Equipment for engineering education

Energy

Renewable energies and energy efficiency

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

Imprint

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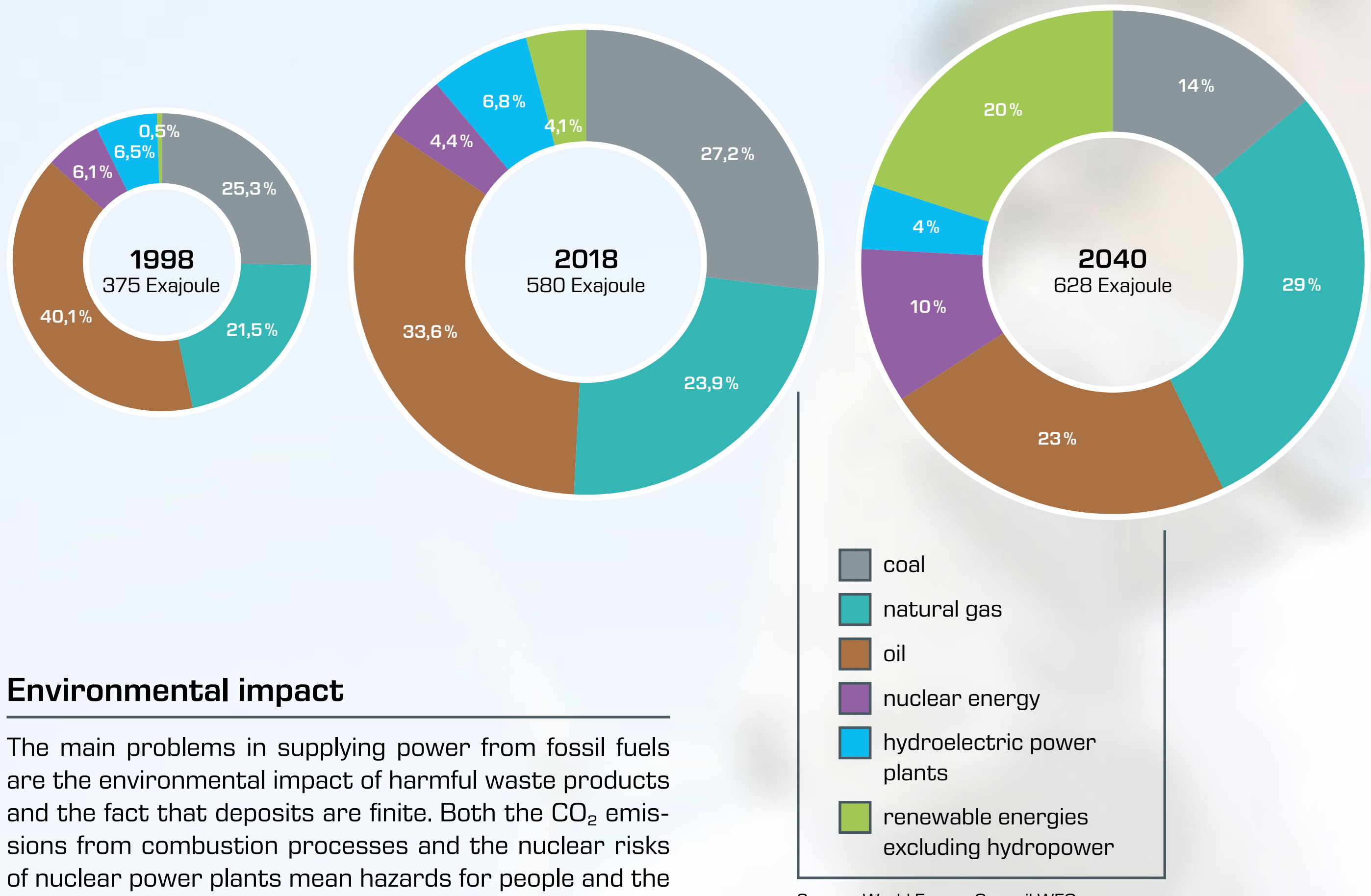
Basic knowledge

Renewable energies and energy efficiency

Rise in global energy consumption

A steadily growing global population and increasing industrialisation have, in recent decades, led to a sharp increase in global energy consumption.

The chart from the World Energy Council (WEC) shows the rising consumption of primary energy from 1998 to 2018 and a forecast for 2040. In the assumed scenario for 2040, it is evident that the total amount of fossil fuels used falls despite a rise in total consumption of primary energy, and that the share of renewable energies rises significantly.



Source: World Energy Council WEC

Environmental impact

The main problems in supplying power from fossil fuels are the environmental impact of harmful waste products and the fact that deposits are finite. Both the CO_2 emissions from combustion processes and the nuclear risks of nuclear power plants mean hazards for people and the ecosystem. Therefore, in addition to covering the energy demand, the main requirement of a future energy supply is the avoidance of waste products.

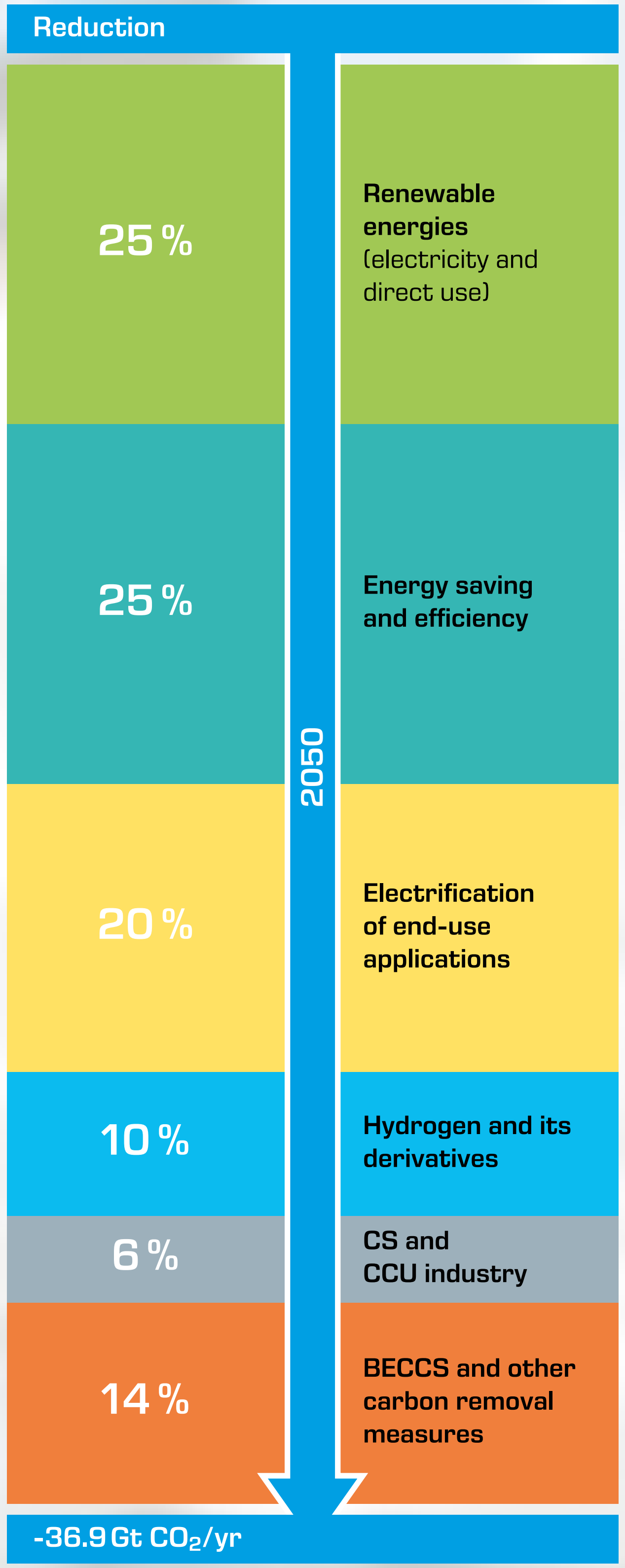
Technological options on the road to the 1.5 degree target

Time is short and emissions of gases harmful to the climate must be drastically reduced with immediate effect in order not to squander the chance of achieving the 1.5°C target. In line with the Intergovernmental Panel on Climate Change (IPCC) report on limiting global warming to 1.5°C by 2050, coal and oil should have already peaked, while natural gas will peak in 2025.

The resources and technologies needed to accelerate the energy transition are already available today.

The chart opposite summarises the results of an IRENA (International Renewable Energy Agency) scenario for achieving the 1.5°C target.

Reduction of CO_2 emissions in the 1.5°C scenario by 2050



The chart shows the contribution that individual measures can make to the global reduction of CO_2 emissions. The target for this IRENA scenario is to achieve a reduction of 36.9 Gt CO_2/yr by 2050.

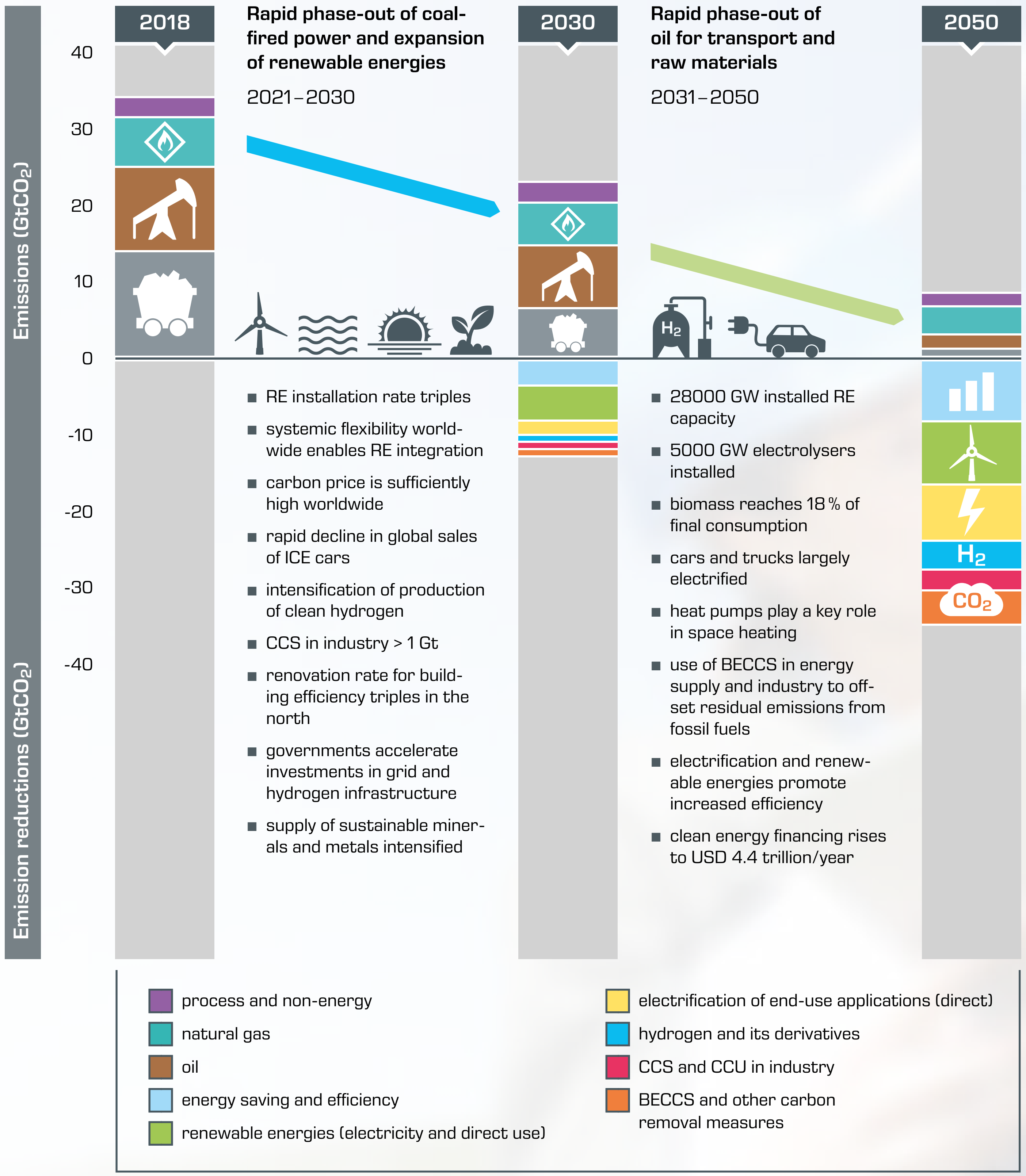
The following page shows in detail the progression over time of the CO_2 reduction through individual measures and renewable energy sources.

CS	Carbon storage
CCU	Carbon capture and utilisation
BECCS	Bioenergy with carbon capture and storage

Basic knowledge

1.5°C Pathway

Reduction of CO_2 emissions with phase-out of coal and oil, 2021 – 2050



RE renewable energy, **VRE** variable renewable energy, **CBAM** Carbon Border Adjustment Mechanism, **ICE** Internal Combustion Engine, **GW** gigawatt, **Gt** gigatonne, **CCS** Carbon Capture and Storage, **BECCS** Bioenergy with carbon capture and storage, **CCU** Carbon Capture and Utilisation

Source: IRENA / 1.5°C Pathway

Efficient use of energy

Besides increasing the share of renewable energies, one considerable challenge lies in the efficient use of available energy. It is only when adequate progress can be made in both areas at the global level that we will succeed in reducing the dangerous output of greenhouse gases to a tolerable level.

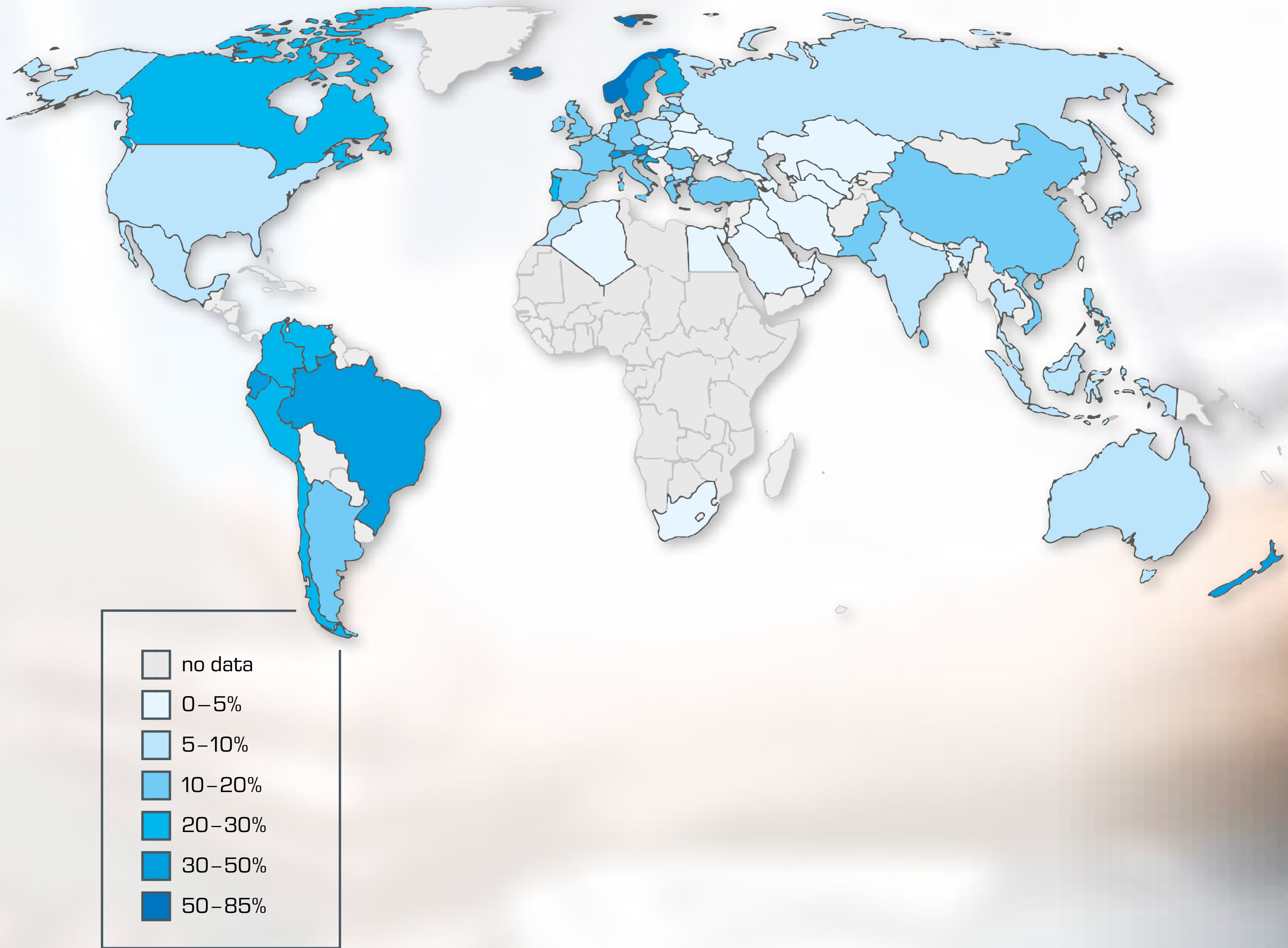
With our carefully structured product range in the Energy area, our intention is to support your efforts in teaching the fully qualified experts required to face up to these challenges.

Energy use in the global context

Climate protection and converting to a sustainable energy supply are tasks that can only be solved in a global context. On the introductory pages to the Solar Energy, Hydropower/Ocean Energy and Wind Power chapters, we offer you a global overview of the availability of the respective energy source in the form of a world map.

The figure below shows a global overview of the regional proportions of all renewable sources in primary energy in 2020.

Percentage of renewable energy in primary energy worldwide



Source: Our World in Data based on BP Statistical Review of World Energy (2020)

Subject areas

Renewable energies and energy efficiency

Energy for the world of tomorrow

Historically, the fields of solar energy, wind power, hydropower, biomass and geothermal energy have emerged from the field of renewable energy engineering. The division of these areas developed out of the various primary sources of renewable energy. Furthermore, we consider the optimisation of energy systems in particular and the improvement of the energy efficiency of buildings especially as the most effective opportunities for more sustainability in the use of energy.

The fundamentals of energy engineering

Knowledge of conventional energy engineering is an important foundation for renewable energies as well. This includes for example, thermodynamics, heat transfer, cyclic processes, steam generation and turbo machines.

Basic knowledge in the field of fluid mechanics is required for understanding wind power and hydropower. Process engineering aspects are an important basis in the field of using biomass to produce energy. Our programme areas include devices that are relevant to these fundamental areas:

Thermal engineering

» Thermal engineering

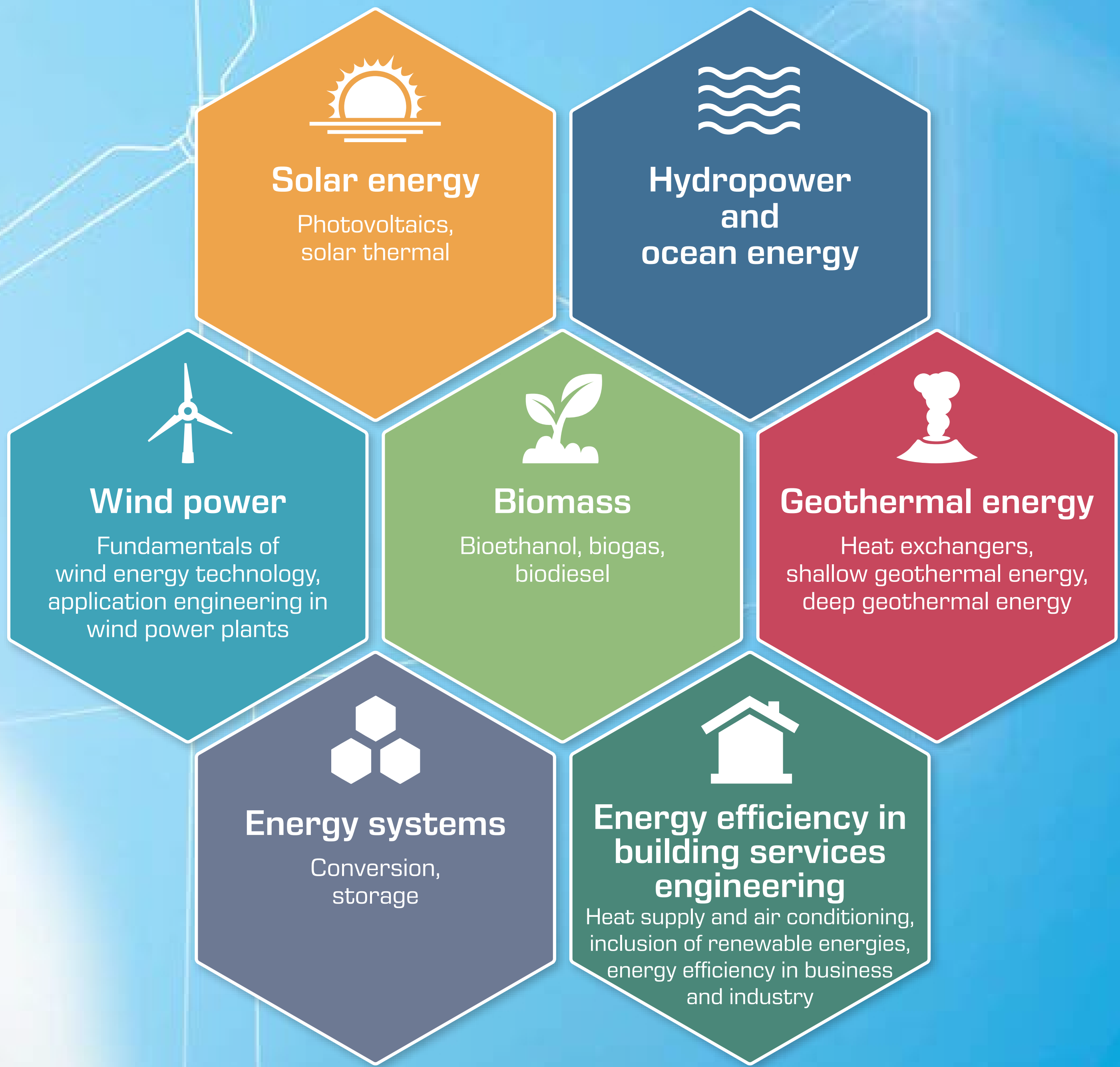
Fluid mechanics

» Fluid mechanics

Process Engineering

»Process engineering

We provide you with the most appropriate teaching systems for putting the areas of the Energy curriculum into practice through experimentation.
The graphic shows the key elements that make up the Energy programme area.



GUNT TECHNOLOGY LIMITED

1 Solar energy

Subject areas
Solar energy

Putting solar energy to good use

In solar energy usage, we distinguish between the areas of photovoltaics, solar thermal energy and solar cooling.

In photovoltaics, electrical energy is generated directly whereas in the case of solar thermal energy, heat is generated first. This heat can either be used directly or converted to electrical energy in large-scale solar power plants by means of heat engines.

Both types of usage compete with each other in the range of a few megawatts of electric power. It is possible to build large photovoltaic installations consisting of several thousand solar modules. However, it is equally conceivable to provide the same power with a concentrating thermal parabolic trough power plant. Which technology is chosen is largely dependent on the planned site and its integration into the supply grid.

The advantage of solar plants for cooling is that the availability of solar energy increases as the demand for cooling increases. Solar cooling concepts gaining popularity both for small decentralised applications and on a large scale.

In order to tap the full potential of solar energy as a sustainable energy supply worldwide, it is essential that we understand and develop sometimes very different concepts of use.

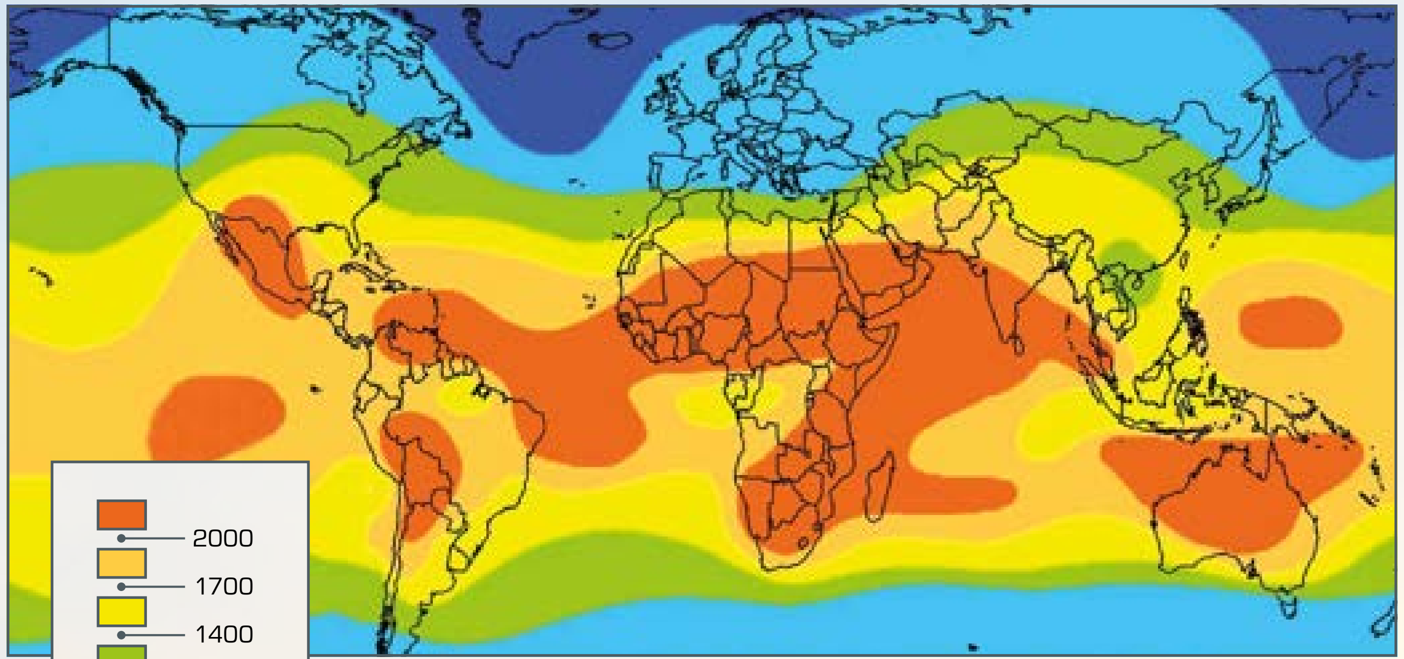
Subject areas	Products
Photovoltaics	
Application engineering 1 – **Correctly installing photovoltaic solar modules**	**ET 250** Solar module measurements **ET 250.01** Photovoltaics in grid-connected operation **ET 250.02** Stand-alone operation of photovoltaic modules
Fundamentals of photovoltaics – **Technological fundamentals of solar cells**	**ET 252** Solar cell measurements
Application engineering 2 – **Investigation and simulation of systems**	**ET 255** Use of photovoltaic modules with hybrid inverter
Solar thermal energy	
Fundamentals of solar thermal energy – **Parameters affecting solar thermal heat**	**ET 202** Principles of solar thermal energy **WL 377** Convection and radiation
Application engineering 1 – **Use of modern collectors**	**HL 313** Domestic water heating with flat collector **HL 314** Domestic water heating with tube collector
Application engineering 2 – **Combined use of renewable heat sources**	**HL 320** Solar thermal energy and heat pump modular system
Concentrating solar thermal energy	**ET 202.01** Parabolic trough collector **ET 203** Parabolic trough collector with solar tracking
Solar cooling	
Use of photovoltaics	**ET 256** Cooling with solar electricity
Use of solar heat	**ET 352.01** Solar heat for refrigeration

Basic knowledge

Solar energy

Energy galore

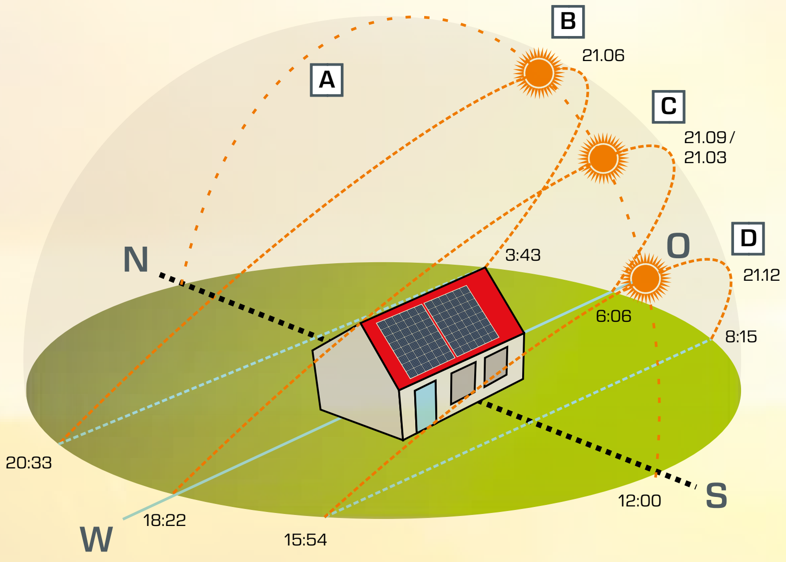
The amount of solar energy that falls on the Earth's land areas in a year is almost 2,000 times greater than the entire world's energy demand. Given the global climate problem, using this potential in the best possible way seems self-evident.



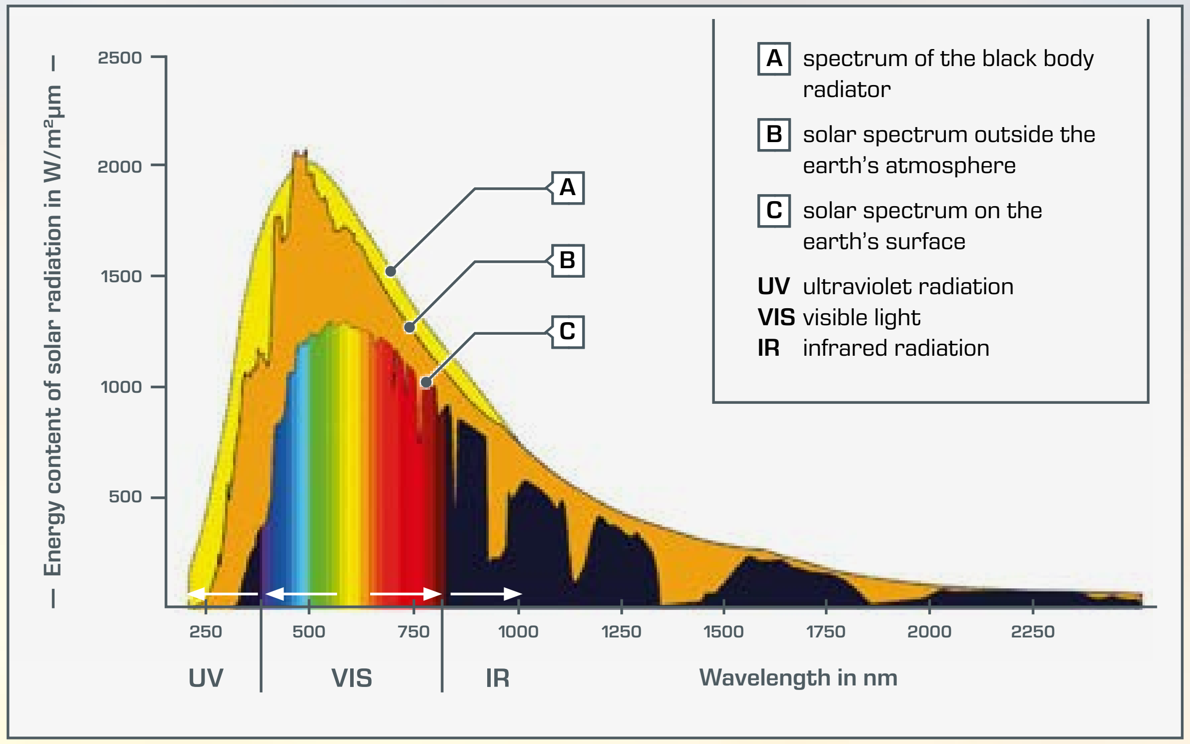
The amount of energy received locally can be stated in kWh/m² and is heavily dependent on the geographical latitude of the location and on meteorological factors. As the map shows, in the Sahara region for example, a quantity of energy of more than 2000 kWh/m² can fall on the earth's surface during a typical year.
(Figure from C. J. Winter, "Die Energie der Zukunft heißt Sonnenenergie")

The orientation of the module surfaces to the cardinal point and their inclination play a significant role in optimising the yield of a solar installation. The illustration shows the path of the sun visible on the Earth at different seasons of the year. The times given for sunrise and sunset are for Berlin:

- A zenith
- B summer solstice
- C beginning of spring/autumn
- D winter solstice



In order to optimise the use of solar radiation, it is first necessary to understand its properties. The spectral composition of sunlight is of particular interest in this regard. Through spectroscopic studies, it is possible to determine the energy content of sunlight at different wavelengths. If one is then able to better adapt the spectral properties of the receiver or absorber to the solar spectrum, then a key condition for improving the energy balance is met.



The spectrum of sunlight

Inside the sun fusion processes lead to temperatures of up to 15 10^6 K. However, the spectrum of emitted sunlight is based on processes in the outer layers of the sun. The spectral composition can be described theoretically by a so-called black body with a surface temperature of 5777K.

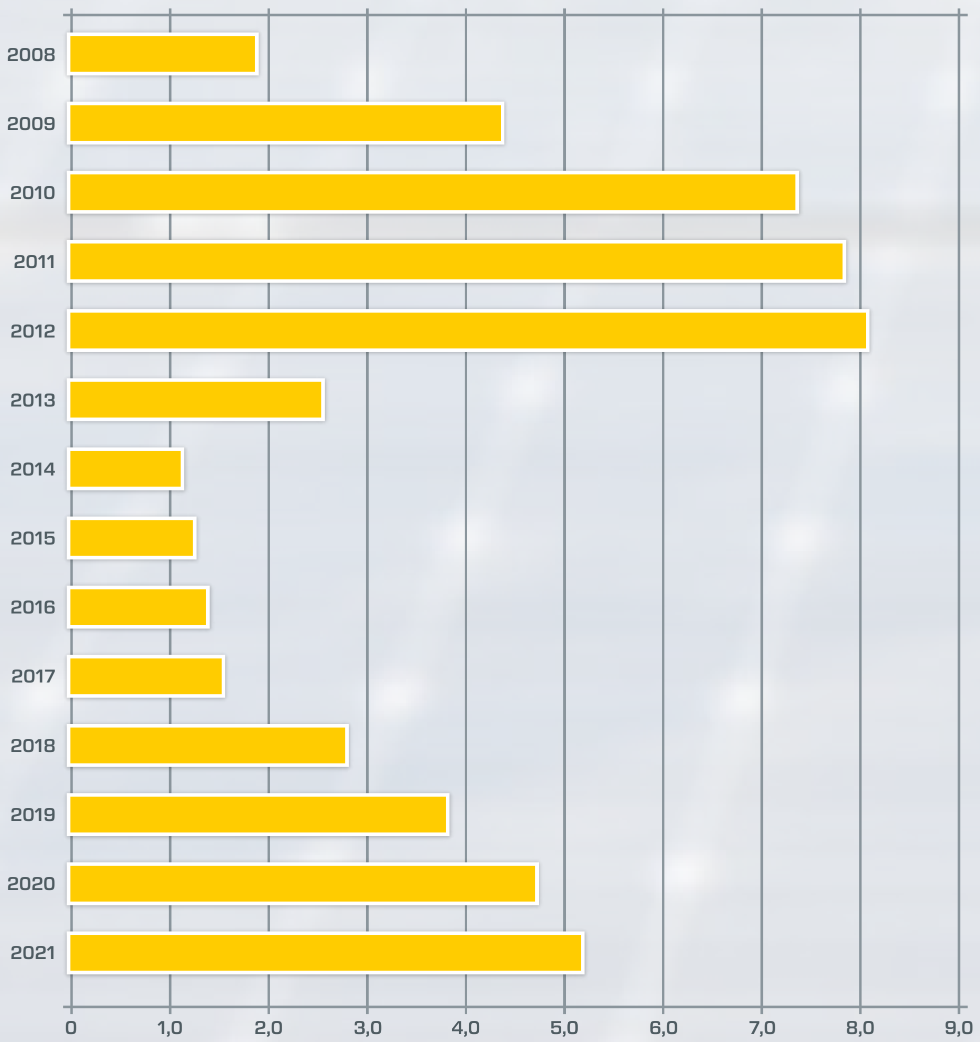
On its way to the earth's surface, the solar radiation is weakened in the atmosphere by scattering and absorption.

Basic knowledge

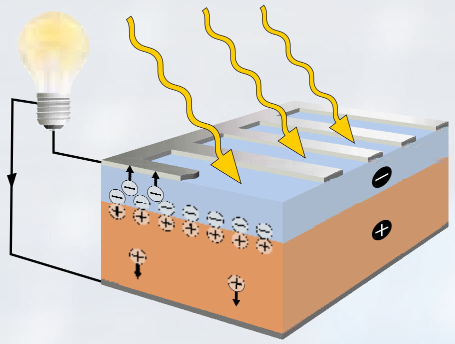
Photovoltaics

In recent years, economic incentives and successful technological developments have led to a significant growth in installed photovoltaic capacity.

The advantages of direct converting light into electricity are well known: solar power contributes to protecting the environment, reduces the cost of electricity transmission and provides an independent and affordable energy supply.



Annually installed photovoltaic capacity in Germany in MW_{pv}
(Source: BSW-Solar)

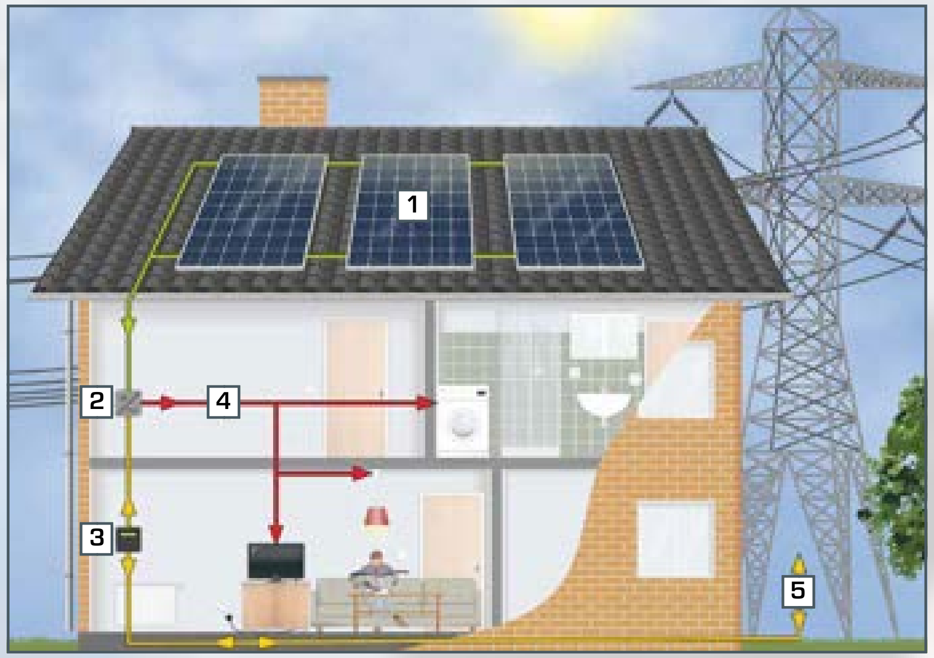


How semiconductor solar cells work

A semiconductor solar cell converts the radiation energy of light into electrical energy. This requires that the absorbed photons have sufficient energy and/or wavelength. An electron can only be released from the bond of the atomic crystal lattice if the absorbed energy in the semiconductor is sufficient. The mobile electron leaves a free space behind in the crystal lattice. This space, known as a hole, has a positive electrical charge and can also move freely in the semiconductor.

In order to be able to use this mobile electrical charge carrier, an electric field is established in the semiconductor by doping it with suitable impurity atoms.

Under the influence of this internal electric field, generated positive and negative charge carriers can be separated in the solar cell. This means it is possible to use the solar cell as a source in an electrical circuit.



1 photovoltaic modules
2 inverter
3 electricity meter
4 connection to consumers
5 feed into grid

Using solar power efficiently

In order to collect the photovoltaic solar power, 36 (for example) individual solar cells are combined into one single module. The subsequent use of the solar power can be divided into different concepts:

- stand-alone operation
- grid-connected operation
- grid-connected operation with storage

Stand-alone operation is suitable for applications in remote locations with no connection to a public power grid. In this case, some kind of storage is crucial for an uninterrupted electricity supply, in order to also be able to use the electrical energy at night, for example.

Grid-connected photovoltaic installations feed the solar power directly into the public grid. This type of setup requires an inverter to convert the direct current of the photovoltaic modules into an alternating current with the appropriate frequency and voltage.

An excess supply of feed-in electricity can cause the public power grid to become unstable. To avoid this effect, there are financial incentives to encourage the private consumption of solar power in Germany. Storage systems are added to the necessary grid-connected photovoltaic installations. By skilfully managing consumption and storage load, the proportion of solar power that is consumed at the point of generation can be increased considerably.

ET 250
Solar module measurements

For laboratory experiments under uniform light conditions, we recommend our artificial light source HL 313.01.
Further information can be found on page 35.

Learning objectives

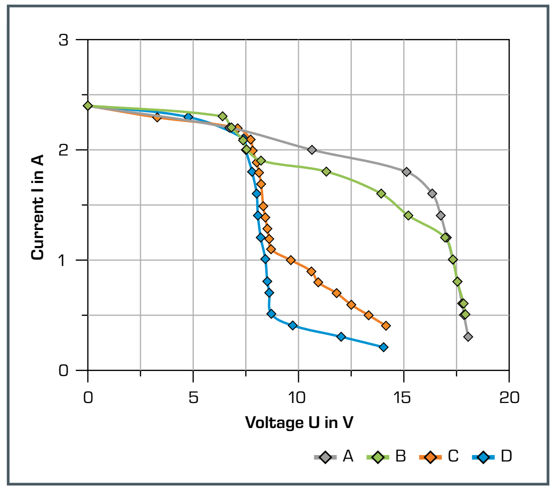
- physical behaviour of photovoltaic modules under varying illuminance, temperature and shading
- familiarisation with key characteristic variables such as short-circuit current, open-circuit voltage and maximum output
- plotting current-voltage curves in parallel and series connection
- influence of the inclination of the solar module
- determining the efficiency

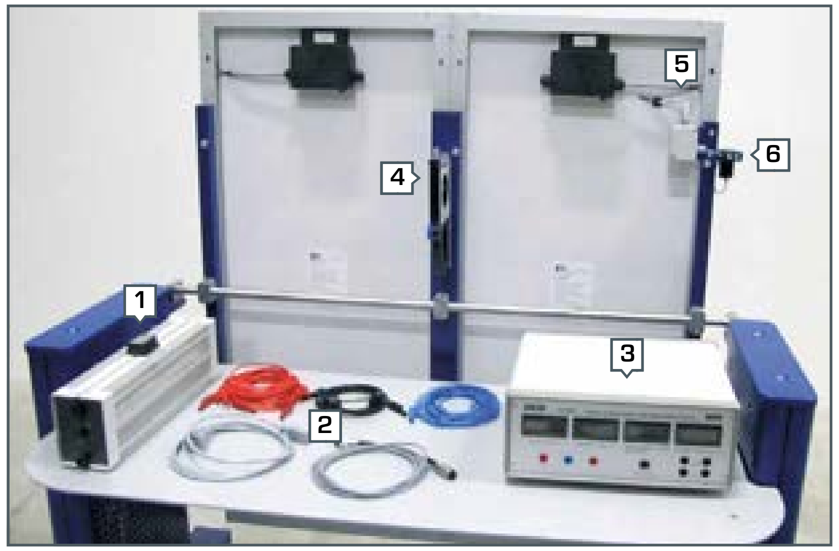
With this trainer, you can practically demonstrate all key aspects in the operation of solar modules. ET 250 has two photovoltaic modules. The modules can be connected either in series or in parallel. You can adjust the tilt angle of the modules individually. A measuring unit is provided for the experiments, which clearly displays all relevant measured values. Current-voltage curves can be created from the measured values. These characteristic curves are an important criterion for assessing the capacity of a photovoltaic system.

About the product:

Experiments in shading

In many places, shading is a major cause of yield losses. ET 250 is also designed for specific experiments on this effect. The results can be compared with documented reference experiments. The figure shows current-voltage curves for different shading levels of individual cells of a module (A, B, C, D).





Accessories and components

1. slide resistor
2. cables sets
3. measuring unit
4. inclinometer
5. temperature sensor
6. illuminance sensor

ET 250.01
Photovoltaics in grid-connected operation

ET 250.01 is designed as an extension module for ET 250 and allows you to meaningfully supplement the learning content of ET 250. ET 250.01 contains practical components from the field of photovoltaics which are needed to use the solar power when connected to a public grid. The inverter works in line-commutated mode and varies current and voltage for maximum output of the solar modules. The quantities of electricity withdrawn or fed in are recorded via a modern bi-directional electricity meter.

Learning objectives

- real-world components from the field of grid-connected solar power usage
- function of direct current switch disconnector and voltage surge protection
- function of a line-commutated inverter with maximum power point tracking (MPPT)
- effect of load on the efficiency of the inverter
- function of modern energy meters
- energy balance in grid-connected operation

About the product:

www

ET 250.02
Stand-alone operation of photovoltaic modules

ET 250.02 is another extension module for ET 250. The unit allows you to teach key aspects of solar energy use in stand-alone systems. ET 250.02 contains all the necessary components: The charge controller monitors the voltage of the battery and optimises the operating point of the photovoltaic modules. Simpler inverters can be used in stand-alone operation, since monitoring of the mains voltage is not necessary.

You can attach the compact ET 250.01 and ET 250.02 extension modules to the main ET 250 unit in just a few steps and simply remove them again in the same way.

Learning objectives

- real-world components from the field of solar power usage in stand-alone operation
- function of direct current switch disconnector and voltage surge protection
- function of a charge controller with maximum power point tracking (MPPT)
- effect of load on the efficiency of the components
- effect of fluctuations in solar energy supply and electricity consumption on system efficiency
- energy balance in stand-alone operation

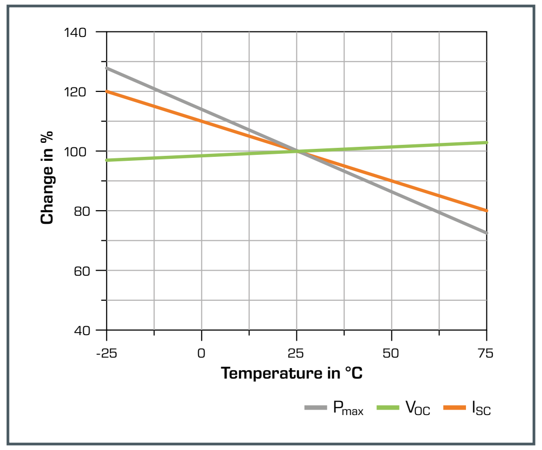
About the product:

www

ET 252
Solar cell measurements

ET 252 allows you to demonstrate the fundamental relationships of photovoltaics in carefully thought out experiments.

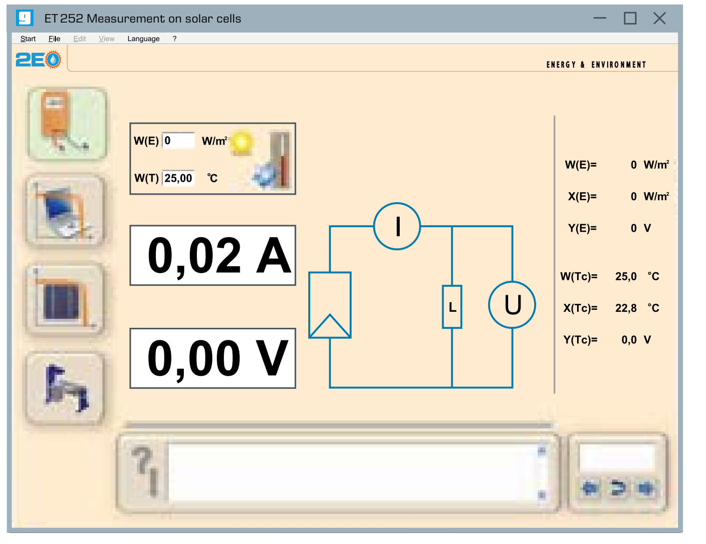
Four solar cells are the main components of the experimental unit. These cells are irradiated with an adjustable lighting unit. A regulated Peltier cooling element selectively controls the temperature of the solar cells. This allows comparative measurements on the influence of temperature on the characteristic variables of the cells.



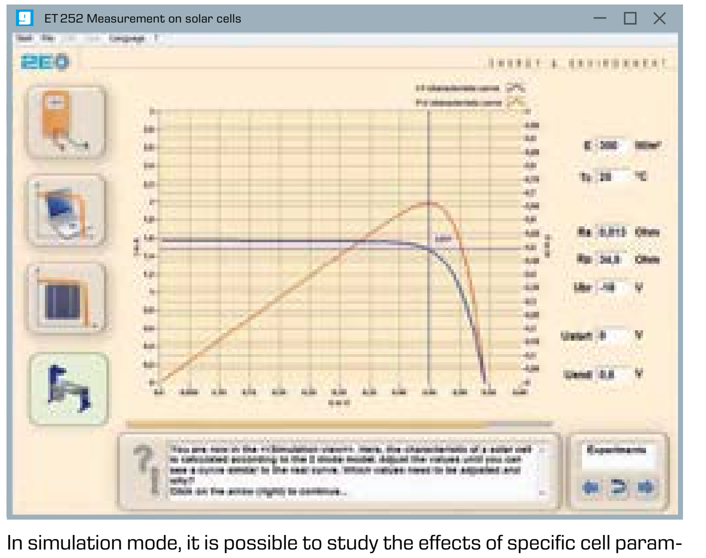
ET 252 allows you to investigate the effect of temperature on the solar cell.

Software with tutorial function

The extensive software can be used to operate all device functions from an external PC or laptop, via a USB interface. Besides controlling the brightness and temperature, it is also possible to configure the automated measurement of the characteristic curve via the controllable current sink.



The software includes an integrated tutorial function that aids the introduction to the fundamentals of photovoltaics in didactically balanced steps and that illustrates the device's various measurement capabilities.



In simulation mode, it is possible to study the effects of specific cell parameters on the current/voltage characteristic.

Learning objectives

- physical behaviour of solar cells under varying illuminance and temperature
- plotting of current-voltage characteristics
- calculation of current strength and achievable output based on the single diode model
- how illuminance and temperature affect the characteristics
- interconnection of solar cells in parallel and serial connection
- effect of bypass diodes
- power degradation due to shading

About the product:

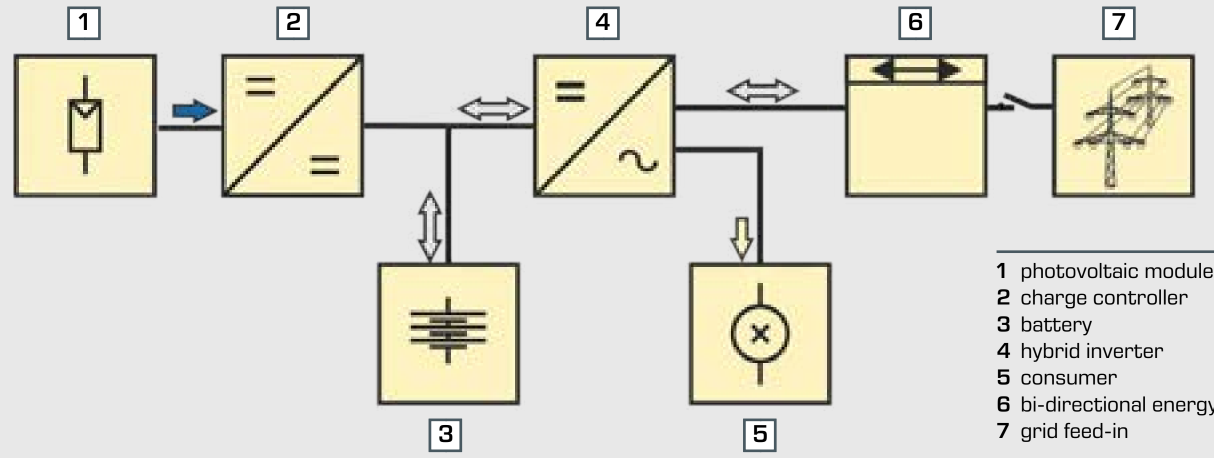
Overview

ET 255 Use of photovoltaic modules with hybrid inverter

Photovoltaic solar electricity can be used both for direct local consumption and for feeding into a public power grid. It is possible to use hybrid inverters that enable the local electricity demand to be covered both by the photovoltaic system and by the grid. Use of solar power for one's own purposes is now politically supported as a way of relieving the public grid and ensuring a more even supply.

The main components of a system for a typical single-family house are shown in the following simplified system diagram.

System components for solar power utilisation

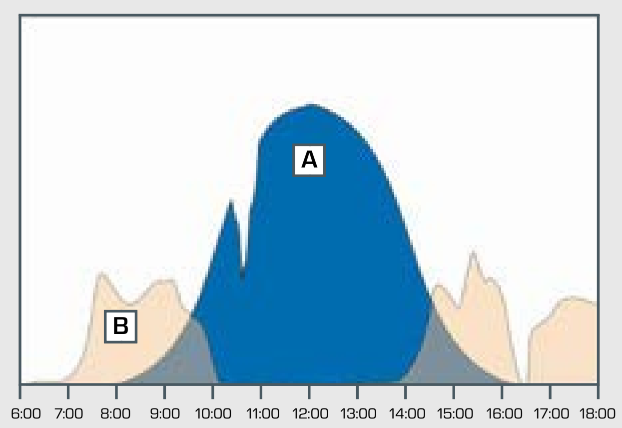


1 photovoltaic modules
2 charge controller
3 battery
4 hybrid inverter
5 consumer
6 bi-directional energy meter
7 grid feed-in

Solar power and electricity demand in a residential building

Typical measurement data for the generated solar electricity and the electricity demand of a residential building throughout a day show the need for stored electricity from batteries. Only batteries make it possible to cover the demand in the morning and evening hours.

For orientation, the energy flows originating from the photovoltaic modules and the battery are colour-coded and can also be assigned in the system diagram.



A electricity generation by photovoltaic modules
B coverage of electricity demand by batteries

For regions with uncertain grid availability, many hybrid inverters offer an emergency power function to ensure local power supply in the event of grid outages. At the same time, any feed-in from the photovoltaic system into the public grid is interrupted when the grid is down.

Experiments with photovoltaic simulator and modern system components

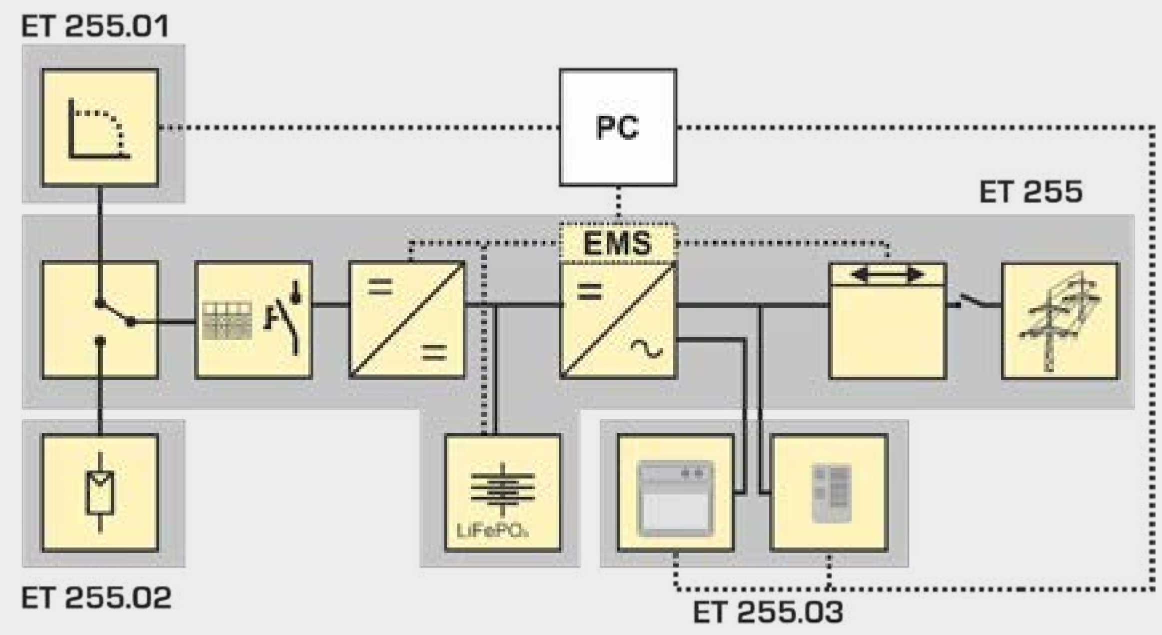
When creating a real-world photovoltaic system, consideration must be given to the regional specifications and safety requirements of the respective grid operator, especially where the system is connected to the grid.

To enable more demanding experiments with modern components from photovoltaic practice, we offer a revised system of experiment modules designed to complement each other. The central module ET 255 contains a hybrid inverter, a lithium iron phosphate battery with charge controller and a bi-directional electricity meter. An Energy Management System (**EMS**) records the energy flows and controls individual components.

Design of the ET 255 equipment series

The ET 255 device can be supplied by the photovoltaic simulator (ET 255.01) or real photovoltaic modules (ET 255.02). The EMS can be used to control consumers with different priorities, which are included on the ET 255.03 experiment module.

The GUNT software on an external PC is used for parametrisation and operation of the photovoltaic simulator and for recording and displaying the measured values. It is also possible to control experiment sequences with defined consumption profiles.



Design of the equipment series ET 255

ET 255
Use of photovoltaic modules with hybrid inverter

ET 255.01
Photovoltaic simulator

ET 255.02
Photovoltaic modules

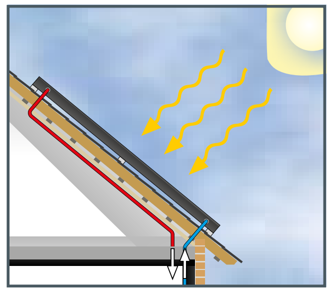
ET 255.03
Consumers for photovoltaic systems

Learning objectives

- modern photovoltaic use with own-consumption and storage
- power optimisation through Maximum Power Point Tracking
- efficiency and dynamic behaviour of system components
- Energy Management Systems (EMS)
- simulation of diurnal variations (meteorological data and consumption profiles)
- system operation during grid outage

Basic knowledge

Solar thermal energy



Solar thermal energy is defined as using solar power to provide heat. The heat can be used for heating in the home and for heating domestic water, as well as for process heat in industry and for steam generation in power stations and even for cooling.

Typical applications for solar thermal collectors:

- heating water in swimming pools
- low-temperature heat for heating rooms
- domestic water heating
- process heat (concentrated solar power)
- electricity generation (concentrated solar power)

Collector types

Heating water in swimming pools
20°C...30°C

Domestic water heating with complementary heating
20°C...200°C

Non-concentrating collectors

- Absorber (plastic)
- Absorber (stainless steel)
- Flat collector
  - Vacuum flat collector
  - Storage collector
- Vacuum collector
  - Vacuum flat collector
  - Vacuum tube collector
    - Direct throughflow
    - Heat pipe
    - With reflector
    - Without reflector
    - Dry connection
    - Wet connection

Collector types for various applications

The main part of any solar thermal installation is the solar collector. Different types of collectors are used, depending on the application. First of all, a distinction is made between non-concentrating and concentrating collectors. In concentrating collectors, mirrors or lenses are used to optically focus the sunlight onto an absorber.

Process heat, power generation in power plants
20°C...4000°C

Concentrating collectors

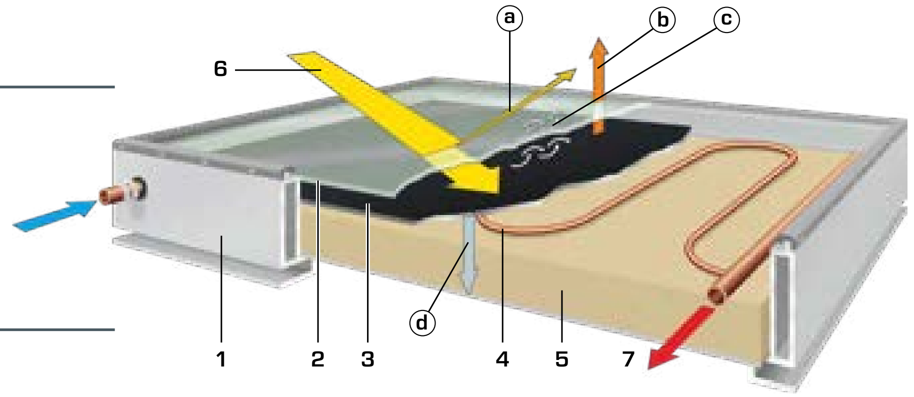
- With line focusing: Parabolic trough collector, Fresnel collector, CPC collector
- With point focusing: Paraboloidal collector, Central receiver (solar tower), Solar oven

Flat collector

A widely used non-concentrating solar collector type is the flat collector. It represents a balanced compromise between a simple, cost-effective design and efficiency.

The back is insulated against heat loss. The copper tube can be fed through the collector in different ways. The absorber may be made of copper, aluminium, or steel. The absorber's dark colour is caused by the selective coating. The glass cover is made of high-quality, low-iron solar glass with a low absorption factor.

In the design, a compromise is sought between good heat transfer through turbulent flow and a low pressure loss. The flat collector is mainly used for hot water preparation and heating support.



Design

1 collector frame
2 solar glass cover
3 absorber
4 copper tube as heat transfer fluid
5 thermal insulation
6 incident solar radiation
7 generated heat at the collector outlet

Main losses

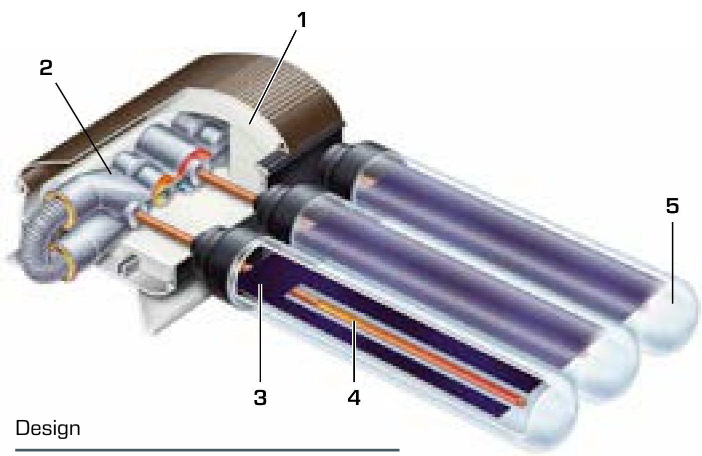
a losses through reflection
b thermal radiation losses
c losses through convection
d losses through heat conduction

Tube collector

While flat collectors are simple in design, tube collectors are made up of technically more complex individual components. The use of double-walled, airless glass tubes (vacuum tubes) prevents heat loss through convection. The glass tubes contain absorbers that are provided with a spectrally selective coating. In so-called heat pipe collectors, the heat transfer from the absorber to the solar circuit takes place through evaporation and condensation of an evaporation liquid in a sealed transfer pipe. The generated heat is transferred to the heat transfer fluid in the solar circuit and from there reaches the consumer or the storage tank.

The efficiency of tube collectors is up to 30 percent higher than that of flat collectors. One advantage of direct-flow tube collectors with a circumferential absorber is that they absorb light from all sides and thus also make better use of diffuse scattered light.

Tube collectors mounted at an optimised angle of incidence on a flat roof



Design

1 thermal insulation
2 tubular heat exchanger outside the heat transfer fluid, dry connection
3 absorber
4 heatpipe
5 glass tube (vacuum)

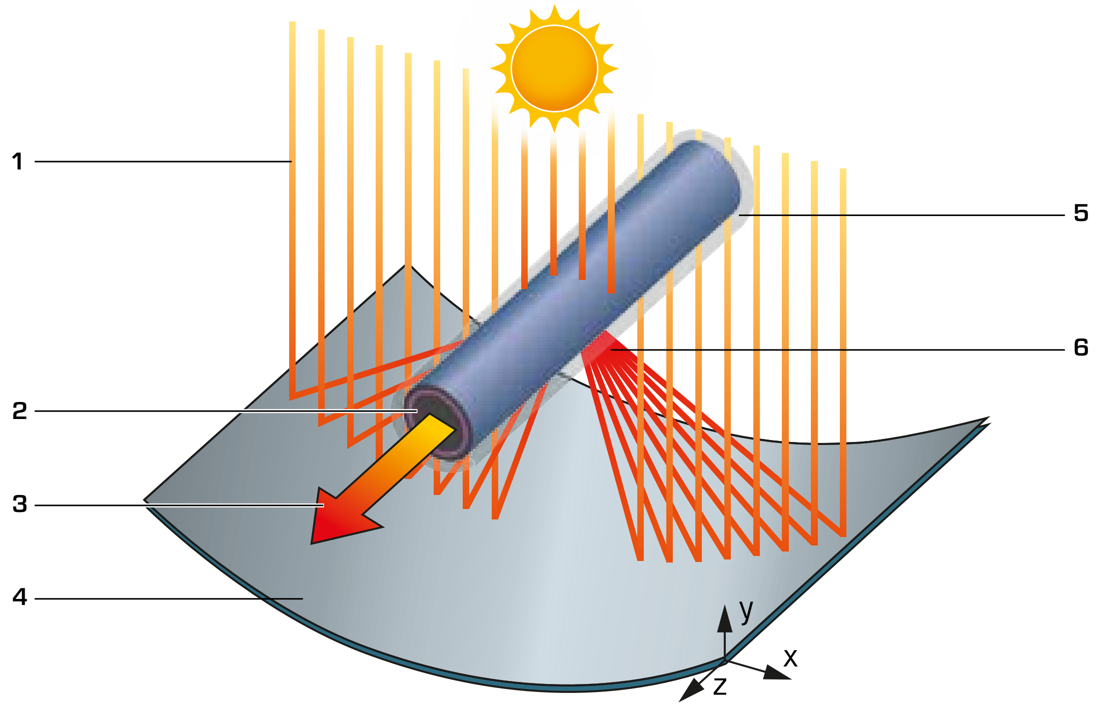
Basic knowledge

Concentrating solar thermal energy

Parabolic trough collector

With concentrating collectors, the irradiation is multiplied optically by mirrors and lenses on the absorber. Since only the direct radiation portion can be concentrated, the use of such systems makes sense in regions with high direct irradiation.

The solar radiation is focused by a parabolic mirror onto an absorber tube. In the process, the radiant energy is absorbed and converted into heat. To reduce heat loss, the absorber pipe is covered with a double-walled glass shell. With the help of a pipe in the absorber, the heat is transferred to a heat transfer fluid in the solar circuit and reaches the storage tank.



Design

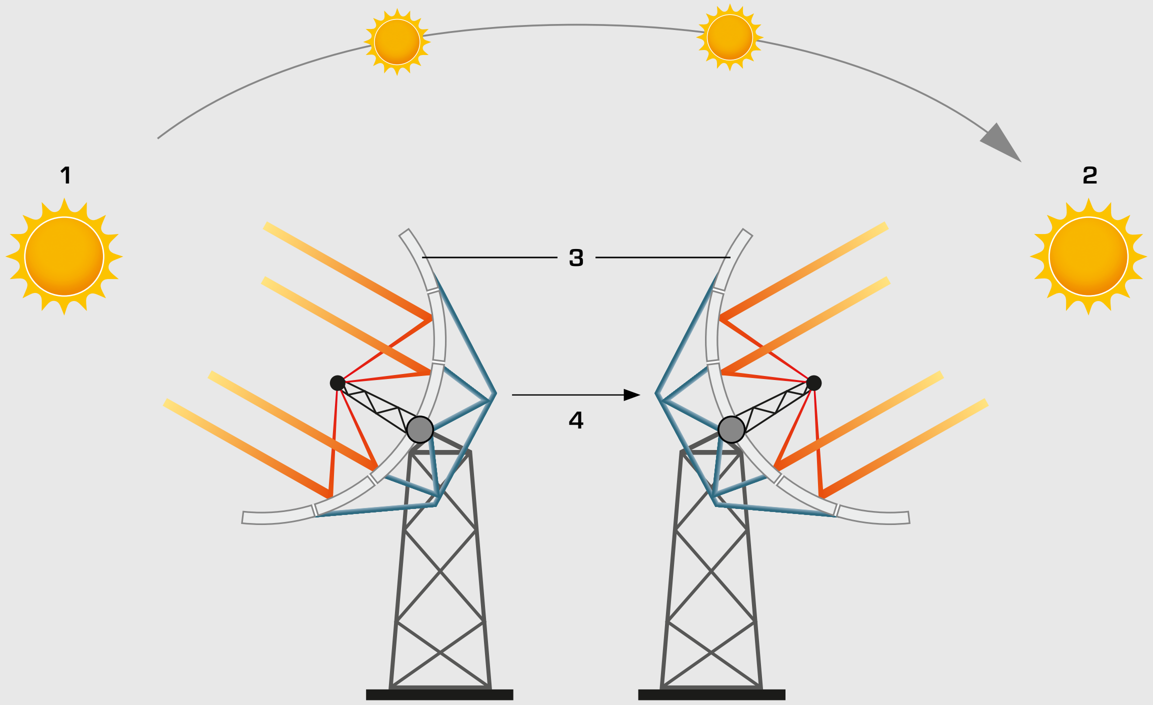
1 incident solar radiatio, **2** absorber tube, **3** heat transfer fluid, **4** parabolic mirror with relflective surface, **5** glass tube, **6** concentrated solar radiation

For a power plant, individual parabolic trough collectors can be connected in a collector field.

Sun tracking

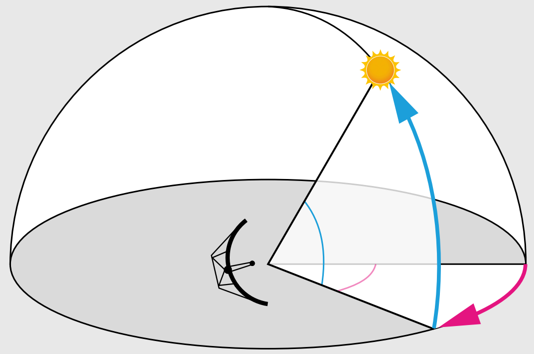
Concentrating systems for solar energy use require tracking of the concentrating optical elements (lenses or mirrors). The orbital and rotational movement of the earth causes the sun's elevation and of the sun's altitude (elevation) and orientation (azimuth). The decisive factors for a single- or double-axis design are the technology used and the geographical location. Large parabolic trough power plants are preferably realised with single-axis tracking at locations with a small geographical latitude.

For so-called tower power plants with point absorbers, the mirrors must be continuously tracked in both directions during the day.



Functional principle of the sun tracking system

1 East, **2** West, **3** pivotable collector with two-axis tracking, **4** position during the day



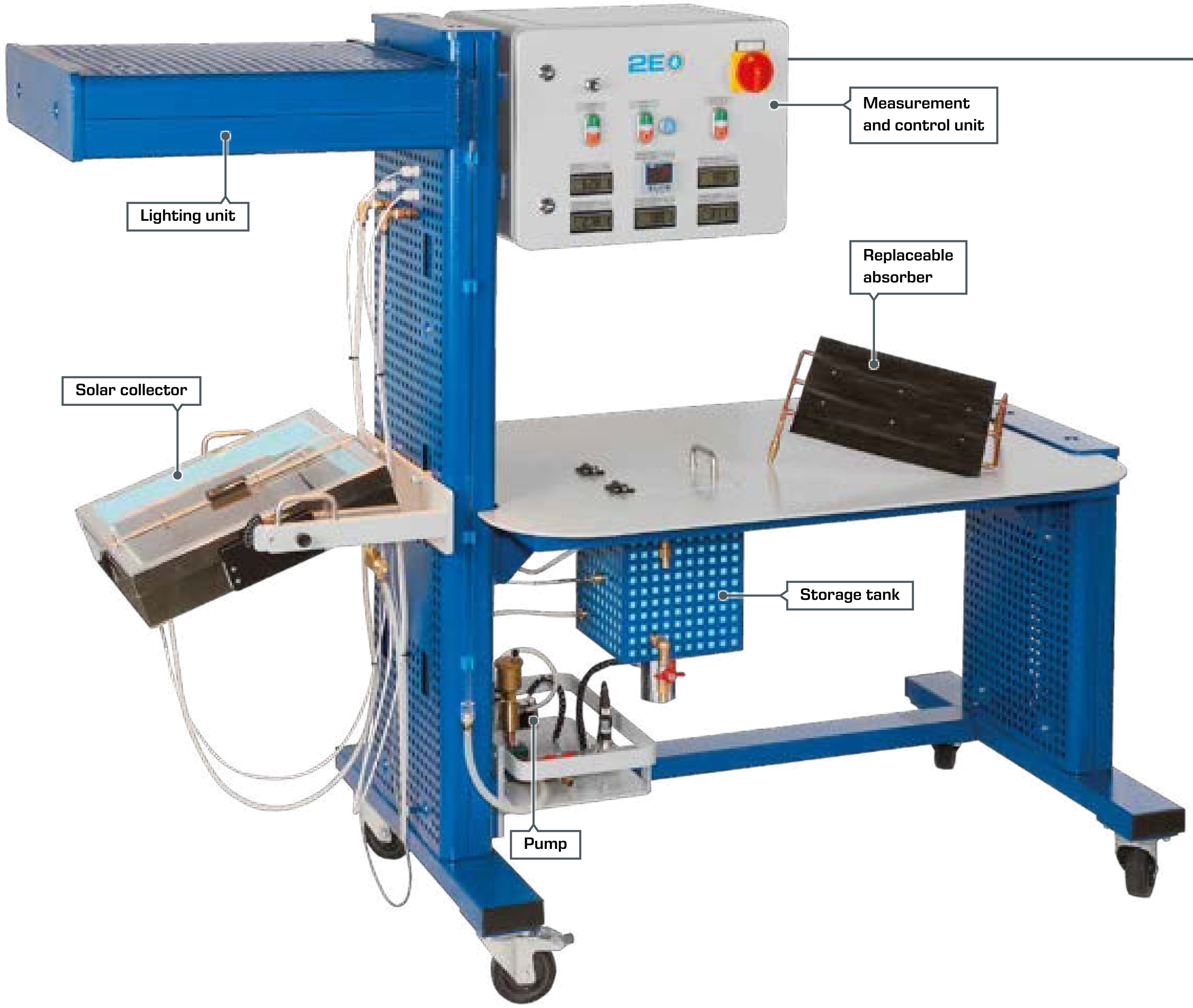
Sun position and angle of incidence

azimuth: horizontal or horizontal angle when adjusting the mirror
elevation: vertical or perpendicular angle when the mirror is adjusted

ET 202
Principles of solar thermal energy

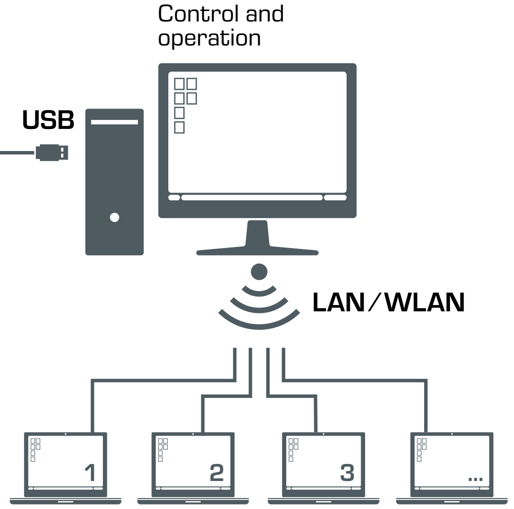
The ET 202 trainer allows you to undertake systematic measurements on a solar thermal system with flat collector. A lighting unit simulates the natural solar radiation. The light is converted into heat in an absorber and transferred to a heat transfer fluid. A pump conveys the heat transfer fluid through a storage tank. There the heat is released to the contents of the tank by an integrated heat exchanger. The pre-installed absorber with selective coating can be replaced for a simpler blackened absorber, to obtain comparative measurements of collector losses. The electric heater in the storage tank shortens the heating times for experiments at higher temperatures.

About the product:



Features

- operation independent of weather conditions
- inclinable flat collector with replaceable absorbers
- network capability: observe, acquire, analyse experiments via customer's own network

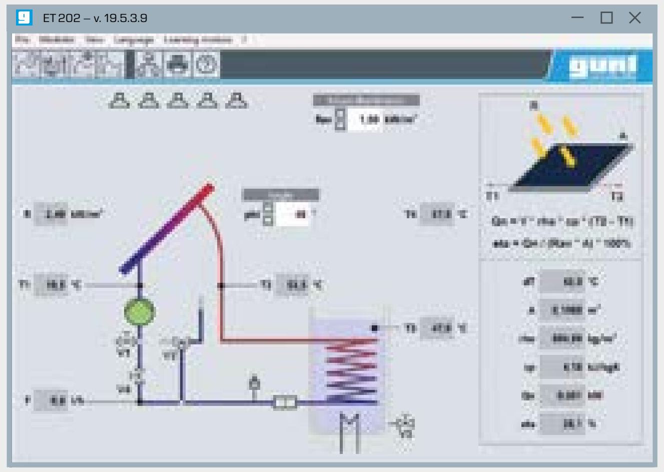


Learning objectives

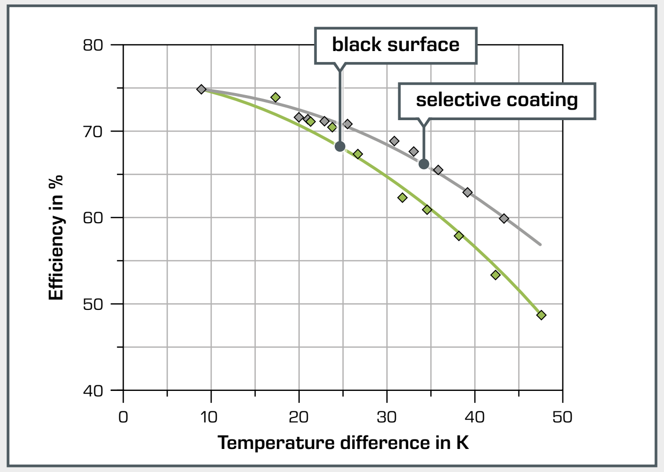
- design and operation of a simple solar thermal system
- determining the net power
- energy balance on the solar collector
- influence of illuminance, angle of incidence and flow rate
- determining efficiency curves
- influence of various absorbing surfaces

Software

The software displays the measured values in a system diagram and enables the recording of individual measuring points or a time function. Stored measurement data can be imported into a spreadsheet programme (e.g. Microsoft Excel) and processed there.



GUNT software for measurement data acquisition via PC



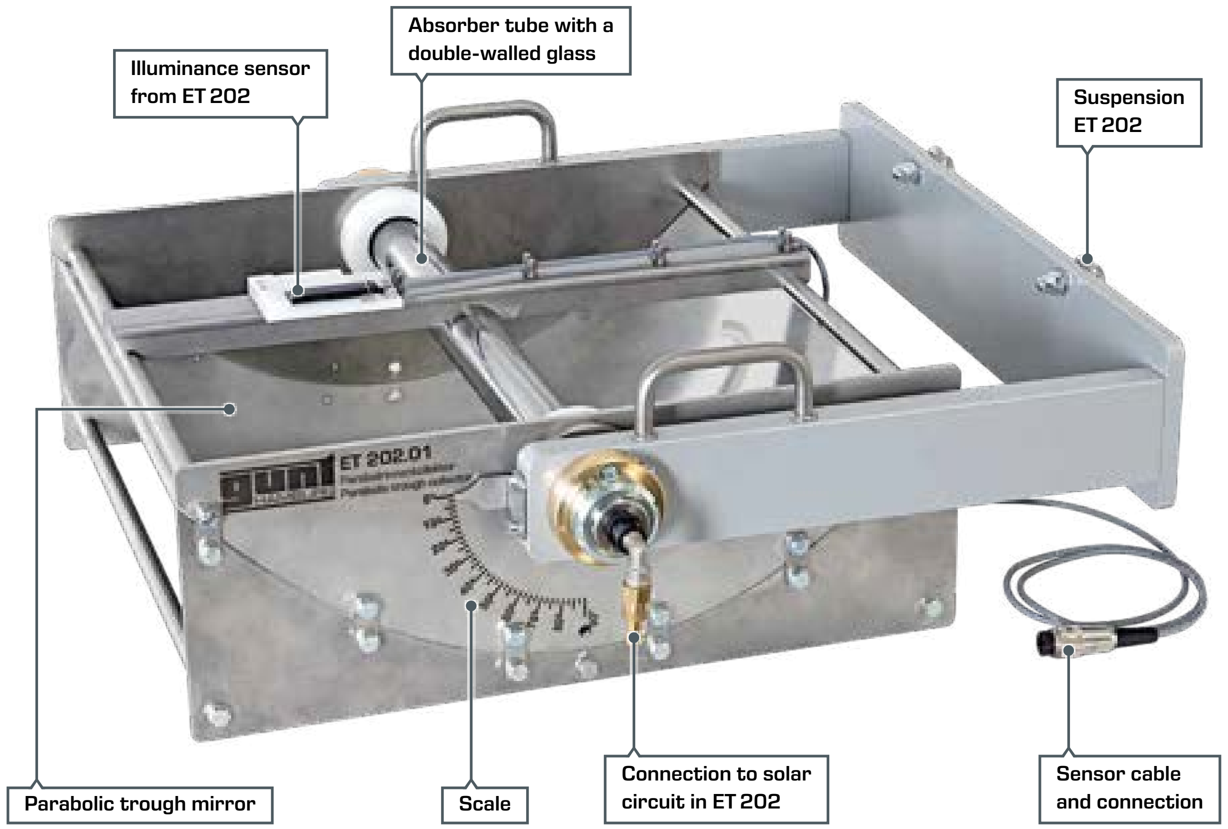
Efficiency depending on the collector temperature.
A special coating of the absorber allows higher efficiencies.

