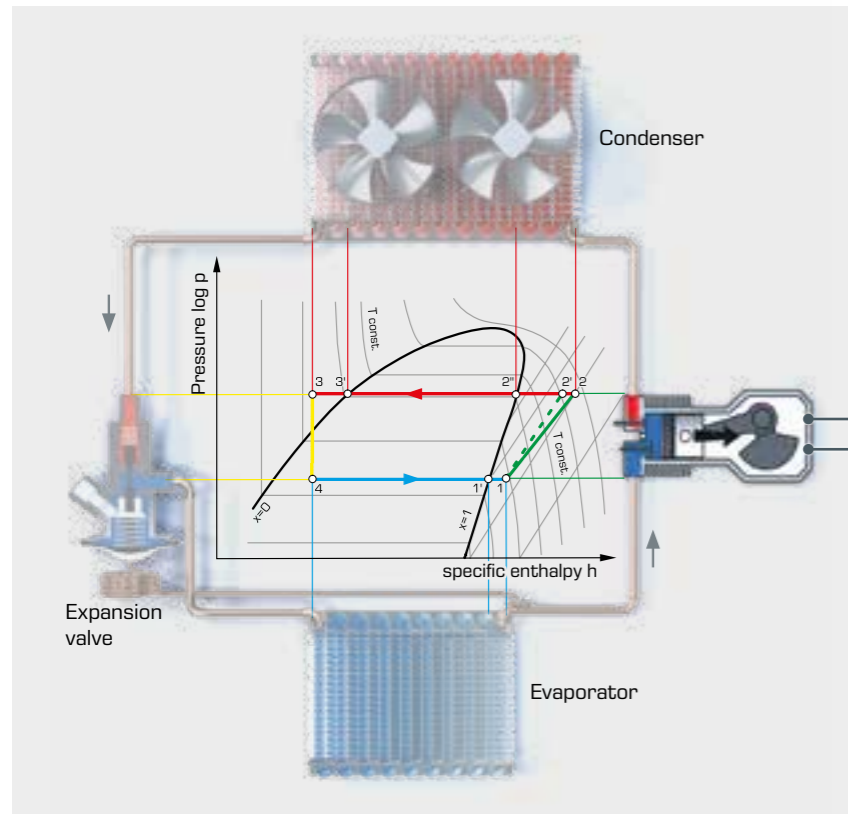
**ET 150.01**  
Refrigerant filling and evacuation equipment

Basic knowledge

# Compressors in refrigeration

Refrigerant compressors compress the gaseous refrigerant from the evaporator pressure level to the condenser pressure level. The mechanical energy is added into the refrigeration cycle via the compressor. Generally the compressors are driven electrically, but there is also the drive via a standard internal combustion engine (vehicle air conditioning system).

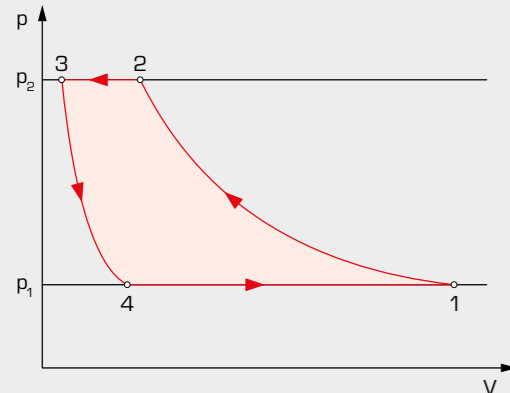
A special case is the steam jet refrigeration system. Here a partial flow of the refrigerant steam is used for the compression itself. Steam jet refrigeration systems are driven thermally and can directly use alternative energy sources such as solar heat or waste heat.



Open 2-cylinder compressor



Hermetic compressor



**p-V diagram of the piston compressor**

The processes in the cylinder can be clearly demonstrated in the p-V diagram. Here the pressure **p** in the cylinder is plotted above the cylinder volume **V**.

- 1 – 2 polytropic compression of pressure **p<sub>1</sub>** to pressure **p<sub>2</sub>**
- 2 – 3 expelling the compressed gas into the pressure pipe
- 3 – 4 polytropic re-expansion of the remaining gas to intake pressure **p<sub>1</sub>**
- 4 – 1 aspiration from the intake pipe

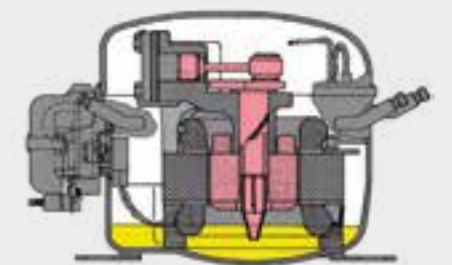
Compressor designs in refrigeration

<b>Piston compressor</b> Small and medium capacities	<b>Screw compressor</b> Medium and high capacities	<b>Scroll compressor</b> Small and medium capacities	<b>Turbo compressor</b> Only for very high capacities	<b>Steam jet compressor</b> Special applications where motive steam is available

Housing designs

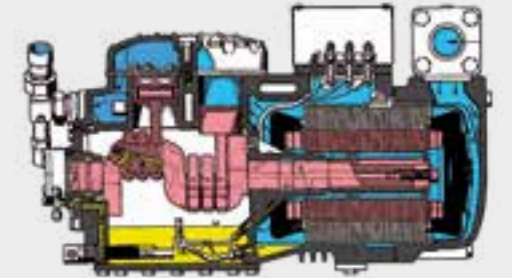
**Hermetic compressor**

- drive motor and compressor in a welded housing without seals (capsule)
- cooling via intake gas
- maintenance-free, must be replaced in case of a fault



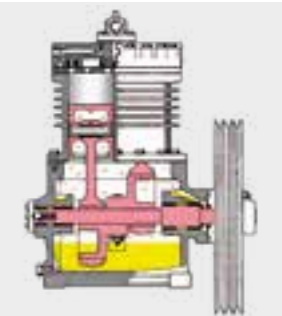
**Semi-hermetic compressor**

- drive motor and compressor in a screwed housing
- cooling via intake gas
- can be repaired if damaged



**Open compressor**

- compressor in a screwed housing
- combined intake gas and air cooling
- drive via an external motor, output can be adjusted via the transmission of the belt drive
- shaft feedthrough prone to failure
- can be repaired if damaged

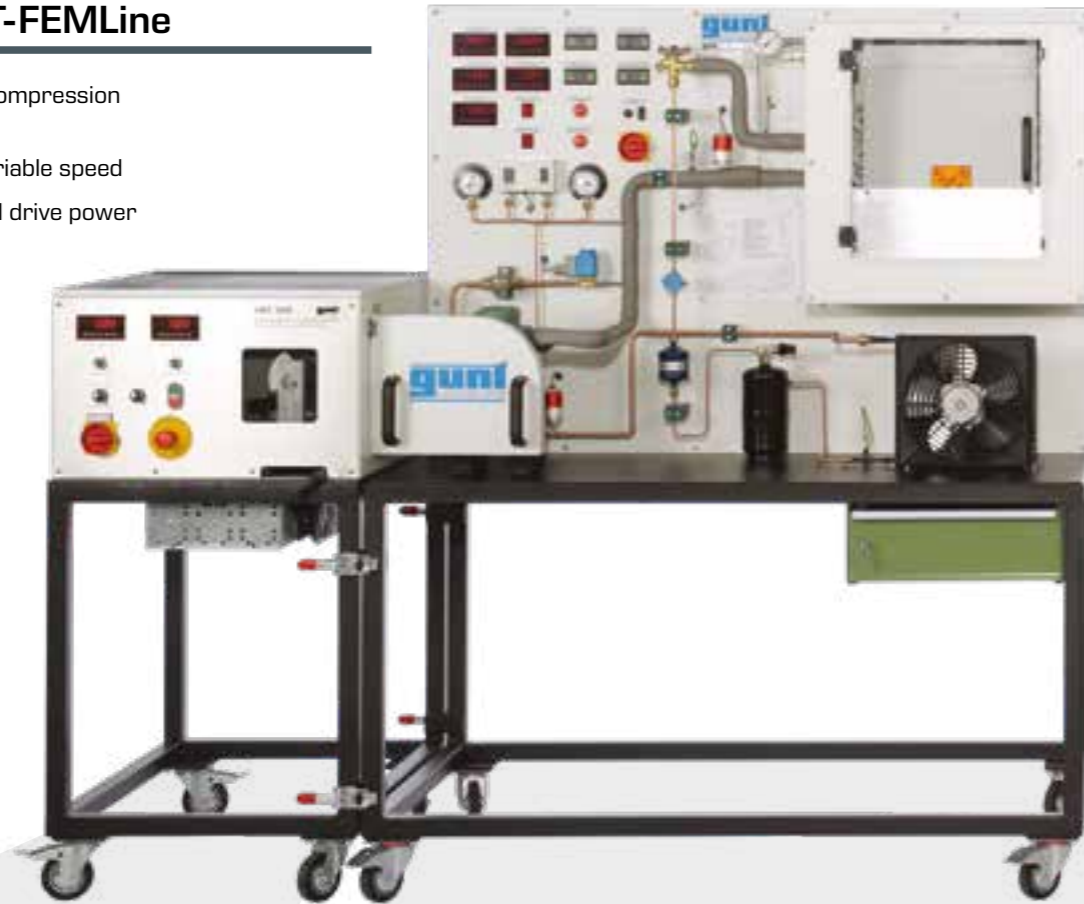




## ET 165 Compression refrigeration system with HM 365

### Part of the GUNT-FEMLine

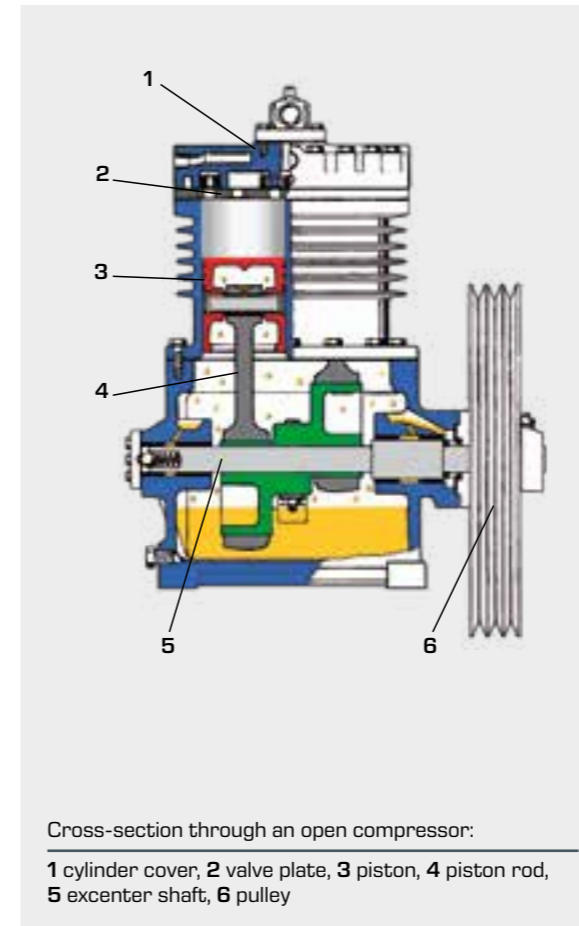
- principle of function of a compression refrigeration system
- open compressor with variable speed
- measuring the mechanical drive power
- determination of the compressor efficiency
- effect of the compressor flow rate on the refrigeration circuit
- drive via the universal drive and brake unit HM 365



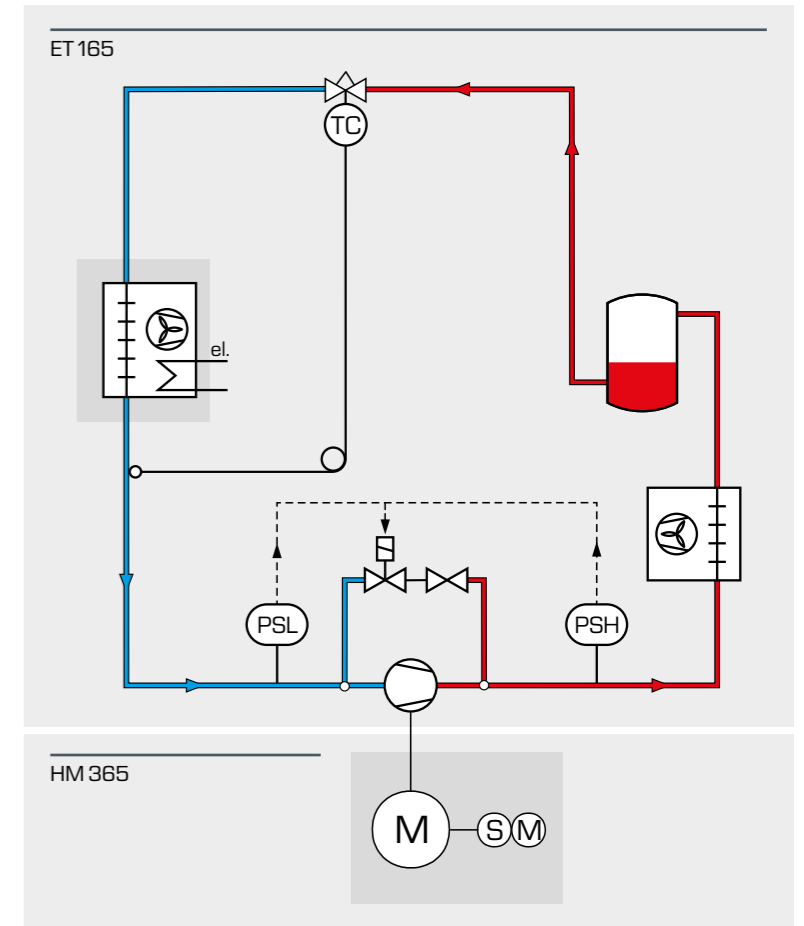
HM 365 Universal drive and brake unit



ET 165 Refrigeration system with open compressor

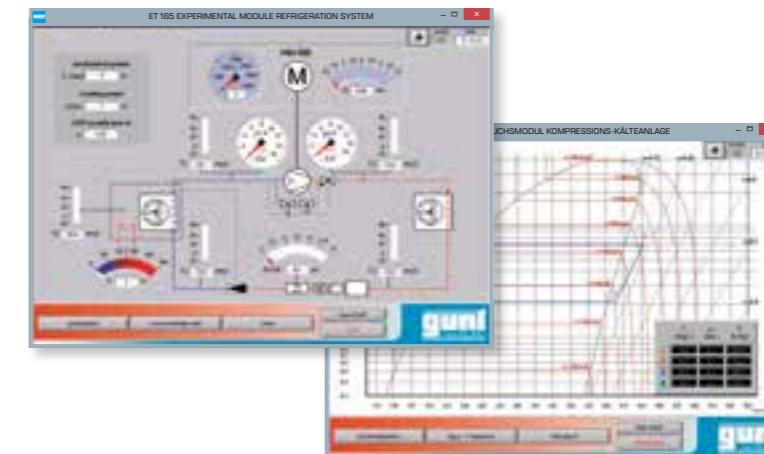


The open compressor of ET 165 is, unlike the hermetic compressor, driven via an external electric motor. Open compressors are used in commercial cooling for medium to high capacities. An advantage is that the flow rate can be easily adjusted via the drive speed. This is done via a speed-controlled electric motor or via different transmissions of the belt drive.



The refrigeration circuit of ET 165 consists of an open compressor, an air-cooled condenser, an expansion valve and an evaporator in a refrigeration chamber. To represent a cooling load, the refrigeration chamber can be heated electrically. Pressure switches protect the compressor against too high or too low pressures by opening a bypass to the compressor.

The drive speed of the compressor is adjustable. This examines the effect of different delivery capacities on the refrigeration system. By measuring the drive speed and drive torque the compressor can be thoroughly examined, e.g. determining the efficiency.



The software enables the clear representation of the measuring data on the PC. Time graphs can be recorded and stored. A very useful property is the display of the cyclic process in the log p-h diagram. Using a spreadsheet program (e.g. MS Excel) the stored data can be analysed. The measured data are transferred to the PC via a USB interface.

## ET 165

### Refrigeration system with open compressor



The illustration shows a similar unit

#### Description

- capacity measurement at the open compressor with variable speed
- refrigeration chamber with adjustable cooling load
- part of the GUNT-FEMLine
- dynamic recording of the refrigerant mass flow rate

ET 165 enables basic experiments in the field of refrigeration. The trainer includes a closed refrigeration circuit with open compressor, a condenser with fan, a thermostatic expansion valve and an evaporator in a refrigeration chamber with transparent door. A fan in the refrigeration chamber ensures an even temperature distribution. A cooling load is simulated by an adjustable heater in the refrigeration chamber.

The drive unit HM 365 drives the compressor via a V-belt. The compressor speed is set at the HM 365. The circuit is equipped with a combined pressure switch for the delivery and intake side of the compressor.

All relevant measured values are recorded by sensors. Digital displays indicate the measured values. The refrigerant mass flow rate is calculated in the software from the recorded measured values. The simultaneous transmission of the measured values to a data recording software enables convenient analysis and the representation of the process in the log p-h diagram. The software also displays the important characteristics variables of the process, such as the refrigeration capacity and the coefficient of performance.

#### Learning objectives/experiments

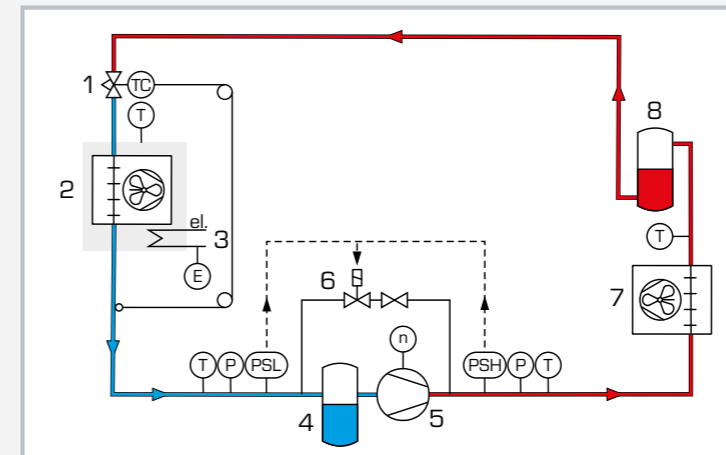
- fundamentals of refrigeration
- design and components of a refrigeration system
  - ▶ open compressor with drive
  - ▶ condenser
  - ▶ evaporator
  - ▶ thermostatic expansion valve
  - ▶ pressure switch
- determination of important characteristic variables
  - ▶ coefficient of performance
  - ▶ compressor capacity
  - ▶ refrigeration capacity
  - ▶ compression ratio
  - ▶ volumetric efficiency
- representation of the thermodynamic cycle in the log p-h diagram
- determination of the compressor efficiency
- effect of the compressor flow rate on the refrigeration circuit

## ET 165

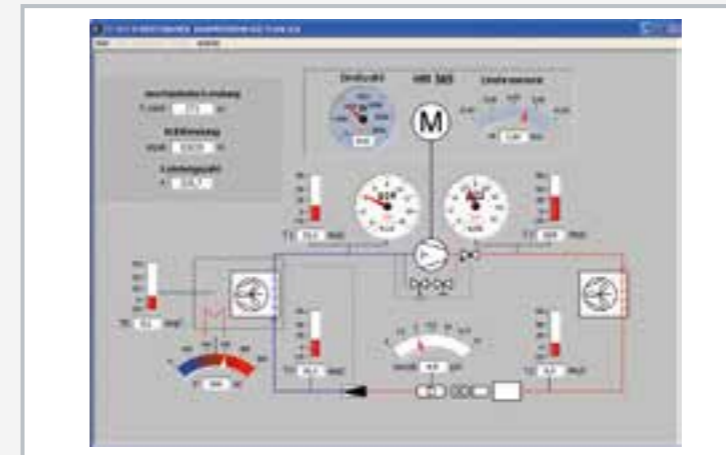
### Refrigeration system with open compressor



1 expansion valve, 2 displays and controls, 3 pressure switch, 4 compressor, 5 condenser, 6 receiver, 7 refrigeration chamber



1 expansion valve, 2 refrigeration chamber, 3 heater, 4 liquid separator, 5 compressor with connection to the HM 365, 6 solenoid valve, 7 condenser, 8 receiver; T temperature, P pressure, PSL, PSH pressure switch, n speed, E electric power; blue: low pressure, red: high pressure



Software screenshot: process schematic

#### Specification

- [1] investigation of a refrigeration circuit with speed-controlled compressor
- [2] refrigeration circuit with open compressor, condenser, thermostatic expansion valve and evaporator in refrigeration chamber
- [3] cooling load in the refrigeration chamber adjustable via heater
- [4] drive and speed adjustment of the open compressor via HM 365
- [5] condenser and evaporator with fan
- [6] pressure switch to protect the compressor
- [7] sensors for pressure, temperature, power and speed
- [8] refrigerant mass flow rate calculated in the software from recorded measured values
- [9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
- [10] refrigerant R513A, GWP: 631

#### Technical data

Open compressor

- refrigeration capacity: approx. 965W (at speed: 1450min<sup>-1</sup> and 5/40°C)

Condenser with fan transfer area: 2,5m<sup>2</sup>

- capacity: approx. 1935W at 25°C air temperature (ambient) / Δt=15°C

Evaporator

- transfer area: 3,62m<sup>2</sup>

- capacity: 460W at 3°C air temperature (chamber) / Δt=13°C

Heater power: 500W

Refrigerant: R513A

- GWP: 631
- filling volume: 1,7kg
- CO<sub>2</sub>equivalent: 1,1t

Measuring ranges

- temperature: 4x -5...105°C, 1x -50...250°C
- pressure: -1...15bar, -1...24bar
- speed: 0...1000min<sup>-1</sup>
- flow rate: 0...17kg/h (refrigerant)
- power: 0...500W

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase

120V, 60Hz, 1 phase

UL/CSA optional

LxWxH: 1470x800x1850mm

Weight: approx. 185kg

#### Required for operation

PC with Windows recommended

#### Scope of delivery

- 1 trainer
- 1 V-belt
- 1 GUNT software CD + USB cable
- 1 set of instructional material



## ET 432

### Behaviour of a piston compressor



#### Description

- open two-cylinder piston compressor from refrigeration
- record of the pressure/volumetric flow rate characteristic
- measurement of intake volume and pressure ratio
- determination of volumetric and mechanical efficiency

Smaller refrigeration systems usually have a piston compressor. Piston compressors are positive displacement machines. These differ in their characteristics decisively from flow equipment which include the turbo compressors that are common in very large systems.

In piston compressors the flow rate is mainly dependent on the displaced volume and speed. Due to the unavoidable dead space the flow rate drops with increasing pressure ratio. Because the flow rate is a measure for the refrigeration capacity of the refrigeration system, the properties of the compressor are important for the capacity of the whole system.

In this trainer a commercial open refrigerant compressor is operated in an open process with air. The inlet and outlet pressures and thus the pressure ratio can be adjusted via valves in wide ranges. The drive via a frequency converter permits variable speeds. Pressures, temperatures, electric power consumption, speed and torque are recorded. The measured values are transmitted directly to a PC via USB. The data acquisition software is included.

#### Learning objectives/experiments

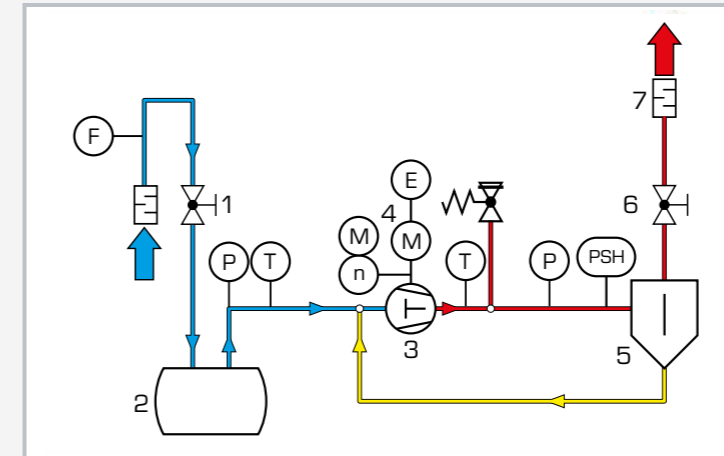
- determine characteristic variables of a piston compressor during experiments
- record of the pressure/volumetric flow rate characteristic
- determination of the volumetric efficiency at different intake pressures, pressure ratios and speeds
- determination of the isothermal compressor capacity
- measurement of the mechanical and electrical power consumption in dependence of the intake pressure and pressure ratio
- determination of the mechanical efficiency and the overall efficiency

## ET 432

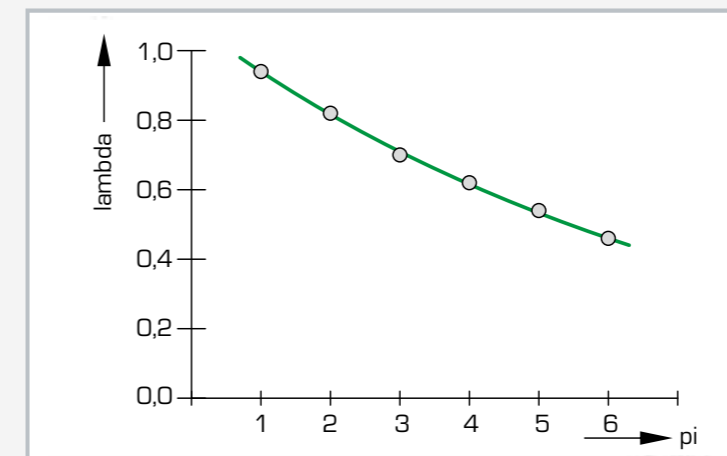
### Behaviour of a piston compressor



1 displays and controls, 2 flow meter, 3 refrigerant compressor, 4 stabilisation tank, 5 drive motor with torque measurement, 6 manometer, 7 oil separator, 8 pressure switch, 9 valve



1 intake side valve, 2 stabilisation tank, 3 compressor, 4 drive motor, 5 oil separator, 6 delivery side valve, 7 silencer; F flow rate, T temperature, P pressure, M torque, n speed, E electric power, PSH pressure switch; blue: low pressure, red: high pressure, yellow: oil return



Progression of the volumetric efficiency lambda in dependence on the pressure ratio pi

#### Specification

- [1] experimental unit for piston compressor from refrigeration
- [2] open process with air
- [3] typical open two-cylinder compressor
- [4] drive via asynchronous motor with frequency converter for speed adjustment
- [5] inlet pressure and outlet pressure (pressure ratio) adjustable via valves
- [6] instruments: 2 manometers, flow meter, sensors for pressure, temperature, speed, torque (via force), flow rate, digital power indication
- [7] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

##### Compressor

- speed: 465...975min<sup>-1</sup>
- number of cylinders: 2
- stroke: 26mm
- borehole: 35mm
- displaced volume: 50cm<sup>3</sup>
- max. displacement: 2,92m<sup>3</sup>/h (at 1450min<sup>-1</sup> motor speed)

##### Drive motor

- power: 550W
- speed: 0...1400min<sup>-1</sup>

##### Measuring ranges

- torque: 0...10Nm
- speed: 0...10000min<sup>-1</sup>
- power: 0...600W
- temperature: 0...100°C, 0...200°C
- flow rate: 0,4...3,2Nm<sup>3</sup>/h
- pressure:
  - ▶ pressure sensor: -1...1,5bar / -1...24bar
  - ▶ manometer: -1...9bar / -1...24bar

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase  
120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1510x790x1750mm  
Weight: approx. 148kg

#### Required for operation

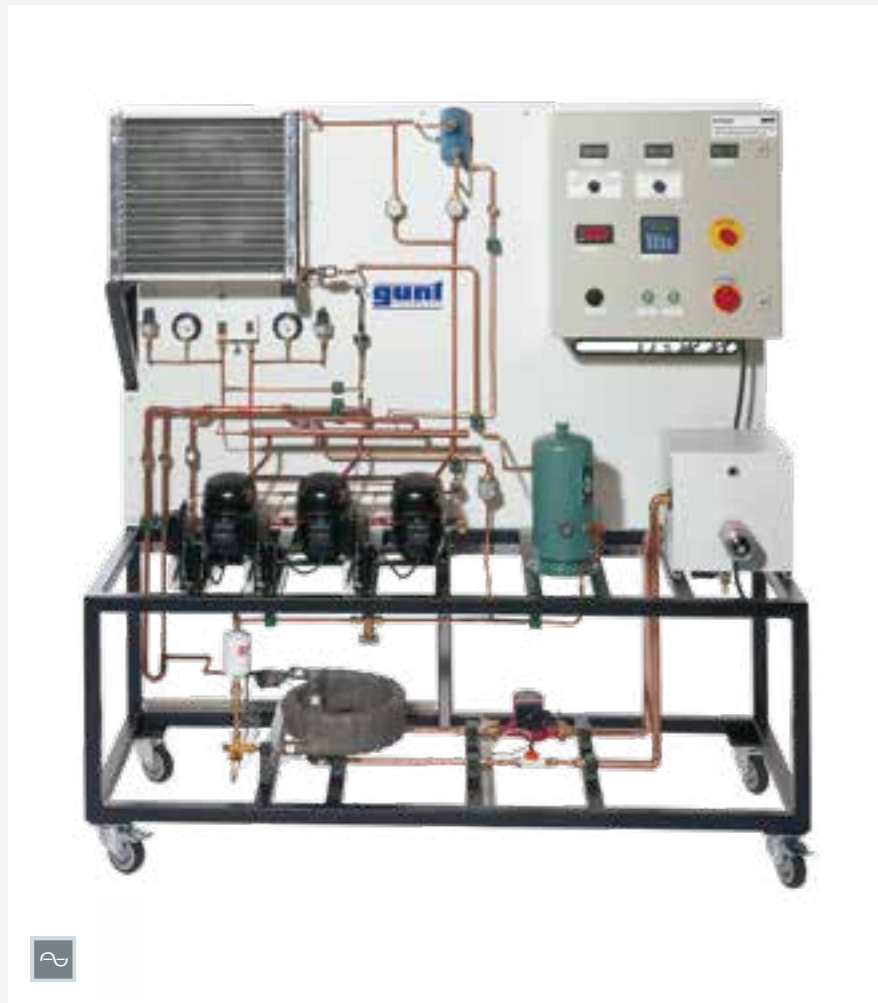
PC with Windows recommended

#### Scope of delivery

- 1 trainer
- 1 GUNT software CD + USB cable
- 1 set of instructional material

## ET 428

### Energy efficiency in refrigeration systems



The illustration shows a similar unit

#### Learning objectives/experiments

- variables affecting energy efficiency
  - ▶ controller parameters
  - ▶ refrigerant supercooling
- interconnected operation of compressors
- operation of a multicompressor controller
- methods for returning oil in a multicompressor refrigeration system
- representation of the thermodynamic cycle in the log p-h diagram

#### Description

- refrigeration system with three compressors in interconnected operation
- ideal adaptation to the capacity requirement by adding and removing individual compressors
- industrial multicompressor controller to add and remove the individual compressors
- add-on heat exchanger for refrigerant supercooling
- monitoring of the lubrication oil transport in the refrigeration circuit

The efficient use of energy in refrigeration is an important topic. A higher capacity requirement is implemented in industry by connecting several small compressors in parallel. This permits the optimum adaptation to the capacity requirement by adding and removing compressors.

ET 428 includes three compressors connected in parallel for this purpose which can be switched on or off via a controller.

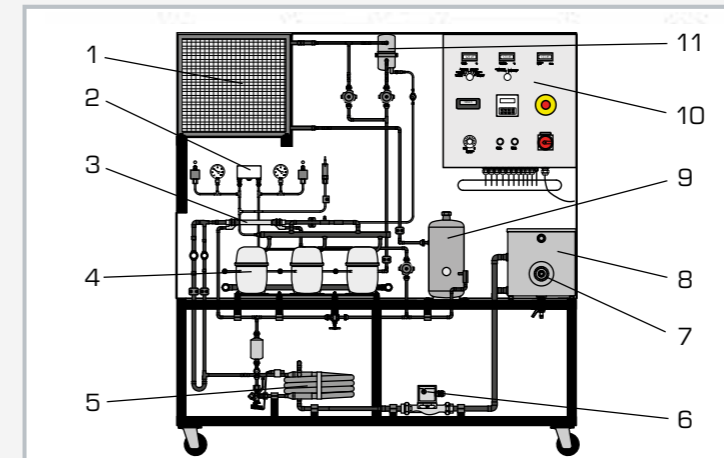
The components of a refrigeration circuit with three compressors are arranged clearly in the trainer. A glycol-water circuit with pump and tank with heater serves as cooling load at the evaporator. An internal heat exchanger in the refrigeration circuit allows for the refrigerant supercooling to be examined for process efficiency. The quantitative analysis of the efficiency takes place using an energy balance in the glycol-water circuit and by measuring the electrical power of the compressors.

To protect the three compressors, the refrigeration circuit is equipped with a combined pressure switch for the delivery and intake sides. To ensure a secure oil supply to the three compressors, an oil separator is provided on the delivery side of the compressors. The separated oil is returned to the compressors on the intake side. The oil is monitored through sight glasses in the respective lines.

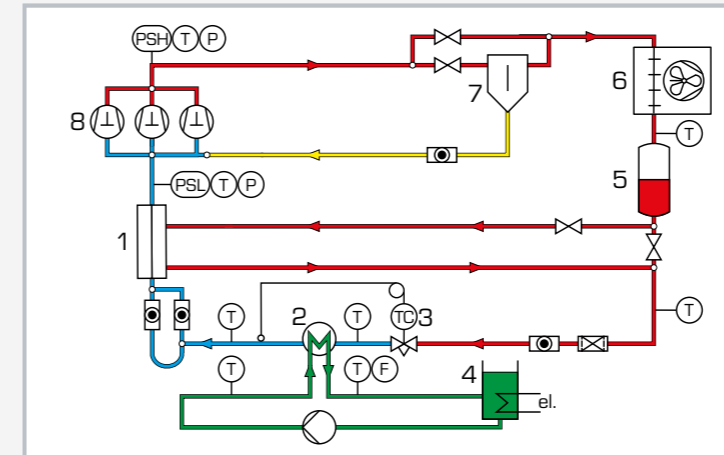
Relevant measured values are recorded by sensors. The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included.

## ET 428

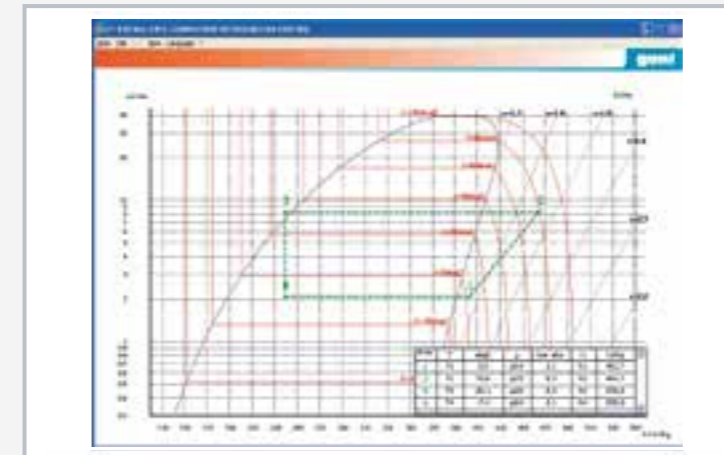
### Energy efficiency in refrigeration systems



1 condenser, 2 pressure switch, 3 heat exchanger, 4 compressor, 5 evaporator, 6 pump, 7 heater, 8 cooling tank (cooling load), 9 receiver, 10 switch cabinet, 11 oil separator



1 heat exchanger, 2 evaporator, 3 expansion valve, 4 cooling tank with heater (cooling load), 5 receiver, 6 condenser, 7 oil separator, 8 compressor; T temperature, P pressure, F flow rate, PSH, PSL pressure switch; blue: low pressure, red: high pressure, green: oil return



Software screenshot: log p-h diagram

#### Specification

- [1] refrigeration system in multicompressor operation to investigate energy efficiency
- [2] refrigeration circuit with 3 compressors connected in parallel, condenser, thermostatic expansion valve and coaxial coil heat exchanger as evaporator
- [3] heat exchanger for refrigerant supercooling can be added via valves
- [4] glycol-water circuit includes pump and tank with heater serving as cooling load at the evaporator
- [5] multicompressor controller for the parallel operation of the compressors
- [6] separation of oil from the refrigerant on the delivery side and return to the intake side of the compressors
- [7] fan at the condenser with adjustable speed
- [8] GUNT software with control functions and data acquisition via USB under Windows 7, 8.1, 10
- [9] refrigerant R513A, GWP: 631

#### Technical data

- 3 compressors
- refrigeration capacity: each 1584W at -10°C/55°C
  - power consumption: each 1156W at -10°C/55°C
- Condenser with fan
- volumetric air flow rate: 1250m<sup>3</sup>/h
- Glycol-water mixture pump
- max. flow rate: 4,2m<sup>3</sup>/h
  - max. head: 5,6m
- Heater power: 3kW
- Tank
- glycol-water mixture: 23L
  - refrigeration circuit receiver: 5,8L

Refrigerant: R513A, GWP: 631

- filling volume: 4,2kg
- CO<sub>2</sub>-equivalent: 2,7t

#### Measuring ranges

- temperature: 4x 0...100°C, 4x -100°C...100°C
- pressure: -1...9bar, -1...24bar
- flow rate: 1...25L/min (water)
- power: 0...4995W (compressor)

400V, 50Hz, 3 phases  
400V, 60Hz, 3 phases; 230V, 60Hz, 3 phases  
UL/CSA optional  
LxWxH: 1810x710x1920mm  
Weight: approx. 265kg

#### Required for operation

PC with Windows recommended

#### Scope of delivery

- 1 trainer
- 1 GUNT software CD + USB cable
- 1 set of instructional material



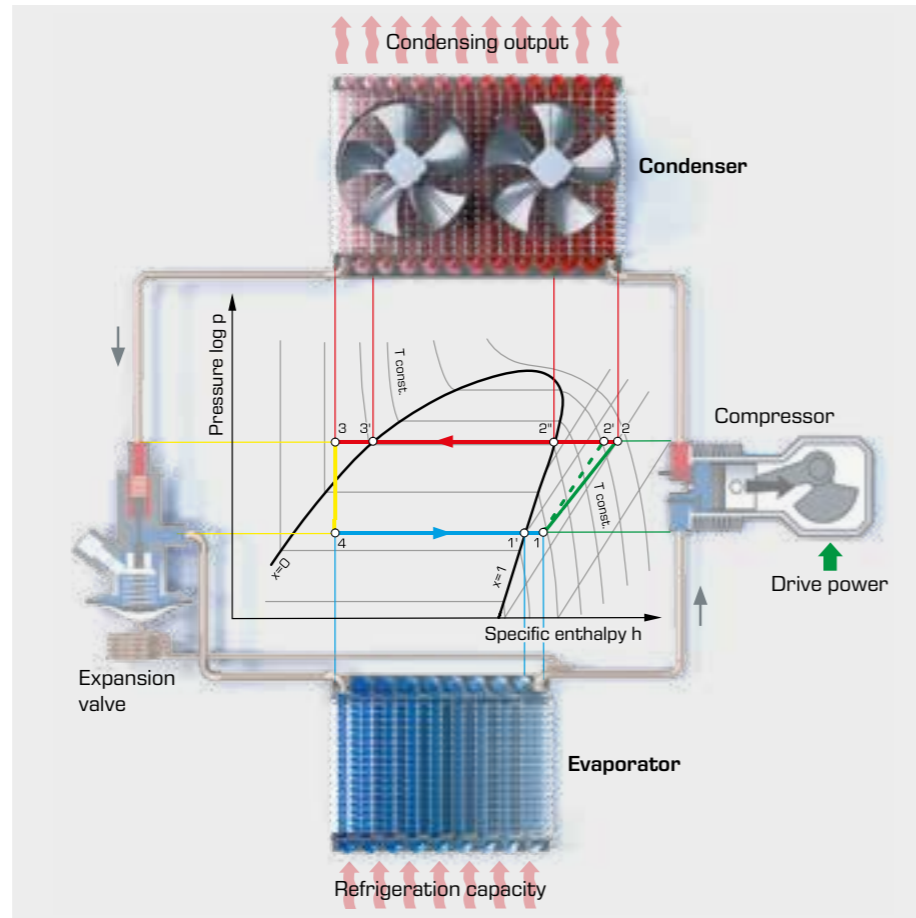
Basic knowledge

# Heat exchangers in refrigeration used as evaporator / condenser

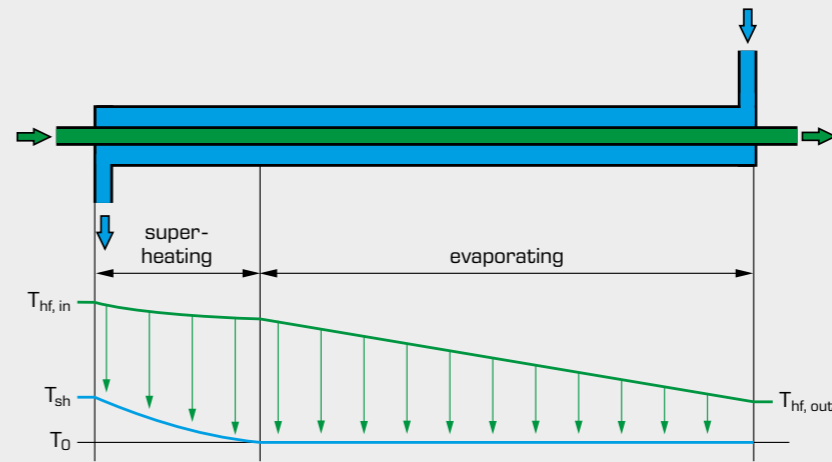
In principle heat exchangers have the purpose to transfer heat from a flowing substance to another flowing substance of a lower original temperature. The substances are gaseous or liquid.

Important for the heat transfer is the temperature difference of the two media as a driving gradient. Dependent on the flow direction (e.g. counterflow, parallel flow) the progression of the temperature difference along the path can be different.

In refrigeration engineering, heat exchangers are equally used as **evaporators** and as **condensers**. In both applications, the refrigerant undergoes a phase transition.



## Heat transfer in the evaporator



Energy processes in the evaporator (counterflow)

- $T_0$  evaporation temperature, refrigerant
- $T_{hf, in}$  inlet temperature, hot medium
- $T_{hf, out}$  outlet temperature, hot medium
- $T_{sh}$  superheating temperature, refrigerant
- refrigerant, ■ heating fluid

The energy processes in an evaporator can be assigned to two different areas.

### 1. Evaporating

The refrigerant absorbs the heat from the medium and evaporates. The temperature of the refrigerant remains constant despite heat absorption. The absorbed energy is used for the phase change.

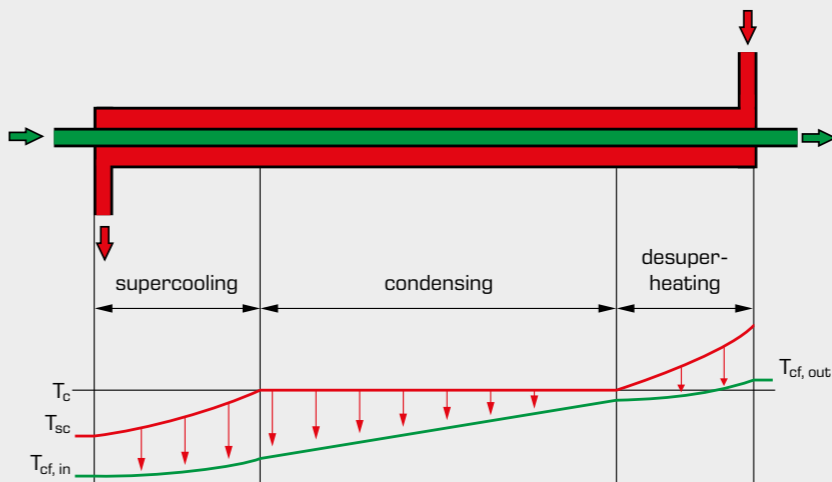
### 2. Superheating

The already completely evaporated refrigerant continues to absorb heat and is heated up in the process. Superheated refrigerant steam is found at the outlet. This operating superheat determines the degree of utilisation of the evaporator and can be adjusted via the expansion valve.

## Overview of different heat exchanger types

Type	Application
<b>Tubular heat exchanger</b> 	<ul style="list-style-type: none"> <li>■ internal heat exchanger for supercooling the refrigerant</li> </ul>
<b>Plate heat exchanger</b> 	<ul style="list-style-type: none"> <li>■ evaporator</li> <li>■ oil cooler</li> </ul>
<b>Coaxial coil heat exchanger</b> 	<ul style="list-style-type: none"> <li>■ water-cooled condenser</li> <li>■ water-heated evaporator</li> </ul>
<b>Finned tube heat exchanger</b> 	<ul style="list-style-type: none"> <li>■ air-cooled condenser</li> <li>■ air cooling evaporator</li> </ul>

## Heat transfer in the condenser



Energy processes in the condenser (counterflow)

- $T_c$  condensation temperature, refrigerant
- $T_{sc}$  supercooling temperature, refrigerant
- $T_{cf, in}$  inlet temperature, cold medium
- $T_{cf, out}$  outlet temperature, cold medium
- refrigerant, ■ cooling fluid

The energy processes in a properly designed condenser can be assigned to three different areas.

### 1. Desuperheating

The superheated, vaporous refrigerant is cooled from the superheating temperature to the condensation temperature (desuperheated).

### 3. Supercooling

The already fully condensed refrigerant continues to release heat to the cooling fluid. The liquid refrigerant is cooled below the condensation temperature.

### 2. Condensing

The refrigerant continuously releases heat to the cooling fluid and condenses at a constant pressure and constant temperature.

## ET 431

### Heat exchangers in the refrigeration circuit



#### Description

- typical heat exchangers from refrigeration
- different media: air / refrigerant, refrigerant / refrigerant and water / refrigerant
- effect of superheating and supercooling of the refrigerant on the cyclic process

Heat exchangers are an elementary part of refrigeration systems. During cooling they are used to absorb the energy of the refrigerant by evaporation. During heating they discharge the energy set free during the condensation of the refrigerant. They are also used for internal energy transfer during superheating or supercooling of the refrigerant.

Dependent on the media, a difference is made between air / refrigerant, water / refrigerant and refrigerant / refrigerant heat exchangers. Dependent on the constructive design, a difference is also made between coaxial, finned tube, plate or shell and tube heat exchangers.

The refrigeration circuit of the trainer ET 431 includes as evaporator an air cooling finned tube heat exchanger and a water-heated plate heat exchanger, as superheater a tubular heat exchanger, and as condenser a water-cooled coaxial coil heat exchanger. These heat exchangers are the ones used most commonly in refrigeration and fulfil different functions dependent on the system type. A finned tube heat exchanger can e.g. also be used as a condenser.

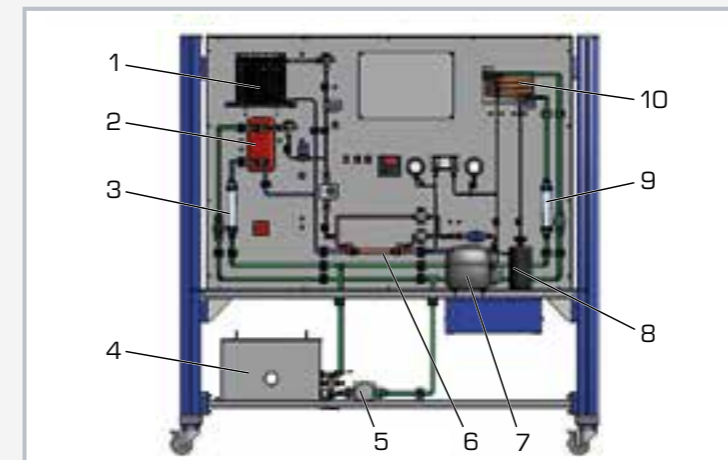
The components are arranged clearly at the front. By measuring the mass flow rates and the inlet and outlet temperatures the transferred energy fluxes can be determined.

#### Learning objectives/experiments

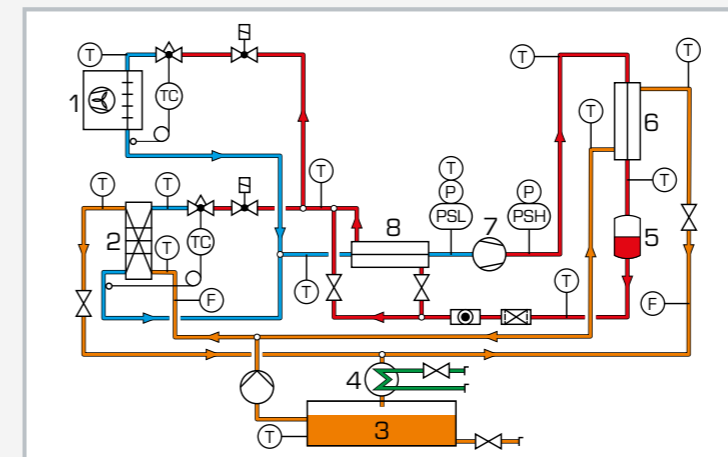
- different heat exchangers and their use in refrigeration
  - ▶ coaxial coil heat exchanger
  - ▶ finned tube heat exchanger
  - ▶ tubular heat exchanger
  - ▶ plate heat exchanger
- find out the correct installation position
- determine energy fluxes
- effect of superheating and supercooling of the refrigerant on the cyclic process
- design of a compression refrigeration system
- representation of the cyclic process in the log p-h diagram

## ET 431

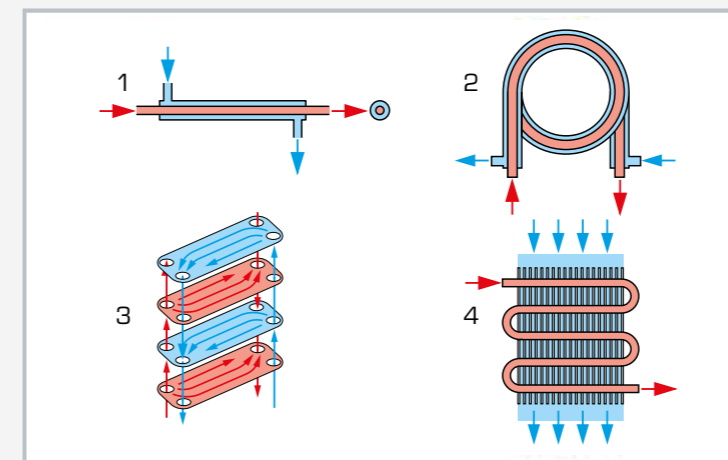
### Heat exchangers in the refrigeration circuit



1 finned tube heat exchanger as evaporator, 2 plate heat exchanger as evaporator, 3 heating water flow meter, 4 water tank, 5 water pump, 6 tubular heat exchanger as superheater, 7 compressor, 8 receiver, 9 cooling water flow meter, 10 coaxial coil heat exchanger as condenser



1 finned tube heat exchanger, 2 plate heat exchanger, 3 tank, 4 water cooler, 5 receiver, 6 coaxial coil heat exchanger, 7 compressor, 8 tubular heat exchanger; T temperature, P pressure, F flow rate



1 tubular heat exchanger, 2 coaxial coil heat exchanger, 3 plate heat exchanger, 4 finned tube heat exchanger

#### Specification

- [1] refrigeration system with 4 different heat exchangers: coaxial coil heat exchanger, finned tube heat exchanger, tubular heat exchanger, plate heat exchanger
- [2] combinations of different media: water / refrigerant, refrigerant / refrigerant, air / refrigerant
- [3] water circuit with tank and pump to cool the condenser and heat the evaporator
- [4] superheater can be disabled via bypass
- [5] flow meter and thermometer in the water circuit to determine the exchanged energy fluxes
- [6] refrigerant mass flow rate calculated in the software from recorded measured values
- [7] thermometers at all relevant points of the system
- [8] refrigerant R513A, GWP: 631

#### Technical data

##### Compressor

- refrigeration capacity: 1308W at 7,2/54,4°C
- power consumption: 514W at 7,2/54,4°C

##### Receiver

- 1,3L

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 1,3kg
- CO<sub>2</sub>-equivalent: 0,8t

##### Measuring ranges

- pressure: -1...9bar / -1...24bar
- temperature: 12x -5...105°C, 1x 0...60°C
- flow rate: 2x 20...250L/h (water)

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1900x800x1900mm  
Weight: approx. 255kg

#### Required for operation

water connection, drain

#### Scope of delivery

- 1 trainer
- 1 set of accessories
- 1 set of instructional material



## ET 405

### Heat pump for cooling and heating operation



#### Description

- air-to-water heat pump
- heating and cooling operation possible
- high practical relevance by using industrial components from refrigeration
- different operating modes can be set via solenoid valves

Refrigeration systems and heat pumps only differ in the definition of their use, but can be of the same design. For example, goods can be refrigerated in a supermarket and the store heated with the waste heat. The store can also be cooled with the same system in the summer.

With ET 405 the cooling and heating operation can be investigated. Different operating modes can be selected via solenoid valves.

The refrigeration circuit with compressor and condenser (heat exchanger with fan) includes two evaporators with fans (refrigeration stage and freezing stage) and thermostatic expansion valves. The two evaporators can be connected in parallel or in series. For the connection in series the capillary tube serves as expansion element for the refrigeration stage evaporator. The refrigerant circuit is connected to a glycol-water circuit via a coaxial coil heat exchanger. Via solenoid valves the coaxial coil heat exchanger can be switched as an evaporator or condenser. Thus the glycol-water mixture in the tank can be heated or cooled. In pure cooling operation (without heating function) the heat exchanger with fan as air-cooled condenser dissipates the heat. This heat exchanger can be also switched as an evaporator.

The measured values are read from digital displays and can at the same time be transmitted via USB directly to a PC where they can be analysed using the software included. The refrigerant mass flow rate is calculated in the software from the recorded measured values. The software enables a clear representation of the process.

#### Learning objectives/experiments

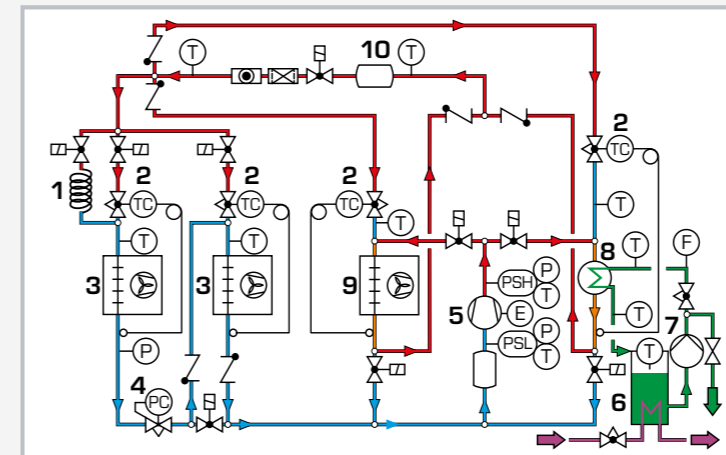
- design, operation and key components of a heat pump or refrigeration system
- representation of the thermodynamic cycle in the log p-h diagram
- comparing different operating modes
- measurement of compressor capacity and heating or cooling capacity in the glycol-water circuit
- determination of
  - ▶ efficiency
  - ▶ coefficient of performance of heat pump and refrigeration system
  - ▶ specific compressor load
  - ▶ compressor pressure ratio
  - ▶ specific cooling capacity
  - ▶ specific refrigeration capacity
- comparing key figures of heat pump and refrigeration system

## ET 405

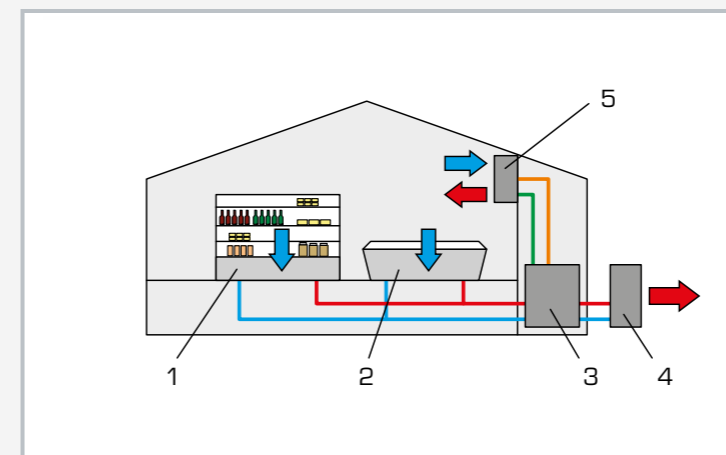
### Heat pump for cooling and heating operation



1 evaporator, 2 expansion valve, 3 capillary tube, 4 freezing stage evaporator, 5 evaporation pressure controller, 6 compressor, 7 receiver, 8 heat exchanger with fan, 9 pump, 10 display and control elements, 11 tank for glycol-water mixture, 12 flow meter (glycol-water), 13 solenoid valve, 14 coaxial coil heat exchanger



1 capillary tube, 2 expansion valve, 3 evaporator, 4 evaporation pressure controller, 5 compressor, 6 tank for glycol-water mixture, 7 pump, 8 coaxial coil heat exchanger, 9 heat exchanger with fan, 10 receiver; T temperature, P pressure, F flow rate, PSH, PSL pressure switch



Supermarket application: 1 refrigeration units, 2 freezer, 3 heat pump, 4 external condenser, 5 convactor to heat or cool the sales room

#### Specification

- [1] different operating modes selectable via solenoid valves
- [2] refrigeration circuit with compressor, condenser (heat exchanger with fan), 2 evaporators with fan (refrigeration and freezing stage)
- [3] glycol-water circuit with tank, pump and coaxial coil heat exchanger
- [4] coaxial coil heat exchanger and heat exchanger with fan can both be used as condenser or evaporator in the refrigeration circuit
- [5] 1 thermostatic expansion valve each for all heat exchangers and evaporators
- [6] 1 additional evaporation pressure controller and 1 capillary tube for the refrigeration stage evaporator
- [7] displays for temperature, pressure, flow rate and power consumption of the compressor
- [8] refrigerant mass flow rate calculated in the software from recorded measured values
- [9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

##### Compressor

- refrigeration capacity: 1561W at 5/40°C
- power consumption: 759W at 5/40°C

##### Heat exchanger with fan

- transfer area: 1,25m<sup>2</sup>
- volumetric air flow rate: 650m<sup>3</sup>/h

##### Evaporators with fan

- refrigeration stage transfer area: 1,21m<sup>2</sup>, volumetric air flow rate: 80m<sup>3</sup>/h
- freezing stage transfer area: 3,62m<sup>2</sup>, volumetric air flow rate: 125m<sup>3</sup>/h

##### Refrigerant: R513A, GWP: 631

- filling volume: 1,5kg, CO<sub>2</sub>-equivalent: 0,9t

##### Measuring ranges

- temperature: 11x -50...150°C
- pressure: 2x -1...15bar, 1x -1...24bar
- flow rate: 2,5...65g/s
- power: 0...1150W

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase

UL/CSA optional

LxWxH: 2210x800x1900mm

Weight: approx. 330kg

#### Required for operation

water connection, drain  
PC with Windows recommended

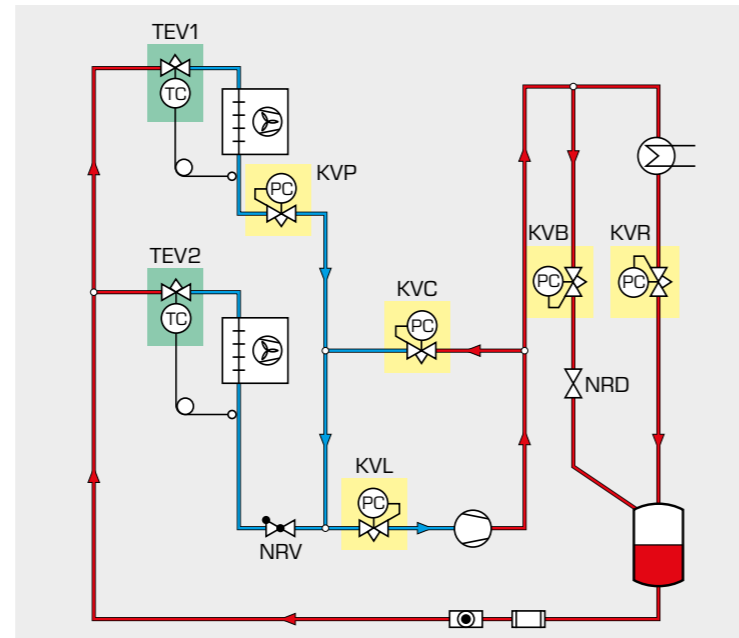
#### Scope of delivery

- 1 trainer
- 1 set of accessories
- 1 GUNT software CD + USB cable
- 1 set of instructional material

## Basic knowledge

## Primary and secondary controllers in refrigeration

Primary and secondary controllers control the refrigerant flow in the refrigeration circuit. The refrigerant flow must match the capacity demand. If a higher refrigeration capacity is required because e.g. goods to be cooled are added to the refrigeration chamber, more refrigerant must be evaporated. In addition, controllers are required to ensure that all components of the refrigeration circuit, such as evaporator, condenser and compressor, are operated in their optimum pressure and temperature range. Only this guarantees that a refrigeration system is operated safely and economic.



