



ENERGY & ENVIRONMENT

EQUIPMENT FOR ENGINEERING EDUCATION

2E a division of



Renewable Energies  
and Energy Efficiency

Sustainable Technology for  
Environmental Protection





# 2E – Energy & Environment

# Contents

## Welcome to 2E

Our 2E section is where we at GUNT meet the challenge of developing a sophisticated range of teaching and research systems for the energy and environment sectors.

The purpose of this catalogue is to provide you with as comprehensive as possible an overview of our innovative teaching and research systems from the energy and environment field.

|     |                                                                                       |                                                    |     |
|-----|---------------------------------------------------------------------------------------|----------------------------------------------------|-----|
| 1   | Energy: Renewable Energies and Energy Efficiency                                      |                                                    | 006 |
| 1.1 |    | Solar Energy                                       | 014 |
| 1.2 |    | Hydropower and Ocean Energy                        | 042 |
| 1.3 |    | Wind Power                                         | 062 |
| 1.4 |    | Biomass                                            | 088 |
| 1.5 |   | Geothermal Energy                                  | 106 |
| 1.6 |  | Energy Systems                                     | 140 |
| 1.7 |  | Energy Efficiency in Building Services Engineering | 180 |
| 2   | Environment: Sustainable Technology for Environmental Protection                      |                                                    | 232 |
| 2.1 |  | Water                                              | 238 |
| 2.2 |  | Air                                                | 282 |
| 2.3 |  | Soil                                               | 294 |
| 2.4 |  | Waste                                              | 314 |
|     | Index                                                                                 |                                                    | 326 |
|     | Product Overview                                                                      |                                                    | 330 |

### Imprint

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# The 2E Curriculum

In the context of global climate change and increasing scarcity of resources, GUNT, with its 2E programme, is assuming responsibility for ensuring principles of sustainability are firmly embedded in engineering education.

The fields of energy and the environment are considered jointly in an integrated curriculum because they play a fundamental and key role in modern engineering.

Lectures and laboratory exercises from the fields of energy and the environment are already standard for a broad range of engineering disciplines, such as electrical engineering, mechanical engineering, plant manufacturing, power engineering, process engineering, environmental engineering and civil engineering. The topics of these specialist fields have become an indispensable part of the teaching programme in vocational education and training for many technical professions.

## The appropriate 2E teaching system for the requirements of your curriculum

The structure and layout of a product catalogue can never be fully adapted to a curriculum. Many experimental units have a complex design and cover several different elements of the curriculum. And not all elements of the curriculum need to be supported by experi-

ment-based investigation. We have provided a thematic index and a product overview in the appendix to this catalogue so that you can find the GUNT device that best suits your specific needs.

## Well-founded knowledge

We are convinced that well-founded knowledge represents a key factor in the development of sustainable energy and environmental engineering. Of course, there are further important experiments in the area

of fundamental principles which are not listed here. With this in mind, we would like to recommend our proven range from catalogues 1 to 5.

## What can GUNT do for you...

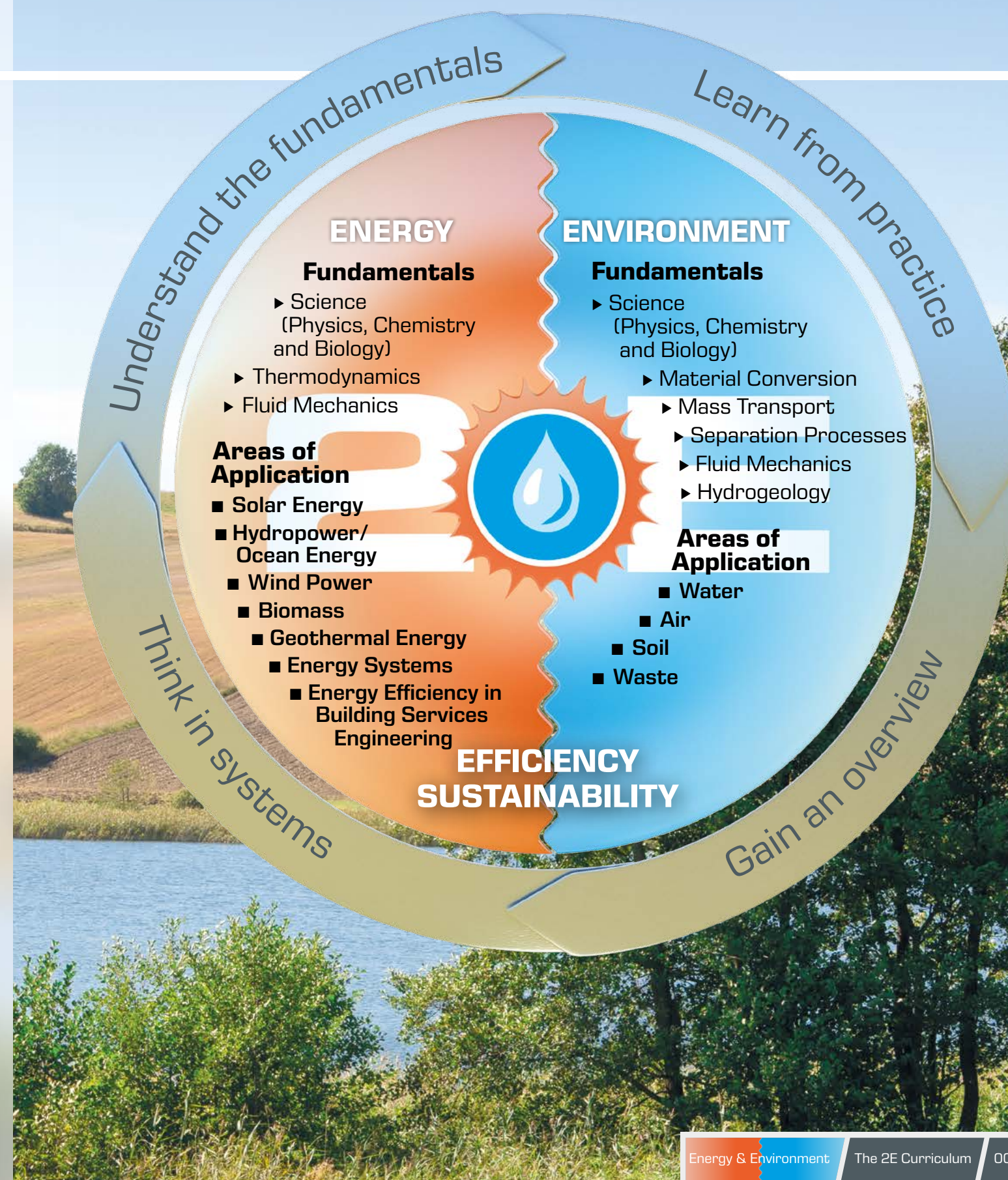
...to support and enrich your lecture or your teaching?

We provide demonstration, experiment and research equipment for the many topics that can be expected as part of a forward-looking curriculum in the area of energy and the environment.

We all know – you being a lecturer in schools and colleges and us being a developer and manufacturer – that well thought-out and clear experiments result in a stable and sustainable foundation for knowledge in pupils and students.

We have been developing experimental units for relevant areas of engineering education for more than 30 years and are constantly improving our product ranges.

When developing and designing this catalogue we have thought through and improved everything once more. You are now holding the result of these efforts in your hands. Should you have further ideas for teaching systems in this product range, please get in touch. We are here for you, anywhere in the world.





# Renewable Energies and Energy Efficiency

2E a division of



Increase your competitiveness in the field of engineering education through experimental units which are didactically fully developed and designed for professionals. Take advantage of the comprehensive conceptual design of the 2E curriculum.

## Contents: Part 1

|                |                                                                    |     |
|----------------|--------------------------------------------------------------------|-----|
|                | <b>Basic Knowledge</b><br>Renewable Energies and Energy Efficiency | 008 |
|                | <b>Subject Areas</b><br>Renewable Energies and Energy Efficiency   | 012 |
| <b>1.1</b><br> | <b>Solar Energy</b>                                                | 014 |
|                | Photovoltaics                                                      | 020 |
|                | Solar Thermal Energy                                               | 030 |
| <b>1.2</b><br> | <b>Hydropower and Ocean Energy</b>                                 | 042 |
|                | Hydropower                                                         | 046 |
|                | Ocean Energy                                                       | 058 |
| <b>1.3</b><br> | <b>Wind Power</b>                                                  | 062 |
|                | Fundamentals of Wind Energy Engineering                            | 068 |
|                | Application Engineering in Wind Power Plants                       | 076 |
| <b>1.4</b><br> | <b>Biomass</b>                                                     | 088 |
|                | Bioethanol                                                         | 092 |
|                | Biogas                                                             | 098 |
|                | Biodiesel                                                          | 104 |
| <b>1.5</b><br> | <b>Geothermal Energy</b>                                           | 106 |
|                | Heat Exchangers                                                    | 112 |
|                | Shallow Geothermal Energy                                          | 122 |
|                | Deep Geothermal Energy                                             | 132 |
| <b>1.6</b><br> | <b>Energy Systems</b>                                              | 140 |
|                | Conversion                                                         | 146 |
|                | Storage                                                            | 160 |
| <b>1.7</b><br> | <b>Energy Efficiency in Building Services Engineering</b>          | 180 |
|                | Heat Supply and Air Conditioning                                   | 184 |
|                | Inclusion of Renewable Energies                                    | 200 |
|                | Energy Efficiency in Business and Industry                         | 214 |



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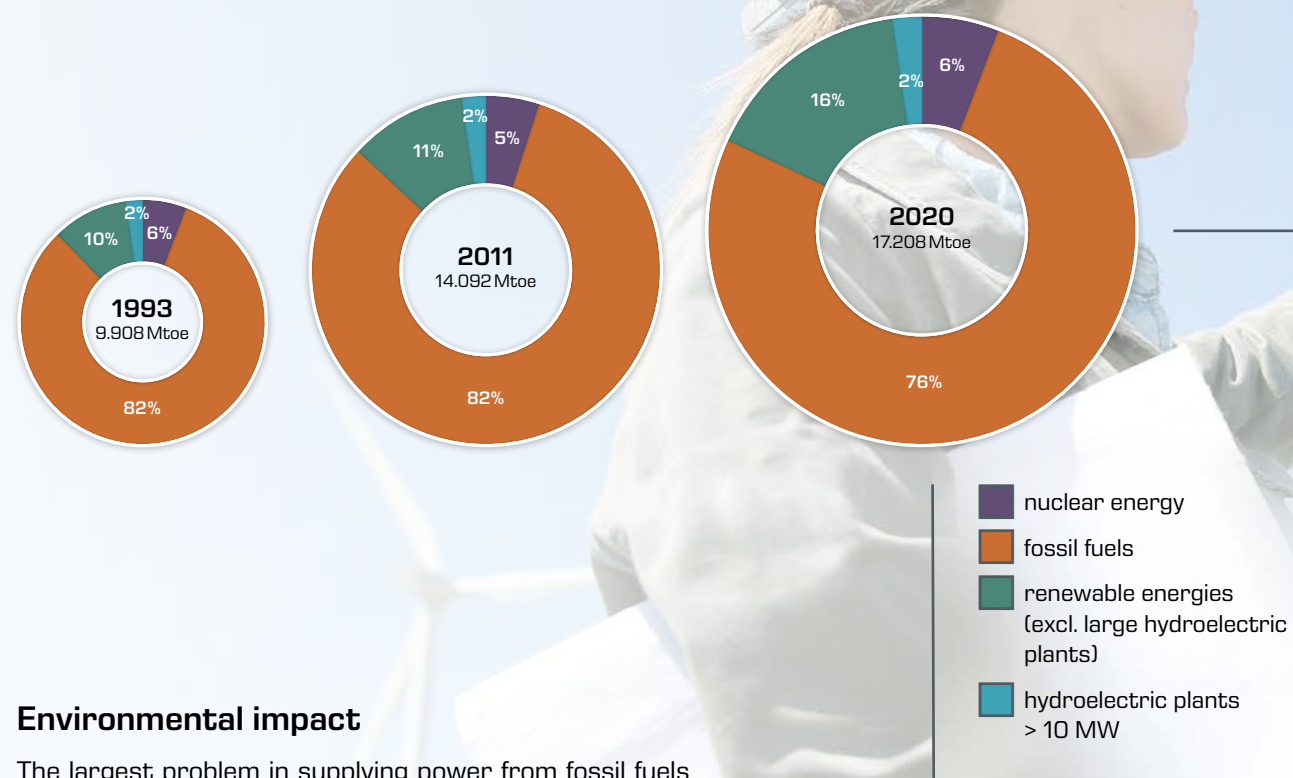
# Basic Knowledge Renewable Energies and Energy Efficiency



## 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 diagram from the World Energy Council (WEC) shows the rising consumption of primary energy from 1993 to 2011 and a forecast for 2020. Despite an increasing share of renewable energies, it is evident that the total quantity of fossil fuels being used is rising.



Source: WEC Survey of Energy Resources  
Mtoe – million tonnes of oil equivalent  
1 Mtoe = 0,041868 EJ (exajoule) = 11630GWh

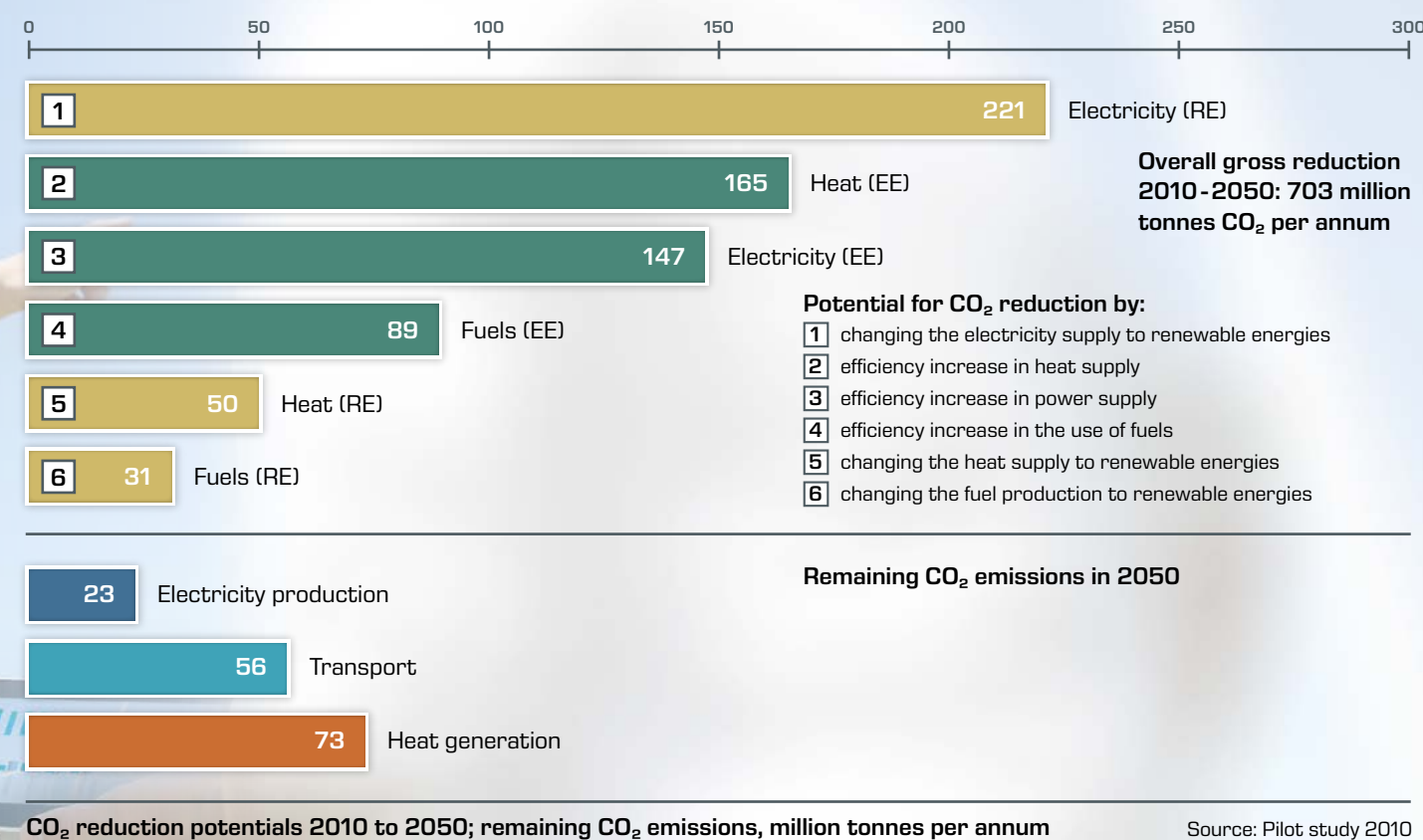
## Environmental impact

The largest problem in supplying power from fossil fuels is the fact that deposits are finite and the environmental impact of harmful waste products. Both the CO<sub>2</sub> 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.

## Protecting the climate through renewable energies (RE) and energy efficiency (EE)

In view of climate change, it is necessary to assess the suitability of energy supply technologies through their potential to reduce greenhouse gases. This is mostly done in consideration of technical, economic and social perspectives. The graphic below summarizes the results

of a study for Germany (pilot study 2010) for a given scenario. It shows the expected reduction in CO<sub>2</sub> emissions for Germany in million tonnes per annum for 2010 to 2050.



Source: Pilot study 2010 (BMU - FKZ 03MAP146)

It is apparent from the graphic that, in the given scenario for Germany, a CO<sub>2</sub> saving of 703 million tonnes total per annum is achieved from 2010 to 2050. The graphic also lists 152 million tonnes of CO<sub>2</sub> emissions remaining in 2050, classified by sector. Energy production from renewable energies delivers the highest contribution to cutting CO<sub>2</sub> emissions. A comparable order of magnitude is achieved by energy efficiencies in heat

and electricity generation. The basis for the scenario is phasing out nuclear energy use by 2020.

The graphic on the following page shows the development of energy production from separate sources over time.

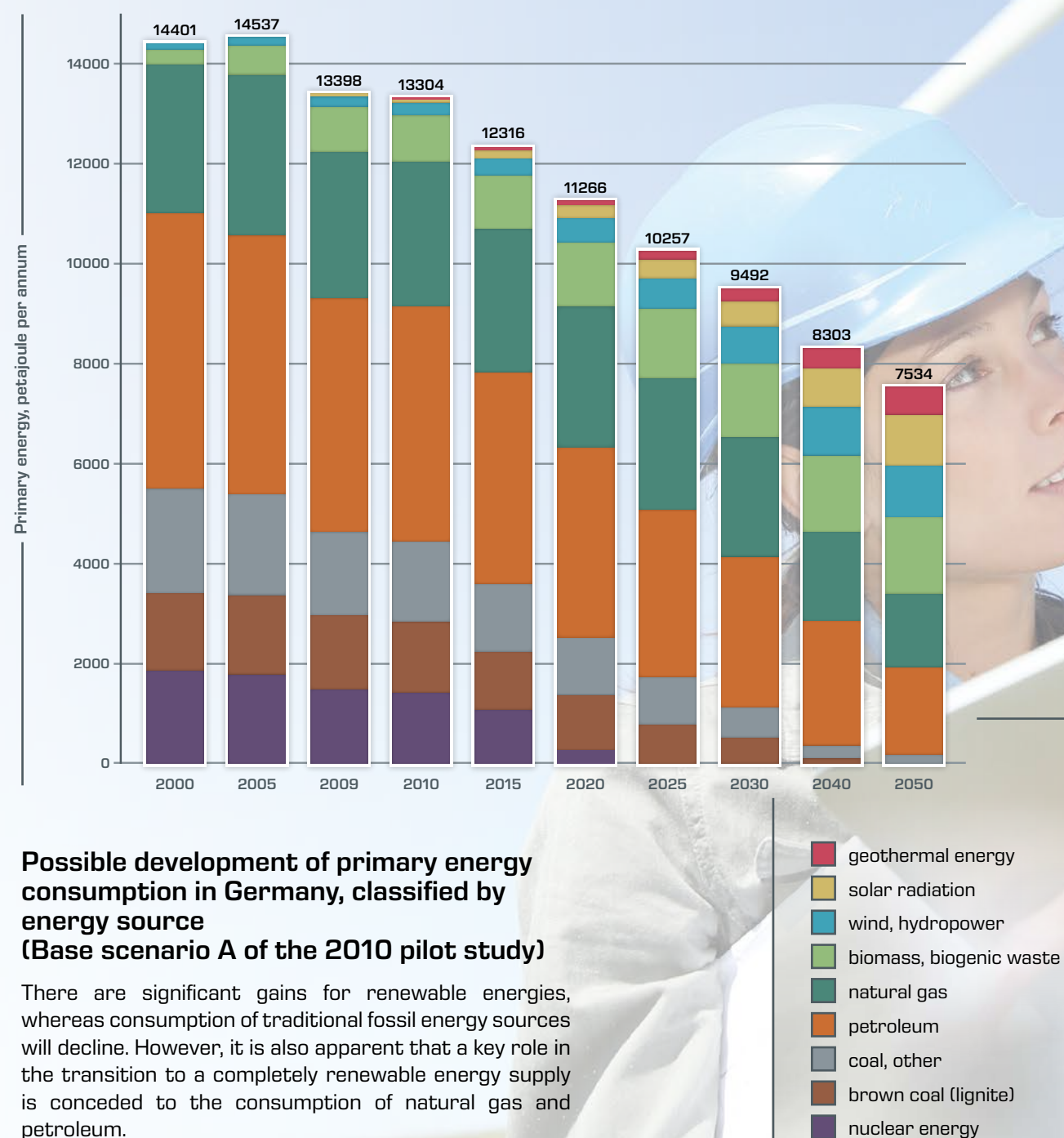


# Basic Knowledge

## Renewable Energies and Energy Efficiency



### Development of renewable energies / Reduction of energy demand



### Efficient use of energy

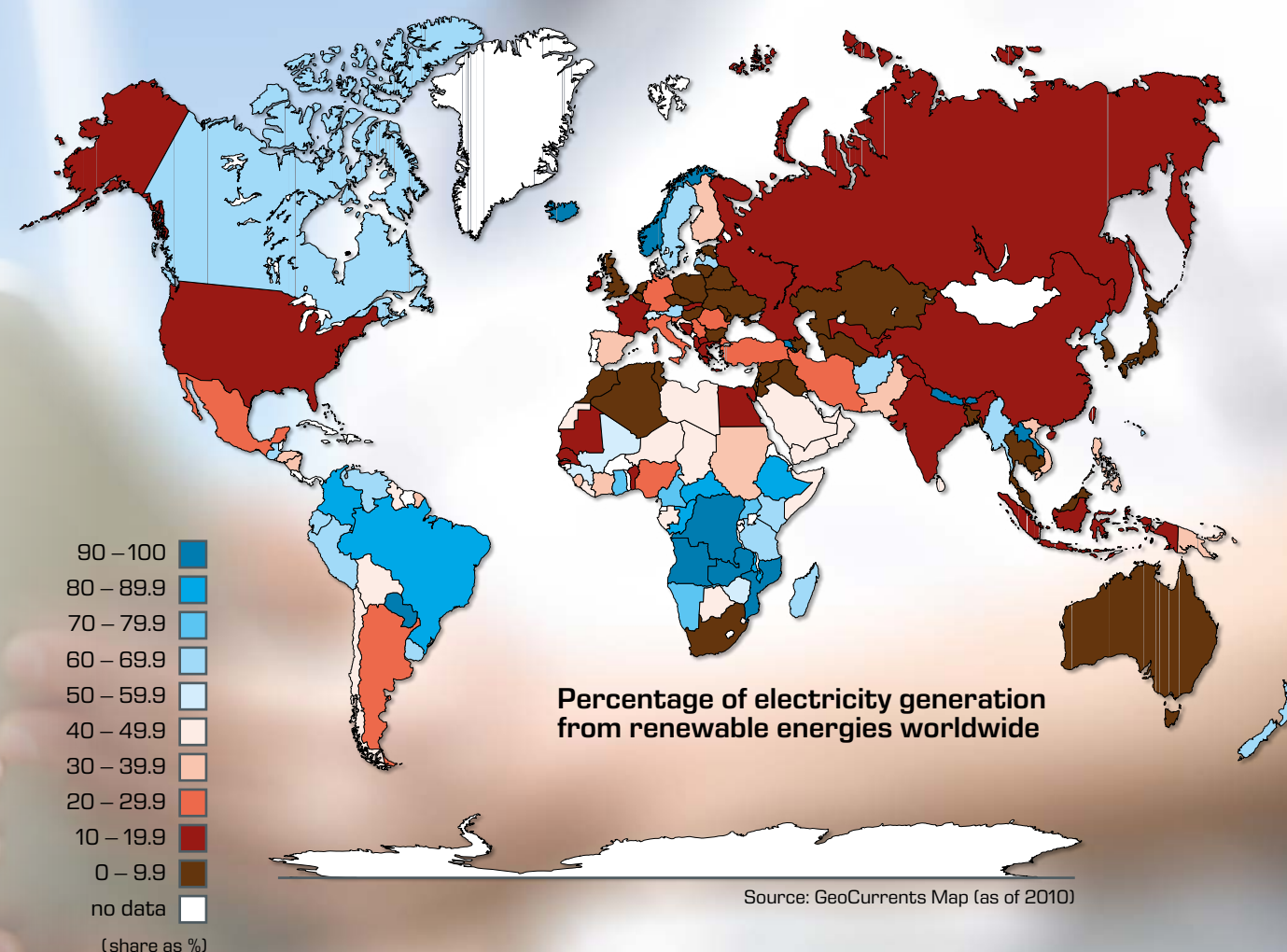
Besides increasing the share of renewable energies, one considerable challenge lies in the efficient use of available energy. It is only once adequate progress can be made in both areas at the global level that we will succeed in reducing the dangerous output of greenhouse gases to a tolerable level.

With our carefully structured product range in the 2E 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 the changeover 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 summary of global energy production by renewable energies:





# 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 from the various primary sources of renewable energy. What is more, we consider the

optimisation of energy systems in particular and the improvement of energy efficiency in buildings especially as the most effective opportunities to implement the holistic approach of the 2E area.

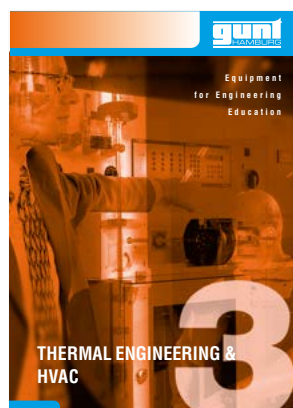
## The fundamentals of energy engineering

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

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 catalogues include devices which are relevant to these fundamental areas:

We provide you with the most appropriate teaching systems for putting the areas of the 2E curriculum into practice through experimentation. The graphic shows the key elements, which we have sub-divided into the main areas.



**Catalogue 3**  
Thermal Engineering  
and HVAC



**Catalogue 4**  
Fluid Mechanics



**Catalogue 5**  
Process Engineering



# Solar Energy

1.1

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| Introduction |                                        |     |
|--------------|----------------------------------------|-----|
|              | <b>Subject Areas</b><br>Solar Energy   | 016 |
|              | <b>Basic Knowledge</b><br>Solar Energy | 018 |

| Photovoltaics |                                                                     |     |
|---------------|---------------------------------------------------------------------|-----|
|               | <b>Basic Knowledge</b><br>Photovoltaics                             | 020 |
|               | <b>ET 250</b><br>Solar Module Measurements                          | 022 |
|               | <b>ET 250.01</b><br>Photovoltaic in Grid-connected Operation        | 024 |
|               | <b>ET 250.02</b> Stand Alone<br>Operation of Photovoltaic Modules   | 025 |
|               | <b>ET 252</b><br>Solar Cell Measurements                            | 026 |
|               | <b>ET 255</b> Using Photovoltaics:<br>Grid connected or Stand-alone | 028 |

| Solar Thermal Energy |                                                                             |     |
|----------------------|-----------------------------------------------------------------------------|-----|
|                      | <b>Basic Knowledge</b><br>Solar Thermal Energy                              | 030 |
|                      | <b>ET 202</b><br>Principles of Solar Thermal Energy                         | 032 |
|                      | <b>WL 377</b><br>Convection and Radiation                                   | 034 |
|                      | <b>HL 313.01</b><br>Artificial Light Source                                 | 035 |
|                      | <b>HL 313</b><br>Domestic Water Heating with Flat Collector                 | 036 |
|                      | <b>Overview</b> HL 320 Solar Thermal Energy<br>and Heat Pump Modular System | 038 |



Our artificial light source HL 313.01 enables laboratory experiments to be conducted under uniform and therefore reproducible boundary conditions. This enables you to plan and carry out your experiments regardless of the weather conditions.


Visit our website at:  
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# Subject Areas

# Solar Energy



Subject Areas

2E Products

## Putting solar energy to good use

In principle, two different areas can be distinguished in solar energy usage: photovoltaics and solar thermal energy.

In photovoltaics, electrical energy is generated directly whereas heat is generated first in the case of solar thermal energy. 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 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 smaller solar installations is the ability to provide electricity and/or heat close to the consumer and according to demand. In order to tap the full potential of solar energy as a sustainable energy supply, it is essential that we understand and develop modern concepts of use.

## Photovoltaics

Application engineering 1 –  
**correct use of photovoltaic solar  
modules**

**ET 250**  
Solar Module Measurements

**ET 250.01**  
Photovoltaic 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**  
Using Photovoltaics: Grid connected or Stand-alone

## 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 flat collectors**

**HL 313**  
Domestic Water Heating with Flat Collector

Application engineering 2 –  
**combined use of renewable  
heat sources**

**HL 320**  
Solar Thermal Energy and Heat Pump Modular System

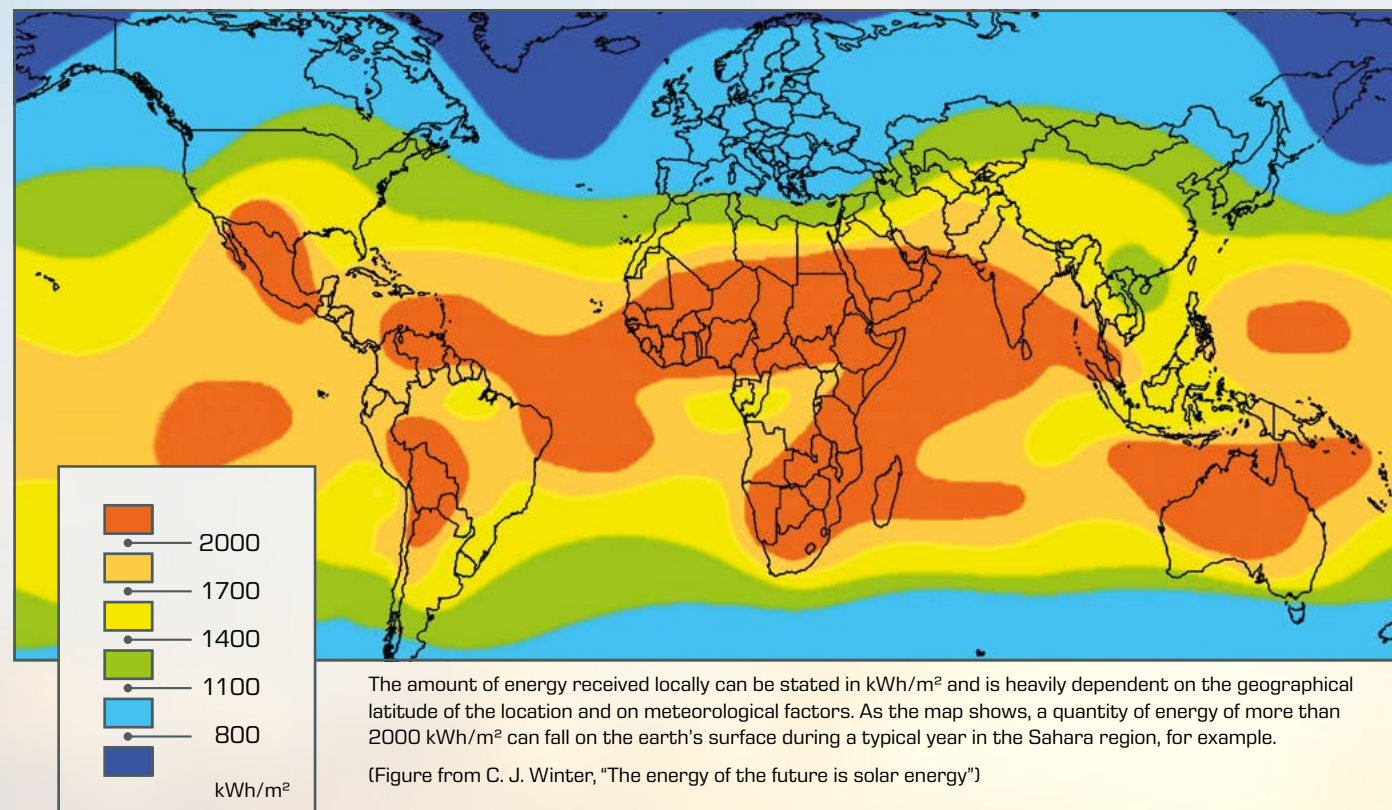


# Basic Knowledge Solar Energy

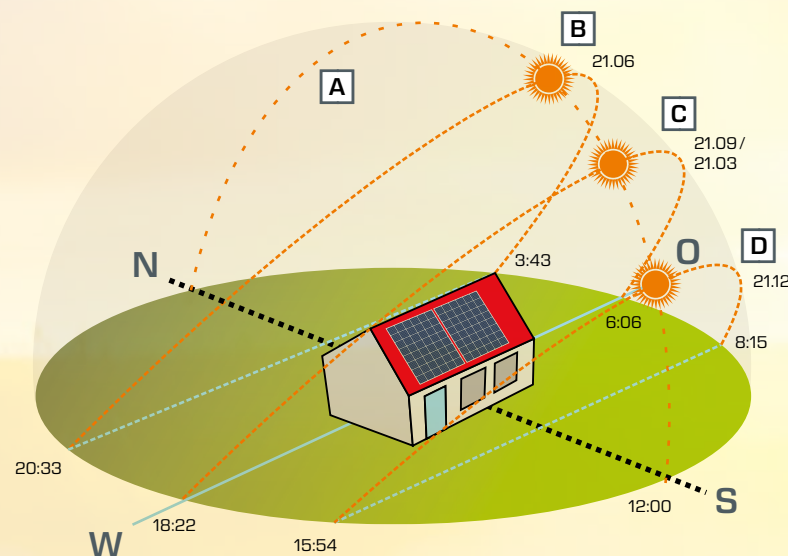


## Energy galore

The amount of solar energy that falls on the Earth's land areas over one year is almost 2000 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.



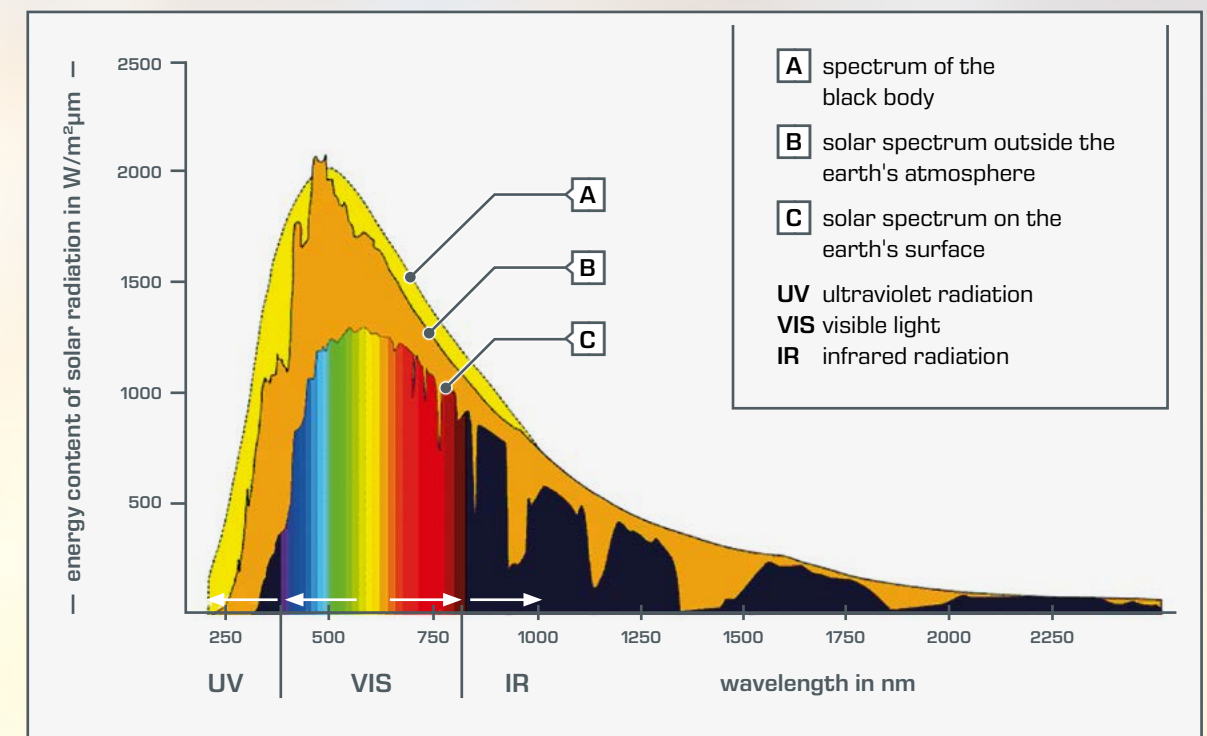
The orientation of the module surfaces to the compass direction and their inclination play a significant role in optimising the yield of a solar installation. The illustration shows the path of the sun visible on the Earth at different seasons of the year. The times given for sunrise and sunset are for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

lengths. 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

Fusion processes inside the sun lead to temperatures of up to  $15 \cdot 10^6$  K. However, the spectrum of emitted sunlight is based on processes in the outer layers of the sun. The spectral composition can be theoretically described by a so-called black body with a surface temperature of 5777 K. On its way to the earth's surface,

solar radiation is weakened in the atmosphere by scattering and absorption.

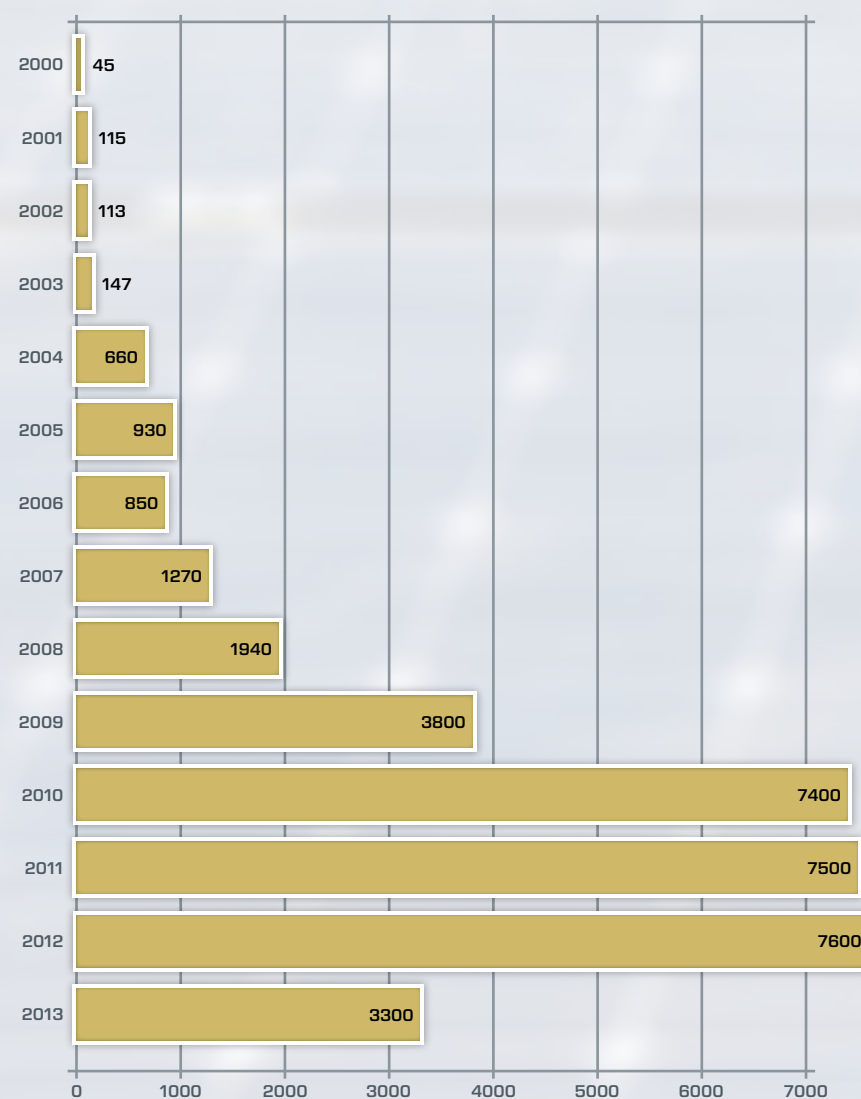


# Basic Knowledge Photovoltaics

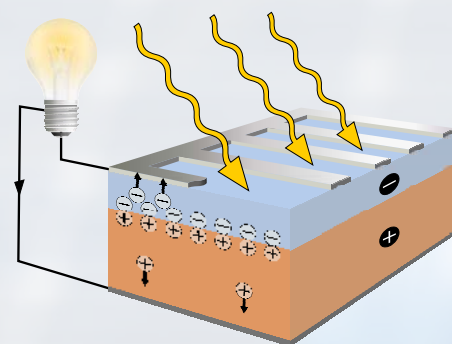


In recent years, economic incentives and successful technological developments have led to a significant growth in installed photovoltaic capacity.

The advantages of converting light into electricity directly 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<sub>p</sub>  
(Source: BSW-Solar)

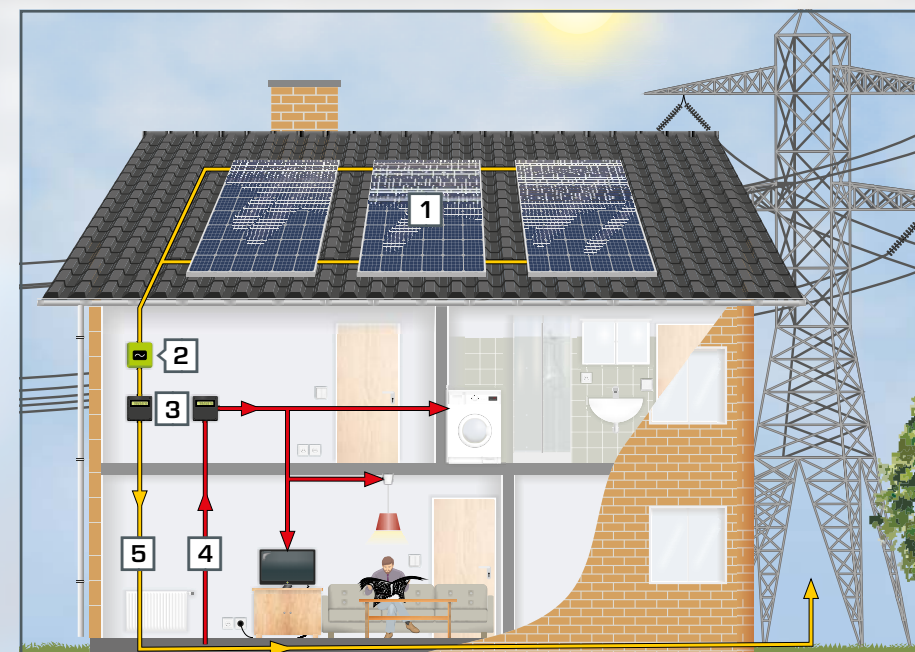


## How semiconductor solar cells work

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.



## Using solar power efficiently

In order to collect the photovoltaic solar power, for example 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 be able to use the electrical energy at night as well, 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.

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

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. The proportion of solar power which is consumed at the point of generation can be considerably increased by skilfully managing consumption and storage load.



# 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.

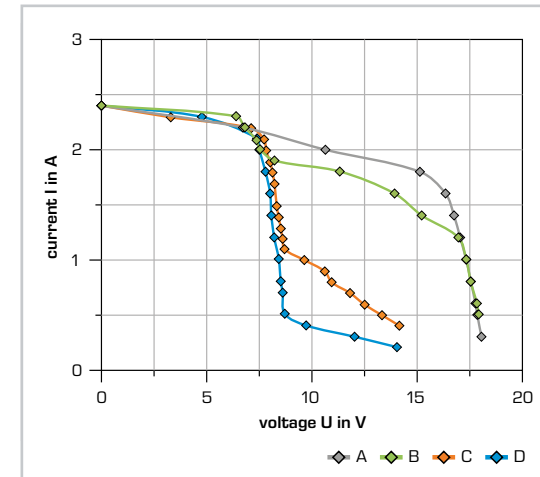


Clearly-arranged measuring unit

Pivoting photovoltaic modules

## Experiments in shading

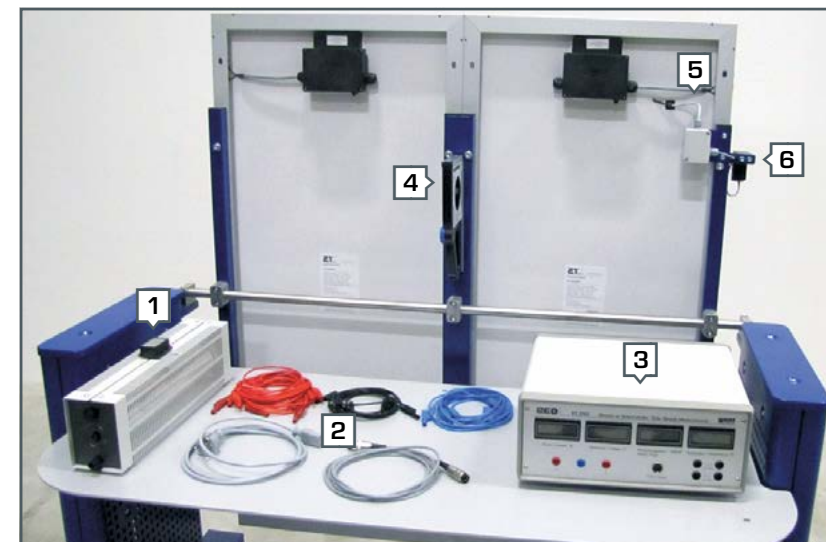
In many places, shading is a major cause of yield losses. ET 250 is also designed for specific experiments on this effect. The results can be compared with documented reference experiments. The figure shows current-voltage curves for different shading levels of individual cells in a module (A, B, C,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



**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 capacity
- plotting current-voltage curves in parallel and series connection
- influence of the solar module inclination
- determining the efficiency

With this trainer, you can demonstrate all the key aspects in the operation of solar modules in practice. 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.



- Accessories and components
- 1 slide resistor
  - 2 cable sets
  - 3 measuring unit
  - 4 inclinometer
  - 5 illuminance sensor
  - 6 temperature sensor



## ET 250.01

Photovoltaic in  
Grid-connected Operation

## ET 250.02

Stand Alone Operation  
of Photovoltaic Modules

The amount of feed-in electricity is measured via a modern bi-directional energy meter.

The inverter works in grid-connected mode and varies current and voltage for maximum output of the solar modules.



Simpler inverters can be used in stand-alone operation, since monitoring of the mains voltage is not necessary.

The charge controller monitors the voltage of the battery and prevents deep discharge.

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

#### Learning objectives

- function of components for grid-connected operation
- safety devices in photovoltaic systems
- function of a line-commutated inverter with capacity optimisation (MPP tracker)
- function of modern bi-directional energy meters
- conversion efficiency of a line-commutated inverter
- energy balance in grid-connected operation

ET250.01 is designed as an extension module for ET250 and allows you to expediently supplement the learning content of ET 250. ET 250.01 contains the practical components from the field of photovoltaics which are needed for utilisation of the solar power when connected to a public grid.

#### Learning objectives

- function of components for stand-alone operation
- function of a charge controller with capacity optimisation (MPP tracker)
- use of accumulators
- inverters in stand-alone operation
- safety devices in photovoltaic systems in stand-alone operation
- conversion efficiency of a stand-alone inverter
- energy balance in stand-alone operation

Product No.  
061.25001  
More details and technical data:  
[gunt.de/static/s5276\\_1.php](http://gunt.de/static/s5276_1.php)



Product No.  
061.25002  
More details and technical data:  
[gunt.de/static/s5277\\_1.php](http://gunt.de/static/s5277_1.php)



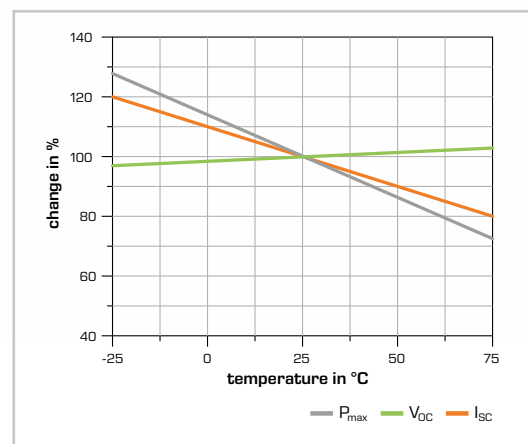


# ET 252 Solar Cell Measurements



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

The main components of the experimental unit are four solar cells. 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.

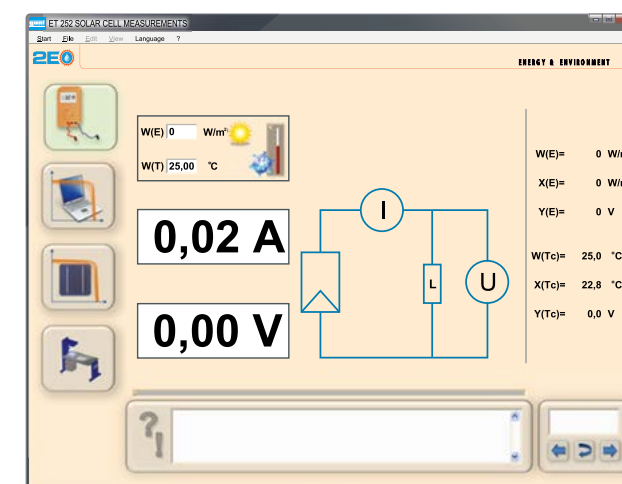


ET 252 allows you to investigate the specific effect of temperature on the solar cell.

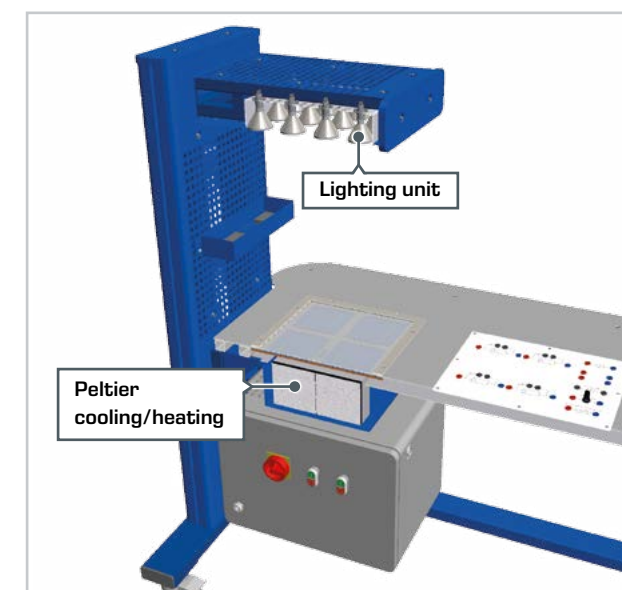


## Software with tutorial function

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 automated measurement of the characteristic curve via the controllable current sink.



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



Sectional view of the components of ET 252



## Learning objectives

- current-voltage curves of solar cells
- series and parallel connection of solar cells
- effect of temperature on the solar cell parameters
- behaviour of the solar cell at different illuminance and partial shading





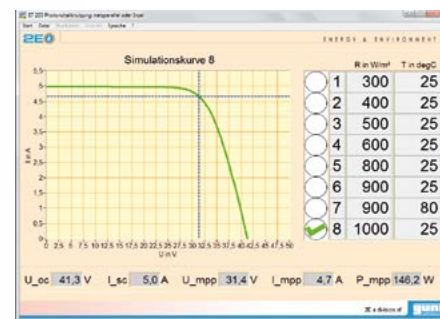
# ET 255 Using Photovoltaics: Grid connected or Stand-alone



The ET 255 trainer allows you to investigate real world components from the field of photovoltaics for mains feed-in and for stand-alone operation under real operating conditions. You can work with real photovoltaic modules (ET 250) or use the integrated photovoltaic simulator.

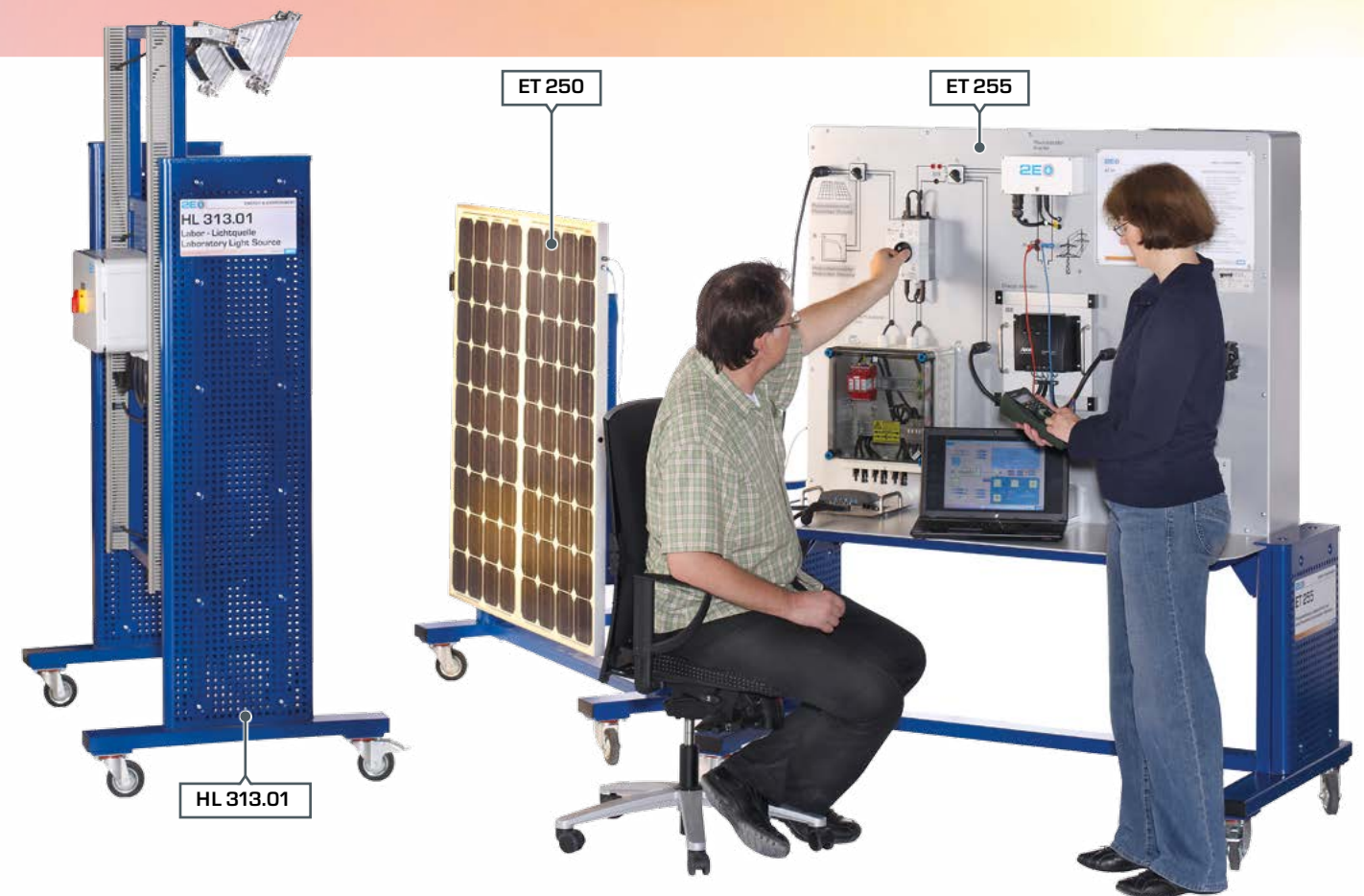
## Software

The photovoltaic simulator makes it possible to investigate the effects of changing illuminance and temperatures. The photovoltaic simulator's easy-to-understand user interface can be used to select different characteristic curves.

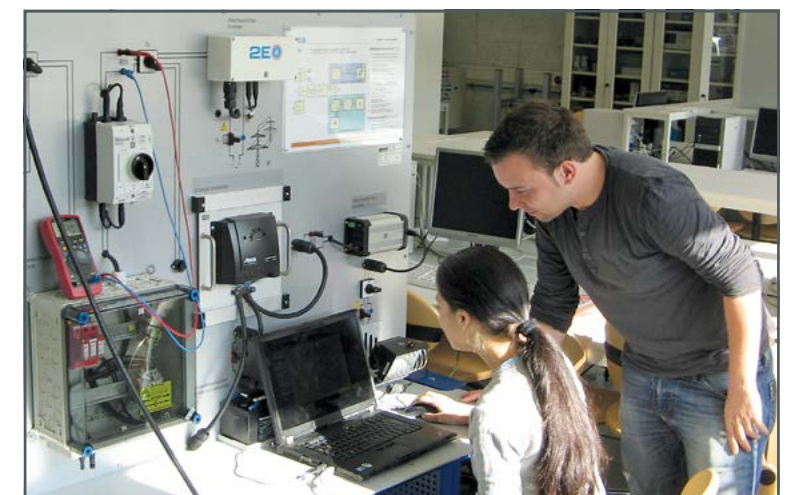
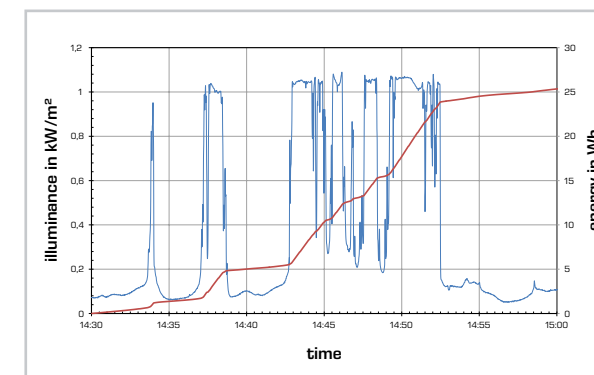


## Learning objectives

- function of line-commutated inverters
- function of charge controllers and accumulators in stand-alone operation
- efficiency and dynamic behaviour of system components
- function of MPP tracker



When connecting ET 250 to ET 255, the measured values from the photovoltaic modules are transmitted to ET 255. The data can be recorded and displayed with the corresponding software. As shown below, this data can be used in spreadsheets for yield calculations.



At Joanneum Technical College in Kapfenberg, Austria, the ET 255 trainer is used for practical experiments in the field of energy and environmental management. The photovoltaic simulator can be used to conduct experiments on the efficiency of photovoltaic systems without interference from the weather.





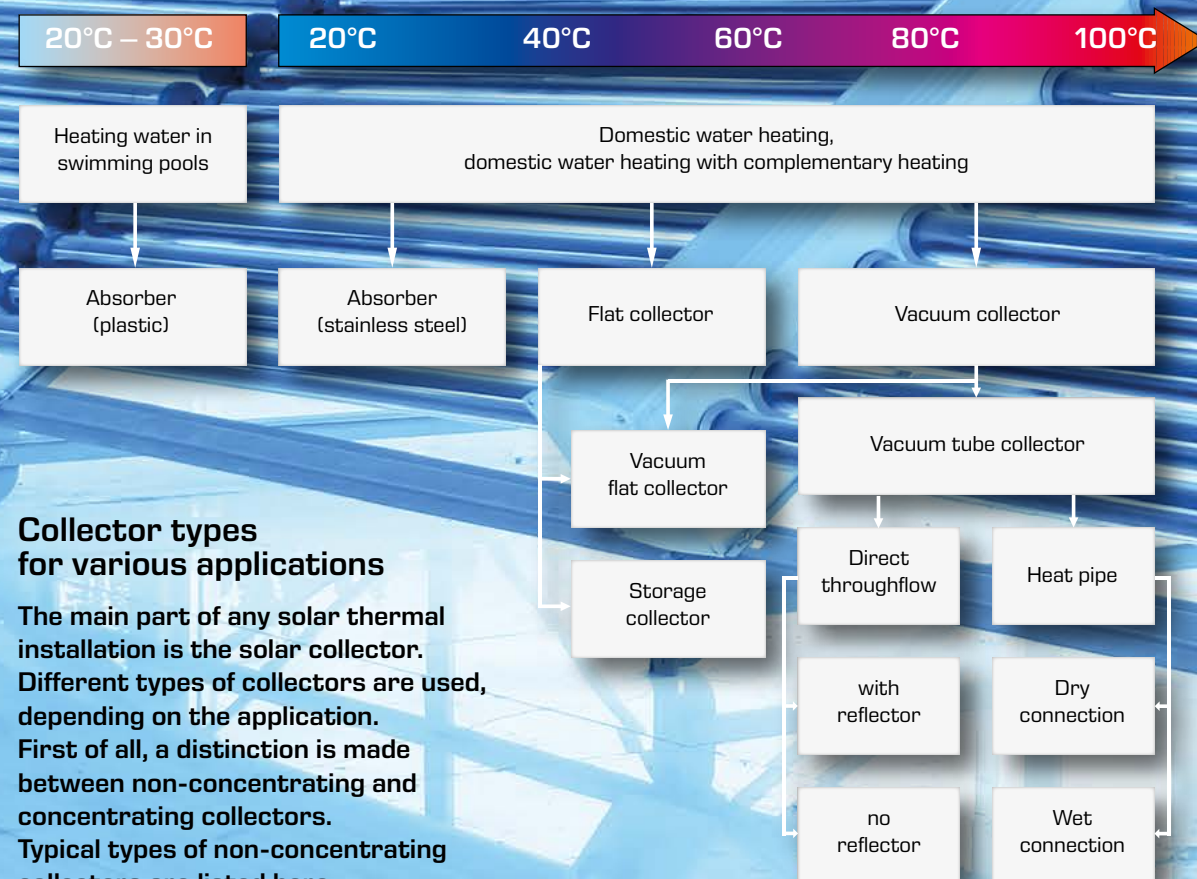
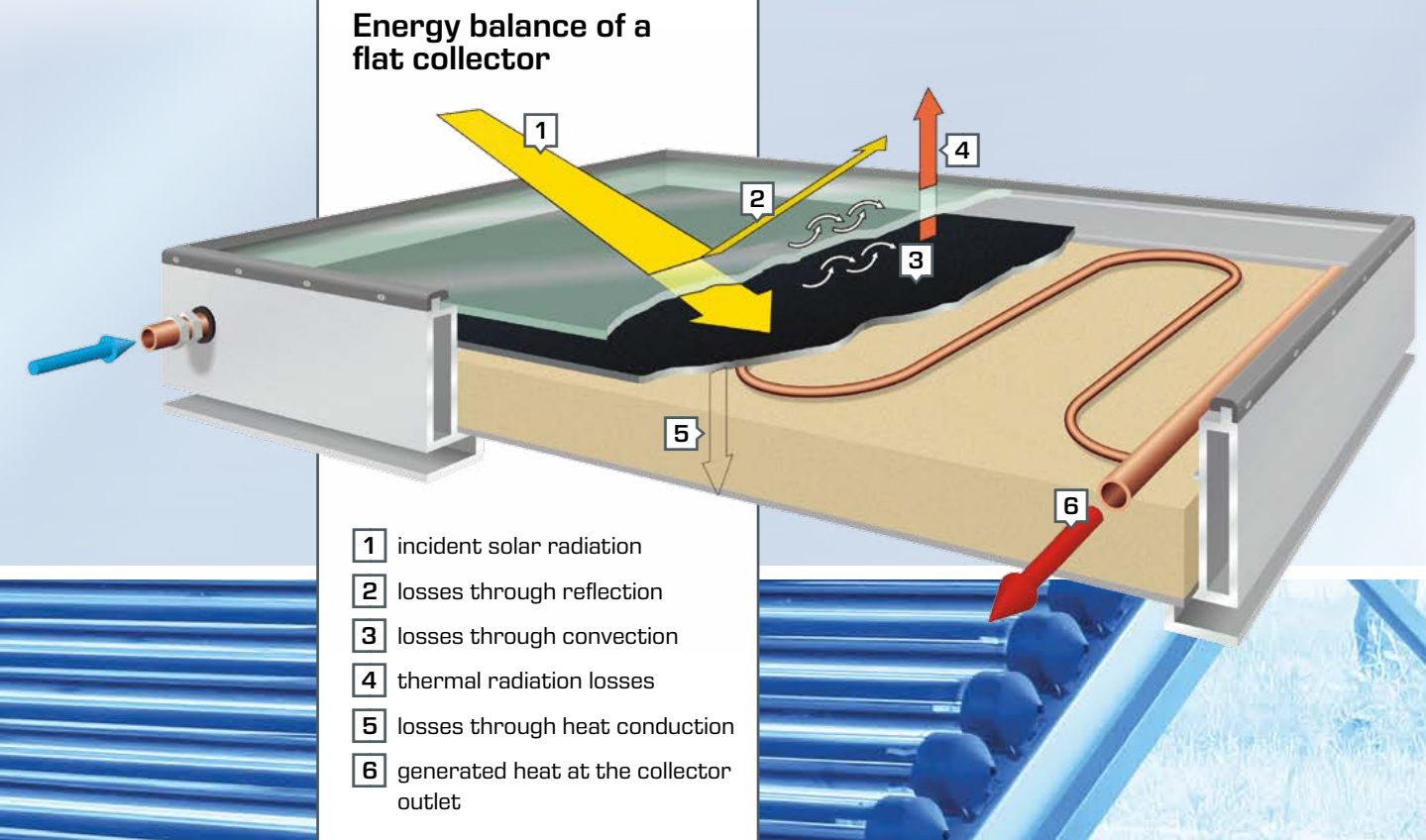
# Basic Knowledge Solar Thermal Energy



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)



## Minimising losses

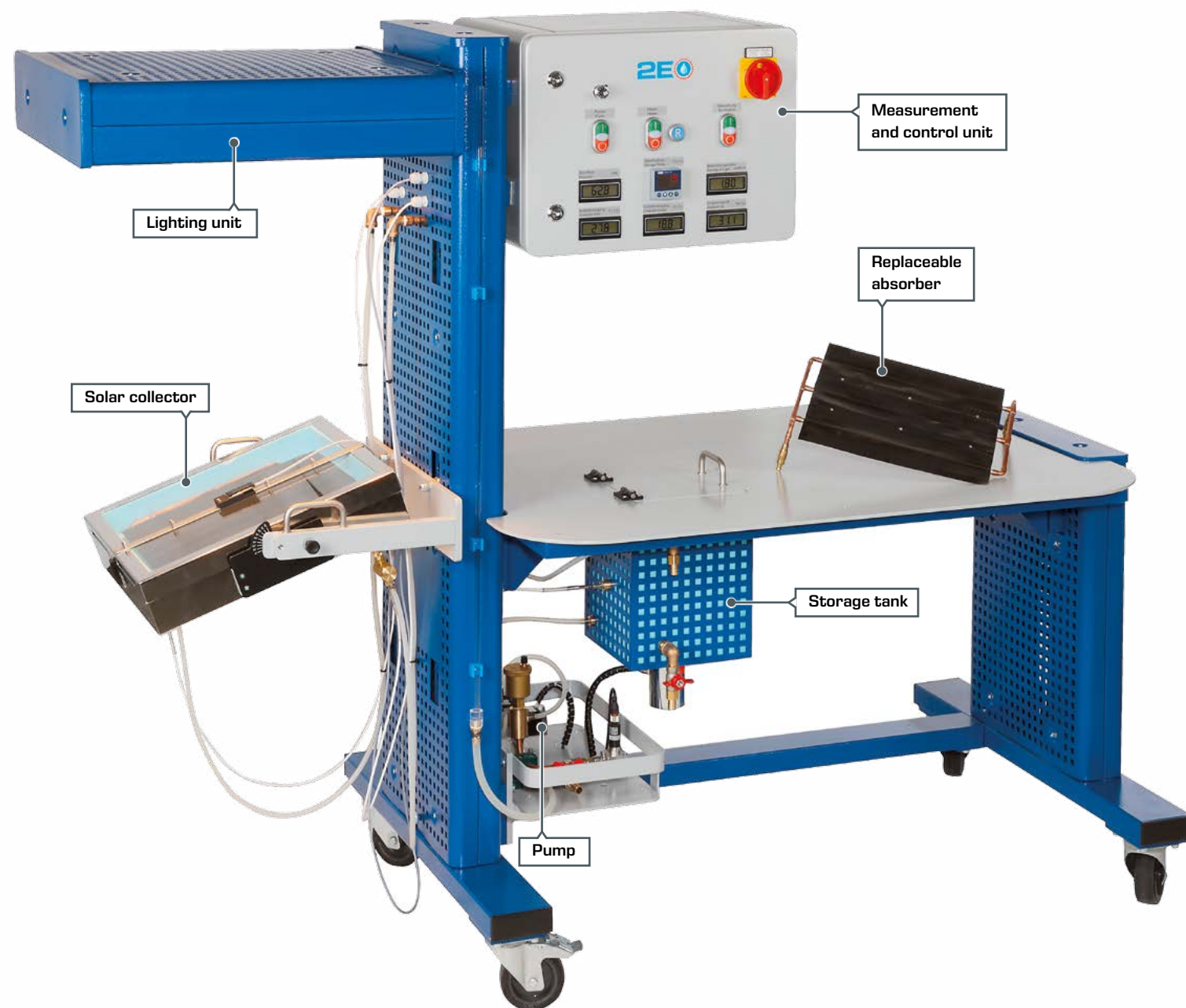
One of the main objectives for modern collectors is to minimise losses. The proportions of the major loss types in thermal solar energy utilisation with flat collectors are shown diagrammally in the figure above.