ET 202.01
Parabolic trough collector

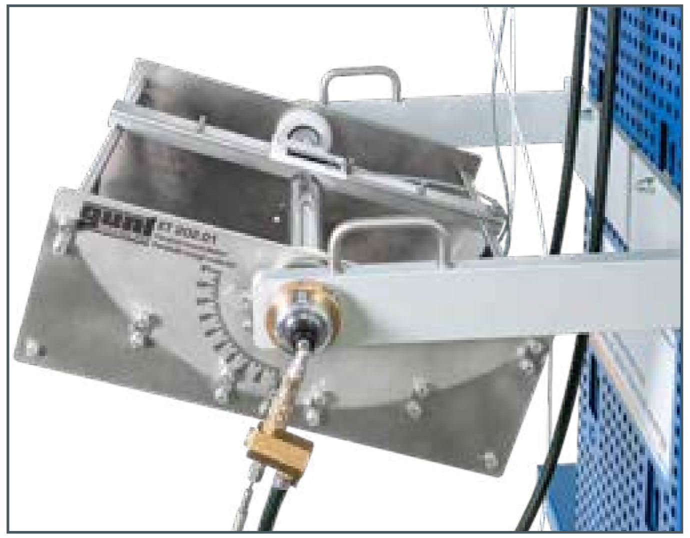
ET 202.01, together with the ET 202 trainer allows you to investigate fundamental aspects of concentrating solar thermal energy use. The light from the lighting unit in ET 202 is focused onto the absorber tube by means of the parabolic mirror. The absorber tube is fitted with a double-walled glass casing to reduce heat losses. The heat is transferred through a pipe in the absorber to a heat transfer fluid in the solar circuit of the ET 202 trainer, where it enters the storage tank.

In experiments, the efficiency of a concentrating parabolic trough collector is directly compared with a classic flat collector.

About the product:




ET 202.01 illuminated with the light source of ET 202


pivoting parabolic trough collector

Learning objectives

- focusing solar radiation with a parabolic trough mirror
- optical concentration factor
- conversion of radiant energy into heat
- losses in thermal solar collectors
- efficiency characteristics

Features

- pivoting parabolic trough collector with highly reflective mirror
- absorber tube with selective coating
- evacuated double-walled glass tube to reduce heat losses


ET 202 together with ET 202.01

WL 377
Convection and radiation

WL 377 allows you to conduct experiments on heat transport under different ambient conditions. In this way you can develop the fundamentals of typical heat transfer processes in a thermal solar collector.

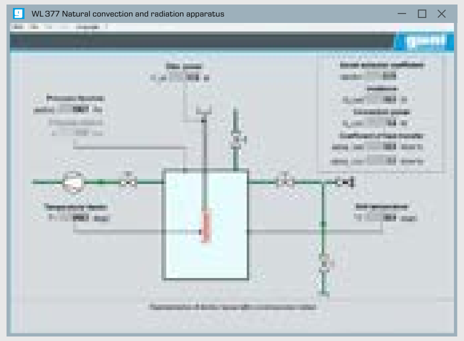
Learning objectives

- heat transfer by convection at ambient pressure
- determining the amount of transferred heat
- heat transfer by radiation in a vacuum
- determining the radiation coefficient

About the product:

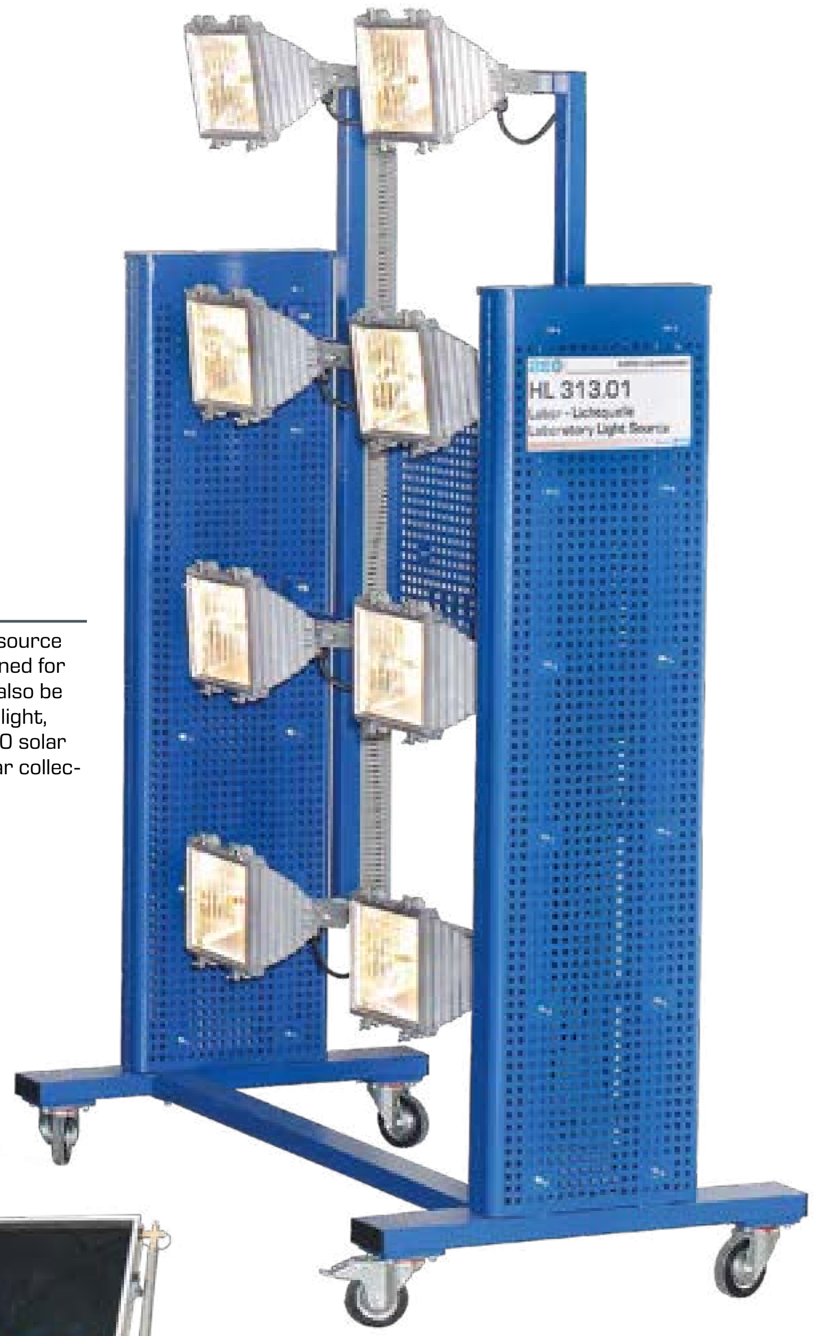
Software

The measurement data can be displayed and logged using the GUNT software.



HL 313.01
Artificial light source

This light source can be used to create reproducible experimental conditions indoors. The light source contains eight halogen spotlights, arranged in two rows. The inclination angle of each halogen spotlight can be adjusted to conduct the respective experiment with incident light that is as perpendicular as possible.



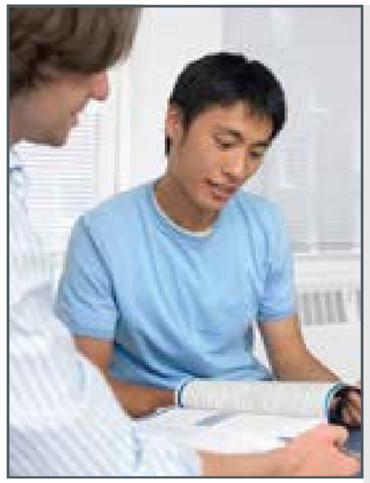
The artificial light source HL 313.01 is designed for trainers that can also be operated with sunlight, such as the ET 250 solar module or the solar collector from HL 313.

The HL 313.01 Artificial light source together with HL 313 flat collector

About the product:

HL 313
Domestic water heating with flat collector

Familiarise yourself with key real-world components from the field of solar thermal domestic water heating with HL 313. From correctly filling with a heat transfer fluid to determining and optimising the net power, the didactic concept includes all important practical and theoretical aspects of modern education.



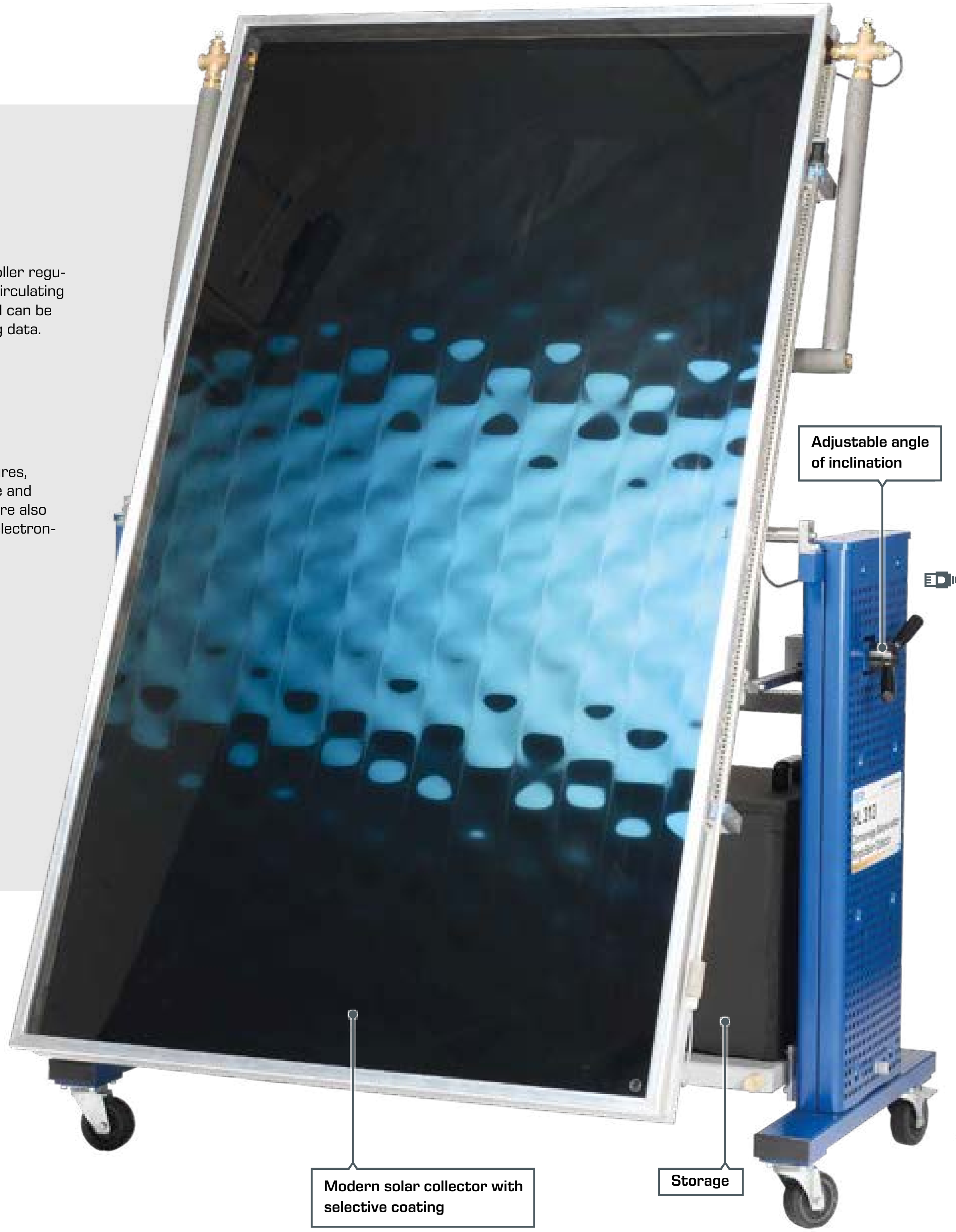
Learning objectives

- functions of the flat collector and solar circuit
- determining the net power
- relationship between flow and net power
- determining the collector efficiency
- relationship between temperature and efficiency of the collector


The controller regulates the circulating pumps and can be used to log data.


Temperatures, illuminance and flow rate are also detected electronically.

The solar circuit station contains a circulating pump and key components for safe operation.



External operation

The solar controller can be operated both by means of control elements on the device and by means of a web browser via an integrated router. The user interface in the web browser also contains the current measured values and can be displayed on any number of end devices.

It is possible to access recorded measured values on Windows-based end devices via a WLAN or LAN connection using the customer's own network. Additional manufacturer software is available for the solar controller for this purpose.

For laboratory experiments under uniform light conditions, we recommend out artificial light source HL 313.01. Further information can be found on page 35.

About the product:

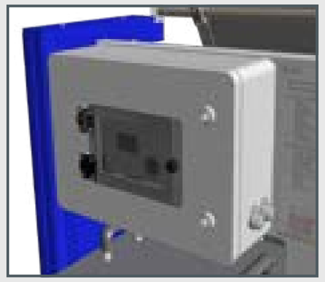
HL 314
Domestic water heating with tube collector

The HL 314 trainer contains modern components from real-world solar thermal heat generation systems. In the evacuated tube collector, the absorbed heat is transferred to a standard heat transfer fluid in the solar circuit. The heat then gets into the hot water circuit via a plate heat exchanger. The solar regulator controls the pumps in the hot water and solar circuits.

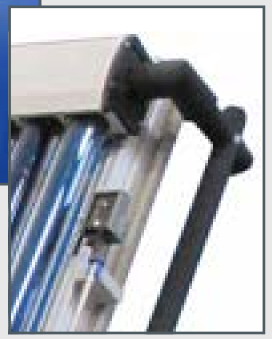
The trainer has been designed so that it is possible to carry out a complete preheating as part of a practical experiment. Experiments can be carried out in the laboratory with the HL 313.01 Artificial light source or outdoors if there is sufficient sunlight.

About the product:

www

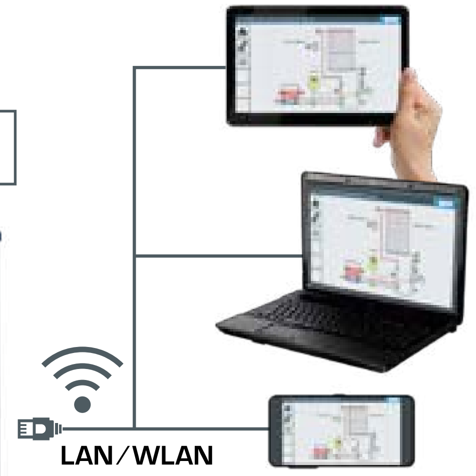


The controller regulates the circulating pumps and can be used to log data.



Temperatures, illuminance and flow rate are also detected electronically.

The solar circuit station contains a circulating pump and key components for safe operation.



External operation

The solar controller can be operated both by means of control elements on the device and by means of a web browser via an integrated router. The user interface in the web browser also contains the current measured values and can be displayed on any number of end devices.

It is possible to access recorded measured values on Windows-based end devices via a WLAN or LAN connection using the customer's own network. Additional manufacturer software is available for the solar controller for this purpose.

Learning objectives

- functions of the tube collector and the solar circuit
- determining the net power
- relationship between flow and net power
- determining the collector efficiency
- relationship between temperature and efficiency of the collector

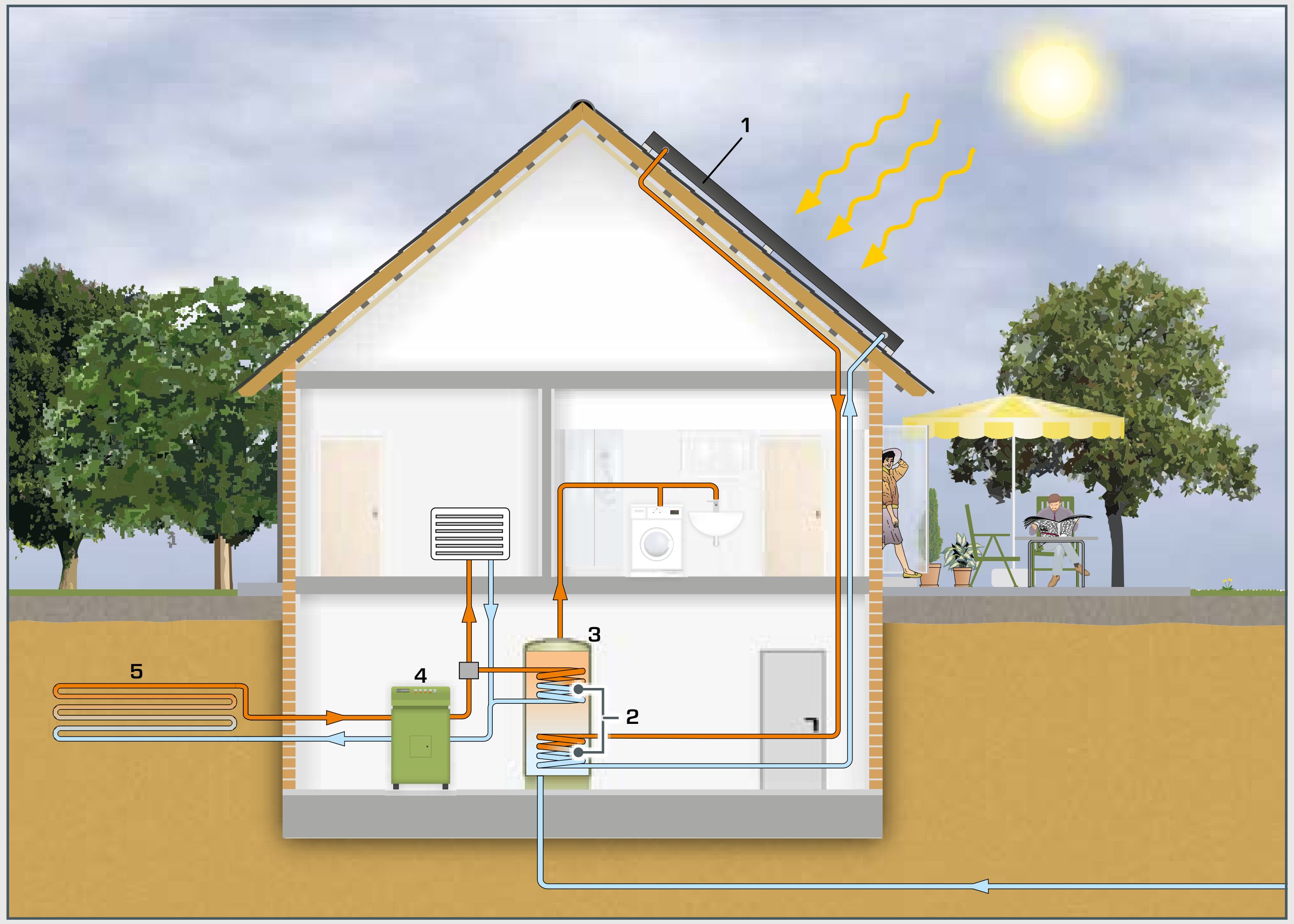
Overview

HL 320 Solar thermal energy and heat pump modular system

The HL 320 modular system allows you to investigate heating systems with various renewable and traditional energy sources. Solar thermal energy can be combined with heat generation from heat pumps. The modular design of the HL 320 system makes it possible to achieve different combinations and configurations.

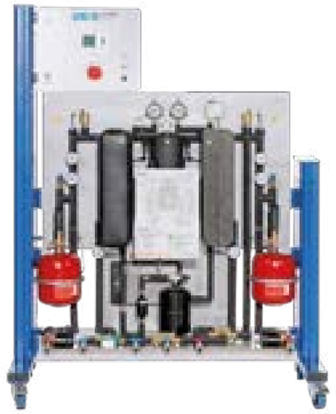
Combined use of renewable heat sources

Doing away with a conventional heating system represents a genuine alternative for modern residential buildings with good thermal insulation in many cases. The combination of solar thermal collectors with a heat pump very often guarantees significant savings with reliable year-round supply.



1 flat collector, **2** heat exchanger, **3** hot water storage tank, **4** heat pump, **5** geothermal energy absorber;
- hot heat transfer fluid,
- cold heat transfer fluid,
- refridgerant, high pressure,
- refridgerant, low pressure

HL 320.01 Heat pump



HL 320.02 Conventional heating

HL 320.03 Flat collector

HL 320.04 Evacuated tube collector

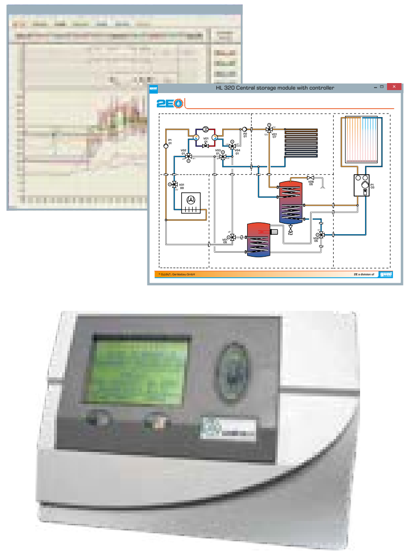
HL 320.05 Central storage module with controller

The storage module provides bivalent storage and buffer storage. The controller can be used to log measured values over longer periods for analysis of the system behaviour.

HL 320.07 Underfloor heating / geothermal energy absorber

HL 320.08 Fan heater / air heat exchanger

Freely programmable controller with extensive software



The HL 320.07 and HL 320.08 modules can be used as heat sources or as heat sinks.

HL 320.03
Flat collector

In conjunction with other HL 320 modules, you can conduct experiments on solar thermal energy domestic water heating with the HL 320.03 Flat collector. The control engineering for the combined production of domestic hot water and heating is of particular practical relevance. Here, the system is controlled and data captured via CAN bus via the HL 320.05 Central storage module.

Modules are easily connected via hoses and quick-release couplings. Different combinations for renewable heat sources can be tested and optimised in conjunction with other modules from the HL 320 system.

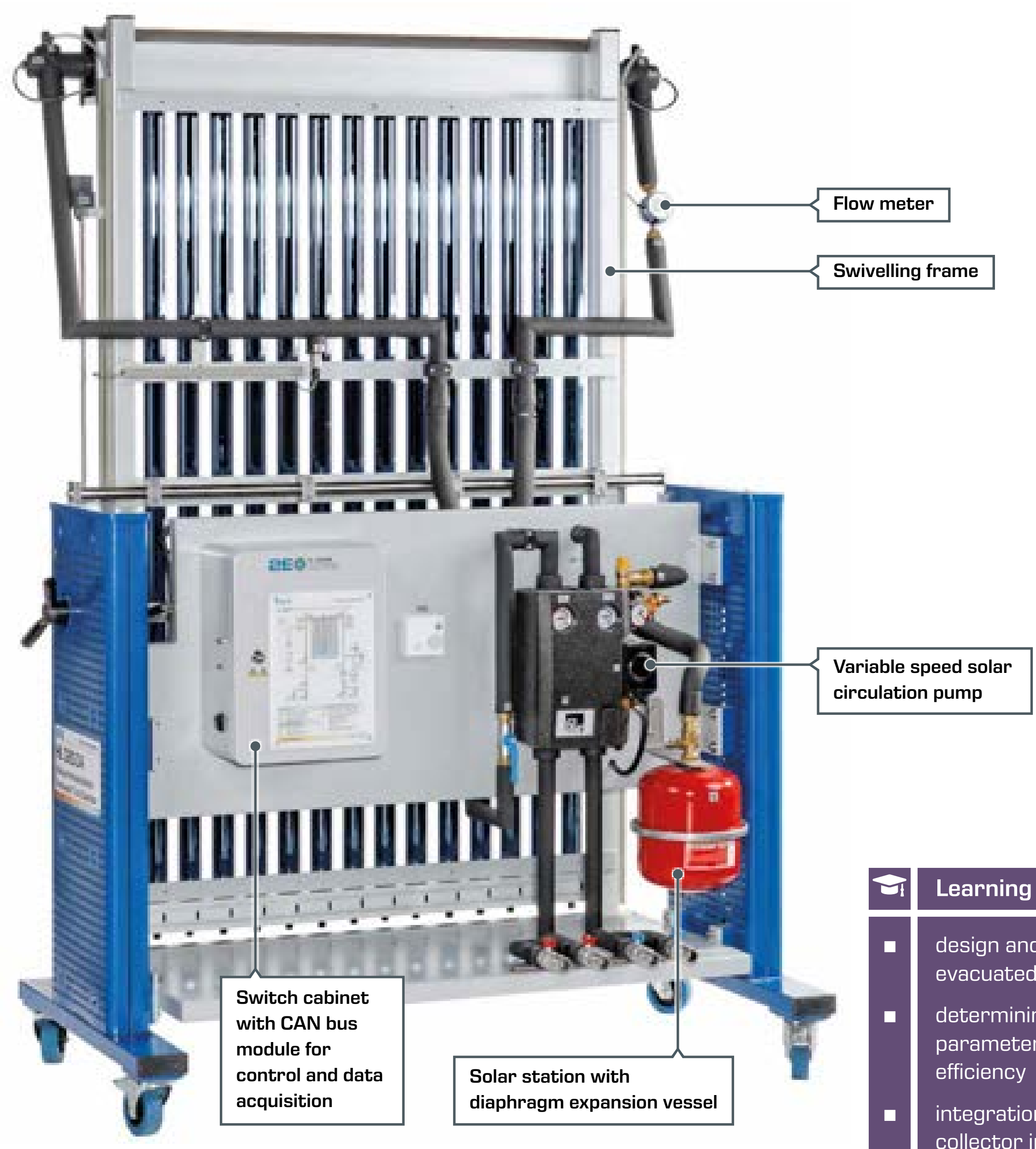
Learning objectives

- determining the net power
- how temperature, illuminance and angle of incidence affect the collector efficiency
- integration of a flat collector in a modern heating system
- hydraulic and control engineering operating conditions
- energy balances
- optimisation of operating conditions for different types of use

About the product:

HL 320.04
Evacuated tube collector

The HL 320.04 unit provides you with an evacuated tube collector in a modern design. Evacuated tube collectors reach much higher operating temperatures compared to simple flat collectors due to the lower thermal losses. In practice, evacuated tube collectors are used where there is limited floor space, for example. In the year-round heating operation, evacuated tube collectors enable the reduction of the seasonal demand on a conventional auxiliary heater. HL 320.04 is one of the modules from the HL 320 Solar thermal energy and heat pump modular system. The experiment module can be incorporated into the modular system in a variety of different ways. The module can be used both for generating heated domestic water and for the combined production of domestic hot water and for heating rooms. Pipe connections for the heat transfer fluid are easy to create and alter thanks to the quick-release couplings.



Learning objectives

- design and operation of an evacuated tube collector
- determining the net power and parameters affecting collector efficiency
- integration of an evacuated tube collector in a modern heating system

About the product:

ET 203
Parabolic trough collector with solar tracking

With the parabolic trough collector, main aspects of solar thermal energy use are being investigated. The solar radiation is focused onto an absorber tube with the help of the parabolic mirror. The radiation energy is absorbed and converted into heat. The heat reaches the solar circuit via a heat transfer fluid and from there the hot water circuit.

The parabolic trough collector can be adjusted to the position of the sun via two geared motors. Both control according to calculated astronomical data and sensor-based control are possible. The collector can be pivoted and aligned vertically for experiments with the artificial light source HL 313.01. Rollers and movable supports allow positioning at a suitable outdoor location.

About the product:

Features

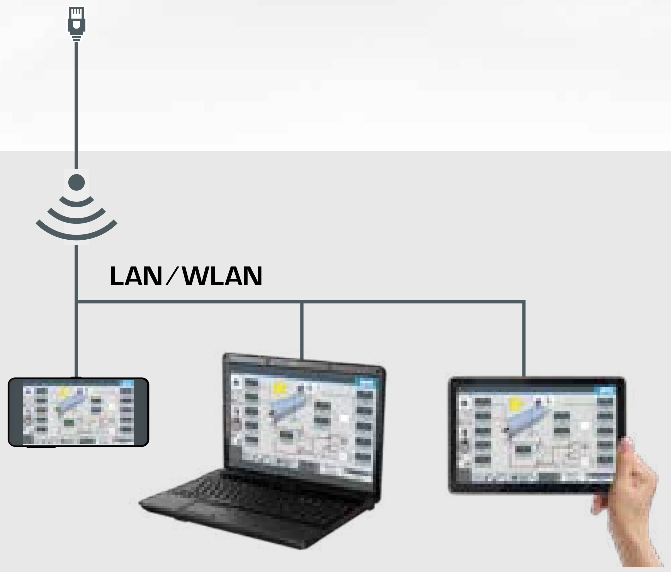
- mobile parabolic trough collector with motorized two-axis tracking
- astronomical and sensor-based tracking
- integrated router for operation and control via an end device and for screen mirroring on additional end devices: PC, tablet, smartphone

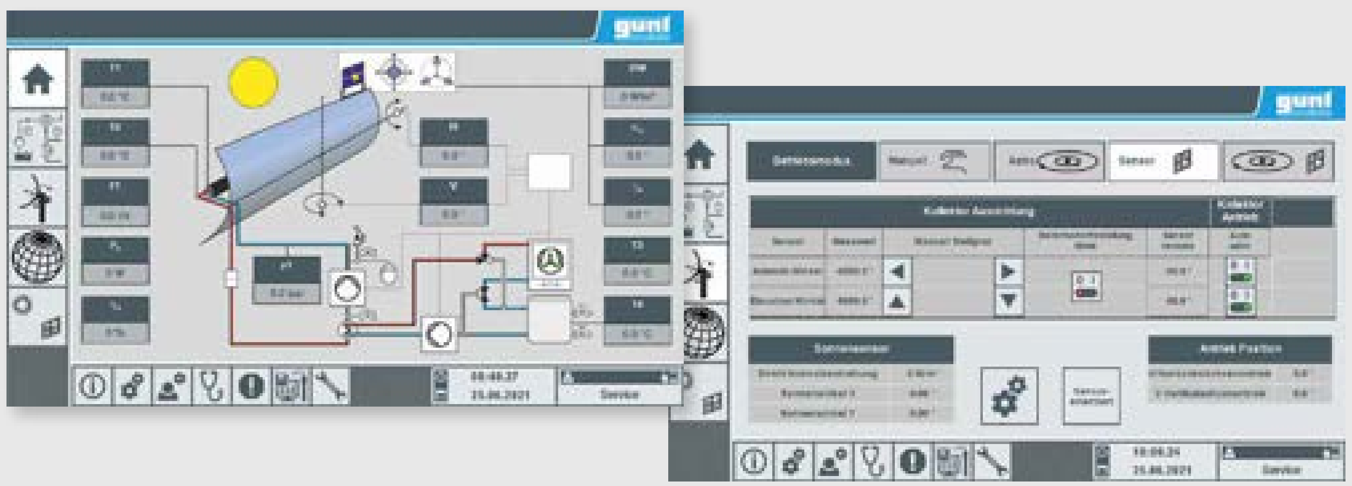
Learning objectives

- optical concentration factor
- DNI: Direct Normal Irradiance
- sensor-based or astronomical sun tracking
- conversion of radiant energy into heat
- efficiency curves

External operation

Operation and control are carried out via the integrated PLC and the touch screen. By means of an integrated router, the trainer can alternatively be operated and controlled via an external end device. The user interface can also be displayed on additional end devices (screen mirroring). Access to stored measured values in the PLC is possible from end devices via WLAN with integrated router / LAN connection to the customer's own network.





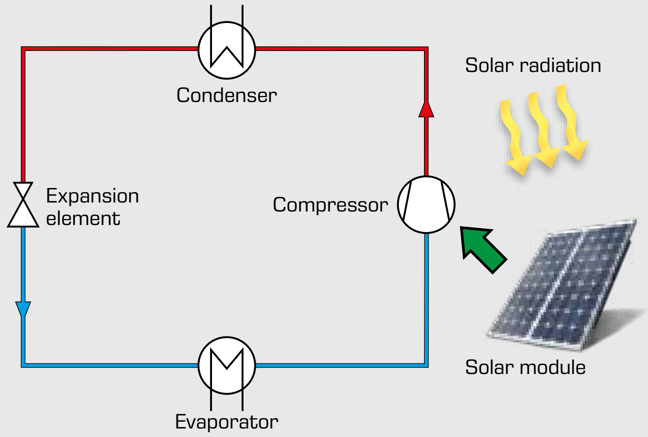
Basic knowledge
Solar cooling

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.

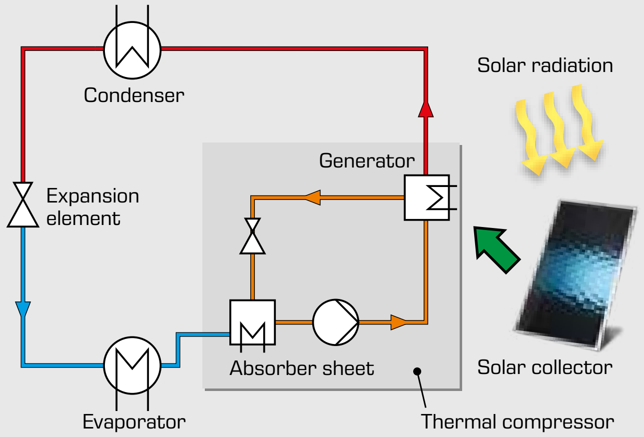
Principle of operation of solar cooling

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



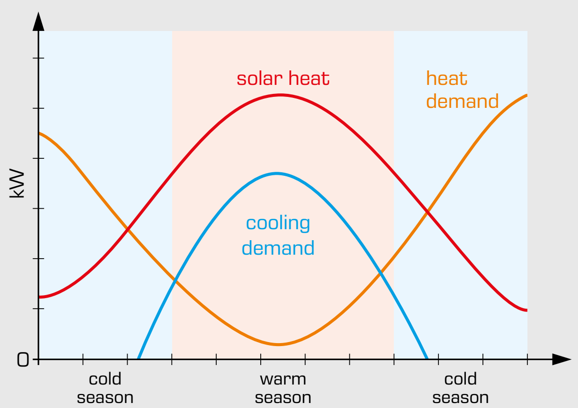
Conversion into heat, thermal process using the example of an absorption refrigeration system with solar collector



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

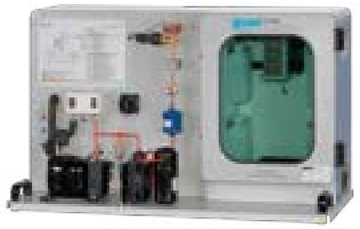
Advantages of solar cooling

- 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.

solar energy

- electrical processes – photovoltaic modules
  - powering compression refrigeration systems
  - thermoelectric process (Peltier)
- thermal processes – solar collectors
  - heat transformation
    - open process
      - liquid sorbents
        - counterflow absorber
      - solid sorbents
        - dehumidification rotor
        - fixed-bed process
    - closed process
      - liquid sorbents
        - water/ammonia
        - water/lithium bromide
        - water/lithium chloride
      - solid sorbents
        - water/silica gel
        - water/zeolite
  - thermomechanical systems
    - Rankine cycle
    - Vuilleumier cycle
    - vapour jet cycle



ET 256 Cooling with solar electricity as an example of the electrical process. The drive energy is supplied by a photovoltaic module.

ET 352 Vapour jet compressor in refrigeration as an example of a thermomechanical process. The drive energy is supplied by a solar collector.

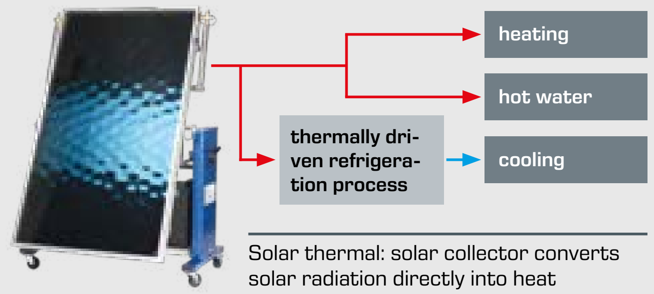
in catalogue 5 Process Engineering

CE 540 Adsorptive air drying, as an example of an open fixed-bed process with the sorbent silica gel. Heating in the desorption process takes place electrically.

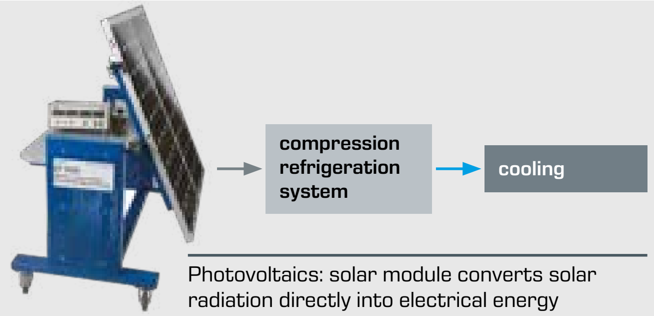
ET 480 Absorption refrigeration system, as an example of a closed process with the liquid sorbents water and ammonia. In this device, the generator is heated either by a gas burner or an electric heater.

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 consumers in a building. The diagram shows two system concepts for incorporating solar thermal energy and photovoltaics.



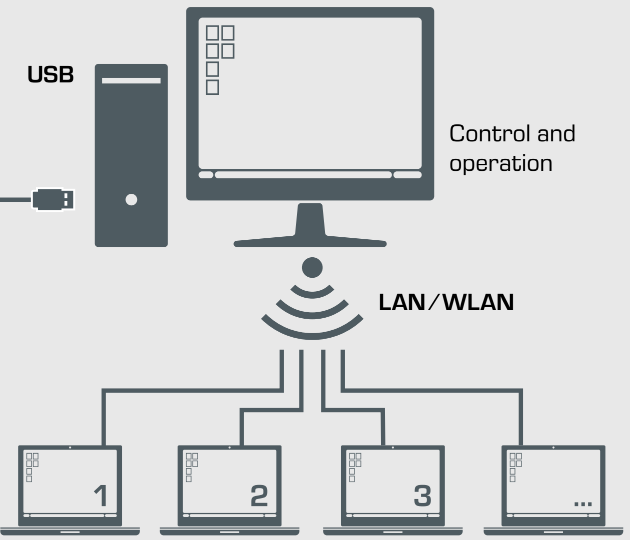
Solar thermal: solar collector converts solar radiation directly into heat



Photovoltaics: solar module converts solar radiation directly into electrical energy

ET 256
Cooling with solar electricity

- compression refrigeration system for operation with photovoltaic modules from ET 250 or with ET 256.01 Laboratory power supply
- control unit starts the compressor as soon as sufficient electrical power is available from the solar modules
- long cooling time due to cold accumulators and insulation
- software for controlling and balancing energy flows



GUNT software for controlling the device and for measurement data acquisition via PC

Learning objectives

- supply a compression refrigeration system with current from photovoltaic modules
- components of a photovoltaic refrigerating plant
- operation of the compressor with changing power supply and cooling demand
- charge and discharge of cold accumulators
- coefficient of performance of the refrigerating plant dependent on operating conditions
- refrigeration cycle in the log p-h diagram
- energy flow balance

About the product:

The ET 256 experimental unit contains a refrigeration chamber that is cooled by a typical compression refrigeration circuit. As a special feature, via a control unit it is possible to supply the reciprocating compressor directly with electricity from the photovoltaic modules of ET 250. Alternatively, the unit can be supplied with power via the ET 256.01 Laboratory power supply unit.

ET 352.01
Solar heat for refrigeration

Thermal processes for cold production offer a promising possibility for solar energy utilisation, especially in subtropical transitional regions. These processes make it possible to use the heat from solar thermal systems, which is often surplus in summer, to generate cooling.

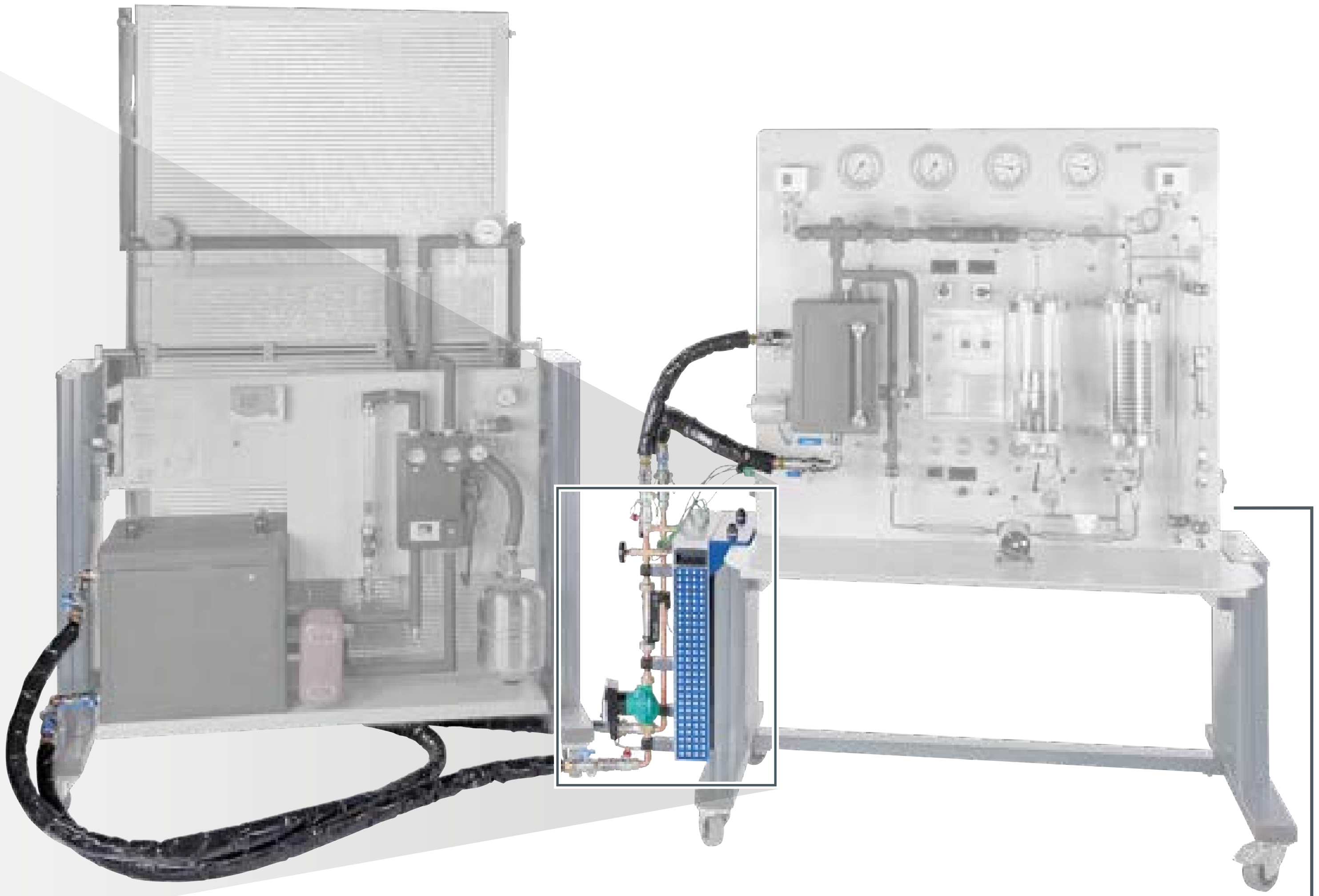
ET 352.01 enables the operation of the steam jet compressor from ET 352 with solar-generated heat from the flat collector HL 313. The pump from ET 352.01 transfers the heated heat transfer fluid from the storage tank of HL 313 to the steam generator of ET 352. The ET 352 software records temperatures and the volumetric flow rate from ET 352.01 to balance the transferred heat.

About the product:

www

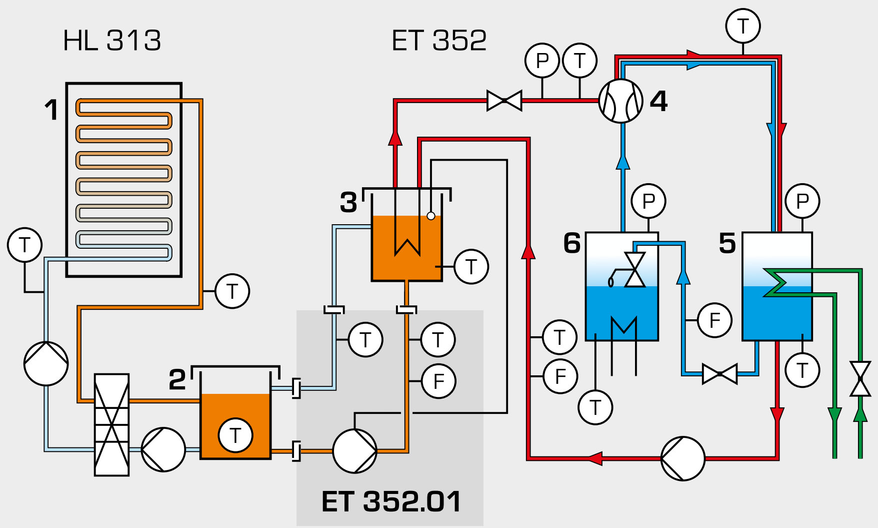
Learning objectives

- components of solar refrigerating plants using the steam jet method
- operation of a steam jet compressor on a solar thermal collector
- advanced concepts for the use of solar thermal systems
- energy management for solar thermal refrigeration systems

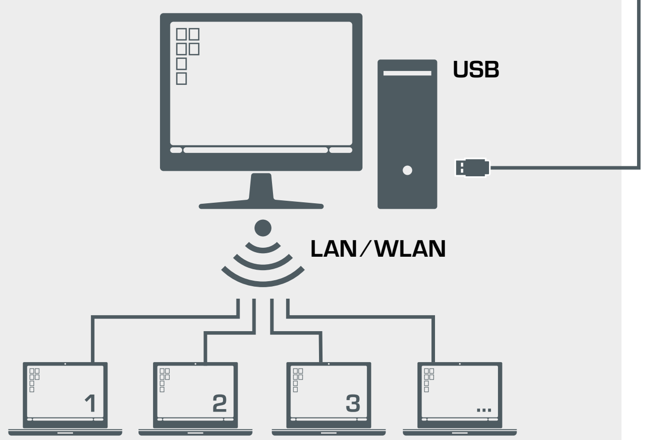


HL 313 Domestic water heating with flat collector or
HL 314 Domestic water heating with tube collector

ET 352 Vapour jet compressor in refrigeration

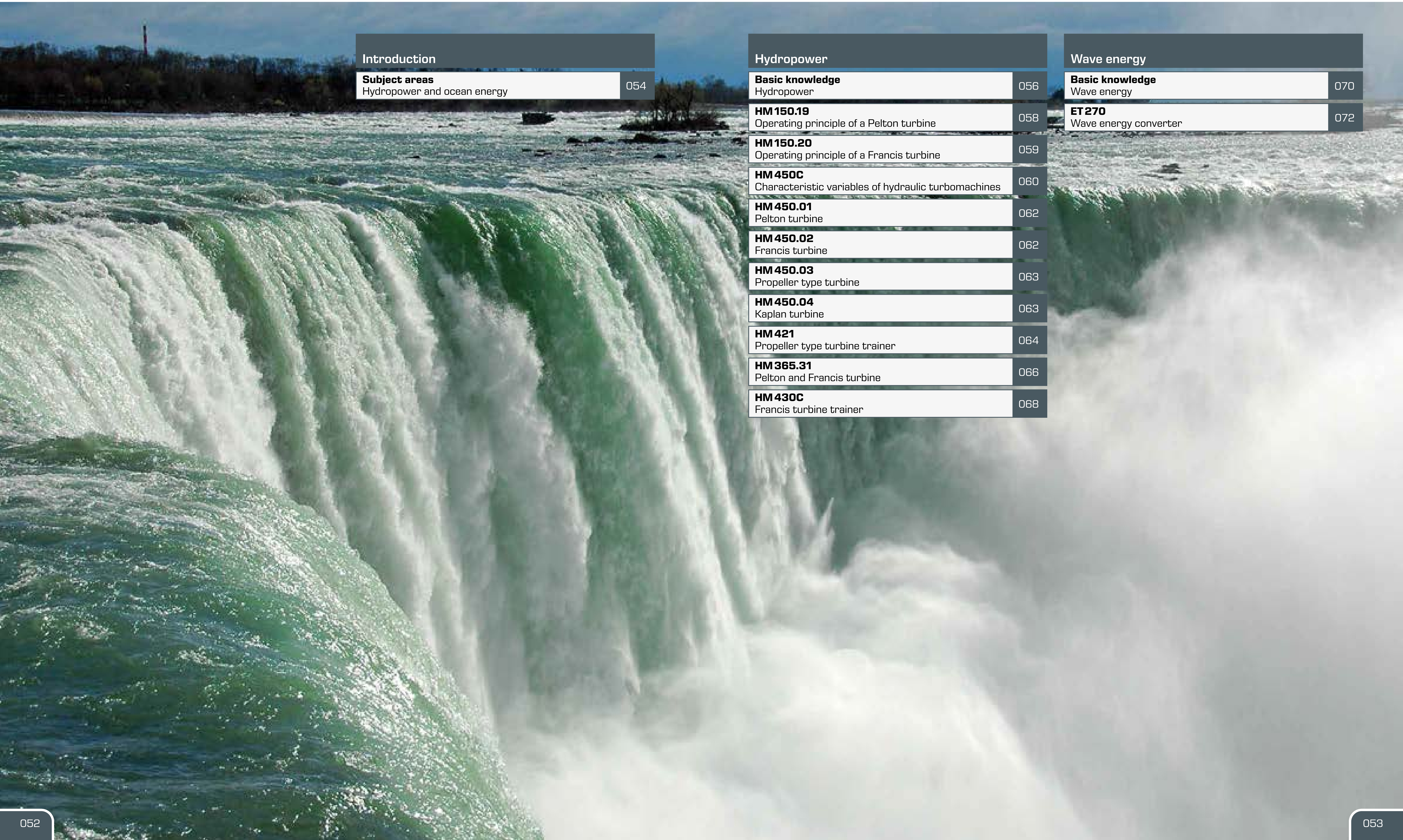


1 solar thermal collector,
2 heat storage tank,
3 steam generator,
4 steam jet compressor,
5 condenser, **6** evaporator;
F flow, **P** pressure, **T** temperature;
red steam cycle,
blue refrigeration cycle,
green cooling water,
orange hot heat transfer fluid,
light blue cold heat transfer fluid



The GUNT software for ET 352 enables the display and analysis of the measurement data. Experiments can be incorporated into a remote learning environment via the network capability.

2 Hydropower and ocean energy



Introduction

Hydropower

Wave energy

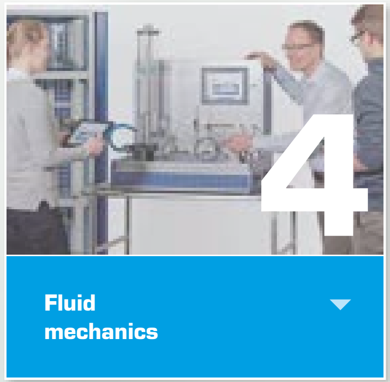
Subject areas

Hydropower and ocean energy

Water's natural flowing movements, such as in rivers and storage lakes, can be used in the production of electricity. Furthermore, with regard to the ocean, both the tidal range (the periodic rise and fall of the sea level) and the energy contained in flow and waves can be used.

Both types of energy conversion are classed as renewable energies. While the typical use of hydropower has been widespread for hundreds of years, using the ocean for energy is in its infancy.

As the table opposite shows, different learning objectives from turbine engineering can be differentiated in the expanded field of hydropower and ocean energy. The corresponding product is listed in the next column.



Additional trainers in the fields of turbines and fluid mechanics in particular can be found in programme area 4 "Fluid Mechanics".

» Fluid mechanics

Subject areas	Products
Hydropower	
Fundamentals of fluid mechanics: Energy conversion in water turbines	**HM 150.19** Operating principle of a Pelton turbine **HM 150.20** Operating principle of a Francis turbine
Turbomachines: Measurements on turbines and pumps	**HM 450C** Characteristic variables of hydraulic turbomachines **HM 450.01** Pelton turbine **HM 450.02** Francis turbine **HM 450.03** Propeller type turbine **HM 450.04** Kaplan turbine
Turbines in run-of-river power plants: River and tidal power plants	**HM 421** Propeller type turbine trainer
Comparing turbine types: Drive of an asynchronous generator	**HM 365.31** Pelton and Francis turbine
How the distributor affects characteristic turbine curves	**HM 430C** Francis turbine trainer
Ocean energy	
Energy gain from wave motion using a Wells turbine	**ET 270** Wave energy converter

Basic knowledge
Hydropower

Traditional hydropower systems have been in use for hundreds of years as a source of energy for a wide variety of mechanical applications. As such, hydropower represents a renewable energy source that has been successfully used for a long time. Since the beginning of electricity being generated by hydropower, the percentage of electrical energy generated in this way has grown to around one quarter of all electricity used worldwide.

However, as the number of turbines in use increases, and with it the necessary retaining dams, the significant drawbacks in the overall ecological balance of this technology has to some extent become apparent. Due to geological conditions, some countries such as Bhutan (99%), Democratic Republic of Congo (99%) and Norway (92%) are able to cover very large proportions of their electrical energy demand with hydropower.

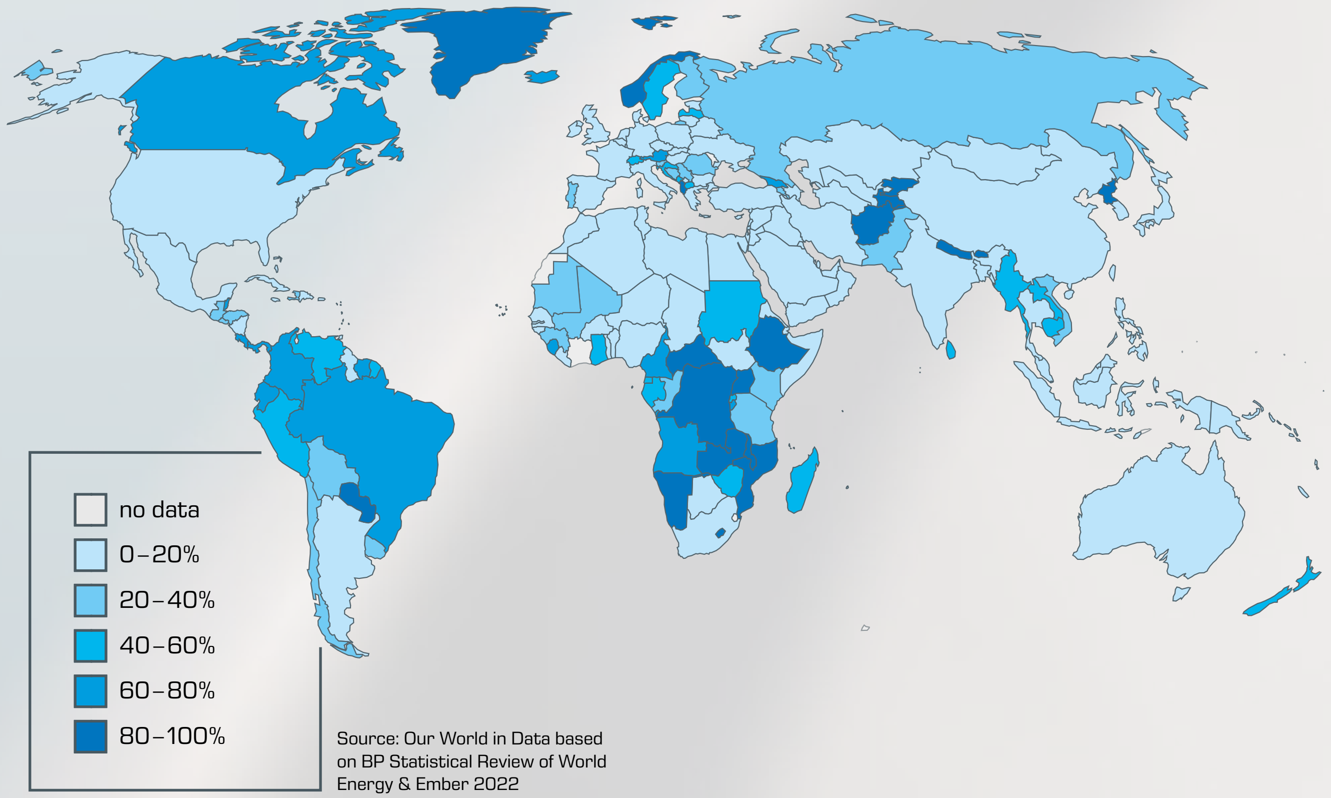
By comparison, in Germany only 3.2 % is covered. China is currently home to the world's largest hydroelectric power plant, where the Three Gorges Dam can generate a total output of up to 18200 megawatts.

Decentralised power supply through small hydroelectric power plants

In regions without a central power supply, decentralised, small hydroelectric power plants with an output up to about 5 kW offer the possibility of supporting sustainable development in an appropriate manner.

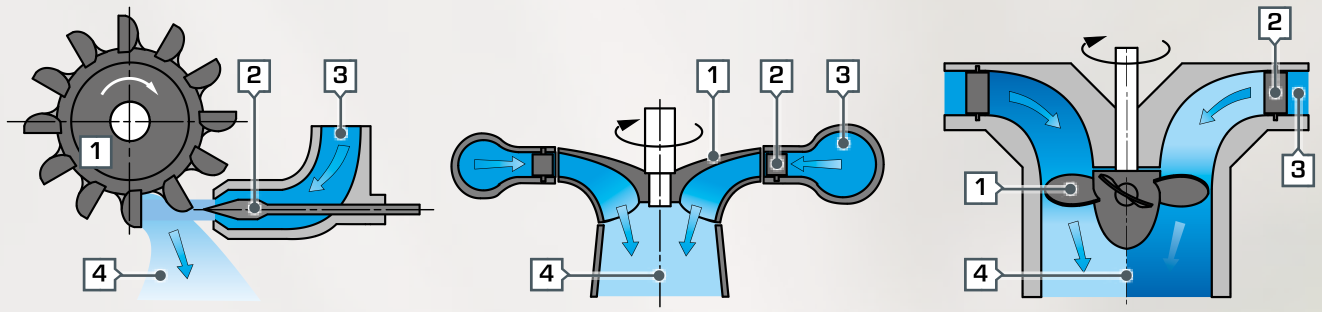
In addition to the typical characteristic variables such as head and flow rate, other aspects such as maintenance issues and accessibility of the installation site are also important to consider when selecting the type of turbine. At heads of 150m and more, it is mostly Pelton turbines that are used. At lower heads on the other hand, Francis or Kaplan turbines are preferred.

Share of hydropower use in electricity supply 2021



Source: Our World in Data based on BP Statistical Review of World Energy & Ember 2022

Turbine types in hydroelectric power plants



Pelton turbine

In the Pelton turbine the water "shoots" out of one or more nozzles onto the vanes of the rotor.

Head: 150-2000 m
Flow rate: 0,02-70 m³/s
Storage power plants

Francis turbine

The Francis turbine operates with positive pressure. The paddles of the distributor can be adjusted.

Head: 20-700 m
Flow rate: 0,3-1000 m³/s
Dams

Kaplan turbine

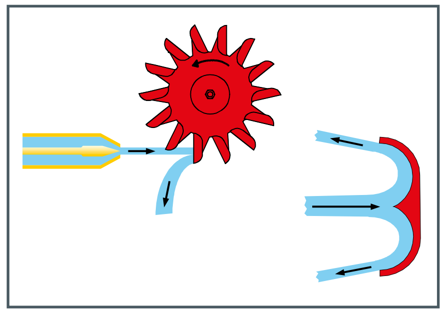
The Kaplan turbine also operates with positive pressure. In this case, distributor and blades can be adjusted.

Head: 2-60 m
Flow rate: 4-2000 m³/s
Rivers

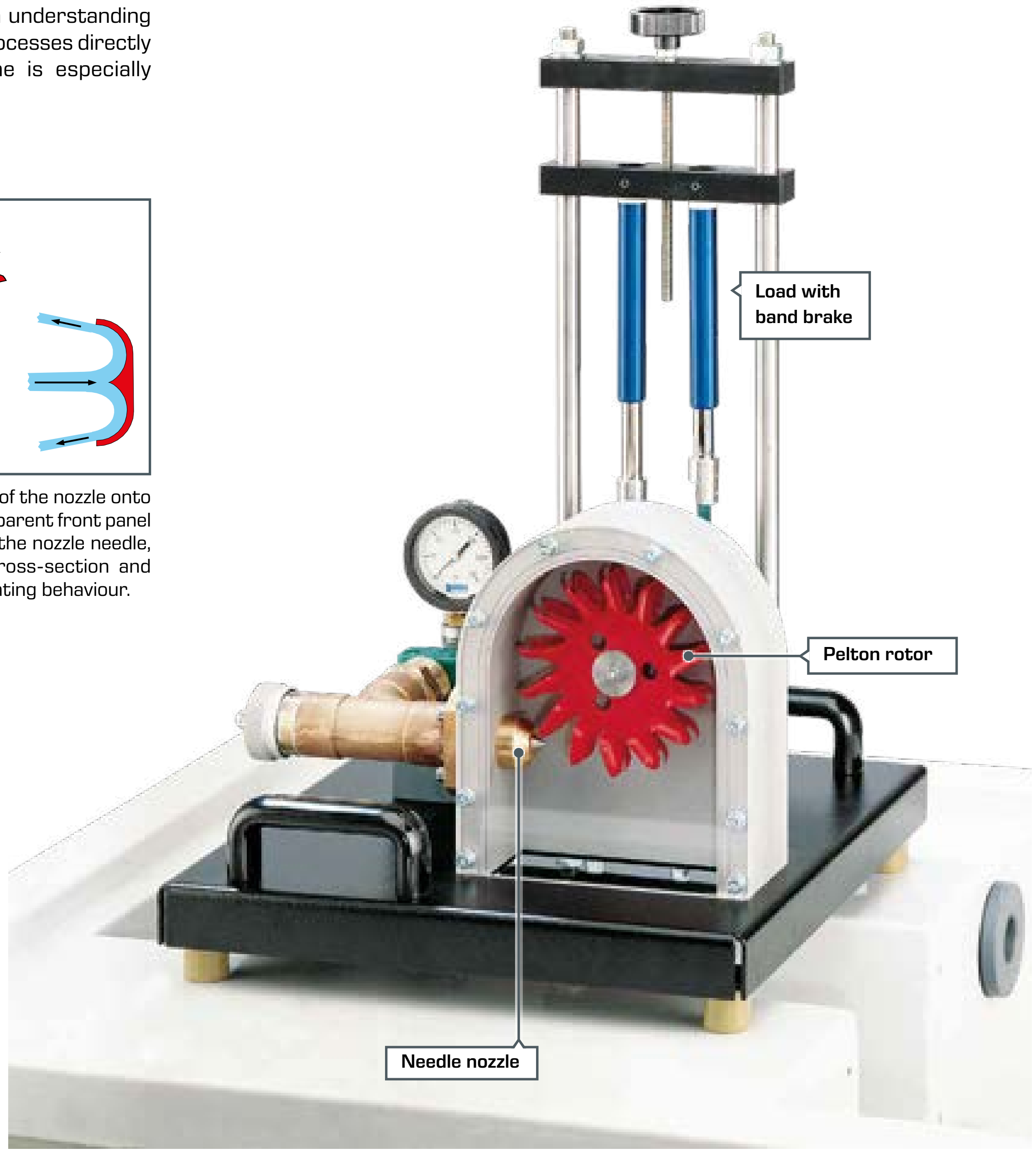
1 rotor 2 distributor 3 water inlet 4 water outlet

HM 150.19
Operating principle of a Pelton turbine

In order to successfully teach the fundamentals of energy conversion in hydroelectric power plants, an understanding of the fluid mechanical processes directly upstream of the turbine is especially important.



Observe the water flow out of the nozzle onto the rotor through the transparent front panel on HM 150.19. By adjusting the nozzle needle, you can vary the nozzle cross-section and study its effect on the operating behaviour.



Learning objectives

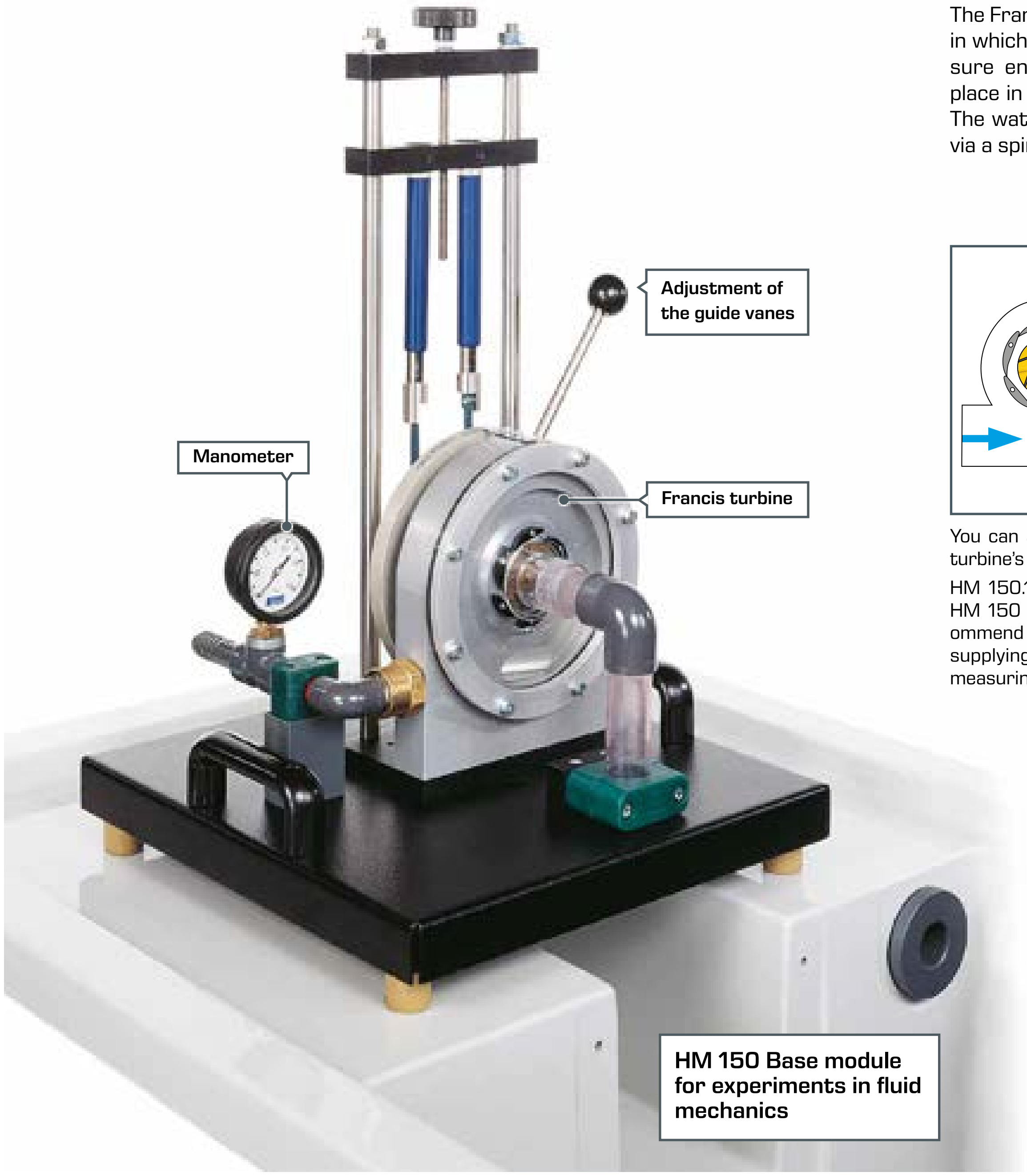
- familiarisation with the design and function of a Pelton turbine
- determination of torque, power and efficiency
- graphical representation of characteristic curves for torque, power and efficiency

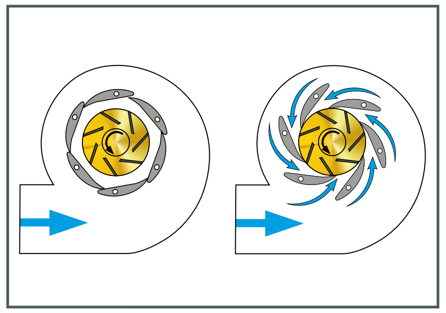
HM 150 Base module

About the product:

HM 150.20
Operating principle of a Francis turbine

The Francis turbine is a reaction turbine, in which conversion of the water's pressure energy into kinetic energy takes place in the distributor and in the rotor. The water is directed to the distributor via a spiral shaped housing.





You can adjust the alignment of the Francis turbine's distributor to optimise performance.

HM 150.19 and HM 150.20 are part of the HM 150 series on fluid mechanics. We recommend using the HM 150 Base module for supplying the turbines with water and for measuring the flow rates.

Learning objectives

- familiarisation with the design and function of a Francis turbine
- determination of torque, power and efficiency
- graphical representation of characteristic curves for torque, power and efficiency

About the product:

HM 450C
Characteristic variables of hydraulic turbomachines

Hydraulic turbomachines are a type of fluid machinery. They operate continuously and feature a steady pressure difference between inlet and outlet. HM 450C is a modular trainer for fundamental experiments in the field of hydraulic turbomachines. HM 450C forms the base unit with a centrifugal pump. A closed water circuit means the trainer can be used anywhere.

Optional accessories include the HM 450.01 Pelton turbine, the HM 450.02 Francis turbine, the HM 450.03 Propeller type turbine and the HM 450.04 Kaplan turbine. The turbines are easy to install on the trainer. They are connected with handles on the pressure side of the centrifugal pump.

One special feature of this trainer is the ability to operate pump and turbine simultaneously. Measured values can be recorded simultaneously on both turbomachines.

GUNT software for displaying and analysing measured values, such as dimensionless ratios and pump characteristics

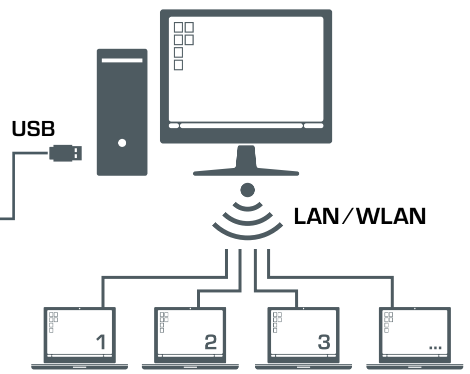
HM 450.01
Pelton turbine

HM 450.02
Francis turbine

HM 450.04
Kaplan turbine

HM 450.03
Propeller type turbine

HM 450C trainer with
HM 450.03 Propeller type turbine



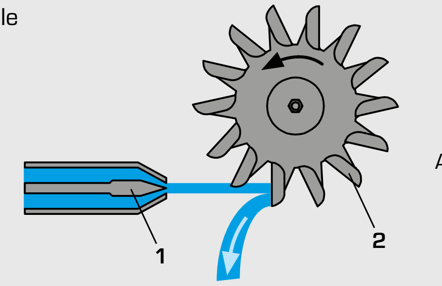
About the product:
www

Learning objectives

- comparison of turbine types
- determining the mechanical power
- effect of nozzle cross-section and/or guide vanes
- plotting characteristic curves
- calculating the efficiency

HM 450.01 Pelton turbine

- **action turbine**
- power adjustment via nozzle needle
- direct view of needle nozzle and rotor during operation
- load via band brake



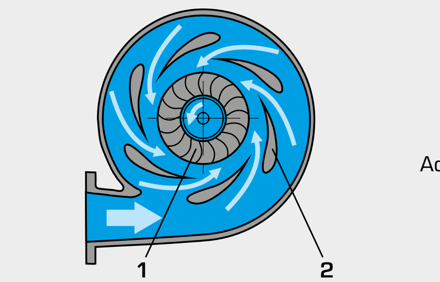
1 needle nozzle, **2** Pelton wheel blades

Needle nozzle and rotor

Adjustment of needle nozzle

HM 450.02 Francis turbine

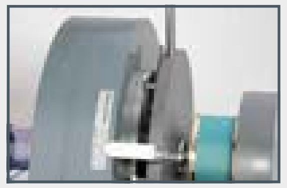
- **radial** flow **reaction turbine**
- power adjustment via guide vane position
- direct view of guide vanes and rotor during operation
- load via band brake



1 rotor, **2** guide vanes, adjustable

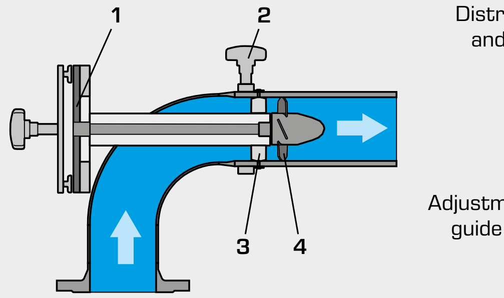
Distributor and rotor

Adjustment of guide vanes



HM 450.03 Propeller type turbine

- **axial** flow **reaction turbine**
- power adjustment via guide vane position
- direct view of guide vanes and rotor during operation
- load via eddy current brake



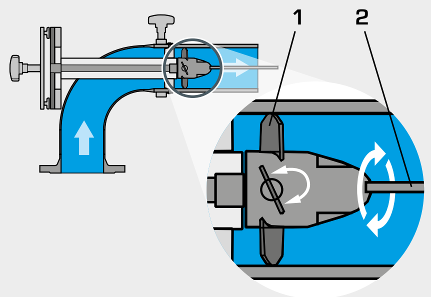
1 eddy current brake, **2** guide vane adjustment,
3 guide vanes, adjustable, **4** blades

Distributor and rotor

Adjustment of guide vanes

HM 450.04 Kaplan turbine

- **axial** flow **reaction turbine**
- power adjustment via **guide vane** and **blade position**
- direct view of guide vane and blades, with adjustment, and rotor during operation
- load via eddy current brake



1 blades, adjustable,
2 guide rod for blade adjustment

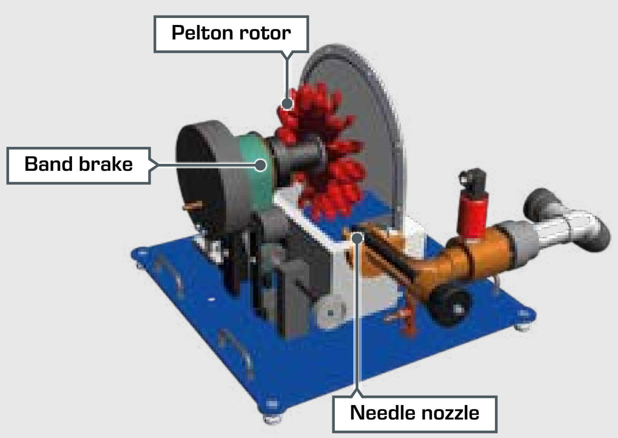
Distributor and blade adjustment

Adjustment of guide vanes

HM 450.01 Pelton turbine
HM 450.02 Francis turbine

HM 450.01 Pelton turbine

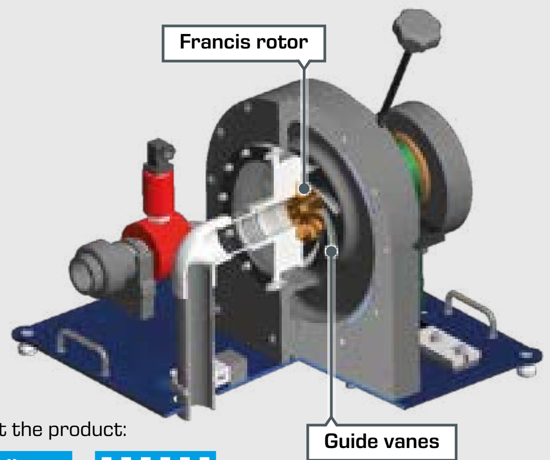
The Pelton turbine is a free-jet or action turbine, in which the conversion of the pressure energy of water into kinetic energy takes place entirely in the distributor. Pelton turbines are used for large heads and relatively low water flow rates. The turbine's power is adjusted via the nozzle cross-section. In practice, Pelton turbines are used to drive synchronous generators, where they run at constant speed.



About the product:

HM 450.02 Francis turbine

The Francis turbine is a reaction turbine, in which conversion of the pressure energy of water into kinetic energy takes place in the distributor and in the rotor. Francis turbines are used for medium heads and high water flow rates. The turbine power is controlled by adjusting the guide vanes. In practice, Francis turbines are used in run-of-river power plants and in storage power plants.

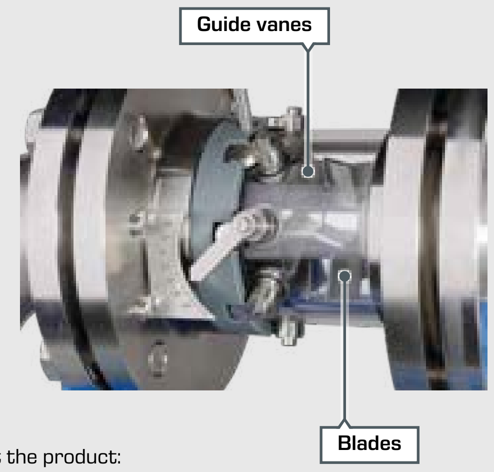


About the product:

HM 450.03 Propeller type turbine
HM 450.04 Kaplan turbine

HM 450.03 Propeller type turbine

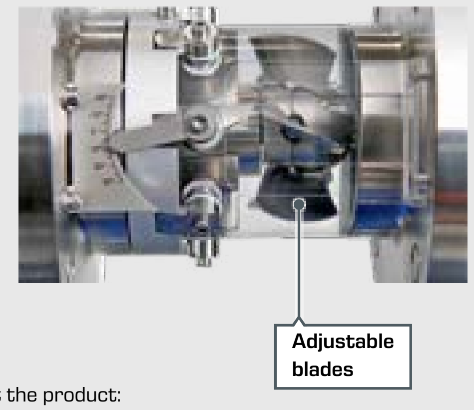
In contrast to Kaplan turbines, propeller type turbines have fixed blades. These turbines are used for low heads and very high water flow rates. The power of the propeller type turbine is controlled by adjusting the guide vanes. In practice, propeller type turbines and Kaplan turbines are used in run-of-river power plants.



About the product:

HM 450.04 Kaplan turbine

Kaplan turbines are characterised by an axial flow and adjustable guide vanes. Kaplan turbines are used for low heads and very high water flow rates. Since they are a type of double-regulated turbine, in which both the guide vanes and the blades can be adjusted, they are suitable for use in fluctuating operating conditions.