Refrigeration circuit with primary and secondary controllers

■ primary controller ■ secondary controller  
**KVP** evaporation pressure controller, **KVR** condensation pressure controller, **KVL** start-up controller, **KVC** capacity controller, **KVD** collector pressure controller, **NRD**, **NRV** non-return valve, **SGN** sight glass, **DN** filter/drier, **AEV** pressure-controlled expansion valve, **TEV** thermostatic expansion valve

## Primary controllers

Four different types are differentiated:

- capillary tube
- pressure-controlled expansion valve
- thermostatic expansion valve
- electronic expansion valve

In technical language primary controllers are also called expansion elements. They control the capacity of the evaporator directly via the injected refrigerant flow.

## Capillary tube

In small systems, such as refrigerators, the capillary tube is preferred as the expansion element. The capillary tube is a copper tube with very small inner diameter. The expansion element effect is set experimentally via the length of the capillary tube.

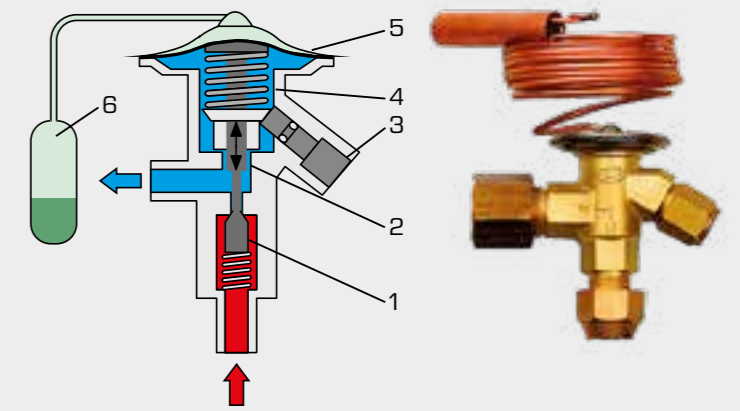
Capillary tube systems do not contain a collector and the refrigerant volume is matched exactly to the system.



## Thermostatic expansion valve

The thermostatic expansion valve (TEV) is used most frequently. The TEV compares the temperature of the refrigerant at the evaporator outlet with the inlet temperature. The TEV ensures superheating of the refrigerant in the outlet of the evaporator. In the optimum case, the TEV introduces the maximum possible amount of refrigerant, which can just be evaporated in full, into the evaporator. It is important that no liquid refrigerant exits the evaporator, because this could cause major damage to the compressor.

The degree of superheating can be adjusted by the pretension of the diaphragm spring.



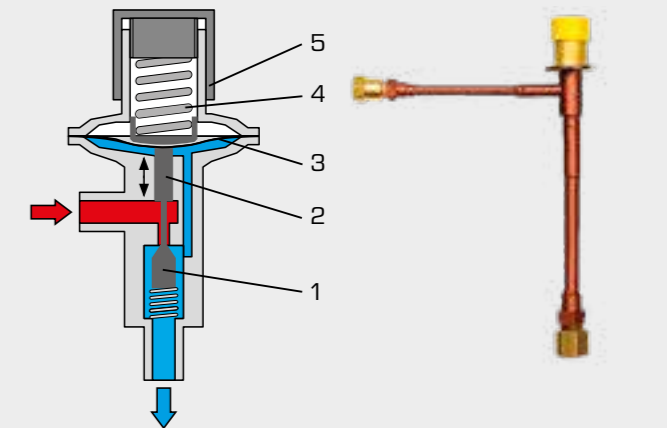
1 nozzle insert with valve cone, 2 tappet, 3 adjustment screw, 4 diaphragm spring, 5 diaphragm, 6 temperature sensor

## Pressure-controlled expansion valve

With the pressure-controlled expansion valve (AEV) the pressure in the evaporator and thus the evaporation temperature is kept constant via the refrigerant supply. This is e.g. important if the goods to be cooled come into direct contact with the evaporator surface.

A disadvantage of the pressure-controlled expansion valve is that liquid refrigerant might exit the evaporator. Therefore, it is only used in special applications.

The evaporation pressure is set via the pretension of the diaphragm spring.

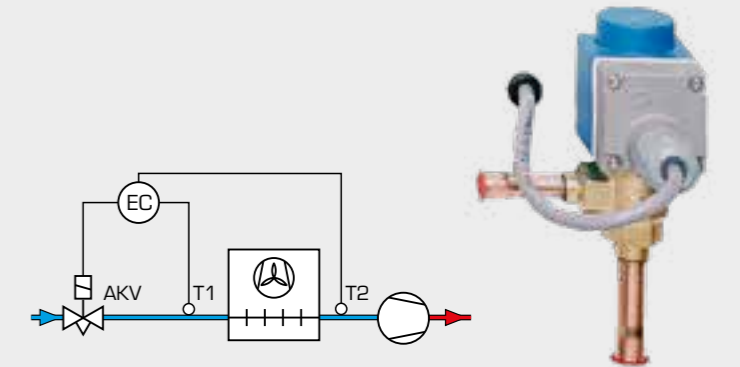


1 nozzle insert with valve cone, 2 tappet, 3 diaphragm, 4 diaphragm spring, 5 adjustment cap

## Electronic expansion valve

The electronic expansion valve is the most flexible one. Here several effects can control the refrigerant flow simultaneously. However, the electronic expansion valve must be controlled via a complex digital control unit and is due to its high cost only economic for larger systems.

In the drive of the valve cone a difference is made between a motorised and electromagnetic drive.



Electronic expansion valve (AKV) with control unit (EC) and two temperature sensors: T1 determination of the evaporation pressure and T2 to measure the superheating



## Basic knowledge

## Primary and secondary controllers in refrigeration

## Secondary controllers

The following types of pressure controllers are differentiated:

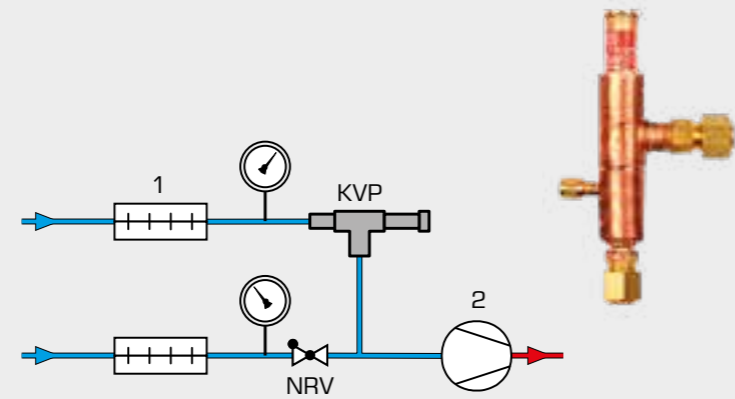
- evaporation pressure controller KVP
- condensation pressure controller KVR
- start-up controller KVL
- capacity controller KVC
- collector pressure controller KVD

(KVP, KVR, KVL, KVC, KVD, NRV were originally type designations by Danfoss which have become common terms in refrigeration language.)

Secondary controllers guarantee the optimum operating conditions for different components of the refrigeration circuit. They are mainly pressure controllers which, dependent on the tasks, keep the inlet, outlet or differential pressure at a desired value. Temperature controllers and electronic capacity controllers are also amongst the secondary controllers.

## Evaporation pressure controller

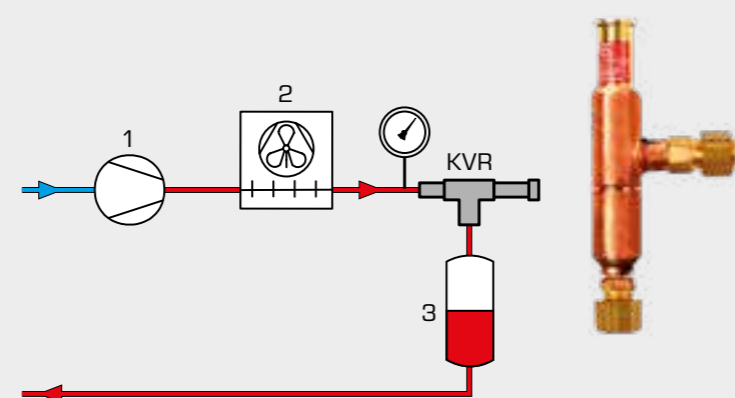
Via the evaporation pressure controller KVP the pressure and thus the temperature of the refrigerant in the evaporator is set. The KVP is often used to supply temperature or pressure levels (standard cooling stage and deep-freeze stage) with the same compressor.



1 heat exchanger, 2 compressor, KVP evaporation pressure controller, NRV non-return valve

## Condenser pressure controller

The condensation pressure controller KVR maintains a minimum pressure in the condenser. The KVR is used in air-cooled outdoor condensers. Using accumulated liquid refrigerant, the effective heat transfer area is reduced at low ambient temperatures. This reduces the condenser capacity.

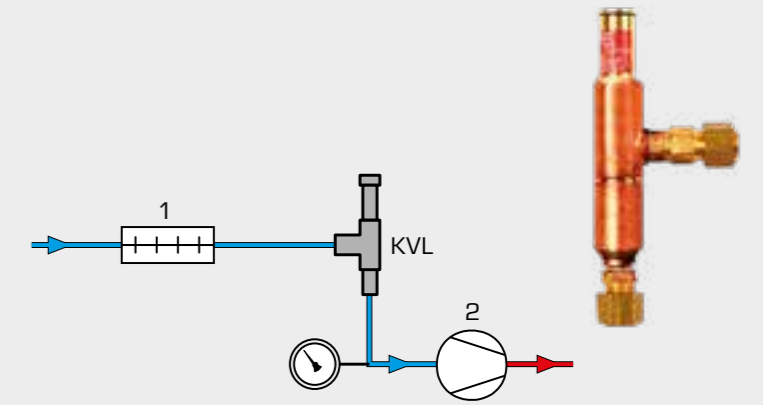


1 compressor, 2 heat exchanger, 3 collector, KVR condensation pressure controller

## Start-up controller

A start-up controller (KVL) or intake pressure controller prevents the compressor from operating if the intake pressure is too high. The highest intake pressure occurs when a refrigerating plant is started up. To protect the drive motor from overload, the intake pressure upstream of the compressor should be reduced.

By using intake pressure controllers, a smaller drive motor for the compressor can be used in the design of refrigerating plants, because this avoids too high intake pressures when the refrigerating plant starts up.

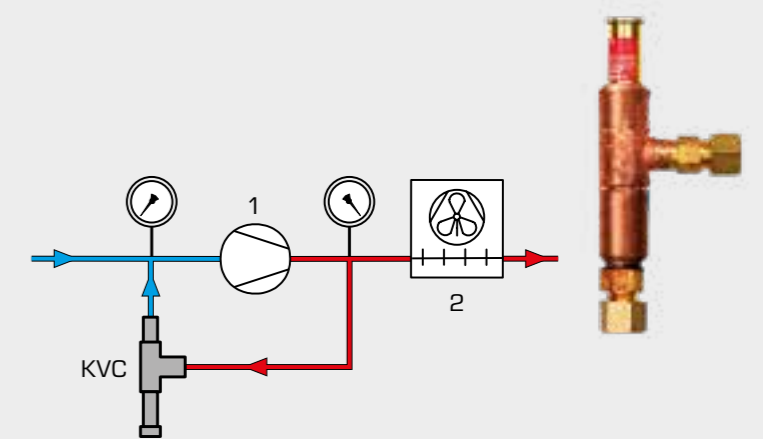


1 heat exchanger, 2 compressor, KVL start-up controller

## Capacity controller

The capacity controller KVC reduces the flow rate of the compressor at low refrigeration capacity and is always used when operating conditions with a low thermal load are to be expected. The KVC limits the minimum intake pressure and prevents the low pressure switch from tripping. This avoids "clocking" and an elevated mechanical strain on the compressor.

If the intake pressure is too low the KVC returns some of the delivery volume via a bypass to the intake side.

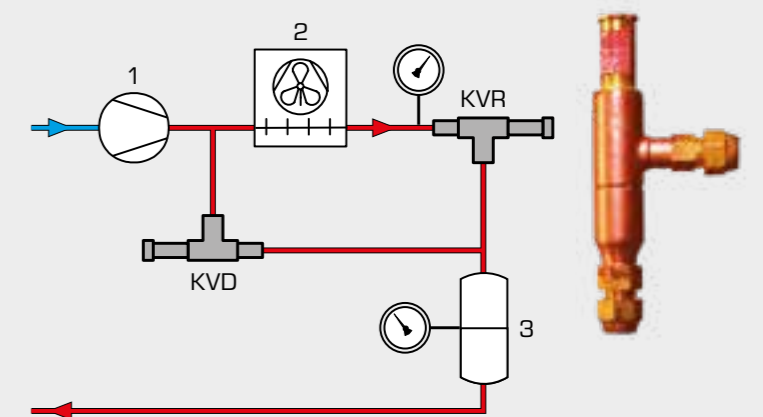


1 compressor, 2 heat exchanger, KVC capacity controller

## Collector pressure controller

The collector pressure controller KVD prevents in conjunction with a condensation pressure controller KVR too low a collector pressure which results in a partial evaporation in the liquid pipes of the refrigeration system.

For this purpose the KVD directs a small quantity of vaporous refrigerant directly from the compressor outlet to the collector.



1 compressor, 2 heat exchanger, 3 collector, KVD collector pressure controller, KVR condenser pressure controller

## ET 426

### Capacity control in refrigeration systems



The illustration shows a similar unit

#### Description

- investigation of different capacity control methods
- open compressor with variable speed
- adjustable cooling load via heater
- controlled defrosting with temperature specification

The efficient control of the capacity and temperature in refrigeration systems is an important topic in refrigeration engineering. With ET 426 different methods of capacity control can be investigated. For this purpose a refrigeration circuit with two refrigeration chambers is available in which a cooling load is generated using an adjustable heater. Fans in both refrigeration chambers ensure an even temperature distribution.

In the first refrigeration chamber a thermostat with solenoid valve and an evaporation pressure controller control the pressure of the refrigerant in the evaporator and thereby the temperature.

Sensors record the temperature in the second refrigeration chamber and the temperature of the refrigerant upstream and downstream of the evaporator. A refrigeration controller processes the signals from the sensors. Via a solenoid valve the refrigeration controller changes the refrigerant flow in the evaporator and controls thereby the temperature in the second refrigeration chamber. The temperatures at which the fans and a defrost heater are switched on or off are also set at the refrigeration controller.

In addition the refrigeration capacity of the overall refrigeration circuit can be adjusted via the speed of the compressor. There also is the option to adjust the refrigeration capacity at a capacity controller in the compressor by-pass.

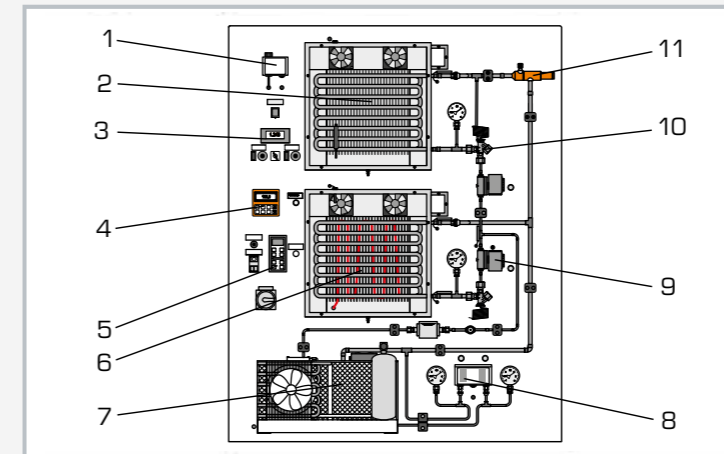
Both refrigeration chambers feature a window to be able to monitor the fan operation and formation of ice. Manometers enable the easy reading of pressures at the relevant points.

#### Learning objectives/experiments

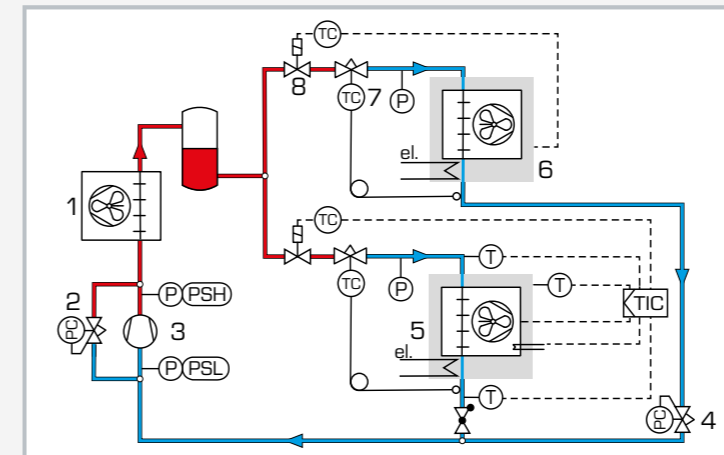
- key devices for changing the refrigeration capacity
  - ▶ thermostat
  - ▶ evaporation pressure controller
  - ▶ refrigeration controller
  - ▶ capacity controller
  - ▶ compressor with variable speed
- operation of a refrigeration controller with specification of temperatures for
  - ▶ controlling the refrigeration capacity
  - ▶ switching the defrost heater on and off
  - ▶ switching the fans on and off

## ET 426

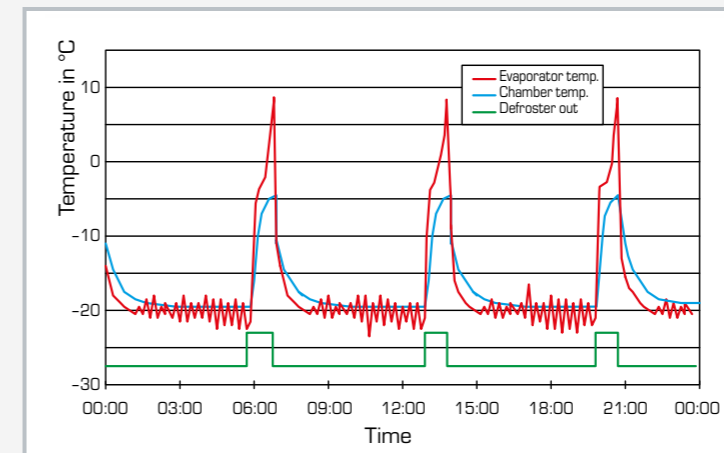
### Capacity control in refrigeration systems



1 thermostat, 2 refrigeration chamber with heater and fan, 3 heater controls, 4 refrigeration controller, 5 compressor controls, 6 refrigeration chamber with heater, fan and defrost heater, 7 compressor and condenser, 8 combined pressure switch, 9 solenoid valve, 10 expansion valve, 11 evaporation pressure controller



1 condenser, 2 capacity controller, 3 compressor, 4 evaporation pressure controller, 5 refrigeration chamber with heater, fan and defrost heater, 6 refrigeration chamber with heater and fan, 7 expansion valve, 8 solenoid valve with thermostat; T temperature, P pressure; PSH, PSL pressure switch, TIC refrigeration controller



Time progression of a defrost controller (green) with temperature of evaporator (red) and refrigeration chamber (blue)

#### Specification

- [1] methods for capacity control in refrigeration systems
- [2] refrigeration circuit with compressor, condenser and 2 evaporators in insulated refrigeration chambers
- [3] each refrigeration cooling chamber with adjustable heater to generate a cooling load, thermostatic expansion valve and fan
- [4] 1 refrigeration chamber with refrigeration controller for temperature control; solenoid valve, fan and defrost heater as actuators
- [5] 1 refrigeration chamber with thermostat, solenoid valve and evaporation pressure controller for temperature control
- [6] compressor with variable speed via frequency converter
- [7] capacity controller in the compressor bypass
- [8] refrigerant R513A, GWP: 631

#### Technical data

##### Compressor

- refrigeration capacity: approx. 560W at -5/25°C and 1450min<sup>-1</sup>
- drive motor: 550W

2 heaters: approx. 500W

4 fans: max. volumetric air flow rate: approx. 36,5m<sup>3</sup>/h

1 defrost heater: approx. 75W

##### Refrigeration controller

- 3 inputs
- 3 outputs

Evaporation pressure controller: 0...5,5bar

Thermostat: -5...20°C

Capacity controller: 0,2...6bar

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 1kg
- CO<sub>2</sub>-equivalent: 0,6t

##### Measuring ranges

- speed: 465...975min<sup>-1</sup> compressor
- temperature: 3x -60...50°C
- power: 2x 0...1000W heater
- pressure: 3x -1...9bar; 1x -1...24bar

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase; 230V, 60Hz, 3 phases

UL/CSA optional

LxWxH: 1100x750x1900mm

Weight: approx. 150kg

#### Scope of delivery

- 1 trainer
- 1 set of instructional material



## ET 180

### Pressure switches in refrigeration



#### Description

- gain expert knowledge of refrigeration through practical exercises
- checking and adjustment of pressure switches in refrigeration
- clear arrangement at the front panel
- display of switching states via lamps
- independent pressure generation via compressor

With this experimental unit the operation of the pressure switches, also called pressostats, used in refrigeration can be demonstrated.

Pressure switches are used to protect the compressor and system components against too high or too low pressures. They are also used in the so-called pump-down circuits for the controlled shut-down of the compressor. Dependent on the application, individual pressure switches or combined pressure switches are used for high and low pressures.

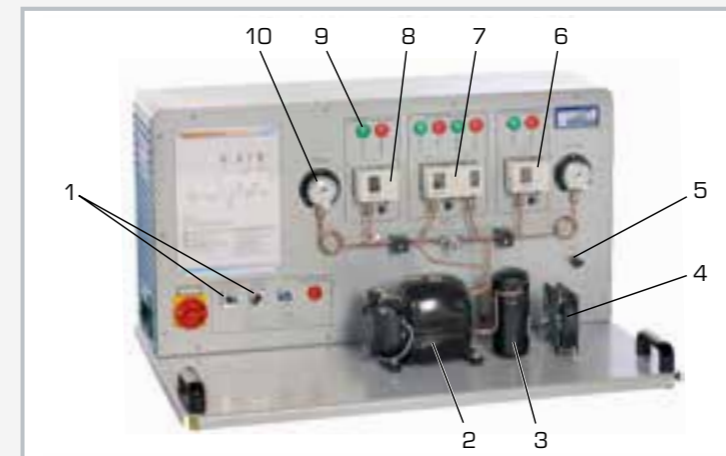
Pressure switches for monitoring the pressures are available. The switching states are indicated by signal lamps. The switching thresholds and hysteresis can be set by the trainee. This allows him to examine and understand the switching behaviour of the pressure switch. A typical refrigerant compressor generates the test pressures. Manometers indicate the pressures. Air is used as a pressure medium. The hazard-free operation of the pressure switches uses 24V.

#### Learning objectives/experiments

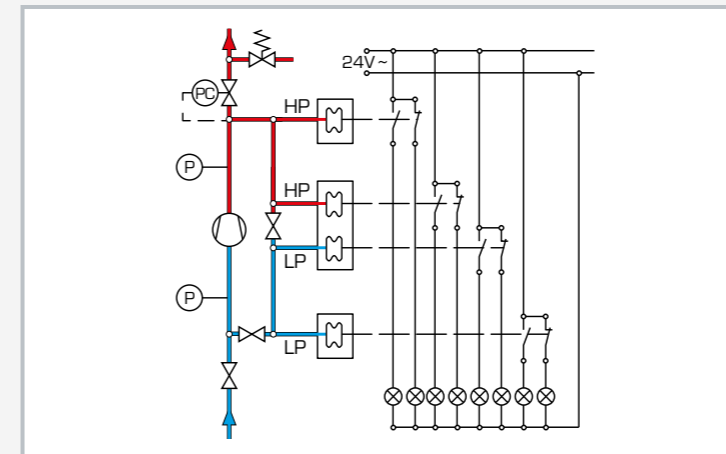
- gain expert knowledge of refrigeration through practical exercises
- operation of a pressure switch
- difference between low and high pressure switches
- difference between NC and NO contacts of a switch
- setting the switching threshold
- setting the differential gap
- recording the switching behaviour of the pressure switch over pressure

## ET 180

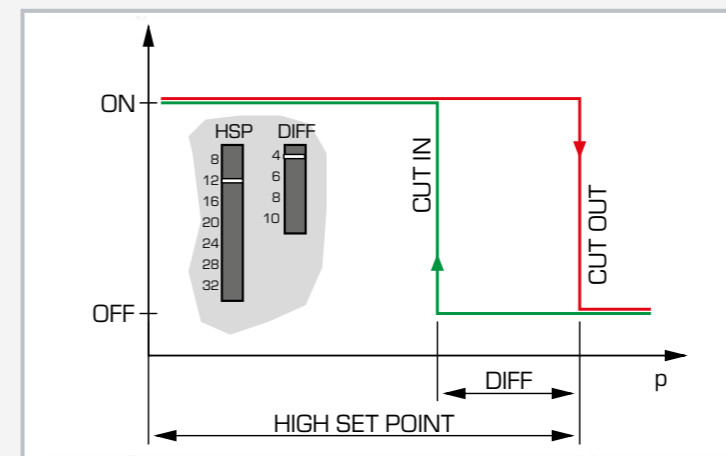
### Pressure switches in refrigeration



1 controls, 2 compressor, 3 receiver, 4 fan, 5 vent valve, 6 high pressure pressure switch, 7 combined pressure switch, 8 low pressure pressure switch, 9 signal lamps for switching state, 10 manometer



P pressure measuring point, PC pressure keeping valve, HP pressure switch, LP pressure switch; blue: low pressure, red: high pressure



Adjustment and operation of a high pressure pressure switch: HSP switch-off pressure, DIFF switch-on difference, CUT IN switch-on, CUT OUT switch-off

#### Specification

- [1] experimental unit from the GUNT practical series for the training of mechatronics engineers for refrigeration
- [2] operation and adjustment of pressure switches in refrigeration
- [3] low pressure, high pressure and combined pressure switches
- [4] indication of switching states via signal lamps
- [5] pressure generation via independent refrigerant compressor, pressure medium air
- [6] pressure adjustment via pressure keeping valve
- [7] hazard-free operation of the pressure switches at 24V

#### Technical data

Compressor pressure range: -0,9...24bar

Pressure switches adjustment range

- low pressure: -0,9...7,0bar, hysteresis: 0,7...4,0bar
- high pressure: 8,0...32,0bar, hysteresis: 4...10bar

Measuring ranges

- manometer:
  - ▶ -1...9bar
  - ▶ -1...24bar

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase

120V, 60Hz, 1 phase

UL/CSA optional

LxWxH: 1000x650x530mm

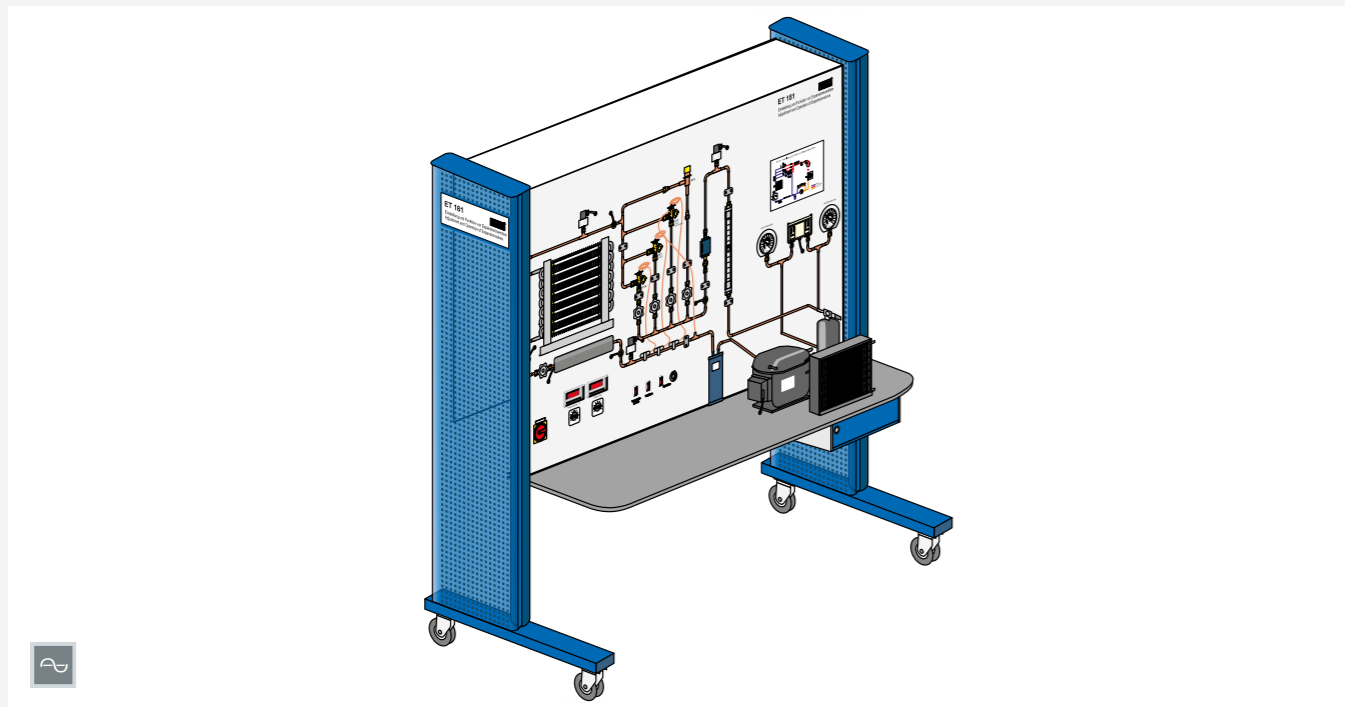
Weight: approx. 60kg

#### Scope of delivery

- 1 experimental unit
- 1 set of instructional material

## ET 181

### Adjustment and operation of expansion valves



The illustration shows a similar unit

#### Description

- refrigeration circuit with different expansion valves
- adjustable superheating
- transparent evaporator to monitor the filling level and evaporation process
- recording of the control behaviour in the software

In the refrigeration circuit the expansion valves, also called primary controllers, also play an important role. The correct selection and adjustment decisively affects the capacity of the overall refrigeration system.

The trainer enables the investigation of four different expansion valves: TEV (Thermostatic Expansion Valve) with internal pressure compensation, TEV with external pressure compensation, TEV with MOP function (Maximum Operating Pressure) and AEV (Automatic Expansion Valve). The expansion valves can be selected via valves.

Via an evaporator with glass tubes the correct injection and evaporation of the refrigerant can be monitored. An additional electrically heated superheater at the output of the evaporator enables the investigation of the control behaviour with different refrigerant superheating. The locations of the temperature sensor at the evaporator output can be selected. The control behaviour can be monitored at a flow meter. Pressure and temperature sensors upstream and downstream of the expansion valve and at the evaporator outlet provide information about the state of the refrigerant and the degree of superheating.

A commercial condensing unit completes the refrigeration circuit.

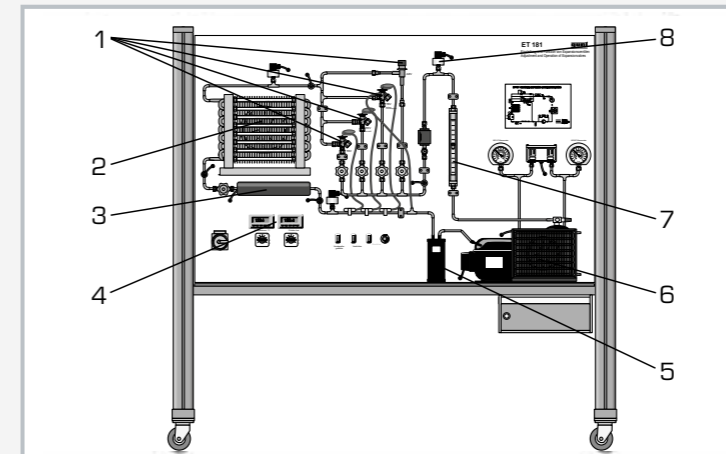
The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included. In the software the control behaviour of the expansion valves is recorded over time. The trainee can check the correct adjustment of the expansion valve and investigate effects such as hunting.

#### Learning objectives/experiments

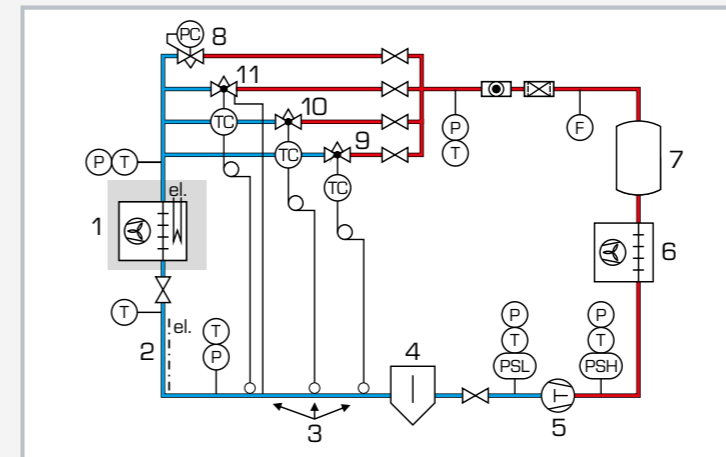
- operation and properties of the various expansion valves
- investigation of the static control characteristic
- investigation of the dynamic control behaviour
- adjustment of the optimum operating point
- benefits and disadvantages of the different expansion valves
  - ▶ thermostatic expansion valve (TEV) with internal pressure compensation
  - ▶ TEV with external pressure compensation
  - ▶ TEV with MOP function (Max. Operating Pressure)
  - ▶ pressure-controlled expansion valve (AEV)
- hunting effect

## ET 181

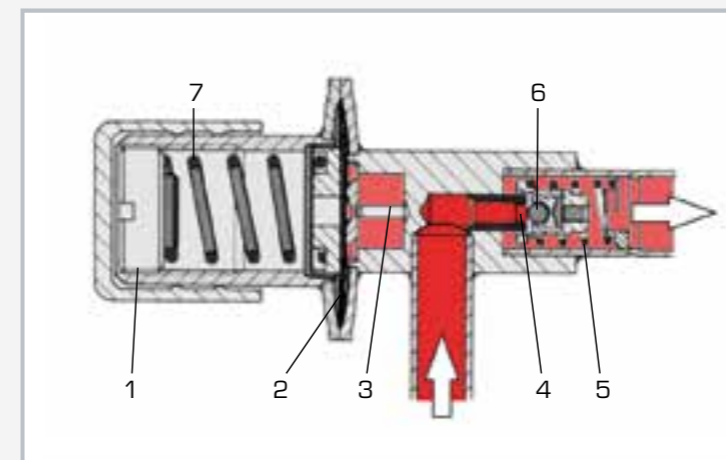
### Adjustment and operation of expansion valves



1 expansion valves, 2 evaporator with glass tubes, 3 superheater, 4 displays for pressure and temperature, 5 liquid separator, 6 condensing unit, 7 flow meter, 8 pressure sensor



1 evaporator, 2 superheater, 3 temperature sensor location, 4 liquid separator, 5 compressor, 6 condenser, 7 receiver, 8 pressure-controlled expansion valve, 9-11 thermostatic expansion valves: 9 with internal pressure compensation, 10 with MOP function, 11 with external pressure compensation; P pressure, T temperature, F flow rate, PSL, PSH pressure switch; blue: low pressure, red: high pressure



Cross-section of a pressure-controlled expansion valve: 1 adjustment screw, 2 diaphragm, 3 pin, 4 nozzle, 5 return spring, 6 needle, 7 adjustment spring

#### Specification

- [1] trainer from the GUNT practical series for the training of mechatronics engineers for refrigeration
- [2] refrigeration system with different expansion elements: thermostatic expansion valve TEV with internal pressure compensation, thermostatic expansion valve TEV with external pressure compensation, thermostatic expansion valve TEV with MOP function, pressure-controlled expansion valve AEV
- [3] evaporator with glass tubes to monitor injection and evaporation
- [4] valve downstream of the evaporator to simulate different pressure losses
- [5] adjustable electric heater for superheating
- [6] air-cooled condensing unit
- [7] sensors record pressures, temperatures, flow rate
- [8] refrigerant R513A, GWP: 631
- [9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

##### Air-cooled condensing unit

- power consumption: 485W at -10/32°C
- refrigeration capacity: 675W at -10/32°C
- receiver: 1,4L

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 1,6kg
- CO<sub>2</sub>-equivalent: 1,0t

##### Measuring ranges

- pressure: 2x -1...9bar, 1x -1...24bar
- temperature: 4 x -40...150°C
- flow rate: 3...41L/h

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1800x750x1900mm  
Weight: approx. 130kg

#### Required for operation

PC with Windows recommended

#### Scope of delivery

- 1 trainer
- 1 GUNT software CD + USB cable
- 1 set of instructional material



## ET 182

### Secondary controllers in refrigeration systems



#### Description

- familiarisation with common secondary controllers in refrigeration systems
- secondary controllers can be decommissioned individually for fault finding
- refrigeration and freezing stage with cooling load
- different secondary controllers at the water-cooled condenser

So-called secondary controllers are used to ensure the optimum operation of large, complex refrigeration systems. They control the evaporation pressure (KVP), the intake pressure of the compressor (KVL), the delivery capacity of the compressor (KVC), the condensation pressure (WVFX, KVR) and the receiver pressure (KVD, NRD).

With this trainer the student can try out the operation of the different secondary controllers. The secondary controllers can be disabled as required by bypassing or blocking. This option can be used for fault finding. By adjusting the secondary controllers the effect on the overall system can be studied.

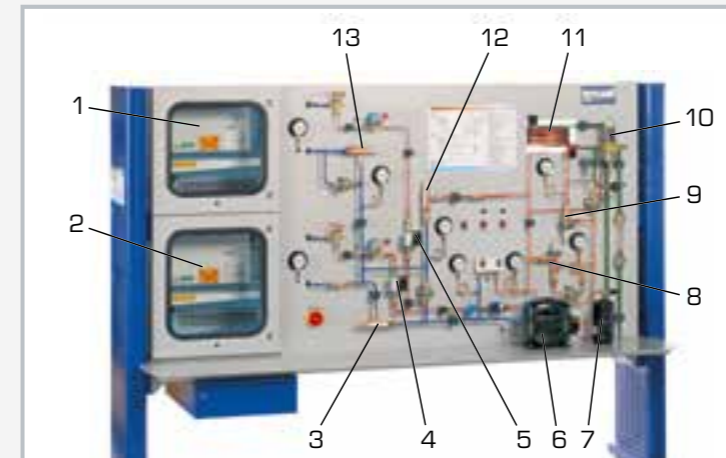
Manometers at all important locations and a manual thermometer enable the monitoring of the system state. The two evaporators for the cooling and freezing stage can be selected via solenoid valves. With an adjustable electrical heater in the refrigeration chamber the effect of a changing cooling load on the secondary controllers can be examined.

#### Learning objectives/experiments

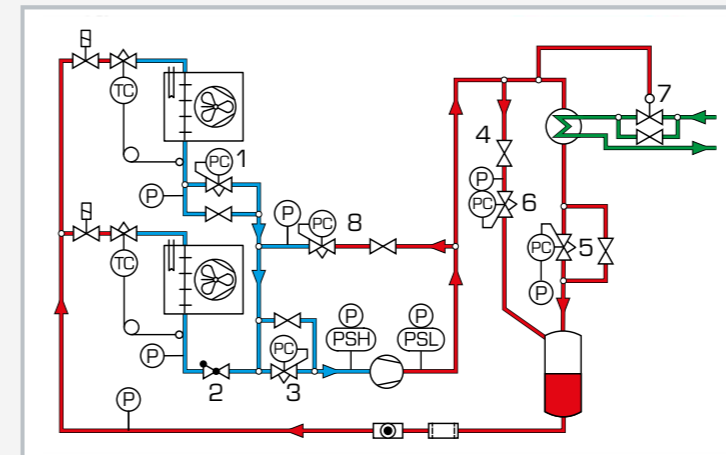
- properties and application options of different secondary controllers
  - ▶ evaporation pressure controller (KVP)
  - ▶ start-up controller (compressor intake control; KVL)
  - ▶ capacity controller (control of the compressor delivery capacity; KVC)
  - ▶ condensation pressure controller (WVFX, KVR)
  - ▶ receiver pressure controller (KVD with NRD)
- adjustment of optimum operating points
- fault finding in secondary controllers

## ET 182

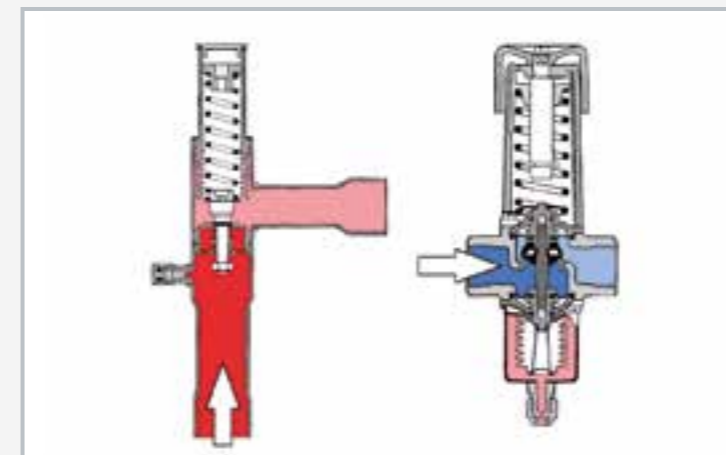
### Secondary controllers in refrigeration systems



1 refrigeration chamber, 2 freezing chamber, 3 start-up controller, 4+5 flow meter, 6 compressor, 7 receiver, 8 receiver pressure controller, 9 condensation pressure controller, 10 pressure-controlled water valve, 11 water-cooled condenser, 12 capacity controller, 13 evaporation pressure controller



1 evaporation pressure controller KVP, 2 non-return valve NRV, 3 start-up controller KVL, 4 non-return valve, 5 condensation pressure controller KVR, 6 receiver pressure controller KVD, 7 pressure-controlled water valve WVFX, 8 capacity controller KVC; blue: low pressure, red: high pressure, green: cooling water



Condensation pressure control: condensation pressure controller KVR (left) and pressure-controlled water valve WVFX (right)

#### Specification

- [1] trainer from the GUNT practical series for the training of mechatronics engineers for refrigeration
- [2] refrigeration system with different secondary controllers: evaporation pressure controller KVP, capacity controller KVC, condensation pressure controller KVR, pressure-controlled water valve WVFX as condensation pressure controller, receiver pressure controller KVD, start-up controller KVL
- [3] 2 refrigeration chambers: refrigeration and freezing stage
- [4] evaporator selectable via solenoid valves
- [5] adjustable electric heater in the refrigeration chambers as cooling load
- [6] water-cooled coaxial condenser
- [7] pressure measurement at all relevant points in the system
- [8] refrigerant R513A, GWP: 631

#### Technical data

##### Compressor

- refrigeration capacity: 990W at 5/40°C
- power consumption: 685W at 5/40°C

Cooling load: 0...500W  
Receiver: 1,3L

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 1,4kg
- CO<sub>2</sub>-equivalent: 0,9t

##### Measuring ranges

- pressure: 5x -1...9bar / 3x -1...24bar
- flow rate:
  - ▶ 20...250L/h (water)
  - ▶ 1...11,5L/h, 2...27L/h (refrigerant)
- temperature: -50...300°C

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 2500x790x1900mm  
Weight: approx. 280kg

#### Required for operation

water connection, drain

#### Scope of delivery

- 1 trainer
- 1 set of accessories
- 1 set of instructional material

## Basic knowledge Piping in refrigeration

Piping is an important part of refrigeration systems. The incorrect design and implementation of the refrigerant pipes could result in faulty operation or even damage to the refrigeration system.

Four different types of piping are basically differentiated in the refrigeration system:

Name	Connects	Aggregate state	Temperature	Length
intake pipe	evaporator – compressor	vaporous	cold	long
delivery pipe	compressor – condenser	vaporous	hot	short
condenser pipe	condenser – collector	liquid	environment	short
liquid pipe	collector – evaporator	liquid	environment / cold	long

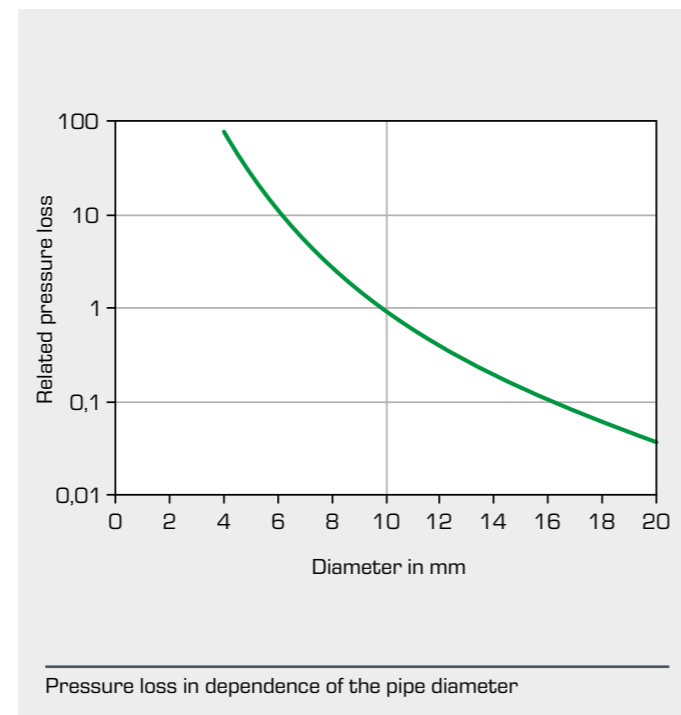
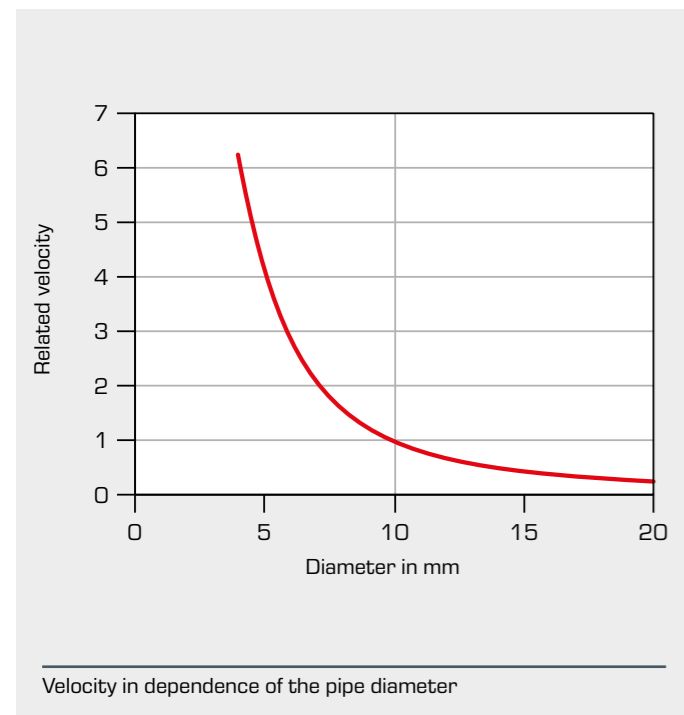
The properties of the different piping types have a direct effect on the constructive design. In long pipelines a low pressure loss must in particular be ensured. In piping with vaporous refrigerant the safe transport of oil must be ensured.

Cold or hot refrigerant pipes must be equipped with insulation to prevent heat loss or condensation on the surface.

### Effect of the pipe diameter on the velocity and the pressure loss

Pressure differences in the refrigerant pipes have an undesired effect on the boiling temperature of the refrigerant and thus on the operation of the system. Pressure differences can be caused by height differences in liquid pipes, or also by pressure losses in the piping. It is therefore important to dimension the piping correctly.

The two diagrams show the effect of the diameter on the velocity and pressure loss in the pipe. Velocity and pressure loss are related to a diameter of 10 mm. For example, an increase in the diameter from 10 mm to 16 mm reduces the velocity by 60%. Conversely the reduction of the pipe diameter from 10 mm to 6 mm causes a tenfold pressure loss.



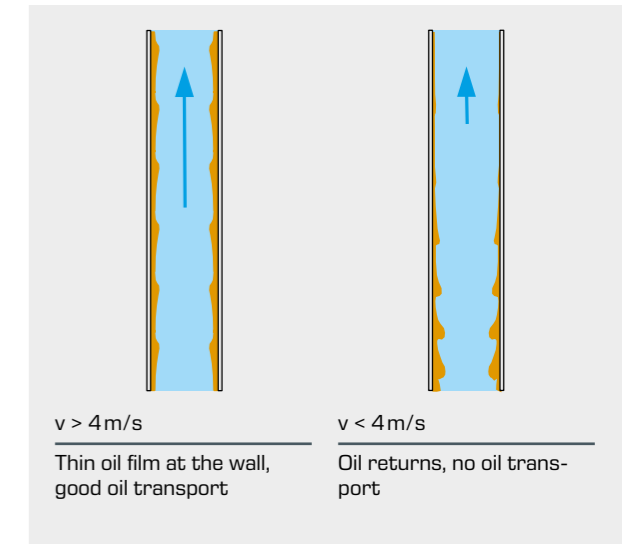
### Oil transport in the refrigerant pipes

In refrigerant compressors some lubrication oil is carried along with the compressed refrigeration steam in the system. To prevent a lubrication oil deficiency in the compressor, this lubrication oil must be returned to the compressor and must not remain in the system.

In pipes with liquid refrigerant this is no problem because the lubrication oil is dissolved in the refrigerant. However, in the evaporator the liquid lubrication oil remains back and must be carried by the refrigerant steam along the wall of the intake pipe.

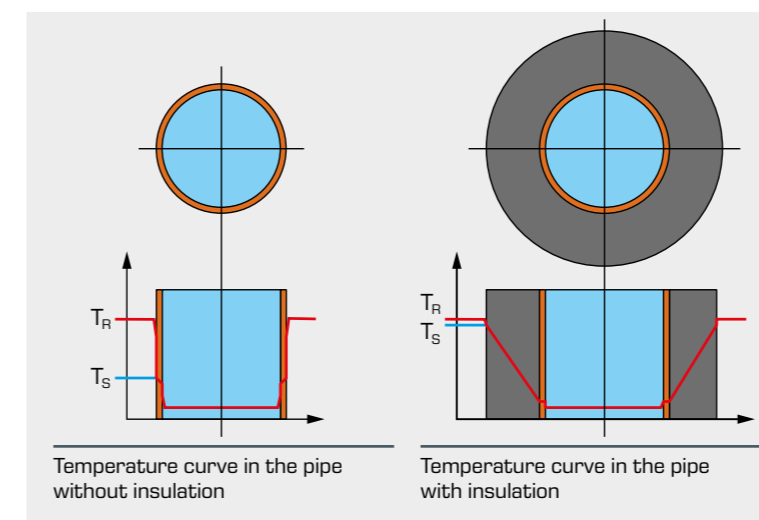
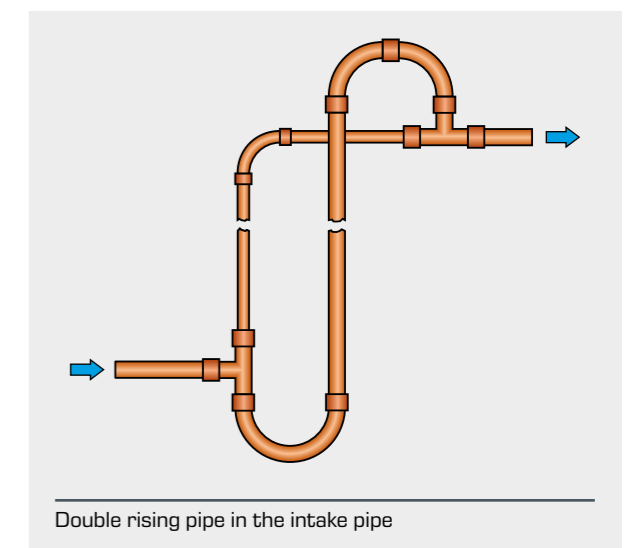
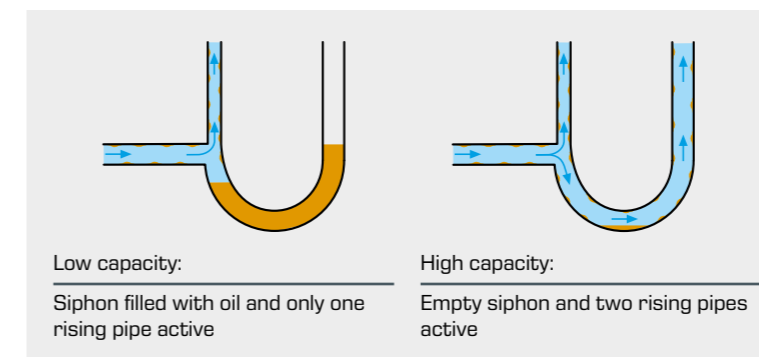
The oil transport is particularly difficult in rising intake pipes. Here a minimum velocity of approx. 4 m/s is required to transport the oil towards the compressor.

In intake pipes a compromise between low pressure losses and safe oil transport must therefore be found. It is recommended to maintain a velocity of 4 m/s for partial load and 9 m/s for full load.



### Double rising pipe for the safe oil transport at low load

At low load an oil-filled siphon closes one rising pipe. This increases the velocity in the remaining pipe. At high capacity the siphon is pressed empty and the second pipe activated. This keeps the pressure losses at high capacity low.



### Pipe insulation

The metallic materials used in refrigerant pipes have a high thermal conductivity so that the surface temperature  $T_s$  of the pipe matches roughly the refrigerant temperature. This means that plenty of heat can be exchanged with the ambient air (temperature  $T_R$ ).

By surrounding the pipes with an insulating layer the surface temperature is adapted to the environment and the heat dissipation reduced.

In cold pipes the surface temperature  $T_s$  is thus kept above the dewpoint temperature and the condensation or freezing of the humidity in the air prevented. Dripping dew water can cause humidity – and corrosion damage.



## Basic knowledge

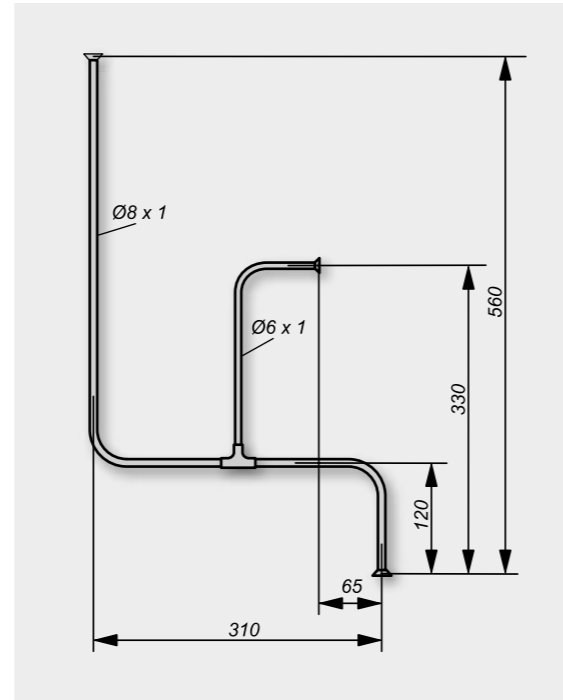
## Making of piping

## Making of piping

In refrigerating plants with HFC refrigerants, the refrigerant lines are usually made of copper tubing. Copper is an extremely low-temperature material and is therefore particularly suitable for components in refrigerating plants. Copper has increasing rigidity and deflection as the temperature decreases. Copper tubes meet special purity and strength requirements in refrigeration technology. The tubes are sealed with plastic caps until use to prevent contamination.

## The making of a piping is divided into several steps:

- determining the required length
- trimming the pipe and preparing the cutting surfaces
- bending in accordance with the desired pipe run
- soldering or flaring to joint the pipe section to other pipe sections or fittings



Sketch for a piping with soldered fittings, pipe ends flanged

## Trimming the pipe and preparing the cutting surfaces



Determining the length of the pipe section. Here the additions for bends and flanges must be taken into account. Sawing off the pipe.



Filing the saw cut smooth, the cutting surface must be perpendicular to the pipe axis



Deburring inside



Deburring outside

## Bending the pipe



Inserting the pipe into the bending device



Bend to the desired angle

## Hard soldering of pipes and fittings – non-detachable joint



Heating the workpieces up to the soldering heat and melting of flux material and solder. By capillary effect solder automatically fills the soldering gap.

Due to the high demands on strength, copper pipes and fittings are hard soldered. During hard soldering the metallic materials are joined with the aid of a filler material (solder). The melting point of the hard solder must be at least 450°C. The materials are not melted.

## Important when hard soldering

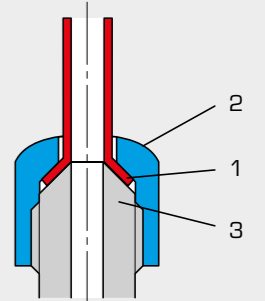
- metallic pure soldering location
- suitable with the correct melting point and flux material
- correct soldering gap between 0.1 and 0.3mm
- correct workpiece and solder temperature
- inert gas (e.g. nitrogen) to prevent scaling inside the pipe

## Flaring of pipes – detachable joints



Flaring of the pipe with the flaring tool

Detachable joints are often made by flared joints. Here the pipe end is widened conically **1** and pressed with a union nut **2** onto the sealing cone **3** of the fitting. When tightening the flared joint the sealing surface must be lightly coated with oil.



Cross-section of a flared joint

## ET 460

### Oil return in refrigeration systems



#### Learning objectives/experiments

- fundamentals of the oil return in refrigeration systems
- effect of the rising pipe diameter on the oil transport
- effect of partial and full load operation on the oil transport
- principle of operation of a double rising pipe
- separate or parallel operation of the compressors

#### Description

- transport of lubricants soluble in refrigerant in refrigeration systems
- transparent material for monitoring the transport states in the rising pipes
- monitoring of the processes in a double rising pipe during partial and full load operation
- separate or parallel operation of two compressors for partial and full load

The oil return in refrigeration systems is of key importance for the service life of the compressor and thus for a secure constant supply of refrigeration.

In most compressors some lubrication oil is carried along with the compressed refrigerant. In the liquid refrigerant the oil is dissolved in the refrigerant and is

transported without problems. In the vaporised refrigerant the oil remains liquid in the lower parts of the system. This can result in lack of oil in the compressor. To return the oil to the compressor, a minimum velocity must be maintained in the pipes. If the velocity in the rising pipe on the intake side of the compressor is too low (partial load), the oil is not returned to the compressor due to its higher density.

The velocity in the rising pipe depends on the pipe diameter and the refrigerant mass flow. A small diameter of the rising pipe results in a high velocity and ensures the return of the oil even under partial load. However, at full load the pressure loss increases due to the small diameter.

To compensate for this disadvantage, double rising pipes are used. During partial load oil gathers in a bend at the bottom of the double pipe. The oil in the bend blocks one of the two pipes so that the refrigerant flows at high velocity through the other pipe and transports the oil to the compressor. At full load the oil in the bend is pressed upwards so that the refrigerant flows through both pipes.

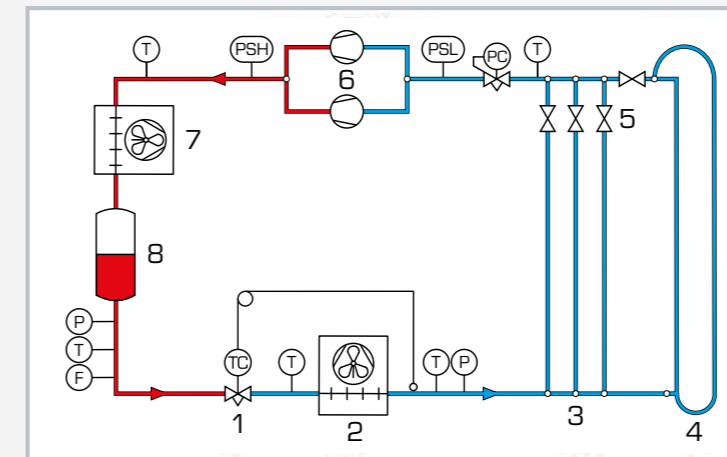
At the front of the ET 460 three transparent rising pipes with different diameters and a double rising pipe have been arranged. The rising pipe selection is via valves. This allows for the oil transport at different velocities to be observed. The other components of the refrigeration circuit are at the back of the trainer. The separate or combined operation of two compressors connected in parallel enables operation at partial or full load.