## Heating using solar energy

The sun's energy keeps our environment at an average temperature which is essential for our survival. Solar radiation creates temperature differences and thus the requirements for local climate and weather conditions. Comparable effects can be seen at both the global level and in the considerably smaller dimensions of a solar thermal collector.

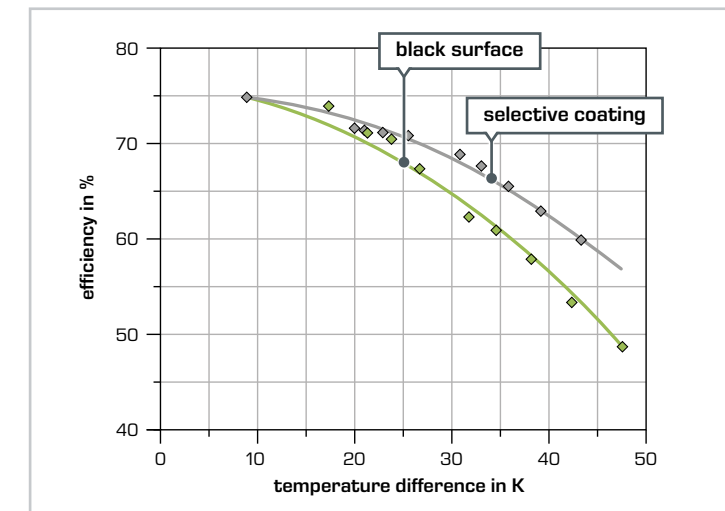


# ET 202 Principles of Solar Thermal Energy



The ET202 trainer allows you to conduct systematic experiments on a solar thermal system with a flat collector. A lighting unit simulates 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 into the contents of the tank by an integrated heat exchanger.

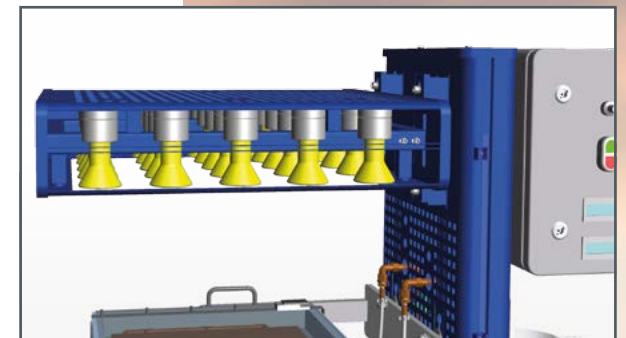
ET202 allows you to investigate how temperature affects the efficiency of various absorbers.



The illustration shows measured values for the efficiency as a function of the collector temperature. A special coating on the absorber allows higher efficiencies.

## Learning objectives

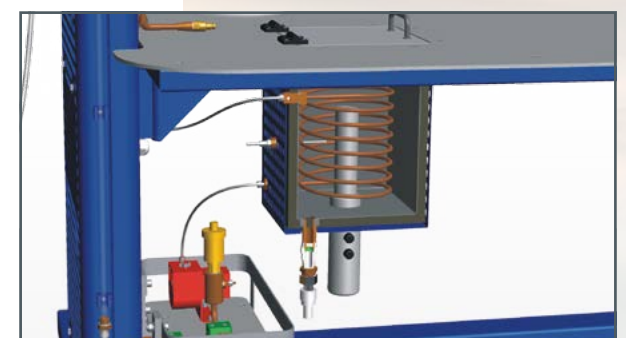
- design and operation of a simple solar thermal system
- determining the net power
- energy balance on the solar collector
- influence of illuminance, angle of incidence and flow rate
- determining efficiency curves
- influence of various absorbing surfaces



The lighting unit ensures uniform illumination. The spectral composition of the light is similar to that of natural solar radiation.



The solar collector converts the absorbed radiation into usable heat. Parts of the insulation and the absorber can easily be removed.

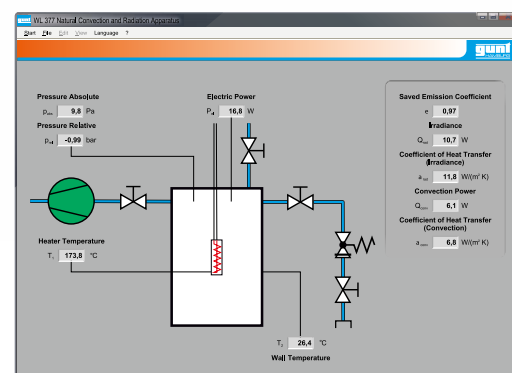


The heat exchanger is built into the storage tank. An electrical heater which makes it possible to achieve different collector operating states in just a short time is additionally available.





# WL 377 Convection and Radiation



## Software

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

Product No.  
060.37700  
More details and technical data:  
[gunt.de/static/s3440\\_1.php](http://gunt.de/static/s3440_1.php)



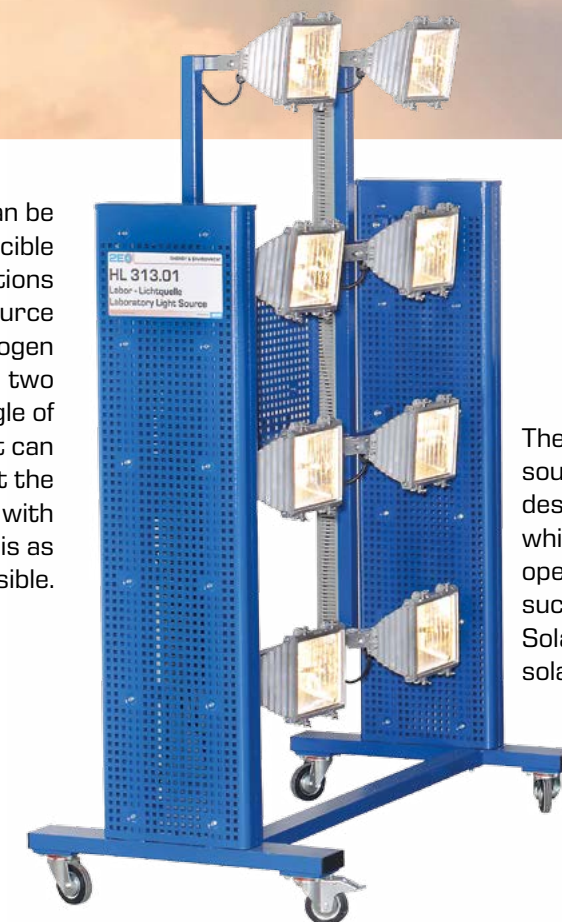
The WL 377 enables you to conduct heat transport experiments under different environmental conditions. This allows you to work out in particular the basics of typical heat transfer processes in a thermal solar collector.

## 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

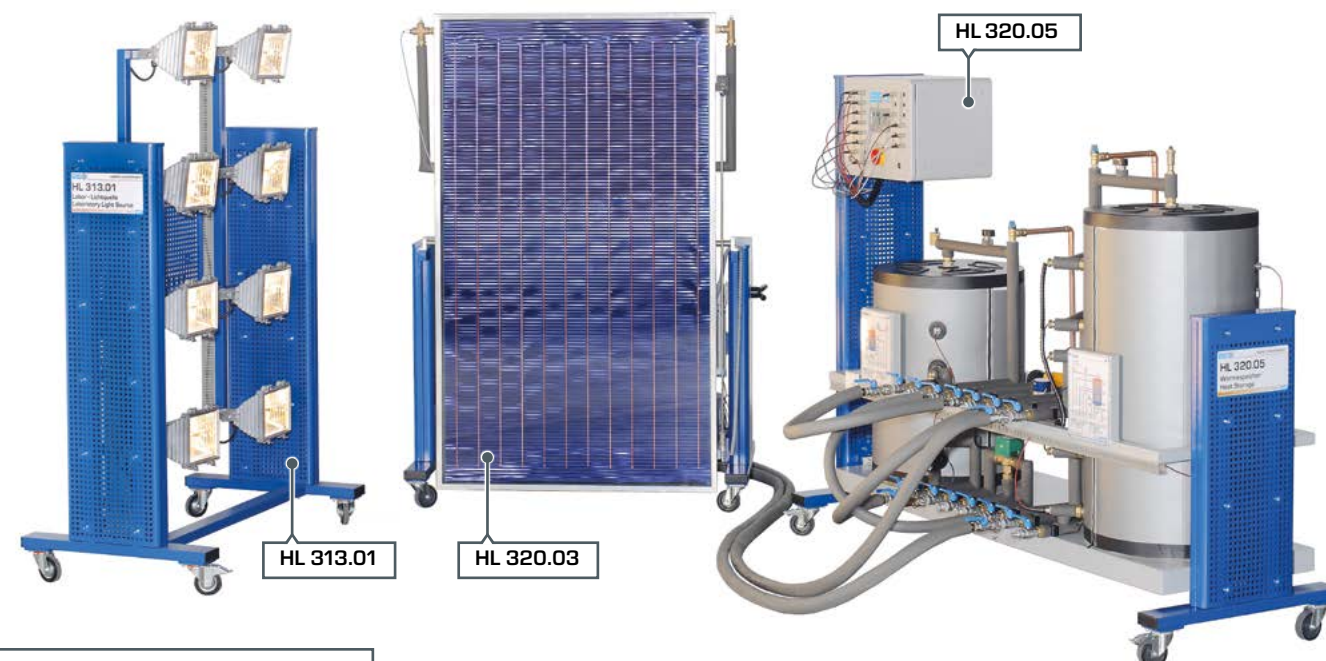
# HL 313.01 Artificial Light Source

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 which is as perpendicular as possible.



The artificial light source HL 313.01 is designed for trainers which can also be operated with sunlight, such as the ET 250 Solar Module or the solar collector of HL 313.

## Using HL 313.01 for laboratory experiments on solar thermal energy



Product No.  
065.31301  
More details and technical data:  
[gunt.de/static/s5094\\_1.php](http://gunt.de/static/s5094_1.php)





# HL 313 Domestic Water Heating with Flat Collector

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

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



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



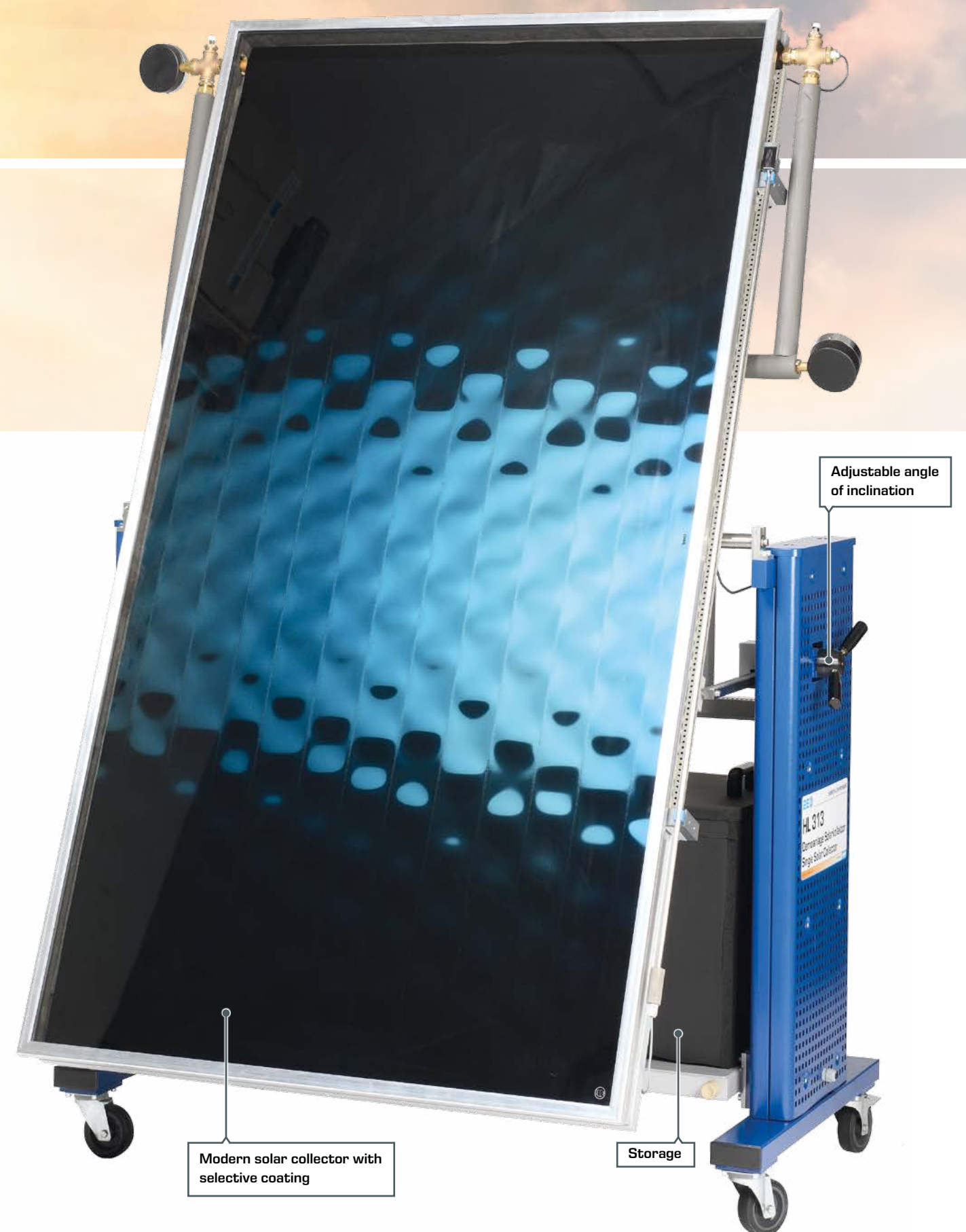
The controller regulates the circulation pumps and can be used to log data.



Temperatures, illuminance and flow rate are also recorded electronically.



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



Modern solar collector with selective coating

Storage

Adjustable angle of inclination





# HL 320

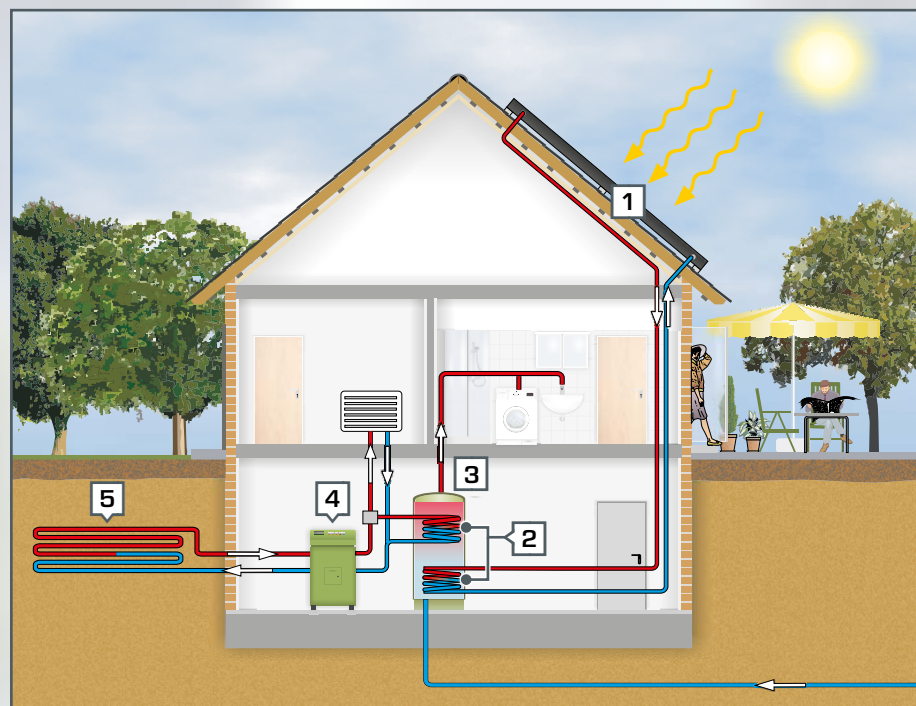
## Solar Thermal Energy and Heat Pump Modular System



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.

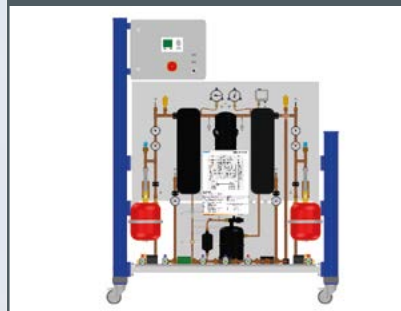
### Combined use of renewable heat sources

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 bivalent storage
- 4 heat pump
- 5 geothermal energy absorber

**HL 320.01**  
Heat Pump



**HL 320.02**  
Conventional Heating



**HL 320.03**  
Flat Plate Collector



**HL 320.04**  
Evacuated Tube Collector



**HL 320.05**  
Central Storage Module with Controller

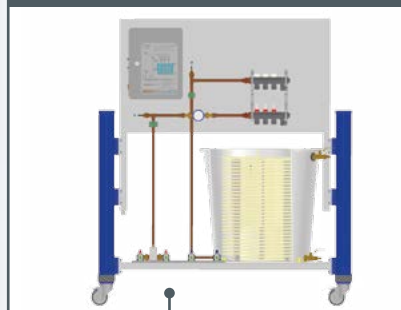


The storage module provides bivalent storage and buffer storage. The controller can be used to log measured values over longer periods for analysis of the system behaviour.

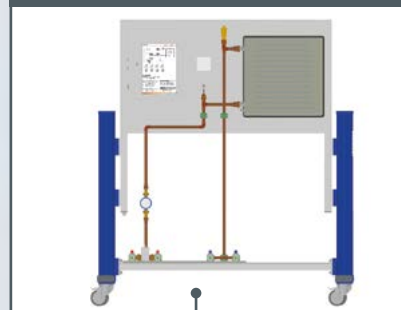
Freely programmable controller with extensive software



**HL 320.07**  
Underfloor Heating / Geothermal Energy Absorber



**HL 320.08**  
Fan Heater / Air Heat Exchanger



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



# HL 320

## Solar Thermal Energy and Heat Pump Modular System

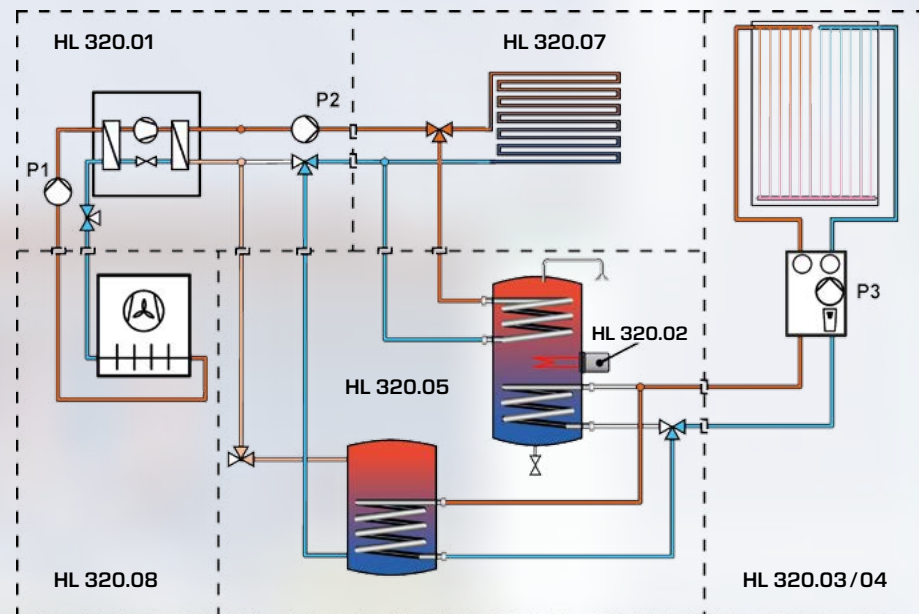


### The right configuration for every application

In practice, both the correct composition of necessary components and the optimisation of cabling and controller settings depend on the local conditions. We have developed a

series of 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 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).

Further information about the individual HL 320 modules can be found in section 1.7 of this catalogue.

### Recommended combinations for the HL 320 modular system

| Combination ▶                                                       | 1 | 2 | 3 | 4 | 5 |
|---------------------------------------------------------------------|---|---|---|---|---|
| <b>HL 320.01</b><br>Heat Pump                                       |   |   |   |   |   |
| <b>HL 320.02</b><br>Conventional Heating                            |   |   |   |   |   |
| <b>HL 320.03</b><br>Flat Plate Collector                            |   |   |   |   |   |
| <b>HL 320.04</b><br>Evacuated Tube Collector                        |   |   |   |   |   |
| <b>HL 320.05</b><br>Central Storage Module with Controller          |   |   |   |   |   |
| <b>HL 320.07</b><br>Underfloor Heating / Geothermal Energy Absorber |   |   |   |   |   |
| <b>HL 320.08</b><br>Fan Heater / 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
- parameterisation 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 fuels for heating and hot water
- bivalent parallel and bivalent alternative heat pump mode



# Hydropower and Ocean Energy

1.2

2E a division of



| Introduction                                                                          |                                                                       |     |
|---------------------------------------------------------------------------------------|-----------------------------------------------------------------------|-----|
|      | <b>Subject Areas</b><br>Hydropower and Ocean Energy                   | 044 |
| Hydropower                                                                            |                                                                       |     |
|    | <b>Basic Knowledge</b><br>Hydropower                                  | 046 |
|    | <b>HM 150.19</b><br>Operating Principle of a Pelton Turbine           | 048 |
|    | <b>HM 150.20</b><br>Operating Principle of a Francis Turbine          | 049 |
|  | <b>HM 450.01</b><br>Pelton Turbine                                    | 050 |
|  | <b>HM 450.02</b><br>Francis Turbine                                   | 050 |
|  | <b>HM 450C</b> Characteristic<br>Variables of Hydraulic Turbomachines | 051 |
|  | <b>HM 421</b><br>Kaplan Turbine Trainer                               | 052 |
|  | <b>HM 365.31</b><br>Pelton and Francis Turbine                        | 054 |
|  | <b>HM 430C</b><br>Francis Turbine Trainer                             | 056 |
| Ocean Energy                                                                          |                                                                       |     |
|    | <b>Basic Knowledge</b><br>Wave Energy                                 | 058 |
|    | <b>ET 270</b><br>Wave Energy Converter                                | 060 |



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# Subject Areas

# Hydropower and Ocean Energy



## Subject Areas

## 2E Products

### Hydropower

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

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 2E product is listed in the next column.



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

**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 450.01**  
Pelton Turbine

**HM 450.02**  
Francis Turbine

**HM 450C**  
Characteristic Variables of Hydraulic Turbomachines

**Turbines in run-of-river power stations:**  
river and tidal power stations

**HM 421**  
Kaplan Turbine Trainer

Comparing turbine types –  
asynchronous generator drive

**HM 365.31**  
Pelton and Francis Turbine

How guide vanes affect  
characteristic turbine curves

**HM 430C**  
Francis Turbine Trainer

### Ocean Energy

How the guide vanes affect  
characteristic turbine curves

**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 hydropower-generated electricity, the percentage of electrical energy generated in this way has grown to around one quarter of all the 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 become apparent to some extent. Due to geological conditions, some countries such as Norway (99%), Congo (97%) and Brazil (96%)

are able to cover very large proportions of their electrical energy demand with hydropower. By comparison, in Germany only 4% is covered. Brazil is currently home to the world's largest hydroelectric power station, where 18 turbines generate a total output of 12,600 megawatts.

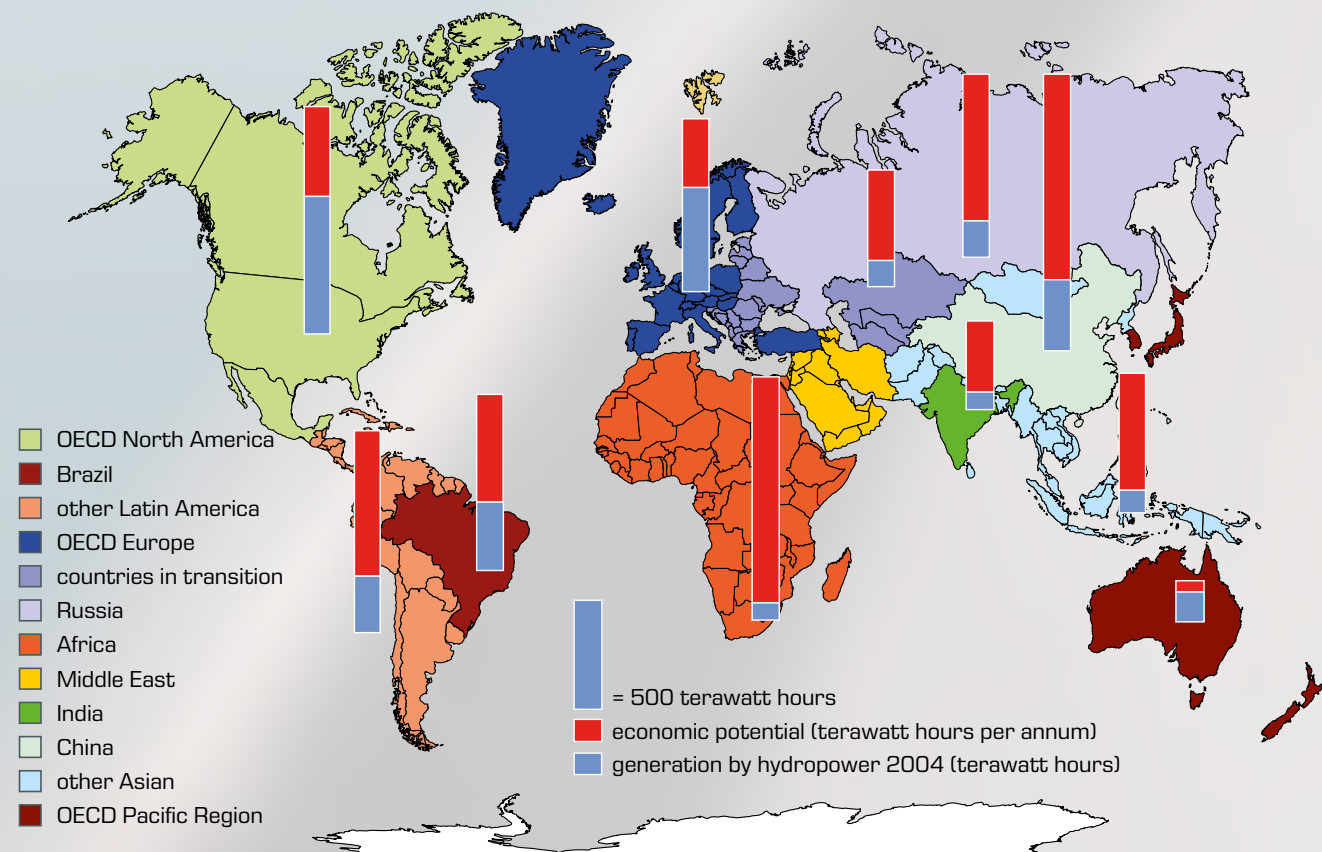


## Decentralised power supply through small hydroelectric power stations

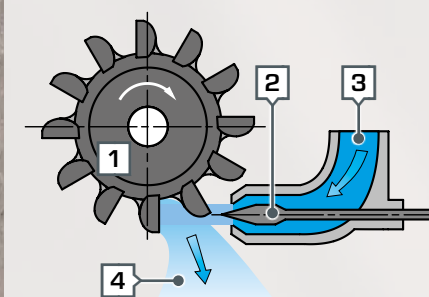
In regions without a central power supply, decentralised, small hydroelectric power stations with an output up to about 5 kW offer the possibility of supporting sustainable development in an appropriate manner.

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 Pelton turbines are mostly used. At lower heads on the other hand, Francis or Kaplan turbines are preferred.

## Expansion potential for use of hydropower



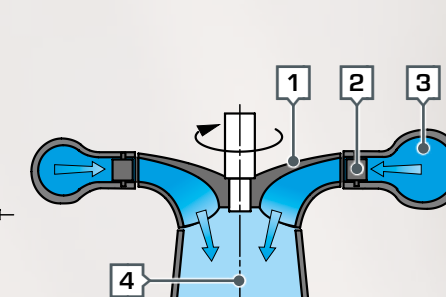
## Turbine types in hydroelectric power stations



### Pelton turbine

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

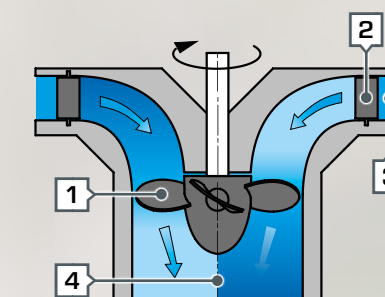
Head: 150-2000m  
Flow rate: 0,02-70m³/s  
Storage power stations



### Francis turbine

The Francis turbine operates with positive pressure. The guide vanes can be adjusted.

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



### Kaplan turbine

The Kaplan turbine also operates with positive pressure. In this case, guide vanes and impeller vanes can be adjusted.

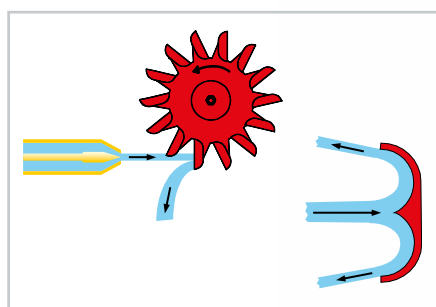
Head: 2-60m  
Flow rate: 4-2000m³/s  
Rivers

1 impeller 2 guide vanes 3 water inlet 4 water outlet

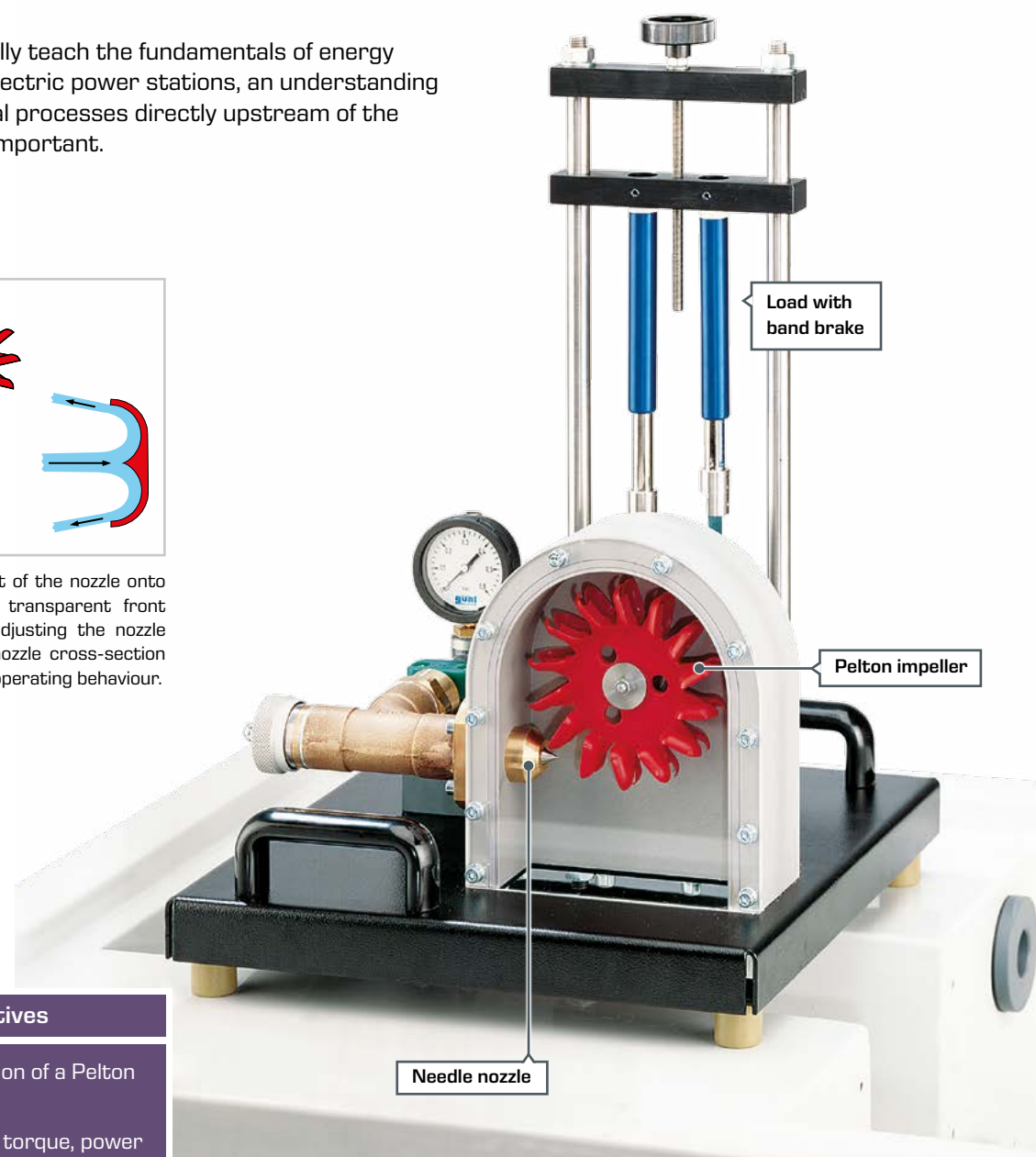


# HM 150.19 Operating Principle of a Pelton Turbine

In order to successfully teach the fundamentals of energy conversion in hydroelectric power stations, 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 impeller 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.



HM 150 Base module



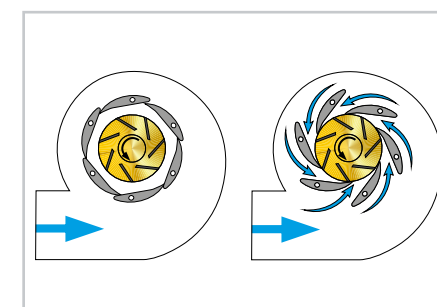
| Learning objectives                                                                                                                                                                                                                          |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>design and function of a Pelton turbine</li> <li>determination of torque, power and efficiency</li> <li>graphical representation of characteristic curves for torque, power and efficiency</li> </ul> |

Product No.  
070.15019  
More details and technical data:  
[gunt.de/static/s4562\\_1.php](http://gunt.de/static/s4562_1.php)



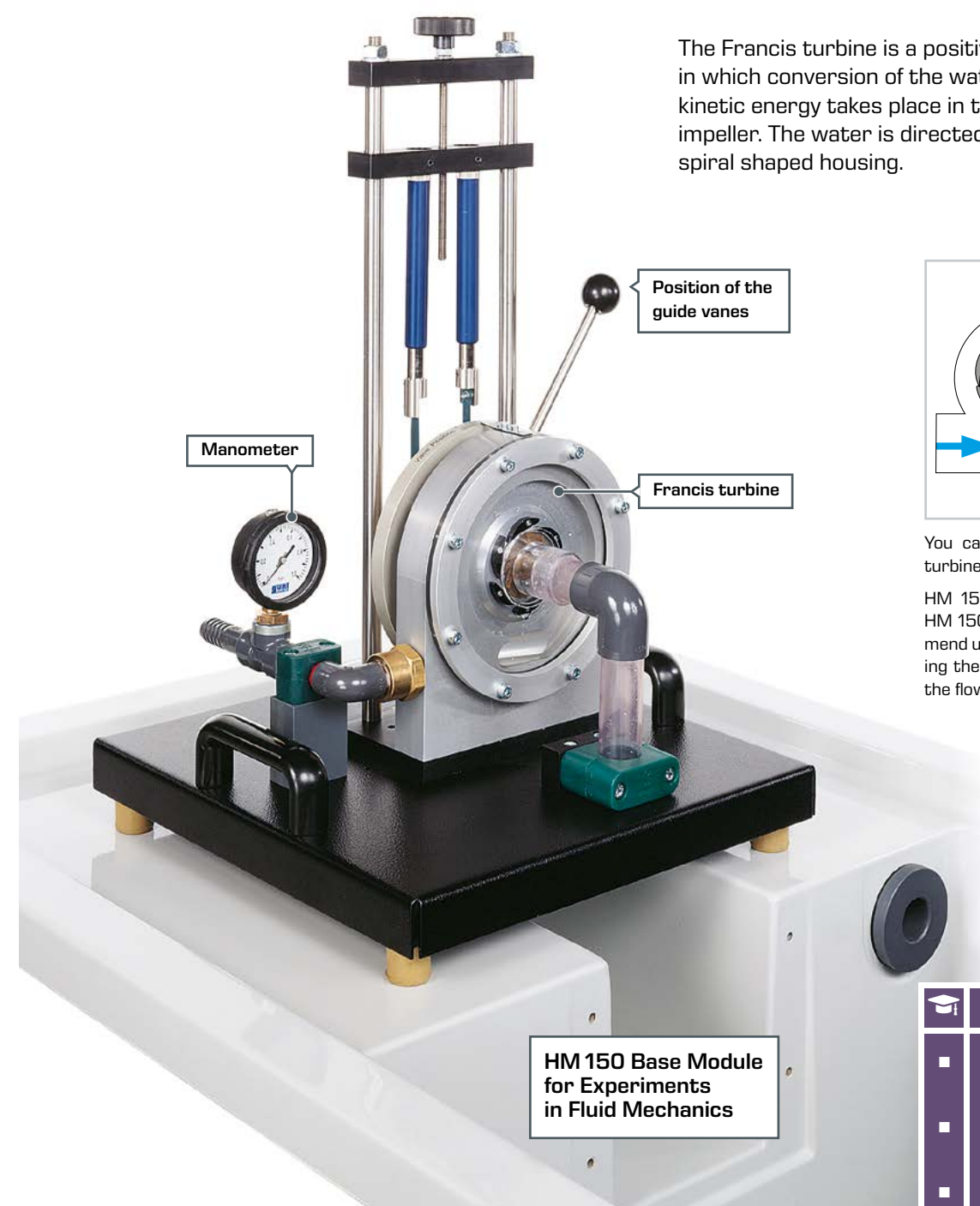
# HM 150.20 Operating Principle of a Francis Turbine

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



You can adjust the alignment of the Francis turbine's guide vanes 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.



HM 150 Base Module for Experiments in Fluid Mechanics

| Learning objectives                                                                                                                                                                                                                           |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>design and function of a Francis turbine</li> <li>determination of torque, power and efficiency</li> <li>graphical representation of characteristic curves for torque, power and efficiency</li> </ul> |

Product No.  
070.15020  
More details and technical data:  
[gunt.de/static/s4572\\_1.php](http://gunt.de/static/s4572_1.php)



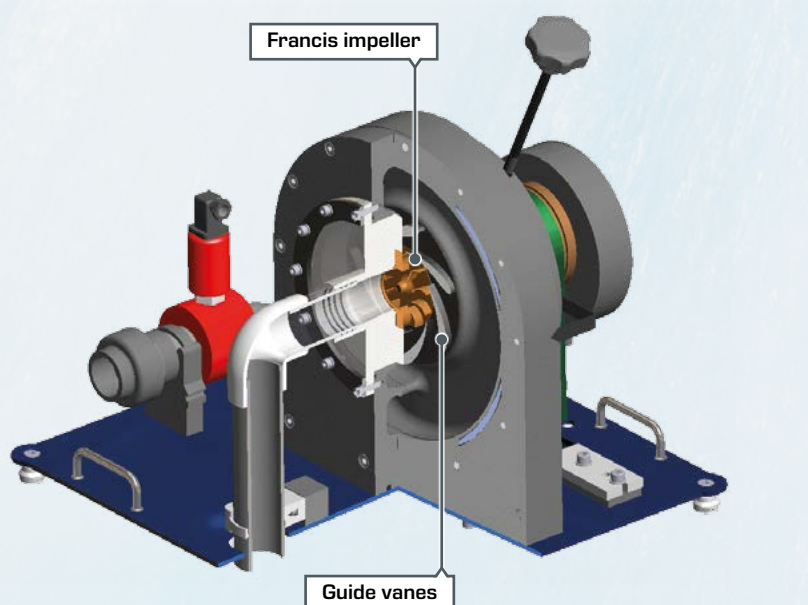
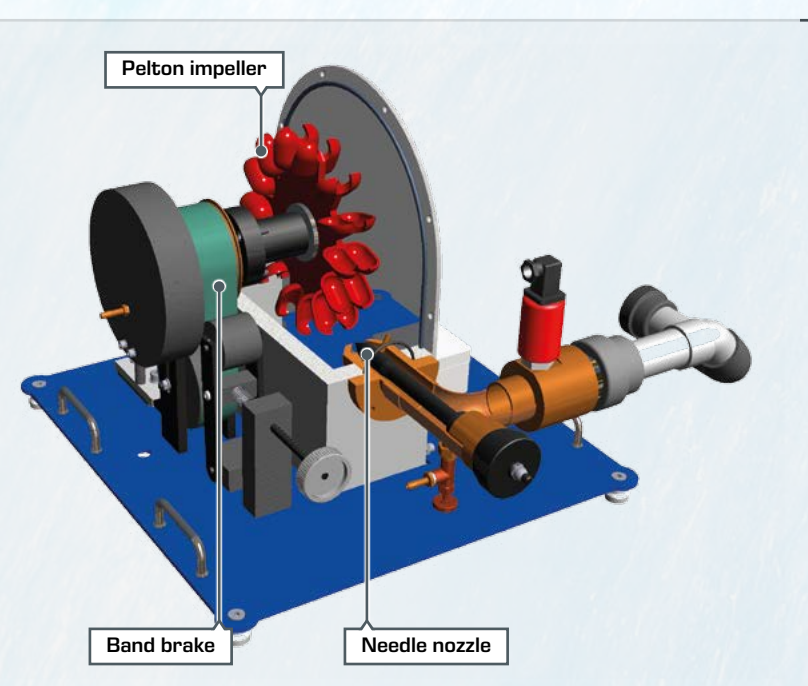


# HM 450.01 HM 450.02

## Pelton Turbine Francis Turbine

With HM 450.01 and HM 450.02 you can systematically investigate energy conversion in various turbine types and compare typical properties. Used in conjunction with the HM 450C trainer, you have a fully equipped system for education in the field of turbomachines.

The water exits the Francis impeller axially. The intake capacity, and therefore the performance of the turbine, can be adjusted by rotating the guide vanes.



# HM 450C

## Characteristic Variables of Hydraulic Turbomachines



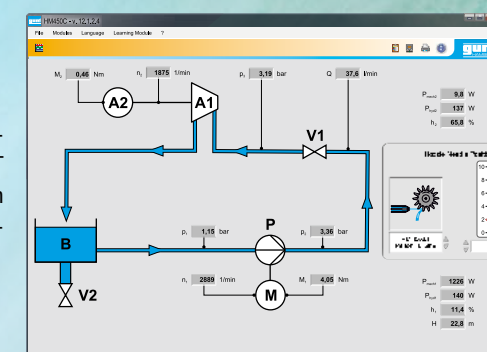
HM 450C contains a closed water circuit to supply the turbines. Pressure, flow rate, torque and rotational speed are detected electronically and displayed digitally.

| Learning objectives |                                                      |
|---------------------|------------------------------------------------------|
| ■                   | comparison of turbine types                          |
| ■                   | determining the mechanical power                     |
| ■                   | influence of nozzle cross-section and/or guide vanes |
| ■                   | plotting characteristic curves                       |
| ■                   | calculating the efficiency                           |



### The HM 450C software

Measured values can be transferred to a PC via USB. The GUNT software provides you with an extensive range of options for displaying and analysing your data.



Product No.  
070.45001  
More details and technical data:  
[gunt.de/static/s4202\\_1.php](http://gunt.de/static/s4202_1.php)



Product No.  
070.45002  
More details and technical data:  
[gunt.de/static/s4201\\_1.php](http://gunt.de/static/s4201_1.php)



Product No.  
070.450C0  
More details and technical data:  
[gunt.de/static/s4242\\_1.php](http://gunt.de/static/s4242_1.php)





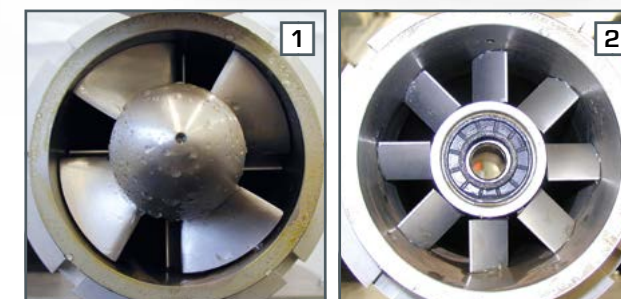
# HM 421 Kaplan Turbine Trainer

Kaplan turbines are used at low hydraulic heads to generate electricity. Low heads occur for example, in run-of-river power stations and tidal power stations.

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

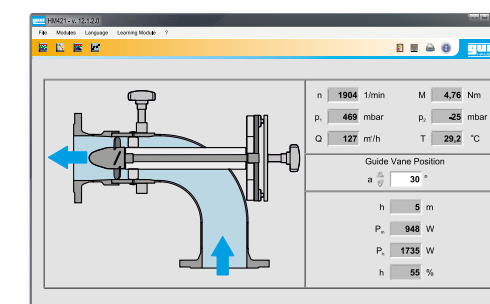


Product No.  
070.42100  
More details and technical data:  
[gunt.de/static/s4917\\_1.php](http://gunt.de/static/s4917_1.php)



Impeller

Guide vanes



## 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

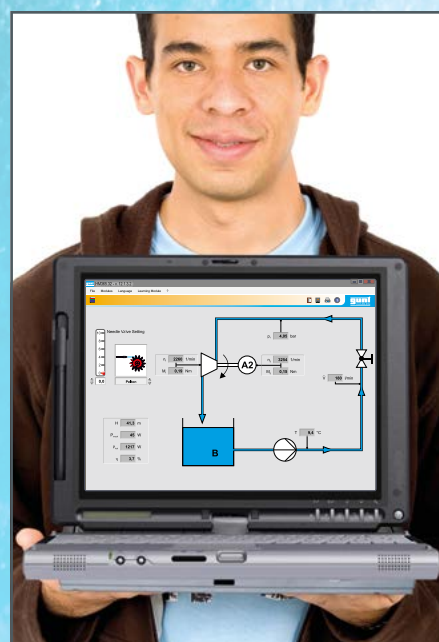
## Learning objectives

- 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



# HM 365.31 Pelton and Francis Turbine

The HM 365 modular system allows you to investigate the characteristic operating behaviour of various turbine types. Water is supplied by the specially designed HM 365.32 supply unit. The energy generated by the turbine is transferred to the asynchronous generator in HM 365. 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 diagram and enables continuous data acquisition via a USB connection. Of course, graphical representations and calculations are also provided for analysis of the measurement data.

Product No.  
070.36531  
More details and technical data:  
[gunt.de/static/s4233\\_1.php](http://gunt.de/static/s4233_1.php)



HM 365.31: Pelton Turbine



HM 365.31: Francis Turbine



HM 365 Universal Drive and Brake Unit

HM 365.32 Turbine Supply Unit

HM 365 has a three-phase asynchronous motor which 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 and flow rate. A power pump – inside an enclosed water circuit – simulates the gradient of a hydroelectric power station.



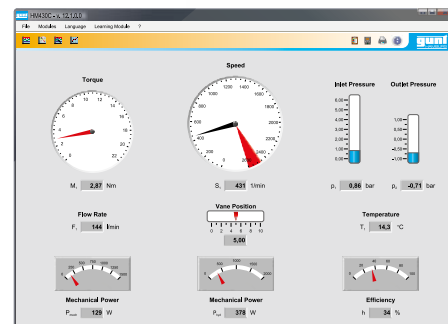
## Learning objectives

- comparison of impulse and reaction turbines
- determination of mechanical and hydraulic power
- determination of efficiency
- recording of characteristic curves
- influence of Pelton turbine nozzle cross-section on characteristic values
- influence of Francis turbine guide vane position on characteristic values



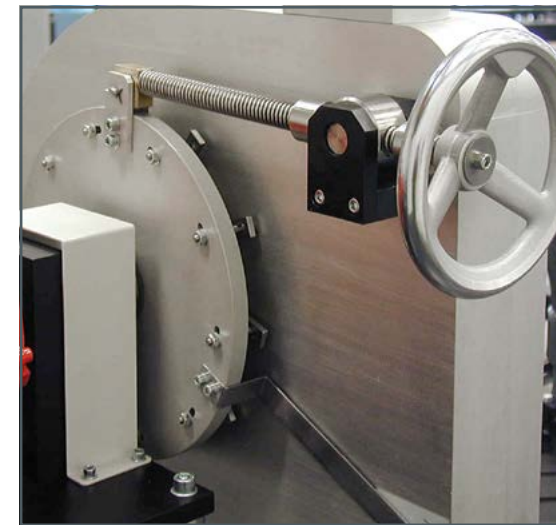
# HM 430C Francis Turbine Trainer

Francis turbines are used for hydropower at medium heads and medium flow rates. HM430C provides you with the facility for using a DC generator for energy conversion.

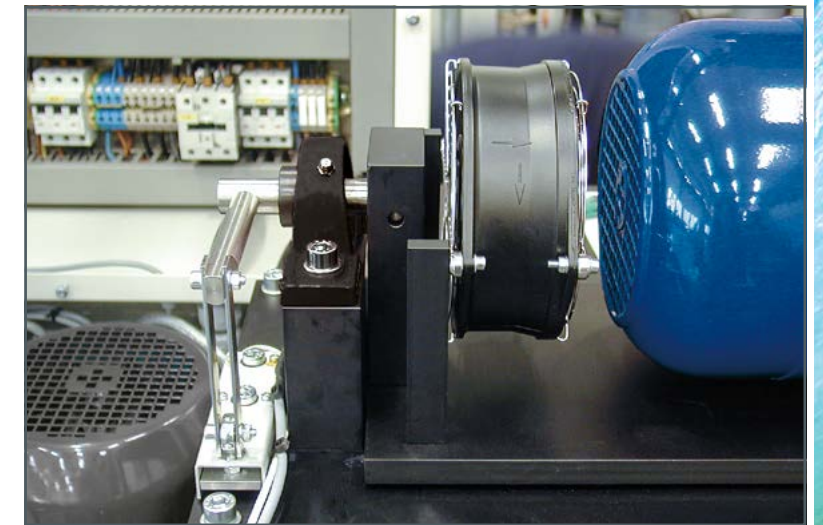


## Software

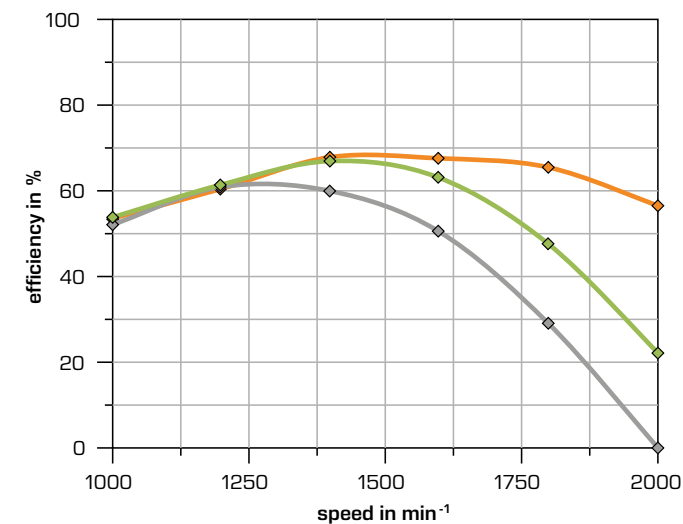
The GUNT software displays torque, speed and pressure to monitor the current system state.



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



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



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 guide vane positions.

## Learning objectives

- investigation of conversion of hydraulic into mechanical energy
- determination of torque and speed of turbine shaft
- determination of mechanical and hydraulic power
- determination of efficiency
- recording of characteristic curves
- investigate the effect of guide vane position
- calculate velocity triangles

Product No.  
070.430C0  
More details and technical data:  
[gunt.de/static/s4585\\_1.php](http://gunt.de/static/s4585_1.php)





# Basic Knowledge Wave Energy

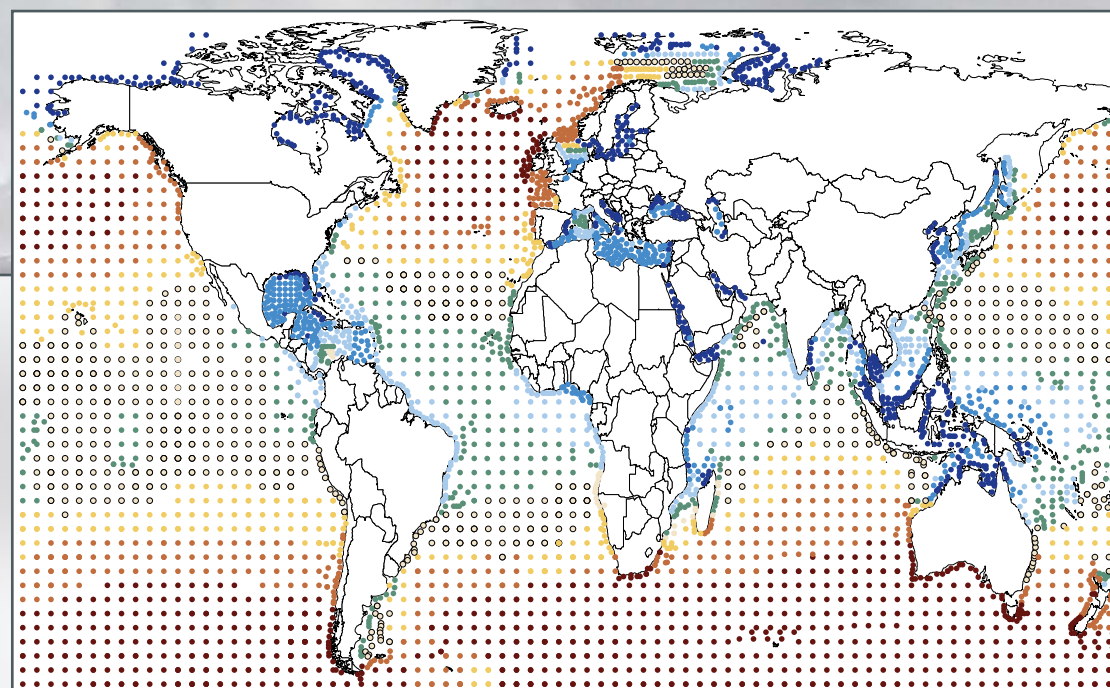


The ocean's waves contain an inexhaustible reserve of energy. They are caused by wind, gravitational forces and atmospheric pressure differences.

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 stations 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 be found at latitudes far from the equator and on the west coasts of the continents.

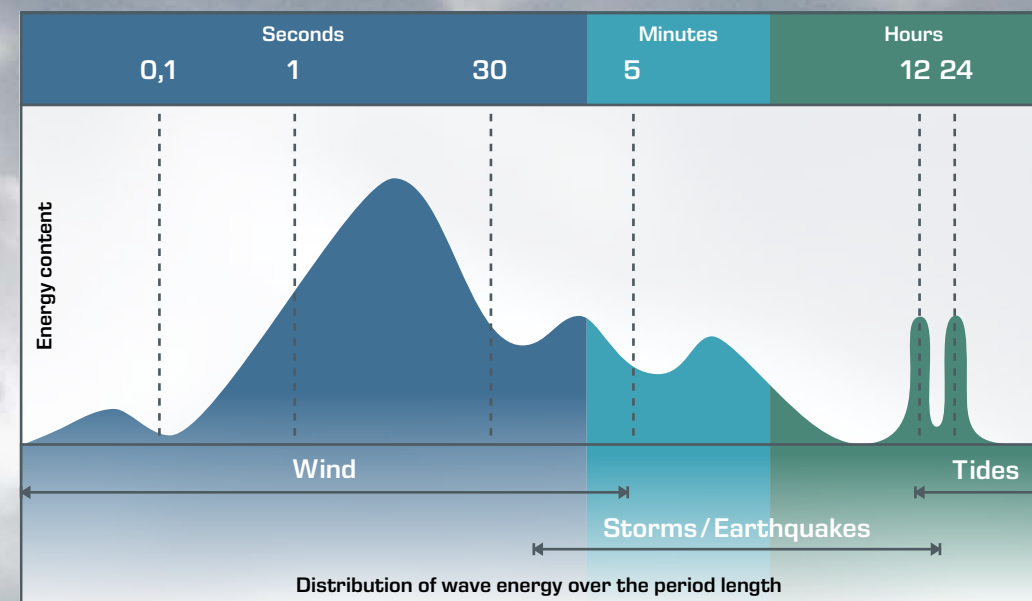
Source: Centre for Renewable and Sustainable Energy Studies, Stellenbosch University

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

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

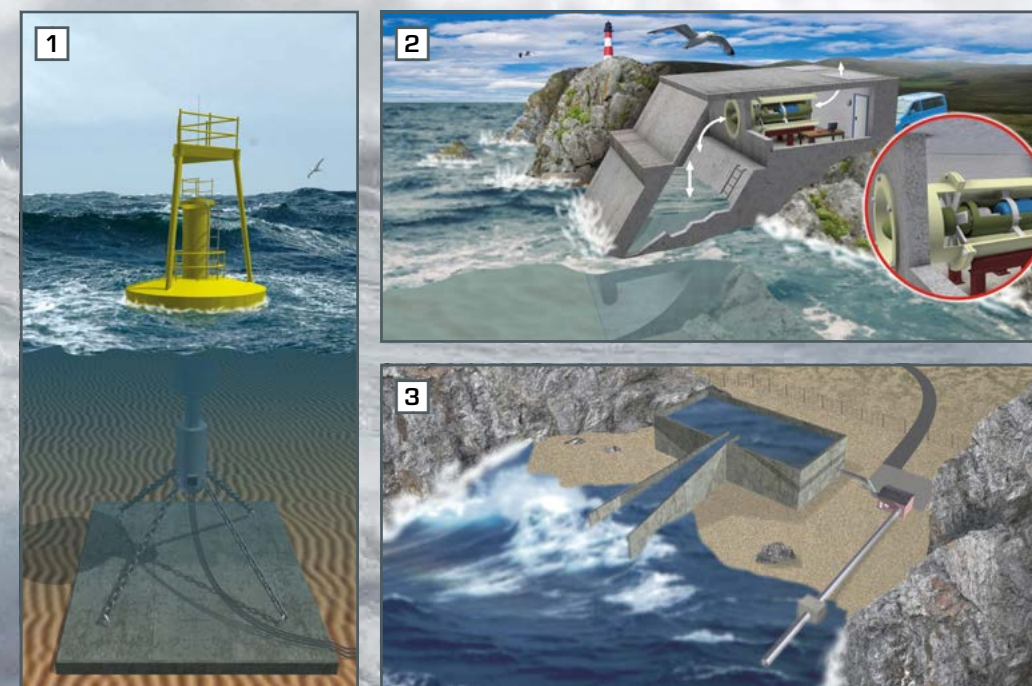
We can see that the power **P** is linearly dependent on the period length **T** and quadratically dependent on the height of the wave **H**.

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 which 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

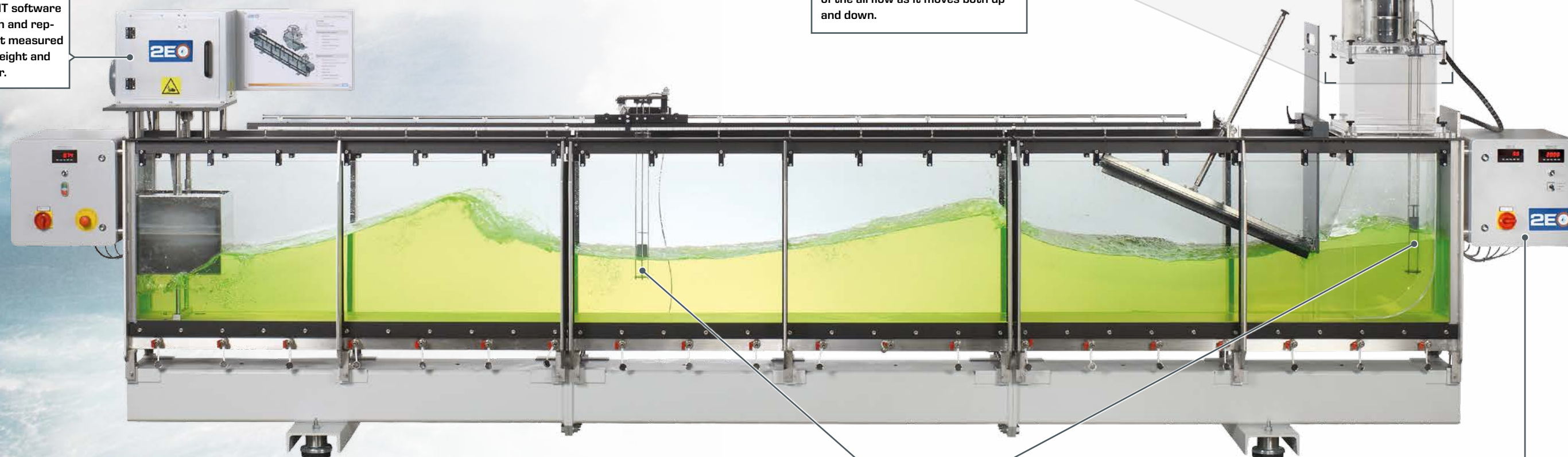
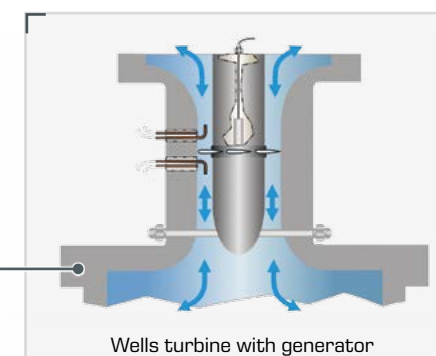


# ET 270 Wave Energy Converter

Wave power stations 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 airflow generated in this way drives the turbine, which generates electricity via a generator.

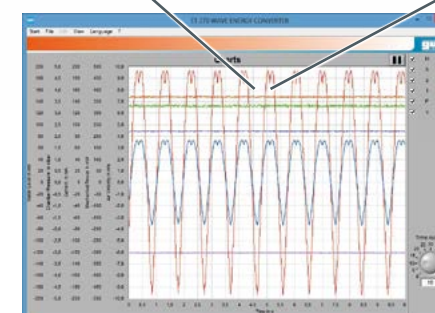
In addition to the usual components of an OWC wave power station, ET 270 contains a water channel with a controllable wave generator for laboratory experiments. The GUNT software enables the acquisition and representation of relevant measured values such as wave height and speed of the generator.

Modelled on 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 airflow as it moves both up and down.



## Learning objectives

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



Software

Measurement of the wave height

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.

Product No.  
061.27000  
More details and technical data:  
[gunt.de/static/s5372\\_1.php](http://gunt.de/static/s5372_1.php)





# Wind Power

1.3

2E a division of

gunt  
HAMBURG

## Introduction

|                                                                                   |                                      |     |
|-----------------------------------------------------------------------------------|--------------------------------------|-----|
|  | <b>Subject Areas</b><br>Wind Power   | 064 |
|  | <b>Basic Knowledge</b><br>Wind Power | 066 |

## Fundamentals and application engineering for using wind energy

In this section you will find suitable teaching systems for developing an understanding of all the principal aspects of wind energy use. The range provides the chance both to teach the fundamentals of aerodynamics and to deepen understanding of topical application issues from machinery monitoring for modern wind power plants.