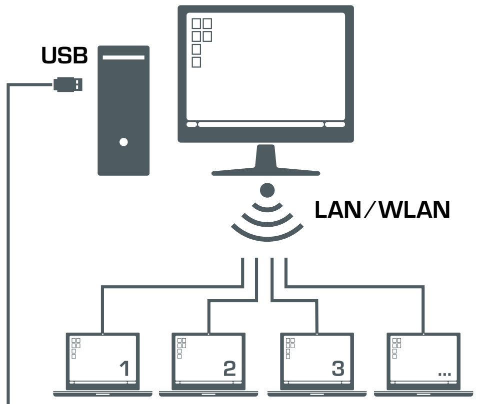


About the product:

HM 421
Propeller type turbine trainer

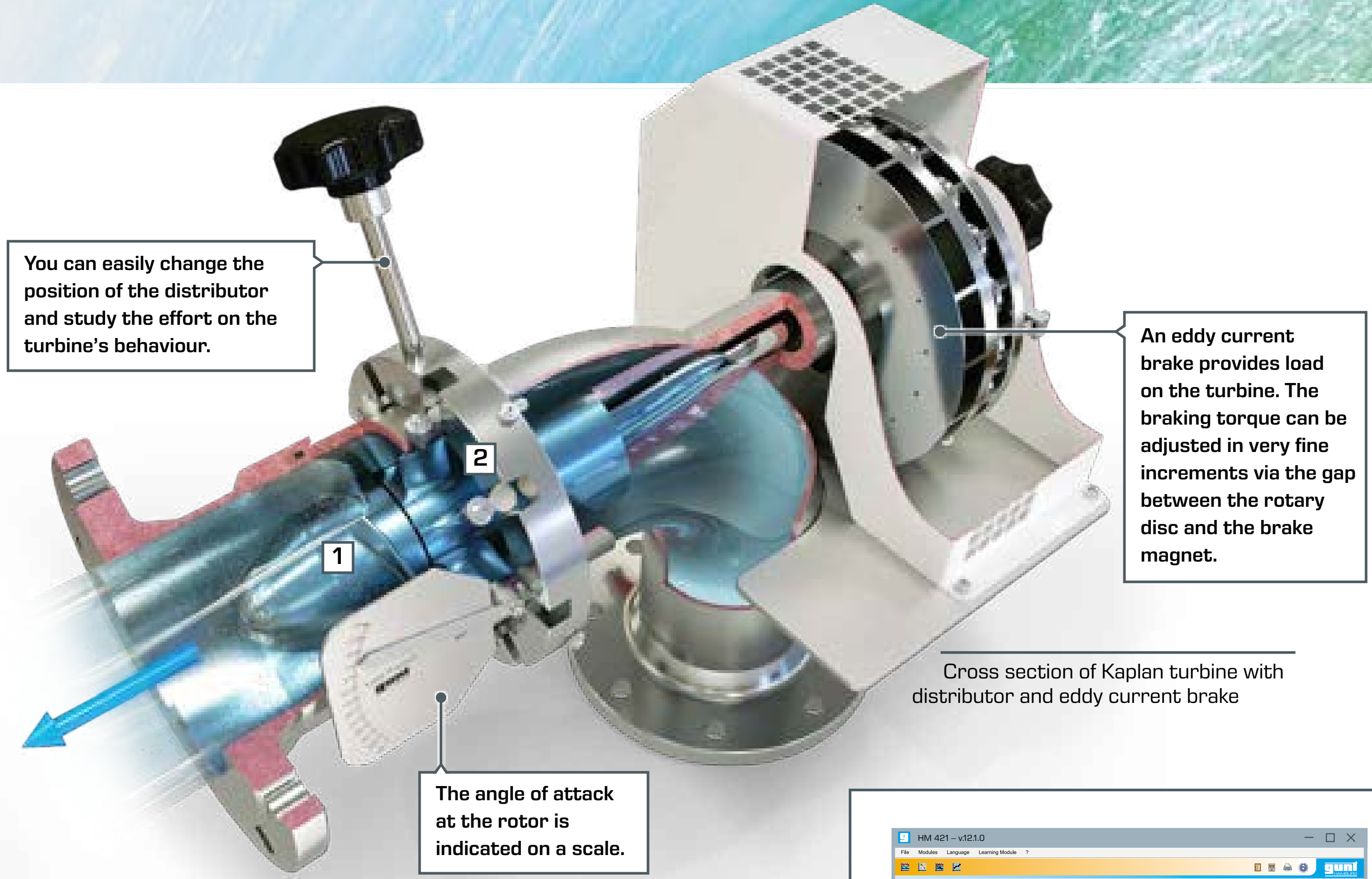
Propeller type turbines are used at low heads to generate electricity. Low heads occur for example, in run-of-river power plants and tidal power plants.

HM 421 provides you with a trainer equipped with a Kaplan turbine in a closed water circuit and a submersible pump.

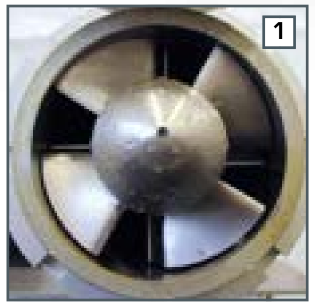


About the product:

www



Cross section of Kaplan turbine with distributor and eddy current brake

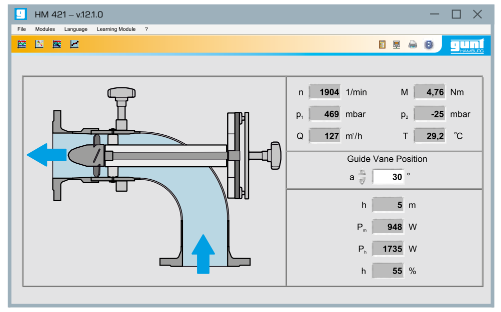


rotor

Distributor

Learning objectives

- measurement of turbine characteristics
- determining power characteristics at different speeds (hydraulic power, mechanical power)
- determining the head
- calculating the turbine efficiency
- how blade position affects power and efficiency



Software

The software for HM 421 allows the most important variables to be captured:

- flow rate
- head
- speed
- torque
- pressure at the inlet and outlet
- temperature

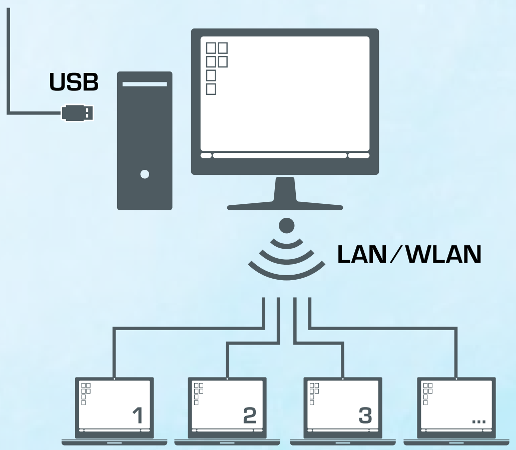
The following variables can be calculated from the measured values

- hydraulic power
- mechanical power
- efficiency
- head

HM 365.31
Pelton and Francis turbine

The HM 365 modular system allows you to investigate the characteristic operating behaviour of various turbine types. The water supply is provided by the specially designed HM 365.32 supply unit. The energy generated by the turbine is transferred to the HM 365 asynchronous generator. Further information about the additional possibilities can be found in the data sheets for the respective devices.

The **GUNT software** provides an intuitive visualisation of current measurement data in a system schematic and enables continuous data acquisition via a USB connection. Of course, graphical representations and calculations are also provided for analysis of the measurement data.



HM 365.31 Pelton turbine

HM 365.31 Francis turbine

Learning objectives

- comparison of action and reaction turbines
- determining the mechanical power and the hydraulic power
- determining the efficiency
- plotting characteristic curves
- effect of the nozzle cross-section of the Pelton turbine on the characteristic values
- effect of the guide vane position of the Francis turbine on the characteristic values

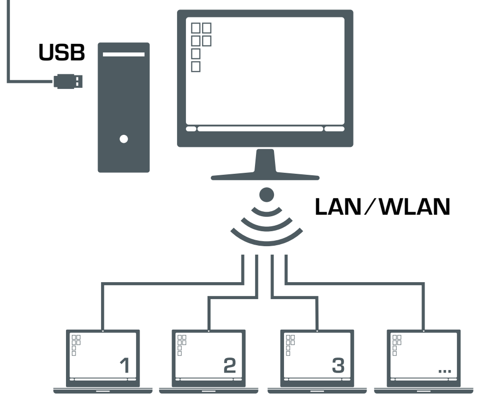
HM 365 has a three-phase asynchronous motor that is used as a generator. Thanks to the possibility of controlling the load via the speed or torque, the turbine being studied can be operated at the optimum operating point with varying hydraulic power.

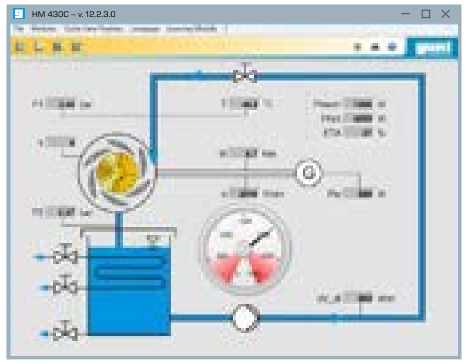
HM 365.32 is equipped with sensors for pressure, temperature and flow rate. A power pump – inside the closed water circuit – simulates the gradient of a hydroelectric power plants.

About the product:

HM 430C
Francis turbine trainer

Francis turbines are used for hydropower at medium heads and medium flow rates. HM 430C provides you with the possibility of using a DC generator for energy conversion.

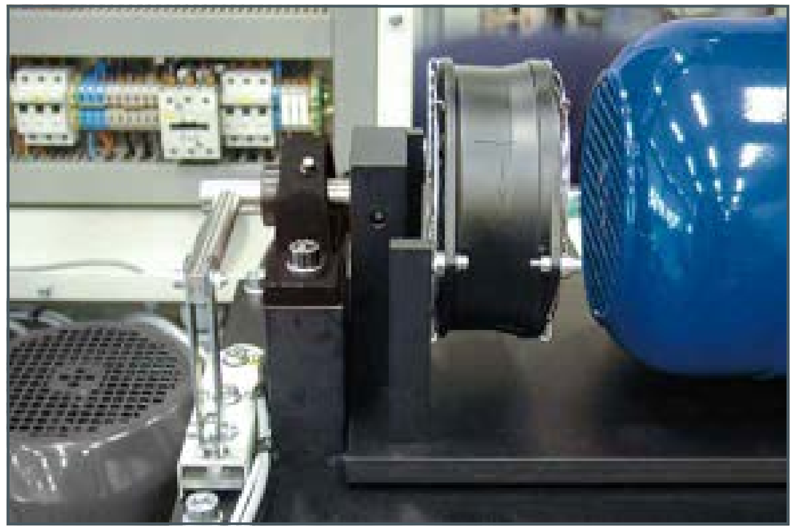




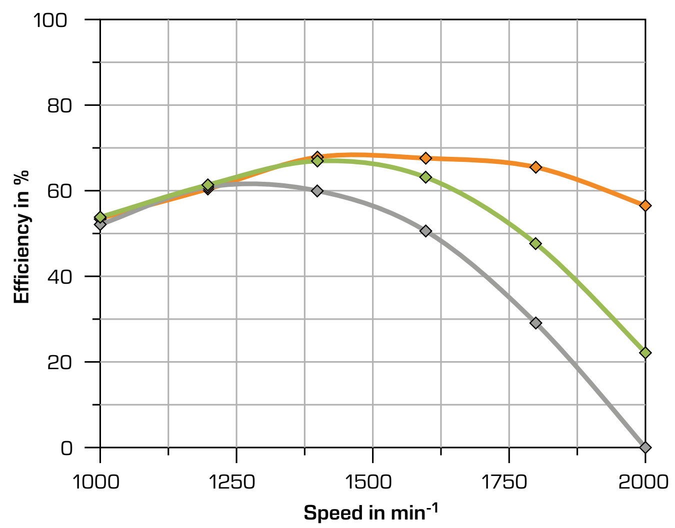
Software

The GUNT software displays torque, speed and pressure to monitor the current system state.

You can easily study the behaviour of the turbine with different distributor positions.



A force sensor detects the torque at the generator's flexible mount.



The mechanical power emitted, the hydraulic power supplied and the efficiency can all be calculated from the measurement data. The chart shows how the efficiency depends on the speed for three different distributor positions.

Learning objectives

- investigate the conversion of hydraulic energy into mechanical energy
- determine torque and speed on the turbine shaft
- determine mechanical power and hydraulic power
- determine efficiency
- plot characteristics
- investigate the effect of the guide vane position
- calculate velocity triangles

About the product:

www

Basic knowledge

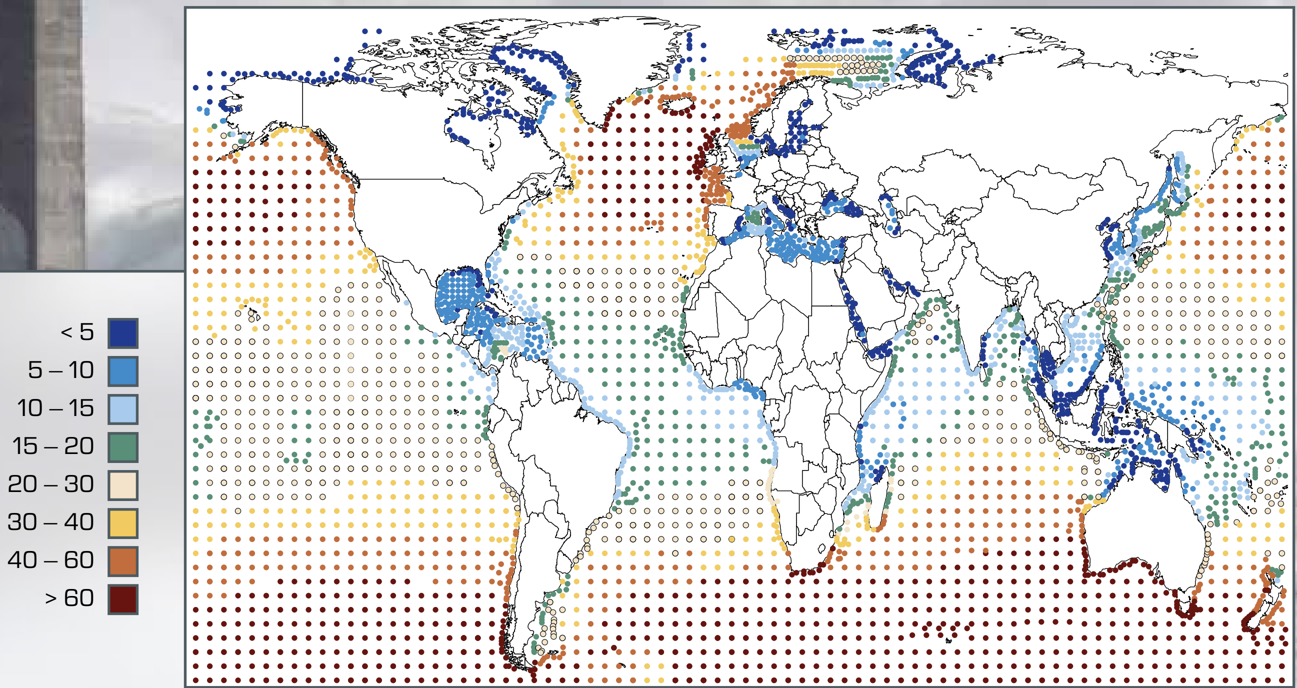
Wave energy

The ocean's waves contain an inexhaustible reserve of energy. They are caused by wind, gravitational forces and atmospheric pressure differences.

The International Energy Agency estimates the possible global contribution of wave energy to the power supply at more than 10 %.

The main challenge in constructing wave power plants is not least that of designing systems that can withstand the sometimes destructive natural conditions. The integration of chamber systems following the principle of the oscillating water column (OWC) has proven promising in existing coastal defence structures.

Annual average power of ocean waves (kW/m)



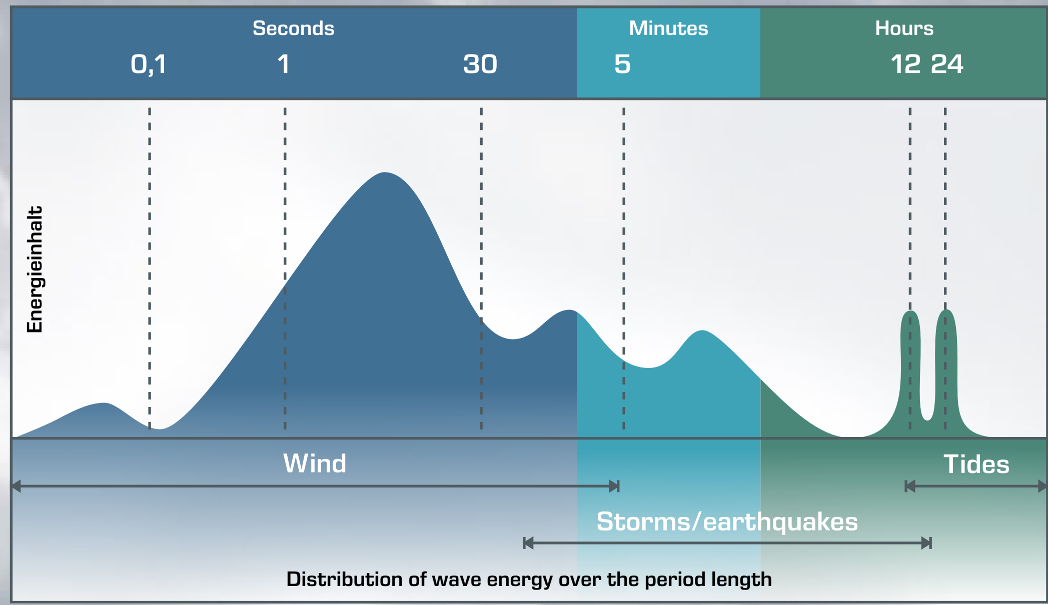
The map shows the average annual wave power. It assumes power along a coastline or along a wave crest. The power densities are specified in kW/m. It should be noted that high powers can broadly be found far from the equator and on the west coasts of the continents.
Source: Centre for Renewable and Sustainable Energy Studies, Stellenbosch University

Linear wave theory provides an estimate for the energy flow of a wave:

$$P \sim T * H^2$$

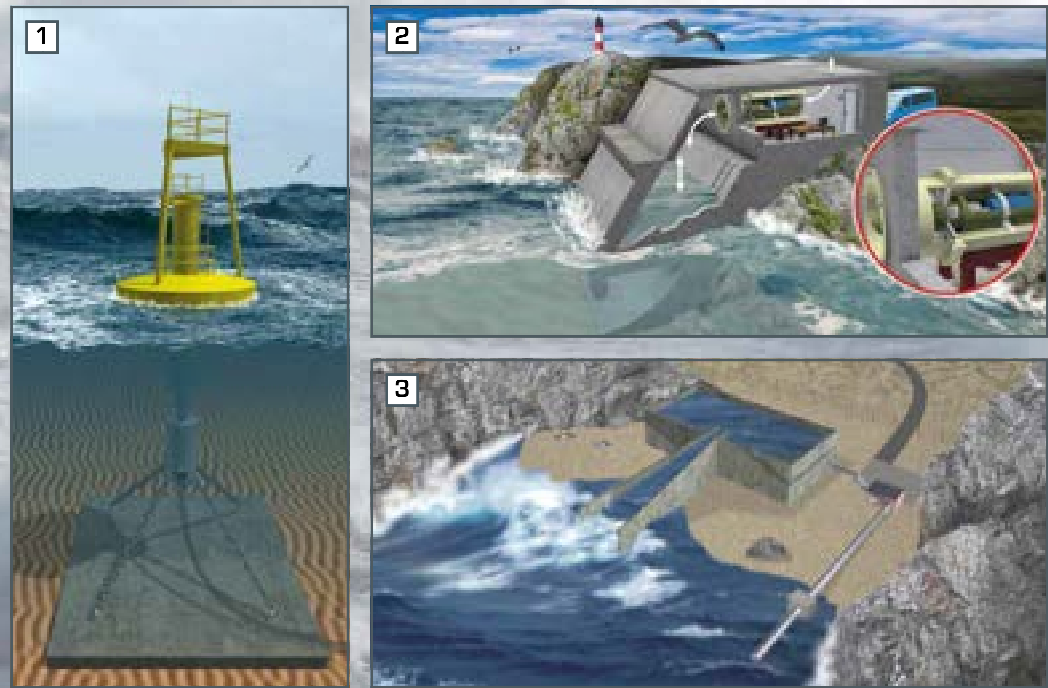
We can see that the power **P** is linearly dependent on the period length **T** and quadratically dependent on the height of the wave **H**.

Distribution of the wave energy supply



When designing systems to use wave energy, the distribution of the wave energy supply is particularly important. Results from global studies show that the largest percentage of wave energy can be assigned to a period length between 1 and 30 seconds.

Basic mechanical principles for using wave power



Systems for using wave energy that have been proposed in the past and also partially put into practice can be classified in the following categories according to the underlying principle:

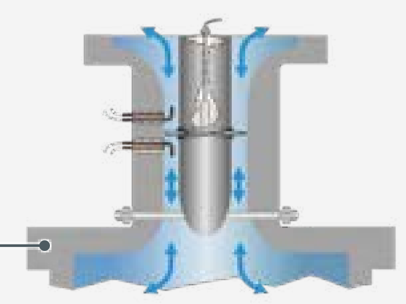
1 floating systems
2 chamber systems (OWC)
3 overflow systems

ET 270
Wave energy converter

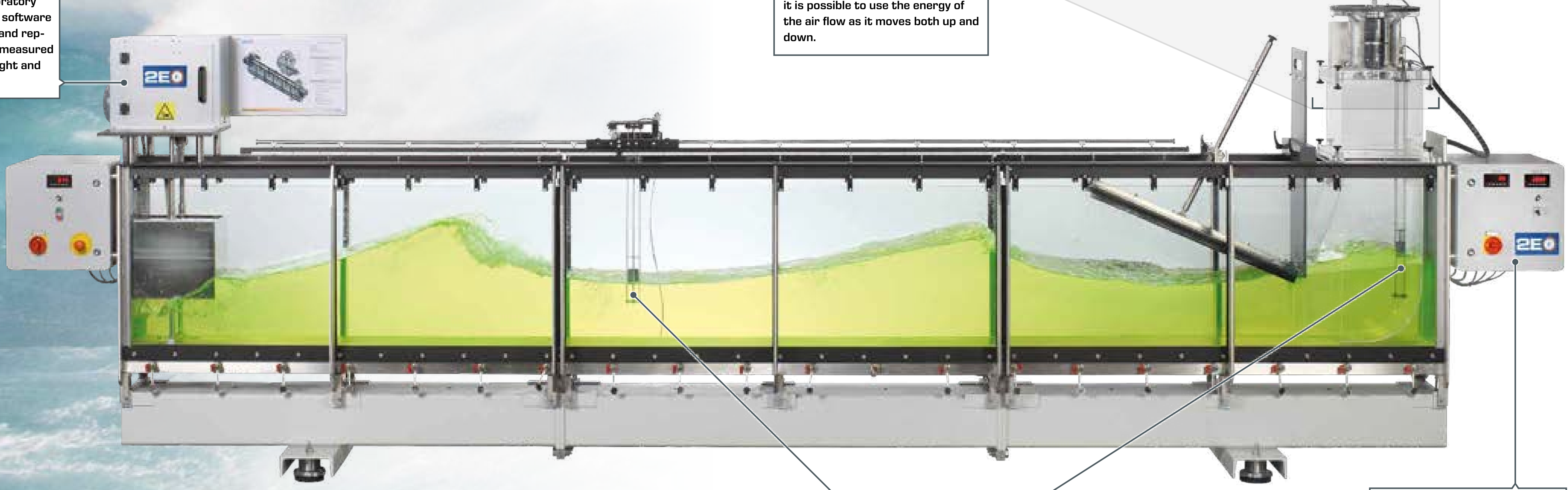
Wave power plants use the energy of ocean waves to generate electricity. Systems designed according to the principle of the oscillating water column (OWC) are fitted with a chamber which opens out below sea level. At the other end is a turbine. The continuous wave motion produces an oscillating water column within the chamber, which causes the air mass above it to move. The air flow generated in this way drives the turbine, which generates electricity via a generator.

In addition to the usual components of an OWC wave power plant, ET 270 contains a water flume with a controllable wave generator for laboratory experiments. The GUNT software enables the acquisition and representation of relevant measured values such as wave height and speed of the generator.

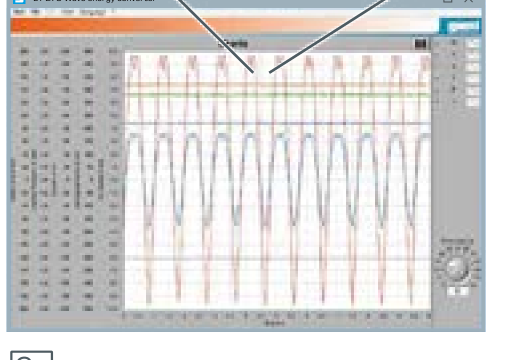
Modelled after large-scale power stations, ET 270 also uses a Wells turbine. This type of turbine functions regardless of the flow direction of the air. Consequently, it is possible to use the energy of the air flow as it moves both up and down.



Wells turbine with generator



The speed of the Wells turbine can be specified by controlling the generator. As a result, it is possible to adjust the most efficient operating point for energy recovery.



Software

Measurement of the wave height

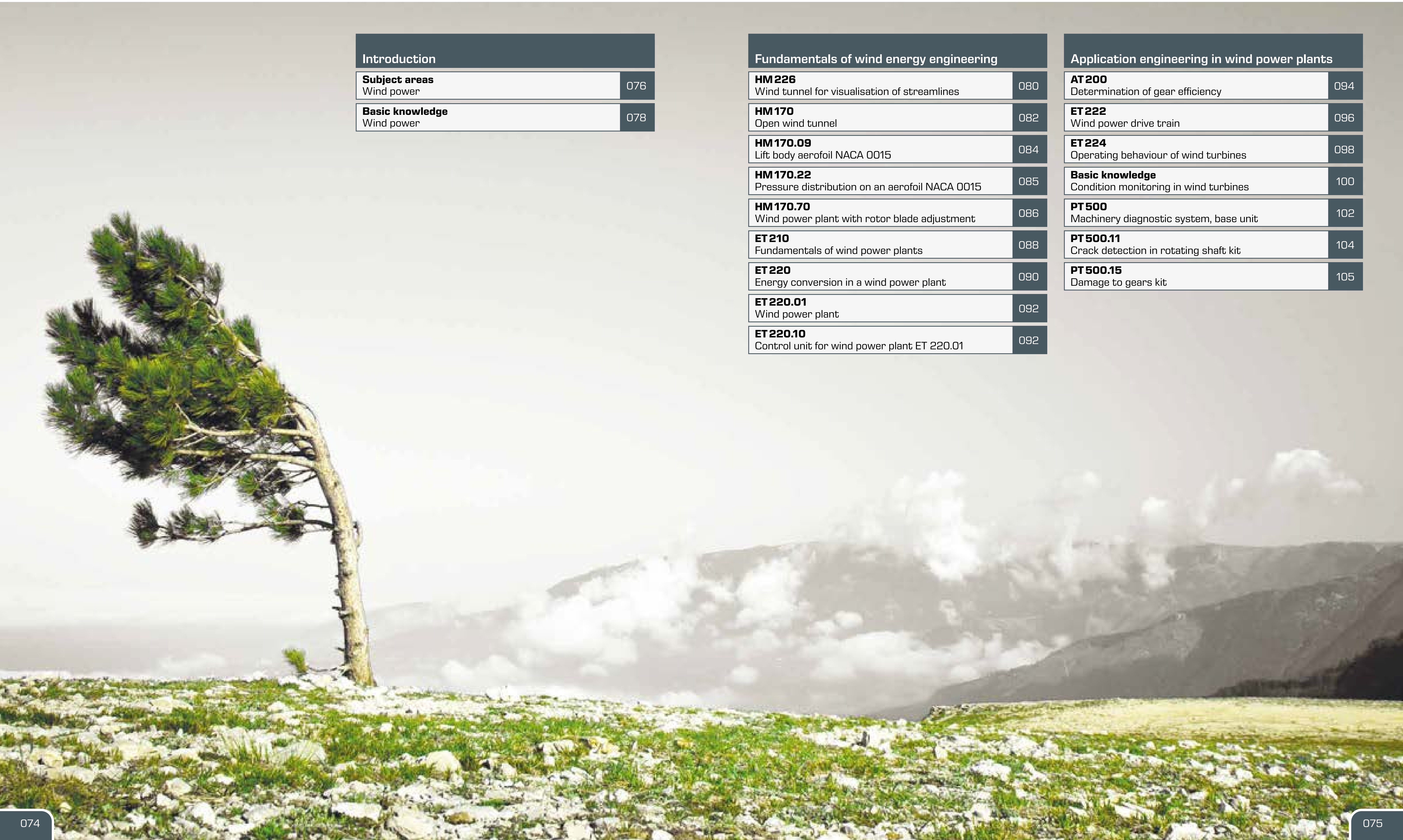
Learning objectives

- familiarisation with wave power plants
- understanding of the energy generation from wave motion
- measurement of wave motion
- familiarisation with the Wells turbine
- optimisation of operating behaviour

About the product:

3

Wind power



Subject areas

Wind power

Technology with a future

While traditional windmills have been widely used for hundreds of years for mechanical drives, generating electricity by means of large wind power plants is currently experiencing a breakthrough.

The current trend is heading towards large wind power plants with large rotors. This is mainly down to the fact that there are high wind Wind velocities at high altitudes. Wind velocity has a huge influence on the rotor's speed of rotation. Nowadays rotors with a diameter of 100 m are the norm.

The process of energy recovery through wind power includes extensive theoretical principles in addition to the practical aspects. Therefore, in our didactic concept on the field of wind power, we differentiate between the areas of learning listed on the right.

Subject areas	Products
Fundamentals of wind energy engineering	
Investigations on flow around bodies	**HM 226** Wind tunnel for visualisation of streamlines **HM 170** Open wind tunnel **HM 170.09** Lift body aerofoil NACA 0015 **HM 170.22** Pressure distribution on an aerofoil NACA 0015
Generating electricity from wind energy	**HM 170.70** Wind power plant with rotor blade adjustment **ET 210** Fundamentals of wind power plants **ET 220** Energy conversion in a wind power plant
How the real wind supply and electricity demand affect the yield from wind power plants	**ET 220.01** Wind power plant **ET 220.10** Control unit for wind power plant ET 220.01
Application engineering in wind power plants	
Energy transmission and system control	**AT 200** Determination of gear efficiency **ET 222** Wind power drive train **ET 224** Operating behaviour of wind turbines
Machine monitoring	**PT 500** Machinery diagnostic system, base unit **PT 500.11** Crack detection in rotating shaft kit **PT 500.15** Damage to gears kit

Basic knowledge

Wind power

The success of modern wind power plants would be inconceivable without contributions from a wide variety of sub-disciplines. Condition Monitoring Systems (CMS) are becoming increasingly important for economic aspects in the operation of wind farms.

Aerodynamics

Aerodynamics is the science of the behaviour of bodies in a compressible gas (air). Aerodynamics describes the forces that make a windmill turn or that lift an aeroplane off the ground.

The design of a rotor blade for modern wind power plants has to take into account both the aerodynamic properties and the mechanical load-bearing capacity. Blade profiles which have been optimised in extensive simulations are often used in order to satisfy the requirements of large-scale wind power plants.

Energy generation from wind power

In order to be able to use wind energy, the kinetic energy of the wind first has to be converted into rotational energy. The rotational energy can then be used in a generator to produce electrical energy. As with all energy conversion processes, losses have to be monitored in each separate step. Assuming the maximum usable wind power (the Betz limit), aerodynamic, mechanical and electrodynamic losses occur.

Gear technology

When transferring power from the rotor axis to the generator, two principle requirements must be met:

- good synchronisation properties with as little fluctuation in the speed and torques as possible
- good adaptation of the speed range between rotor and generator

Although considerable progress has been made in recent years in the development of frequency converters, established drive train designs are based on the use of transmission gearing. The gears make it possible to adjust the speed and/or frequency of the generator to the requirements of the alternating current grid.

Plant control

The performance of wind turbines depends on mechanical and electrical components as well as on efficient plant control. The influence of the effective parameters under all relevant operating conditions must be known. For this purpose, the dependence of the rotor power on wind speed, rotor speed and rotor blade angle is taken into account in corresponding characteristic diagrams.

Machine monitoring

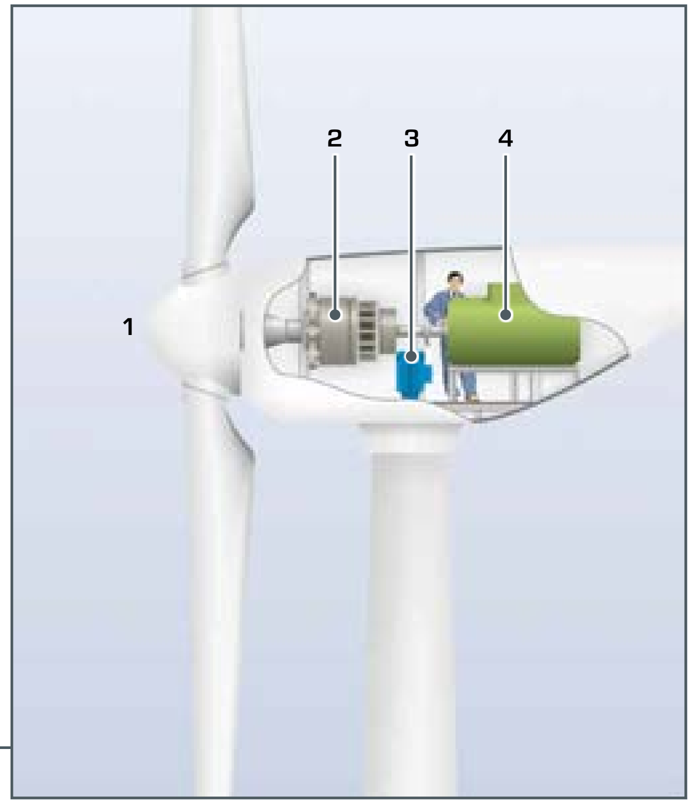
The construction and operation of a wind power plant go hand in hand with high investment costs. Failure of the rotor bearings, gears or rotor shaft leads to financial losses.

In order to avoid failure, wind power plants are continuously monitored by vibration analysis. The aim of these analyses is to detect and replace damaged components early, before the damage results in failure of the turbine.

Besides the rotor and the generator, wind power plants consist of lots of individual components which together form a functional and efficient wind power plant.

The following aspects play a key role in education specialist technicians and engineers in the field of wind energy engineering:

- functional principle and interaction of the individual components
- installation and operational monitoring

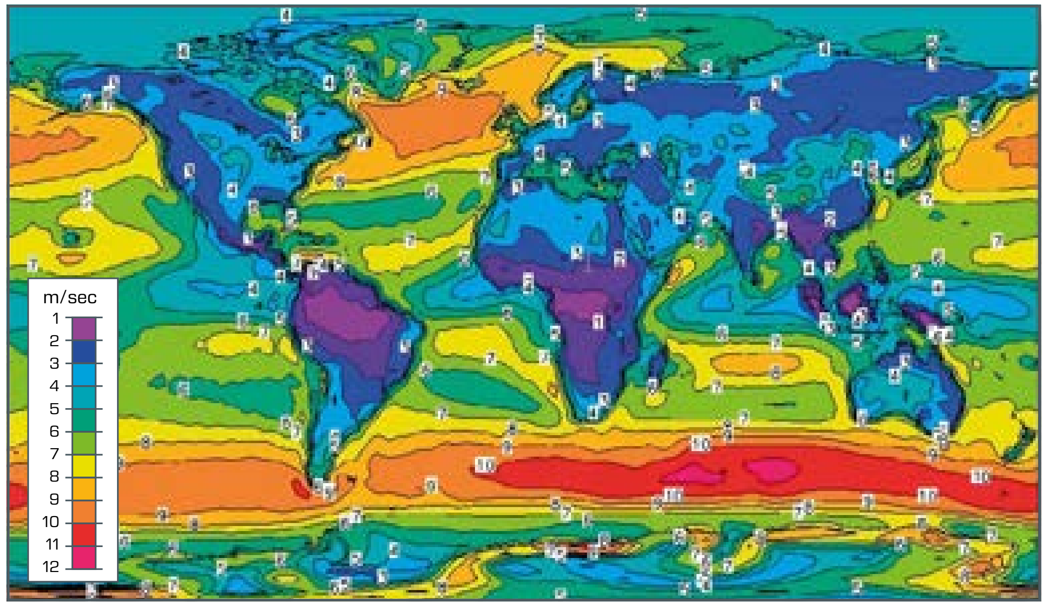


Setup of a typical wind power plant

1 rotor, **2** gearing, **3** yaw motor, **4** generator

Global wind energy supply

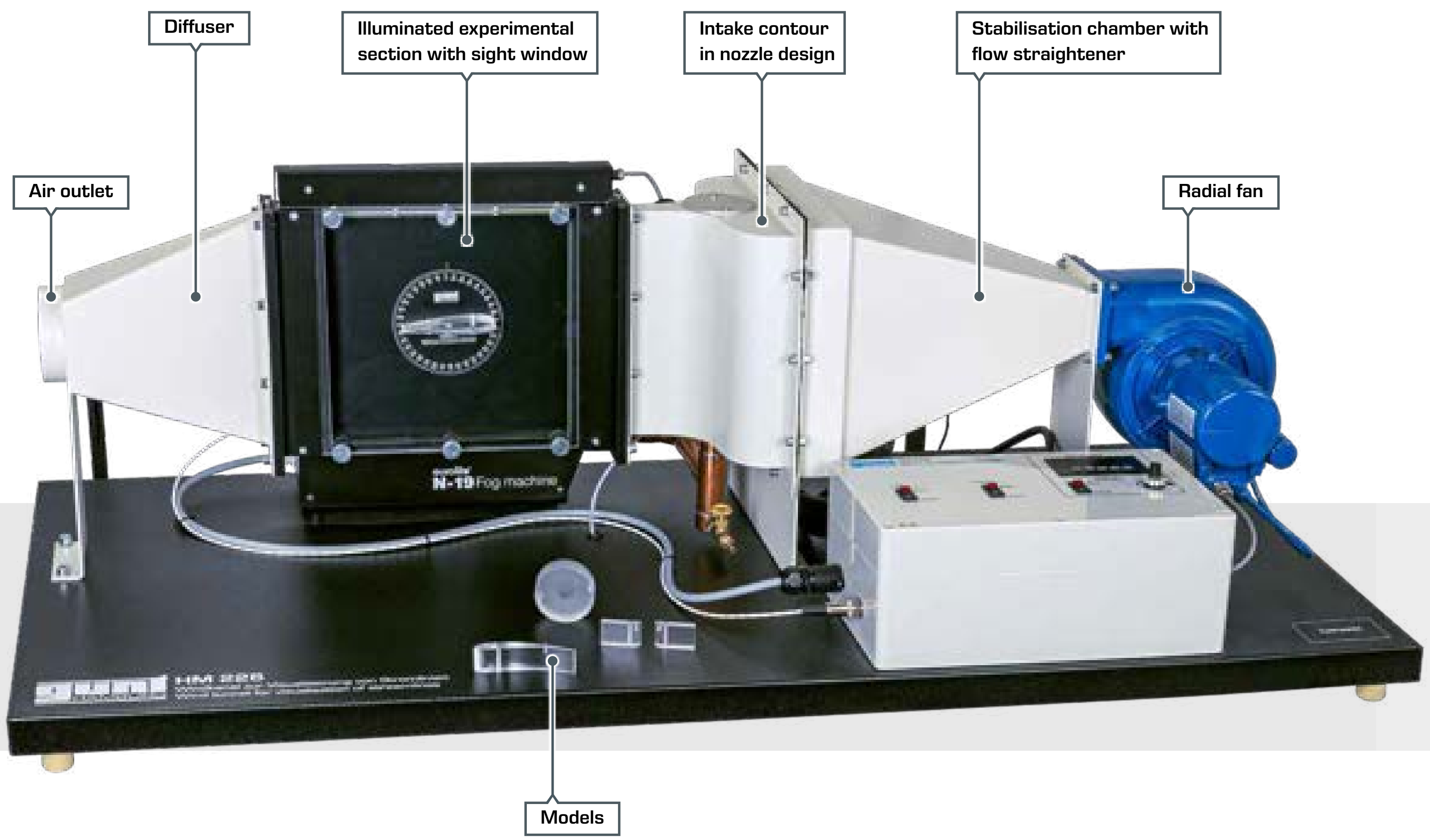
The graphic shows the average global wind energy supply as regions marked in colour



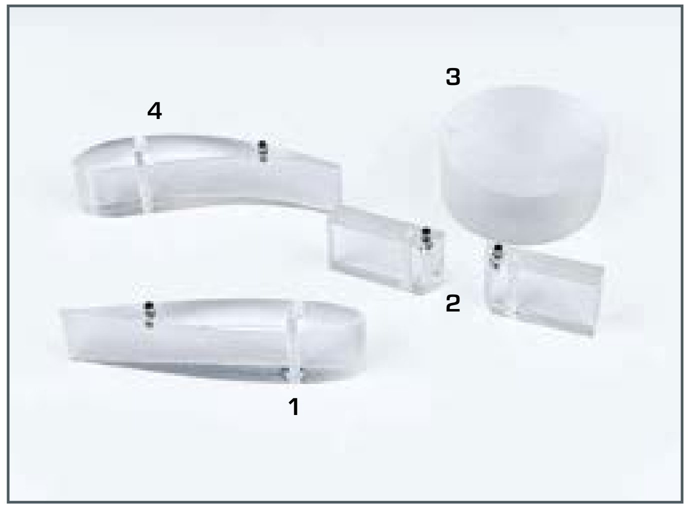
HM 226
Wind tunnel for visualisation of streamlines

The experimental unit HM 226 is an open wind tunnel, in which streamlines, flow separation and turbulence can be made visible by using fog. The evaporated fog fluid is non-toxic, water soluble and the precipitate does not affect common materials.

The experimental section has a black background and a sight window; additional lighting makes the streamlines clearly visible.

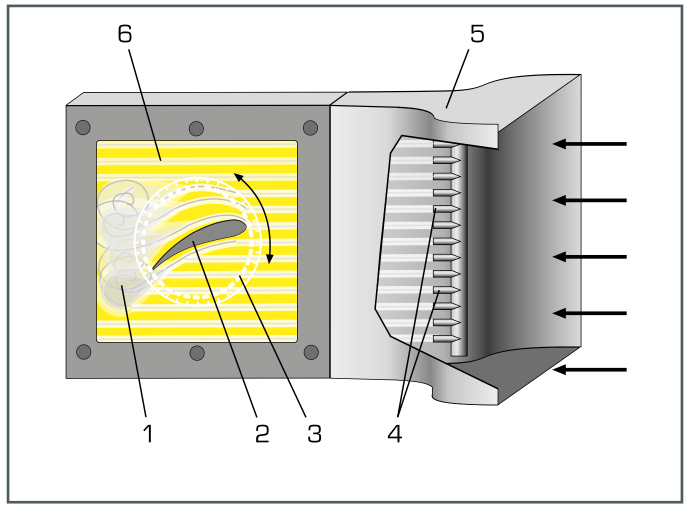


Four interchangeable models are included. The aerofoil's angle of attack is adjustable.



Models

1 aerofoil, **2** orifice plate, **3** cylinder, **4** guide vane profile



Setup of the experimental section

1 turbulence, **2** model, **3** scale for adjusting the angle of attack, **4** nozzles for injecting fog, **5** intake contour in nozzle design, **6** illuminated experimental section

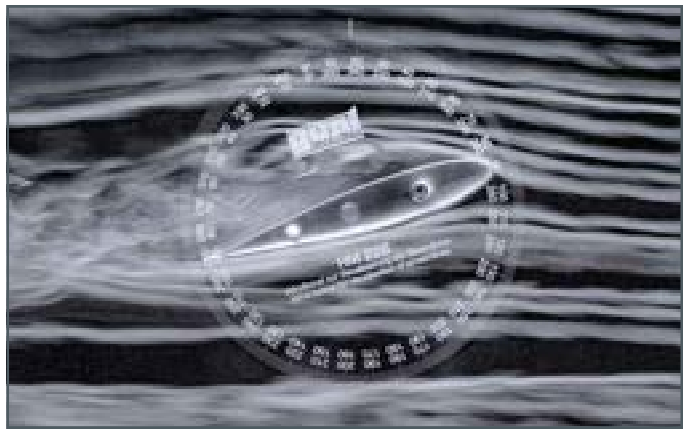
About the product:

Learning objectives

- visualisation of streamlines
- flow around or through differently shaped models
- flow separation and turbulence
- stall as a function of the angle of attack

Features

- transparent, illuminated viewing area for optimal observation of streamlines
- low-turbulence flow
- streamline field is generated by injecting fog from multiple nozzles
- fog generator is included in the scope of delivery



Detailed view of the experimental section

Stall as a function of the angle of attack

HM 170
Open wind tunnel with accessories

Fundamentals of converting wind energy

The effect chain of a wind power plant starts with the rotor. How much energy is converted into mechanical work essentially depends on the aerodynamic properties of the rotor blade.

The HM 170 wind tunnel can be used to conduct experiments with different profile shapes and drag bodies. As a result it is possible to measure, for example, how the angle of incidence affects the pressure distribution on the profile. Lift and drag forces resulting from this determine the conversion of the kinetic energy of the wind into mechanical energy on the rotor shaft.

HM 170 is an "Eiffel" type open wind tunnel used to demonstrate and measure the aerodynamic properties of various models. For this purpose, air is drawn in from the environment through a flow straightener and accelerated. The air flows around a model, such as an aerofoil, in a measuring section. Then the air is pumped back into the open by the fan.

An extensive range of accessories is available for individual experiments with HM 170.

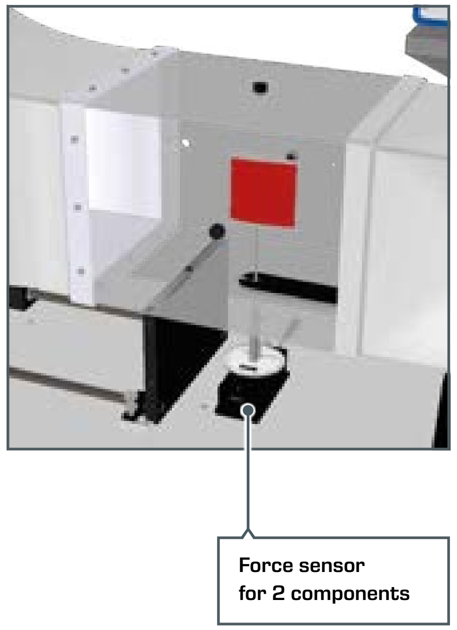
About the product:

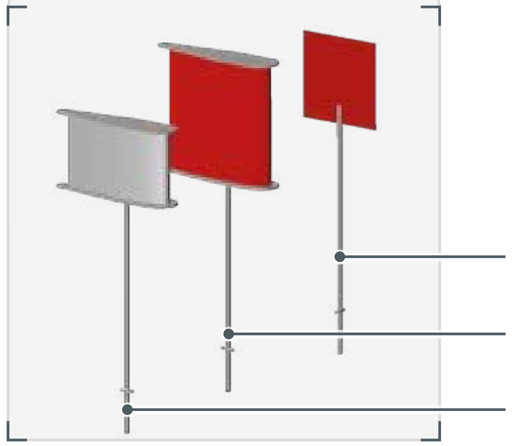
Features

- open wind tunnel for a variety of aerodynamic experiments
- homogeneous flow through the flow straightener and special nozzle contour
- transparent measuring section

Learning objectives

- investigations on flow around bodies
- record pressure distribution on an aerofoil under surrounding flow
- measure lift and drag force
- lift and flow separation as a function of the angle of incidence and the flow velocity





For a detailed introduction to the aerodynamics of wind power plants, we recommend experiments with the following accessories:

HM 170.05
Drag body square plate

HM 170.09
Lift body aerofoil NACA 0015

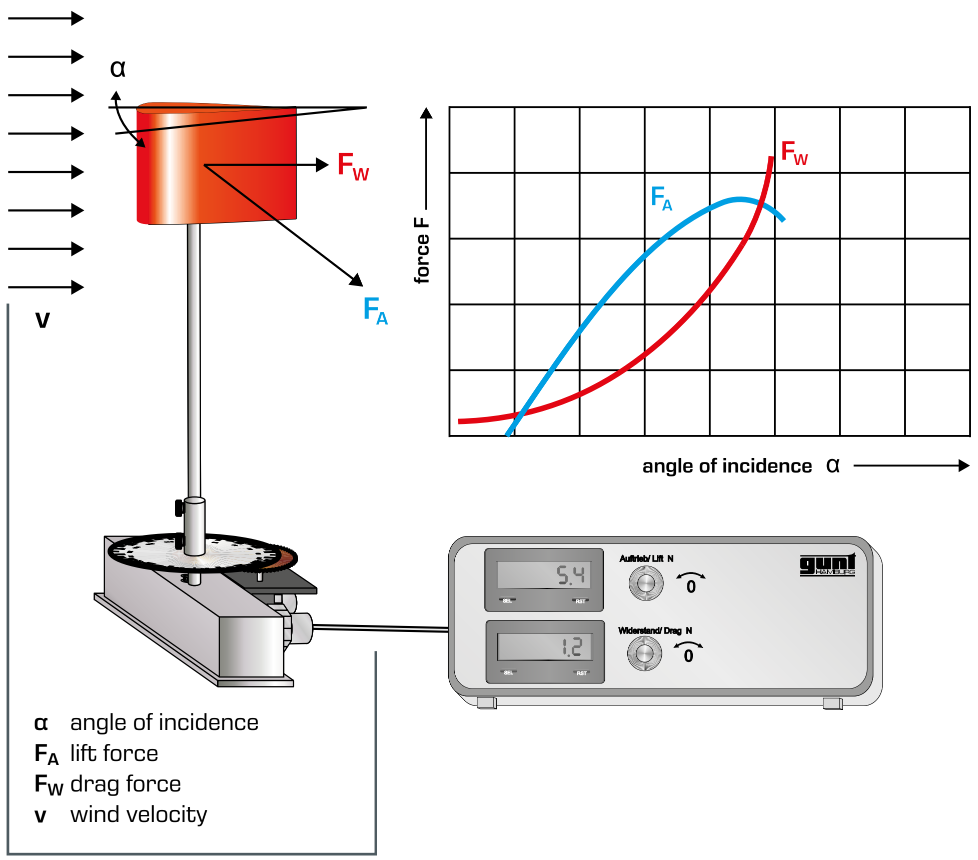
HM 170.22
Pressure distribution on an aerofoil NACA 0015

HM 170.09
Lift body aerofoil NACA 0015

The lift force is by definition perpendicular to the inflow direction. At a given wind velocity, the maximum lift force under an angle of incidence characteristic for the blade profile being used can be observed.

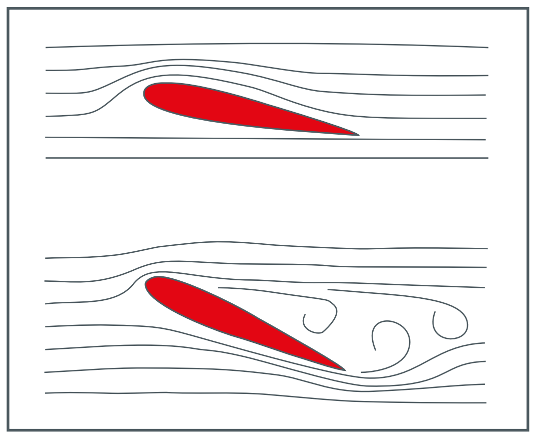
Using HM 170.09 you can systematically log the forces acting on a blade profile.

About the product:



Learning objectives

- experiments on bodies immersed in a flow
- determination of the drag coefficient (c_d factor)
- determination of the lift coefficient
- together with the force sensor HM 170.40
  - determination of the moment coefficient



“Pitch” and “stall” determine the operating behaviour of the wind power plant.

The effective force on the rotor blade can be adjusted via the angle of incidence (pitch).

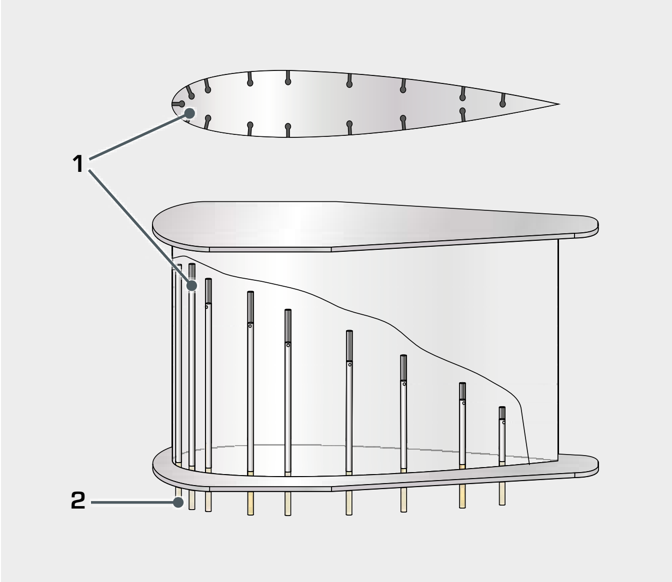
Stall is used specifically in smaller wind power plants to limit the speed of the rotor.

HM 170.22
Pressure distribution on an aerofoil NACA 0015

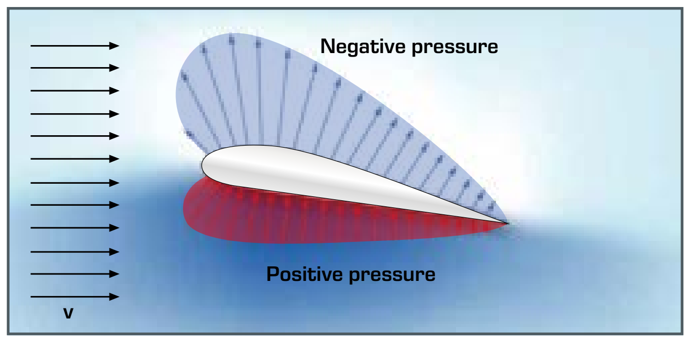
Measurement of the pressure distribution around an aerofoil profile under surrounding flow teaches students fundamental knowledge about the occurrence of lift force.

HM 170.22 demonstrates the pressure distribution on the NACA 0015 blade profile.

About the product:



The blade profile has openings **1** for pressure measurement at regular distances on the upper side and the underside. Hoses **2** connect the blade profile to pressure sensors.



In order for lift to occur on a body under surrounding flow, there must be positive pressure on the underside of the body and negative pressure on the upper side.

Learning objectives

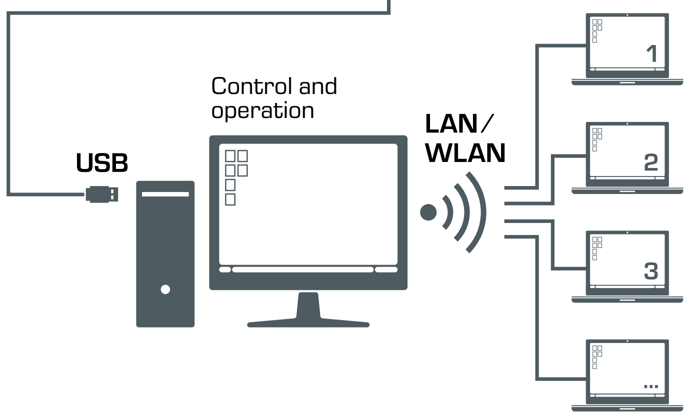
- record pressure distribution on an aerofoil immersed in a flow
  - as a function of the angle of attack

HM 170.70
Wind power plant with rotor blade adjustment

HM 170.70, together with the HM 170 wind tunnel, allows you to demonstrate a wind turbine with rotor blade pitching and variable-speed generator. The axial fan in the wind tunnel has a variable speed and provides the air flow required for the experiments. The generator is driven directly by a 3-blade rotor. A servo motor is used to change the angle of the rotor blades.

In order to approach different operating points, the nominal speed of the generator can be set via a controller. The rotor speed is precisely measured by Hall sensors built into the generator. For the investigation of different shapes, rotor blades with straight and with optimised profile are included in the scope of delivery.

About the product:

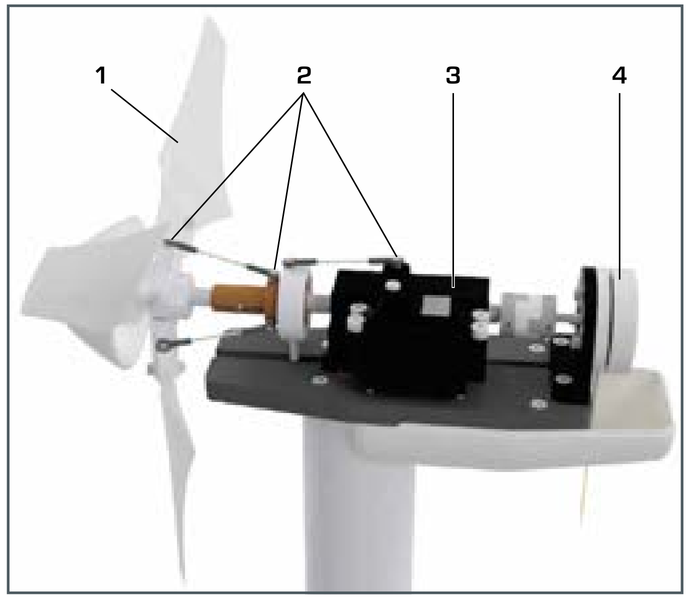


Features

- wind turbine with variable speed
- rotor blades adjustment angle adjustable via servo motor
- investigation of own rotor blade shapes (3D printing) possible
- network capability: observe, acquire, analyse experiments via customer's own network

Learning objectives

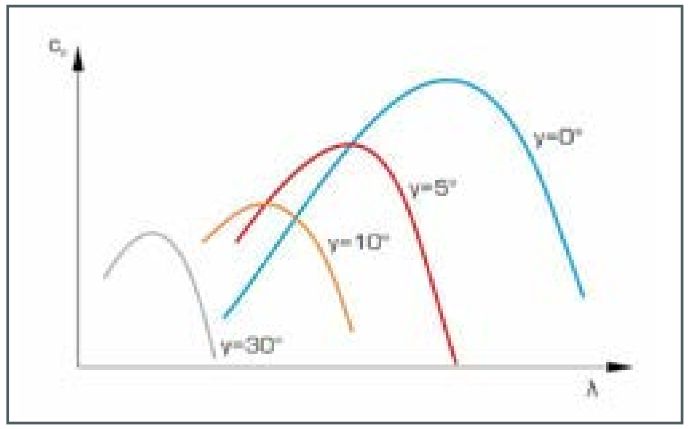
- conversion of kinetic energy into electrical energy
- power adjustment by means of
  - speed adjustment
  - rotor blade adjustment
- behaviour in the case of oblique flow
- determine the power coefficient tip-speed ratio characteristic diagram
- comparison of different rotor blade shapes



Components of the wind power plant

1 rotor blade, **2** rotor blade pitching, **3** servo motor, **4** generator

HM 170.70 connected to the open wind tunnel HM 170



Power coefficient via tip-speed ratio at different rotor blade angles and constant wind velocity

ET 210
Fundamentals of wind power plants

In modern wind power plants, the power output from the wind is adapted to the changing wind conditions. In the strong wind range, power output is limited to protect the turbine. The rotor blade adjustment serves this purpose. By adjusting the angle, this changes the forces acting on the rotor blade. In the normal wind range, power consumption is optimised by means of generator systems with variable speed.

ET 210 demonstrates a wind power plant with rotor blade adjustment and generator with variable speed. The air flow is generated by an fan. A flow straightener ensures consistent and low-turbulence flow. A three-blade rotor drives the generator directly. For the investigation of different shapes, rotor blades with straight and with optimised profile are included in the scope of delivery.

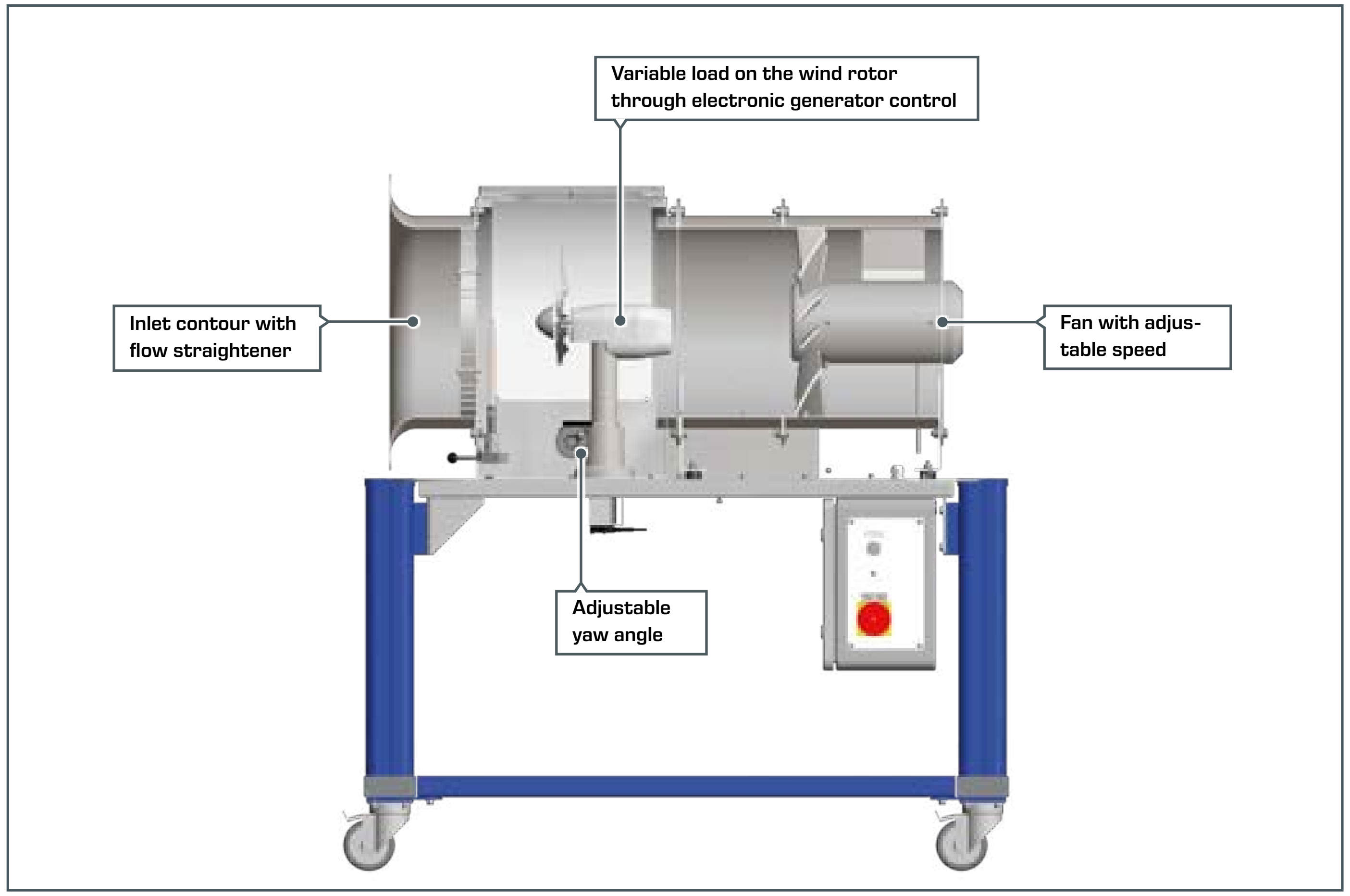
About the product:

Features

- compact unit, experiments can be carried out without additional accessories
- wind power plant with variable speed
- adjustment of rotor blade and yaw angle
- network capability: observe, acquire, analyse experiments via customer's own network

Learning objectives

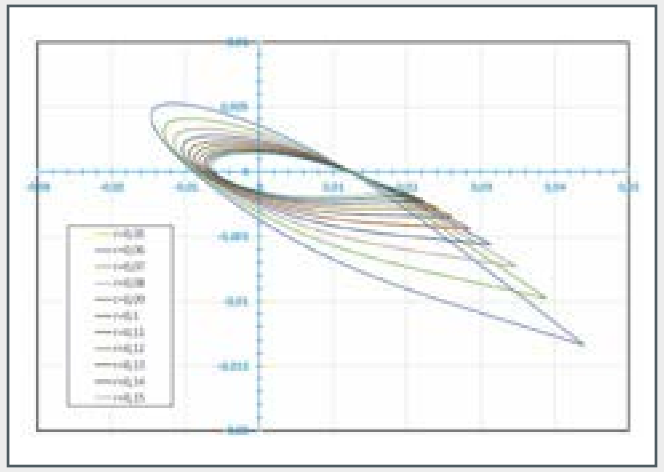
- conversion of kinetic energy into electrical energy
- power adjustment by means of
  - speed adjustment
  - rotor blade adjustment
- behaviour in the case of oblique flow
- determine the power coefficient tip-speed ratio characteristic diagram
- comparison of different rotor blade shapes



Software

The software calculates the converted electrical power, the generator torque and system-specific parameters.

GUNT software for unit control and measurement data acquisition via PC



Calculated results for a sequence of segments on a rotor blade. Change in blade depth and twist as a function of blade radius.

ET 220
Energy conversion in a wind power plant

The ET 220 device allows you to teach the individual stages from conversion of wind flow into rotational energy through to storing the electrical energy in accumulators, in clear and easy-to-understand steps.

To investigate the operation of a wind power plant under real weather conditions outdoors, ET 220 can be operated together with ET 220.01.

About the product:

UNIVERSITY OF LEEDS

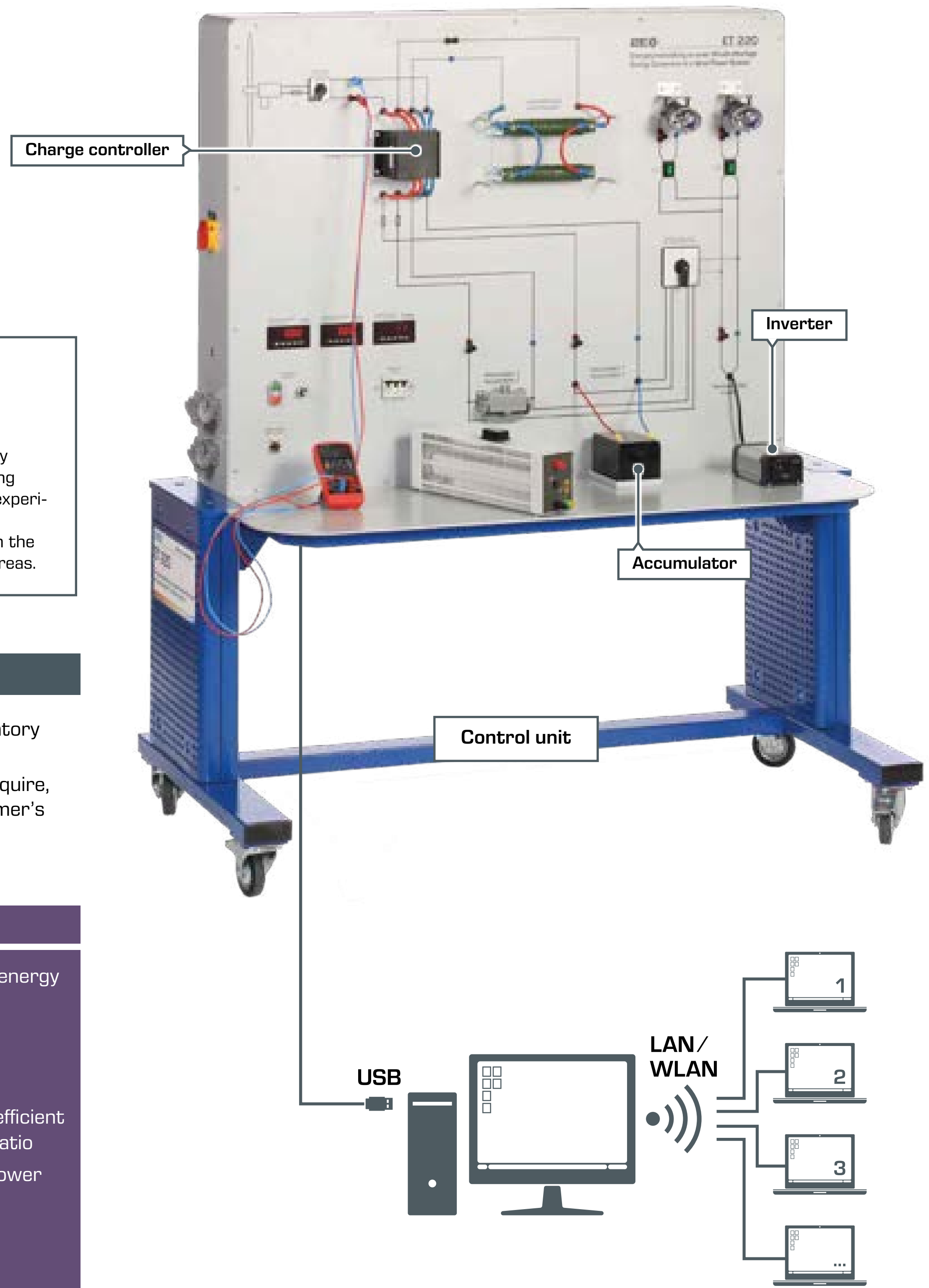
ET 220 is also used at the University of Leeds, UK, for teaching engineering students. Extensively documented experiments are available for a variety of educational situations to cover both the fundamentals and more advanced areas.

Features

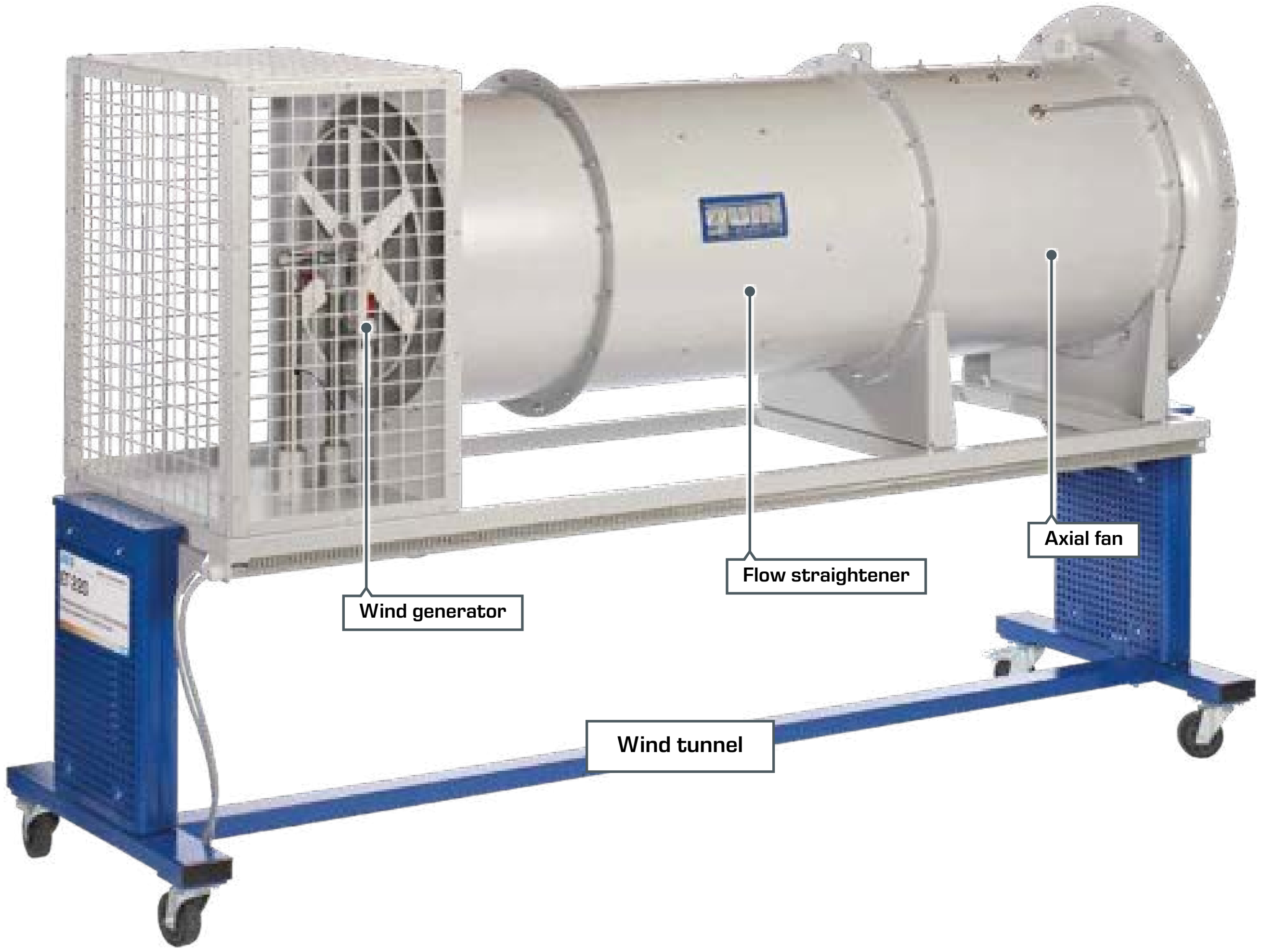
- practical experiments in laboratory scale
- network capability: observe, acquire, analyse experiments via customer's own network

Learning objectives

- conversion of kinetic wind energy into electrical energy
- function and design of a stand-alone system with a wind power plant
- determining the power coefficient as a function of tip speed ratio
- energy balance in a wind power plant
- determining the efficiency of a wind power plant



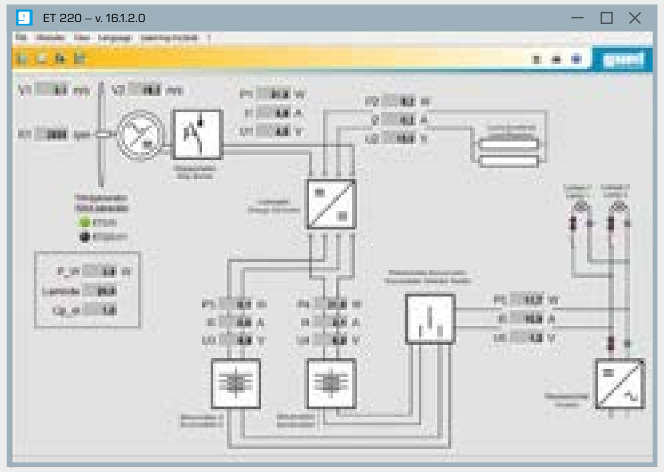
The ET 220 wind tunnel allows experiments under defined conditions. As a result, you can systematically study characteristic system variables regardless of the weather conditions, even with shorter experiment times.



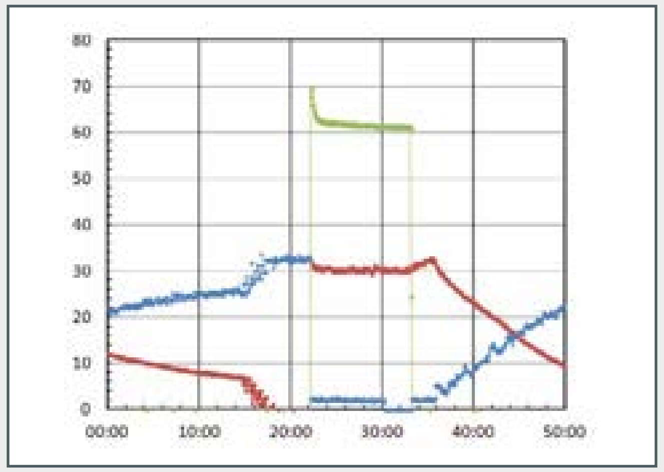
Software

With the software, current and voltage are measured at various points of the stand-alone system.

Energy balances are possible for the entire system and for separate components.



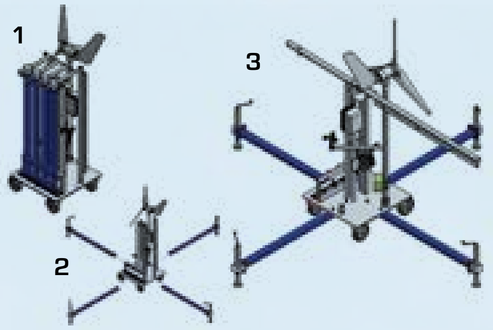
GUNT software for measurement data acquisition via PC



Measured time graphs of the electrical powers

ET 220.01 Wind power plant
ET 220.10 Control unit for wind power plant ET 220.01

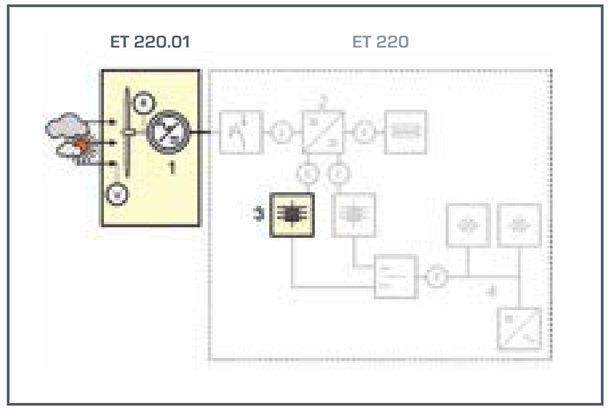
The yield of a wind power plant depends on the prevailing wind speeds and the usability of the electricity generated. The wind power plant ET 220.01 is either used together with ET 220 or together with ET 220.10.



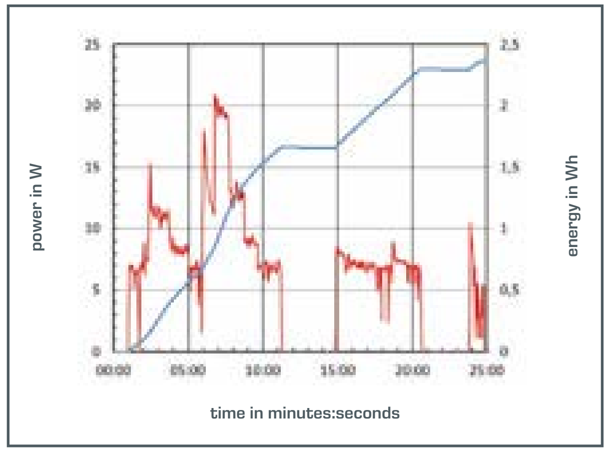
Commissioning ET 220.01

In its transport state **1**, the wind power plant can easily be brought to the experiment site. After the supports have been assembled **2**, the wind power plant is placed on the swivelling mast **3**.

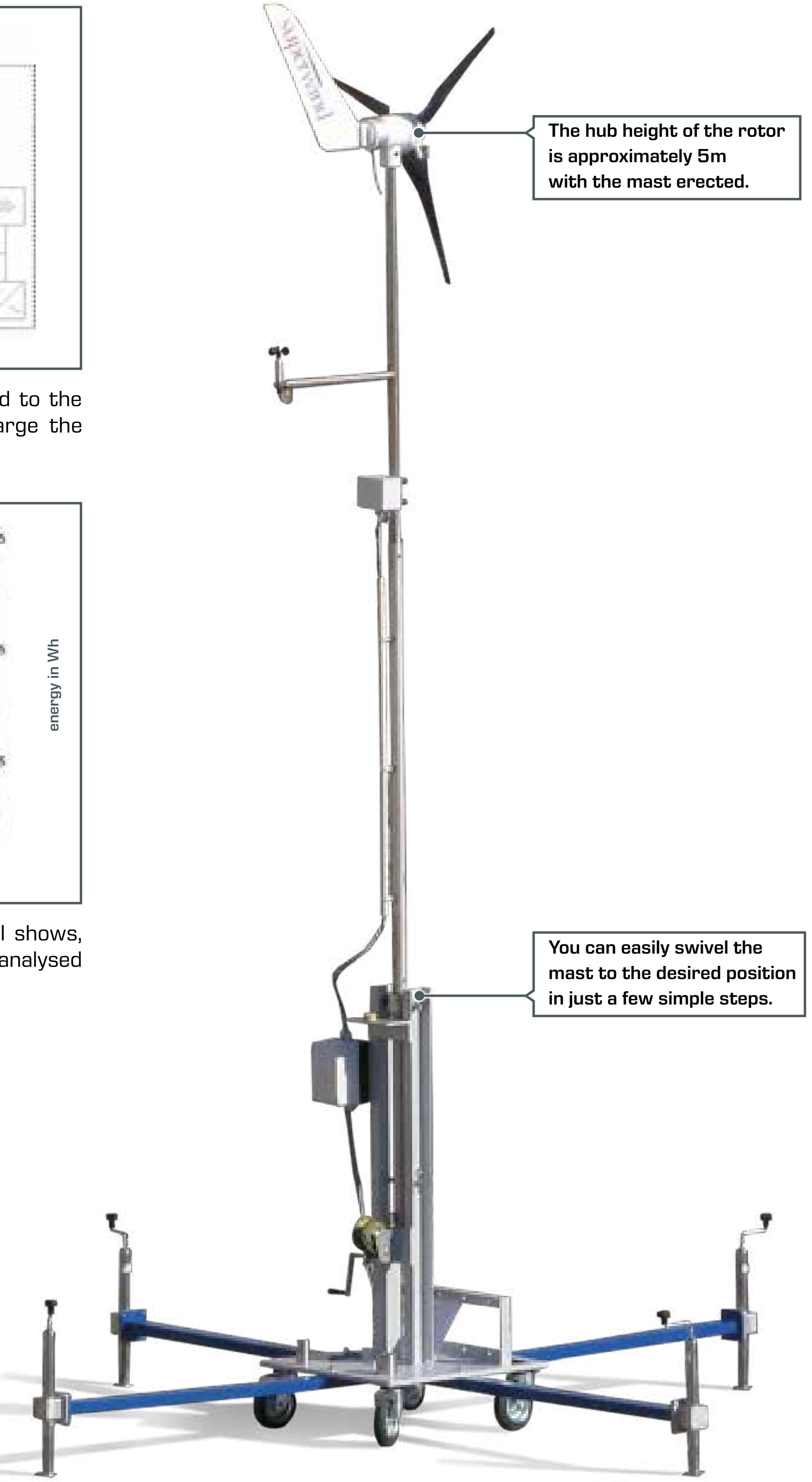
About the product:



The generated electrical energy is transferred to the ET 220 control unit and can be used to charge the accumulators or for direct consumption.