## ET 460

### Oil return in refrigeration systems



1 manometer delivery side, 2 manometer intake side, 3 flow meter, 4 display and control elements, 5 rising pipe Ø 6mm, 6 rising pipe Ø 10mm, 7 rising pipe Ø 14,4mm, 8 double rising pipe, 9 valve for rising pipe selection



1 expansion valve, 2 evaporator, 3 rising pipes, 4 double rising pipe, 5 valves for rising pipe selection, 6 compressor, 7 condenser, 8 receiver; P pressure, F flow rate, T temperature, PSH, PSL pressure switch; blue: low pressure, red: high pressure

#### Specification

- [1] investigation of the oil return to the compressor in refrigeration circuits with oil soluble in refrigerant
- [2] refrigeration circuit with 2 compressors connected in parallel, condenser with 2 fans, evaporator with fan and thermostatic expansion valve
- [3] 3 single and 1 double rising pipes from glass in the suction pipe of the refrigeration circuit
- [4] rising pipes selectable via valves
- [5] flow rate in the refrigeration circuit adjustable by single or combined operation of the two compressors
- [6] fan speed adjustable
- [7] temperature measurement with thermowells
- [8] refrigerant R513A, GWP: 631

#### Technical data

- 2 compressors with condenser
- refrigeration capacity: 1920W at 5/55°C
  - power consumption: 1190W bei 5/55°C
  - volumetric air flow rate fan: 1300m<sup>3</sup>/h

#### Evaporator

- transfer area: 5,7m<sup>2</sup>
- volumetric air flow rate fan: 720m<sup>3</sup>/h

#### Rising pipes

- Ø 14,4mm; L=1110mm
- Ø 10mm; L=1110mm
- Ø 6mm; L=1110mm
- Ø 8/10mm (double rising pipe); L approx. 1300mm

#### Refrigerant

- R513A
- GWP: 631
- filling volume: 1,5kg
- CO<sub>2</sub>-equivalent: 0,9t

#### Measuring ranges

- pressure: -1...9bar; -1...24bar
- flow rate: 2...27L/h
- temperature: 5x -50...100°C

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1410x800x1900mm  
Weight: approx. 216kg

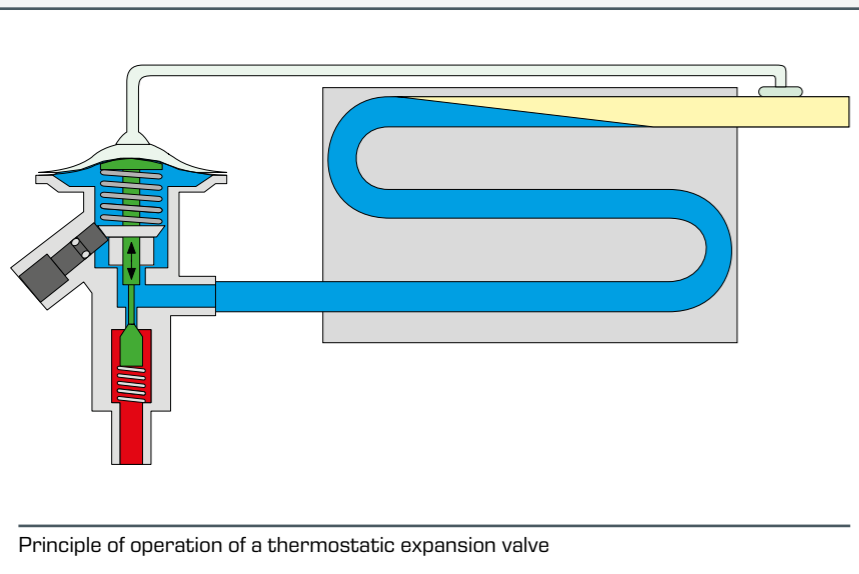
#### Scope of delivery

- 1 trainer
- 1 set of instructional material



## ET 499 Cutaway models from refrigeration

**ET 499.30**  
Cutaway model:  
ceiling air cooler



### Cutaway models from refrigeration

- become familiar with components and their function
- gain an insight into component details and understand functional principles
- all movements are fully reproduced

The cutaway models on the following pages show standard commercially available items from the field of refrigeration engineering, such as compressors, valves, driers and liquid separators. Each of the cutaway models come with a short description and a sectional drawing. This enables the didactic application of the models to be extended to exercises in technical drawing. The larger cutaway models are mounted on a solid base. Two handles aid transportation.

For ET 499.30, a commonly used ceiling air cooler, a thermostatic expansion valve and a filter drier are used. The cutaways are arranged to allow design details to be clearly identified.

**ET 499.01**  
Cutaway model: hermetic refrigerant compressor



**ET 499.02**  
Cutaway model: semi-hermetic refrigerant compressor



**ET 499.03**  
Cutaway model: open refrigerant compressor, 2-cylinder.



**ET 499.12**  
Cutaway model: block drier



**ET 499.13**  
Cutaway model: oil separator



**ET 499.14**  
Cutaway model: liquid separator





**ET 499.16**

Cutaway model: ball valve

**ET 499.18**

Cutaway model: thermostatic expansion valve

**ET 499.19**

Cutaway model: automatic expansion valve

**ET 499.21**

Cutaway model: sight glass with humidity indicator

**ET 499.25**

Cutaway model: 4-way reversing valve

**ET 499.26**

Cutaway model: condensation pressure control valve



# First-rate handbooks



**GUNT's policy is simple:**  
high quality hardware and clearly developed instructional material ensure successful teaching and learning about an experimental unit.

The core of this material are detailed reference experiments that we have carried out. The description of the experiment contains the actual experimental setup right through to the interpretation of the results and findings. A group of experienced engineers develops and maintains the instructional material.

Nevertheless, we are here to help should any questions remain unanswered, either by phone or – if necessary – on site.



## Basic knowledge

Assembly, troubleshooting and maintenance  
in refrigeration

The refrigerating plant is a closed piping system in which complex changes of state take place. Since in practice it is impossible to look into the closed piping system, it is important to have a basic understanding of these processes in order to be able to comprehend what is happening inside the system. For this reason, GUNT devices explain the function of the components of the refrigerating plant and their functional interrelationships.

Frequently occurring faults are also considered and analysed with the help of the basic knowledge previously taught.

Only a refrigeration technician who has learned to understand what is happening inside a system in this way can make the correct diagnosis on the basis of his measured values and take steps to correct the fault.

In addition to technical equipment, successful **fault finding** and **fault analysis** in refrigerating plants requires expert knowledge. The most important tools for fault finding are manometers and thermometers. The refrigerant conditions such as superheating and supercooling provide important information when searching for a fault.

A technician's own senses are also important tools in fault finding: bubbles in the sight glass, dirt and frosting can be seen. If the compressor takes in wet steam, this can be seen on the intake line and may also be heard. You can even smell an overloaded compressor.

## Assembly exercises with MT 210



## Commissioning sequence

1. visual inspection
2. pressure test
3. leak test
4. drying, evacuating
5. filling, determining the required fill quantity
6. review and adjustment of the safety devices

- delivery as assembly kit
- mechanical assembly of individual components, in accordance with customary industry standard
- hydraulic assembly of pipe connections according to system schematic
- electrical installation according to circuit diagram
- evacuation and filling of refrigerating plants
- fault finding in refrigerating plants
- clear arrangement of the assembled components
- fully functional refrigerating plant, which can be commissioned

## Maintenance exercises with ET 192, ET 150.01 and ET 150.02



ET 192 Replacement of refrigeration components

- mechanical and electrical assembly and disassembly of various refrigeration components
- refrigerant displacement (pump-down)
- refill refrigerant and compressor oil
- leak test
- compressor test run
- adjustment of expansion valve and pressure switch



ET 150.01 Refrigerant filling and evacuation equipment

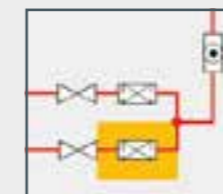
ET 150.02 Tool set

## Fault finding exercises with ET 422

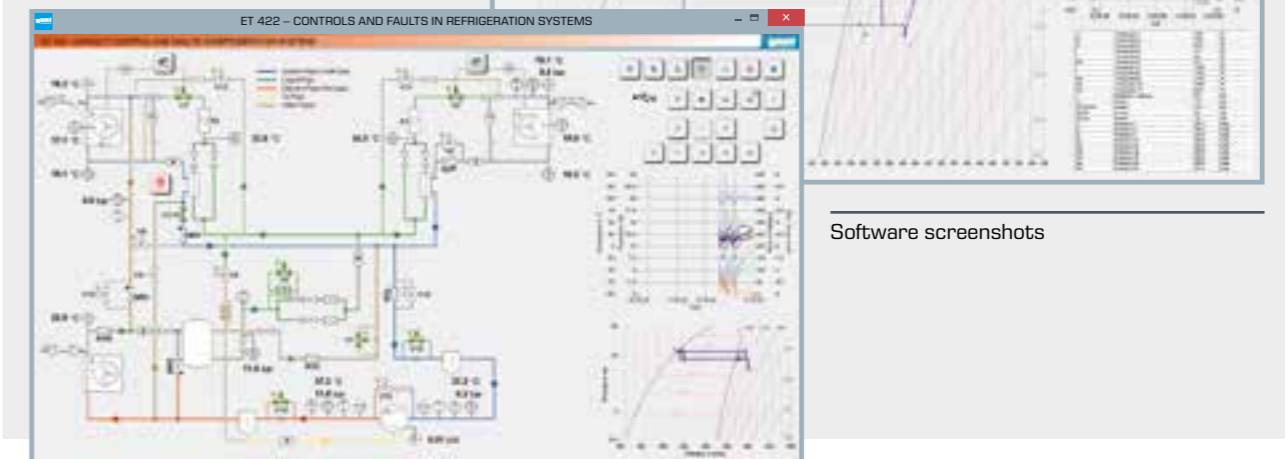
The simulation of 12 different faults, such as defective valves or blocked lines, is activated via a touch panel PC.

Numerous refrigerant lines are mounted on the back of the device to simulate system faults, such as bypassing a refrigeration component.

The software is a key component of ET 422, since it is used to directly control the majority of the components. In order to make fault finding more difficult, the fault lines and the faulty components can be hidden in the software.



Active fault



Software screenshots



## MT 210

### Assembly & maintenance exercise: refrigeration



#### Learning objectives/experiments

- reading and understanding technical documentation
- in conjunction with ET 150.02
  - ▶ planning and executing assembly steps and processes
  - ▶ making pipe joints in accordance with a system diagram
  - ▶ carrying out electrical installation in accordance with a circuit diagram
- in conjunction with ET 150.01
  - ▶ filling and evacuating of the refrigeration system
  - ▶ commissioning and checking the refrigeration system after successful assembly
  - ▶ familiarisation with the function of a refrigeration system as a system and its components as system components
  - ▶ fault analysis: fault finding, fault evaluation and repair
  - ▶ planning, executing and evaluating maintenance processes

#### Description

- **study project with high practical relevance**
- **suitable for training in metal and electrical professions**
- **interdisciplinary and covering several subject areas**
- **assembly of a refrigeration system from individual components**

Using MT 210 trainees can learn working within a complex project. This involves the planning, implementation and checking of processes related to assembly, commissioning and maintenance. The assembly relates to refrigeration installation: installation of the LP and HP pressure switches, the expansion valve and the pipework of the refrigeration circuit. The pipe joints are not soldered but bolted. The electrotechnical installation includes the wiring and connection of all units and switching elements.

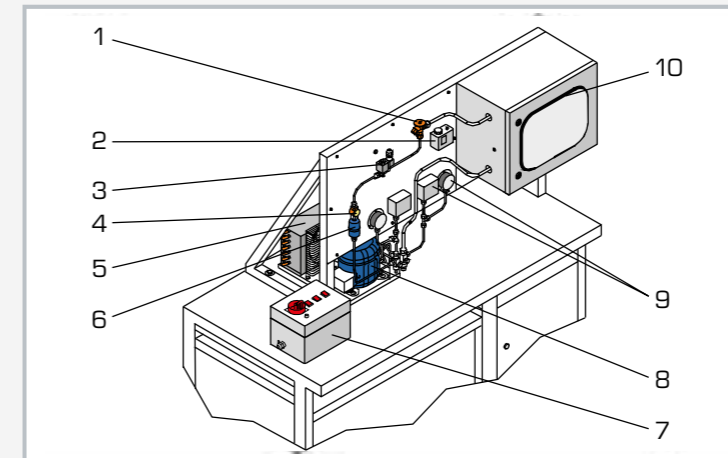
For assembly the tool set ET 150.02, for commissioning the system the filling and evacuation equipment ET 150.01 are required.

The fully assembled system MT 210 represents a fully functional, temperature-controlled refrigeration system with refrigeration chamber and electrical thermostat. Repeated assembly and disassembly are possible.

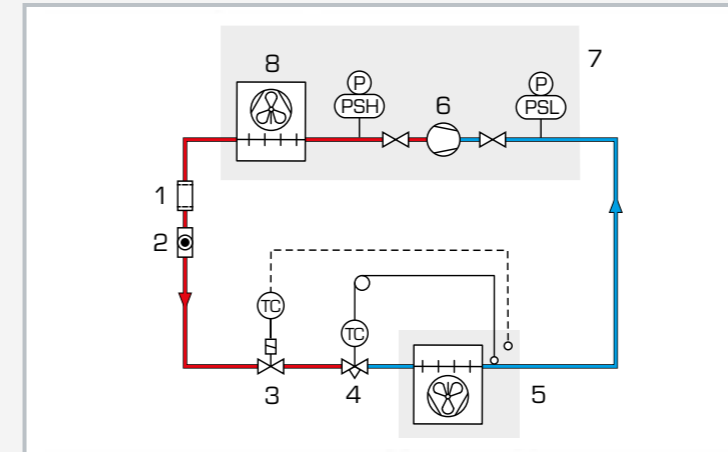
The experiment is arranged on a workbench with drawers for storing the components and tools. Assembly panel and refrigeration chamber are mounted on a frame. Frame, condensing unit and switch cabinet are bolted permanently to the working surface. The refrigeration and electrical components are attached to the aluminium assembly panel.

## MT 210

### Assembly & maintenance exercise: refrigeration



1 expansion valve, 2 thermostat, 3 solenoid valve, 4 sight glass, 5 condenser with fan, 6 filter/drier, 7 switch cabinet, 8 compressor, 9 pressure switch with manometer, 10 refrigeration chamber with sight window and integrated evaporator



1 filter/drier, 2 sight glass, 3 thermostat, 4 expansion valve, 5 refrigeration chamber with evaporator, 6 compressor, 7 condensing unit, 8 condenser; P pressure, PSL, PSH pressure switch; blue: low pressure, red: high pressure



Leak test at the expansion valve of the fully assembled system

#### Specification

- [1] assembly project for the training of mechatronics engineers for refrigeration
- [2] assembly of a refrigeration system with refrigeration chamber from a complete kit
- [3] refrigeration system designed for operation with refrigerant R513A
- [4] temperature control via thermostat
- [5] air-cooled condensing unit with compressor
- [6] refrigeration chamber with integrated show case evaporator and fan
- [7] refrigeration chamber with large sight window
- [8] assembly panel to mount the refrigeration and electrical components
- [9] electrical assembly in accordance with the circuit diagram
- [10] easy pipeworking of the refrigeration circuit using bolted pipe joints
- [11] workbench with drawers to store the components
- [12] part of the GUNT-Practice Line for assembly, maintenance and repair

#### Technical data

##### Condensing unit

- power consumption: 190W
- receiver: approx. 1L

##### Show case evaporator

- capacity: 50W at  $t_0 = -6^\circ\text{C}$ ,  $\Delta T = 8\text{K}$
- transfer area: 1,06m<sup>2</sup>

##### Refrigeration chamber with sight window

- LxWxH: 480x280x390mm

##### Aluminium assembly panel

- LxW: 710x500mm

##### Thermostatic expansion valve, adjustable

Thermostat, adjustable:  $-30 \dots 15^\circ\text{C}$

230V, 50Hz, 1 phase

120V, 60Hz, 1 phase; 230V, 60Hz, 1 phase

UL/CSA optional

LxWxH: 1530x750x1670mm

Weight: approx. 155kg

#### Required for operation

approx. 1kg refrigerant (R513A)

#### Scope of delivery

- 1 workbench with drawers, switch cabinet, condensing unit, assembly panel and refrigeration chamber kit, 1 set of small parts
- 1 set of instructional material, consisting of: technical description of system, complete set of drawings with lists of parts, description of assembly and disassembly sequences, description of maintenance and repair processes



## ET 192

### Replacement of refrigeration components



#### Description

- practical service tasks in refrigeration systems
- replace typical components of a refrigeration system: compressor, pressure switch, filter/drier, solenoid valve and expansion valve
- refrigerant displacement, replacement, evacuation, filling and siphoning off

The replacement of a faulty compressor or other components of the refrigeration system are amongst the repeated activities of a mechatronics engineer for refrigeration. ET 192 allows for training in these processes. The consequences of incorrect procedures can be demonstrated.

The components are integrated into an operational refrigeration system. This allows for the practical testing of the functionality of individual components after replacement.

The following activities must be carried out e.g. after replacing a compressor:

- refrigerant displacement (pump-down) into the condenser/receiver (should this not be possible, siphoning off the refrigerant)
- disconnection of the compressor at the service valves
- disconnection of electrical connections
- compressor replacement, correcting oil level, if necessary
- reconnecting electrical connections
- reconnecting the compressor with the service valves
- evacuating the compressor and making the connection to the system
- compressor test run, checking for leaks and replenish refrigerant, if necessary
- checking the system pressures

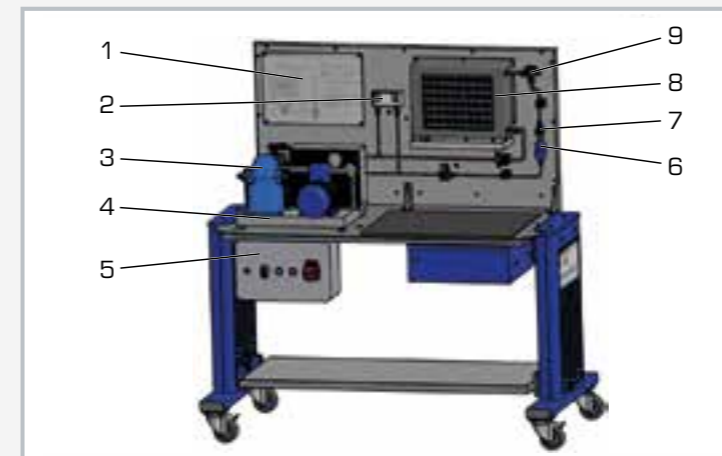
To carry out the service tasks, the tool set ET 150.02 and the filling and evacuation equipment ET 150.01 are required.

#### Learning objectives/experiments

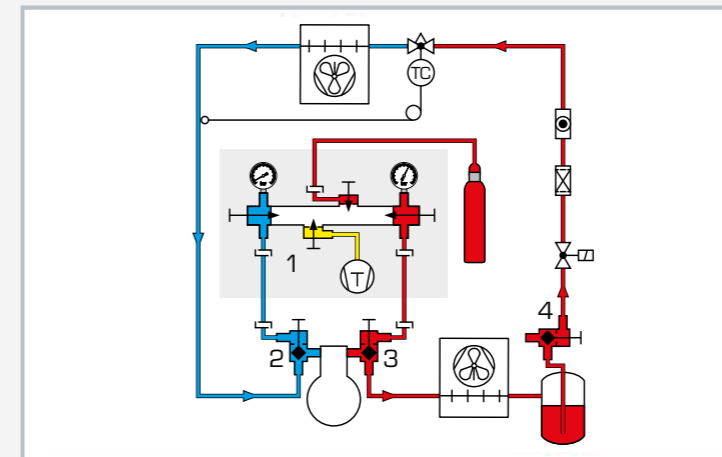
- familiarisation with and carry out basic activities for the servicing of refrigeration systems
- replacement of
  - ▶ compressor
  - ▶ pressure switch
  - ▶ filter/drier
  - ▶ solenoid valve
  - ▶ expansion valve
- refrigerant displacement (pump-down)
- mechanical and electrical assembly and disassembly of components
- replenish refrigerant and compressor oil
- leak test
- compressor test run
- adjustment of expansion valve and pressure switch

## ET 192

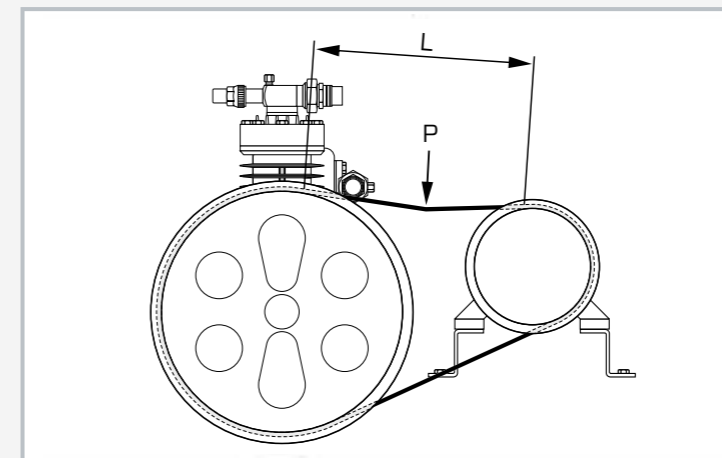
### Replacement of refrigeration components



1 process schematic, 2 pressure switch, 3 condenser, 4 compressor, 5 controls, 6 filter/drier, 7 sight glass, 8 evaporator, 9 expansion valve



Example: valve position for normal operation, assembly aid is connected and indicates operating pressures  
1 assembly aid, 2 intake side service valve, 3 delivery side service valve, 4 receiver shut-off valve; blue: low pressure, red: high pressure



Checking and adjustment of the belt tension

#### Specification

- [1] trainer from the GUNT practical series for the training of mechatronics engineers for refrigeration
- [2] service exercises in refrigeration systems
- [3] complete refrigeration circuit with open compressor, air-cooled condenser, receiver and air cooling evaporator
- [4] replaceable components: compressor, filter/drier, pressure switch and solenoid valve
- [5] required accessories evacuation equipment ET 150.01 and tool set ET 150.02
- [6] overall arrangement on robust workbench
- [7] refrigerant R513A, GWP: 631

#### Technical data

Open refrigerant compressor

- refrigeration capacity: 450W at -5°C/40°C and 1450min<sup>-1</sup>
- maximum system pressure: 18bar

Pressure switch

- LP: -0,2...7bar
- HP: 10...32bar

Refrigerant

- R513A
- GWP: 631
- filling volume: 1kg
- CO<sub>2</sub>-equivalent: 0,6t

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase  
120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1400x750x1650mm  
Weight: approx. 150kg

#### Scope of delivery

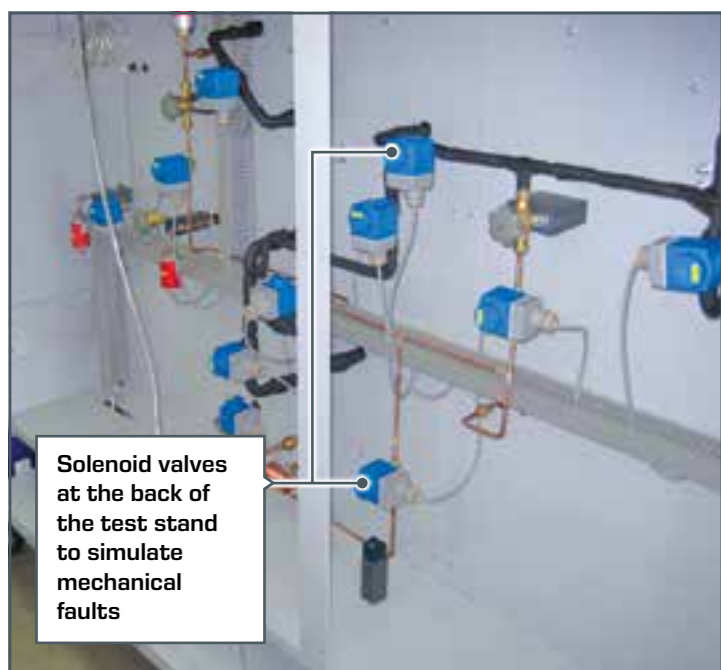
- 1 trainer
- 1 set of instructional material

# ET 422 Capacity control and faults in refrigeration systems



- Software for optimum support of the learning process:**
- process schematic with display of the measured values
  - recording of time graphs
  - representation of the thermodynamic cycle process in the log p-h diagram

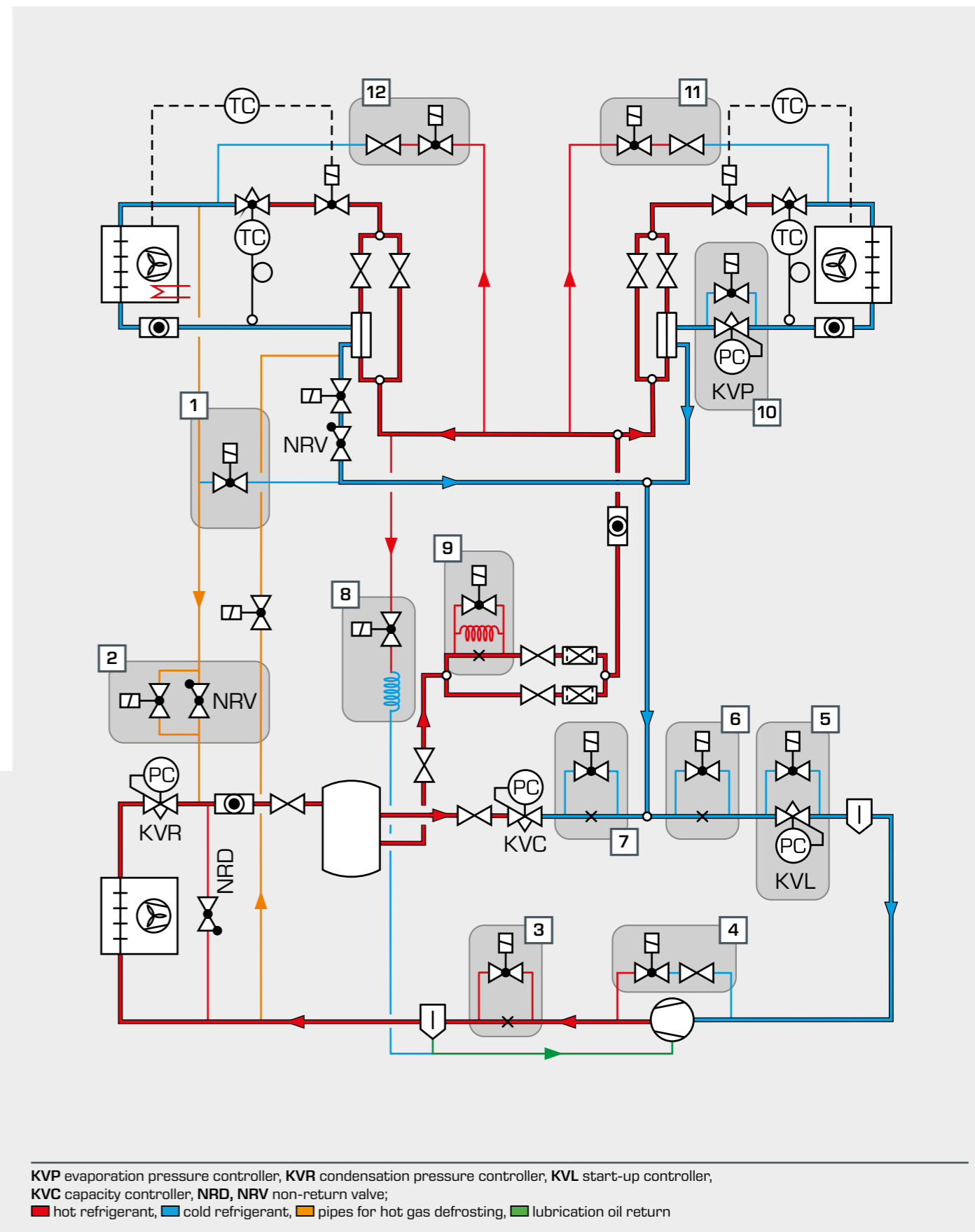
## Simulation of typical faults in refrigeration systems



Solenoid valves at the back of the test stand to simulate mechanical faults

### Typical mechanical faults

- 1 non-return valve upstream of the start-up controller faulty
- 2 non-return valve for hot gas defrosting faulty
- 3 delivery pipe at the compressor clogged
- 4 leak at the compressor
- 5 start-up controller KVL faulty
- 6 intake pipe at the compressor clogged
- 7 capacity controller KVC faulty
- 8 oil separator faulty (float valve blocked)
- 9 filter/drier blocked (iced)
- 10 faulty KVP evaporation pressure controller in refrigeration chamber
- 11 expansion valve at the refrigeration chamber faulty
- 12 expansion valve at the freezing chamber faulty





## ET 422

### Capacity control and faults in refrigeration systems



#### Description

- practice-oriented model of a commercial refrigeration system
- refrigeration and freezing chamber to investigate different methods for capacity control
- simulation of twelve faults
- two defrosting methods for freezing chamber

The efficient control of the capacity and temperature in refrigeration systems is an important topic in refrigeration technology. With ET 422 different methods of capacity control can be investigated.

The components of a refrigeration circuit with refrigeration and freezing chambers are arranged clearly in the trainer. Solenoid valves enable the separate or parallel operation of the evaporators in the two chambers. The circuit is equipped with a capacity controller, a start-up controller and a combined pressure switch for the delivery and intake sides of the compressor. One heat exchanger each in the inlet of the two evaporators enables the supercooling of the refrigerant to be investigated for the efficiency of the process. The refrigeration capacity of the two individual chambers is controlled by a thermostat. The refrigeration chamber also features an evaporation pressure controller.

There are two defrosting methods for the freezing chamber: an electric defrost heater and a hot gas defrosting where hot refrigerant is fed directly from the compressor in the opposite direction through the evaporator.

The simulation of twelve different faults, such as e.g. faulty valves or clogged pipes, is activated using a touch panel PC.

Relevant measured values are transmitted directly to the touch panel PC and analysed. The software enables e.g. the representation of the cycle in the log p-h diagram.

#### Learning objectives/experiments

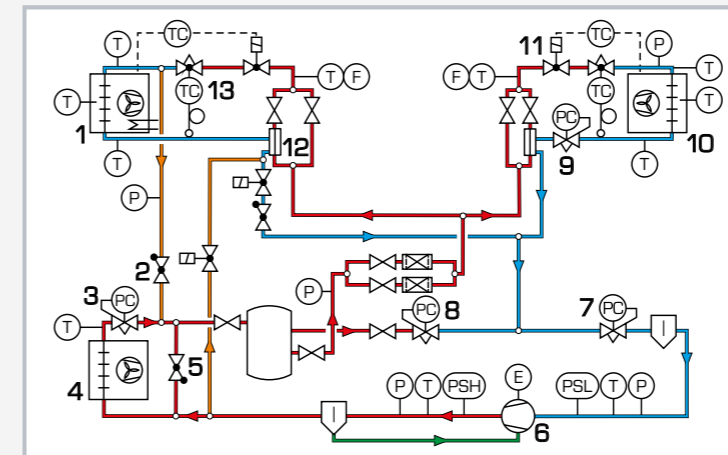
- familiarisation with the key devices for changing the refrigeration capacity
  - ▶ thermostat
  - ▶ capacity controller
  - ▶ start-up controller
  - ▶ evaporation pressure controller
  - ▶ condensation pressure controller
- fault finding in refrigeration system components
- effect of refrigerant supercooling
- familiarisation with defrosting methods
  - ▶ electric defrost heater
  - ▶ hot gas defrosting
- representation of the thermodynamic cycle in the log p-h diagram

## ET 422

### Capacity control and faults in refrigeration systems



1 expansion valve, 2 freezing chamber, 3 thermostat, 4 heat exchanger, 5 solenoid valve, 6 condenser, 7 condensation pressure controller, 8 capacity controller, 9 compressor, 10 start-up controller, 11 pressure switch, 12 evaporation pressure controller, 13 flow meter, 14 refrigeration chamber, 15 touch panel PC



1 freezing chamber, 2 non-return valve hot gas defrosting, 3 condensation pressure controller, 4 condenser, 5 receiver pressure controller, 6 compressor, 7 start-up controller, 8 capacity controller, 9 evaporation pressure controller, 10 refrigeration chamber, 11 solenoid valve (thermostat), 12 heat exchanger, 13 expansion valve; T temperature, P pressure, F flow rate; PSH, PSL pressure switch



Software screenshot: log p-h diagram

#### Specification

- [1] investigation of a refrigeration system with refrigeration and freezing chambers
- [2] refrigeration circuit with compressor, condenser, capacity controller, start-up controller, combined pressure switch and 2 evaporators in insulated chambers
- [3] each chamber with solenoid valve, thermostat, thermostatic expansion valve, fan and heat exchanger for refrigerant supercooling
- [4] refrigeration chamber with evaporation pressure controller
- [5] freezing chamber with electric defrost heater and hot gas defrosting
- [6] separate or parallel operation of the chambers via solenoid valves
- [7] simulation of 12 faults
- [8] touch panel PC for fault activation, data acquisition, evaluation and representation in the log p-h diagram
- [9] refrigerant R449A, GWP: 1397

#### Technical data

##### Compressor

- refrigeration capacity: 1640W at -10/50°C
- power consumption: 980W at -10/50°C

##### Condenser with fan

- volumetric air flow rate: 570m<sup>3</sup>/h

##### Evaporator transfer areas

- refrigeration chamber: 1,12m<sup>2</sup>
- freezing chamber: 1,88m<sup>2</sup>

Electric defrost heater: approx. 125W

Capacity controller: 0,2...6bar

Start-up controller: 0,2...6bar

Thermostat: 2x -25...15°C

Evaporation pressure controller: 0...5,5bar

##### Refrigerant

- R449A
- GWP: 1397
- filling volume: 3,21kg
- CO<sub>2</sub>-equivalent: 4,5t

##### Measuring ranges

- temperature: 6x -50...50°C; 5x 0...100°C
- pressure: 3x -1...15bar; 2x -1...24bar
- flow rate: 2x 2...29L/h
- power consumption: 0...5kW (compressor)

400V, 50Hz, 3 phases

230V, 60Hz, 3 phases; 400V, 60Hz, 3 phases

UL/CSA optional

LxWxH: 2420x780x1900mm

Weight: approx. 280kg

#### Scope of delivery

- 1 trainer
- 1 set of instructional material

## ET 150.01

### Refrigerant filling and evacuation equipment



#### Learning objectives/experiments

- prepare the filling station
- evacuate the refrigeration system
- fill the refrigeration system

#### Specification

- [1] portable equipment
- [2] vacuum pump and filling balance
- [3] 4-valve assembly aid
- [4] pulsation-damped manometer for intake pressure, high pressure; vacuum meter
- [5] manometer for intake and high pressure
- [6] high pressure and intake pressure connections

#### Technical data

Vacuum pump  
 ■ motor power: 0,25kW

Intake volume: 66L/min

Final vacuum: 0,02mbar

Measuring ranges  
 ■ intake pressure: -1...8bar  
 ■ high pressure: 0...31bar  
 ■ vacuum: 0...1000mbar

230V, 50Hz, 1 phase  
 230V, 60Hz, 1 phase  
 120V, 60Hz, 1 phase  
 UL/CSA optional  
 LxWxH: 510x175x485mm  
 LxWxH: 370x270x60mm (balance)  
 Weight: approx. 15kg

#### Scope of delivery

- 1 vacuum pump
- 3 filling hoses
- 1 balance
- 1 manual

#### Description

- **evacuation and filling of refrigeration systems**
- **suitable for refrigerant R513A**

The accessory ET 150.01 is used to evacuate and fill refrigeration systems. The components used are common in refrigeration and therefore closely related to practice.

The refrigeration system is evacuated using a vacuum pump. Evacuation using the vacuum pump removes air and humidity from the refrigeration system to allow subsequent filling with refrigerant. The correct amount of refrigerant is monitored using the filling balance.

## ET 150.02

### Tool set



#### Specification

- [1] commercial tools for the assembly and servicing of refrigeration systems
- [2] battery operated leak detection device suitable for refrigerant R513A
- [3] digital multimeter for direct and alternating current, battery operated

#### Technical data

LxWxH: 420x210x180mm (case)  
 Weight: approx. 10kg

#### Scope of delivery

- 1 case
- 1 set of tools
- 1 leak detection device
- 1 multimeter

#### Description

- **case with tools for the assembly and maintenance of refrigeration systems**

With the ET 150.02 accessory, maintenance work and troubleshooting of refrigeration systems are carried out.

One of each of following tools is included: pipe cutter, adjustable spanner, jointing clamp, flanging tool, manual countersink, side cutter, cable stripping knife, crimping tool, wire strippers, set of Allen keys (7 pieces), set of pipe bending pliers (3 pieces), set of screwdrivers (4x straight, 2x Philips), set of ring spanners (17 pieces), steel ruler, small saw, deburring miller, file.

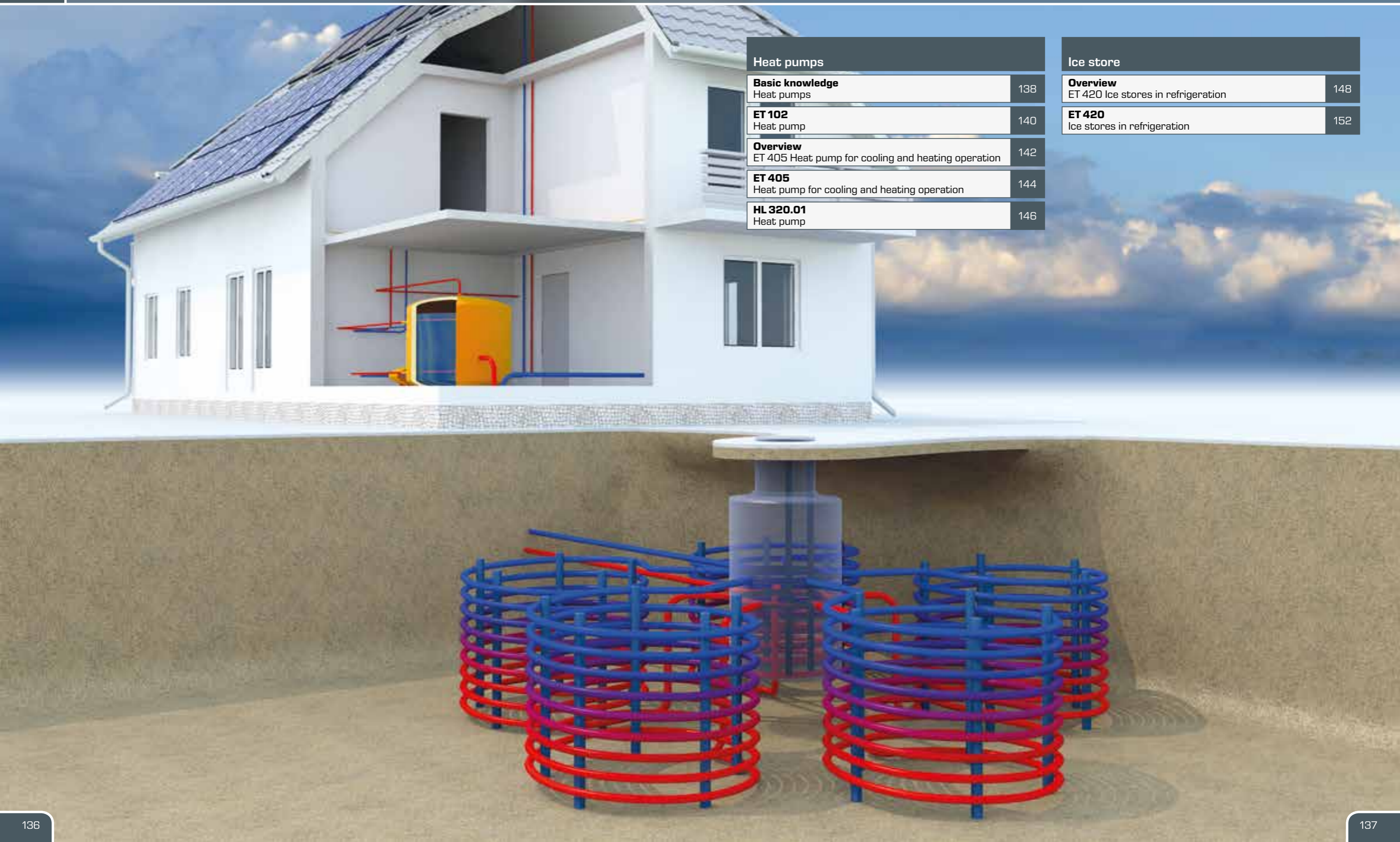
A multimeter is included for electrical fault finding. The leak test in refrigeration systems is carried out using a high quality leak detection device for refrigerant gases.

A stable plastic tool case is included.



4  
❄️

# Heat pumps and ice store



Heat pumps	
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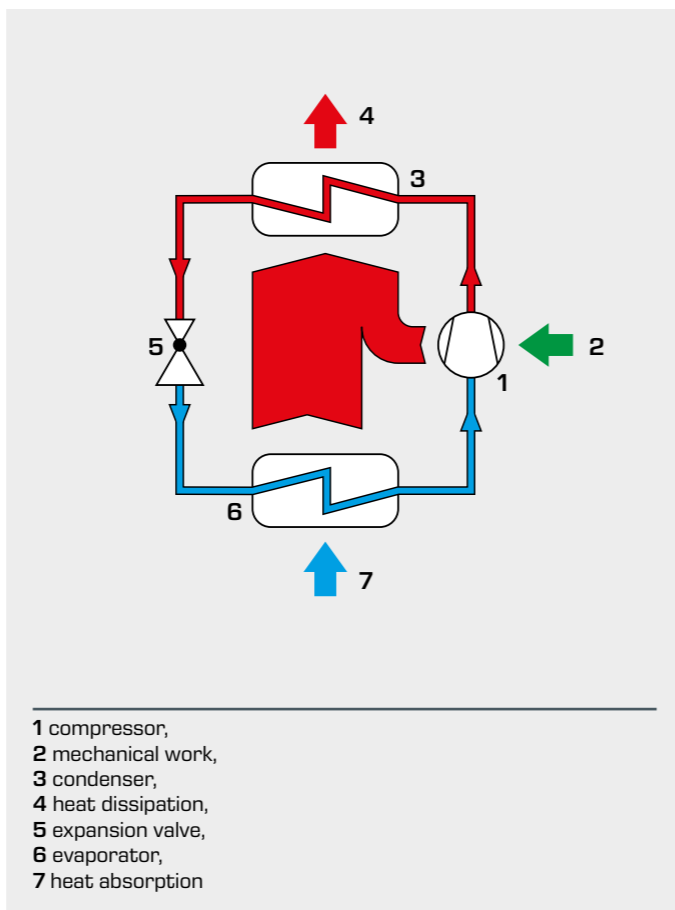
## Basic knowledge Heat pumps

### What is a heat pump?

A heat pump transports heat from a low temperature level to a higher temperature level. To do this, the heat pump requires drive power. This can be mechanical, electrical or thermal. Usually heat pumps which operate according to the principle of a compression refrigeration system are used. Less often, heat pumps running on the absorption process are used.

The COP is an important indicator for the operation of heat pumps. COP stands for "Coefficient of Performance". The COP indicates how efficiently a heat pump works. The COP indicates the ratio of heat capacity and the required drive power. This value allows an easy comparison between different heat pumps.

The COP is directly dependent on the temperature of the heat source and the heating temperature in the building. Therefore, the COP changes at each operating point of the heat pump. The larger the COP, the more effective the heat pump.



### Where does the heat pump get its energy from?

A heat pump usually extracts the energy from the environment. Air, groundwater, the earth or river water are common. If the energy is extracted from the ground, this is known as shallow geothermal energy. An energy source temperature which is as high and constant as possible is the key for high efficiency. The temperature must not drop off too much in winter, when the most heating power has to be provided. For groundwater

and the ground, the heat exchangers have to be very large in order to avoid any local sub-cooling. When choosing the heat source, factors such as investment cost, efficiency, availability and obtaining permission have to be weighed against each other. Using low-order waste heat such as exhaust air or cooling water is particularly cost-effective.

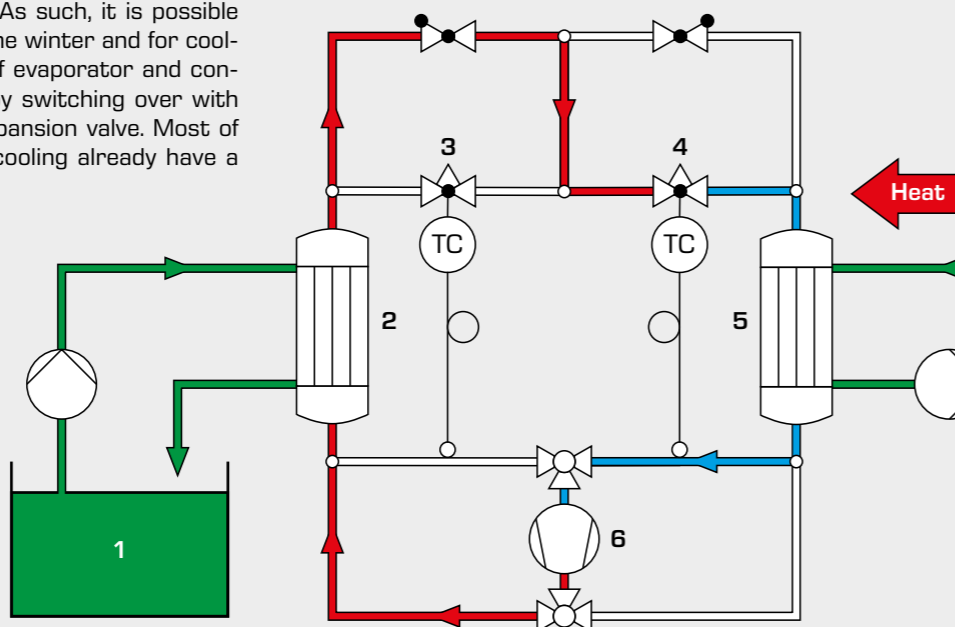
Energy source	Advantage	Disadvantage
outside air	low investment	low COP in winter
river water	low investment	low COP in winter
groundwater	good, constant power	high investment, permission
ground	good, constant power	large space requirement

### A heat pump can be used for cooling or heating

Because they have the same principle of operation, a heat pump can function as a refrigeration system. As such, it is possible to use the same system for heating in the winter and for cooling in the summer. Only the functions of evaporator and condenser are swapped. This takes place by switching over with two non-return valves and a second expansion valve. Most of these so-called split devices for room cooling already have a heater function included.

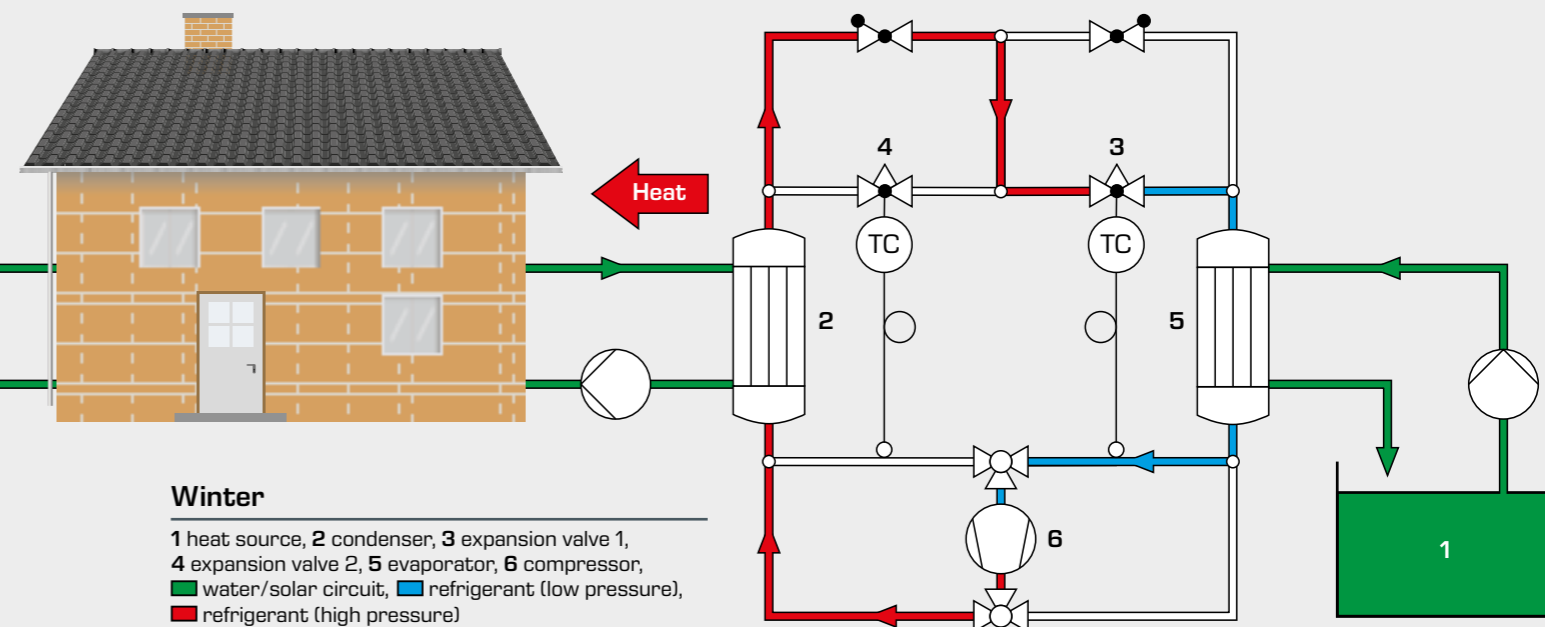
#### Summer

- 1 heat sink, 2 condenser, 3 expansion valve 1,
- 4 expansion valve 2, 5 evaporator,
- 6 compressor,
- water/solar circuit, ■ refrigerant (low pressure), ■ refrigerant (high pressure)



#### Winter

- 1 heat source, 2 condenser, 3 expansion valve 1,
- 4 expansion valve 2, 5 evaporator, 6 compressor,
- water/solar circuit, ■ refrigerant (low pressure), ■ refrigerant (high pressure)





**ET 102**  
Heat pump**Learning objectives/experiments**

- design and operation of an air-to-water heat pump
- representation of the thermodynamic cycle in the log p-h diagram
- energy balances
- determination of important characteristic variables
  - ▶ compressor pressure ratio
  - ▶ ideal coefficient of performance
  - ▶ real coefficient of performance
- dependence of the real coefficient of performance on the temperature difference (air-to-water)
- operating behaviour under load

**Description**

- utilisation of ambient heat for water heating
- display of all relevant values at the location of measurement
- dynamic recording of the refrigerant mass flow rate

With the air-to-water heat pump ET 102 the ambient heat of the air is used to heat water.

The heat pump circuit consists of a compressor, an evaporator with fan, a thermostatic expansion valve and a coaxial coil heat exchanger as condenser. All components are clearly arranged in the trainer.

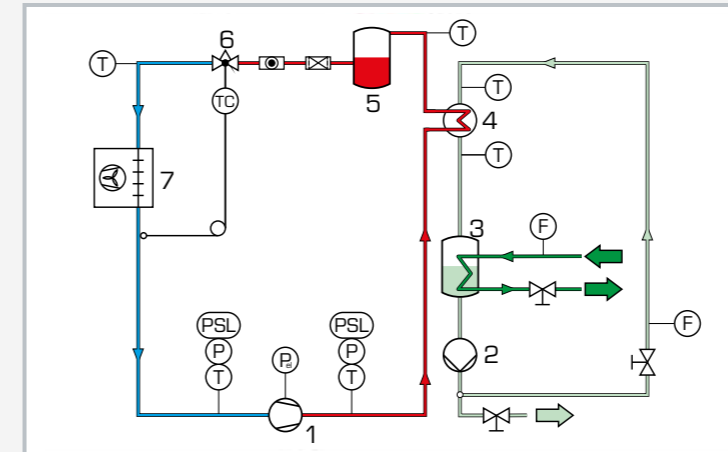
The compressed refrigerant vapour condenses in the outer pipe of the condenser and thereby discharges heat to the water in the inner pipe. The liquid refrigerant evaporates at low pressure in the finned tube evaporator and thereby absorbs heat from the ambient air.

The hot water circuit consists of a tank, a pump and the condenser as heater. For a continuous operation the generated heat is dissipated via an external cooling water connection. The cooling water flow rate is set via a valve and measured.

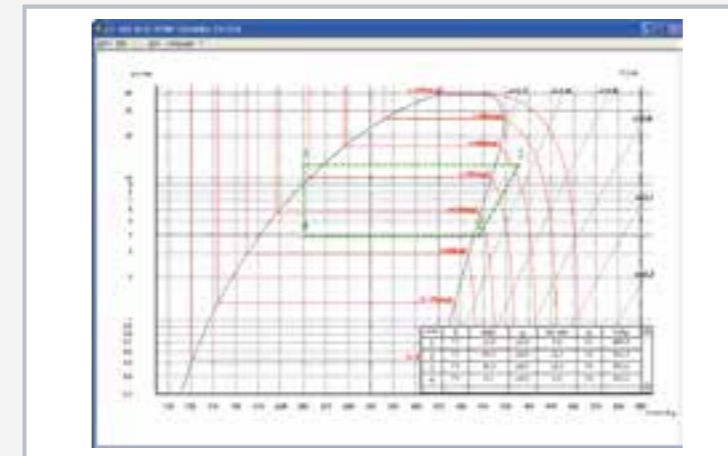
All relevant measured values are recorded by sensors and displayed. The simultaneous transmission of the measurements to a data recording software enables analysis and the representation of the process in the log p-h diagram. The refrigerant mass flow rate is calculated in the software from the recorded measured values. The software also displays the key characteristics variables of the process, such as the compressor pressure ratio and the coefficient of performance.

**ET 102**  
Heat pump

1 expansion valve, 2 evaporator with fan, 3 pressure sensor, 4 pressure switch, 5 displays and controls, 6 compressor, 7 cooling water flow meter, 8 pump, 9 hot water tank, 10 receiver, 11 cocondenser



1 compressor, 2 pump, 3 hot water tank with external cooling water connection, 4 condenser, 5 receiver, 6 expansion valve, 7 evaporator with fan;  
T temperature, P pressure, F flow rate, P<sub>el</sub> power, PSH, PSL pressure switch;  
blue/red: refrigeration circuit, light green: hot water circuit, green: cooling water



Software screenshot: log p-h diagram

**Specification**

- [1] investigation of a heat pump with a water circuit as load
- [2] refrigeration circuit with compressor, evaporator with fan, thermostatic expansion valve and coaxial coil heat exchanger as condenser
- [3] hot water circuit with pump, tank and condenser as heater
- [4] additional cooling via pipe coil in the hot water tank and external cooling water
- [5] record and display of all relevant measured values
- [6] refrigerant mass flow rate calculated in the software from recorded measured values
- [7] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
- [8] refrigerant R513A, GWP: 631

**Technical data****Compressor**

- refrigeration capacity: 372W at 7,2/55°C
- power consumption: 205W at 7,2/55°C

**Coaxial coil heat exchanger (condenser)**

- refrigerant content: 0,55L

**Finned tube evaporator**

- transfer area: approx. 0,175m<sup>2</sup>

**Pump**

- max. flow rate: 1,9m<sup>3</sup>/h
- max. head: 1,4m

**Hot water tank volume: approx. 4,5L****Refrigerant: R513A**

- GWP: 631
- filling volume: 1kg
- CO<sub>2</sub>-equivalent: 0,6t

**Measuring ranges**

- pressure: 2x -1...15bar
- temperature: 4x 0...100°C, 2x -100...100°C
- power: 0...6000W
- flow rate: 0...108L/h (water)
- flow rate: 10...160L/h (cooling water)
- flow rate: 0...17kg/h (refrigerant)

230V, 50Hz, 1 phase; 230V, 60Hz, 1 phase  
120V, 60Hz, 1 phase

UL/CSA optional  
LxWxH: 1620x790x1910mm

Weight: approx. 192kg

**Required for operation**

water connection, drain, PC with Windows recommended

**Scope of delivery**

- 1 trainer
- 1 GUNT software CD + USB cable
- 1 set of instructional material

# ET 405 Heat pump for cooling and heating operation

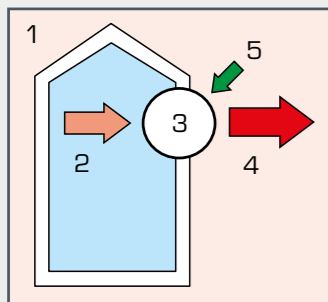
With suitable arrangement of compressor, condenser and evaporator, the same heat pump can be used for heating and for cooling. In the air-conditioning of buildings, this is advantageous since rooms are heated in winter and cooled in summer by the same system. In addition, heat pumps are already widely used to generate hot water. The heat source always plays a central role in heat pump technology. The design of the heat pump is particularly important in order to be able to use the existing heat sources effectively at a low temperature level.

ET 405 enables the investigation of a multitude of component arrangement options. A compressor, a condenser (heat exchanger with fan) and two evaporators with fans (standard cooling stage and deep-freeze stage) are available. A coaxial coil heat exchanger can optionally be operated as an evaporator or a condenser. It connects the heat pump circuit to another circuit filled with a glycol-water mixture.



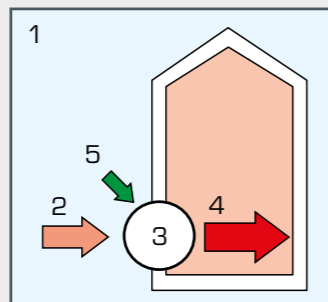
## Cooling and heating using the heat pump

### Cooling



During cooling the absorbed heat at the heat pump provides the gain. It is absorbed from a room and discharged into the environment. Electrical energy to operate the compressor of the heat pump is required for this purpose.

### Heating



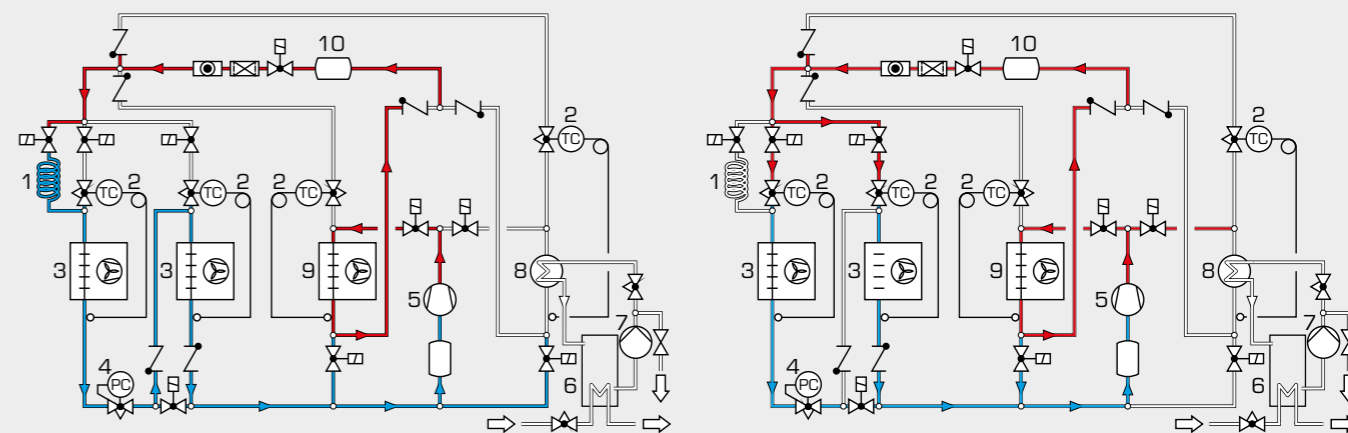
During heating the heat discharged by the heat pump is the gain. The heat pump absorbs heat from the environment and discharges it to the room.

1 environment, 2 absorbed heat, 3 heat pump, 4 discharged heat, 5 electric energy

## Different operating modes for typical applications

### Two evaporators – connected in series or parallel

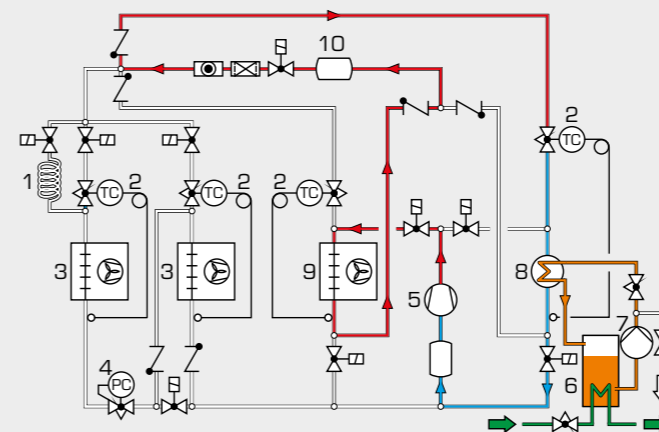
The two evaporators can optionally be connected parallel or in series. It is also possible to operate only one evaporator. The condenser 9 operates as an air heater. At both evaporators 3 the heat is absorbed from the environment.



1 capillary tube, 2 expansion valve, 3 evaporator, 4 evaporation pressure controller, 5 compressor, 6 tank for glycol-water mixture, 7 pump, 8 coaxial coil heat exchanger, 9 heat exchanger with fan, 10 receiver

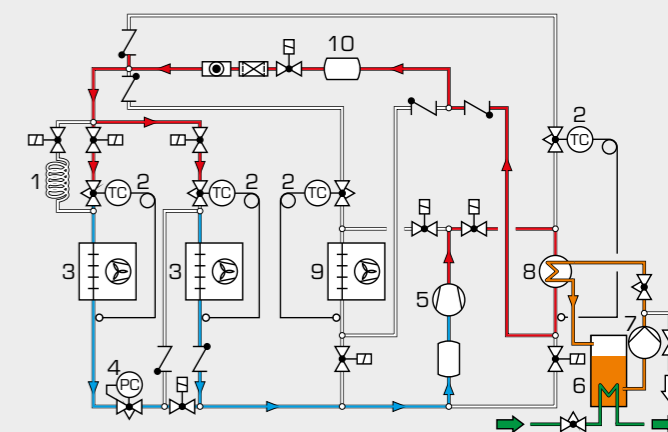
### Coaxial coil heat exchanger as evaporator (cooling)

The liquid refrigerant is expanded using a thermostatic expansion valve 2 and evaporated in the coaxial coil heat exchanger 8. This cools the glycol-water mixture. The condensation of the refrigerant takes place in the air-cooled finned tube heat exchanger 9. In the tank 6 the glycol-water mixture absorbs heat from the pipe coil through which water flows.



### Coaxial coil heat exchanger as condenser (heating)

The refrigerant steam flows through the coaxial coil heat exchanger 8. Here the refrigerant is condensed and heats the glycol-water mixture. The refrigerant then flows through two evaporators 3 which can optionally be connected in parallel or in series. The glycol-water mixture discharges its heat in the tank 6 to a water-cooled pipe coil.