## Fundamentals of Wind Energy Engineering

|                                                                                       |                                                                    |     |
|---------------------------------------------------------------------------------------|--------------------------------------------------------------------|-----|
|    | <b>HM 170</b><br>Open Wind Tunnel (with Accessories)               | 068 |
|    | <b>HM 170.05</b><br>Drag Body Square Plate                         | 069 |
|    | <b>HM 170.09</b><br>Drag Body Aerofoil NACA 0015                   | 070 |
|  | <b>HM 170.22</b> Pressure Distribution<br>on an Aerofoil NACA 0015 | 071 |
|  | <b>ET 220</b><br>Energy Conversion in a Wind Power Plant           | 072 |
|  | <b>ET 220.01</b><br>Wind Power Plant                               | 074 |

## Application Engineering in Wind Power Plants

|                                                                                       |                                                                     |     |
|---------------------------------------------------------------------------------------|---------------------------------------------------------------------|-----|
|    | <b>AT 200</b><br>Determination of Gear Efficiency                   | 076 |
|    | <b>GL 210</b> Dynamic Behaviour<br>of Multi-Stage Spur Gears        | 078 |
|    | <b>GL 212</b> Dynamic Behaviour<br>of Multi-Stage Planetary Gears   | 079 |
|  | <b>Basic Knowledge</b><br>Condition Monitoring in Wind Power Plants | 080 |
|  | <b>PT 500</b><br>Machinery Diagnostic System, Base Unit             | 082 |
|  | <b>PT 500.11</b><br>Crack Detection in Rotating Shaft Kit           | 084 |
|  | <b>PT 500.12</b><br>Roller Bearing Faults Kit                       | 085 |
|  | <b>PT 500.15</b><br>Damage to Gears Kit                             | 086 |
|  | <b>PT 500.19</b><br>Electromechanical Vibrations Kit                | 087 |

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[www.gunt2e.de](http://www.gunt2e.de)



# Subject Areas Wind Power



## Subject Areas

## 2E Products

### 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 speeds at high altitudes. Wind speed has a huge influence on the rotor's speed of rotation. Nowadays rotors with a diameter of 100m 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 subject areas listed on the right.

### Fundamentals of Wind Energy Engineering

#### Investigations on flow around bodies

##### HM 170

Open Wind Tunnel

##### HM 170.05

Drag Body Square Plate

##### HM 170.09

Drag Body Aerofoil NACA 0015

##### HM 170.22

Pressure Distribution on an Aerofoil NACA 0015

#### Generating electricity from wind energy

##### 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

### Application Engineering in Wind Power Plants

#### Energy transmission in gears

##### AT 200

Determination of Gear Efficiency

##### GL 210

Dynamic Behaviour of Multi-Stage Spur Gears

##### GL 212

Dynamic Behaviour of Multi-Stage Planetary Gears

#### Machine monitoring

##### PT 500

Machinery Diagnostic System, Base Unit

##### PT 500.11

Crack Detection in Rotating Shaft Kit

##### PT 500.12

Roller Bearing Faults Kit

##### PT 500.15

Damage to Gears Kit

##### PT 500.19

Electromechanical Vibrations 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.

## 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.

## Energy conversion

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.

## 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.

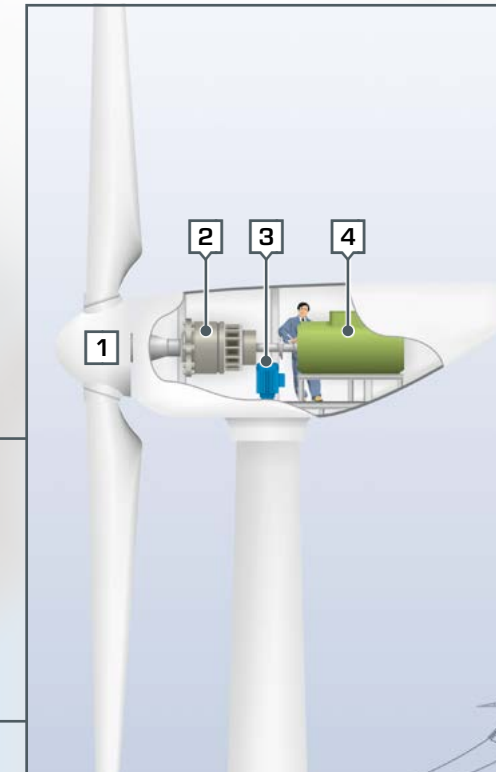
Besides the rotor and the generator, wind power plants consist of lots of individual components which together form a functional and efficient wind power plant.

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

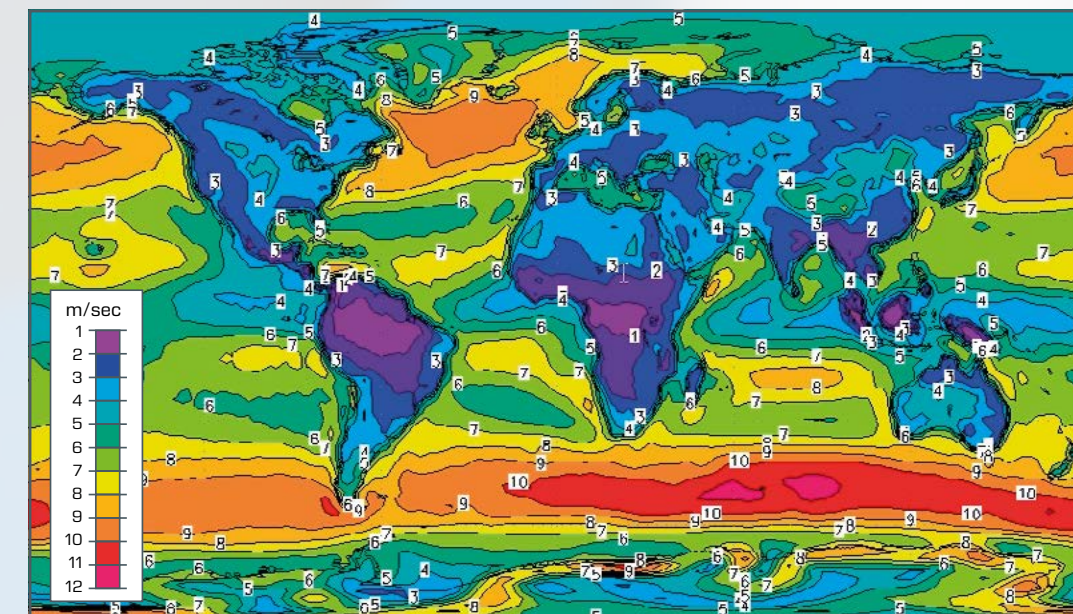
Wind power plant:

- 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 170

## Open Wind Tunnel with Accessories

### Fundamentals of converting wind energy

The chain effect 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.

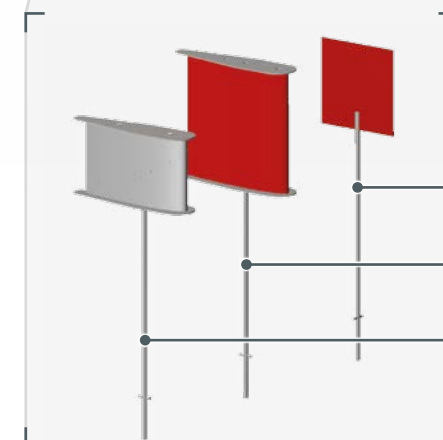


### Learning objectives

- 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



Force sensor for 2 components



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

Drag Body Aerofoil NACA 0015

#### HM 170.22

Pressure Distribution on an Aerofoil NACA 0015

Product No.  
070.17000

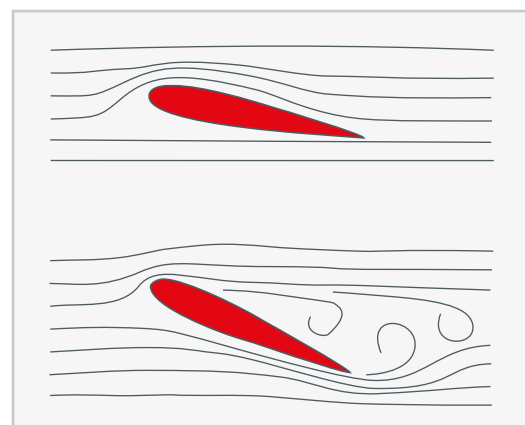
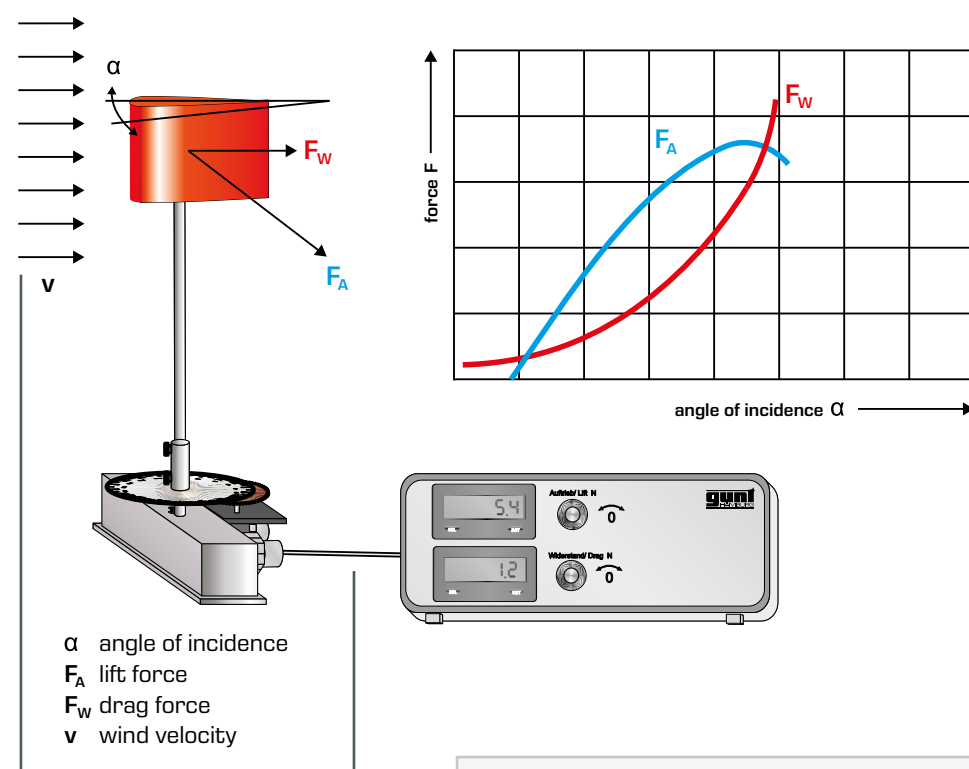
More details and technical data:  
[gunt.de/static/s3399\\_1.php](http://gunt.de/static/s3399_1.php)





# HM 170 Open Wind Tunnel with Accessories

## HM 170.09 Drag 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.

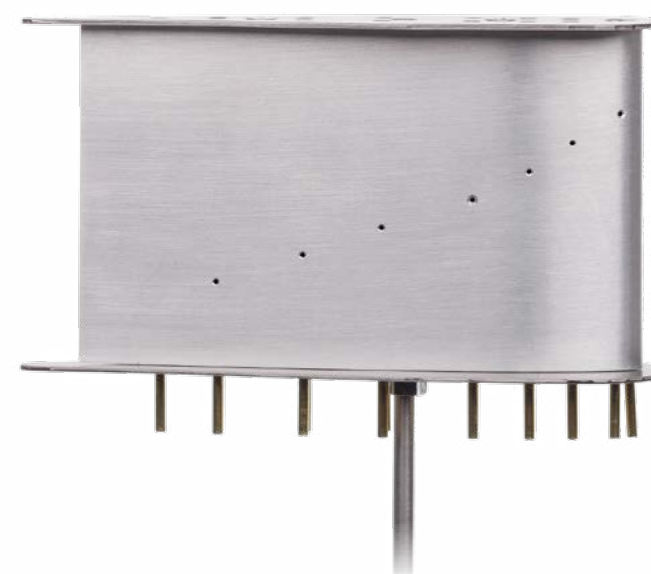
Using HM 170.09 you can systematically log the forces acting on a blade profile.

**“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).

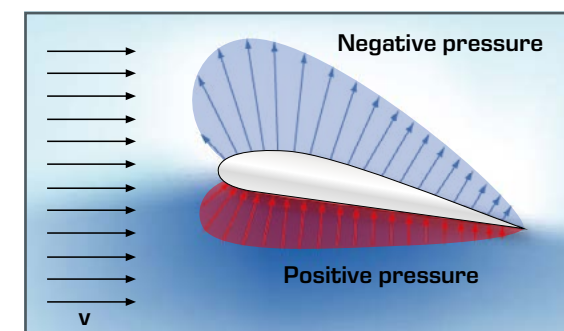
Stall is used specifically in smaller wind power plants to limit the speed of the rotor.

## HM 170.22 Pressure Distribution on an Aerofoil NACA 0015

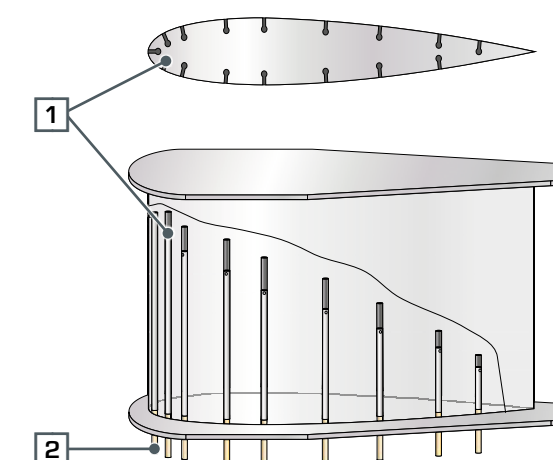


Measurement of the pressure distribution around an aerofoil profile under surrounding flow teaches students fundamental knowledge about the occurrence of lift force.

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



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.



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.



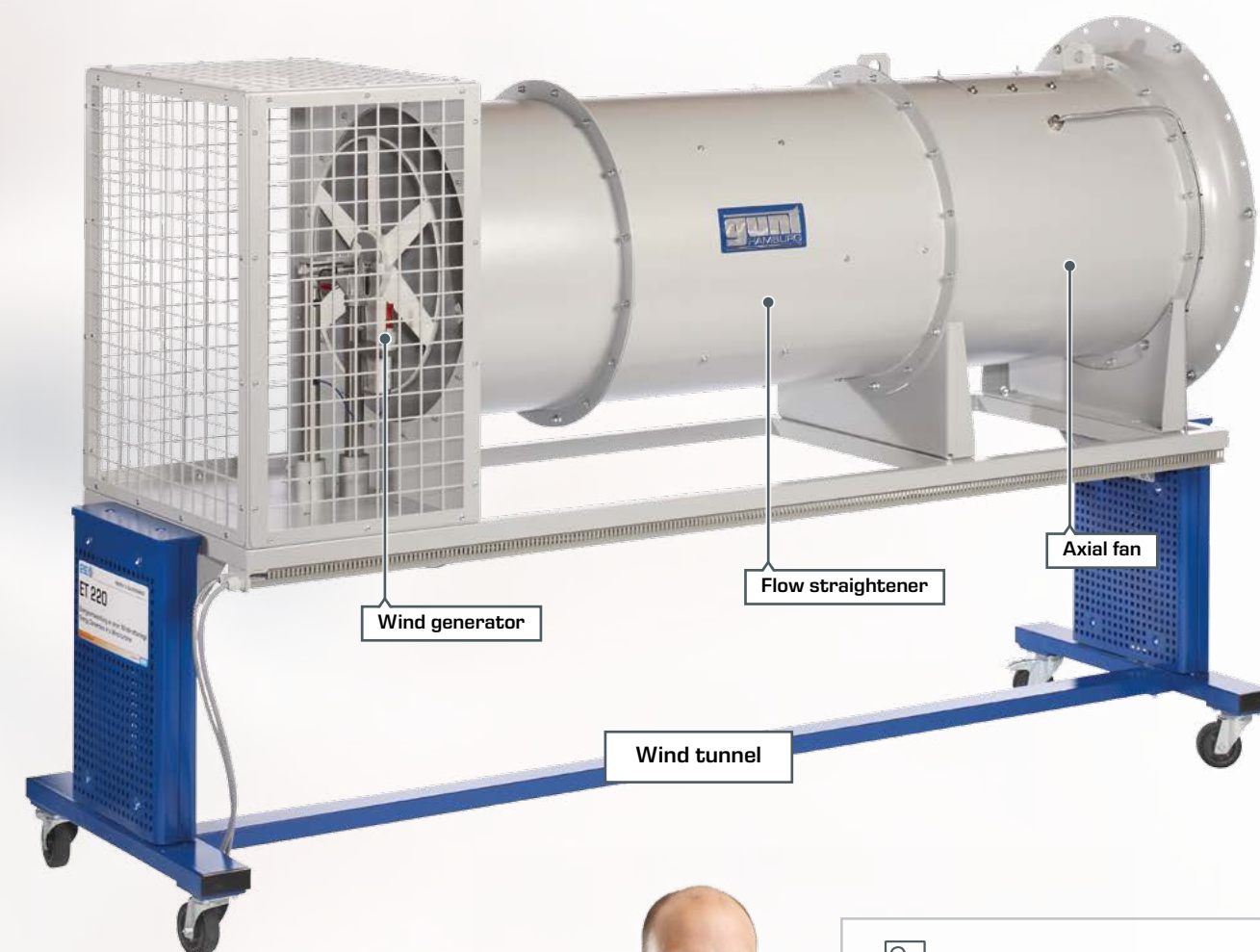
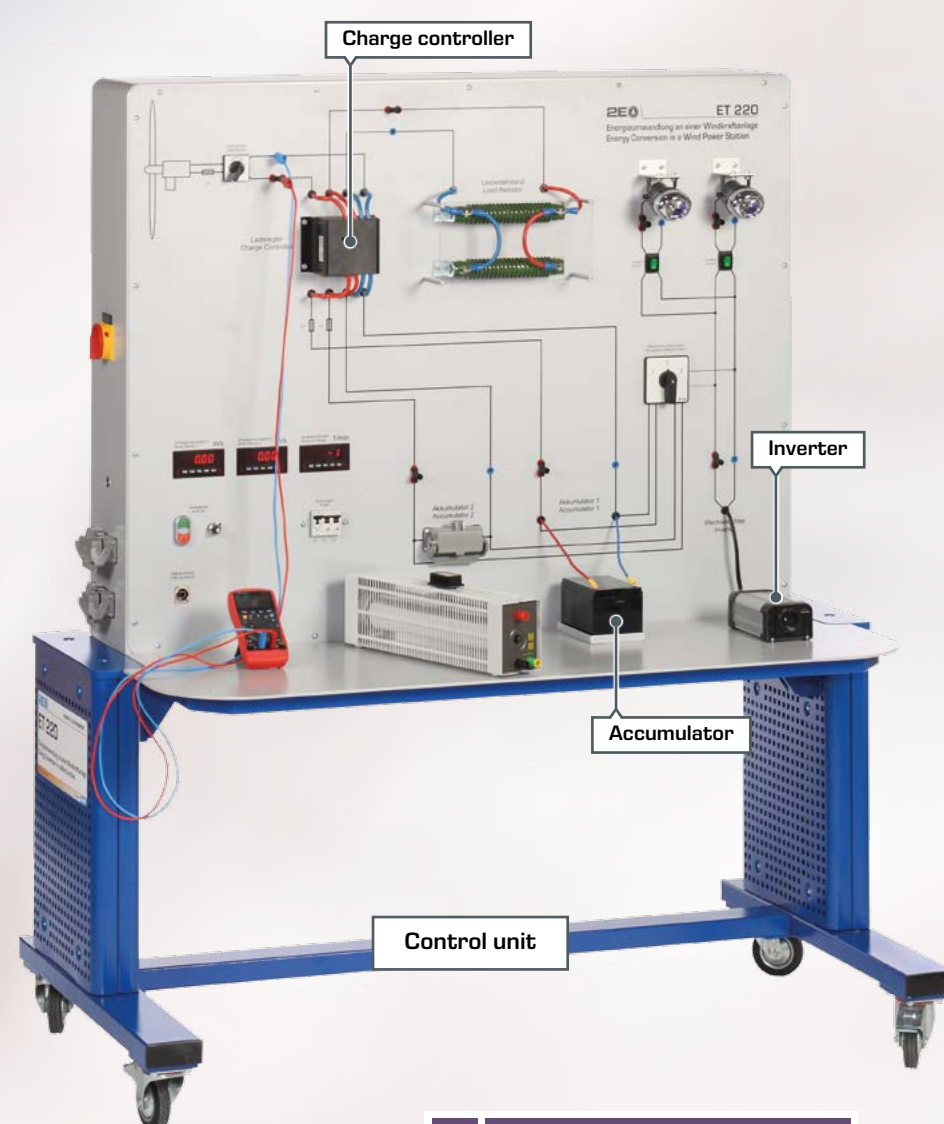


# ET 220

## 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 wind tunnel of ET 220 or the ET 220.01 Wind Power Plant can be connected to the control unit of ET 220 for installation outdoors.



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.

### Learning objectives

- conversion of kinetic wind energy into electrical energy
- function and design of an 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

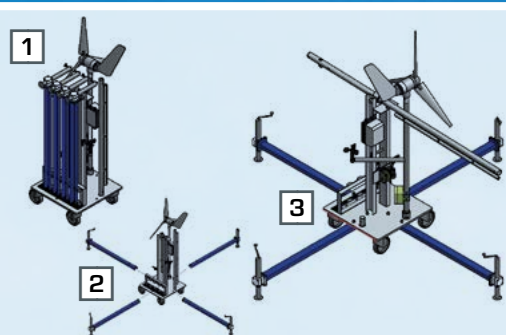
The software for ET 220 enables the acquisition, representation and analysis of the measured values. Consequently, current and voltage are measured at various points of the stand-alone system. Energy balances are possible for the entire system and for separate components.





# ET 220.01 Wind Power Plant

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



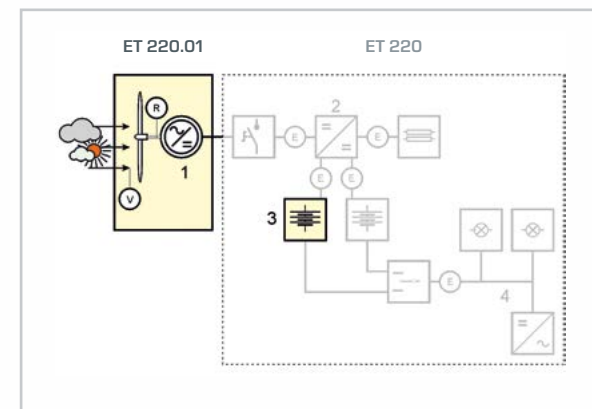
## Commissioning ET 220.01

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**.

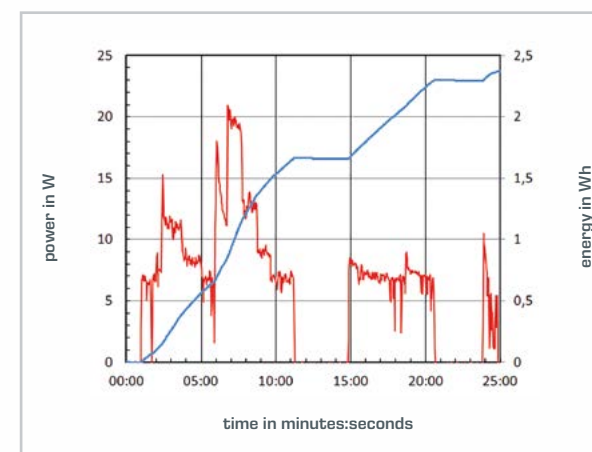
Product No.  
061.22001  
More details and technical data:  
[gunt.de/static/s5247\\_1.php](http://gunt.de/static/s5247_1.php)



| Learning objectives                                                                                                                                                                           |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>design and function of a wind power plant in stand-alone operation</li> <li>energy balance of a wind power plant under real wind conditions</li> </ul> |



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).



A video showing the setup and commissioning of ET 220.01 is available at:  
[www.gunt2e.de](http://www.gunt2e.de)



The hub height of the rotor is approximately 5m with the mast erected.

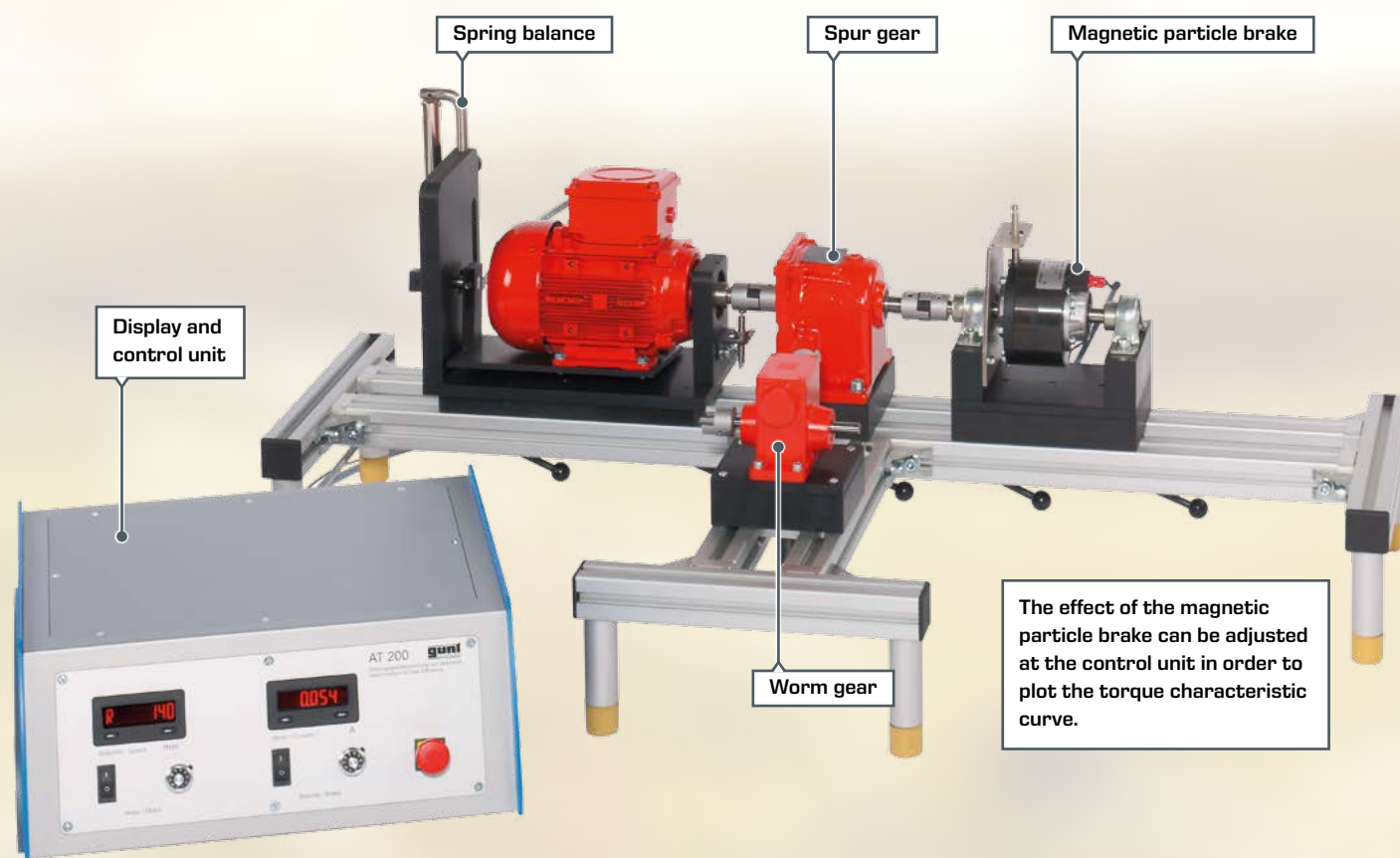
You can easily swivel the mast to the desired position in just a few simple steps.



# AT 200

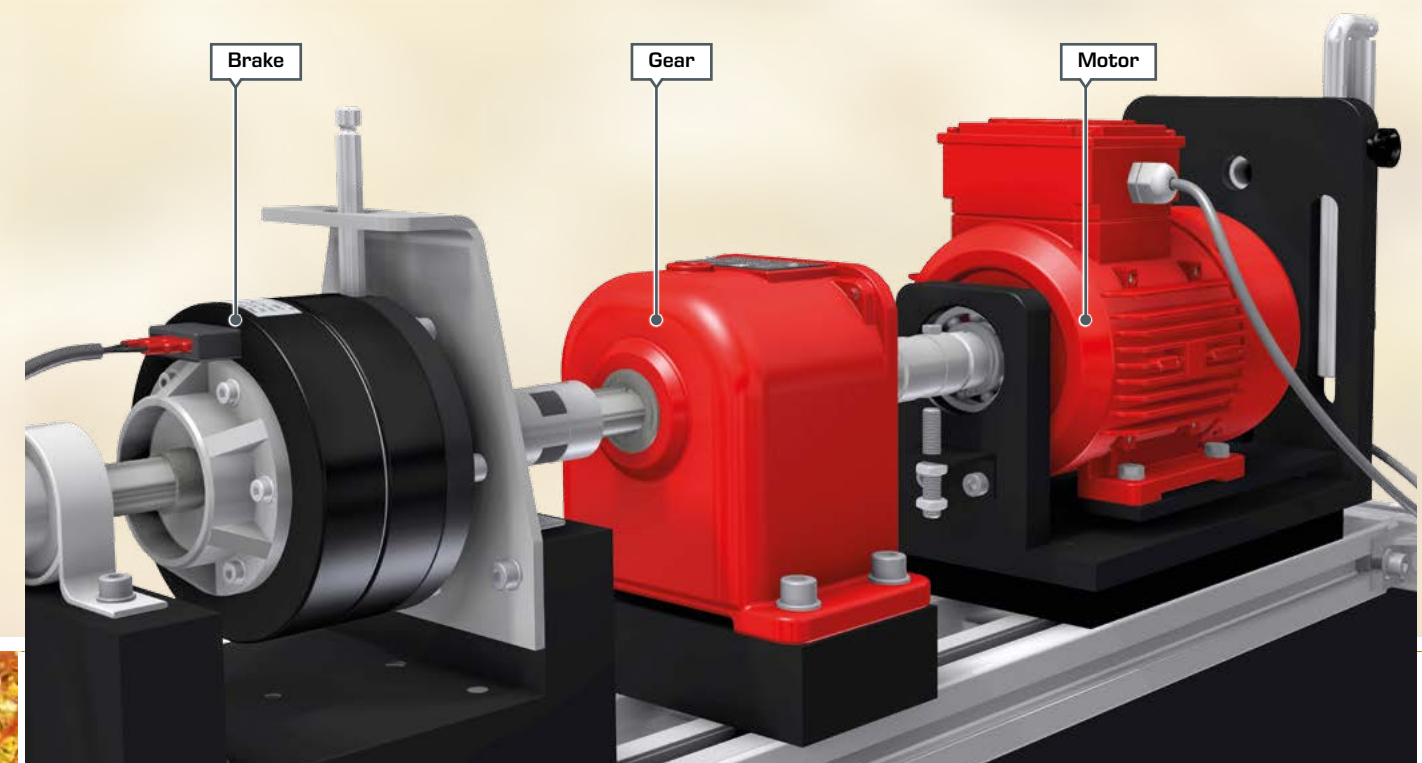
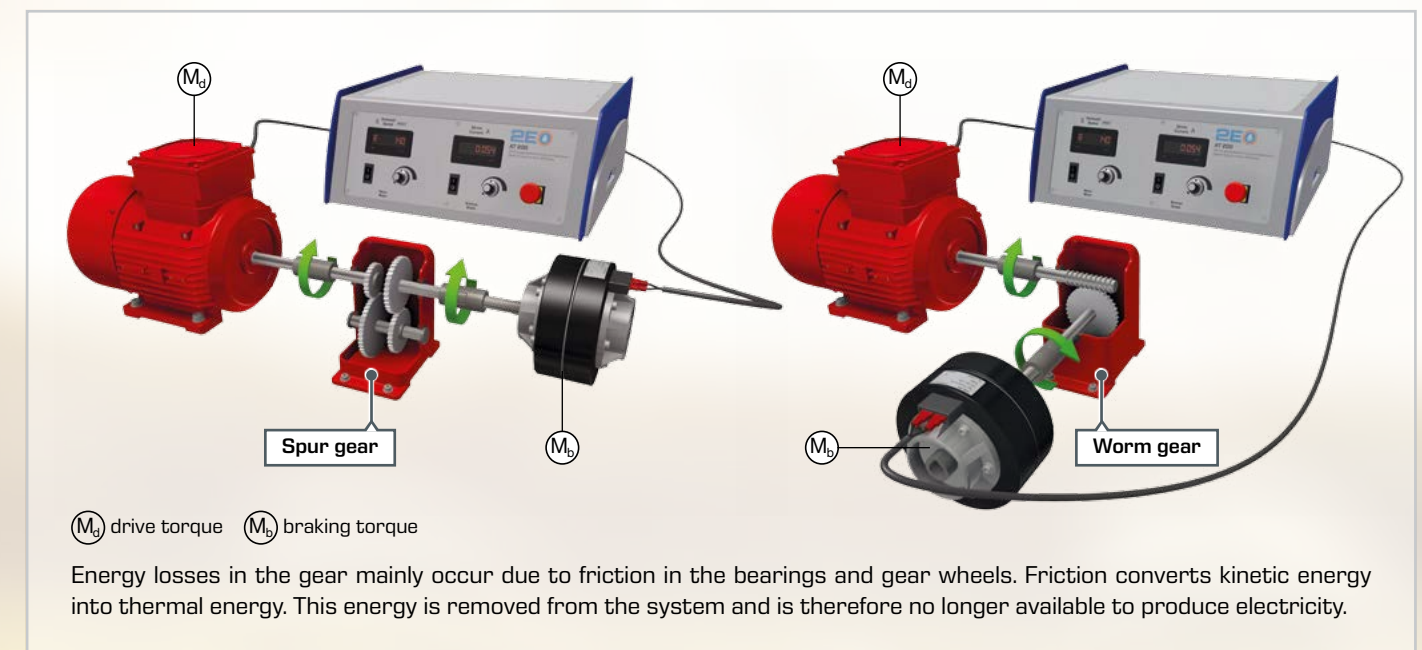
## Determination of Gear Efficiency

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.

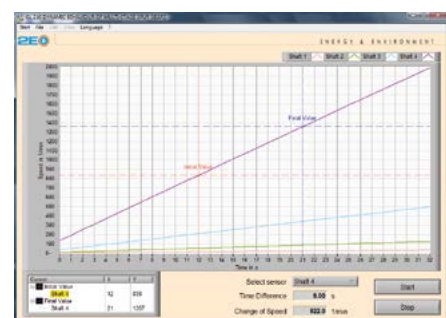
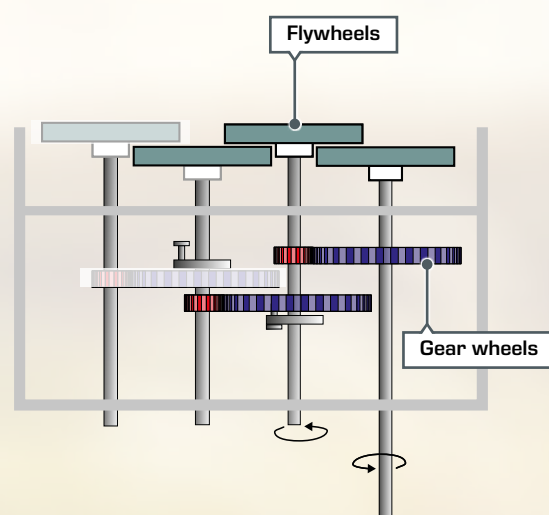
|   | Learning objectives                                                                                                                                                                                         |
|---|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ■ | determination of the mechanical efficiency of gears by comparing the mechanical driving and braking power for <ul style="list-style-type: none"> <li>▶ spur gear, two-stage</li> <li>▶ worm gear</li> </ul> |
| ■ | plot the torque/current characteristic curve for a magnetic particle brake                                                                                                                                  |
| ■ | drive and control engineering                                                                                                                                                                               |





# GL 210 Dynamic Behaviour of Multi-Stage Spur Gears

With our GL 210 and GL 212 trainers, you can clearly demonstrate the structure and function of commonly used types of gears in wind power plants and investigate their rotational dynamics.



## Software

For GL 210 and GL 212, the speeds of the various rotational axes are recorded via the measurement data acquisition using the GUNT software. The speed-time diagrams can be used to read off the acceleration for various gear configurations.

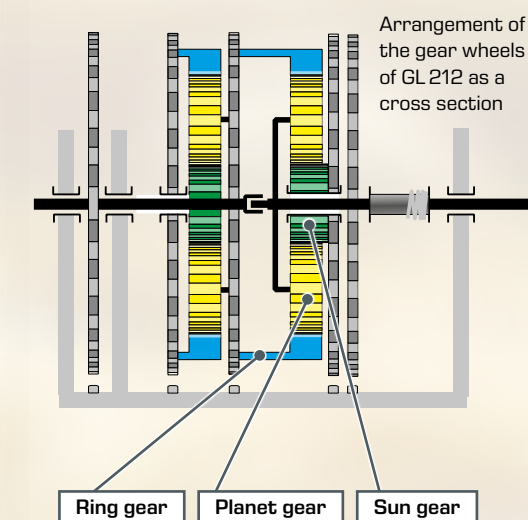
GL 210 can be used to configure single-stage, two-stage or three-stage spur gears.

A set of weights with rope and pulley is used as a drive with constant torque.

# GL 212 Dynamic Behaviour of Multi-Stage Planetary Gears

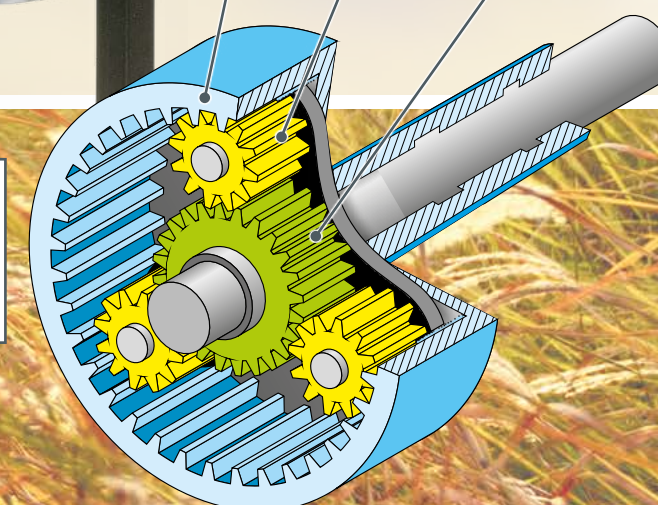
In large wind power plants, a combination of spur gears and planetary gears is often used.

GL 212 enables experiments on a two-stage planetary gear. Using adjustable locking mechanisms, a total of four different transmission ratios can be created.



A set of weights with rope and pulley is used as a drive with constant torque.

The planetary gear is a special type of gear mechanism, in which multiple planet gears revolve around a centrally arranged sun gear.



## Learning objectives

The following variables have to be determined in order to study the dynamics of multi-stage gears:

- angular acceleration
- mass moment of inertia
- friction
- gear efficiency

Product No.  
030.21000

More details and technical data:  
[gunt.de/static/s3640\\_1.php](http://gunt.de/static/s3640_1.php)



Product No.  
030.21200

More details and technical data:  
[gunt.de/static/s3402\\_1.php](http://gunt.de/static/s3402_1.php)





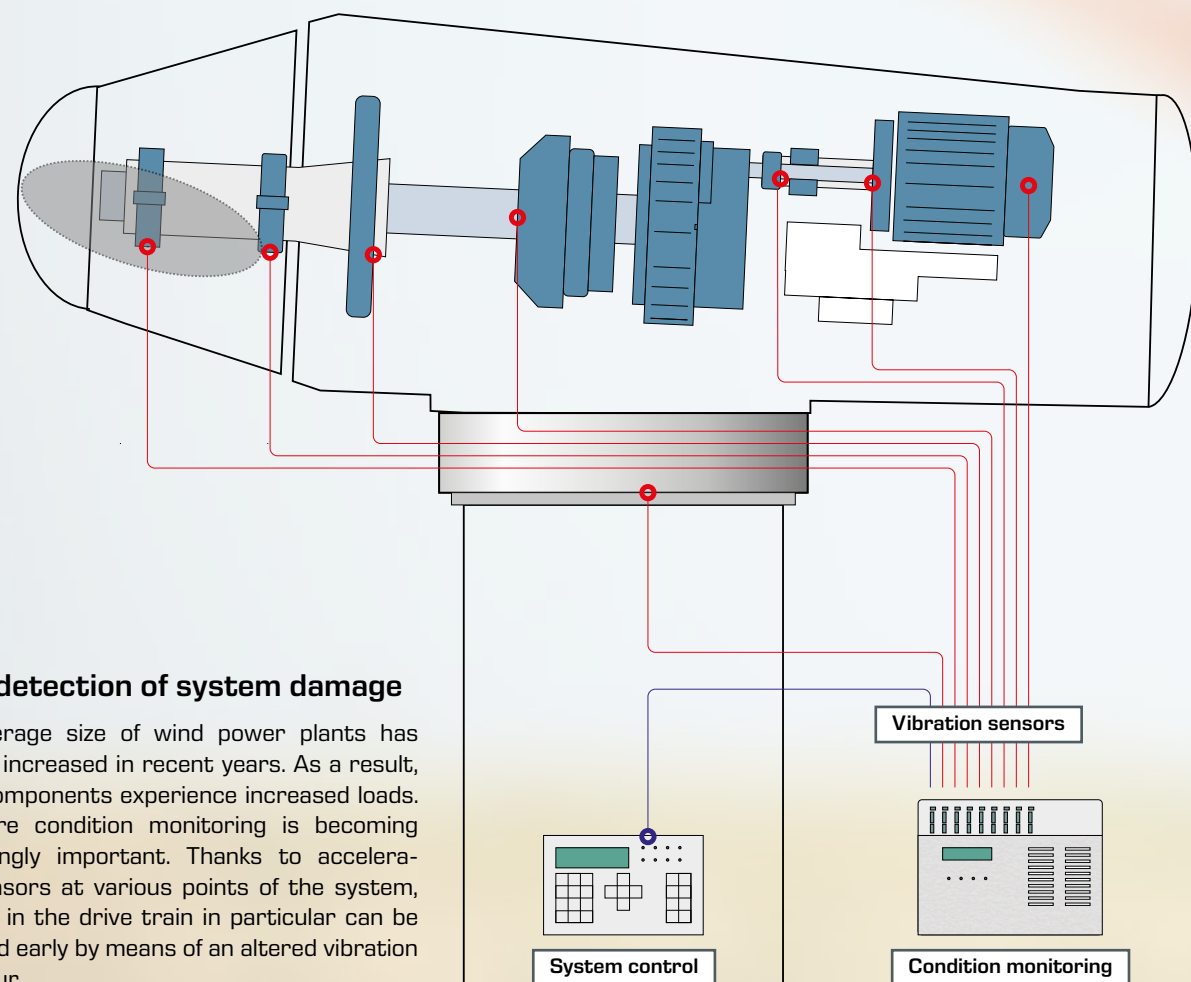
# Basic Knowledge Condition Monitoring in Wind Power Plants



In order to reduce technical and economic risks, systems for monitoring the status of the equipment (CMS, **Condition Monitoring Systems**) 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 perspec-

tive 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.

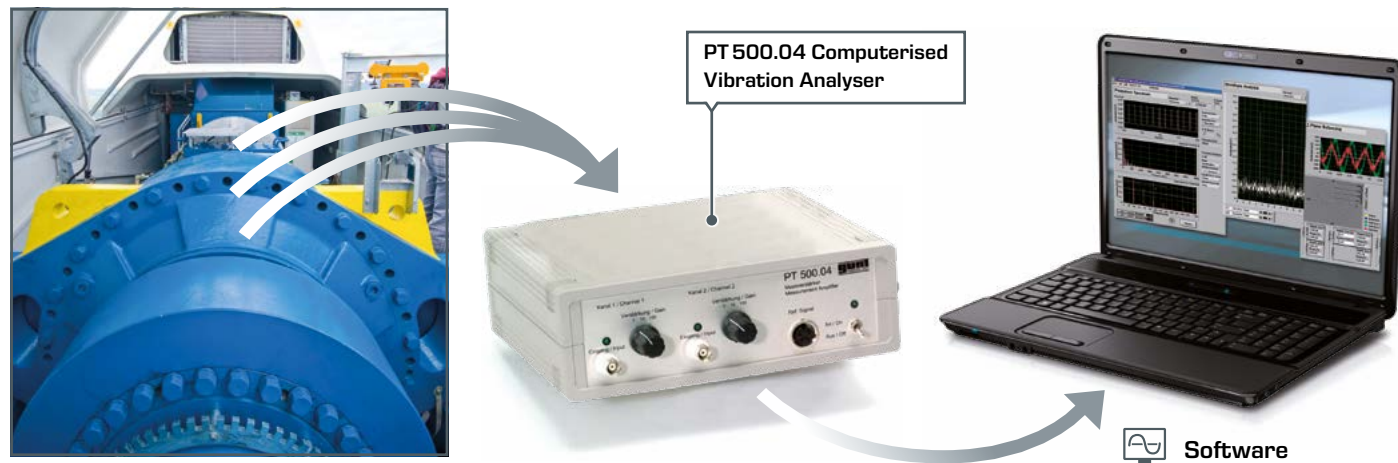
In many cases, experienced experts are also required to safely distinguish between measurements caused by the condition of the component and those simply caused by operation. We are pleased to present to you important experiments with our equipment in the field of wind energy in order to teach the necessary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



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



## 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](http://www.gunt.de).

## 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

## 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 Tecnica de Capacitación 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.

Product No.  
052.50000  
More details and technical data:  
[gunt.de/static/s3680\\_1.php](http://gunt.de/static/s3680_1.php)





## PT 500.11 Crack Detection in Rotating Shaft Kit

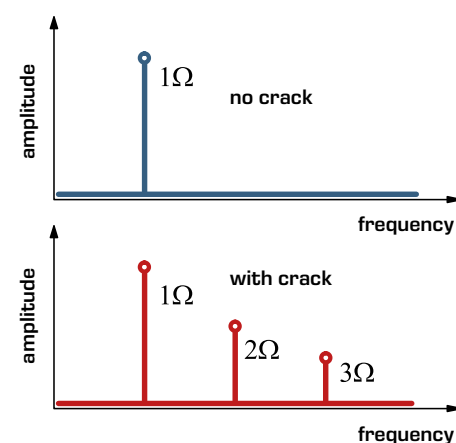


The rotor shaft of a wind power plant transfers the mechanical energy from the rotor to the gear. By detecting cracks in the shaft early, the risk of a costly failure and/or the danger of destruction of the turbine can be minimised.

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.

### 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.

Product No.  
052.50011  
More details and technical data:  
[gunt.de/static/s4634\\_1.php](http://gunt.de/static/s4634_1.php)

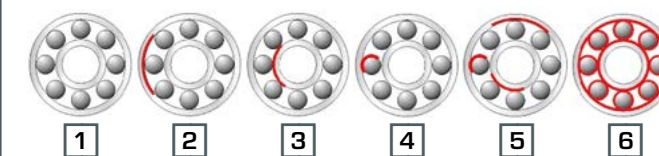


## PT 500.12 Roller Bearing Faults Kit



Dynamic forces with extreme peak loads and minimum loads, sudden load changes and vastly different temperatures represent considerable challenges for modern bearing technology in wind power plants. Bearing materials and structural shapes are constantly being developed for both rotor shafts and for gears and generators in order to satisfy the increasing demands of larger turbines.

PT 500.12 gives you the option of studying modern methods of bearing diagnostics on real roller bearings.



The following bearings have been prepared for the experiments:

- 1 undamaged bearing
- 2 bearing with damage to the outer race
- 3 bearing with damage to the inner race
- 4 bearing with damage to a rolling element
- 5 bearing with damage to rolling element, outer race and inner race
- 6 bearing with heavy wear

### Learning objectives

- vibrational spectrum of roller bearing running noise
- influence of damage to outer race, inner race or roller body on the spectrum
- estimating roller bearing service lives
- influence of the lubricant on the vibration spectrum
- detection of faulty roller bearings
- understanding and interpreting frequency spectra
- use of a computerised vibration analyser

The slow change of the vibration spectrum is one criterion for the remaining lifespan of a bearing and its replacement. The spectral distribution allows accurate conclusions on the type and location of the damage.

In condition monitoring, a distinction is made between the simpler monitoring of characteristic variables and the more complex analysis in the frequency range.

Product No.  
052.50012  
More details and technical data:  
[gunt.de/static/s4633\\_1.php](http://gunt.de/static/s4633_1.php)



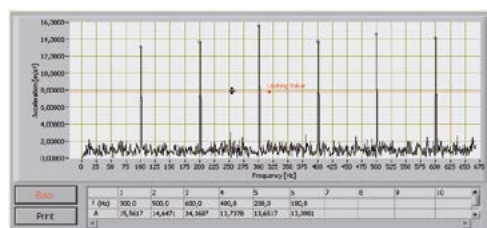


# PT 500.15 Damage to Gears Kit



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 toothings damage and on locating damage in gears.



Spectrum of a straight-toothed gear at 1800 min<sup>-1</sup> and tooth engagement frequency of 752 Hz

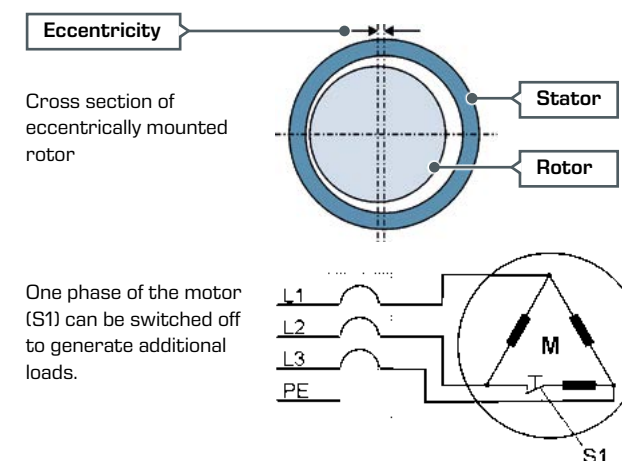
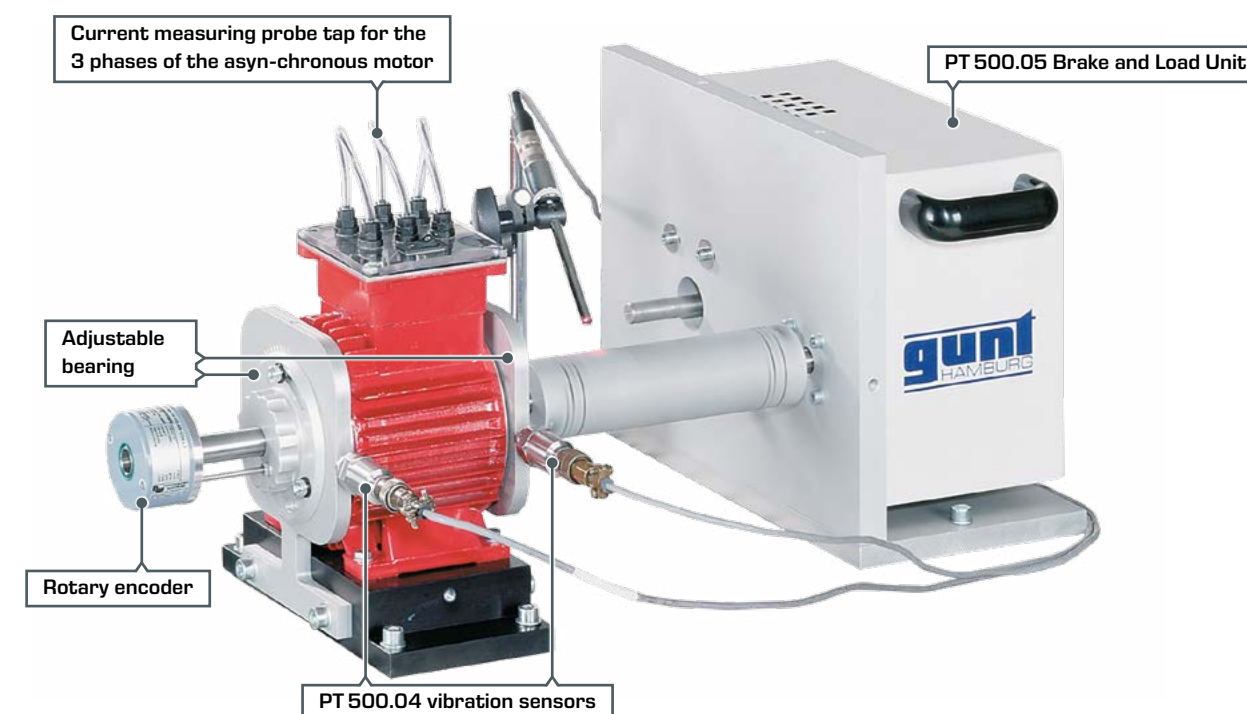
Product No.  
052.50015  
More details and technical data:  
[gunt.de/static/s4630\\_1.php](http://gunt.de/static/s4630_1.php)



# PT 500.19 Electromechanical Vibrations Kit

The occurrence of electromechanical vibrations can be a considerable load for motor and generator systems. Due to the extreme strain at their points of use, these effects are often especially important in wind power plant generators.

PT 500.19 provides you with an ideal expansion for the PT 500 system in order to investigate electromechanical vibrations.



## 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

## Learning objectives

- influence of the gap on vibration behaviour
- influence of electromagnetic asymmetry on vibration behaviour
- influence of the load on the level of vibration
- influence of the gap on electromagnetic losses and efficiency
- influence of speed on vibration behaviour
- understanding and interpreting frequency spectra
- use of a computerised vibration analyser

Product No.  
052.50019  
More details and technical data:  
[gunt.de/static/s4627\\_1.php](http://gunt.de/static/s4627_1.php)





# Biomass

1.4

2E a division of



This product area is one of GUNT's current areas of development. If you have any ideas for future teaching and research equipment in this field, please get in touch. We would love to work with you.

## Introduction

**Subject Areas**  
Biomass

090

## Bioethanol

**Basic Knowledge**  
Bioethanol

092

**CE 640**  
Biotechnical Production of Ethanol

094

## Biogas

**Basic Knowledge**  
Biogas

098

**CE 642**  
Biogas Plant

100

## Biodiesel

**Basic Knowledge**  
Biodiesel

104

**CE 650**  
Biodiesel Plant

105



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[www.gunt2e.de](http://www.gunt2e.de)





# Subject Areas Biomass



## Subject Areas

## 2E Products

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 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.



### Bioethanol

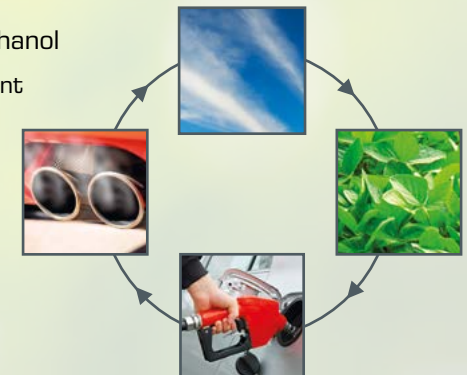
### Biogas

### Biodiesel

#### CE 640

##### Biotechnical Production of Ethanol

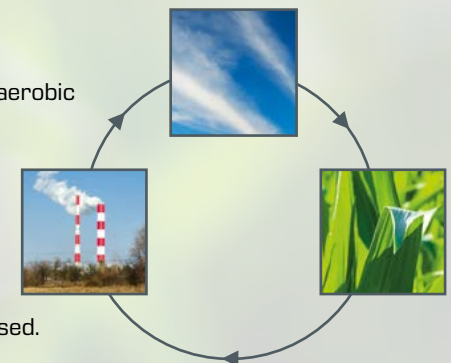
The anaerobic degradation of plant components (e.g. potatoes) through enzymes and yeasts can produce bioethanol, which can be used as a fuel. The waste gas is in turn absorbed by the plants and the circuit is closed.



#### CE 642

##### Biogas Plant

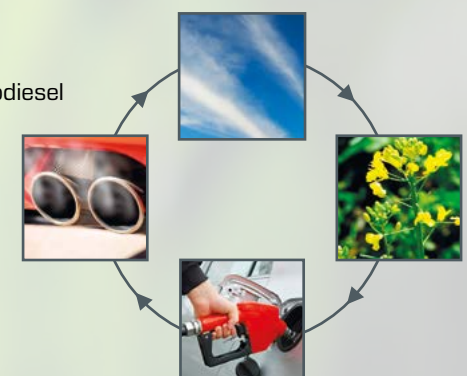
Biogas can be produced by the anaerobic degradation of plant components (e.g. maize) through biomass and, for example, be converted into electricity in combined heat and power plants and the waste heat used for heating purposes. The waste gas is in turn absorbed by the plants and the circuit is closed.



#### 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.

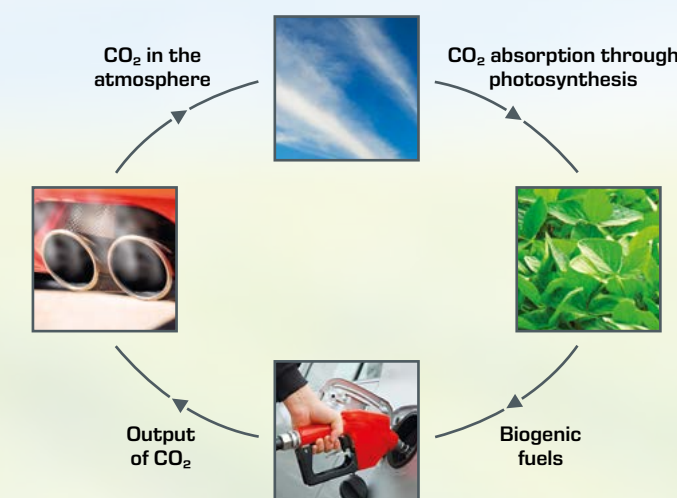
Replenishable biomass can be used to produce storable carbon neutral energy sources. These energy sources play an important role alongside discontinuous sources such as solar and wind in realising a carbon-neutral and renewable energy supply.

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



## The CO<sub>2</sub> cycle of bioethanol

Photosynthesis, with the aid of sunlight, enables plant growth. In this process CO<sub>2</sub> 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 residence time play an important role in these processes, so as to achieve the greatest yield of energy sources from the biomass.

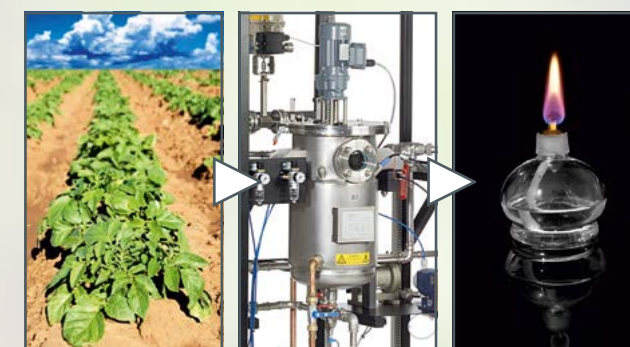
Biofuels are substitutes for super unleaded and diesel fuels, which are either mixed with fossil fuels or used directly

with appropriate engine technology. The basis of biofuel is ethanol for super unleaded fuel and vegetable oil for diesel fuel.

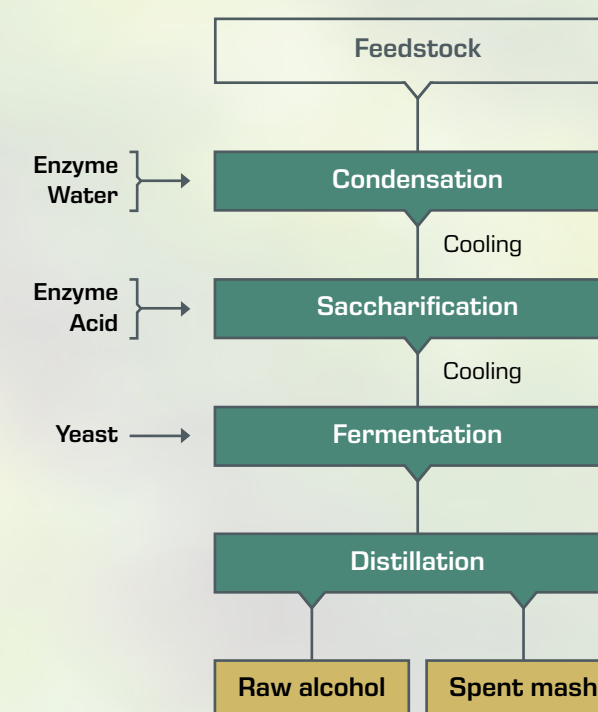
For the field of biofuels, we supply a complete system that uses enzymes and yeasts to convert starch ethanol. The integrated distillation system is used to separate the ethanol from the digestate.

Another system for the conventional production of bio-diesel by means of transesterification is in development.

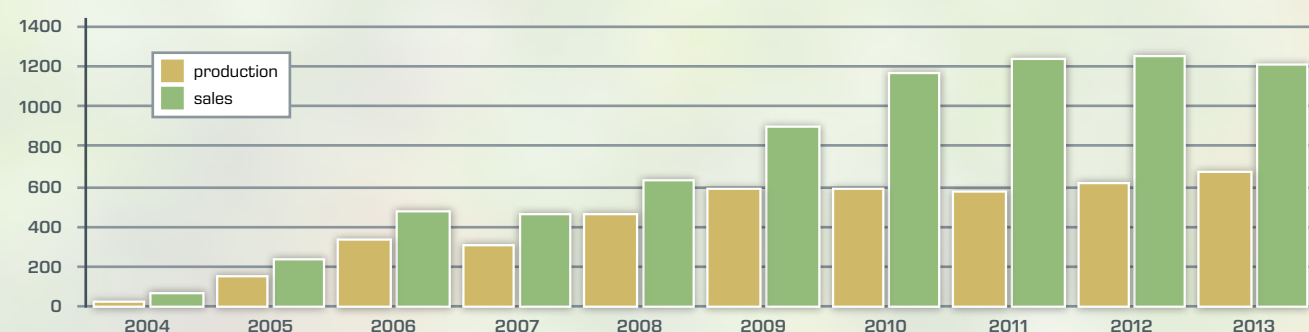
Starting materials for bioethanol are the carbohydrates (sugars) contained in the plants, from which alcohol is created with the aid of enzymes and yeast fungus. While plants containing sugar are fermented directly, in the case of starchy plants it is the actual alcoholic fermentation of the enzymatic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



Fundamental principle of bioethanol production



Growth of bioethanol in Germany (in 1000t)

(Source: BDBe/FNR)



# CE 640 Biotechnical Production of Ethanol

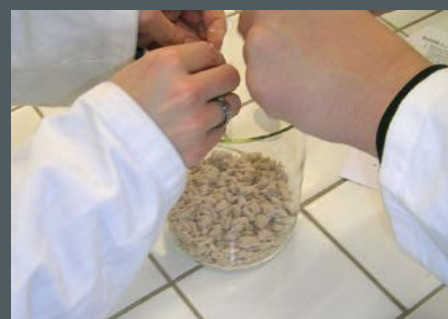
## Understand the production process of bioethanol in a laboratory experiment

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 the yeast into the fermentation tank



Preparation of the yeast



Addition of feedstocks into the mash tank

## Satisfied customers

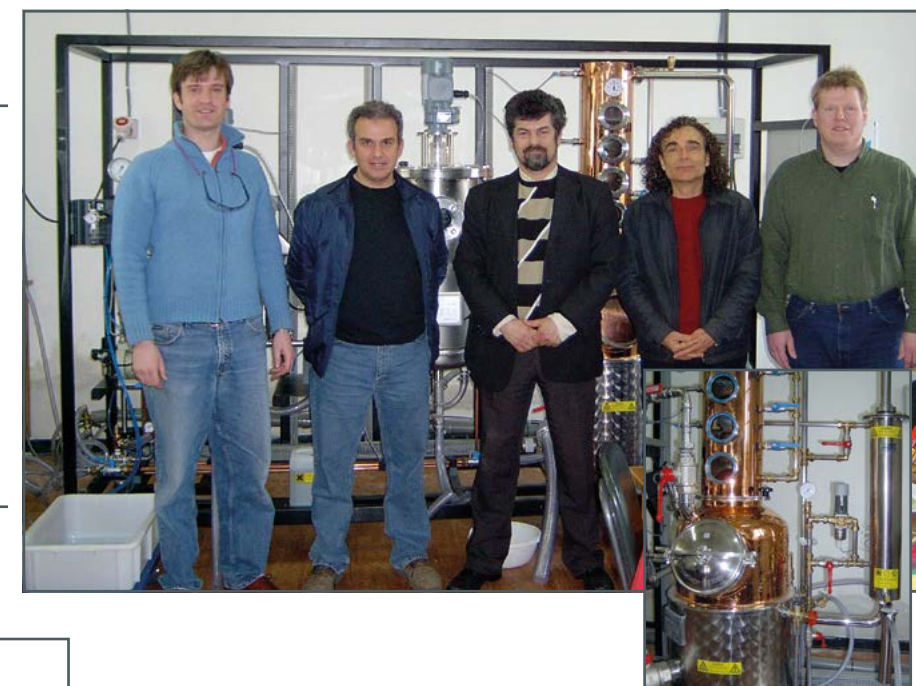


### AGRICULTURAL RESEARCH INSTITUTE

Nicosia/Cyprus

Dr. Polycarpou 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 (Germany)

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 in their own experiments.



An interesting film and a brochure for CE 640 can be found on our 2E website [www.gunt2e.de](http://www.gunt2e.de)





# 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 the laboratory. 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.

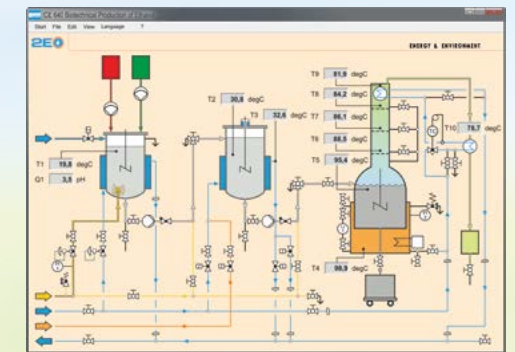
Once the fermentation process has ended, the ethanol is separated from the waste materials using a distillation unit (still).



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

still

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



## Software

The software for CE 640 allows the most important variables to be captured

- temperature
- pH value
- fermentation temperature
- water temperature
- boiler temperature
- bubble tray temperatures
- dephlegmator temperature
- condenser temperature

mash tank

fermentation tank

still

## Learning objectives

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





# Basic Knowledge Biogas



Rising energy requirements and the limited availability of fossil energy sources make new energy supply concepts necessary. Energy production from biomass plays an important role in future energy concepts besides solar and wind energy.

In a biogas plant, microorganisms biologically degrade the organic starting substances (substrate) under exclusion of light and oxygen. The product of this anaerobic degradation is a gas mixture which primarily consists of methane. This gas mixture is called biogas.



The complex processes of anaerobic degradation can be simplified as four consecutive phases.

## Phase 1: Hydrolysis

The substrate used in biogas plants is available as undissolved, high-molecular compounds such as proteins, fats and carbohydrates. Therefore these compounds first have to be broken down into their individual components. Hydrolysis products are amino acids, sugars and fatty acids.