As a typical diagram from the ET 220 manual shows, power curves (red) caused by the weather are analysed to calculate the energy yields (blue).



ET 220.10
Control unit for wind power plant ET 220.01

The electrical energy from the wind power plant ET 220.01 is fed into the stand-alone system of ET 220.10, which is independent from the power grid.

Sensors record the wind velocity and the rotor speed of ET 220.01 as well as the current and voltage of the stand-alone system. The measured values are transmitted directly to a PC via USB, where they can be analysed using the software included. In addition, digital displays indicate the wind velocity and rotor speed.

About the product:

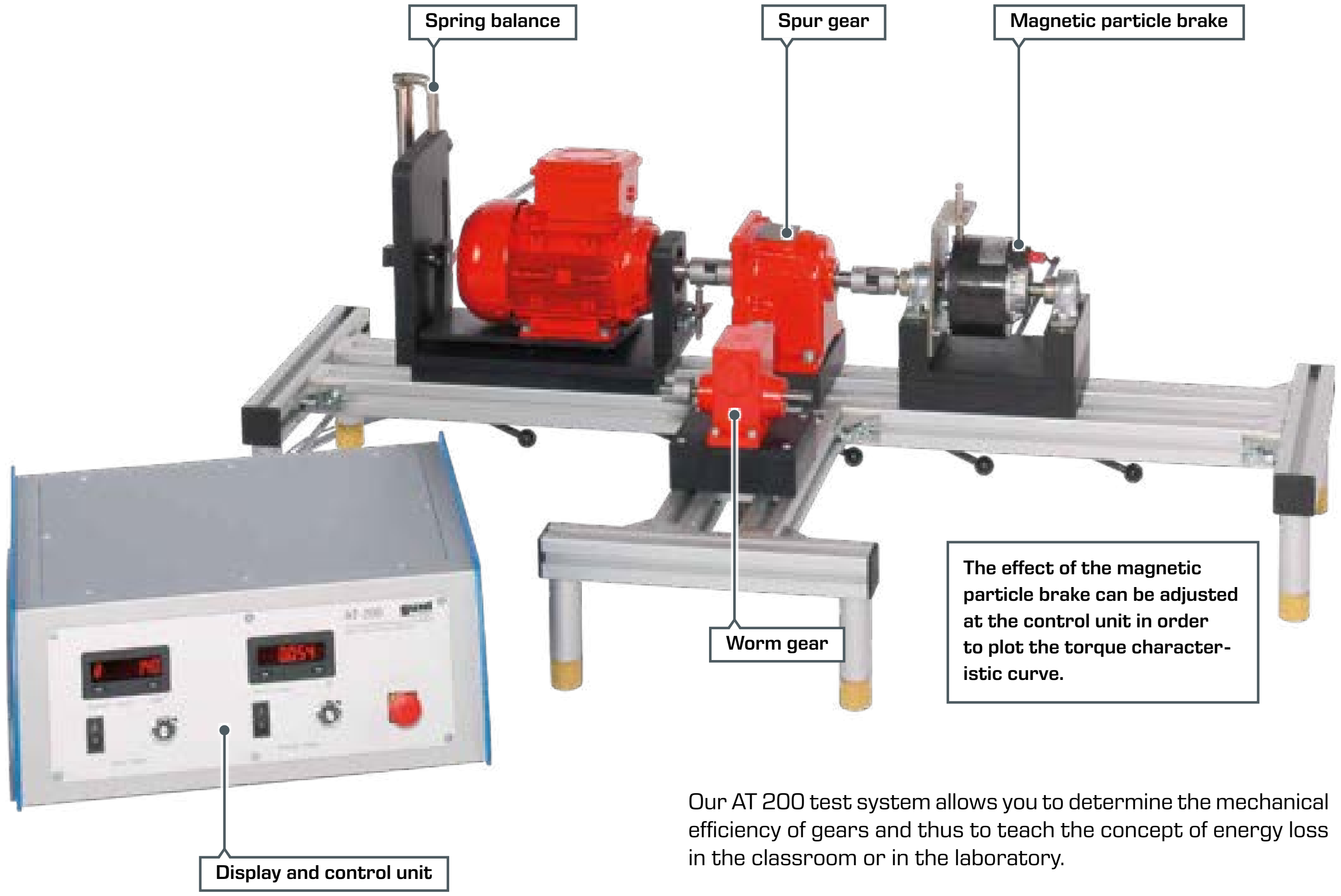
Learning objectives

- design and function of a wind power plant in stand-alone operation
- energy balance of a wind power plant under real wind conditions

AT 200
Determination of gear efficiency

Gears play an essential role in energy conversion in wind power plants. The purpose of a gear is to transfer the kinetic energy of the rotor to the generator with as little loss as possible.

In typical applications the comparatively low speed of the rotor has to be adjusted to the much higher speeds on the generator.



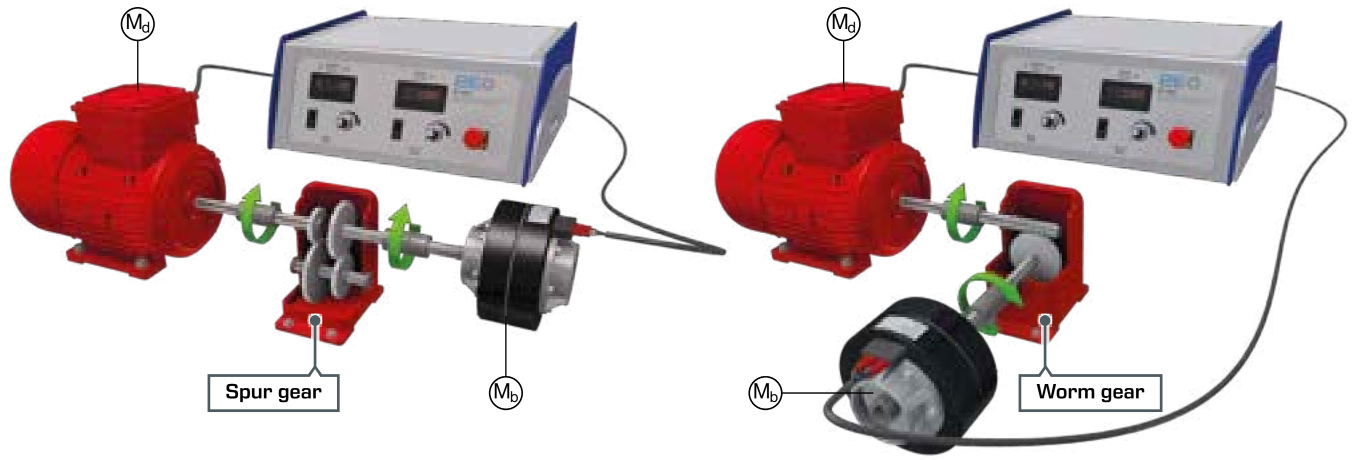
Our AT 200 test system allows you to determine the mechanical efficiency of gears and thus to teach the concept of energy loss in the classroom or in the laboratory.

Learning objectives

- determination of the mechanical efficiency of gears by comparing the mechanical driving and braking power for
  - spur gear, two-stage
  - worm gear
- plot the torque/current characteristic curve for a magnetic particle brake
- drive and control engineering

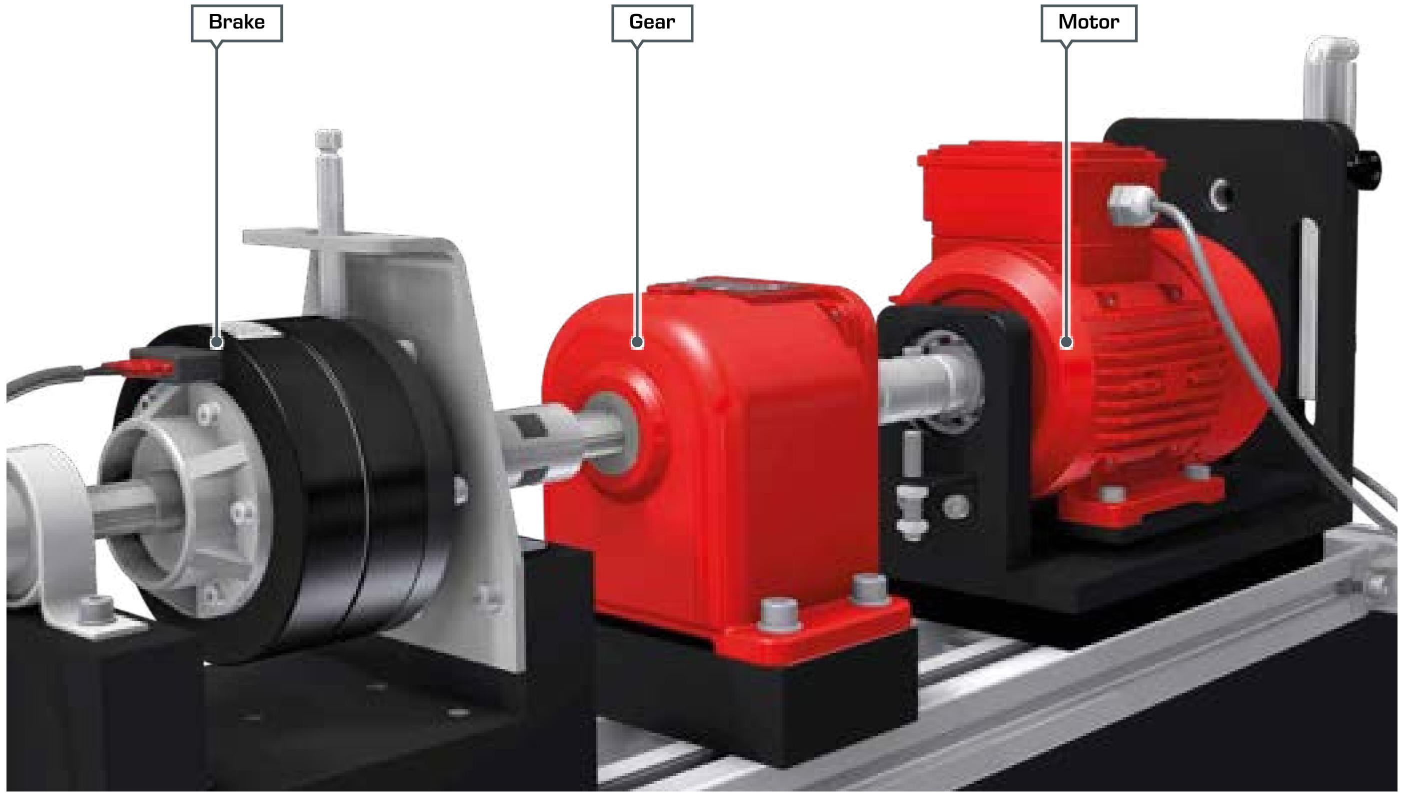
About the product:

WWW



M_d drive torque M_b braking torque

Energy losses in the gear mainly occur due to friction in the bearings and gear wheels. Friction converts kinetic energy into thermal energy. This energy is removed from the system and is therefore no longer available to produce electricity.

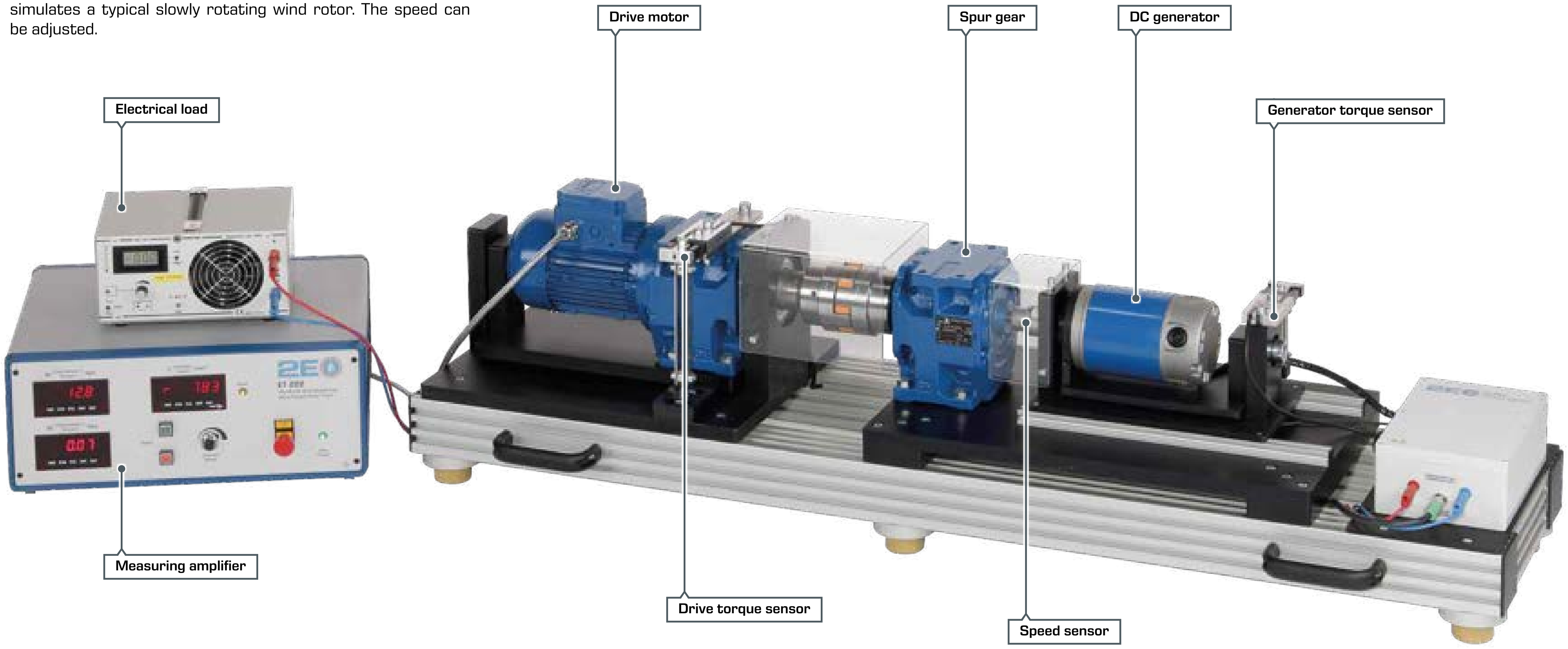


ET 222
Wind power drive train

Modern wind turbines should be optimally adapted to the wind available at their location and allow efficient operating conditions. In addition to the wind rotor itself, components of the drive train such as the transmission and the electric generator are crucial.

About the product:

The ET 222 experimental unit contains a typical wind power drive train at laboratory scale, which is driven by an electric motor. The motor enables low speeds with high torque. This simulates a typical slowly rotating wind rotor. The speed can be adjusted.

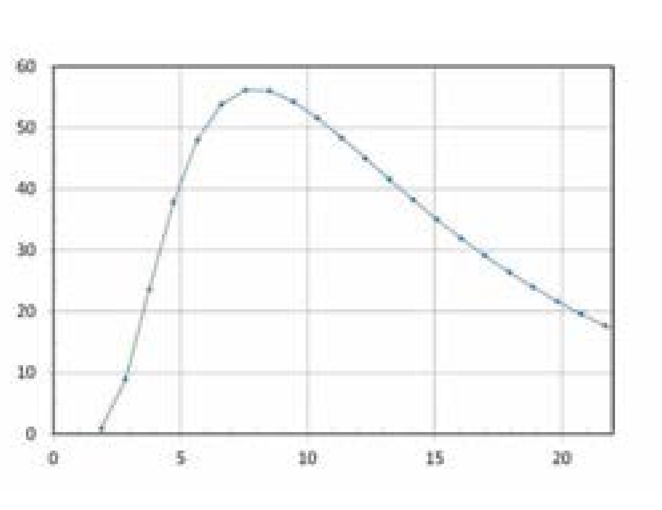


Features

- low-speed electric motor simulates wind rotor
- generator with adjustable electrical load
- torque measurements on drive and generator

Learning objectives

- conversion of rotational energy into electrical energy
- influence of torque and speed on the efficiency of the transmission
- influence of torque and speed on the efficiency of the generator
- influence of the typical torque characteristic of a wind rotor on the overall efficiency of the drive train



Simulated torque characteristic of a wind rotor:
x axis: shaft speed in min^{-1}
y axis: torque in Nm

The experiments with ET 222 simulate typical operating conditions of a drive train. To do this, the electrical load of the generator and the speed of the drive motor are varied. This makes it possible to approximate operating points of a typical torque characteristic. The calculated characteristic results from the mechanical power of a wind rotor for a given wind speed.

The generator speed and the torques of the drive side and generator are captured by sensors and displayed digitally on the measuring amplifier. The measured values are also available as analogue signals for optional external capture or processing.

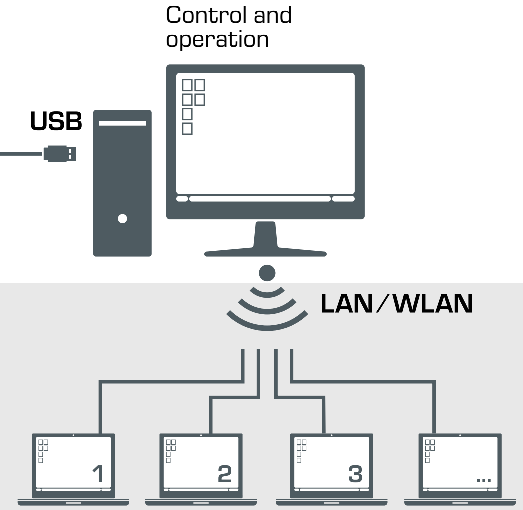
NOTTINGHAM TRENT UNIVERSITY

ET 222 was developed specifically for wind energy training at NOTTINGHAM TRENT UNIVERSITY (UK).

ET 224
Operating behaviour of wind turbines

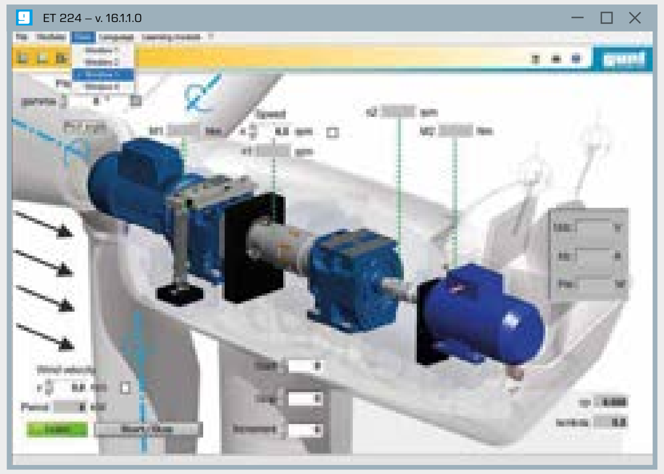
The performance of wind power plants depends on mechanical and electrical components, and on an efficient turbine control system. Therefore, it is essential that the influence of the effective parameters under all relevant operating conditions be known.

ET 224 looks at the components of a wind power drive train. To aid understanding, the main turbine parameters are studied in experiments with simulated characteristic diagrams. An adjustable speed gear motor simulates the typical slowly rotating wind rotor with high torque. A three-stage spur gear is located between the slow-rotating drive side and the fast-rotating generator side. A three-phase synchronous generator with rectifier converts the mechanical energy into electrical energy. The electrical energy is transferred to an electronic load.

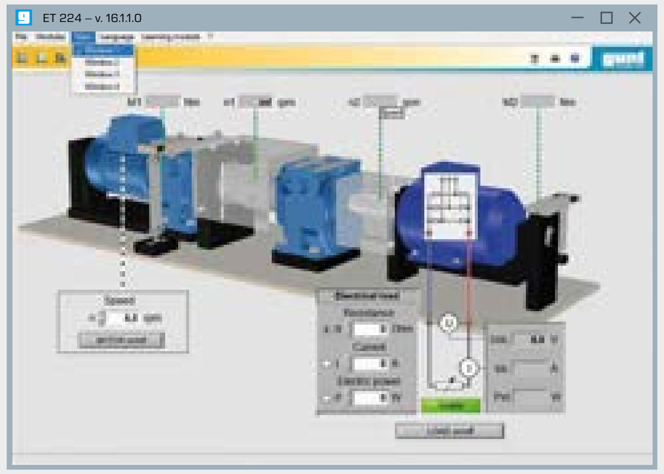


Software

The electronic load can be controlled directly or via the simulation module in the supplied GUNT software. It is possible to perform single measurements, automated capture of characteristic curves and characteristic diagrams, as well as measurements in autonomous wind-guided turbine mode.



Automated measurements in simulation mode



Plant control without simulation

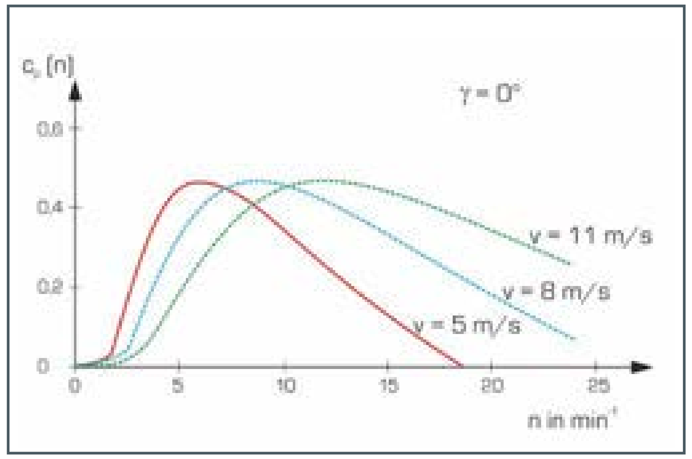
About the product:

Learning objectives

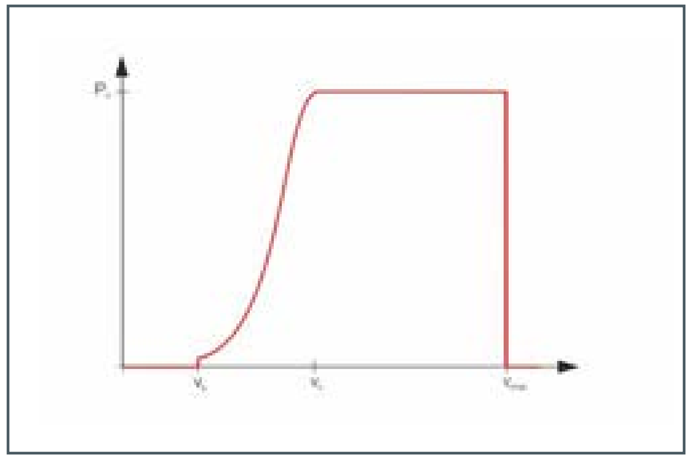
- conversion of kinetic energy into electrical energy
- power coefficient and tip-speed ratio
- study how torque and speed affect the efficiency of the gearbox and generator
- study how wind speed and rotor blade angle affect the typical torque characteristic of a wind rotor
- power limitation by controlling speed and rotor blade angle
- familiarisation with wind-guided turbine control in autonomous mode

Features

- low speed drive unit simulates wind rotor
- GUNT measurement and simulation software with control function for electronic load
- automated capture of characteristic diagrams as a function of wind speed, rotor blade angle and rotor speed
- network capability: observe, acquire, analyse experiments via customer's own network



Power coefficient as a function of rotor speed: simulation of typical characteristic diagrams at different wind velocities and rotor blade angles



Power curve for autonomous mode with increasing wind velocity: power output is limited by the turbine control system by adjusting rotor speed and rotor blade angle

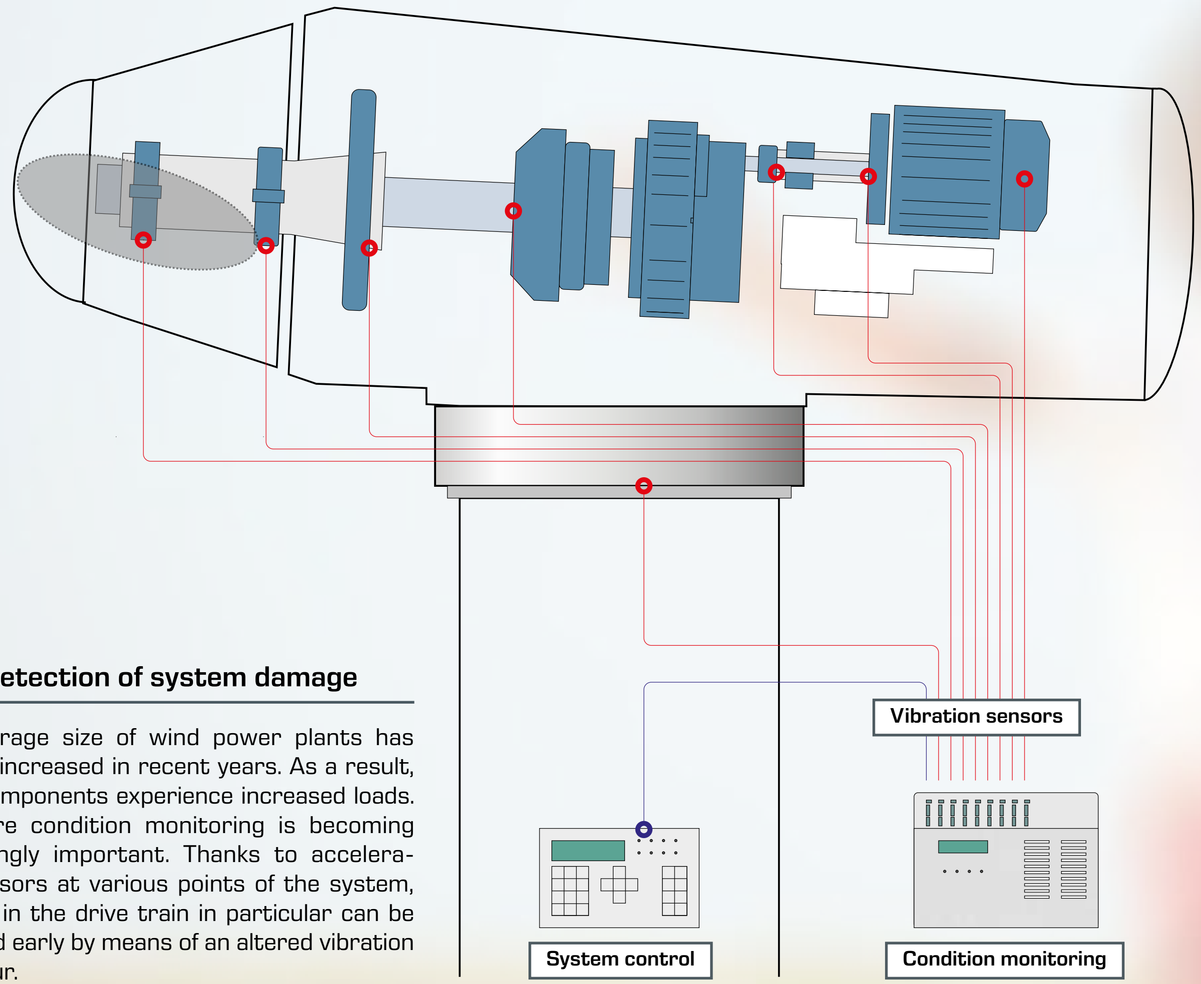
Basic knowledge

Condition monitoring in wind turbines

In order to reduce technical and economic risks, systems for monitoring the status of the equipment (CMS, **C**ondition **M**onitoring **S**ystems) are now used in all large-scale wind power plants.

In addition to typical data such as wind velocity, speed, electrical power and temperature, these systems also detect vibrations at all relevant points of a turbine. By analysing the vibration data and comparing it with set values, it is possible to detect and replace damaged components in good time before the components fail.

From the perspective of operational management, both the adaptation of suitable maintenance intervals and the early detection of damage are important. Taking into account CM systems, downtimes of much less than 10% are now agreed in contracts between wind power plant manufacturers, operators and insurance companies.



Early detection of system damage

The average size of wind power plants has steadily increased in recent years. As a result, many components experience increased loads. Therefore condition monitoring is becoming increasingly important. Thanks to acceleration sensors at various points of the system, damage in the drive train in particular can be detected early by means of an altered vibration behaviour.

Preventing hazards

Faults may occur in sensitive components of a wind power plant, such as bearings and gear wheels, due to a number of causes. These include regular wear and tear, extreme environmental conditions, overloads as well as installation and manufacturing faults. If resulting defects remain undiscovered for too long and are not rectified in good time, this can lead to significant damage up to destruction of a wind power plant.

Therefore continuous monitoring of the turbine condition is essential for larger wind power plants in particular, not least because of risks to the environment.

Expert knowledge ensures reliable system monitoring

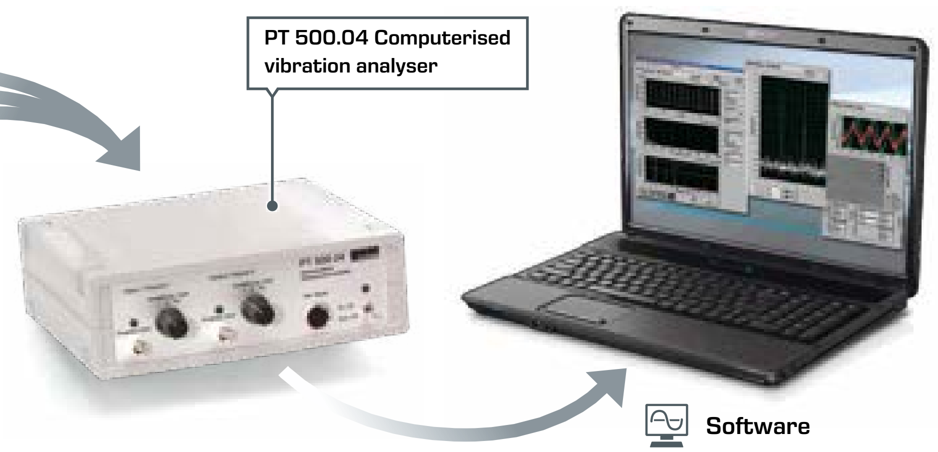
Condition monitoring includes vibration measurements on various system components in a suitable frequency range. By analysing the structure-borne sound, it is possible to draw conclusions about the condition of the components. Other important measured variables for example are speed and the temperature of the oil and the bearings.

In many cases, experienced experts are also required to safely distinguish between measurements caused by the condition of the component and those simply caused by operation. We are pleased to present to you important experiments with our equipment in the field of wind energy in order to teach the necessary expert knowledge.

PT 500
Machinery diagnostic system, base unit

Using the teaching system PT 500 Machinery diagnostic, you can simulate, measure and evaluate vibration signals from various typical malfunctions and damage. The interpretation of measurement signals can be practised extensively.

Professional measurement technology supports the transfer of experience gained in the day-to-day operation of modern wind power plants.



About the product:

The PT 500 base unit, together with the PC-based PT 500.04 vibration analyser, allows a series of experiments on the topic of machinery diagnostics and machinery monitoring. The GUNT software offers a variety of analysis options for the evaluation. These include, for example:

- oscilloscope
- frequency spectrum
- vibration intensity
- envelope analysis
- damage analysis on roller bearings and gears using envelope spectra

Learning objectives

- introduction to vibration measurement methods on rotating machinery systems
  - fundamentals of measurement of shaft and bearing vibrations
  - basic variables and parameters
  - sensors and measuring devices
  - influences of speed and shaft layout
  - influence of transducer positioning
- understanding and interpreting frequency spectra
- use of a computerised vibration analyser

Detailed information about the PT 500 system

A complete summary of all options of the modular system can be found in our PT 500 brochure, which is available for download at **www.gunt.de.**

References

Many customers around the world are already successfully working with our PT 500 teaching system.

Below are a few selected references:

- Hamburg University of Applied Sciences, Germany
- Dresden University of Applied Sciences, Germany
- Reinhold-Würth University, Künzelsau, Germany
- Warsaw University, Poland
- RFPC Training Center, Bandar Iman, Iran
- INTECAP Instituto Technica de Capacitatión y Productividad, Guatemala

Accessories for PT 500 system

PT 500.01 Laboratory trolley
PT 500.04 Computerised vibration analyser
PT 500.05 Brake & load unit
PT 500.10 Elastic shaft kit
PT 500.11 Crack detection in rotating shaft kit
PT 500.12 Roller bearing faults kit
PT 500.13 Couplings kit
PT 500.14 Belt drive kit
PT 500.15 Damage to gears kit
PT 500.16 Crank mechanism kit
PT 500.17 Cavitation in pumps kit
PT 500.18 Vibrations in fans kit
PT 500.19 Electromechanical vibrations kit
PT 500.41 Two displacement sensors

The base unit contains a vibration-damped fixing plate, a speed-controlled drive motor with tachometer, a shaft with two mass discs and two bearing units, a coupling and balancing weight. Almost any topic of machinery diagnostics can be covered thanks to a wide range of accessories.

PT 500.11
Crack detection in rotating shaft kit

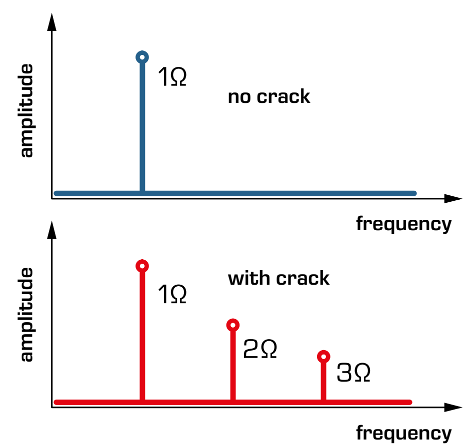
The rotor shaft of a wind power plant transfers the mechanical energy from the rotor to the gear. By detecting cracks in the shaft early, the risk of a costly failure and/or the danger of destruction of the turbine can be minimised.

Our PT 500.11 accessory allows you to conduct vibration analyses on faulty shafts. Different shafts are available, with which different sized cracks can be simulated.

About the product:

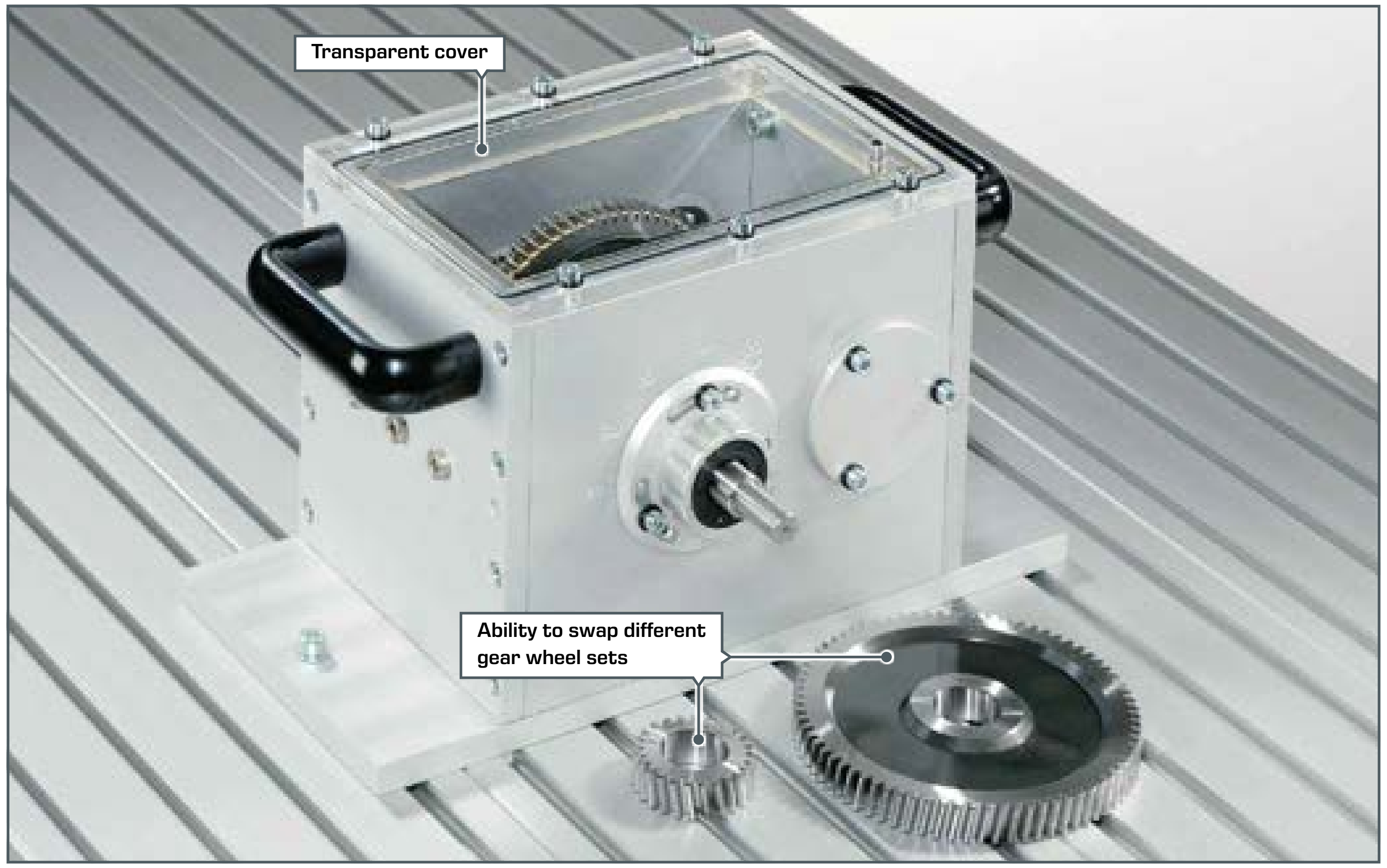
Learning objectives

- change in characteristic vibration behaviour (natural frequency, resonance speed, amplitude and phase of vibrations) due to a crack
- crack identification from the change in vibration spectrum
- detection of cracks in rotating shafts at the protruding shaft end
- understanding and interpreting frequency spectra
- use of a computerised vibration analyser



The opening and closing of a crack during one revolution of the damaged shaft leads to additional frequency components. The second order harmonic in particular increases rapidly compared to the undamaged shaft.

PT 500.15
Damage to gears kit

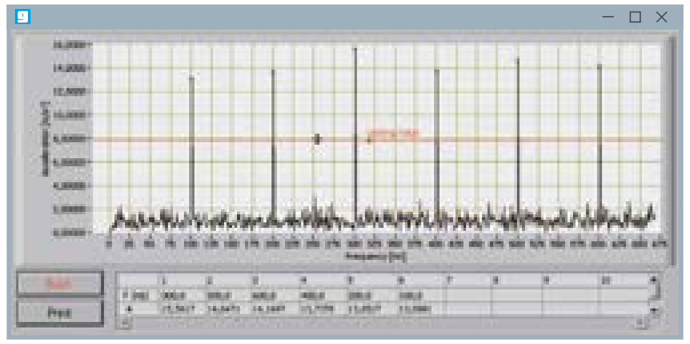


The PT 500.15 accessory set provides you with a variety of gear wheel sets with damaged teeth. Undamaged wheels are also included for comparative measurements. PT 500.15 enables you to conduct targeted experiments on the vibration analysis of toothing damage and on locating damage in gears.

About the product:

Learning objectives

- identification of gear damage from vibration behavior
- influence of gearing type
- localisation of damage
- influence of lubrication
- influence of centre distance and of backlash
- understanding and interpreting frequency spectra
- use of a computerised vibration analyser



Spectrum of a straight-toothed gear at 1800min^{-1} and tooth engagement frequency of 752 Hz

4

Biomass

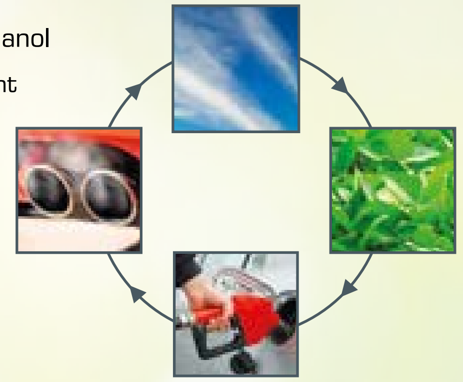
Subject areas
Biomass

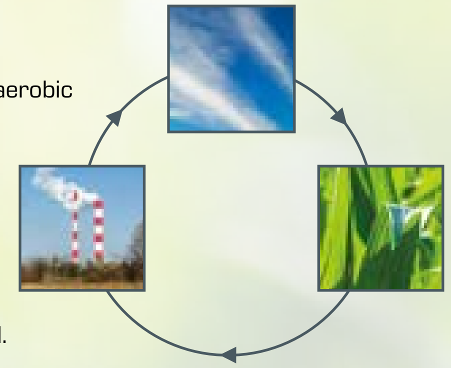
General biomass is an extremely versatile starting material. You can use the various plants and fruits as food, as animal feed, as fuel for heat generation, as fertiliser, as an additive or base of creams and lotions and as fuel for mobility purposes. Many of the uses listed overlap with other areas, so that any by-products created may be used as starting material in another branch.

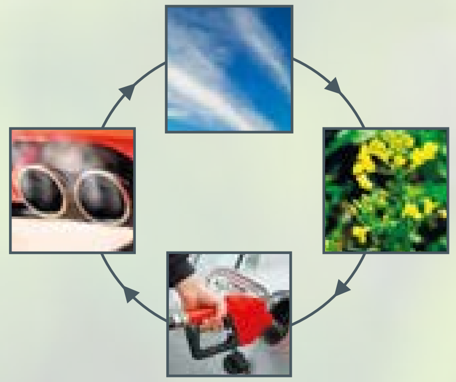
We offer three devices in the biomass field, which provide a practical representation and illustration of the fundamental processes. Use of any by-products created is also possible. For example, with CE 640 on the biotechnical production of ethanol, you gain ethanol as the main product and mash as the by-product. You can either discard the mash or use it as substrate in the CE 642 biogas plant. When you operate the biogas plant, you receive biogas as the main product and a high-quality fertiliser, the digestate, as a by-product. This digestate is low in odour compared to manure and the nutrients are better absorbed by plants.

The main product of the CE 650 biodiesel plant, after the optional purification process, is biodiesel. With the optional treatment of the by-products, you can also obtain glycerin, which is used in the food and cosmetics industries, and a portion of additives.

Subject areas	Products
Bioethanol	**CE 640** Biotechnical production of ethanol The anaerobic degradation of plant components (e.g. potatoes) by enzymes and yeasts can produce bioethanol, which can be used as a fuel. The waste gas is in turn absorbed by the plants and the circuit is closed.
Biogas	**CE 642** Biogas plant Biogas can be produced by the anaerobic degradation of plant components (e.g. maize) by biomass and, for example, be converted into electricity in combined heat and power plants and the waste heat used for heating purposes. The waste gas is in turn absorbed by the plants and the circuit is closed.
Biodiesel	**CE 650** Biodiesel plant Both glycerin and the desired biodiesel are obtained with the transesterification of plant-based oils, and with the help of a few additives. The waste gas is in turn absorbed by the plants and the circuit is closed.







Basic knowledge

Bioethanol

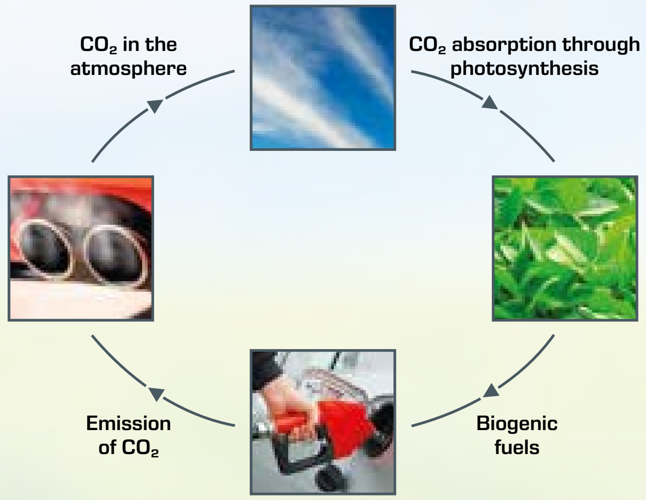
The consumption of fossil fuels (coal, petroleum, natural gas) has risen sharply in recent decades. The outputs required to cover the energy demand are leading to an ever more rapid depletion of deposits. Newly discovered deposits are difficult to extract due to the location and frequent impurities. Therefore alternatives are being sought.

Replenishable biomass can be used to produce storable carbon neutral energy sources. These energy sources play an important role alongside discontinuous sources such as solar and wind in realising a carbon neutral and renewable energy supply.

Different biological and thermal processes are used to convert the biogenic energy feedstock into a storable energy source.

The CO_2 cycle of bioethanol

Photosynthesis, by means of sunlight, enables plant growth. In this process, CO_2 from the atmosphere, as well as water and inorganic substances from the plants are absorbed and converted into energy-rich organic compounds. This biomass can be regarded as the product of a biochemical process, in which a portion of the absorbed sunlight is stored in the form of chemical energy. Being able to use the biomass as an energy source in various technical processes requires special treatment processes. These include simple physical processes as well as more complex thermochemical and biological processes.



Biofuels for carbon neutral energy

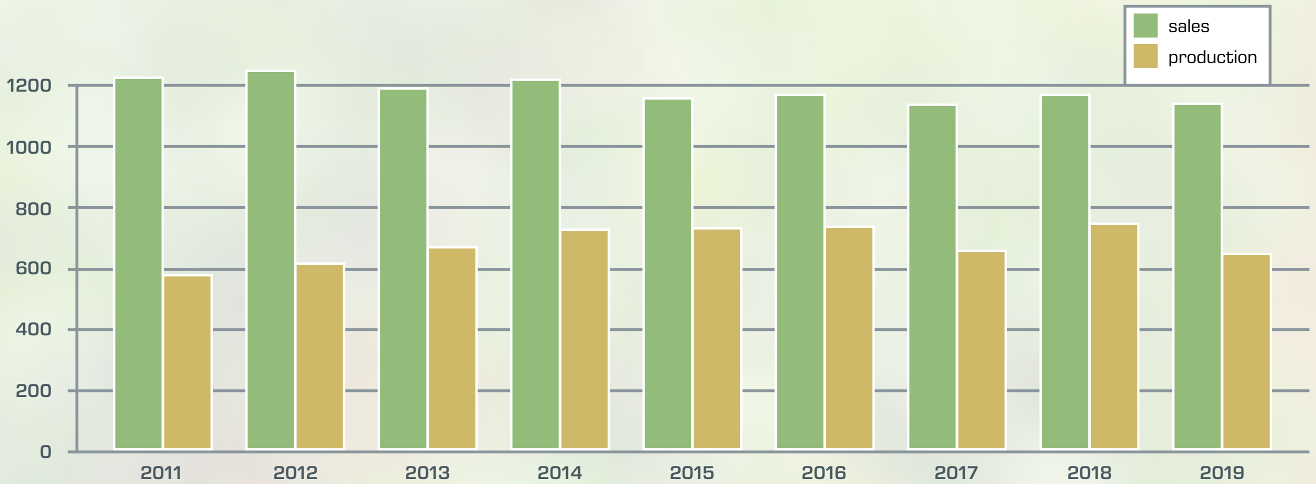
In addition to the simple mechanical processes such as comminution and press agglomeration used to produce solid energy sources (pellets), complex biological processes are used to produce biofuels and biogas.

These methods are applications of natural processes on an industrial scale. Factors such as temperature, pH value, mixing and retention time play an important role in these processes, so as to achieve the greatest yield of energy sources from the biomass.

Biofuels are substitutes for super unleaded and diesel fuels, which are either mixed with fossil fuels or used directly with appropriate engine technology. The basis of biofuel is ethanol for super unleaded fuel and vegetable oil for diesel fuel.

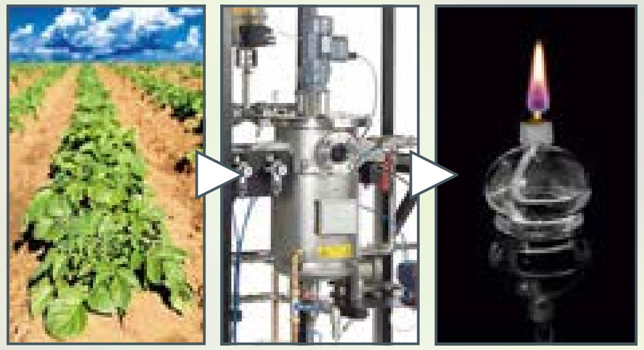
For the field of biofuels, we supply both a complete system that uses enzymes and yeasts to convert starch ethanol, and another system for the conventional production of biodiesel from vegetable oils by means of transesterification.

In addition to the distillation unit for the separation of ethanol from the digestate, our bioethanol plant also contains the previously required mash and fermentation tanks for the complete production process.

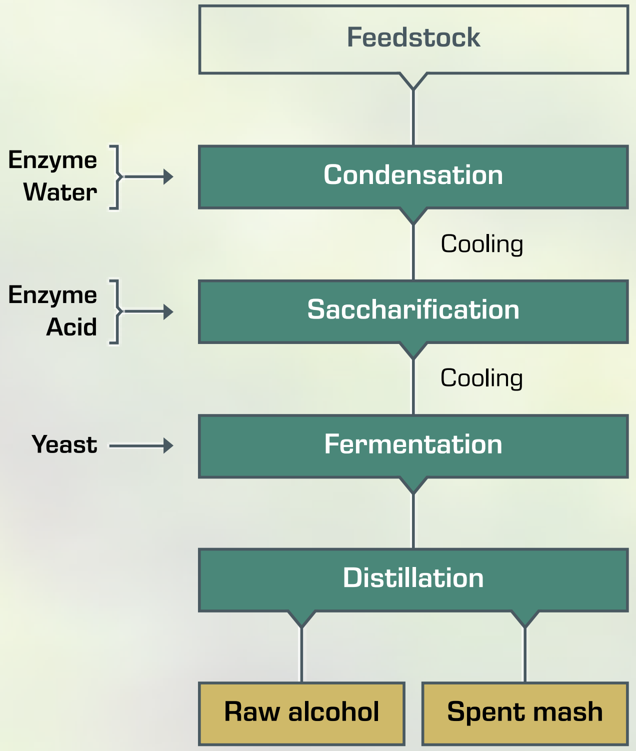


Growth of bioethanol in Germany (in 1000 t) (source: BDBe/FNR)

Starting materials for bioethanol are the carbohydrates (sugars) contained in the plants, from which alcohol is created with the aid of enzymes and yeast fungus. While plants containing sugar are fermented directly, in the case of starchy plants it is the actual alcoholic fermentation of the enzymatic digestion of the plant material that comes first.



The fermentation process is completed once either the sugar is consumed or a maximum alcohol concentration is reached. The resulting bioethanol is separated by distillation. The product of distillation is called raw alcohol.



Basic principle of bioethanol production

CE 640
Biotechnical production of ethanol

Understand the production process of bioethanol in a laboratory experiment

The experimental plant on the biotechnical production of ethanol is ideal for teaching professionals and students in the fields of chemical and bioprocess engineering. Bioethanol will be the world's leading biofuel in the future. Students learn the complete process from feedstock to end product.

Using the CE 640 Biotechnical production of ethanol experimental plant, you can follow and investigate all necessary process steps from condensation and saccharification of the feedstocks, through to the conversion of sugar into ethanol and distillation.

Addition of feedstocks into the mash tank

Preparation of the yeast

Addition of the yeast into the fermentation tank

Satisfied customers

AGRICULTURAL RESEARCH INSTITUTE
Nicosia/Cyprus

Dr Polycarpos Polycarpou

Agricultural Research
Officer Head of Soils and Water Use Department
Agricultural Engineering
Agricultural Research Institute

Fachhochschule Münster University of Applied Sciences

Chemical engineering department in Steinfurt

The production of ethanol with CE 640 is offered as a practical course in the laboratory for chemical process engineering at the Münster University of Applied Sciences. Two sessions are scheduled so that all participants can follow both the preparation of the mash and the results of fermentation and distillation in their own experiments.

About the product:

www

CE 640
Biotechnical production of ethanol

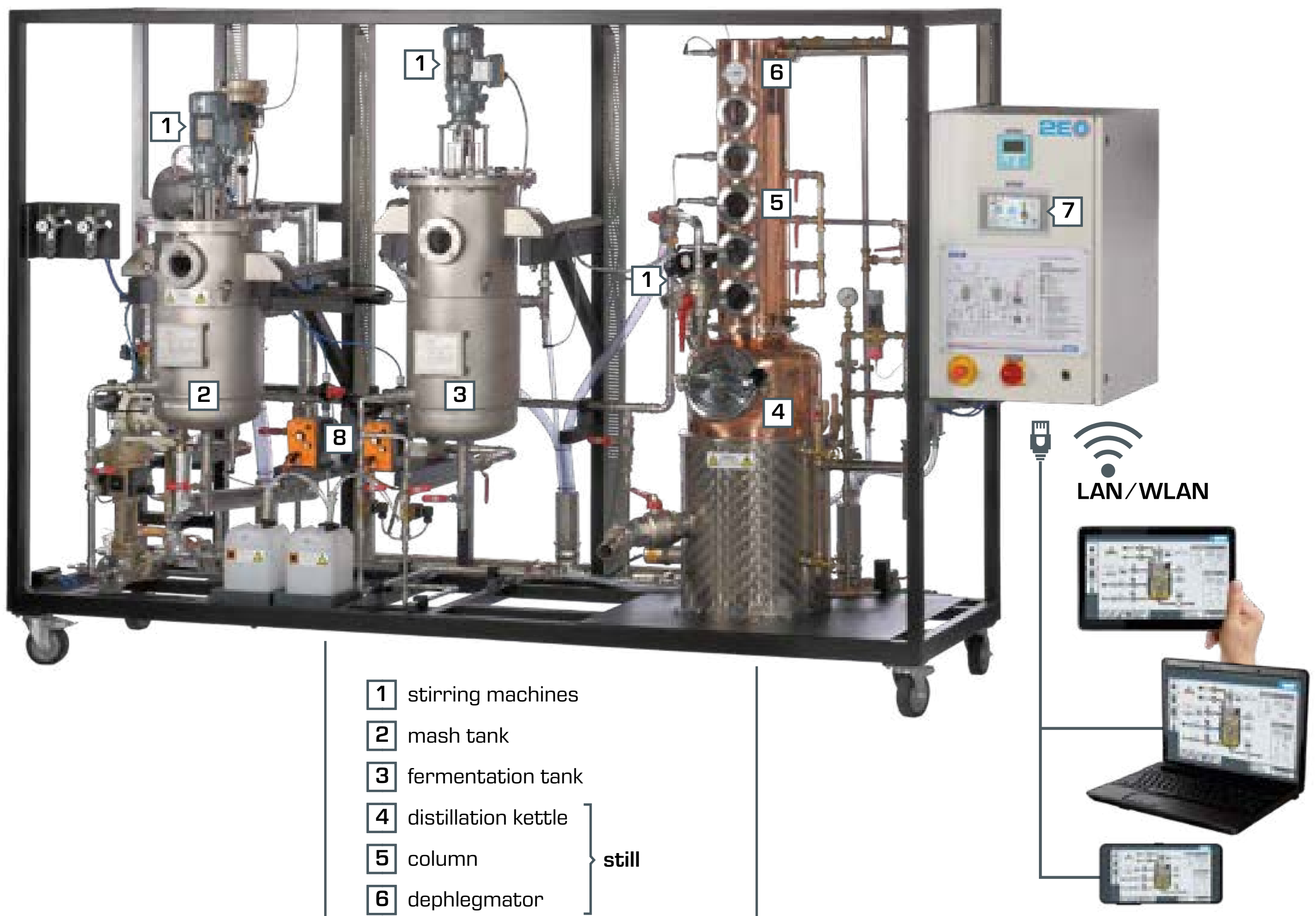
From plant to biofuel

Using the CE 640 trainer you can go through the whole process used to produce ethanol in laboratory scale.. Ethanol is produced from raw materials containing starch and sugar, as a starting material for biofuels and many other products. When converting starch to ethanol, different conversion processes have to be conducted using enzymes and yeasts.

The starch is converted into sugar in the first tank by glucoamylase and alpha-amylase enzymes. The temperature and pH value are monitored and controlled while this process takes place.

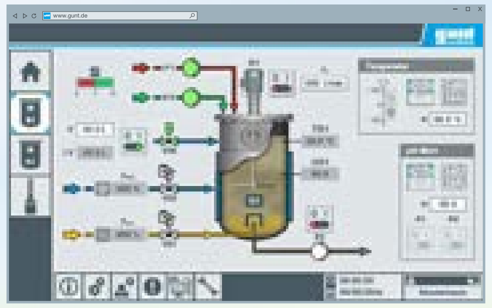
After the material has been pumped over into the second tank and yeast has been added, the fermentation process takes place sealed off from the outside atmosphere. The yeast converts the sugar into ethanol and carbon dioxide. The carbon dioxide escapes into the environment via a fermentation lock. The temperature in the fermentation tank is monitored and regulated throughout the process.

Once the fermentation process has ended, the ethanol is separated from the waste materials using a distillation unit (still).



1 stirring machines
2 mash tank
3 fermentation tank
4 distillation kettle
5 column
6 dephlegmator
(4–6: still)
7 PLC with touch panel
8 metering pumps for acid or caustic solution

Thick-walled, highly polished and hammered pure copper distillation kettle.



System control and data acquisition via PLC

The experimental plant is controlled by a PLC via a touch panel. The PLC allows the most important variables to be captured to the internal memory:

- temperature
- pH value

(**mash tank**)

- fermentation temperature
- water temperature

(**fermentation tank**)

- boiler temperature
- bubble cap tray temperatures
- dephlegmator temperature
- condensate temperature

(**still**)

Learning objectives

- gelatinisation by steam injection
- liquefaction using alpha-amylase
- saccharification using glucoamylase
- fermentation: conversion of sugar to ethanol from yeast cultures under anaerobic conditions
- distillation: separation of ethanol from the mash

Basic knowledge

Biogas

Increasing energy demand and the limitation of fossil energy sources require new approaches to ensure the energy supply. In addition to solar and wind energy, energy production from biomass is an important component of future energy concepts.

In a biogas plant, microorganisms, in the absence of light and oxygen, biodegrade the organic starting materials (substrate). The product of this anaerobic degradation is a gas mixture predominantly consisting of methane. This gas mixture is known as biogas.

The complex processes of anaerobic degradation can be divided into four consecutive phases.

Phase 1: Hydrolysis
The substrate used in biogas plants is in the form of unresolved, high-molecular-weight compounds such as proteins, fats and carbohydrates. Therefore, these compounds must first be broken down into their individual components. The products of hydrolysis are amino acids, sugars and fatty acids.

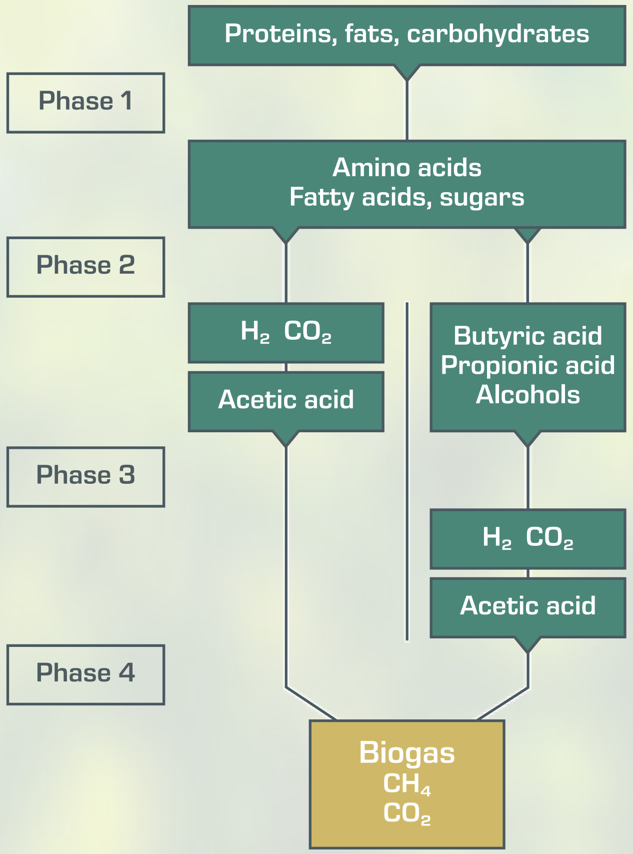
Phase 2: Acidification
From the products of hydrolysis, there now emerges the biochemical degradation of mainly propionic acid, butyric acid, acetic acid, alcohols, hydrogen and carbon dioxide.

Phase 3: Acetic acid formation
The products from the previous phase are then converted into acetic acid, hydrogen and carbon dioxide.

Phase 4: Methane formation
Methane bacteria can utilize either acetic acid (CH_3COOH) or carbon dioxide and hydrogen for their metabolism. The following two biochemical reactions can lead to the formation of methane (CH_4):

$$CH_3COOH \longrightarrow CH_4 + CO_2$$

$$4H_2 + CO_2 \longrightarrow CH_4 + 2H_2O$$



Basic principle of anaerobic degradation

Ambient conditions

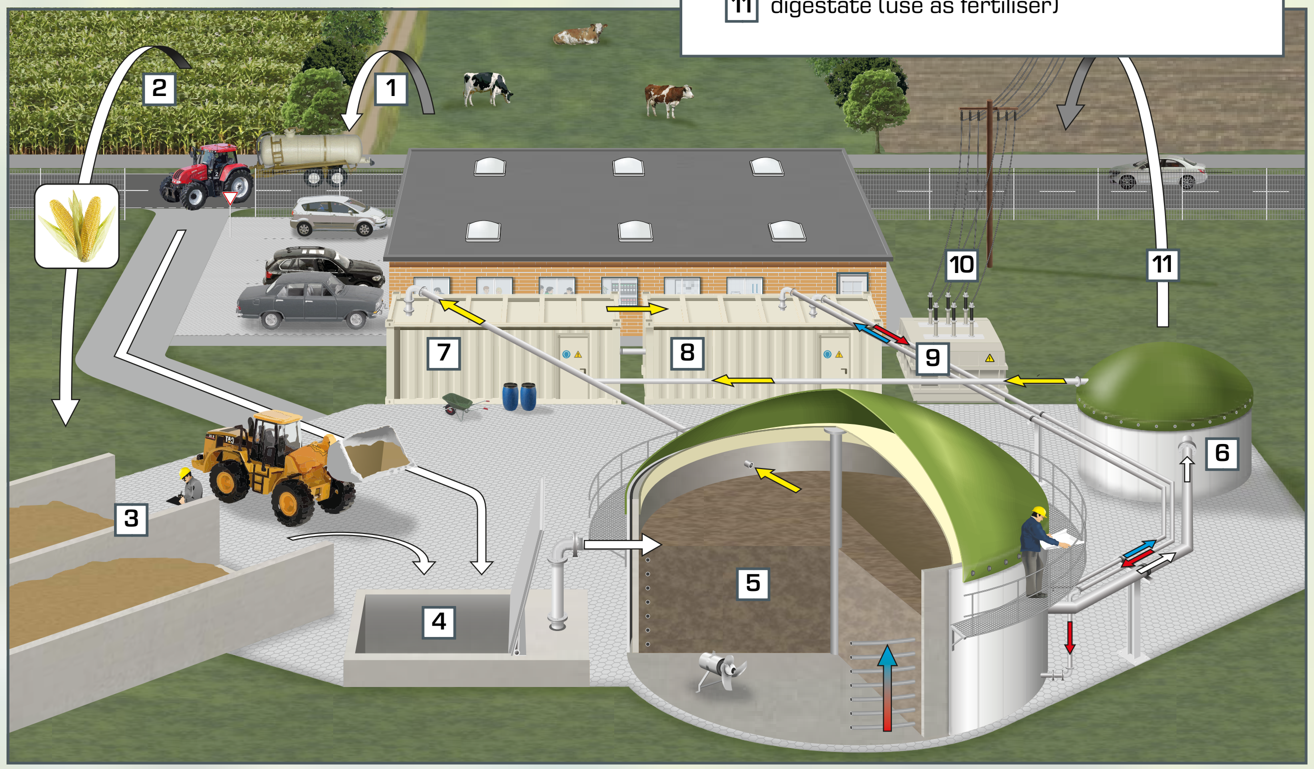
The microorganisms involved in the anaerobic degradation have different requirements as regards the ambient conditions. This relates primarily to the pH value and the temperature. In particular, the methane bacteria are very sensitive to deviations of these two process variables from their optimum value. If all the four phases of degradation take place in a reactor, it is necessary to find a compromise in terms of temperature and pH value. This results in a lower biogas yield. From a process engineering point of view, a two-stage process control in two separate reactors is more practical. In this way, the ambient conditions can be better adapted to the respective microorganisms.

Use of biogas

The resulting biogas can then be burned in a combined heat and power plant. This converts the energy stored in the biogas into rotational energy. An attached generator in turn generates electricity. A combined heat and power plant produces heat in addition to electrical energy, which can be used to heat the reactor or the premises.

Principle of operation of a biogas plant:

1 slurry from livestock farming
2 renewable raw materials (e.g. maize)
3 storage for comminuted raw materials
4 storage for feeding the bioreactor
5 bioreactor (fermenter)
6 digestate storage tank
7 biogas treatment
8 combined heat and power plant
9 water circuit for heating the bioreactor
10 feed-in of electricity into the public grid
11 digestate (use as fertiliser)



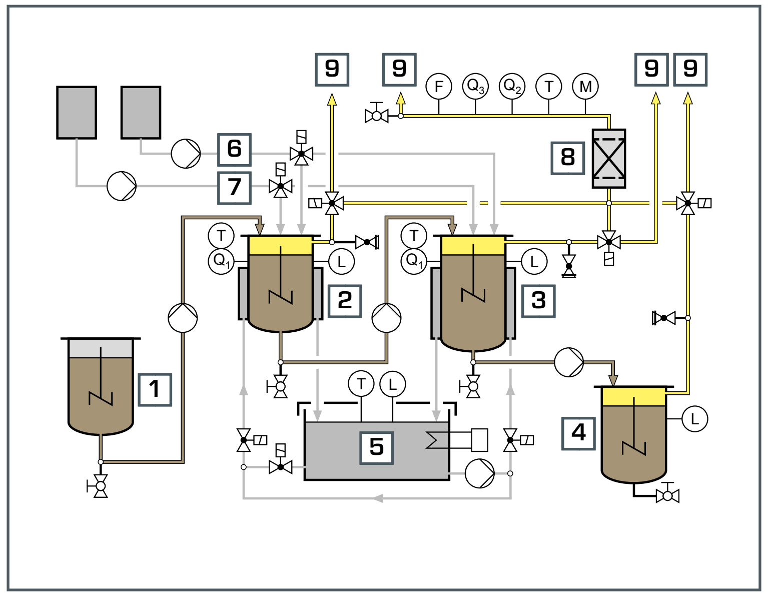
CE 642
Biogas plant

In CE 642 we have developed a practical system for the production of biogas under laboratory conditions. CE 642 allows you to study all important factors that influence biogas production. The necessary process steps can be controlled and automated via the PLC. The plant is equipped with extensive measurement technology and data acquisition in order to capture all necessary process variables.

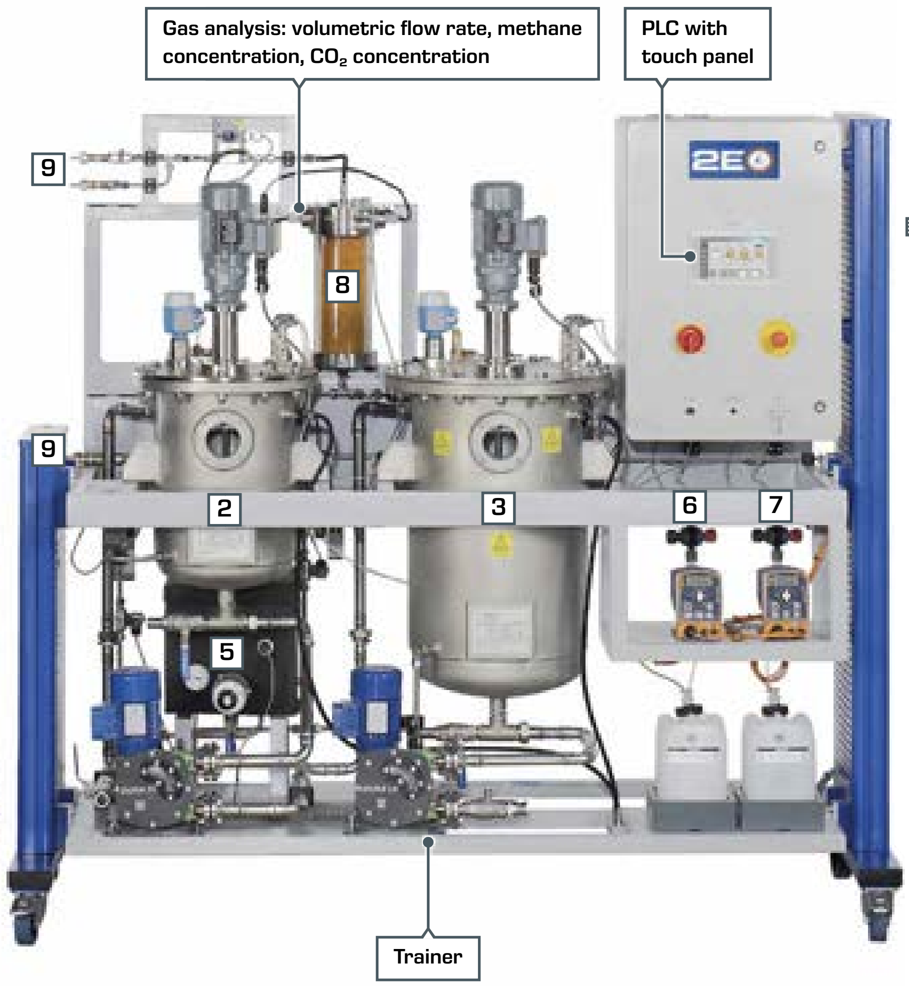
A suspension of comminuted organic solids is used as the substrate. Hydrolysis and acidification of the substrate take place in the first stirred reactor. Here, anaerobic microorganisms convert the long-chain organic substances into short-chain organic substances. In the second stirred reactor, biogas is created in the final step of the anaerobic degradation. This biogas primarily contains methane and carbon dioxide. This two-stage method means you can adjust and optimise the ambient conditions in the two reactors independently of each other. The digestate is collected in a separate tank.

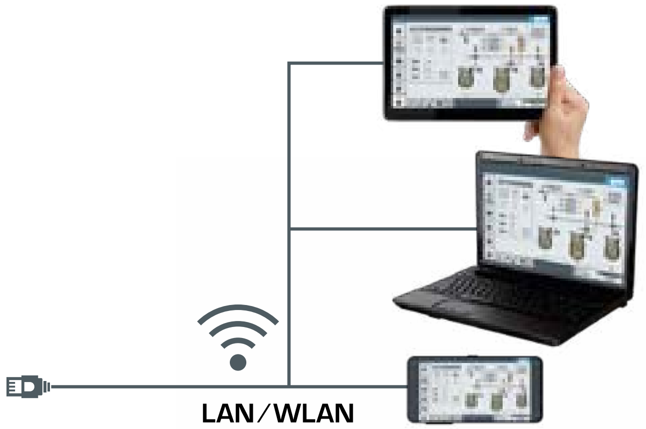
About the product:

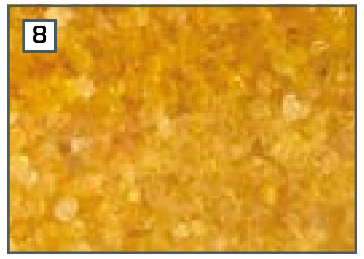
1	substrate tank	F	flow rate
2	reactor 1	L	level
3	reactor 2	M	moisture
4	digestate tank	Q_1	pH value
5	heating water tank	Q_2	methane concentration
6	acid dosing	Q_3	CO_2 concentration
7	alkaline dosing	T	temperature
8	drying column		
9	biogas		



Industrial peristaltic pump







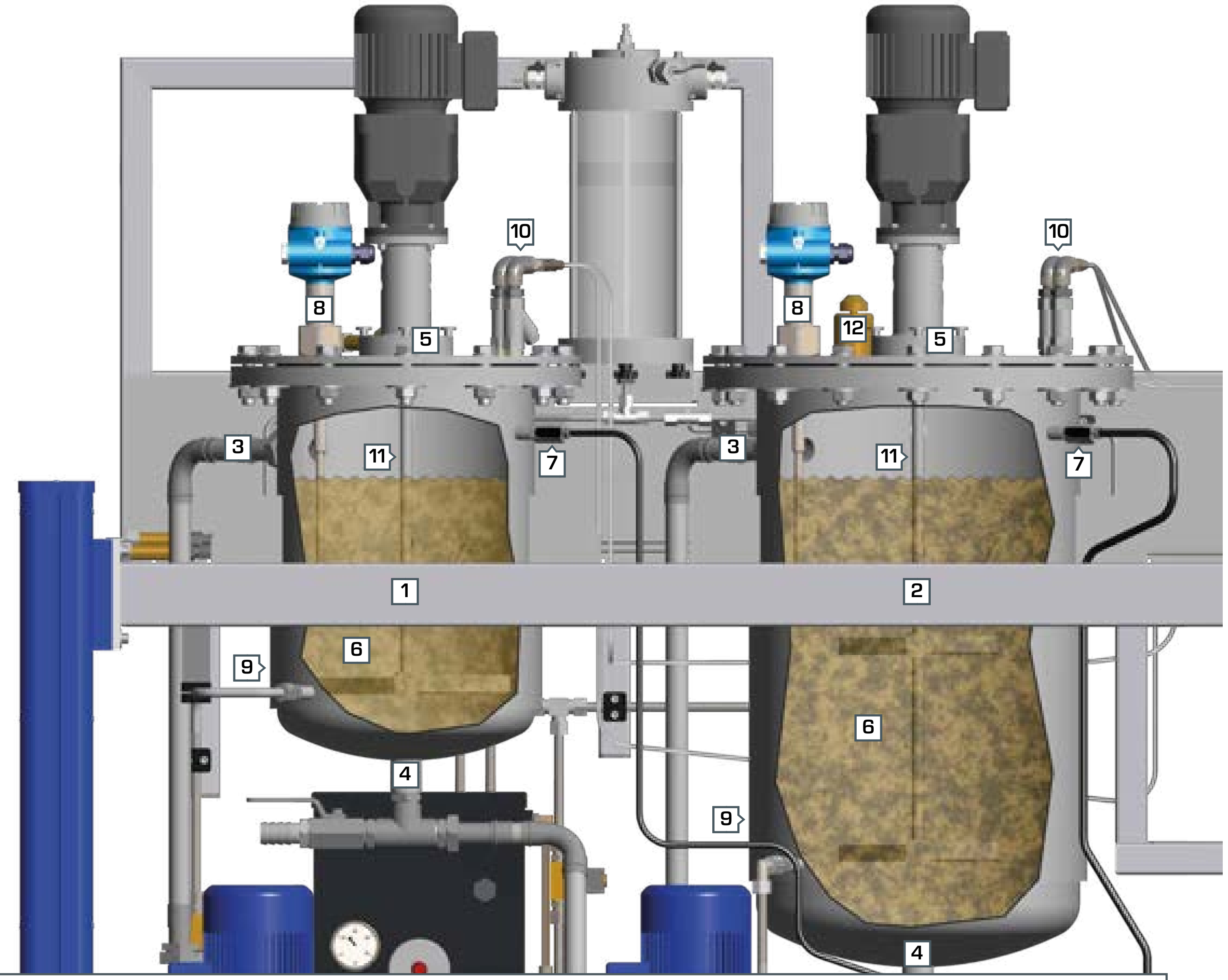
Silica gel in the drying column

Connectors for biogas without gas analysis

Learning objectives

- creation of a stable operating state
- effect of the following process variables on biogas production
  - temperature
  - substrate
  - volumetric loading
  - pH value
- effect of operating mode on biogas yield
  - single-stage and double-stage
  - with and without secondary digestion
  - continuous and discontinuous
- determination of following variables as a function of operating conditions
  - biogas yield
  - biogas formation rate
  - biogas quality

CE 642
Biogas plant



1	reactor 1	4	outlet	7	connector for inert gas	10	acid and alkaline dosing
2	reactor 2	5	fill opening	8	level measurement	11	stirring machine
3	feed	6	biomass	9	double jacket for heating	12	safety valve

Each reactor can measure fill level, pH value and temperature. Substrate and biomass are pumped by peristaltic pumps typical of biogas plants. Temperature is controlled via a double jacket with heating water. The biogas can be analysed or passed directly for consumption.

PLC user interface

In the **gas analysis** menu in the PLC user interface, you are given a summary of the current direction of flow of the gas and the current measured values of the gas analysis. Furthermore, this menu is where you select the **auto** or **manual** measuring mode, with the measurement times for each tank. You can also retrieve saved measured values via this menu.

The software for CE 642 allows the most important variables to be captured:

per reactor
- temperature
- pH value
- level
- speed of the stirring machines
- volumetric flow rate

gas analysis
- methane concentration
- carbon dioxide concentration
- temperature
- humidity
- volumetric flow rate and quantity

Customer reference from Argentina

INTI
Instituto Nacional de Technología Industrial

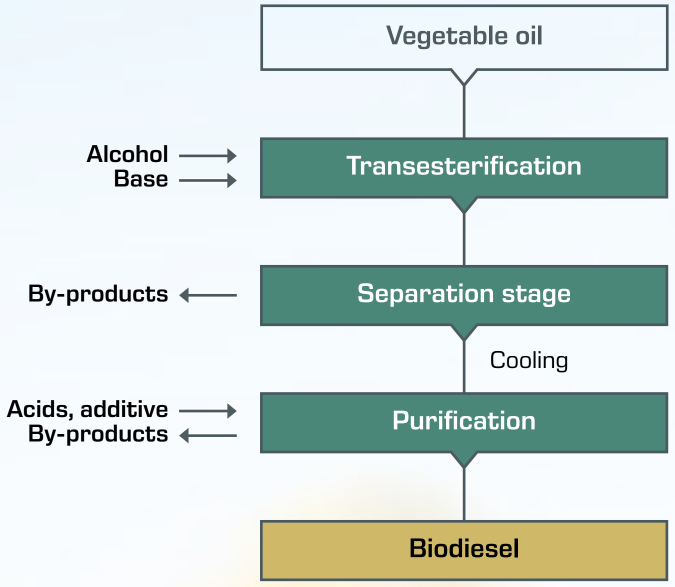
Basic knowledge
Biodiesel

Biodiesel is an important part of the field of biofuels. Biodiesel can be produced from a wide variety of raw materials, which mainly vary by region.

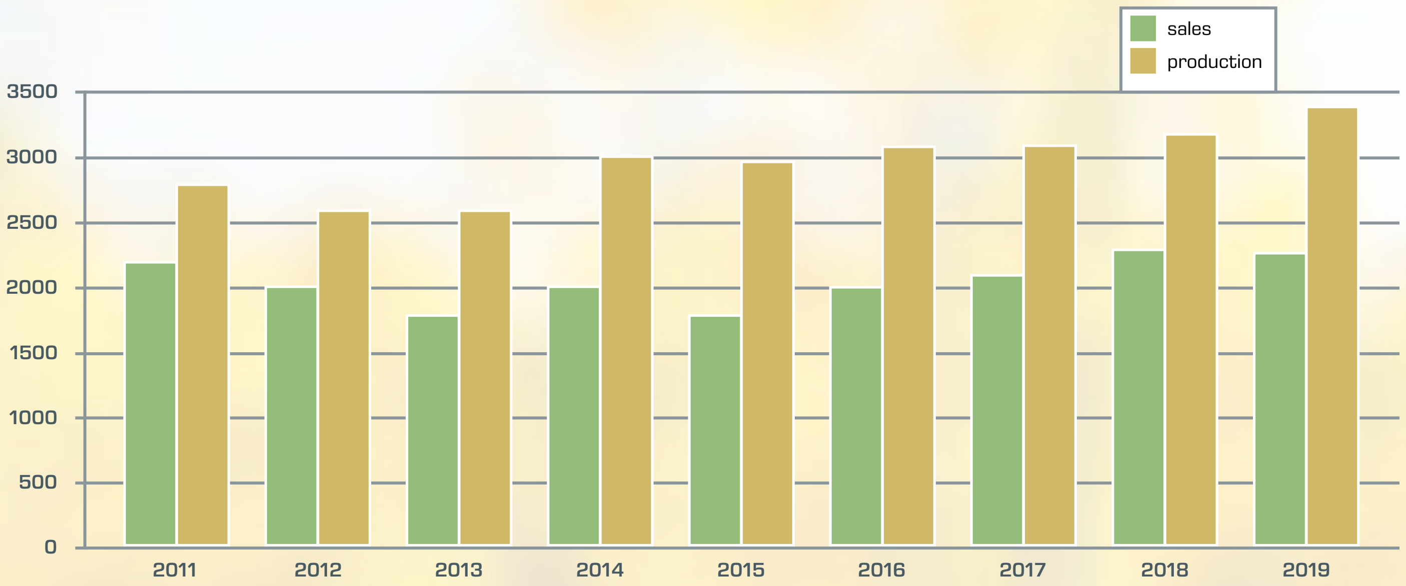
It is mainly vegetable oils that are used, which are chemically or biologically converted into biodiesel. In temperate regions, rapeseed oil is used in many cases. In sub-tropical regions on the other hand, palm oil is often used.