## ET 405

### Heat pump for cooling and heating operation



#### Description

- air-to-water heat pump
- heating and cooling operation possible
- high practical relevance by using industrial components from refrigeration
- different operating modes can be set via solenoid valves

Refrigeration systems and heat pumps only differ in the definition of their use, but can be of the same design. For example, goods can be refrigerated in a supermarket and the store heated with the waste heat. The store can also be cooled with the same system in the summer.

With ET 405 the cooling and heating operation can be investigated. Different operating modes can be selected via solenoid valves.

The refrigeration circuit with compressor and condenser (heat exchanger with fan) includes two evaporators with fans (refrigeration stage and freezing stage) and thermostatic expansion valves. The two evaporators can be connected in parallel or in series. For the connection in series the capillary tube serves as expansion element for the refrigeration stage evaporator. The refrigerant circuit is connected to a glycol-water circuit via a coaxial coil heat exchanger. Via solenoid valves the coaxial coil heat exchanger can be switched as an evaporator or condenser. Thus the glycol-water mixture in the tank can be heated or cooled. In pure cooling operation (without heating function) the heat exchanger with fan as air-cooled condenser dissipates the heat. This heat exchanger can be also switched as an evaporator.

The measured values are read from digital displays and can at the same time be transmitted via USB directly to a PC where they can be analysed using the software included. The refrigerant mass flow rate is calculated in the software from the recorded measured values. The software enables a clear representation of the process.

#### Learning objectives/experiments

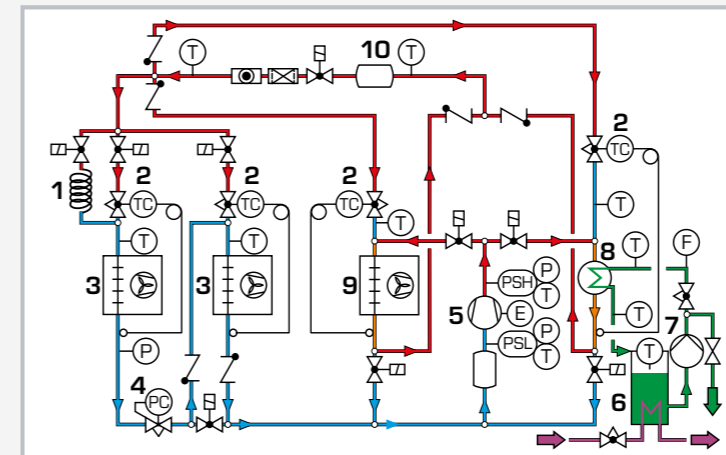
- design, operation and key components of a heat pump or refrigeration system
- representation of the thermodynamic cycle in the log p-h diagram
- comparing different operating modes
- measurement of compressor capacity and heating or cooling capacity in the glycol-water circuit
- determination of
  - ▶ efficiency
  - ▶ coefficient of performance of heat pump and refrigeration system
  - ▶ specific compressor load
  - ▶ compressor pressure ratio
  - ▶ specific cooling capacity
  - ▶ specific refrigeration capacity
- comparing key figures of heat pump and refrigeration system

## ET 405

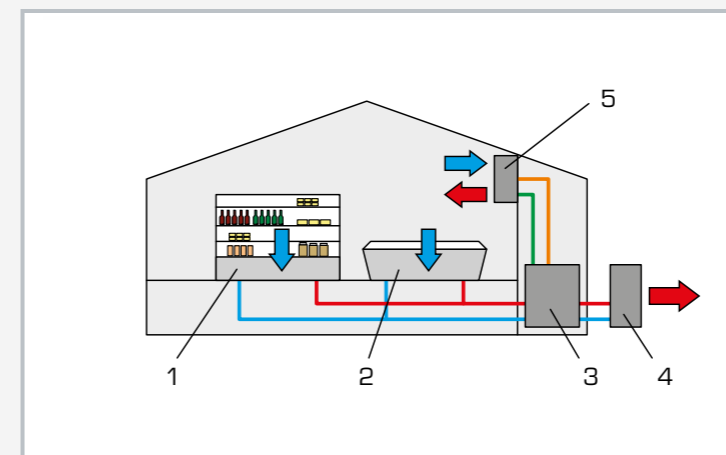
### Heat pump for cooling and heating operation



1 evaporator, 2 expansion valve, 3 capillary tube, 4 freezing stage evaporator, 5 evaporation pressure controller, 6 compressor, 7 receiver, 8 heat exchanger with fan, 9 pump, 10 display and control elements, 11 tank for glycol-water mixture, 12 flow meter (glycol-water), 13 solenoid valve, 14 coaxial coil heat exchanger



1 capillary tube, 2 expansion valve, 3 evaporator, 4 evaporation pressure controller, 5 compressor, 6 tank for glycol-water mixture, 7 pump, 8 coaxial coil heat exchanger, 9 heat exchanger with fan, 10 receiver; T temperature, P pressure, F flow rate, PSH, PSL pressure switch



Supermarket application: 1 refrigeration units, 2 freezer, 3 heat pump, 4 external condenser, 5 convactor to heat or cool the sales room

#### Specification

- [1] different operating modes selectable via solenoid valves
- [2] refrigeration circuit with compressor, condenser (heat exchanger with fan), 2 evaporators with fan (refrigeration and freezing stage)
- [3] glycol-water circuit with tank, pump and coaxial coil heat exchanger
- [4] coaxial coil heat exchanger and heat exchanger with fan can both be used as condenser or evaporator in the refrigeration circuit
- [5] 1 thermostatic expansion valve each for all heat exchangers and evaporators
- [6] 1 additional evaporation pressure controller and 1 capillary tube for the refrigeration stage evaporator
- [7] displays for temperature, pressure, flow rate and power consumption of the compressor
- [8] refrigerant mass flow rate calculated in the software from recorded measured values
- [9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

##### Compressor

- refrigeration capacity: 1561W at 5/40°C
- power consumption: 759W at 5/40°C

##### Heat exchanger with fan

- transfer area: 1,25m<sup>2</sup>
- volumetric air flow rate: 650m<sup>3</sup>/h

##### Evaporators with fan

- refrigeration stage transfer area: 1,21m<sup>2</sup>, volumetric air flow rate: 80m<sup>3</sup>/h
- freezing stage transfer area: 3,62m<sup>2</sup>, volumetric air flow rate: 125m<sup>3</sup>/h

##### Refrigerant: R513A, GWP: 631

- filling volume: 1,5kg, CO<sub>2</sub>-equivalent: 0,9t

##### Measuring ranges

- temperature: 11x -50...150°C
- pressure: 2x -1...15bar, 1x -1...24bar
- flow rate: 2,5...65g/s
- power: 0...1150W

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase

UL/CSA optional

LxWxH: 2210x800x1900mm

Weight: approx. 330kg

#### Required for operation

water connection, drain  
PC with Windows recommended

#### Scope of delivery

- 1 trainer
- 1 set of accessories
- 1 GUNT software CD + USB cable
- 1 set of instructional material

# HL 320.01

## Heat pump



### Description

- **trainer from the HL 320 modular system**
- **heat pump for operation with different sources**
- **multiple system variants possible in conjunction with other HL 320 modules**

The HL 320 modular system allows experiments on the generation, storage and use of heat from renewable energies. HL 320.01 is one module in this system and includes a heat pump that can be connected to different heat sources and consumers.

The heat pump comprises a compressor, a condenser, an expansion valve and an evaporator. These components are connected to each other via a refrigeration circuit. The refrigerant circulates in the refrigeration circuit powered by the compressor. A source's thermal energy is absorbed at the evaporator. Additional energy is added to the evaporated refrigerant in the compressor. This energy can be output to a consumer as heat.

On the HL 320.01 trainer, the condenser can be incorporated into a heating circuit consisting of various consumers. The evaporator can be connected to a source circuit with different heat sources. The pipes with quick release couplings, circulation pumps and accessories necessary to create these connections are provided.

In practice and depending on the application, different system configurations are often required for optimal efficiency of a heating system. Using HL 320.01 and other HL 320 modules it is possible to systematically investigate the possible variants for incorporating a heat pump into a modern heating system.

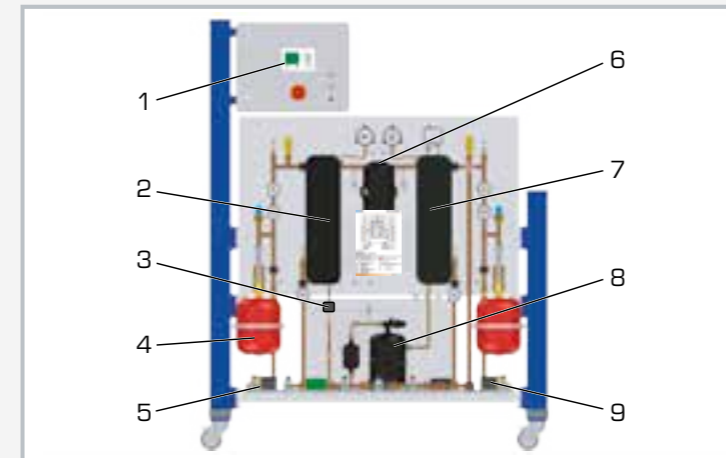
Carefully structured instructional materials have been created for the recommended modular combinations with the HL 320.01 module. As part of the documentation for the HL 320 modular system, these materials set out the basic principles and provide a step-by-step guide through the experiments.

### Learning objectives/experiments

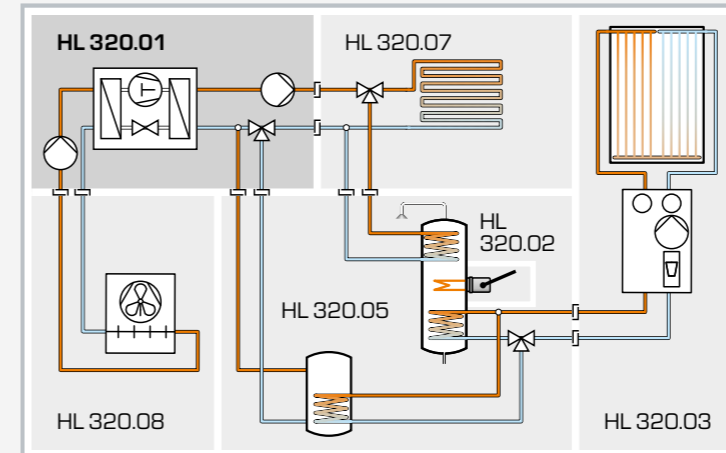
- familiarisation with heat pump applications for heating rooms and hot water
- using the heat pump for cooling
- advantages and disadvantages of various system configurations (brine heat pump, air heat pump)
- configuring and adjusting a heat pump controller
- operating behaviour under varying heat supply and demand
- dependence of the coefficient of performance on source and sink temperature
- possibilities for optimising the seasonal performance factor

# HL 320.01

## Heat pump



1 controller, 2 evaporator, 3 expansion valve, 4 expansion vessel, 5 pump source circuit, 6 scroll compressor, 7 condenser, 8 receiver, 9 pump heating circuit



Inclusion of HL 320.01 in one possible configuration of the HL 320 modular system

	1	2	3	4	5
HL 320.01			X	X	X
HL 320.02		X			X
HL 320.03	X	X		X	X
HL 320.04	(X)	(X)		(X)	(X)
HL 320.05	X	X		X	X
HL 320.07		X	X	X	X
HL 320.08			X	X	X

Recommended combinations of the HL 320 modular system

### Specification

- [1] heat pump for the HL 320 modular system
- [2] connections for various heat sources and sinks
- [3] one circulation pump and one safety module each with expansion vessel for heating and source circuit
- [4] sensors for temperature, flow rate and pressure with connection to the controller
- [5] controller with data logger and LAN connection for data acquisition and for controlling the system
- [6] software for transferring, displaying and evaluating the controller's measured data
- [7] refrigerant R410A, GWP: 2088

### Technical data

Heat pump  
 ■ heating capacity: approx. 2,3 kW at 5/65°C

Heating and source circuit pumps  
 ■ max. flow rate: 3m<sup>3</sup>/h  
 ■ max. head: 4m

Universal controller  
 ■ inputs: up to 16  
 ■ outputs: up to 16  
 ■ interfaces: DL bus, CAN, LAN

Refrigerant  
 ■ R410A, GWP: 2088, filling volume: 2,4kg, CO<sub>2</sub>-equivalent: 5t

Measuring ranges  
 ■ temperature:  
 ▶ 4x -50...180°C  
 ▶ 3x 0...120°C  
 ▶ 1x -20...60°C  
 ■ flow rate: 2x 0,02...1,5m<sup>3</sup>/h (water)  
 ■ pressure:  
 ▶ 1x -1...15bar  
 ▶ 1x -1...49bar  
 ▶ 2x 0...6bar  
 ▶ 2x 0...50bar  
 ▶ 1x 0...18bar  
 ▶ 2x 0...10bar

230V, 50Hz, 1 phase  
 230V, 60Hz, 1 phase; 230V, 60Hz, 3 phases  
 UL/CSA optional  
 LxWxH: 1500x800x1700mm  
 Weight: approx. 125kg

### Required for operation

PC with Windows

### Scope of delivery

- 1 trainer
- 1 manual



## ET 420 Ice stores in refrigeration

With growing decentralisation of the energy supply, the storage of energy is becoming increasingly important. The storage of thermal energy for domestic water heating has been used successfully in building services engineering for years. However, the use of ice stores for cooling buildings is still an exception.

The heat to be dissipated, to cool buildings, fluctuates during the course of the day. The demand for cooling is usually much higher during the day than at night. In order to be able to cool buildings under the highest possible load demand, refrigeration plants are designed to meet the expected peak load. This leads to an over-dimensioning of the refrigeration technology, so that affected plants are operated very inefficiently under partial load conditions.

Ice stores can support the refrigeration plant in the case of particularly high cooling loads. Ice stores for assisting the refrigeration plant are mainly used in large non-residential buildings. In times of low cooling demand, the store is charged via the refrigeration plant and can be discharged again in case of peak loads to support the refrigeration plant. The capacity of the refrigeration technology can thus be designed to be smaller. The use of smaller refrigeration plants saves operating and investment costs.

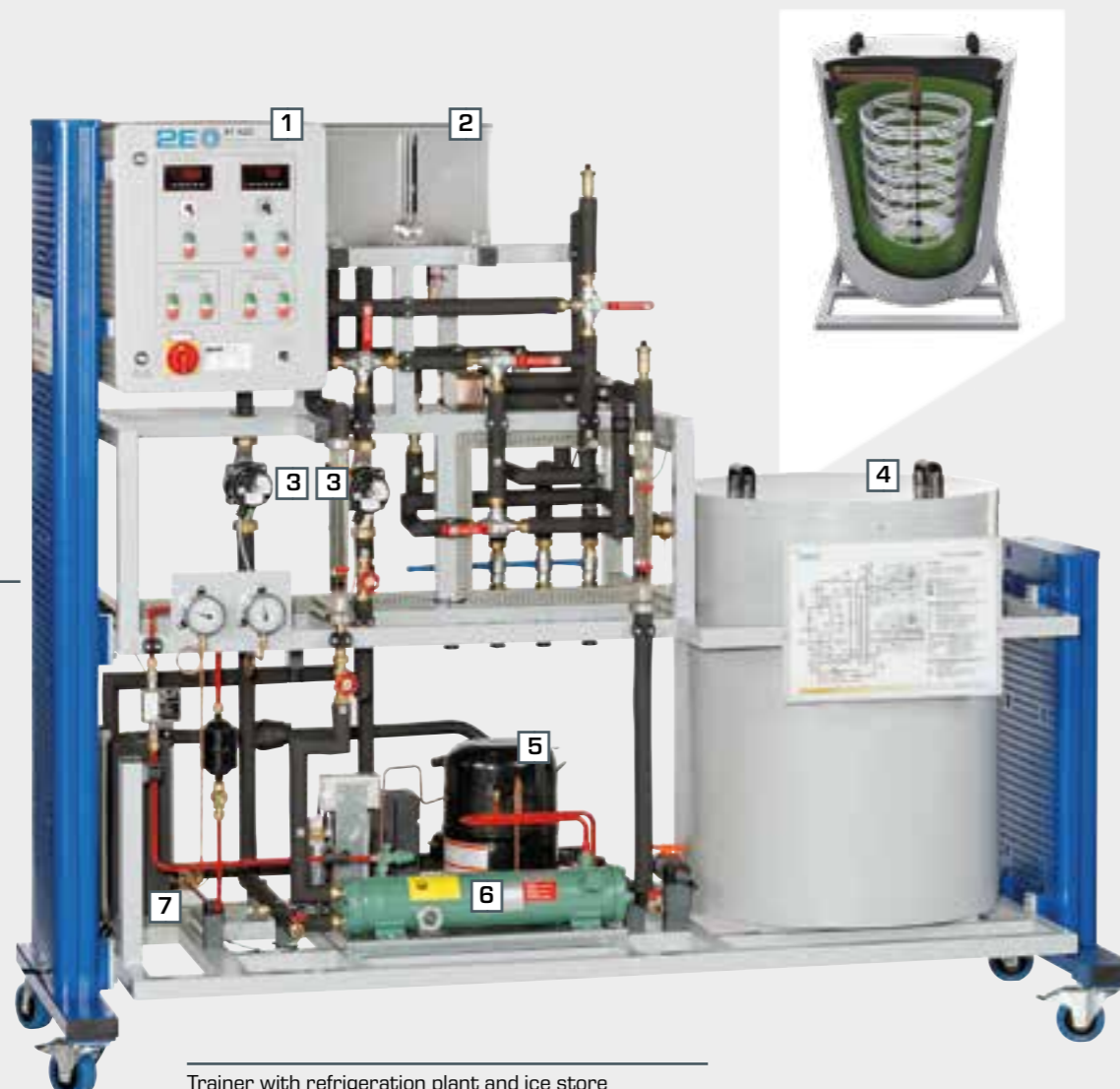
If heat is removed from a liquid store, the temperature of the storage medium falls. The water remains liquid and there is no change to the aggregate state. The ice store belongs to the group of latent storage. The water in the ice store changes its aggregate state. The temperature of the water is constant during the phase transition. If heat is still dissipated, the temperature of the water in the ice store remains constant at 0°C. The discharged energy corresponds to the phase change work during water freezing.

To discharge the ice store, heat is transferred to the ice. The temperature is constant until the ice in the store has melted. Due to the phase change work, a large amount of thermal energy can be stored at a low temperature difference.

ET 420 offers a refrigeration plant with ice store, which can be operated entirely as required. The plant concept includes a dry cooling tower **9**, which represents the heat exchanger in the building to be supplied during the experiments and a wet cooling tower **8**, which represents the heat dissipation to the free environment. The ice store enables various operating states to efficiently serve as the fluctuating heating and cooling demand of a building.

The following operating states can be set via the position of the valves:

- charging the ice store
- cooling via the ice store
- cooling via the refrigeration plant
- cooling via the refrigeration plant and ice store
- heating via heat pump
- heating via heat pump and charging the ice store
- heat dissipation via the wet cooling tower



Trainer with refrigeration plant and ice store



Wet cooling tower



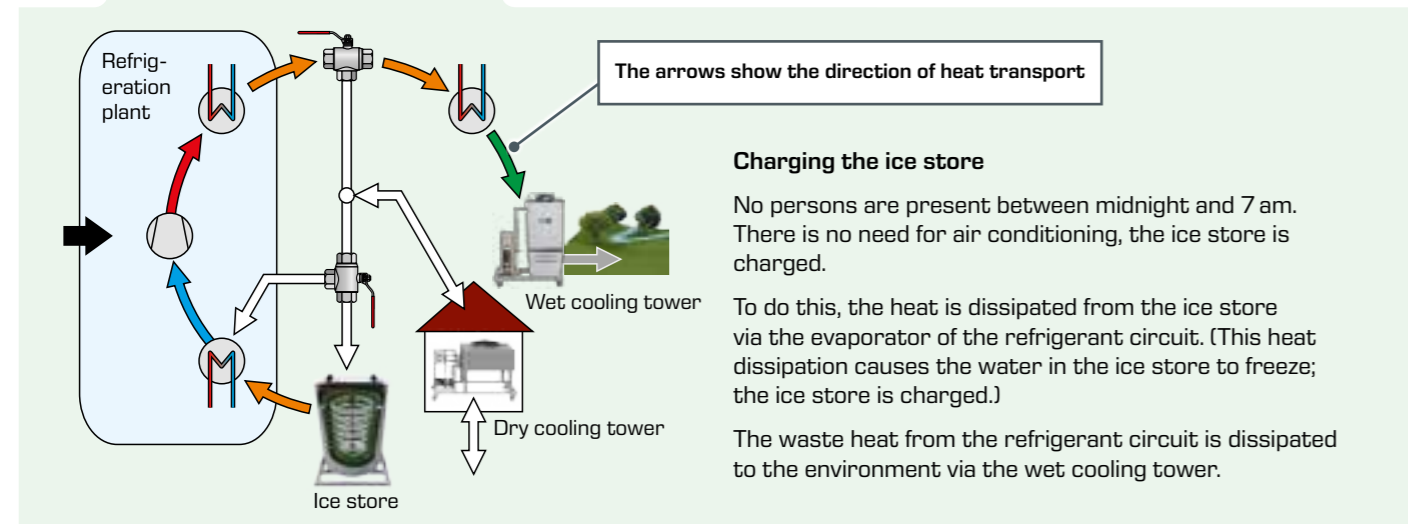
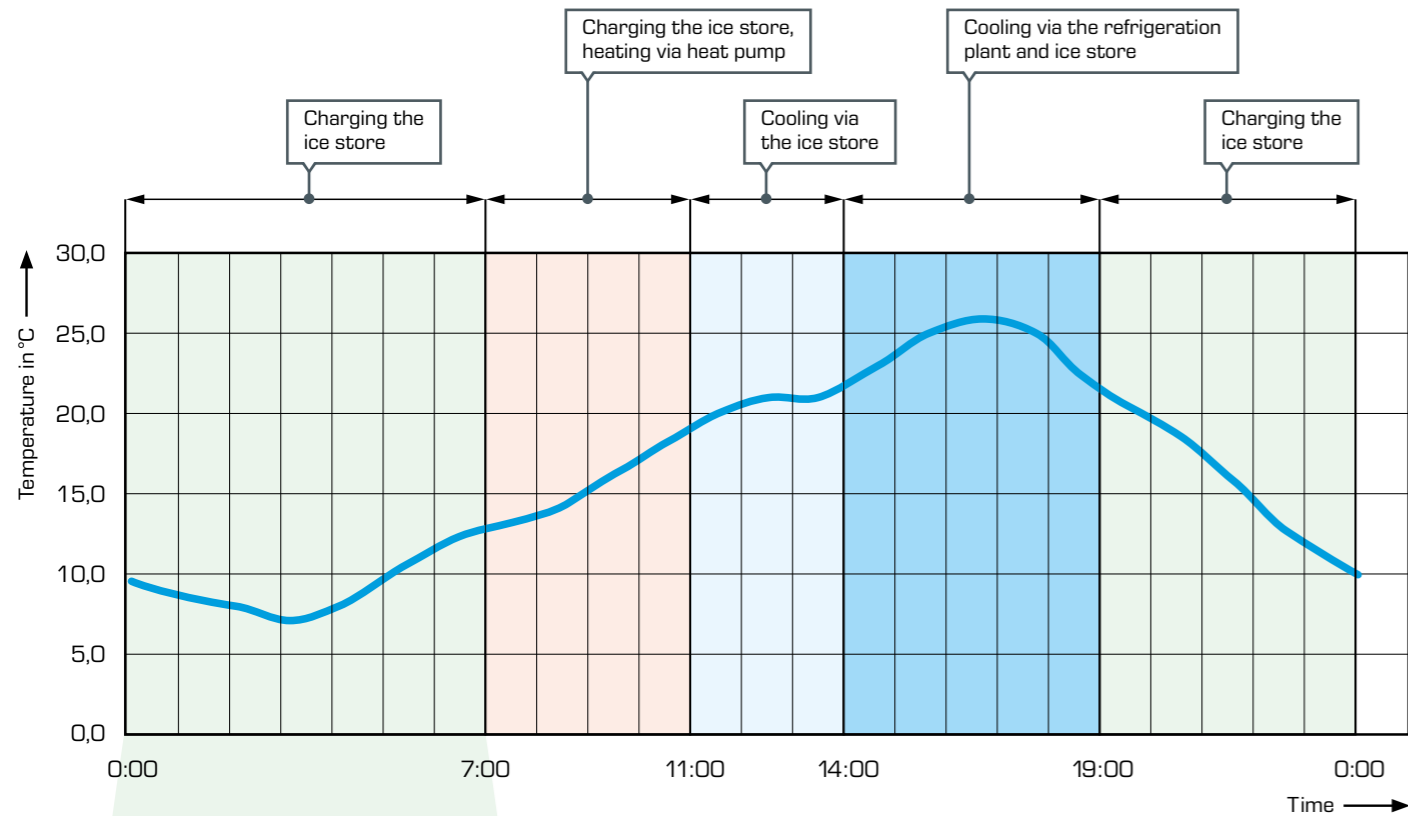
Dry cooling tower

# ET 420 Ice stores in refrigeration

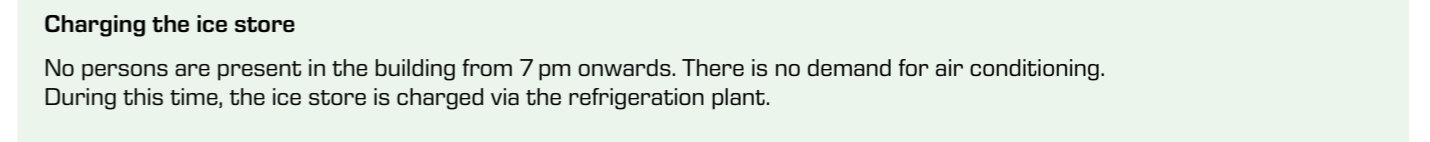
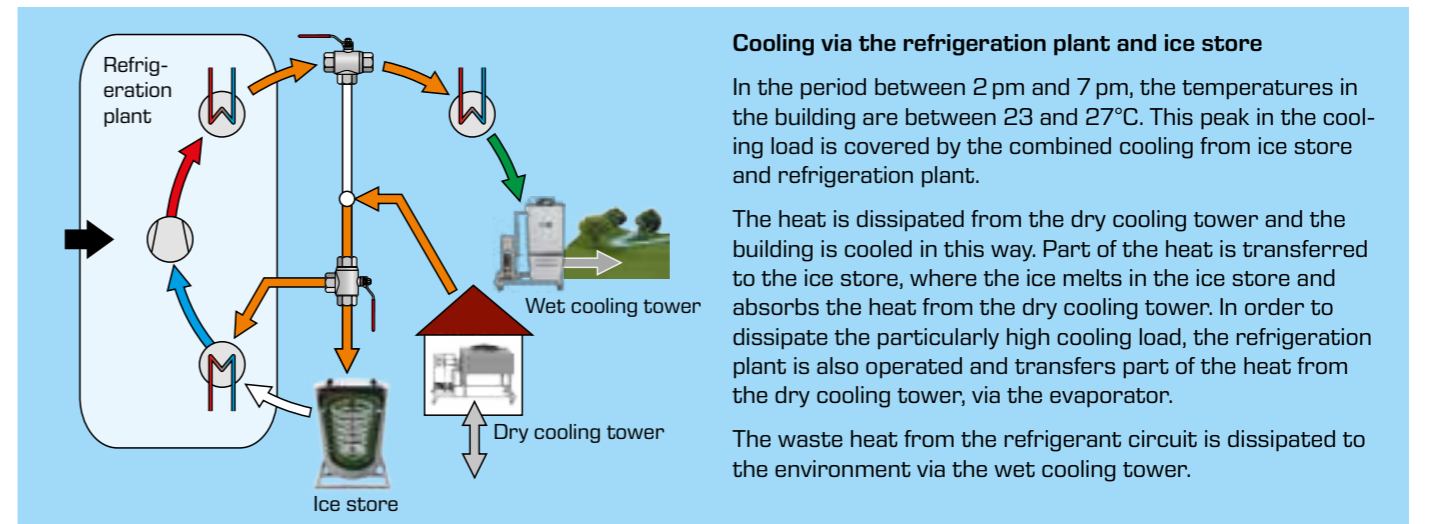
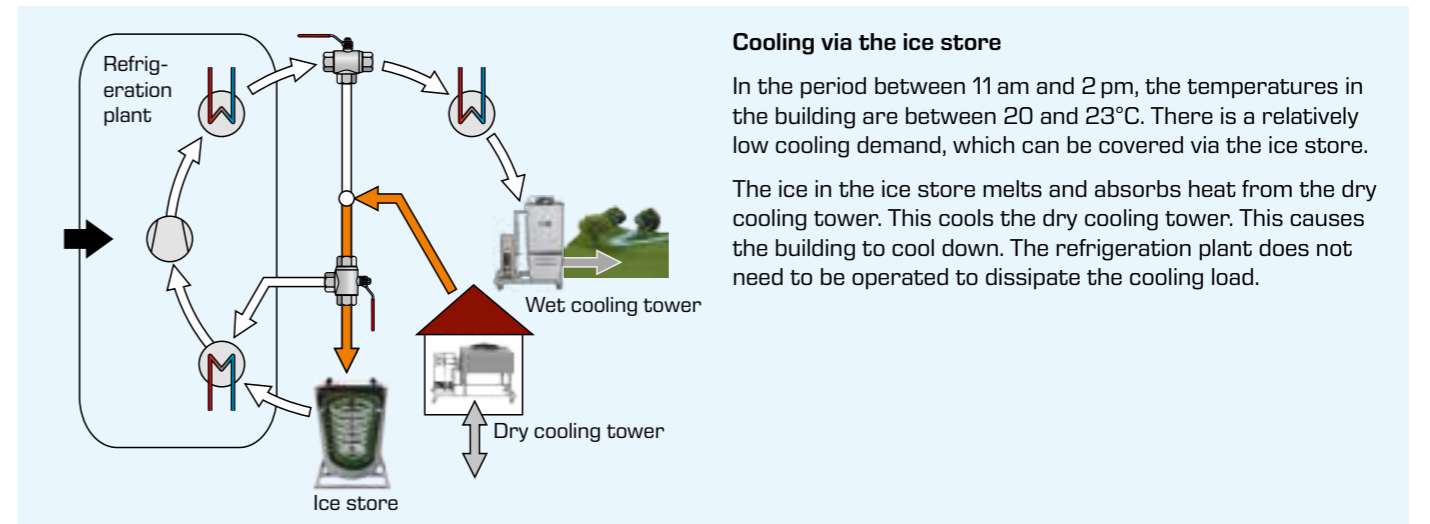
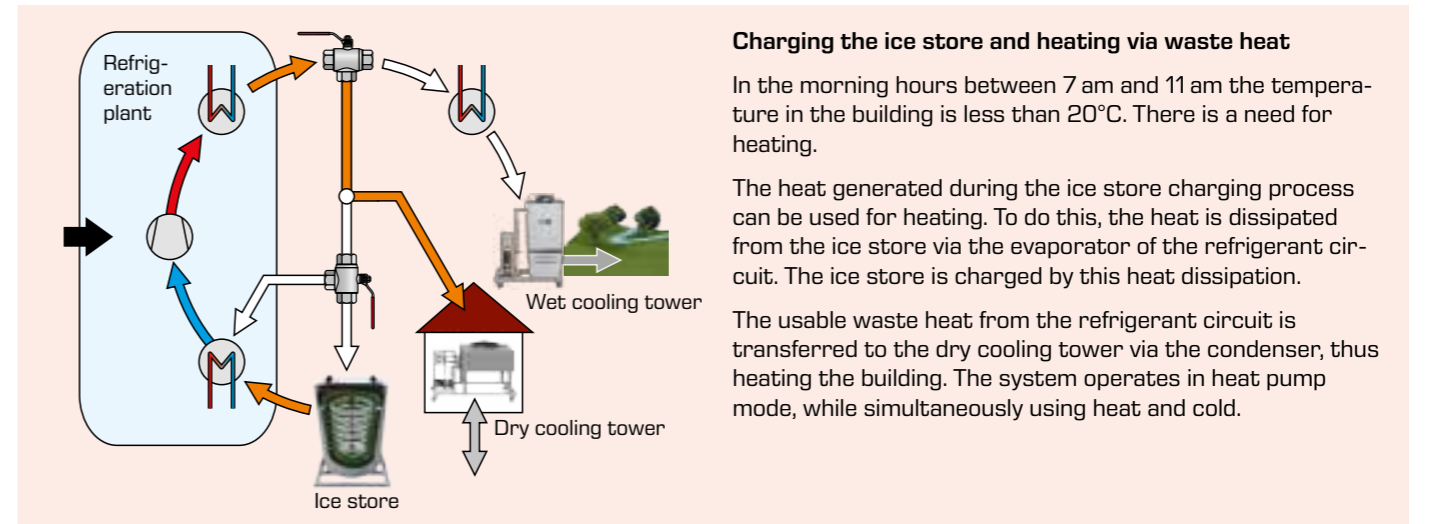
## Thermal supply of a building, using the operating modes of ET 420 as an example

The following shows how a demand-based supply of thermal energy via a refrigeration plant with ice store functions in practice. The load profile of an office building is taken as an example.

The ice store is operated using the example of a daily cycle. The primary objective is to respond to variable cooling and heating loads and to achieve an efficient supply of the building via a sensible sequence of operating states.



█ glycol, █ LP refrigerant, █ HP refrigerant, █ water, █ air,  
█ electrical power,  inactive process





## ET 420

### Ice stores in refrigeration



The illustration shows the trainer on the left, the wet cooling tower in the middle and the dry cooling tower on the right.

#### Description

- industrial refrigeration system with ice store, dry cooling tower and wet cooling tower
- energy efficiency in refrigeration and air conditioning technology

Ice stores are used in refrigeration to cover an increased additional cooling requirement (peak load). The ice stores are usually charged over night when general energy requirements and energy costs are low.

To charge and discharge the ice store a circuit with glycol-water mixture is used between the ice store and the compression refrigeration system. When charging the ice store the glycol-water mixture is cooled via a compression refrigeration system to below 0°C and thereby withdraws heat from the water in the ice store, causing the water to freeze. During discharging the melting ice withdraws heat from the glycol-water mixture causing the mixture to cool down. During this cooling process the ice store replaces or supports the compression refrigeration system.

ET 420 consists of an ice store, a refrigeration system, a circuit with glycol-water mixture, a dry and a wet cooling tower. During the evaporation of the refrigerant in the refrigeration circuit and during discharging of the ice store, heat is withdrawn from the mixture, whereas during the condensing of the refrigerant heat is added. As required the cooling towers add heat to or withdraw heat from the mixture.

The record of all required variables enables an energy balance for the individual processes. The measured values are read from digital displays and can be transmitted simultaneously via USB directly to a PC where they can be analysed using the software included.

#### Learning objectives/experiments

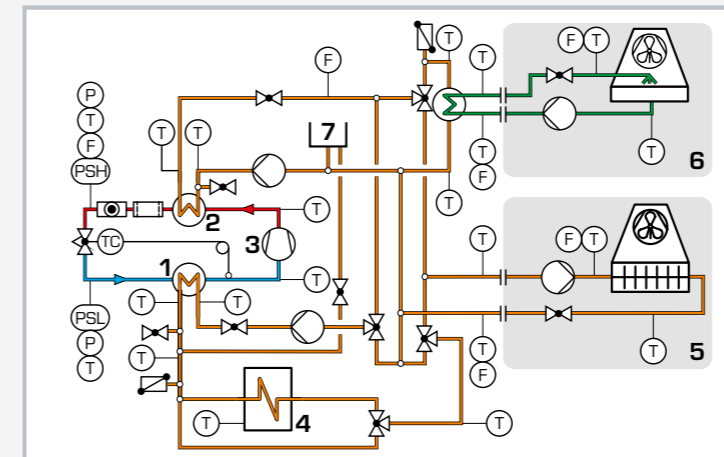
- design and operation of an energy-efficient refrigeration system
- function and operation of an ice store
  - ▶ charge
  - ▶ discharge
- energy flow balance
- energy transport via different media
- compression refrigeration cycle in the log p-h diagram
- function and operation of a wet cooling tower
- function and operation of a dry cooling tower

## ET 420

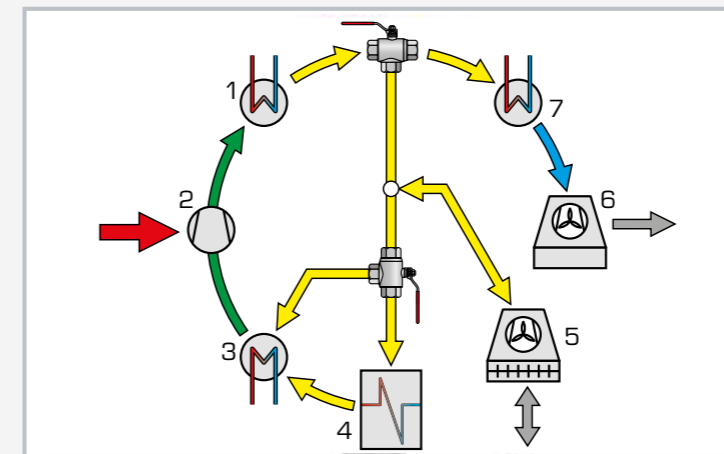
### Ice stores in refrigeration



1 displays and controls, 2 pump, 3 manometer, 4 flow meter, 5 evaporator, 6 condenser, 7 compressor, 8 ice store, 9 3-way valve, 10 compensation tank (glycol-water mixture)



1 evaporator, 2 condenser, 3 compressor, 4 ice store, 5 dry cooling tower, 6 wet cooling tower, 7 compensation tank; pipes: green: water, blue/red: refrigerant, orange: glycol-water mixture



Energy flows in the system: 1 condenser, 2 compressor, 3 evaporator, 4 ice store, 5 dry cooling tower, 6 wet cooling tower, 7 heat exchanger to wet cooling tower; blue: water, yellow: glycol-water mixture, green: refrigerant, grey: air, red: electric power

#### Specification

- [1] investigation of the charging and discharging of an ice store
- [2] system with ice store, compression refrigeration system, dry and wet cooling towers
- [3] refrigeration circuit for R513A with compressor, condenser, evaporator and expansion valve
- [4] glycol-water circuits with pumps: cooling of the refrigerant condenser, heating of the refrigerant evaporator, charging/discharging of the ice store, operation of the dry cooling tower
- [5] water circuit with pump to operate the wet cooling tower
- [6] measurement of all relevant temperatures, pressures, flow rates and power consumption to balance the processes
- [7] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

##### Compressor

- refrigeration capacity: approx. 1434W at -15/32°C
- power consumption: 1209W at -15/32°C

##### Pumps (glycol-water mixture)

- max. flow rate: 4,5m<sup>3</sup>/h
- max. head: 5,6m

##### Pump wet cooling tower (water)

- max. flow rate: 4,5m<sup>3</sup>/h
- max. head: 18m

##### Ice store: 150L

##### Compensation tank: 20L

##### Wet cooling tower, rated cooling capacity: 12kW

##### Dry cooling tower, rated cooling capacity: 13,8kW

##### Refrigerant: R513A, GWP: 631

- filling volume: 2,5kg
- CO<sub>2</sub>-equivalent: 1,6t

##### Measuring ranges

- temperature: 12x -20...100°C, 4x -50...150°C, 4x 0...60°C
- pressure: -1...9bar, -1...24bar
- flow rate: 3x 100...1200L/h, 2x 60...1500L/h, 1x 150...1600L/h, 1x 10...100L/h (R513A)
- power: 0...2250W

##### 230V, 50Hz, 1 phase

##### 230V, 60Hz, 1 phase; 230V, 60Hz, 3 phases

##### UL/CSA optional

##### LxWxH: approx. 2200x790x1900mm (trainer)

##### LxWxH: approx. 1250x790x1700mm (wet cool. tower)

##### LxWxH: approx. 1600x900x1140mm (dry cool. tower)

##### Total weight: approx. 650kg

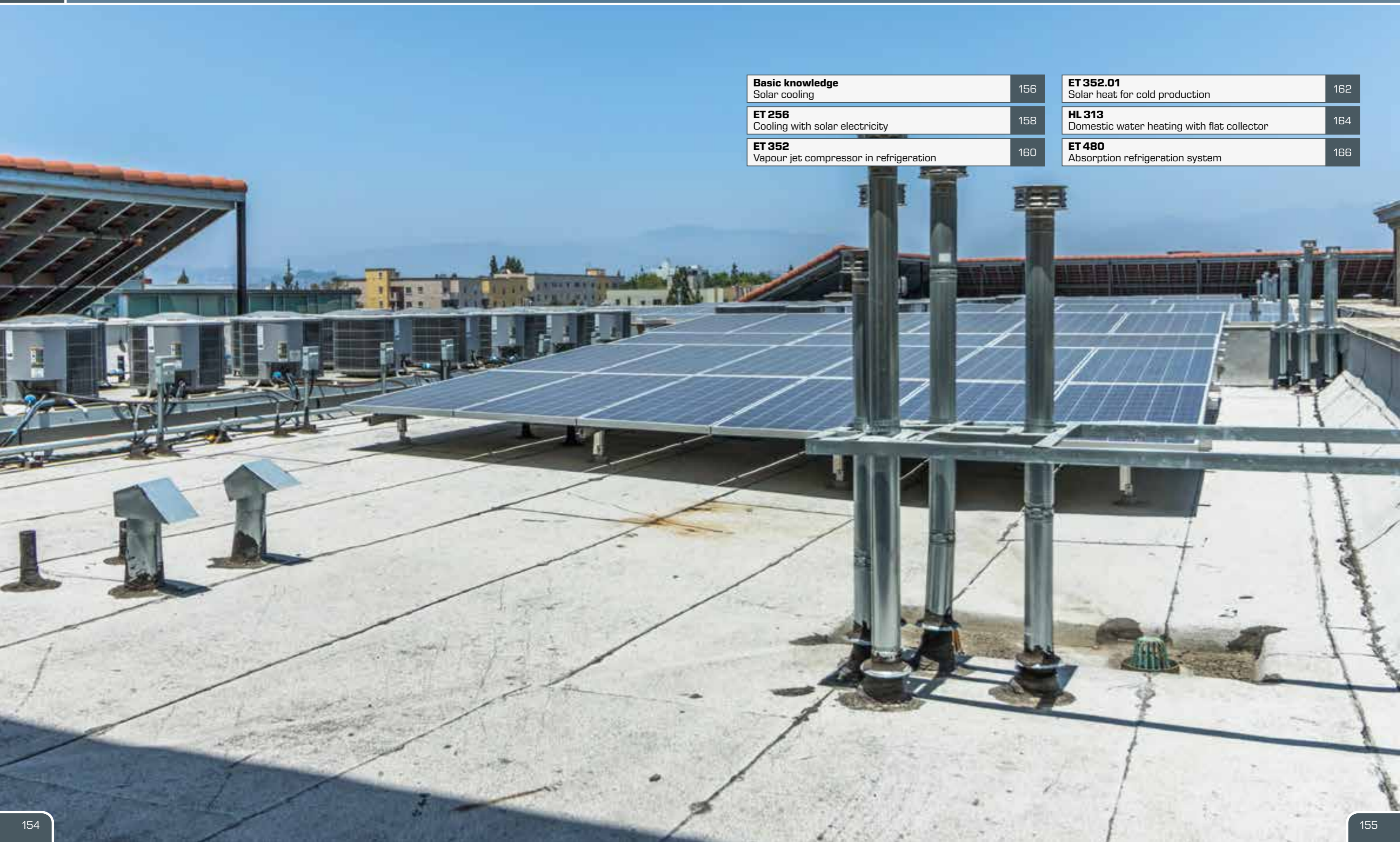
#### Required for operation

water connection, drain, ventilation, exhaust air, PC with Windows recommended

#### Scope of delivery

trainer, wet cooling tower, dry cooling tower, set of hoses, GUNT software CD + USB cable, set of instructional material





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<b>ET 480</b> Absorption refrigeration system	166
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# Basic knowledge Solar cooling

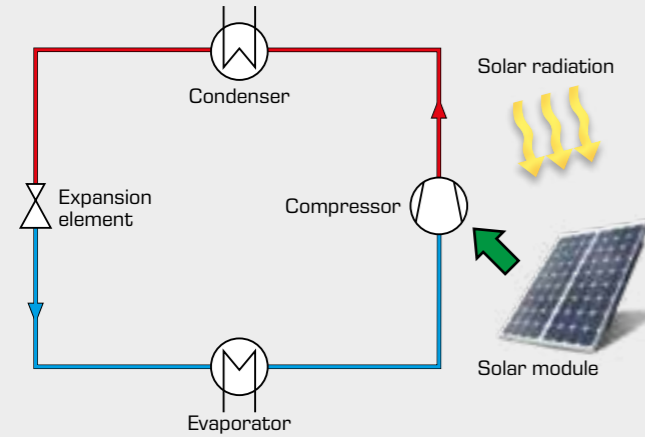
Interest in alternative processes for cold production that can be supplied from renewable energy sources is steadily growing. The basic idea of solar cooling is to use solar energy to cool buildings or equipment, especially during the hot hours

of the day. The future market of "solar cooling" is extremely important when it comes to the sustainability of buildings with air-conditioning systems, both in temperate climates and in warm countries.

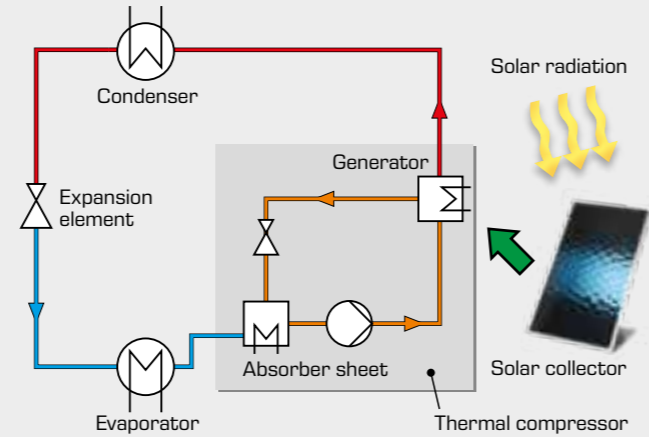
## Principle of operation of solar cooling

Solar cooling means a process in which the cooling process is powered directly by solar energy. Solar energy thus serves as a regenerative source of drive heat. Essentially, a distinction is made between two processes for the conversion of solar energy into useful energy:

Conversion into electric current, electric process with photovoltaic module



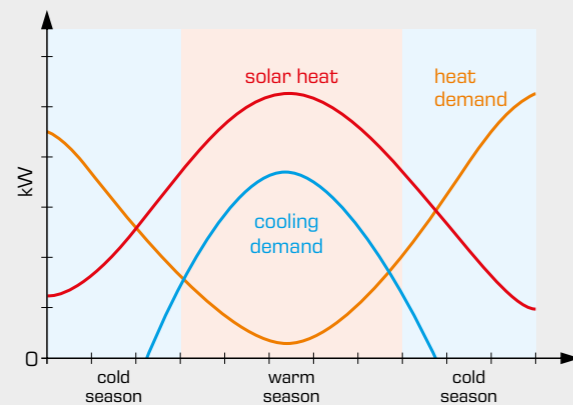
Conversion into heat, thermal process using the example of an absorption refrigeration system with solar collector



In solar refrigeration machines, the electric compressor is replaced by a thermal compressor.

## Available solar energy

Solar radiation and cooling demand correlate with each other in terms of time. This state should be exploited. The advantages of supplying cooling systems with solar energy are therefore obvious.

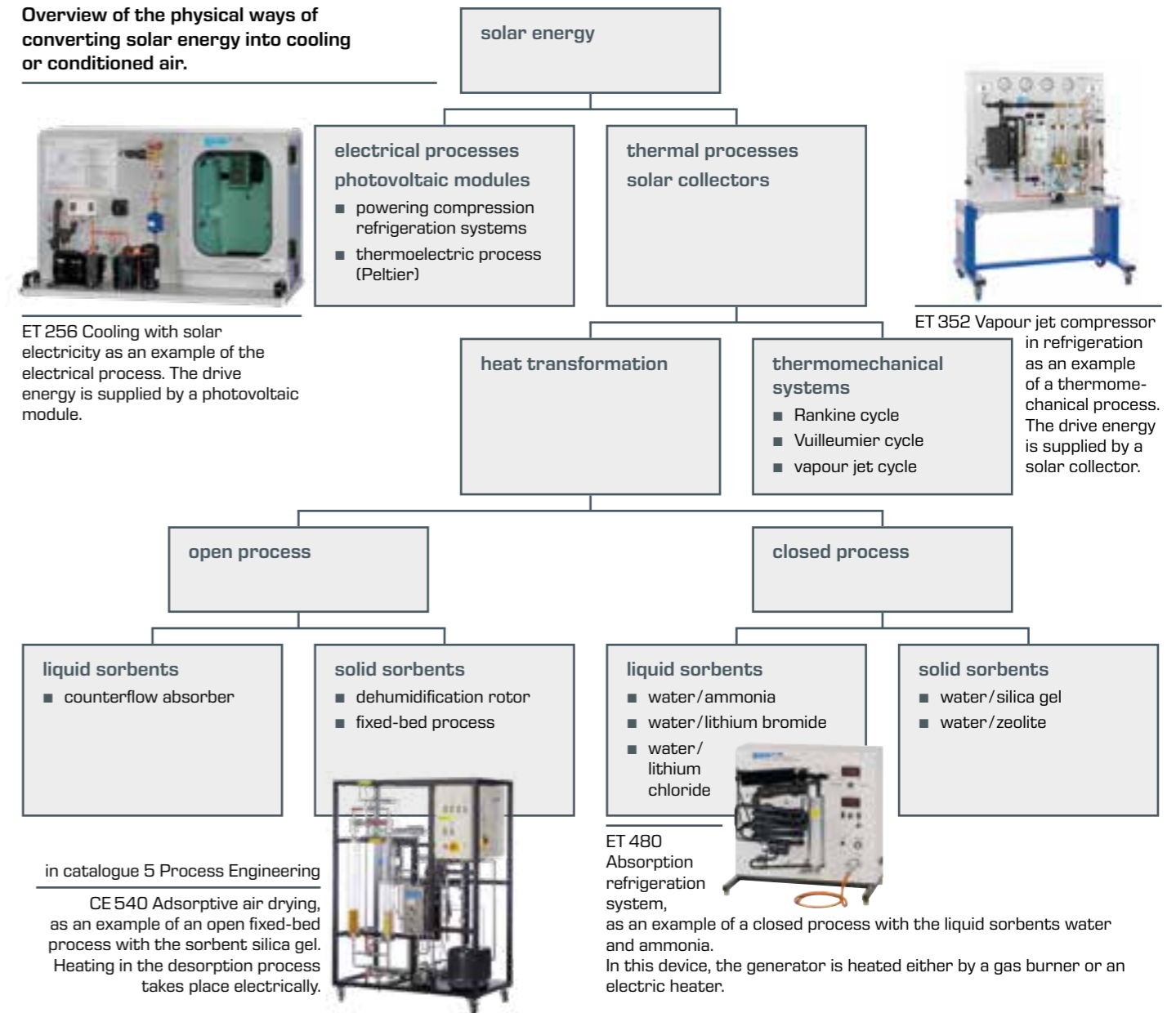


Typical annual trends for available solar energy and the heating and cooling demand of a building

## Advantages of solar cooling

- Instead of high electrical power output for a conventional cooling system, the consumption of electrical energy can be limited to the drives of pumps and fans.
- On warm summer days in particular, when the need for cooling is particularly high, electricity consumption is reduced.

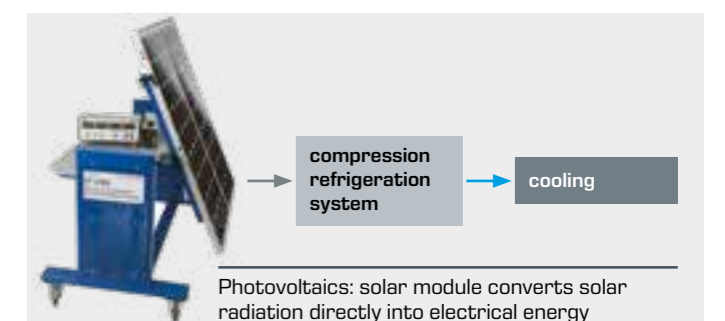
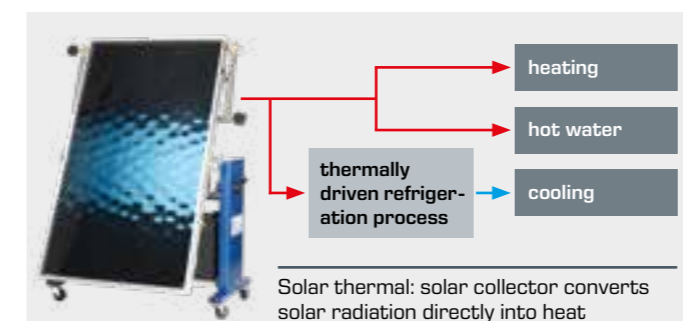
## Overview of the physical ways of converting solar energy into cooling or conditioned air.



## Supply of buildings as one area of application

A large proportion of possible solar cooling applications concern the building supply sector. With regard to energy optimisation, it therefore makes sense to also consider other energy consum-

ers in a building. The diagram shows two system concepts for incorporating solar thermal energy and photovoltaics.



## ET 256

### Cooling with solar electricity



#### Description

- **compression refrigeration system for operation with ET 250 photovoltaic modules or with laboratory power supply ET 256.01**
- **long cooling time due to cold accumulators and insulation**
- **software for controlling and balancing energy flows**
- **dynamic recording of the refrigerant mass flow rate**

With the increasing demand for refrigeration worldwide, the interest in processes of cold production which can be supplied from renewable energy sources is also growing. The use of solar electricity offers particular advantages for mobile and very remote applications.

ET 256 contains a typical compression refrigeration system with refrigeration chamber. It is possible to supply the refrigerant compressor directly with current from photovoltaic modules. To do this, the photovoltaic modules from ET 250 are connected to ET 256. For some experiments, the laboratory power supply ET 256.01 can also be used. The artificial light source HL 313.01 enables solar energy experiments independently of natural sunlight.

The refrigerant compressor is a piston compressor with adjustable speed. A thermostatic expansion valve is used in the refrigeration circuit. The insulated refrigeration chamber contains a refrigerant evaporator with fan, removable cold accumulator and a heater for generating a cooling load.

For cooling, the compressor is started by the control unit when sufficient electrical power is available from the solar modules. Operating the compressor reduces the temperature in the refrigeration chamber. Should the cold accumulators be fully or partially discharged, they are charged again as soon as sufficiently low temperatures are reached. If there is no current available to operate the compressor, the cold accumulators increase the remaining cooling time in the refrigeration chamber and are discharged in this way.

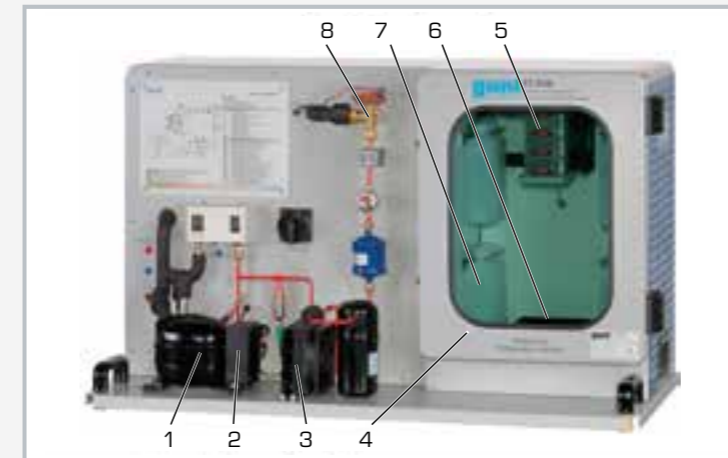
Relevant measured values are recorded by sensors, displayed and can be processed in a PC. The refrigerant mass flow rate is calculated in the software from the recorded measured values.

#### Learning objectives/experiments

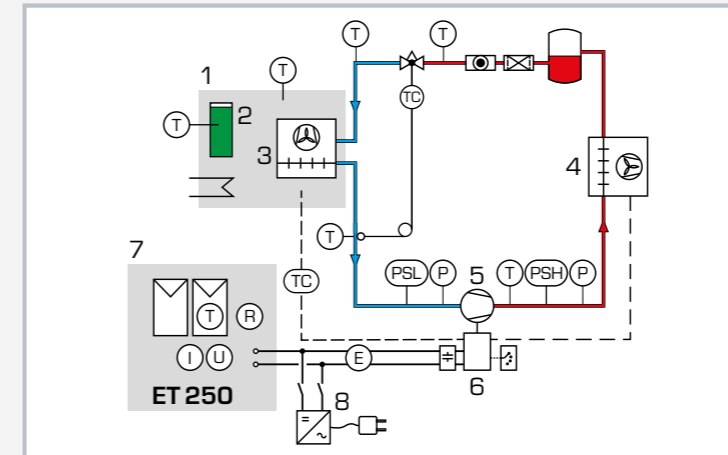
- supply a compression refrigeration system with current from photovoltaic modules
- components of a photovoltaic refrigerating plant
- operation of the compressor with changing power available and cooling demand
- charge and discharge cold accumulators
- coefficient of performance of the refrigerating plant dependent on operating conditions
- refrigeration cycle in the log p-h diagram
- energy flow balance

## ET 256

### Cooling with solar electricity



1 compressor, 2 control unit, 3 condenser, 4 refrigeration chamber, 5 evaporator, 6 heater, 7 cold accumulator, 8 expansion valve



1 refrigeration chamber, 2 cold accumulator, 3 evaporator, 4 condenser, 5 compressor, 6 control unit, 7 photovoltaic modules, 8 laboratory power supply (ET 256.01)



ET 256 together with the optional artificial light source HL 313.01 and solar modules ET 250

#### Specification

- [1] compression refrigeration system for operation with electricity from ET 250 photovoltaic modules or from laboratory power supply ET 256.01
- [2] compression refrigeration system: refrigerant compressor with adjustable speed, insulated refrigeration chamber with evaporator, cold accumulators and cooling load, thermostatic expansion valve and condenser
- [3] supply with direct current from photovoltaic modules in ET 250
- [4] heater to generate a cooling load
- [5] control unit for temperature-controlled compressor operation
- [6] rechargeable cold accumulators
- [7] sensors to capture temperature and pressure
- [8] refrigerant mass flow rate calculated in the software from recorded measured values
- [9] GUNT software with control functions and data acquisition via USB under Windows 7, 8.1, 10
- [10] refrigerant R513A, GWP: 631

#### Technical data

##### Compressor

- speed: 2000...3500min<sup>-1</sup>
- refrigeration capacity: approx. 90W at 0/55°C and 2000min<sup>-1</sup>
- electrical power consumption: approx. 46W at 0/55°C and 2000min<sup>-1</sup>

Control unit: input voltage range: 10...45V DC  
Refrigeration chamber: LxWxH: 400x250x500mm  
Cold accumulators: phase transition: 5...6°C

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 1kg
- CO<sub>2</sub>-equivalent: 0,6t

##### Measuring ranges

- temperature: 4x -30...80°C, 3x 0...120°C
- pressure: 2x 0...6bar, 2x 0...30bar
- current: 0...10A
- voltage: 0...60V
- flow rate: 0...11kg/h (refrigerant)

230V, 50Hz, 1 phase  
LxWxH: 980x400x580mm  
Weight: approx. 65kg

#### Required for operation

PC with Windows

#### Scope of delivery

- 1 experimental unit
- 1 set of cables
- 1 GUNT software CD + USB cable
- 1 set of instructional material



## ET 352

### Vapour jet compressor in refrigeration



#### Learning objectives/experiments

- understanding compression refrigeration systems based on the vapour jet method
- clockwise and anticlockwise Rankine cycle
- energy balances
- calculation of the coefficient of performance of the refrigeration circuit
- thermodynamic cycle in the log p-h diagram
- operating behaviour under load
- solar thermal vapour jet refrigeration

#### Description

- refrigeration system with vapour jet compressor
- cold production using heat
- transparent condenser and evaporator
- together with ET 352.01 and HL 313: using solar heat as drive energy for the vapour jet compressor

Unlike standard compression refrigeration systems, vapour jet refrigeration machines do not have a mechanical but a vapour jet compressor. This makes it possible to use different heat sources for cold production. Such sources could e.g. be solar energy or process waste heat.

The system includes two refrigerant circuits: one circuit is used for cold production (refrigeration cycle), the other circuit is used for the generation of motive vapour (vapour cycle).

The vapour jet compressor compresses the refrigerant vapour and transports it to the condenser. A transparent tank with a water-cooled pipe coil serves as condenser.

In the refrigeration cycle some of the condensed refrigerant flows into the transparent evaporator connected to the intake side of the vapour jet compressor. The evaporator is a so-called flooded evaporator where a float valve keeps the filling level constant. The refrigerant absorbs the ambient heat or the heat from the heater and evaporates. The refrigerant vapour is aspirated by the vapour jet compressor and compressed again.

In the vapour cycle a pump transports the other part of the condensate into a vapour generator. An electrically heated tank with water jacket evaporates the refrigerant. The generated refrigerant vapour drives the vapour jet compressor. Alternatively to the electric heater, solar heat can be used as drive energy by using ET 352.01 and the solar thermal collector HL 313.