## Phase 2: Acidification

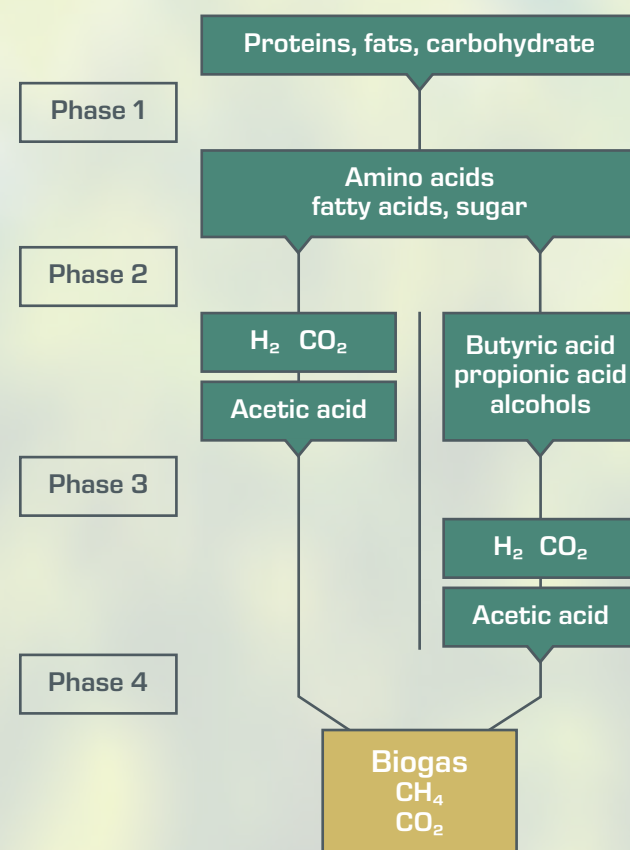
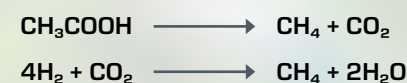
The hydrolysis products are then biochemically decomposed further, primarily into propionic acid, butyric acid, acetic acid, alcohols, hydrogen and carbon dioxide.

## Phase 3: Formation of acetic acid

The products of the previous phase are now converted into acetic acid, hydrogen and carbon dioxide.

## Phase 4: Formation of methane

Methanogens can use either acetic acid ( $\text{CH}_3\text{COOH}$ ) or carbon dioxide and hydrogen for their metabolism. So methane ( $\text{CH}_4$ ) can be produced in the following two reactions:



Fundamental principle of anaerobic degradation

## Ambient conditions

The microorganisms involved in the anaerobic degradation have different requirements regarding the ambient conditions. This applies primarily to the pH value and the temperature. Especially methanogens are very sensitive to deviations of these two process variables from their respective optimal value.

If all 4 phases of the degradation take place in one reactor, a compromise regarding the pH value and temperature needs to be found. This results in a lower biogas yield. From a process engineering point of view, a two-stage process in two separate reactors is more practical as this enables the ambient conditions to be adjusted more specifically to the respective bacteria.

## Use of biogas

The biogas produced can now be combusted in a combined heat and power plant. This converts the energy stored in the biogas to mechanical energy. A connected generator

then converts this mechanical energy into electric power. In addition to electrical energy, a combined heat and power plant also produces heat which can, for example, be used to heat the reactor or buildings.

How a biogas plant works:

- 1 slurry from livestock husbandry
- 2 renewable raw materials (e.g. maize)
- 3 storage for shredded raw materials
- 4 storage for feeding the bioreactor
- 5 bioreactor (fermenter)
- 6 storage for digestate
- 7 biogas treatment
- 8 combined heat and power plant
- 9 water circuit to heat the bioreactor
- 10 feed of the current into the public power grid
- 11 digestate (use as fertilizer)





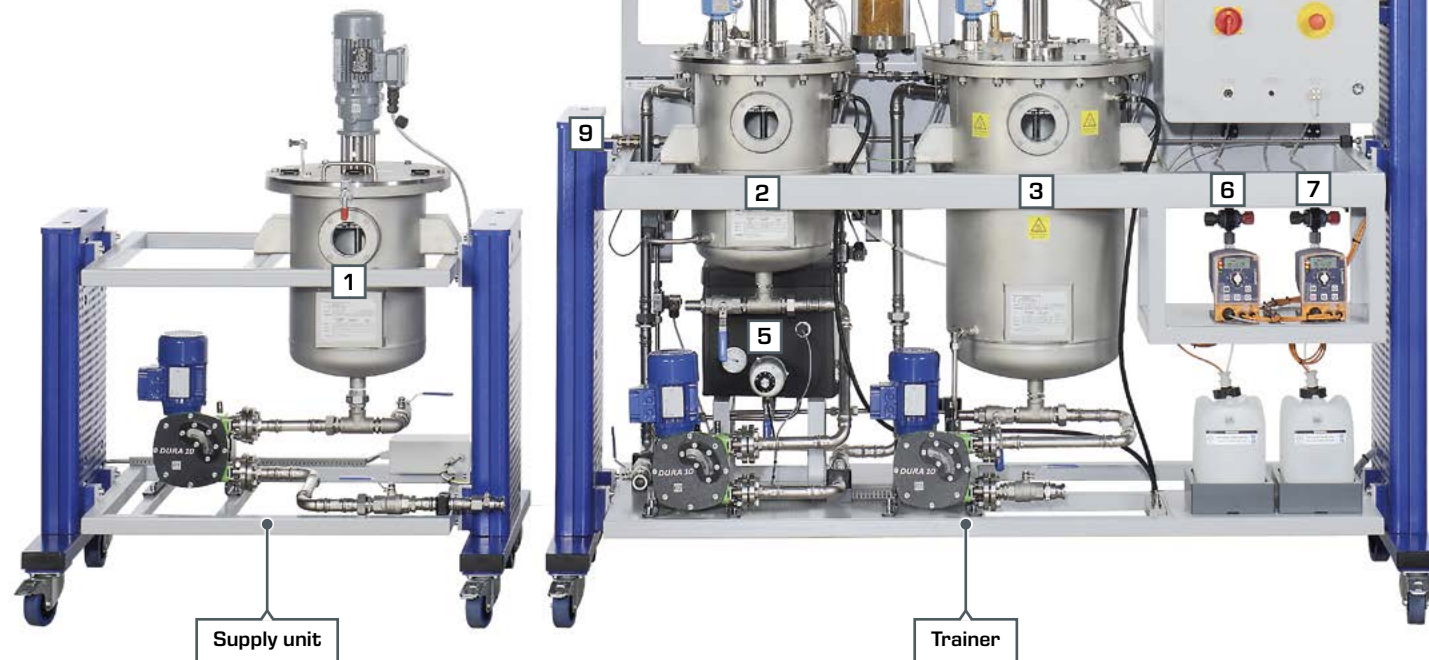
# CE 642 Biogas Plant

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.

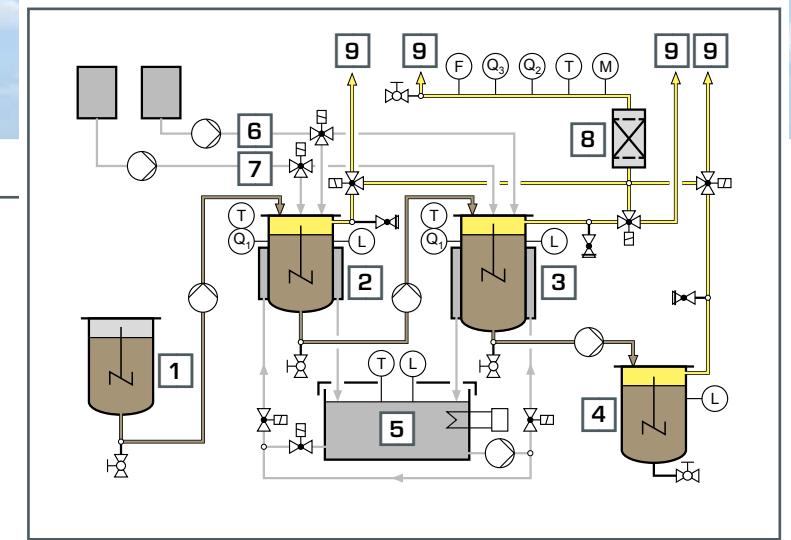
A suspension of comminuted organic solids is used as the substrate. Hydrolysis and acidification of the substrate take place in the first stirred reactor. Here, anaerobic microorganisms convert the long-chain organic substances into short-chain organic substances. In the second stirred reactor, biogas 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.



Industrial peristaltic pump



- |                      |                                              |
|----------------------|----------------------------------------------|
| 1 substrate tank     | F flow rate                                  |
| 2 reactor 1          | L level                                      |
| 3 reactor 2          | M humidity                                   |
| 4 digestate tank     | Q <sub>1</sub> pH value                      |
| 5 heating water tank | Q <sub>2</sub> methane concentration         |
| 6 acid dosing        | Q <sub>3</sub> CO <sub>2</sub> concentration |
| 7 alkaline dosing    | T temperature                                |
| 8 drying column      |                                              |
| 9 biogas             |                                              |



**Learning objectives**

- achieving a stable operating state
- influence of the following parameters on the biogas generation:
  - temperature
  - substrate
  - volumetric loading
  - pH value
- influence of the operation mode on the biogas yield
  - single stage or dual stage
  - with and without post-fermentation
  - continuous and discontinuous
- determining the following parameters depending on the operating conditions:
  - biogas yield
  - biogas flow rate
  - biogas quality



Silica gel in the drying column



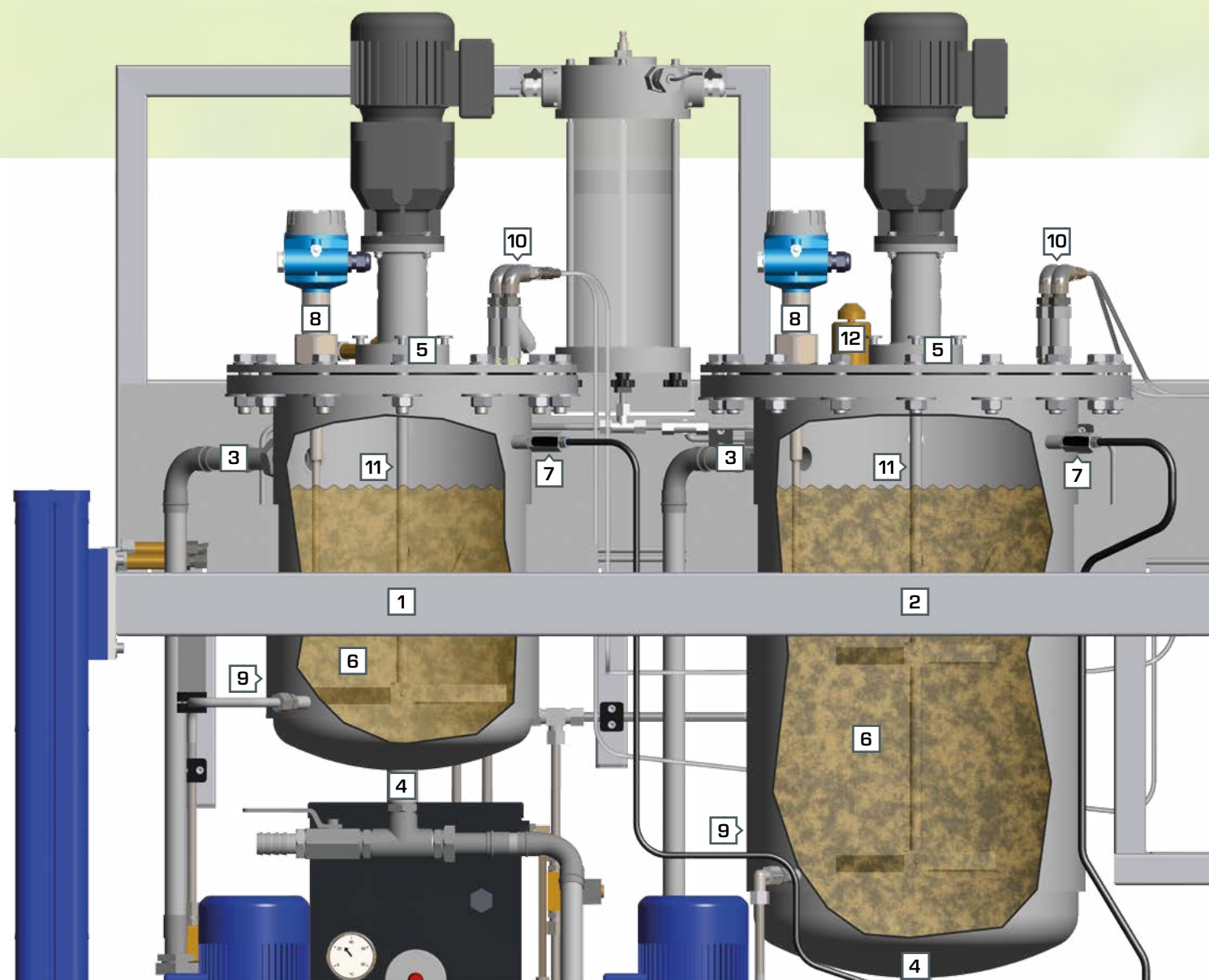
Connectors for biogas with gas analysis





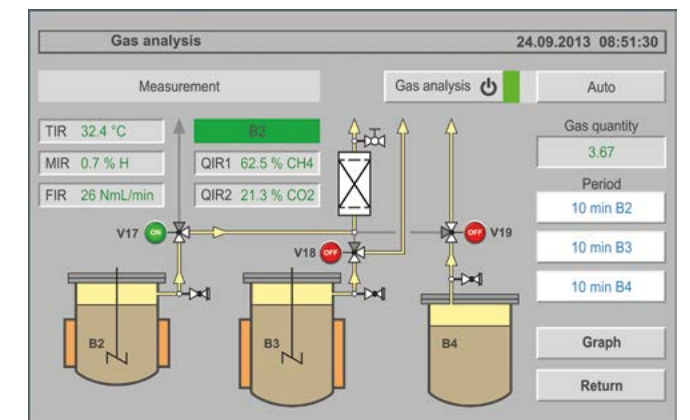
# CE 642 Biogas Plant

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.



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

## Software



In the gas analysis menu in the PLC user interface, you are given a summary of the current flow direction of the gas and the current measured values of the gas analysis. Further-more, 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:

- |                                     |                       |
|-------------------------------------|-----------------------|
| ■ temperature                       | } <b>per reactor</b>  |
| ■ pH value                          |                       |
| ■ level                             |                       |
| ■ speed of the stirring machines    |                       |
| ■ volumetric flow rate              |                       |
| ■ methane concentration             | } <b>gas analysis</b> |
| ■ carbon dioxide concentration      |                       |
| ■ temperature                       |                       |
| ■ humidity                          |                       |
| ■ volumetric flow rate and quantity |                       |





# Basic Knowledge Biodiesel

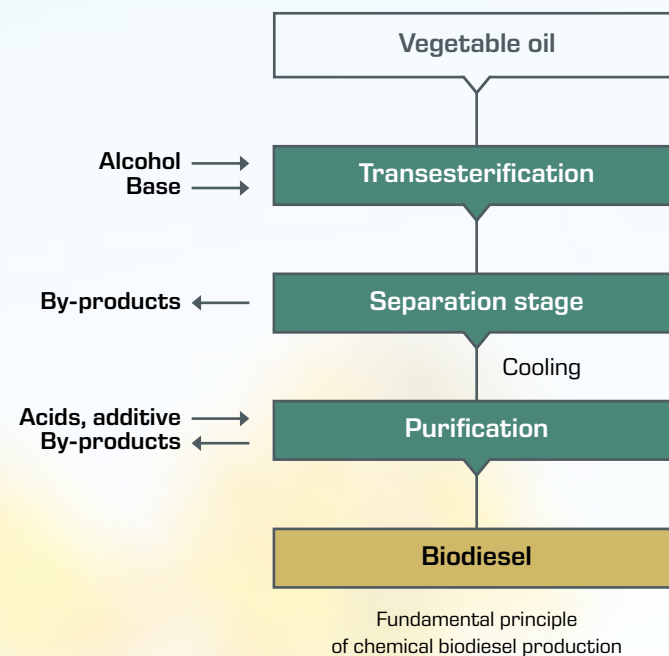


Biodiesel is an important element in the biofuels field. Biodiesel can be produced from a wide variety of raw materials, which mainly vary by region.

It is mainly vegetable oils which are used, and these 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.

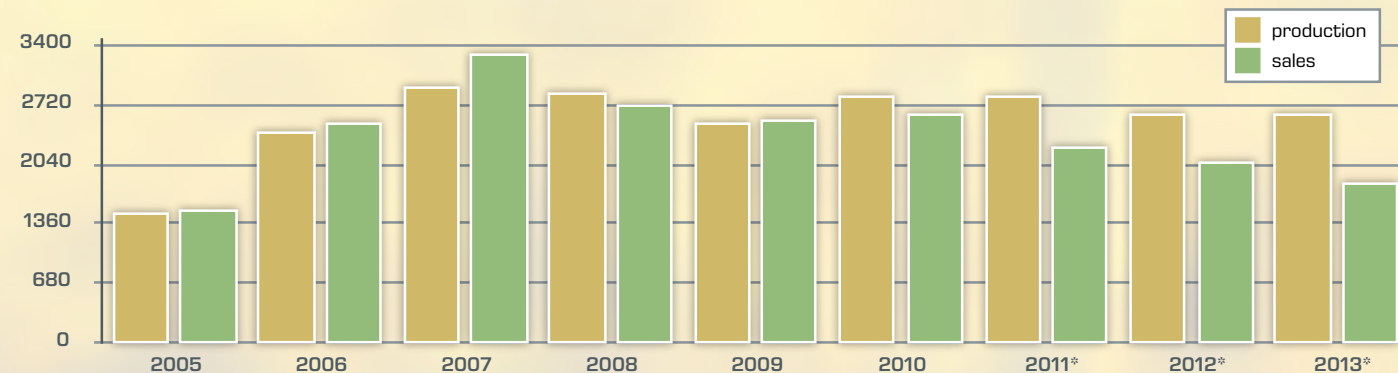
After biodiesel has been successfully produced, it is necessary to clean the biodiesel for use in engines. It is mainly water which is separated out in the additional step. The main by-product is glycerin. A variety of processes are currently being developed to use this glycerin. Thanks to the high level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



## Growth of biodiesel

The growth of biodiesel production and biodiesel sales in Germany is linked to political targets. The proportion of biodiesel has been steadily rising for a few years due to the tax benefits and admixtures, and in 2007 reached its peak of 12% of the

German diesel fuel market. Production and sales fell in subsequent years due to the declining price advantage and rising raw material costs.



Growth of biodiesel in Germany (in 1000t)

\*Sales excluding hydrogenated vegetable oils

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

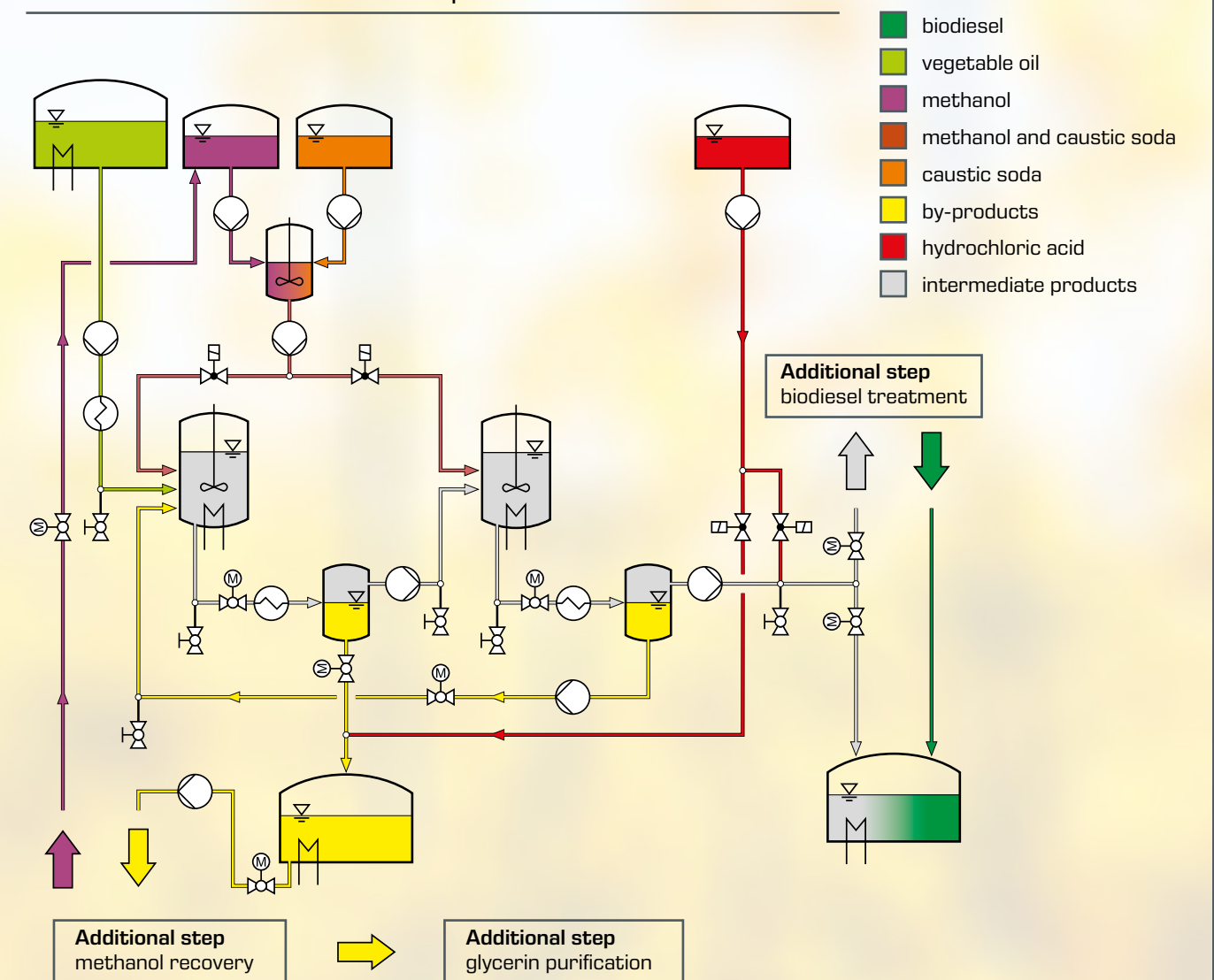
## CE 650 Biodiesel Plant

### Biofuels for carbon neutral energy

In addition to the biotechnical production of ethanol (CE 640), an experimental plant for biodiesel production from vegetable oils is being developed. Biodiesel is produced with a chemical reaction, namely transesterification. With the added alcohol, e.g. methanol, the vegetable oil feedstock is separated into biodiesel

and the by-product glycerin. CE 650 offers you the traditional chemical production method for biodiesel and unwanted by-products can be removed by the optional treatment.

### Schematic of chemical biodiesel production



Product No.  
083.65000  
More details and technical data:  
[gunt.de/static/s5449\\_1.php](http://gunt.de/static/s5449_1.php)





# Geothermal Energy

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| Introduction                                                                      |                                             |     |
|-----------------------------------------------------------------------------------|---------------------------------------------|-----|
|  | <b>Subject Areas</b><br>Geothermal Energy   | 108 |
|  | <b>Basic Knowledge</b><br>Geothermal Energy | 110 |

| Heat Exchangers                                                                       |                                                           |     |
|---------------------------------------------------------------------------------------|-----------------------------------------------------------|-----|
|    | <b>Basic Knowledge</b><br>Heat Exchangers                 | 112 |
|    | <b>Overview</b><br>WL 110-Series: Modular Heat Exchangers | 114 |
|    | <b>WL 110</b><br>Heat Exchanger Supply Unit               | 116 |
|  | <b>WL 110.01</b><br>Tubular Heat Exchanger                | 118 |
|  | <b>WL 110.02</b><br>Plate Heat Exchanger                  | 118 |
|  | <b>WL 110.03</b><br>Shell & Tube Heat Exchanger           | 119 |
|  | <b>WL 110.04</b><br>Jacketed Vessel with Stirrer & Coil   | 119 |
|  | <b>WL 315C</b><br>Trainer for Various Heat Exchangers     | 120 |

| Shallow Geothermal Energy                                                             |                                                                                            |     |
|---------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-----|
|    | <b>Basic Knowledge</b><br>Shallow Geothermal Energy                                        | 122 |
|    | <b>ET 101</b><br>Simple Compression Refrigeration Circuit                                  | 124 |
|    | <b>ET 262</b><br>Geothermal Probe with Heatpipe Principle                                  | 126 |
|  | <b>ET 264</b><br>Geothermal Energy with 2-Well System                                      | 128 |
|  | <b>Overview</b> HL320 Solar Thermal Energy and<br>Heat Pump Modular System (Combination 3) | 130 |

| Deep Geothermal Energy                                                                |                                                                            |     |
|---------------------------------------------------------------------------------------|----------------------------------------------------------------------------|-----|
|  | <b>Basic Knowledge</b><br>Deep Geothermal Energy                           | 132 |
|  | <b>Overview</b> ET 850 & ET 851<br>Steam Generator and Axial Steam Turbine | 134 |
|  | <b>ET 850</b><br>Steam Generator                                           | 136 |
|  | <b>ET 851</b><br>Axial Steam Turbine                                       | 138 |

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# Subject Areas Geothermal Energy



## Subject Areas

## 2E Products

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.

### 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 110.04

Jacketed Vessel with Stirrer & Coil

#### WL 315C

Trainer for Various Heat Exchangers

### Shallow geothermal energy

#### ET 101

Simple Compression Refrigeration Circuit

#### ET 262

Geothermal Probe with Heatpipe Principle

#### ET 264

Geothermal Energy with 2-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



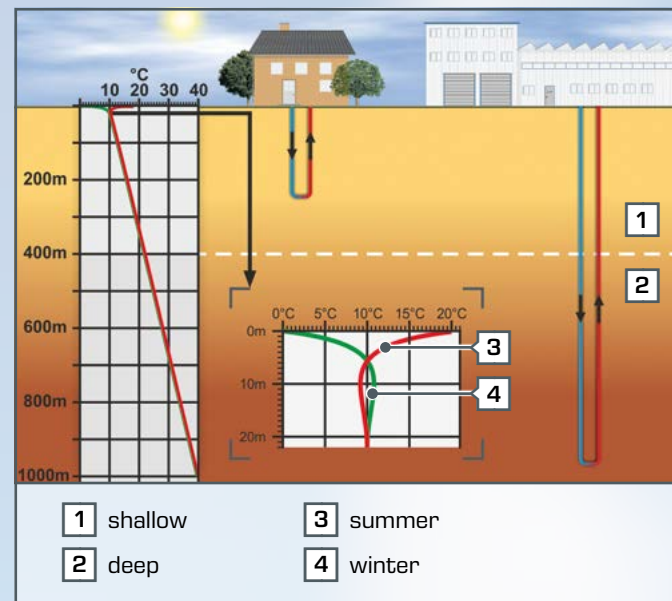
# Basic Knowledge Geothermal Energy



## 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...20m) 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 100m. For the most part, the thermal energy is the result of the decay of radioactive isotopes of uranium, thorium and potassium.



## Differentiating geothermal fields

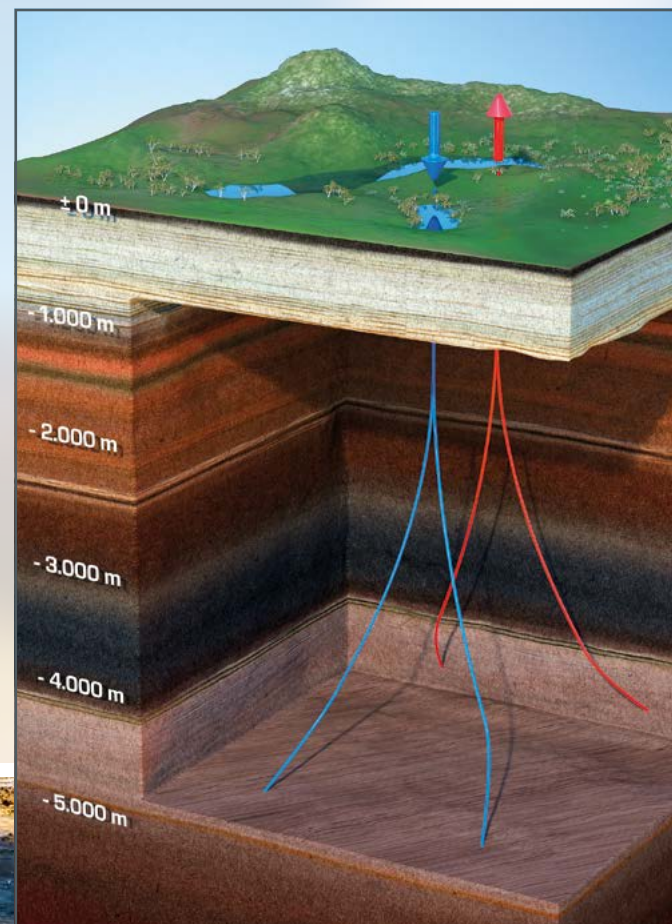
Usually when talking about geothermal energy a distinction is made between shallow geothermal energy and deep geothermal energy.

### 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...400m). 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 which 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

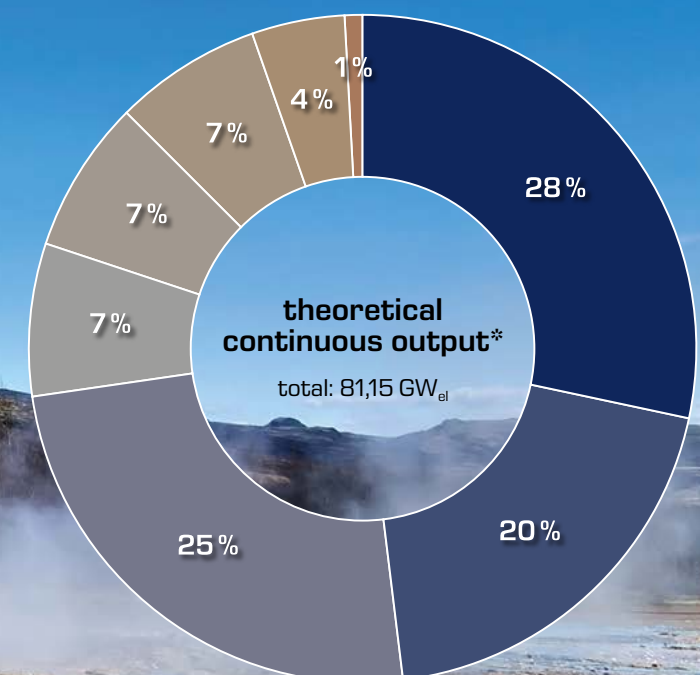
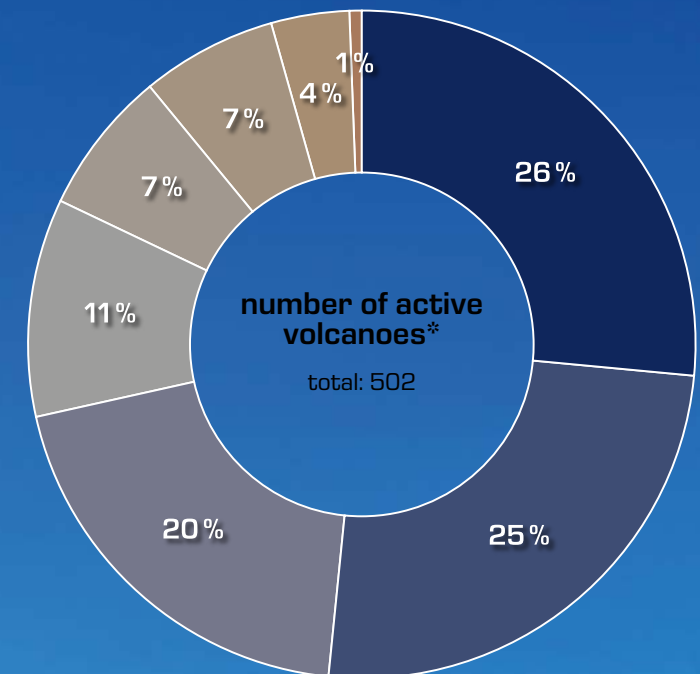
The potential for use of geothermal energy is divided according to the geothermal fields. For thermal anomalies with volcanic activity, a theoretical continuous electrical output of around 81 GW<sub>el</sub> has been determined in just 8 countries. As a comparison by size, the gross electricity consumption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

The global comparison shows that exploiting the theoretical continuous output of active volcanic regions alone could cover 4 % of the global electricity demand. If other geothermal energy fields, both shallow and deep, are exploited as well, coverage of the global demand for heat and electricity is possible.



\*selected countries

Source: V. Steffansson:  
World geothermal assessment





# Basic Knowledge Heat Exchangers

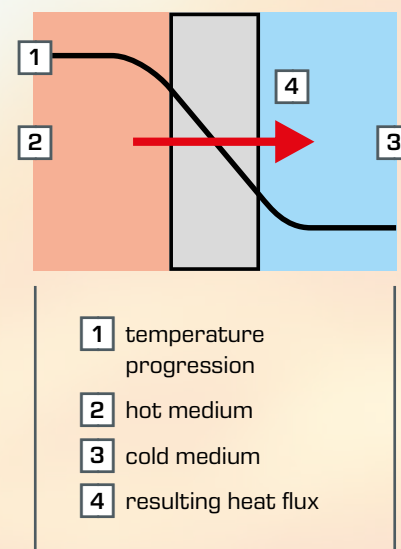


## Heat transfer

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 between the two media as the driving differential is essential for heat transfer.

The entire transferred heat flux is 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.

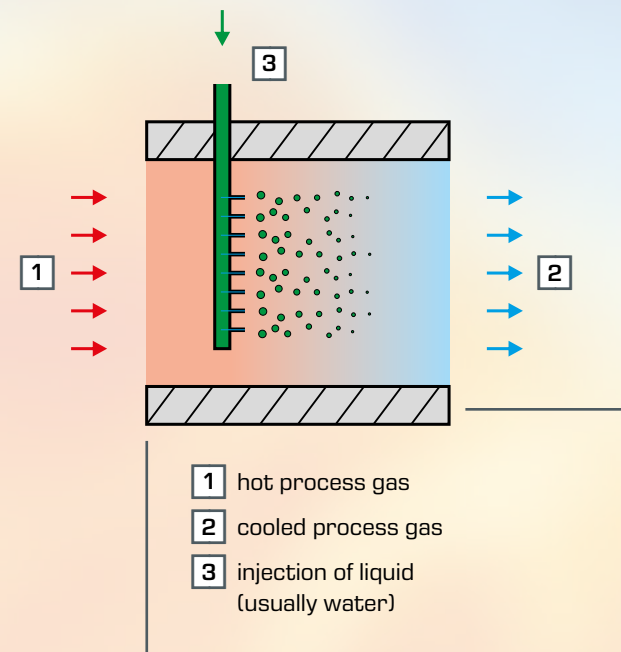
Heat transfer is divided into three stages: Heat transfer from the warmer medium to the wall, heat conduction through the wall and heat transfer from the wall to the colder medium.



The 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 on the wall depends on 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 station sector.

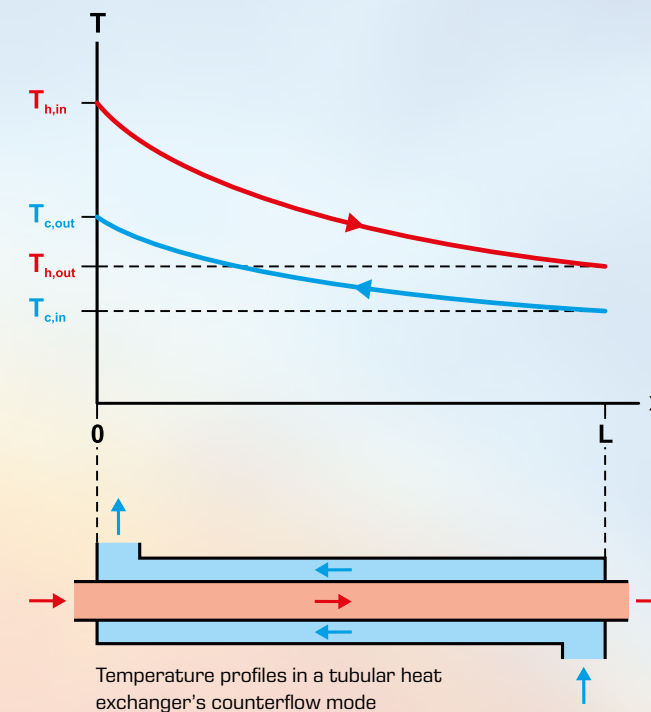


In contrast to direct heat transfer, the transfer of heat in spatially separated media is known as indirect transfer. The two materials are separated by a heat-permeable wall. The most well-known heat exchanger with indirect heat transfer is the domestic radiator.

Semi-indirect heat transfer is a special case which 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.

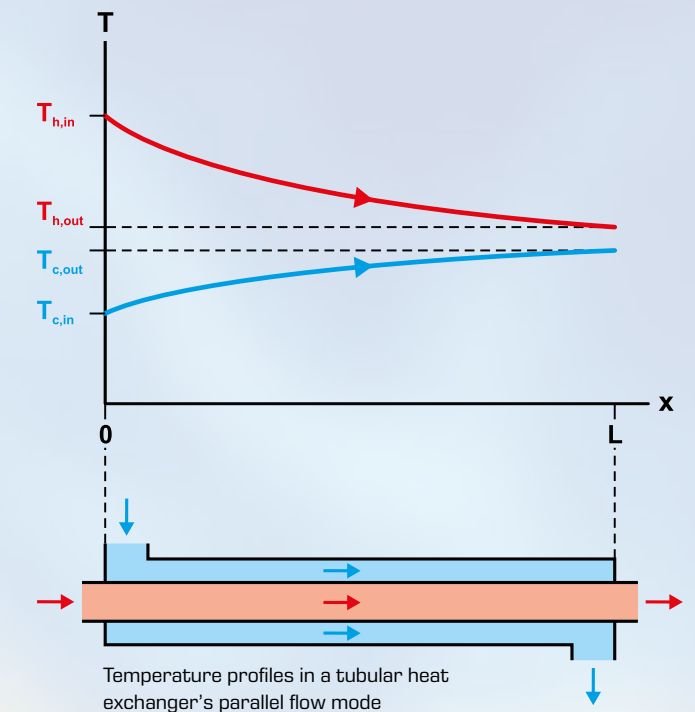
## Flow conditions

The possible flow conditions of indirect heat exchangers are counterflow, parallel 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.



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.

This is not possible when operating the heat exchanger in parallel 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 parallel.



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.



# WL 110-Series Modular Heat Exchangers

## Experiments on the fundamentals of heat transfer

Clear, simple, reliable, learning progress monitoring

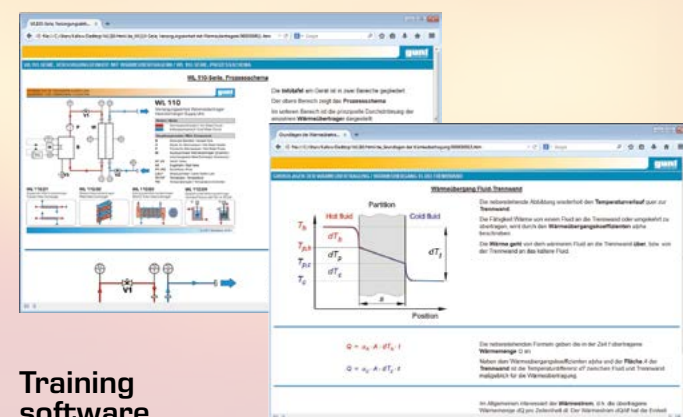


## Didactic advantages

Ideally suited for student-led experiments

A small group of 2-3 students can easily and independently conduct a variety of experiments. The lecturer can present characteristic aspects of the heat exchanger using software for data acquisition and a projector connected to the computer. The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

Supply unit for  
heat exchangers WL 110  
with WL 110.03 Shell and  
Tube Heat Exchanger



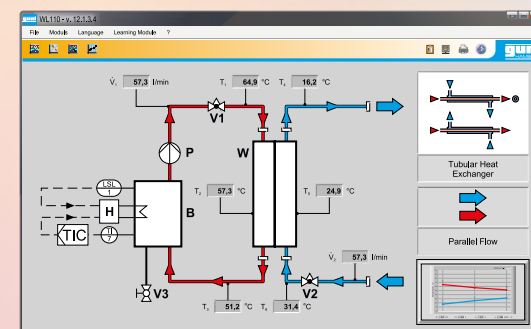
## Training software

Our training software, specially developed for this equipment series, provides a multimedia-based and interactive course of study on the fundamentals of heat transfer and on operating the WL 110 series. Didactically thought-out test questions at the end of the course allow you to review students' learning progress directly on the PC.



## WL 110.20 Water Chiller for WL 110

The cold water required for all experiments is usually provided by the laboratory supply. If the ambient temperature of the laboratory is too high, we recommend using the water chiller to obtain meaningful experimental conditions. Hot water is also needed for the experiments. It is provided by the WL 110 supply unit.



## Software

The software for WL 110 has the following main features:

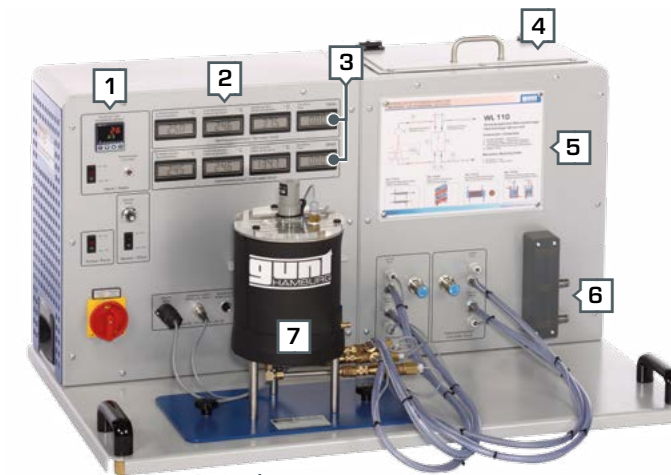
- measurement of temperatures and flow rates
- operation in parallel flow or counterflow
- calculation of the mean heat transfer coefficient
- calculation of the heat fluxes

## Learning objectives

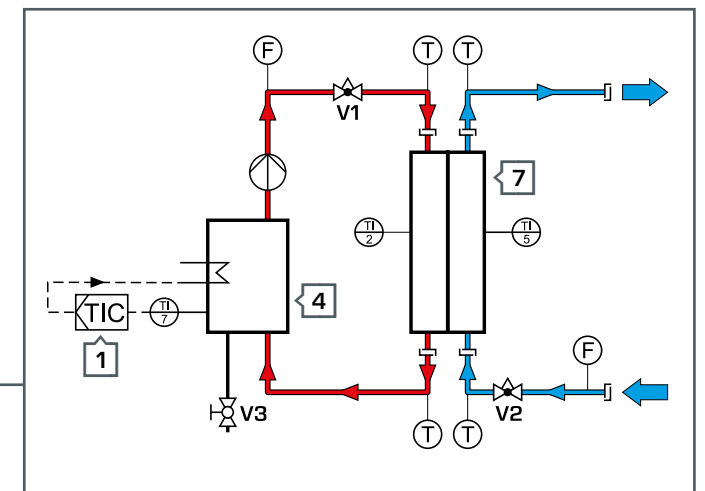
- function and operational behaviour and different heat exchangers
- plotting temperature curves
  - ▶ in parallel flow mode
  - ▶ in counterflow mode
- calculation of the mean heat transfer coefficient
- comparison of different heat exchanger types



# WL 110 Heat Exchanger Supply Unit



- 1 temperature controller
- 2 temperature displays
- 3 flow rate displays
- 4 tank for hot water
- 5 process schematic
- 6 connections for cold water circuit
- 7 jacketed vessel with stirrer and coil (or other accessory)



All 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 mean overall heat transfer coefficients are determined as typical characteristic variables in experiments.

Using the WL 110 supply unit you can operate the following four basic types of heat exchanger:

- Tubular Heat Exchanger (WL 110.01)
- Plate Heat Exchanger (WL 110.02)
- Shell & Tube Heat Exchanger (WL 110.03)
- Jacketed Vessel with Stirrer & Coil (WL 110.04)

Water is used as the medium. The heat exchanger being studied is connected to the supply unit. The hot water flows through the heat exchanger and emits some of its thermal energy to the cold water. By rearranging the water connections, you can easily change the flow direction in order to achieve parallel flow and counterflow.



Software screenshot with WL 110.02 in parallel flow mode

- representation of the process media temperature profiles along the heat exchanger
- calculation of the mean heat transfer coefficient
- calculation of the heat fluxes
- display of the characteristic values of the heat exchanger
- selection and display of the current operating mode and of the heat exchanger

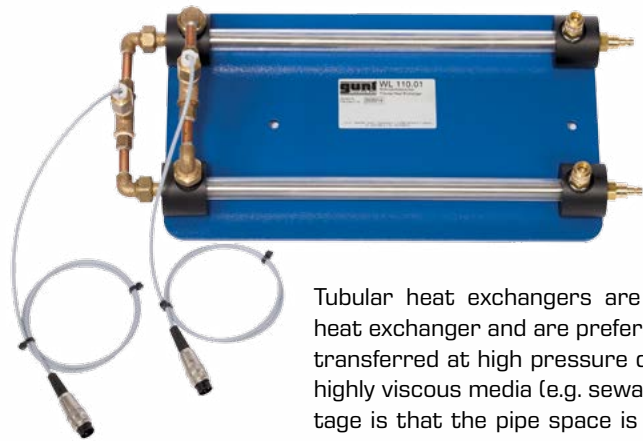
## Learning objectives

- in conjunction with a heat exchanger:
  - plotting temperature profiles
  - determining overall heat transfer coefficient
  - comparing different heat exchanger types

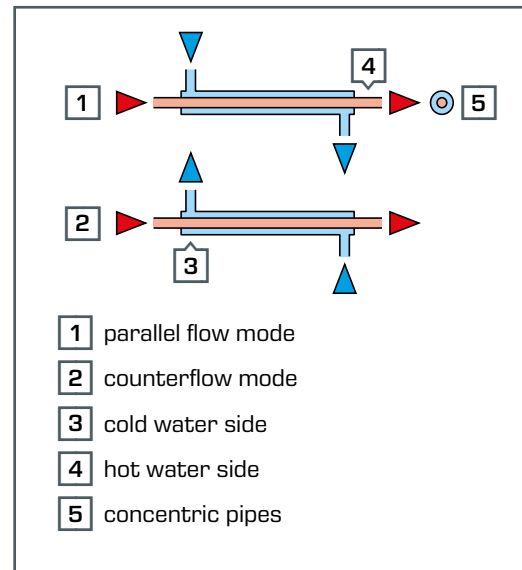




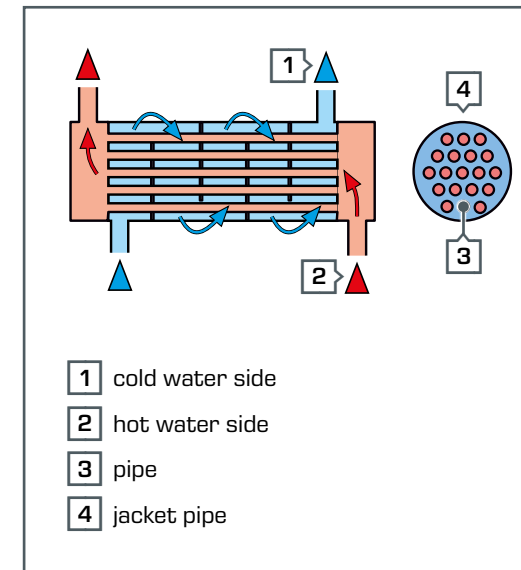
## WL 110.01 Tubular Heat Exchanger



Tubular heat exchangers are the simplest type of heat exchanger and are preferably used when heat is transferred at high pressure differences or between highly viscous media (e.g. sewage sludge). One advantage is that the pipe space is flowed through evenly and is free of flow dead zones.



## WL 110.03 Shell & Tube Heat Exchanger

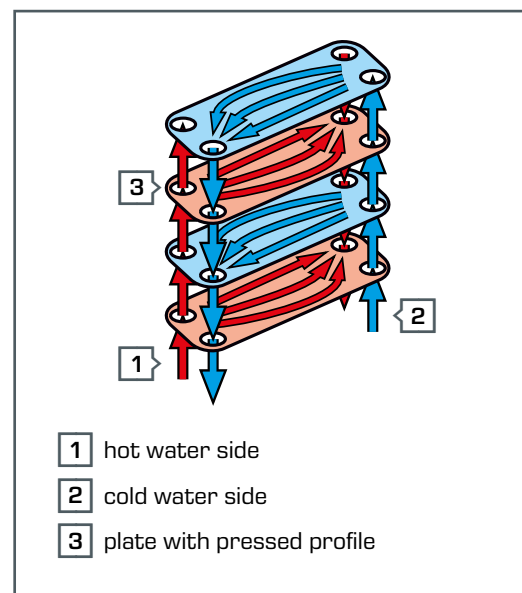


Shell & tube heat exchangers are a widely-used design. The advantages of this design are the large heat transfer area and the compact size. Shell and tube heat exchangers are used in the chemical and pharmaceutical industry, in refining and process engineering plants.

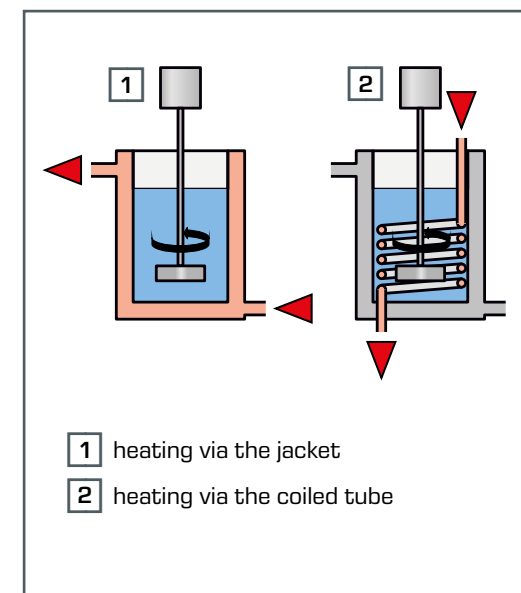
## WL 110.02 Plate Heat Exchanger



Plate heat exchangers are mainly characterised by their compact design, in which the entire medium is used for heat transfer. The profile pressed onto the plates forms narrow flow chambers in which extensive turbulence occurs. The turbulent flow enables an effective heat transfer at low flow quantities and also has a self-cleaning effect. Plate heat exchangers are used for example in the food industry, marine engineering, refrigeration technology and in domestic engineering.



## WL 110.04 Jacketed Vessel with Stirrer & Coil



Simple stirrer tanks are widely used in process engineering. These are often fitted with a double jacket or a coiled tube for cooling or heating. Stirring machines are used for better mixing of the tank contents and for an even temperature distribution.



# WL 315C

## Trainer for 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. Heat transfer in different heat exchangers takes place with different fluids according to the counterflow or parallel flow principle. The heat exchanger being studied is selected at the switch cabinet. Valves are used to switch between parallel 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.

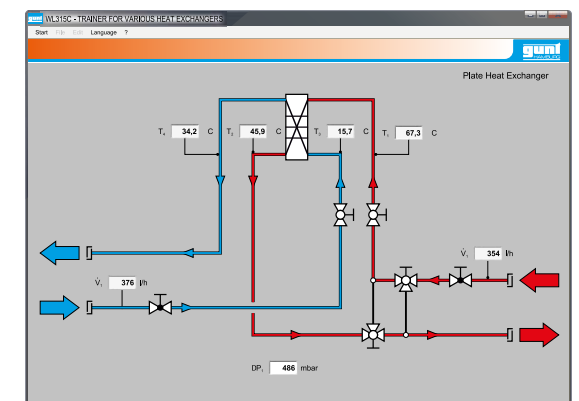
Using the hot water supply (WL 312.10) and the cold water supply (WL 312.11), you can operate WL 315C as an independent system with closed water circuit. An optionally available steam/water heat exchanger (WL 315.01) and an electrical steam generator (WL 315.02) complement the scope of experiments.



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 exchange

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 and tube heat exchanger
- 11 jacketed vessel with stirrer and coil
- 12 switch cabinet



### Learning objectives

- familiarisation with heat transfer processes
  - ▶ heat transfer
  - ▶ heat conduction
- measuring of relevant temperatures and flow rates
- determination of the overall heat transfer coefficient
- preparation of temperature curves for the various types of heat exchanger
  - ▶ parallel flow
  - ▶ counterflow
  - ▶ cross parallel flow
  - ▶ cross counter flow
- comparison of various types of heat exchanger
  - ▶ plate heat exchanger
  - ▶ tubular heat exchanger
  - ▶ shell and tube heat exchanger
  - ▶ finned cross-flow heat exchanger
  - ▶ jacketed vessel with stirrer

Product No.  
060.315C0  
More details and technical data:  
[gunt.de/static/s4642\\_1.php](http://gunt.de/static/s4642_1.php)





# Basic Knowledge Shallow Geothermal Energy



## Fundamental principle

Shallow geothermal energy is based on the same fundamental principle as solar thermal energy. However, in this case it is the ground which 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 cycle).

## Technical implementations

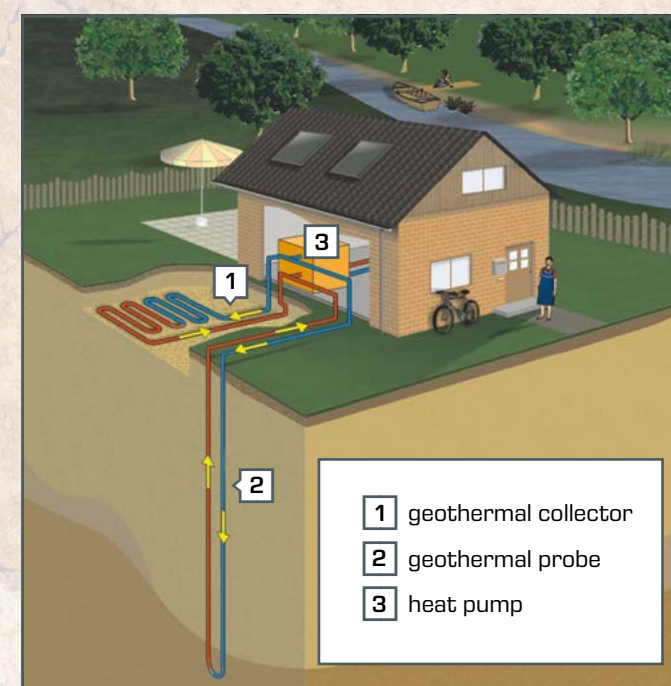
There are various options for using the thermal energy of the earth's surface. The technical implementation is dependent upon the local conditions, the desired power and the combination with other energy systems. In the field of shallow geothermal energy, a distinction is firstly made between open and 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 hori-

zontally in the ground. This pipe is located at a depth of about 1...2m. Geothermal probes are oriented vertically and can reach down to a depth of about 100m under the ground. Well systems use the thermal energy of the groundwater by means of two wells. Feed-in occurs with the source well and return occurs with the sink well against the direction of flow.

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

## 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 cycle of heat pumps. The cyclic processes illustrate the economic use of geothermal heat for heating purposes, even with source temperatures which are actually too low.



## Resource-efficient heating

Geothermal energy can be used effectively even at shallow depths of up to 100m. Shallow geothermal energy is mainly suited to providing heat in private households and small industrial companies.

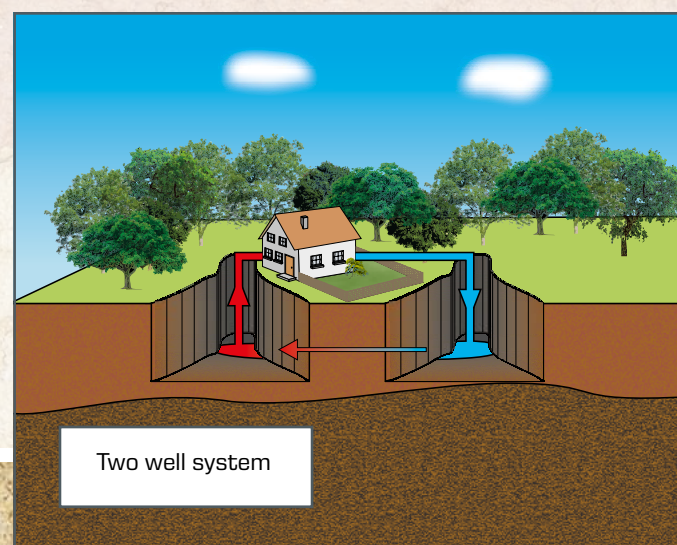
By using heat pumps, heating and operating costs can be reduced to the electrical consumption of the circulation pumps.

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.

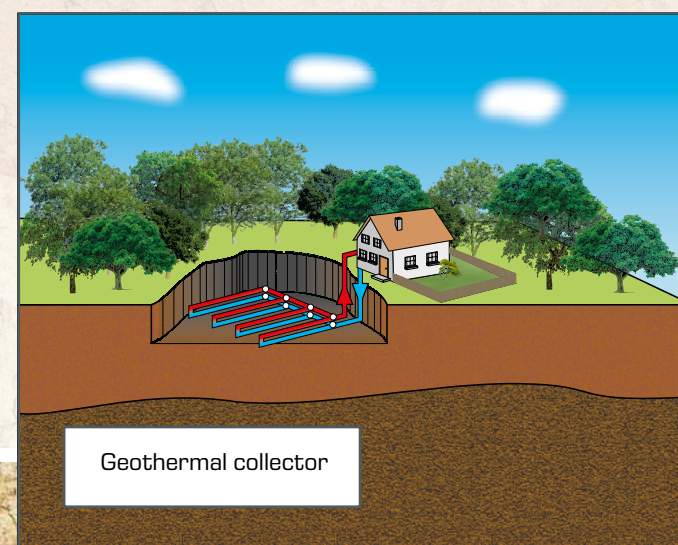
## Geothermal probes

Different designs, which offer different benefits, are available for geothermal probes. The U-shaped probe and the dual U-shaped probe are already widely used, for example embedded

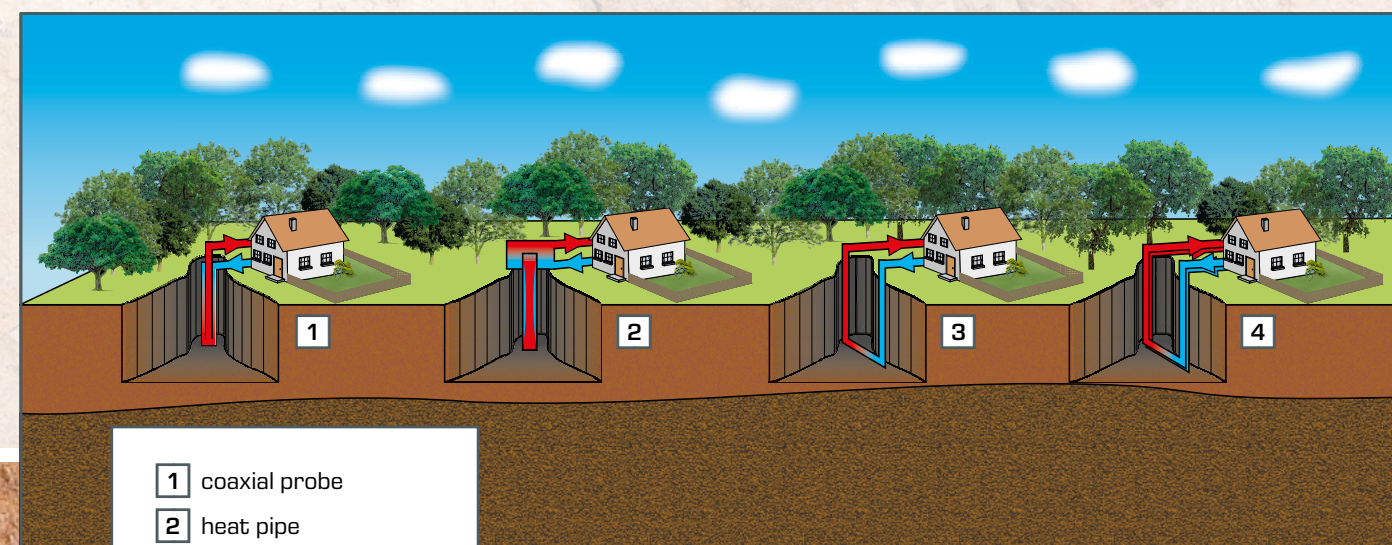
in piled foundations. Heat can therefore be supplied with geothermal heat with little additional investment.



Two well system



Geothermal collector



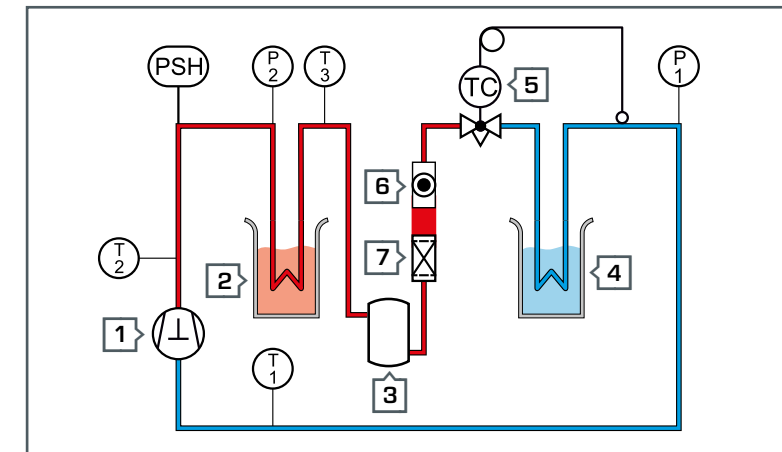
- 1 coaxial probe
- 2 heat pipe
- 3 U-shaped probe
- 4 dual U-shaped probe



# 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 to 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.

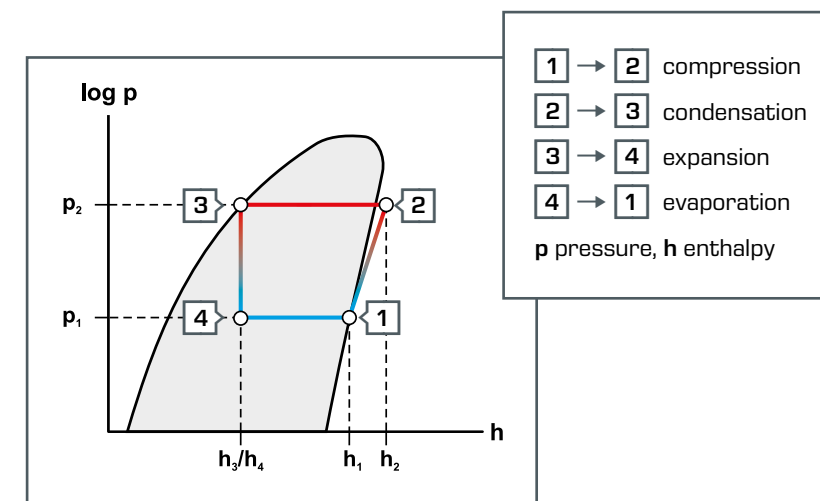


- |              |                   |
|--------------|-------------------|
| 1 compressor | 5 expansion valve |
| 2 condenser  | 6 sight glass     |
| 3 collector  | 7 filter/dryer    |
| 4 evaporator |                   |
- P pressure, PSH pressure switch, T temperature

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 cycle is an indispensable part of training for engineering students and specialists in the field of energy technology.



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.

## Learning objectives

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

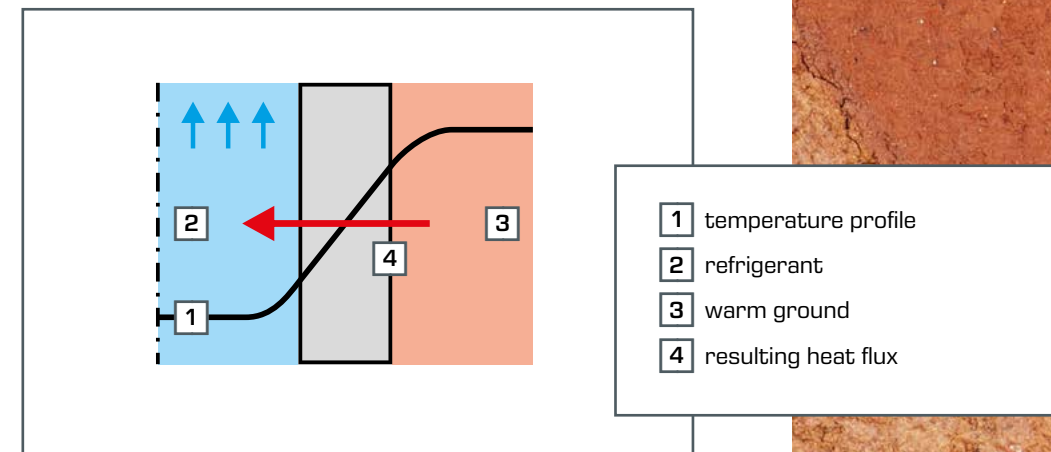
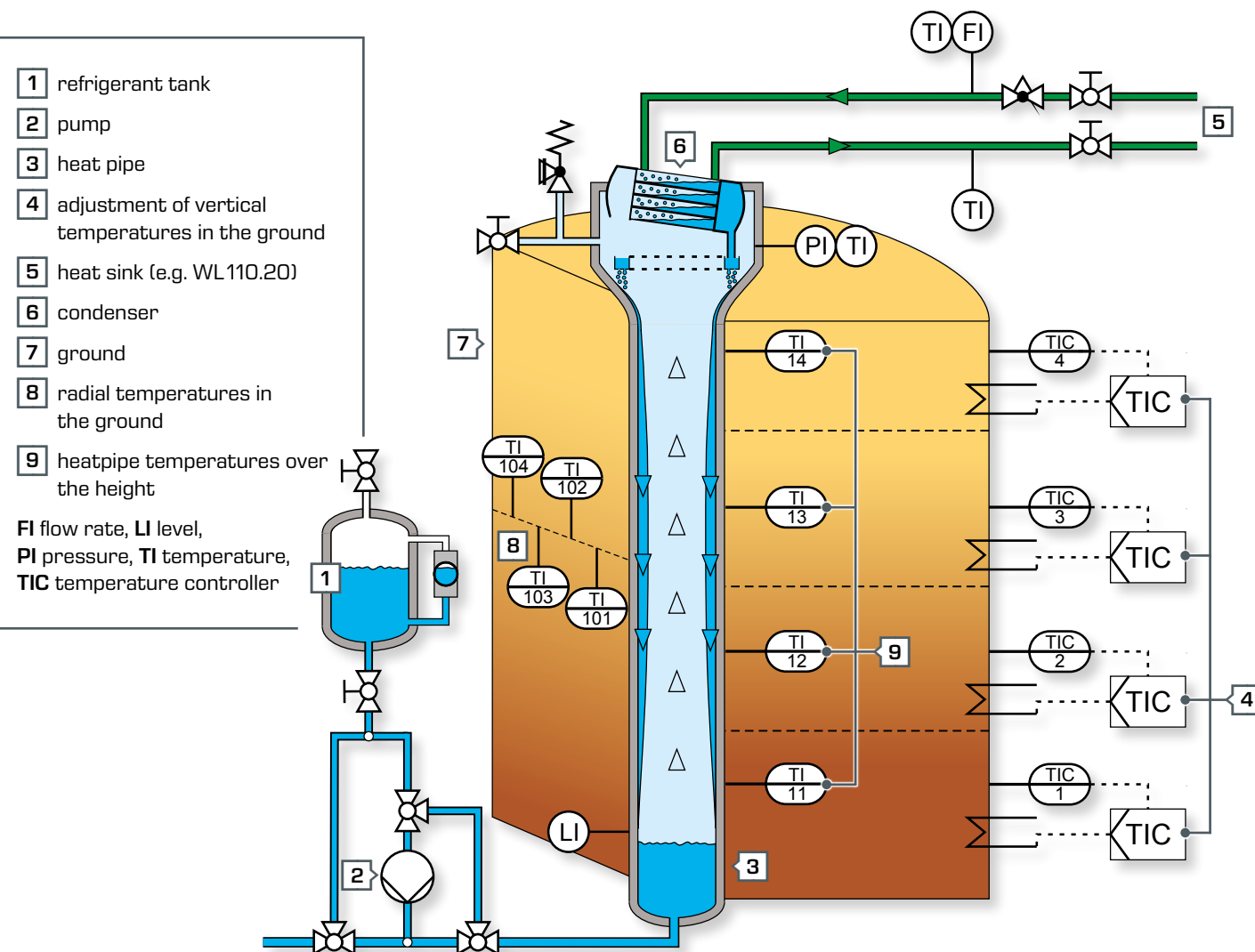




# ET 262 Geothermal Probe with Heatpipe Principle

Our ET 262 trainer provides you with a geothermal probe with refrigerant. You can make various adjustments, thereby configuring various operating conditions. For example, these include the thermal load and heat conduction within the fill material as a function of humidity.