Furthermore, various input materials such as short-chain alcohols and bases are required for the chemical process of transesterification.

After biodiesel has been successfully produced, it is necessary to clean the biodiesel for use in engines. It is mainly water that is separated out in the additional step. The main by-product is glycerin. A variety of processes are currently being developed to use this glycerin. Thanks to the high level of biodiesel production, large quantities of glycerin are available that exceed the demand from the conventional use as antifreeze and a base for ointments.



Basic principle of chemical biodiesel production



Growth of biodiesel in Germany (in 1000t)

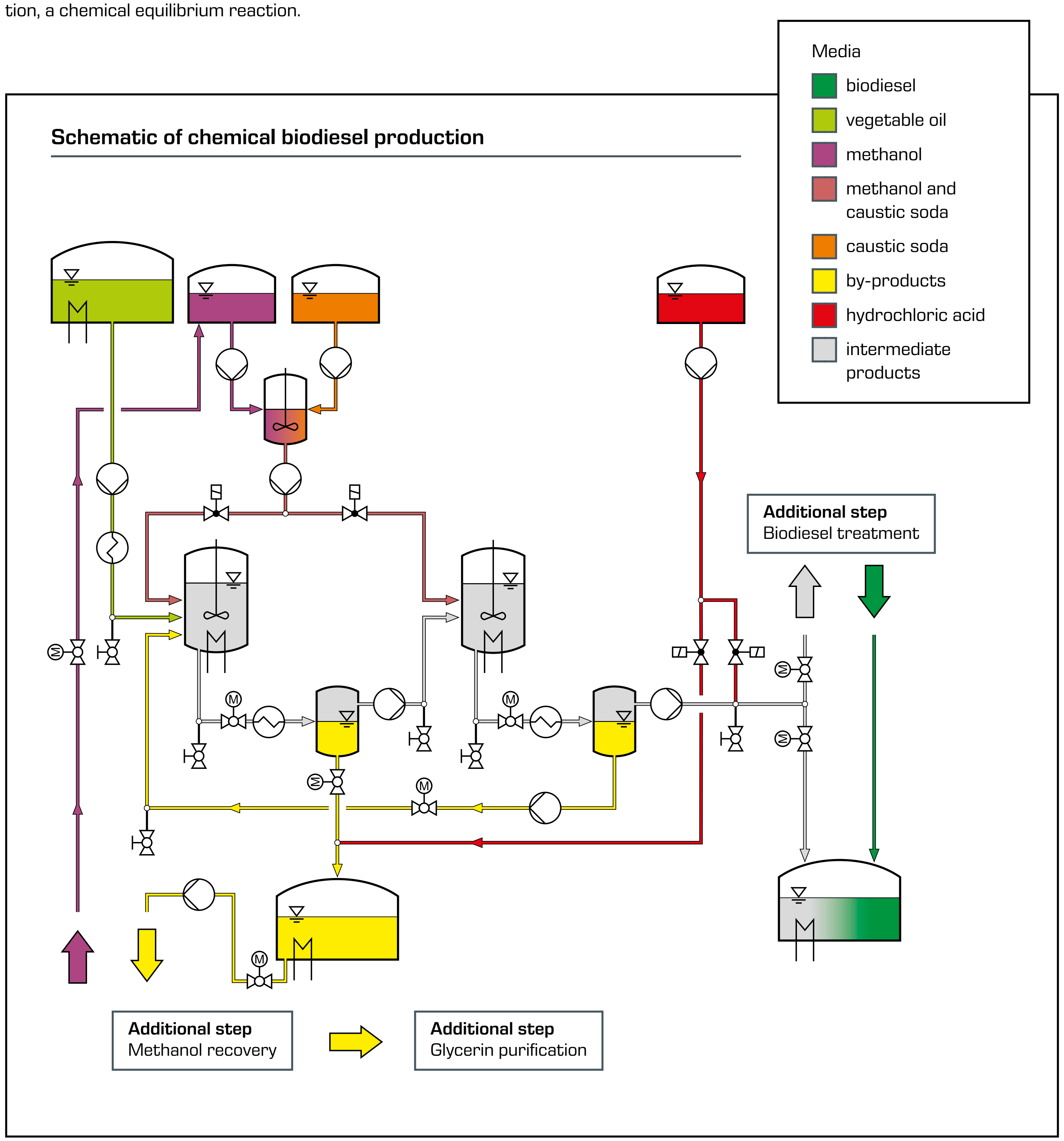
(source: Ufop, VDB, BAFA, BMF, FNR (April 2014) © FNR 2014

CE 650
Biodiesel plant

Biofuels for carbon neutral energy

The use of renewable energy carriers in the mobility sector can happen by replacing fossil fuels. One option is biodiesel, which is obtained from vegetable oils. It is produced by adding methanol and potassium hydroxide (as catalyst) and is a transesterification, a chemical equilibrium reaction.

On a large industrial scale, production is carried out continuously in stirred tank reactors. This process is demonstrated on a small scale by the CE 650 experimental plant.



CE 650
Biodiesel plant

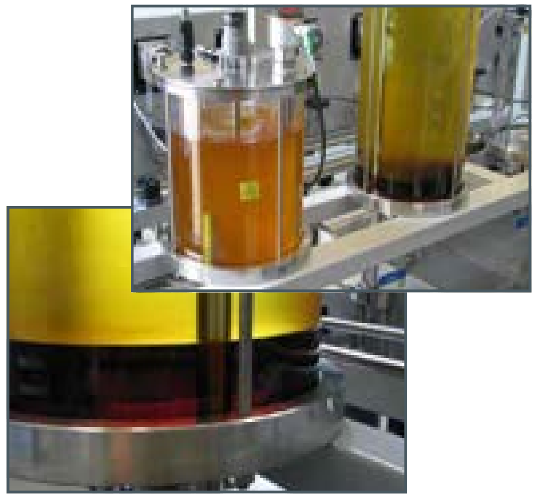
From a technical point of view, the catalytically activated production of biodiesel from vegetable oils represents an equilibrium reaction of chemical reaction engineering, which falls under the domain of chemical process engineering.

Experiments with CE 650 on the production of biodiesel in a two-stage process with methanol recovery and biodiesel washing offer a variety of different process parameters. These can be adapted to optimize the process.

Steps in biodiesel production

The chemical reaction takes place at temperatures of around 60°C. The products leave the reactor after a predefined retention time. The products are a two-phase mixture: A biodiesel-rich phase and a phase with by-products. The by-products are pumped out of the downstream phase separator. The options for the biodiesel-rich phase are: Return to the reactor, second transesterification stage, methanol recovery (distillation) and biodiesel washing (absorption).

About the product:

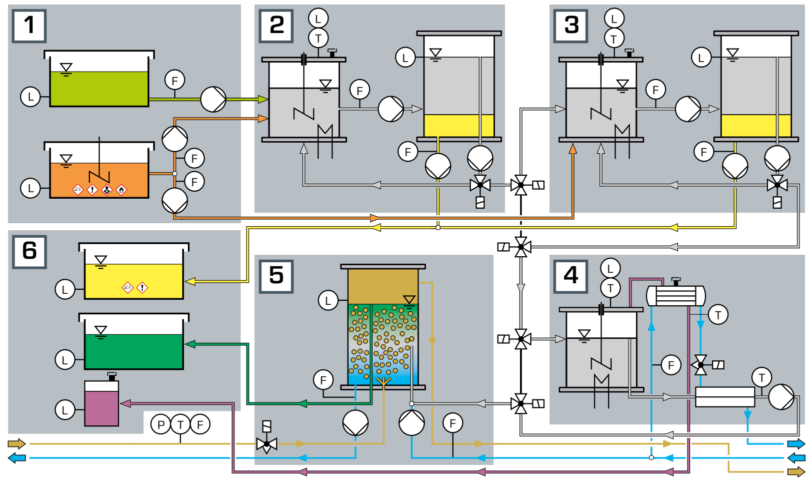


Transparent tanks allow continuous observation of reactions and separation processes.

CE 650 plant sections

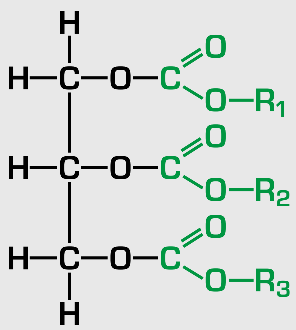
1. supply
2. transesterification 1st stage
3. transesterification 2nd stage
4. methanol recovery
5. biodiesel washing
6. storage

The plant sections 1 to 6 are clearly arranged on the two-part trainer and can be easily identified even by less experienced users.



Learning objectives

- production of biodiesel from vegetable oil
  - effect of retention time
  - effect of temperature
- chemical transesterification
- phase separation in the gravity field
- distillation
- liquid-liquid extraction
- approach of a continuous process consisting of several basic operations



Preparation for the experiment

The CE 650 experimental instructions include detailed descriptions of the equipment and experiments. They also deal with fundamentals such as the chemistry of triglycerides to help prepare for the experiments.

Plant control by PLC

The experimental plant is controlled by a PLC, which is operated by means of a touch panel. Clear operating screens for all system components make it possible to track current measured values and to vary process parameters. The user interface can also be displayed on other end devices via the integrated router (screen mirroring). Access to saved measured values is also possible via LAN/WLAN.

5

Geothermal energy

Subject areas

Geothermal energy

The effective use of geothermal energy requires a geothermal field with elevated temperature, effective heat transfer to the subsequent cycles and the efficient use of the energy. Depending on the temperature level of the source, geothermal energy can be used for heating only or for conversion to electricity with utilisation of the residual heat.

Both types of usage require heat exchangers to transfer the extracted heat to the subsequent cycles. The disadvantage of multiple cycles is the energy loss during heat transfer. The main advantage is a much longer service life of the system, since corrosive components are prevented.

In geothermal systems, water circuits and refrigerant circuits with heat pumps are used for heating purposes. The water circuit is the more efficient option, since it does not require electrical energy for a heat pump. However, the temperature of the geothermal field must be higher.

The conversion into electricity, for example in steam turbines, requires higher temperatures again, which can be found in deep geothermal energy. The energy gained is used to operate a steam circuit with turbine and generator, which produces electricity.

Subject areas	Products
Heat exchangers	**WL 110** Heat exchanger supply unit **WL 110.01** Tubular heat exchanger **WL 110.02** Plate heat exchanger **WL 110.03** Shell & tube heat exchanger **WL 110.05** Finned tube heat exchangers **WL 315C** Comparison of various heat exchangers
Shallow geothermal energy	**ET 101** Simple compression refrigeration circuit **ET 262** Geothermal probe with heat pipe principle **ET 264** Geothermal energy with two-well system **HL 320** Solar thermal energy and heat pump modular system (Combination 3)
Deep geothermal energy	**ET 850** Steam generator **ET 851** Axial steam turbine

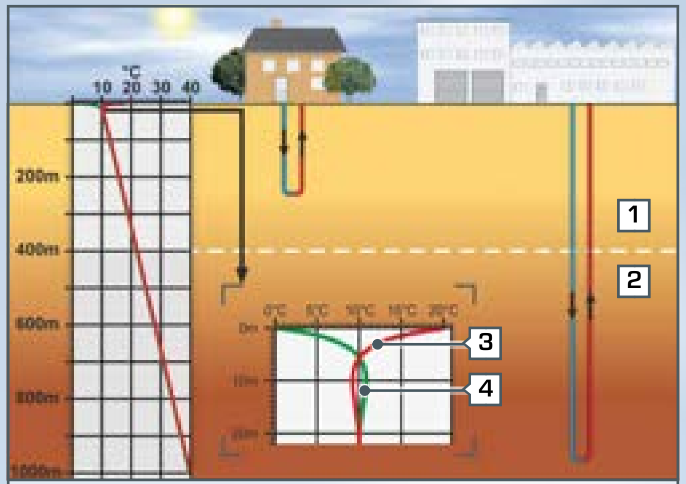
Basic knowledge

Geothermal energy

Thermal energy from the ground

Geothermal energy refers to the use of thermal energy stored beneath the earth's surface. This thermal energy is usually available anywhere and at any time, which is a significant advantage compared to other renewable energies such as solar energy and wind power. Therefore, it makes sense to take advantage of this geothermal energy.

In the upper area of the earth's crust (about 0...20 m) the temperature is determined by the climatic conditions at the earth's surface. Below this region, the temperature is constant over time and only depends on depth. On average, the temperature increases by 3°C for every 100 m. For the most part, the thermal energy is the result of the decay of radioactive isotopes of uranium, thorium and potassium.



1 shallow
2 deep
3 summer
4 winter

Differentiating geothermal fields

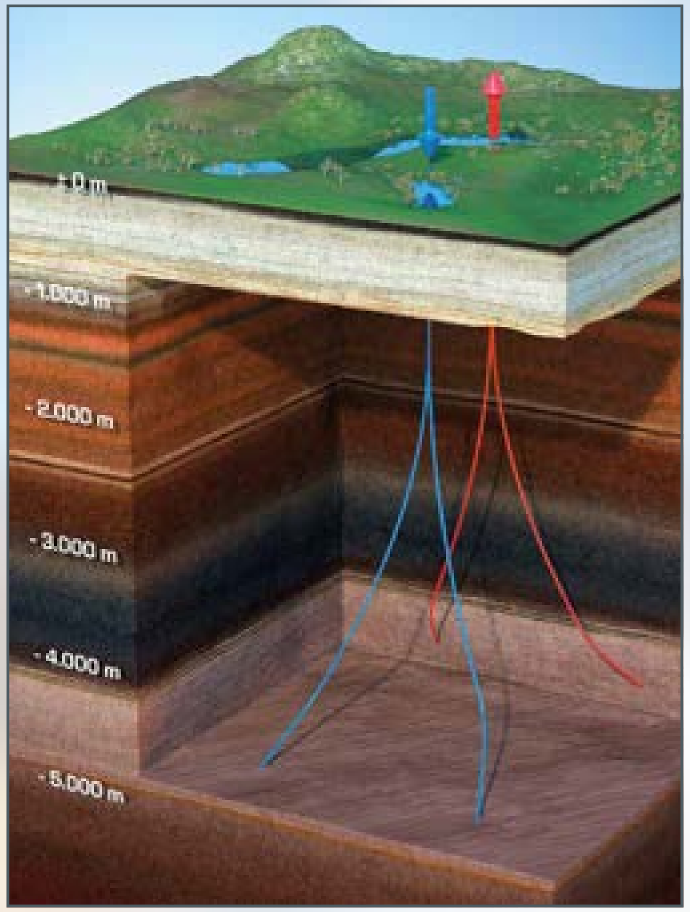
Usually, when talking about geothermal energy a distinction is made between **shallow** geothermal energy and **deep** geothermal energy.

Shallow geothermal energy

Shallow geothermal energy refers to the use of thermal energy stored in the upper area of the earth's crust (about 0...400 m). Shallow geothermal energy is particularly useful for heating private households.

Deep geothermal energy

Deep geothermal energy is when the thermal energy is stored in regions about 400...5000m below the surface. Since this requires deep drilling, this form of usage is significantly more cost-intensive than shallow geothermal energy. Therefore, deep geothermal energy is mainly suited to industrial applications.



Using geothermal energy

Using geothermal energy requires interdisciplinary expertise in a variety of fields, such as mining, geology, mechanical engineering, plant engineering and civil engineering.

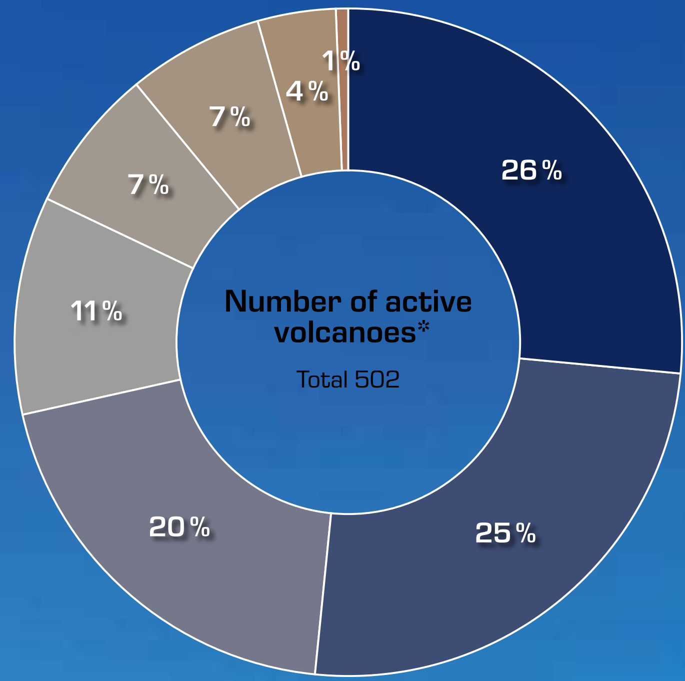
The use of geothermal energy also depends on the temperature of the geothermal field. If the temperature is low, the energy is used for heating and cooling. If a higher temperature is present, the energy is used to produce electricity.

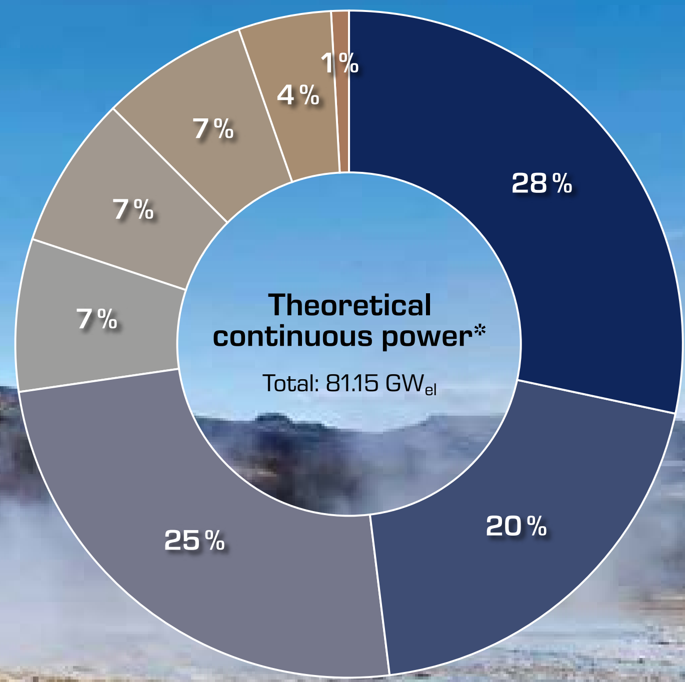
In building services engineering, only low feed flow temperatures are required for underfloor heating, for example. Heat pumps are used in order to keep the drilling depth low. Therefore environments that are putatively too cold or too warm can also be used for cooling and heating purposes. Operating costs can therefore be reduced to operation of the heat pumps.

Potential and outlook

The potential for use of geothermal energy is divided according to the geothermal fields. For thermal anomalies with volcanic activity, a theoretical continuous electrical output of around 81 GWel has been determined in just 8 countries. As a comparison by size, the gross electricity consumption in Germany was around 600 TWh in 2013. This is equivalent to a continuous output of 68 GW_{el}.

The global comparison shows that exploiting the theoretical continuous output of active volcanic regions alone could cover 4 % of the global electricity demand. If further deposits are developed both near the surface and at greater depths, it would be conceivable in the near future to cover a significantly higher share of the global demand for electricity and heat from geothermal sources.





- USA
- Indonesia
- Japan
- Philippines
- Mexico
- Iceland
- New Zealand
- Tuscany (Italy)

*selected countries
Source: V. Steffansson: World geothermal assessment

Basic knowledge

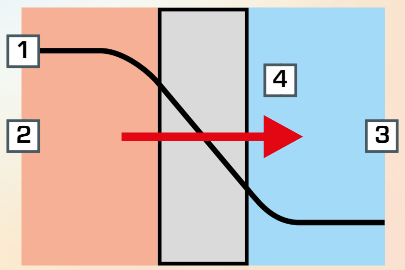
Heat exchangers

Heat transfer

Essentially the role of heat exchangers is to transfer the heat of a flowing material to another flowing material with a lower starting temperature. The materials can be gaseous or liquid. The temperature difference of the two media as the driving differential is essential for heat transfer.

The entire transferred heat flux is also directly dependent on the transference surface. This is why different wall geometries (e.g. fins) are used, in order to increase the transference surface area.

Heat transfer is divided into three stages: Convective heat transfer from the warmer medium to the wall, heat conduction through the wall and convective heat transfer from the wall to the colder medium.

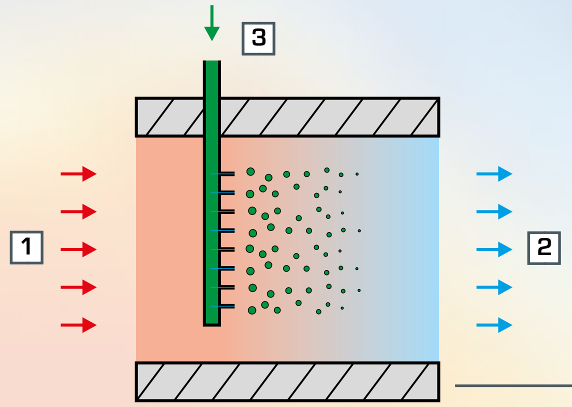


1 temperature profile
2 hot medium
3 cold medium
4 resulting heat flux

The convective heat transfer from the medium to the wall or from the wall to the medium is dependent upon the material type, the flow velocity and the aggregate states of the media, amongst other things. The heat conduction in the wall depends in the wall thickness and the wall material.

Type of contact between the media involved

If water is injected into a production process for cooling, this is known as direct heat transfer. There is no separation of the coolant and the product. The direct injection of water is used for example in the steel industry for intercooling or in wet cooling towers in the power plant sector.



1 hot process gas
2 cooled process gas
3 injection of liquid (usually water)

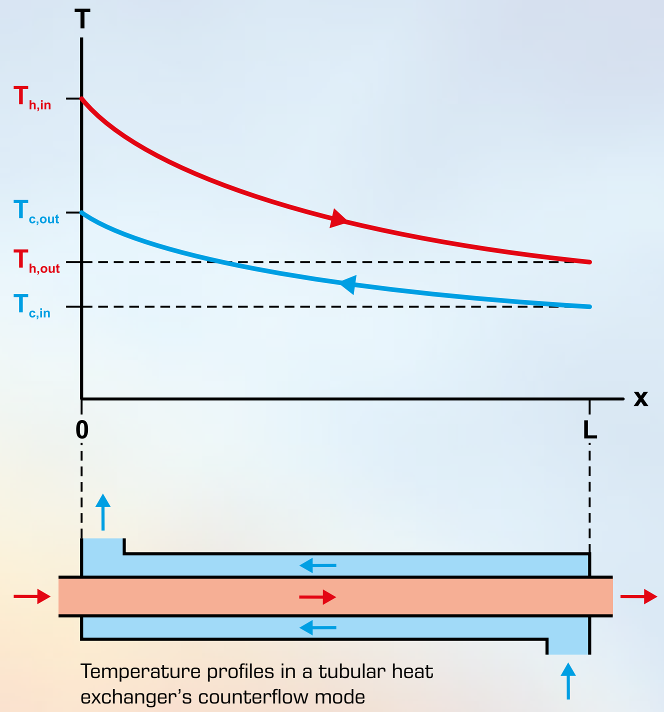
In contrast to direct heat transfer, the transfer of heat in spatially separated media is known as indirect transfer. The two materials are separated by a heat-permeable wall. The most well-known heat exchanger with indirect heat transfer is the domestic radiator.

Semi-indirect heat transfer is a special case that is used especially for heat storage. This mixed form is achieved by usage separated by time. During the day, heat storage is charged by a solar thermal system and during the night the thermal energy is discharged to heat rooms or as hot water.

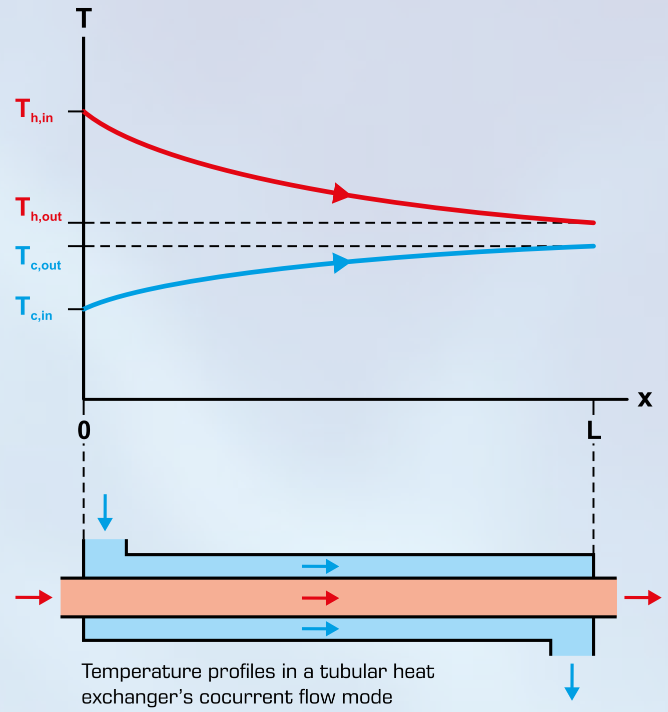
Flow conditions

The possible flow conditions of indirect heat exchangers are counterflow, cocurrent flow, cross flow or combinations thereof. One example of a combination is cross counter flow, which is commonly used in shell and tube heat exchangers. If the space available is limited, plate heat exchangers are often used. These are operated in counterflow.

This is not possible when operating the heat exchanger in cocurrent flow. The maximum outlet temperature of the cold side can be equal to the outlet temperature of the hot side. The media flow next to each other in cocurrent flow.



Temperature profiles in a tubular heat exchanger's counterflow mode



Temperature profiles in a tubular heat exchanger's cocurrent flow mode

In counterflow mode, the cold medium exits at the input of the hot medium. If the heat exchanger is well designed, it is possible to achieve a higher outlet temperature on the cold side than on the hot side.

The third variant is cross flow, which is used in particular for the precise temperature control of a temperature-sensitive product.

In order to use the advantages of all flow conditions, combinations of the basic forms are common. For example, a multiple-channel shell and tube heat exchanger can be used for quick and safe temperature control of large quantities of aggressive chemicals.

Overview

WL 110 equipment series – Experiments on the fundamentals of heat transfer

WL 110
Heat exchanger supply unit

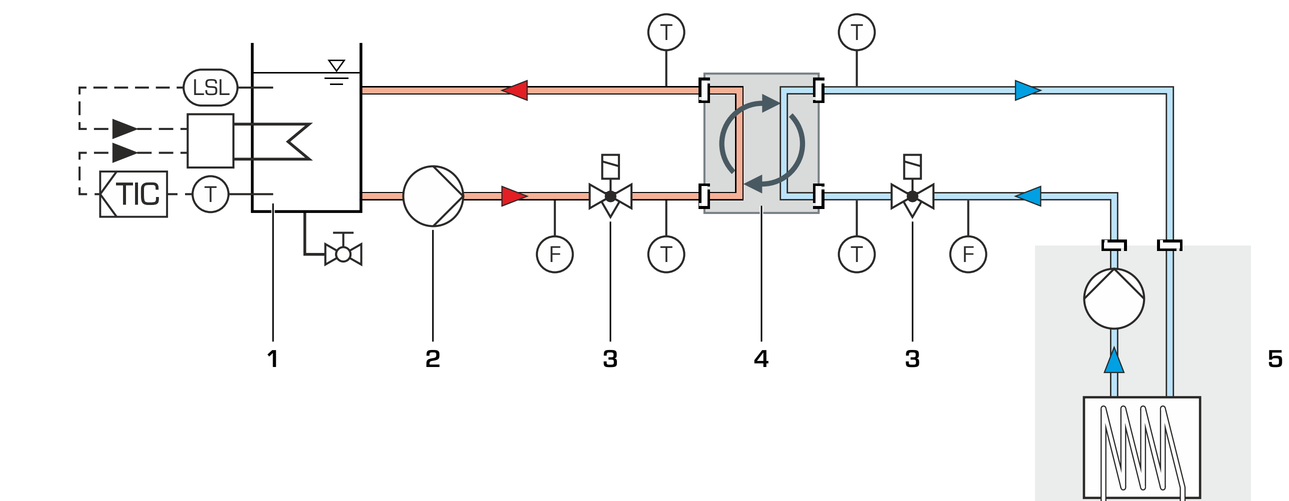
The supply unit produces hot water. All measured values are displayed on the unit's touch screen and can be transmitted via a LAN / WLAN connection.

WL 110.20
Water chiller

The water chiller can be used to operate the heat exchangers under suitable experimental conditions.

- automatic identification of accessories via RFID technology
- energy and water-saving technology, space-saving design

RFID



1 heated tank, **2** pump, **3** solenoid valve,
4 replaceable heat exchanger WL 110.01 – WL 110.05,
5 water chiller WL 110.20 with refrigeration system and tank for cold water (only for WL 110.01 – WL 110.04)

cold water circuit, hot water circuit;
F flow rate, **T** temperature, **TIC** temperature controller, **LSL** fill level switch

About the product:

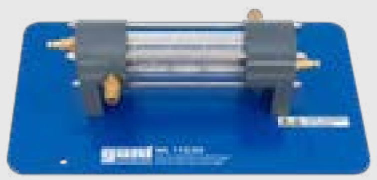
www

WL 110.01
Tubular heat exchanger

- simple design
- transparent outer tube offers visible flow space
- parallel flow and counterflow operation possible

WL 110.02
Plate heat exchanger

- compact design
- parallel flow and counterflow operation possible

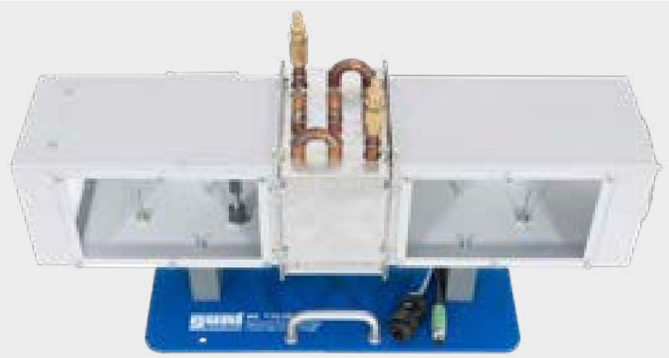


WL 110.03
Shell & tube heat exchanger

- transparent jacket pipe
- media flow in cross parallel flow and cross counterflow

WL 110.04
Stirred tank with double jacket and coil

- heating using jacket or coiled tube
- stirrer for improved mixing of medium



WL 110.05
Finned tube heat exchanger

- heat transfer between water and air in cross-flow
- increase of the heat transferring surface due to fins on the pipes

WL 110
Heat exchanger supply unit

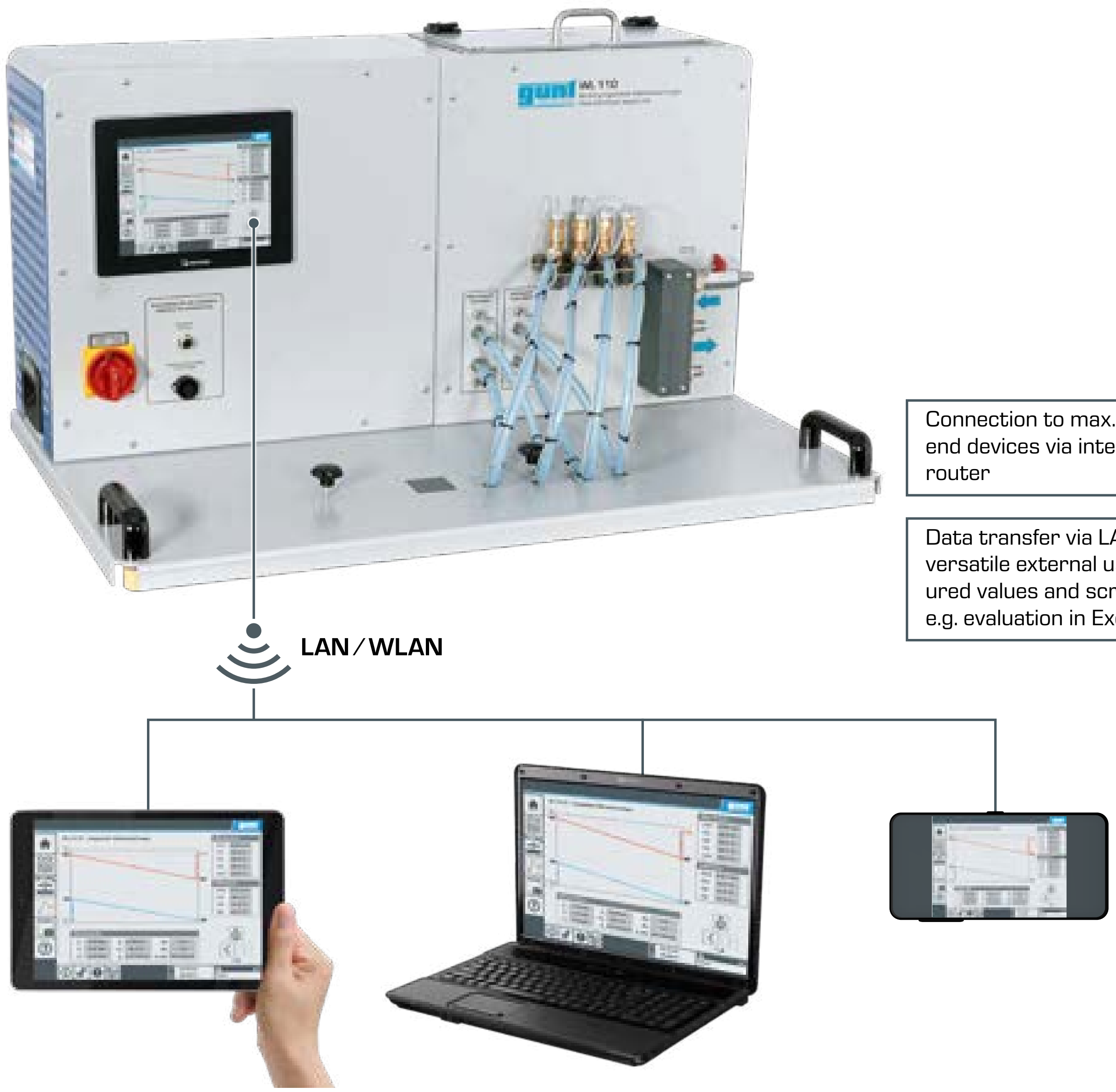
Real experiments – digital media

The digital teaching-learning concept offers an interaction between real experiments and digital teaching with:

1. **preparation**
2. **execution**
3. **evaluation**

of the experiments.

The WL 110 supply unit provides the basic supply in each case. Measurement and control systems as well as the interfaces are also provided by the supply unit.



Connection to max. 10 mobile end devices via integrated WLAN router

Data transfer via LAN / WLAN for versatile external use of measured values and screenshots e.g. evaluation in Excel

- **intuitive** execution of experiments via **touch screen** (HMI)
- device control with **PLC**, operation via touch screen or an end device
- integrated WLAN router for operation and control via an end device and for **screen mirroring** on up to 10 end devices: PC, tablet, smartphone
- automatic system configuration
- data acquisition in the PLC
- access to stored measured values is possible from end devices via WLAN with integrated router / LAN connection to the customer's own network is possible

1. Preparation

Location-independent experiment preparation with GUNT E-Learning courses or directly at the experimental unit with the basic knowledge pages in the PLC.

2. Execution

Investigation and comparison of different heat exchangers, intuitive guidance through the experiments via touch screen.

3. Evaluation

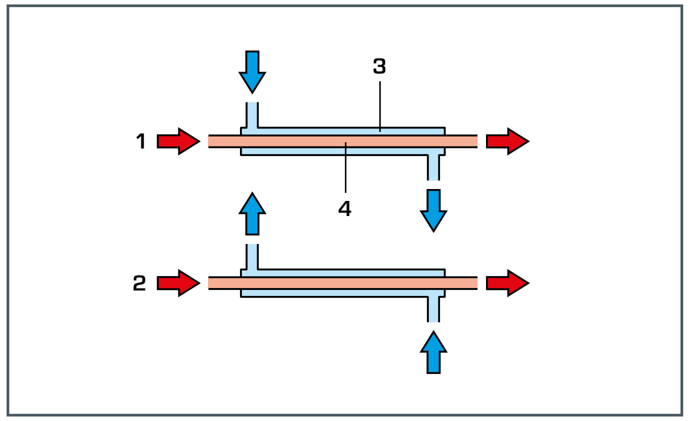
Directly at the experimental unit and via data transfer of measured values and screenshots also possible independent of location.

WL 110.01
Tubular heat exchanger

Tubular heat exchangers are the simplest type of heat exchanger design. They are preferred when heat is being transferred at high pressure differences or between highly viscous media. One advantage is that flow through the pipe space is even and free of flow dead zones.

The hot water is fed through the core tube (inner) and the cold water fed through the jacket tube (outer). In doing so, the hot water continuously emits some of its thermal energy to the cold water.

Two additional temperature sensors are located on the tubular heat exchanger to measure the temperature after one half of the transfer section.



1 parallel flow operation, **2** counterflow operation,
3 outer tube with cold water,
4 inner tube with hot water

cold water side, hot water side

About the product:

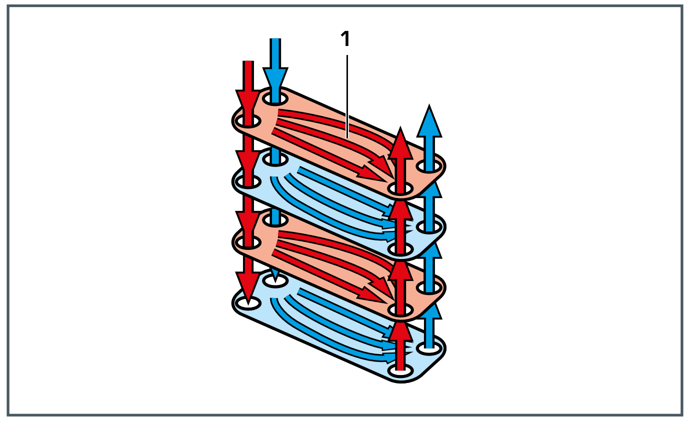
Learning objectives

- function and behaviour of a tubular heat exchanger during operation
- recording temperature curves
  - in parallel flow operation
  - in counterflow operation
- calculation of mean heat transfer coefficient
- comparison with other heat exchanger types

WL 110.02
Plate heat exchanger

Plate heat exchangers are mainly characterised by their compact structural shape, in which the entire medium is used for heat transfer. One advantage is the low space requirement, relative to the heat transfer area.

The plate heat exchanger consists of several profiled plates. Connecting the plates to each other results in two hermetically separated tube channels. A cold tube channel and a hot tube channel alternate in the arrangement. The profiled plates ensure mixing of the water and improve heat transfer.



1 plate with pressed profile

cold water side, hot water side

About the product:

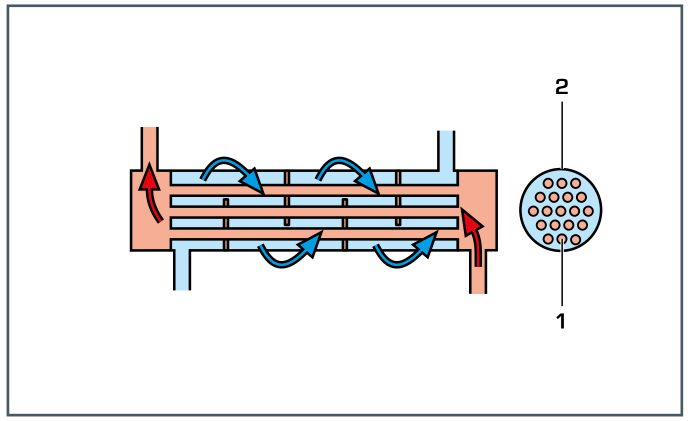
Learning objectives

- function and behaviour of a plate heat exchanger during operation
- plotting temperature curves
  - in parallel flow operation
  - in counterflow operation
- calculation of mean heat transfer coefficient
- comparison with other heat exchanger types

WL 110.03
Shell & tube heat exchanger

Shell and tube heat exchangers are characterised by the large heat transfer area and the compact structural shape.

The shell and tube heat exchanger consists of seven core tubes, surrounded by a transparent jacket tube. The hot water flows through the core tubes and the cold water flows through the jacket tube. In doing so, the hot water emits some of its thermal energy to the cold water. Using baffle plates, the flow in the inside of the shell is diverted in order to produce stronger turbulence and more intensive convective heat transfer. The media flow continuously in cross parallel flow and cross counterflow.



1 core tube, **2** jacket tube
cold water side, hot water side

About the product:

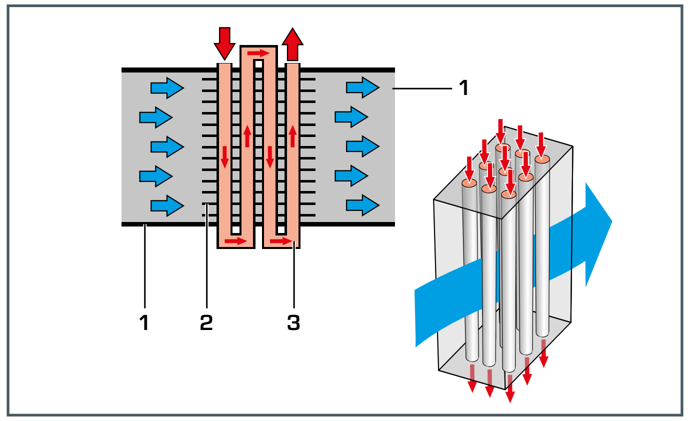
Learning objectives

- function and behaviour of a shell and tube heat exchanger during operation
- plotting temperature curves
  - in cross parallel flow operation
  - in cross counterflow operation
- calculation of mean heat transfer coefficient
- comparison with other heat exchanger types

WL 110.05
Finned tube heat exchanger

The heat transfer surface of a heat exchanger can be effectively increased by attaching fins. This principle is used in the finned tube heat exchanger primarily to cool or heat a closed circuit using the ambient air.

The finned tube heat exchanger consists of a box shaped profile through which air flows and which is traversed several times by the pipe section carrying hot water. This creates a cross-flow of the heat-transferring media. The hot water emits part of its thermal energy to the air. Fins are applied to the pipe section to increase the heat-transferring surface.



1 air duct, **2** fins, **3** water pipe section,
cold air, pipe section with hot water

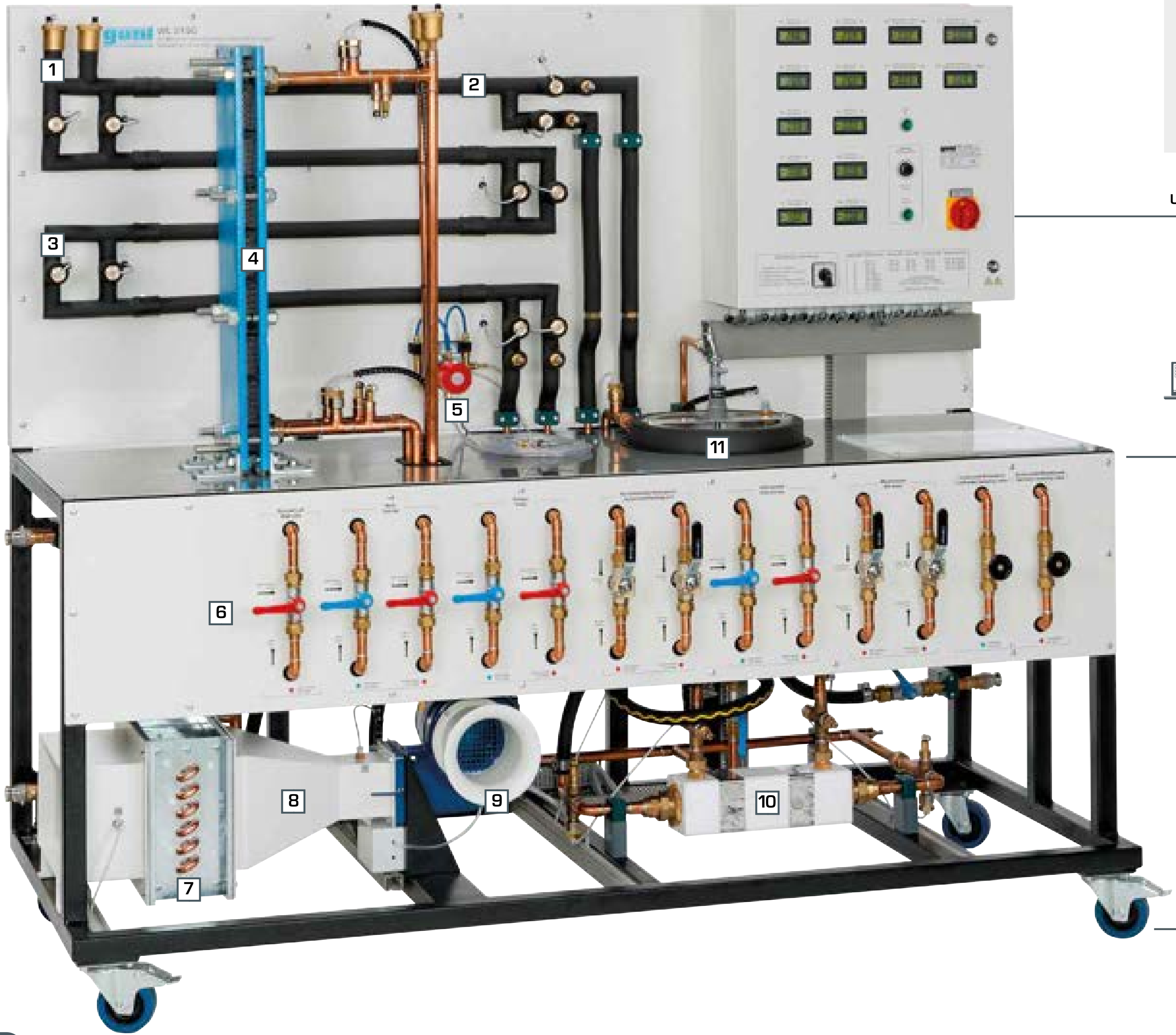
About the product:

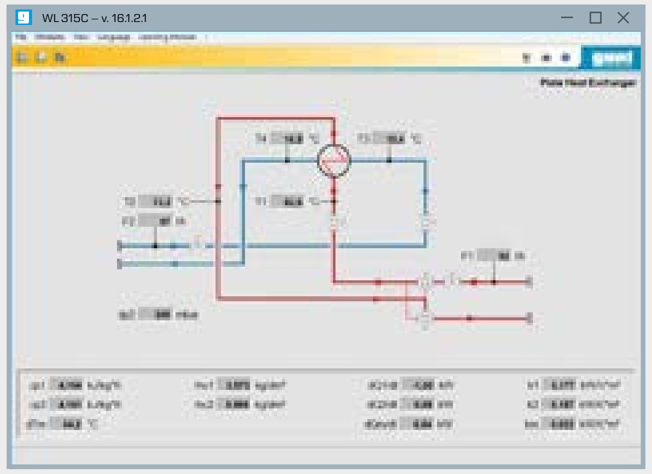
Learning objectives

- function and behaviour of a finned tube heat exchanger
- heat transfer between water and air in cross-flow
- plotting temperature curves
- determine the mean heat transfer coefficient
- compare with other heat exchanger types

WL 315C
Comparison of various heat exchangers

In practice different heat exchanger types are used depending on the requirements. You can investigate and compare five different heat exchanger designs with the WL 315C trainer. Convective heat transfer in different heat exchangers takes place with different fluids according to the counterflow or cocurrent flow principle. The heat exchanger being studied is selected on the switch cabinet. Valves are used to switch between cocurrent flow and counterflow. You can also adjust the flow rate in the hot water or cold water circuit by means of valves. The hot water flows through the heat exchanger and emits some of its thermal energy to the cold water. The trainer is equipped with sensors for temperatures and differential pressures. The flow rate is measured by an electromagnetic flow meter. 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.

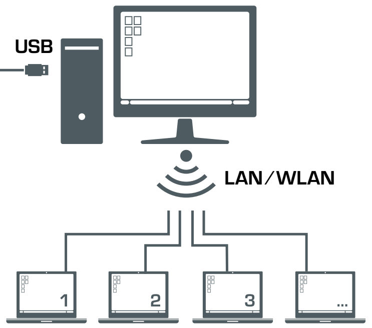




The software for WL 315C measures the following variables

- temperature profiles along the heat exchanger
- inlet and outlet temperatures
- flow rate of the hot and cold water
- pressure loss across the heat exchanger

Using the software you can also determine the mean overall heat transfer coefficients of the various heat exchangers. A separate view lists the physical properties of the heat transfer fluid and calculates the characteristic values with the measurement data.



1 ventilator
2 tubular heat exchanger
3 temperature sensor
4 plate heat exchanger
5 pressure sensor
6 adjusting valves
7 finned tube heat exchanger
8 flow channel
9 fan
10 shell & tube heat exchanger
11 stirred tank with double jacket and coiled tube
12 switch cabinet

Using the hot water supply (WL 312.10) and the cold water supply (WL 312.11), you can operate WL 315C as an independent system with closed water circuit. An optionally available steam/water heat exchanger (WL 315.01) and the electrical steam generator (WL 315.02) complement the scope of experiments.

About the product:

www

Learning objectives

- familiarisation with heat transfer processes
  - heat transfer
  - heat conduction
- measurement of relevant temperatures and flow rates
- determining the overall heat transfer coefficients
- plotting temperature curves for the various heat exchanger types
  - parallel flow
  - counterflow
  - cross parallel flow
  - cross counterflow
- comparison of the various heat exchanger types with each other
  - plate heat exchanger
  - tubular heat exchanger
  - shell & tube heat exchanger
  - finned tube heat exchanger
  - stirred tank with double jacket and coiled tube

Basic knowledge

Shallow geothermal energy

Basic principle

Shallow geothermal energy is based on the same basic principle as solar thermal energy. However, in this case it is the ground that is acting as a heat source, not the sun. There is an underground pipe system in which a liquid heat transfer medium circulates. This medium heats up under the ground and transfers the stored heat to a heat pump in the house. The heat pump raises the heat transfer medium to a higher and thus usable temperature (thermodynamic cyclic process).

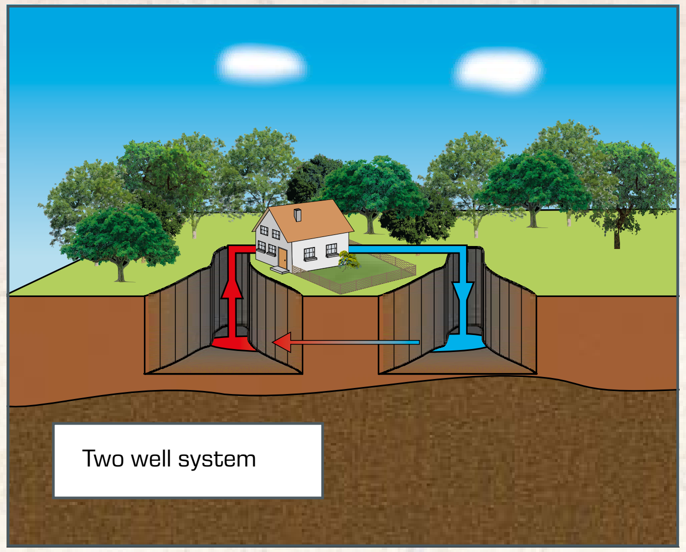
Technical implementations

There are various options for using the thermal energy of the earth's surface. The technical implementation is dependent upon the local conditions, the desired power and the combination with other energy systems. In the field of shallow geothermal energy, firstly a distinction is made between open and closed systems and secondly between collectors and probes. Moreover, different piping systems are available for geothermal probes. Geothermal heat collectors consist of a pipe laid horizontally in the ground. This pipe is located at a depth of about 1...2 m. Geothermal probes are oriented vertically and can reach down to a depth of about 100 m under the ground. Well systems use the thermal energy of the groundwater by means of two wells. Transport occurs with the source well and return occurs with the sink well, against the direction of flow.

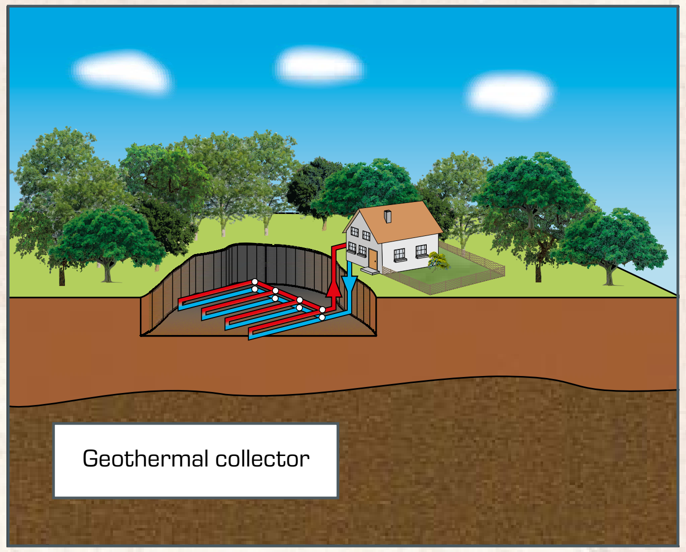
Heat exchangers and heat pumps

Geothermal collectors, geothermal probes and well systems function as heat exchangers in shallow geothermal energy and therefore represent the drive power of the thermodynamic cyclic process of heat pumps. The cyclic processes illustrate the economic use of geothermal heat for heating purposes, even with source temperatures that are actually too low.

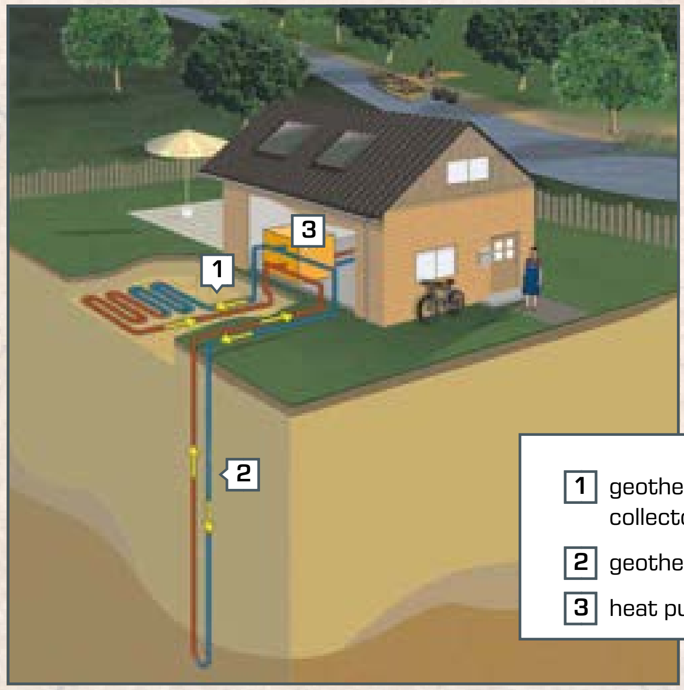
In addition to operation with water as the heat transfer medium, refrigerant is also used. The heat pipe systems as geothermal probe type use the large quantity of energy in evaporation and condensation for an effective transfer of energy.



Two well system



Geothermal collector



1 geothermal collector
2 geothermal probe
3 heat pump

Resource efficient heating

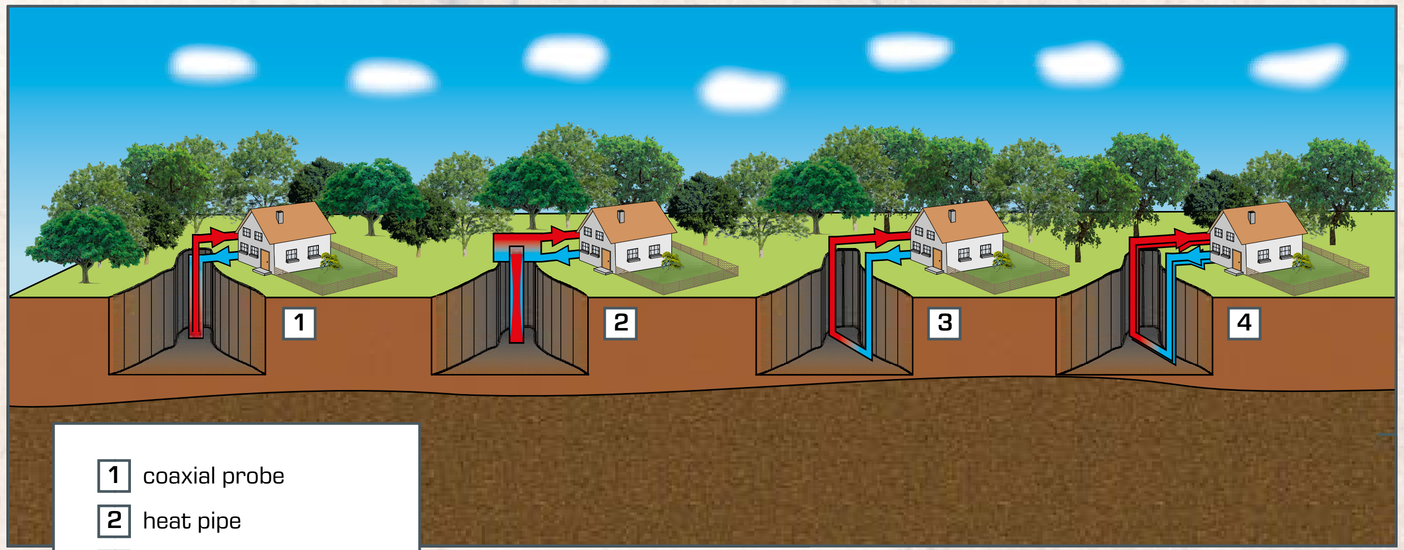
Geothermal energy can be used effectively even at shallow depths. Shallow geothermal energy is mainly suited to providing heat in private households and small industrial companies.

By using heat pumps, heating and operating costs can be reduced to the electrical consumption of the circulating pumps and the compressor.

It is also possible to combine different usage types. If open areas are available a collector can be used in conjunction with a geothermal probe, for example.

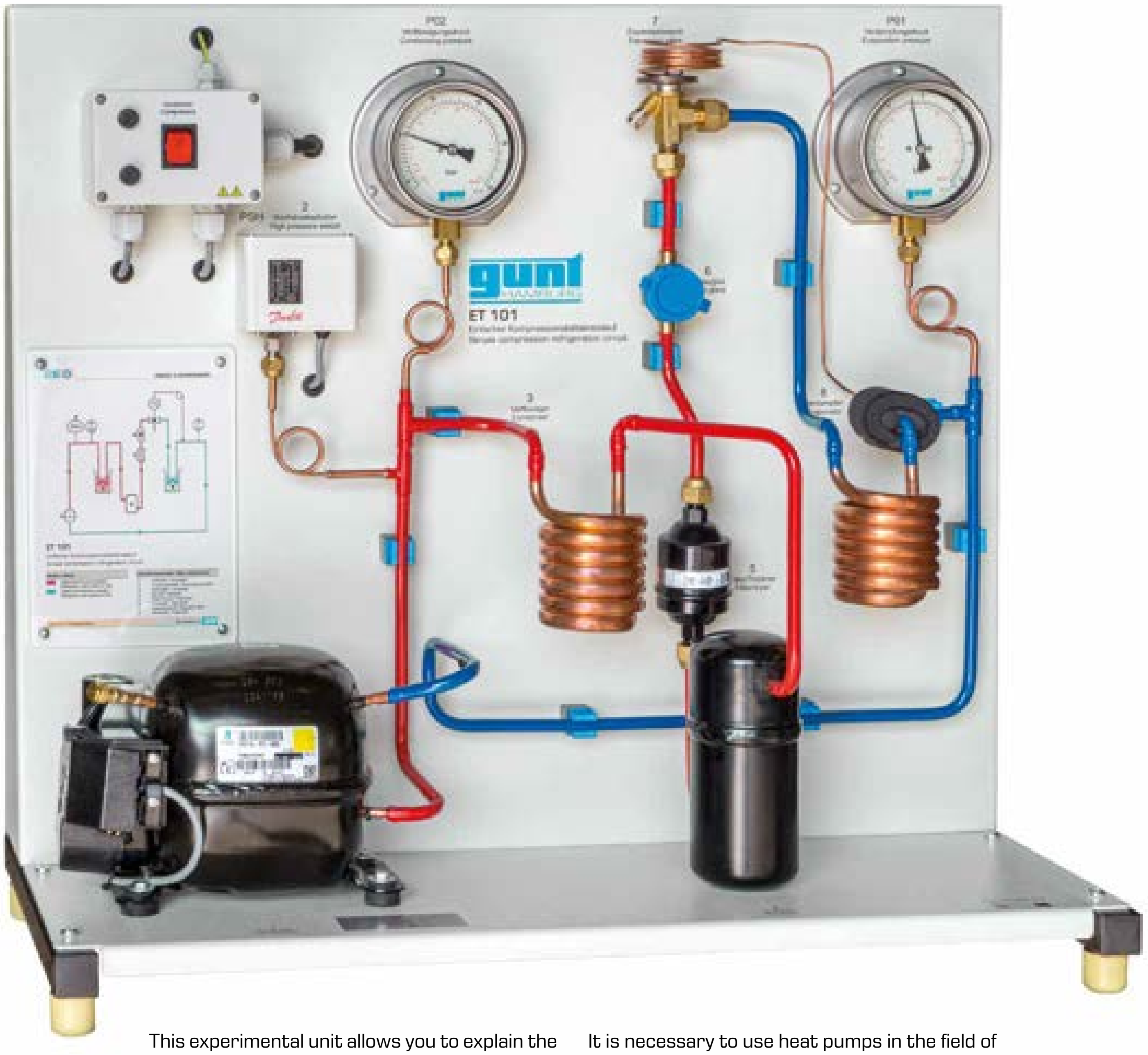
Geothermal probes

Different designs are available for geothermal probes, which offer different benefits. The U-shaped probe and the dual U-shaped probe are already widely used, for example embedded with piled foundations. Heat can therefore be supplied with geothermal heat with little additional investment.



1 coaxial probe
2 heat pipe
3 U-shaped probe
4 dual U-shaped probe

ET 101
Simple compression refrigeration circuit

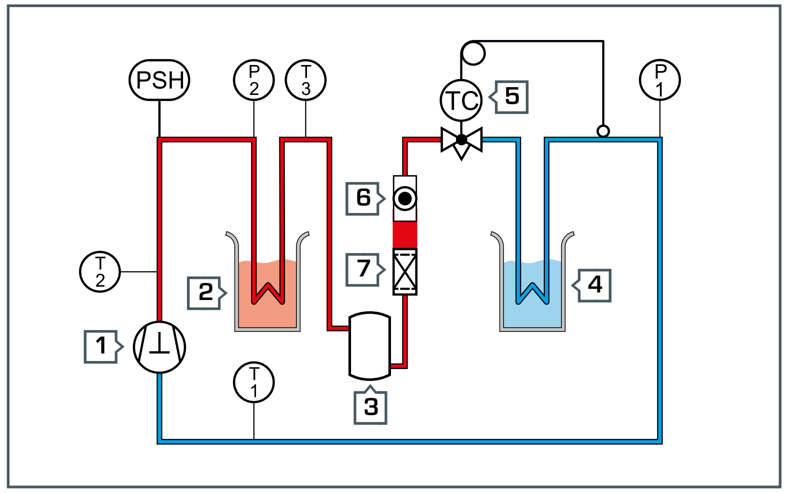


This experimental unit allows you to explain the structure and function of a heat pump using a simple compression refrigeration circuit, and tangibly demonstrate it for your students.

It is necessary to use heat pumps in the field of shallow geothermal energy in order to raise the thermal energy extracted from the ground to a usable energy level. The energy in the ground is transmitted to a heat transfer medium, usually water, and thus can be used for heating.

About the product:

www



1 compressor
2 condenser
3 receiver
4 evaporator
5 expansion valve
6 sight glass
7 filter/dryer

P pressure, **PSH** pressure switch,
T temperature

ET 101 contains all components necessary to operate a heat pump. The use of commercially available components from the field of refrigeration engineering ensures a high level of practically-oriented recognition value.

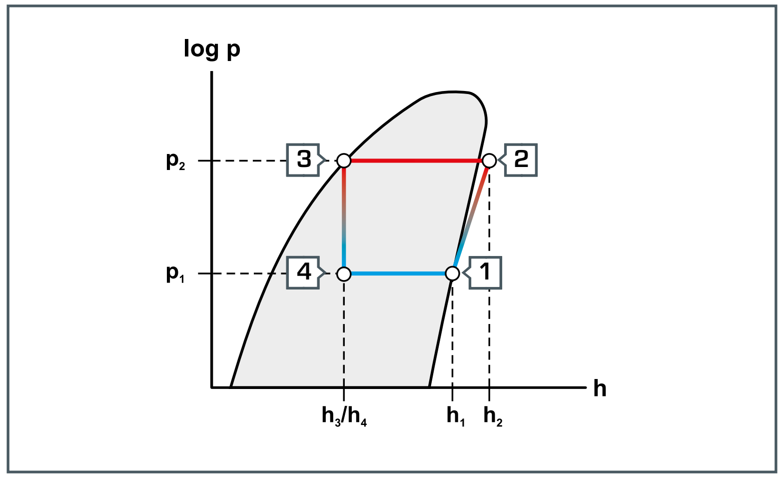
All variables necessary for the process are displayed analogously at the respective measurement locations.

Knowledge about this cyclic process is an indispensable part of training for engineering students and specialists in the field of energy technology.

Learning objectives

- fundamentals of a compression refrigeration circuit
- key components of a refrigerating plant
  - compressor
  - evaporator
  - condenser
  - expansion element
- relationship between pressure and boiling point of a liquid
- operation of a refrigerating plant/heat pump
- develop a basic understanding of the thermodynamic cyclic process
- simple energy balance

The energy for compression is applied electrically. The energy required for evaporation is extracted from the ground and, after compression at a higher pressure, is used for underfloor heating, for example.

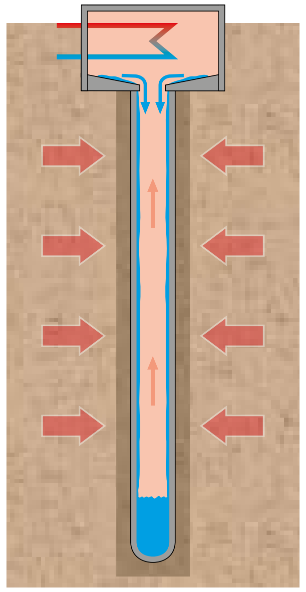


1 → 2 compression
2 → 3 condensation
3 → 4 expansion
4 → 1 evaporation

p pressure, **h** enthalpy

ET 262
Geothermal probe with heat pipe principle

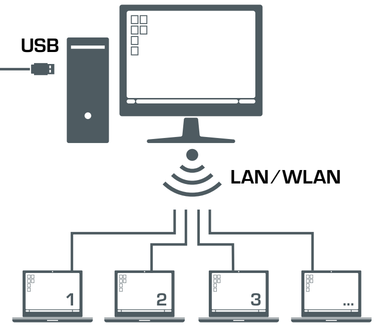
A heat pipe is a heat exchanger that allows a high heat flux density by using the evaporation heat of a material. The application of heat pipes in geothermal energy is demonstrated with ET 262.

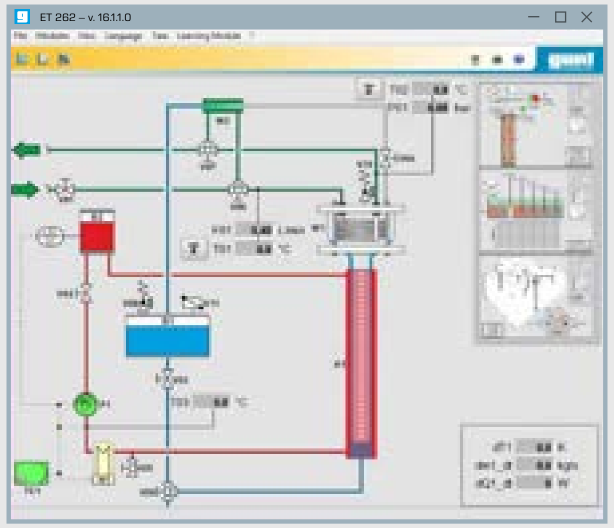


Geyser boiling in the heat pipe

Geothermal probe with heat pipe principle

The core element of the trainer is the transparent heat pipe with a low-boiling heat transfer medium. The heat input from the ground is simulated via a temperature control jacket with heating circuit. The heat from the heat transfer medium is transferred to a working medium in the probe head.





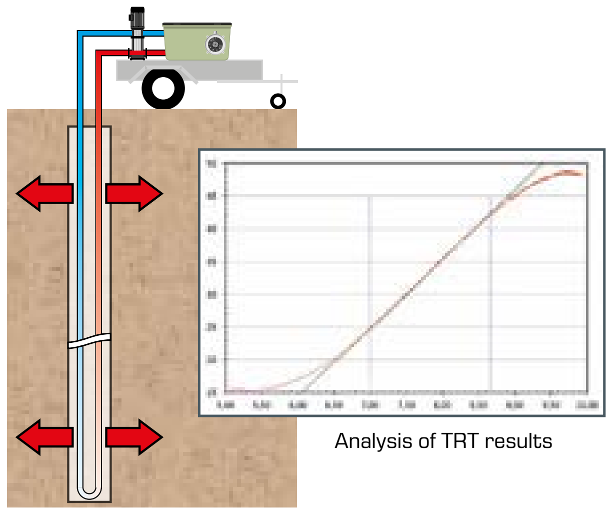
Software

Sensors record temperatures and the flow rate of the working medium in the heat exchanger. The transferred thermal power is calculated from the measured values. The measured values are used to simulate the energy balance of a connected heat pump in the GUNT software.

About the product:

Learning objectives

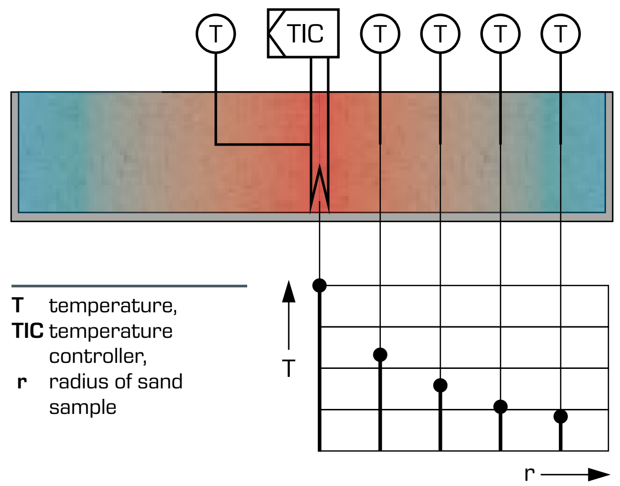
- fundamentals of geothermal energy
- operating behaviour of a geothermal probe with heat pipe principle
- determination of the quantity of heat that can be dissipated by the heat pipe with variation of the thermal load
- variation of fill quantity of the contained heat transfer medium
- investigation of the radial temperature profile in a sand sample and determination of thermal conductivity
- determination of the thermal conductivity of sand by means of a thermal response test
- fundamentals and energy balance of a heat pump



Analysis of TRT results

Thermal response test (TRT)

The second section of the trainer allows the study of the Thermal Response Test (TRT) used to evaluate the yield of a geothermal heat source.



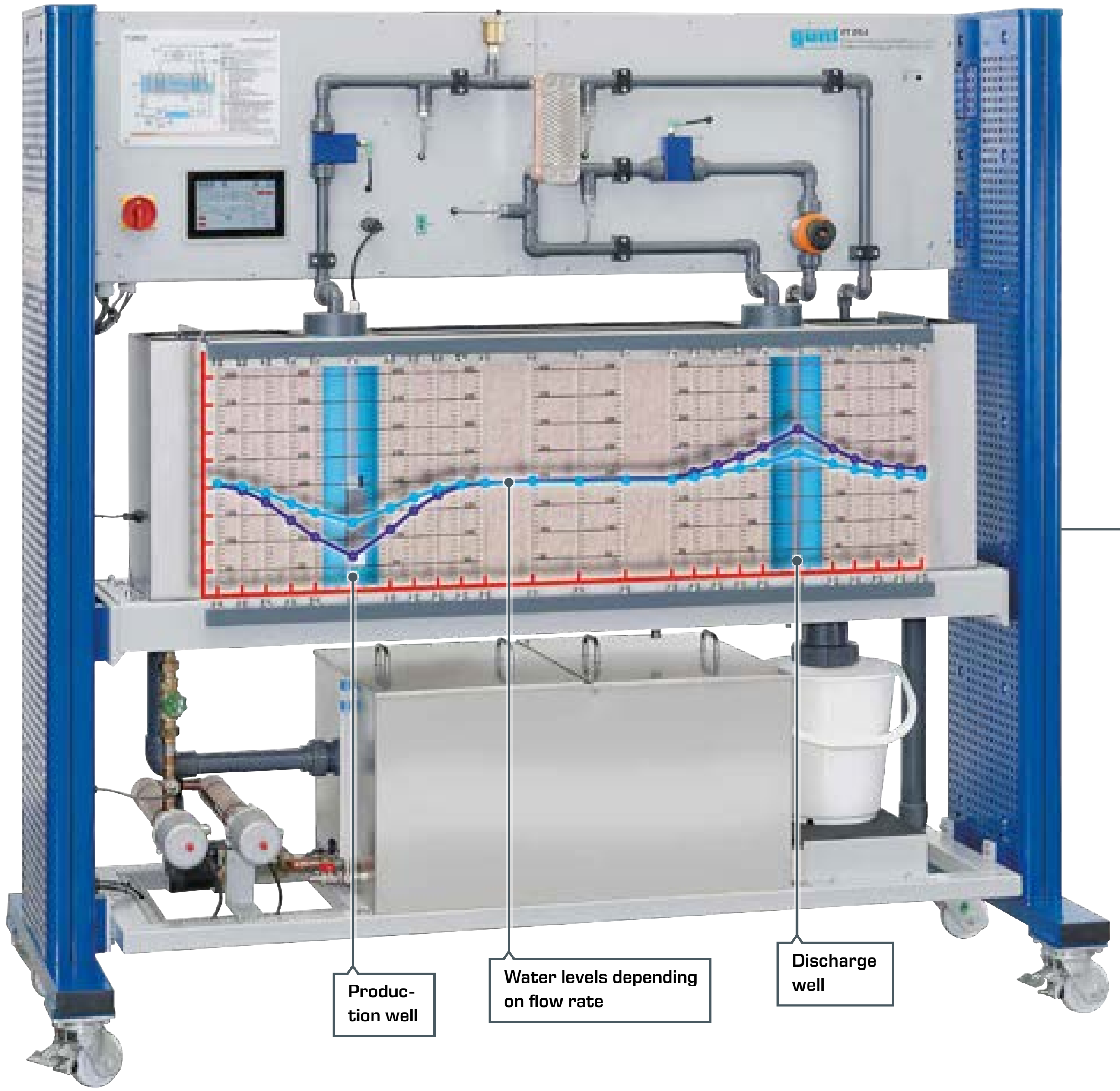
T temperature,
TIC temperature controller,
r radius of sand sample

Radial heat conduction in a sand sample

In the third section, a sand cylinder is heated by a cylindrical heat source. The radially propagating temperature profile in the sand sample is recorded and the thermal conductivity of the sand sample is calculated.

ET 264
Geothermal energy with two-well system

In geothermal heat recovery with two-well systems, the thermal energy is extracted directly from the groundwater near the surface. The ET 264 trainer contains all the essential components for investigating the important aspects of this process.



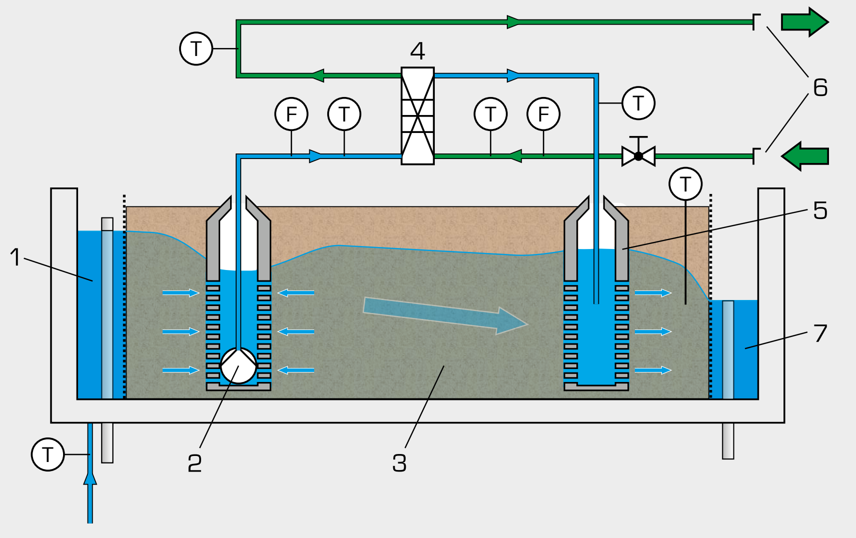
The core element of the trainer is a sand bed through which water flows, with a production well and a discharge well. The simulated groundwater flow can enter and exit the sand bed via two laterally adjacent chambers with adjustable fill levels. The water is supplied via a heatable water circuit with storage tank and pump.

About the product:

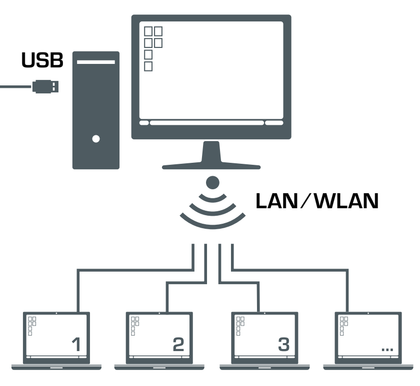
WWW

Learning objectives

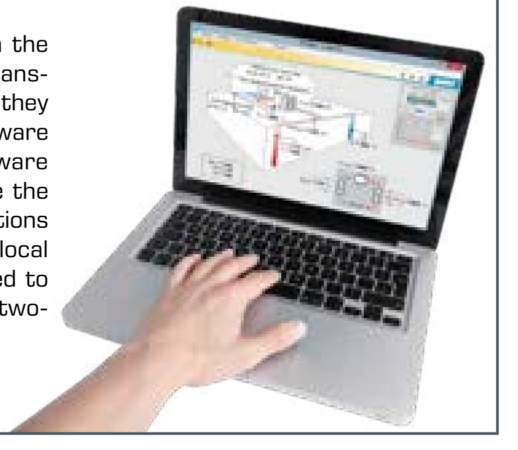
- fundamentals of geothermal utilisation
- operating behaviour of a two-well system
- hydraulic and thermal properties of the ground
- determination of usable heat capacity
- fundamentals and energy balance of a heat pump



1 feed chamber, **2** production well, **3** experimental section, **4** heat exchanger, **5** discharge well, **6** connection for working medium, **7** drainage chamber; **F** flow rate, **T** temperature, **blue:** water, **green:** working medium



The measured values are displayed on the trainer and can simultaneously be transmitted via USB directly to a PC, where they can be analysed using the GUNT software included. The network-capable software makes it possible to follow and analyse the experiments at any number of workstations via a LAN/WLAN connection to the local network. The measured values are used to simulate a heat pump connected to the two-well system.



Manometer panel on the sand bed

Pressure measuring points and drain valve

Temperature measurements with hand-held probe

Overview

HL 320 Solar thermal energy and heat pump modular system

Combination 3

The HL 320 modular system allows you to conduct experiments on the topics of geothermal and solar thermal energy in a modern heating system. In combination 3, the following modules are combined to create a system:

- **HL 320.01** Heat pump
- **HL 320.07** Underfloor heating / geothermal energy absorber
- **HL 320.08** Fan heater / air heat exchanger

Sensors for temperature and flow rate are included at all necessary points to draw up an energy balance of the energy flows. The measured values of all modules are transferred to the controller of the heat pump module via a shared data line (CAN bus) and logged by an integrated data logger. Data can be exchanged with a PC via a network connection.

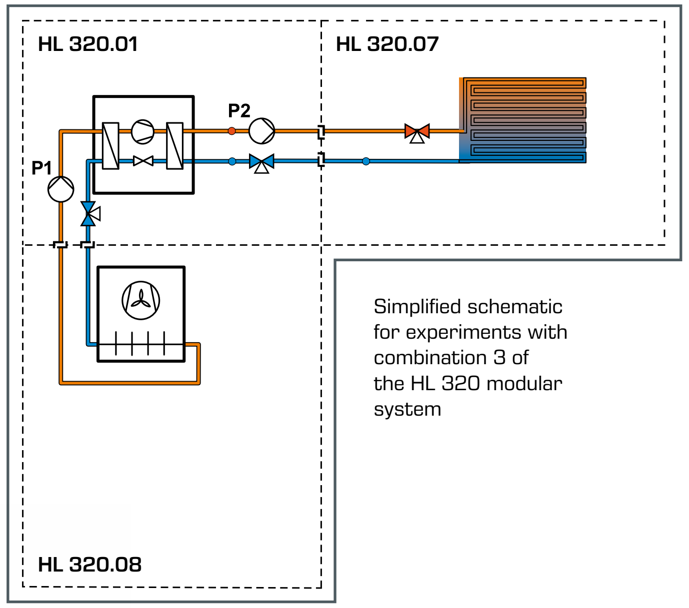
HL 320.08
Fan heater / air heat exchanger

HL 320.01
Heat pump

About the product:

About the product:

Combination 3 allows targeted experiments on a heating system based on a heat pump. HL 320.07 is used as a heat source for investigations on a system on the use of shallow geothermal energy, i.e. operated as a geothermal energy absorber.