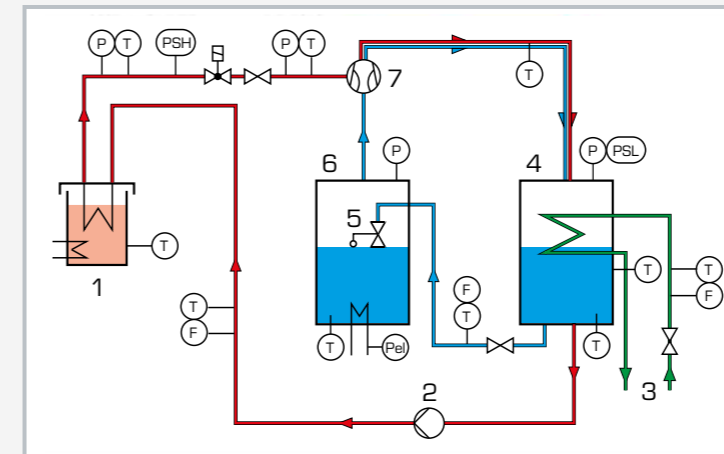
Relevant measured values are recorded by sensors, displayed and can be processed onto a PC. The heater power at the evaporator is adjustable. The cooling water flow rate at the condenser is adjusted using a valve.

## ET 352

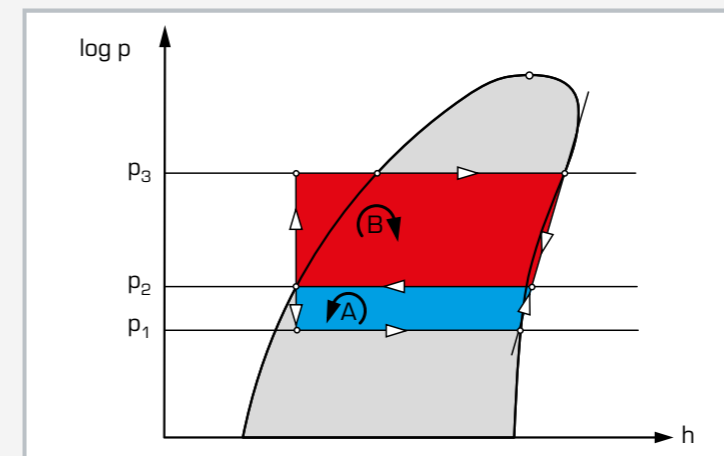
### Vapour jet compressor in refrigeration



1 manometer, 2 pressure switch, 3 displays and controls, 4 vapour generator, 5 evaporator, 6 pump, 7 cooling water connections, 8 flow meter, 9 condenser, 10 vapour jet compressor



1 vapour generator, 2 pump, 3 cooling water connections, 4 condenser, 5 float valve, 6 evaporator, 7 vapour jet compressor; T temperature, P pressure, PSL, PSH pressure switch, F flow rate, P<sub>a</sub> power; red: vapour cycle, blue: refrigeration cycle, green: cooling water



log p-h diagram: A refrigeration cycle, B vapour cycle,  $p_1$  pressure in the evaporator,  $p_2$  pressure in the condenser,  $p_3$  pressure in the vapour generator

#### Specification

- [1] investigation of a vapour jet compressor
- [2] refrigeration circuit with condenser, evaporator and vapour jet compressor for refrigerant
- [3] vapour circuit with pump and vapour generator for operating the vapour jet compressor
- [4] transparent tank with water-cooled pipe coil as condenser
- [5] transparent tank with adjustable heater as evaporator
- [6] flooded evaporator with float valve as expansion element
- [7] vapour generator with heated water jacket (electrically or solar thermally using ET 352.01, HL 313)
- [8] refrigerant R1233zd, GWP: 1
- [9] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

##### Vapour jet compressor

- $d_{\min}$  convergent-divergent nozzle: approx. 1,7mm
- $d_{\min}$  mixing jet: approx. 7mm

##### Condenser

- tank: approx. 3,5L
- pipe coil area: approx. 0,17m<sup>2</sup>

##### Evaporator

- tank: approx. 3,5L
- heater power: 4x 125W

##### Vapour generator

- refrigerant tank: approx. 0,75L
- water jacket: approx. 9L
- heater power: 2kW

##### Pump

- max. flow rate: approx. 1,7L/min
- max. head: approx. 70mWS

##### Refrigerant

- R1233zd
- GWP: 1
- filling volume: 5kg
- CO<sub>2</sub>-equivalent: 0t

##### Measuring ranges

- temperature: 12x -20...100°C
- pressure: 2x 0...10bar; 2x -1...9bar
- flow rate: 3x 0...1,5L/min
- power: 1x 0...750W, 1x 0...3kW

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase, 230V, 60Hz, 3 phases

UL/CSA optional

LxWxH: 1460x790x1890mm

Weight: approx. 225kg

#### Required for operation

water connection, drain, PC with Windows recommended

#### Scope of delivery

- 1 trainer + 1 set of accessories
- 1 GUNT software CD + USB cable
- 1 set of instructional material

## ET 352.01

### Solar heat for cold production



#### Learning objectives/experiments

- use of solar heat for cold production
- components of solar refrigerating plants according to the vapour jet method
- operation of a vapour jet compressor on a solar thermal flat collector
- optimisation of the operating point
- energy balances
- extended concept on the use of thermal solar plants
- energy management for solar thermal cooling systems

#### Description

- **in combination with ET 352 and HL 313: use of solar heat as drive energy for a vapour jet compressor**
- **energy flow balances**

With the increasing demand for refrigeration and air conditioning worldwide, the interest in alternative processes of cold production which can be supplied from renewable energy sources is also growing. One promising possibility is thermal processes. In these processes, thermal energy is used to generate cold.

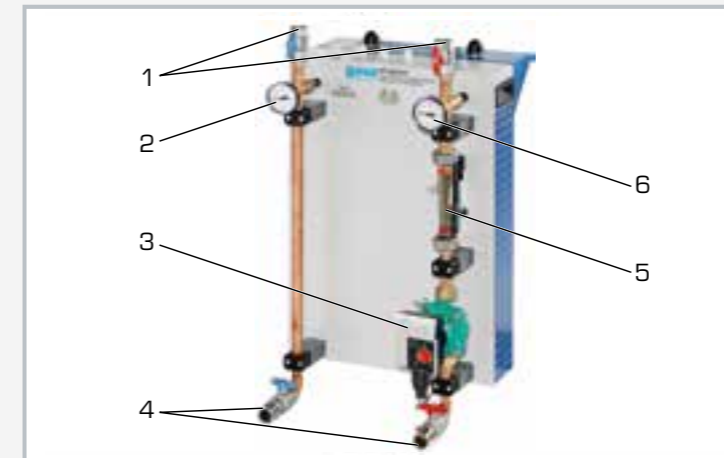
ET 352.01 allows the vapour jet compressor from ET 352 to be operated with solar-generated heat from the HL 313 flat collector.

After sufficient solar thermal heating, the heat transfer fluid from HL 313 is pumped into the vapour generator of ET 352 by the pump from ET 352.01. The pump is operated via ET 352. ET 352 and HL 313 are connected by hoses.

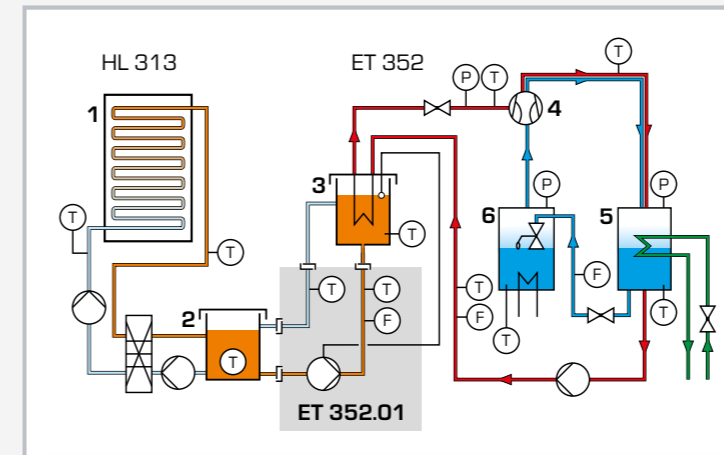
The energy added from solar heat is determined by two temperature sensors and one flow rate sensor. The measured values are transferred to ET 352 and can be processed on a PC. They are also displayed directly on ET 352.01.

## ET 352.01

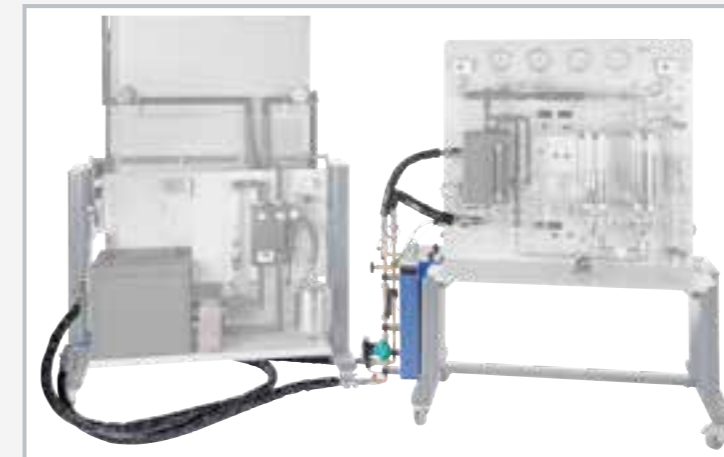
### Solar heat for cold production



1 feed/return line ET 352, 2 return line thermometer, 3 circulating pump, 4 feed/return line HL 313, 5 flow rate sensor, 6 feed line thermometer



1 solar thermal collector, 2 heat accumulator, 3 vapour generator, 4 vapour jet compressor, 5 condenser, 6 evaporator; F flow rate, P pressure, T temperature; red: vapour cycle, blue: refrigeration cycle, green: cooling water, orange: warm heat transfer fluid, light blue: cold heat transfer fluid



Functional experimental setup: HL 313 Domestic water heating with flat collector (left), ET 352.01 Solar heat for cold production (middle), ET 352 Vapour jet compressor in refrigeration engineering (right)

#### Specification

- [1] supply of the vapour jet compressor in ET 352 with solar heat from the flat collector HL 313
- [2] pump for pumping the heat transfer fluid from HL 313 to the vapour generator in ET 352
- [3] feed line to the vapour generator with temperature and flow rate measurement
- [4] return line with temperature measurement
- [5] measured values transferred to ET 352 for further processing in the software
- [6] pump operated via ET 352
- [7] ET 352, HL 313 and ET 352.01 connected via hoses and quick-release couplings

#### Technical data

##### Pump

- power consumption: 40W
- max. flow rate: 1m<sup>3</sup>/h
- head: 4,8m

##### Measuring ranges

- temperature: 2x 0...120°C
- flow rate: 10...300L/h

LxWxH: 430x430x790mm  
Weight: approx. 30kg

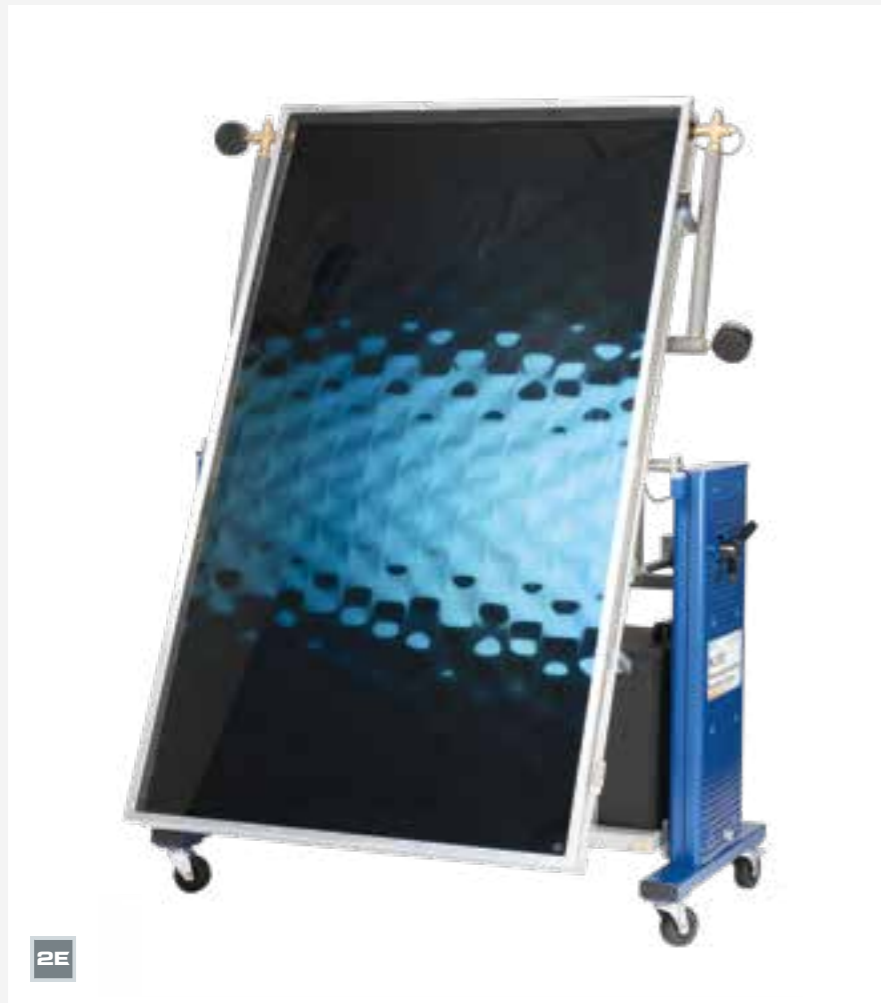
#### Scope of delivery

- 1 experimental unit
- 1 set of hoses
- 1 set of instructional material



## HL 313

### Domestic water heating with flat collector



#### Learning objectives/experiments

- familiarisation with the functions of the flat collector and the solar circuit
- determining the net power
- relationship between flow and net power
- determining the collector efficiency
- relationship between temperature difference (collector/environment) and collector efficiency

2E

#### Description

- conversion of solar energy into heat
- trainer with real-world components
- pivotable flat collector
- system with heat exchanger and two separate circuits
- solar controller with data logger and USB interface

The HL 313 trainer can be used to demonstrate the principal aspects of solar thermal domestic water heating in a system with components used in real world applications.

Radiant energy is converted into heat in a commercially available flat collector and transferred to a heat transfer fluid in the solar circuit. The heat then gets into the hot water circuit via a heat exchanger.

A solar controller controls the pumps for the hot water and solar circuits. The solar circuit is protected by an expansion tank and a safety valve.

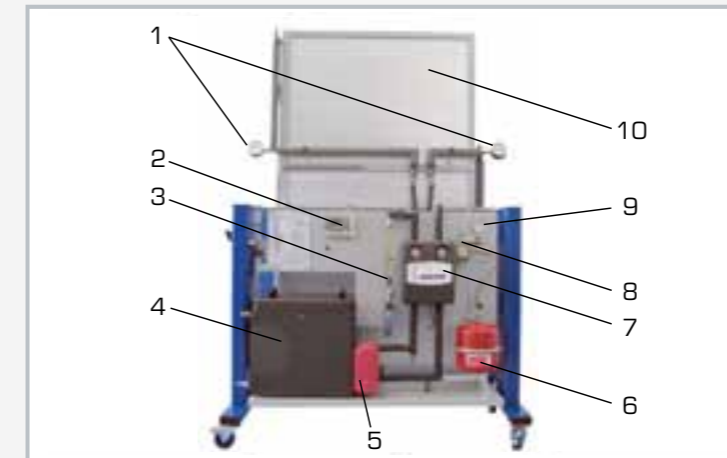
The trainer has been designed so that it is possible to carry out a complete pre-heating as part of a practical experiment.

The temperatures in the storage tank, at the outlet from and the inlet to the collector are measured, as is the flow in the solar circuit. Additionally, as in practice, the temperatures of the inlet and return are displayed on the solar circulation station.

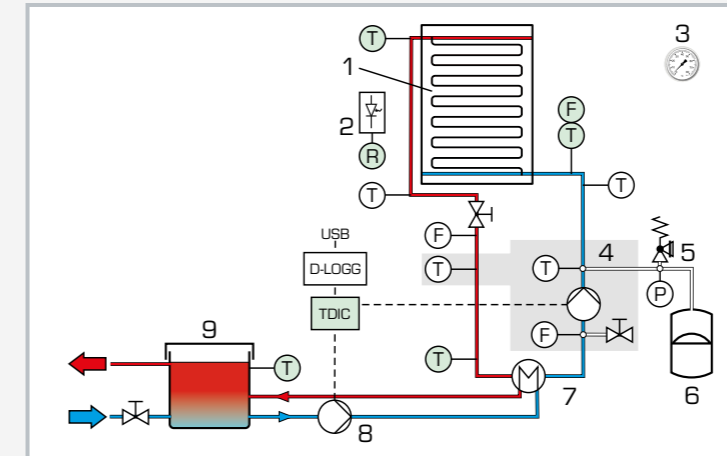
In order to ensure there is sufficient illumination, the system should be operated with solar radiation or the optionally available HL 313.01 Artificial light source.

## HL 313

### Domestic water heating with flat collector



1 inlet and return thermometer, 2 solar controller, 3 flow meter, 4 buffer tank, 5 heat exchanger, 6 expansion vessel, 7 solar circuit pump, 8 pressure relief valve, 9 ambient air thermometer, 10 collector



TDIC solar controller with USB interface  
1 collector, 2 illuminance sensor, 3 ambient air thermometer, 4 solar circulation station with solar circuit pump, 5 safety valve, 6 expansion tank, 7 heat exchanger, 8 hot water circuit pump, 9 buffer tank;  
F flow rate, T temperature, P pressure, R illuminance

#### Specification

- [1] trainer for investigating the function and operating behaviour of a flat collector
- [2] solar thermal flat collector with selectively absorbing coating
- [3] adjustable collector inclination angle
- [4] solar circuit with collector, pump, expansion vessel and safety valve
- [5] hot water circuit with buffer tank, pump and plate heat exchanger
- [6] 4 bimetallic thermometers
- [7] solar controller with temperature, flow rate and illuminance sensors
- [8] data logger with USB interface
- [9] operation with solar radiation or HL 313.01 Artificial light source

#### Technical data

##### Solar circuit

- collector
  - ▶ absorbing surface: 2,3m<sup>2</sup>
  - ▶ rated throughput: 20...70L/h
  - ▶ operating pressure: 1...3bar
- safety valve 4bar

##### Hot water circuit

- plate heat exchanger: 3kW, 10 plates
- buffer tank 70L

##### Measuring ranges

- flow rate: 20...150L/h
- temperature: 4x 0...120°C

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase  
120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1660x800x2300mm  
Weight: approx. 240kg

#### Scope of delivery

- 1 trainer
- 1 set of instructional material

## ET 480

### Absorption refrigeration system



#### Description

- model of an absorption refrigeration system
- boiler operated alternatively by gas or electrically
- adjustable heating at the evaporator serves as cooling load

Refrigerating plants make use of the fact that a refrigerant evaporates at low pressure. In absorption refrigeration systems, the absorption of ammonia in the water produces this low pressure. The absorption process is driven by thermal energy, which can come for example from industrial waste heat or solar collectors to operate these systems.

This basic principle of an absorption refrigeration system is demonstrated in the ET 480 experimental unit taking the example of an ammonia-water solution with the ammonia acting as refrigerant. In the evaporator the liquid ammonia evaporates and withdraws heat from the environment. To keep the evaporation pressure low, the ammonia vapour in the absorber is absorbed by the water. In the next step, ammonia is permanently removed from the high concentration ammonia solution to prevent the absorption process from being halted. For this purpose, the high concentration ammonia solution is heated in a generator until the ammonia evaporates

again. In the final step, the ammonia vapour is cooled in the condenser to the base level, condenses and is returned to the evaporator. The low concentration ammonia solution flows back to the absorber. To maintain the pressure differences in the system, hydrogen is used as an auxiliary gas.

In process technology systems the resulting waste heat can be used for cooling. In small mobile systems, such as a camping refrigerator or minibar in a hotel, the required heat is generated electrically or by gas burner. Another benefit of absorption refrigeration systems is their silent operation.

ET 480 demonstrates the functional principle of an absorption refrigeration system with its main components: evaporator, absorber, boiler as generator with bubble pump, condenser. The boiler can alternatively be operated with gas or electrically. Another electric heater at the evaporator generates the cooling load.

Temperatures in the refrigeration circuit and the heating power at the boiler and at the evaporator are recorded and displayed digitally.

#### Learning objectives/experiments

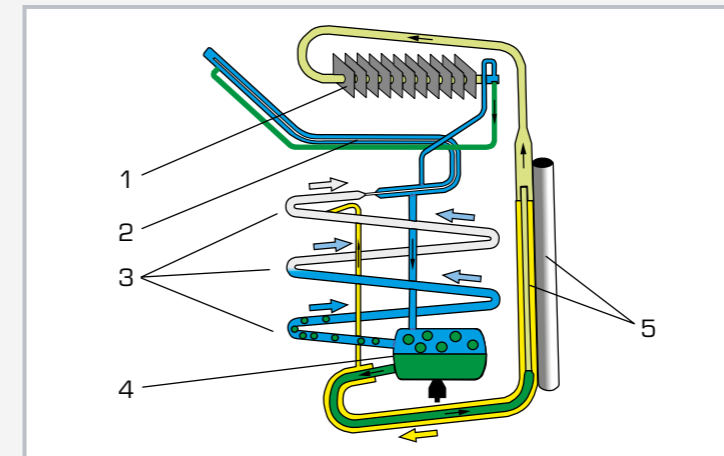
- demonstrate the basic principle of an absorption refrigeration system
- absorption refrigeration system and its main components
- operating behaviour under load

## ET 480

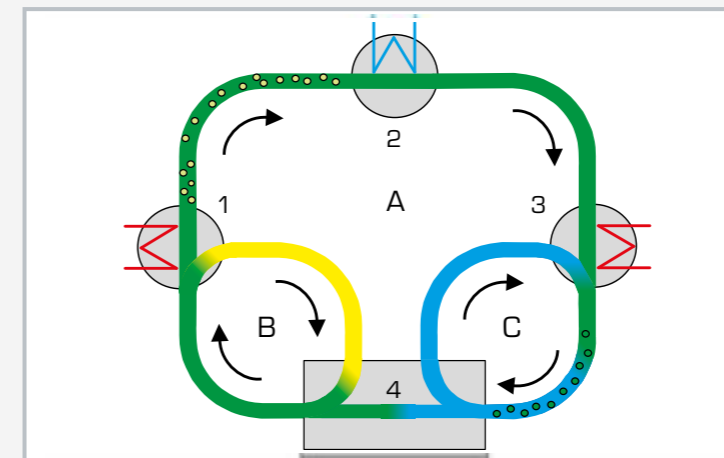
### Absorption refrigeration system



1 condenser, 2 evaporator with heater, 3 absorber, 4 tank, 5 gas burner, 6 pressure reducing valve for propane gas operation, 7 boiler with bubble pump to separate the ammonia, 8 displays and controls



1 condenser, 2 evaporator, 3 absorber, 4 tank, 5 boiler with bubble pump; green: high concentration ammonia solution, yellow: low concentration ammonia solution, blue: gas mixture ammonia-hydrogen



1 boiler with bubble pump, 2 condenser, 3 evaporator, 4 absorber; A: ammonia circuit, B: water circuit, C: hydrogen circuit

#### Specification

- [1] operation of an absorption refrigeration system
- [2] main system components: evaporator, absorber, boiler with bubble pump, condenser
- [3] ammonia-water solution as working medium, hydrogen as auxiliary gas
- [4] boiler to separate ammonia
- [5] bubble pump for transportation in the circuit
- [6] adjustable electrical heater at the evaporator serves as cooling load
- [7] boiler is alternatively heated by electrical heater or gas burner
- [8] piezoelectric igniter for gas operation
- [9] digital displays for temperature and power

#### Technical data

Working medium: ammonia-water solution  
 Auxiliary gas: hydrogen  
 Electric heater: 125W  
 Gas burner, adjustable: propane gas  
 Evaporator heater, adjustable: 50W

#### Measuring ranges

- temperature: 4x -80...180°C
- power: 0...150W

230V, 50Hz, 1 phase  
 230V, 60Hz, 1 phase  
 120V, 60Hz, 1 phase  
 UL/CSA optional  
 LxWxH: 750x450x750mm  
 Weight: approx. 47kg

#### Required for operation

propane gas: 30...50mbar

#### Scope of delivery

- 1 experimental unit
- 1 hose
- 1 pressure reducer
- 1 set of instructional material





# Air conditioning technology

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## Basic knowledge

## Fundamentals of air conditioning

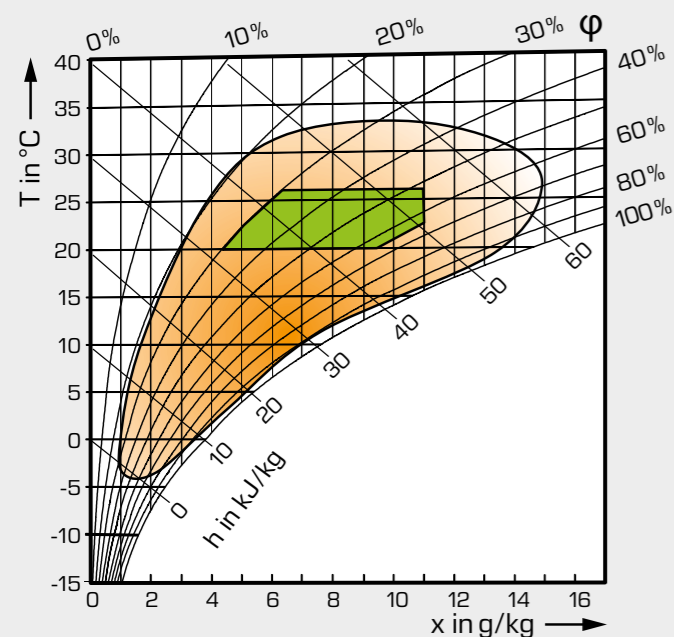
The purpose of air conditioning is to create a room climate comfortable for people. The conditions for describing comfort are standardised in accordance with DIN 1946 and DIN EN 13779. While the temperature should be between 20 and 26°C, a relative humidity between 30 and 65% is permitted.

Air conditioning therefore means to affect the room air in such a way that people are comfortable and their productivity is not impeded.

The condition of the air is characterised by temperature, pressure and humidity.

Normally, the air pressure is not changed. Exception: air conditioning in the aircraft cabin.

## Comfort zone in the h-x diagram for humid air by mollier



In the h-x diagram temperature  $T$ , enthalpy  $h$  and relative humidity  $\phi$  are plotted above the absolute humidity  $x$ .

In the exemplary diagram the comfort zone according to DIN 1946 is drawn in green.

The orange area represents the range of outside temperatures and humidities prevailing in Central Europe. You can see that the outside temperatures and humidities usually do not match the conditions for comfort and that the room air needs to be air conditioned.

In Central Europe this is usually heating and humidification, whereas in the Tropics cooling and dehumidification is required.

For full air conditioning there are four partial functions:

- heating
- cooling
- humidifying
- dehumidifying

## Air humidity

Humid air contains water in a vaporous state. A difference is made between absolute humidity and relative humidity. Absolute humidity is measured in  $\text{g H}_2\text{O/kg dry air}$ .

For air conditioning the relative humidity is more important. It is perceived by humans. Relative humidity is measured in % of the maximum possible humidity at a given temperature. 100% r.h. means that the air cannot absorb any more humidity, it is saturated. Excessive humidity then remains as a liquid (mist) in the air. The saturation curve is the lower limit curve in the h-x diagram.

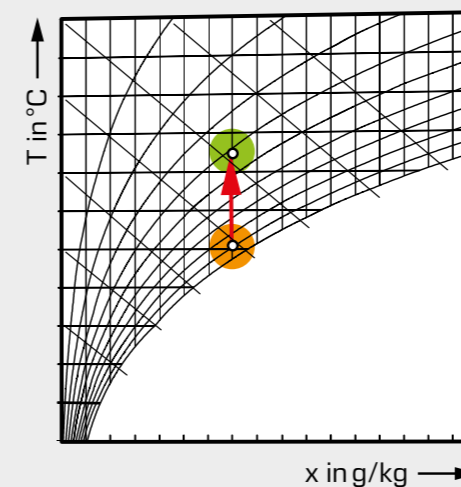
## Basic processes of air conditioning

The basic processes of air conditioning can be exceptionally well represented in the h-x diagram.

A change of temperature at constant absolute humidity also always results in a change of the relative humidity and enthalpy. The relative humidity and enthalpy also change with a change of the absolute humidity at constant temperature.

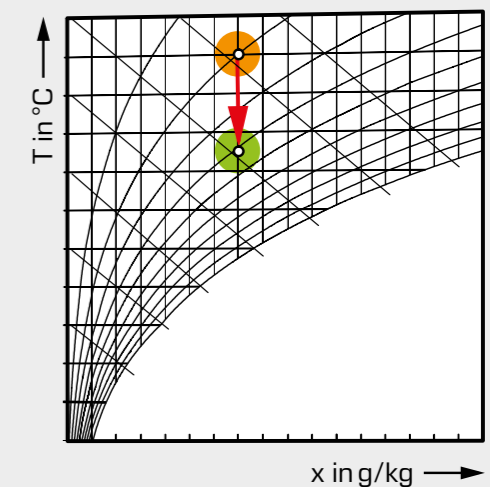
Thus temperature and relative humidity cannot be set independently of each other. An increase in the air temperature (heating), for example, always also results in a reduction in the relative humidity. To keep the relative humidity constant, humidification is therefore also required when heating. Conversely, the relative humidity increases during cooling.

## Four basic processes of air conditioning in the h-x diagram



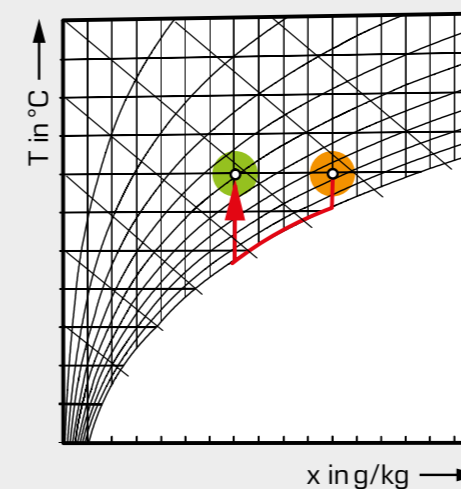
## Heating

Supply of heat, relative humidity reduces



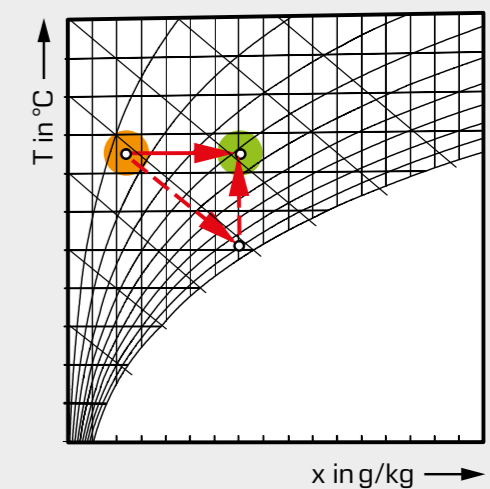
## Cooling

Removal of heat, relative humidity increases



## Dehumidifying

Cooling to 100% r.h. (saturation), condensation of the humidity on cold surfaces. Followed by heating to the desired temperature.



## Humidifying

Supply of water steam or water mist (for mist additional heating required to compensate cooling due to vaporisation enthalpy  $1 \cdot 1' \cdot 2$ )



## WL 201

### Fundamentals of humidity measurement



#### Description

- different measuring methods for measuring humidity
- climatic chamber with adjustable humidity and transparent door

The measurement of air humidity plays an important role in many branches of industry, e.g. during drying or in the air conditioning of buildings and vehicles. There are different measuring methods to determine humidity.

The trainer WL 201 enables the measurement of air humidity with four different instruments which can be directly compared to each other: two different hygrometers, a capacitive hygrometer and a psychrometer.

Psychrometers operate based on the principle of evaporation cooling and compare the ambient temperature with the wet bulb temperature to determine the humidity. Hygrometers utilise the property of specific fibres, e.g. hair, to expand with increasing air humidity. In the capacitive sensor the dielectricity constant of a layer and with it its capacity changes due to the water molecules absorbed.

The core element of the trainer is a climatic chamber with transparent door. This chamber can be humidified and dehumidified and contains the four instruments. A Peltier cooling element is used for dehumidification. An ultrasonic atomiser is used for humidification. To circulate the air and ensure good mixing a fan is used.

#### Learning objectives/experiments

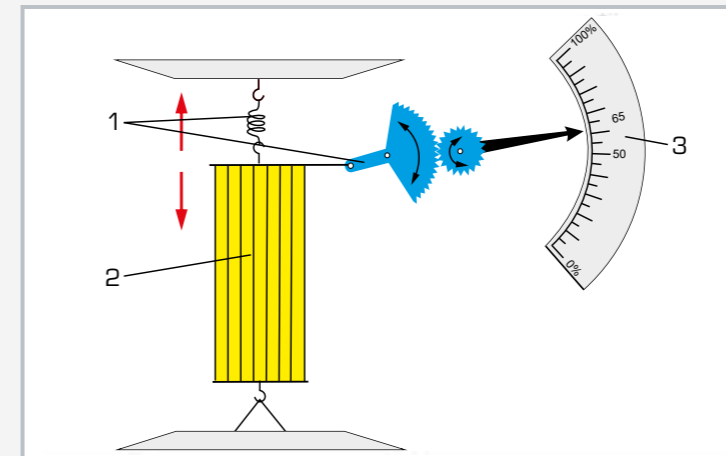
- measuring methods for air humidity measurement
  - ▶ psychrometric humidity measurement
  - ▶ hygrometric humidity measurement
  - ▶ capacitive humidity measurement
- characteristic variables to describe air humidity
- changes of the state of humid air in the h-x diagram
- determination of the relative air humidity with
  - ▶ psychrometer
  - ▶ hair hygrometer
  - ▶ hygrometer with synthetic fibre
  - ▶ capacitive humidity sensor
- design and operation of the instruments
- comparison of the instruments

## WL 201

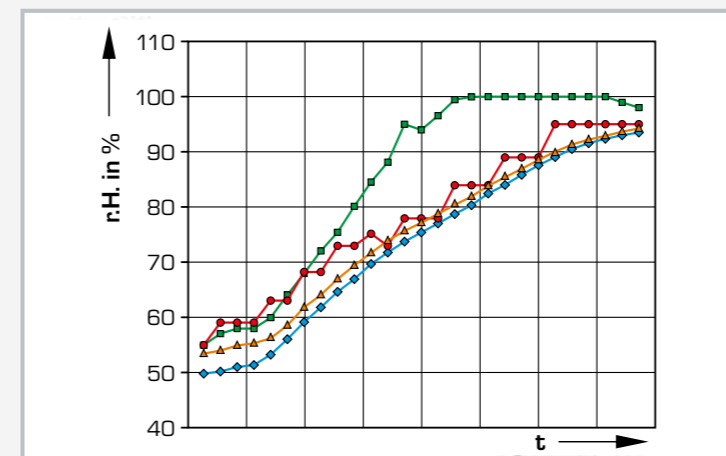
### Fundamentals of humidity measurement



1 capacitive humidity sensor, 2 displays and controls, 3 humidifier, 4 psychrometer, 5 hair hygrometer, 6 dehumidifier, 7 hygrometer with synthetic fibre and combined temperature sensor



Principle of the hair hygrometer: 1 mechanism to measure the humidity-dependent change in length of the hair bundle, 2 hair bundle, 3 humidity scale



Relative humidity (r. h.) over time (t) with rising content of humidity; blue: capacitive sensor, orange: hygrometer with synthetic fibre, red: psychrometer, green: hair hygrometer

#### Specification

- [1] different measuring methods for measuring humidity
- [2] climatic chamber with adjustable humidity and transparent door
- [3] humidification via ultrasonic atomiser
- [4] dehumidification via Peltier cooling element
- [5] fan for air recirculation
- [6] 2 mechanical instruments: psychrometer, hair hygrometer
- [7] 2 electronic instruments: capacitive sensor, hygrometer with synthetic fibre and combined temperature sensor

#### Technical data

##### Humidifier

- ultrasonic atomiser
- power consumption: 21,6W
- low water cut-off

##### Dehumidifier

- Peltier element
  - ▶ cooling capacity: 56,6W [50°C ambient temperature]
  - ▶ cooling surface: 1600mm<sup>2</sup>

##### Hair hygrometer with deflective needle

- measuring range: 0...100% r. h.

##### Hygrometer with synthetic fibre

- output voltage: 0...10V
- measuring ranges: 0...100% r. h. / -30...80°C

##### Capacitive sensor with digital display

- output voltage: 0...10V
- measuring range: 1...100% r. h.

##### Psychrometer with thermometer

- measuring range: -10...60°C, graduation: 0,5°C

230V, 50Hz, 1 phase  
120V, 60Hz, 1 phase; 230V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1400x800x1630mm  
Weight: approx. 110kg

#### Scope of delivery

- 1 trainer
- 1 psychrometer
- 2 hygrometers
- 1 set of instructional material

## WL 320 Wet cooling tower

With interchangeable cooling columns the wet cooling tower WL 320 is used for basic experiments as well as comparative measurements in different types of cooling columns. Thus the key properties of the wet cooling tower can be traced in the experiment.

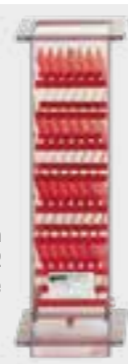
**Cooling column type 1**  
medium surface (included in the scope of delivery of WL 320)



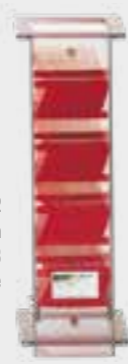
WL 320 Wet cooling tower

**Additional cooling columns for comparative measurements**

**WL 320.01**  
Cooling column type 2  
small surface



**WL 320.02**  
Cooling column type 3  
large surface



**WL 320.03**  
Cooling column type 4  
empty for wet deck surfaces of your own design



**WL 320.04**  
Cooling column type 5  
variable wet deck surfaces



### Interchangeable cooling columns

Five different cooling columns are available

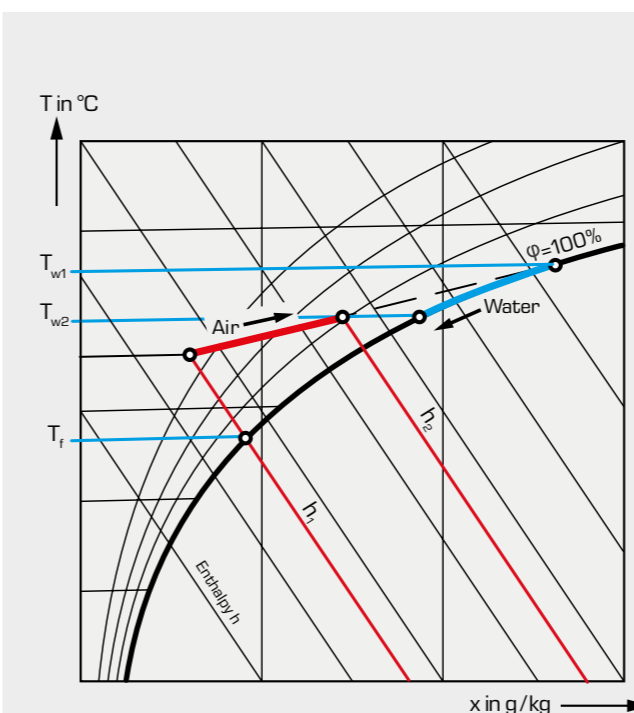
- three cooling columns with different wet deck surfaces
- one cooling column without wet deck surfaces for investigating the heat transfer in the free water drop or for own wet deck surfaces
- one cooling column with divided wet deck surfaces so that the surface of the wet deck surfaces can be varied and the distribution of the temperature and humidity within the cooling column is measured

### How does a cooling tower work?

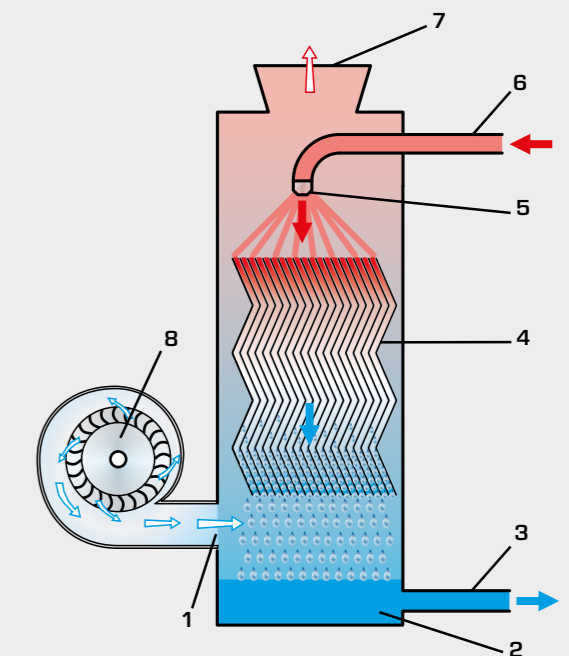
Cooling towers are used to dissipate heat arising during thermal processes, e.g. in steam power plants, air conditioning systems and process chillers. A difference is made between dry and wet cooling towers. Wet cooling towers can be constructed more easily and smaller for the same capacity. However, they feature high water losses in the range of 1...2,5% of the cooling water volume.

WL 320 is a wet cooling tower. The water to be cooled comes into direct contact with the air. The hot water is sprayed at the top of the cooling tower, trickles down the wet deck surface and is cooled in the process. The cooled water is removed at the bottom. The air enters the cooling tower from the bottom, flows upwards in a counterflow along the water trickling down, and exits at the top end.

A difference is made between cooling towers with atmospheric and forced ventilation. Very large cooling towers utilise the principle of atmospheric ventilation. Here the difference in density between the air inside and outside the cooling tower ensures the movement of the air. In small cooling towers the difference in density is insufficient for adequate air movement; they are forcefully ventilated by a fan.



Representation of the changes of state of air and water in the cooling tower in the h-x diagram



Principle of a wet cooling tower with forced ventilation

1 air inlet, 2 drip pan, 3 cold water outlet, 4 wet deck surface, 5 water distribution nozzle, 6 hot water inlet, 7 air outlet, 8 fan

There are two types of heat transfer in a wet cooling tower. First the heat is transferred by convection directly from the water to the air. In addition the water cools by partial evaporation. Decisive for the good operation of a wet cooling tower is that the air does not contain too much humidity. Therefore the water temperature  $T_{w2}$  must be clearly above the saturation temperature (wet bulb temperature)  $T_f$  of the air.



## WL 320

### Wet cooling tower



#### Description

- principle and characteristic variables of a wet cooling tower with forced ventilation
- transparent, easily interchangeable cooling column with wet deck surface
- 4 additional cooling columns available as accessory

Wet cooling towers are a proven method of closed-circuit cooling and heat dissipation. Typical areas of application are: air conditioning, heavy industry and power plants.

In wet cooling towers the water to be cooled is sprayed over a wet deck surface. Water and air come into direct contact in the counterflow. The water is cooled by convection. Some of the water evaporates and the evaporation heat removed further cools down the water.

WL 320 examines the main components and principle of a wet cooling tower with forced ventilation. Water is heated in a tank and transported by a pump to an atomiser. The atomiser sprays the water to be cooled over the wet deck surface. The water trickles from the top to the bottom along the wet deck surface whilst air flows from the bottom to the top. The heat is transferred directly from the water to the air by convection and evaporation.

The evaporated water volume is recorded. The air flow is generated by a fan and adjusted using a throttle valve.

The cooling column is transparent allowing clear observation of the wet deck surface and the trickling water. Interchangeable cooling columns (WL 320.01 – WL 320.04) enable comparative studies. GUNT software for data acquisition via USB under Windows 7, 8.1, 10

All important process parameters are recorded (volumetric air flow rate, temperatures of air and water, air humidity, water flow rate). The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included. The changes of state of the air are represented in an h-x diagram.

#### Learning objectives/experiments

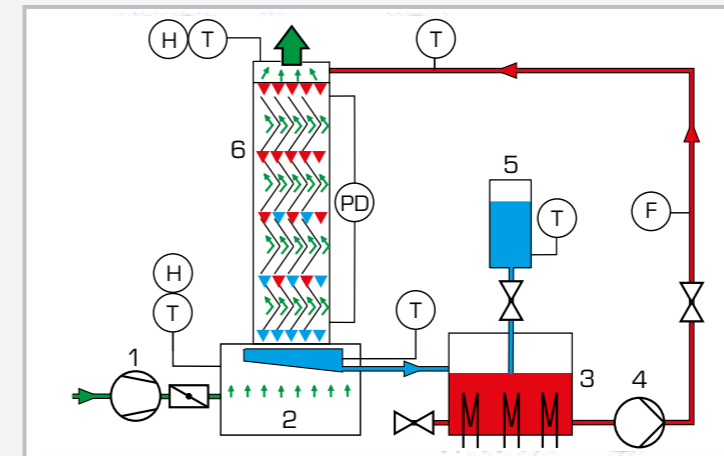
- thermodynamic principles of the wet cooling tower
- changes of state of the air in the h-x diagram
- determination of the cooling capacity
- energy balances
- calculation of process parameters, such as maximum cooling distance, cooling zone width etc.
- in conjunction with the cooling columns WL 320.01-WL 320.04
  - ▶ comparison of different wet deck surfaces

## WL 320

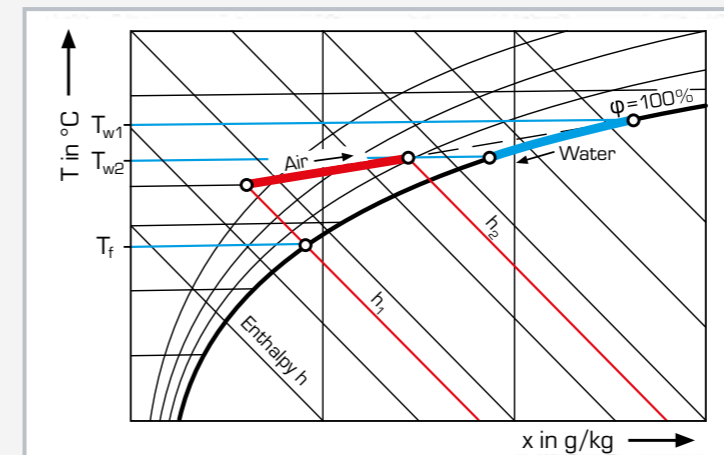
### Wet cooling tower



1 nozzle as atomiser, 2 wet deck surface, 3 displays and controls, 4 air chamber, 5 fan with throttle valve, 6 pump, 7 tank with heating, 8 tank for additional water, 9 combined temperature/humidity sensor



1 fan, 2 air chamber, 3 tank with heater, 4 pump, 5 tank for additional water, 6 cooling column with wet deck surface; T temperature, H humidity, dp differential pressure, F water flow rate



Changes of state of air and water in the h-x diagram as online representation in the software

#### Specification

- [1] principle of a wet cooling tower with cooling column and forced ventilation
- [2] interchangeable cooling columns with different wet deck surfaces available as accessories
- [3] water circuit with pump, filter, valve and a nozzle as atomiser
- [4] three-stage heater with thermostat for water heating
- [5] radial fan for forced ventilation
- [6] throttle valve to adjust the air flow
- [7] demister unit at the outlet of the cooling columns minimises water loss
- [8] tank for additional water compensates for water loss
- [9] display of temperature, differential pressure, flow rate and humidity
- [10] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

- Cooling column
- specific surface of the wet deck surface:  $110\text{m}^2/\text{m}^3$
  - cross-section:  $150 \times 150\text{mm}$
  - Volumetric air flow measurement via orifice:  $\varnothing 80\text{mm}$
- Heater, adjustable in three stages:
- 500W
  - 1000W
  - 1500W
- Thermostat: switches off at  $50^\circ\text{C}$
- Fan
- power consumption: 250W
  - max. pressure difference: 430Pa
  - max. volumetric flow rate:  $13\text{m}^3/\text{min}$
- Pump
- max. head: 70m
  - max. flow rate: 100L/h
- Tank for additional water: 4,2L

#### Measuring ranges

- differential pressure: 0...1000Pa (air)
- flow rate: 12...360L/h (water)
- temperature: 2x 0... $50^\circ\text{C}$ , 3x 0... $100^\circ\text{C}$
- rel. humidity: 10...100%

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 230V, 60Hz, 3 phases  
UL/CSA optional  
LxWxH: 1100x470x1230mm  
Weight: approx. 120kg

#### Required for operation

PC with Windows recommended

#### Scope of delivery

- 1 trainer
- 1 cooling column type 1
- 1 GUNT software CD + USB cable
- 1 set of instructional material

# ET 915 HSI training system refrigeration and air conditioning technology

The ET 915 HSI Training system refrigeration and air conditioning technology, base unit provides basic experiments for the different areas of refrigeration and air conditioning technology.

The term HSI refers to our overall didactic concept:  
Hardware – Software – Integrated.

## Refrigeration

### ET 915.01 Refrigerator model



### ET 915.02 Model of a refrigeration system with refrigeration and freezing stage



All attachments contain expansion elements and evaporators

## Air conditioning

### ET 915.06 Model of a simple air conditioning system



### ET 915.07 Air conditioning model



The ET 915 base unit contains the main compressor and condenser components

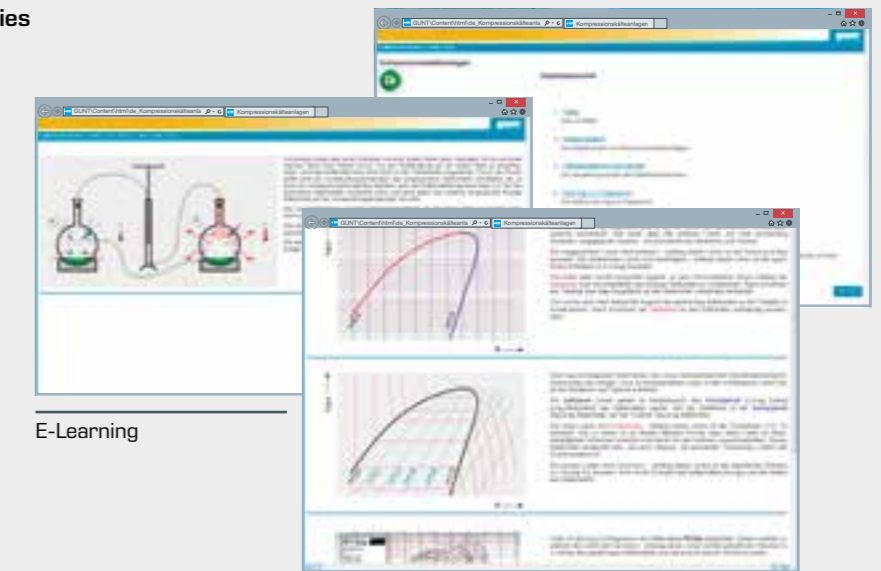
**Modular system with extensive teaching possibilities**



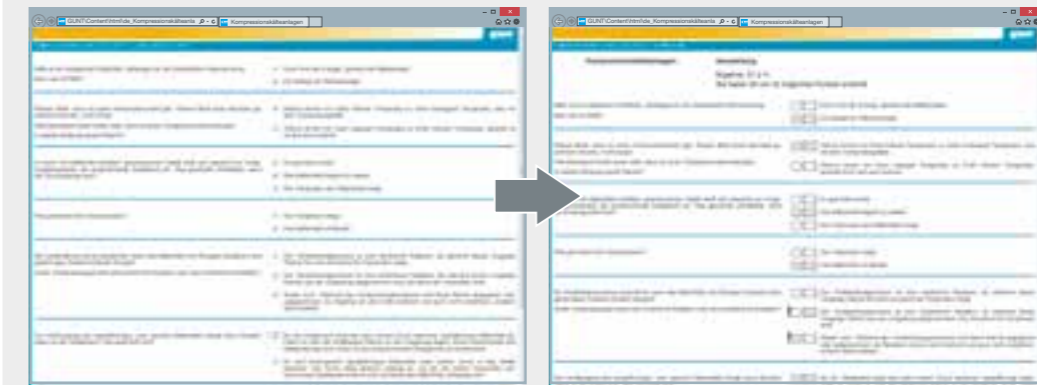
## Educational software

...with didactically valuable course of studies

- use the educational software on the students' own PCs
- complete course of studies for refrigeration and air-conditioning technology including quiz
- very flexible thanks to the structure of own learning modules and tests
- intuitive user interface



E-Learning



Quiz with detailed evaluation

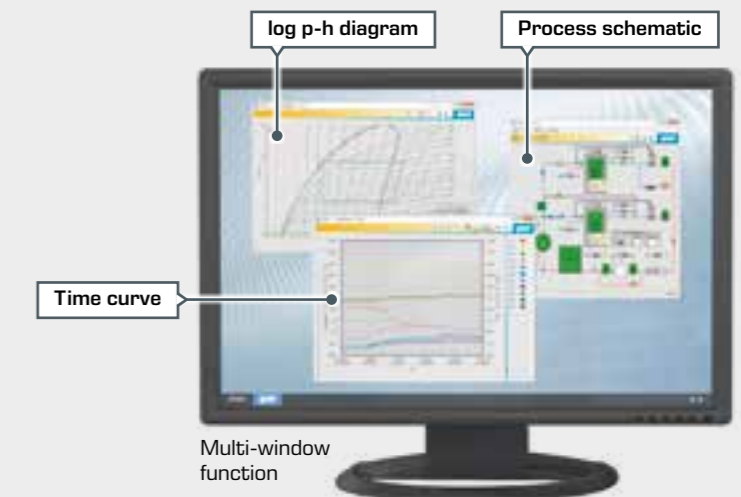
Targeted review of the learning content

- learning progress can be monitored discretely and automatically
- detect weaknesses and provide targeted support

## Data acquisition

...with unlimited networking capability

- interactive experiments for students via network connection
- real-time display of the processes in the log p-h diagram and h-x diagram
- plug & play system via USB connection



Multi-window function



## ET 915

### HSI training system refrigeration and air conditioning technology, base unit



#### Description

- base unit for the setup of basic experiments in refrigeration and air conditioning technology
- modern learning environment through hardware/software integration (HSI)
- four models on refrigeration and air conditioning technology
- dynamic recording of the refrigerant mass flow rate

The base unit ET 915 is, dependent on the objective of the experiment, extended into complete refrigeration circuit with one of the models available as accessories (ET 915.01 refrigerator, ET 915.02 refrigeration system with refrigeration and freezing stage, ET 915.06 simple air conditioning system, ET 915.07 air conditioning).

The main components of ET 915 are compressor, condenser and receiver plus electrical and communications systems. The models are plugged onto the base unit and connected hydraulically with refrigerant hoses and electrically with cables. Self-sealing couplings reduce the refrigerant loss to a minimum. All components are arranged well visible to allow their operation to be monitored.

The modern and powerful software is an integral part of the training system in the form of hardware/software integration (HSI). It enables the comfortable execution and analysis of the experiments. The experimental unit is connected to the PC via a USB interface.

The GUNT software consists of a software for system operation and for data acquisition and an educational software. With explanatory texts and illustrations the educational software significantly aids the understanding of the theoretical principles. Each model has its own GUNT software matching the learning objectives. With the aid of an authoring system, the teacher can create further exercises.

Temperatures and pressures in the system are recorded by sensors and displayed dynamically in the software for system operation and data acquisition. The refrigerant mass flow rate is calculated in the software from the recorded measured values. The effect of parameter changes can be tracked in log p-h and h-x diagrams. The system is also operated via the software.

#### Learning objectives/experiments

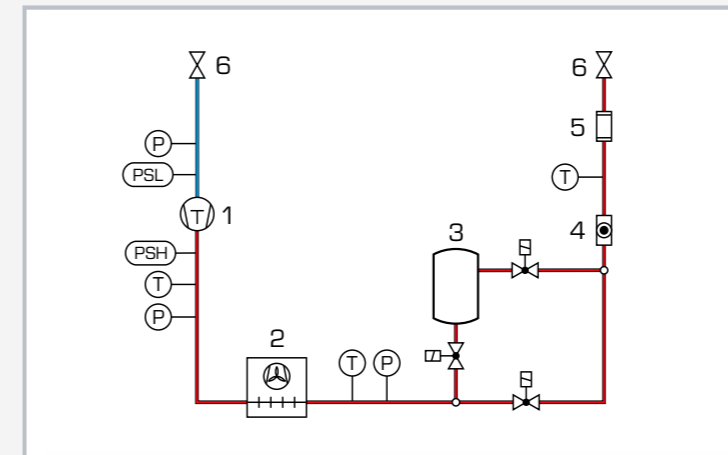
- in conjunction with ET 915.01, ET 915.02, ET 915.06 and ET 915.07
  - ▶ fundamentals of the refrigeration cycle
  - ▶ fundamentals of air conditioning
  - ▶ components in a refrigeration system/air conditioning system
  - ▶ system operation
  - ▶ fault finding

## ET 915

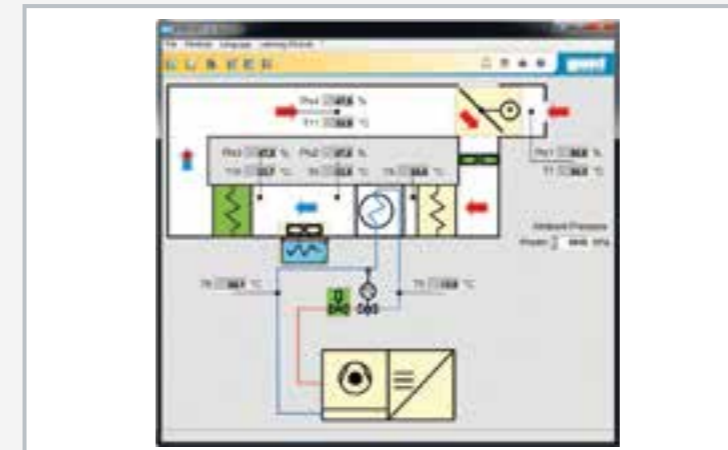
### HSI training system refrigeration and air conditioning technology, base unit



1 compressor, 2 condenser with add-on fan, 3 receiver, 4 solenoid valve, 5 frame to mount the models, 6 filter/drier, 7 manometer, 8 pressure switch, 9 refrigerant hose



1 compressor, 2 condenser, 3 receiver, 4 sight glass, 5 filter/drier, 6 refrigerant hose for the models; PSH, PSL pressure switch; T temperature, P pressure; blue: low pressure, red: high pressure



Software screenshot: process schematic of the model ET 915.07. Measured values are displayed „online“.

#### Specification

- [1] basic experiments on the operation of refrigeration and air conditioning systems by combining the base unit and models
- [2] GUNT training system with HSI technology
- [3] condensing unit consisting of compressor, condenser and receiver
- [4] connection between condensing unit and model via refrigerant hoses
- [5] model attached securely on ET 915 with fasteners
- [6] manometer for refrigerant with temperature scale
- [7] refrigerant mass flow rate calculated in the software from recorded measured values
- [8] refrigerant R513A, GWP: 631
- [9] system control via solenoid valves and software
- [10] functions of the GUNT software: educational software, data acquisition, system operation

#### Technical data

##### Compressor

- refrigeration capacity: 463W at 7,2/54,4°C
- power consumption: 288W at 7,2/54,4°C

##### Receiver: 0,7L

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 700g
- CO<sub>2</sub>-equivalent: 0,4t

##### Measuring ranges

- temperature: 1x -50...50°C, 3x 0...100°C
- pressure:
  - ▶ 1x intake side: -1...9bar
  - ▶ 2x delivery side: -1...15bar
- flow rate: 0...19kg/h (refrigerant)

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase  
120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 830x650x320mm  
Weight: approx. 60kg

#### Required for operation

PC with Windows

#### Scope of delivery

- 1 condensing unit, filled with refrigerant
- 1 CD with authoring system for GUNT educational software
- 1 set of instructional material

**ET 915.06****Model of a simple air conditioning system****Description**

- model of a simple air conditioning system for room cooling
- component operation and fault simulation via the GUNT software

ET 915.06 is part of the HSI training system for refrigeration and air conditioning technology. In combination with the base unit ET 915 the operational model of a simple air conditioning system is created. The model is plugged onto the base unit, secured using fasteners and connected with refrigerant hoses to become a complete refrigeration circuit for the air cooler.

In systems for room cooling the air to be cooled is aspirated from the room by a fan, cooled and fed back into the room. This model demonstrates the principles of room cooling and the components of an air conditioning system.

The model ET 915.06 includes an air duct with transparent front, fan for air transport, an evaporator as air cooler and an expansion valve. All components are clearly arranged on a panel.

The individual components of the system, here the compressor and the fan, are operated via the software. The software offers the option to simulate faults.

The volumetric air flow rate is determined via a differential pressure measurement. Temperatures and humidity before and after the evaporator are recorded by sensors, digitised and dynamically represented in the software.

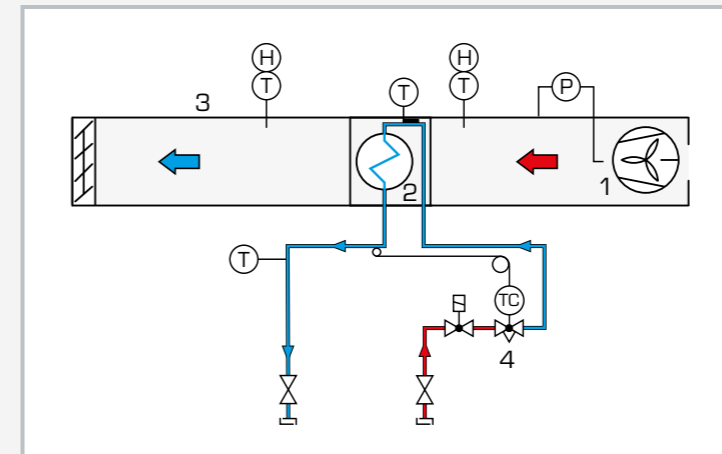
Fundamentals and individual components are represented in the educational software for ET 915.06. Performance assessments check the learning progress. With the aid of the authoring system further exercises and performance assessments can be created.