The trainer consists of the geothermal probe, the surrounding ground, the condenser for heat dissipation and a filling and draining system for the refrigerant. The geothermal probe is partially transparent, so that the evaporation and condensation of the refrigerant can be observed.



The surrounding ground is represented by gravel with different moisture and grain size, so that the different thermal resistances can be studied. The change is illustrated partly by the radial temperature profile and partly by the water temperatures in the condenser feed and return. As an additional option, you can adjust the vertical temperature profile of the ground in four zones to study condensation before heat dissipation.

## The software for ET 262 measures the following variables

- radial temperature profile
- axial temperature profile of the ground
- axial temperature profile of the heatpipe
- feed and return temperature of the condenser

The vertical temperature profile superimposed from the outside results in the operating fluid evaporating in the heatpipe. After condensation it flows back for re-evaporation along the inner wall of the probe. This creates a closed circuit.

| Learning objectives                                                                                                                                                                                                                                                                                                              |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>■ investigation of the radial temperature profile</li> <li>■ variation of the thermal load</li> <li>■ variation of the quantity of operating fluid contained</li> <li>■ overlay of a vertical temperature profile</li> <li>■ investigation of the vertical temperature profile</li> </ul> |





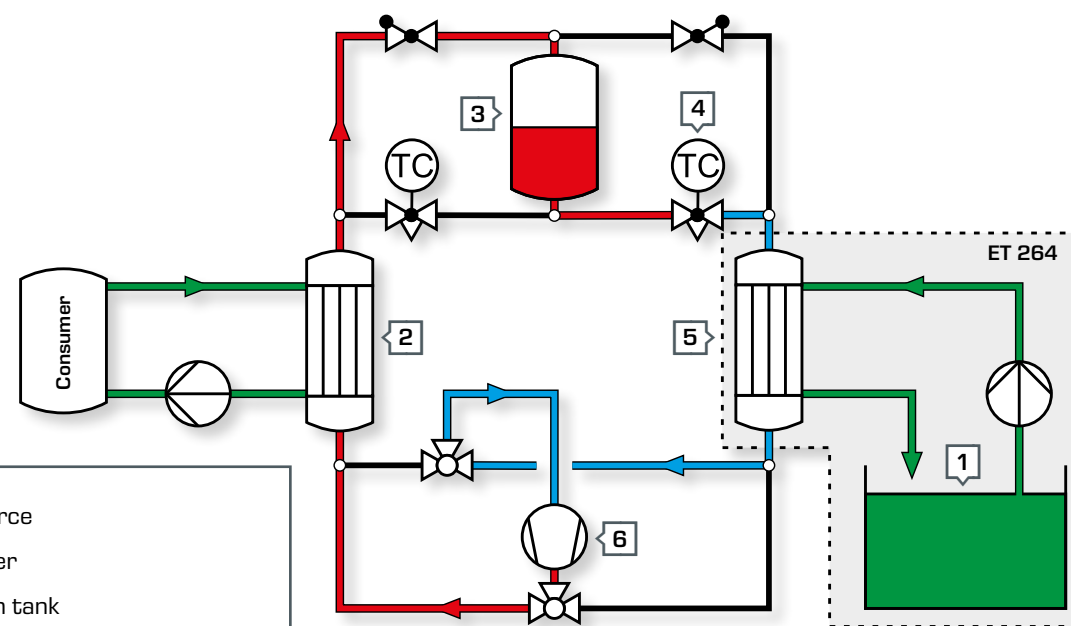
# ET 264 Geothermal Energy with 2-Well System

The trainer ET 264 offers you a dual well system with source and sink wells. ET 264 illustrates the installation in the ground with the characteristic parameters and requires, for example, WL 110.20 as a cold water substitute. The combination for domestic engineering with heat pumps is presented by the HL 320 series.

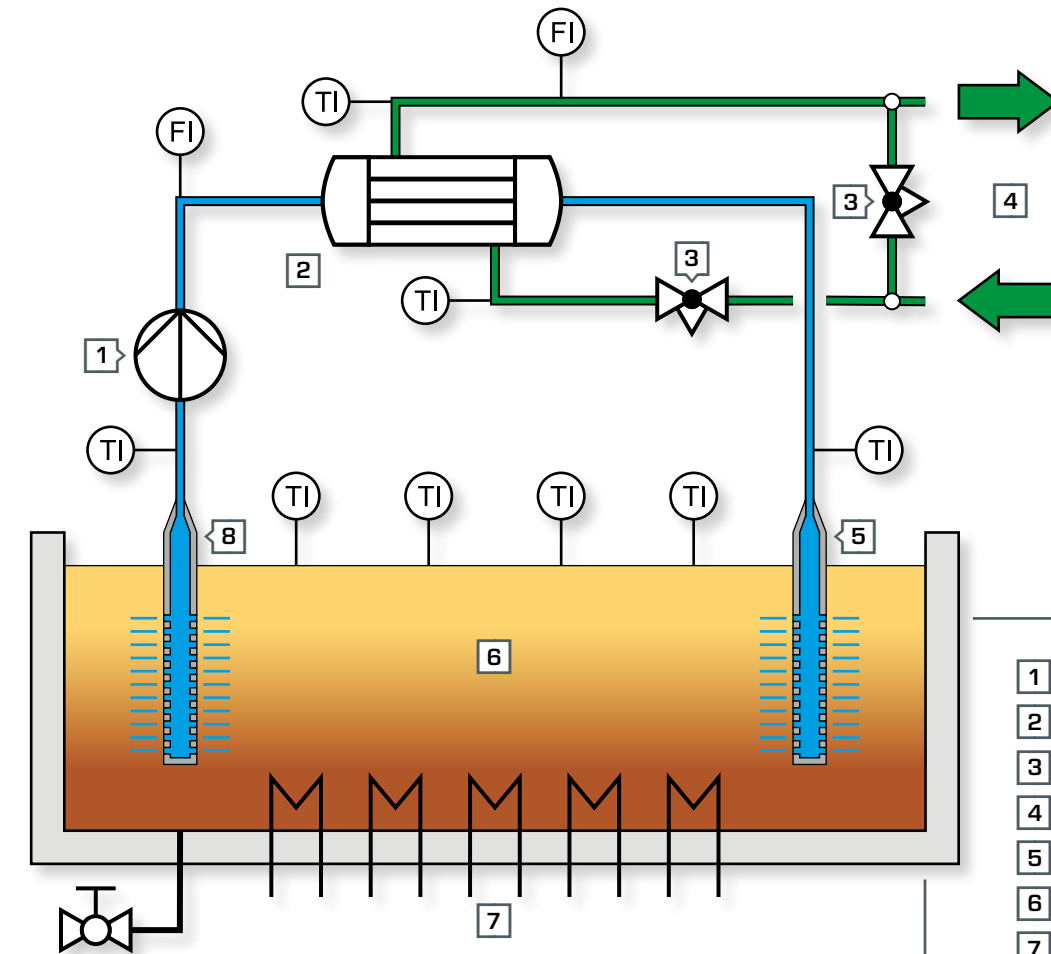
The energy dissipated via the heat exchanger is used in domestic engineering, for example to operate a heat pump (HL 320.01). In order to increase the system's operating efficiency, cooling operation is also possible. The usual water temperatures of around 7...12°C can be used directly in this case. You only need

to circulate the heat exchanger, so the additional installation of air conditioning units with very high energy consumption can be avoided.

Using the ET 264 trainer you can investigate the steady-state operation of an open system for using shallow geothermal energy. The temperature and flow rate measurements allow you to establish the energy balance and the amount of heat that can be dissipated in relation to the ground temperature. To expand the range of possible experiments, you can set different temperatures in the ground and use different materials.



- 1 heat source
- 2 condenser
- 3 collection tank
- 4 expansion valve
- 5 evaporator
- 6 compressor
- water/solar circuit
- refrigerant (low pressure)
- refrigerant (high pressure)



- 1 centrifugal pump
- 2 centrifugal pump
- 3 cooling water metering valve
- 4 heat sink (e.g. WL 110.20)
- 5 sink well
- 6 ground
- 7 temperature overlay
- 8 source well
- FI flow rate, TI temperature

## Features:

- trainer to replicate operation of a dual well system
- controlled electrical heating
- temperature and flow rate measurement for the cooling medium
- open circuit
- GUNT software for data acquisition via USB under Windows 7 or Windows 8



## Learning objectives

- steady-state operation of an open system
- determining the amount of usable heat
- energy balance
- determining the possible flow rate





# 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:

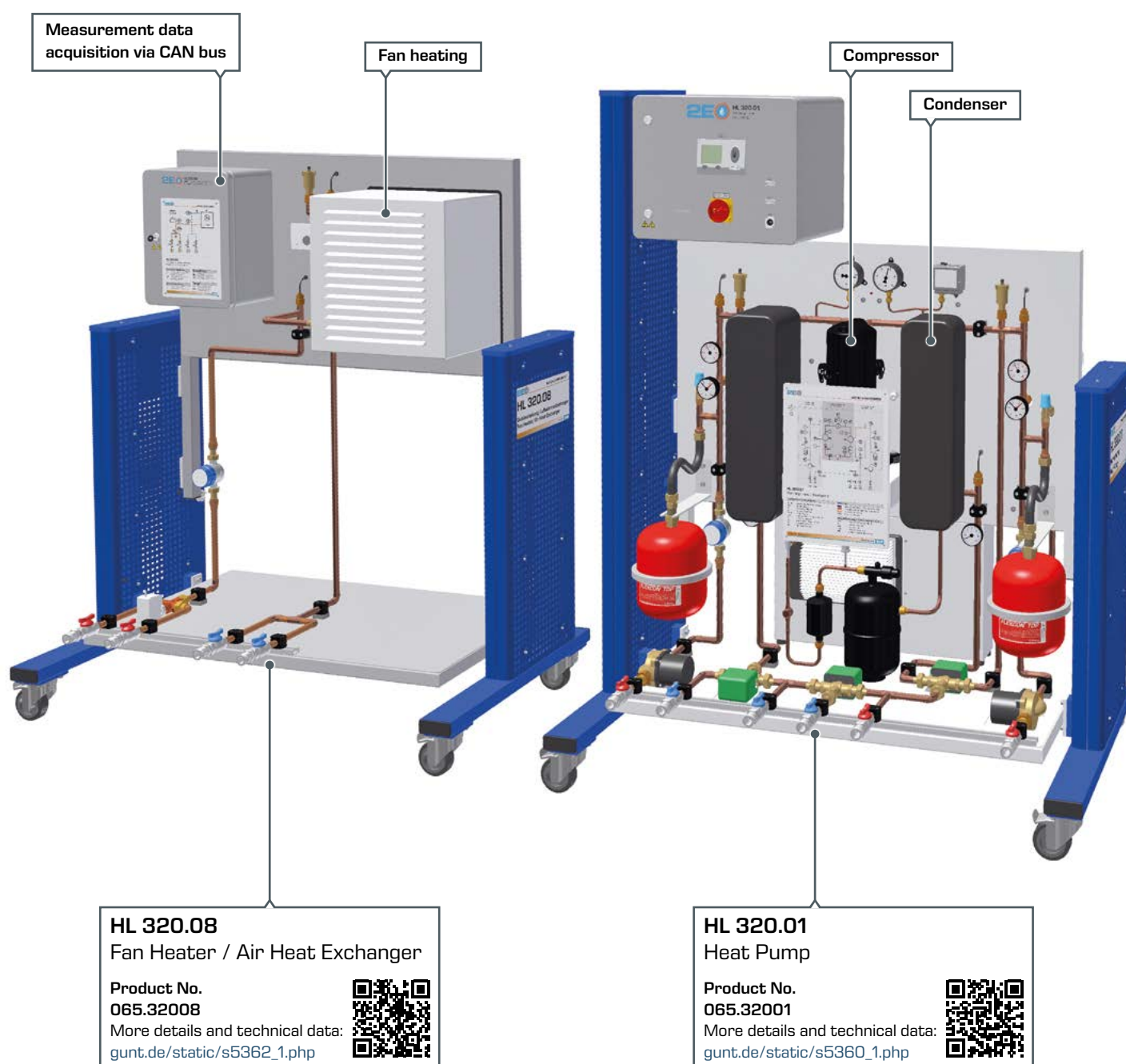
**HL 320.01** Heat Pump

**HL 320.07** Underfloor Heating/Geothermal Energy Absorber

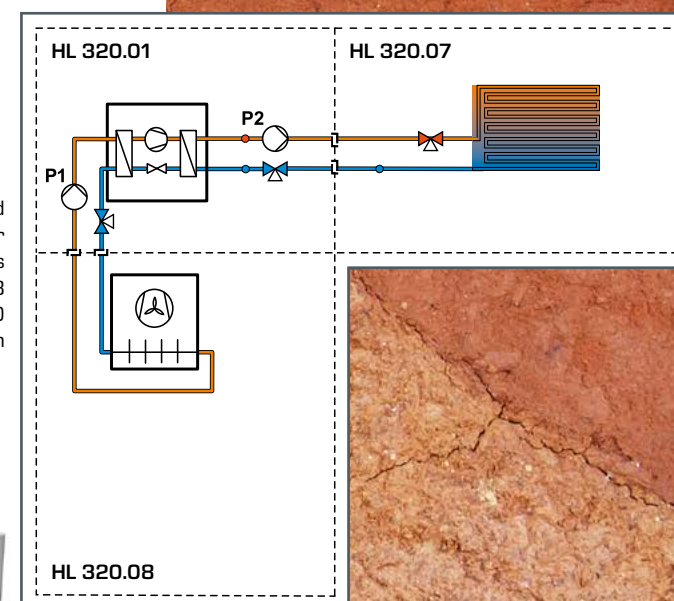
**HL 320.08** Fan Heater/Air Heat Exchanger

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 heat pump module controller 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.

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 for 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



### Learning objectives

- function and design of a heat pump
- comparison of different heat sources
- factors influencing the COP (coefficient of performance)
- parameterisation of a heat pump controller

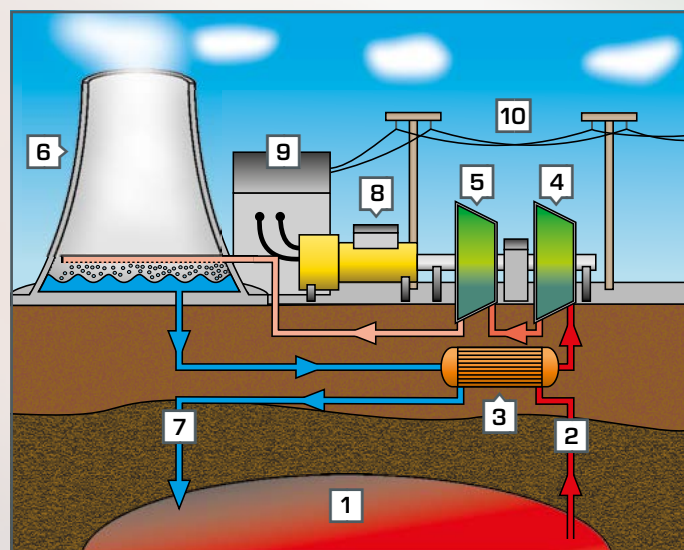


# Basic Knowledge Deep Geothermal Energy



## Fundamental principle

Deep geothermal energy, like shallow geothermal energy, is also based on the fundamental principle of solar thermal energy. The difference is that the ground, and not the sun, is used as a heat source. 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 public power grid

## Differentiating geothermal fields

There are different ways of distinguishing between the various geothermal fields 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, distinction by temperature level of the geothermal field is usually chosen. In this case, 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 direct conversion of the hot steam and low depth. The deeper the borehole, the warmer the earth. Thermal anomalies with comparable temperatures are usually reached at depths of 4000 – 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 is only carried out in special cases. In these cases, closed Organic Rankine Cycle (ORC) systems are employed in order to use temperatures from 80°C onwards 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

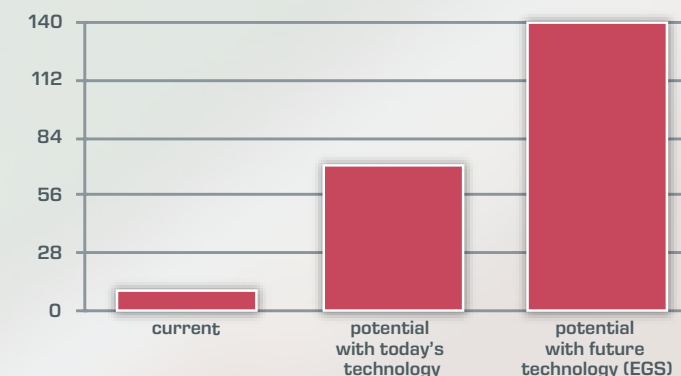
Apart from deep geothermal probes, these are open systems which are designed as dual well systems for environmental reasons. A power station site is equipped with up to four boreholes. After pumping and using the hot water or steam, the cold working medium is pumped back into the holes. Doing so does not reduce the operating pressure, and the efficiency and capacity remain largely unaffected.

## Outlook

At present, an electrical output of 10 GW<sub>el</sub> is installed worldwide. Using currently available technology for hydrothermal systems, this could be increased to 70 GW<sub>el</sub> by 2050.

Including Enhanced Geothermal Systems (EGS), i.e. petrothermal systems, it could even be possible to reach 140 GW<sub>el</sub>. However, these systems are not yet state of the art.

Globally installed power in gigawatts

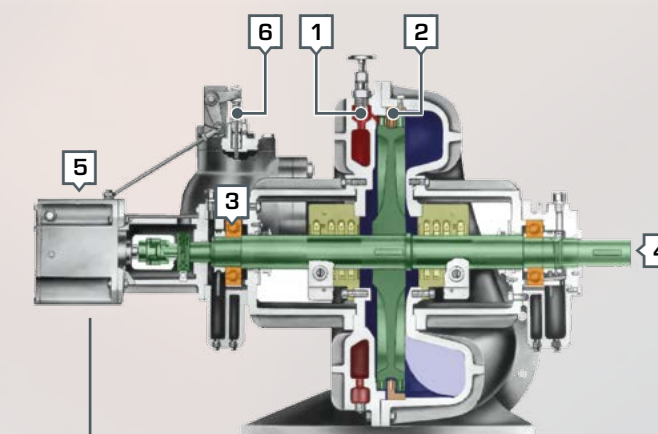


Source: Bertani 2010 Geothermal Power Generation in the World

## 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 impulse 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 impeller
- 3 roller bearing
- 4 impeller shaft
- 5 speed controller
- 6 flow control valve

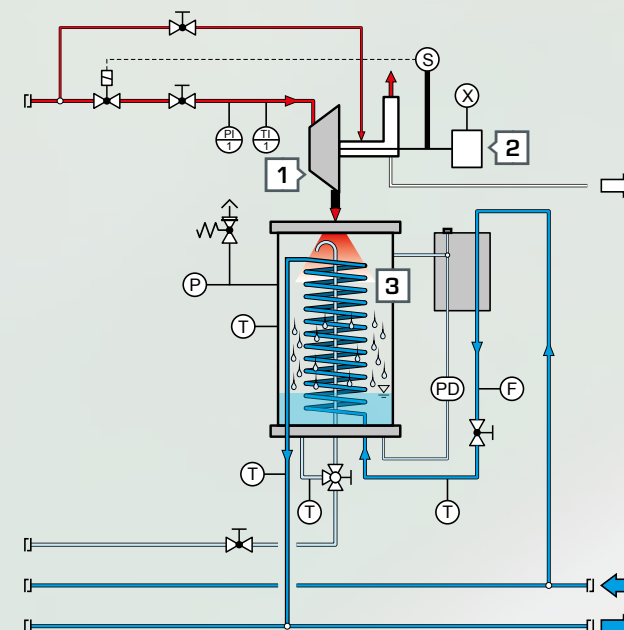
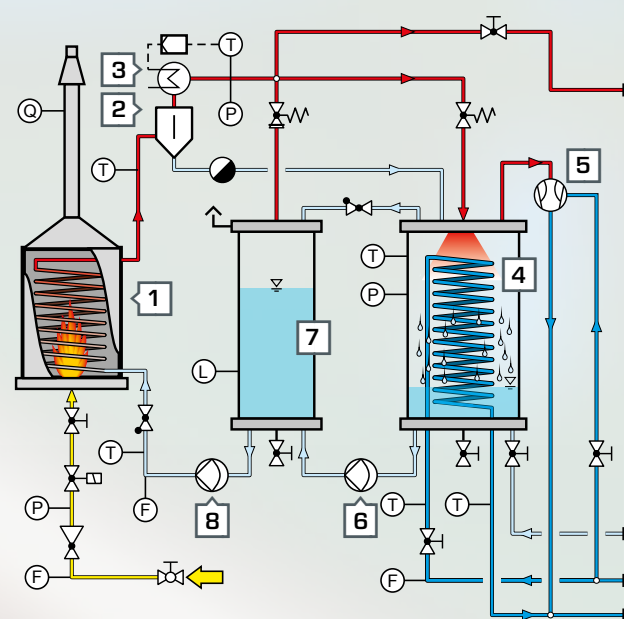


# ET 850 & ET 851 Steam Generator and Axial Steam Turbine



The combination of the ET 850 Steam Generator and ET 851 Axial Steam Turbine from GUNT give you the opportunity to set up a real steam power station at a laboratory scale.

As the process diagram shows, the system includes all the key components of a real large-scale system: pass-through water tube boiler with superheater, condenser with water jet pump for vacuum operation, feedwater tank, condensate and feedwater pumps, steam turbine with dynamometer, shaft sealing with labyrinth and sealing steam and many more. The operating behaviour is also similar to a real system. In this way accurate matching of steam generator, turbine, condenser and superheater can be demonstrated and practised. The data acquisition software relieves students of routine tasks and gives a quick overview.



## ET 850

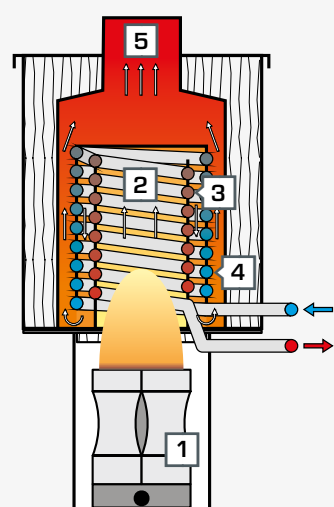
- 1 steam boiler
- 2 water separator
- 3 superheating
- 4 condenser
- 5 water jet pump
- 6 condensate pump
- 7 feedwater tank
- 8 feedwater pump

## ET 851

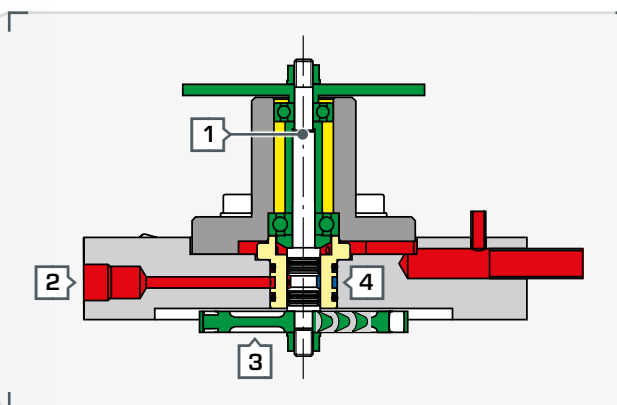
- 1 turbine
- 2 brake
- 3 condenser

## Measuring points

F flow rate, P pressure, PD differential pressure, Q exhaust gas analysis, S speed, T temperature, X torque



- 1 burner
- 2 1<sup>st</sup> draw
- 3 2<sup>nd</sup> draw
- 4 3<sup>rd</sup> draw
- 5 exhaust gas



- 1 turbine shaft
- 2 sealing steam inlet
- 3 impeller
- 4 labyrinth seal





# ET 850 Steam Generator

A steam generator creates steam which is then used for heat power plants or to drive machinery. The 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 ET850 Steam Generator, together with the ET 851 Axial Steam Turbine, forms a complete laboratory-scale steam power plant. The ET 850 trainer teaches

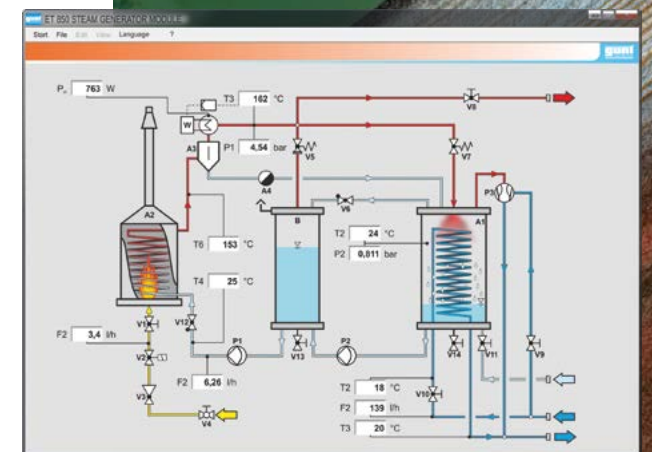
students the components and operating principle of a steam generator. Students can study the characteristic values of the plant. The diverse safety devices of the steam generator can be tested and inspected using various monitoring systems.

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.

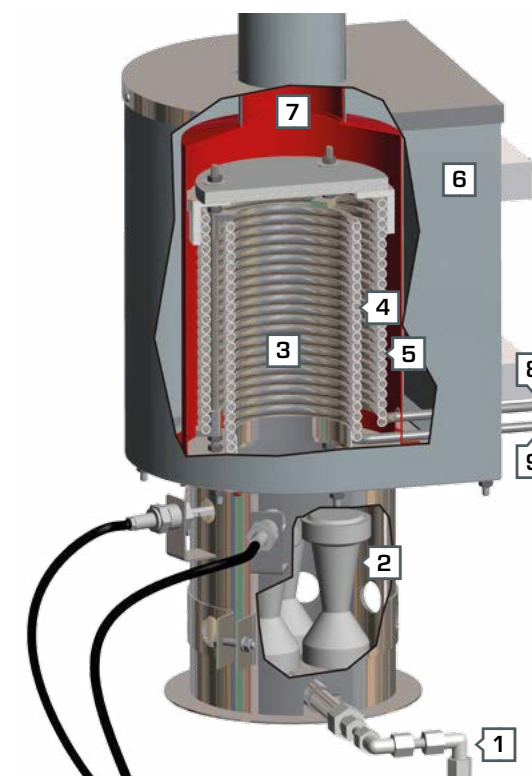
The steam generator is designed and pressure tested according to the "Technical Regulations for Steam" (TRD, german: Technischen Regeln Dampf) and has all the safety valves prescribed by law.

## 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.



Product No.  
061.85000  
More details and technical data:  
[gunt.de/static/s3484\\_1.php](http://gunt.de/static/s3484_1.php)



- |                        |                |
|------------------------|----------------|
| 1 gas feed             | 6 insulation   |
| 2 burner               | 7 exhaust gas  |
| 3 1 <sup>st</sup> draw | 8 water intake |
| 4 2 <sup>nd</sup> draw | 9 steam output |
| 5 3 <sup>rd</sup> draw |                |

## Learning objectives

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



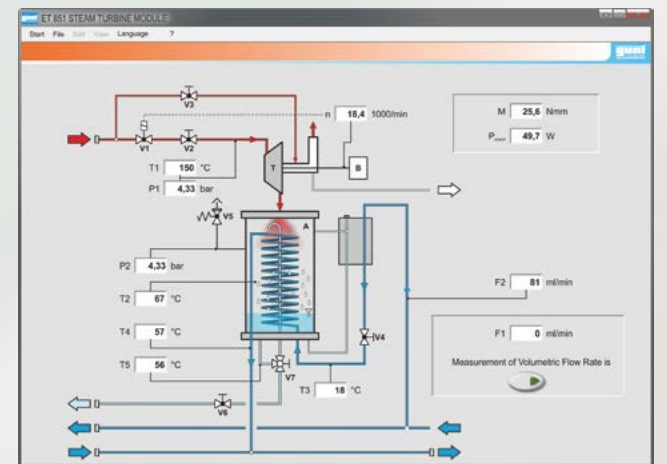
# ET 851 Axial Steam Turbine

The ET 851 trainer provides you with an axial steam turbine with eddy current brake, condenser, piping, instrumentation and safety devices. All the 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. It is therefore 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.

The ET 851 experimental unit is a single-stage axial impulse 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 excessively high speed or overpressure in the system.

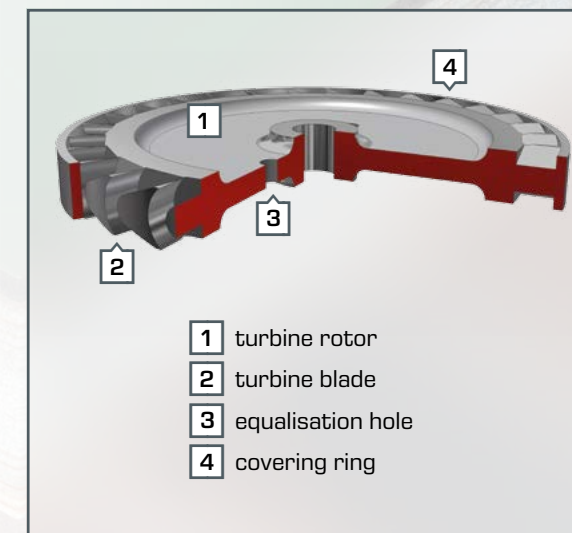


## Software

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

## Learning objectives

- 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



Product No.  
061.85100  
More details and technical data:  
[gunt.de/static/s3483\\_1.php](http://gunt.de/static/s3483_1.php)





# Energy Systems

1.6

2E a division of

gunt  
HAMBURG

## Introduction

**Basic Knowledge**  
Energy Systems

142

## Conversion

**Subject Areas**  
Conversion in Energy Systems

146

**ET 292**  
Fuel Cell System

148

**ET 794**  
Gas Turbine with Power Turbine

152

**Basic Knowledge**  
Heat Pump

154

**ET 102**  
Heat Pump Trainer

156

**HL 320.01**  
Heat Pump

158

## Storage

**Subject Areas**  
Storage in Energy Systems

160

**ET 513**  
Single-Stage Compressor

162

**HM 143** Transient Drainage  
Processes in Storage Reservoirs

164

**Basic Knowledge**  
Thermal Storage

166

**HL 320.05**  
Central Storage Module with Controller

168

**ET 420**  
Ice Stores in Refrigeration

170

**Basic Knowledge**  
Electrochemical Storage

174

**ET 255** Using Photovoltaics:  
Grid connected or Stand-alone

176

**ET 220**  
Energy Conversion in a Wind Power Plant

178

**ET 220.01**  
Wind Power Plant

179

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# Basic Knowledge Energy Systems



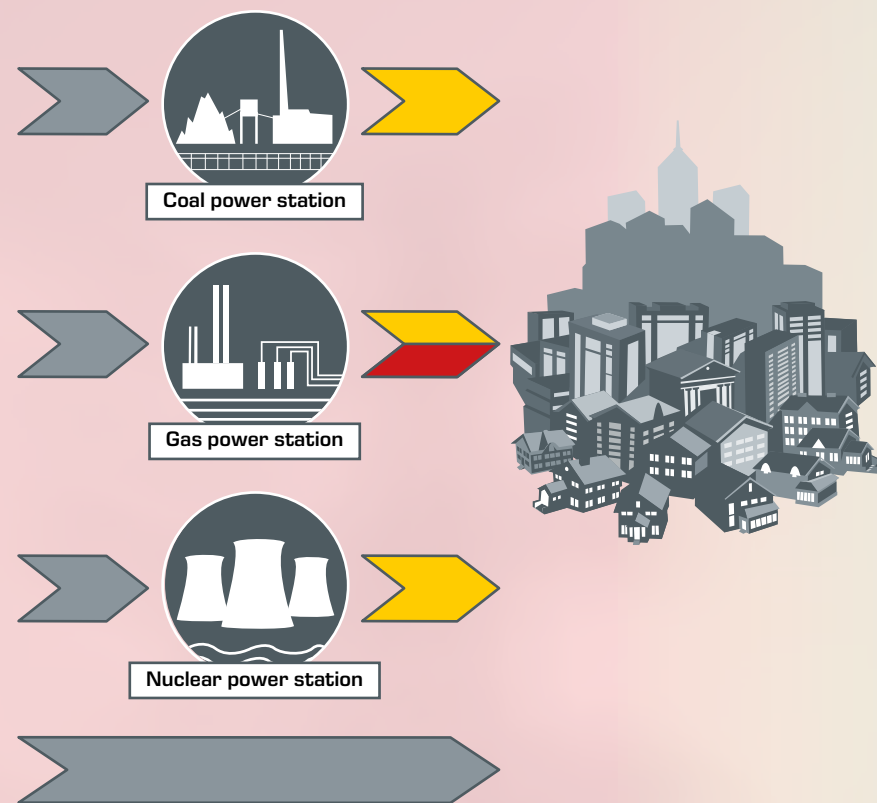
For a long time, fossil fuels have been used almost exclusively as an energy source. Electricity was generated in a few central power stations. Heat was mainly supplied by coal stoves, oil heaters or gas boilers. Oil and coal require local provisioning. Gas is stored in pressure vessels when there is 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, being 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.

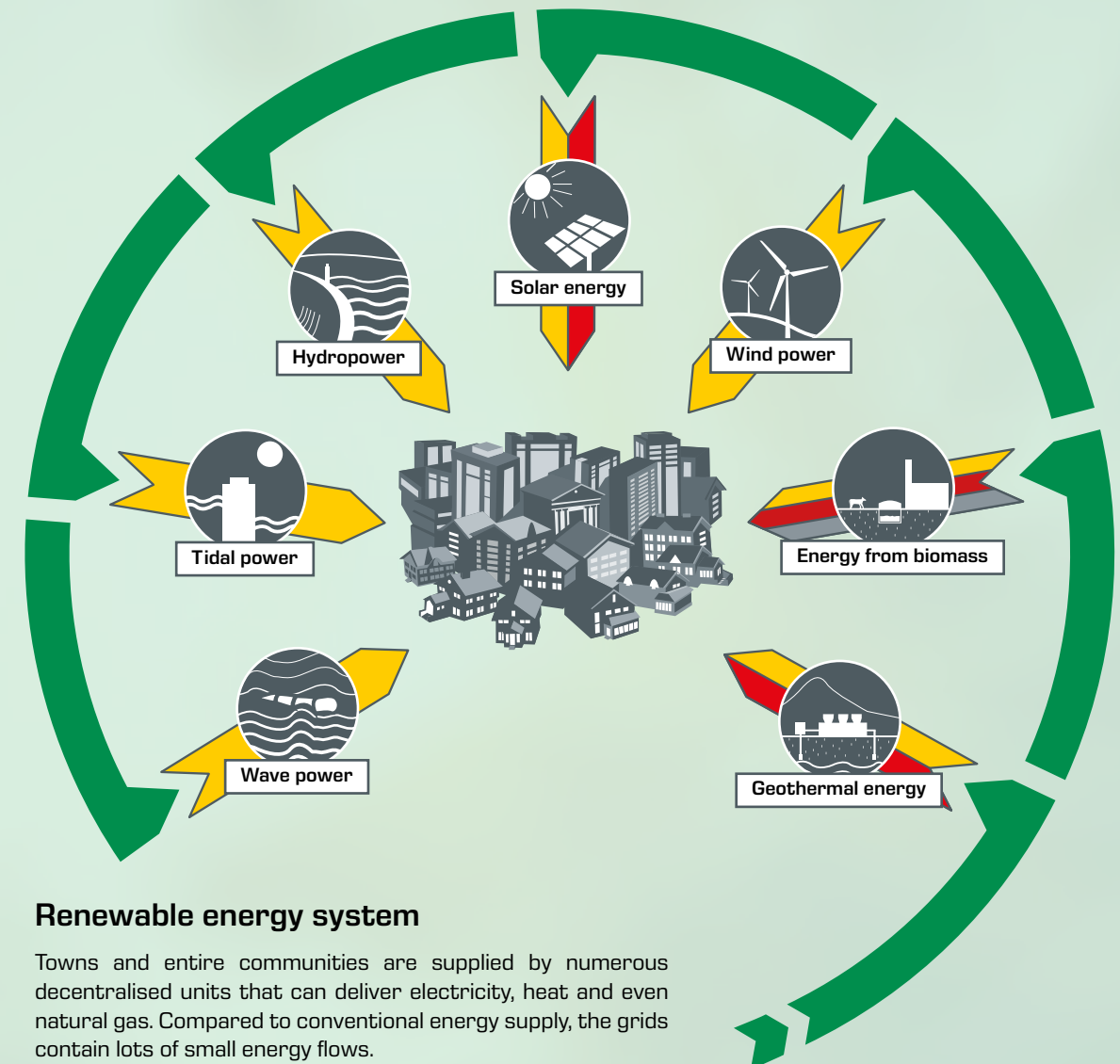
Storage systems can be based on potential energy (e.g. pumped storage), pressure energy (e.g. compressed air storage), thermal energy (e.g. hot water reservoir) or electrochemical energy (e.g. accumulator). Depending on the available energy, conversion into a storable form is also required, and reversion 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

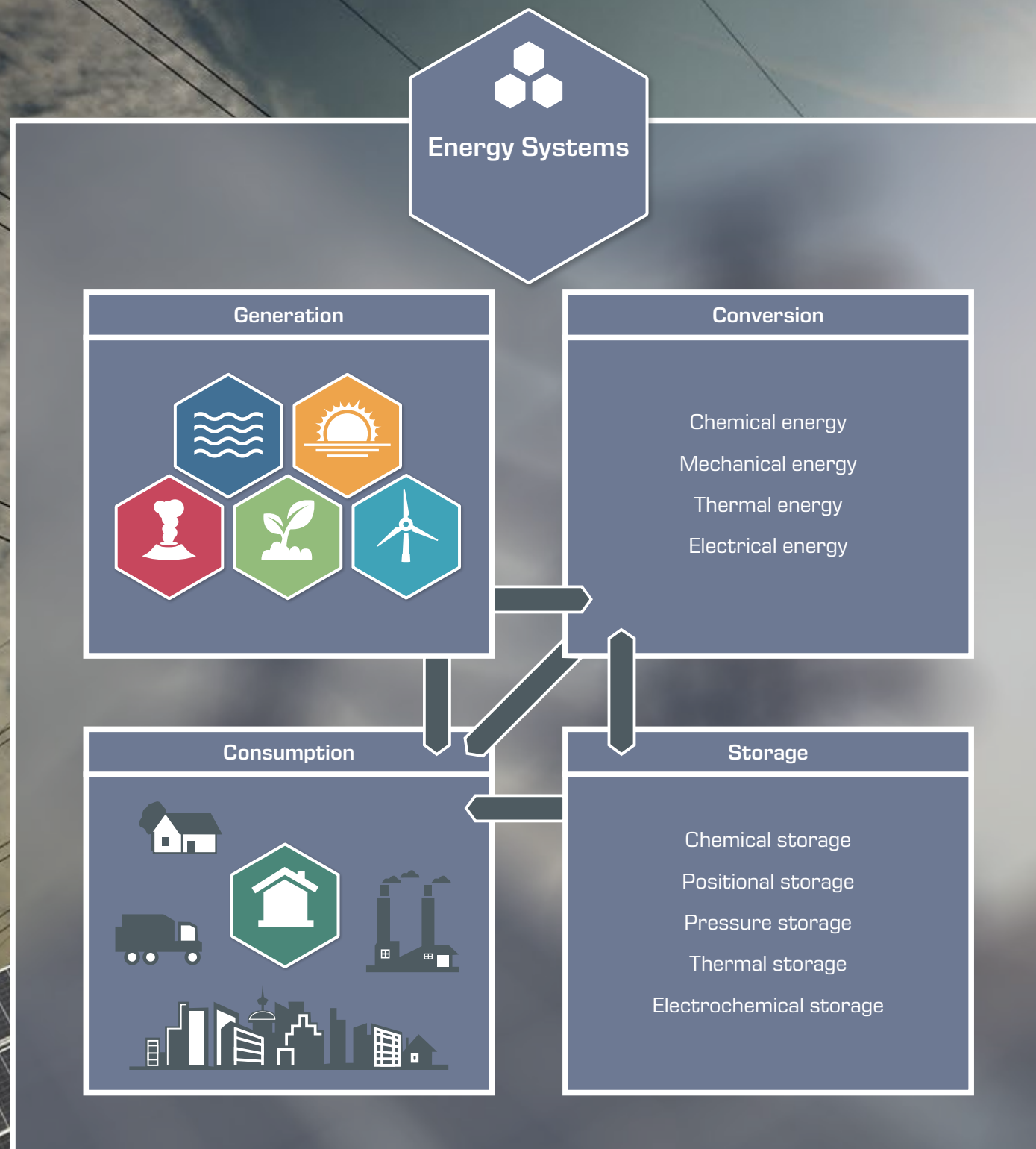
## Surplus electricity

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

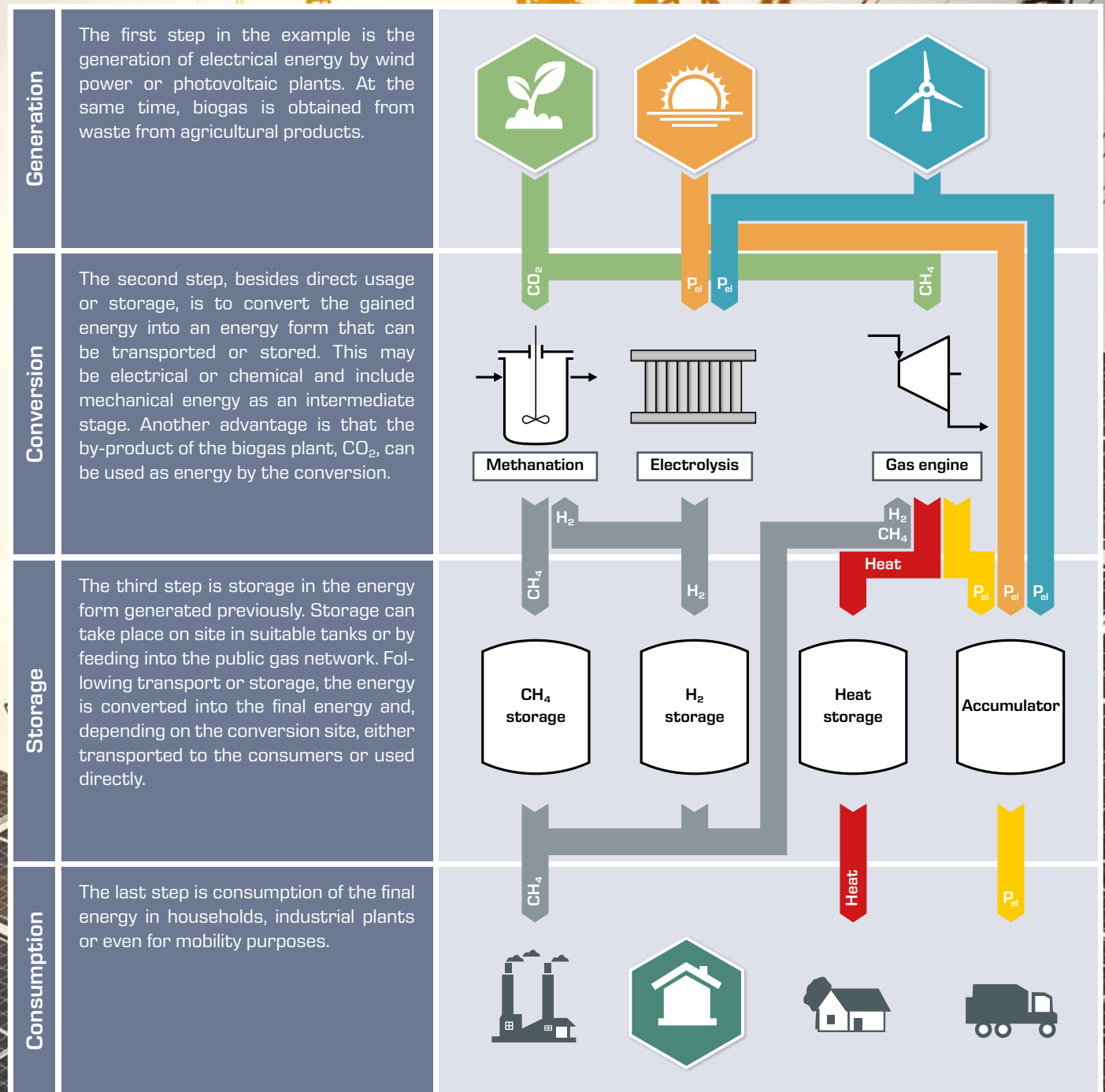
consumed, the surplus can be used to operate an electrolyser, for example. In this process, hydrogen and oxygen are obtained from water. The hydrogen can then be mixed with natural gas or natural gas is produced in downstream methanation. The formerly surplus energy is therefore available at another time and location.



# Basic Knowledge Energy Systems



## Example of an energy system





# Subject Areas Conversion in Energy Systems



## Subject Areas

## 2EO 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 Trainer

#### HL 320.01

Heat Pump

In supply networks with high proportions of renewable energies, supply and demand are often differentiated by energy. 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 re-

conversion 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.



# ET 292 Fuel Cell System

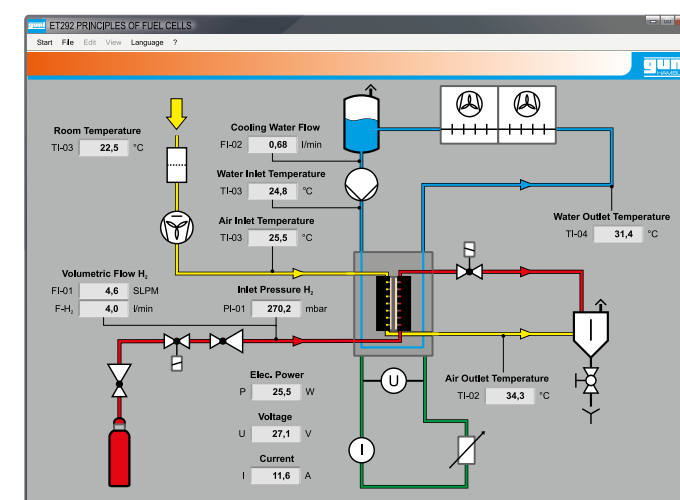
Modern fuel cell systems are becoming increasingly important in supplying households, for example in the decentralised conversion of energy. Local energy supply has the advantage of reducing transport losses to a significant extent. In addition, combined heat and power (cogeneration) provides excellent 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 system.

- 1 high-pressure reducing valve with hydrogen pressure vessel
- 2 inlet valve
- 3 low-pressure reducing valve
- 4 hydrogen flow rate measurement
- 5 filter with cathode fan
- 6 fuel cell
- 7 water cooler
- 8 cooling water tank
- 9 cooling water pump
- 10 water separator



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

| Learning objectives                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>■ conversion of chemical energy into electrical and thermal energy</li> <li>■ function and design of a fuel cell system</li> <li>■ relationships of fuel cell operating parameters</li> <li>■ effects on the electrical performance of fuel cells</li> <li>■ recording and visualisation of all relevant voltage/current characteristics</li> <li>■ calculation of relevant variables</li> </ul> |



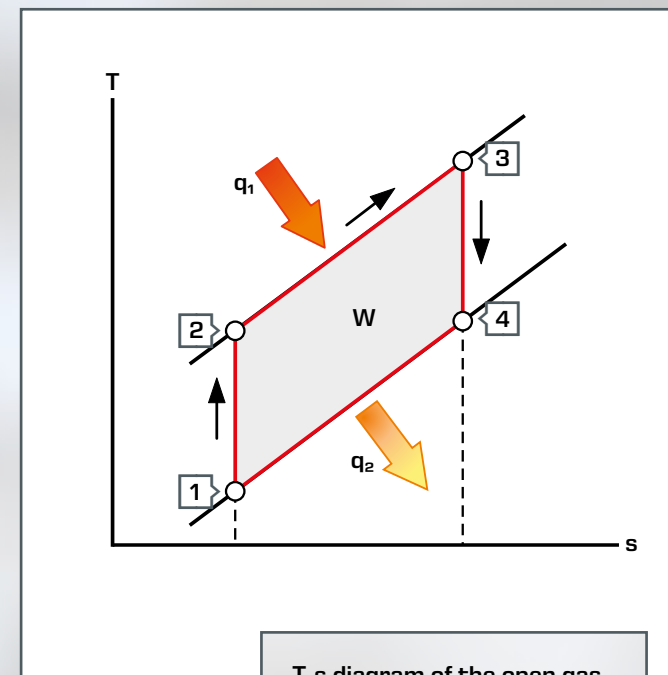
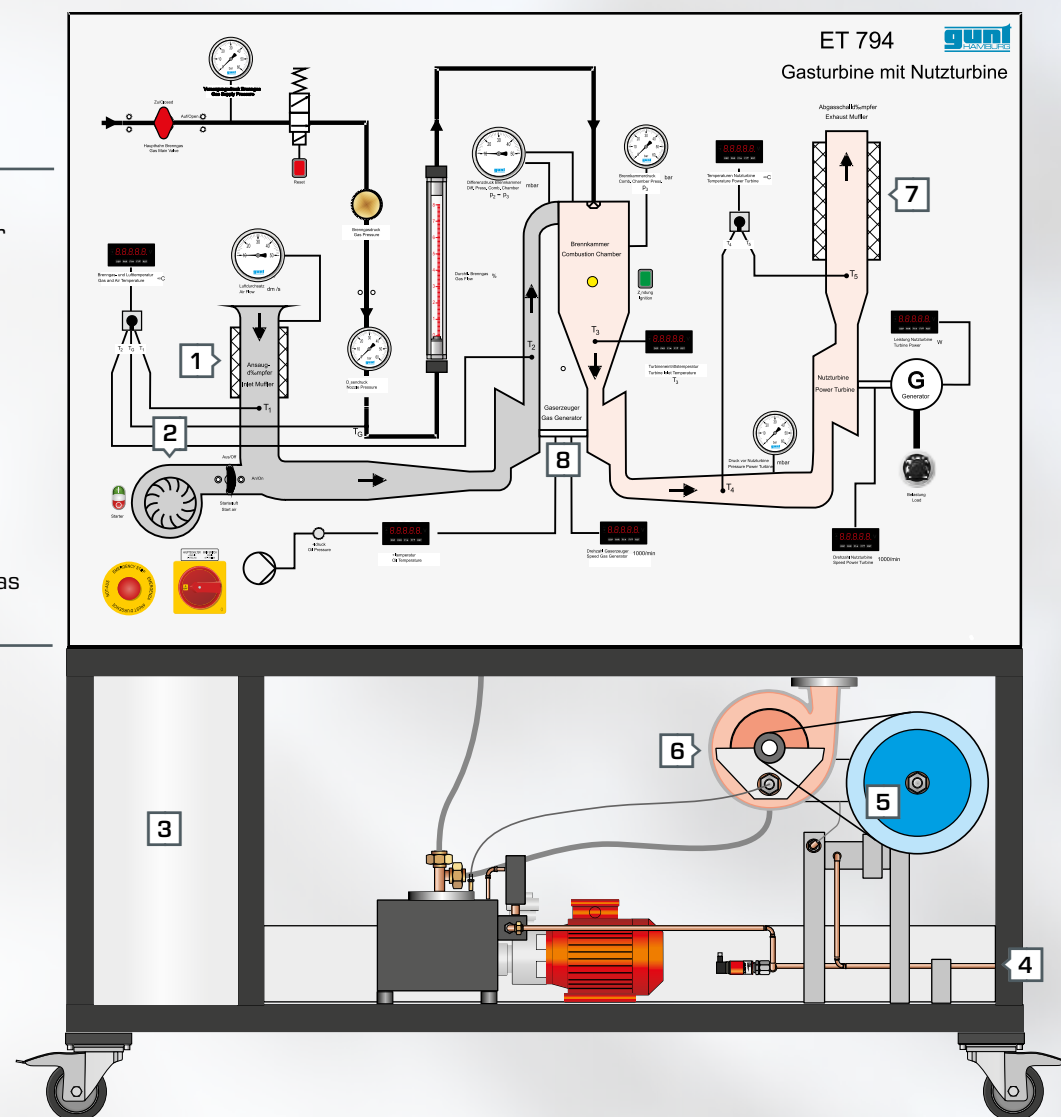


# ET 794 Gas Turbine with Power Turbine

Gas turbines with free-running power turbines are preferred as drive systems for widely varying power requirements in power stations, 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.

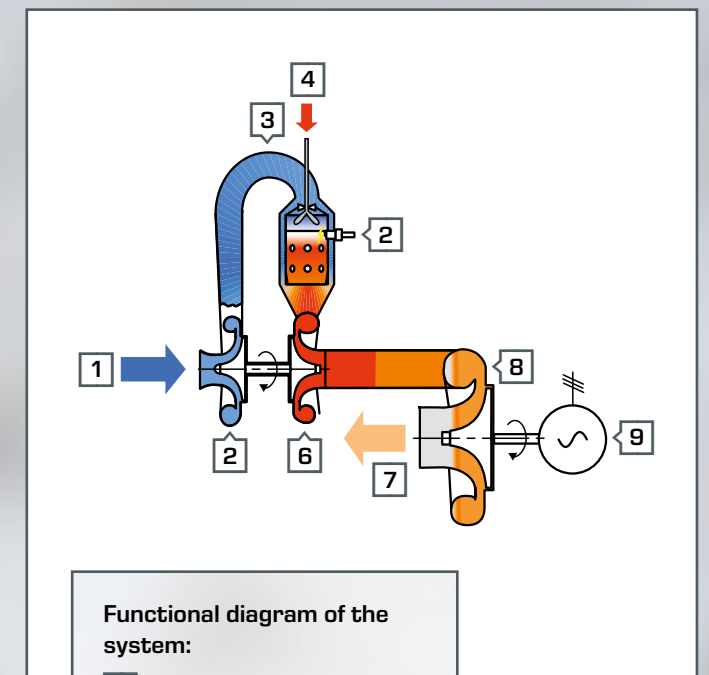
Output changes in the power turbine do not affect the compressor, which can continue running with optimum speed at the best efficiency point. Speed, temperatures, pressures and mass flow rates of air and fuel are detected and displayed by means of sensors. Typical characteristic variables are determined.

- 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 exhaust gas



T-s diagram of the open gas turbine process:

- 1 → 2 compression
- 2 → 3 heat supply
- 3 → 4 expansion
- $q_1$  supplied heat flux
- $q_2$  removed heat flux
- $W$  useful work



Functional diagram of the system:

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



## Learning objectives

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





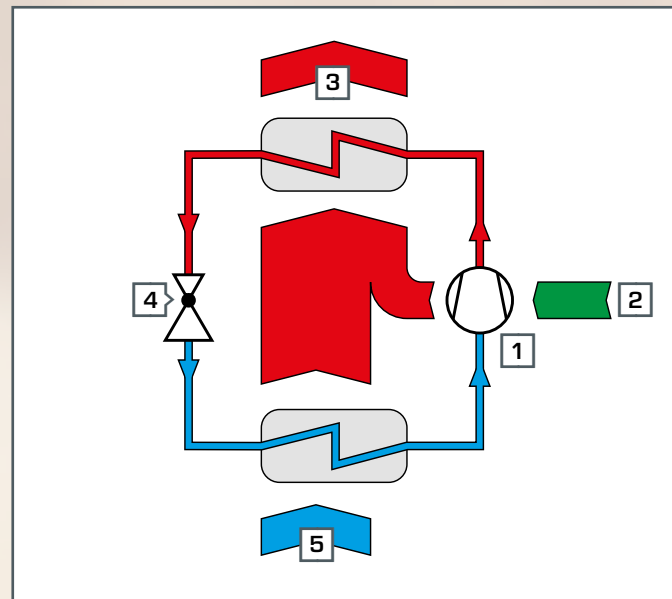
# Basic Knowledge Heat Pump



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

- 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 which is as high and constant as possible is the key for high efficiency. The temperature must not drop off too much in winter, when the most heating power has to be provided. For groundwater and

the ground, the heat exchangers have to be very large in order to avoid any local sub-cooling. When choosing the heat source, factors such as investment cost, efficiency, availability and obtaining permission have to be weighed against each other. Using low-order waste heat such as exhaust air or cooling water is particularly cost-effective.

| Energy source | Advantage            | Disadvantage                |
|---------------|----------------------|-----------------------------|
| outside air   | low investment       | 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     |

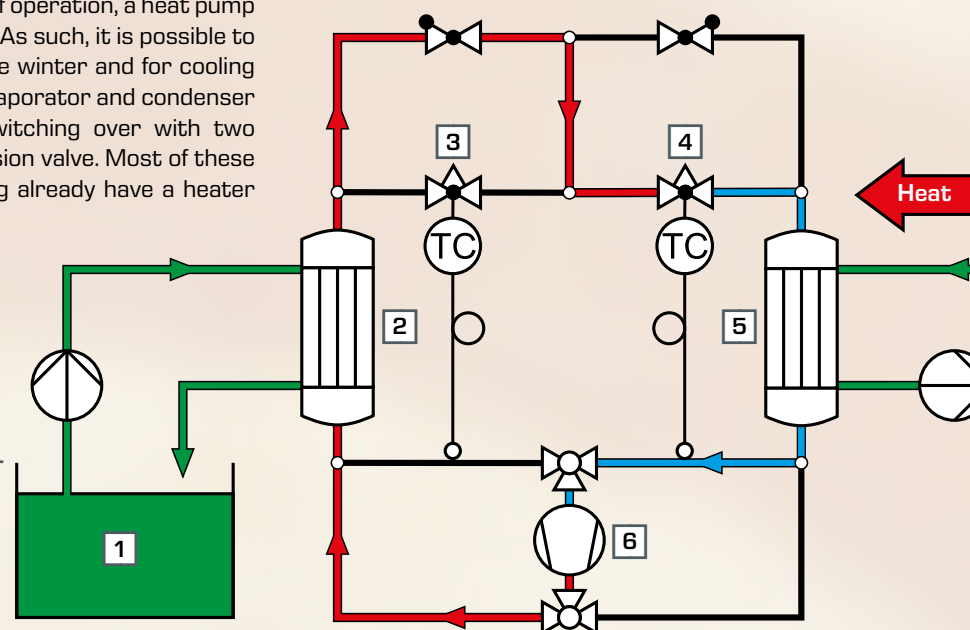
## A heat pump can be used for cooling or heating

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 takes place by switching over with two non-return valves and a second expansion valve. Most of these so-called split devices for room cooling already have a heater function included.

### Summer

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

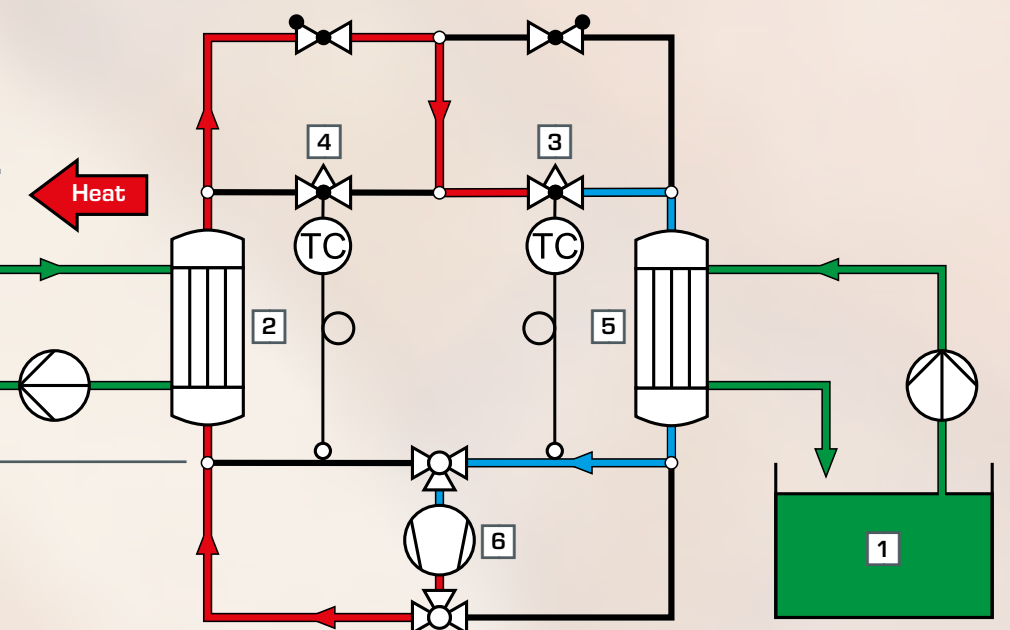
- water / solar circuit
- refrigerant (low pressure)
- refrigerant (high pressure)



### Winter

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

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





# ET 102 Heat Pump Trainer

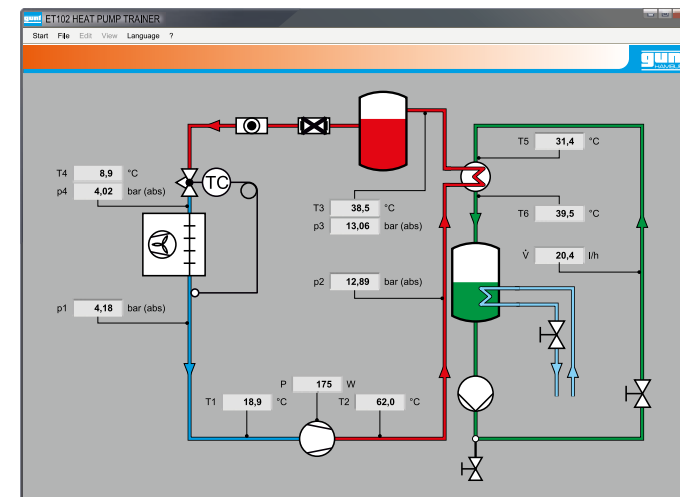
The GUNT ET102 Heat Pump Trainer contains a complete functional model of an air-to-water heat pump. The clear and spacious layout of the components allows for an easy understanding of the design of a heat pump system. All components are common components in heat pump and refrigeration technology. This means there is high recognition factor and the experiments are close to practice. The system has a variety of sensors which 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 specific training on the heat pump, you can also demonstrate the fundamentals of refrigeration technology. In addition to a 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



Product No.  
061.10200  
More details and technical data:  
[gunt.de/static/s3458\\_1.php](http://gunt.de/static/s3458_1.php)



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

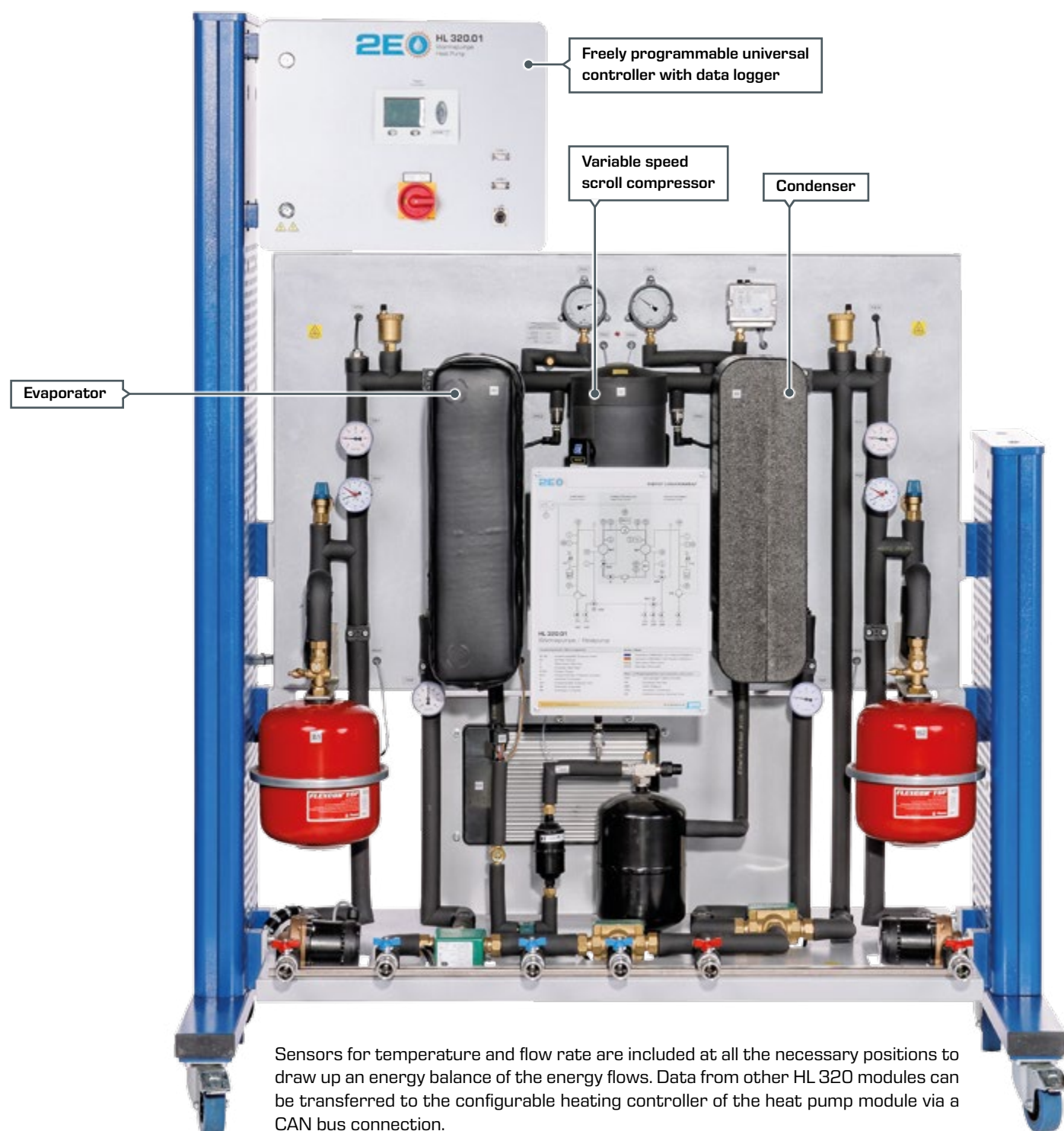


## Learning objectives

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



# HL 320.01 Heat Pump

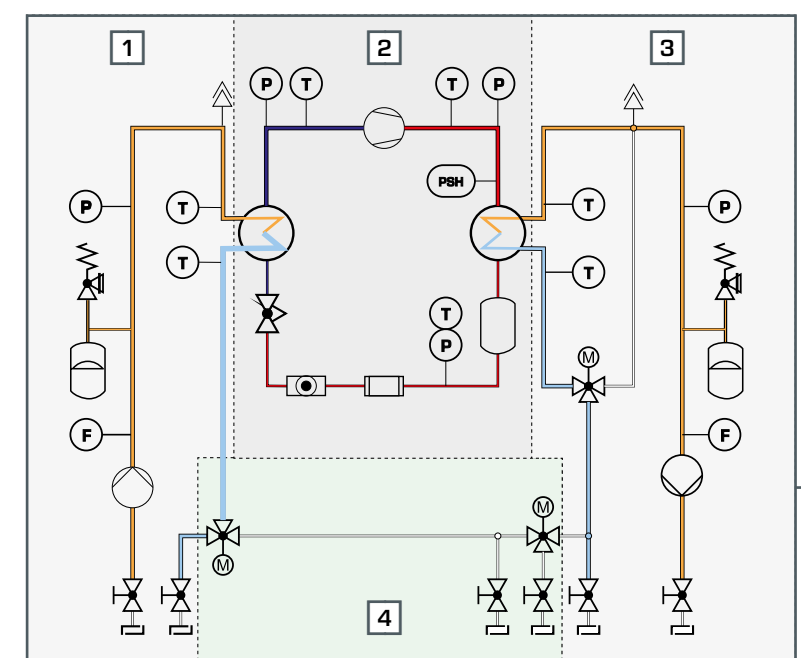


Sensors for temperature and flow rate are included at all the necessary positions to draw up an energy balance of the energy flows. Data from other HL 320 modules can be transferred to the configurable heating controller of the heat pump module via a CAN bus connection.