Simplified schematic for experiments with combination 3 of the HL 320 modular system

HL 320.07
Underfloor heating / geothermal energy absorber

About the product:

Learning objectives

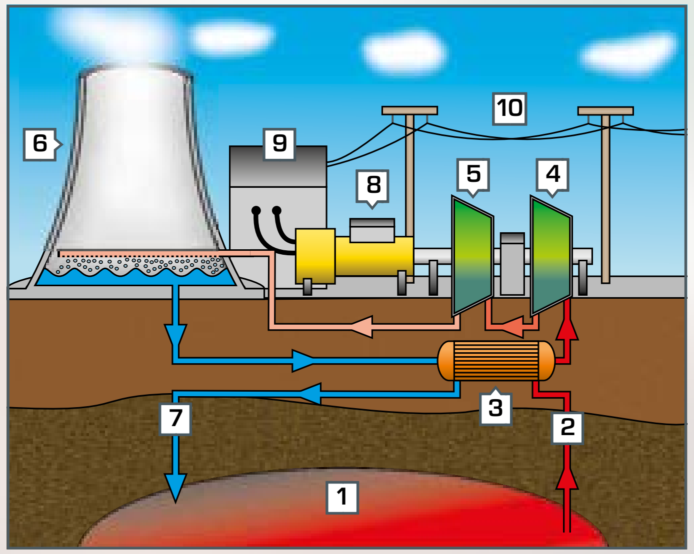
- function and design of a heat pump
- comparison of different heat sources
- factors affecting the COP (Coefficient of Performance)
- parametrisation of a heat pump controller

Basic knowledge

Deep geothermal energy

Basic principle

Deep geothermal energy is based on the use of the thermal energy of the earth's crust from depths of more than 400 m. In contrast to shallow geothermal energy, climatic influences at these depths are negligible. Unlike shallow geothermal energy, the earth's heat can be used directly. Depending on the temperature level of the geothermal field, there is either direct conversion to electricity or direct use for heating purposes.



1 heat reservoir
2 transport
3 steam generator
4 first turbine stage
5 second turbine stage
6 cooling tower
7 return
8 generator
9 transformer
10 power grid

Differentiating geothermal fields

There a different ways of distinguishing between the various geothermal fields that are attributed to deep geothermal energy. Criteria for the different deposits include the necessary drilling depth, the origin of the geothermal energy, the type of usage or the temperature level. From the point of view of technical usage of the geothermal energy, usually a distinction by temperature level of the geothermal field is chosen. In this case, a distinction is made between two different types of deposits.

The highest temperatures occur in areas known as thermal anomalies. These are mainly active or formerly active volcanic regions, but may also occur without volcanism. The deposits are referred to as high enthalpy deposits. The advantages of these deposits are the direct conversion of the hot steam and the low depth. The deeper the drill hole, the warmer the earth. Thermal anomalies with comparable temperatures are usually reached at depths of 4000 to 5000 m. These deposits no longer have the advantage of lower drilling costs.

Low enthalpy deposits are somewhat colder. It is only profitable to operate a geothermal energy source with low temperature level when using the heat for heating purposes. Converting the geothermal energy of these deposits into electricity in only done in special cases. In these cases, closed Organic Rankine Cycle (ORC) systems are employed in order to use temperatures from 80°C for electrical purposes.

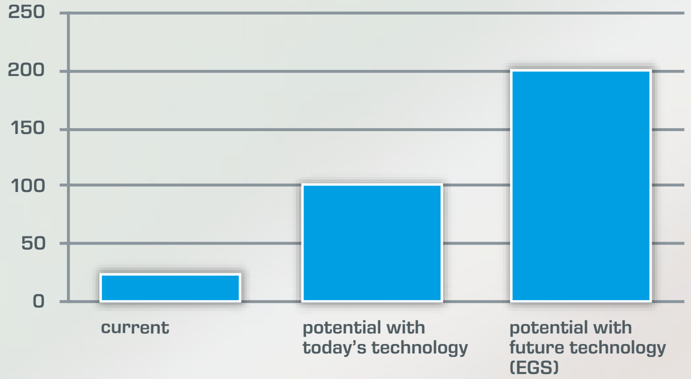
There are several technical solutions available to exploit both deposit types. The following systems are differentiated by the pressure and temperature conditions, any gases contained in the deposits, or by the quantity of water:

- hydrothermal systems
- petrothermal systems
- deep geothermal probes
- geothermal energy from tunnels
- geothermal energy from mining installations

Technical implementation

Up to the deep geothermal probes, these are open systems that are designed as 2-well systems for environmental reasons. A power plant site is equipped with up to four drill holes. After transport and using the hot water or steam, the cold working medium is pumped back into the holes. Doing so does not reduce the operating pressure and the efficiency and capacity remain largely unaffected.

Globally installed power in gigawatts



Source: Technology Roadmap/ Geothermal Heat and Power – International Energy Agency

Outlook

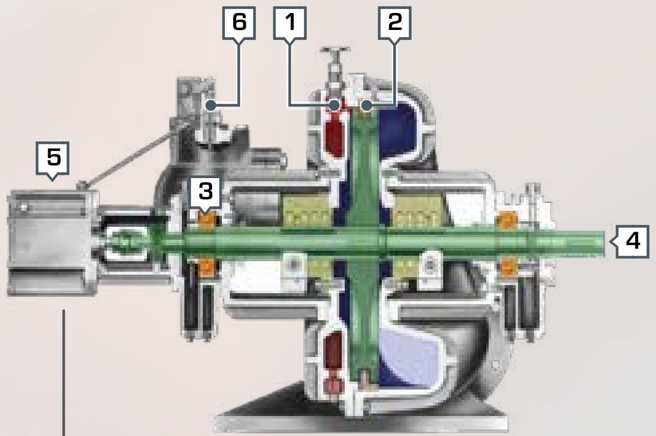
At present, an electrical output of 23GW$_{el}$ is installed worldwide. Using currently available technology of hydrothermal systems, this could be increased to around 100 GW$_{el}$ by 2050.

Including Enhanced Geothermal Systems (EGS), i.e. petrothermal systems, it could even be possible to reach 200 GW$_{el}$. However, these systems are not yet state of the art.

Converting thermal energy into kinetic energy

It is necessary to use steam turbines in the field of deep geothermal energy in order to convert the thermal energy extracted from the ground into electricity. The steam turbine converts the energy of the steam from the ground into rotational kinetic energy. A generator then produces electric current from the kinetic energy of this rotation.

A typical industrial steam turbine is the action turbine, shown in cross section, with a Curtis wheel. The turbine is designed to drive generators directly and does not have any gearing.



1 nozzle
2 deflection in the rotor
3 roller bearing
4 rotor shaft
5 speed controller
6 flow control valve

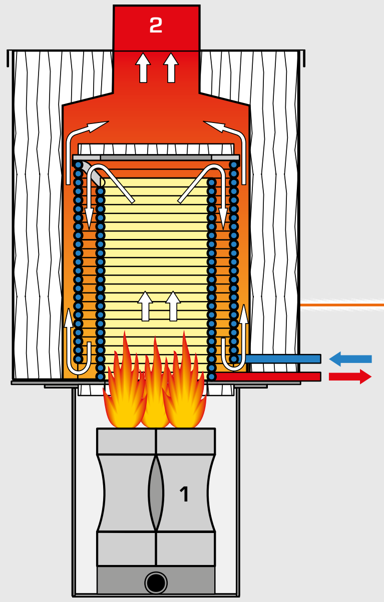
Overview

ET 850 & ET 851 Steam generator and Axial steam turbine

When combined, the ET 850 Steam generator and the ET 851 Axial steam turbine from GUNT represent a real laboratory-sized steam power plant.

This plant has all the important components of a real large-scale plant: A once-through water-tube boiler with superheater, a condenser with water jet pump for vacuum operation, a feed water tank, pumps for condensate and feed water, a steam turbine with dynamometer, shaft sealing with labyrinth and sealing steam.

- once-through water-tube steam boiler design assures highest safety
- quick steam generation due to small water capacity
- electrical superheater enables adjustable superheating of steam
- clean and odourless combustion due to heating with propane or natural gas
- water-cooled condenser evacuated by water jet pump enables operation without steam turbine ET 851 as well



Sectional view of the ET 850 Steam generator

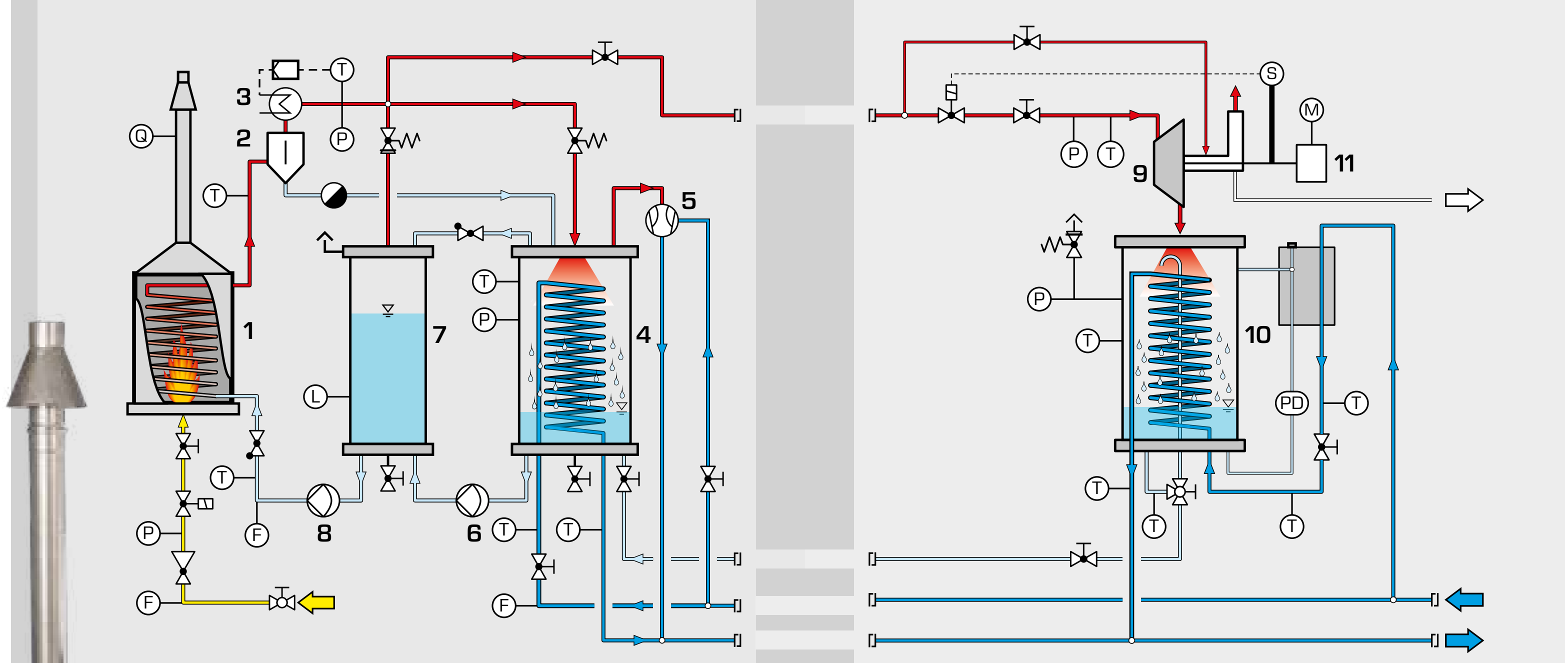
1 burner, **2** exhaust gas, ↑ direction of flow of the heated air along the heat exchanger

ET 850 Steam generator

1 steam boiler, **2** water separator, **3** superheater, **4, 10** condenser, **5** water jet pump, **6** condensate pump, **7** feed water tank, **8** feed water pump,

ET 851 Axial steam turbine

9 turbine, **11** brake; **F** flow, **P** pressure, **PD** differential pressure, **Q** exhaust gas analysis, **S** speed, **T** temperature, **M** torque

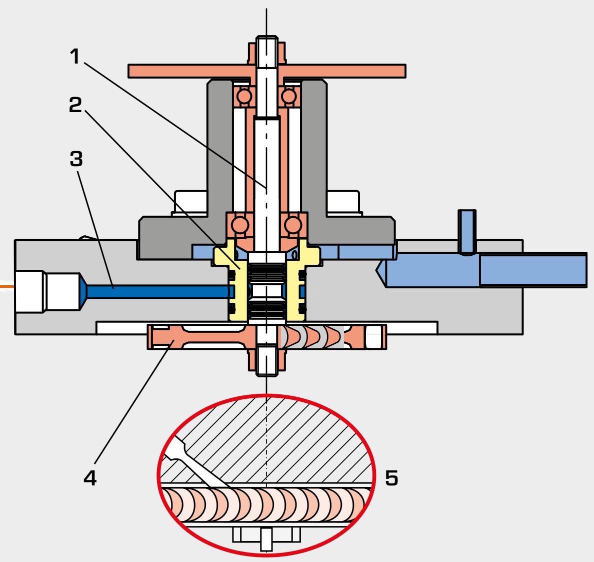


ET 850 Steam generator

ET 851 Axial steam turbine

The operating behaviour is very similar to that of a real plant. Students can observe and practice the careful adjustment of the steam generator, turbine, condenser and superheater. The data acquisition software evaluates the results efficiently and accurately, and provides a quick overview.

- single-stage axial flow impulse turbine
- vertical shaft mounted on ball bearings
- contactless labyrinth gland with sealing steam enables vacuum operation
- transparent, water-cooled condenser
- wearless eddy current brake with permanent magnet
- safety cut-off in case of overspeed via trip valve
- steam flow rate determined via condensate level

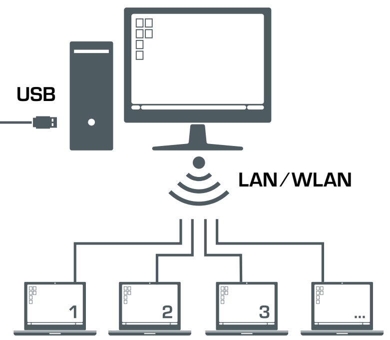


1 shaft, **2** labyrinth unit, **3** steam inlet, **4** rotor, **5** sectional view of nozzle and blades

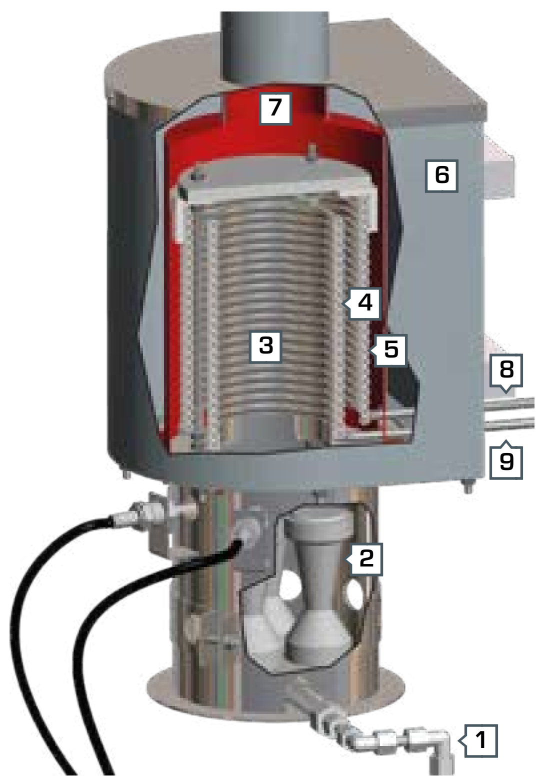
ET 850
Steam generator

A steam generator creates steam that is then used for heat power plants or to drive machinery. Steam generator and steam consumer together form a steam power plant. Steam power plants work according to the steam power process, which even today is still one of the most important industrial cyclic processes. Steam power plants are mainly used to generate electricity. The ET 850 Steam generator, together with the ET 851 Axial steam turbine, forms a complete laboratory-scale steam power plant. The ET 850 trainer teaches students the components and operating principle of a steam generator. Students can study the characteristic values of the plant. The diverse safety devices of the steam generator can be tested and inspected using various monitoring systems.

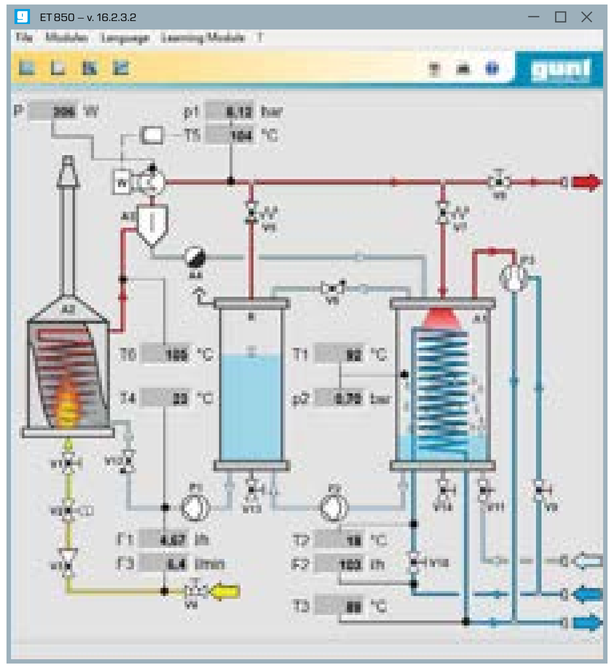
If the steam generator is operated without the steam turbine, the generated steam is condensed directly via a condenser and fed back into the evaporation circuit via a tank.



The steam generator is designed and pressure tested according to the "Technical Regulations for Steam" (TRD, Technischen Regeln Dampf) and has all safety valves prescribed by law.



1 gas feed
2 burner
3 1st draw
4 2nd draw
5 3rd draw
6 insulation
7 waste gas
8 water intake
9 steam output



Software

Sensors record temperatures, pressures and flow rates at all relevant points. The software allows measurement data to be clearly displayed on the PC. Time dependencies can be recorded and saved. A spreadsheet program (e.g. MS Excel) can be used to analyse the stored data.

Learning objectives

- familiarisation with and investigation of the specific characteristic values of a steam boiler
- efficiency of a steam generator
- investigation of the waste gases
- effect of different burner settings
- saturation temperature and pressure
- steam enthalpy
- determination of heat flux density and heat transfer coefficient

About the product:

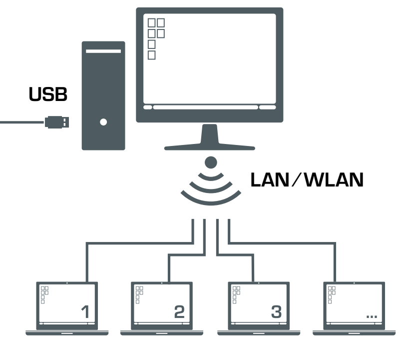
www

ET 851
Axial steam turbine

The ET 851 trainer provides you with an axial steam turbine with eddy current brake, condenser, piping, instrumentation and safety devices. All relevant measured values such as temperatures, pressures and flow rates are recorded and displayed digitally. User-friendly software enables you to easily process the measured values further using a PC.

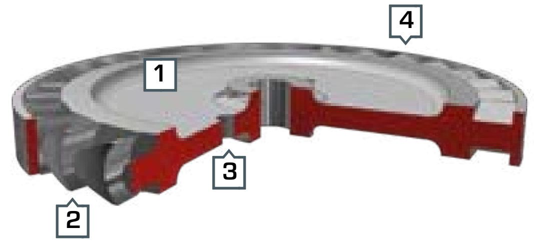
ET 851 is optimally adapted to the ET 850 steam generator. Therefore it is possible to operate and investigate the steam turbine in a closed steam circuit.

Knowledge about the steam turbine process is an indispensable part of training for engineering students and specialists in the field of energy engineering.



1 turbine
2 brake
3 condenser
4 water supply
5 main steam valve
6 sealing steam valve

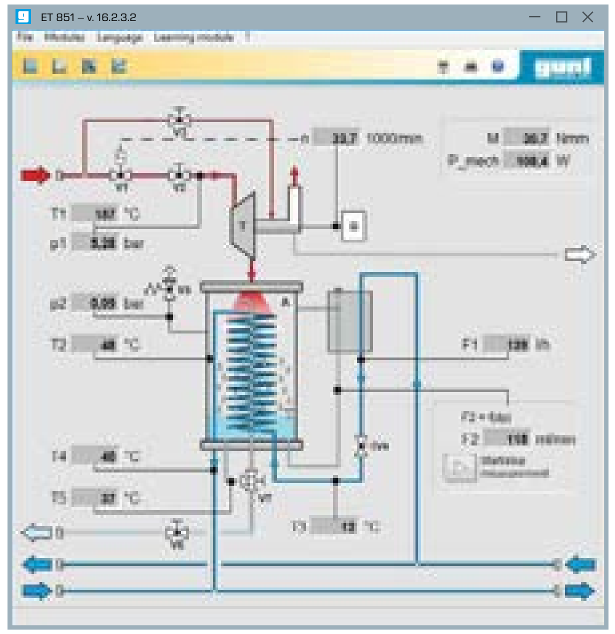
The ET 851 experimental unit is a single-stage axial action turbine with a vertical axis. The steam required must be generated externally (e.g. via the ET 850 steam generator). The turbine can be operated with saturated steam or superheated steam. The steam is expanded in the turbine and condensed via the water-cooled condenser. Load is applied to the turbine via an eddy current brake. The turbine has a non-contact labyrinth seal on the shaft with sealing steam circuit. The turbine is fitted with various safety devices in order to prevent damage such as by excessively high speed or pressure in the system.



1 turbine rotor
2 turbine blade
3 equalisation hole
4 covering ring

About the product:

WWW



Software

Sensors record temperatures, pressures and flow rates at all relevant points. Turbine speed and torque are measured electronically at the eddy current brake. 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

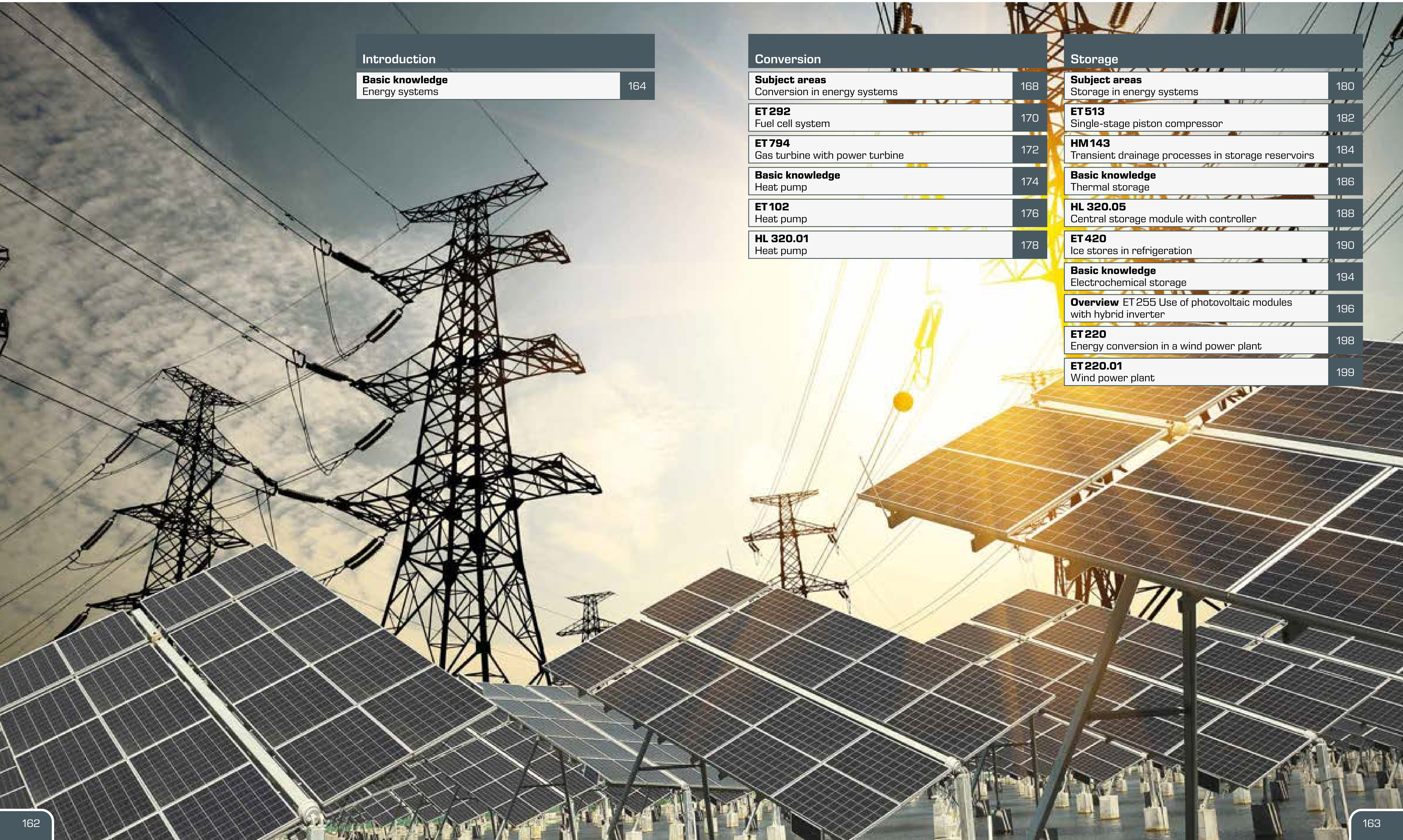
- principle of operation of a steam turbine
- steam consumption of the turbine
- turbine output at different settings
- investigation of the losses occurring in different turbine components
- power and torque curve
- overall efficiency compared to the theoretical efficiency

6 Energy systems

Introduction

Conversion

Storage



Basic knowledge

Energy systems

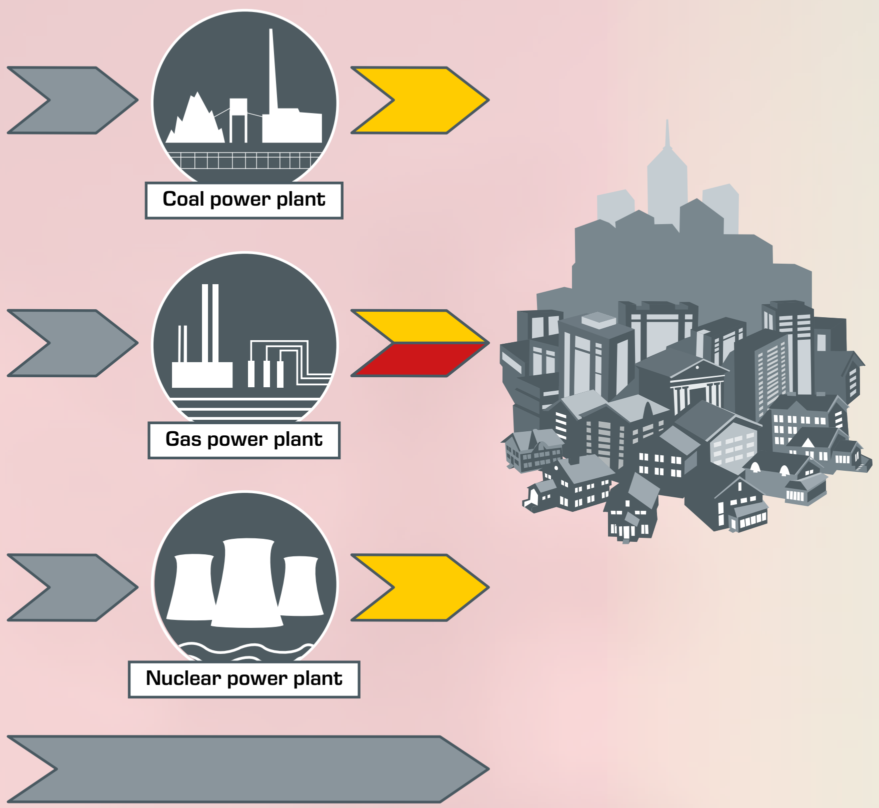
For a long time, fossil fuels have been used almost exclusively as an energy source. Electricity was generated in a few central power plants. Heat was mainly supplied by coal stoves, oil heaters or gas boilers. Oil and coal require local provisioning. Gas is stored in pressure vessels when there is no connection to the gas network.

The expansion of renewable energies has led to many small decentralised energy producers, such as wind power plants and photovoltaic installations, have been set up. This led to a complex system with new challenges such as the varying availability of solar energy and wind energy. Effective storage is necessary in order to be able to use these energy sources to cover the base load.

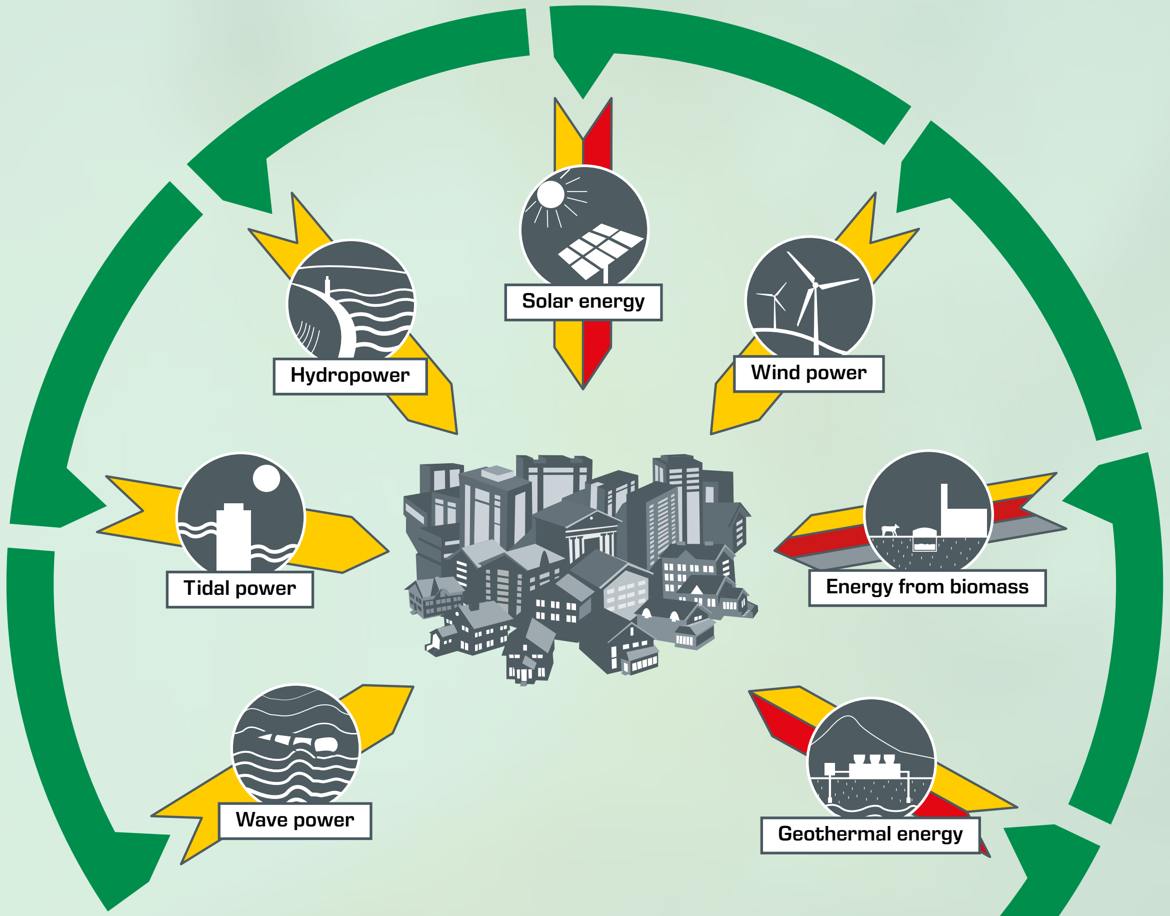
Storage systems can be based on potential energy (e.g. pumped storage), pressure energy (e.g. compressed air storage), thermal energy (e.g. hot water storage tank) or electrochemical energy (e.g. accumulator). Depending on the available energy, conversion into a storable form is also required, and reconversion if necessary. In the event of excess energy, electricity and gas can also be fed into the general utility grids. Balancing feed-in and consumption is a complex task and requires professional management.

An energy system consists of the following sub-areas:

- generation
- conversion
- storage
- transport
- reconversion
- consumption



Conventional energy system



Renewable energy system

Towns and entire communities are supplied by numerous decentralised units that can deliver electricity, heat and even natural gas. Compared to conventional energy supply, the grids contain lots of small energy flows.

- fossil fuel
- electrical energy
- thermal energy
- renewable energy

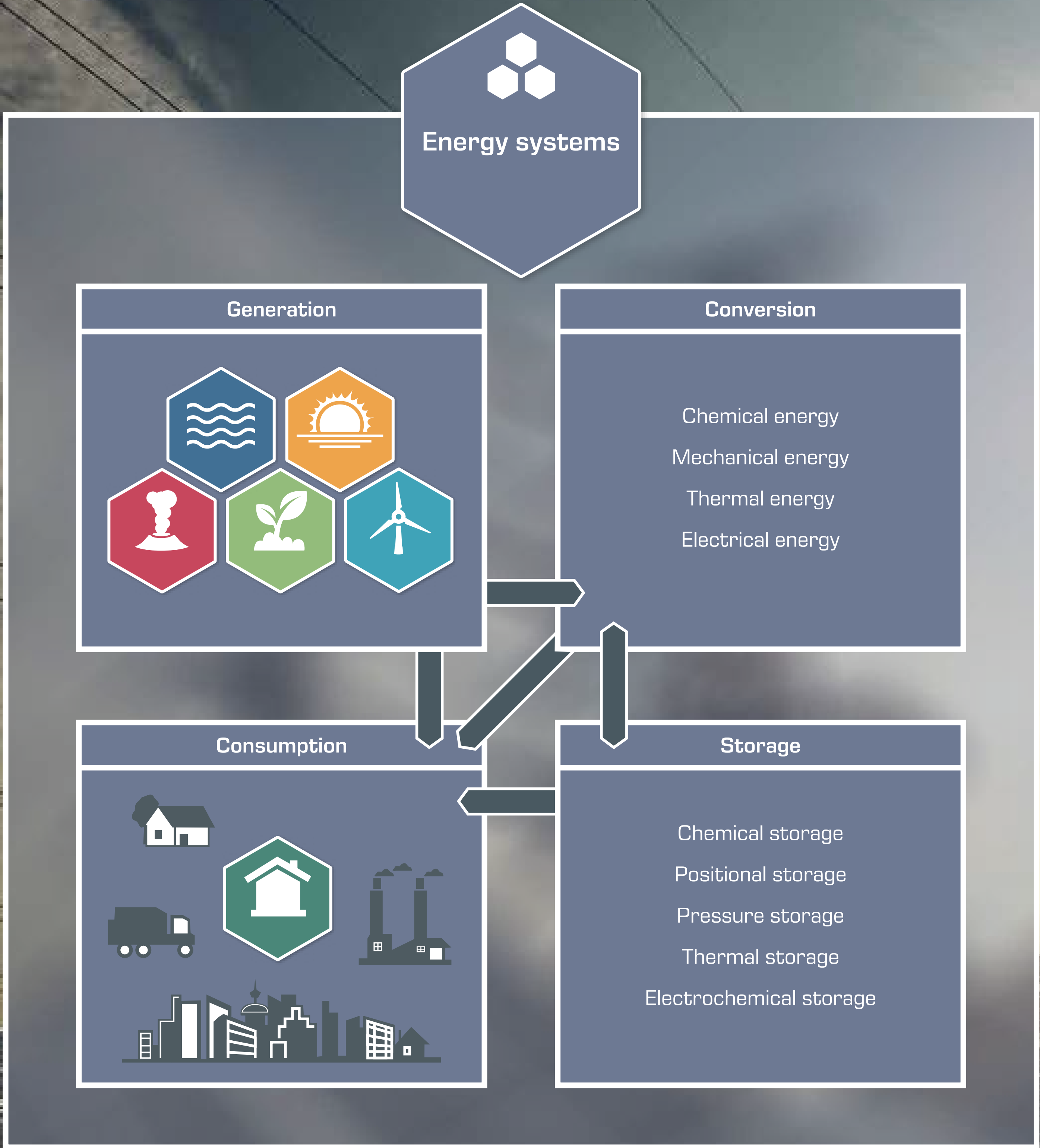
Surplus electricity

One feature of renewable energies is the surplus electricity produced, which is created for example when photovoltaic installations feed their peak output into the grid at midday. In order to keep the voltage constant, renewable energies therefore often have to be throttled. This potential can be used in an optimised energy system. As soon as more electricity is produced than is consumed, the surplus can be used to operate an electrolyser, for example. In this process, hydrogen and oxygen are obtained from water. If required, the hydrogen can be used again in fuel cells to generate electricity or mixed with natural gas, for example. The formerly surplus energy is therefore available at another time and location.

GUNT TECHNOLOGY LIMITED

Basic knowledge

Energy systems



Example of an energy system

Generation

The first step in the example is the generation of electrical energy by wind power or photovoltaic plants. At the same time, biogas is obtained from waste from agricultural products.

Conversion

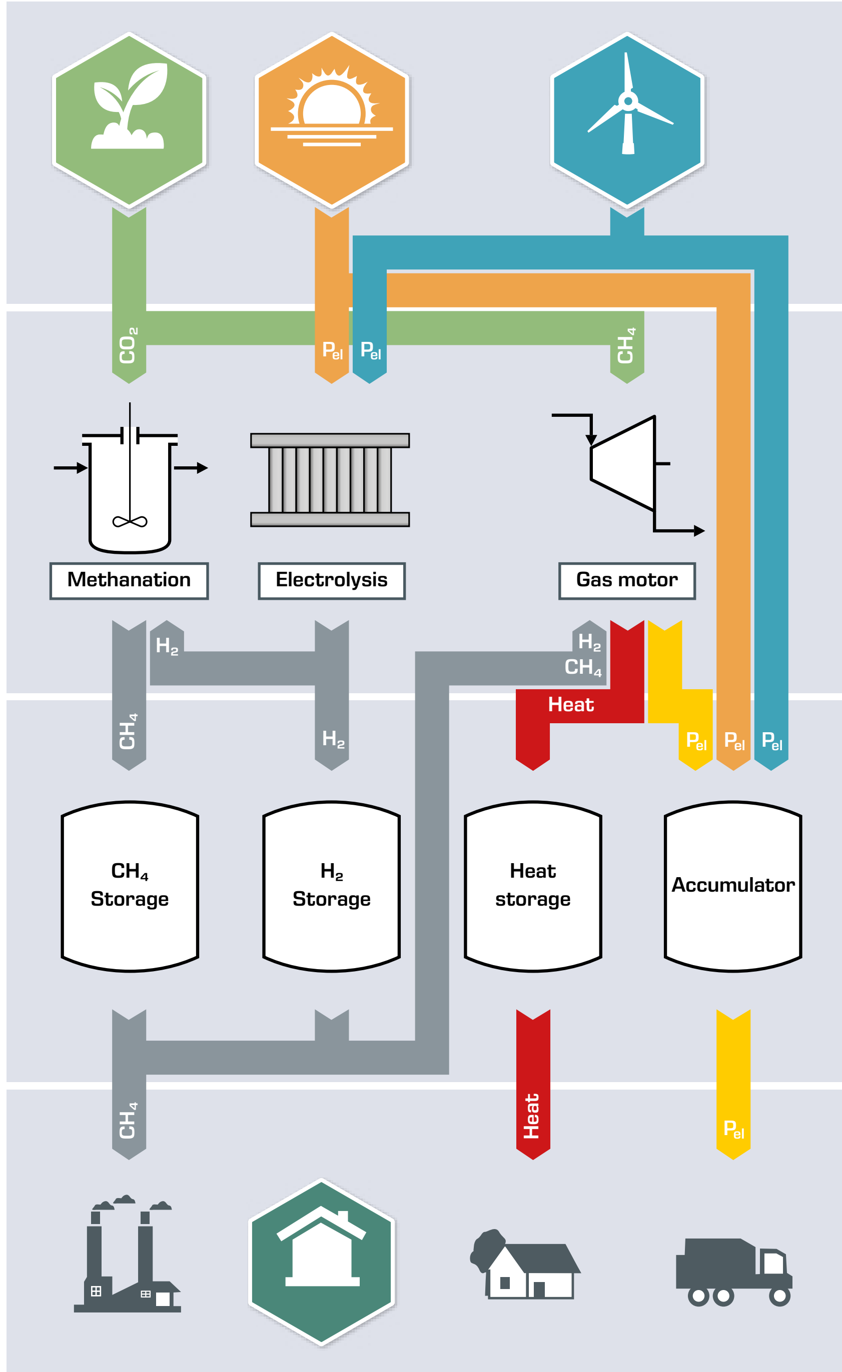
The second step, besides direct usage or storage, is to convert the gained energy into an energy form that can be transported or stored. This may be electrical or chemical and include mechanical energy as an intermediate stage. Another advantage is that the by-product of the biogas plant, CO_2, can be used as energy by the conversion.

Storage

The third step is storage in the energy form generated previously. Storage can take place on site in suitable tanks or by feeding into the public gas network. Following transport or storage, the energy is converted into the final energy and, depending on the conversion site, either transported to the consumers or used directly.

Consumption

The last step is consumption of the final energy in households, industrial plants or even for mobility purposes.



Subject areas

Conversion in energy systems

In supply networks with high shares of renewable energies, the supply and demand for energy often differ. The causes for this are both a lack of energy storage and remote generation locations. As part of renewable energies with lots of decentralised photovoltaic and solar thermal energy installations, stand-alone solutions are also possible.

For example, surplus electricity is used to load a suitable storage system. In this case, the electrical energy is used in an electrolyser to split water and the resulting hydrogen stored directly or converted chemically by methanation. After conversion, the generated methane can be stored and used in a gas turbine for reconversion into thermal, mechanical and even electrical energy. An electrolyser therefore represents an electrical-chemical conversion, whereas methanation is a chemical-chemical conversion.

A well-known conversion component in energy systems used in building services engineering is the heat pump. This transfers electrical and thermal low calorific energy into thermally usable energy for heating purposes.

Subject areas	Products
Chemical-electrical	**ET 292** Fuel cell system
Chemical-thermal-mechanical-electrical	**ET 794** Gas turbine with power turbine
Electrical-thermal-thermal	**ET 102** Heat pump **HL 320.01** Heat pump

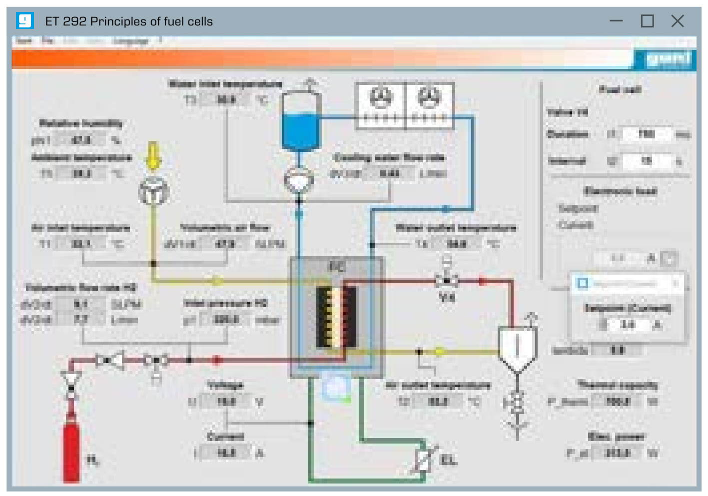
ET 292
Fuel cell system

Modern fuel cell systems are becoming increasingly important in supplying households, for example in the decentralised conversion of energy. Local energy supply has the advantage of reducing transport losses to a significant extent. In addition, combined heat and power (cogeneration) provides excellent efficiency overall due to using both thermal and electrical energy. Companies in the field of heating engineering have recognised the potential of these systems and are currently working hard on the market maturity and commercialisation of fuel cell systems for domestic energy supply. The requirements for fuel cell systems to become established in the liberalised energy market don't just include the matter of energy efficiency, but equally the economic potential. A future determined by the hydrogen energy economy is inconceivable without the use of fuel cells for energy conversion.

ET 292 is a fuel cell system which is operated in combined heat and power generation. The components of the fuel cell system are clearly mounted on a panel. The fuel cell is charged via an electronic load and operated voltage-regulated, current-regulated or power-regulated as desired.

The fuel cell uses oxygen and high purity hydrogen as working media. The oxygen is fed into the fuel cell via the ambient air by means of an integrated fan. The hydrogen is provided by a compressed gas cylinder and expanded to the fuel cell's system pressure through a multi-stage pressure reduction.

1 low-pressure reducing valve
2 inlet valve
3 cathode fan
4 fuel cell
5 water separator
6 main switch
7 cooling water pump
8 water cooler
9 optical flow control
10 cooling water tank



The software for ET 292 allows the most important variables to be captured

- inlet and outlet temperatures
  - air side
  - water side
- system pressure
- hydrogen volumetric flow rate
- electrical power
- current
- voltage

About the product:

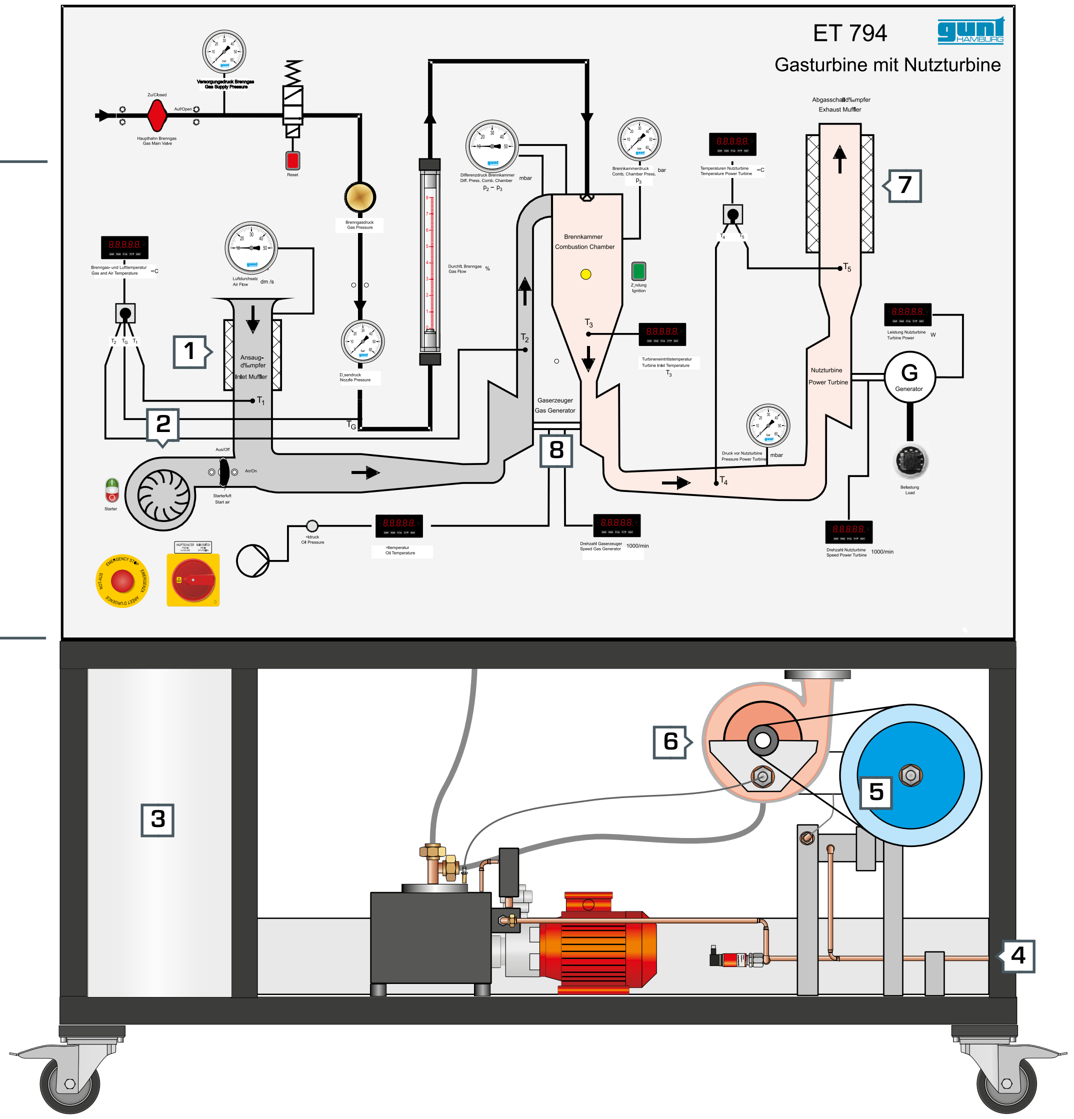
www

Learning objectives

- conversion of chemical energy into electrical and thermal energy
- function and design of a fuel cell system
- relationships of fuel cell operating parameters
- effects on the electrical output of fuel cells
- recording and visualisation of all relevant voltage/current characteristics
- calculation of relevant characteristic variables

ET 794
Gas turbine with power turbine

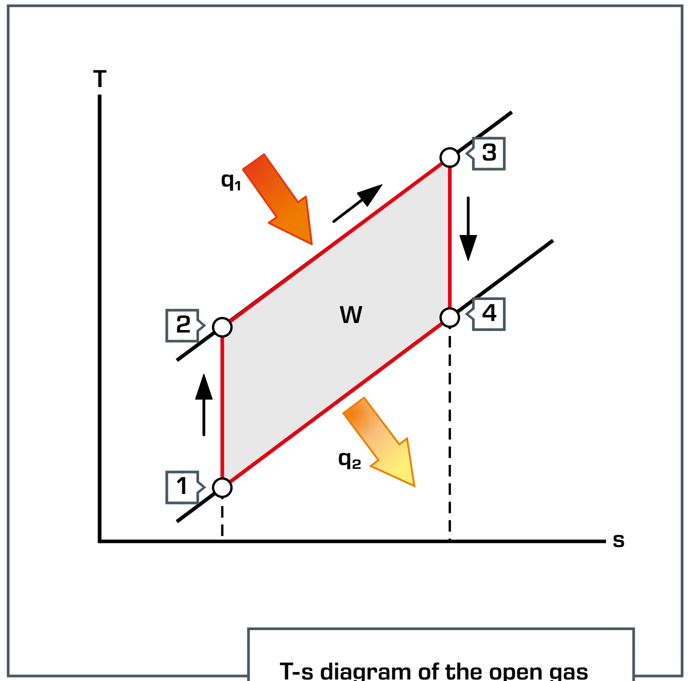
Gas turbines with free-running power turbines are preferred as drive systems for widely varying power requirements in power plants, ships, locomotives and in automotive engineering. ET 794 studies the behaviour in operating a system with two independent turbines in a two-shaft arrangement. One turbine (high-pressure turbine) drives the compressor and the other turbine (power turbine) delivers the net power. Output changes in the power turbine do not affect the compressor, which can continue running with optimum speed at the best efficiency point. Speed, temperatures, pressures and mass flow rates of air and fuel are detected and displayed by means of sensors. Typical characteristic variables are determined.



1 air intake with sound absorber
2 starter fan
3 switch cabinet
4 cooling water connection
5 generator
6 power turbine
7 gas generator (compressor, combustion chamber, turbine)
8 sound absorber for waste gas

About the product:

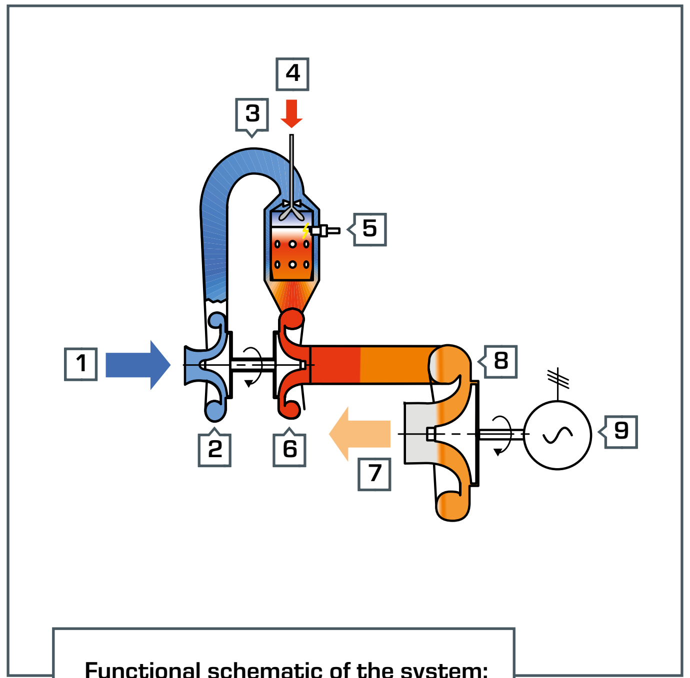
www



T-s diagram of the open gas turbine process:

1 → 2 compression
2 → 3 heat supply
3 → 4 expansion

q_1 supplied heat flux,
q_2 dissipated heat flux,
W useful work



Functional schematic of the system:

1 cold air
2 compressor
3 tubular combustion chamber
4 fuel
5 ignition plug
6 high-pressure turbine
7 waste gas
8 power turbine
9 generator

Learning objectives

- determining shaft power
- determining specific fuel consumption
- recording turbine characteristic curve of the power turbine
- determining the efficiency of the system

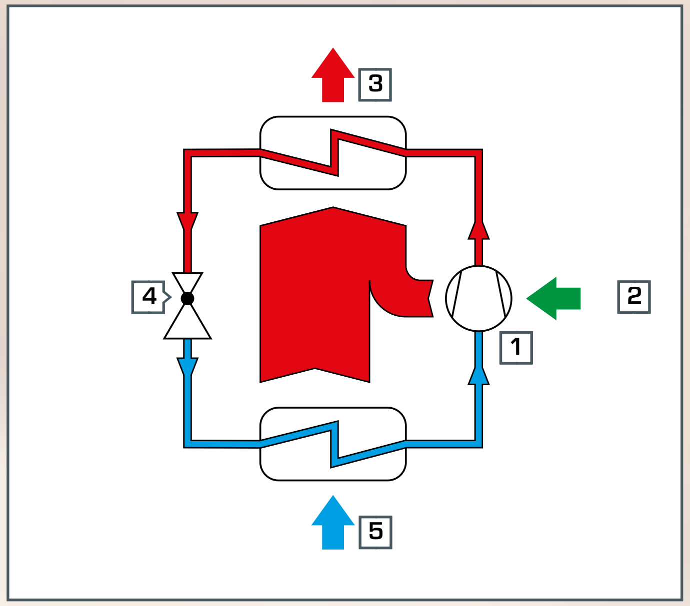
Basic knowledge

Heat pump

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 are used, which operate according to the principle of a compression refrigeration system. Less often, heat pumps are used according to the absorption process.

1 compressor
2 drive energy
3 heat dissipation
4 expansion valve
5 heat absorption



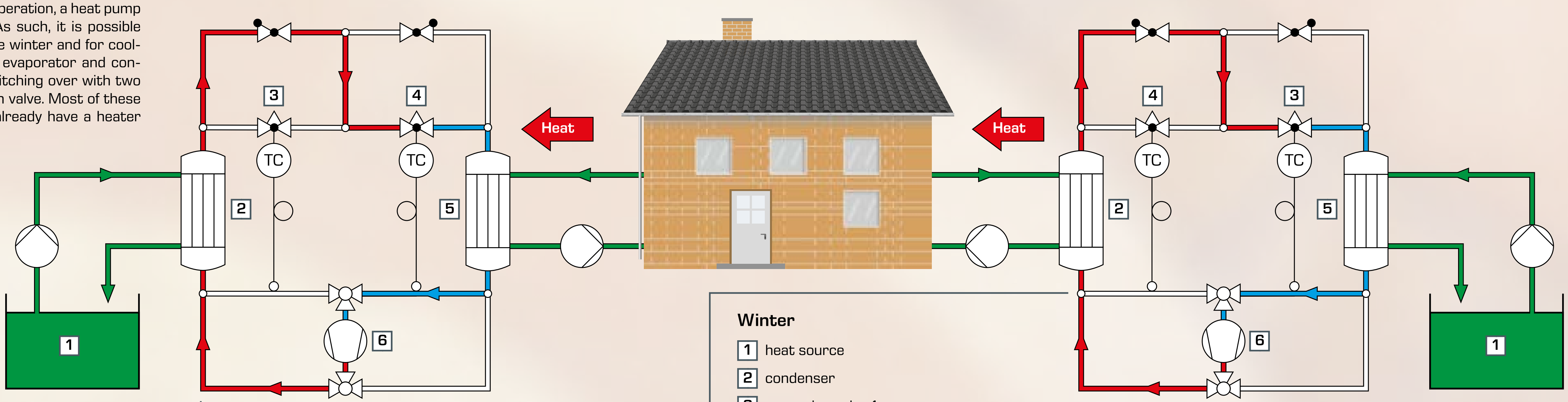
Where does the heat pump get its energy from?

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 that 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
Outdoor air	Low investment	Poor performance in winter
River water	Low investment	Poor performance 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 happens 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)

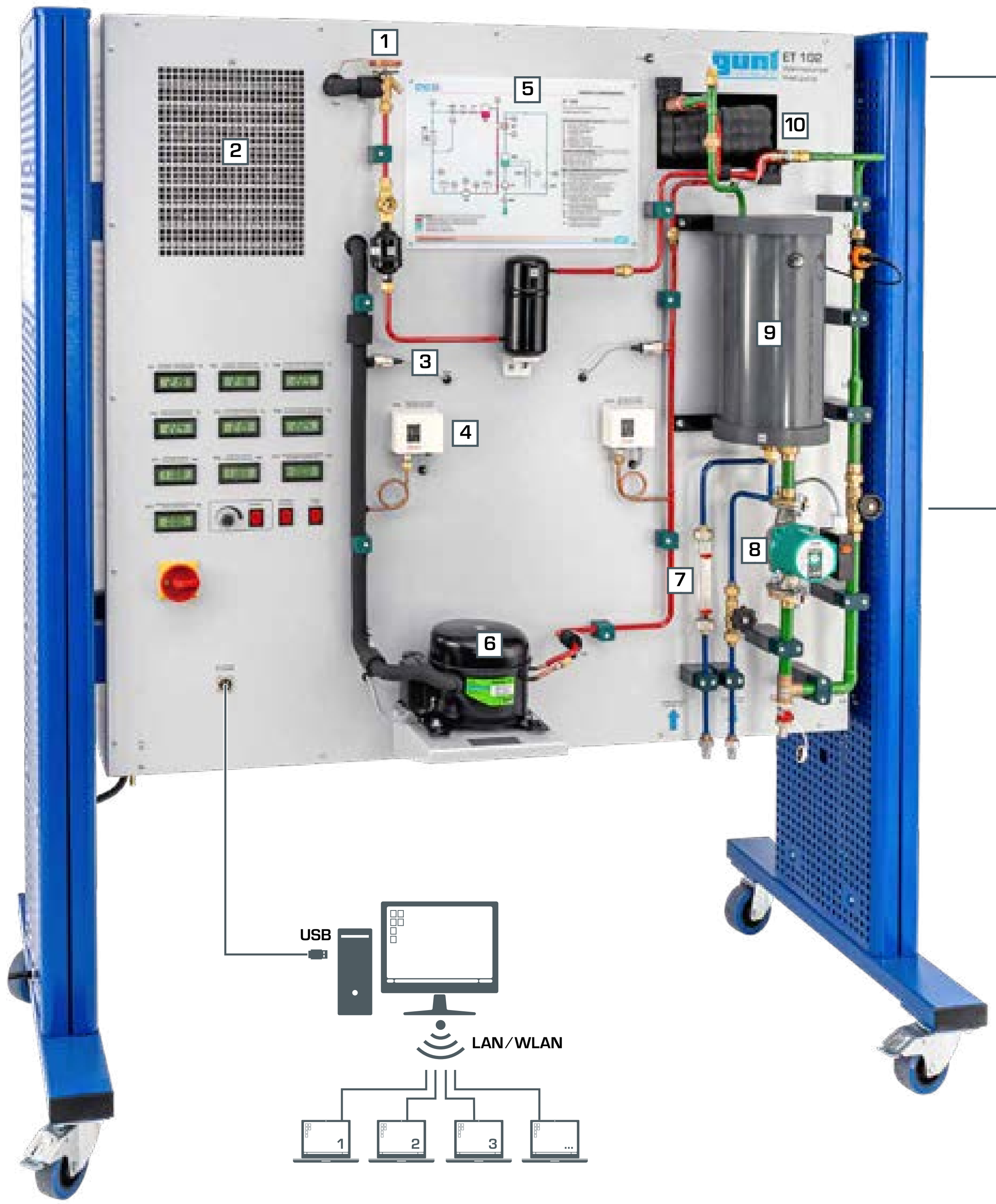
Winter

1 heat source
2 condenser
3 expansion valve 1
4 expansion valve 2
5 evaporator
6 compressor

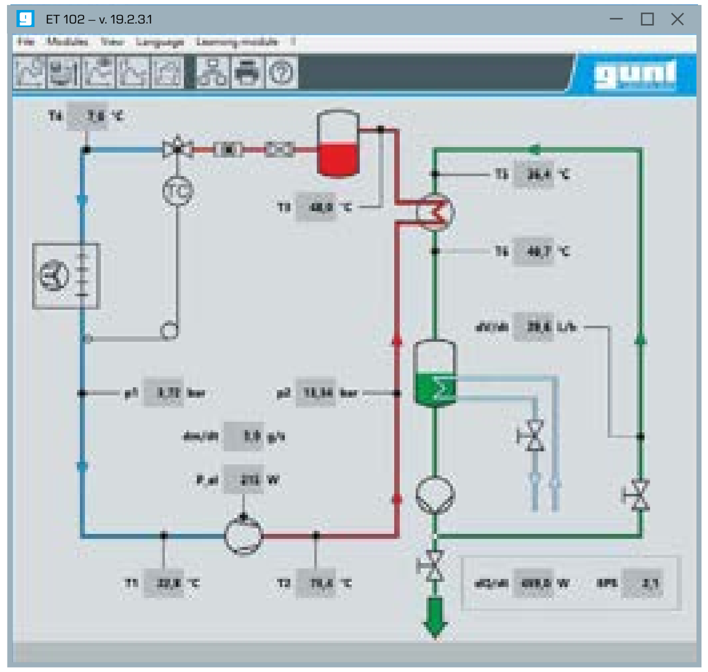
water/solar circuit
refrigerant (low pressure)
refrigerant (high pressure)

ET 102
Heat pump

The GUNT ET 102 device contains a complete functional model of an air-to-water heat pump. The clear and spacious layout of the components allows for an easy understanding of the design of a heat pump system. All components are common components in heat pump and refrigeration technology. This means there is high recognition factor and the experiments are close to practice. The system has a variety of sensors that measure pressures, temperatures and flow rates. Displaying the measured values allows student to study the processes within a heat pump. At the same time, measurements are displayed and analysed on a PC. In addition to the specific training on the heat pump, you can also demonstrate the fundamentals of refrigeration technology. Besides the fundamental explanation of the function of a heat pump/refrigerator, you can also take quantitative measurements such as determining the coefficient of performance.



1 expansion valve
2 evaporator with fan
3 pressure sensor
4 pressure switch
5 process schematic
6 compressor
7 cooling water flow meter
8 pump
9 hot water tank
10 condenser



The software for ET 102 allows the most important variables to be captured

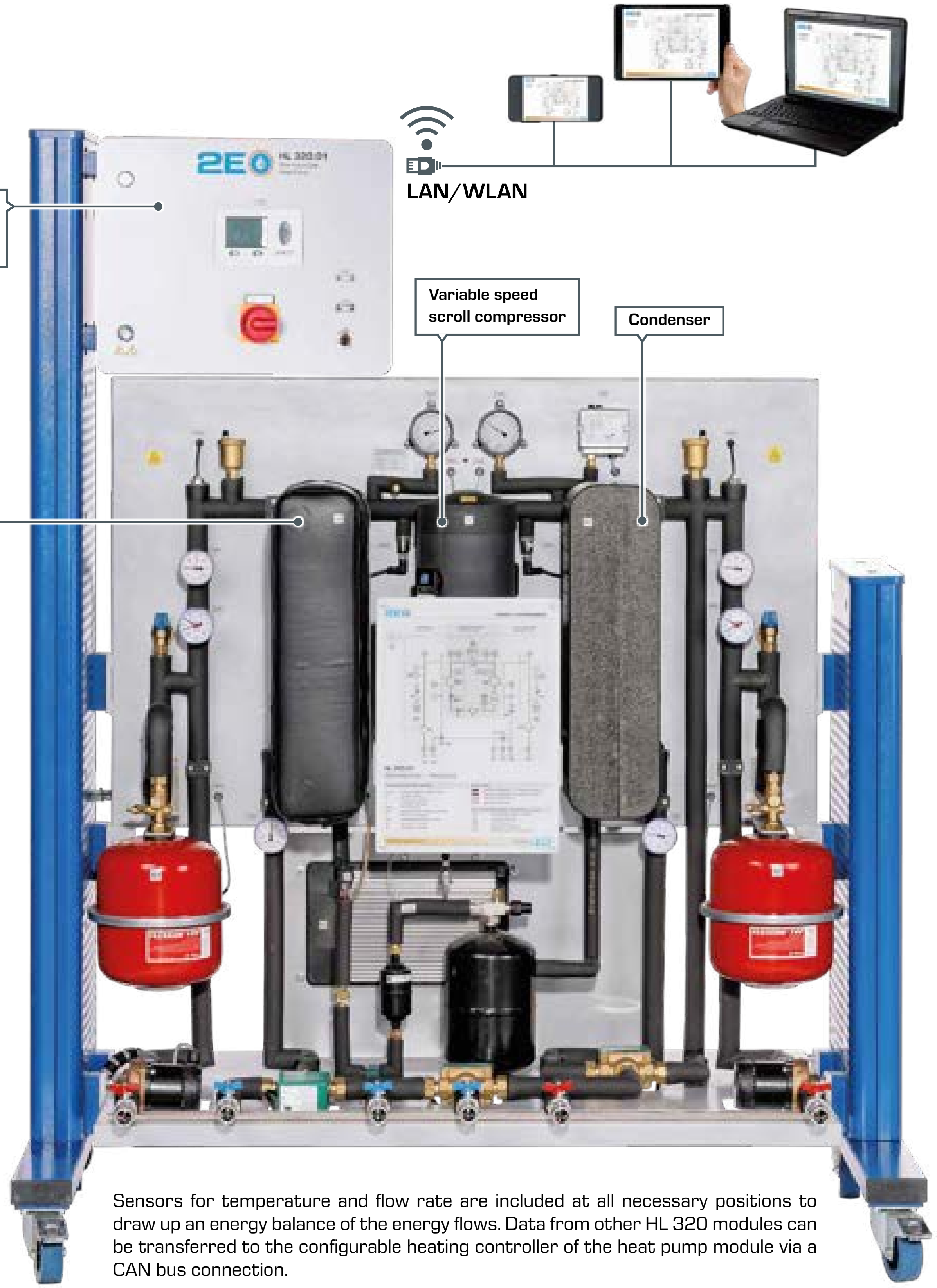
- temperatures
  - low pressure side (blue)
  - high pressure side (red)
  - hot water side (green)
- pressures downstream of the
  - evaporator
  - compressor
- compressor power consumption

Learning objectives

- design and operation of an air/water heat pump
- representation of the thermodynamic cyclic process in the log p-h diagram
- energy balances
- determination of key characteristic variables
  - pressure ratio in the compressor
  - ideal coefficient of performance
  - actual coefficient of performance
- dependence of the actual coefficient of performance on the temperature difference (air/water)
- operating behaviour under load

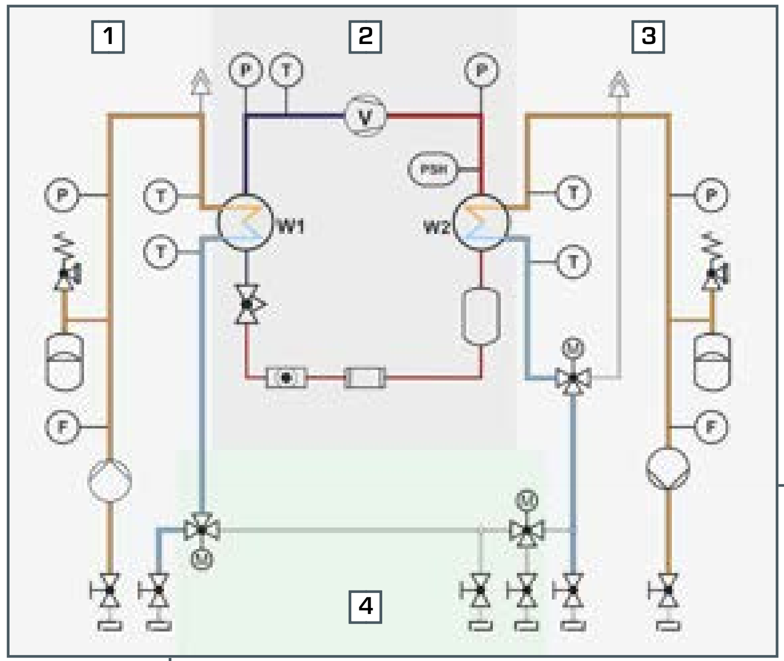
About the product:

HL 320.01
Heat pump



Sensors for temperature and flow rate are included at all necessary positions to draw up an energy balance of the energy flows. Data from other HL 320 modules can be transferred to the configurable heating controller of the heat pump module via a CAN bus connection.

The HL 320.01 heat pump is part of the HL 320 modular system and provides you with a variety of combination options of geothermal and solar thermal energy in a modern heating system. The heat pump is driven by a variable speed scroll compressor. This means it is possible to adapt the heating power of the heat pump to the current demand of the heating system.



Process schematic of the HL 320.01 heat pump module

- 1 source circuit connections
- 2 refrigeration circuit
- 3 heating circuit connections
- 4 additional options for including HL 320 modules

Fixed and movable spirals of a scroll compressor

Learning objectives

- function and design of a heat pump
- distinguishing different operating conditions
- factors influencing the COP (Coefficient of Performance)
- parametrisation of a heat pump controller

In combination 3 of the HL 320 system, the following modules are combined to create one system:

- **HL 320.01** Heat pump
- **HL 320.07** Underfloor heating / geothermal energy absorber
- **HL 320.08** Fan heater / air heat exchanger

This combination allows fundamental experiments on the operating behaviour of the heat pump. For more detailed experiments a storage module (HL 320.05) and a thermal solar collector, for example, can be connected.

About the product:

Subject areas

Storage in energy systems

Renewable energy systems produce different amounts of energy depending on the available wind power or changing solar radiation. Coverage of the energy demand from evening to morning therefore requires suitable intermediate storage of the surplus energy from the day, if no constant supply of energy is possible, for example by a biogas plant.

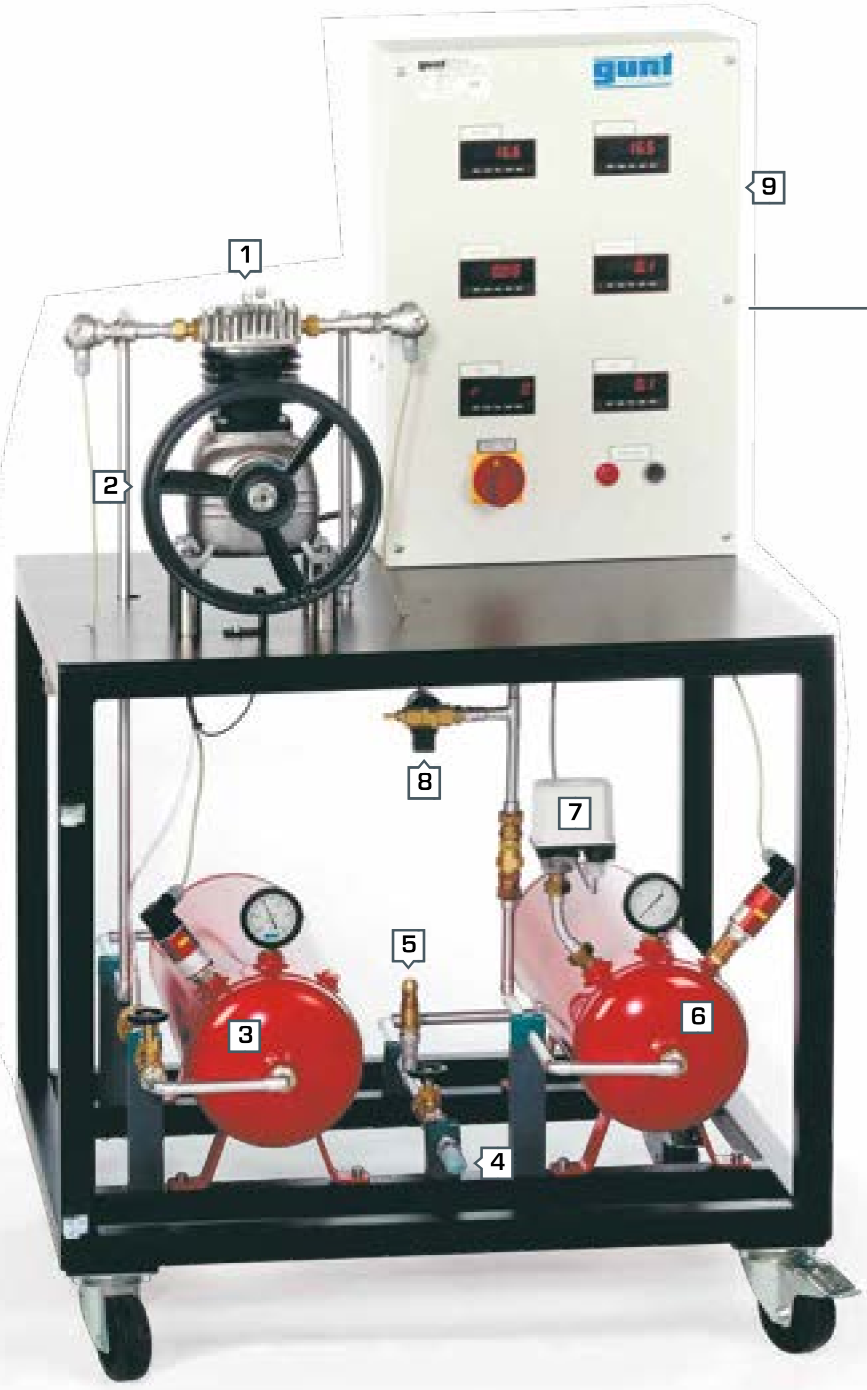
There are already various technologies available for storage, with differing efficiencies. The current state of the art includes pumped-storage power plants, which pump water to an elevated storage lake during periods of surplus electricity. If more energy is required again, the water is released to drive a generator by turbines.

Thermal storage systems are common in the field of refrigeration engineering, for example an ice store. The refrigeration system is operated at the optimal operating point and enables surplus refrigeration capacity during the night to cover the higher daytime demand with the ice store.

Subject areas	Products
Compressed air storage	**ET 513** Single-stage piston compressor
Water storage reservoir	**HM 143** Transient drainage processes in storage reservoirs
Thermal storage	**HL 320.05** Central storage module with controller **ET 420** Ice stores in refrigeration
Electrochemical storage	**ET 255** Use of photovoltaic modules with hybrid inverter **ET 220** Energy conversion in a wind power plant **ET 220.01** Wind power plant

ET 513
Single-stage piston compressor

To generate compressed air for industry and commerce, in which compressed air is used as an energy source, equipment known as compressed air generating systems are used. A central component of these systems is the compressor. It is responsible for increasing the air pressure by means of mechanical energy. Compressed air generating systems are used to drive machinery in mining, for pneumatic controllers in assembly plants or to inflate tyres at petrol stations. The ET 513 single-stage piston compressor, together with the HM 365 universal brake and drive unit, forms a complete compressed air generating system. The HM 365 drive unit drives the compressor via a V-belt. The compressor speed is set on the HM 365 unit. The air is sucked into the intake vessel, where it is settled before being compressed in the piston compressor. The compressed air is then pressurised in a pressure vessel and is available as a working medium.



1 compressor
2 V-belt pulley
3 intake vessel
4 blow-off valve with sound absorber
5 safety valve
6 pressure vessel
7 pressure switch
8 solenoid valve
9 switch cabinet with digital displays

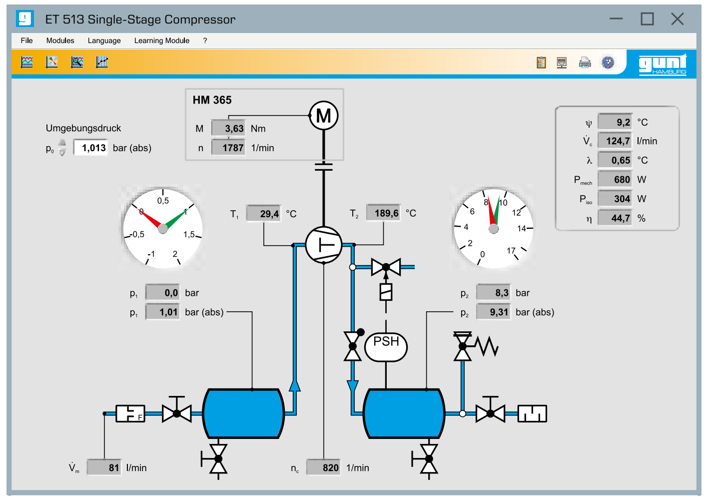
The software for ET 513 allows the most important variables to be captured and calculated

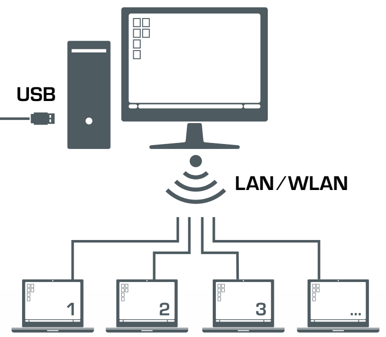
Captured:

- temperature
- pressure
  - upstream pressure
  - storage pressure
- volumetric flow rate
- speed
- torque

Calculated:

- volumetric flow rate
- volumetric efficiency
- mechanical power
- isothermal power
- efficiency





A pressure switch with solenoid valve and a safety valve complete the system. The intake volume flow is determined by a nozzle on the intake vessel. Sensors capture the pressures and temperatures upstream and downstream of the compressor. The measured values are displayed digitally and can simultaneously be transmitted via USB directly to a PC, where they can be analysed using the software included. Measurement of speed and torque is integrated into HM 365. In addition, the pressure in the tanks can be read off manometers.

In the same way as pumped-storage power plants, compressed air storage power stations with pressure vessels or caverns are used as short-term storage to cover peak loads. Load regulation of these types of power plant is especially beneficial. The time required to ramp up to full power is only around 10 minutes. Using ET 513 you can investigate a single-stage piston compressor and study the properties of a compressed air storage system during charging and discharge.

Combination:
Setup of a complete compressor system together with the HM 365 universal brake and drive unit.

Learning objectives

- measurement of
  - intake and delivery pressure
  - air flow rate
  - compressor speed
  - temperatures
- determining the volumetric efficiency
- determining the isothermal efficiency

About the product:

www

HM 143
Transient drainage processes in storage reservoirs

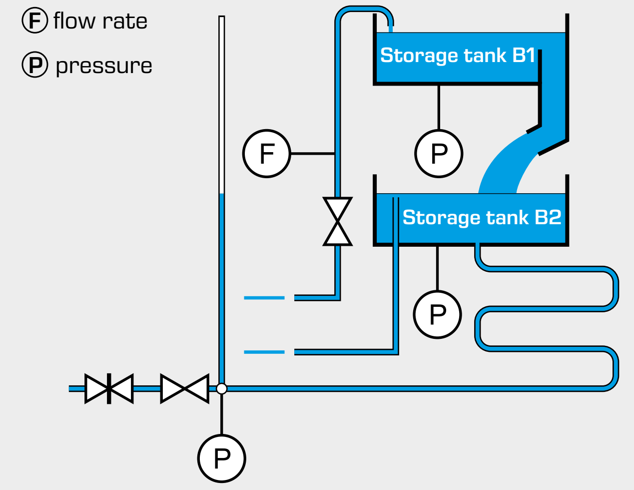
Transient drainage processes are taken into consideration when deciding on the dimensions of storage reservoirs. The processes occur for example, in rainwater retention basins and storage lakes. Storage lakes are used as permanent storage reservoirs in the water supply, in energy conversion, or in flood protection. The water rises before it is discharged over an overflow. The drainage processes from reservoirs occur through pipelines or tunnels. A surge chamber prevents water hammers in valves and fittings in the event of rapid changes in flow rate.