**Learning objectives/experiments**

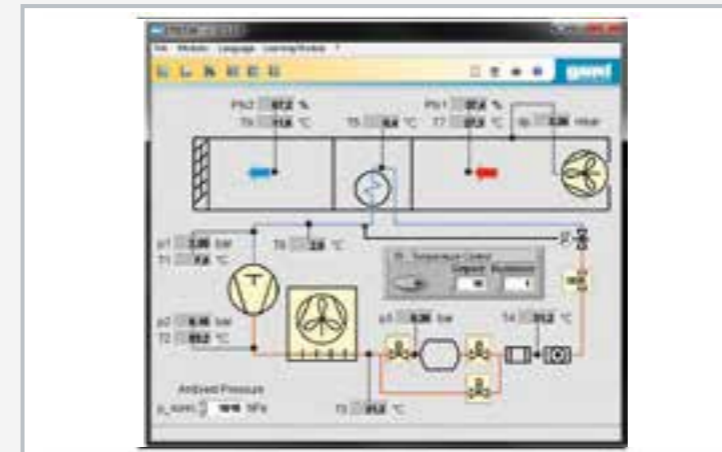
- air conditioning system for room cooling and its main components
- principle of operation of an evaporator as air cooler
- fault simulation

**ET 915.06****Model of a simple air conditioning system**

1 evaporator as air cooler, 2 air duct, 3 temperature and humidity sensor, 4 process schematic, 5 connections for ET 915, 6 solenoid valve, 7 expansion valve, 8 radial fan, 9 differential pressure sensor



Process schematic of the simple air conditioning system model: 1 radial fan, 2 air cooler, 3 air duct, 4 expansion valve; T temperature, P pressure, H humidity; red arrow: hot, blue arrow: cold; blue: low pressure, red: high pressure



Software screenshot: process schematic

**Specification**

- [1] model of a simple air conditioning system to plug onto the base unit ET 915
- [2] GUNT training system with HSI technology
- [3] air duct with transparent front
- [4] evaporator as air cooler
- [5] radial fan with throttle valve
- [6] thermostatic expansion valve as expansion element
- [7] sensors to record temperature, humidity and differential pressure for determining the volumetric air flow rate
- [8] operation of individual components and of the system and fault simulation via software
- [9] GUNT software with control functions and data acquisition via USB under Windows 7, 8.1, 10
- [10] GUNT software: educational software, data acquisition, system operation

**Technical data**

Air duct: 136x136x435mm

Evaporator as air cooler  
 ■ transfer area: approx. 900cm<sup>2</sup>

Radial fan  
 ■ max. power consumption: 80W  
 ■ max. flow rate: 255m<sup>3</sup>/h

Measuring ranges  
 ■ temperature: 2x ±50°C, 2x 0...100°C  
 ■ differential pressure: 0...10mbar  
 ■ humidity: 2x 10...100% rel.

LxWxH: 970x370x600mm

Weight: approx. 35kg

**Scope of delivery**

- 1 model of a simple air conditioning system, filled with refrigerant
- 1 GUNT software CD + USB cable



## ET 915.07

### Air conditioning model



#### Description

- complete model of a full air conditioning system
- heating, cooling, humidifying and dehumidifying
- outer air and recirculation operation possible
- component operation and fault simulation via the GUNT software

ET 915.07 is part of the HSI training system for refrigeration and air conditioning technology. In combination with the base unit ET 915 the operational model of a full air conditioning system is created. The model is plugged onto the base unit, secured using fasteners and connected with refrigerant hoses to become a complete refrigeration circuit for the air cooler.

The room climate is created by the interaction of air temperature, heating temperature and air humidity. The purpose of room air conditioning is to shape the room climate in accordance with the requirements of people or sensitive goods. This model introduces the operation of an air conditioning system and the recirculating air and outer air operating modes.

The model ET 915.07 includes two air ducts with transparent front. The top air duct serves as climatic chamber whilst the bottom air duct contains the air cooler, two electric air heaters and a steam humidifier. A fan between the two air ducts recirculates the air. A motorised butterfly valve in the top air duct allows a change between outer air and recirculating operation. Dependent on the switching of the two air heaters, the air cooler and the humidifier, the air in the duct system can be cooled, heated, humidified or dehumidified.

The individual system components are operated via the GUNT software. Temperature and humidity before and after the evaporator and in the climatic chamber are recorded by sensors, digitised and represented dynamically in the software. The conditioning of the air can be monitored online in the h-x diagram.

Fundamentals and individual components are represented in the educational software for ET 915.07. Performance assessments check the learning progress. With the aid of the authoring system further exercises and performance assessments can be created.

#### Learning objectives/experiments

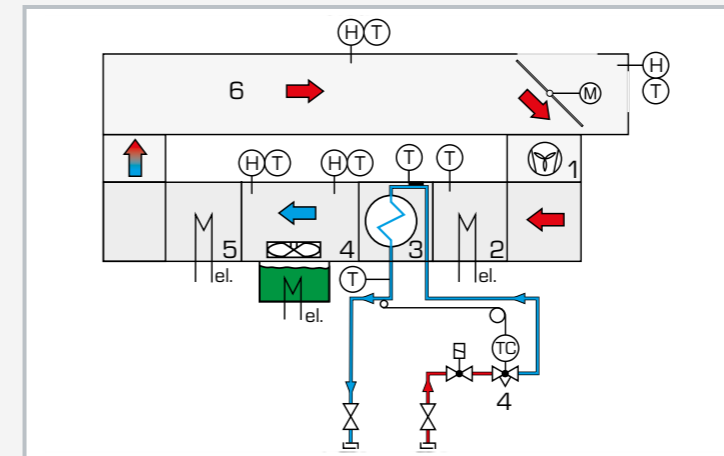
- full air conditioning system and its main components
- heating and cooling in the h-x diagram
- humidifying and dehumidifying in the h-x diagram
- outer air and recirculating operation
- fault simulation

## ET 915.07

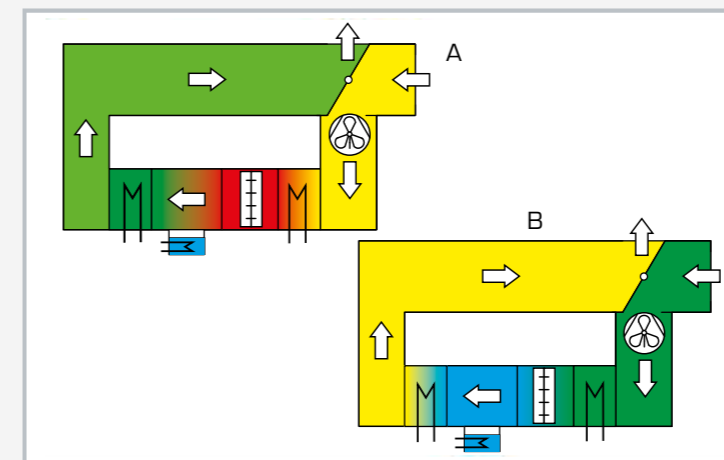
### Air conditioning model



1 air duct, 2 air reheater, 3 process schematic, 4 air humidifier, 5 connections for ET 915, 6 evaporator, 7 expansion valve, 8 air preheater, 9 fan, 10 sensors for humidity and temperature, 11 ventilation flap



Air conditioning with recirculating operation:  
1 fan, 2 air preheater, 3 air cooler, 4 air humidifier, 5 air reheater, 6 air duct, 7 ventilation flap with servomotor, 8 expansion valve; T temperature, P pressure, H humidity; red arrow: hot, blue arrow: cold; blue: low pressure, red: high pressure



Air conditioning with outer air operation; A: humidification, B: dehumidification; yellow: dry, green: humid, blue: cooling, red: heating

#### Specification

- [1] model of an air conditioning system to plug onto the base unit ET 915
- [2] GUNT training system with HSI technology
- [3] air duct with transparent front and adjustable ventilation flap for recirculating or outer air operation
- [4] evaporator as air cooler
- [5] 2 heaters as air preheater and reheater
- [6] air humidifier with float switch, fan, filling level indication
- [7] thermostatic expansion valve as expansion element
- [8] sensor to record temperature and combined sensor for humidity and temperature
- [9] operation of individual components and of the system and fault simulation via software
- [10] GUNT software with control functions and data acquisition via USB under Windows 7, 8, 1, 10
- [11] GUNT software: educational software, data acquisition, system operation

#### Technical data

Air duct, top: 136x136x800mm

Evaporator as air cooler  
■ transfer area: approx. 900cm<sup>2</sup>

Air heater:  
■ 2x 250W  
Axial fan  
■ max. power consumption: 20W  
■ max. flow rate: 160m<sup>3</sup>/h

Humidifier  
■ heater: 200W

Measuring ranges  
■ temperature: 2x -50...50°C, 5x 0...50°C  
■ rel. humidity: 4x 10...100%

LxWxH: 850x400x680mm  
Weight: approx. 51kg

#### Scope of delivery

- 1 air conditioning system model, filled with refrigerant
- 1 narrow mouth bottle
- 1 GUNT software CD + USB cable

## ET 605 Air conditioning system model plus automation solutions

### A practical air conditioning system model with all elements and functions

The principles of air conditioning technology can be taught optimally with the model ET 605. The air conditioning system consists of an air duct with transparent front and a climatic chamber with two different cooling loads. The overall design of the system is guided by instructional and methodological aspects and thereby supports the learning process.

The main functions of the system – cooling, heating, humidifying, air transport – are activated or deactivated via switches. Recirculating and outer air operation are possible. All relevant measuring data can be read on digital displays.

An important extension of the teaching objectives is provided by the option to extend the system with different additions into a fully automated system.

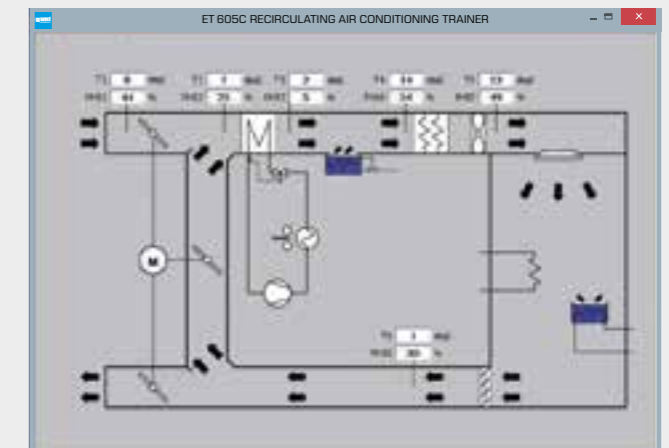


### The software solution: clear and versatile

#### ET 605.01 Software controller with data acquisition

Data acquisition and visualisation, control and operation in a single software solution.

This solution is recommended if the focus is on instructional and methodological criteria. Compared to an industrial controller the software offers an attractive and very clear representation of the air conditioning process.



### The industrial solution

#### ET 605.02 Air conditioning controller

This automation solution is recommended if the training objective focuses on the exact familiarisation with an industrial air conditioning controller. The controller matched to the ET 605 system offers a wide functional spectrum and a graphical display. Dependent on the desired temperature and humidity in the climatic chamber it controls the components.



### The right tool for implementing your own ideas

#### ET 605.03 I/O connection box

This solution is recommended if the focus is on the topic of automation and own solutions are to be created. The connection box provides all relevant input and output signals which the user can further process according to his own requirements and ideas. The connection of any industrial air conditioning controller or independently written software are possible.





## ET 605

### Air conditioning system model



#### Description

- climatic chamber with latent and sensitive heat source as cooling load
- recirculating and outer air operation
- optional data acquisition software (ET 605.01)
- connection options for the use of different automation solutions

Air conditioning technology is a key topic in building services engineering. For this reason air conditioning technology plays an important role during the training of skilled workers and engineers.

The clear trainer ET 605 represents a complete air conditioning system with an air duct and a climatic chamber. The main components of the air conditioning system are the air cooler with condensing unit, fan, steam humidifier and air heater. Three motorised ventilation flaps control the air distribution in the air conditioning system. The climatic chamber is equipped with two different heat sources (wet and dry). Temperature and relative humidity are measured at relevant points in the air duct and displayed digitally. For the refrigeration circuit two manometers with integrated temperature scale and a flow meter provide all relevant measurements.

ET 605 is operated manually. A key feature of the air conditioning system is that it is fully ready for various automation solutions. The user can thus focus on this important topic during a lesson. The following solutions are available:

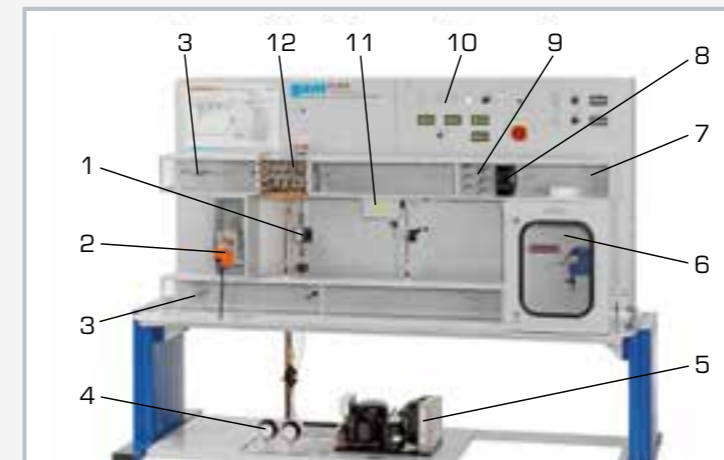
- software controller ET 605.01
- industrial air conditioning controller ET 605.02
- signal connection box ET 605.03 for the integration of an individual user solution.

#### Learning objectives/experiments

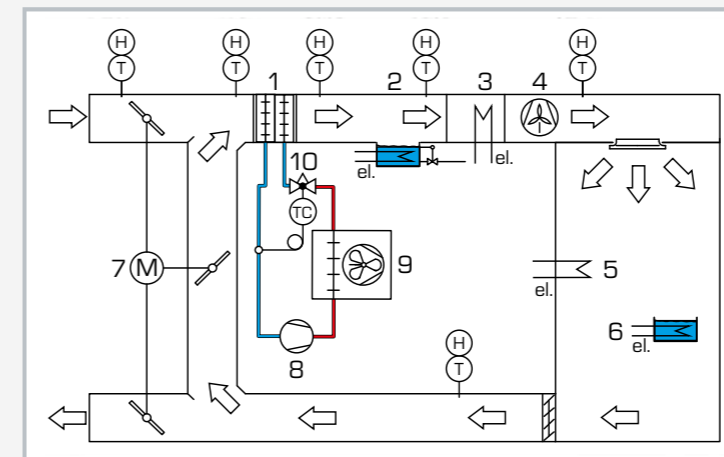
- air conditioning system and its components
- conditioning room air
- mixing different air flows
- representation in the h-x diagram for humid air
  - ▶ humidification and dehumidification
  - ▶ heating and cooling
- representation of the circuit in the log p-h diagram
- effect of a cooling load (dry and wet)
- recirculating and outer air operation
- in conjunction with optional accessories
  - ▶ automation in an air conditioning system

## ET 605

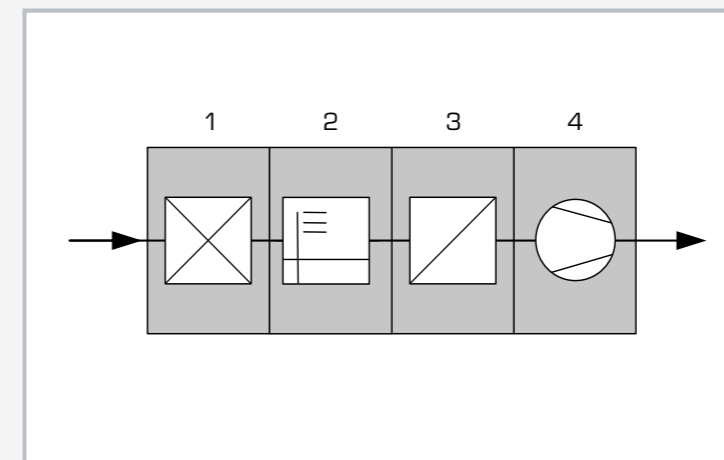
### Air conditioning system model



1 refrigerant flow meter, 2 servomotor, 3 ventilation flap, 4 refrigerant manometer, 5 condensing unit, 6 climatic chamber with sensitive and latent heat source, 7 air duct with temperature/humidity sensor, 8 fan, 9 air heater, 10 displays and controls, 11 humidifier, 12 air cooler



1 air cooler, 2 humidifier, 3 air heater, 4 fan, 5 sensitive heat source, 6 latent heat source, 7 servomotor for ventilation flaps, 8 compressor, 9 condenser, 10 expansion valve; T temperature, H humidity



Schematic setup of the air conditioning system in accordance with DIN 1946  
1 air cooler, 2 air humidifier, 3 air heater, 4 fan

#### Specification

- [1] model of an air conditioning system with outer air and recirculating operation
- [2] air duct with transparent front
- [3] air duct with fan, air cooler, humidifier, flaps, air heater and sensors
- [4] chamber with wet (latent) and dry (sensitive) heat source as cooling load
- [5] motorised flaps for recirculating and outer air operation
- [6] process schematic with signal lamps
- [7] air conditioning system ready for different automation solutions: 4 data cable connections to integrate the accessories
- [8] refrigerant R513A, GWP: 631

#### Technical data

Compressor (air-cooled condensing unit)  
 ■ power consumption: 159W at 7,2/54,4°C  
 ■ refrigeration capacity: 380W at 7,2/54,4°C

Humidifier  
 ■ heating power: 400W

Air heater  
 ■ heating power: 360W

2 heaters in the chamber as cooling load  
 ■ power output: 0...250W each, freely adjustable

Flow cross-section of the air duct  
 ■ WxH: 155x155mm

Refrigerant: R513A, GWP: 631  
 ■ filling volume: 1,2kg  
 ■ CO<sub>2</sub>-equivalent: 0,8t

Measuring ranges  
 ■ temperature: 0...50°C  
 ■ rel. humidity: 10...90%  
 ■ power consumption: 0...600W (condensing unit)  
 ■ power: 2x 0...300W (cooling load)  
 ■ pressure: -1...9bar / -1...24bar (refrigerant)  
 ■ flow rate: 1,5...23,5L/h (refrigerant)  
 ■ air velocity: 0...2,5m/s

230V, 50Hz, 1 phase  
 230V, 60Hz, 1 phase  
 230V, 60Hz, 3 phases  
 UL/CSA optional  
 LxWxH: 2210x800x1740mm  
 Weight: approx. 280kg

#### Required for operation

water connection, drain

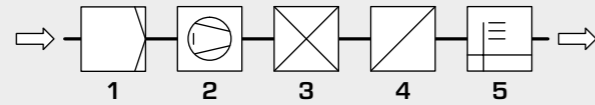
#### Scope of delivery

- 1 trainer, filled with refrigerant
- 1 set of instructional material

## Basic knowledge

## Setup of an air conditioning system

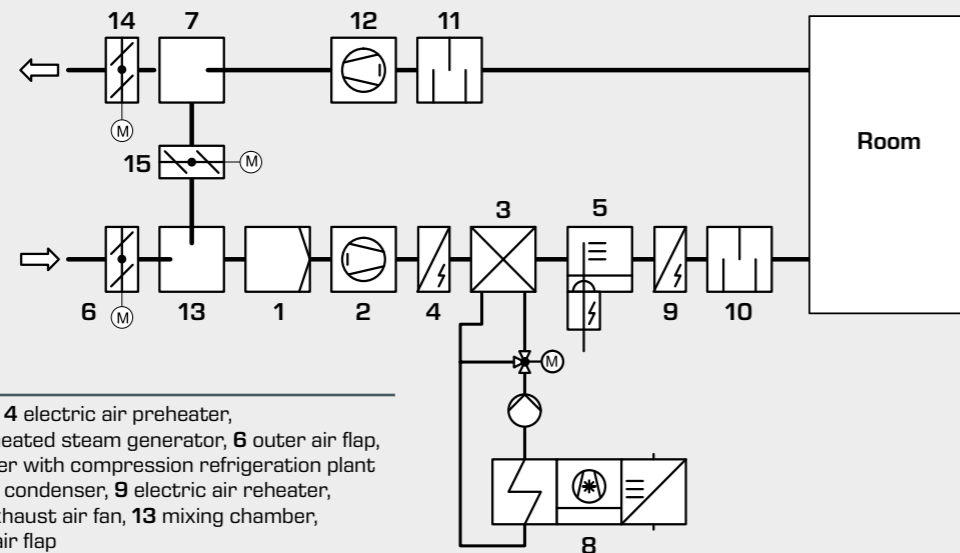
## Simple full air conditioning system



A full air conditioning system consists in its most simple form of the following components:

- 1 air filter: removes dust and dirt from the air
- 2 fan: aspirates the air and transports it through the system
- 3 air cooler: cools and dehumidifies the air
- 4 air heater: heats the air and compensates for the temperature loss during humidification and dehumidification
- 5 air humidifier: adds humidity to the air

Real air conditioning systems are usually more complex in design. To save energy, the waste air from the room can be returned to the room after processing. This is called recirculating operation. The ratio of recirculating air and outer air is controlled by throttle valves or flaps. In the diagram shown below the air cooler is supplied with cold water from a water chiller. Steam humidifier and air heater are heated electrically.



## Complex air conditioning system with recirculating operation

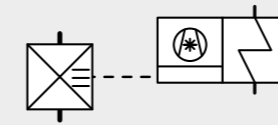
- 1 air filter, 2 air inlet fan, 3 air cooler, 4 electric air preheater,
- 5 steam humidifier with electrically heated steam generator, 6 outer air flap,
- 7 distribution chamber, 8 water chiller with compression refrigeration plant in block construction with air-cooled condenser, 9 electric air reheater,
- 10 inlet air silencer, 11 silencer, 12 exhaust air fan, 13 mixing chamber,
- 14 exhaust air flap, 15 recirculating air flap



## ET 620 Air conditioning and ventilation system

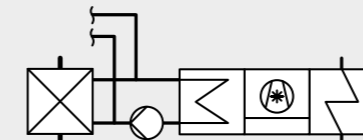
- 1 air filter,
- 2 fan,
- 3 air cooler,
- 4 air heater,
- 5 humidification chamber,
- 6 ventilation flap,
- 7 distribution system with flaps and outlets

## Air cooler



- direct evaporator of a compression refrigeration system

**Advantage:**  
simple and cheap design



- cold water circuit with compression refrigeration system

**Advantage:**  
several coolers can be operated via one refrigeration system



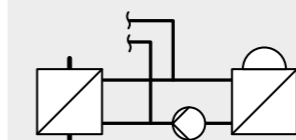
Direct evaporator as air cooler

## Air heater



- electric air heater

**Advantage:**  
simple design, easy to control



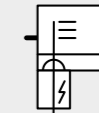
- hot water circuit with boiler

**Advantage:**  
all fuels and heat sources possible, several air heaters can be connected to one heat source



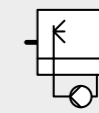
Electric air heater

## Air humidifier



- steam humidifier

**Advantage:**  
no cooling by condensation, hygienic



- spray humidifier with mist collector

**Advantage:**  
can also operate as air cooler



Steam humidifier



An example from practice: industrial air conditioning system with comprehensive filters for clean room production



## ET 600

### Conditioning of room air



#### Description

- air conditioning system with steam humidifier
- wide experimental program for conditioning of room air
- representation of the thermodynamic principles in the log p-h and h-x diagram
- dynamic recording of the refrigerant mass flow rate

In many daily situations the condition of the ambient air does not meet requirements for e.g. a tropical greenhouse, the manufacture of sensitive components or even comfortable offices. The flow velocity, temperature and humidity of the air can be modified by air conditioning systems in accordance with the requirements for the desired room climate.

The trainer ET 600 examines the operation and effect of the individual components of an air conditioning system. ET 600 includes all the components also used in building services engineering. Particular importance was placed on the use of original components.

For air conditioning, air cooler (direct evaporator with condensing unit), steam humidifier, fan, air preheaters and reheaters are arranged in an open air duct. Each of these components can be switched on or off individually. The effect of each individual component on the conditioning of the air is as interesting as the effect of any combination of components.

Sensors record the air temperature and air humidity before and after each stage as well as the pressures and temperatures of the refrigerant. The refrigerant mass flow rate is calculated in the software from the recorded measured values. The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included.

#### Learning objectives/experiments

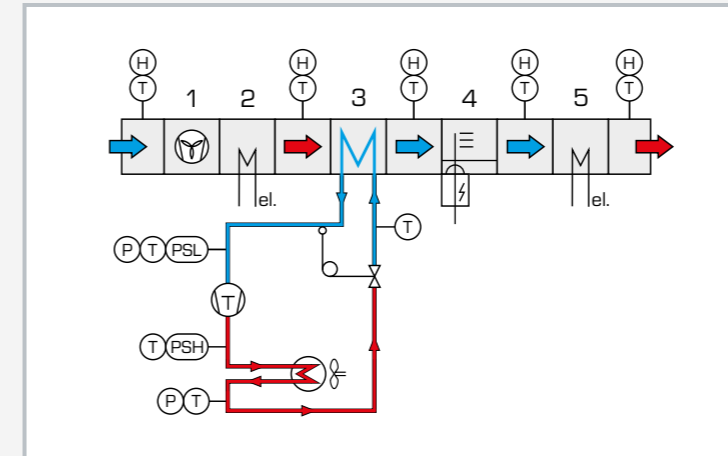
- air conditioning of room air
  - ▶ setup of an air conditioning system: main components and their function
  - ▶ variables in air conditioning
  - ▶ measure temperature and air humidity
  - ▶ effect of the air flow
  - ▶ changes of state in the h-x diagram
- setup of a refrigeration system: main components and their function
- measurements in the refrigeration circuit
  - ▶ cyclic process in the log p-h diagram
  - ▶ determine heating and cooling capacities

## ET 600

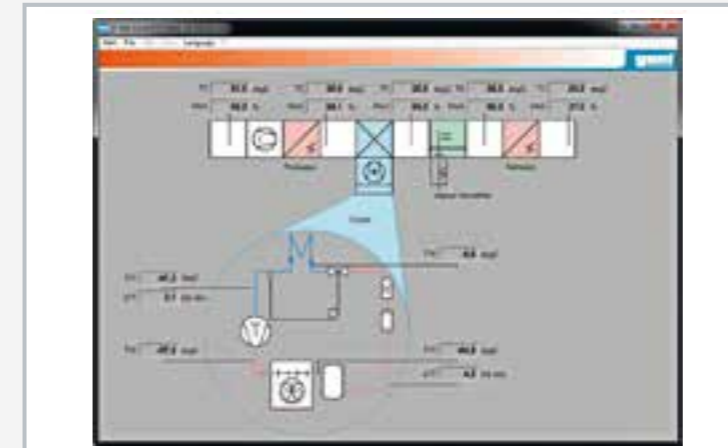
### Conditioning of room air



1 controls, 2 air cooler (direct evaporator), 3 fan, 4 air preheater, 5 temperature sensor, 6 condensing unit, 7 air humidifier, 8 air reheater, 9 air duct, 10 inclined tube manometer, 11 displays



Setup of the air conditioning system: 1 fan, 2 air preheater, 3 air cooler, 4 air humidifier, 5 air reheater; sensors: H humidity, T temperature, P pressure



Software screenshot: process schematic

#### Specification

- [1] effect of typical air conditioning system components on the conditioning of room air
- [2] air conditioning system with open air duct, air cooler, steam humidifier, fan, air preheaters and reheaters
- [3] all components can be switched on and off individually
- [4] determination of the volumetric air flow rate by differential pressure measurement using an inclined tube manometer
- [5] combined sensors for the air humidity and temperature before and after each stage
- [6] sensor for the pressure and temperature of the refrigerant, refrigerant mass flow rate calculated in the software from recorded measured values
- [7] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
- [8] refrigerant: R513A, GWP: 631

#### Technical data

##### Steam humidifier

- power consumption: 4kW
- steam capacity: 5,5kg/h, switchable in three stages

##### Fan

- power consumption: 167W
- max. volumetric flow rate: 1150m<sup>3</sup>/h
- speed: 1000...2600min<sup>-1</sup>
- $\Delta p_{max}$ : 460Pa

##### Air preheater: 1kW, switchable in two stages

##### Air reheater: 2kW, switchable in two stages

##### Air duct, WxH: 300x300mm

##### Compressor

- power consumption: 1kW at -5/50°C
- refrigeration capacity: 2,1kW at -5/50°C

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 3,1kg
- CO<sub>2</sub>-equivalent: 2t

##### Measuring ranges

- differential pressure: 0...100Pa
- temperature: 5x 0...50°C, 4x -100...200°C
- humidity: 5x 10...90%
- pressure: -1...15bar, -1...24bar (refrigerant)
- flow rate: 0...80kg/h (refrigerant)

##### 400V, 50Hz, 3 phases

##### 400V, 60Hz, 3 phases; 230V, 60Hz, 3 phases

##### UL/CSA optional

##### LxWxH: 2570x790x1750mm

##### Weight: approx. 330kg

#### Required for operation

water connection, drain, PC with Windows recommended

#### Scope of delivery

- 1 trainer, filled with refrigerant
- 1 GUNT software CD + USB cable
- 1 set of instructional material

## ET 611 Air conditioning system with chamber for comfort investigations



Water chiller

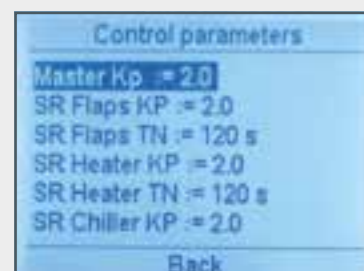
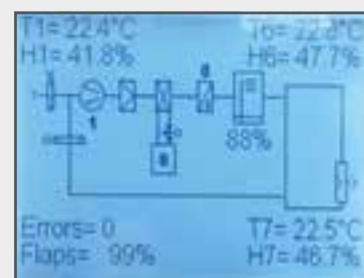
Climatic chamber

More than a quantitative investigation of the room climate:  
experience comfort with your own body

The air conditioning of the air takes place in a closed chamber large enough for test persons to be inside. This allows for the effect of the room climate on the personal perception to be investigated. ET 611 is a real system including typical com-

ponents of larger air conditioning systems: water chiller, PLC controller, filter cartridge. The system operates in outer air and recirculating operation.

### Climate controller with PLC

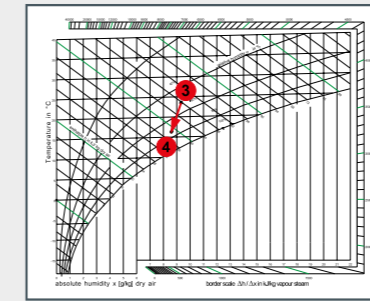


The operation of the air conditioning system is via a PLC. Handling the different PLC functions is learned step by step:

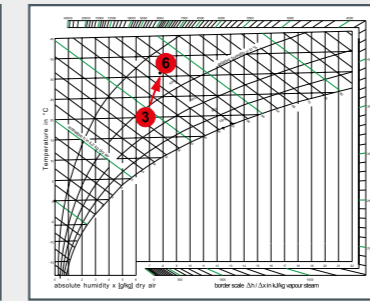
- display of alarms
- display of measured values
- input of reference variables
- input of control parameters
- input of limit values

...and much more.

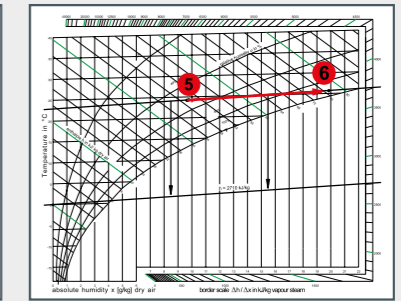
### Instructional material and software: the aid for fast learning success



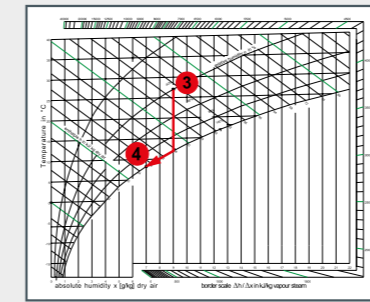
Cooling



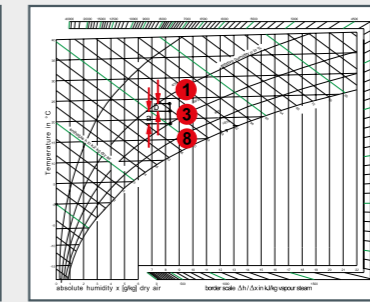
Heating



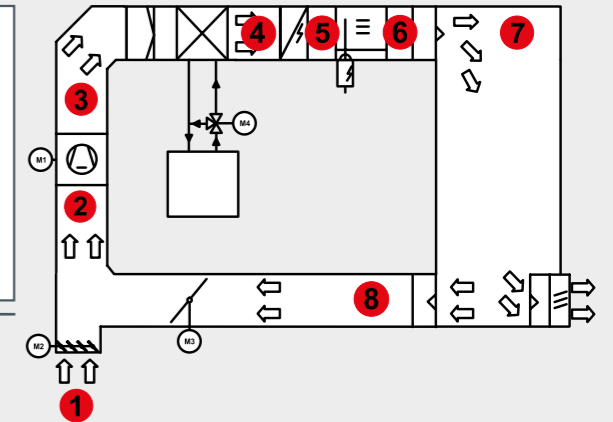
Humidifying



Dehumidifying

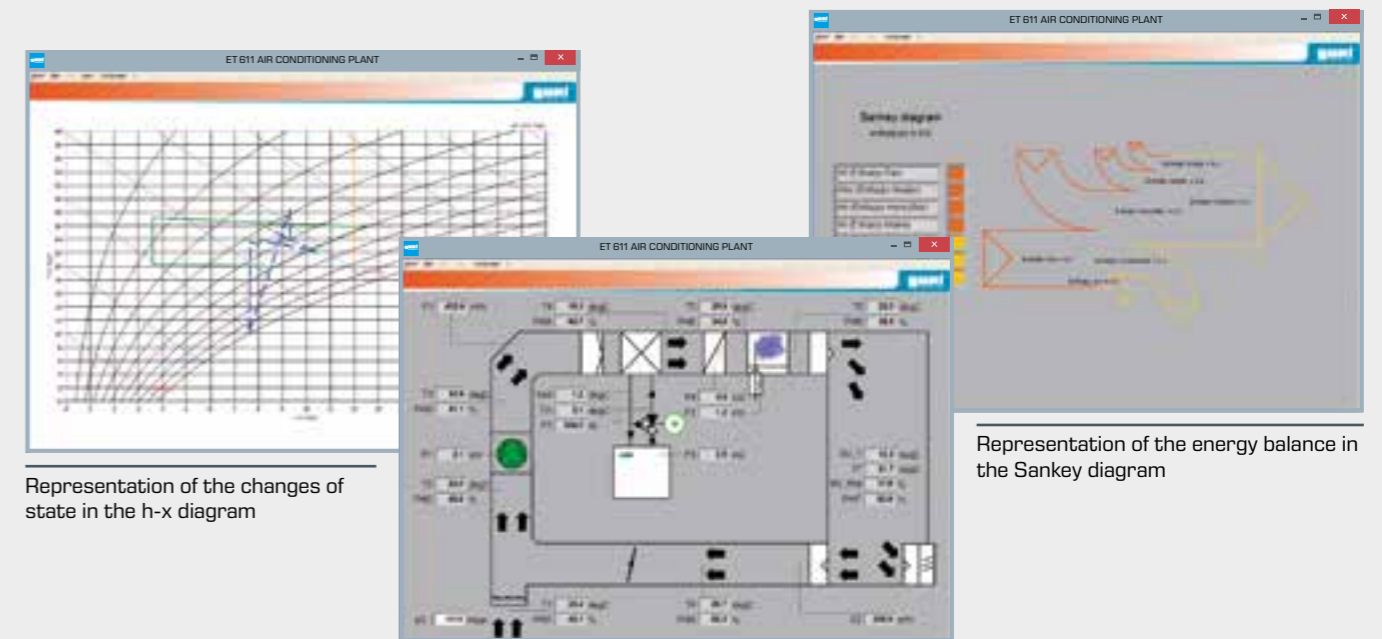


Mixing



The instructional material clearly demonstrates at which locations of the air conditioning system the different changes of the state of the air take place. The manual measurement only indicates the stationary states. In addition to time curves the software enables the dynamic display of the measured

values in the h-x diagram to better monitor transient processes. The task of the trainee is to read the measured values at the relevant locations of the air conditioning system, enter these data correctly into the h-x diagram and analyse them.



Representation of the changes of state in the h-x diagram

Representation of the energy balance in the Sankey diagram

Process schematic with online representation of the data



## ET 611

### Air conditioning system with chamber



#### Description

- real air conditioning system with water chiller and climatic chamber
- chamber for comfort investigations, suitable for test persons to be inside
- air conditioning controller with integrated PLC

Comfort is of great importance in the air conditioning of rooms and buildings. The comfort depends on the temperature, the relative humidity and the flow velocity of the air. According to DIN 13779 a so-called "comfort zone" has been defined which specifies the values an air conditioning system should achieve.

ET 611 is a full air conditioning system with comprehensive test options. The effect of the air humidity and temperature on the comfort is examined. The system has a climatic chamber designed for test persons to be inside. This allows the trainee to study the effect of different system operating states on his own well-being. The components used, such as radial fan, electric air heater, steam humidifier and water chiller are all used in commercial air conditioning and ventilation technology. A PLC air conditioning controller monitors and controls all functions. In addition to the automatic operation it also enables the manual operation of the system.

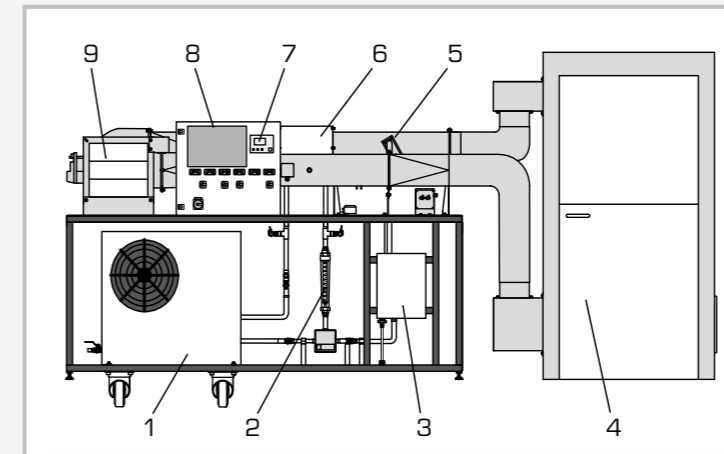
Sensors record air humidity, temperature, power, flow rate, and flow velocity. The measured values can be read on digital displays. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is included.

#### Learning objectives/experiments

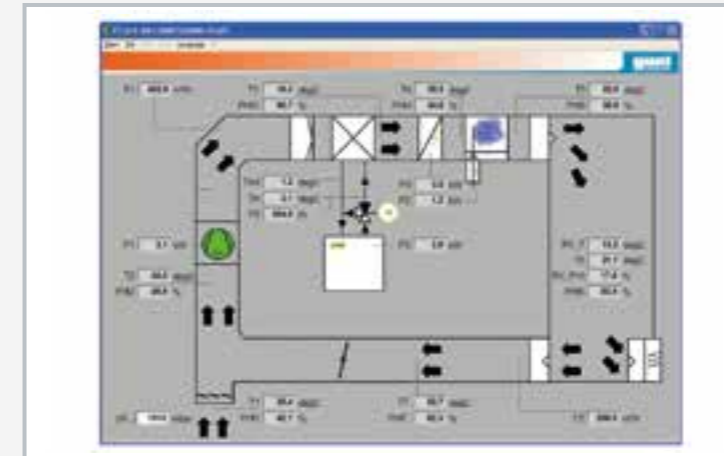
- design, operation and operating behaviour of a real air conditioning system
- recirculating and outer air operation
- changes of state in the h-x diagram for humid air: heating, cooling, humidifying or dehumidifying, mixing
- application of the mixing line
- comfort studies, limit of comfortable humidity
- energy balance in the Sankey diagram
- PLC air conditioning controller
  - ▶ humidity control
  - ▶ temperature control
  - ▶ manual or automatic operation

## ET 611

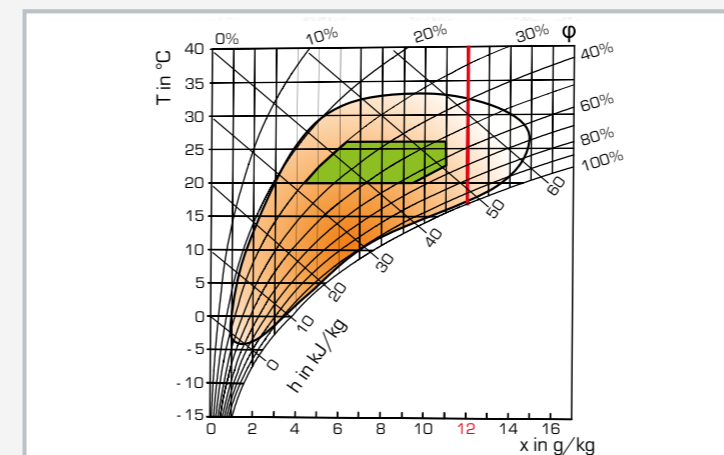
### Air conditioning system with chamber



1 water chiller, 2 flow meter, 3 steam humidifier, 4 climatic chamber, 5 steam distributor (humidifier), 6 air cooler, 7 PLC air conditioning controller, 8 switch cabinet with process schematic, displays and controls, 9 outer air inlet with fan; covered: air heater



Software screenshot: process schematic



h-x diagram with comfort zone (green) and limit of comfortable humidity (red;  $x=12\text{g/kg}$ ); h enthalpy, x absolute air humidity, T temperature,  $\phi$  relative air humidity

#### Specification

- [1] air conditioning system with chamber for conditioning and air technology investigations
- [2] chamber suitable for test persons to be inside
- [3] PLC air conditioning controller, manual and automatic operation
- [4] industrial components: fans, air-cooled water chiller, air cooler, air heater, steam humidifier
- [5] digital displays for air temperature, air humidity, air velocity, temperature of the cold water, power
- [6] GUNT software for data acquisition via USB under Windows 7, 8.1, 10
- [7] refrigerant: R410A, GWP: 2088

#### Technical data

PLC air conditioning controller

- 17 universal inputs, 4 analogue outputs, 10 switching outputs

Radial fan

- power consumption: 0,75kW
- max. flow rate:  $39\text{m}^3/\text{min}$
- pressure difference: 450Pa

Air heater: 6x 250W

Steam humidifier

- steam capacity: 6kg/h
- power consumption: 4,5kW

Water chiller

- power consumption: 2,1kW
- refrigeration capacity: 6,2kW at  $32^\circ\text{C}$ ,  $\Delta T=5\text{K}$
- fan, volumetric air flow rate:  $3500\text{m}^3/\text{h}$

Air cooler, capacity: 4,84kW

Refrigerant

- R410A, GWP: 2088, filling volume: 1,3kg,  $\text{CO}_2$ -equivalent: 2,7t

Measuring ranges

- flow rate: 0...1500L/h (water)
- temperature: 7x 0...50°C (air), 2x 0...50°C (water)
- humidity: 7x 10...90%
- flow velocity: 2x 0...20m/s (air)
- power: 2x 0...6kW, 2x 0...1,5kW

400V, 50Hz, 3 phases

400V, 60Hz, 3 phases; 230V, 60Hz, 3 phases

UL/CSA optional

LxWxH: 2700x1480x1450mm (system)

LxWxH: 1550x1270x2250mm (chamber)

LxWxH: 1400x600x900mm (water chiller)

Total weight: approx. 830kg

#### Required for operation

water connection, drain

PC with Windows recommended

#### Scope of delivery

- 1 trainer, filled with refrigerant
- 1 GUNT software CD + USB cable
- 1 set of instructional material

## ET 450

### Vehicle air conditioning



#### Learning objectives/experiments

- principle of operation, design and handling of a vehicle air conditioning system
- detection of typical faults and repair of a faulty air conditioning system
  - ▶ simulation of 8 system faults
- typical components of a refrigeration system
- refrigeration circuit as thermodynamic cycle
  - ▶ log p-h diagram
  - ▶ determine the coefficient of performance of the system
  - ▶ determine the compressor pressure ratio

#### Description

- **typical vehicle air conditioning system for cooling the vehicle interior**
- **use of components from automotive technology**
- **simulation of eight system faults**

Vehicle air conditioning systems are used to cool down the vehicle interior. They usually work on the basis of the recirculating air principle and aspirate the air to be cooled from the interior. The cold air generated in the air conditioning system is transported by a fan into the vehicle interior.

The refrigeration circuit to generate the cold air in the trainer ET 450 includes a compressor, a condenser with fan and an evaporator as air cooler with three-stage fan and expansion valve.

All system components are typical elements used in vehicle technology. The air cooler with three-stage fan is e.g. equipped with typical air vents for the vehicle interior. This achieves a close proximity to practice.

The trainer operates with the 12VDC supply common in vehicles. Even the ignition lock function has been implemented to switch on the system. An electric motor drives the compressor via a V-belt and a magnetic coupling. The speed of the motor and thus the compressor is variably adjustable by a frequency converter to simulate the drive via the vehicle engine.

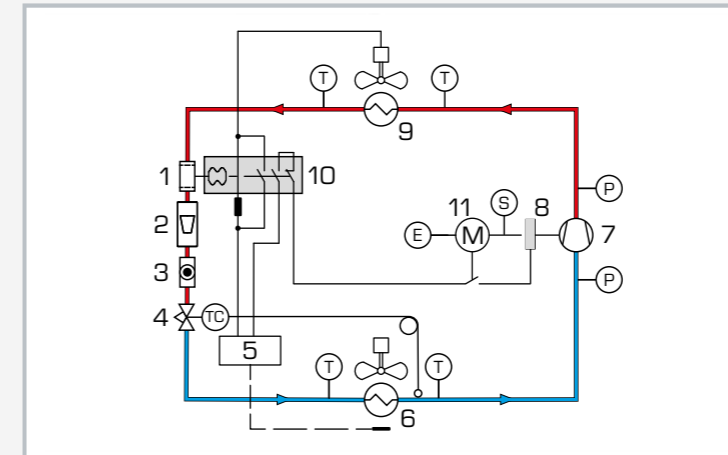
Important characteristic variables, such as pressure, temperature, flow rate and the power consumption of the compressor are displayed. As a particularity eight connectable faults have been installed. The system is particularly suited for the training of motor mechanics.

## ET 450

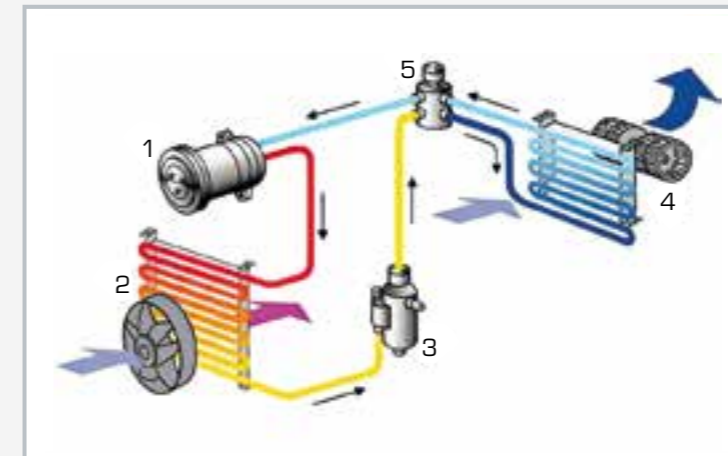
### Vehicle air conditioning



1 box with fault buttons, 2 ignition key, 3 air cooler with three-stage fan, 4 switch cabinet, 5 flow meter, 6 compressor, 7 condenser with fan, 8 electric motor



1 filter/drier, 2 flow meter, 3 sight glass, 4 expansion valve, 5 switch cabinet, 6 evaporator, 7 compressor, 8 magnetic coupling, 9 condenser, 10 combined pressure switch, 11 motor; red: high pressure, blue: low pressure



Refrigeration circuit: 1 compressor, 2 condenser with fan, 3 filter/drier, 4 air cooler with three-stage fan, 5 expansion valve; red: high pressure gaseous, yellow: high pressure liquid; blue: low pressure liquid, light blue: low pressure gaseous

#### Specification

- [1] investigation of a typical vehicle air conditioning system for cooling the vehicle interior
- [2] compression refrigeration system with compressor, condenser, filter/drier, expansion valve and evaporator
- [3] electric motor with variable speed as compressor drive
- [4] condenser with fan
- [5] evaporator as air cooler with three-stage fan
- [6] compressor drive via V-belt and magnetic coupling
- [7] simulation of 8 faults via buttons in the connectable box
- [8] system is switched on via ignition lock
- [9] display of temperatures, pressures (refrigerant), flow rate (refrigerant), pick-up current, speed
- [10] refrigerant R513A, GWP: 631
- [11] air conditioning system voltage supply: 12VDC

#### Technical data

##### Electric motor

- rotary current motor
- variable speed via frequency converter: 500...3000min<sup>-1</sup>
- power: 4kW at 3000min<sup>-1</sup>

##### Axial piston compressor

- refrigeration capacity: approx. 3kW at 3000min<sup>-1</sup>

Condenser: capacity: 6,6kW

Evaporator: capacity: 5,3kW

##### Refrigerant

- R513A
- GWP: 631
- filling volume: 800g
- CO<sub>2</sub>-equivalent: 0,5t

##### Measuring ranges

- temperature: 4x -100...100°C
- flow rate: (R513A): 10...95L/h
- pressure: -1...9bar / -1...24bar
- speed: 0...3000min<sup>-1</sup>
- current: 0...10A

400V, 50Hz, 3 phases

400V, 60Hz, 3 phases; 230V, 60Hz, 3 phases

UL/CSA optional

LxWxH: 1210x800x1520mm

Weight: approx. 185kg

#### Scope of delivery

- 1 trainer filled with refrigerant
- 1 set of instructional material



## ET 630

### Split system air conditioner



2E

#### Description

- modern air conditioning unit with heat pump function: cooling and heating
- six different operating modes

Split system air conditioners are used to cool, dehumidify and also heat rooms. They consist of an inner and outer unit.

In the inner unit there is a heat exchanger with fan working as an evaporator in the refrigeration circuit during cooling operation. During heating operation it works as a condenser. The outer unit contains a compressor, another heat exchanger, expansion element (e.g. capillary tube) and an element enabling the change-over from cooling to heating operation. In cooling operation the evaporating refrigerant in the heat exchanger of the inner unit withdraws heat from the room air. In the outer unit the heat in the heat exchanger is discharged to the ambient air by condensing the refrigerant. During heating operation the heat transport is reversed.

ET 630 includes a dividing wall onto whose front and rear panel a modern split system air conditioner has been mounted. To better demonstrate its operation, an additional two pressure displays are available for the refrigerant. The operating mode, fan stage of the inner unit (fan operation) and desired room temperature are selected via a remote control. During automatic operation the actual room temperature is recorded and an operating mode automatically selected to achieve the specified room temperature.

In addition the following functions are set at the remote control: Timer for the regular switching on and off, single remaining operating time in hours (sleep mode; suitable for energy-saving operation) and horizontal position of the lamella at the air outlet for air distribution (swing mode; fixed or movable).

#### Learning objectives/experiments

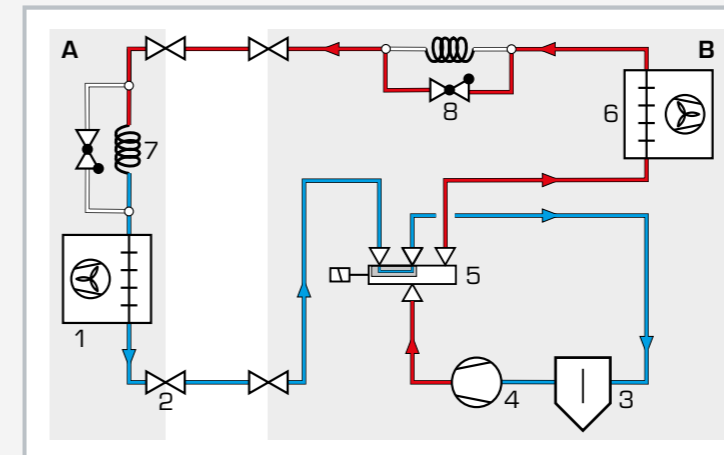
- design and operation of a split system air conditioner
- 6 operating modes
  - ▶ cooling
  - ▶ dehumidifying (slight cooling)
  - ▶ heating
  - ▶ ventilation (only the fan of the inner unit)
  - ▶ automatic (operating mode suitable for the room temperature)
  - ▶ test of cooling function
- 3 additional functions
  - ▶ "sleep" (switch-off after several hours)
  - ▶ "swing" (air outlet lamella position)
  - ▶ timer for switching on and off
- remote control functions

## ET 630

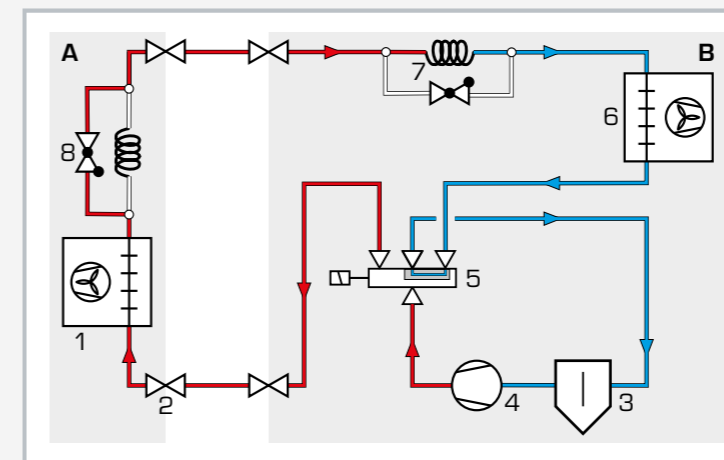
### Split system air conditioner



1 air inlet inner unit, 2 air outlet inner unit, 3 switch cabinet, 4 manometer, 5 remote control, 6 outer unit, 7 dividing wall



Exemplary process schematic: cooling process  
inner unit (A) and outer unit (B)  
1 heat exchanger inner unit, 2 valve, 3 liquid separator, 4 compressor, 5 reversing valve, 6 heat exchanger outer unit, 7 capillary tube, 8 non-return valve; red arrow: heating, blue arrow: cooling



Exemplary process schematic: heating process  
inner unit (A) and outer unit (B)  
1 heat exchanger inner unit, 2 valve, 3 liquid separator, 4 compressor, 5 reversing valve, 6 heat exchanger outer unit, 7 capillary tube, 8 non-return valve; red arrow: heating, blue arrow: cooling

#### Specification

- [1] trainer from the GUNT practical series for the training of mechatronics engineers for refrigeration design and operation of a commercial split system air conditioner
- [2] illustration of the split principle using a dividing wall
- [3] 6 different operating modes: heating, cooling, dehumidifying, ventilation, automatic, test
- [4] 3 additional functions configurable via remote control: sleep, swing, timer
- [5] 2 refrigerant manometers indicate the low and high pressure of the compressor
- [6] refrigerant R32, GWP: 675
- [7] battery operated remote control

#### Technical data

Split system air conditioner

- power consumption: approx. 1,2kW at 24/35°C
- cooling capacity: approx. 3,5kW at 24/35°C
- max. volumetric air flow rate (inner unit): approx. 420m<sup>3</sup>/h
- dehumidification (inner unit): approx. 0,8L/h
- timer: 24h

Refrigerant

- R32
- GWP: 675
- filling volume: 700g
- CO<sub>2</sub>-equivalent: 0,5t

Measuring ranges

- pressure: 2x -1...40bar

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 1000x1000x1500mm  
Weight: approx. 80kg

#### Scope of delivery

- 1 split system air conditioner
- 1 remote control
- 1 manual

## Ventilation systems and their components

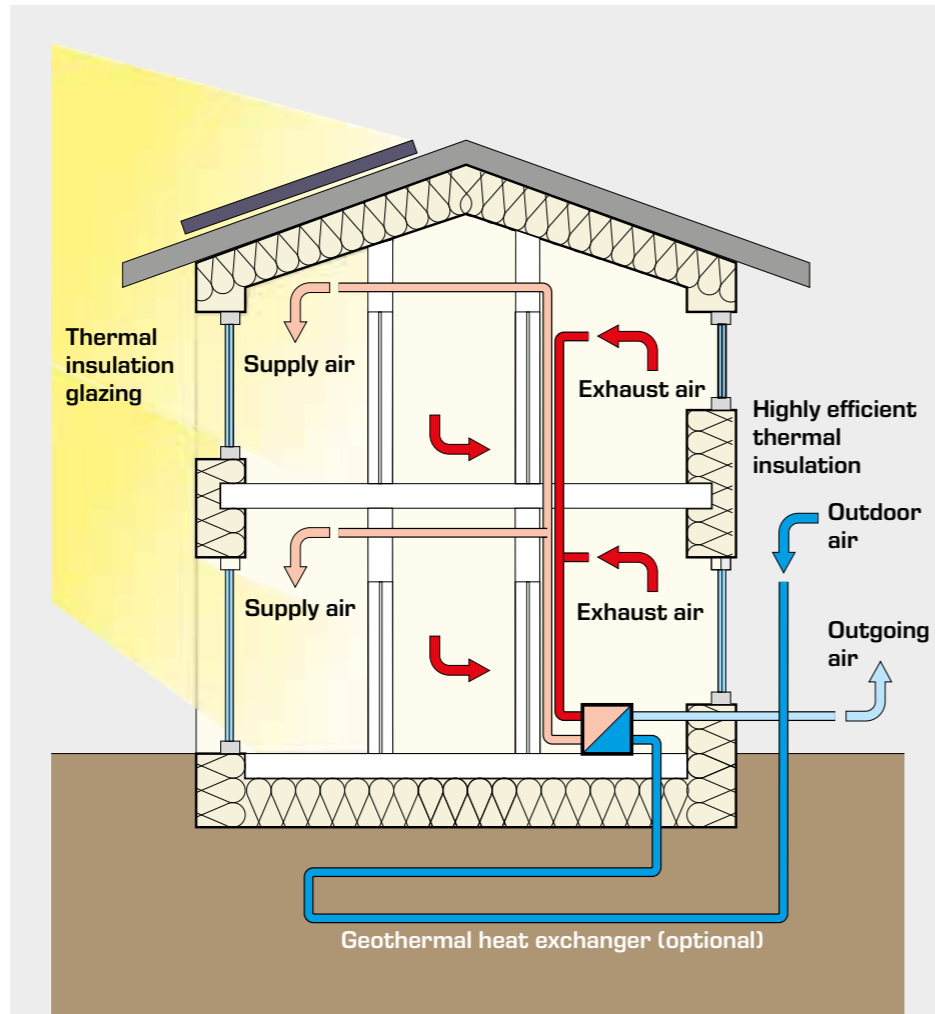
Ventilation systems ensure the change of air in residential, office and equipment rooms.

Ventilation systems are not only concerned with air supply and exhaust, but also with the consideration of **thermal energy**: sophisticated ventilation systems can transfer the heat of the outflowing air to the incoming air, so that hardly any thermal energy leaves the system.

There are basically three types of system:

1. **exhaust air system**: the "used" air from the building is expelled to the outside (outgoing air)
2. **ventilation system**: in addition to the exhaust air system, a supply system supplies fresh air to the living areas
3. **different techniques** that target the saving of heating energy, e.g. via heat recovery or geothermal heat exchangers

These systems are grouped together under the term controlled residential ventilation. Non-controlled ventilation of living space, on the other hand, is the free ventilation of living space by means of window ventilation, joint ventilation or shaft ventilation.



Ventilation with heat recovery

- **outside air**: air drawn in from the environment,
- **outgoing air**: air released into the environment,
- **supply air**: air entering a room or facility after it has been treated, e.g. by filtering or heating
- **exhaust air**: air leaving a room

### Components and their roles in ventilation systems

The concept of controlled domestic ventilation works by means of an intelligent interaction of various technical components such as fans/ventilators, heat exchangers, filters, control devices and air distribution. These components are parts of ventilation systems.

Ventilation systems are divided into

- **central systems**: one system controls the ventilation of the entire living space
- **decentralised systems**: several systems used specifically in individual rooms, e.g. kitchen, bathroom, etc.

GUNT offers various experimental units for the investigation of individual components and complete ventilation systems.