Product No.  
065.32001  
More details and technical data:  
[gunt.de/static/s5360\\_1.php](http://gunt.de/static/s5360_1.php)



The HL320.01 Heat Pump is part of the HL320 modular system and provides you with a variety of combination options from 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 heating system demand.



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

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.



Fixed and movable spirals of a scroll compressor

| Learning objectives                                                                                                                                                                                                                                                       |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>■ function and design of a heat pump</li> <li>■ distinguishing different operating conditions</li> <li>■ factors influencing the COP (coefficient of performance)</li> <li>■ parameterisation of a heat pump controller</li> </ul> |



# Subject Areas

# Storage in Energy Systems



## Subject Areas

## 2E Products

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 from a biogas plant.

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

### Compressed air storage

#### ET 513

Single-Stage 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

Using Photovoltaics: Grid connected or Stand-alone

#### ET 220

Energy Conversion in a Wind Power Plant

#### ET 220.01

Wind Power Plant



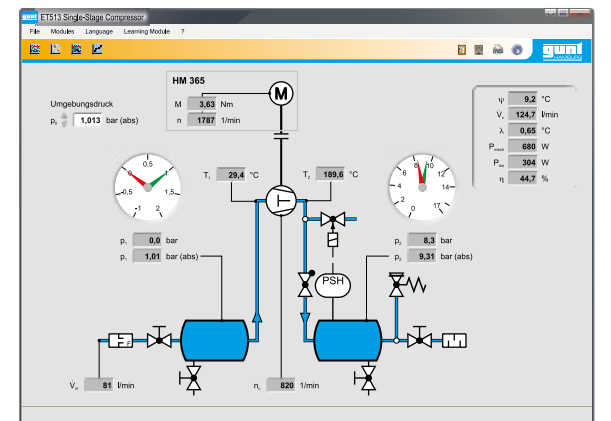
# ET 513 Single-Stage Compressor

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 Drive and Brake Unit, forms a complete

compressed air generating system. The unit HM 365 drives the compressor via a V-belt. The compressor speed is set on the HM 365 unit. The air is sucked into the intake tank, where it is settled before being compressed in the piston compressor. The compressed air is then squeezed into a pressure vessel and is then available as a working medium.

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 tank. Sensors capture the pressures and temperatures upstream and downstream of the compressor. The measured values are displayed digitally. At the same time, the measured values can also be transmitted directly to a PC via USB. The data acquisition software is 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 stations, compressed air storage power stations with pressure vessels or caverns is used as short-term storage to cover peak loads. This type of power station is especially beneficial for load regulation. 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 loading and discharge.



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

## Capture of:

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

## Calculation of:

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

## Learning objectives

- measurement of
  - intake and delivery pressure
  - airflow rate
  - compressor speed
  - temperatures
- determination of the volumetric efficiency
- determination of the isothermal efficiency

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



Combination:  
Setup of a complete compressor system together with the HM 365 Universal Drive and Brake Unit.



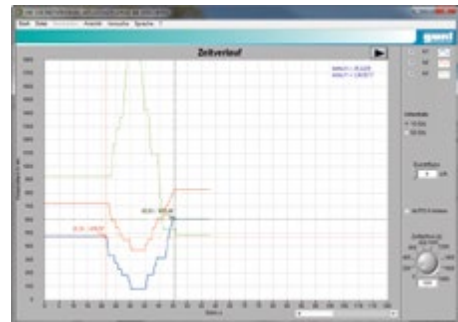


# HM 143 Transient Drainage Processes in Storage Reservoirs

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 reservoirs. Reservoirs are used as permanent storage reservoirs for water supply, energy conversion, or flood protection. The water rises before it is discharged over an overflow. The water flows out of reservoirs through pipelines or tunnels. A surge chamber prevents water hammers in pipes and fittings in the event of rapid changes in flow rate.

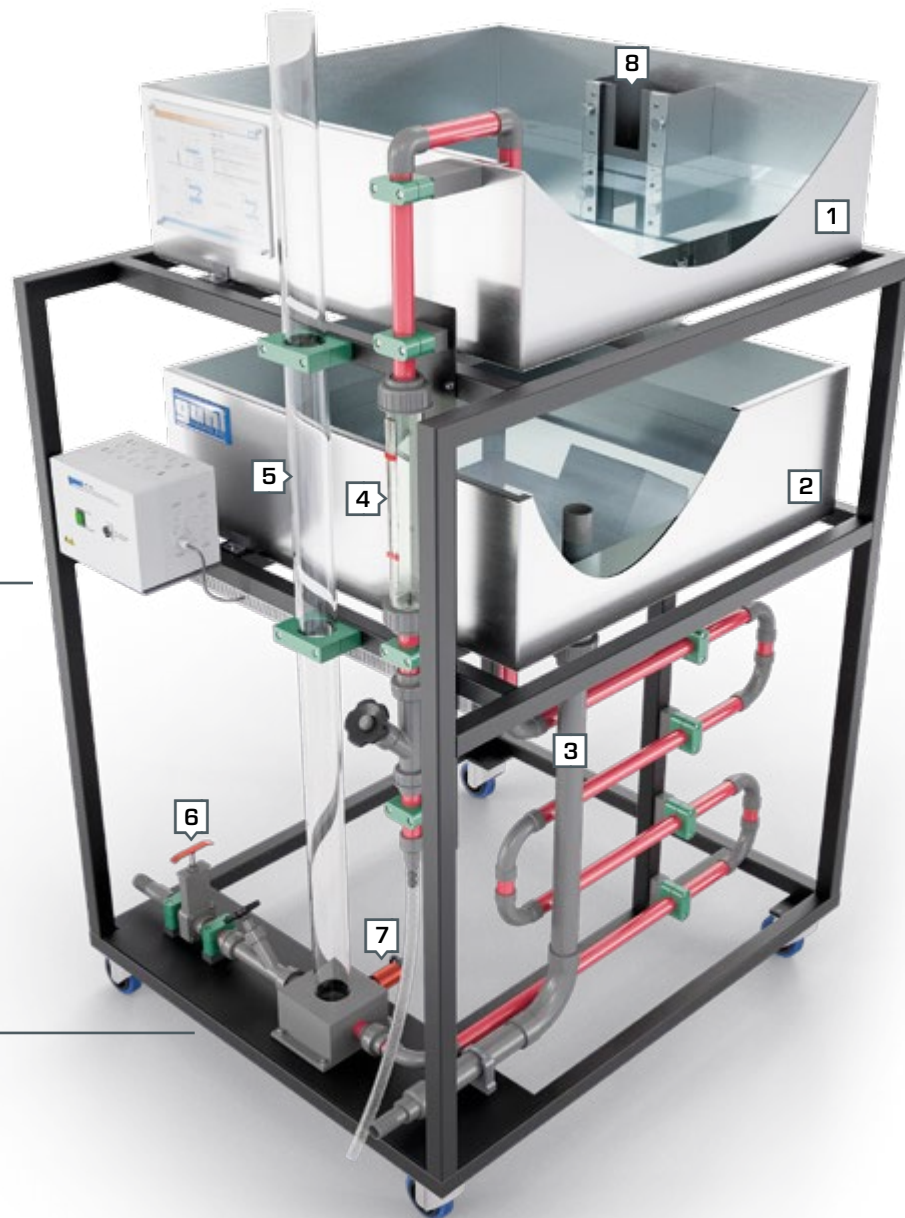
HM 143 is used to demonstrate transient drainage processes from storage reservoirs and how a surge chamber works. The trainer includes a basin with adjustable weir and a second, deeper-lying basin with overflow and drainage line. A surge chamber is installed in the drainage line. The “Reservoirs” experiment 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 line. The vibration can be seen as oscillation of the water level in the surge chamber.

## Software



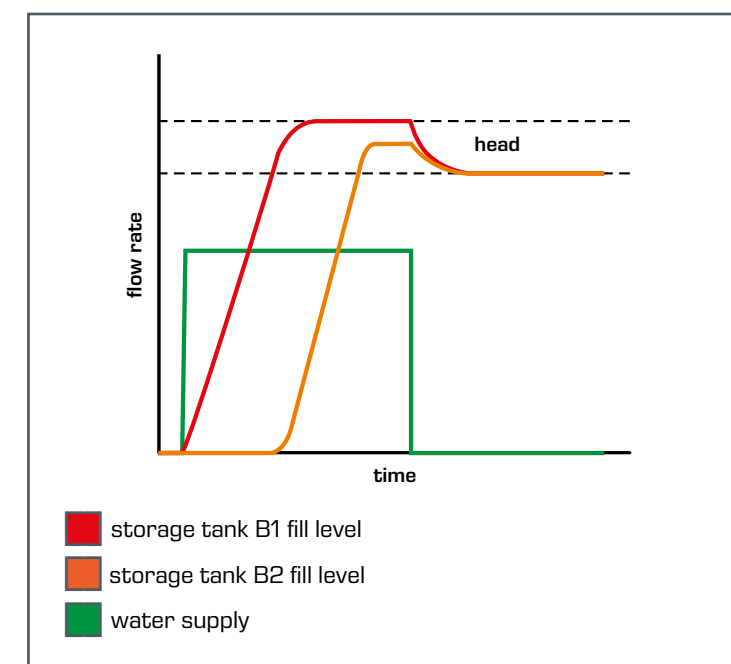
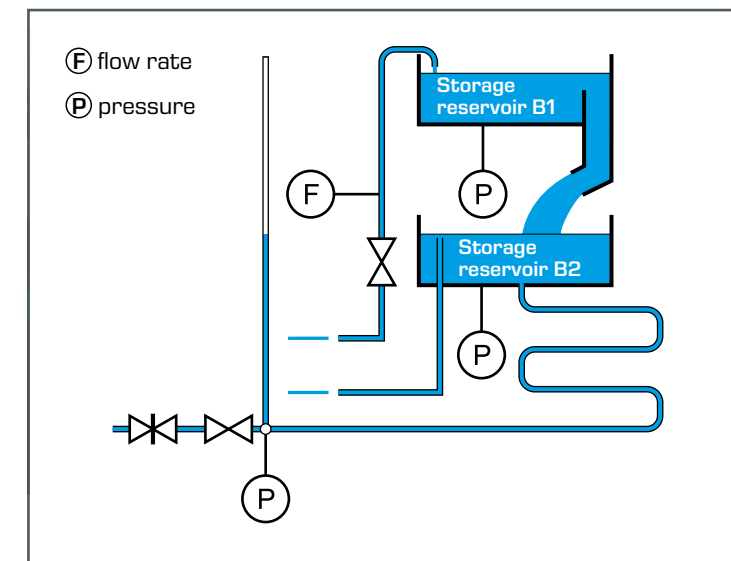
The water levels in the basins and in the surge chamber are detected by pressure sensors and displayed using the GUNT software.

- 1 storage reservoir B1
- 2 storage reservoir B2
- 3 overflow pipe
- 4 flow meter
- 5 surge chamber
- 6 gate for generating water hammer
- 7 pressure sensor
- 8 weir (adjustable)



## “Reservoirs” experiment

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



## Learning objectives

- demonstrating transient drainage processes in two rainwater retention basins located one behind the other
- demonstrating transient drainage processes in two reservoirs located one behind the other
- recording oscillations of the water level in a surge chamber after water hammer
- recording and displaying water level fluctuations





# 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 classified 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.

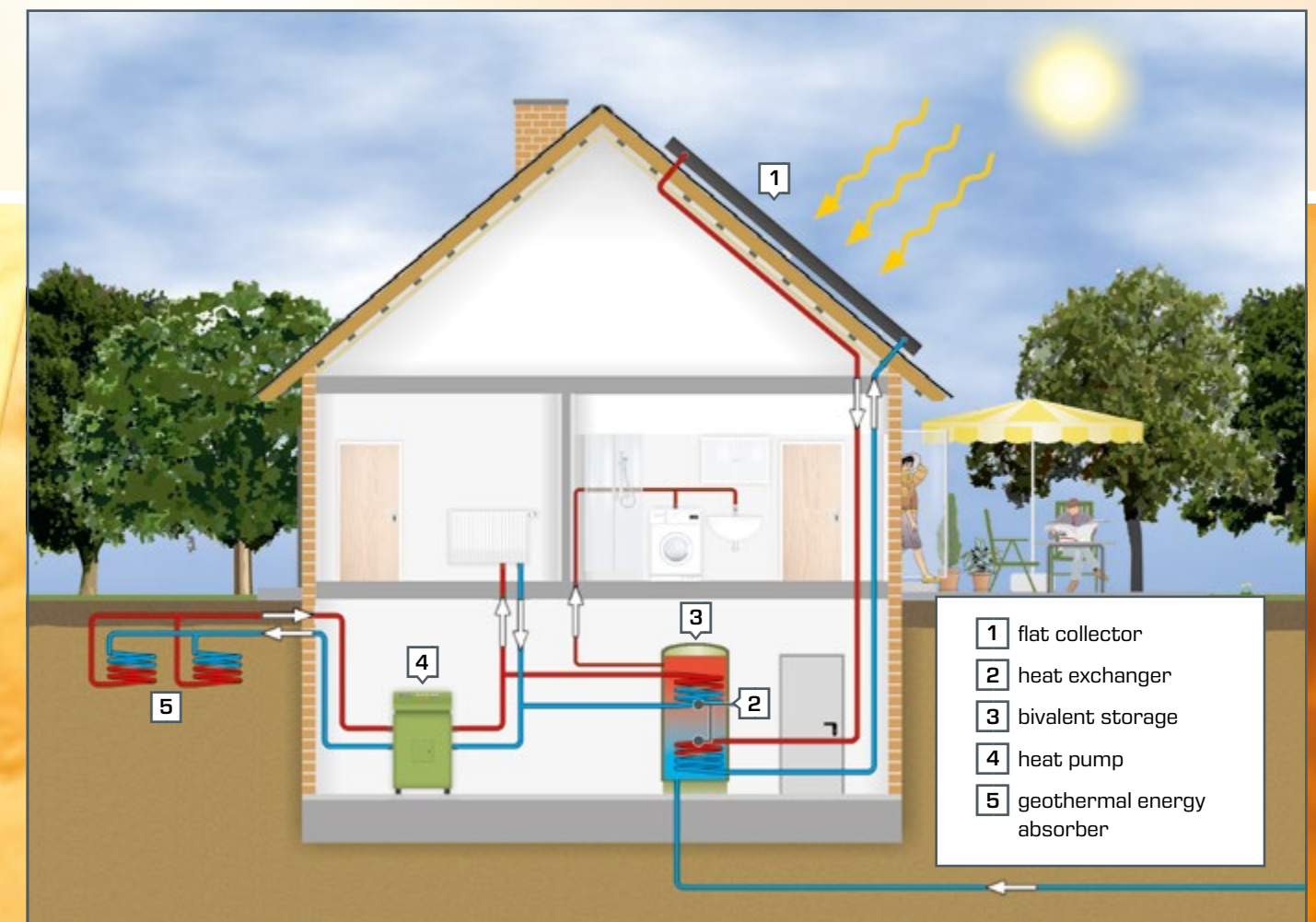
Thermal storage systems with liquid and solid materials without phase change are also called sensitive thermal storage systems. The concept is to heat and cool a material by means of a heat medium. This heat medium may be a hydraulic oil or brine for example, which enables the entire indirect storage 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 for a storage concept are the level 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

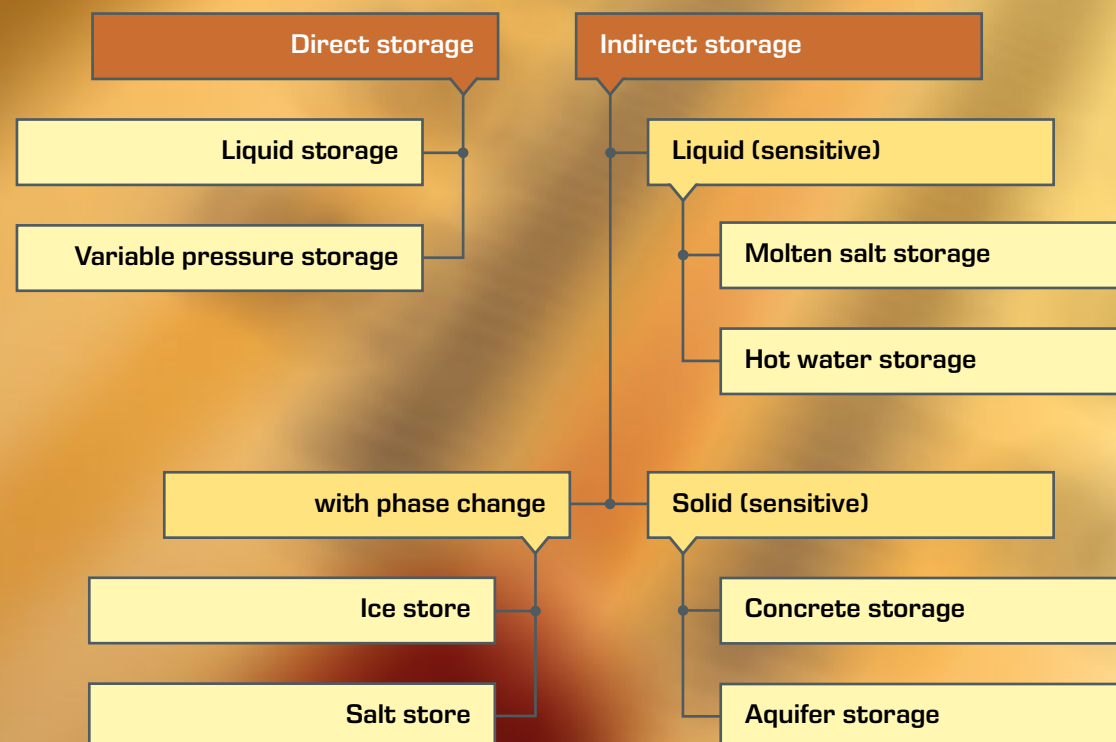
In many cases doing away with a conventional heating system represents a genuine alternative for modern residential buildings with good thermal insulation. The combination of solar thermal collectors with a heat pump very often guarantees significant savings with reliable year-round supply.

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 integration of different heat sources and creates a balance between heat supply and demand.

## Thermal storage concepts





# HL 320.05 Central Storage Module with Controller

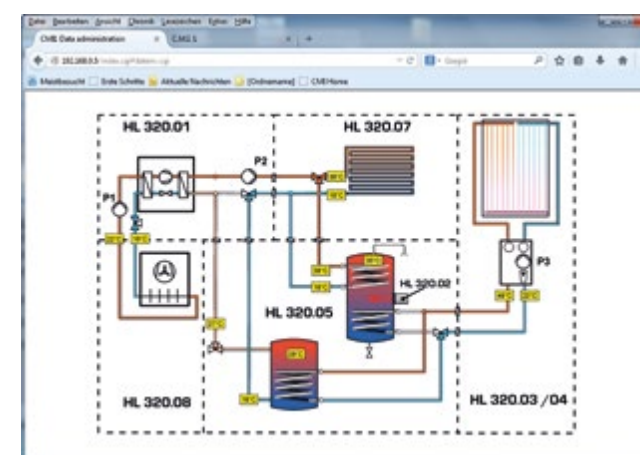


- 1 freely programmable heating controller with data logger
- 2 ports for CAN bus and network
- 3 process schematic
- 4 buffer storage
- 5 heat exchanger
- 6 3-way change-over valve
- 7 circulation pump
- 8 bivalent storage

Product No.  
065.32005  
More details and technical data:  
[gunt.de/static/s5289\\_1.php](http://gunt.de/static/s5289_1.php)



The HL 320.05 Central Storage Module with Controller can be connected to the HL 320 modular system in a variety of ways using 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

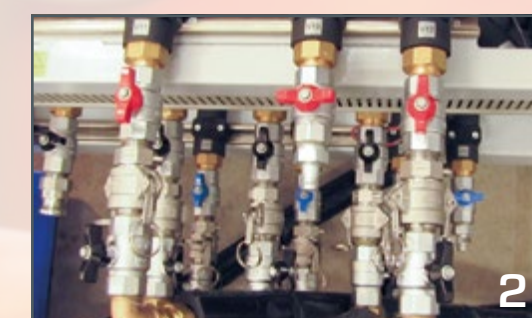
The controller is controlled and data acquired via a network module to a PC. Current system data can be represented in a diagram, for example. This representation can be called up on any current web browser.



Hochschule für  
Wirtschaft und Recht Berlin  
Berlin School of Economics and Law

At the Berlin School of Economics and Law, HL 320.05 is used in conjunction with HL 320.03 and HL 313.01 for experiments in the field of renewable energies.

## 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).



# ET 420

## Ice Stores in Refrigeration

The demand for cooling in buildings, such as in shopping centres and hospitals, fluctuates widely over the course of the day. During the day, the demand for cooling is usually much higher than at night. Refrigerating plants are designed for peak load. In times of little cooling demand, these plants are inefficient and cost-intensive. Ice stores are loaded using cheap night-time electricity and discharged during the day to cover the peak

load. This means a lower capacity can be installed. The result is lower investment and operating costs. Another advantage is the safe supply of cooling even in the event of a power failure, e.g. in hospitals. Ice stores use the absorption of energy when water changes from the solid to the liquid aggregate state. The advantage over other storage methods (e.g. hot water tanks) is the relatively large amount of heat per volume at a very low

temperature difference. The stored cooling energy can be almost entirely re-used.

ET 420 is a refrigerating plant with ice store that can also be operated as a heat pump. A dry cooling tower and a wet cooling tower are included as a heat source and heat sink. The dry cooling tower replaces a conventional air-conditioning system

in the various connection options or provides the necessary temperature level. Surplus heat is released by the wet cooling tower or the ice store. The possible operating modes are listed on the following page.



- 1 switch cabinet
- 2 storage tank
- 3 circulation pump
- 4 ice store
- 5 process schematic
- 6 refrigerant compressor
- 7 refrigerant condenser
- 8 refrigerant evaporator
- 9 dry cooling tower
- 10 wet cooling tower

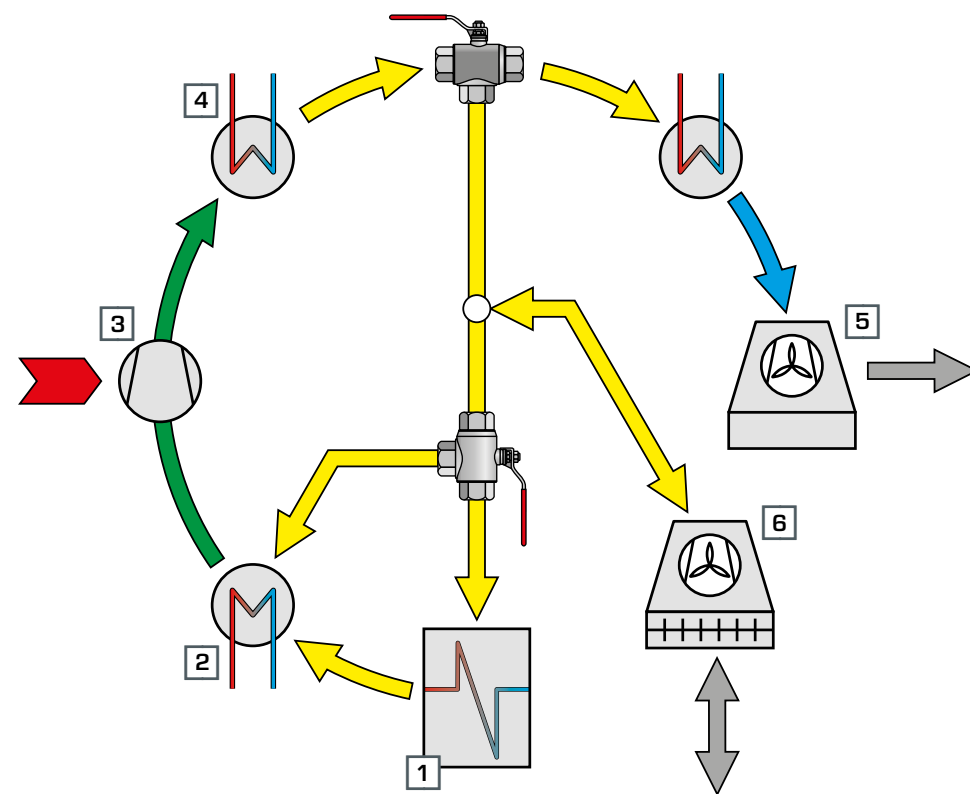




# ET 420 Ice Stores in Refrigeration

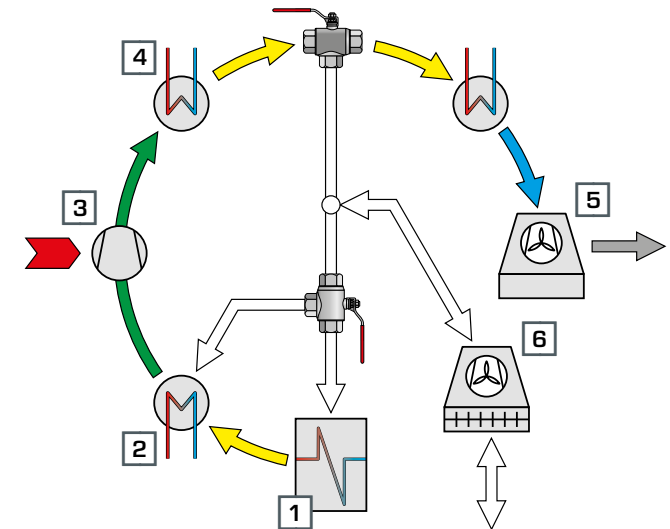
## Operating modes

The ET 420 trainer provides you with a variety of different operation modes. You can combine cooling and heating and the respective loading or discharging of the ice store or only load or discharge the ice store. The sections and circuits contain different working media. The heat is released by the cooling towers (1, 8) to the ambient air. A glycol-water mixture is used as the heat carrier for the dry cooling tower (1). A water circuit with automatic compensation for lost water is installed for heat transport to the wet cooling tower (8). The cooling circuit (4, 5, 6) is operated with a standard refrigerant. The other components are connected to the glycol-water circuit in the same way as the dry cooling tower.



## Charging the ice store (night-time operation)

The compressor of the refrigeration circuit is operated with cheap night-time electricity. The refrigeration circuit evaporator cools the glycol-water mixture in a further circuit. The glycol-water mixture flows through a coiled tube in the insulated ice store. The glycol-water mixture extracts energy from the water in the ice store so that it freezes. The waste heat occurring on the condenser of the refrigeration circuit is dissipated to a cooling tank filled with glycol-water mixture. The mixture in the cooling tank is cooled by individual or combined operation of the cooling towers.

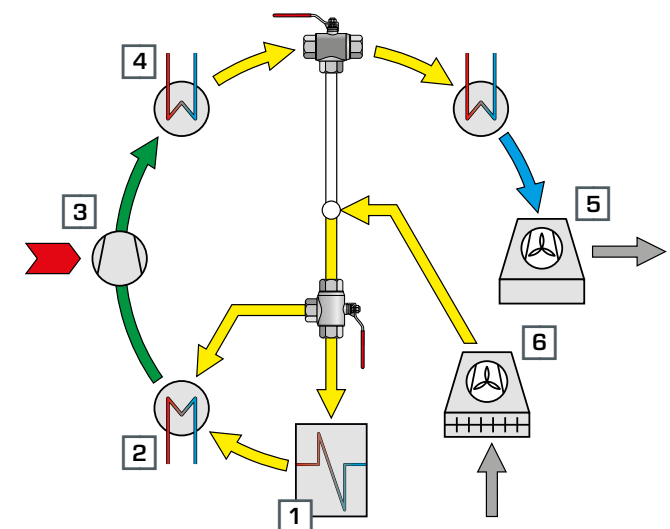


## Discharging the ice store (daytime operation)

The refrigeration circuit compressor is switched off so that expensive electricity is not used at peak rates. The glycol-water mixture from the cooling tank (cooling load) releases its energy to the ice in the ice store. The ice melts and its melting energy is available for cooling.

## Cooling with ice store and refrigeration circuit

If the cooling capacity of the ice store is not sufficient during the day, ice store and refrigeration circuit can also be operated in parallel. It is especially energy-efficient to cover peak loads using the ice store so that the compressor capacity which needs to be installed is lower. This also leads to lower power consumption in night-time operation, since the compressor can be operated at a good efficiency and not with an inefficient partial load.



- |                          |                      |
|--------------------------|----------------------|
| 1 ice store              | glycol-water mixture |
| 2 refrigerant evaporator | water                |
| 3 refrigerant compressor | refrigerant          |
| 4 refrigerant condenser  | air                  |
| 5 wet cooling tower      | electrical power     |
| 6 dry cooling tower      |                      |







# 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 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, it is cost-effectiveness and long-term stability which are important when looking at the integration of large electrochemical storage capacities in modern utility grids.

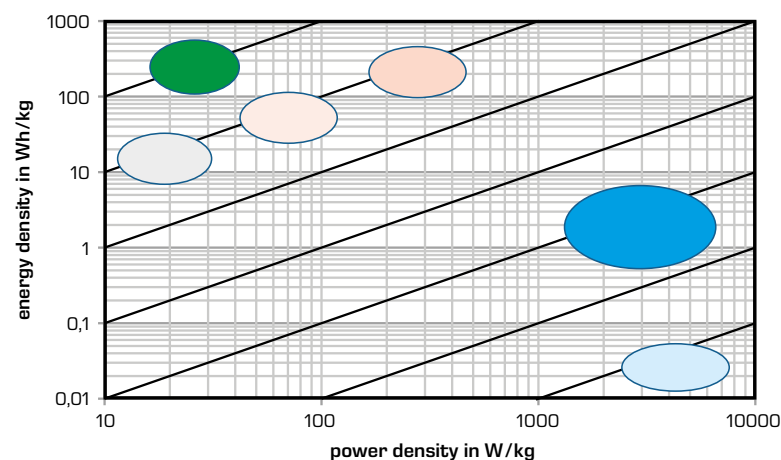
Listed below are the most important industrial electrochemical energy storage systems which are currently commercially significant:

- 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<sub>2</sub>O<sub>4</sub>, LiCoO<sub>2</sub> or LiFePO<sub>4</sub>)

## 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.



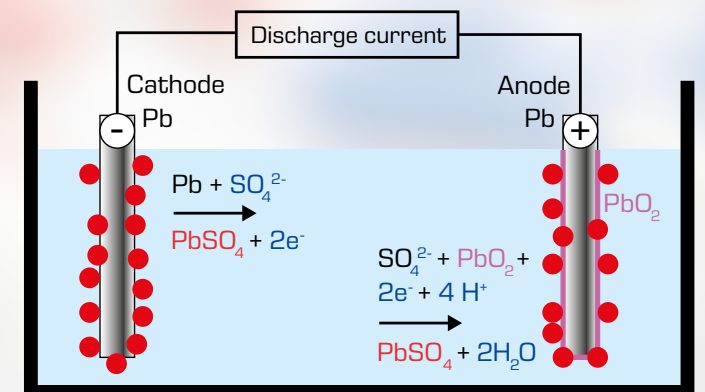
- fuel cell
- lead battery
- NiCd battery
- lithium battery
- Boostcap ultracapacitor
- conventional capacitor

## 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. This chemical energy is made available again as electrical energy during discharge.

This can be demonstrated in detail using the example of the lead accumulator. In addition to the positive and negative lead electrodes (Pb), an important component is an electrolyte (H<sub>2</sub>SO<sub>4</sub>) which enables the underlying oxidation and reduction reactions.

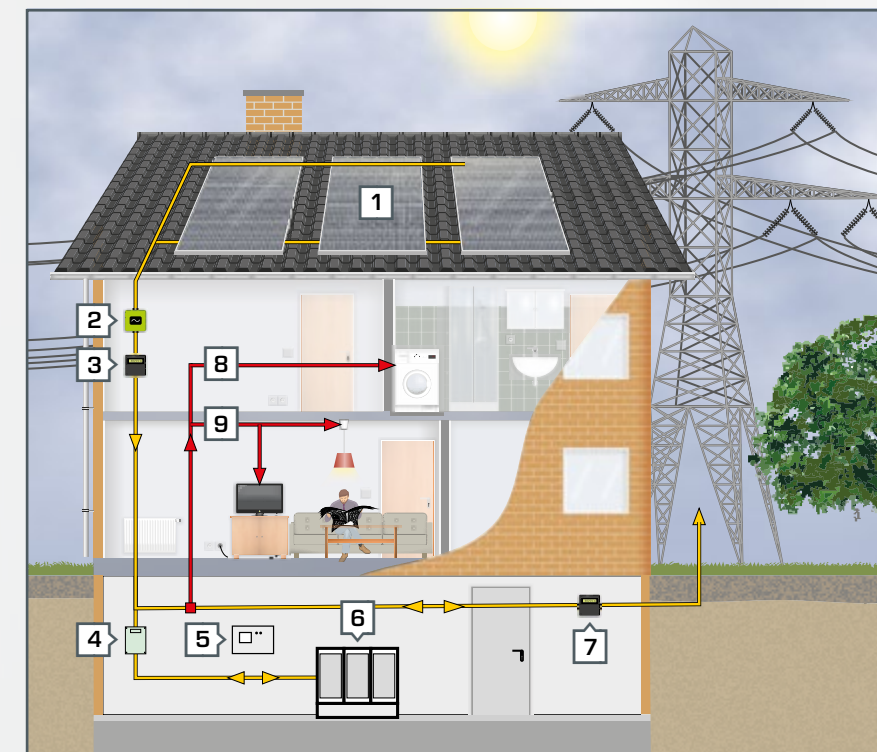
In the discharged state, a layer of lead sulphate (PbSO<sub>4</sub>) is attached to both electrodes. In the charged state, the positive electrode is coated with lead oxide (PbO<sub>2</sub>) while the negative electrode consists of pure (porous) lead.



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

The overall reaction is:  
 $\text{Pb} + \text{PbO}_2 + 2\text{H}_2\text{SO}_4 \rightarrow 2\text{PbSO}_4 + 2\text{H}_2\text{O} + \text{electrical energy}$

## 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 in-house consumption and to reduce the extraction of electricity from the grid.

- 1 electrical energy
- 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



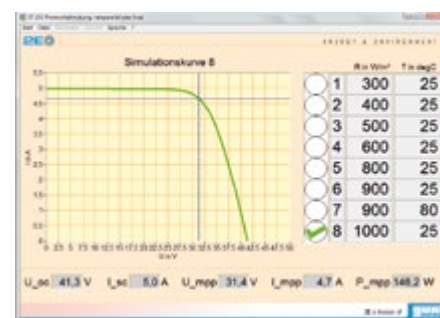
# ET 255 Using Photovoltaics: Grid connected or Stand-alone



The ET 255 trainer allows you to investigate real world components from the field of photovoltaics for mains feed-in and for stand-alone operation under real operating conditions. You can work with real photovoltaic modules (ET 250) or use the integrated photovoltaic simulator.

## Software

The photovoltaic simulator makes it possible to investigate the effects of changing illuminance and temperatures. The photovoltaic simulator's easy-to-understand user interface can be used to select different characteristic curves.

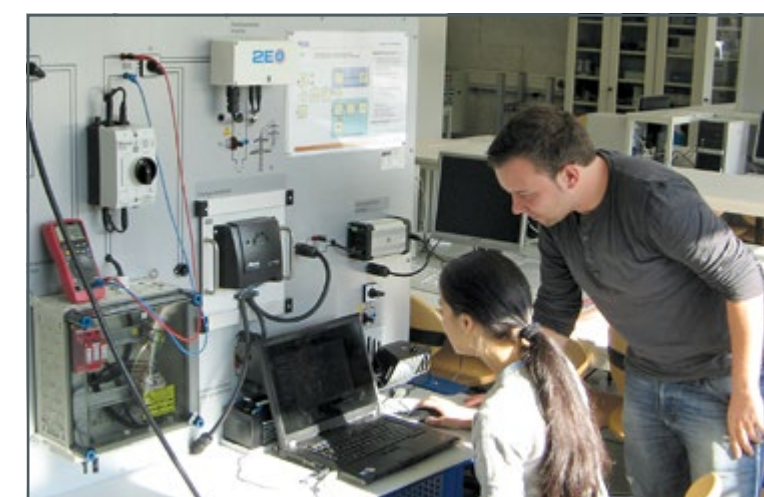
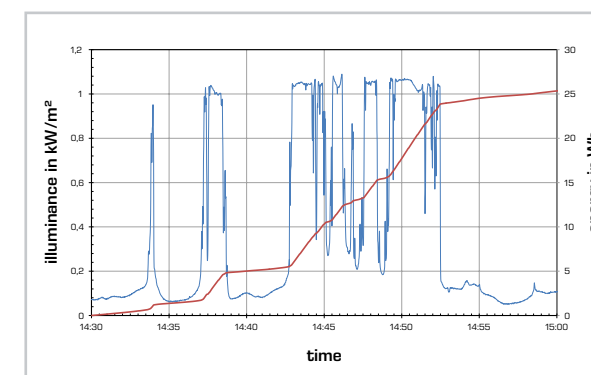


## Learning objectives

- function of line-commutated inverters
- function of charge controllers and accumulators in stand-alone operation
- efficiency and dynamic behaviour of system components
- function of MPP tracker



When connecting ET 250 to ET 255, the measured values from the photovoltaic modules are transmitted to ET 255. The data can be recorded and displayed with the corresponding software. As shown below, this data can be used in spreadsheets for yield calculations.



At Joanneum Technical College in Kapfenberg, Austria, the ET 255 trainer is used for practical experiments in the field of energy and environmental management. The photovoltaic simulator can be used to conduct experiments on the efficiency of photovoltaic systems without interference from the weather.





# 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 wind tunnel of ET 220 or the ET 220.01 Wind Power Plant can be connected to the control unit of ET 220 for installation outdoors.



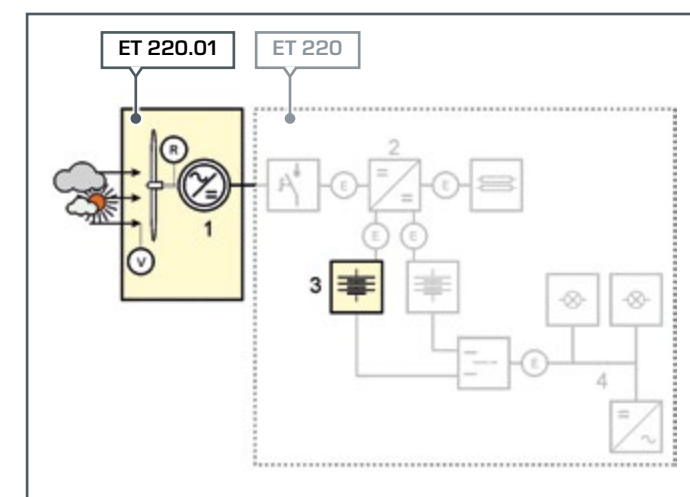
In experiments with ET 220.01, you can connect an additional accumulator to the control unit of ET 220 in order to expand the storage capacity.

Product No.  
061.22000  
More details and technical data:  
[gunt.de/static/s5226\\_1.php](http://gunt.de/static/s5226_1.php)



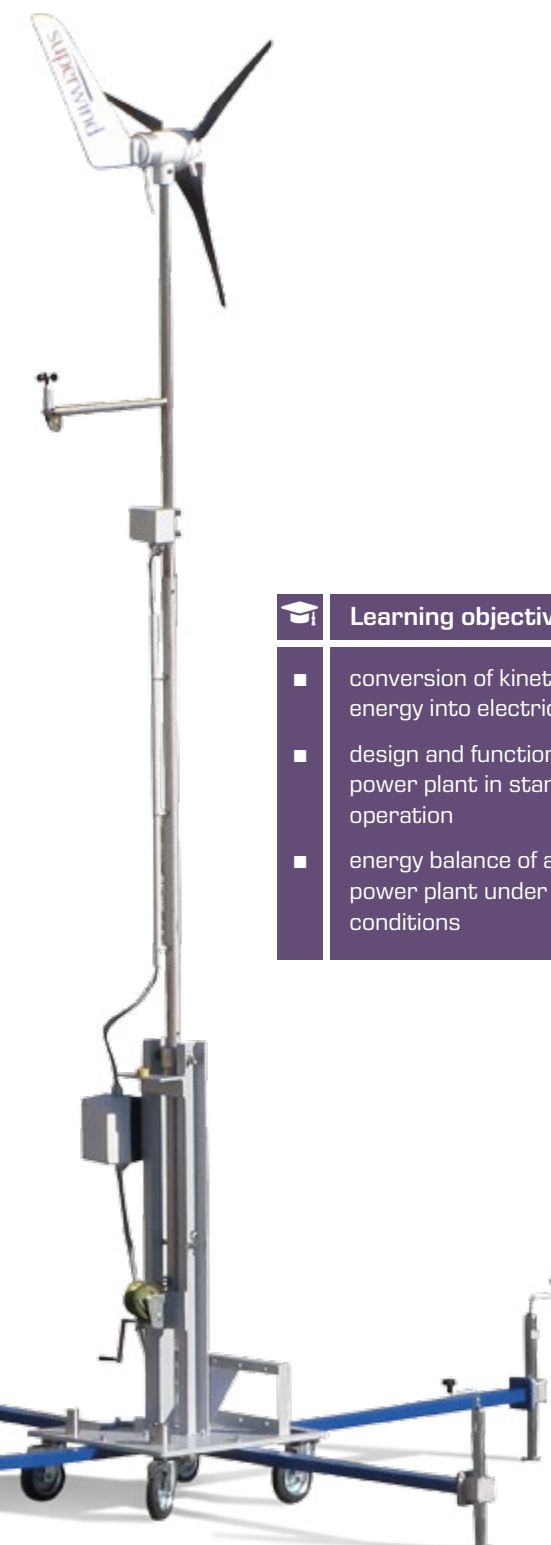
## ET 220.01 Wind Power Plant

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



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

Product No.  
061.22001  
More details and technical data:  
[gunt.de/static/s5247\\_1.php](http://gunt.de/static/s5247_1.php)



- Learning objectives**
- conversion of kinetic wind energy into electrical energy
  - design and function of a wind power plant in stand-alone operation
  - energy balance of a wind power plant under real wind conditions



# Energy Efficiency in Building Services Engineering

1.7

## Introduction

**Basic Knowledge** Energy Efficiency  
in Building Services Engineering

182

## Heat Supply and Air Conditioning

**Subject Areas**  
Heat Supply and Air Conditioning

184

**Basic Knowledge**  
Thermal Insulation and Heat Recovery

186

**WL 376**  
Thermal Conductivity of Building Materials

188

**Overview**  
WL 110-Series: Modular Heat Exchangers

190

**Basic Knowledge**  
Efficient Heating Technology

192

**HL 305**  
Hydronic Balancing of Radiators

194

**HM 283**  
Experiments with a Centrifugal Pump

196

**HL 630**  
Efficiency in Heating Technology

197

**ET 340** Building Automation  
in Heating and Air Conditioning Systems

198

**ET 630**  
Split System Air Conditioner

199

## Inclusion of Renewable Energies

**Subject Areas**  
Inclusion of Renewable Energies

200

**Overview** HL 320 Solar Thermal Energy  
and Heat Pump Modular System

202

**HL 320.01**  
Heat Pump

204

**HL 320.02**  
Conventional Heating

206

**HL 320.03**  
Flat Plate Collector

207

**HL 320.04**  
Evacuated Tube Collector

208

**HL 320.05**  
Central Storage Module with Controller

209

**HL 320.07** Underfloor Heating/  
Geothermal Energy Absorber

212

**HL 320.08**  
Fan Heater/Air Heat Exchanger

213

## Energy Efficiency in Business and Industry

**Subject Areas**  
Energy Efficiency in Business and Industry

214

**Basic Knowledge**  
Energy Efficiency in Refrigeration Technology

216

**ET 420**  
Ice Stores in Refrigeration

218

**ET 428**  
Energy Efficiency in Refrigeration Systems

220

**Basic Knowledge** Process Engineering  
and Building Services Engineering

222

**RT 682**  
Multivariable Control: Stirred Tank

224

**RT 396**  
Pump and Valves and Fittings Test Stand

226

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# Basic Knowledge

# Energy Efficiency in Building Services Engineering



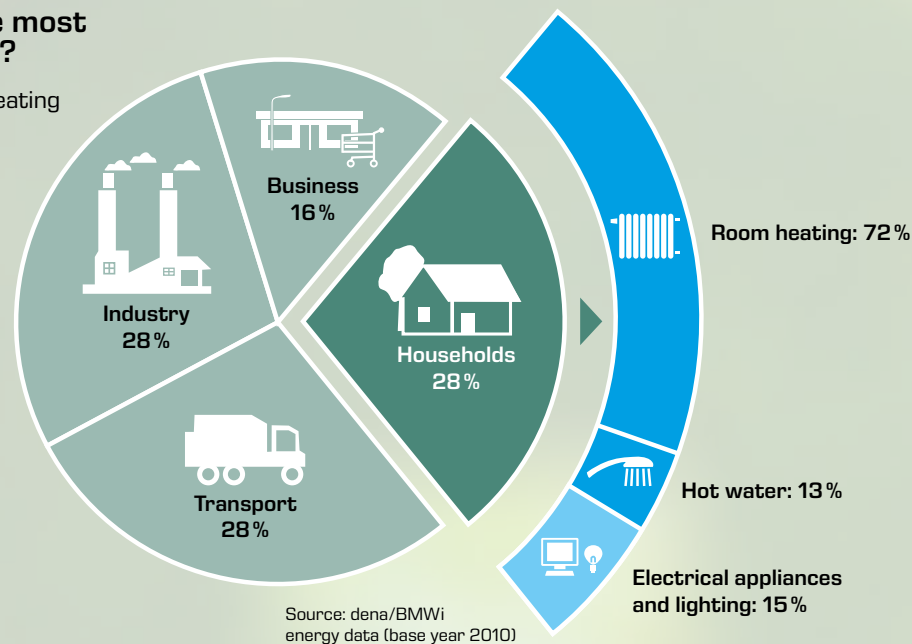
## Climate protection through increased energy efficiency in building services engineering

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 proportion of globally-consumed energy relates to the supply of buildings, this area offers enormous potential for delivering a significant contribution in reducing the use of primary energy through energy efficiency increases. Measures

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

### Who consumes the most energy in Germany?

Energy consumption of heating often underestimated



Based on our 2E 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 convert 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 in 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 modern concepts for combined heat and power, distributed power grids and energy storage into account, it is possible to achieve energy production and distribution which 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 G 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



## Subject Areas

## 2E0 Products

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 be reduced by more than 80% through a combination of measures in some cases. These include improved insulation materials, optimised hydronic balancing of radiators and the use of more modern, controlled circulation pumps.

Since the energy consumption required to cool buildings is becoming an increasingly important factor in warmer regions of the world, and due to generally rising average temperatures, our building services engineering teaching equipment also covers this area. Further efficiency improvements in air conditioning are possible, for example, with new materials and the intelligent control of combined systems for heating and cooling.

### Thermal insulation and heat recovery

#### WL 376

Thermal Conductivity of Building Materials

#### WL 110

Heat Exchanger Supply Unit

### Efficient heating technology

#### HL 305

Hydronic Balancing of Radiators

#### HM 283

Experiments with a Centrifugal Pump

#### HL 630

Efficiency in Heating Technology

### Air conditioning

#### ET 340

Building Automation in Heating and Air Conditioning Systems

#### 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:

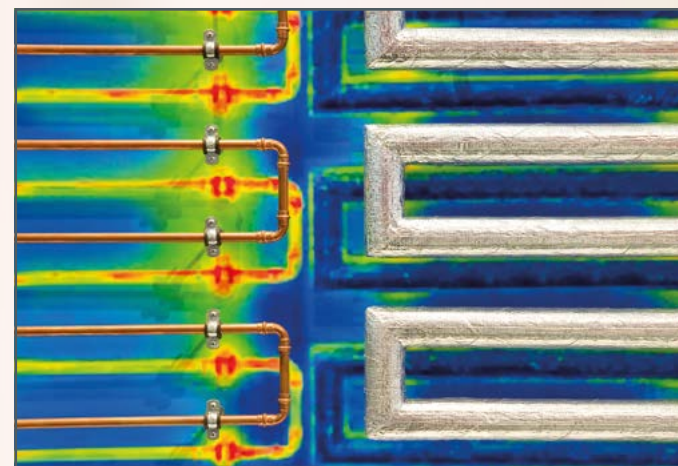
- heat conduction
- convection
- heat radiation

Enabling 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 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 which 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.

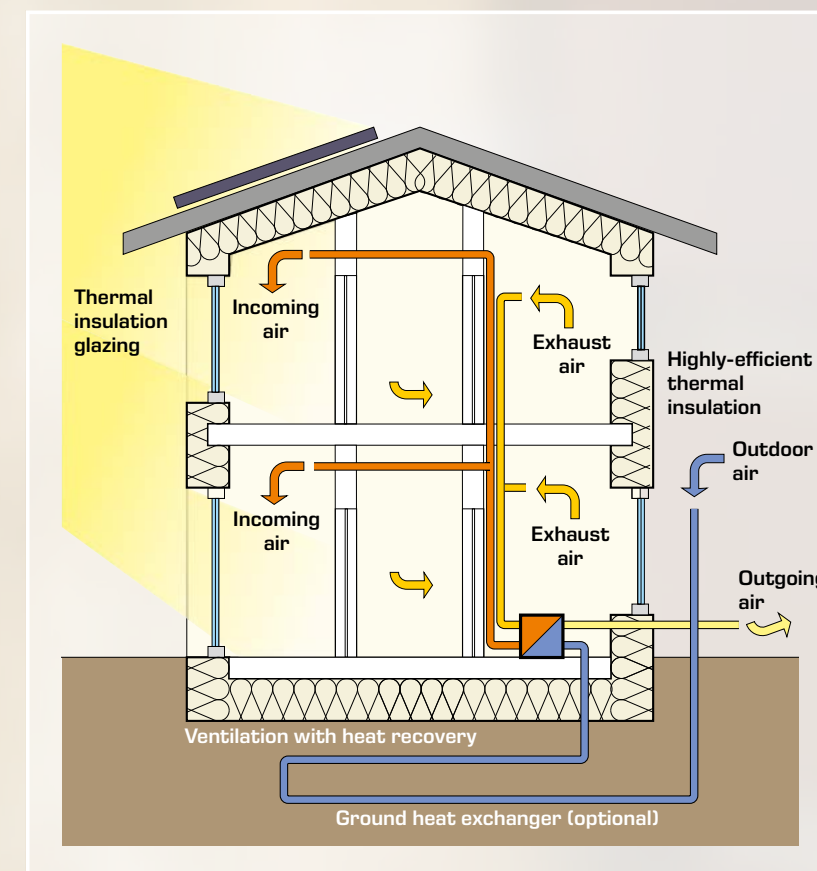
### Heat recovery

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.

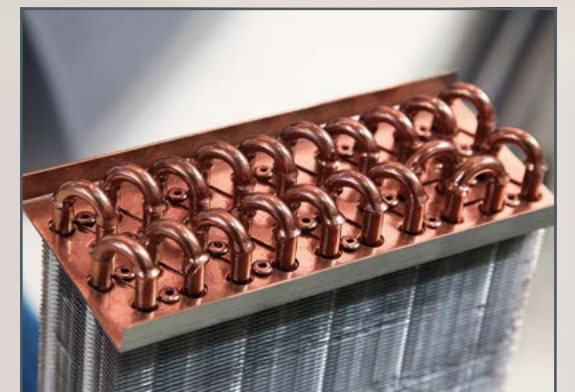
The greatest energy savings potential from heat recovery comes from heating and ventilation systems. In addition, heat recovery systems are conceivable in principle in many other supply and disposal processes in building services engineering.

### 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 in existing building stock. Highly effective insulating materials and triple glazing are used in passive houses. 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.



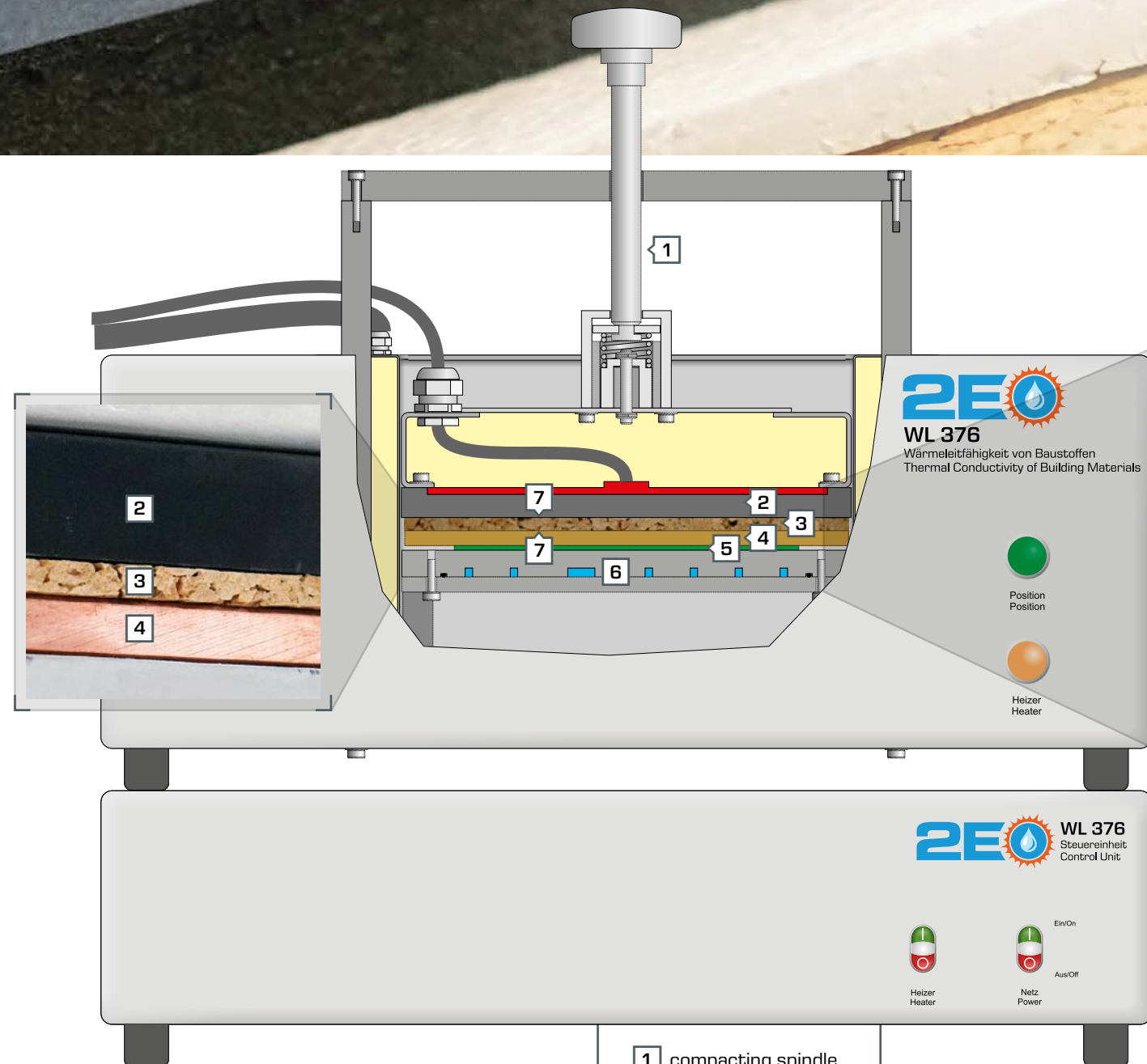
In so-called circuit compound systems, two separate air-to-water heat exchangers are employed in order to use the heat contained in the exhaust air to heat the incoming air.



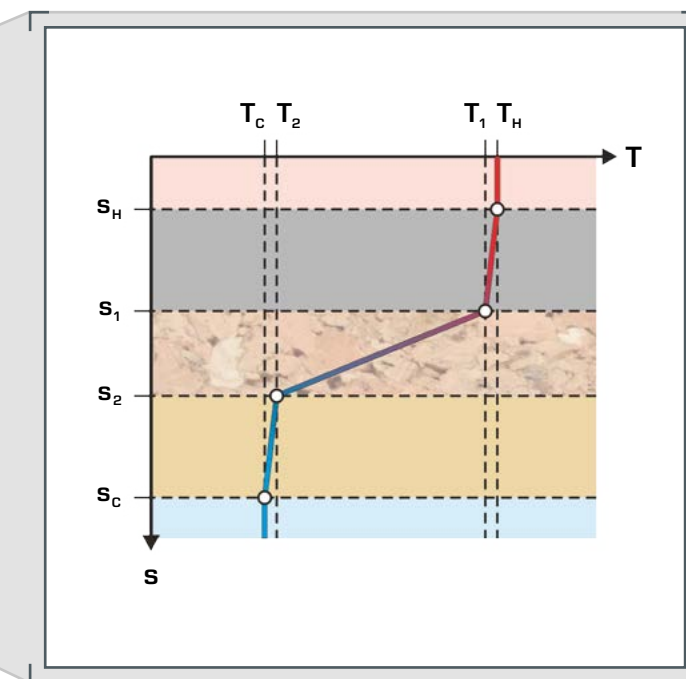
# WL 376 Thermal Conductivity of Building Materials

This experimental device 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, apply a

reproducible clamping force 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.



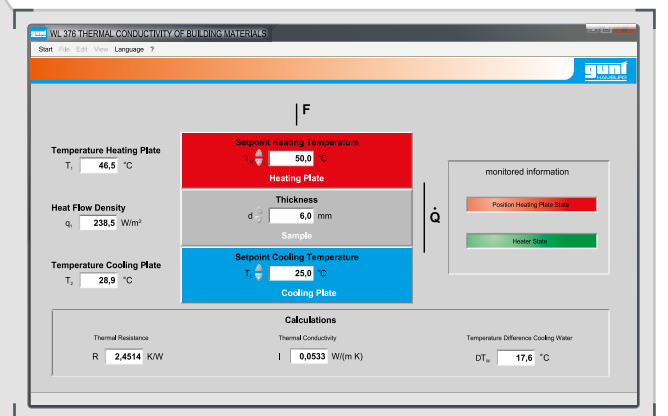
- 1 compacting spindle
- 2 hot plate
- 3 sample
- 4 clamping plate
- 5 heat flux sensor
- 6 cold plate
- 7 temperature sensor



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 WL376 detects the measurement data via USB and offers extensive options for analysing and displaying the results.



## Learning objectives

- determination of the thermal conductivity  $k$  of different materials
- determination of the thermal resistance
- thermal conductivity  $k$  of several specimens connected in series (up to a thickness of 50 mm)





# WL 110-Series Modular Heat Exchangers

## Experiments on the fundamentals of heat transfer

Clear, simple, reliable, learning progress monitoring

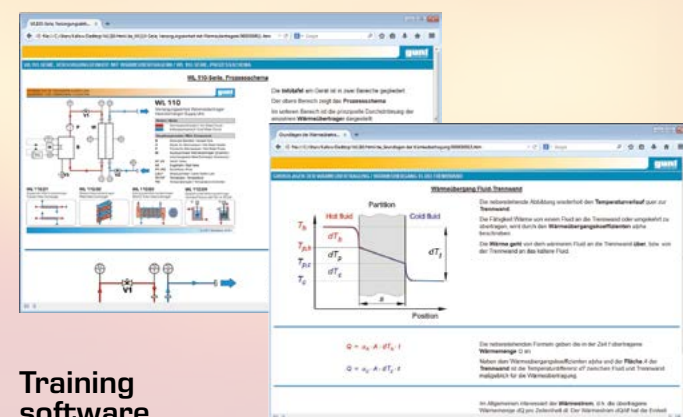


## Didactic advantages

Ideally suited for student-led experiments

A small group of 2-3 students can easily and independently conduct a variety of experiments. The lecturer can present characteristic aspects of the heat exchanger using software for data acquisition and a projector connected to the computer. The well-structured instructional material sets out the fundamentals and provides a step-by-step guide through the experiments.

Supply unit for heat exchangers WL 110 with WL 110.03 Shell and Tube Heat Exchanger



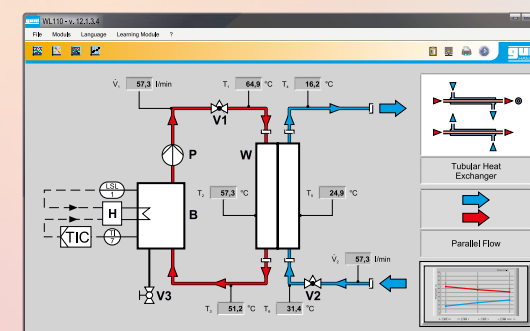
## Training software

Our training software, specially developed for this equipment series, provides a multimedia-based and interactive course of study on the fundamentals of heat transfer and on operating the WL 110 series. Didactically thought-out test questions at the end of the course allow you to review students' learning progress directly on the PC.



## WL 110.20 Water Chiller for WL 110

The cold water required for all experiments is usually provided by the laboratory supply. If the ambient temperature of the laboratory is too high, we recommend using the water chiller to obtain meaningful experimental conditions. Hot water is also needed for the experiments. It is provided by the WL 110 supply unit.



## Software

The software for WL 110 has the following main features:

- measurement of temperatures and flow rates
- operation in parallel flow or counterflow
- calculation of the mean heat transfer coefficient
- calculation of the heat fluxes

## Learning objectives

- function and operational behaviour and different heat exchangers
- plotting temperature curves
  - ▶ in parallel flow mode
  - ▶ in counterflow mode
- calculation of the mean heat transfer coefficient
- comparison of different heat exchanger types



# 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.

Significant efficiency gains can be achieved in heating technology using modern circulation 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 circulation 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 circulation 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 circulation 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.



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

## 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, each room is supplied with the amount of heat required to achieve the desired room temperature at a certain feed flow temperature at the heating system operating point. Hydronic balancing also ensures that the return feeds on all radiators have the same temperature.

## Thermostatic valves for demand-based room heating

Before the widespread introduction of thermostatic valves, the only option for adjusting individual room temperatures was often 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 which 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 as possible to ensure good efficiency.

## Heating system operation under varying heat demand

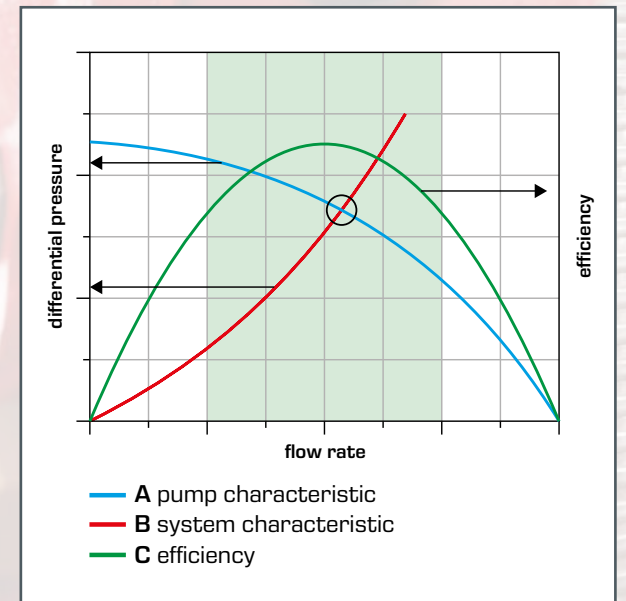
Naturally, the performance capacity of a heating system should cover the maximum heat demand from room heating and hot water supply in winter. Nevertheless, in order to keep year-round energy demand to a minimum, it is essential to create adaptive heating systems for a highly fluctuating energy demand. 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 it 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 circulation 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.

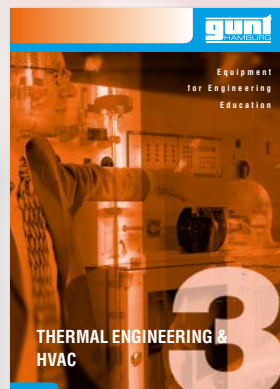
In addition to using efficient components and optimising systems, a key element for the long-term reduction of energy demand is regular monitoring of the proper functioning of the system. Nowadays, modern and inter-linkable heating controllers greatly facilitate system monitoring.