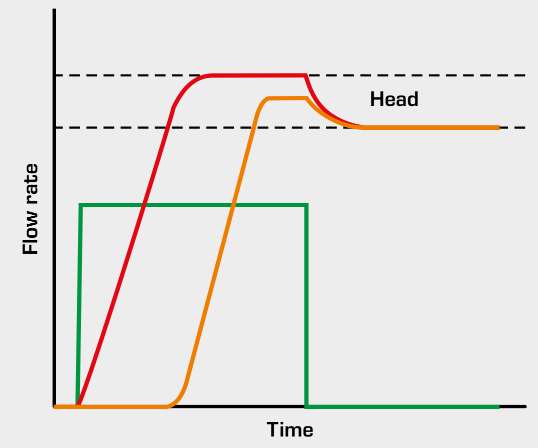
HM 143 is used to demonstrate transient drainage processes from storage reservoirs and how a surge chamber works. The trainer includes a basin with adjustable weir and a second, deeper-lying basin with overflow and drainage pipe. A surge chamber is installed in the drainage pipe. The "Storage lakes" experiment demonstrates the transient drainage processes in the case of long-term storage. In the "Surge chamber" experiment a water hammer is produced by rapidly closing a gate in the drainage pipe. The pendulum movement can be seen as oscillation of the water level in the surge chamber.

1 storage tank B1
2 storage tank B2
3 overflow pipe
4 flow meter
5 surge chamber
6 gate valve for generating water hammers
7 pressure sensor

"Storage lakes" experiment

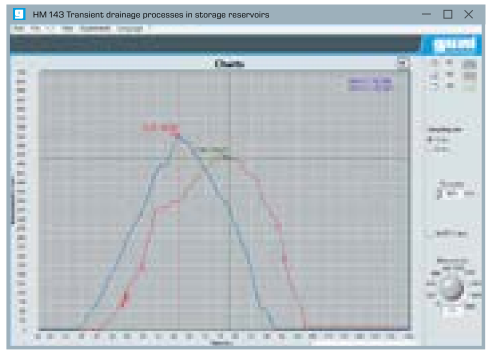
Storage lakes are used for long-term water storage. The first time a flood occurs, a river feeds the first storage lake. If the overflow of the lake is reached, the water continues to flow into the second, downstream storage lake. If this is also filled, the water continues to flow into the receiving water.





storage tank B1 fill level
storage tank B2 fill level
water supply

Software



The water levels in the basins and in the surge chamber are detected by pressure sensors and displayed using the GUNT software.

Learning objectives

- demonstrate transient drainage processes in two consecutive rainwater retention basins
- demonstrate transient drainage processes in two consecutive storage lakes
- record oscillations in the water level in a surge chamber after a water hammer
- record and represent water level fluctuations

About the product:

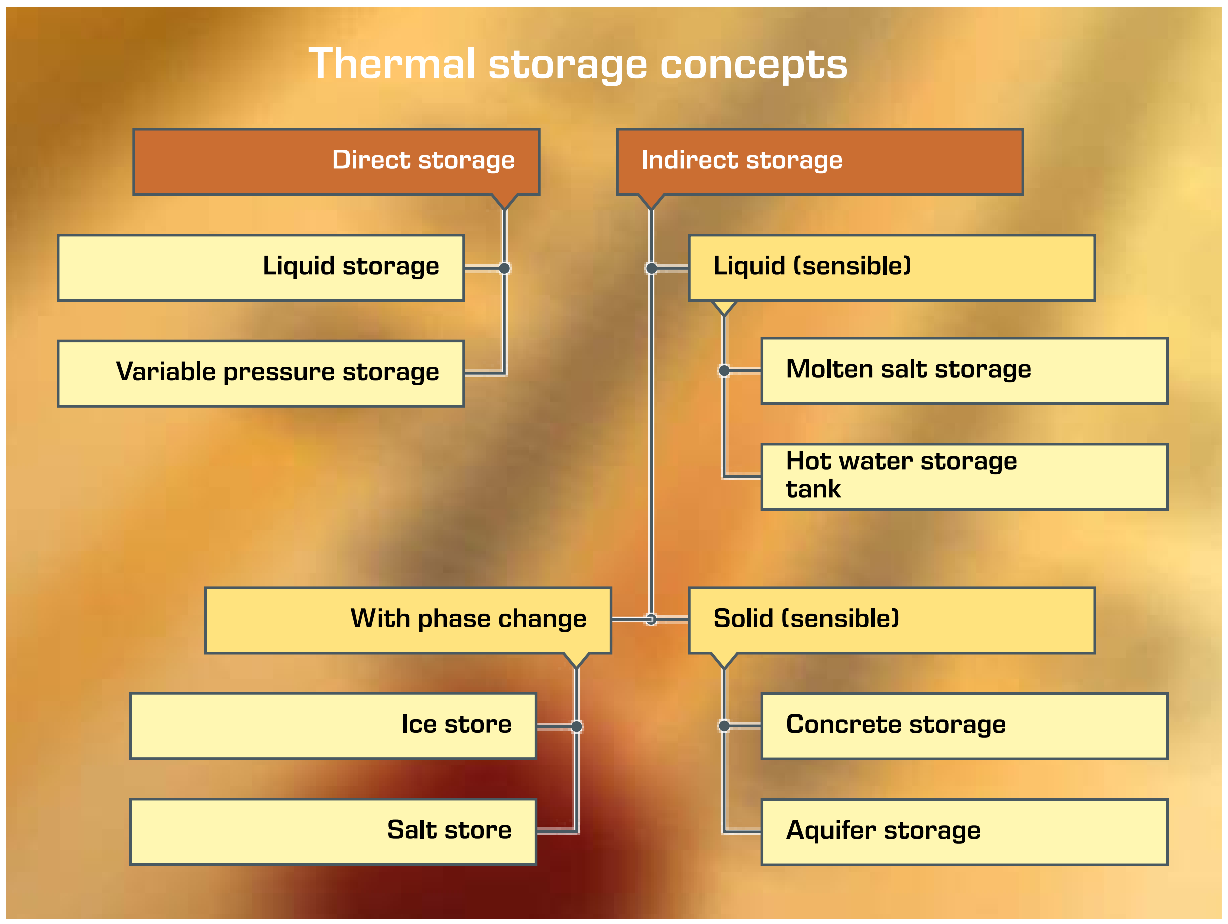
Basic knowledge
Thermal storage

Thermal storage is used for heat and cold. The storage and release of the heat and/or cold may be direct or indirect. Indirect storage can be divided by the aggregate states of the heat-storage medium.

Liquid and solid storage media are used in order to keep the required space low. A particularly high energy density is achieved in thermal storage systems with phase change, known as latent heat storage systems. The technical effort required is increased significantly for systems with a phase change. Another advantage is the isothermal loading and discharge temperature of a latent heat storage system, which is particularly relevant to process engineering.

Thermal storage systems with liquid and solid materials without phase change are also called sensible thermal storage systems. The concept is to heat and cool a material by means of a heat medium. This heat medium may be a hydraulic oil or brine for example, which allows the entire indirect storage process by being pumped around between source, consumer and storage.

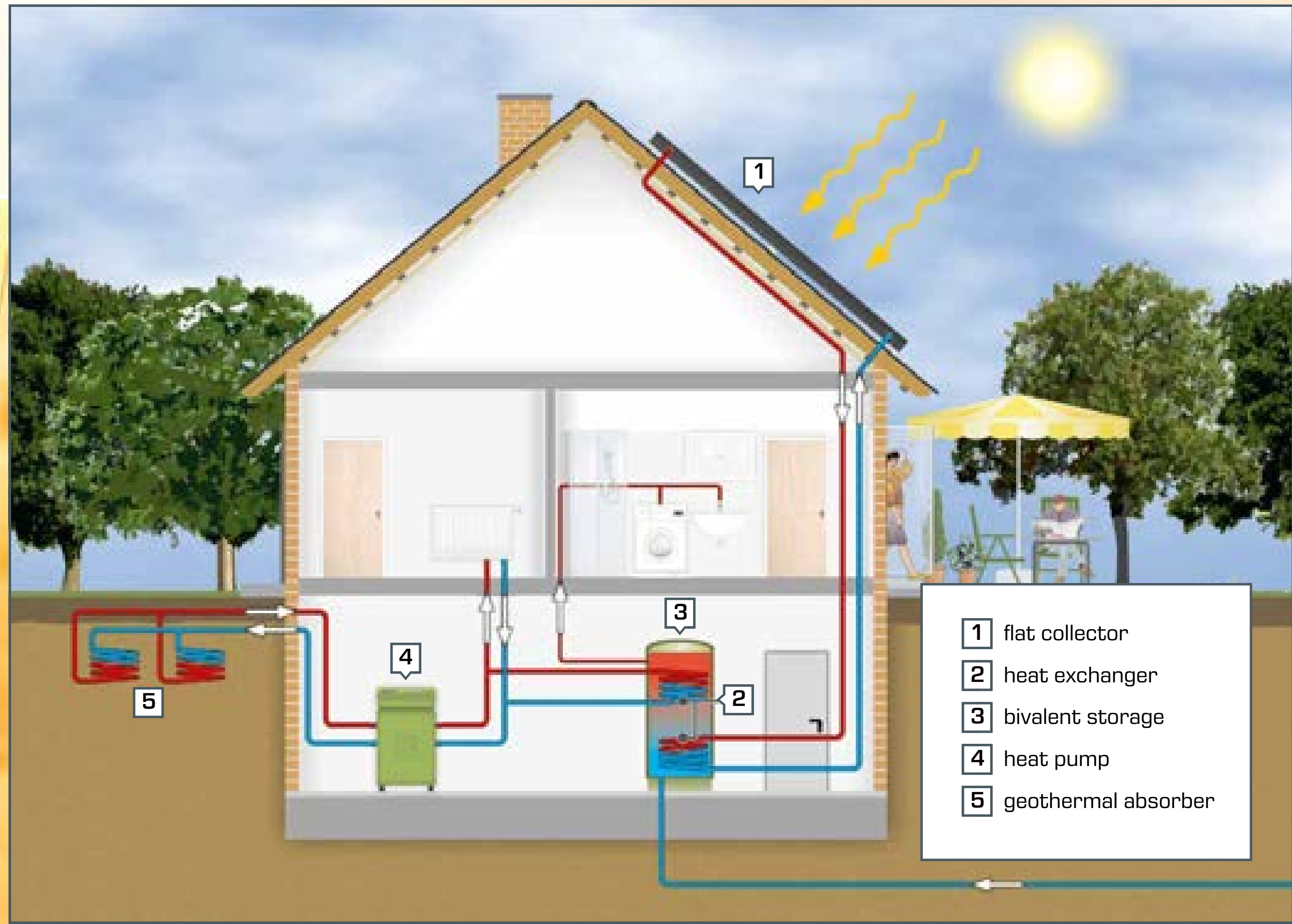
Different storage systems have to be used depending on the desired application. The selection criteria of a storage concept are the height and consistency of the required temperature level, the desired storage time, the losses and the technical effort with the associated costs under consideration of the load.



Example: Heat from renewable energies in the home

For modern residential buildings with good thermal insulation, in many cases doing away with a conventional heating system represents a genuine alternative. The combination of solar thermal collectors with a heat pump very often guarantees significant savings with reliable year-round supply.

The use of a thermal storage system allows particularly good use of the solar thermal energy. During the day, the storage system is loaded with surplus heat in order to heat the house in the evening and morning hours, or to provide hot water for everyday needs.

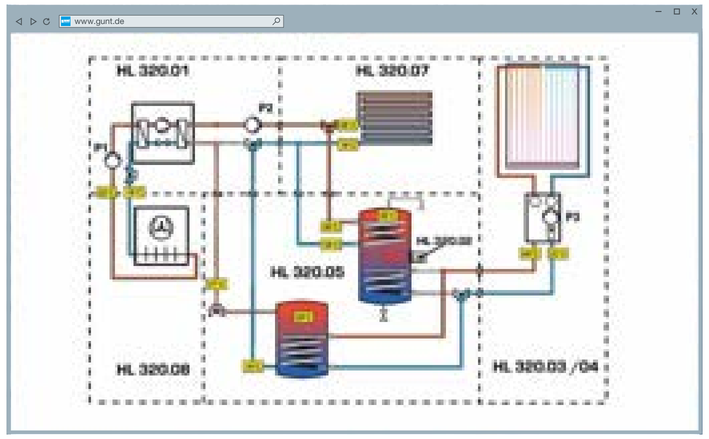


The illustration shows a system for room heating and domestic water heating. The flat collector **(1)** supports the heat generation, thus reducing the energy consumption of the brine heat pump **(4)**. Heat is supplied for the heat pump by the geothermal heat absorber **(5)**. The bivalent storage **(3)** enables the integration of different heat sources and creates a balance between heat supply and demand.

HL 320.05
Central storage module with controller

1 freely programmable heating controller with data logger
2 ports for CAN bus and network
3 process schematic
4 buffer storage
5 heat exchanger
6 3-way change-over valve
7 circulating pump
8 bivalent storage

The HL 320.05 storage module can be connected to the HL 320 modular system in a variety of ways through individually accessible inputs and outputs. Schematics and controller configurations are provided for five pre-defined combinations. First of all, the labelled pipe connections are established in preparation for the experiment. Then a controller connection and a data connection (CAN bus) are made to each module. The experiment can begin once the prepared controller configuration has been activated. Different PC programs are available for the controller and data logger, which allow individual adaptation of the configuration or the desired data logging options as required.



Visualisation in the web browser via LAN/WLAN

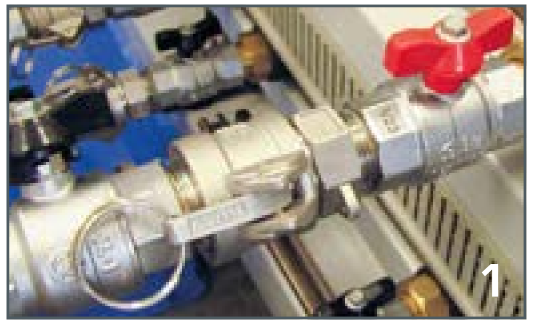
The controller is controlled and data acquired via a network module to a PC. The connection can be established via the integrated router by LAN or wirelessly by WLAN. Current system data can be represented in a schematic, for example. This representation can be retrieved with any current web browser.

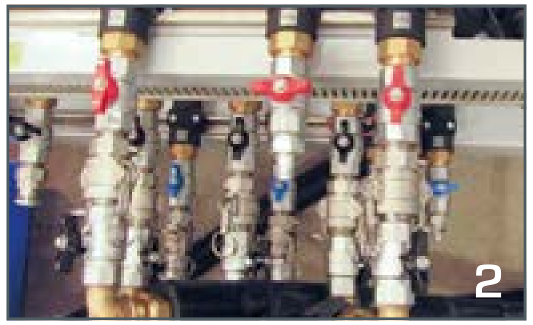
References

Many customers around the world are already successfully working with our HL 320 modular system. Below are a few selected references:

- University College London (UCL), United Kingdom
- ROC Kop van Noord-Holland, Netherlands
- Politechnika Slaska w Gliwicach, Poland
- Universidad de Huelva (UHU), Spain
- Montanuniversität Leoben, Austria
- Hochschule Ansbach, Germany
- Hochschule Wismar, Germany
- IUT Amiens, France

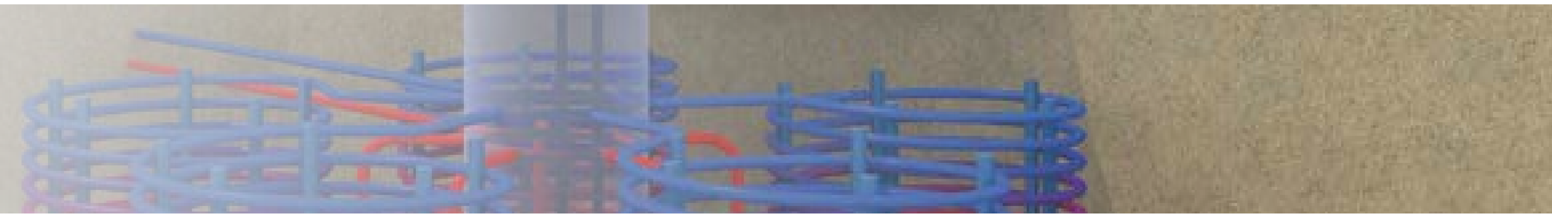
Preparation for the experiment





Secured cable connections (1, 2) allow safe modification of the cable routing. Current system data can be visualised both on the controller (3) and via a network connection (4).

About the product:



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.

About the product:

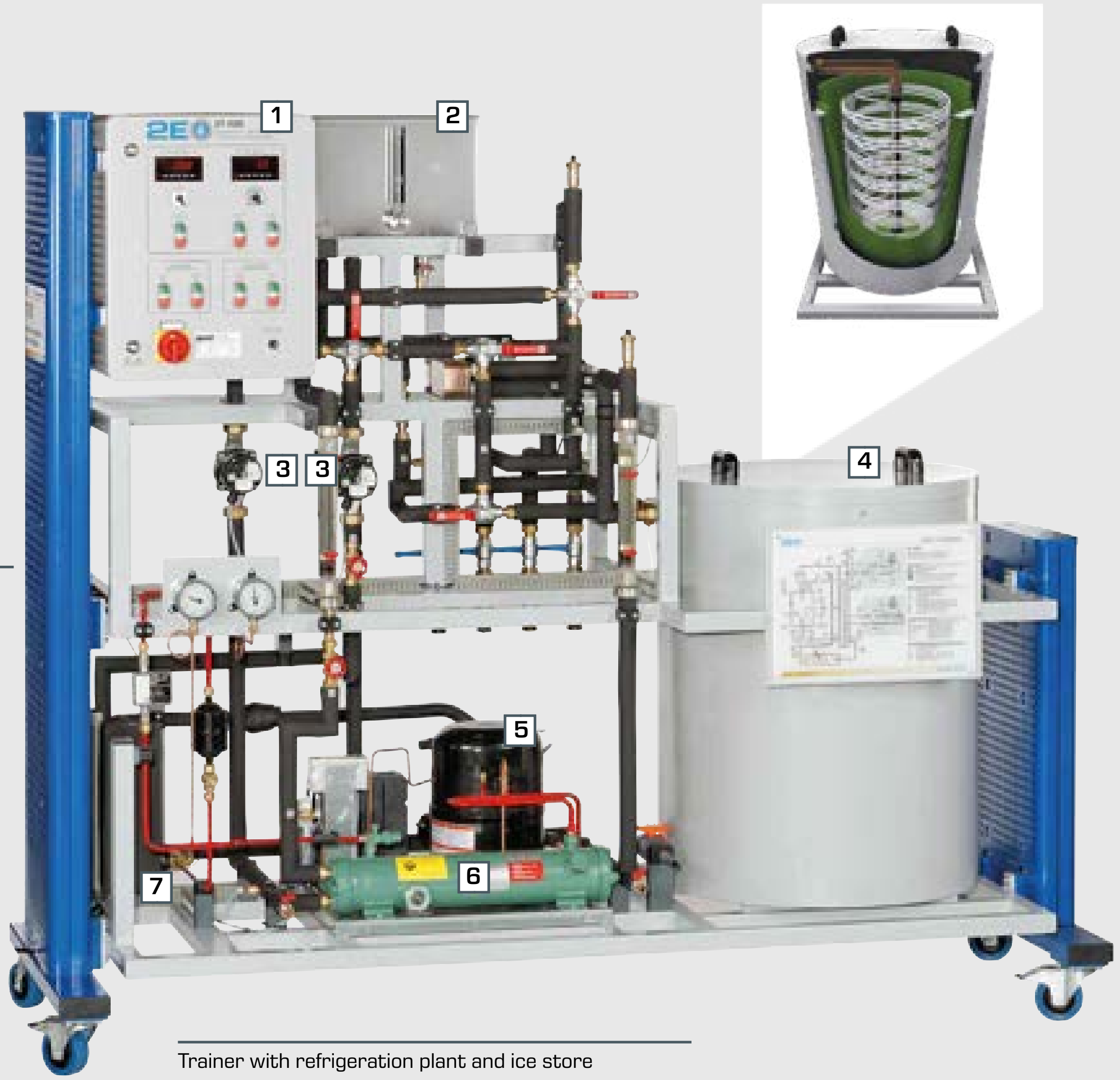
ET 420 offers a refrigeration plant with ice store, which can be operated entirely as required. The plant concept includes a dry cooling tower **9**, which represents the heat exchanger in the building to be supplied during the experiments and a wet cooling tower **8**, which represents the heat dissipation 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

Learning Objectives

- Learning Objectives
- 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



1 switch cabinet,
2 glycol storage tanks,
3 circulation pumps,
4 ice store,
5 refrigerant compressor,
6 refrigerant condenser,
7 refrigerant evaporator,
8 wet cooling tower,
9 dry cooling tower

Trainer with refrigeration plant and ice store

Wet cooling tower

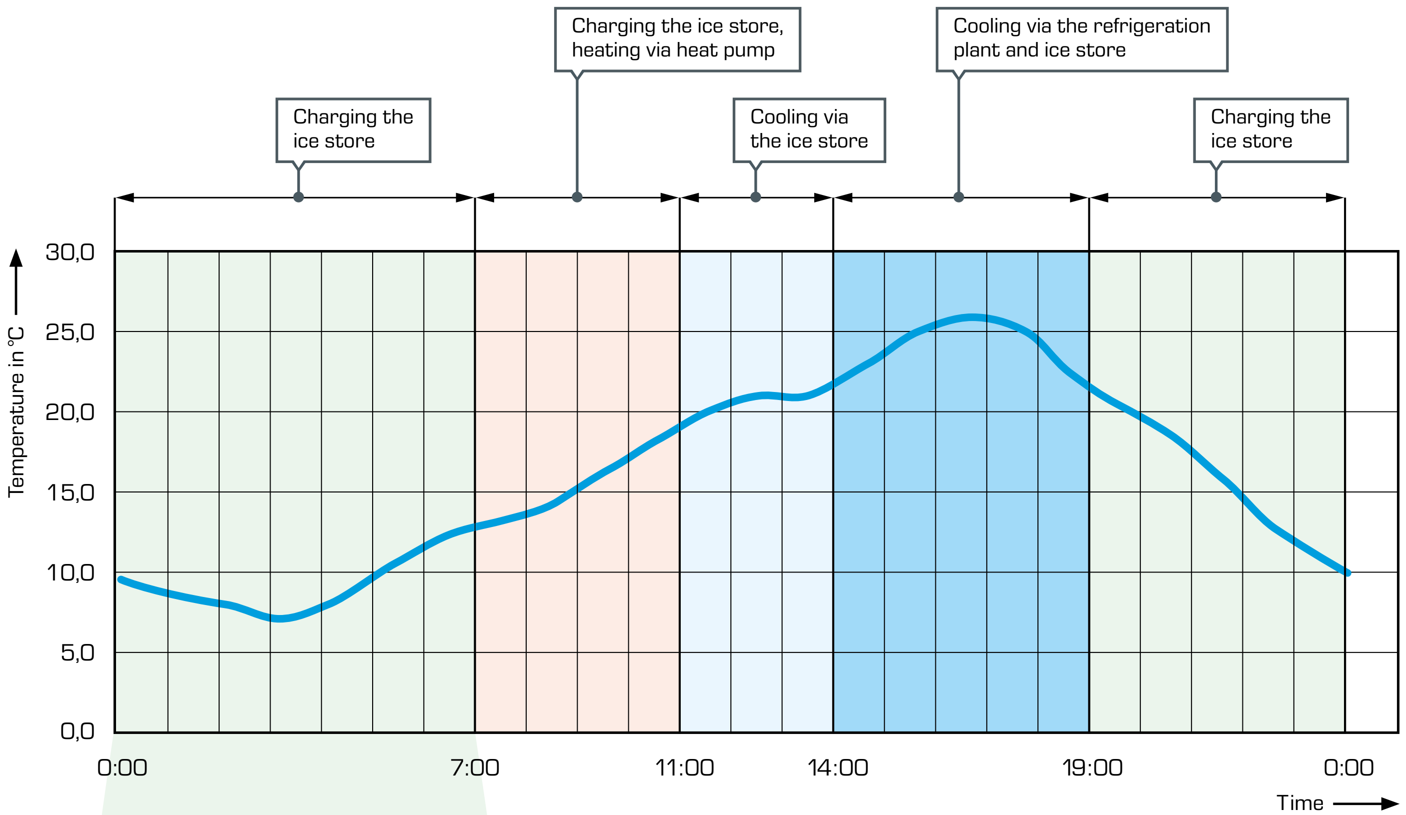
Dry cooling tower

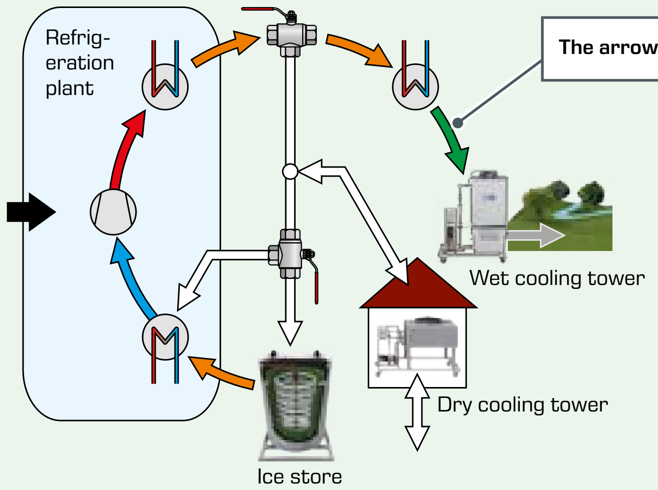
ET 420
Ice stores in refrigeration – Operating states

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.





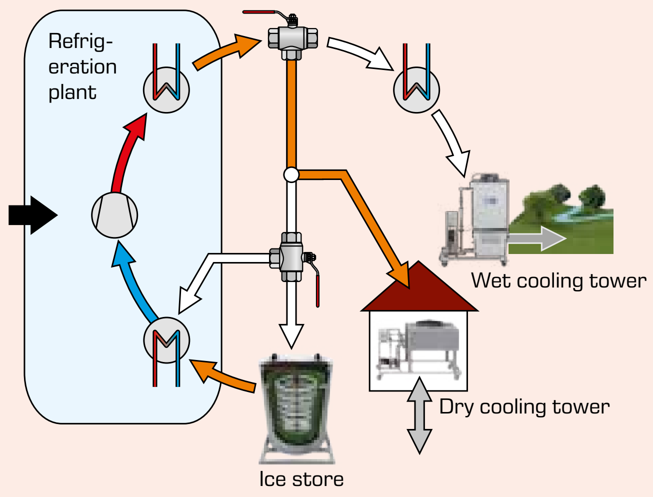
Charging the ice store

No persons are present between midnight and 7 am. There is no need for air conditioning, the ice store is charged.

To do this, the heat is dissipated from the ice store via the evaporator of the refrigerant circuit. (This heat dissipation causes the water in the ice store to freeze; the ice store is charged.)

The waste heat from the refrigerant circuit is dissipated to the environment via the wet cooling tower.

glycol, LP refrigerant, HP refrigerant, water, air,
electrical power, inactive process

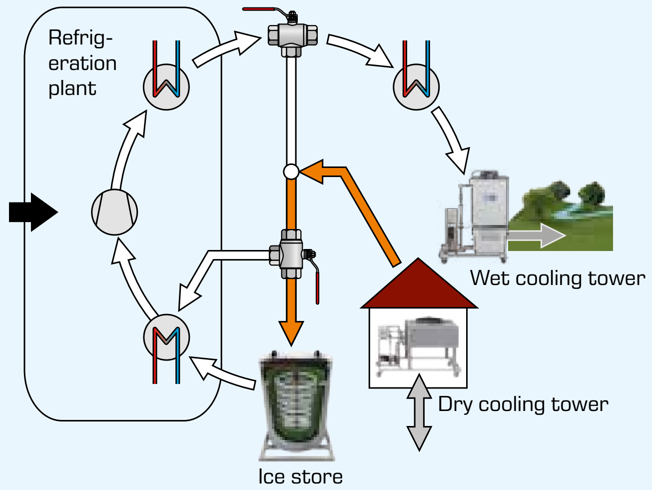


Charging the ice store and heating via waste heat

In the morning hours between 7 am and 11 am the temperature in the building is less than 20°C. There is a need for heating.

The heat generated during the ice store charging process can be used for heating. To do this, the heat is dissipated from the ice store via the evaporator of the refrigerant circuit. The ice store is charged by this heat dissipation.

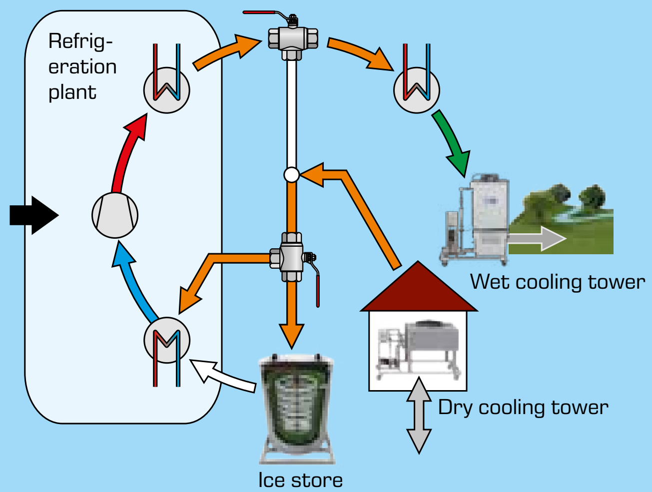
The usable waste heat from the refrigerant circuit is transferred to the dry cooling tower via the condenser, thus heating the building. The system operates in heat pump mode, while simultaneously using heat and cold.



Cooling via the ice store

In the period between 11 am and 2 pm, the temperatures in the building are between 20 and 23°C. There is a relatively low cooling demand, which can be covered via the ice store.

The ice in the ice store melts and absorbs heat from the dry cooling tower. This cools the dry cooling tower. This causes the building to cool down. The refrigeration plant does not need to be operated to dissipate the cooling load.



Cooling via the refrigeration plant and ice store

In the period between 2 pm and 7 pm, the temperatures in the building are between 23 and 27°C. This peak in the cooling load is covered by the combined cooling from ice store and refrigeration plant.

The heat is dissipated from the dry cooling tower and the building is cooled in this way. Part of the heat is transferred to the ice store, where the ice melts in the ice store and absorbs the heat from the dry cooling tower. In order to dissipate the particularly high cooling load, the refrigeration plant is also operated and transfers part of the heat from the dry cooling tower, via the evaporator.

The waste heat from the refrigerant circuit is dissipated to the environment via the wet cooling tower.

Charging the ice store

No persons are present in the building from 7 pm onwards. There is no demand for air conditioning.
During this time, the ice store is charged via the refrigeration plant.

Basic knowledge

Electrochemical storage

Electrochemical energy storage with accumulators

The usability of electrical power from large-scale renewable sources depends not least on the inclusion of efficient storage systems in order to balance the unavoidable fluctuations between supply and demand for electrical power. While electrochemical energy storage in the domain of small storage capacities has been in widespread use for mobile applications (e.g. car batteries), the development and integration of large storage systems is still in its infancy. Low-loss, efficient and economical accumulators with high number of cycles and long-term stability are in demand for typical applications.

Accumulator types

Extensive research and development activities have to be recognised in the field of electrochemical energy storage systems. New concepts are based, for example, on high-temperature batteries and on the separation of electrochemical converters and storage systems (fuel cell, redox flow battery).

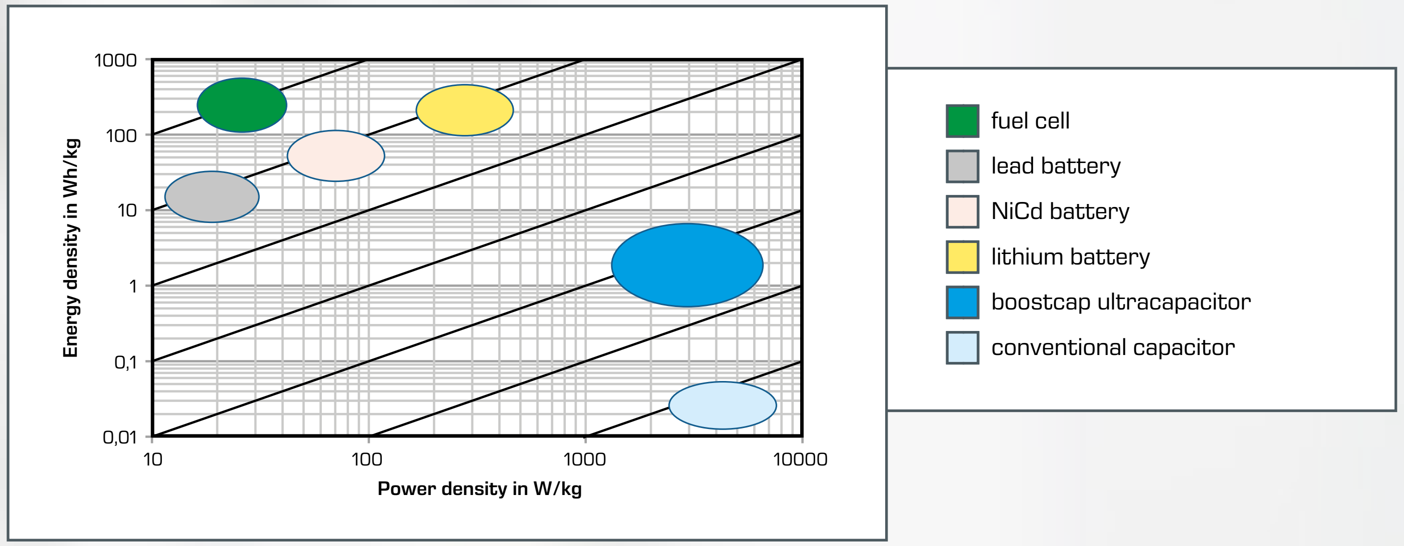
Each intended application results in different requirements for the properties of the accumulators. For example, while the specific weight of an accumulator is crucial in the area of electro-mobility, when looking at the integration of large electrochemical storage capacities in modern utility grids, it is cost-effectiveness and long-term stability that are important.

Listed below are the most important industrial electrochemical energy storage systems that are currently commercially significant:

- lead batteries (Pb, as wet or dry cell)
- nickel cadmium (NiCd, as wet or dry cell)
- nickel metal hydride (NiMH, as dry cell)
- lithium-ion ($LiMn_2O_4$, $LiCoO_2$ or $LiFePO_4$)

Energy density and power density

The specific energy density and specific power density are two important criteria for electrochemical storage systems. The Ragone chart, or Ragone plot, gives an overview of these properties for different types of storage. The power density is plotted on the horizontal axis in watts per kilogram. The vertical axis indicates the energy density in watt-hours per kilogram.

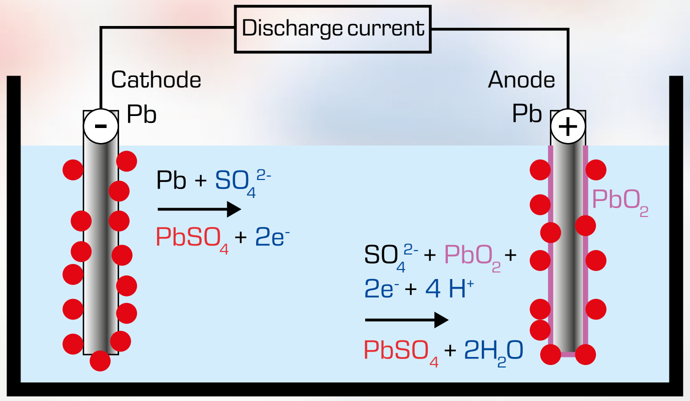


Energy storage in the lead accumulator

Chemical material conversions on the two electrodes are a fundamental process in the charging and discharging of an accumulator. While charging, a voltage applied externally causes an increase in chemical energy. During the discharge, the chemical energy is made available again as electrical energy.

This can be demonstrated in detail used the example of the lead accumulator. Besides the positive and negative lead electrodes (Pb), an important component is an electrolyte (H_2SO_4) that enables the underlying oxidation and reduction reactions.

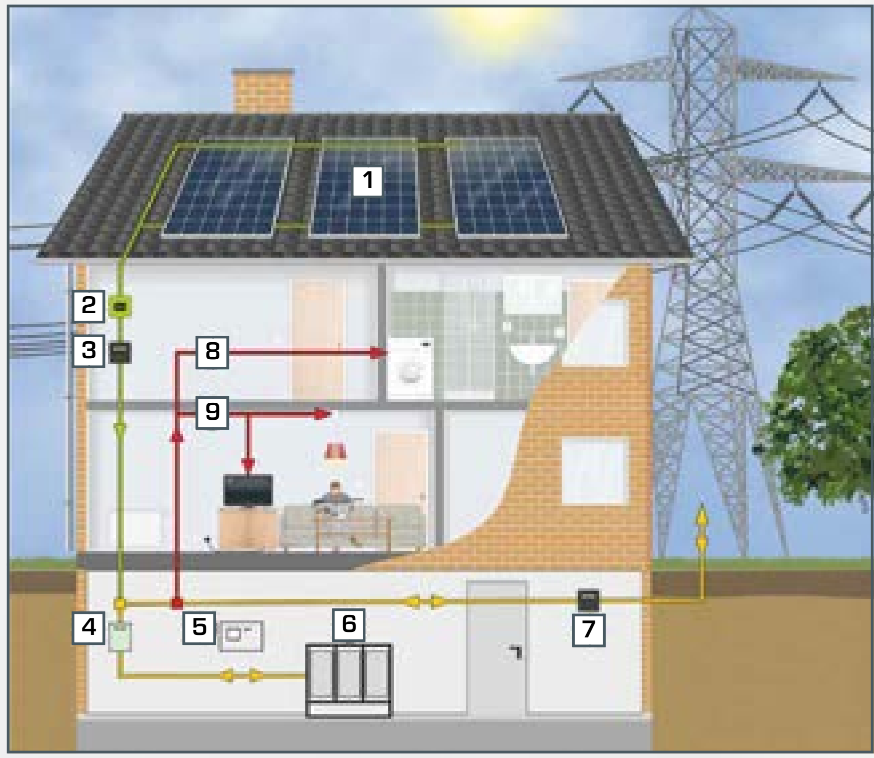
In the discharged state, a layer of lead sulphate ($PbSO_4$) is attached to both electrodes. In the charged state, the positive electrode is coated with lead oxide (PbO_2) while the negative electrode consists of pure (porous) lead.



The illustration shows the sub-reactions during discharge of a lead accumulator.

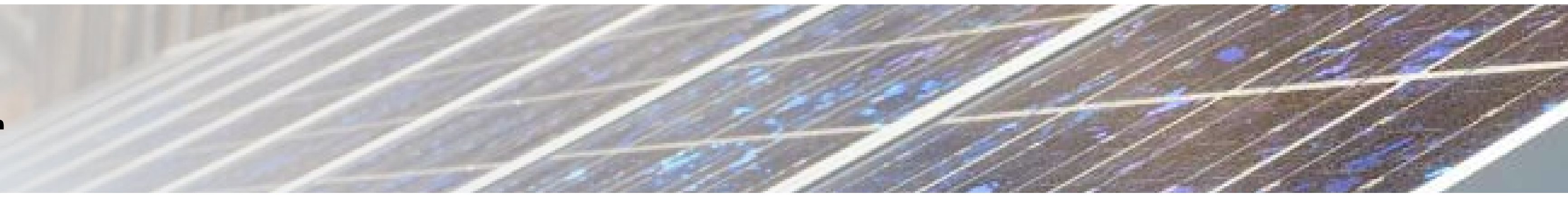
The overall reaction is:
$Pb + PbO_2 + 2\,H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$ + electrical energy

Example of a grid-connected photovoltaic installation with battery storage



Increasingly larger battery storage systems are also planned as part of grid-connected photovoltaic installations. Consequently it is possible to increase own consumption and to reduce the extraction of electricity from the grid.

1 photovoltaic modules
2 inverter
3 yield meter
4 battery charge controller
5 system control
6 battery storage
7 bi-directional energy meter
8 controlled consumer
9 non-controlled consumer



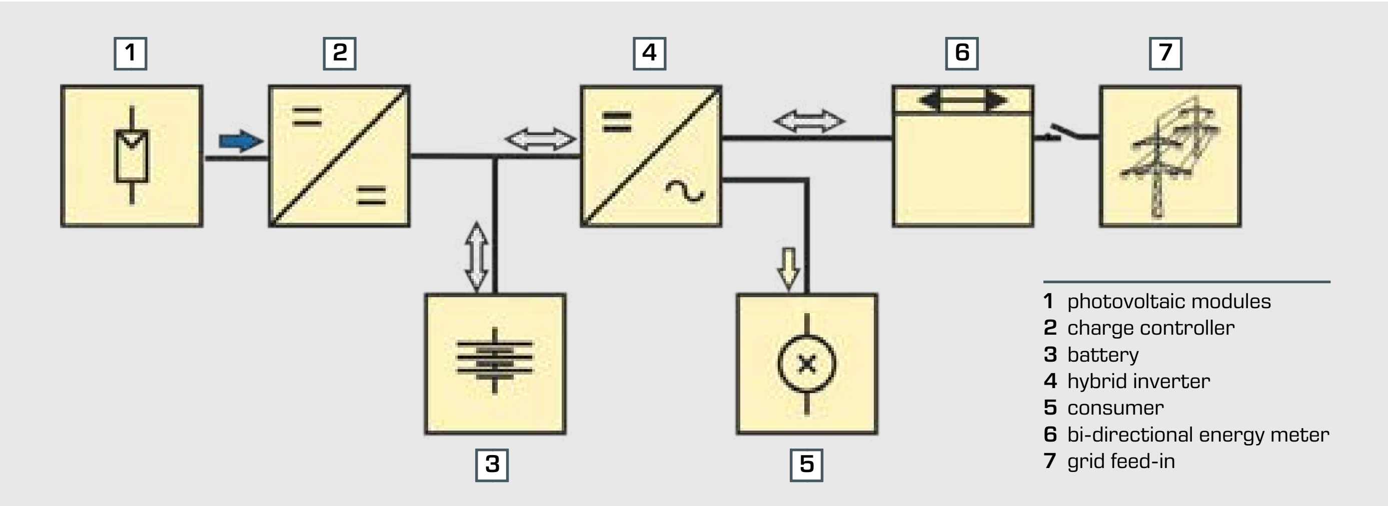
Overview

ET 255 Use of photovoltaic modules with hybrid inverter

Photovoltaic solar electricity can be used both for direct local consumption and for feeding into a public power grid. It is possible to use hybrid inverters that enable the local electricity demand to be covered both by the photovoltaic system and by the grid. Use of solar power for one's own purposes is now politically supported as a way of relieving the public grid and ensuring a more even supply.

The main components of a system for a typical single-family house are shown in the following simplified system diagram.

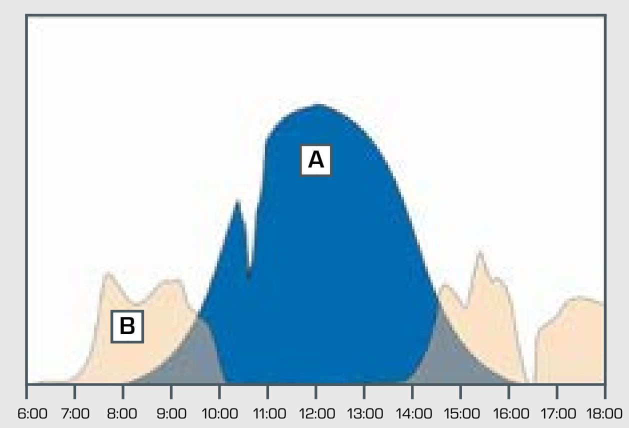
System components for solar power utilisation



Solar power and electricity demand in a residential building

Typical measurement data for the generated solar electricity and the electricity demand of a residential building throughout a day show the need for stored electricity from batteries. Only batteries make it possible to cover the demand in the morning and evening hours.

For orientation, the energy flows originating from the photovoltaic modules and the battery are colour-coded and can also be assigned in the system diagram.



A electricity generation by photovoltaic modules
B coverage of electricity demand by batteries

For regions with uncertain grid availability, many hybrid inverters offer an emergency power function to ensure local power supply in the event of grid outages. At the same time, any feed-in from the photovoltaic system into the public grid is interrupted when the grid is down.

Experiments with photovoltaic simulator and modern system components

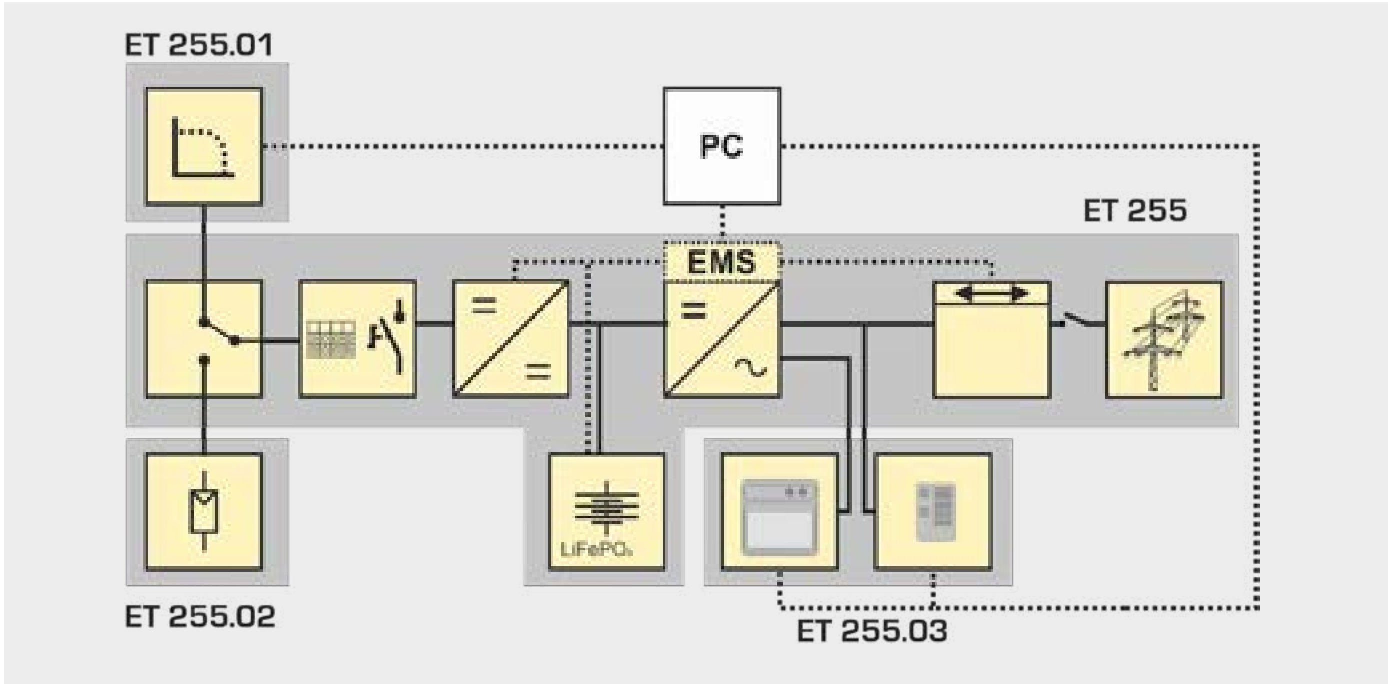
When creating a real-world photovoltaic system, consideration must be given to the regional specifications and safety requirements of the respective grid operator, especially where the system is connected to the grid.

To enable more demanding experiments with modern components from photovoltaic practice, we offer a revised system of experiment modules designed to complement each other. The central module ET 255 contains a hybrid inverter, a lithium iron phosphate battery with charge controller and a bi-directional electricity meter. An Energy Management System (**EMS**) records the energy flows and controls individual components.

Design of the ET 255 equipment series

The ET 255 device can be supplied by the photovoltaic simulator (ET 255.01) or real photovoltaic modules (ET 255.02). The EMS can be used to control consumers with different priorities, which are included on the ET 255.03 experiment module.

The GUNT software on an external PC is used for parametrisation and operation of the photovoltaic simulator and for recording and displaying the measured values. It is also possible to control experiment sequences with defined consumption profiles.



Design of the equipment series ET 255

ET 255
Use of photovoltaic modules with hybrid inverter

ET 255.01
Photovoltaic simulator

ET 255.02
Photovoltaic modules

ET 255.03
Consumers for photovoltaic systems

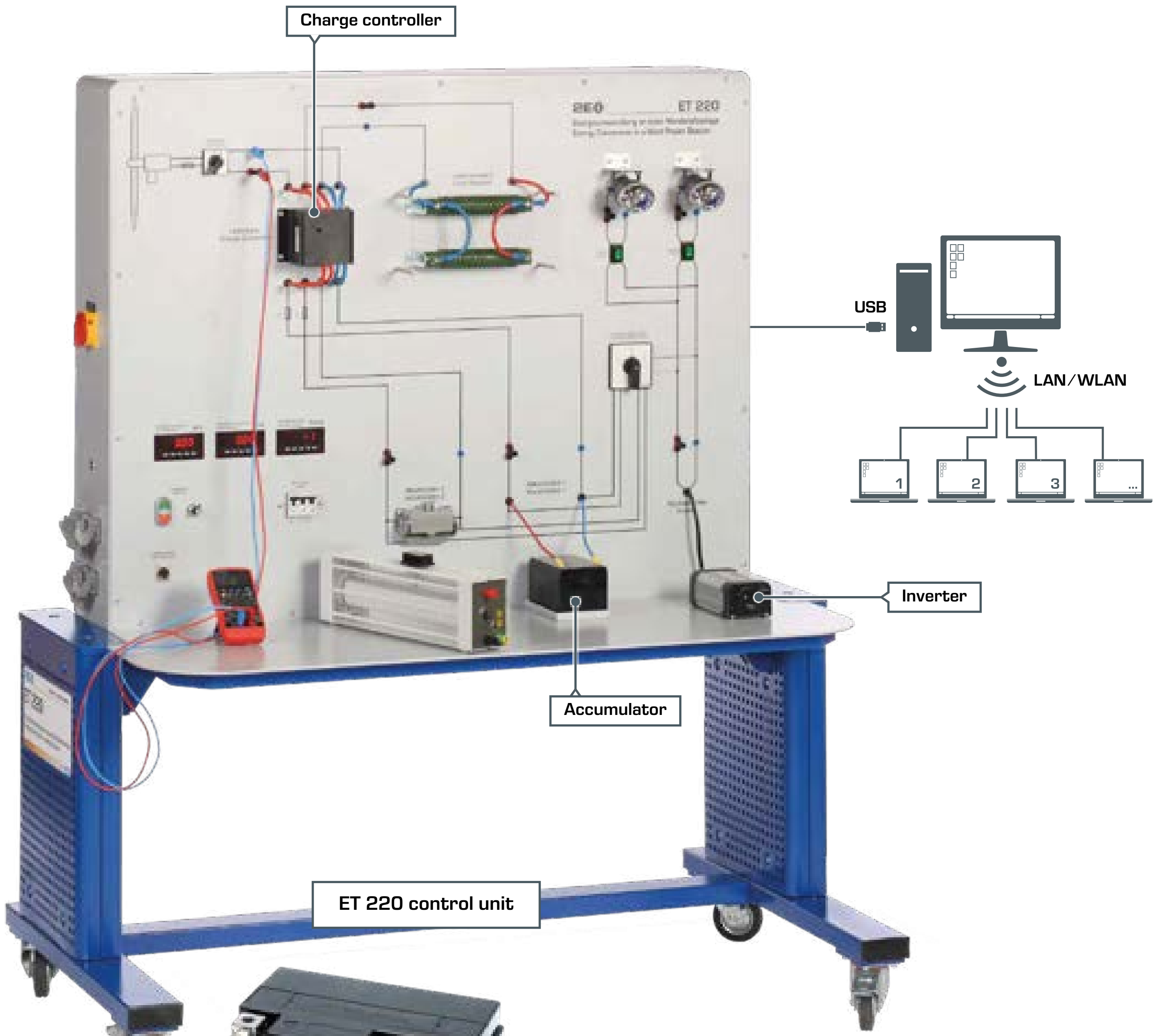
Learning objectives

- modern photovoltaic use with own-consumption and storage
- power optimisation through Maximum Power Point Tracking
- efficiency and dynamic behaviour of system components
- Energy Management Systems (EMS)
- simulation of diurnal variations (meteorological data and consumption profiles)
- system operation during grid outage

ET 220
Energy conversion in a wind power plant

The ET 220 device allows you to teach the individual stages from conversion of wind flow into rotational energy through to storing the electrical energy in accumulators, in clear and easy-to-understand steps.

The ET 220 wind tunnel or the ET 220.01 wind turbine can be connected to the ET 220 control unit for installation outdoors.

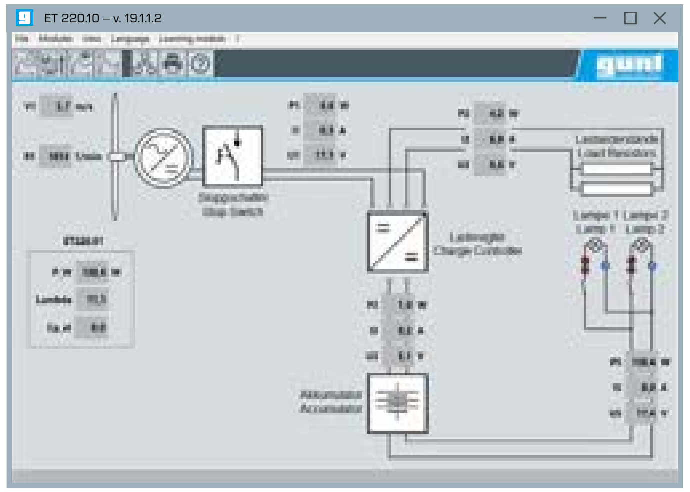


The ET 220.01 device comes with an accumulator of suitable capacity, which can be charged and discharged via the charge controller of the separate control unit.

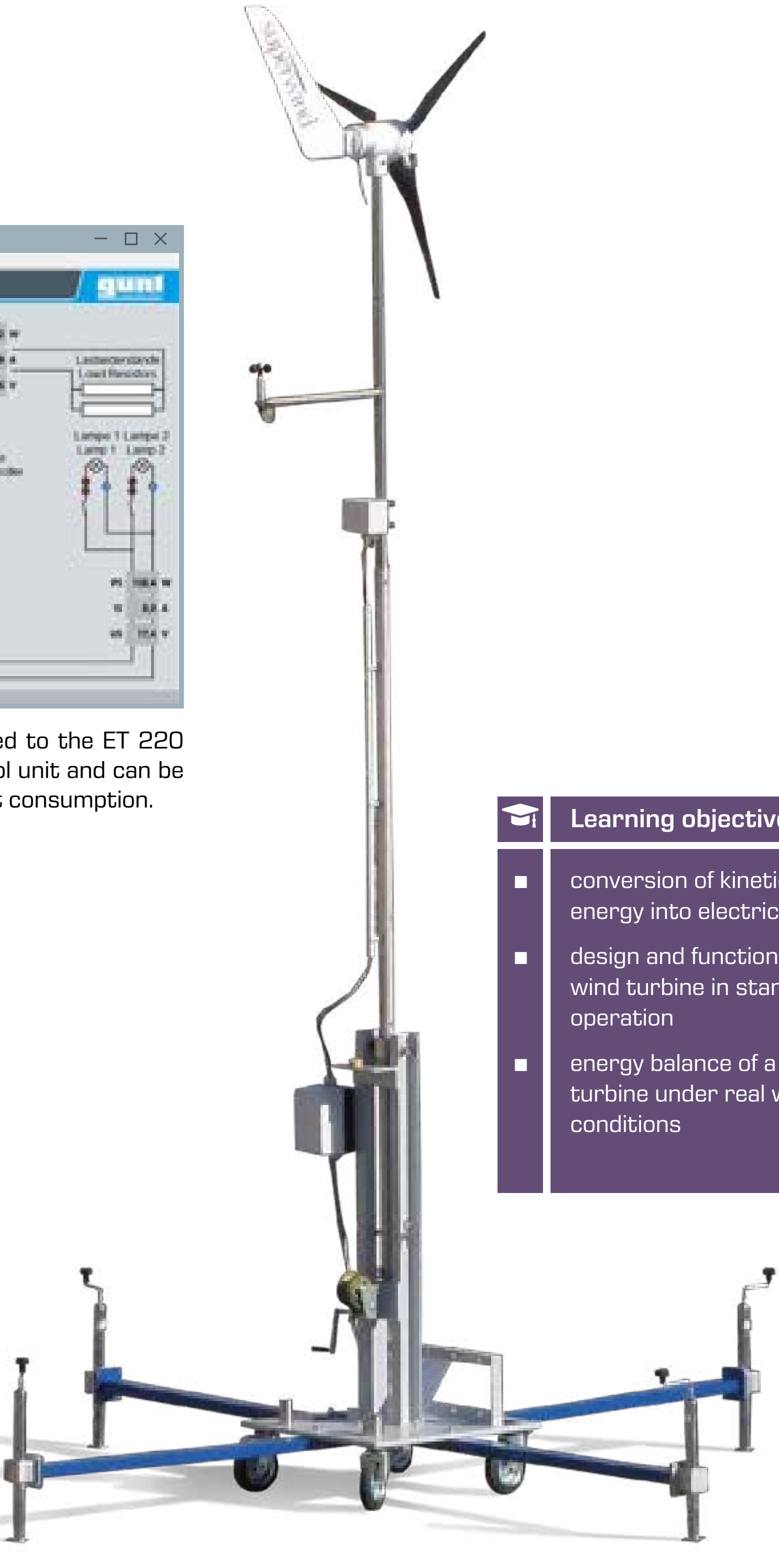
About the product:

ET 220.01
Wind power plant

The yield of a wind turbine depends on the prevailing wind Wind velocities and the usability of the electricity generated. In order to study the operation of a wind turbine under real weather conditions, ET 220.01 has been developed for the ET 220 trainer.



The generated electrical energy is transferred to the ET 220 control unit or the separate ET 220.10 control unit and can be used to charge the accumulators or for direct consumption.



Learning objectives

- conversion of kinetic wind energy into electrical energy
- design and function of a wind turbine in stand-alone operation
- energy balance of a wind turbine under real wind conditions

About the product:

7 Energy efficiency in buildings

Basic knowledge

Energy efficiency in building services engineering

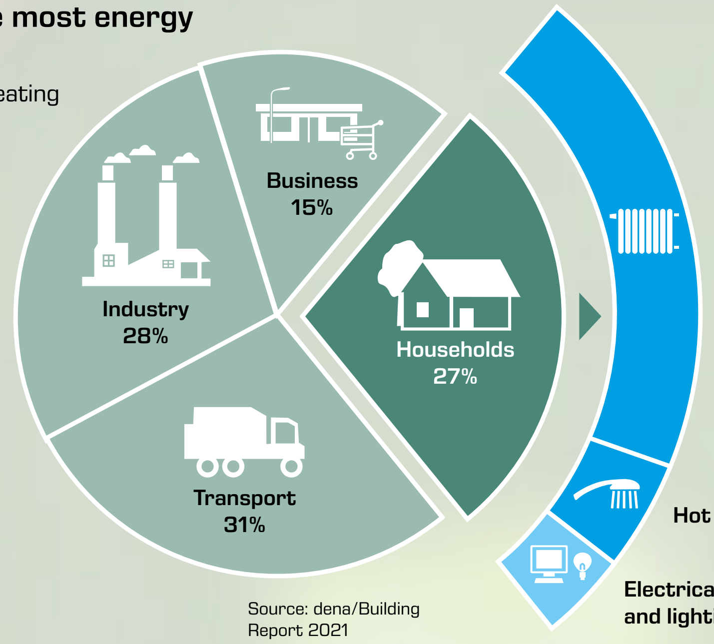
Climate protection through increased energy efficiency in building services engineering

The efforts to encourage climate protection through the use of renewable energies can only be successful if, at the same time, all measures to increase energy efficiency are consistently used. Since the main share of globally consumed energy relates to the supply of buildings, this area offers enormous potential to deliver a significant contribution to reducing the use of primary energy through energy efficiency increases.

Measures that result in a building using energy more efficiently involve the nearly all areas of modern building services engineering. In addition to consumption by electronic equipment, lighting and water heating, these include in particular the consumption by heating, ventilation and air conditioning. As can be seen using the example of Germany from the diagram, the area of heat supply for buildings represents a major energy consumer.

Who consumes the most energy in Germany?

Energy consumption of heating often underestimated



Source: dena/Building Report 2021 (reference year 2020)

Based on our Energy curriculum, we offer you teaching equipment from the following subject areas to allow you to focus on energy efficiency in building services engineering:

Heat supply and air conditioning	Inclusion of renewable energies	Energy efficiency in business and industry

We believe that knowledge in these subject areas is indispensable for engineering students and professionals in the field of building services engineering, in order to create sustainable and energy efficient buildings and to transform existing buildings to be more energy efficient.

Structural and technical techniques for resource conservation

Structural and technical measures are needed in order to reduce the primary energy demand of buildings. Heat insulation and the use of transparent façades, for example, are some of the possible structural measures. This area is becoming increasingly important in the training of architects, urban planners and construction engineers.

Efficient components and systems, controlled by means of modern building services engineering, are at the forefront of technical measures for heating optimisation. Taking into account modern concepts for combined heat and power, distributed power grids and energy storage, it is possible to achieve energy production and distribution that is optimally adapted to demand.

Standards for energy efficiency in building services engineering

Directives have been passed by the European Parliament on energy efficiency in buildings. Below is an excerpt from Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings:

> [...] (3) Buildings account for 40% of total energy consumption in the Union. The sector is expanding, which is bound to increase its energy consumption. Therefore, reduction of energy consumption and the use of energy from renewable sources in the buildings sector constitute important measures needed to reduce the Union's energy dependency and greenhouse gas emissions. Together with an increased use of energy from renewable sources, measures taken to reduce energy consumption in the Union would allow the Union to comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC). [...]

To implement the EU Directive in Germany, the energy efficiency of buildings is categorised in the energy efficiency classes A+ to H in an energy certificate in accordance with the German Energy Efficiency Act. Buildings are classified according to the specific primary and final energy demand. For highly efficient passive houses, the annual energy demand is well below 50 kWh/m².

Subject areas

Heat supply and air conditioning

Significant savings can often be achieved just through simple measures and the more conscious use of energy. In the field of building heating, the necessary energy can in some cases be reduced by more than 80% through a combination of measures. These include improved insulation materials, optimised hydronic balancing of radiators and the use of more modern, controlled circulating pumps.

Since in warmer regions of the world, and due to generally rising average temperatures, the energy consumption required to cool buildings is becoming an increasingly important factors, our building services engineering teaching equipment also covers this area. In order to provide you with the best possible support in your efforts to teach the fundamentals of engineering in an appealing way, special attention has been paid to intuitive operability of the experiments, especially in our completely revised WL 110 equipment series.

Subject areas	Products
Thermal insulation and heat recovery	**WL 376** Thermal conductivity of building materials **WL 110** Experiments on the fundamentals of heat transfer
Efficient heating technology	**HL 305** Hydronic balancing of radiators **HM 283** Experiments with a centrifugal pump **HL 630** Efficiency in heating technology
Air conditioning	**WL 110.05** Finned tube heat exchanger **ET 630** Split system air conditioner

Basic knowledge

Thermal insulation and heat recovery

Improving the thermal insulation of walls and roofs is only one possible measure towards energy savings in buildings. An economic assessment requires an analysis of the savings to be expected through reduced heat losses in each individual case.

A lack of insulation in old buildings can lead to heat leakages. These problem areas can be detected by means of sensitive infrared cameras based on the emitted heat radiation. It is not just the heat conduction of materials, but also how they are fabricated that determine the effectiveness of insulation in walls and heat transfer conduits.

Heat transport

Temperature differences result in the transport of thermal energy. Transport takes place in the direction of the lower temperature. There are three different heat transport processes:

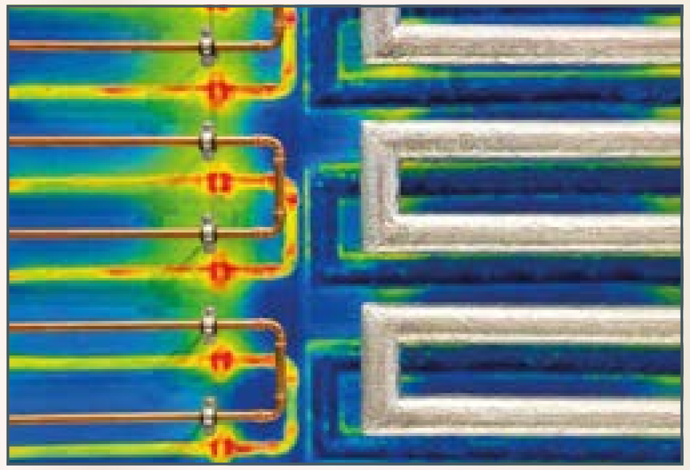
- heat conduction
- convection
- heat radiation

Either allowing heat transport with as little obstruction as possible, or suppressing heat transport, are crucial in providing an efficient heat supply for buildings.

If a heat transfer medium is used for transporting heat (forced convection), then an unimpeded intake at the heat source and an unimpeded heat dissipation at the place of use are the ideal. However, heat dissipation should be suppressed as much as possible during the actual transport.

In the case of heating for rooms, heat dissipation out of the room being used and into adjacent areas should be prevented. Besides the heat transfer surface, the heat conduction properties of the heat transfer material are a key factor for heat transfer that is as unobstructed as possible. Heat conduction is typically expressed as a coefficient of thermal conductivity.

In contrast, construction materials for suppressing heat dissipation are usually described by the overall heat transfer coefficient. This also includes the thermal resistance of the adjacent air layers.



The insulation of heat transfer conduits also provides a significant contribution to energy efficiency.

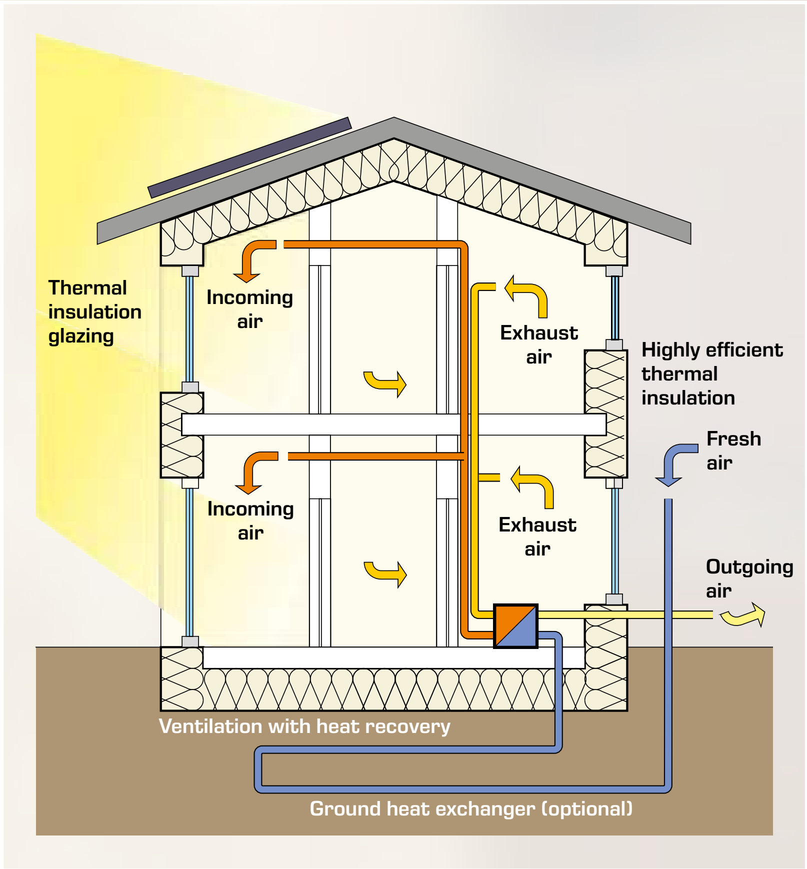
Heat recovery

Processes in which the residual heat of a mass flow is used after its primary use are referred to as heat recovery. The heat gained in this way would otherwise be wasted without heat recovery.

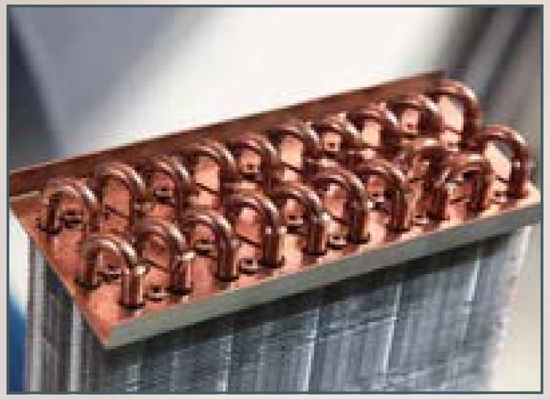
The greatest energy savings potential from heat recovery comes from heating and ventilation systems. In addition, heat recovery systems are in principle conceivable in many other supply and disposal processes in building services engineering.

Heat demand of a passive house

In buildings known as passive houses the heat demand is reduced by up to 90% by thermal insulation and heat recovery, compared to typical houses of existing building stock. Highly effective insulating materials and triple glazing are used in the passive house. One particularly efficient measure is heat recovery from the ventilation system's exhaust air.



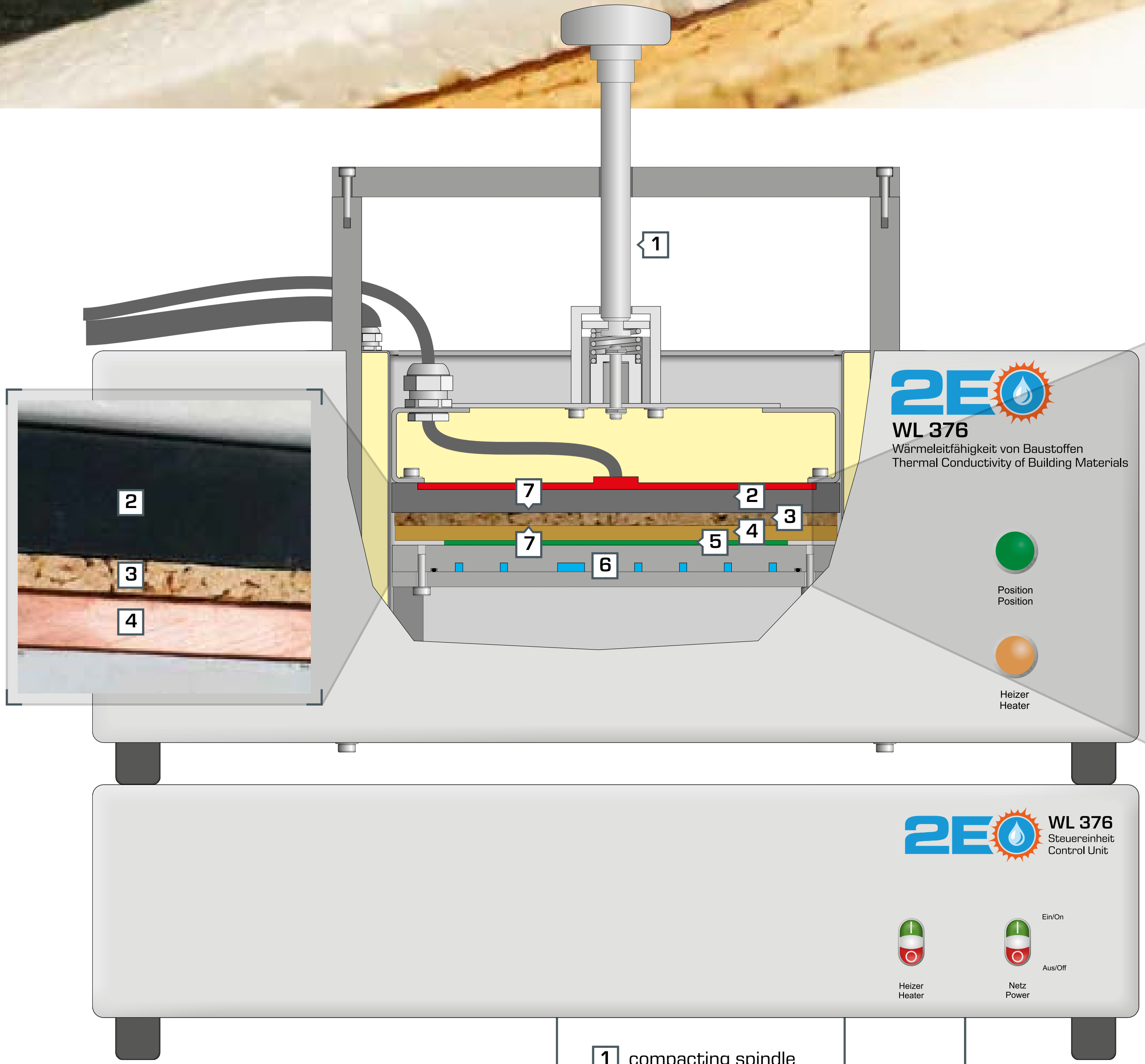
In larger buildings in particular, the optimisation of ventilation technology often results in huge savings opportunities in the year-round energy demand for heating and air conditioning.



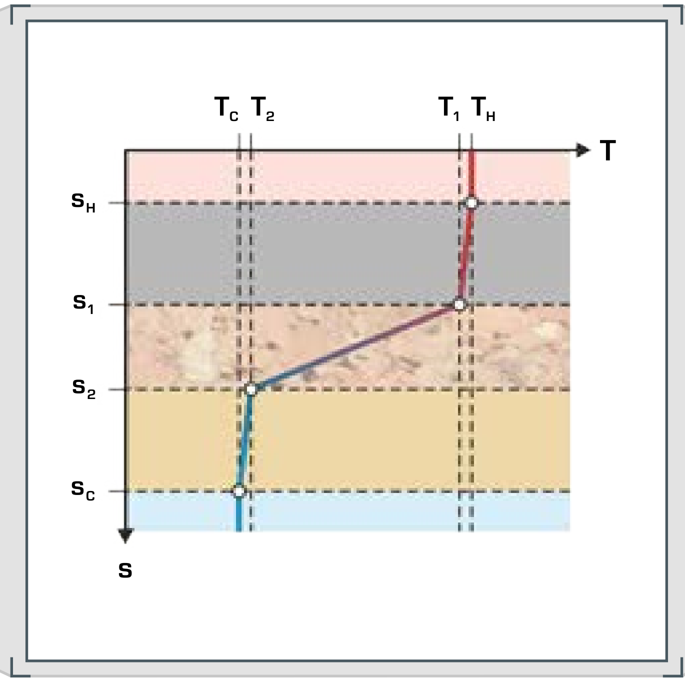
In so-called circuit compound systems, two separate air-to-water heat exchangers are employed in order to use the heat contained in the exhaust air to heat the incoming air.

WL 376
Thermal conductivity of building materials

This experimental unit allows you to conduct experiments on steady-state heat conduction in non-metallic materials such as polystyrene, PMMA, cork or plaster according to DIN 52612. You can place flat samples between a hot plate and a water-cooled plate and apply reproducible clamping forces with the compacting spindle and adjust the heat contacts. The special heat flux sensor is used to measure the actual heat flux and to regulate the temperatures of the hot and cold plate by means of the integrated software controller.



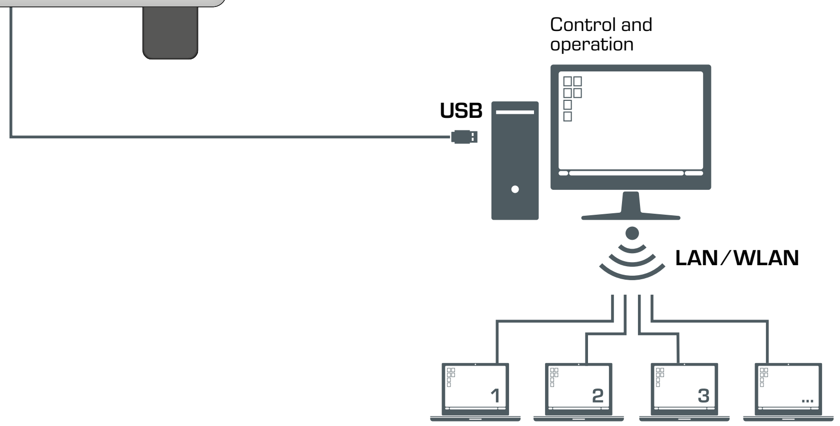
1 compacting spindle
2 heating plate
3 sample
4 clamping plate
5 heat flux sensor
6 cooling plate
7 temperature sensor



The analysis of the experimental data clearly shows the temperature gradients across the cork material. The hot plate, clamping plate and cold plate only show very small temperature gradients due to the much higher thermal conductivity of copper.

Software

The GUNT software for WL 376 detects the measurement data via USB and offers extensive options for analysing and displaying the results.



About the product:

Learning objectives

- determining the thermal conductivity λ of different materials
- determining the thermal resistance
- thermal conductivity λ in serial connection of several samples (up to a thickness of 50 mm)

Overview

WL 110 equipment series – Experiments on the fundamentals of heat transfer

WL 110
Heat exchanger supply unit

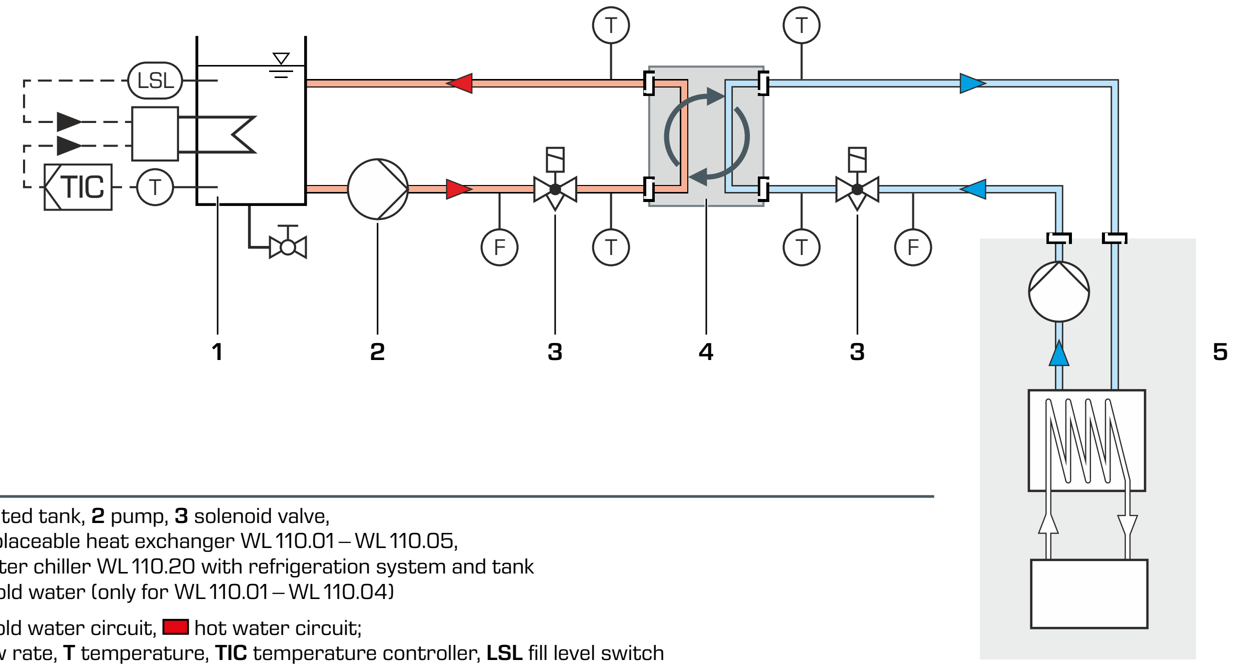
The supply unit produces hot water. All measured values are displayed on the unit's touch screen and can be transmitted via a LAN / WLAN connection.

WL 110.20
Water chiller

The water chiller can be used to operate the heat exchangers under suitable experimental conditions.