Component	Learning objectives	GUNT product
<b>Fans</b> intake and discharge of outside and outgoing air	<ul style="list-style-type: none"> <li>■ familiarisation with operating behaviour and characteristic variables of fans</li> <li>■ effect of different impeller shapes on fan characteristic and efficiency</li> <li>■ effect of the impeller speed on flow rate and pressure</li> </ul>	HM 280 Experiments with a radial fan HM 282 Experiments with an axial fan HM 210 Characteristic variables of a radial fan HL 710 Air duct systems HL 720 Ventilation system
<b>Heat exchangers</b> transfer of heat from the exhaust air to the supply air for heat recovery	<ul style="list-style-type: none"> <li>■ investigation of convective heat transfer</li> <li>■ effect of different pipe surfaces on temperature change of the air</li> </ul>	WL 312 Heat transfer in air flow
<b>Tubes, pipe bends, angles, distributors guide</b> direct and distribute air flows	<ul style="list-style-type: none"> <li>■ determine pressure losses due to friction</li> <li>■ measure air flow and velocity</li> </ul>	HM 220 Air flow experimental plant HM 240 Principles of air flow
<b>Throttle valves, shut-off butterfly valves</b> adjustment of air volume flows	<ul style="list-style-type: none"> <li>■ calculation of the volumetric flow rate and the flow velocity</li> </ul>	HM 220 Air flow experimental plant HL 710 Air duct systems HL 720 Ventilation system
<b>Filters, air distribution and diffusers, fire protection, sound absorbers</b>	<ul style="list-style-type: none"> <li>■ familiarisation with design and function</li> <li>■ measure pressure losses</li> </ul>	HL 710 Air duct systems HL 720 Ventilation system





## HM 280

### Experiments with a radial fan



#### Learning objectives/experiments

- operating behaviour and characteristic variables of a radial fan
- recording the fan characteristic (pressure difference as a function of the flow rate)
- effect of the rotor speed on the pressure
- effect of the rotor speed on the flow rate
- effect of different blade shapes on the fan characteristic and efficiency
- determination of hydraulic power output and efficiencies

#### Description

- **2 interchangeable rotors**
- **transparent delivery pipe and intake pipe**
- **GUNT software for data acquisition, visualisation and operation**
- **part of the GUNT-Labline fluid energy machines**

Radial fans are used to transport gases with non-excessive pressure differences. The medium is drawn in axially to the drive shaft of the radial fan and is deflected by 90° by the rotation of the rotor and discharged radially.

The experimental unit provides the basic experiments to get to know the operating behaviour and the most important characteristic variables of radial fans.

HM 280 features a radial fan with variable speed via a frequency converter, an intake pipe and a delivery pipe. The transparent intake pipe is fitted with flow straightener to calm the air. This enables precise measurements even with heavily reduced operation. The air flow is adjusted by a throttle valve at the end of the delivery pipe.

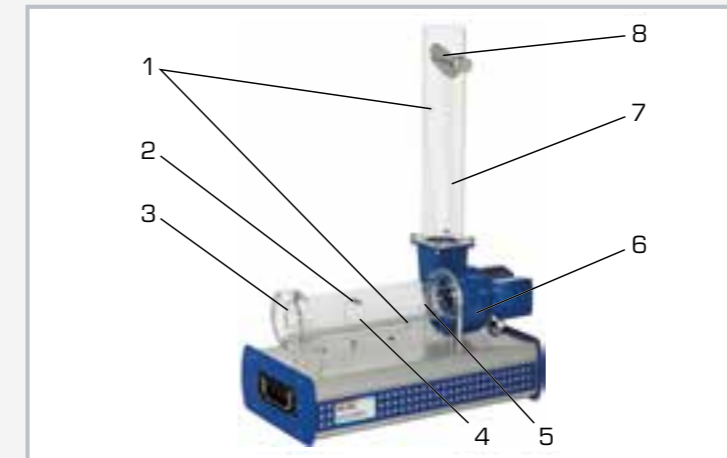
To demonstrate the effect of different blade shapes two rotors are included in the scope of delivery: one rotor with forward curved blades and one with backward curved blades. The rotors are easily interchangeable.

The experimental unit is fitted with sensors for pressure and temperature. The flow rate is determined via differential pressure measurement on the intake nozzle. The microprocessor-based measuring technique is well protected in the housing. The measured values are transmitted directly to a PC via USB where they can be analysed using the software included.

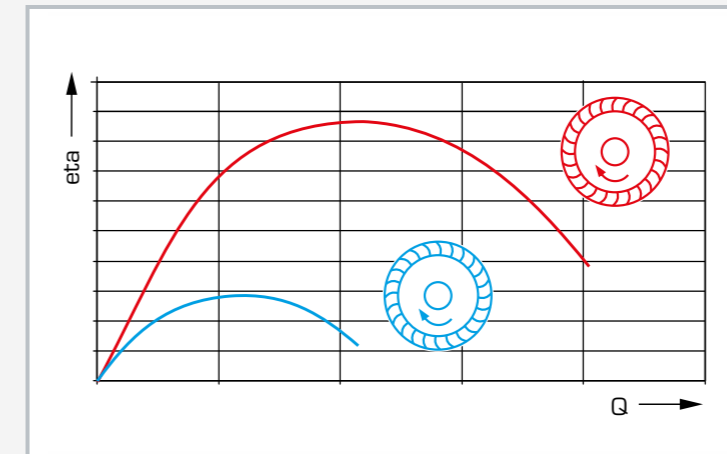
All the advantages of software-supported experiments with operation and evaluation are offered by the GUNT software and the microprocessor.

## HM 280

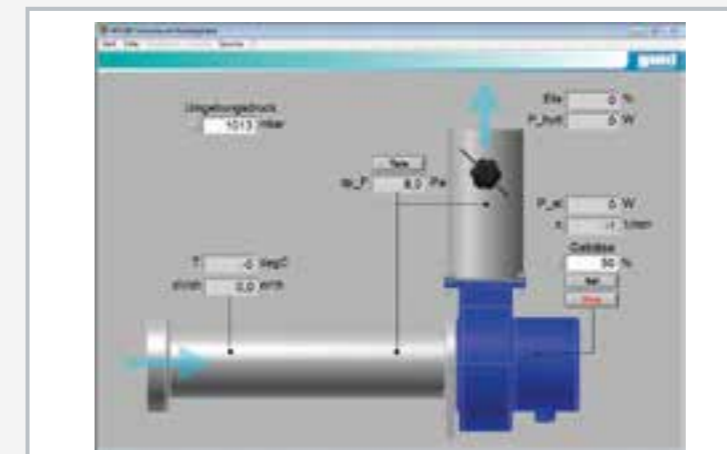
### Experiments with a radial fan



1 measuring points for pressure, 2 measuring point for temperature, 3 inlet nozzle with measuring point for static pressure, 4 intake pipe, 5 guide plates, 6 radial fan with drive motor, 7 delivery pipe, 8 throttle valve



Efficiencies in comparison; red: rotor with forward curved blades, blue: rotor with backward curved blades;  $\eta$  efficiency,  $Q$  débit



Operating interface of the powerful software

#### Specification

- [1] functioning and operating behaviour of a radial fan
- [2] radial fan with 3-phase AC motor
- [3] variable speed via frequency converter
- [4] transparent intake and delivery pipes
- [5] throttle valve to adjust the air flow in the delivery pipe
- [6] interchangeable rotors: 1 rotor with forward curved blades and 1 rotor with backward curved blades
- [7] determination of flow rate via intake nozzle
- [8] display of differential pressure, flow rate, speed, electrical power consumption and hydraulic power output, temperature and efficiency
- [9] due to integrated microprocessor-based instrumentation no additional devices with error-prone wiring are required
- [10] display and evaluation of the measured values as well as operation of the unit via software
- [11] GUNT software with control functions and data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

##### Intake pipe

- inner diameter: 90mm
- length: 430mm

##### Delivery pipe

- inner diameter: 100mm
- length: 530mm

##### Radial fan

- power consumption: 110W
- nominal speed: 2800min<sup>-1</sup>
- max. volumetric flow rate: 480m<sup>3</sup>/h
- max. pressure difference: 300Pa

##### Measuring ranges

- differential pressure: 0...1800Pa
- flow rate: 0...1000m<sup>3</sup>/h
- temperature: 0...100°C
- speed: 0...3300min<sup>-1</sup>
- el. power consumption: 0...250W

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 670x340x940mm  
Weight: approx. 20kg

#### Required for operation

PC with Windows

#### Scope of delivery

- 1 experimental unit
- 2 rotors
- 1 GUNT software CD + USB cable
- 1 set of instructional material

## HM 282

### Experiments with an axial fan



#### Description

- illustrative model of an axial fan
- transparent delivery pipe and intake pipe
- GUNT software for data acquisition, visualisation and operation
- part of the GUNT-Labline fluid energy machines

Axial fans are used to transport gases. The medium to be transported is drawn in axially to the drive shaft of the axial fan by the rotation of the rotor. The medium flows through the rotor and is discharged axially behind the rotor.

The experimental unit provides the basic experiments to get to know the operating behaviour and the important characteristic variables of axial fans.

HM 282 features an axial fan with variable speed via an integrated controller, an intake pipe and a delivery pipe. The transparent intake and delivery pipes are fitted with guide plates for flow guidance.

A flow straightener in the intake pipe serves to calm the air. This enables precise measurements even with heavily reduced operation. The air flow is adjusted by a throttle valve at the end of the delivery pipe.

The experimental unit is fitted with sensors for pressure and temperature. The flow rate is determined via differential pressure measurement on the intake nozzle. The microprocessor-based measuring technique is well protected in the housing. The measured values are transmitted directly to a PC via USB where they can be analysed using the software included.

All the advantages of software-supported experiments with operation and evaluation are offered by the GUNT software and the microprocessor.

#### Learning objectives/experiments

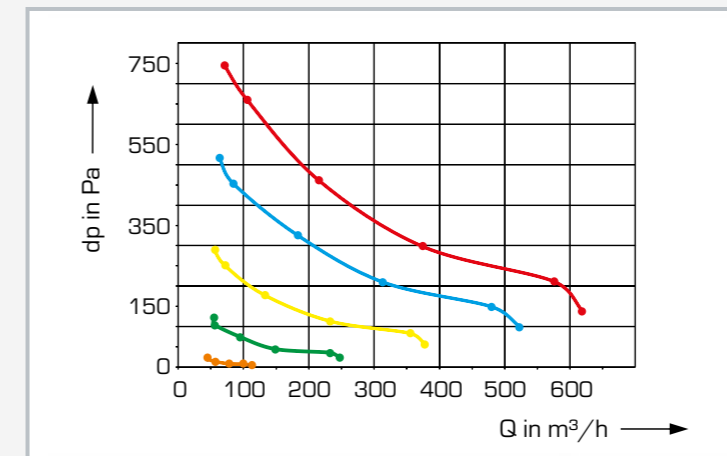
- operating behaviour and characteristic variables of an axial fan
- recording the fan characteristic (differential pressure as a function of the flow rate)
- effect of the rotor speed on the pressure
- effect of the rotor speed on the flow rate
- stall
- determination of hydraulic power output and efficiencies

## HM 282

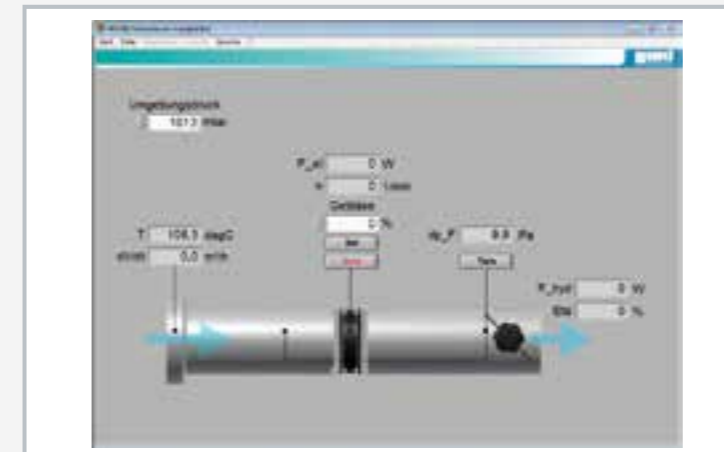
### Experiments with an axial fan



1 guide plates for flow guidance, 2 measuring point for temperature, 3 intake nozzle at intake pipe, 4 measuring point for pressure (to determine the flow rate), 5 flow straightener, 6 measuring points for pressure, 7 delivery pipe, 8 throttle valve, 9 axial fan



Characteristic curves for an axial fan: differential pressure dependent on the flow rate at different speeds;  $p_d$  differential pressure,  $Q$  flow rate



Operating interface of the powerful software

#### Specification

- [1] functioning and operating behaviour of an axial fan
- [2] axial fan with electronically commutated drive motor
- [3] variable speed via integrated controller
- [4] transparent intake and delivery pipes
- [5] throttle valve to adjust the air flow in the delivery pipe
- [6] determination of flow rate via intake nozzle
- [7] display of differential pressure, flow rate, speed, electrical power consumption and hydraulic power output, temperature and efficiency
- [8] due to integrated microprocessor-based instrumentation no additional devices with error-prone wiring are required
- [9] display and evaluation of the measured values as well as operation of the unit via software
- [10] GUNT software with control functions and data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

##### Intake pipe

- inner diameter: 110mm
- length: 275mm

##### Delivery pipe

- inner diameter: 110mm
- length: 310mm

##### Axial fan

- power consumption: 90W
- nominal speed: 9500min<sup>-1</sup>
- max. volumetric flow rate: approx. 600m<sup>3</sup>/h
- max. pressure difference: approx. 700Pa

##### Measuring ranges

- differential pressure: 0...1800Pa
- flow rate: 0...1000m<sup>3</sup>/h
- temperature: 0...100°C
- speed: 0...9999min<sup>-1</sup>
- power consumption: 0...500W

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 670x340x370mm  
Weight: approx. 15kg

#### Required for operation

PC with Windows

#### Scope of delivery

- 1 experimental unit
- 1 GUNT software CD + USB cable
- 1 set of instructional material



## HM 210

### Characteristic variables of a radial fan



#### Learning objectives/experiments

- setup and principle of a radial fan
- plotting fan and system characteristics
- flow rate measurement methods based on the differential pressure method using:
  - ▶ iris diaphragm
  - ▶ Venturi nozzle
  - ▶ comparison of both measurement methods
- familiarisation with various differential pressure gauges
- determining efficiency

#### Description

- investigation of a radial fan and determination of characteristic variables
- determination of flow rate via iris diaphragm or Venturi nozzle
- different liquid column manometers measure the differential pressure with varying accuracy

Fans are key components of ventilation systems, providing ventilation, cooling, drying or pneumatic transport. For optimum design of such systems, it is important to know the characteristic variables of a fan.

HM 210 investigates a radial fan. This trainer determines the interdependencies between the head and flow rate as well as the influence of the fan speed on the head and flow rate.

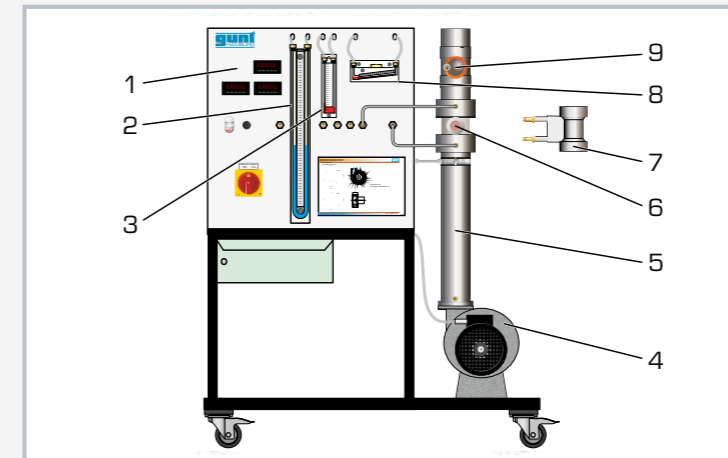
The radial fan aspirates the air in axially from the surrounding environment. The high-speed rotating rotor accelerates the air outwards. The high velocity at the outlet from the rotor is partially converted into pressure energy in the spiral housing. The vertical pipe section is connected to the spiral housing. A Venturi nozzle to measure the flow rate and a throttle valve to adjust the flow rate are inserted into the pipe section. An iris diaphragm can optionally be used. Its variable cross-section enables simultaneous adjustment and determination of the flow rate. The effective pressures to calculate the flow rate are read from liquid column manometers. The head of the radial fan is likewise measured by liquid column manometers. U-tube manometer, single tube manometer and inclined tube manometer with graduated measuring ranges are available.

A frequency converter is used to adjust the fan speed. The speed, torque and electric power capacity are digitally displayed. This permits energy analyses, and enables the efficiency of the fan to be determined.

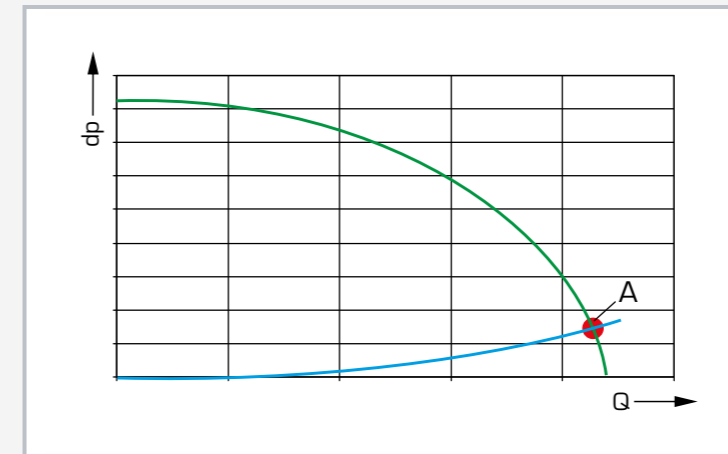
The system characteristic curve is determined by recording the characteristic variables at a constant throttle setting but at variable speed. The interaction of the fan and system at the operation point – the so-called system dimensioning – is investigated.

## HM 210

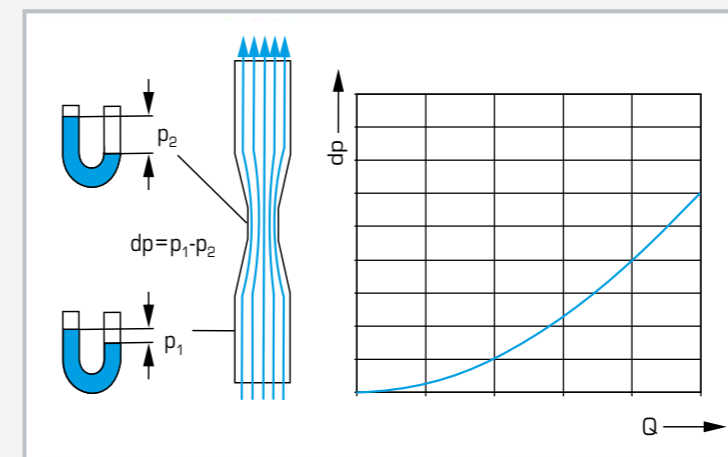
### Characteristic variables of a radial fan



1 switch cabinet with display elements, 2 U-tube manometer, 3 single tube manometer, 4 radial fan with air intake, 5 pipe section, 6 iris diaphragm, 7 Venturi nozzle, 8 inclined tube manometer, 9 throttle valve



Green: fan characteristic; blue: system characteristic; A, red: system operation point



Air flow in the Venturi nozzle;  $p_1$ ,  $p_2$  pressure measuring points; graph: differential pressure  $dp$  as function of flow rate  $Q$

#### Specification

- [1] radial fan as turbomachine
- [2] iris diaphragm or Venturi nozzle to determine flow rate via the differential pressure
- [3] speed adjustment by frequency converter
- [4] U-tube manometer, single tube manometer and inclined tube manometer measure the differential pressure
- [5] air flow rate in pipe section adjustable by throttle valve or iris diaphragm
- [6] speed, torque and electric power capacity digitally displayed

#### Technical data

##### Radial fan

- max. power consumption: 370W
- max. pressure difference: 860Pa
- max. volumetric flow rate:  $4\text{m}^3/\text{min}$
- nominal speed:  $3000\text{min}^{-1}$
- speed range:  $1000\text{...}3000\text{min}^{-1}$

##### Iris diaphragm adjustable in 6 stages

- diameter: 40...70mm
- $k=1,8\text{...}7,8$

##### Venturi nozzle

- air inlet diameter: 100mm
- pipe neck diameter: 80mm
- $k=7,32$

##### Measuring ranges

- differential pressure:
  - ▶ 30...0...30mbar (U-tube manometer)
  - ▶ 0...15mbar (single tube manometer)
  - ▶ 0...50Pa (inclined tube manometer)

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 230V, 60Hz, 3 phases  
UL/CSA optional  
LxWxH: 1300x720x1640mm  
Weight: approx. 123kg

#### Scope of delivery

- 1 trainer
- 1 Venturi nozzle
- 1 iris diaphragm
- 1 set of accessories
- 1 set of instructional material

## HM 220 Air flow experimental plant








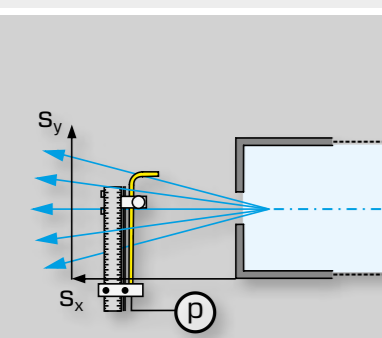
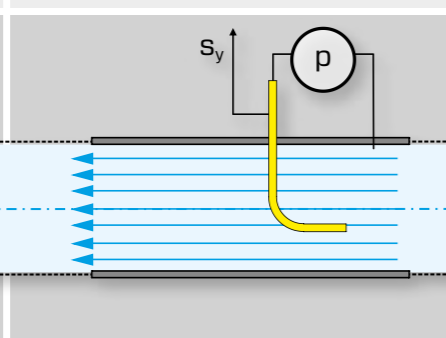
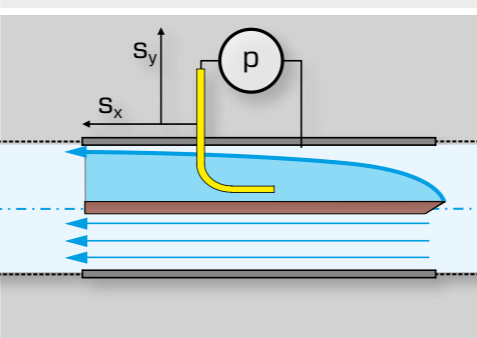
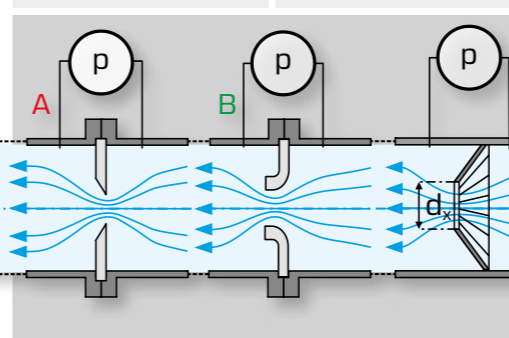
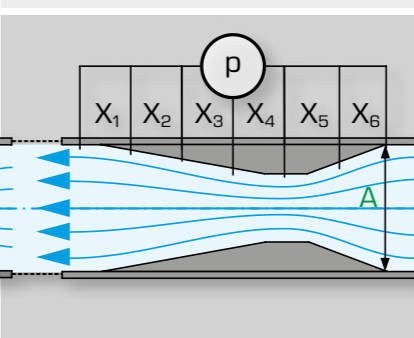
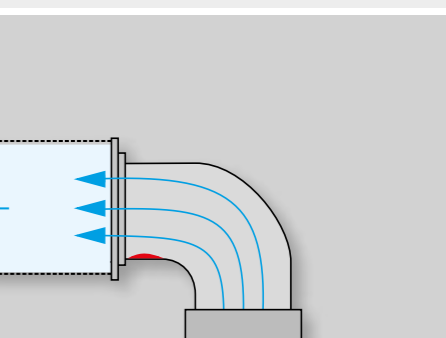
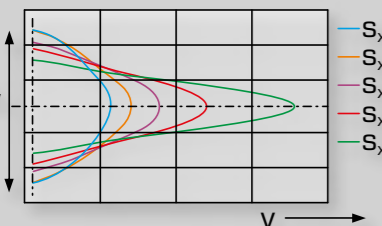
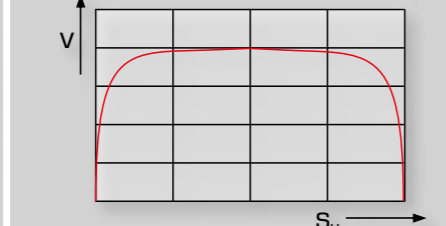
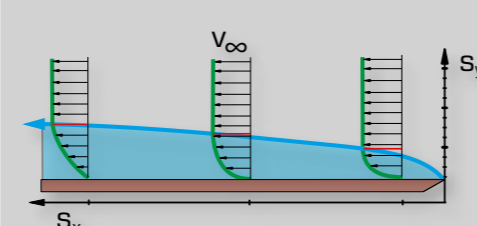
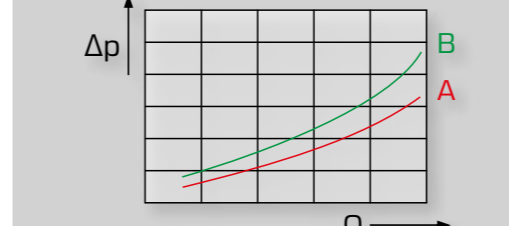
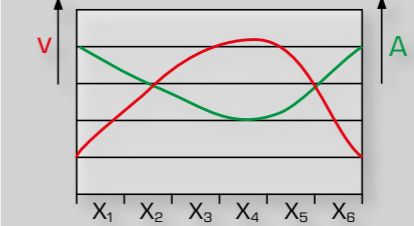
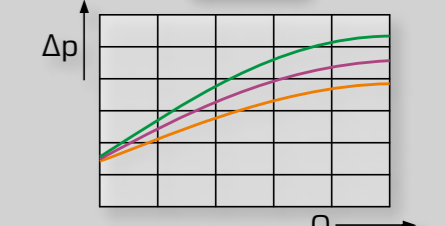
In practice, when designing turbomachines or pipe systems it is important to know the flow course and the corresponding pressure and velocity distribution. The experimental plant HM 220, together with the extensive range of accessories, offers a variety of fluid mechanics experiments.

The illustrative experiments provide an in-depth understanding and knowledge of the physical laws of steady flows. The experiments impart knowledge about determining the flow course, pressure distribution and velocity profiles.



- use of various pipe elements
- adjustment of the air flow through a frequency converter
- up to 20 pressure measuring points
- calculation of the volumetric flow rate and the flow velocity from the measurement results
- representation of system characteristics
- recording the different velocity profiles in both the free jet and the pipe cross-section
- representation of the increase in pressure loss due to pipe friction at different pipe elements
- optimal formation of the air flow due to a low-loss inlet and the large length of the pipe section

The HM 220 experimental plant allows an extensive range of experiments with the varied accessories:

						
Measuring and investigating the air flow via a Pitot tube	Boundary layer measurements on a flat plate in longitudinal flow via a Pitot tube (HM 220.02 accessory)	Change in volumetric flow rate	Measurement and investigation of air flow			
In a free jet	Within a pipe	In an orifice plate or nozzle	In an iris diaphragm	Via a Venturi tube (accessory HM 220.01)	In different pipe fittings	
						
						
Velocity profile $v$ in the air outlet jet	Velocity profile $v$ along the pipe cross-section $s_y$	Velocity distribution (green) and boundary layer thickness (blue)	Comparison of the change in volumetric flow rate $Q$ through an orifice plate <b>A</b> or nozzle <b>B</b>	Velocity profile (red) along the contraction in cross-section (green)	Investigation of pipe friction losses in pipe bend (green), segment bend (purple), pipe angle (orange)	



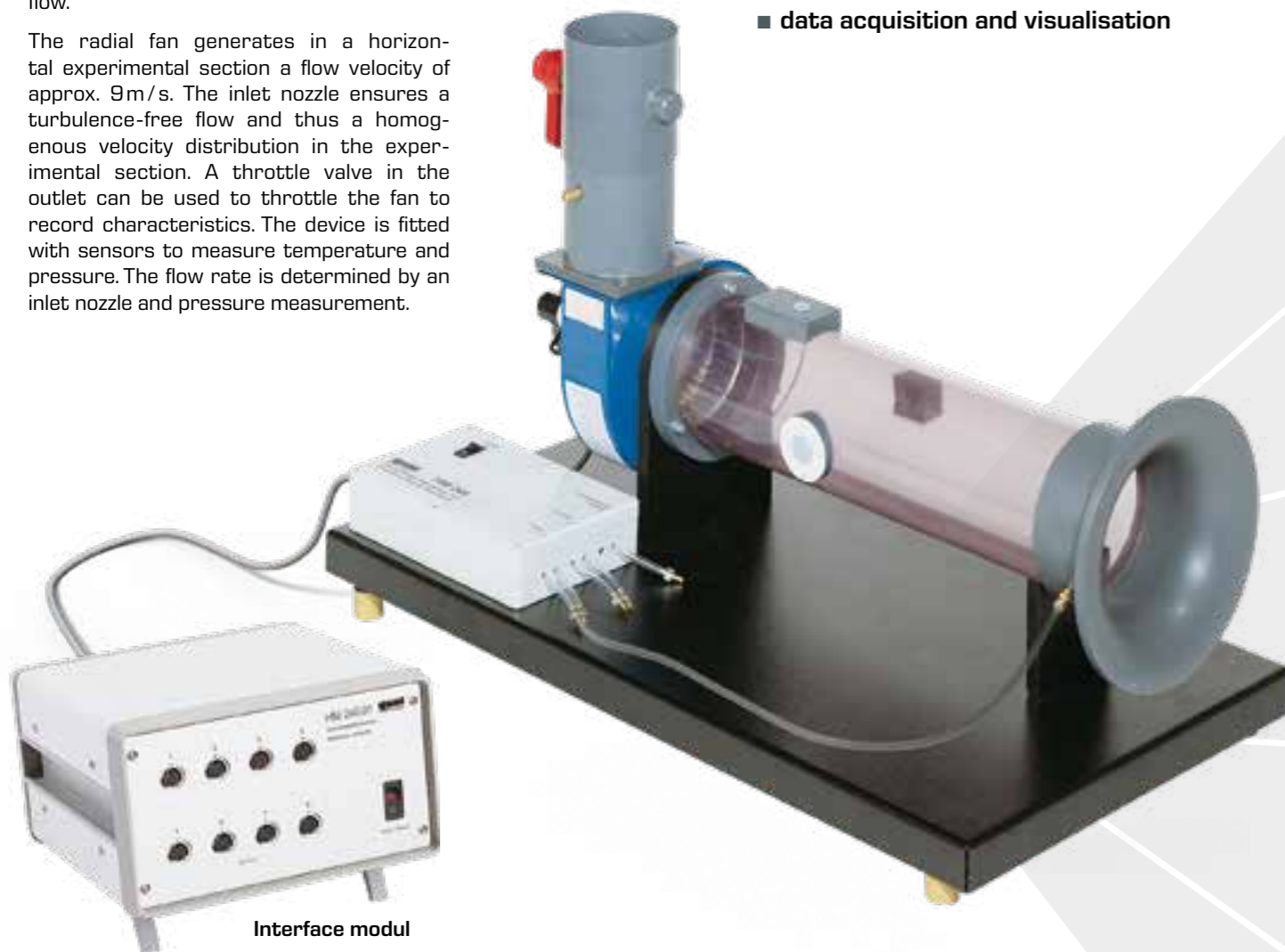


## HM 240 Principles of air flow

The HM 240 base unit allows experiments on a radial fan. The unit can be used in conjunction with the extensive range of accessories to open up a large number of additional experiments on the topic of air flow.

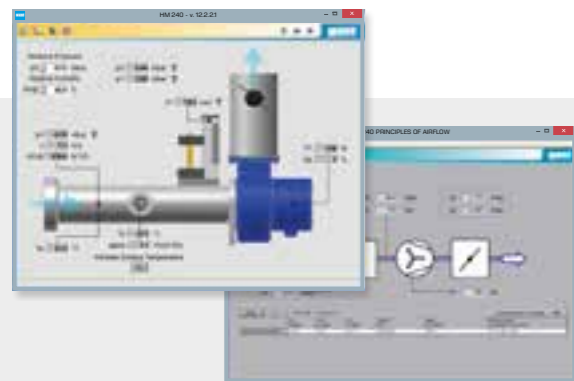
The radial fan generates in a horizontal experimental section a flow velocity of approx. 9m/s. The inlet nozzle ensures a turbulence-free flow and thus a homogeneous velocity distribution in the experimental section. A throttle valve in the outlet can be used to throttle the fan to record characteristics. The device is fitted with sensors to measure temperature and pressure. The flow rate is determined by an inlet nozzle and pressure measurement.

- modular system for experiments with air flows
- numerous experiments from fan-characteristic to heat transfer
- data acquisition and visualisation



**Interface modul**

- digitisation of measurement data
- PC connection via USB



### GUNT software

displays the measured values at the PC clearly and enables a comfortable evaluation. Various functions make it possible to graphically record the measured values and to store the results.

### Base unit and accessories enable a variety of fluid mechanics and thermodynamic experiments



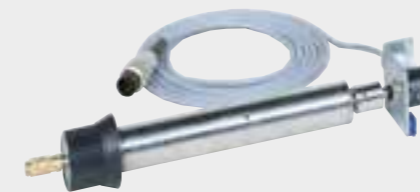
#### HM 240.02 Power meter

- measurement of the electrical fan power
- determination of the fan efficiency



#### HM 240.03 Electronic total pressure sensor

- movable Pitot tube
- electronic record of the position
- pressure transducer in the base unit
- investigation of flow fields and recording of flow profiles



#### HM 240.04 Pressure distribution on a cylinder

The cylinder can be rotated about its axis and includes a pressure measurement hole. It is inserted transverse to the direction of flow so that air flow circulates around the cylinder. Thus the complete pressure distribution can be measured by rotating the cylinder. The angular position is measured. The pressure transducer is located in the base unit.



#### HM 240.05 Friction losses in pipe elements

The set consists of a smooth pipe section with extension, two different inlets and two different 90° deflections. All parts are fitted with pressure measurement ports so that the pressures can be measured along the pipe section. From this the friction losses for the different components can be determined.



#### HM 240.06 Heat transfer at a cylinder in transverse flow

The accessory consists of a copper cylindrical test piece and an electric heater for the test piece. The test piece is fitted with a temperature measurement point. It is heated to a defined temperature prior to the experiment and then inserted into the flow section. The cooling process occurs by forced convection in the air flow. The heat transfer on the test piece can be determined from the cooling rate.



## HM 240

### Principles of air flow



#### Description

- wide range of accessories for basic experiments with air flow
- record a fan characteristic

HM 240 is part of a series that allows experiments on the fundamentals of air flow. The software for data acquisition and visualisation makes the experiments especially clear and enables fast execution of experiments with reliable results.

The experimental unit includes a radial fan, which can be used to generate flow velocities up to  $9\text{m/s}$ . An inlet contour on the intake side ensures a low-turbulence flow and thus a homogeneous velocity distribution in the measuring section. A throttle valve on the end of the pressure pipe can be used to adjust the air flow to allow the fan characteristic curve to be recorded. When used in conjunction with the power meter HM 240.02 it is possible to determine the efficiency of the fan.

Further accessories for additional experiments can be attached in the intake pipe: electronic total pressure sensor HM 240.03, pressure distribution on a cylinder HM 240.04 and heat transfer at a cylinder in transverse flow HM 240.06. To study the friction losses, the intake pipe is replaced with pipe elements from HM 240.05 (straight pipes, pipe bends and pipe angles).

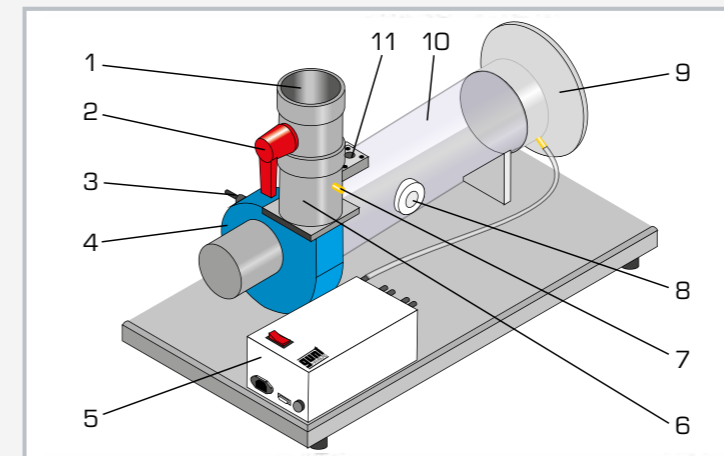
Measuring points along the measuring section allow temperature, pressure and velocity measurements to be taken. The flow rate is determined by means of the inlet contour and the pressure measurement. The measured values are transmitted directly to a PC via USB. The data acquisition software is included.

#### Learning objectives/experiments

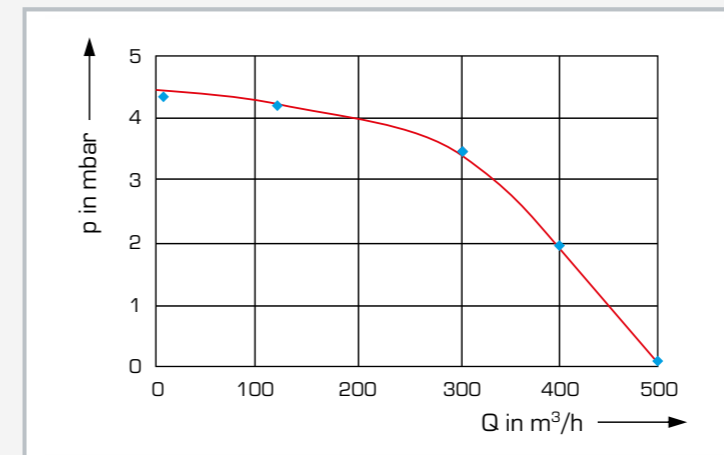
- recording a fan characteristic
- in conjunction with the power meter HM 240.02
  - ▶ determining the fan efficiency
- in conjunction with corresponding accessories
  - ▶ velocity distribution in the pipe
  - ▶ velocity distribution behind a cylinder subject to transverse incident flow
  - ▶ pressure distribution around a cylinder subject to transverse incident flow
  - ▶ friction losses in pipes, pipe bends and pipe angles
  - ▶ recording the cooling curve of a copper cylinder subject to incident flow
  - ▶ determining the heat transfer coefficients from the cooling curve

## HM 240

### Principles of air flow



1 air outlet, 2 throttle valve for adjusting the air flow, 3 measuring point for temperature, 4 fan, 5 switch box with pressure transducer, 6 delivery pipe, 7 measuring point for pressure, 8 connector for accessory HM 240.04 / HM 240.06, 9 air inlet, 10 intake pipe, 11 connector for Pitot tube HM 240.03



Representation of a fan characteristic  
blue: measured values, red fan characteristic; p pressure, Q volumetric flow rate



Screenshot of the software together with the electronic total pressure sensor accessory HM 240.03 and pressure distribution on a cylinder HM 240.04

#### Specification

- [1] investigation of the principles of air flow
- [2] transparent intake pipe with mounting options for additional accessories
- [3] inlet contour minimises turbulence on the intake side
- [4] throttle valve on the delivery pipe to adjust the air flow
- [5] electronic measurement of temperature and pressure
- [6] determine velocity by means of the dynamic pressure
- [7] determine flow rate via differential pressure
- [8] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

##### Radial fan

- max. power consumption: 90W
- speed:  $2800\text{min}^{-1}$
- max. flow rate:  $460\text{m}^3/\text{h}$
- max. differential pressure: 480Pa

##### Delivery pipe

- outer  $\varnothing$ : 110mm
- inner  $\varnothing$ : 99,4mm

##### Intake pipe

- outer  $\varnothing$ : 140mm
- inner  $\varnothing$ : 134,4mm

##### Measuring ranges

- pressure:  $1x \pm 10\text{mbar}$
- pressure:  $2x \pm 1\text{mbar}$
- temperature:  $0 \dots 200^\circ\text{C}$

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 850x450x600mm  
Weight: approx. 23kg

#### Required for operation

PC with Windows

#### Scope of delivery

- 1 experimental unit
- 1 set of hoses
- 1 GUNT software CD + USB cable
- 1 set of instructional material

## WL 312 Heat transfer in air flow

The base unit and an extensive range of accessories enable comprehensive investigations on heat exchangers, as used in air conditioning and ventilation technology.

- investigation of convective heat transfer in heat exchangers from air conditioning and ventilation technology
- how different pipe surfaces affect the temperature change of the air

- determination of the flow profile in the air duct downstream of the heat exchanger with the vertically movable Pitot tube, the static probe at the air duct and an inclined tube manometer
- determination of the air flow velocity over the measuring nozzle at the inlet into the air duct. The velocity can be set within wide limits via a throttle valve at the blower outlet.
- optional hot and cold water generators (WL 312.10, WL 312.11) allow operation independent of the laboratory network
- optional condensing unit WL 312.12 for use with the direct evaporator WL 312.03



### Optional accessories for supplying the heat exchangers



**WL 312.10**  
Hot water generator

The heat exchangers WL 312.01 and WL 312.02 can be supplied from the hot water generator. The heat exchangers then function as air heaters.



**WL 312.11**  
Water chiller

The heat exchangers WL 312.01 and WL 312.02 can be supplied from the cold water generator. The heat exchangers then function as air coolers.



**WL 312.12**  
Condensing unit

The condensing unit is used for air cooling while operating the WL 312.03 direct evaporator.

### WL 312 + heat exchangers WL 312.01 – WL 312.03

**WL 312.01**  
Heat transfer with plain tubes



Heat exchangers with **smooth tubes** are used in systems where deposits on the tube must be avoided and fast and effective cleaning is desirable. This **water-to-air heat exchanger** is inserted into the air duct of WL 312 and fixed in place with fasteners. It is connected to the hot or cold water supply via hoses with quick-release couplings. A transparent cover provides a view inside the heat exchanger. The water flows through the tube bundle. The air travels through the heat exchanger in cross flow.

**WL 312.02**  
Heat transfer with finned tubes



Heat exchangers with **finned tubes** are used when optimum heat transfer between gaseous media and liquids is to be achieved and the media must not be contaminated. This **water-to-air heat exchanger** is inserted into the air duct of WL 312 and fixed in place with fasteners. It is connected to the hot or cold water supply via hoses with quick-release couplings.

The tube bundle consists of finned tubes, which are often used in water-air heat exchangers. A transparent cover provides a view inside the heat exchanger. The water flows through the tube bundle. The air travels through the heat exchanger in cross flow.

**WL 312.03**  
Heat transfer on refrigerant evaporator



This device, known as a **direct evaporator**, is inserted into the air duct of WL 312 and fixed in place with fasteners. It is connected to a condensing unit via hoses with quick-release couplings.

The refrigerant evaporates in the tubes and extracts heat from the air. The **tubes** are **ribbed** to increase the heat transfer surface. Again, the transparent cover provides a view inside the evaporator.

### Optional accessories

**WL 312.10**  
Hot water generator

or

**WL 312.11**  
Water chiller

**WL 312.10**  
Hot water generator

or

**WL 312.11**  
Water chiller

**WL 312.12**  
Condensing unit



## WL 312

### Heat transfer in air flow



#### Description

##### ■ investigation of convective heat transfer together with accessories

In many industrial production processes, as well as in the air conditioning of buildings, heat transfer takes place with the assistance of air flow. In these cases, convective heat transfer is determined by the temperature differences of the media involved and the flow.

The WL 312 trainer studies convective heat transfer on various pipe surfaces. The flow movement takes place by forced convection.

An insulated air duct with fan serves as the measuring section. A streamlined inlet element and a flow straightener in the air duct provide a homogeneous flow for conducting the experiment. The volumetric flow rate is set via a throttle valve at the fan outlet and measured by a measuring nozzle at the inlet into the air duct.

Heat exchangers with different tube surfaces can be used in the air duct. Heat exchangers with smooth tubes, finned tubes or a refrigerant evaporator are available as accessories.

The air duct includes two windows to observe the experiments.

Combined sensors measure the temperature and relative humidity at the inlet and outlet of the heat exchanger. Pressures upstream and downstream of the measuring section are also recorded in order to determine the pressure loss at the heat exchanger. The velocity distribution in the air duct is measured by a Pitot tube. The temperatures, pressures and relative humidity are displayed digitally.

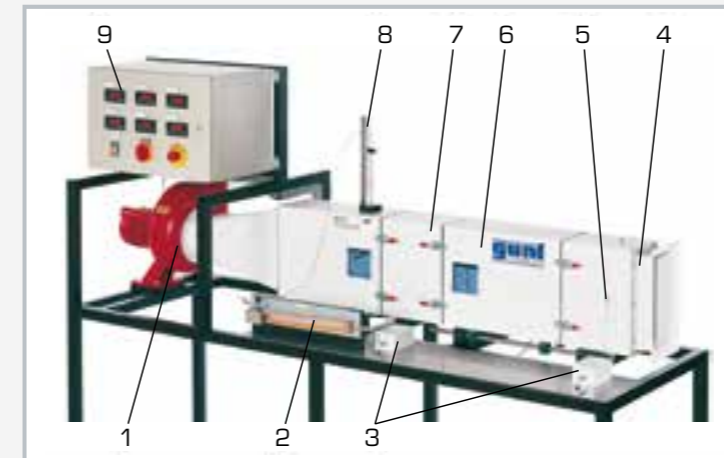
The following accessories are recommended for supplying the heat exchangers: Hot water generator (WL 312.10), water chiller (WL 312.11) and condensing unit (WL 312.12).

#### Learning objectives/experiments

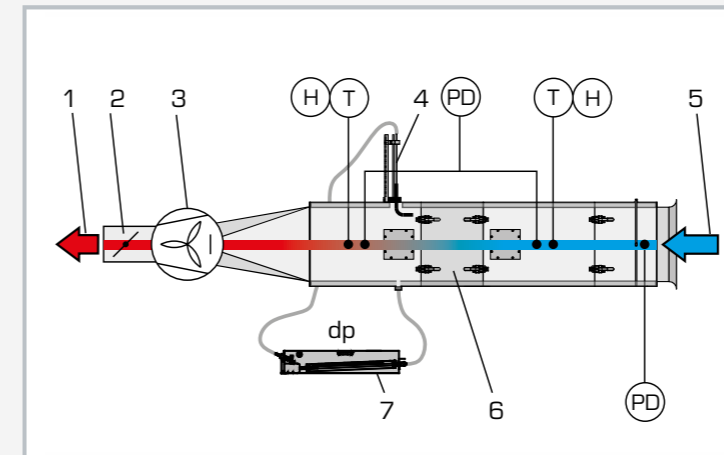
- experiments without accessories
  - ▶ recording the fan characteristic
  - ▶ velocity distribution in the air duct
- experiments with accessories
  - ▶ heat transfer with plain tubes (WL 312.01, together with WL 312.10 / WL 312.11)
  - ▶ heat transfer with finned tubes (WL 312.02, together with WL 312.10 / WL 312.11)
  - ▶ heat transfer on refrigerant evaporator (WL 312.03, together with WL 312.12)

## WL 312

### Heat transfer in air flow



1 fan with throttle valve, 2 inclined tube manometer, 3 differential pressure sensor, 4 streamlined inlet, 5 pressure measurement via measuring nozzle, 6 air duct with windows, 7 measuring section for exchangeable accessories, 8 Pitot tube, 9 displays and controls



1 air outlet, 2 throttle valve, 3 fan, 4 Pitot tube, 5 air inlet, 6 measuring section for exchangeable accessories, 7 inclined tube manometer; H humidity, T temperature, dp differential pressure, PD differential pressure sensor



Accessories for the trainer:  
WL 312.01 Heat transfer with plain tubes  
WL 312.02 Heat transfer with finned tubes  
WL 312.03 Heat transfer on refrigerant evaporator

#### Specification

- [1] air duct for studying heat transfer in air flows
- [2] insulated air duct with flow straightener and streamlined inlet
- [3] determination of the volumetric flow rate of the air via differential pressure at the measuring nozzle
- [4] fan with adjustable flow rate
- [5] movable Pitot tube with inclined tube manometer for measuring velocity distributions
- [6] combined temperature and humidity sensor
- [7] digital displays of differential pressure, temperature and relative air humidity
- [8] various heat exchangers available as accessories

#### Technical data

Air duct cross-section: 150x300mm

#### Fan

- output: 1100W
- max. flow rate: 1680m<sup>3</sup>/h
- max. pressure difference: 1000Pa
- rated speed: 2800min<sup>-1</sup>
- air velocity: max. 10m/s

Pitot tube: travel 300mm

#### Measuring ranges

- temperature: 2x 0...50°C
- humidity: 2x 0...100%
- differential pressure: 0...100Pa

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 2350x750x1800mm  
Weight: approx. 150kg

#### Scope of delivery

- 1 trainer
- 1 set of accessories
- 1 set of instructional material

## HL 710 Planning and set-up of air duct systems

System at  
original scale,  
individual  
set-up

## Air duct systems with typical components from ventilation technology: set-up and experiments

## The components



Pipe bends



Reduction (left) and connection elements



Branches



Throttle valve (left) and iris diaphragm (right)



Disc valve (left) and slotted vent (right)



Filter

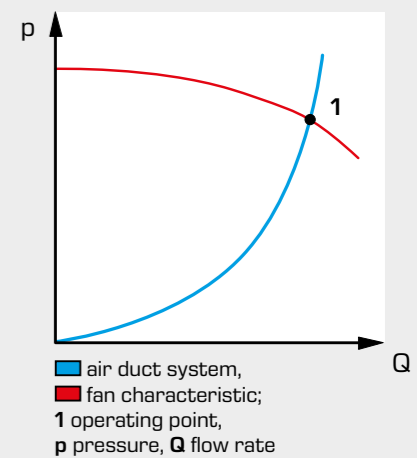
## The experiments

In the air duct system several components with measuring points for pressure measurements are installed. With an inclined tube and a digital manometer the static and dynamic pressure can be measured at these points. This allows a determination of the pressure losses of the individual components in the whole air duct system.

With the anemometer the air velocities and air flows are measured at the outlets of the system. The measured values are used to generate the system and fan characteristics. From the characteristics the operating point is determined.

1 digital manometer, 2 inclined tube manometer,  
3 anemometer

Measuring points for static and dynamic pressure





## HL 710

### Air duct systems



#### Description

- **planning and setup of simple and complex air duct systems**
- **measurement of the dynamic and static pressures in air duct systems**
- **measurement of the air velocity and volumetric flow rate under different conditions**

Ventilation systems are used in many areas. They are used to ventilate offices, sports halls, production halls, conference halls etc. These systems consist of an air duct system and often other facilities for the conditioning of room air. There may also be elements for air purification or sound insulation, e.g. filters.

The trainer HL 710 examines how the air can be distributed in a building. The air duct system is supplied via a speed-controlled fan. The trainee constructs variable air duct systems from commercial components, such as pipes, pipe bends, branches, filters and disk valves. Connections for pressure measurements can be installed at any position.

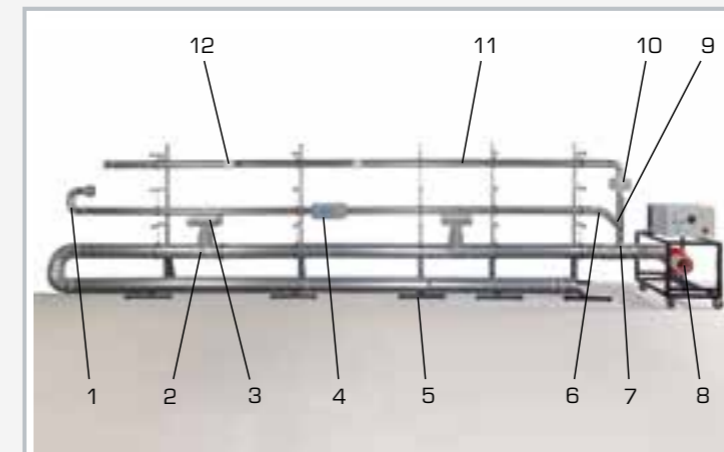
The effects of the individual components on the pressure loss and thus on the velocity and flow rate of the air are examined. For this purpose there are two manometers with different measuring ranges and a manual device for measuring the air velocity. The fan characteristic is also determined and the power consumption of the fan is measured.

#### Learning objectives/experiments

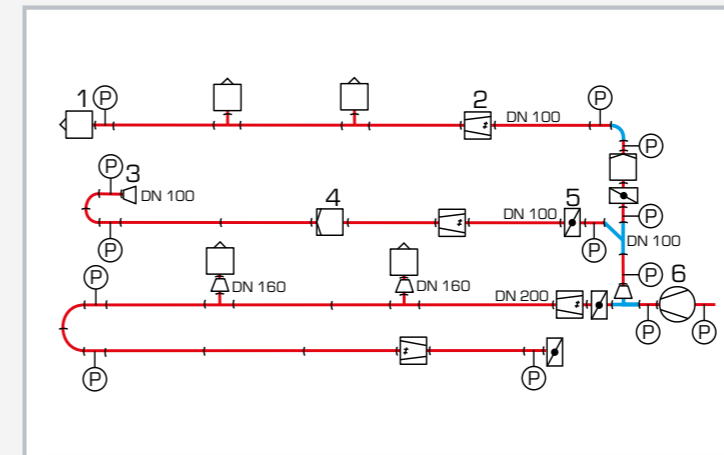
- plan, setup and test air duct systems
- typical components of ventilation technology
- measure the flow rate and velocity of the air
- measure dynamic and static pressures
- determination of the pressure loss via different components: pipe bends, angles, distributors etc.
- recording of system characteristics
- recording of the fan characteristic
- determination of the operating point
- calculate the electric capacity of the fan motor with regard to current and voltage
- calculate the fan efficiency

## HL 710

### Air duct systems



1 90° pipe bend, 2 reducer, 3 slotted outlet, 4 pocket filter, 5 assembly stand, 6 45° pipe bend, 7 T piece, 8 fan, 9 branch, 10 filter cartridge, 11 iris diaphragm, 12 disk valve



Pipe routing diagram: 1 inlet air or disk valve, 2 iris diaphragm, 3 reducer, 4 filter, 5 throttle valve, 6 fan; P pressure measuring point; blue: pipe bends and joints



1 fan speed adjustment, 2 fan on/off switch, 3 main switch, 4 power meter

#### Specification

- [1] experimental setup for training in ventilation engineering
- [2] radial fan, on mobile frame, to connect air ducts
- [3] air ducts from galvanised folded spiral-seam pipe with pipe bends, joints and components
- [4] pressure measuring connections with variable locations
- [5] 6 assembly stands to attach the air ducts
- [6] inclined tube manometer and digital manometer for 2 different measuring ranges
- [7] measuring of the air velocity by anemometer
- [8] switch cabinet with display of power consumption

#### Technical data

##### Fan

- power consumption: 900W
- max. volumetric flow rate: 1680m<sup>3</sup>/h
- max. pressure difference: 1000Pa
- speed: 0...2840min<sup>-1</sup>

##### Pipes

- length: 1600mm
- diameter: 8x DN200, 8x DN100

##### Pipe bends and connections, each DN100 and DN200

- 90° pipe bend, 45° pipe bend
- 45° branch
- T piece, T piece with reducer
- reducer, plug-in connection, pipe coupling

##### Flow restriction elements, each DN100 and DN200

- throttle valve
- iris diaphragm

##### Filters, each DN100 and DN200

- pocket filter
- filter cartridge

##### Measuring ranges

- pressure: 0...200Pa / 0...2000Pa
- velocity: 0,25...30m/s
- power: 0...5,75kW

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase

UL/CSA optional

LxWxH: 800x810x1250mm [fan]

Total weight: approx. 180kg

#### Scope of delivery

- 1 radial fan on mobile frame
- 6 assembly stands
- 1 set of pipes, pipe bends, connections, components (outlets, filters etc.)
- 1 inclined tube manometer
- 1 digital manometer
- 1 anemometer
- 1 set of instructional material

## HL 720 Ventilation system



### Learning objectives/experiments

- design and operation of a ventilation system
- pressure measurements in the air duct
- determine the electric drive power of the fan
- determine the flow rate
- design and operation of components such as
  - ▶ protective grating
  - ▶ multi-leaf damper
  - ▶ filter
  - ▶ heat exchanger (no operation)
  - ▶ fan
  - ▶ inspection cover
  - ▶ sound insulation link
  - ▶ ventilation grill with adjustable flow rate
  - ▶ fire protection flap
  - ▶ ceiling vents

### Description

- ventilation system with air handler
- high practical relevance due to the use of industrial components from ventilation technology
- representation of pressure curves

In building services engineering ventilation systems are used for commercial premises, hospitals, restaurants or conference rooms to ensure the air exchange in the individual rooms. In real air handling units the air is heated or cooled by a heat exchanger and cleaned by filters, e.g. from pollen.

HL 720 demonstrates the operation of a ventilation system and its components. The components used are common in commercial ventilation technology and therefore are of high practical relevance. The ventilation system is operated as a pure air supply system.

The air enters via a weather louvre and flows through the components of the ventilation system, such as multi-leaf damper and filter. A fan ensures the air transport. Further down the air duct, typical components, such as sound insulation link, inspection flap, various air outlets and fire protection flap are arranged.

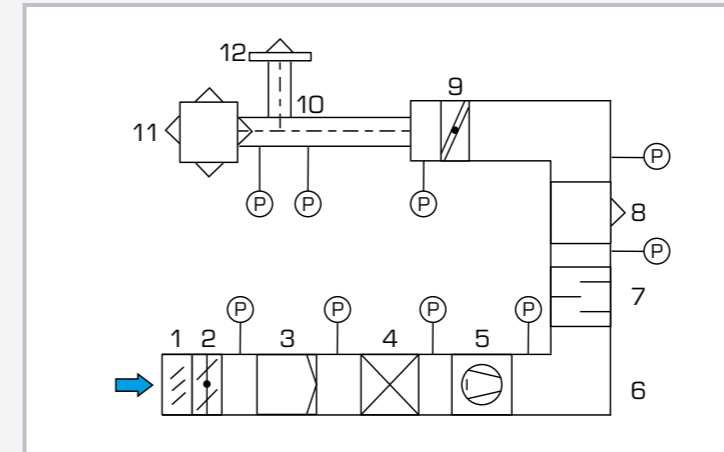
Sight windows enable an insight into the sound insulation link, filter and fan. The original component function remains intact.

The record of pressures and differential pressures at relevant measuring points enables the representation of a pressure curve for the whole system. The components act as in real ventilation systems as flow resistances. The electric drive power of the fan and the volumetric air flow rate are calculated.