Ideal operating point of a heating system



Checking the system components



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

**Catalogue 3**  
Thermal Engineering  
and HVAC



# HL 305 Hydronic Balancing of Radiators

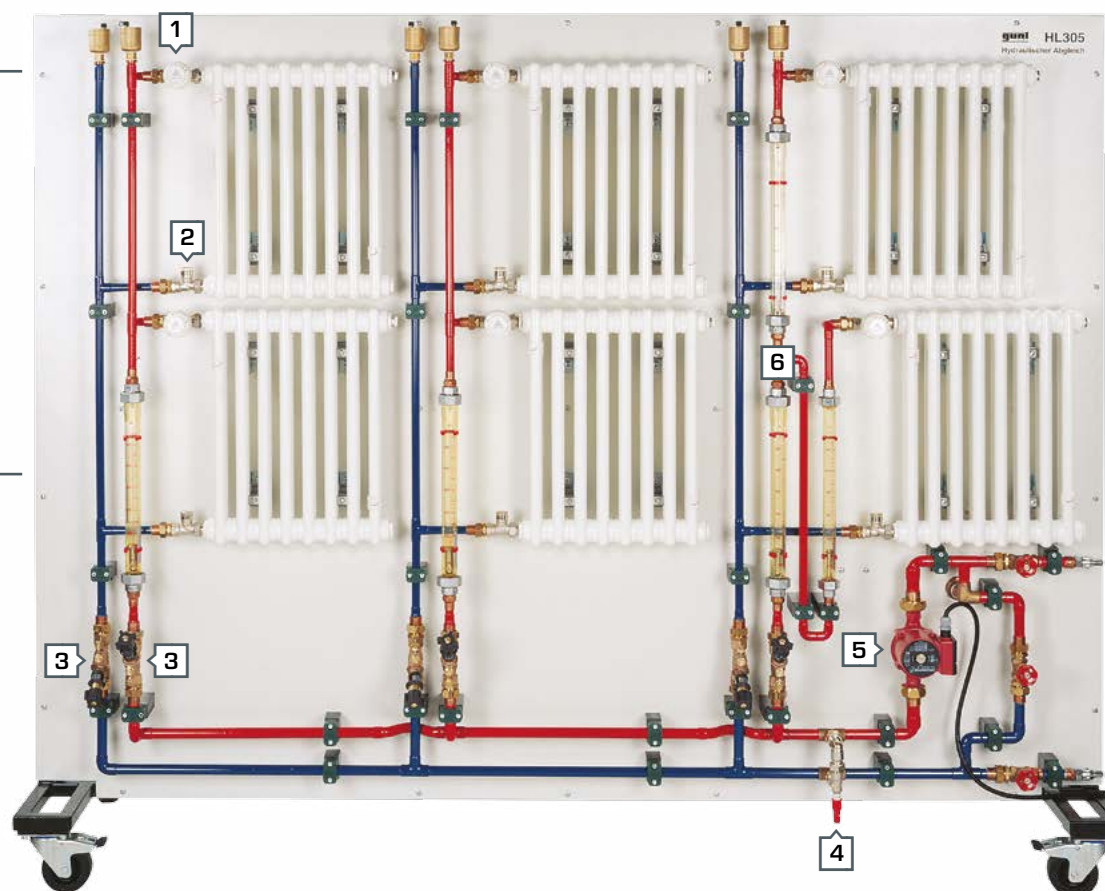
Typical heating problems, most of which are based on an insufficient hydronic balancing, are sometimes incorrectly dealt with even by professionals. The widely-adopted but usually ineffective measures include:

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

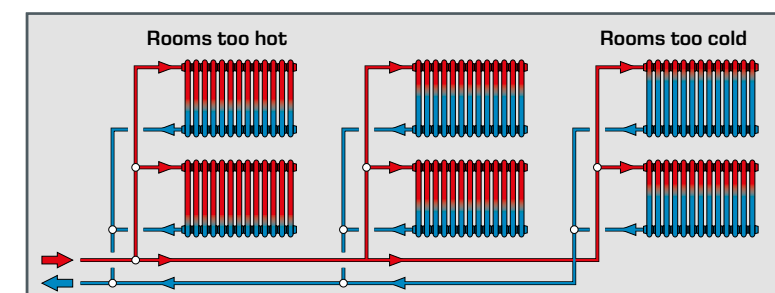
These measures are associated with additional energy losses and thus impair the efficiency of the heating system to a considerable extent. It is estimated that, in Germany, the hydronic balancing of heating systems is inadequate in up to 90% of all cases. The resultant potential for improving energy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

This demonstration unit allows you to teach the 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 circulation pump. The flow rates in all three sections can be adjusted separately. As a result, hydronic balancing of the sub-sections amongst themselves is possible. Within a section, lockshield valves enable separate radiators to be balanced. A differential pressure relief valve is integrated in the circuit parallel to the circulation pump. This valve limits the pressure drop across the piping system to a predetermined range.

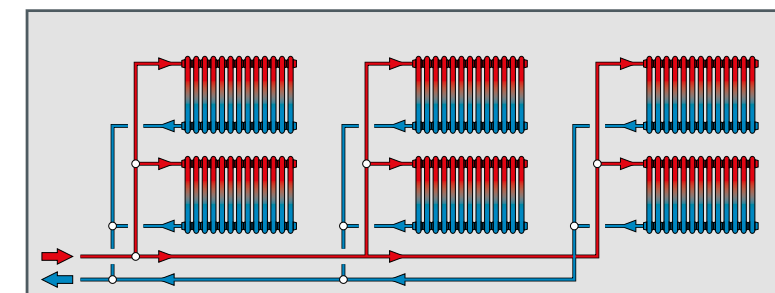
Hydronic balancing is used to limit the amount of water which is available within a heating system for each radiator. The aim is to ensure that, at a specific operating point of the heating system, each room is supplied with exactly the amount of heat needed to achieve the desired room temperature. The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



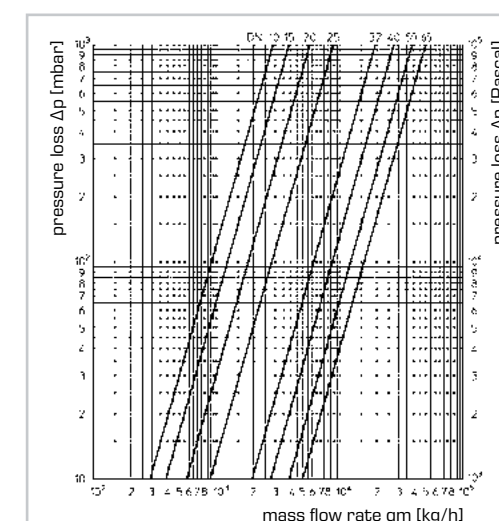
- 1 thermostatic valve
- 2 lockshield valve
- 3 balancing valve
- 4 differential pressure relief valve
- 5 pump
- 6 flow meter



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 valve capacity diagrams included it is possible to determine and carry out the required settings for 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

Product No.  
065.30500  
More details and technical data:  
[gunt.de/static/s3416\\_1.php](http://gunt.de/static/s3416_1.php)

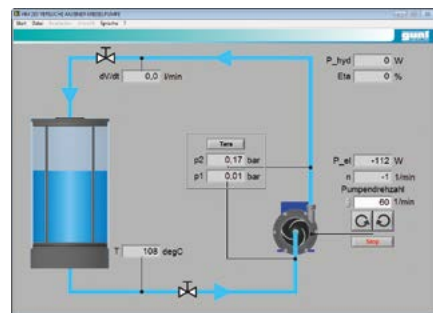




## HM 283

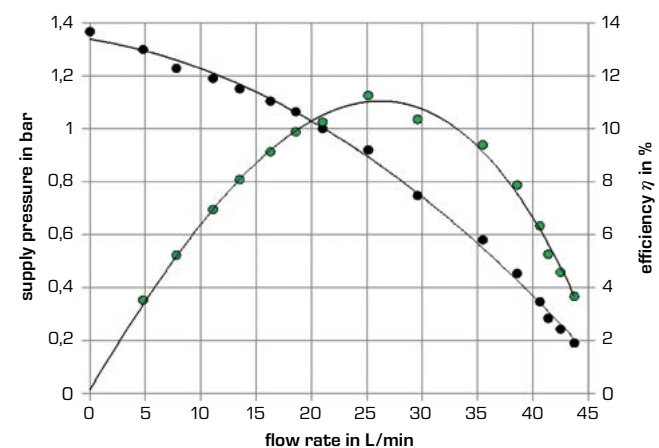
## Experiments with a Centrifugal Pump

Centrifugal pumps are used in many modern heating systems as circulation pumps and can therefore make a significant contribution to energy savings. The efficiency of a centrifugal pump is defined 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 included with HM 283 displays the key measured variables continuously. The logged measured values can be saved for analysis. This supports you while carrying out experiments.



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

## HL 630

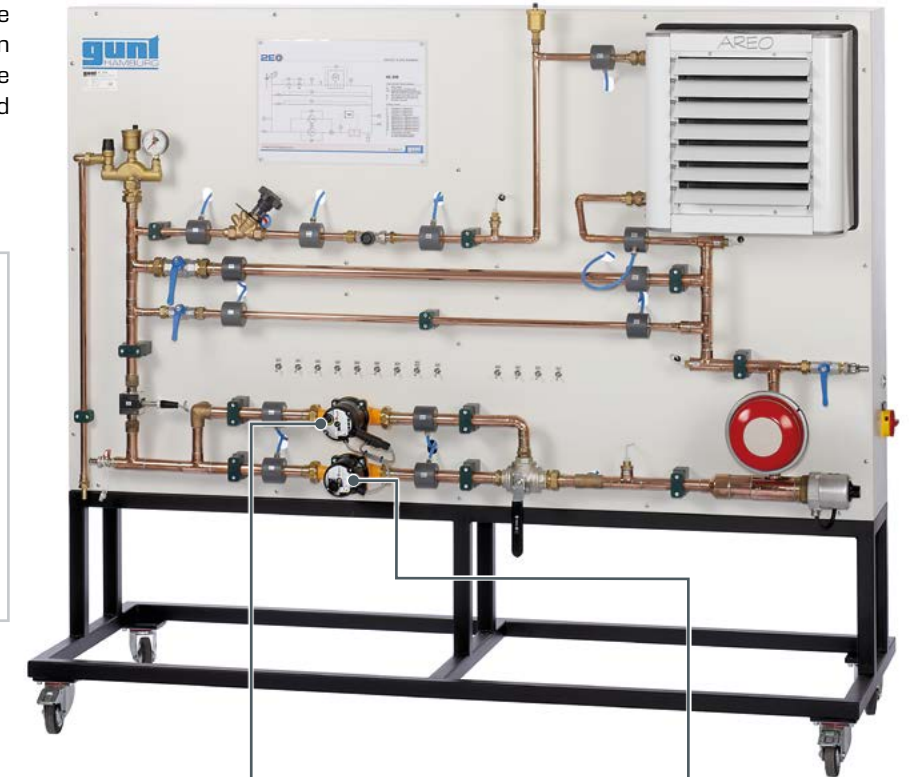
## Efficiency in Heating Technology

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

### Software

The software included with 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.



### Learning objectives

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



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



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

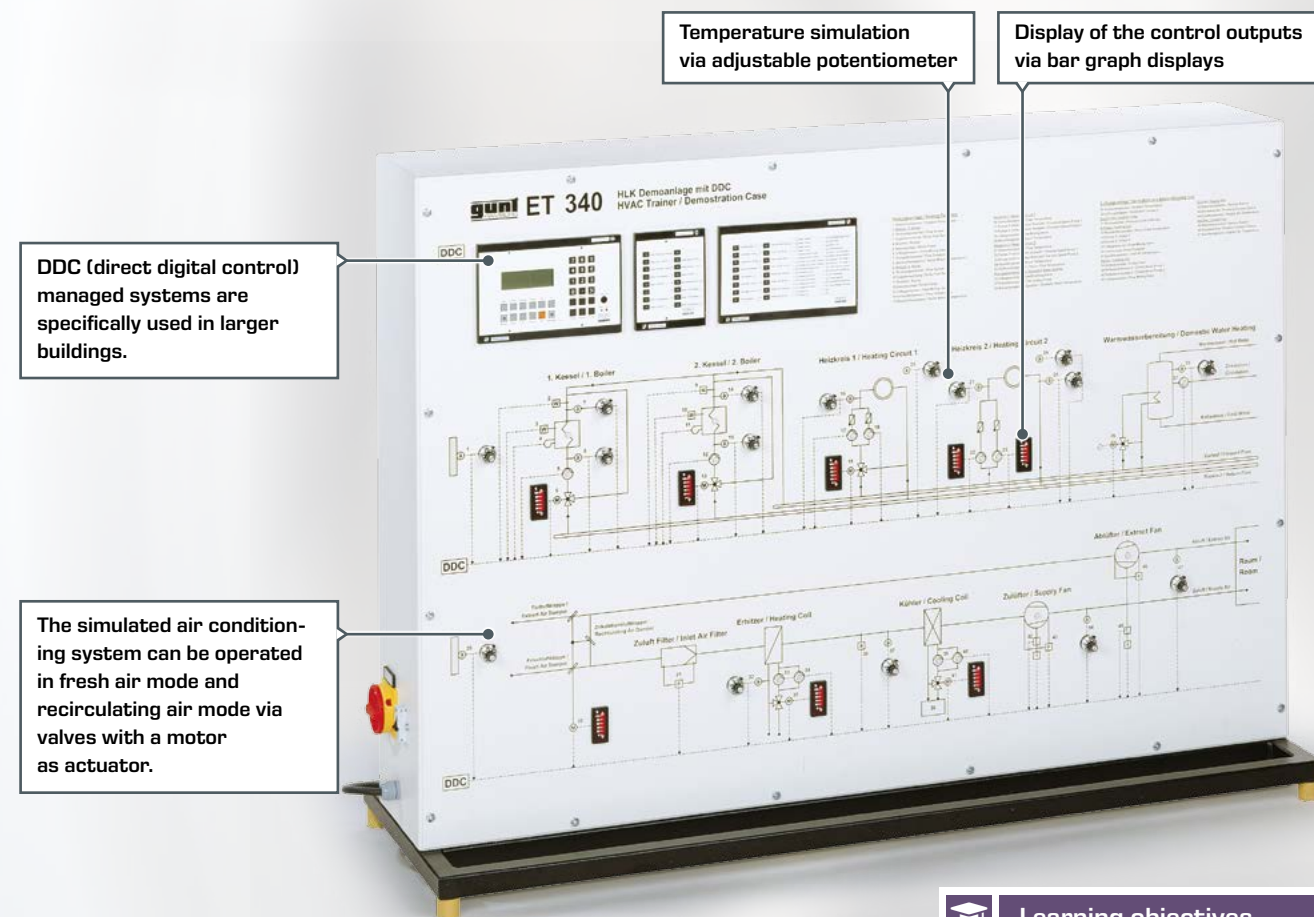




# ET 340 Building Automation in Heating and Air Conditioning Systems

The ET 340 unit allows you to teach the programming of DDC-controlled (Direct Digital Control) heating and ventilation systems. To this end, this trainer simulates a heating circuit with domestic water heating and a ventilation/air conditioning

system with mixed air control. Different operating conditions and control systems can be simulated. Furthermore, it is possible to simulate faults in the system and to observe the system's resulting behaviour.



DDC (direct digital control) managed systems are specifically used in larger buildings.

The simulated air conditioning system can be operated in fresh air mode and recirculating air mode via valves with a motor as actuator.

## Software

In addition to manually operating the controller, the DDC's configuration software allows you to create and save modified or new controller programs.

Product No.  
061.34000  
More details and technical data:  
[gunt.de/static/s3237\\_1.php](http://gunt.de/static/s3237_1.php)



## Learning objectives

- operation and programming of a DDC
- effects of temperature changes on the operating behaviour of a
  - heating system
  - air conditioning system
- fault finding in a
  - heating system
  - air conditioning system
- safety devices

# 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.

The device consists of an inner unit and an outer unit. The inner unit includes a heat exchanger with fan, which acts as an evaporator in the refrigeration circuit in cooling mode. In 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).



Heat flux in cooling mode

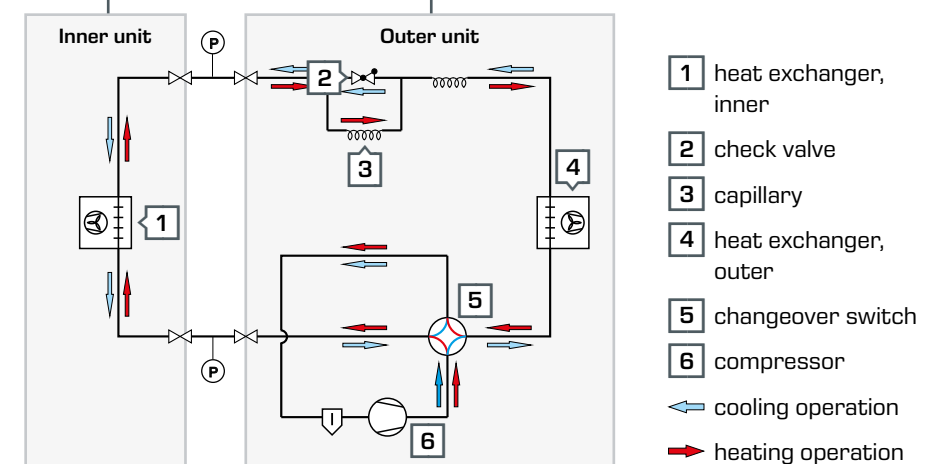
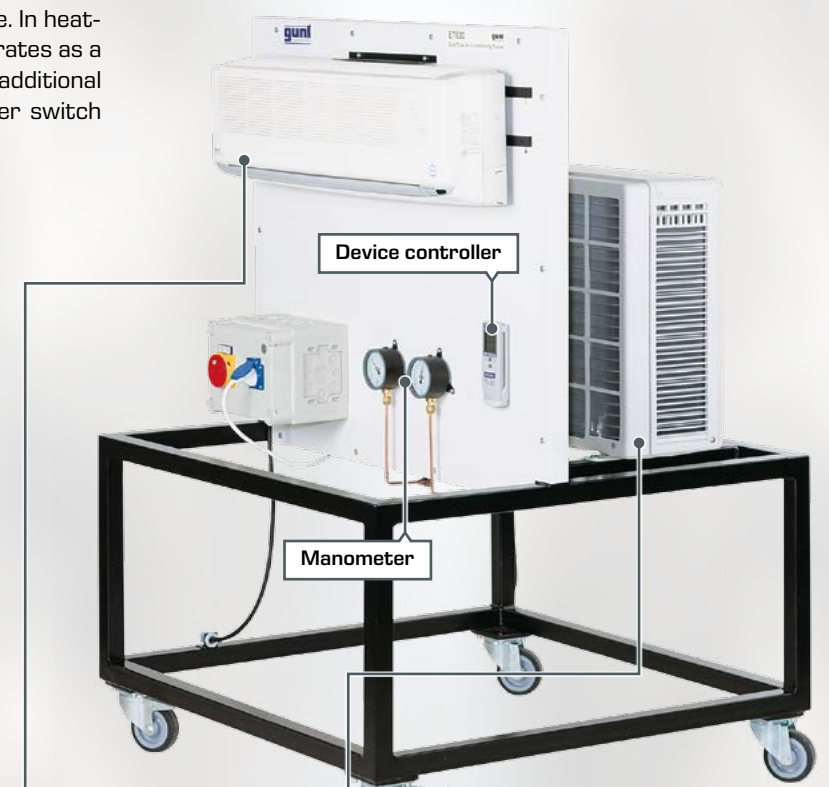
## Learning objectives

- 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 outlet, timer for switching on and off
- system control by remote control

Product No.  
061.63000  
More details and technical data:  
[gunt.de/static/s3469\\_1.php](http://gunt.de/static/s3469_1.php)



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



Schematic representation of the ET 630



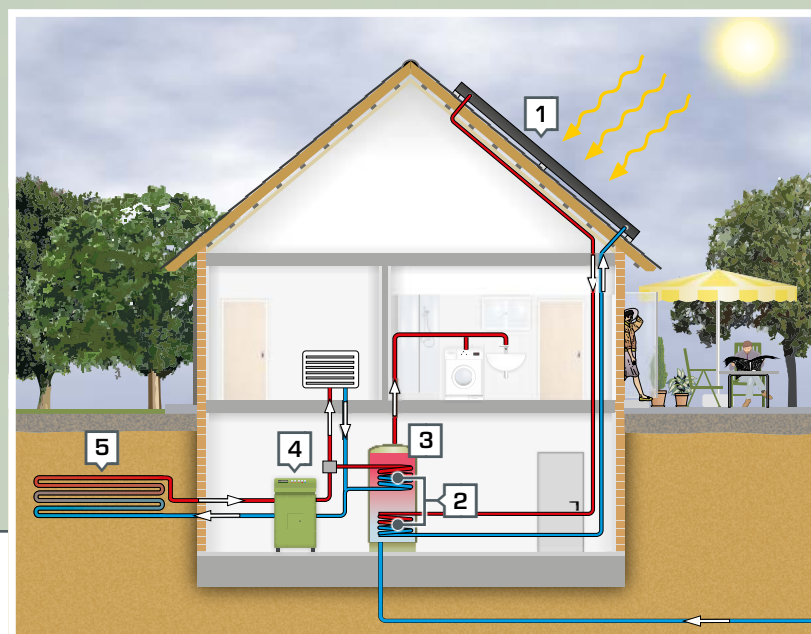
# Subject Areas Inclusion of Renewable Energies



## Subject Areas

## 2E Products

Our HL 320 modular system covers essential Subject Areas 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 energy absorber

## HL 320 Solar Thermal Energy and Heat Pump Modular System

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 Plate 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



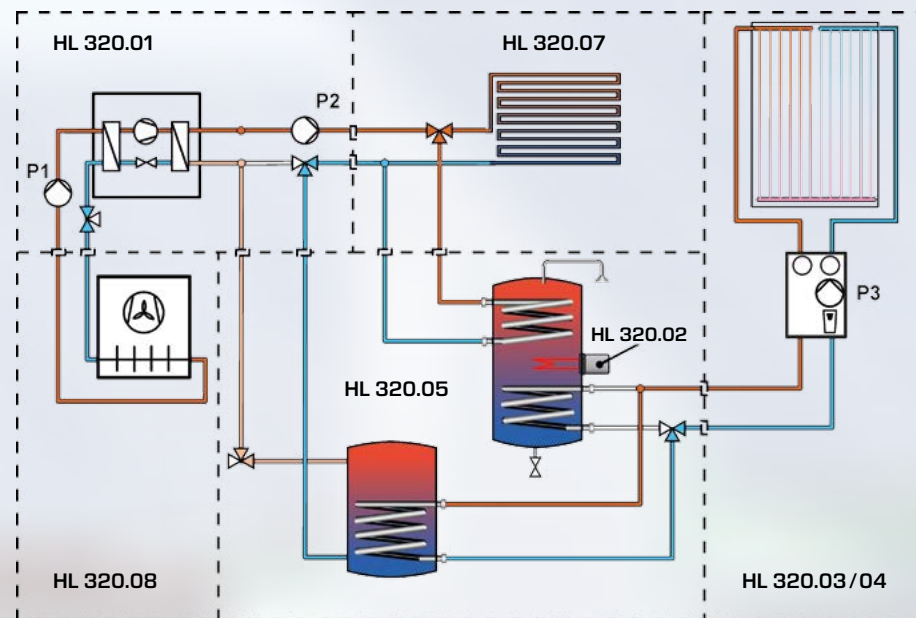
# HL 320

## Solar Thermal Energy and Heat Pump Modular System



### The right configuration for every application

In heating technology, both correct composition of necessary components and 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 diagram 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 |
|---------------------------------------------------------------------|---|---|---|---|---|
| <b>HL 320.01</b><br>Heat Pump                                       |   |   |   |   |   |
| <b>HL 320.02</b><br>Conventional Heating                            |   |   |   |   |   |
| <b>HL 320.03</b><br>Flat Plate Collector                            |   |   |   |   |   |
| <b>HL 320.04</b><br>Evacuated Tube Collector                        |   |   |   |   |   |
| <b>HL 320.05</b><br>Central Storage Module with Controller          |   |   |   |   |   |
| <b>HL 320.07</b><br>Underfloor Heating / Geothermal Energy Absorber |   |   |   |   |   |
| <b>HL 320.08</b><br>Fan Heater / 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
- parameterisation of a heat pump controller
- factors influencing the COP (Coefficient of Performance)

#### Combination 4

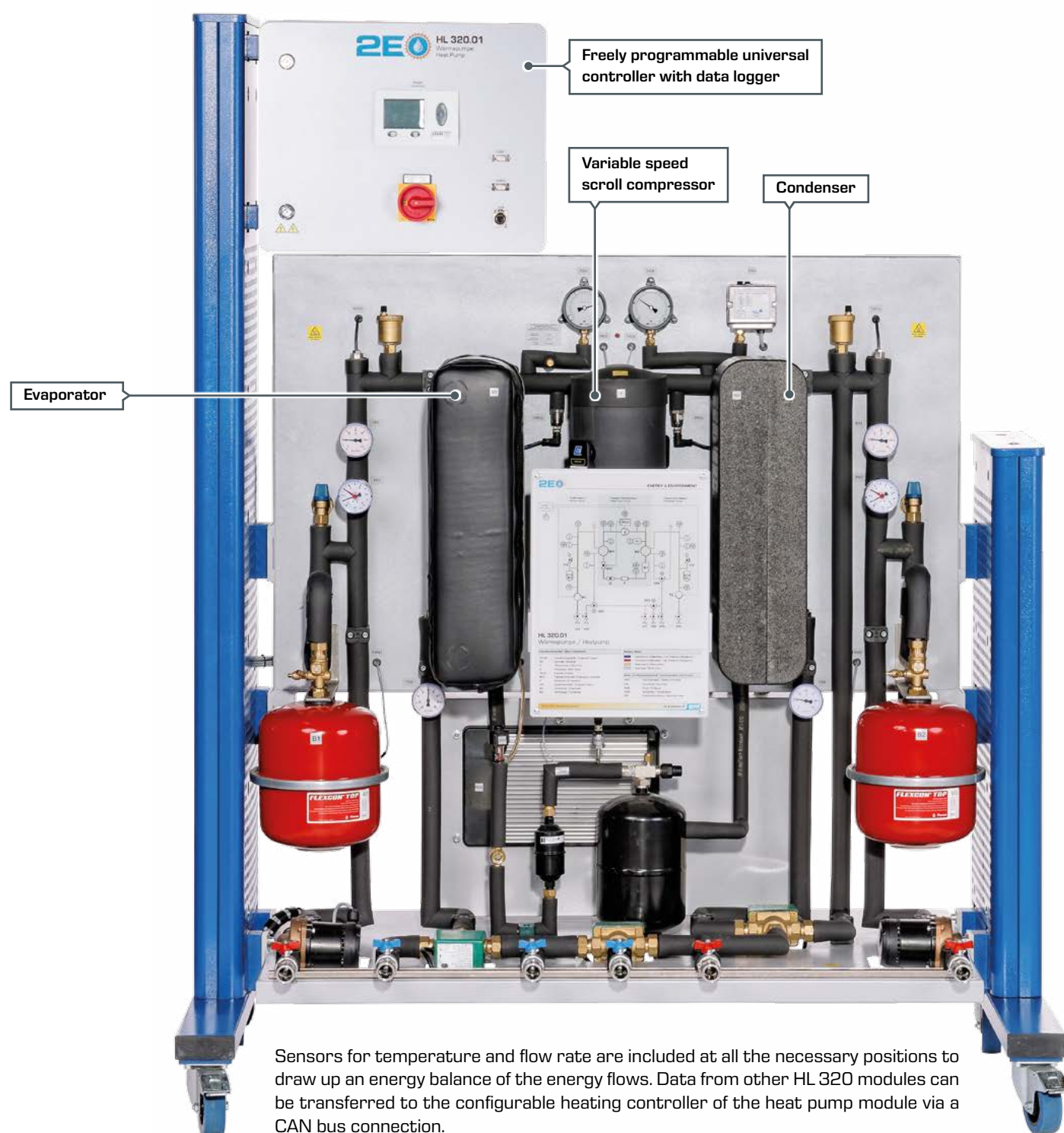
- efficient use of solar thermal and geothermal energy
- strategies for heat supply in various consumption profiles

#### Combination 5

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



# HL 320.01 Heat Pump

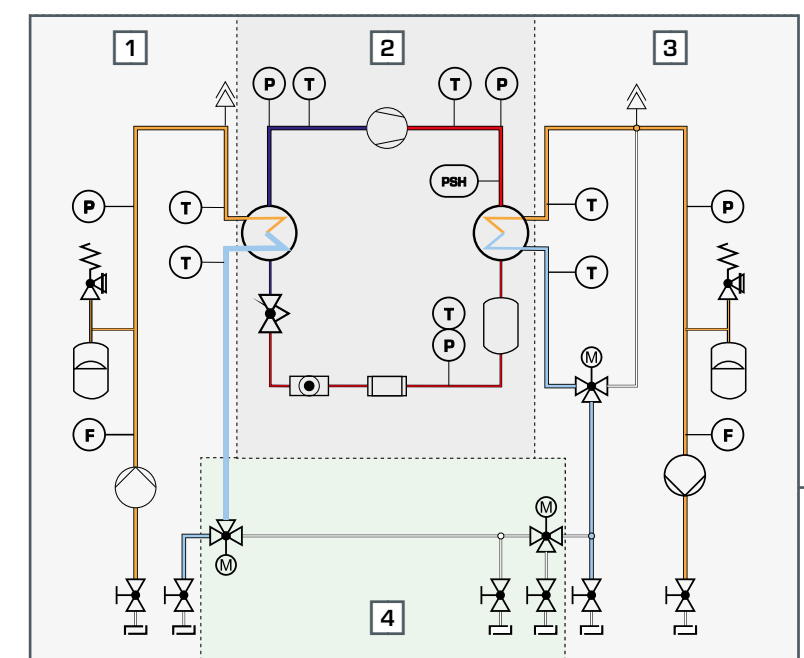


Sensors for temperature and flow rate are included at all the necessary positions to draw up an energy balance of the energy flows. Data from other HL 320 modules can be transferred to the configurable heating controller of the heat pump module via a CAN bus connection.

Product No.  
065.32001  
More details and technical data:  
[gunt.de/static/s5360\\_1.php](http://gunt.de/static/s5360_1.php)



The HL320.01 Heat Pump is part of the HL320 modular system and provides you with a variety of combination options from 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 heating system demand.



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

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.



Fixed and movable spirals of a scroll compressor

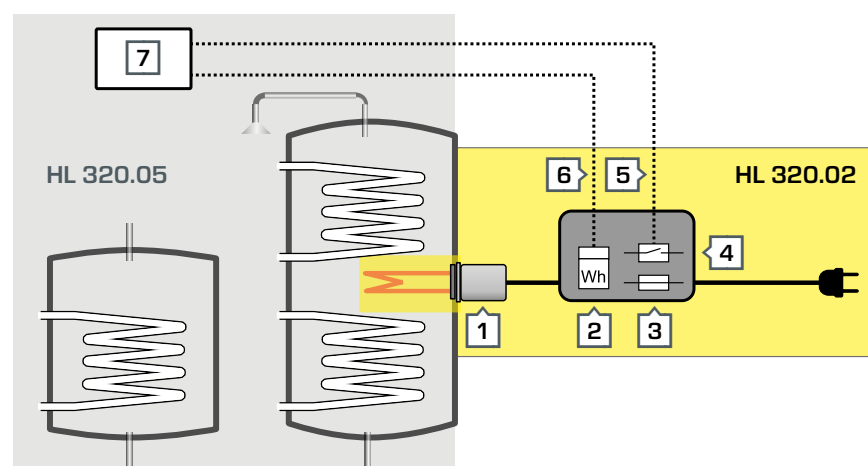
| Learning objectives                                                                                                                                                                                                                                                       |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>■ function and design of a heat pump</li> <li>■ distinguishing different operating conditions</li> <li>■ factors influencing the COP (coefficient of performance)</li> <li>■ parameterisation of a heat pump controller</li> </ul> |



## 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 Central 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 Central 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 contactor and controller output
- 6 connection between energy meter and controller input
- 7 HL 320.05 module's controller

Product No.  
065.32002  
More details and technical data:  
[gunt.de/static/s5364\\_1.php](http://gunt.de/static/s5364_1.php)



### Learning objectives

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



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

## HL 320.03 Flat Plate 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 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.



Product No.  
065.32003  
More details and technical data:  
[gunt.de/static/s5285\\_1.php](http://gunt.de/static/s5285_1.php)



### Learning objectives

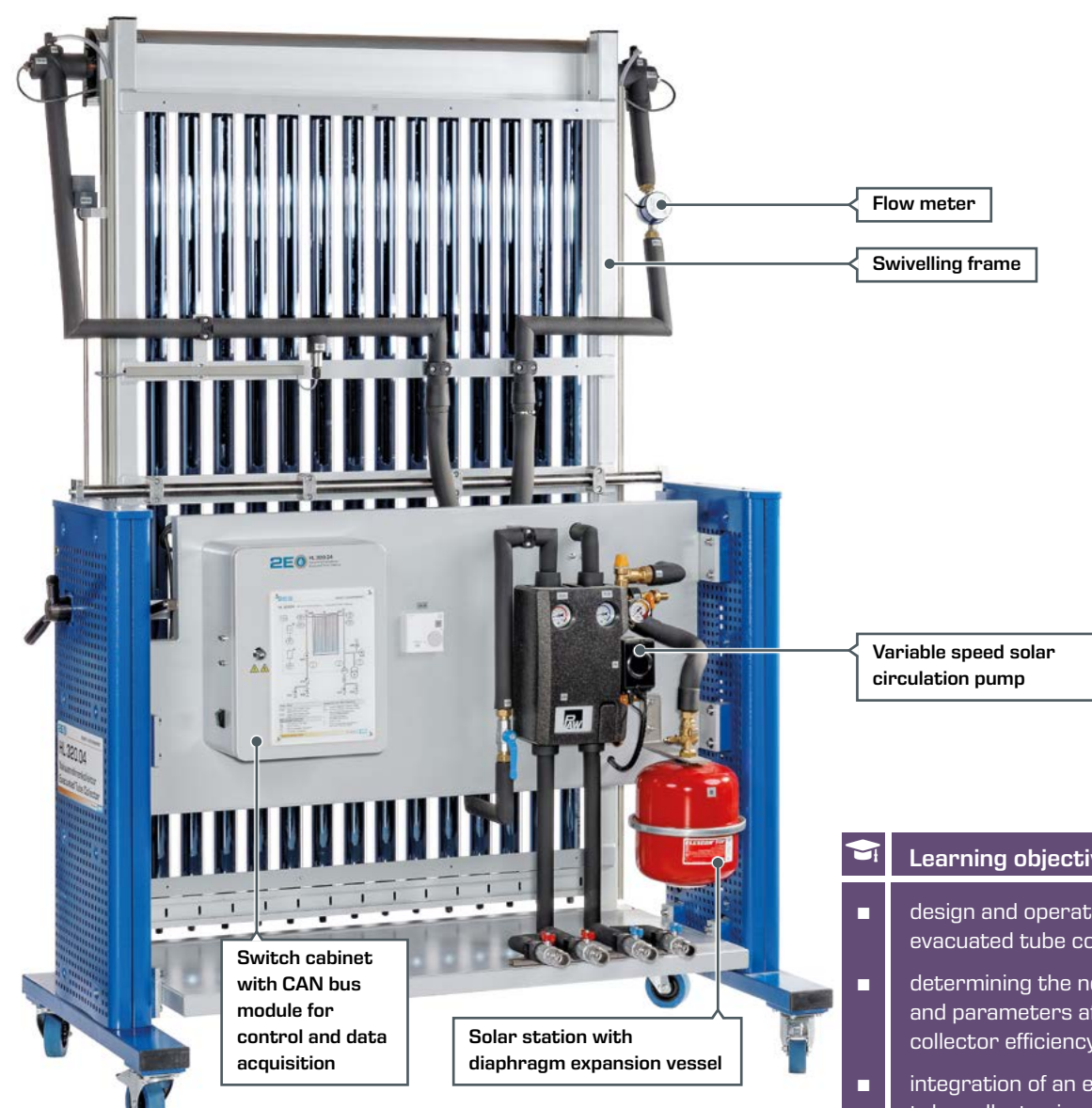
- determining the net power
- how temperature, illuminance and angle of incidence affect the collector efficiency
- integration of a flat collector in a modern heating system
- hydraulic and control engineering operating conditions
- energy balances
- optimisation of operating conditions for different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



# 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 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.



Product No.  
065.32004  
More details and technical data:  
[gunt.de/static/s5287\\_1.php](http://gunt.de/static/s5287_1.php)



- 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

# HL 320.05 Central Storage Module with Controller

The HL 320.05 Central Storage Module with Controller 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 hydraulic connections to other modules in 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.



Product No.  
065.32005  
More details and technical data:  
[gunt.de/static/s5289\\_1.php](http://gunt.de/static/s5289_1.php)



- 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 solar station with different operating modes



# HL 320.05 Central Storage Module with Controller

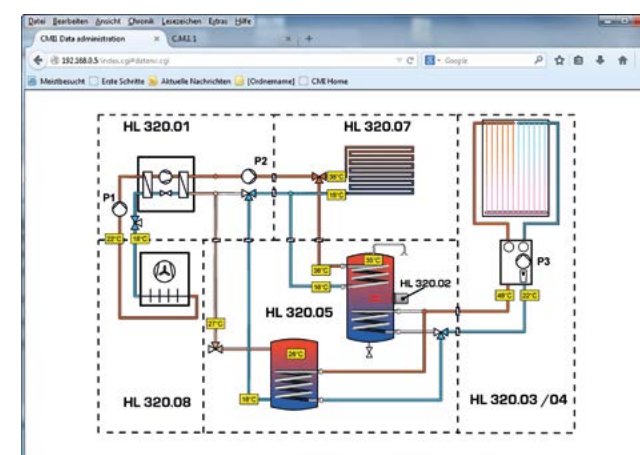


- 1 freely programmable heating controller with data logger
- 2 ports for CAN bus and network
- 3 process schematic
- 4 buffer storage
- 5 heat exchanger
- 6 3-way change-over valve
- 7 circulation pump
- 8 bivalent storage

Product No.  
065.32005  
More details and technical data:  
[gunt.de/static/s5289\\_1.php](http://gunt.de/static/s5289_1.php)



The HL 320.05 Central Storage Module with Controller can be connected to the HL 320 modular system in a variety of ways using 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

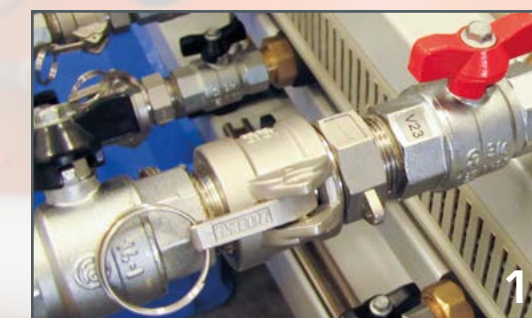
The controller is controlled and data acquired via a network module to a PC. Current system data can be represented in a diagram, for example. This representation can be called up on any current web browser.



Hochschule für  
Wirtschaft und Recht Berlin  
Berlin School of Economics and Law

At the Berlin School of Economics and Law, HL 320.05 is used in conjunction with HL 320.03 and HL 313.01 for experiments in the field of renewable energies.

## 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).



# HL 320.07 Underfloor Heating/ Geothermal Energy Absorber

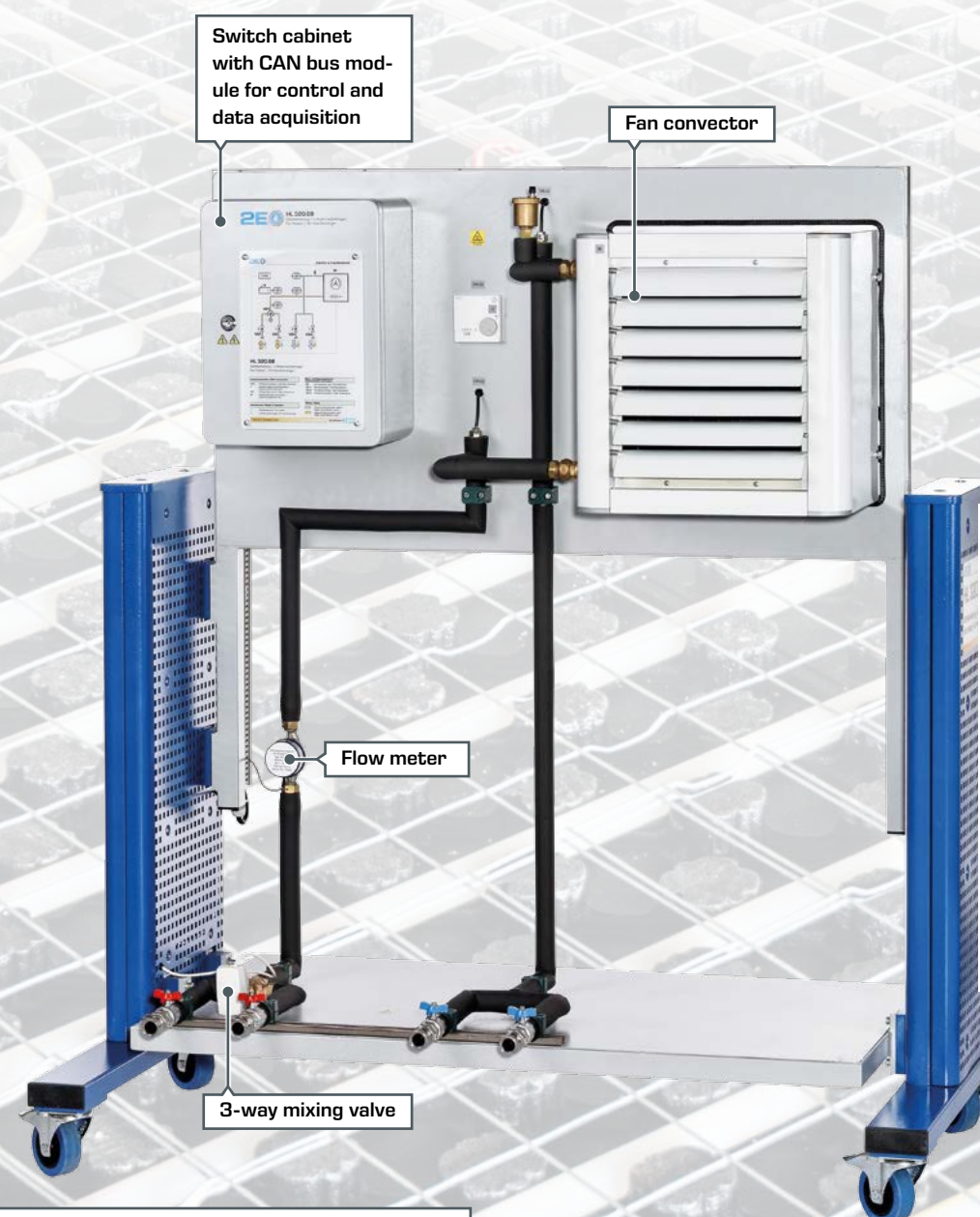
Underfloor heating systems transfer heat through piping systems arranged in a spiral or winding pattern underneath the floor covering. Underfloor heating requires much lower feed flow temperature than conventional radiators. Besides its function as a heat sink when used as an underfloor heating system, HL320.07 can also be used as a heat source for a heat pump in the HL320 modular system. In this case, the direction of the heat transport is reversed. HL320.07 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.

# HL 320.08 Fan Heater/ Air Heat Exchanger

When heating rooms, fan heaters offer the possibility of achieving a comparatively good transfer of heat to the room air compared to traditional heating radiators, 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**
- energy balance in combined heating systems for domestic hot water production and heating
  - heat transfer in an underfloor heating system
  - use of heat sources for heat pump systems

- Learning objectives**
- how the temperature difference between the 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

Product No.  
065.32007  
More details and technical data:  
[gunt.de/static/s5291\\_1.php](http://gunt.de/static/s5291_1.php)



Product No.  
065.32008  
More details and technical data:  
[gunt.de/static/s5362\\_1.php](http://gunt.de/static/s5362_1.php)





# Subject Areas

## Energy Efficiency in Business and Industry



### Subject Areas

### 2E Products

In business and industry, measures to improve energy efficiency are connected to both the optimisation of building services engineering and to the relevant value creation processes. Close integration of these two areas often results in novel approaches to improving energy efficiency. For example, 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 a 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 our standard product range, in addition to our 2E devices.

#### Energy efficiency in refrigeration technology

##### 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 Technology



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 of the use of waste heat for cold production in absorption refrigeration systems, for example.

## Measures to improve energy efficiency

In refrigeration technology the implementation of energy-efficient concepts for refrigerating plants is often associated with increased investment costs. In 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 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 2020.



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.



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.

## 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 sufficient cold storage. Integration into the energy management system of the entire building should also be considered alongside an intelligent control system.

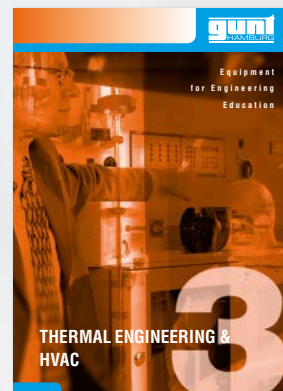


Goods often have to be stored in refrigeration for a long time, and not only in the food sector. Substantial savings in energy consumption are also possible even with low efficiency gains, due to the required continuous operation of refrigerating plants.

## 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
- deep freeze -15°C ... -30°C
- shock freezing -35°C ... -50°C



Many of the fundamental themes of refrigeration technology are also covered by a wide selection of educational systems from our catalogue 3.

**Catalogue 3**  
Thermal Engineering and HVAC

## 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.

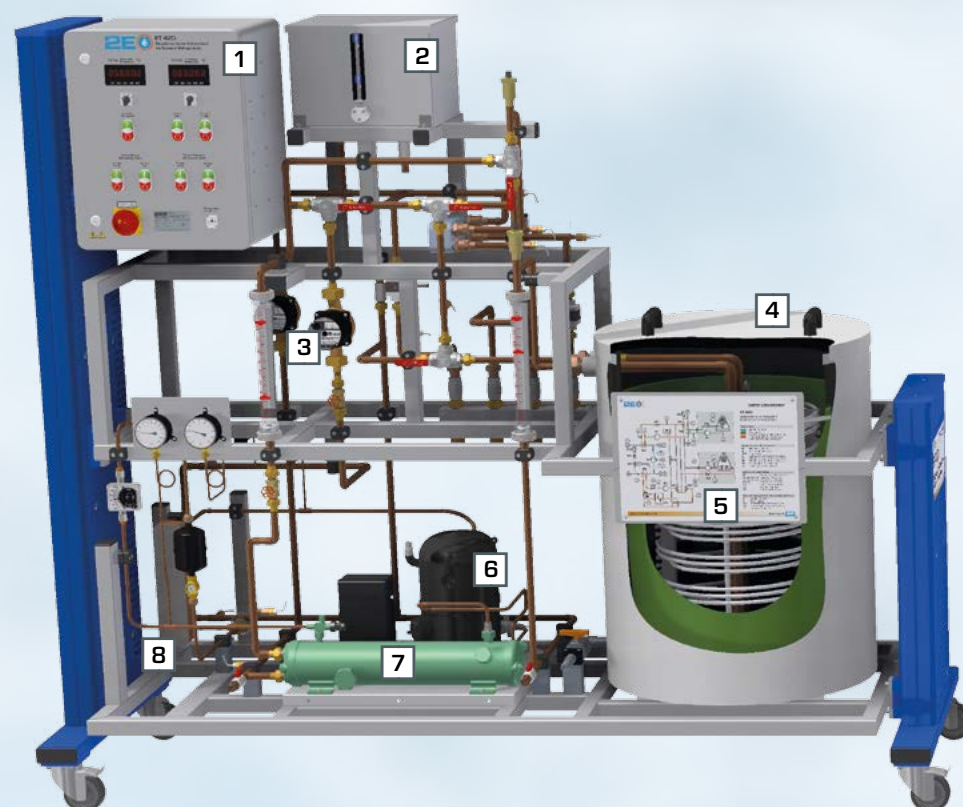


# ET 420 Ice Stores in Refrigeration

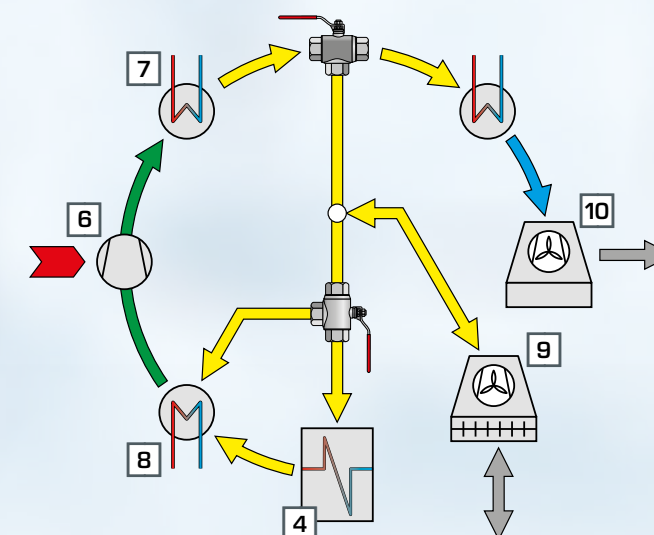
The ET 420 experimental unit provides you with a refrigerating plant with two cooling towers and an ice store. The advantage of this ice store is the higher peak load, without the need for a larger refrigerating plant. The refrigerating plant may also be operated at the optimal operating point all the time. The

ice store is charged during the night when cooling demand is lower, and discharged during the day as additional refrigeration capacity. You can adjust the different operating modes with the experimental unit and demonstrate the direct increase in efficiency with ice stores.

| Learning objectives                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>design and operation of an energy-efficient refrigeration system</li> <li>function and operation of an ice store           <ul style="list-style-type: none"> <li>charge</li> <li>discharge</li> </ul> </li> <li>energy flow balance</li> <li>energy transport via different media</li> <li>compression refrigeration cycle in the log p-h diagram</li> <li>function and operation of a wet cooling tower</li> <li>function and operation of a dry cooling tower</li> </ul> |



System components with efficiency gain



- |                          |                      |
|--------------------------|----------------------|
| 1 switch cabinet         | glycol-water mixture |
| 2 storage tank           | water                |
| 3 circulation pumps      | refrigerant          |
| 4 ice store              | air                  |
| 5 process schematic      | electrical power     |
| 6 refrigerant compressor |                      |
| 7 refrigerant condenser  |                      |
| 8 refrigerant evaporator |                      |
| 9 dry cooling tower      |                      |
| 10 wet cooling tower     |                      |



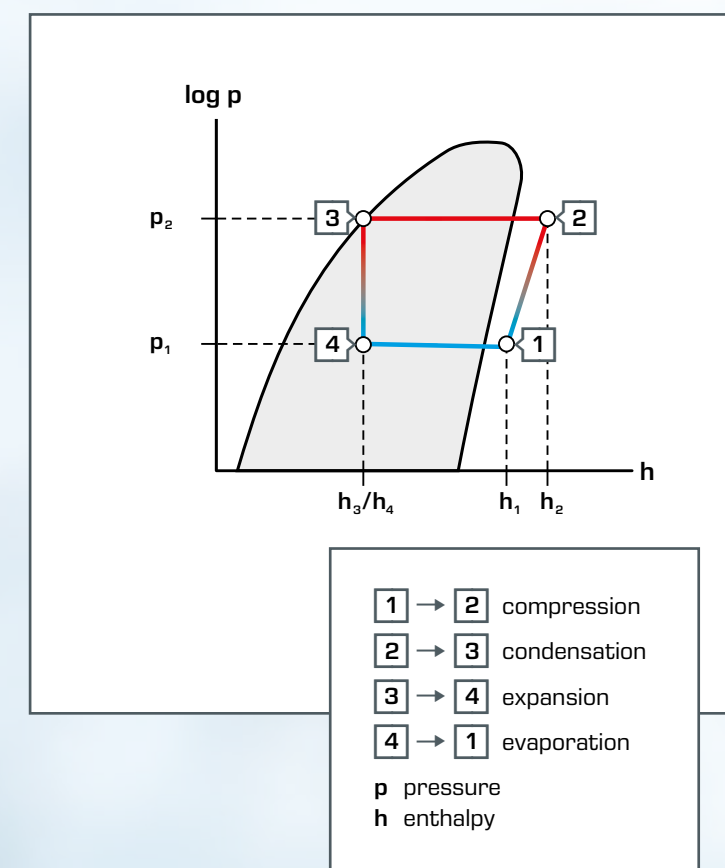


# ET 428 Energy Efficiency in Refrigeration Systems

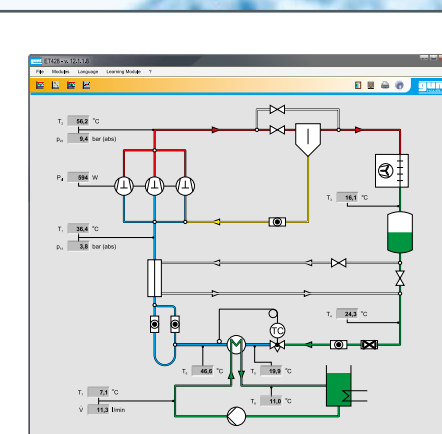
The efficient use of energy in refrigeration technology is an important contribution to a sustainable energy supply. In order to ensure energy-efficient operation even when power demand is high, small compressors are connected in parallel in industry. The optimal adaptation to the power demand is achieved 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 cycle is equipped with a combined pressure switch for the pressure and intake sides. To ensure a reliable 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.



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.

## 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 thermodynamic cycle in the log p-h diagram





# Basic Knowledge

## Process Engineering and Building Services Engineering



The implementation of energy-efficient concepts is much easier if they can be incorporated into the planning of production at an early stage.

### 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 gained from projects implemented to date. 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 extensive experiments are usually required in order to simultaneously maintain the same product quality.

### 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 of 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

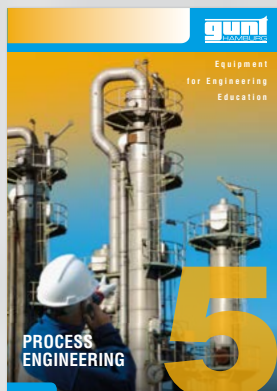
Efficient control systems are needed in order to meet all the requirements, alongside a possibility for heat recovery. What effects are possible, such as changes in the control parameters, can be studied using our RT 682 trainer.



Large-scale stirred tanks



Detecting and measuring the energy flows is a prerequisite for the optimisation of existing plants.



Many of the fundamental themes of process engineering are also covered by a wide selection of educational systems from our catalogue 5.

**Catalogue 5**  
Process Engineering



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.

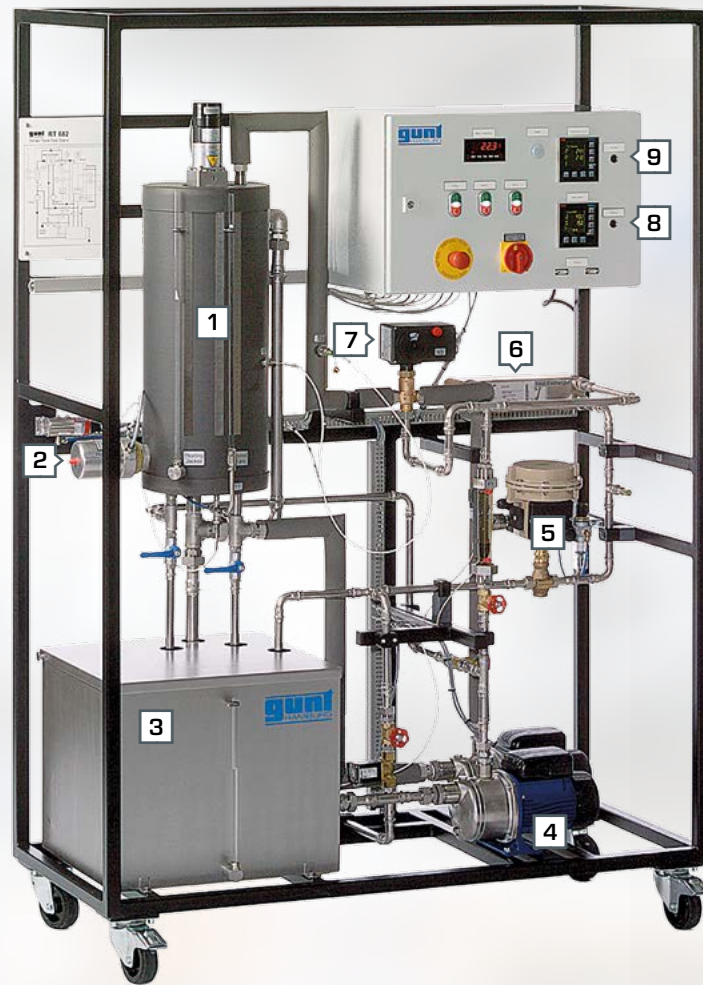
Naturally, limiting a given flow rate through a valve or fitting is associated with a pressure drop and thus with a loss of hydraulic power. If the only aim is to adjust the flow rate through a main pipe, it is for example more energy efficient to use a pump with an adjustable flow rate. In branched 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

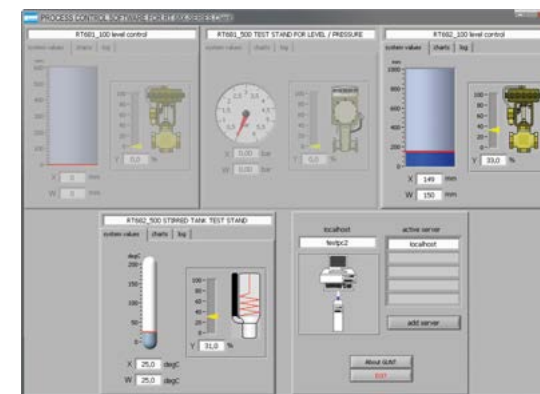
- 1 stirred tank
- 2 heater
- 3 collection tank
- 4 pumps
- 5 level control valve
- 6 heat exchanger
- 7 3-way motorised valve
- 8 level controller
- 9 temperature controller



In process engineering, 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 room 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 for increasing energy efficiency is in-process heat recovery. For example, this could be implemented by using the still-warm products to preheat the input materials. The modified plant behaviour has to be adapted for the production process using 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 mode
- how a programmer works
- networking with server/client
- control panel function with both trainers connected

If you require a Profibus card, this can be ordered using product number 080.65012.

Product No.  
080.68200  
More details and technical data:  
[gunt.de/static/s3335\\_1.php](http://gunt.de/static/s3335_1.php)



Product No.  
080.65060  
More details and technical data:  
[gunt.de/static/s4589\\_1.php](http://gunt.de/static/s4589_1.php)



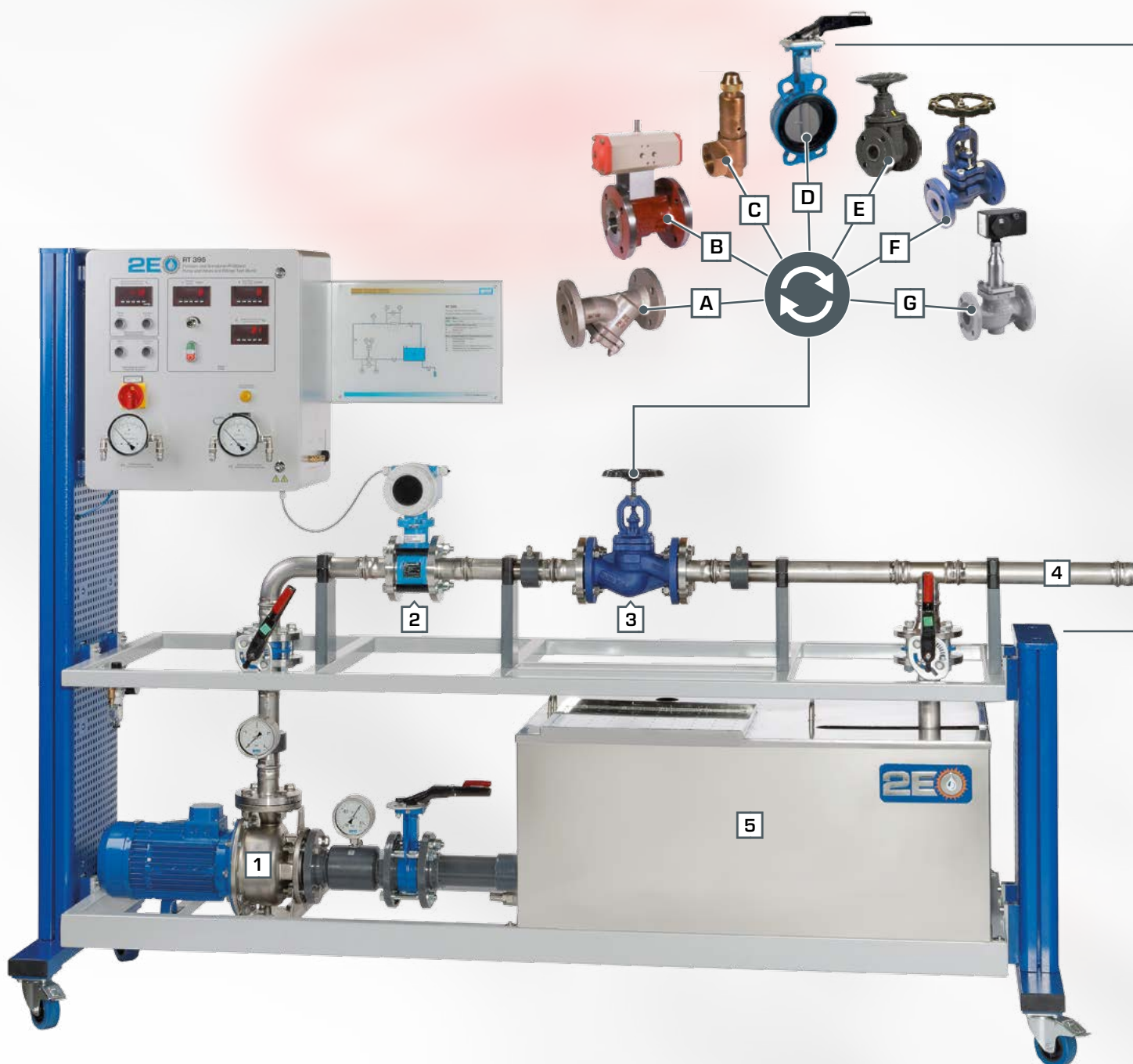
## Learning objectives

- coupled level and temperature control
- level control with
  - ▶ PI controller
  - ▶ disturbance feedforward control
- temperature control
  - ▶ with two-point controller
  - ▶ with three-point controller (split range)
  - ▶ with override control
  - ▶ via motorised valve with position feedback
- plotting step responses



# RT 396

## Pump and Valves and Fittings Test Stand

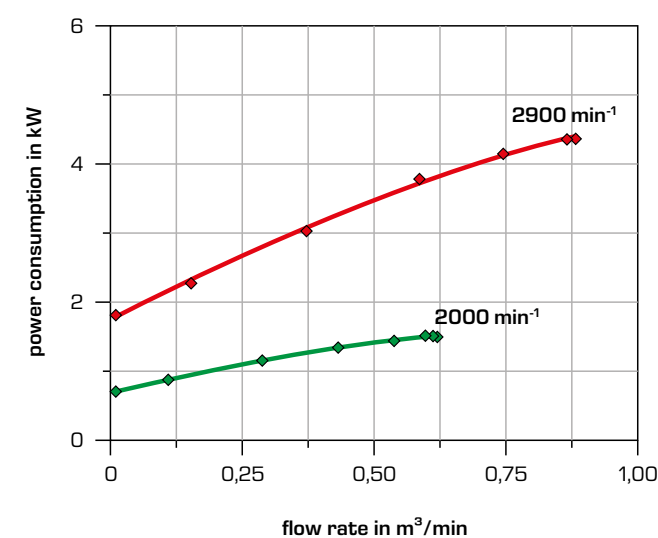


- A dirt trap
- B ball valve
- C safety valve
- D butterfly valve
- E wedge gate valve
- F shut-off valve
- G control valve

- 1 pump
- 2 flow rate sensor
- 3 interchangeable valve or fitting
- 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 functional 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. 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.

| Learning objectives |                                                                                                                                                                                                                                                                  |
|---------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ■                   | behaviour during operation and function of <ul style="list-style-type: none"> <li>▶ ball valve</li> <li>▶ butterfly valve</li> <li>▶ shut-off valve</li> <li>▶ wedge gate valve</li> <li>▶ control valve</li> <li>▶ safety valve</li> <li>▶ dirt trap</li> </ul> |
| ■                   | determining the Kvs value of the control valve                                                                                                                                                                                                                   |
| ■                   | pressure losses at the dirt trap depending on the filter and its load                                                                                                                                                                                            |
| ■                   | reading and understanding engineering drawings and operating instructions                                                                                                                                                                                        |



Power consumption of the centrifugal pump at different speeds





# Energy Efficiency in other Programme Areas from GUNT

Given the issue of resources and climate, the topic of energy efficiency is essentially vital for all areas of engineering education. Even if, for example, the analysis of energy flows and transformation processes in the field of engineering mechanics is usually not discussed explicitly, the fundamental learning objectives of this subject area is often crucial to the development of energy-efficient methods or materials.

A typical example from engineering mechanics and mechatronics is the minimisation of friction losses in bearings. Many other aspects of energy efficiency arise in the field of mechatronics, for example in the areas of automation and machine condition monitoring.

It is beyond the scope of this overview to show all possible references from the context of our other programme areas on the topic of energy efficiency. Rather, we would like to present a brief summary of catalogues 1 to 5 as an incentive for your own considerations.



## Catalogue 1

### Engineering Mechanics and Machine Elements

- Statics
- Strength of Materials
- Dynamics
- Fundamentals of Engineering Design
- Machinery Diagnosis
- Properties of Materials



## Catalogue 2

### Mechatronics

- Engineering Drawing
- Cutaway Models
- Dimensional Metrology
- Fasteners and Machine Parts
- Manufacturing Engineering
- Assembly Projects
- Maintenance
- Machinery Diagnosis
- Automation



## Catalogue 3

### Thermal Engineering and HVAC

- Fundamentals of Thermodynamics
- Applied Thermodynamics
- Renewable Energies
- Power Engines and Machines
- Internal Combustion Engines
- Refrigeration and Air Conditioning Technology
- Heating and Ventilation in Buildings
- Sanitary Systems



## Catalogue 4

### Fluid Mechanics

- Fundamentals of Fluid Mechanics
- Steady Flow
- Flow around Bodies
- Examples of Transient Flow
- Hydraulic Fluid Energy Machines
- Components in Piping Systems and Plant Design
- Fluidic Experimental Plants
- Hydraulics for Civil Engineering
- Fluid Energy Machines



## Catalogue 5

### Process Engineering

- Fundamentals of Control Engineering
- Components and Calibration
- Simple Process Engineering Control Systems
- Complex Process Engineering Control Systems
- Fundamentals of Process Engineering
- Mechanical Process Engineering
- Thermal Process Engineering
- Chemical Process Engineering
- Biological Process Engineering
- Water Treatment



# Planning your Laboratory for the Field of Renewable Energies

We have put together a series of teaching systems from the 2E area for planning your renewable energy laboratory and will work out a proposal for you for a placement which is suitable for your applications. We are available for any requests, questions and suggestions you may have.