- automatic identification of accessories via RFID technology
- energy and water-saving technology, space-saving design

RFID



1 heated tank, **2** pump, **3** solenoid valve,
4 replaceable heat exchanger WL 110.01 – WL 110.05,
5 water chiller WL 110.20 with refrigeration system and tank for cold water (only for WL 110.01 – WL 110.04)

cold water circuit, hot water circuit;
F flow rate, **T** temperature, **TIC** temperature controller, **LSL** fill level switch

About the product:

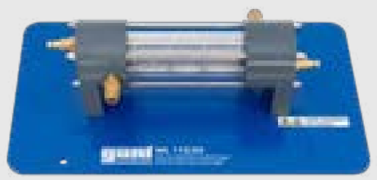
www

WL 110.01
Tubular heat exchanger

- simple design
- transparent outer tube offers visible flow space
- parallel flow and counterflow operation possible

WL 110.02
Plate heat exchanger

- compact design
- parallel flow and counterflow operation possible

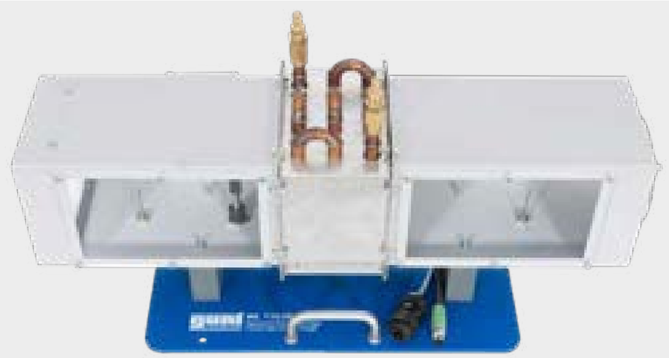


WL 110.03
Shell & tube heat exchanger

- transparent jacket pipe
- media flow in cross parallel flow and cross counterflow

WL 110.04
Stirred tank with double jacket and coil

- heating using jacket or coiled tube
- stirrer for improved mixing of medium



WL 110.05
Finned tube heat exchanger

- heat transfer between water and air in cross-flow
- increase of the heat transferring surface due to fins on the pipes

Basic knowledge

Efficient heating technology

Considerable savings possibilities, without any reduction in comfort, are often possible in modern heating systems through more efficient components and a demand-based supply of heat.

High-efficiency heating circulating pumps provide the same capacity as conventional pumps while consuming up to 80 % less power.

» Thermal engineering

Many of the fundamental themes of heating technology are also covered by a wide selection of educational systems from our programme area 3.

Significant efficiency gains can be achieved in heating technology by modern circulating pumps or by hydronic balancing of installed heating systems, for example. Our educational equipment on heating technology helps you to teach the detailed knowledge necessary to achieve significant energy savings through a suitable combination of various measures.

Energy-efficient circulating pumps

A heating pump ensures that each radiator is supplied with hot water. Standard pumps with an electrical output of 45 to 90 watts are often still being used even in newer buildings. These circulating pumps are preconfigured according to the amount of water in the heating system – regardless of the actual heating demand. This is very inefficient and consumes a lot of electricity unnecessarily. Modern circulating pumps on the other hand, are adjusted to demand by means of the differential pressure, thereby saving up to 80 % of electricity costs for heating alone.

Optimisation through hydronic balancing

Hydronic balancing adjusts the flow rates of the hot water through all radiators or heating circuits of a surface heater to a certain value. As a result, at a certain feed flow temperature as the heating system operating point, each room is supplied with the amount of heat required to achieve the desired room temperature. Hydronic balancing also ensures that the return feeds on all radiators have the same temperatures.

Thermostatic valves for demand-based room heating

Before the widespread introduction of thermostatic valves, often the only option for adjusting the temperatures of individual rooms was to open the windows. This approach was naturally associated with considerable energy losses. Nowadays, however, thermostatic valves are widely used and allow the heat supply to be adjusted according to demand.

Thermostatic valves are mechanical temperature controllers that permit the flow of a heat transfer fluid depending on the ambient temperature. A valve ensures a lower or higher flow rate in order to keep the temperature of the surrounding space constant.

Design of the heating system

When designing heating systems, it is important to make sure that the components used are well matched to each other. Typical characteristics of the pump and the piping system help with this. This is shown in the diagram by way of example. The efficiency of the pump (C) is also plotted. The operating point of a system is determined by the intersection of the pump characteristic (A) and the system characteristic (B). The operating point should be as close to the central region of the pump characteristic to ensure good efficiency.

Heating system operation under varying heat demand

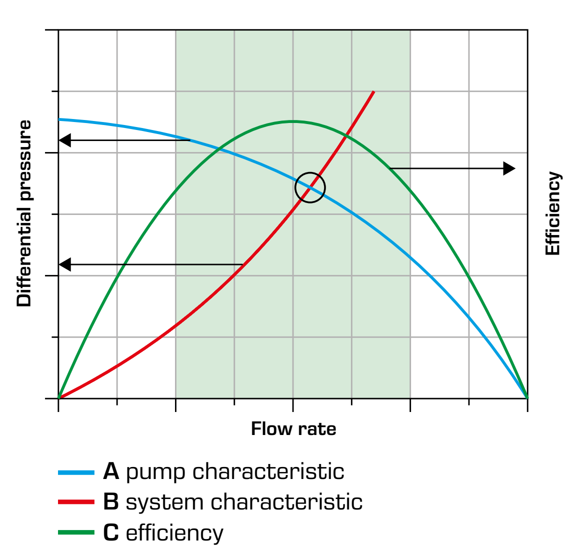
Naturally, the performance capacity of a heating system should cover the maximum heat demand from room heating and hot water supply in winter. Nevertheless, in order to keep year-round energy demand to a minimum, it is essential to create adaptive heating systems for a highly fluctuating energy demand. In addition to an intelligent control system, factors such as adequate storage and an appropriate mix of renewable heat sources where possible are important.

Heating controller

The central element of modern heating systems is the heating controller. The heating controller measures the outdoor temperature and the room temperature, and from these calculates the house's heat demand by means of the heating curve. The feed flow temperature needed to cover the heat demand is adjusted by the flow rate of the circulating pump and/or the position of the mixing valve.

In most cases, hot water is also supplied with heating energy via the boiler. In this regard, the controller switches the charging pump on as required.

In addition to using efficient components and optimising systems, a key element for the long-term reduction of energy demand is regular monitoring of the proper functioning of the system. Nowadays, modern and inter-linkable heating controllers greatly facilitate system monitoring.



Ideal operating point of a heating system

Checking the system components

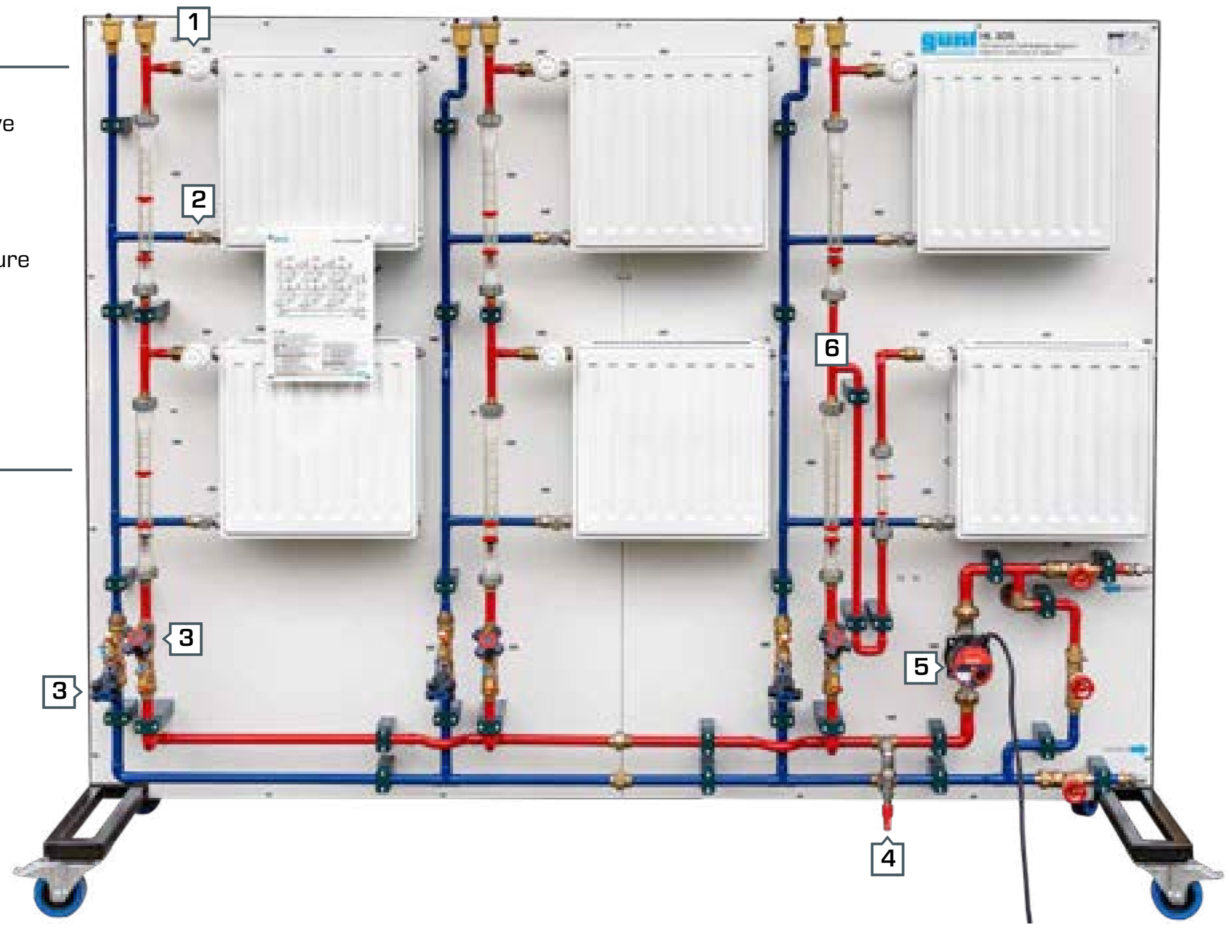
HL 305
Hydronic balancing of radiators

Typical heating problems, most of which are based on an insufficient hydronic balancing, are sometimes even incorrectly dealt with by professionals. The widely adopted but usually ineffective measures include:

- increasing the feed flow temperature
- increasing the pump power
- bringing the reheating time forward

These measures are associated with additional energy losses and thus impair the efficiency of the heating system to a considerable extent. It is estimated that, in Germany, the hydronic balancing of heating systems is inadequate in up to 90 % of all cases. The resultant potential for improving energy efficiency is therefore considerable.

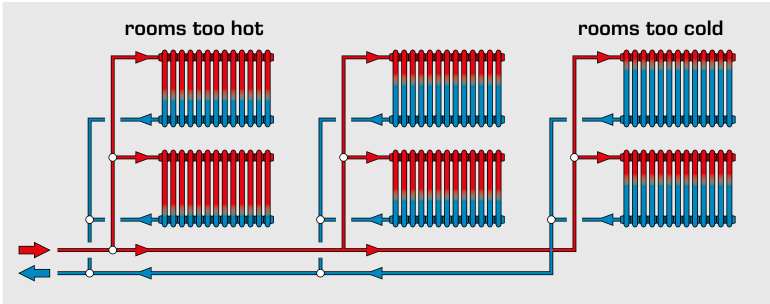
This demonstration unit allows you to teach essential fundamentals of heating technology for energy-efficient room heating. The demonstration unit contains commercially available components and consists of three heating sections with radiators, thermostatic valves and a circulating pump. The flow rates in all three sections can be adjusted separately. As a result, hydronic balancing of the sub-sections among each other is possible. Within a section, lockshield valves enable the separate radiators to be balanced. A differential pressure relief valve is integrated in the circuit parallel to the circulating pump. This valve limits the pressure drop across the piping system to a predetermined range.



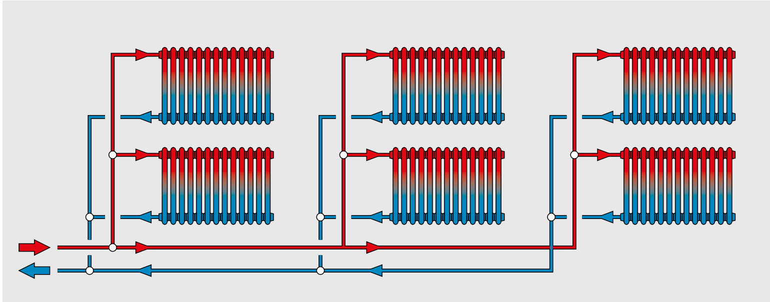
1 thermostatic valve
2 lockshield valve
3 balancing valve
4 differential pressure relief valve
5 pump
6 flow meter

About the product:

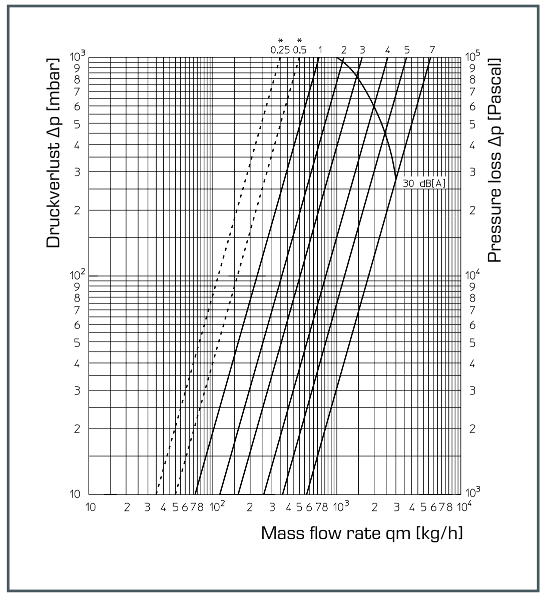
Hydronic balancing is used to limit the amount of water that is available within a heating system for each radiator. The aim is to ensure that, at a specific operating point of the heating system, each room is supplied with exactly the amount of heat needed to achieve the desired room temperature. The figure below shows the distribution of heat in a heating system before and after hydronic balancing.



Temperature distribution in radiators without hydronic balancing



Temperature distribution in radiators with hydronic balancing leads to uniform room temperatures



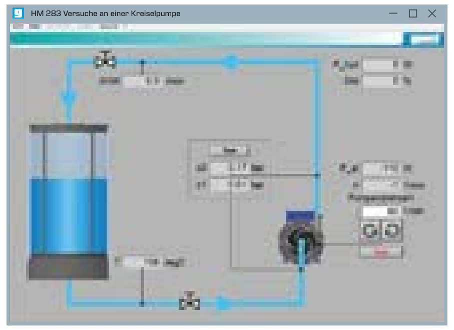
Our instructional material contains all the relevant information about the HL 305 demonstration unit. Using the included valve capacity diagrams, it is possible to determine and carry out the required settings for the hydronic balancing.

Learning objectives

- optimisation of heat distribution in heating systems
- effects from changing pipe network resistances
- use of:
  - balancing valves
  - programmable thermostatic valves
  - differential pressure relief valves

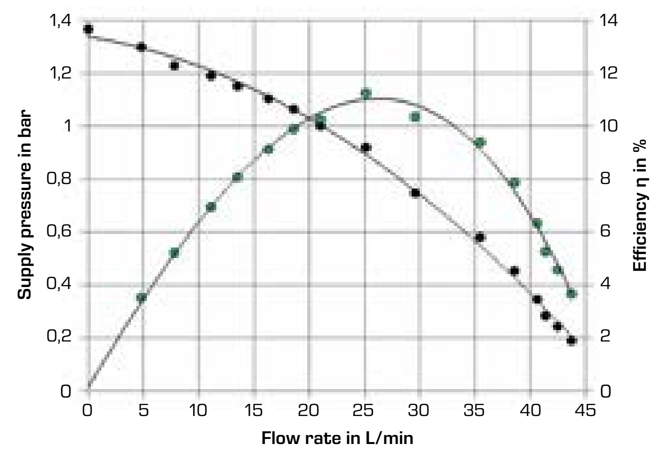
HM 283
Experiments with a centrifugal pump

Centrifugal pumps are used in many modern heating systems as circulating pumps and can therefore make a significant contribution to saving energy. The efficiency of a centrifugal pump is given by the ratio of the hydraulic power generated in the respective operating point to the electrical power used. With HM 283, you can investigate the underlying factors affecting operation of a centrifugal pump. The experiments focus on both the operating behaviour under varying flow rates and pressure differences, and the power balance.



Software

The clear software of HM 283 displays the key measured variables continuously. The logged measured values can be saved for analysis. This supports you while carrying out the experiments.



In the case shown here, the energy balance results in maximum efficiency at a flow rate of 25 L/min

Learning objectives

- principle of operation of a centrifugal pump
- relationships between head, flow rate and speed
- recording pump characteristics and determining the pump efficiency

About the product:

WWW

HL 630
Efficiency in heating technology

HL 630 allows further experiments on energy efficiency in heating technology. The HL 630 unit provides you with a trainer with a complete heating circuit. In addition to the circulating pump, a heat source and a heat sink, the device also includes various pipe sections, valves and fittings and safety elements.

Software

The software of HL 630 displays the temperatures, pressure differences and the electrical power consumption of the pumps in the process schematic.

As such, it is possible to clearly teach both the influence of modern, high-efficiency pumps and the drawbacks of incorrectly sized pipe sections.

Non-controlled circulating pump with selectable speed (efficiency class C)

Energy-efficient circulating pump with adjustable differential pressure control (efficiency class A)

Learning objectives

- comparison of conventional and differential pressure controlled circulating pumps
- determining pump efficiency
- recording of system and pump characteristics
- pressure losses at various pipe diameters, valves and fittings

About the product:

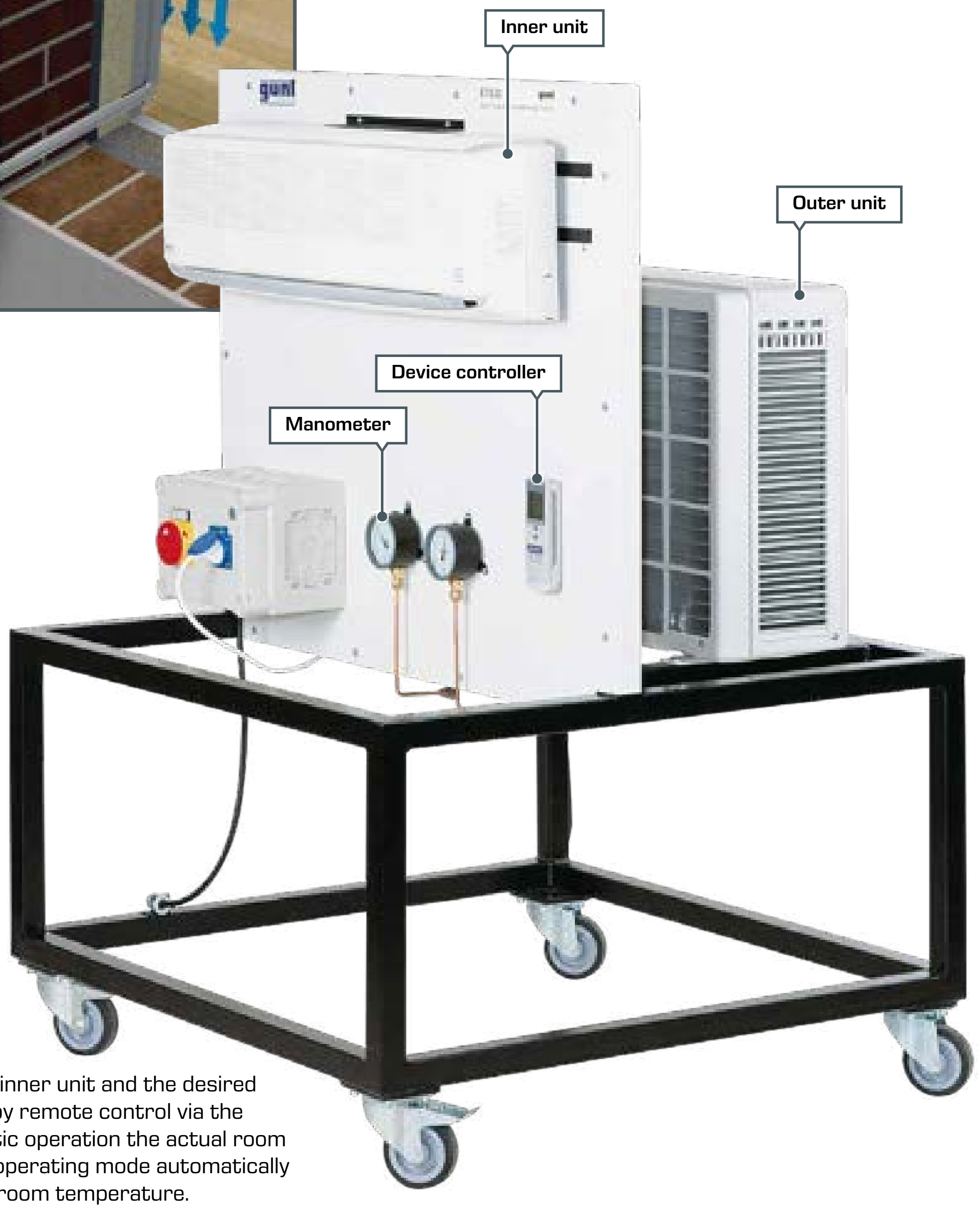
WWW

ET 630
Split system air conditioner

Energy consumption for room air conditioning has risen sharply in recent years. ET 630 contains all the necessary components to enable you to teach the design and function of air conditioning units in as practical a way as possible.

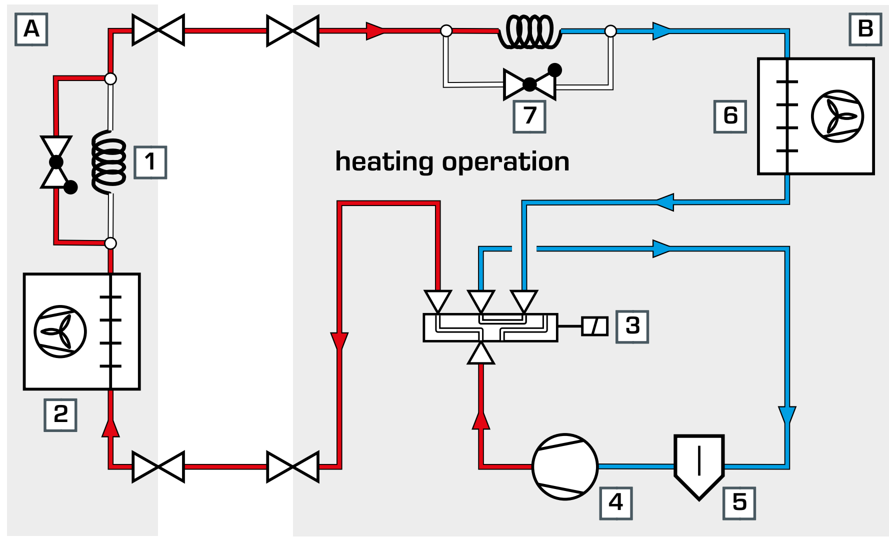
Heat flux in cooling operation

The device consists of an inner unit and an outer unit. The inner unit includes a heat exchanger with fan, which in cooling mode acts as an evaporator in the refrigeration circuit. During the heating mode on the other hand, the heat exchanger operates as a condenser. The outer unit includes a compressor, an additional heat exchanger, an expansion valve and a changeover switch for the operating mode (cool/heat).

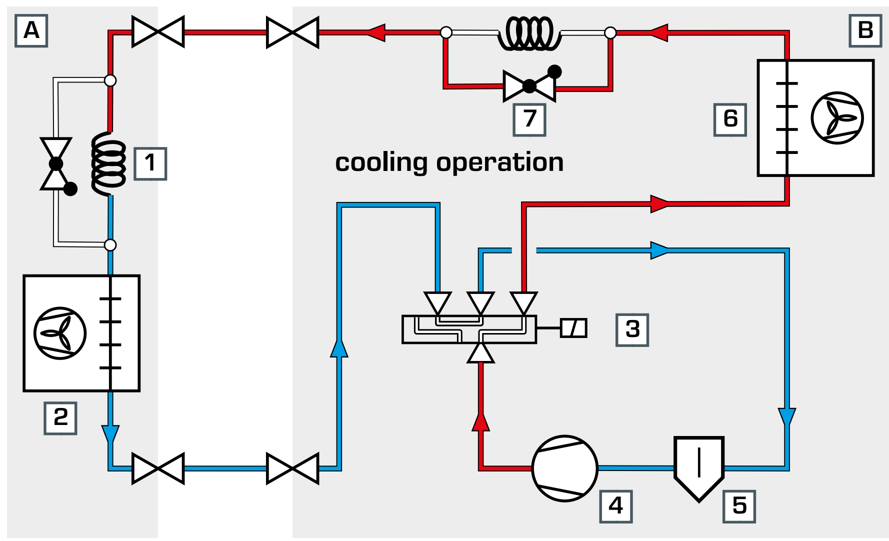


Operating mode, fan stage of the inner unit and the desired room temperature are selected by remote control via the device controller. During automatic operation the actual room temperature is captured and an operating mode automatically selected to achieve the specified room temperature.

Selectable operating mode as cooling or heat pump heating



In heating mode the heat exchanger of the inner unit operates as a condenser



In cooling operation the heat exchanger of the inner unit operates as an evaporator

- A inner unit
- B outer unit
- 1 capillary
- 2 heat exchanger, inner
- 3 4-way change-over valve
- 4 compressor
- 5 liquid separator
- 6 heat exchanger, outer
- 7 non-return valve
- Refrigerant/high pressure
- Refrigerant/low pressure

Learning objectives

- design and function of a split unit air conditioner
- basic operating modes: cooling, dehumidification, heating, ventilation, automatic
- additional functions: shutdown after a few hours, slat position at the air vent, timer for switching on and off
- system control by remote control

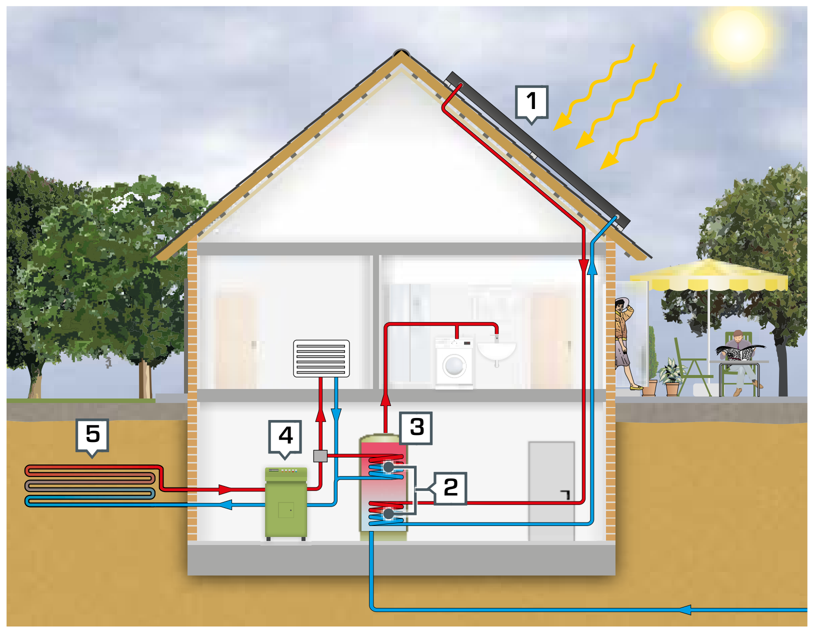
About the product:

GUNT TECHNOLOGY LIMITED

Subject areas

Inclusion of renewable energies

Our HL 320 modular system covers essential areas of learning from the field of renewable energy usage in building services engineering. The HL 320 modular system allows you to investigate heating systems with various renewable and traditional energy sources. Solar thermal energy can be combined with heat generation from heat pumps. The modular concept of the HL 320 system allows you to create a variety of configurations.



Components for the combined use of renewable heat sources in the domestic supply:

1 flat collector
2 heat exchanger
3 bivalent storage
4 heat pump
5 geothermal absorber

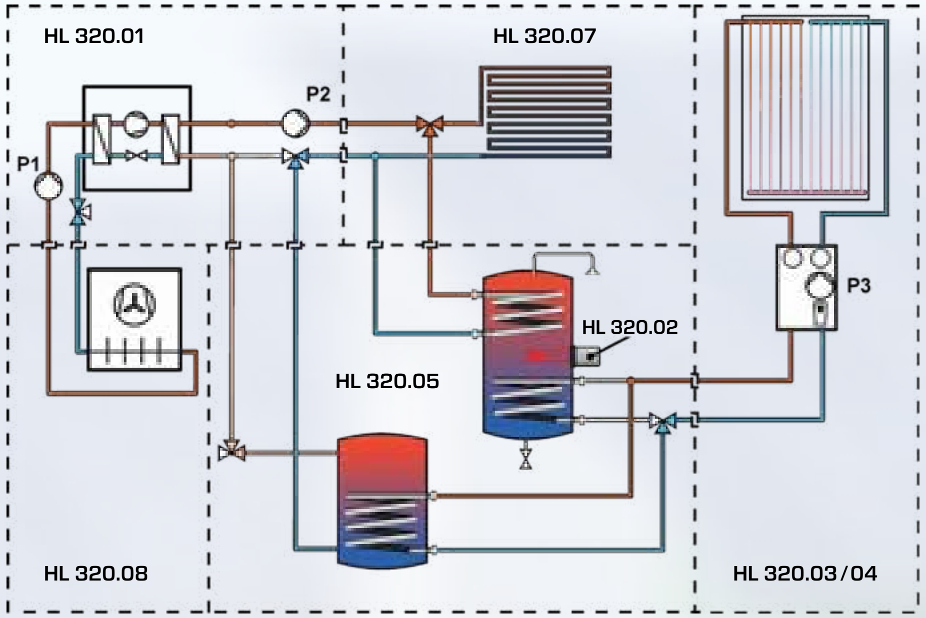
Subject areas	Products
Possible applications of modern heat pumps	**HL 320.01** Heat pump
Combination of regenerative and conventional heat sources	**HL 320.02** Conventional heating
Solar thermal heat generation	**HL 320.03** Flat collector **HL 320.04** Evacuated tube collector
Storage in regenerative heating systems	**HL 320.05** Central storage module with controller
Heat sources and heat sinks	**HL 320.07** Underfloor heating/geothermal energy absorber **HL 320.08** Fan heater/air heat exchanger

Overview

HL 320 Solar thermal energy and heat pump modular system

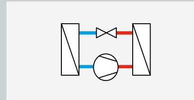
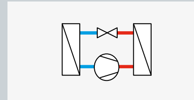
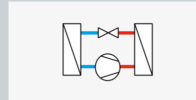
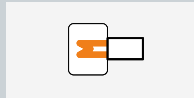
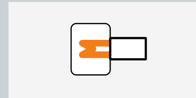
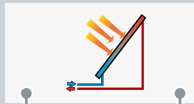
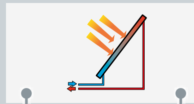
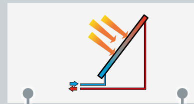
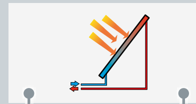
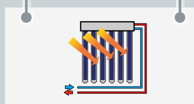
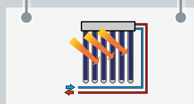
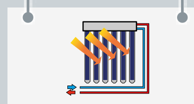
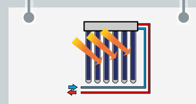
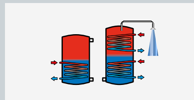
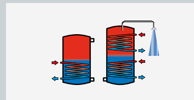
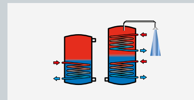
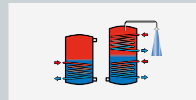
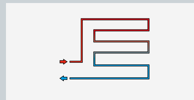
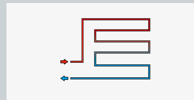
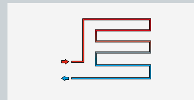
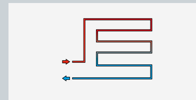
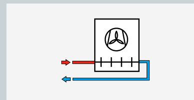
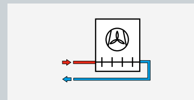
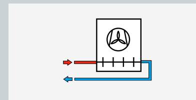
The right configuration for every application

In heating technology, both the correct composition of necessary components and the optimisation of cabling and controller settings depend on the local conditions. We have developed experiments for a selection of relevant module combinations in order to be able to teach the corresponding learning content in balanced steps. In addition, you may of course create your own system configurations to investigate further issues from the field of regenerative heating technology.



Example for a system schematic for complementary heating and domestic water heating with a solar thermal collector and a heat pump (combination 5).

Recommended combinations for the HL 320 modular system

Combination	1	2	3	4	5
HL 320.01 Heat pump					
HL 320.02 Conventional heating					
HL 320.03 Flat collector					
HL 320.04 Evacuated tube collector					
HL 320.05 Central storage module with controller					
HL 320.07 Underfloor heating/ geothermal energy absorber					
HL 320.08 Fan heating/ air heat exchanger					

Learning objectives and experiments

Combination 1

- function of a solar thermal heating system
- commissioning
- collector efficiency and losses

Combination 2

- combined use of traditional and solar thermal energy
- efficient indoor heating with underfloor heating

Combination 3

- function and design of a heat pump
- parametrisation of a heat pump controller
- factors influencing the COP (Coefficient of Performance)

Combination 4

- efficient use of solar thermal and geothermal energy
- strategies for heat supply in various consumption profiles

Combination 5

- use of renewable and fossil sources for heating and hot water
- bivalent parallel and bivalent alternative heat pump mode

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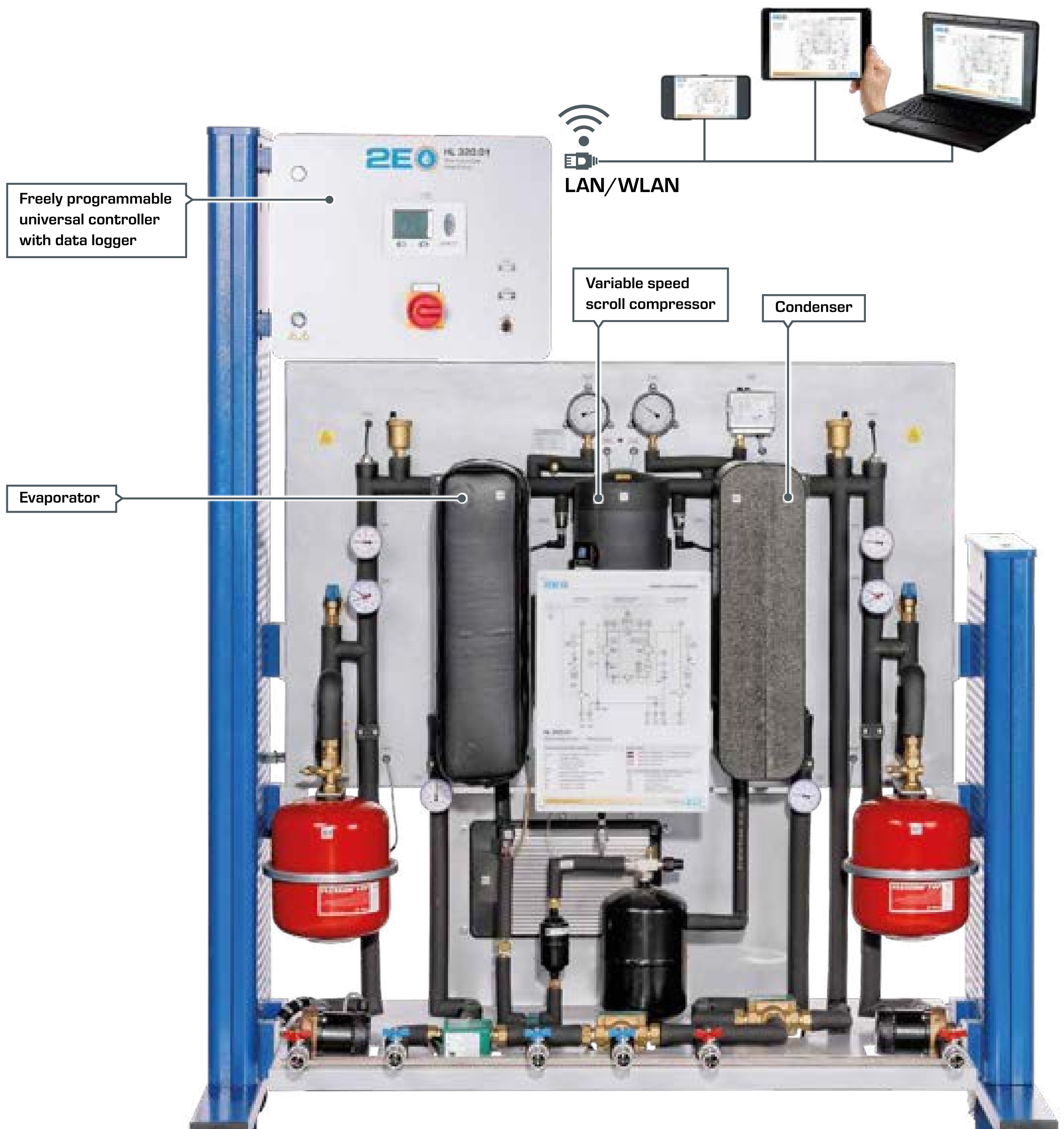
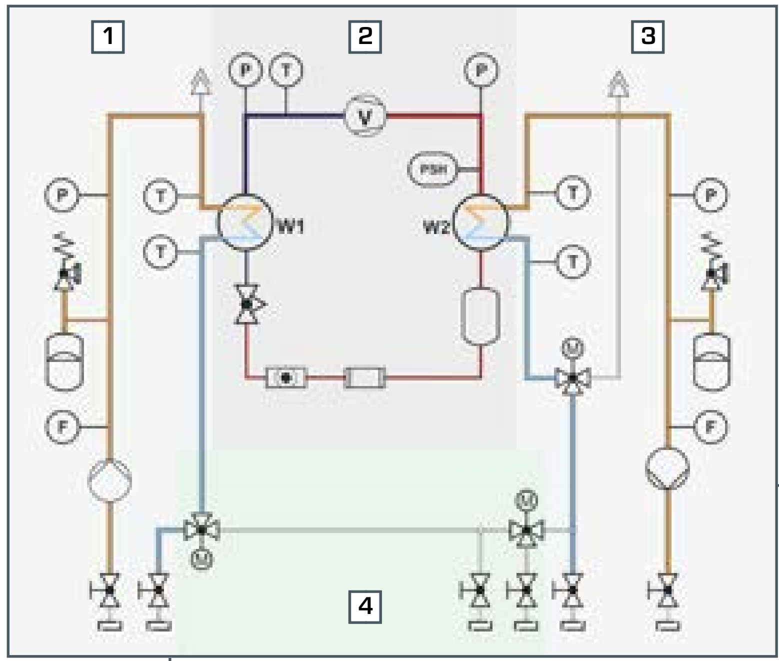
HL 320.01
Heat pump



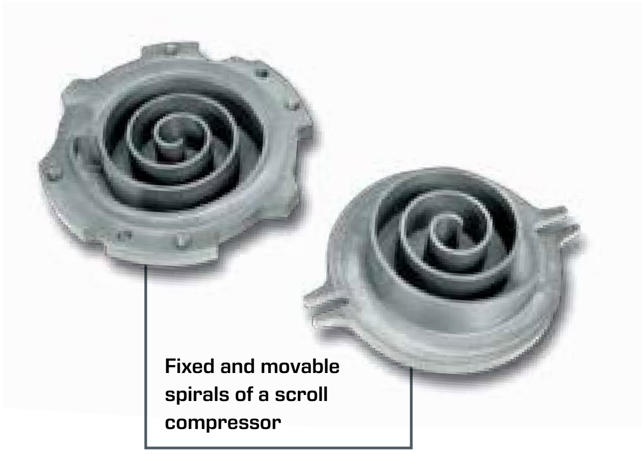
Sensors for temperature and flow rate are included at all necessary positions to draw up an energy balance of the energy flows. Data from other HL 320 modules can be transferred to the configurable heating controller of the heat pump module via a CAN bus connection.

The HL 320.01 heat pump is part of the HL 320 modular system and provides you with a variety of combination options of geothermal and solar thermal energy in a modern heating system. The heat pump is driven by a variable speed scroll compressor. This means it is possible to adapt the heating power of the heat pump to the current demand of the heating system.



Process schematic of the HL 320.01 heat pump module

1 source circuit connections
2 refrigeration circuit
3 heating circuit connections
4 additional options for including HL 320 modules



Fixed and movable spirals of a scroll compressor

Learning objectives

- function and design of a heat pump
- distinguishing different operating conditions
- factors influencing the COP (Coefficient of Performance)
- parametrisation of a heat pump controller

In combination 3 of the HL 320 system, the following modules are combined to create one system:

- **HL 320.01** Heat pump
- **HL 320.07** Underfloor heating / geothermal energy absorber
- **HL 320.08** Fan heater / air heat exchanger

This combination allows fundamental experiments on the operating behaviour of the heat pump. For more detailed experiments a storage module (HL 320.05) and a thermal solar collector, for example, can be connected.

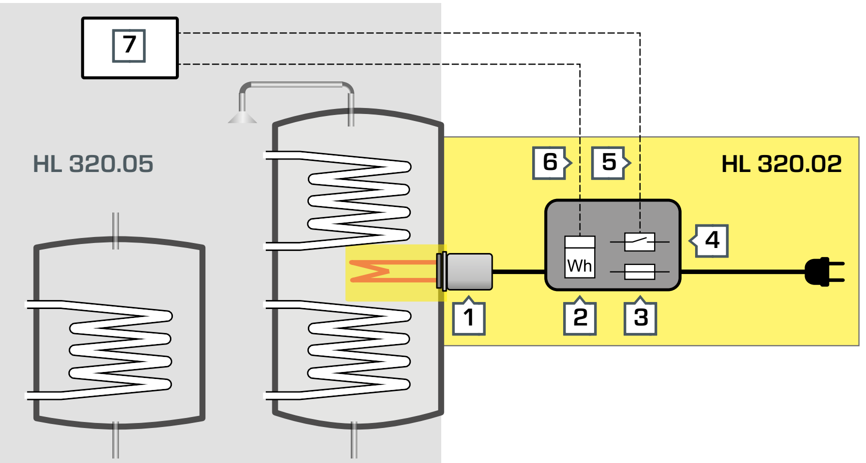
About the product:

WWW

HL 320.02
Conventional heating

In heating systems using different renewable heat sources, it may be economically feasible to cover the peak demand by means of a conventional heater. In order to be able to investigate this aspect in the HL 320 modular system, the HL 320.02 module provides an additional heater that can easily be integrated into different system configurations.

The practical cost of operating this heater for your experiments remains low because an electrically operated heating element is used. The heating element is inserted into the storage tank of the HL 320.05 storage module and can be controlled by the storage module's controller via CAN bus. An integrated meter records the amount of electricity consumed. The data from this meter can be sent to the controller of the HL 320.05 storage module via the CAN bus connection for capture by a data logger.



1 heating element
2 energy meter
3 fuse
4 switch box
5 connection between power contactor and controller output
6 connection between energy meter and controller input
7 controller for HL 320.05 module

The storage tank is emptied in preparation for the experiment. Subsequently, the auxiliary heater can easily be inserted into just a few steps.

Learning objectives

- complementary heating and/or domestic water heating by conventional additional heater
- bivalence point and heating load
- control strategies for complementary heating

About the product:

HL 320.03
Flat collector

In conjunction with other HL 320 modules, you can conduct experiments on solar thermal energy domestic water heating with the HL 320.03 flat plate collector. The control engineering for the combined production of domestic hot water and heating is of particular practical relevance. Here, the system is controlled and data captured via CAN bus via the HL 320.05 storage module.

Modules are easily connected via hoses and quick-release couplings. Different combinations for renewable heat sources can be tested and optimised in conjunction with other modules from the HL 320 system.

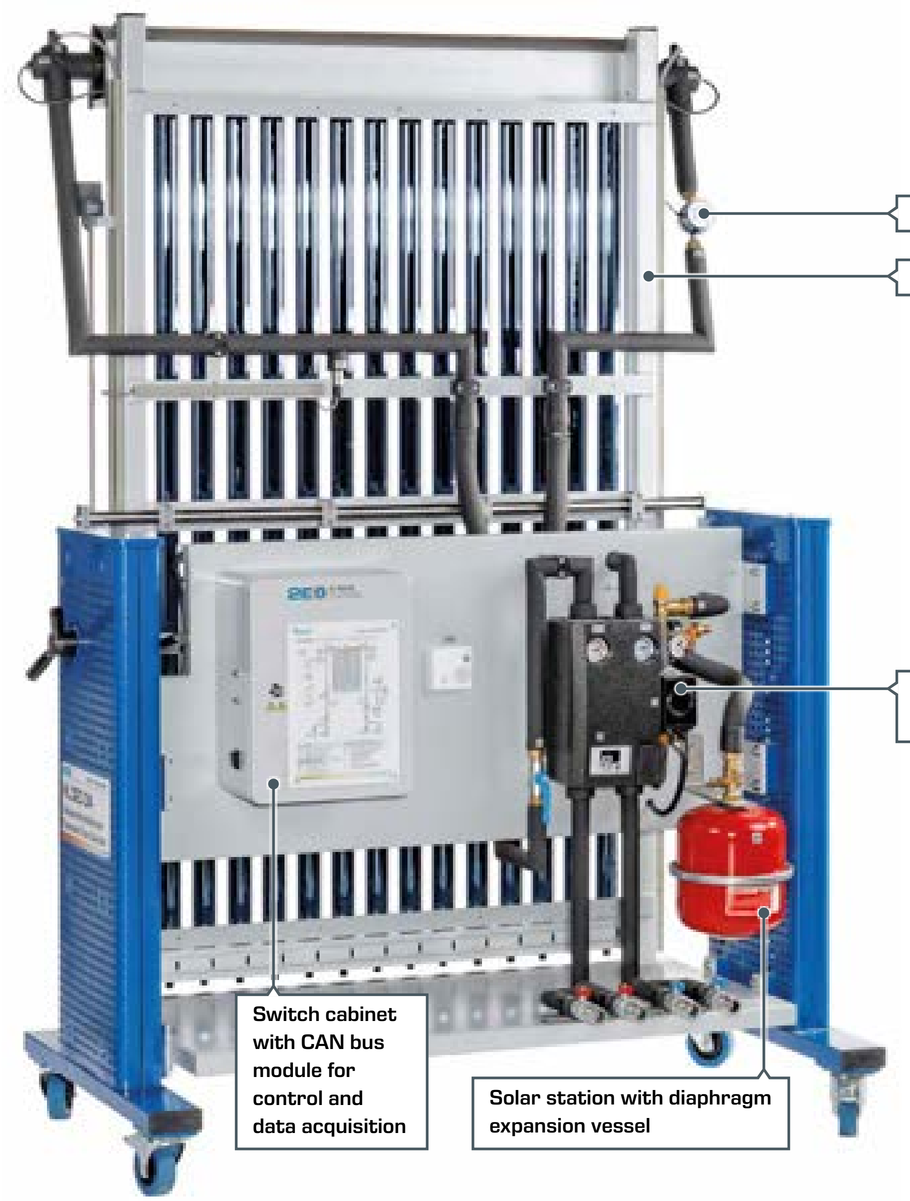
Learning objectives

- determining the net power
- effect of temperature, illuminance and angle of incidence on collector efficiency
- integration of a flat collector in a modern heating system
- hydraulic and control engineering operating conditions
- energy balances
- optimisation of operating conditions for different types of use

About the product:

HL 320.04
Evacuated tube collector

The HL 320.04 unit provides you with a modern design evacuated tube collector. Evacuated tube collectors reach much higher operating temperatures compared to simple flat plate collectors due to the lower thermal losses. In practice, evacuated tube collectors are used where there is limited floor space, for example. In the year-round heating operation, evacuated tube collectors enable the reduction of the seasonal demand on a conventional auxiliary heater. HL 320.04 is one of the modules from the HL 320 solar thermal energy and heat pump modular system. The experiment module can be incorporated into the modular system in a variety of different ways. The module can be used both for generating heated domestic water and for the combined production of domestic hot water and for heating rooms. Pipe connections for the heat transfer fluid are easy to create and alter thanks to the quick-release couplings.



Learning objectives

- design and operation of the evacuated tube collector
- determining the net power and factors affecting the collector efficiency
- integration of an evacuated tube collector in a modern heating system

About the product:

HL 320.05
Central storage module with controller

The HL 320.05 storage module has been developed for your experiments as a central component of the HL 320 modular system. HL 320.05 contains two different heat storage systems, pipes, a pump, two motorised 3-way valves and safety devices. Quick-release couplings on the front of the module enable the hydraulic connection to other modules of the modular system. In addition, HL 320.05 contains a freely programmable heating controller, which is connected to the respective modules via control and data lines (CAN bus). This controller allows you to operate and study all intended module combinations.

Learning objectives

- fundamentals and commissioning of heating systems with solar thermal energy and heat pump
- properties of various heat storage methods
- electrical, hydraulic and control engineering operating conditions
- energy balances for different system configurations
- optimisation of control strategies for different operating modes

About the product:

HL 320.05
Central storage module with controller

1 freely programmable heating controller with data logger

2 ports for CAN bus and network

3 process schematic

4 buffer storage

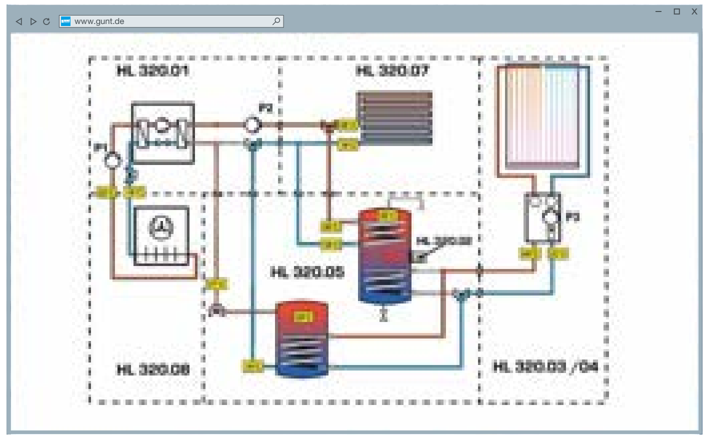
5 heat exchanger

6 3-way change-over valve

7 circulating pump

8 bivalent storage

The HL 320.05 storage module can be connected to the HL 320 modular system in a variety of ways through individually accessible inputs and outputs. Schematics and controller configurations are provided for five pre-defined combinations. First of all, the labelled pipe connections are established in preparation for the experiment. Then a controller connection and a data connection (CAN bus) are made to each module. The experiment can begin once the prepared controller configuration has been activated. Different PC programs are available for the controller and data logger, which allow individual adaptation of the configuration or the desired data logging options as required.



Visualisation in the web browser via LAN/WLAN

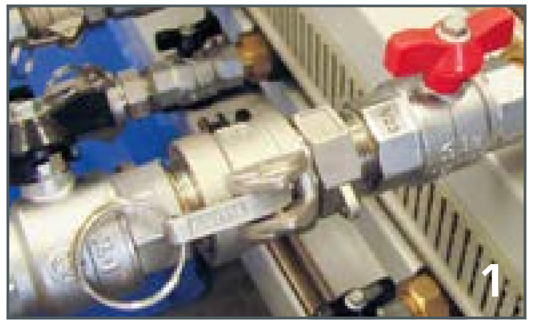
The controller is controlled and data acquired via a network module to a PC. The connection can be established via the integrated router by LAN or wirelessly by WLAN. Current system data can be represented in a schematic, for example. This representation can be retrieved with any current web browser.

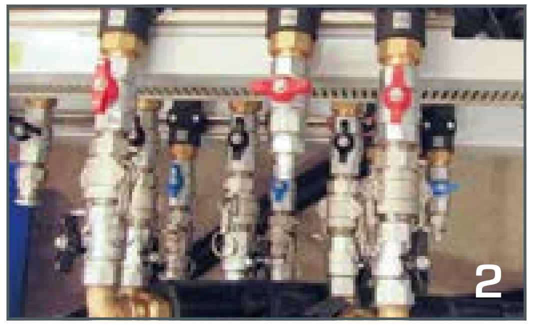
References

Many customers around the world are already successfully working with our HL 320 modular system. Below are a few selected references:

- University College London (UCL), United Kingdom
- ROC Kop van Noord-Holland, Netherlands
- Politechnika Slaska w Gliwicach, Poland
- Universidad de Huelva (UHU), Spain
- Montanuniversität Leoben, Austria
- Hochschule Ansbach, Germany
- Hochschule Wismar, Germany
- IUT Amiens, France

Preparation for the experiment





Secured cable connections (1, 2) allow safe modification of the cable routing. Current system data can be visualised both on the controller (3) and via a network connection (4).

About the product:

HL 320.07
Underfloor heating/geothermal energy absorber

Underfloor heating systems transfer heat by piping systems arranged in a spiral or winding pattern beneath the floor covering. Underfloor heating requires much lower feed flow temperature than conventional radiators. Besides its function as a heat sink when used as an underfloor heating system, HL 320.07 can also be used as a heat source for a heat pump in the HL 320 modular system. In this case, the direction of the heat transport is reversed. HL 320.07 is equipped with three separately selectable piping systems of different lengths. The pipes are surrounded by a tank which can be filled with water.

Sensors are mounted on the piping system to detect the temperatures in the feed and return. Heat quantities and energy balances can be calculated using these temperatures together with the measurement data from the integrated flow meter. Data is transferred to the controller of each main module (HL 320.01 or HL 320.05) via the CAN bus connection. The integrated 3-way mixing valve can also be controlled by the controller via the CAN bus connection.

Learning objectives

- energy balance in combined heating systems for domestic water heating and indoor heating
- heat transfer in an underfloor heating system
- use of heat sources for heat pump systems

About the product:

HL 320.08
Fan heater/air heat exchanger

In the case of heating rooms, compared to traditional heating radiators, fan heaters offer the possibility of achieving a comparatively good transfer of heat to the room air, even at small dimensions. When combined with a heat pump, the fan heater often represents a beneficial application both economically and in terms of energy, especially when renovating heating systems in old buildings. The HL 320.08 experiment module completes your HL 320 modular system. This module can also be operated as either a heat sink or a heat source for a heat pump. Sensors for temperature and flow rate are available to create energy balances. Data is transferred to the controller of each main module (HL 320.01 or HL 320.05) via the CAN bus connection.

Learning objectives

- how the temperature difference between heating feed and return affects the overall efficiency of a heating system
- operating conditions when used as an air heat exchanger in a heat pump system
- comparison of an air heat exchanger with other heat sources in a heat pump system

About the product:

Subject areas

Energy efficiency in business and industry

In business and industry, measures to improve energy efficiency are connected to both the optimisation of building services engineering and to relevant value creation processes. The close integration of these two areas often results in novel approaches to improving energy efficiency. For example, the waste heat from cooling equipment can be used in the food trade for air conditioning in the showrooms. In industrial environments, the use of process engineering waste heat is a good example of more efficient measure.

On these pages we have compiled only a very small selection of devices on this topic. The basic approach to analysing energy flows in given application environments in order to achieve a reduction of primary energy use can also be demonstrated by many devices from GUNT's standard product range, in addition to equipment from the Energy product area.

Subject areas	Products
Energy efficiency in refrigeration	**ET 420** Ice stores in refrigeration **ET 428** Energy efficiency in refrigeration systems
Outlook: Energy efficiency in process engineering	**RT 682** Multivariable control: stirred tank **RT 396** Pump and valves and fittings test stand

Basic knowledge

Energy efficiency in refrigeration

Typical application for refrigeration systems: Sales counters in supermarkets operating in the standard cooling range.

Refrigerating plants in building services engineering

Refrigerating plants consist of various components, in which energy is transferred. All of these components are associated with different efficiencies, and can therefore be regarded as potential adjusting points for optimisation. Building services engineering in particular provides the option of significantly increasing the efficiency and cost-effectiveness of the overall system by, for example, utilising the waste heat from a refrigerating plant to heat the building. Another interesting concept for interlinked operation of heat sources and heat sinks consists, for example, in the use of waste heat for cold production in absorption refrigeration systems.

Condenser in a refrigerant network

Refrigerant networks for building supply

In larger refrigerating plants, cold generators and refrigeration points are often physically separated from each other. Sometimes several refrigeration points at different locations are supplied by a central plant. There is often not enough space at the refrigeration points (e.g. the sales counter) to install a cooling unit. It is also crucial for the system design whether the waste heat is to be released to the outside air or into the building supply. In principle, it is the task of refrigerant networks to transport refrigerant from the cooling unit to the refrigeration point and back.

» Thermal engineering

Many of the fundamental themes of heating technology are also covered by a wide selection of educational systems from our programme area 3.

Temperature ranges in refrigeration technology

The integration of refrigeration technology into building services engineering first requires consideration of the temperature range of the application. Typically, the following ranges are identified:

- air conditioning +25°C ... +15°C
- standard cooling +10°C ... -5°C
- freezing -15°C ... -30°C
- shock freezing -35°C ... -50°C

Measures to improve energy efficiency in refrigeration

The implementation of energy-efficient concepts for refrigerating plants is often associated with increased investment costs. By contrast, achievable savings and economic benefits for some solutions are only significant when viewed over the entire life of the system. Therefore, it may be useful to create economic incentives for specific applications or technologies to reduce the risks for new systems, especially in the initial phase.

In Germany, refrigeration plants and air conditioning units consume about 15% of the electrical energy. Under EU rules, the German government has set up special support programmes to increase efficiency in this area in order to achieve the planned savings targets by 2025.

Individual production steps in food production often require very precise preset temperatures. One particular challenge when planning production facilities is the energy efficient integration of the required refrigerating plants into the rest of the building supply.

Energy efficiency under varying cooling demand

Naturally, the performance of a refrigerating plant should cover the maximum demand of all refrigeration consumers at peak times. Adaptive refrigeration systems can be used to keep the energy demand as low as possible when cooling demand varies widely. These systems include, for example, variable speed or multi-stage compressors and electronic expansion valves. Efficient plant control avoids frequent switching on and off. However, it also requires a sufficiently large cold storage. Integration into the energy management system of the entire building should also be considered alongside an intelligent control system.

Goods often have to be stored in refrigeration for a long time, and not only in the food sector. Substantial savings in energy consumption are also possible even with low efficiency gains, due to the required continuous operation of the refrigerating plants.

System monitoring by energy management systems

In addition to the implementation of efficient system concepts and the use of optimised components, regular monitoring of all operating parameters is crucial for the long-term reduction of energy demand. Interlinkable refrigeration controllers, whose data is collected by a modern energy management system for the entire building, are becoming increasingly important for system monitoring.

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.

About the product:

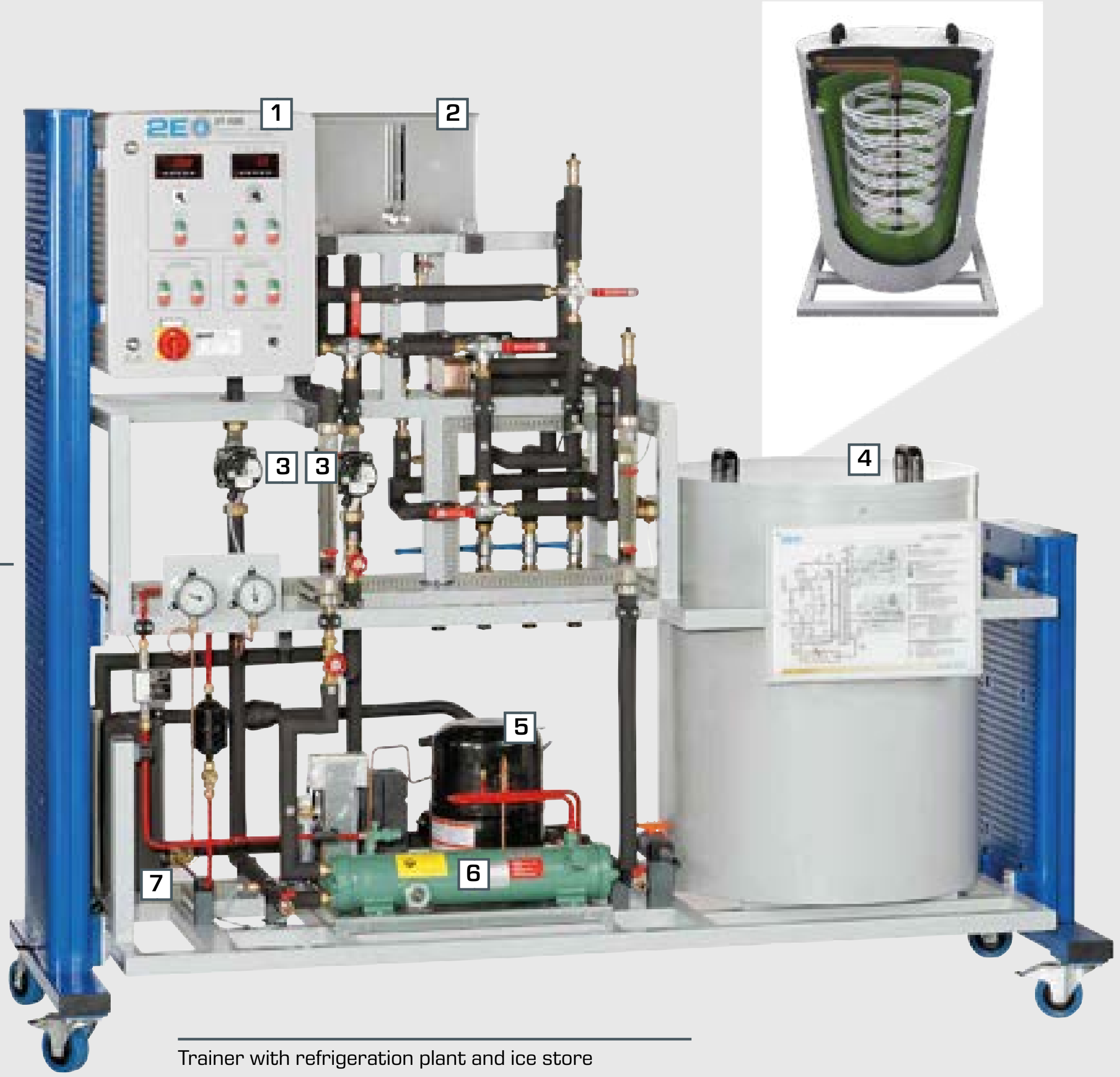
ET 420 offers a refrigeration plant with ice store, which can be operated entirely as required. The plant concept includes a dry cooling tower **9**, which represents the heat exchanger in the building to be supplied during the experiments and a wet cooling tower **8**, which represents the heat dissipation 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

Learning Objectives

- Learning Objectives
- 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



1 switch cabinet, **2** glycol storage tanks, **3** circulation pumps, **4** ice store, **5** refrigerant compressor, **6** refrigerant condenser, **7** refrigerant evaporator, **8** wet cooling tower, **9** dry cooling tower

Trainer with refrigeration plant and ice store

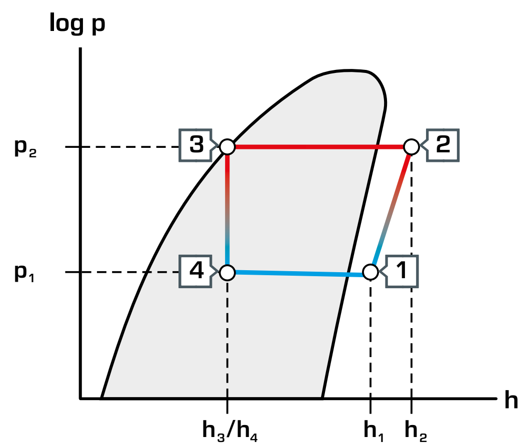
Wet cooling tower

Dry cooling tower

ET 428
Energy efficiency in refrigeration systems

The efficient use of energy in refrigeration technology is an important contribution to a sustainable energy supply. In order to ensure energy-efficient operation even when power demand is high, small compressors are connected in parallel in industry. The optimal adaptation to the power demand is achieved by switching the compressors on and off. The ET 428 trainer includes three compressors connected in parallel, which can be switched on or off via a controller. The components of the refrigeration circuit with the three compressors are clearly arranged on the trainer. The 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 you to study how refrigerant supercooling affects process efficiency. You can undertake a quantitative analysis of the efficiency using an energy balance in the glycol-water circuit and by measuring the electrical output of the compressors.

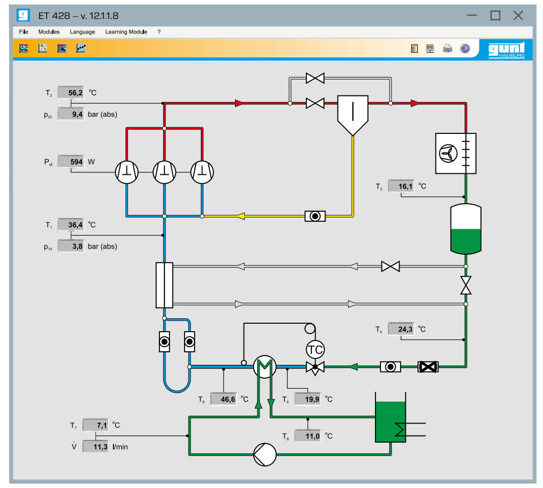
To protect the three compressors, the refrigeration circuit is equipped with a combined pressure switch for the pressure and intake sides. To ensure a secure oil supply to the three compressors, an oil separator is provided on the pressure side of the compressors. The separated oil is returned to the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



1 → 2 compression
2 → 3 condensation
3 → 4 expansion
4 → 1 evaporation

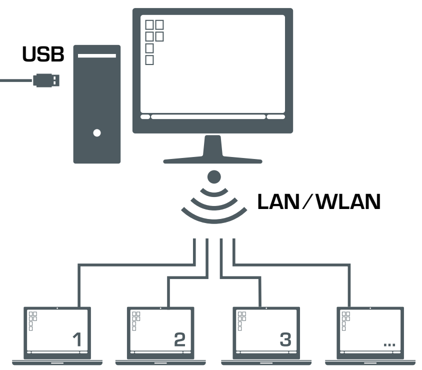
p pressure,
h enthalpy

The representation of the process in the log p-h diagram is a standard for illustrating the cyclic process in refrigerating plants. ET 428 also provides you with an online view of the cyclic process with the current measured values.



Software

The GUNT software for ET 428 enables the acquisition, storage and display of all relevant measured values.



About the product:

www

Learning objectives

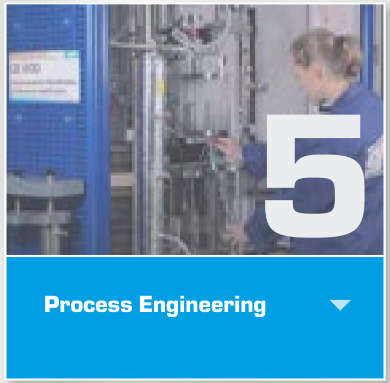
- variables affecting energy efficiency
  - controller parameters
  - refrigerant supercooling
- interconnected operation of compressors
- operation of a multicompressor controller
- methods for returning oil in a multi-compressor refrigeration system
- representation of the cyclic thermodynamic process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

Basic knowledge

Process engineering and building services engineering

This trainer considerably facilitates the implementation of energy-efficient concepts when they can be incorporated into the planning of production plants early on.

Detecting and measuring the energy flows is a prerequisite for the optimisation of existing plants.



» Process Engineering

Many of the fundamental themes of process engineering are also covered by a wide selection of educational systems from our programme area 5.

Resource-efficient production plants

Nowadays an interdisciplinary approach is needed, as indicated in the example of a resource-efficient supply of raw materials and energy. Various aspects from the fields of energy engineering, building services engineering and process engineering must be taken into consideration. The combination of the otherwise mostly independent subject areas of building services engineering and process engineering is based on this knowledge. Any future-oriented education must include this combination of these two subject areas. This ensures that the challenges of designing energy-efficient production plants will be met in the future.

Joining sub-systems

The joint approach of building services engineering and process engineering has been successfully implemented in the construction of new industrial or commercial buildings or the modernisation of old ones. A significant increase can be noted in this regard. The willingness to accept the associated higher expense has increased significantly due to the positive experience of already implemented projects. This trend is supported by government funding. The valuable lessons learned from the operation of coupled systems flow into the further development of individual components and energy-efficient control systems.

Energy-optimised plant control

For the energetic optimisation of process engineering plants, it is first necessary to consider which sub-processes or components are affected by energy losses. In existing plants, additional components and measuring equipment often have to be installed for this purpose. It should then be possible to measure all relevant energy flows of the plant. In order to identify potential savings, the measurement data must first be analysed and the individual process steps accounted for. These savings can then be exploited by optimising the plant control system. However, in order to simultaneously maintain the same product quality, extensive experiments are usually required.

Heat recovery in food production

Lots of energy is used during the production of food, in the form of hot water, process heat, cooling and heating. An example for process engineering from this field is the use of a temperature-controlled stirred tank. Typical requirements for such a system are:

- rapid heating of the components to be treated prior to entry into the tank
- constant temperature during treatment in the tank
- rapid cooling of the products produced by the treatment
- energy-efficient operation of the plant

Efficient control systems are needed in order to meet all the requirements, alongside a possibility for heat recovery. What effects are possible, such as changes in the control parameters, can be studied in our RT 682 trainer.

Large-scale stirred tanks

Valves and fittings of a large-scale distribution station

Valves and fittings in process engineering

Adjustable valves and fittings are used in process engineering when materials with fluid properties have to be transported in piping systems. They are responsible for limiting the flow rate to a certain value.

Naturally, limiting a given flow rate through a valve or fitting is associated with a pressure drop and thus with a loss of hydraulic power. If the only aim is to adjust the flow rate through a main pipe, it is more energy efficient, for example, to use a pump with adjustable flow rate. In branched piping systems however, this is not always possible or economically viable. In this case, adjustable valves and fittings are often used.

When selecting suitable valves and fittings, besides the specific requirements of the intended application, basic design questions must be taken into account in order to ensure a low-loss operation. For experiments in this field of process engineering, we recommend our RT 396 pumps, valves and fittings test stand.

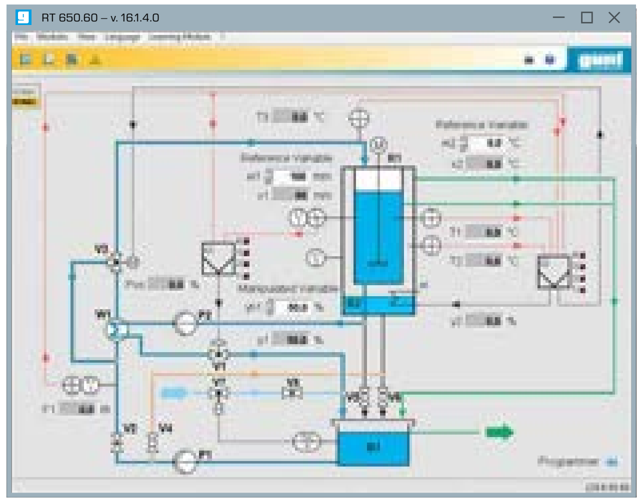
RT 682
Multivariable control: stirred tank

1 stirred tank
2 heater
3 collection tank
4 pumps
5 level control valve
6 heat exchanger
7 3-way motorised valve
8 level controller
9 temperature controller

In process engineering, the energy-efficient operation of the individual components is also of great importance. The less energy required to manufacture the products, the more cost-effective the production process, so that the products can be offered more cheaply. In this case, the cost of maintenance of the production building, the control station and the office building must be considered. The waste heat occurring during production can be used, for example to heat buildings, which can reduce operating costs. Automation and monitoring of individual flows and temperatures are required for this purpose.

Another measure to increase energy efficiency is in-process heat recovery. For example, this could be done by using the still-warm products to preheat the input materials. The modified plant behaviour has to be adapted for the production process with the control parameters.

With RT 682, you can teach the complex relationships of a multivariable control system in a practical way and display and compare the system behaviour with heat recovery.



Software

The process control software specially developed for RT 681 and RT 682 allows you to connect, monitor and control both trainers simultaneously. The software offers the following options:

- process schematics and display of all measured values
- warning function with logging
- parameterisation of the controller
- controller manual or automatic operation
- how a programmer works
- networking with server/client
- control panel function with both trainers connected

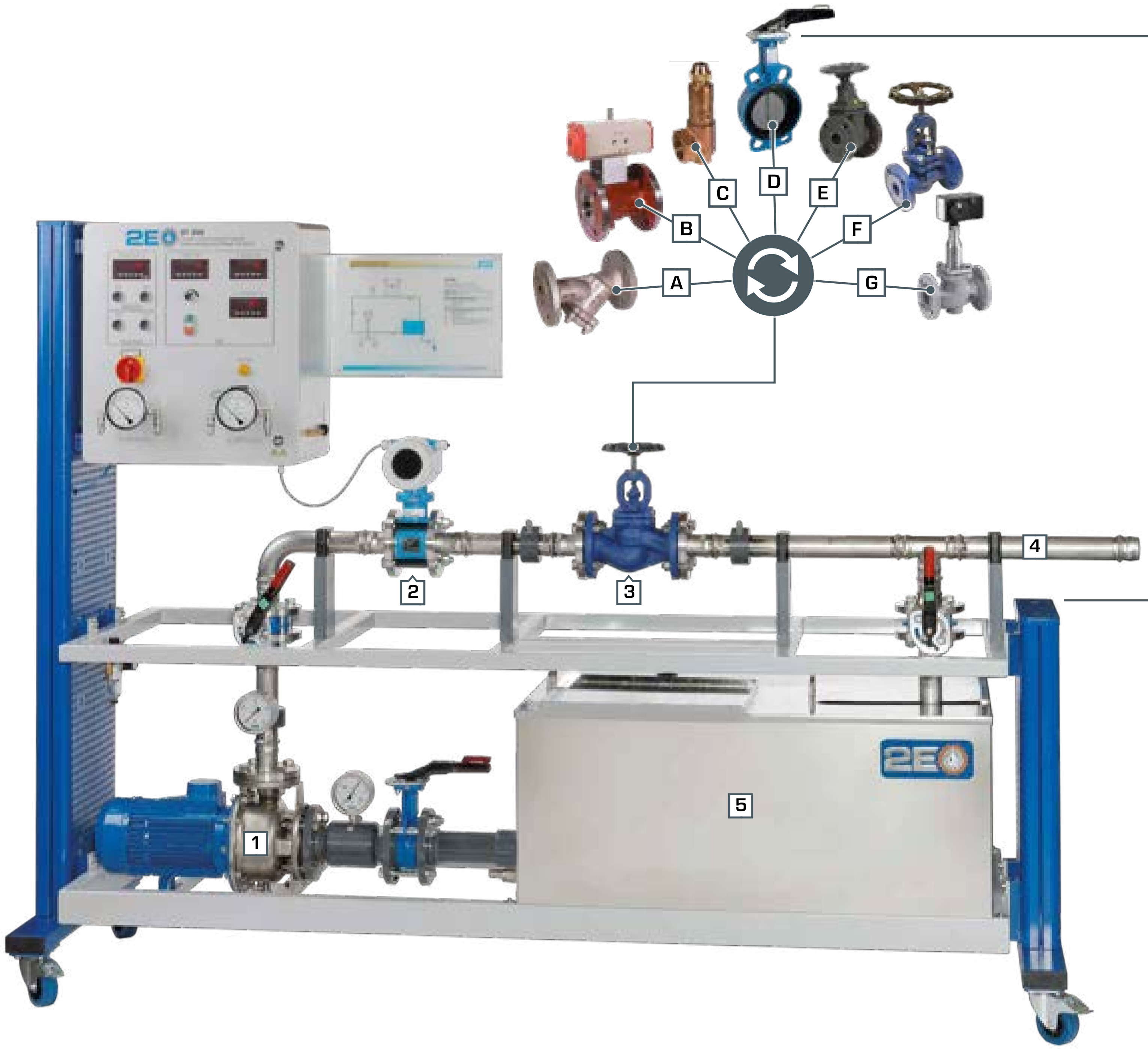
About the product:

www

Learning objectives

- coupled level and temperature control
- level control with
  - PI controller
  - feedforward control
- temperature control
  - with two-point controller
  - with three-point controller (split range)
  - with override control
  - via motorised valve with position monitoring
- recording of step responses

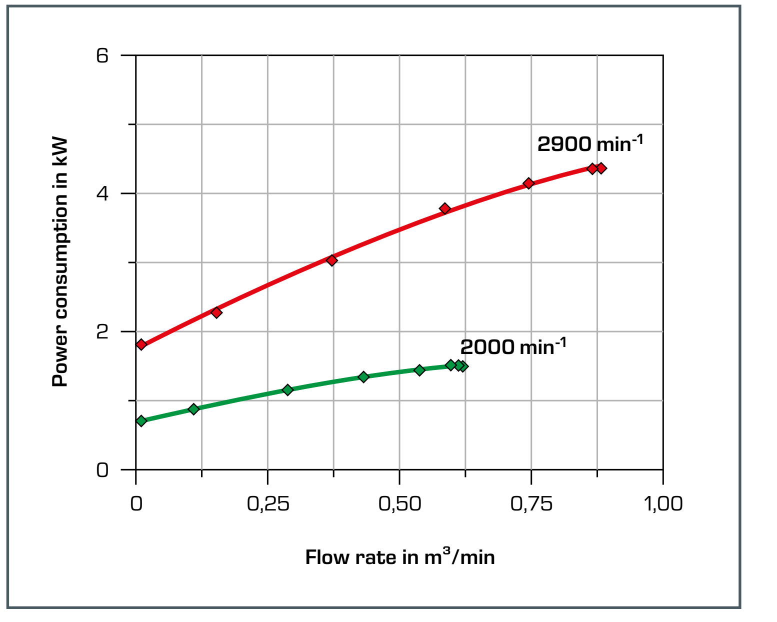
RT 396
Pump and valves and fittings test stand



A strainer
B ball valve
C safety valve
D shut-off butterfly valve
E wedge gate valve
F shut-off valve
G electric control valve

1 pump
2 flow rate sensor
3 interchangeable valve
4 pipe section
5 storage tank

The RT 396 trainer provides you with a test bench for pumps, valves and fittings. The test bench can be used to investigate a total of seven valves and fittings with regard to their operating principle and characteristic. You can also plot the pump characteristic and the power demand of the installed centrifugal pump, as well as determining the power demand of the series-connected centrifugal pump and valves and fittings for various flow rates. The Comparing the power demand without valves and fittings and the pressures occurring also allows you to determine the flow coefficients of the various valves and fittings.



Power consumption of the centrifugal pump at different speeds

Learning objectives

- operating behaviour and function of
  - ball valve
  - shut-off butterfly valve
  - shut-off valve
  - wedge gate valve
  - control valve
  - safety valve
  - strainer
- determining the Kvs value of the control valve
- pressure losses at the strainer according to the filter
- read and understand engineering drawings and operating instructions

About the product:

The complete GUNT programme – equipment for engineering education

Engineering mechanics and engineering design

- statics
- strength of materials
- dynamics
- machine dynamics
- engineering design
- materials testing

Mechatronics

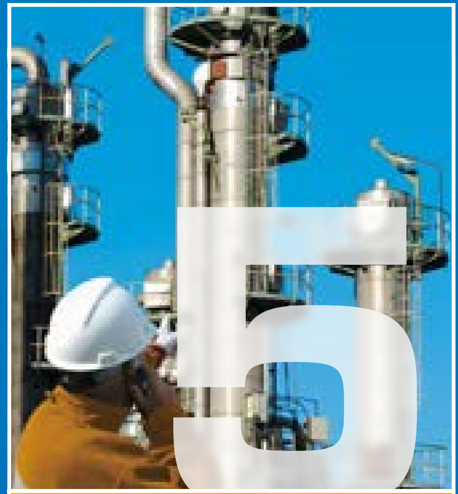
- engineering drawing
- cutaway models
- dimensional metrology
- fasteners and machine parts
- manufacturing engineering
- assembly projects
- maintenance
- machinery diagnosis
- automation and process control engineering

Thermal engineering

- fundamentals of thermodynamics
- thermodynamic applications in HVAC
- renewable energies
- thermal fluid energy machines
- refrigeration and air conditioning technology

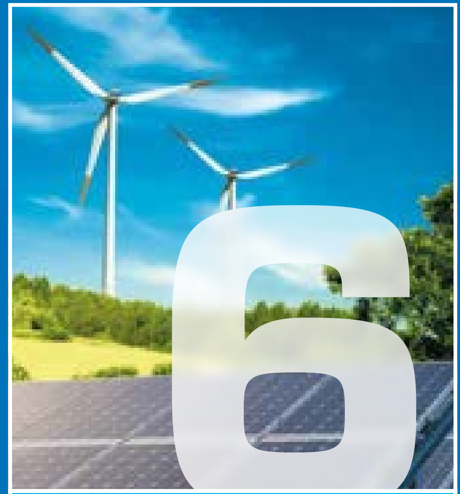
Fluid mechanics

- steady flow
- transient flow
- flow around bodies
- fluid machinery
- components in piping systems and plant design
- hydraulic engineering



Process engineering

- mechanical process engineering
- thermal process engineering
- chemical process engineering
- biological process engineering
- water treatment



2E Energy & Environment

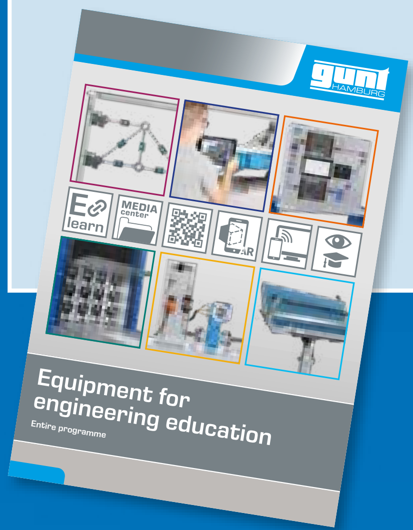
Energy

- 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



Product overview

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