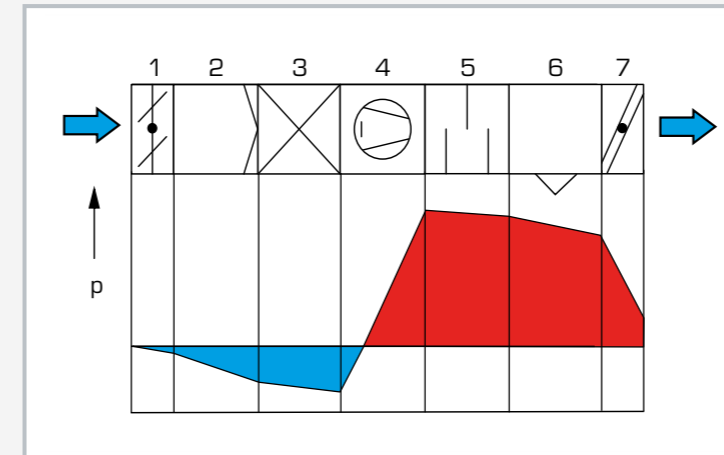
## HL 720 Ventilation system



1 fire protection flap, 2 inclined tube manometer, 3 weather louvre, 4 multi-leaf damper, 5 filter, 6 heat exchanger, 7 inspection cover, 8 fan with drive motor, 9 air duct, 10 ceiling vent, 11 wall vent



1 weather louvre, 2 multi-leaf damper, 3 filter, 4 heat exchanger, 5 fan, 6 air duct, 7 sound insulation link, 8 wall vent, 9 fire protection flap, 10 branch, 11 air outlet for ceiling installations, 12 disc valve; P pressure



Pressure curve within the ventilation system: 1 multi-leaf damper, 2 filter, 3 heat exchanger, 4 fan, 5 sound insulation link, 6 wall vent, 7 fire protection flap; red: overpressure, blue: vacuum

### Specification

- [1] design and operation of a ventilation system
- [2] all components from ventilation technology, some with sight windows
- [3] protective grating and adjustable multi-leaf damper at the air inlet
- [4] filter for air purification
- [5] belt-driven radial fan
- [6] 2 sound insulation links
- [7] various air outlets for air distribution in the room: disc valve, ceiling vent and ventilation grill with adjustable flow rate
- [8] inspection cover for inspection purposes
- [9] fire protection flap prevents the cross-over of fire and smoke in the air duct
- [10] air duct with pressure measurement connections
- [11] pressure measurements with inclined tube manometer
- [12] current measurement to determine the power consumption of the fan
- [13] determine the flow rate via differential pressure

### Technical data

#### Air duct

- 2 parts with WxH 630x305mm and 630x630mm

#### Fan

- max. flow rate: 2500m<sup>3</sup>/h
- drive motor: 750W

#### Measuring ranges

- pressure: 0...7,5mbar
- current: 0...4A

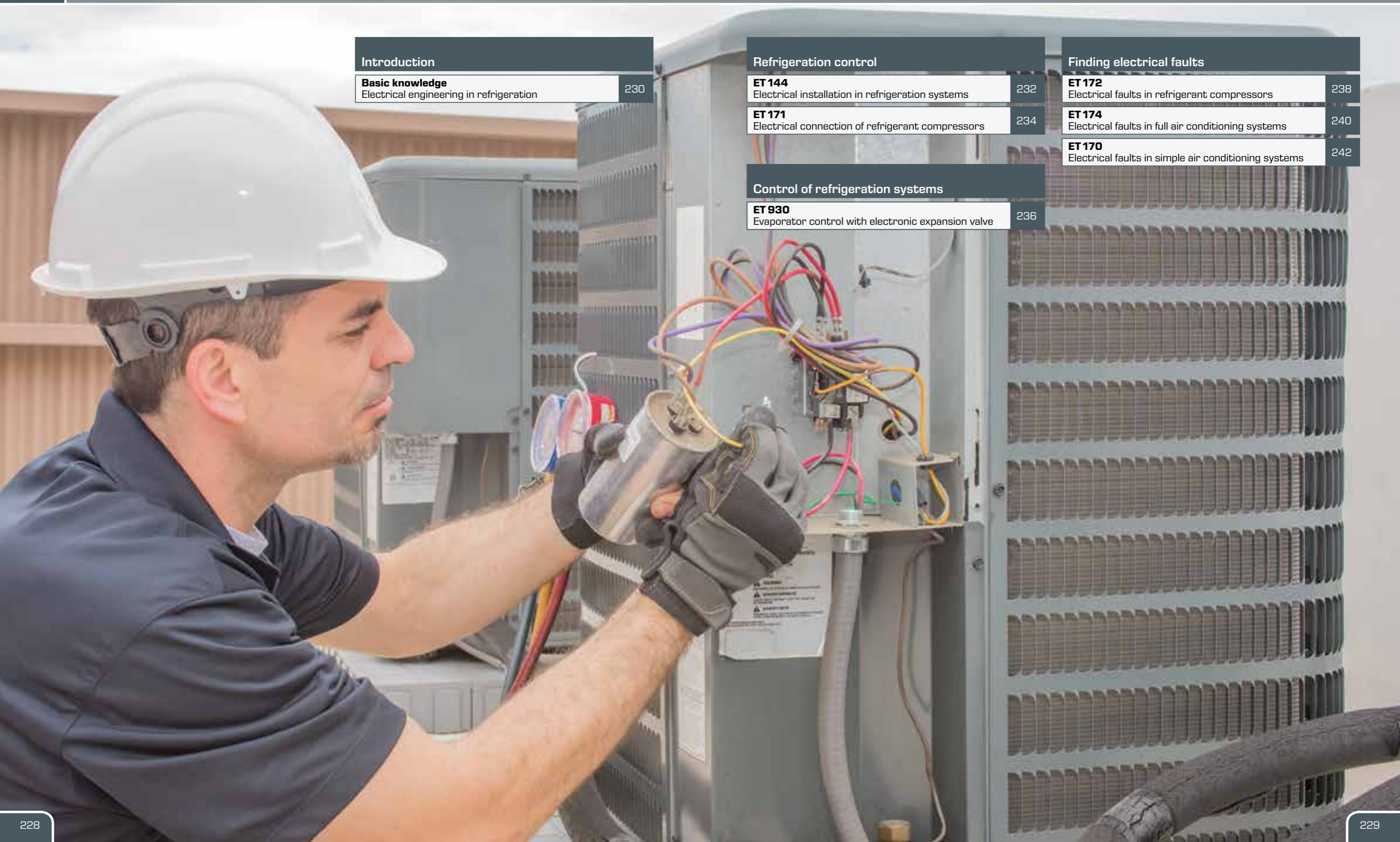
400V, 50Hz, 3 phases  
400V, 60Hz, 3 phases; 230V, 60Hz, 3 phases  
UL/CSA optional  
LxWxH: 1960x900x2000mm  
Weight: approx. 263kg

### Scope of delivery

- 1 experimental plant
- 1 set of instructional material



# Electrical engineering in refrigeration and air conditioning technology



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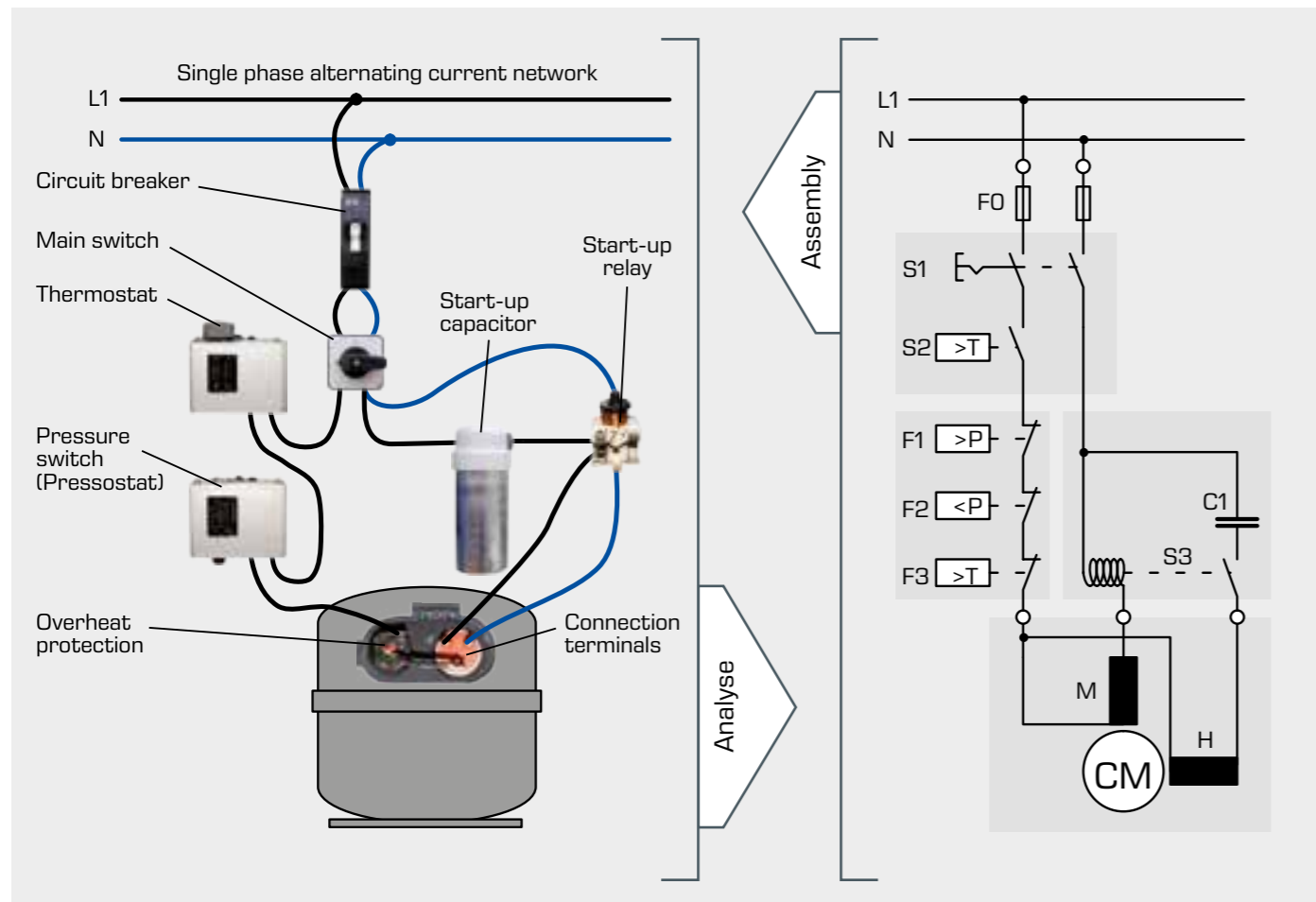
## Basic knowledge

## Electrical engineering in refrigeration

Refrigeration systems contain many electrical components, such as compressors, pressure switches, thermostats, fans, solenoid valves or controls. Therefore, electrical engineering is an important field in refrigeration. This is reflected in the high share of electrical engineering content in the training of the mechatronics engineer for refrigeration. The mechatronics engineer for refrigeration should be capable of planning, designing and commissioning electrical systems.

In the service field the testing, fault finding and repair of electrical systems is also an important item. During service you are often confronted with incomplete documentation, which is why the mechatronics engineer for refrigeration must be able to analyse the system and comprehend its operation. This requires a good basic knowledge of electrical engineering.

## Electric connection of a refrigerant compressor to the alternating current network



The connection of a refrigerant compressor and its protective elements to the single phase alternating current network is part of the standard activities of the mechatronics engineer for refrigeration. This task requires the correct preparation of an electric circuit diagram (flow diagram) and the practical wiring of the electrical components in the refrigeration system.

The wiring of the compressor **CM** consists of three functional groups:

- controller, consisting of main switch **S1** and thermostat **S2**
- safety module, consisting of pressure switches (Pressostat) **F1**, **F2** and overheated protection of the compressor **F3**
- start-up circuit, consisting of the start-up relay **S3** and start-up capacitor **C1**

## Start-up circuits for single phase compressor motors

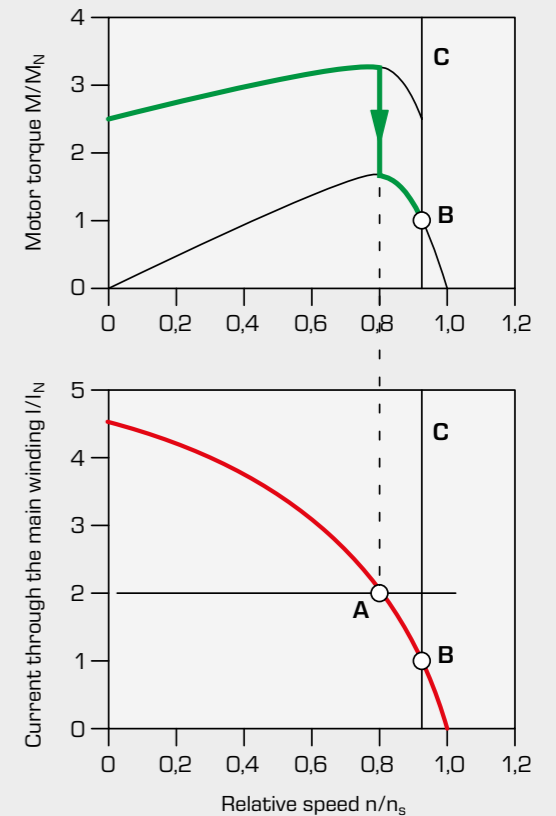
Drive motors for refrigerant compressors require a high start-up torque. For low compressor capacities single phase alternating current motors are used as drive motors. These are of simple design, maintenance-free, cheap and can run inside the refrigerant (hermetic compressor).

Due to their principle of operation these motors do not have any or only a low torque at rest. To increase the torque the motors must be equipped with a start-up circuit. Here an auxiliary winding is additionally supplied with current via a capacitor until the operating speed is reached. The automatic switching on and off of the auxiliary winding can be implemented via different options.

The most common is a start-up relay whose winding is connected in series to the main winding. When starting the motor a very high current first flows through the main winding, the start-up relay responds and activates the auxiliary winding via the capacitor. Once the motor has reached its speed, the current through the main winding drops. If the current falls below a certain value, the relay is released and the auxiliary winding is disabled.

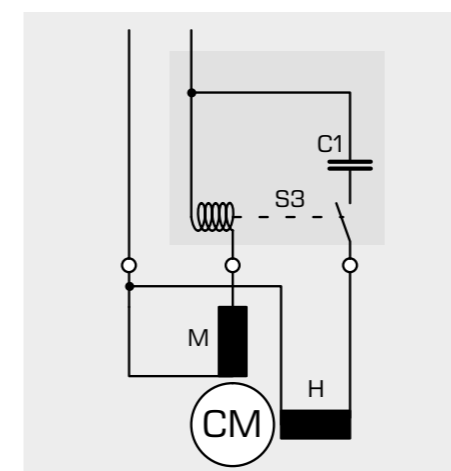
The switching of the auxiliary winding can also take place via a centrifugal force switch directly dependent on the speed. In some motors the auxiliary winding is permanently activated via an operating capacitor. Here a second start-up capacitor is connected in parallel during start-up to increase the torque.

Another particularly wear-free method is the use of a PTC element. This heats due to the current flowing in the auxiliary winding and increases its resistance. This reduces the current through the auxiliary winding after a brief period of time.

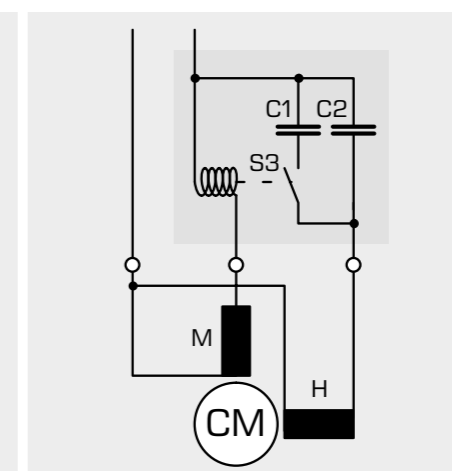


Start of a single phase alternating current motor with auxiliary winding: auxiliary winding is switched off at  $I = 2 I_N$

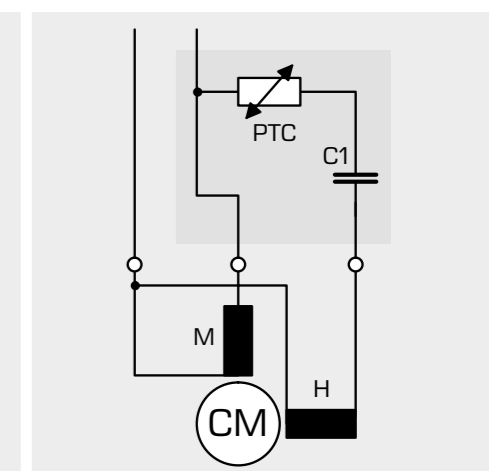
$M_N$  nominal torque,  $I_N$  nominal current,  $n_s$  synchronous torque, **A** switching point, **B** operating point, **C**  $n_N/n_s$  = nominal speed



Start-up capacitor **C1**  
via start-up relay **S3**



Operating capacitor **C2**  
and start-up capacitor **C1**  
via start-up relay **S3**



Start-up capacitor **C1**  
via **PTC**



## ET 144

### Electrical installation in refrigeration systems



#### Learning objectives/experiments

- read, understand, wire and test electric circuit diagrams
- design and operation of electrical components from refrigeration
  - ▶ start-up capacitor
  - ▶ operating capacitor
  - ▶ start-up relay
  - ▶ time relay
  - ▶ timer
  - ▶ circuit breaker
  - ▶ start-up current limiter
  - ▶ contactors
  - ▶ pressure switch
  - ▶ thermostat
  - ▶ solenoid valve
- design and testing of a safety chain
- star / delta connection
- change of direction of rotation in an alternating current circuit
- **safety aspects when handling mains voltage**

#### Description

- **design and wiring of typical electrical circuits from refrigeration**
- **investigation of important electrical components from refrigeration**
- **design and investigation of a safety chain**

The wiring of electrical components is a typical task in the field of refrigeration. Besides the design and operation of the individual components, knowledge about the interaction of the components in circuits is an important learning objective. Safety aspects also play an important role. With ET 144 this knowledge and these skills can be acquired.

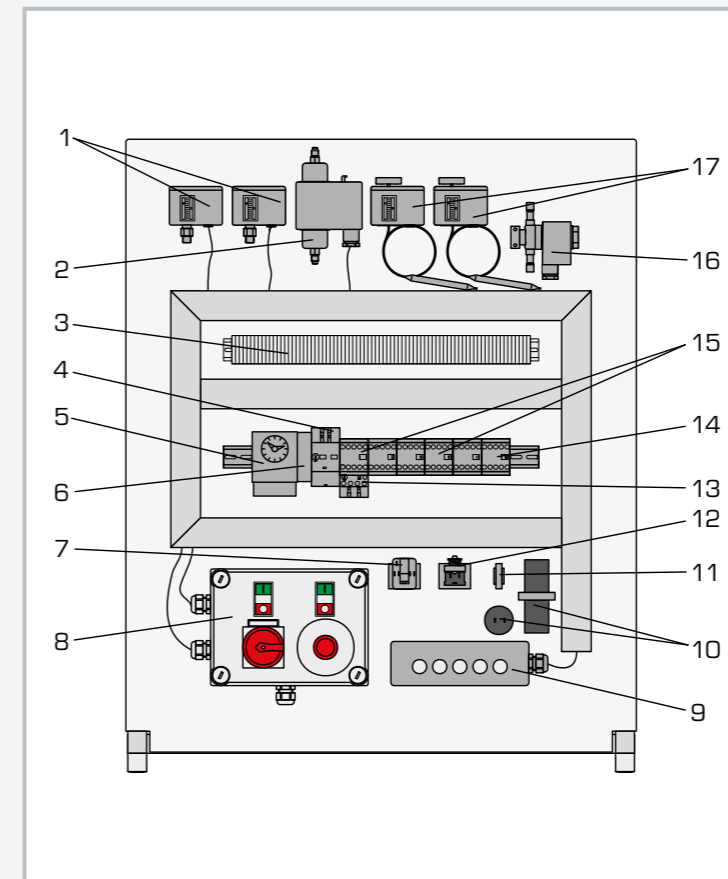
The electrical components are arranged clearly visible. All components are connected on terminal blocks. Using the cables included in the scope of delivery it is possible to set up different circuits correctly and operationally. Lamps simulate the consumers. All components are operated and tested with mains voltage to provide high relevance for practice.

There are electrical components for the start and operation of refrigerant compressors, such as e.g. electromagnetic start-up relay and capacitor.

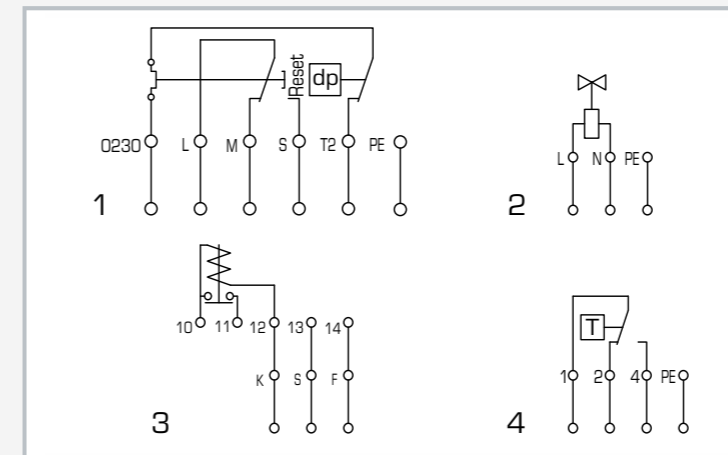
With a timer, circuits can be designed and examined for cyclical defrosting in refrigeration systems. This also includes the correct programming of the timer. Typical safety components, such as pressure switches, thermostats and circuit breakers are also included in the scope of delivery. These components enable the design and examination of a typical safety chain for refrigeration.

## ET 144

### Electrical installation in refrigeration systems



1 pressure switch, 2 differential pressure switch, 3 terminal block, 4 circuit breaker with start-up current limiter, 5 timer, 6 thermistor circuit breaker, 7 PTC start-up relay, 8 switch cabinet, 9 lamps, 10 capacitors, 11 bimetallic circuit breaker, 12 electromagnetic start-up relay, 13 adjustable protection relay, 14 time relay, 15 contactor, 16 solenoid valve, 17 thermostat



Circuit diagrams: 1 differential pressure switch, 2 solenoid valve, 3 electromagnetic start-up relay, 4 thermostat

#### Specification

- [1] experimental unit from the GUNT practical series for the training of mechatronics engineers for refrigeration
- [2] design and investigation of circuits with electrical components from refrigeration
- [3] electrical components mounted clearly visible and connected on terminal blocks
- [4] 1 set of cables with wire end ferrules for wiring electrical components on terminal blocks
- [5] 3 pressure switches, 2 thermostats, 1 solenoid valve, 1 timer, 4 circuit breakers, 5 contactors, 3 relays, 2 capacitors
- [6] 5 lamps to simulate consumers

#### Technical data

- 3 pressure switches
- high pressure: 8...32bar
  - low pressure: -0,9...7bar
  - differential pressure: 0,3...4,5bar
- 2 thermostats: -5...20°C
- 1 timer
- 2 switchable outputs
  - switching time: 1...60min
- 4 circuit breakers
- bimetallic circuit breaker
  - thermistor circuit breaker
  - circuit breaker with start-up current limiter
  - adjustable protection relay
- 5 contactors
- 2x: 3 NO, 1 NC
  - 3x: 4 NO
- 3 relays
- electromagnetic start-up relay
  - PTC start-up relay
  - time relay

Start-up and operating capacitor: 15µF, 80µF

400V, 50Hz, 3 phases  
400V, 60Hz, 3 phases; 230V, 60Hz, 3 phases  
UL/CSA optional  
LxWxH: 820x420x1010mm  
Weight: approx. 42kg

#### Scope of delivery

- 1 experimental unit
- 1 set of accessories (cables + wire end ferrules)
- 1 set of instructional material

## ET 171

### Electrical connection of refrigerant compressors



#### Description

- correct electrical connection of a refrigerant compressor
- use of a real refrigerant compressor
- design and investigation of a safety chain

The wiring of electrical components for the start and operation of refrigerant compressors is a typical task in the field of refrigeration. Safety aspects also play an important role. With ET 171 this knowledge and these skills can be acquired. All components are operated and tested with mains voltage to provide high relevance for practice.

The electrical components for the start and operation of the refrigerant compressor are arranged clearly visible. The electrical connection of the individual components is made with cables via the lab jacks. The components are e.g. the capacitor and start-up relay necessary to start the motor. The circuit diagram on the front panel enables the easy allocation of the individual components.

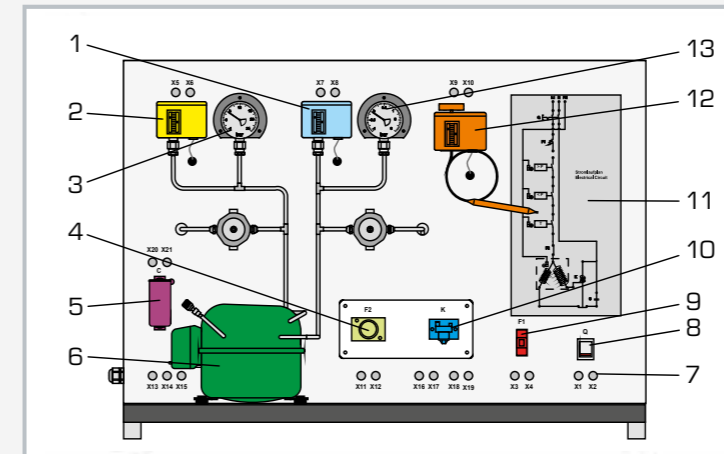
The refrigeration circuit with compressor and receiver enables the checking of the pressure switches on the intake and delivery side of the compressor. The pressure is set via valves and the pressure switch tripped. Two manometers enable the monitoring of the pressure curve. If one of the pressure switches trips, the current supply to the compressor is interrupted. The wiring and checking of other typical components of the safety chain, e.g. circuit breaker and automatic fuse, is also carried out.

#### Learning objectives/experiments

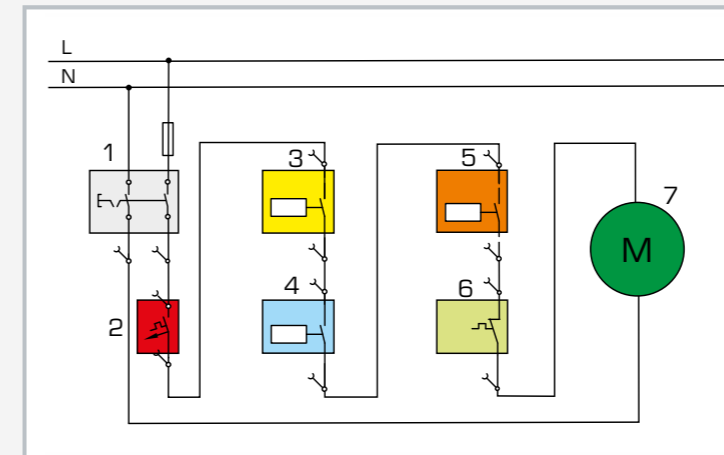
- read, understand, wire and test electric circuit diagrams for refrigerant compressors
- design and operation of electrical components of refrigerant compressors
  - ▶ start-up capacitor
  - ▶ start-up relay
  - ▶ overheating protection
  - ▶ automatic fuse
  - ▶ pressure switch
  - ▶ thermostat
- design and testing of a safety chain
- representation methods in electrical engineering
  - ▶ symbols
  - ▶ circuit diagrams
- safety aspects when handling mains voltage

## ET 171

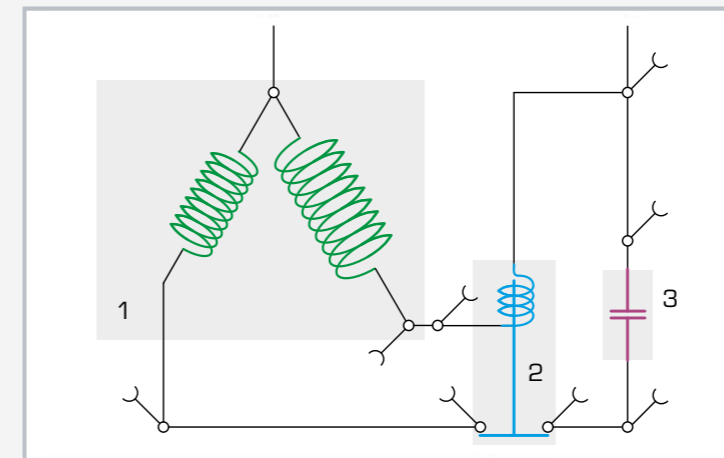
### Electrical connection of refrigerant compressors



1 pressure switch intake side, 2 pressure switch delivery side, 3 manometer delivery side, 4 overheating protection, 5 start-up capacitor, 6 refrigerant compressor, 7 lab jacks, 8 main switch, 9 automatic fuse, 10 start-up relay, 11 circuit diagram, 12 thermostat, 13 manometer intake side



Safety chain: 1 main switch, 2 automatic fuse, 3 pressure switch delivery side, 4 pressure switch intake side, 5 thermostat, 6 overheating protection, 7 refrigerant compressor with start-up components



Refrigerant compressor with start-up components 1 refrigerant compressor, 2 start-up relay, 3 start-up capacitor

#### Specification

- [1] experimental unit from the GUNT practical series for the training of mechatronics engineers for refrigeration
- [2] correct electrical connection of a refrigerant compressor
- [3] refrigerant circuit with compressor, receiver, 2 valves and 2 manometers to investigate pressure switches on the delivery and intake sides
- [4] electrical components for the start and operation of the compressor mounted clearly visible
- [5] lab jacks and cables to connect the electrical components
- [6] operation of a thermostat
- [7] circuit diagram on the front panel for easy identification of the components
- [8] refrigerant R513A, GWP: 631

#### Technical data

Refrigerant compressor

- power consumption: approx. 193W at 5/55°C
- refrigeration capacity: 374W at 5/55°C

Receiver: 0,8L

Manometer measuring ranges

- delivery side: -1...24bar
- intake side: -1...9bar

Pressure switch control range

- delivery side: 8...32bar
- intake side: -0,9...7bar

Thermostat: -5...35°C

Electrical components for the compressor

- start-up capacitor
- start-up relay
- overheating protection (bimetallic)
- automatic fuse

Refrigerant

- R513A
- GWP: 631
- filling volume: 300g
- CO<sub>2</sub>-equivalent: 0,2t

230V, 50Hz, 1 phase

230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase

UL/CSA optional

LxWxH: 920x410x660mm

Weight: approx. 45kg

#### Scope of delivery

- 1 experimental unit
- 1 multimeter
- 1 set of laboratory cables
- 1 set of instructional material



## ET 930

### Evaporator control with electronic expansion valve



#### Description

- practical programming of a modern refrigeration controller
- software to simulate a commercial freezer
- real components of evaporator control fitted to front panel for demonstration purposes

The control of refrigeration units such as chiller cabinets, refrigerated display cases and freezers is a key topic in commercial refrigeration. The control aims at safeguarding a high level of food quality with simultaneous energy-efficient operation.

With ET 930 the operation and programming of an industrial evaporator controller (refrigeration controller) is taught in the example of a freezer. Software simulates the freezer. The schematic depicted on the front panel aids comprehension. Lamps in the schematic indicate the operating state of the individual components.

The refrigeration controller controls the temperature of the freezer via the electronic expansion valve. It also controls the air circulation fan.

It provides for the defrosting of the evaporator and prevents the freezing of the freezer lid by way of a frame heating. The refrigeration controller continuously monitors the operation of the components and issues an alarm signal should errors occur.

The controller is programmed via a data cable using a programming device. This allows for adjustments of the thermostat function, daytime/night-time operation, the defrosting function, energy saving functions and safety functions.

In the simulation software the outside temperature is entered, the refrigerant selected and the door of the freezer opened or closed. In the "time graph" menu, the operating states of the individual components are displayed and the temperature and pressure graphs recorded.

Additional real components, such as expansion valve and pressure and temperature sensors, are used for demonstration purposes and increase the practical relevance.

#### Learning objectives/experiments

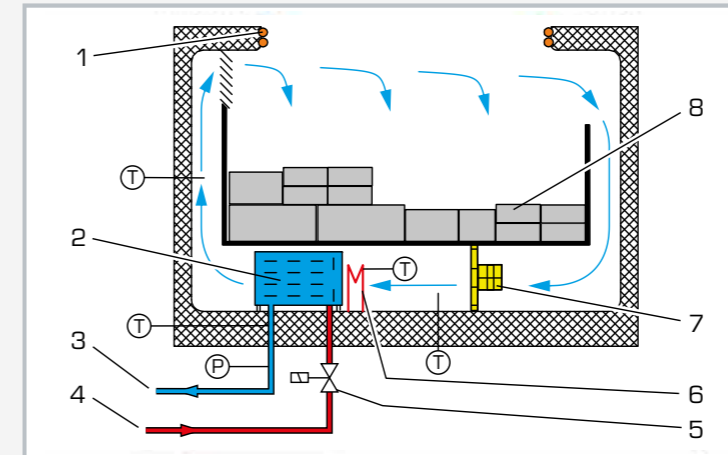
- modern refrigeration controller with electronic expansion valve
- functional principle of the controller
  - ▶ thermostat function
  - ▶ daytime and night-time operation
  - ▶ operation with open and closed freezer
  - ▶ defrost functions
  - ▶ safety functions
  - ▶ alarm functions
  - ▶ monitoring of the components
- controller programming
- fault finding

## ET 930

### Evaporator control with electronic expansion valve



1 pressure sensor, 2 electronic expansion valve, 3 display of the refrigeration controller, 4 temperature sensor, 5 diagram of the simulated freezer



Simulated freezer: 1 heating at the frame, 2 evaporator, 3 intake side condensing unit connection, 4 delivery side condensing unit connection, 5 expansion valve, 6 electric defrost heater, 7 fan, 8 refrigerated goods; T temperature, P pressure



Screenshot of the simulation software: temperature graphs (top), switching states (bottom)

#### Specification

- [1] experimental unit from the GUNT practical series for the training of mechatronics engineers for refrigeration
- [2] investigation and programming of an industrial refrigeration controller in the example of a freezer
- [3] simulation of the freezer by way of software
- [4] schematic on the front panel with lamps to indicate the operating states of the actuators
- [5] programming of the refrigeration controller using a programming device
- [6] simulated freezer with compressor, electronic expansion valve, fan, electric defrost heater for the evaporator, frame heating, pressure and temperature sensors
- [7] real freezer components for demonstration purposes: 1 electronic expansion valve, 1 pressure sensor, 2 temperature sensor
- [8] GUNT software for data acquisition via USB under Windows 7, 8.1, 10

#### Technical data

Functions of the refrigeration controller

- thermostat function
- daytime/night-time operation
- defrost functions
- messages and alarms
- fan operation
- energy saving functions
- safety functions

Simulated sensors

- air temperature upstream of the evaporator
- air temperature downstream of the evaporator
- evaporator surface temperature
- refrigerant temperature upstream of the compressor
- refrigerant pressure upstream of the compressor

Functions of the simulation software

- outer temperature input
- opening/closing the door
- selection of refrigerant
- pressure and temperature time graphs

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 660x350x570mm  
Weight: approx. 30kg

#### Required for operation

PC with Windows

#### Scope of delivery

- 1 experimental unit
- 1 GUNT software CD + USB cable
- 1 set of instructional material

## ET 172

### Electrical faults in refrigerant compressors



#### Description

- real refrigerant compressor from practice
- investigation of important electrical components from refrigeration
- simulation of 15 faults

Identifying electrical faults in refrigeration systems requires comprehensive knowledge. This knowledge includes the design and operation of the individual electrical components as well as the reading of circuit diagrams. ET 172 helps to acquire this knowledge.

The electrical components for the start and operation of a refrigerant compressor are clearly visibly arranged in a transparent showcase and already wired. The capacitor and start-up relay required for the motor are examined. Typical protection devices, such as circuit breaker and automatic fuse, are also arranged clearly visible.

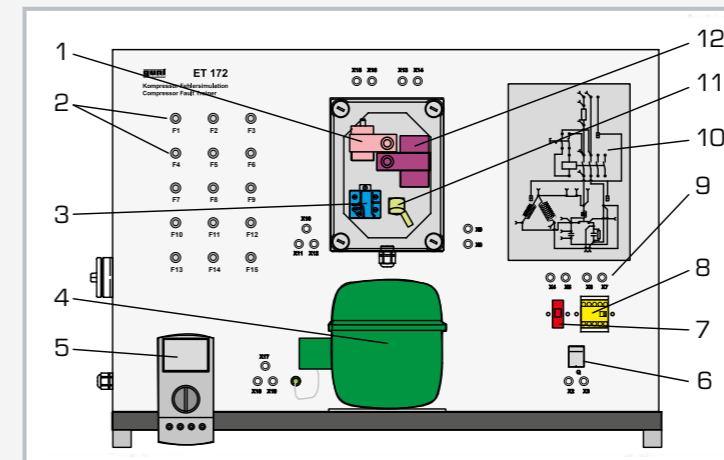
The simulation of 15 different faults, e.g. coil fracture in the motor, short circuit in the operating capacitor or welded contacts in the start-up relay, is possible. For fault indication, voltages and resistances are checked at the lab jacks with the multimeter. The depiction of the circuit diagram on the front panel facilitates the allocation of the measuring points.

#### Learning objectives/experiments

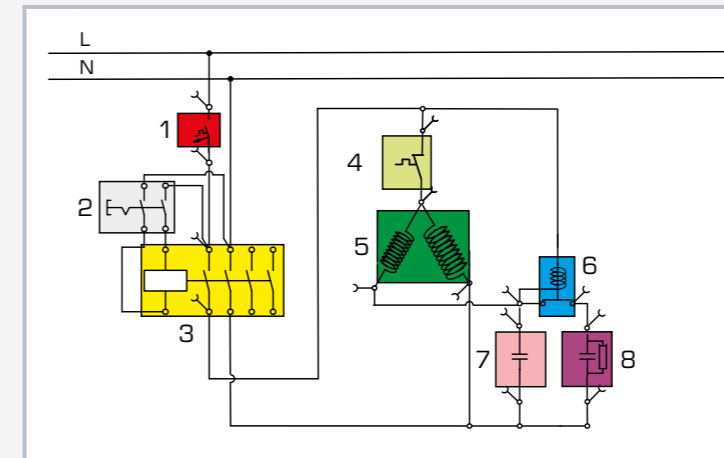
- electrical connection of refrigerant compressors
- read and understand electrical circuit diagrams
- design and operation of the electrical components of a refrigerant compressor
  - ▶ start-up capacitor
  - ▶ start-up relay
  - ▶ operating capacitor
  - ▶ overheating protection
  - ▶ main contactor
  - ▶ automatic fuse
- fault finding in electrical components
  - ▶ in idle state
  - ▶ under mains voltage

## ET 172

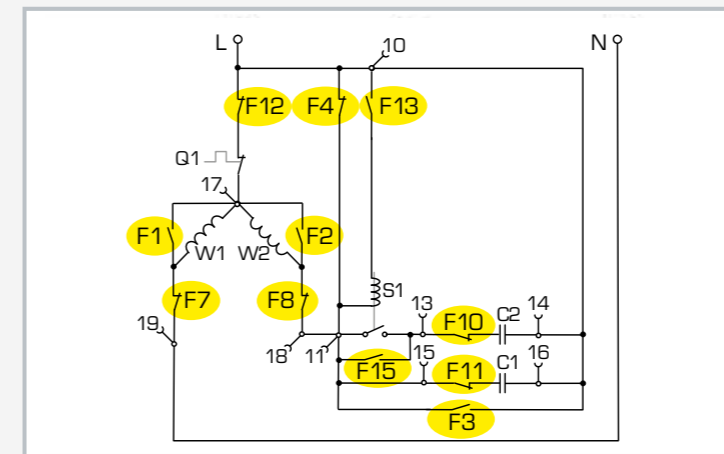
### Electrical faults in refrigerant compressors



1 operating capacitor, 2 buttons for faults, 3 start-up relay, 4 refrigerant compressor, 5 multimeter, 6 main switch, 7 automatic fuse, 8 main contactor, 9 lab jacks, 10 circuit diagram, 11 overheating protection, 12 start-up capacitor



1 automatic fuse, 2 main switch, 3 main contactor, 4 overheating protection, 5 refrigerant compressor, 6 start-up relay, 7 operating capacitor, 8 start-up capacitor



Fault simulation in the compressor: F1, F7 main winding fault, F2, F8 auxiliary winding fault, F3, F10, F11 operating and start-up capacitor fault, F12 overheating protection faulty, F13, F15 start-up relay faulty

#### Specification

- [1] experimental unit from the GUNT practical series for the training of mechatronics engineers for refrigeration
- [2] investigation of the electrical components for the operation of a refrigerant compressor
- [3] real refrigerant compressor from practice
- [4] electrical components for the start and operation of the compressor arranged in the transparent switch cabinet
- [5] general safety devices mounted clearly visible
- [6] circuit diagram depicted on the front panel
- [7] identification of 15 faults: multimeter measures voltages or resistances at the lab jacks
- [8] refrigerant R449A, GWP: 1397

#### Technical data

Refrigerant compressor

- power consumption: approx. 870W

Electrical components for the compressor

- start-up capacitor
- start-up relay
- operating capacitor
- overheating protection (bimetallic)

General safety devices

- main contactor
- automatic fuse

Refrigerant

- R449A
- GWP: 1397
- filling volume: 80g
- CO<sub>2</sub>-equivalent: 0,1t

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 900x400x650mm  
Weight: approx. 60kg

#### Scope of delivery

- 1 experimental unit
- 1 multimeter
- 1 set of instructional material



## ET 174

### Electrical faults in full air conditioning systems



#### Description

- simulation of the electrical circuit of a complex conditioning system with humidifying and heat pump function
- investigation of key electrical components from air conditioning technology
- simulation of 30 faults

Identifying electrical faults in air conditioning systems requires comprehensive knowledge. This knowledge includes the design and operation of the individual electrical components as well as the reading of circuit diagrams. ET 174 helps to acquire this knowledge.

ET 174 demonstrates the electrical circuit of a complex full conditioning system with heat pump function. The control circuits are actually present. The components in the load circuits are simulated (e.g. compressor, heater, four-way reversing valve).

The air conditioning system with heat pump function cools in the summer and heats in the winter. During heating operation the defrost timer introduces a hot gas defrosting by briefly switching the four-way reversing valve. At very low outdoor temperatures an electrical auxiliary heating is activated during heating operation. With low air humidity the hygrometer activates the humidifying function.

Typical protection devices, such as circuit breaker and frost protection monitor, complete the electrical circuit. The operating state of the simulated components is indicated via lamps in the circuit diagram on the front panel.

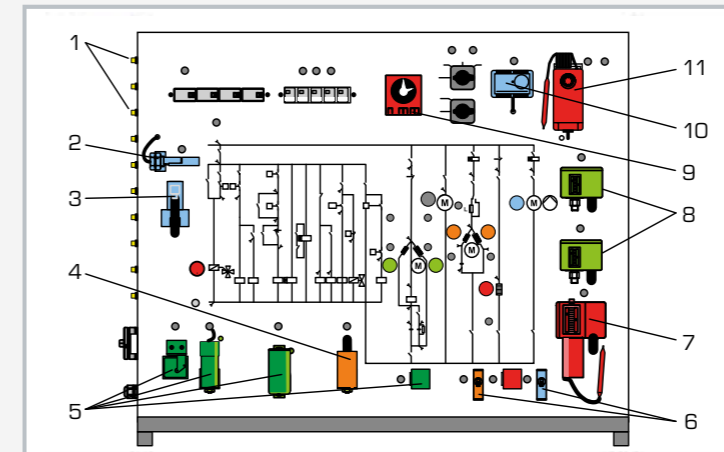
The simulation of 30 different faults, such as coil fracture in the motor or faulty relays, is possible. For fault identification the voltages or resistances at the lab jacks are checked with the multimeter. The depiction of the circuit diagram on the front panel facilitates the allocation of the measuring points.

#### Learning objectives/experiments

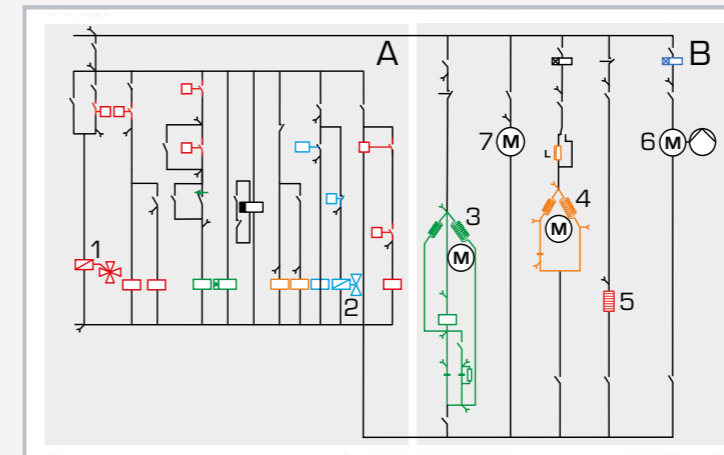
- electrical design and operation of full conditioning systems
- reading and understanding electrical circuit diagrams
- design and operation of electrical components in an air conditioning system
  - ▶ start-up capacitor
  - ▶ start-up relay
  - ▶ operating capacitor
  - ▶ overheat protection
  - ▶ Heinemann circuit breaker
  - ▶ solenoid valve
  - ▶ defrost timer
  - ▶ float switch
  - ▶ thermostat
  - ▶ hygrometer
  - ▶ frost protection monitor
- fault finding in electrical components
  - ▶ in idle state
  - ▶ under mains voltage

## ET 174

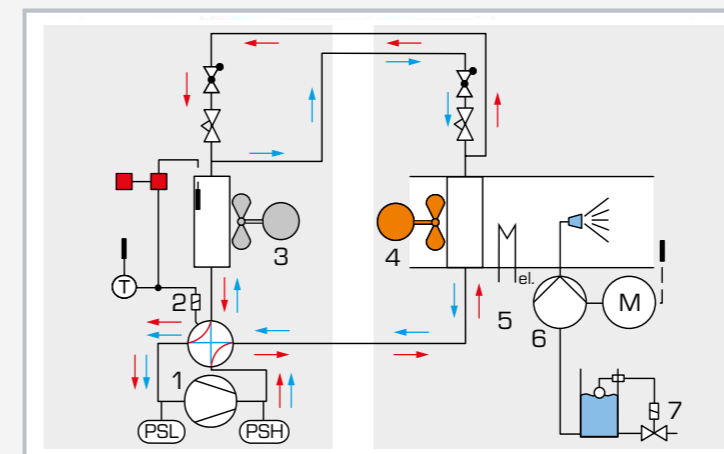
### Electrical faults in full air conditioning systems



1 buttons for faults, 2 float switch, 3 humidifier solenoid valve, 4 room air fan start-up capacitor, 5 electrical compressor components, 6 circuit breaker for room air fan and humidifier pump, 7 frost protection monitor, 8 compressor pressure switch, 9 defrost timer, 10 hygrometer, 11 thermostat



A control circuit, B load circuit; 1 four-way reversing valve heating/cooling, 2 humidifier solenoid valve, 3 compressor, 4 room air fan, 5 auxiliary heating, 6 humidifier pump, 7 outer air fan



Simulated air conditioning system: 1 compressor, 2 four-way valve heating/cooling, 3 outer air fan, 4 room air fan, 5 auxiliary heating, 6 humidifier pump, 7 humidifier solenoid valve

#### Specification

- [1] experimental unit from the GUNT practical series for the training of mechatronics engineers for refrigeration
- [2] simulation of the electrical circuit of a complex conditioning system with humidifier and heat pump function for heating, cooling and humidifying
- [3] real control circuits with electrical components, simulated load circuits
- [4] electrical simulation of compressor, 2 fans (room air, outer air), four-way reversing valve, auxiliary heating
- [5] humidifier with hygrometer, solenoid valve and float switch (pump simulated)
- [6] hot gas defrosting by switching the four-way reversing valve
- [7] operating states of the simulated components indicated via lamps in the circuit diagram
- [8] circuit diagram depicted on the front panel
- [9] identification of 30 faults: multimeter measures voltages or resistances at the lab jacks

#### Technical data

Thermostat to switch between heating/cooling  
 ■ measuring range: 1...60°C

Electrical compressor components

- start-up relay
- start-up capacitor
- operating capacitor
- overheat protection
- 2 pressure switches

Electrical components of room air fan

- start-up capacitor
- Heinemann circuit breaker

Humidifier components

- hygrometer: measuring range 30...100% r.h.
- float switch
- solenoid valve
- Heinemann circuit breaker

Defrosting components

- frost protection monitor: -10...12°C
- timer: switching time 10...60min

Circuit breaker for auxiliary heating

230V, 50Hz, 1 phase  
 230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
 UL/CSA optional  
 LxWxH: 1050x400x860mm  
 Weight: approx. 48kg

#### Scope of delivery

- 1 experimental unit
- 1 multimeter + set of accessories
- 1 set of instructional material

## ET 170

### Electrical faults in simple air conditioning systems



#### Description

- simulation of a simple air conditioning system with compressor, fan and thermostat
- investigation of key electrical components from air conditioning technology
- simulation of 15 faults

Identifying electrical faults in air conditioning systems requires comprehensive knowledge. This knowledge includes the design and operation of the individual electrical components as well as the reading of circuit diagrams. ET 170 helps to acquire this knowledge.

ET 170 demonstrates the electrical circuit of a simple air conditioning system, consisting mainly of a refrigerant compressor and fan at the air cooler. The control circuits are actually present. Compressor and fan motor are simulated.

The compressor is controlled via a thermostat. Via a ballast the fan motor speed can be switched in two stages. The start of the compressor motor takes place via a start-up relay and start-up capacitor.

Typical protection devices, such as circuit breaker, complete the electrical circuit. The operating state of the simulated components compressor and fan is indicated via lamps in the circuit diagram on the front panel.

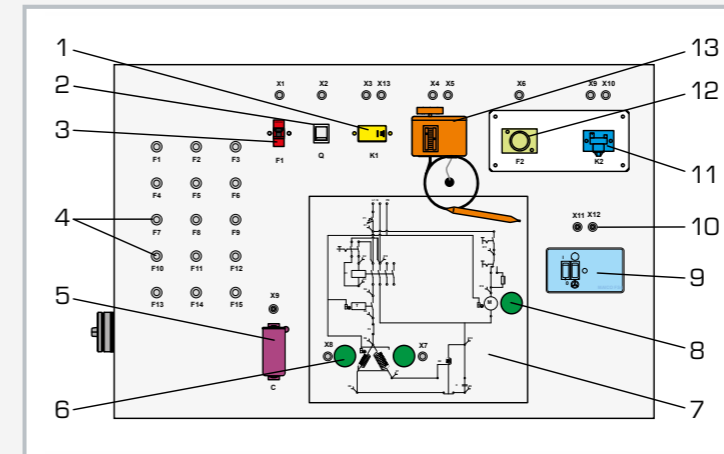
The simulation of 15 different faults, such as coil fracture in the motor or faulty switching contact, is possible. For fault indication, voltages and resistances are checked at the lab jacks with the multimeter. The depiction of the circuit diagram on the front panel facilitates the allocation of the measuring points.

#### Learning objectives/experiments

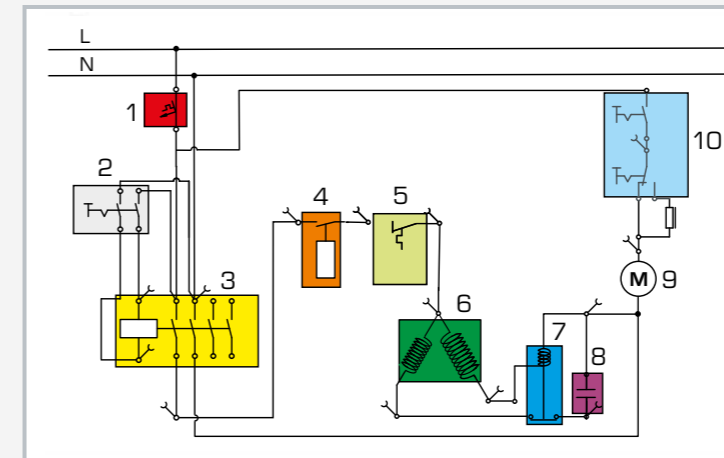
- electrical design and principle of operation of simple air conditioning systems
- read and understand electrical circuit diagrams
- design and operation of electrical components in an air conditioning system
  - ▶ start-up capacitor
  - ▶ start-up relay
  - ▶ overheat protection
  - ▶ main contactor
  - ▶ automatic fuse
  - ▶ on/off switch
  - ▶ speed switch
  - ▶ thermostat
- fault finding in electrical components
  - ▶ in idle state
  - ▶ under mains voltage

## ET 170

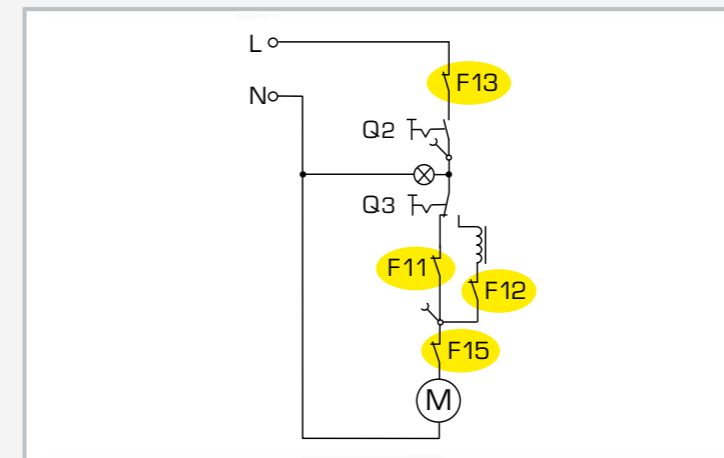
### Electrical faults in simple air conditioning systems



1 main contactor, 2 main switch, 3 automatic fuse, 4 buttons for faults, 5 start-up capacitor, 6 lamp for simulated compressor, 7 circuit diagram, 8 lamp for simulated fan, 9 fan switch, 10 lab jacks, 11 start-up relay, 12 overheat protection, 13 thermostat



1 automatic fuse, 2 main switch, 3 main contactor, 4 thermostat, 5 overheat protection, 6 simulated compressor, 7 start-up relay, 8 start-up capacitor, 9 simulated fan, 10 fan switch



Faults in the fan: F11 high speed faulty, F12 low speed faulty, F13 no power supply, F15 fan motor faulty

#### Specification

- [1] experimental unit from the GUNT practical series for the training of mechatronics engineers for refrigeration
- [2] simulation of the electrical circuit of a simple air conditioning system for cooling
- [3] real control circuits with electrical components, simulated load circuits
- [4] electrical simulation of compressor and fan
- [5] temperature control with thermostat and compressor
- [6] fan with 2 adjustable speeds
- [7] operating states of the simulated components indicated via lamps in the circuit diagram
- [8] circuit diagram depicted on the front panel
- [9] identification of 15 faults: multimeter measures voltages or resistances at the lab jacks

#### Technical data

Simulated compressor  
■ start-up current: > 3A

Electrical components for the compressor  
■ start-up capacitor  
■ start-up relay  
■ overheat protection (bimetallic)

Electrical components for the fan  
■ on/off switch  
■ speed switch

Thermostat: -5...35°C

General safety devices  
■ main contactor  
■ automatic fuse

230V, 50Hz, 1 phase  
230V, 60Hz, 1 phase; 120V, 60Hz, 1 phase  
UL/CSA optional  
LxWxH: 900x400x650mm  
Weight: approx. 30kg

#### Scope of delivery

- 1 experimental unit
- 1 multimeter
- 1 set of instructional material



## Symbols and terms

In refrigeration and air conditioning technology standardised symbols are used for process schematics. For refrigeration, the standard EN 1861 Refrigeration Systems and Heat Pumps applies, and for air conditioning technology, the standard

DIN 1946 Ventilation and Air Conditioning Technology applies. This page introduces the most frequent symbols used in this catalogue. The list only provides an extract of the available symbols.

Refrigeration			
Compressors and pumps			
	Compressor, general		Axial fan
	Piston compressor		Pump, general with motor
	Scroll compressor		Centrifugal pump
	Jet compressor		Piston pump
Heat exchangers			
	Heat exchanger, general		Plate heat exchanger
	Finned tube heat exchanger		Air-cooled finned tube heat exchanger with axial fan
	Tubular heat exchanger		Wet cooling tower with aspirating axial fan
Tanks			
	Tank, general		Collector, pressure vessel
	Tank with electric heater		

Shut-off and expansion elements			
	Valve, general		Valve with continuous adjusting behaviour
	Ball valve		Adjustment valve with drive
	Non-return valve		Thermostatic expansion valve with capillary sensor
	Safety valve		
	Liquid filter		Sight glass with humidity indicator
	Fixed bed filter, e.g. filter/drier		
	Separator, general		Constant pressure valve such as intake pressure controller, evaporation pressure controller or capacity controller
	Baffle plate separator		
Air conditioning technology			
	Distribution chamber		Air cooler, general
	Mixing chamber		Air cooler with direct evaporator
	Filter element		Steam humidifier, electrically heated
	Sound insulation		Spray humidifier with mist collector and pump
	Divided flap, motorised		Water chiller set with compression refrigeration system
	Fire protection flap		
	Axial fan		Air heater, electrically heated
	Radial fan		Steam boiler
Measuring and control technology			
	Measuring points for: Pressure (P) Temperature (T) Level (L)		Pressure switches for high pressure (PSH) and low pressure (PSL)
			Control unit for level with signal path

# The complete GUNT programme – equipment for engineering education



# 1

## Engineering mechanics and engineering design

- statics
- strength of materials
- dynamics
- machine dynamics
- engineering design
- materials testing



# 2

## Mechatronics

- engineering drawing
- cutaway models
- dimensional metrology
- fasteners and machine parts
- manufacturing engineering
- assembly projects
- maintenance
- machinery diagnosis
- automation and process control engineering



# 3

## Thermal engineering

- fundamentals of thermodynamics
- thermodynamic applications in HVAC
- renewable energies
- thermal fluid energy machines
- refrigeration and air conditioning technology



# 4

## Fluid mechanics

- steady flow
- transient flow
- flow around bodies
- fluid machinery
- components in piping systems and plant design
- hydraulic engineering



# 5

## Process engineering

- mechanical process engineering
- thermal process engineering
- chemical process engineering
- biological process engineering
- water treatment



# 6

## 2E Energy & environment

- Energy**
- solar energy
  - hydropower and ocean energy
  - wind power
  - biomass
  - geothermal energy
  - energy systems
  - energy efficiency in building service engineering
- Environment**
- water
  - air
  - soil
  - waste

Planning and consulting · Technical service  
Commissioning and training



## Allocation of GUNT units by subject areas for training as a mechatronics engineer for refrigeration



### Refrigeration

Subject area	Code (page)	Subject area	Code (page)	
Functional interrelationships in the refrigeration circuit	ET 101 (16)	Heat exchangers	ET 431 (98)	
	ET 102 (140)		ET 405 (100/144)	
	ET 400 (32)		ET 499.30 (120)	
	ET 411C (28)	Compressors	ET 165 (90)	
	ET 350 (30)		ET 192 (128)	
	ET 352 (20/160)		ET 428 (94)	
	ET 900 (38)		ET 432 (92)	
	ET 910 (40)		ET 499.01 (121)	
	ET 910.10 (42)		ET 499.02 (121)	
	ET 910.11 (44)		ET 499.03 (121)	
	ET 915.01 (64)	Piping	MT 210 (126)	
	ET 915.02 (66)		ET 460 (118)	
	ET 480 (24/166)		ET 499.12 (121)	
	ET 120 (18)		ET 499.13 (121)	
	ET 122 (22)		ET 499.14 (121)	
	ET 405 (100/144)		ET 499.16 (122)	
	HL 320.01 (146)		ET 499.21 (122)	
	ET 256 (158)		ET 499.25 (122)	
	Thermodynamics, log p-h diagram	ET 350 (30)	Production of mechanical subsystems	MT 210 (126)
		ET 351C (74)		ET 192 (128)
ET 412C (76)		ET 910 (40)		
ET 430 (78)		ET 910.10 (42)		
ET 441 (80)		ET 910.11 (44)		
ET 420 (152)		Troubleshooting, maintenance and disposal	ET 411C (28)	
ET 256 (158)	ET 412C (76)			
Primary and secondary controllers	ET 180 (108)		ET 192 (128)	
	ET 181 (110)		ET 150.01 (134)	
	ET 182 (112)		ET 150.02 (135)	
	ET 411C (28)	ET 422 (132)		
	ET 422 (132)	MT 210 (126)		
	ET 426 (106)			
	ET 499.18 (122)			
	ET 499.19 (122)			
ET 499.26 (122)				



### Air conditioning

Subject area	Code (page)	Subject area	Code (page)
Investigation of the states of the air	WL 201 (172)	Air conditioning, h-x diagram	ET 915.06 (182)
	WL 320 (176)		ET 915.07 (184)
Basic interrelationships in ventilation and room air conditioning	ET 915.06 (182)		ET 600 (192)
	ET 915.07 (184)		ET 605 (188)
	HL 710 (224)		ET 611 (196)
	WL 312 (220)	Air circuit in the ductwork	HM 280 (204)
HM 220 (212)	HM 282 (206)		
Construction elements and function of the air conditioning system	ET 600 (192)		HM 210 (208)
	ET 605 (188)		HM 240 (216)
	ET 611 (196)		HM 220 (212)
Energy saving	ET 915.06 (182)	HL 710 (224)	
	ET 915.07 (184)	HL 720 (226)	
	ET 450 (198)	ET 428 (94)	
	ET 630 (200)	ET 420 (152)	
		ET 256 (158)	
		HL 313 (164)	



### Electrical engineering in refrigeration and air conditioning technology

Subject area	Code (page)	Subject area	Code (page)
Principles of electrical engineering	ET 144 (232)	Control of refrigeration systems	ET 174 (240)
	ET 171 (234)		ET 441 (80)
Consumers of single phase alternating current	ET 170 (242)		ET 605 (188)
	ET 171 (234)		ET 611 (196)
Protection against electrical hazards	ET 144 (232)		ET 930 (236)
Simple refrigeration controls	ET 144 (232)	Building automation	ET 605 (188)
	ET 171 (234)		ET 611 (196)
	ET 174 (240)		
Electrical drives and fault finding	ET 144 (232)		
	ET 170 (242)		
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	ET 174 (240)		

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air conditioning system	ET 600 (192) ET 605 (188) ET 611 (196) ET 630 (200) ET 915.06 (182) ET 915.07 (184)
air duct	ET 915.06 (182) ET 915.07 (184) HL 720 (226)
air humidity	ET 915.06 (182) ET 915.07 (184) HL 720 (226) WL 201 (172) WL 320 (176)
air vent	HL 720 (226)
ammonia as refrigerant	ET 480 (24/166)
automation of an air conditioning system	ET 605 (188)

<b>C</b>	
capacity controller	ET 182 (112) ET 422 (132) ET 426 (106) ET 910.11 (44)
capillary tube	ET 405 (100/144) ET 915.01 (64) ET 915.02 (66)
change of state of the air	ET 605 (188) ET 915.06 (182) ET 915.07 (184) WL 201 (172) WL 312 (220) WL 320 (176)
characteristic of a Peltier element	ET 120 (18)
climatic chamber	ET 605 (188) ET 611 (196) WL 201 (172)
coefficient of performance	ET 102 (140) ET 350 (30) ET 352 (20/160) ET 400 (32) ET 405 (100/144) ET 420 (152)
cold accumulator	ET 256 (158)
cold production with compressed air	ET 122 (22)
cold production with thermal energy	ET 352 (20/160) ET 480 (24/166)
comparison of characteristic variables of a refrigeration system / heat pump	ET 405 (100/144)
comparison of different expansion elements	ET 181 (110) ET 411C (28) ET 910 (40) ET 915.01 (64) ET 915.02 (66)
compression refrigeration system	ET 102 (140) ET 256 (158) ET 350 (30) ET 400 (32) ET 420 (152) ET 915 (62/180)
compressor pressure ratio	ET 102 (140)
cyclone tube	ET 122 (22)

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defrost control	ET 441 (80)
defrost controller	ET 441 (80)
defrost heater	ET 412C (76) ET 422 (132) ET 426 (106) ET 441 (80) ET 930 (236)
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determination of refrigeration capacity	ET 256 (158) ET 400 (32) ET 420 (152) ET 350 (30)
direct evaporator	ET 600 (192) WL 312 (220)
dry cooling tower	ET 420 (152)

Keyword	Code (page)
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ideal coefficient of performance	ET 102 (140)
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ventilation technology	HL 710 (224) HL 720 (226)
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