Access to an outdoor area for optional experiments in the fields of solar energy and wind energy (ET 250, HL 320.04, ET 220.01). Weather-independent experiments can be ensured with both ET 220 and HL 313.01.

- ET 220 Energy Conversion in a Wind Power Plant
- ET 220.01 Wind Power Plant
- ET 250 Solar Module Measurements
- ET 255 Using Photovoltaics: Grid connected or Stand-alone
- ET 292 Fuel Cell System
- HL 313.01 Artificial Light Source
- HL 320.01 Heat Pump
- 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 Heater/Air Heat Exchanger
- HM 150 Base Module for Experiments in Fluid Mechanics
- HM 150.19 Operating Principle of a Pelton Turbine
- HM 150.20 Operating Principle of a Francis Turbine



2E a division of



## Contents: Part 2

|            |                                                                               |     |
|------------|-------------------------------------------------------------------------------|-----|
|            | <b>Basic Knowledge</b><br>Sustainable Technology for Environmental Protection | 234 |
|            | <b>Subject Areas</b><br>Sustainable Technology for Environmental Protection   | 236 |
| <b>2.1</b> | <b>Water</b>                                                                  | 238 |
|            | Mechanical Water Treatment                                                    | 244 |
|            | Biological Water Treatment                                                    | 252 |
|            | Physical/Chemical Water Treatment                                             | 264 |
|            | Multi-Stage Water Treatment                                                   | 276 |
| <b>2.2</b> | <b>Air</b>                                                                    | 282 |
|            | Mechanical Processes                                                          | 288 |
|            | Thermal Processes                                                             | 290 |
| <b>2.3</b> | <b>Soil</b>                                                                   | 294 |
|            | Hydrogeology                                                                  | 298 |
|            | Soil Treatment                                                                | 308 |
| <b>2.4</b> | <b>Waste</b>                                                                  | 314 |
|            | Comminution                                                                   | 320 |
|            | Separation Processes                                                          | 322 |



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[www.gunt2e.de](http://www.gunt2e.de)





# Basic Knowledge

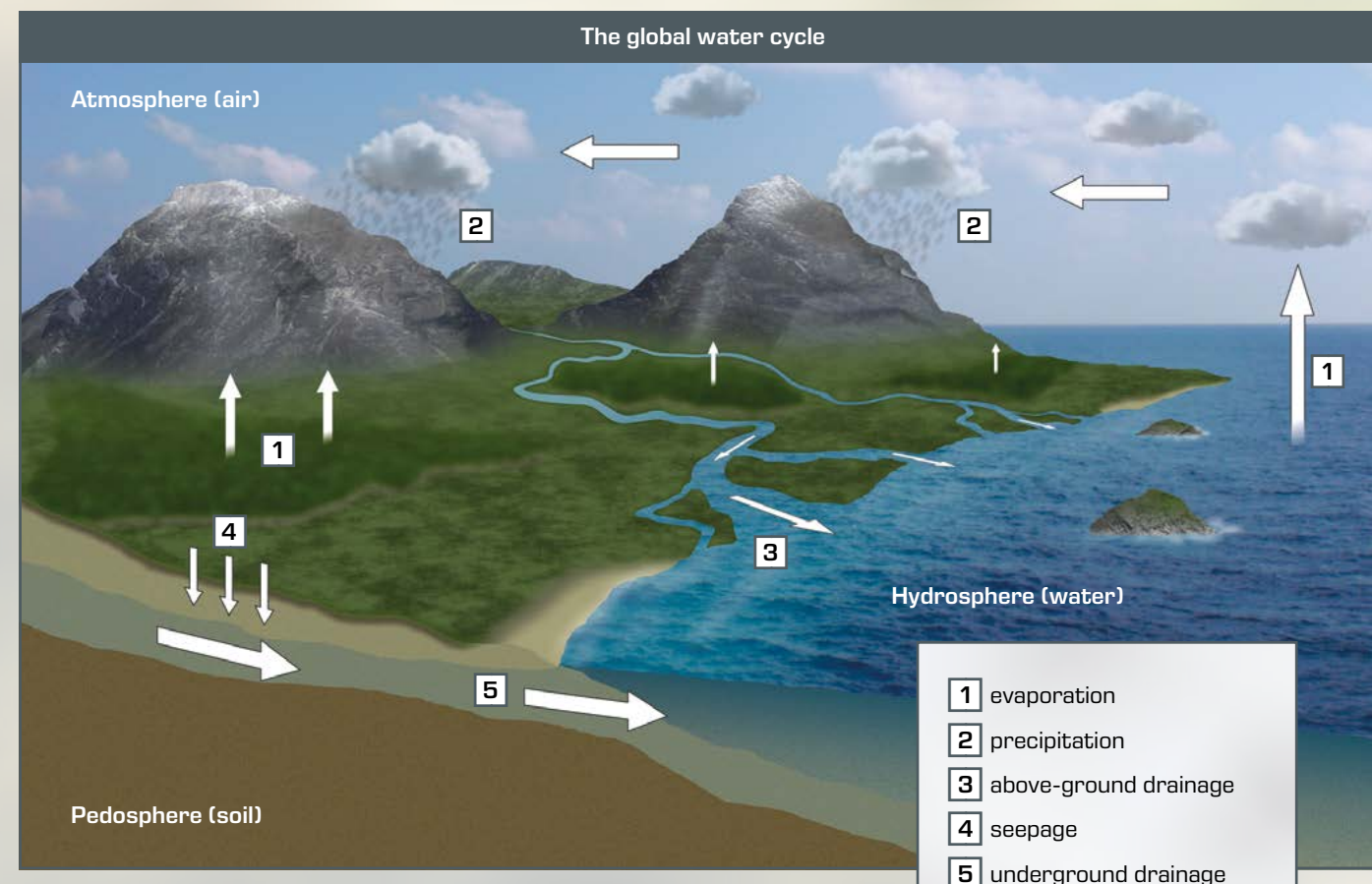
## Sustainable Technology for Environmental Protection

### The global water cycle: link between the environmental compartments

Approximately three quarters of the earth's surface is covered by water. The water on earth is part of a constant cycle, and passes through all aggregate states. The driving forces of this cycle are the sun and gravity. The water cycle connects the three environmental compartments of atmosphere (air), hydrosphere (water) and pedosphere (soil).

The solar radiation warms the water on the earth's surface and in the oceans. As a result, water evaporates and enters the atmosphere as water vapour, where eventually it forms clouds. The water returns to the earth's surface in the form of rain. About half of it then evaporates again. The vast majority of the remaining precipitation flows above the ground back into the oceans in the form of rivers. The remaining precipitation seeps into the ground, forming the groundwater. Most of the groundwater is returned to the oceans beneath the ground. The remainder exits the ground at above-ground sources and leads to the formation of rivers, which in turn flow back into the oceans above ground.

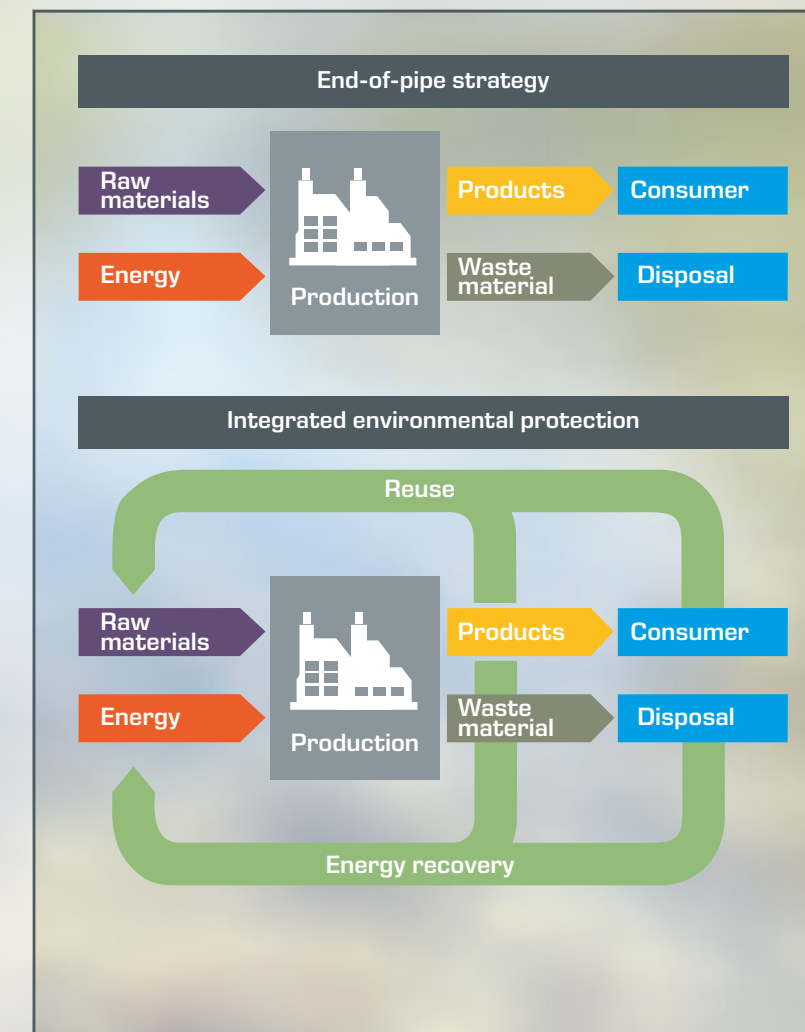
Humans withdraw water from the water cycle for different purposes, and return it to the cycle after use. Often the water is loaded with many contaminants when it is returned. As a result, the natural balance of the water cycle has been noticeably disturbed. For example, in many places the water seeping into the ground is no longer cleaned, but rather contaminated. The soil can no longer fulfil its natural cleaning function. Other examples of a negative influence on the global water balance include sealing formerly porous surfaces, deforestation and the depositing of hazardous waste in landfills.



### From “end-of-pipe” strategy to integrated environmental protection

For a long time people have been pursuing “end-of-pipe” strategies in order to counteract increasing environmental pollution. These strategies add downstream environmental protection measures to production processes, without involving the production processes themselves. Furthermore, water, air and soil were largely considered separately. However, it has been shown that this one-dimensional approach was inadequate considering the complexity of environmental sustainability. So for example, the fields of water and air often simply delayed the problem to the field of waste, such as the disposal of sludge from wastewater treatment.

Modern environmental protection concepts, however, adopt a holistic approach that includes all environmental sectors. Another goal today is to address the problems at an earlier stage of their development. Consequently, measures for environmental protection are now integrated into many production processes. The reuse of materials and the environmentally friendly use of energy play a central role here.







# Subject Areas

## Sustainable Technology for Environmental Protection

### Water, air and soil: central components of teaching curricula

One of the biggest challenges is maintaining a clean environment. Once contaminants enter the environment, they do not necessarily remain at the site of contamination. Instead, the water cycle and winds mean these contaminants are transported worldwide. Contaminants can be transported and transformed in the atmosphere (air), hydrosphere (water) and pedosphere (soil). Understanding the complex processes in these three environmental compartments is essential for the development of modern environmental protection technologies.

Accordingly, sound knowledge of the basic relationships in the three environmental compartments of water, air and soil forms the foundation of environmental engineering professions. Since sustainable environmental protection also requires specialised and careful handling of waste, problems from the field of waste management are additional indispensable components of curricula in the field of environmental engineering.

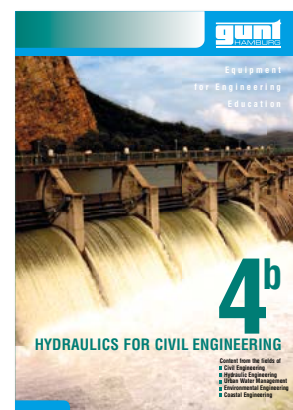
### Interdisciplinary thinking for holistic environmental protection

Our range of devices is generally structured in line with the generally accepted curricula in the field of environmental engineering. The devices have been developed by experienced engineers who have well-founded expertise thanks to their education, especially in the field of environmental engineering.

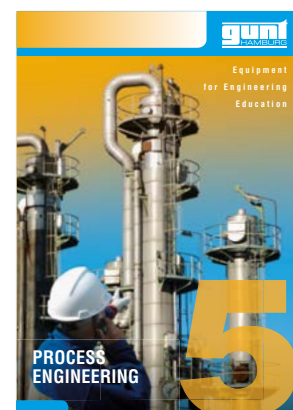
Environmental engineering is a relatively new engineering discipline. Many of the methods used in this area to protect the environment have their origins in other engineering disciplines. Thus, the methods used in water treatment and air pollution control are based on conventional process engineering. Similarly, groundwater flows in soils are also of course an integral part of hydraulics and hydraulic engineering.

This highlights the need for interdisciplinary thinking and action by aspiring engineers in the field of environmental engineering in order to face up to the complex challenges.

The devices presented in this catalogue represent a selection of teaching systems, which are a perfect complement to the theoretical basis for education in the field of environmental engineering. Most of these devices have their origins in other traditional fields of engineering. Similarly, you can find further, subject-related devices in our catalogue 4b "Hydraulics for Civil Engineering" and catalogue 5 "Process Engineering".



**Catalogue 4b**  
Hydraulics for Civil  
Engineering



**Catalogue 5**  
Process Engineering



|                                                                                       |                                                             |     |
|---------------------------------------------------------------------------------------|-------------------------------------------------------------|-----|
| Introduction                                                                          |                                                             |     |
|      | <b>Subject Areas</b><br>Water                               | 240 |
|      | <b>Basic Knowledge</b><br>Wastewater Treatment Plant        | 242 |
| Mechanical Water Treatment                                                            |                                                             |     |
|    | <b>Basic Knowledge</b><br>Mechanical Water Treatment        | 244 |
|    | <b>HM 142</b><br>Separation in Sedimentation Tanks          | 246 |
|    | <b>CE 587</b><br>Dissolved Air Flotation                    | 248 |
|  | <b>CE 579</b><br>Depth Filtration                           | 250 |
| Biological Water Treatment                                                            |                                                             |     |
|  | <b>Basic Knowledge</b><br>Biological Water Treatment        | 252 |
|  | <b>CE 705</b><br>Activated Sludge Process                   | 254 |
|  | <b>CE 701</b><br>Biofilm Process                            | 258 |
|  | <b>CE 730</b><br>Airlift Reactor                            | 260 |
|  | <b>CE 702</b><br>Anaerobic Water Treatment                  | 262 |
| Physical/Chemical Water Treatment                                                     |                                                             |     |
|    | <b>Basic Knowledge</b><br>Physical/Chemical Water Treatment | 264 |
|    | <b>CE 583</b><br>Adsorption                                 | 268 |
|    | <b>CE 530</b><br>Reverse Osmosis                            | 270 |
|  | <b>CE 300</b><br>Ion Exchange                               | 271 |
|  | <b>CE 586</b><br>Precipitation and Flocculation             | 272 |
|  | <b>CE 584</b><br>Advanced Oxidation                         | 274 |
| Multi-Stage Water Treatment                                                           |                                                             |     |
|  | <b>Basic Knowledge</b><br>Multi-Stage Water Treatment       | 276 |
|  | <b>CE 581</b><br>Water Treatment Plant 1                    | 278 |
|  | <b>CE 582</b><br>Water Treatment Plant 2                    | 280 |





# Subject Areas Water



Subject Areas

2E Products

## Unit Operations of Water Treatment

The area of water focuses on water treatment. The aim of water treatment is always to remove specific substances from the water. This can be used to clean wastewater in a wastewater treatment plant prior to discharge into a body of water. From the perspective of environmental protection, the remediation of contaminated groundwater and landfill leachate is another broad application example. However, the aim of water treatment may also be to make water usable for a particular purpose, e.g. in the treatment of potable water.

Regardless of the application, there are a number of basic methods available to water treatment which are classically divided into three groups.

This section contains a teaching unit for each of the most important basic procedures, with which all important aspects of the respective method can be illustrated and taught in a clear and informative manner.

Water treatment plants are usually built in several stages and represent a combination of various basic processes. Therefore, we also offer two devices that enable you to illustrate the complexities of multi-stage water treatment

### Mechanical processes

**HM 142**  
Separation in Sedimentation Tanks  
**CE 587**  
Dissolved Air Flotation  
**CE 579**  
Depth Filtration

### Biological processes

**CE 705**  
Activated Sludge Process  
**CE 701**  
Biofilm Process  
**CE 730**  
Airlift Reactor  
**CE 702**  
Anaerobic Water Treatment

### Physical/chemical processes

**CE 583**  
Adsorption  
**CE 530**  
Reverse Osmosis  
**CE 300**  
Ion Exchange  
**CE 586**  
Precipitation and Flocculation  
**CE 584**  
Advanced Oxidation

## Multi-Stage Water Treatment

### Combined unit operations

**CE 581**  
Water Treatment Plant 1  
**CE 582**  
Water Treatment Plant 2



# Basic Knowledge Wastewater Treatment Plant



## Environmental protection through wastewater treatment

If untreated wastewater is discharged into a body of water, microorganisms destroy the organic matter contained in the water through high oxygen consumption. This leads to a lack of oxygen in the water, which in turn destroys the ecological balance. To prevent this from happening, wastewater must be treated in wastewater treatment plants beforehand. The most important component of a wastewater treatment plant is the biological purification by microorganisms. The natural degradation processes are thus shifted from the body of water into an industrial plant, where they take place in controlled and optimised conditions.

## Mechanical treatment

First the wastewater is treated mechanically. The aim is to remove solids from the water. A bar screen first removes coarse solids such as textiles, paper and plastic bags from the wastewater. Then mineral solids such as entrained sand are separated in grit chambers by sedimentation. Organic solids, such as food scraps, are also separated by sedimentation in the primary clarification.



## Biological treatment

After the mechanical treatment, the wastewater contains almost exclusively dissolved substances. These dissolved substances are biodegraded by microorganisms in the biological treatment. The most commonly used method here is the aerobic activated sludge process. In this treatment stage, the wastewater is aerated in order to supply the microorganisms (activated sludge) with oxygen. Since the activated sludge is suspended in the aeration tank, activated sludge is also continuously discharged along with the wastewater flow. In the secondary clarifier the activated sludge is discharged mechanically separated (usually by sedimentation) from the treated water. A portion of the separated activated sludge is fed back into the aeration tank as return sludge. Without return sludge, it would not be possible to achieve stable operation of the biological treatment. Although the secondary clarifier is actually a mechanical process, it is still therefore classed as a biological treatment.

## Sludge treatment

The non-recycled portion of the sludge separated in the secondary clarifier is referred to as surplus sludge or secondary sludge. Surplus sludge and sludge from the primary clarification (primary sludge) mainly contain organic ingredients and are a by-product of wastewater treatment. Therefore, a separate treatment is required for this sludge (sewage sludge). This is usually implemented in digestion towers, where the sewage sludge is digested under anaerobic conditions. Digested sludge can then be used as fertiliser in agriculture, for example.

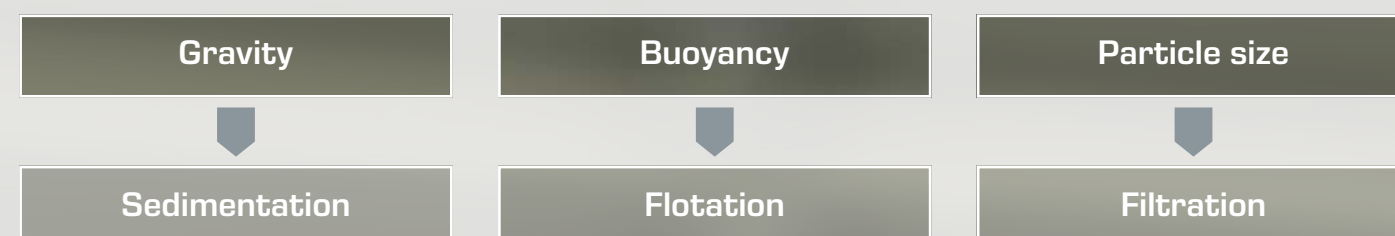




# Basic Knowledge Mechanical Water Treatment



Solids can easily lead to blockages in plant components such as pipes, valves and fittings. In multi-stage water treatment plants the first stage is usually to remove solids by mechanical means for this reason. In mechanical processes, the solids are not altered either physically or chemically. Only separation of the solids from the liquid phase (water) takes place. This can be implemented according to the following three principles:



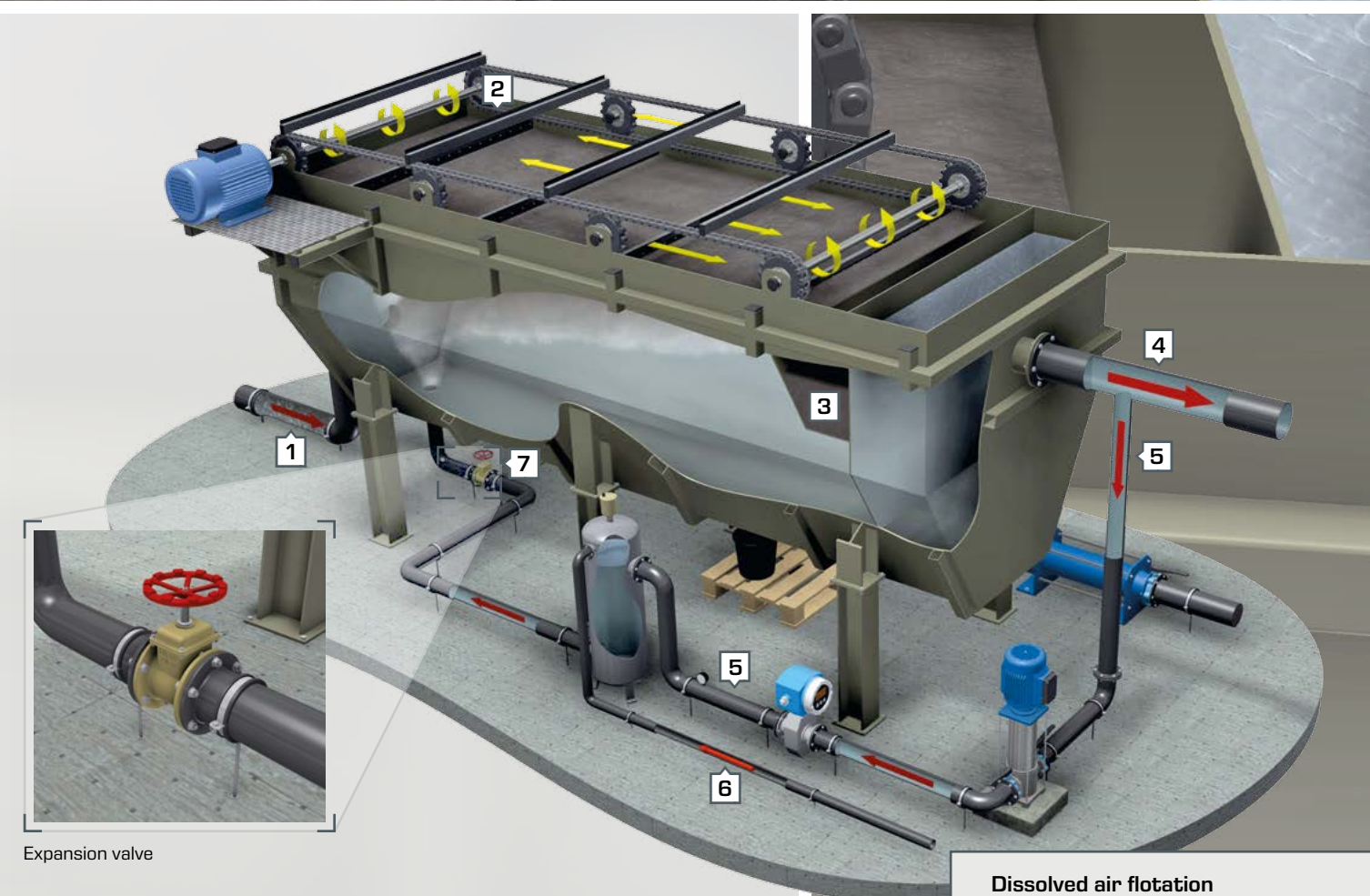
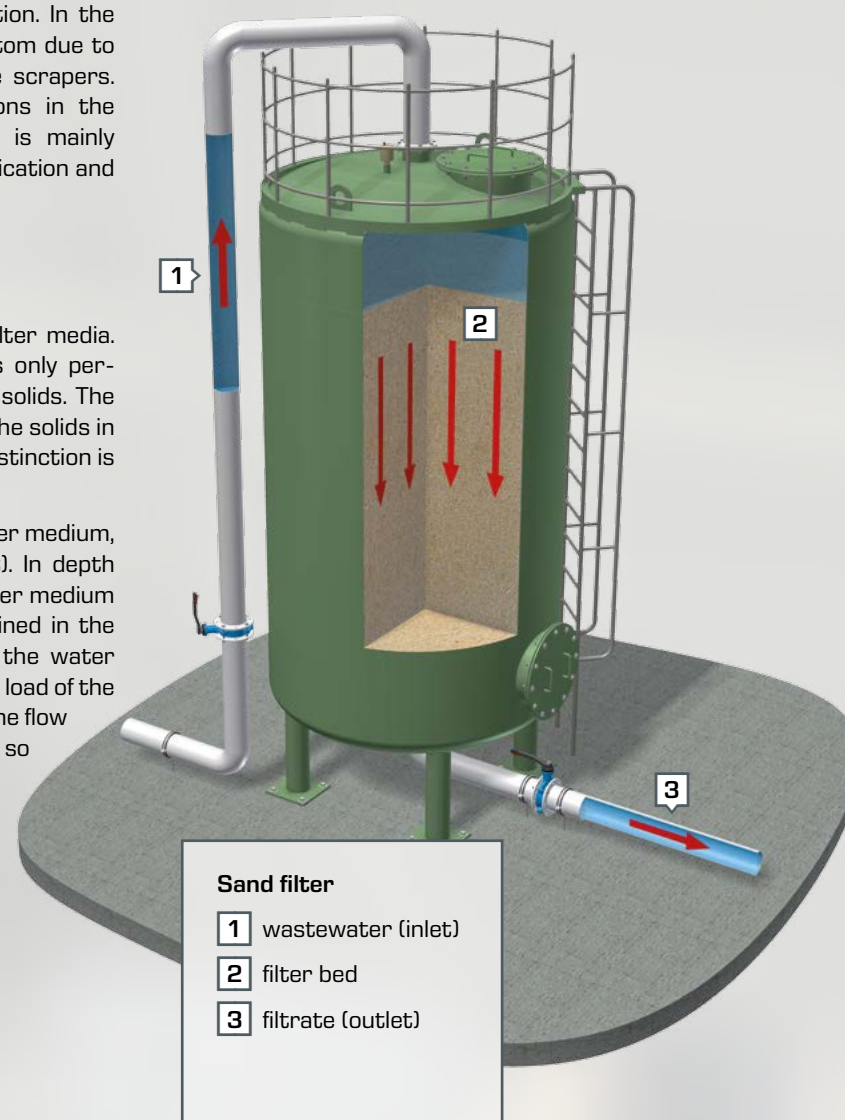
## Sedimentation

The easiest way to separate solids is by sedimentation. In the sedimentation tank, the solid particles fall to the bottom due to gravity and can then easily be removed with sludge scrapers. Effective sedimentation requires calm flow conditions in the sedimentation tank (no turbulence). Sedimentation is mainly used in wastewater treatment plants in primary clarification and secondary clarification.

## Filtration

During filtration, the solids are retained by porous filter media. Effective filtration requires that the filter medium is only permeable for the liquid phases (water), but not for the solids. The success of treatment depends on the particle size of the solids in relation to the pore size of the filter medium. A basic distinction is made between surface filtration and depth filtration.

In surface filtration, the solids do not penetrate the filter medium, but instead are retained on its surface (sieve effect). In depth filtration, however, the wastewater penetrates the filter medium (e.g. fixed bed of sand or gravel). The solids are retained in the pores between the individual sand grains, whereas the water flows through the fixed bed unimpeded (filtrate). As the load of the fixed bed increases, the pressure drop increases and the flow rate decreases. A backwash cleans the fixed bed again, so that the pressure drop decreases.



## Flotation

Solids with low settling velocities cannot be effectively separated by sedimentation because this would require very large sedimentation tanks. In this case, flotation processes provide a sensible alternative. The basic principle is still the same. Gas bubbles attach themselves to the bottom of the solids and drive the solids to the surface. Once there, the floated solids can be removed with special scrapers. Flotation processes differ mainly in the way the gas bubbles are produced.

In water treatment, the most commonly used method is dissolved air flotation. In this process, a partial flow of the treated water is saturated with air under pressure. The air-saturated water is then passed back to the inlet region of the flotation tank (circulation). An expansion valve is located just before the inlet to the flotation tank, which causes the water to suddenly re-expand to atmospheric pressure. This expansion causes the dissolved air to form fine bubbles.

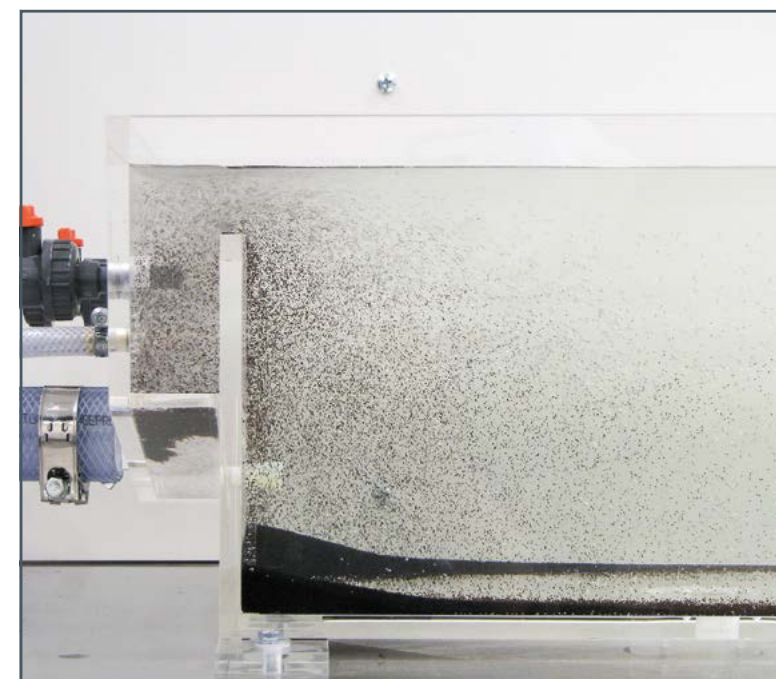


# HM 142 Separation in Sedimentation Tanks

In water treatment, sedimentation is a very commonly used method for the separation of solids.

Our HM 142 device allows you to clearly demonstrate this process. You can change all the significant factors influencing the sedimentation. These include the solids concentration and flow rate, for example. Solids concentrations can be displayed

graphically and quantified with Imhoff cones. In order to make the flow conditions in the sedimentation tank visible, you can add ink to the water using a piston burette. Imhoff cone and piston burette are included with the device. The transparent sedimentation tank allows optimum observation of the sedimentation process and flow conditions.



The sedimentation process can be clearly and impressively demonstrated through the use of transparent materials.



Along with your product, you receive two Imhoff cones to clearly represent and quantify the treatment success of the process.



Students at the Jade University of Applied Sciences in Wilhelmshaven (Germany) prepare experiments with our HM 142 trainer.

| Learning objectives                                                                                                                                                                                                                                                |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>familiarisation with the basic principle of sedimentation</li> <li>effectiveness of the separation process depending on the solids concentration and the flow rate</li> <li>investigation of the flow conditions</li> </ul> |





# CE 587 Dissolved Air Flotation

## Removal of solids by flotation

Flotation, alongside sedimentation, is another process often used in water treatment to remove solids. Dissolved air flotation is the most commonly used flotation process.

## Experiments with great practical relevance

Our CE 587 teaching unit allows you to study all important aspects of this process. In order to create high practical relevance, we have placed great emphasis on the highest possible realism in the development of this device.

The device consists of a supply unit and a trainer. First, the raw water is pre-treated by flocculation. Then the flocs are transported to the surface of the water in the flotation tank by means of small air bubbles. An electrically driven scraper allows you to clear the water surface of the floating substances. Many of the components used, such as electromagnetic flow rate sensors and metering pumps, are also used in large-scale industrial plants. By using transparent materials you can optimally observe all the stages in the process.



Standard at GUNT: use of high-quality industrial components such as professional metering pumps and electromagnetic flow meters

| Learning objectives                                                                                                                                                                                                                                                                   |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>functional principle of dissolved air flotation</li> <li>creation of a stable operating state</li> <li>effects of the coagulant and flocculant concentration</li> <li>determination of the hydraulic loading rate (rising velocity)</li> </ul> |



- 1 storage tank for raw water
- 2 pretreatment with flocculation
- 3 electrically driven scraper
- 4 flotation tank
- 5 metering pumps
- 6 electromagnetic flow meter

Trainer

Based on large-scale flotation plants, CE 587 is equipped with an electrically driven scraper which removes the floated solids from the surface of the water.

Product No.  
083.58700  
More details and technical data:  
[gunt.de/static/s4864\\_1.php](http://gunt.de/static/s4864_1.php)



An interesting video and more information about CE 587 can be found on our 2E website [www.gunt2E.de](http://www.gunt2E.de)



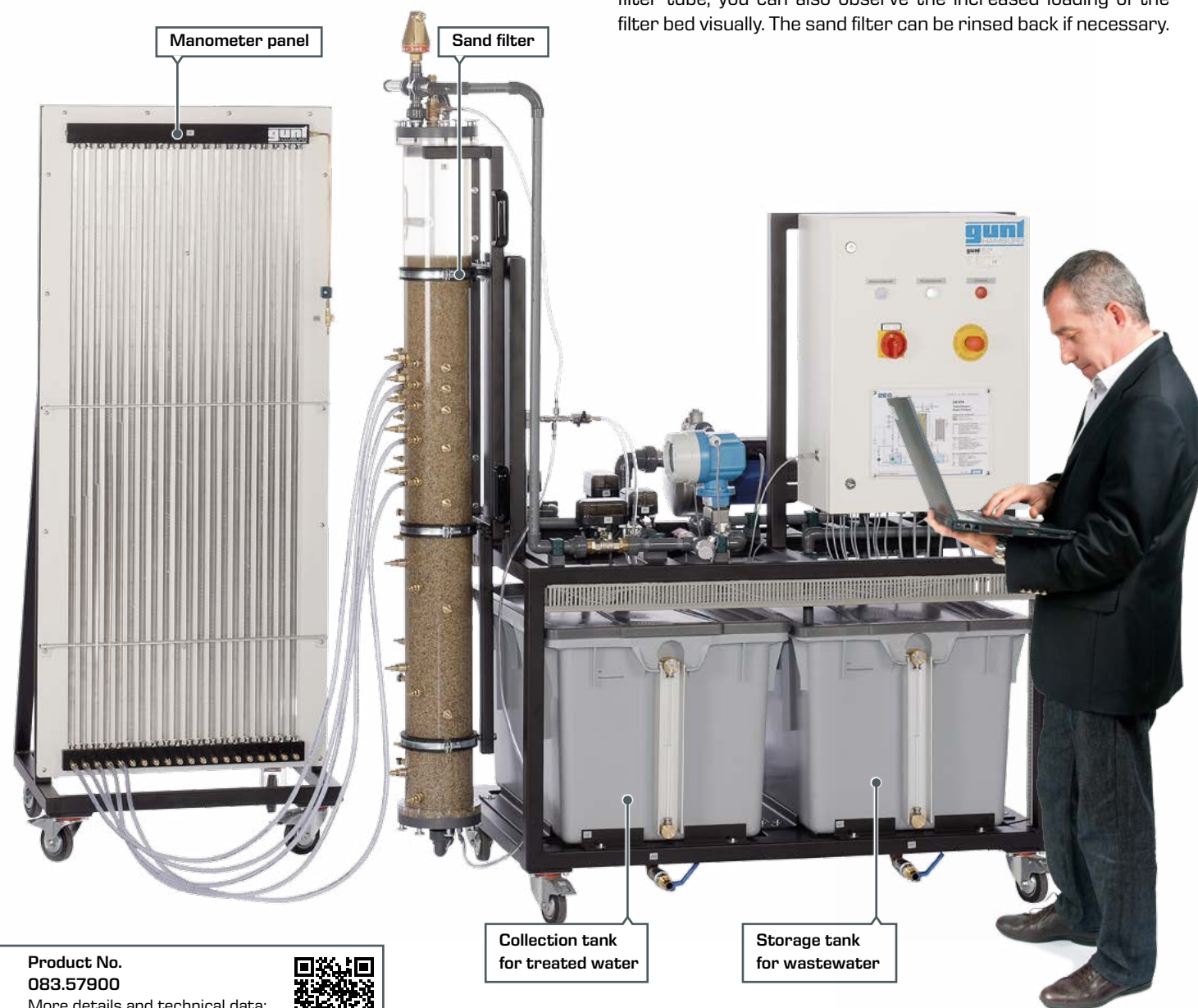
# CE 579 Depth Filtration

## Depth filtration: indispensable in water treatment

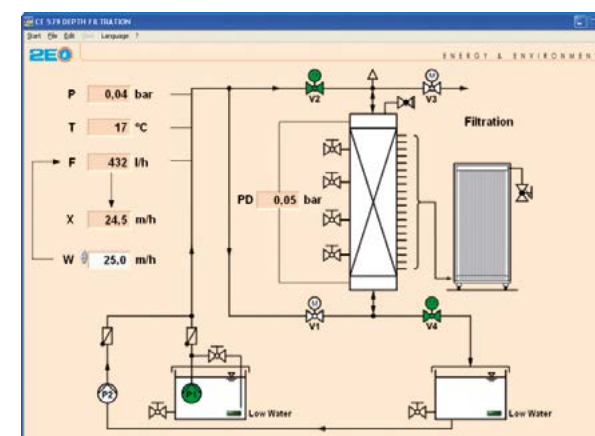
Depth filtration with sand filters is an important and frequently used process step in water treatment. Exact knowledge of the principle of operation and the characteristics of this process are an indispensable component in the education of budding engineers and specialist technicians. The pressure conditions in the filter bed are of particular interest.

## Concept and features

The educational focus of this trainer is the investigation of the pressure conditions in the filter bed. In order to measure the pressures, the sand filter is fitted with a differential pressure measurement and a number of individual measuring points along the filter bed. These measurement points can be connected to a manometer panel, enabling you to very accurately measure the pressure conditions in the filter bed. The manometer panel has 20 separate tube manometers. By using a transparent filter tube, you can also observe the increased loading of the filter bed visually. The sand filter can be rinsed back if necessary.



Product No.  
083.57900  
More details and technical data:  
[gunt.de/static/s4869\\_1.php](http://gunt.de/static/s4869_1.php)



## Software

The clearly-arranged software included with CE 579 continuously displays all key process variables. You can of course save the measured values for analysis. Depending on the selected operating mode (filtration or backwashing), the software moves electrically-driven valves to each corresponding position.



## High-quality components

We use high-quality industrial components such as an electromagnetic flow meter and electrically-driven ball valves in this device too.

| Learning objectives                                                                                                                                                                                                                                                                                                  |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>■ learning the fundamental principle of depth filtration using sand filters</li> <li>■ observation of the pressure conditions in a filter bed</li> <li>■ determination of pressure losses</li> <li>■ plotting of Mischeu diagrams</li> <li>■ principle of backwash</li> </ul> |



# Basic Knowledge Biological Water Treatment



## Microorganisms clean wastewater

The aim of biological wastewater treatment is the elimination of organic, biodegradable materials. This elimination is carried out by microorganisms which use organic substances as a source of food. This biodegradation also causes a conversion of materials to take place. This is a significant advantage that biological processes have over other methods. In adsorption, for example, it is simply a matter of displacing the substances to be removed from the wastewater onto the adsorbent (mass transport). Biodegradation may occur under either aerobic or anaerobic conditions. A number of methods are available in order to bring the wastewater to be treated into contact with the microorganisms (biomass). Regardless of whether the degradation is carried out aerobically or anaerobically, a distinction is made between the following two principles:

### Suspended biomass

The biomass is present in the form of small flocs (activated sludge). The activated sludge is suspended in the wastewater.

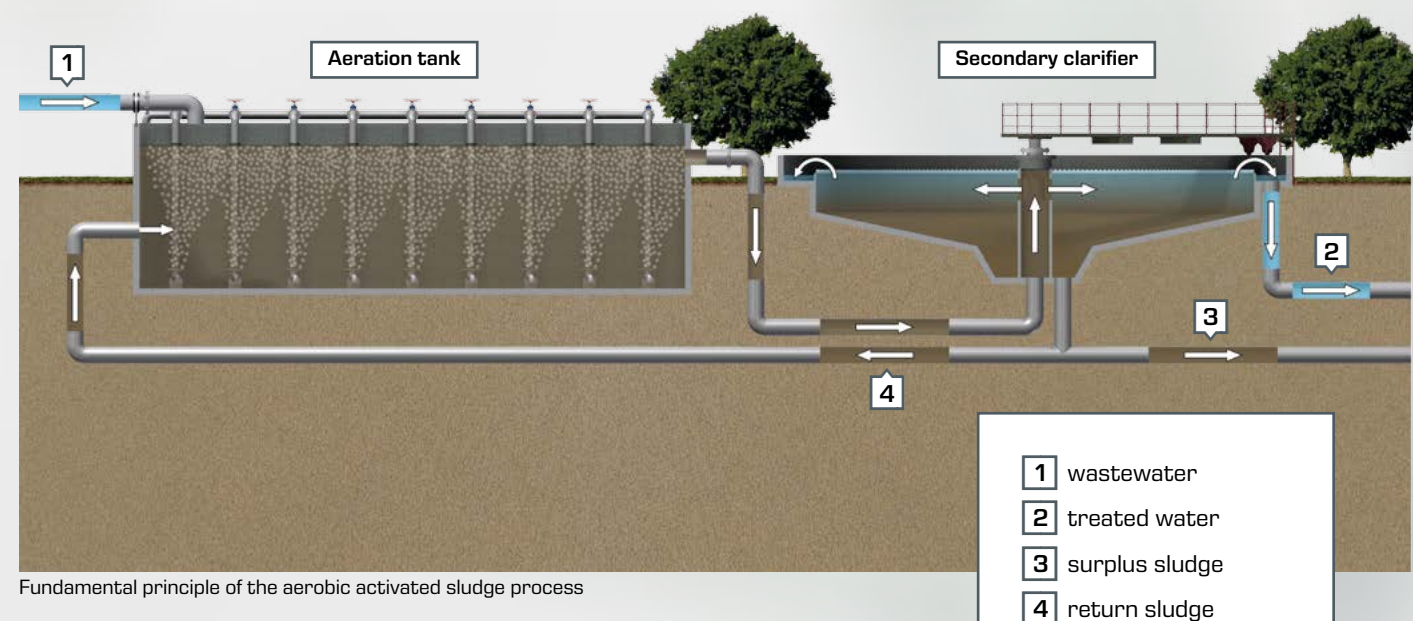
### Sessile biomass

The biomass is fixed on surfaces of solid bodies as a biofilm. The wastewater runs away over the biofilm as a thin film.

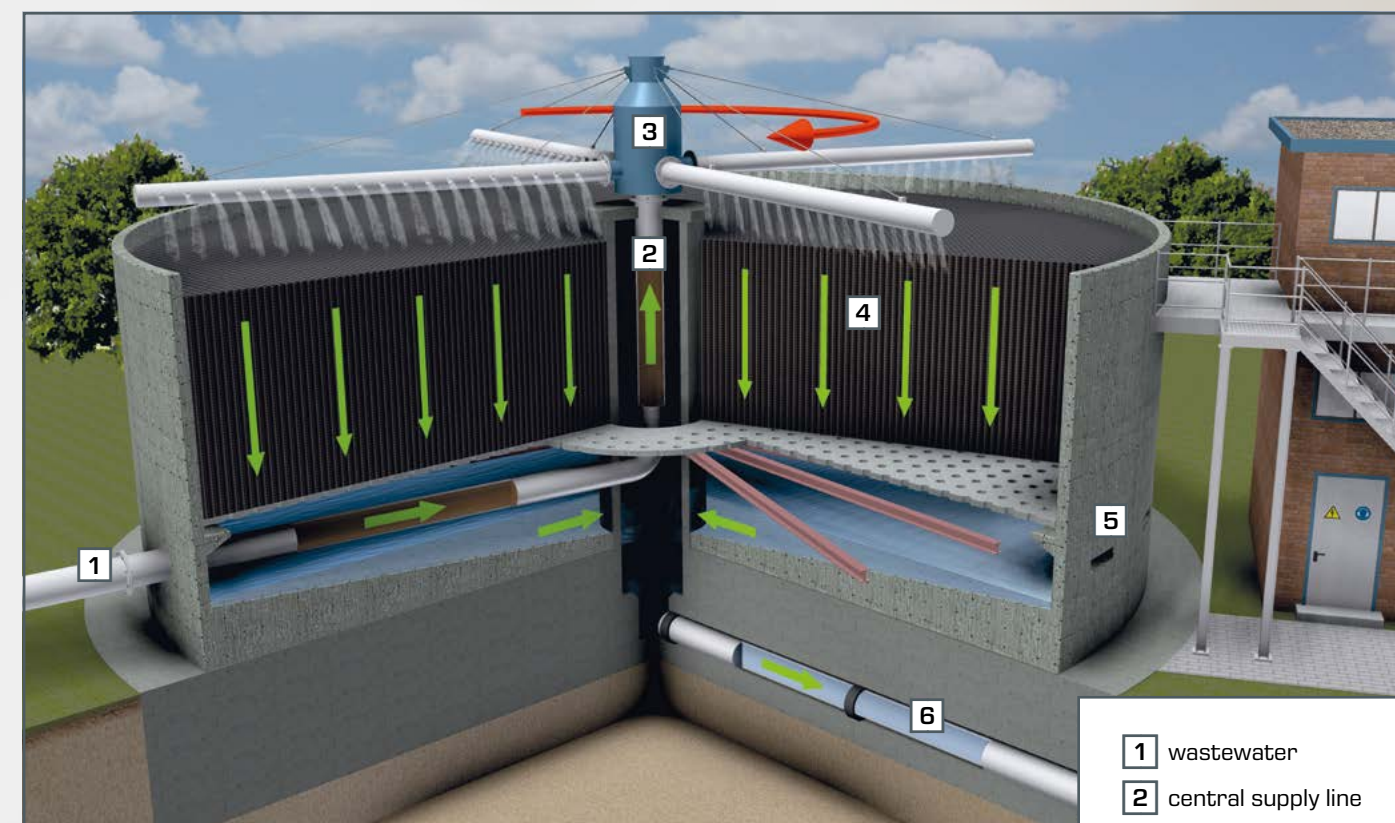
## Aerobic activated sludge process

The aerobic activated sludge process is the most widely used biological wastewater treatment process. The biomass is a suspended activated sludge in the aeration basin through which the wastewater flows continuously. The wastewater is also aerated here in order to supply the microorganisms with oxygen. Biomass (activated sludge) also continuously leaves

the aeration tank along with the wastewater flow. Therefore, the discharged activated sludge must be separated from the treated wastewater in a secondary clarifier (usually by sedimentation). Part of it is fed back into the aeration tank (return sludge). The non-recycled fraction is referred to as surplus sludge and is a waste product of this process.



Fundamental principle of the aerobic activated sludge process



Design and function of a trickling filter

- 1 wastewater
- 2 central supply line
- 3 rotary distributor
- 4 fixed bed with biofilm
- 5 aeration openings
- 6 treated water

## Trickling filters

Trickling filters are an aerobic biofilm process. In this process, a rotary sprinkler spreads the wastewater evenly over a fixed bed. The fixed bed consists of special support material on the surface of which a thin layer of microorganisms (biofilm) forms. While the wastewater trickles through the fixed bed, the microorganisms clean the wastewater by biological processes. Trickling filters usually have an open design and offer lateral openings below the fixed bed. This allows aeration by natural convection (chimney effect). Energy-intensive artificial aeration, such as that used in the activated sludge process, is not necessary.

## Anaerobic processes

Anaerobic processes are particularly suitable for industrial wastewater, which is often heavily contaminated with organic substances (e.g. food industry). There is a variety of different processes or reactor types available for this purpose. Under anaerobic conditions, the degradation of organic matter creates biogas, which consists mainly of methane. Biogas can be used, for example, with combined heat and power plants to generate electricity. This is a positive secondary aspect of anaerobic wastewater treatment and clearly illustrates the close interconnection of issues from the field of energy and environment.



# CE 705 Activated Sludge Process

## A laboratory-scale wastewater treatment plant

The aerobic activated sludge process is the most widely-used biological process in wastewater treatment plants worldwide. Sound knowledge of this process is therefore essential for budding engineers and specialist technicians in the field of environmental engineering.

This device has been designed by experienced engineers with the aim of being able to clearly teach the complex processes involved in this process in continuous operation in a practical manner. The device is designed for carbon elimination and nitrogen elimination. The nitrogen is removed by nitrification and pre-denitrification. To this end, the aeration tank is divided into an aerobic and an anoxic area.

The device consists of a separate supply unit with a large storage tank for wastewater and a trainer. All process-relevant components are located on the trainer. This includes in particular the aeration tank and secondary clarifier.

You can adjust all process-relevant parameters in order to investigate their influence on the cleaning process. Moreover, the device is equipped with modern instrumentation and control technology and software. This supports you while carrying out the experiments.

- laboratory-scale wastewater treatment plant
- continuous operation
- nitrification
- pre-denitrification
- comprehensive instrumentation and control technology
- modern software with control functions and data acquisition



Product No.  
083.70500  
More details and technical data:  
[gunt.de/static/s4865\\_1.php](http://gunt.de/static/s4865_1.php)



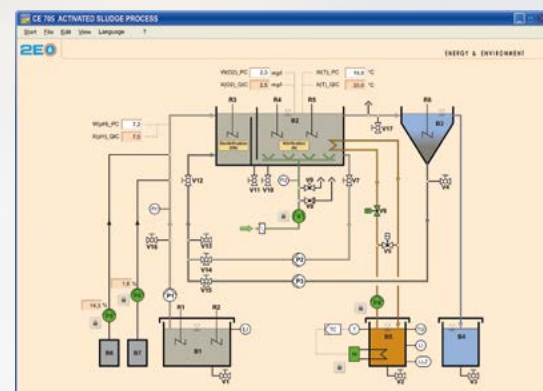
An interesting video and more information about CE 705 can be found on our 2E website [www.gunt2E.de](http://www.gunt2E.de)



# CE 705 Activated Sludge Process

## Instrumentation and control technology

Nowadays, complex processes such as the activated sludge process are largely automated. The use of modern instrumentation and control technology is indispensable for this purpose. This also requires that engineers in the field of environmental engineering have at least basic knowledge of such systems. To prepare students for the challenges of professional practice, we have also observed this important aspect when developing the device. CE 705 is therefore equipped with extensive instrumentation and control technology and modern software.



CE 705 Software



Professional controller for the oxygen concentration in the nitrification area

## Measured variables in CE 705

|                      |                      |  |
|----------------------|----------------------|--|
| flow rate            | wastewater           |  |
|                      | aeration             |  |
| oxygen concentration | denitrification area |  |
|                      | nitrification area   |  |
| pH value             | wastewater           |  |
| temperature          | nitrification area   |  |

measurement control

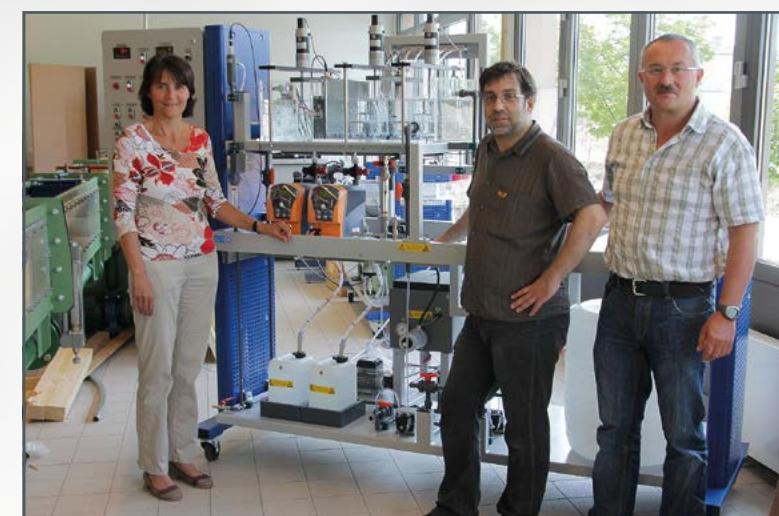


## Instructional material

You also receive comprehensive instructional material about this device, which quickly helps you become familiar with its operation. In addition, the theoretical fundamentals of the activated sludge process are clearly represented in detail.

## Commissioning and training

CE 705 is used in many educational institutions worldwide. Commissioning and training for customers is carried out by expert GUNT employees. In addition to testing the delivered products, GUNT technicians provide in-depth instruction to the customer on operation of the devices. This allows you to quickly incorporate the teaching system in your classroom.



After successful commissioning and training, a GUNT employee hands over CE 705 to Mrs. Professor Dr.-Ing. Deininger of the Deggendorf Institute of Technology (Germany).

| Learning objectives |                                                                                                                                                                                                                                                                                   |
|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ■                   | functional principle of nitrification and pre-denitrification                                                                                                                                                                                                                     |
| ■                   | creation of a stable operating state                                                                                                                                                                                                                                              |
| ■                   | identification of the following influencing factors <ul style="list-style-type: none"> <li>▶ sludge age</li> <li>▶ volumetric loading</li> <li>▶ sludge loading</li> <li>▶ return sludge ratio</li> <li>▶ return ratio of the internal recirculation (denitrification)</li> </ul> |
| ■                   | efficiency of the pre-denitrification                                                                                                                                                                                                                                             |
| ■                   | influence of the following ambient conditions to the biological degradation <ul style="list-style-type: none"> <li>▶ pH value</li> <li>▶ temperature</li> <li>▶ oxygen concentration</li> </ul>                                                                                   |

For more information on this device, please see our brochure at:  
[gunt.de/download/CE705\\_flyer\\_english.pdf](http://gunt.de/download/CE705_flyer_english.pdf)



DEGGENDORF  
INSTITUTE OF  
TECHNOLOGY

Modern and practical training –  
supported by high-quality educational systems  
from GUNT



# CE 701 Biofilm Process

## Laboratory-Scale Trickling Filter

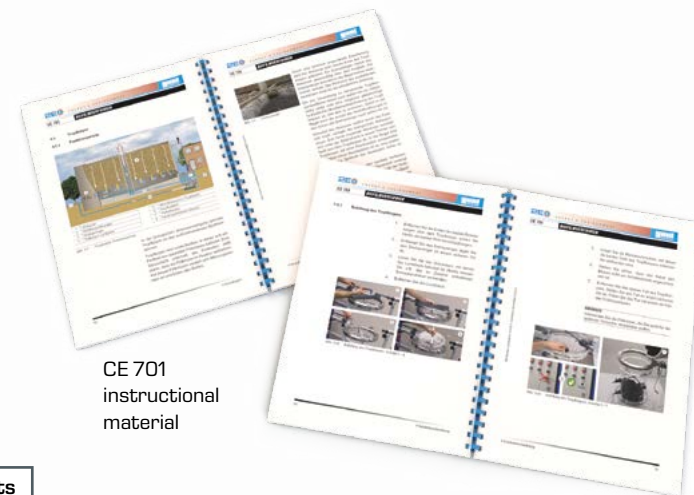
### Trickling filters: an aerobic biofilm process

Although trickling filters are one of the oldest biological wastewater treatment processes, they are still widely in use. The trickling filter process is therefore still an integral part of the curriculum in the field of water treatment.

The CE 701 trickling filter is designed for carbon elimination and nitrification. A rotary distributor distributes the wastewater to be treated evenly over the fixed bed. You can adjust the speed of the rotary distributor. There are two different HDPE packing types available for the fixed bed. The packing differs in terms of the specific surface area.

The trickling filter of CE 701 has aeration vents below the fixed bed. This allows for aeration by natural convection. If necessary, you can also close the aeration vents to artificially aerate the trickling filter with a compressor.

The instructional material sets out the fundamentals and design of trickling filter plants in detail. A detailed description of the device and the experiments enables you to quickly incorporate this training system into your classroom.



CE 701 instructional material



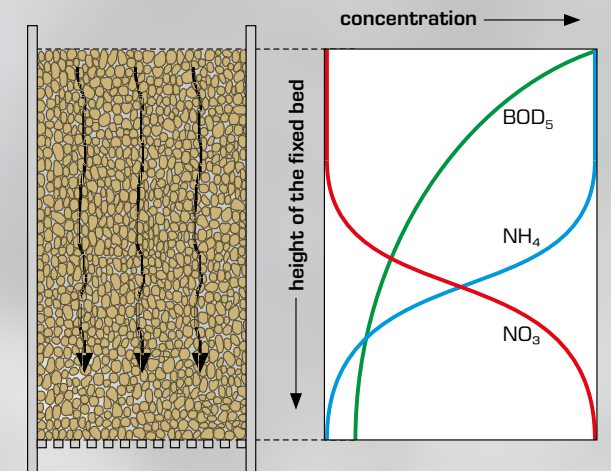
Rotary distributor on the head of the trickling filter with variable speed adjustment



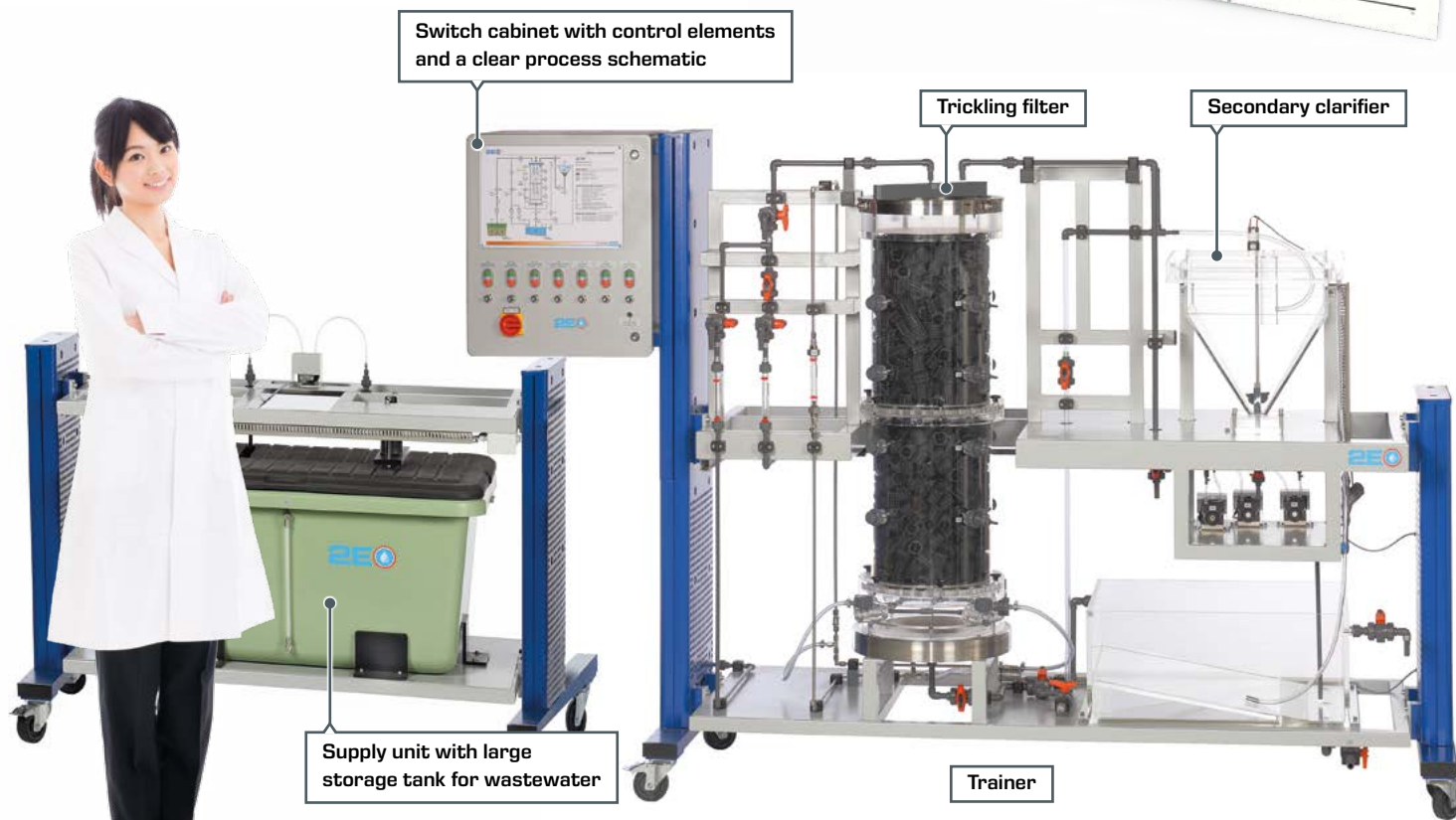
Sampling point within the trickling filter

### Concentration profiles

Sampling points are located within the fixed bed. This allows you to determine the concentration profiles of BOD<sub>5</sub>, ammonia and nitrate which are characteristic for trickling filters.



Typical concentration profiles of BOD<sub>5</sub>, ammonia (NH<sub>4</sub>) and nitrate (NO<sub>3</sub>) in a trickling filter



Product No.  
083.70100  
More details and technical data:  
[gunt.de/static/s4867\\_1.php](http://gunt.de/static/s4867_1.php)

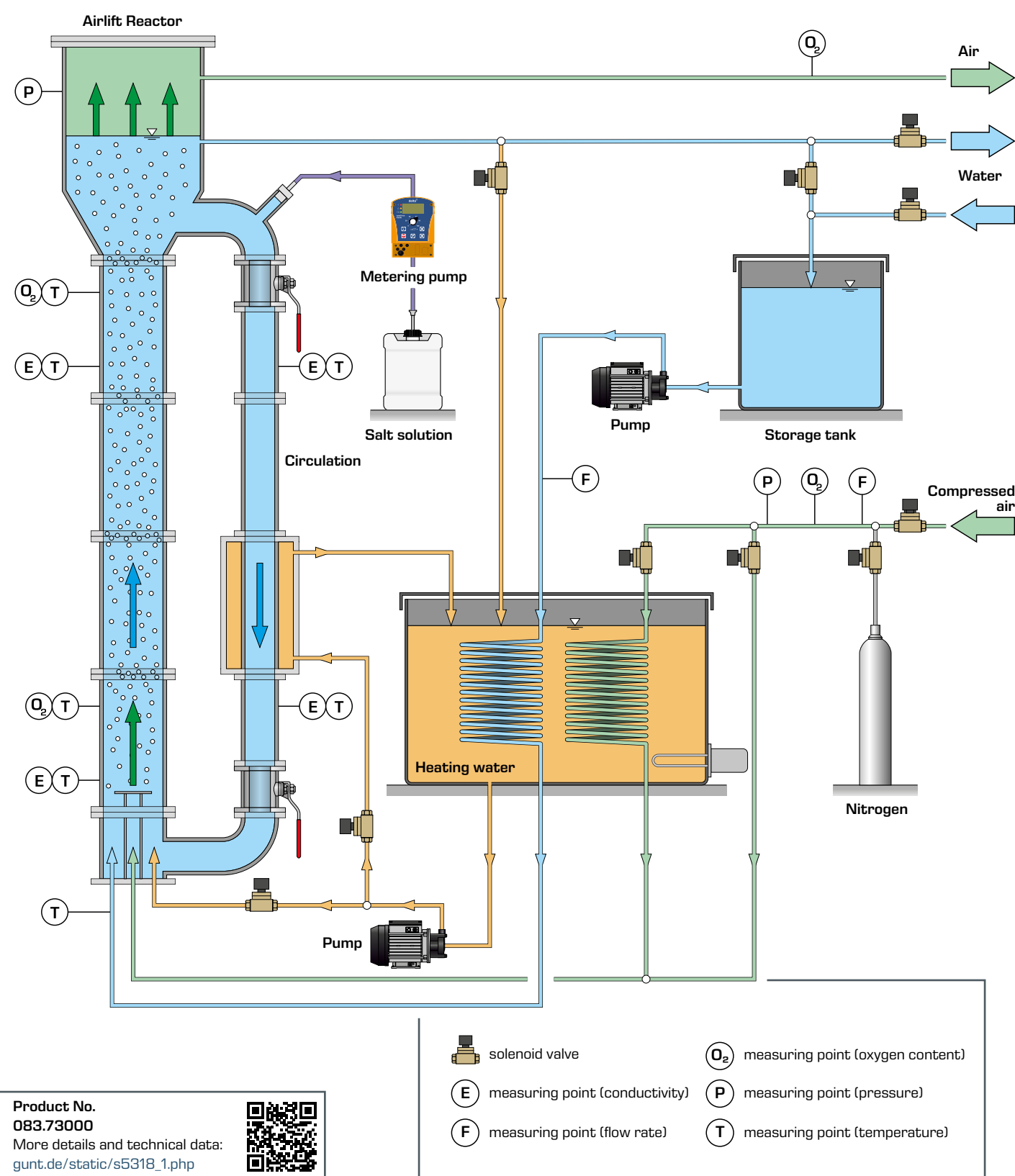


### Learning objectives

- functional principle of a trickling filter
- recording of concentration profiles
- creation of a stable operating state
- identification of the following influencing factors
  - ▶ flow rate of recirculation
  - ▶ volumetric loading of the trickling filter
  - ▶ surface loading of the trickling filter
- comparison of various packing types



# CE 730 / Airlift Reactor



## Powerful bioreactors

Supplying the microorganisms (biomass) with oxygen is of crucial importance for the performance of an aerobic bioreactor. Another important aspect is uniform mixing of the reactor contents. Airlift reactors meet both of these challenges to a particular degree.

In an airlift reactor mixing occurs exclusively through the aeration, which is necessary anyway. Mechanically moving parts (e.g. stirring machines) are not necessary. The retention of the biomass in the reactor required for effective operation is achieved by circulation. Airlift reactors are used in biotechnology and in biological wastewater treatment.

### Airlift reactor CE 730

This trainer is one of our latest developments in the field of biological process engineering. The core of the trainer is an airlift reactor with external circulation. The educational focus of CE 730 is the functioning and operation of an airlift reactor. These mainly include releasing oxygen in the liquid phase (water) and determining the flow conditions in the reactor.

There are several different distributors available for aeration of the reactor. This allows you to study how bubble size influences mass transfer. In addition, you can adjust the temperature in the reactor.

Two measuring points for conductivity are located on the circulation at defined intervals. Adding a salt solution causes a sharp increase (peak) in conductivity at both measurement points, with some delay between them. The time difference between the two peaks and the distance between the measuring points can be used to determine the flow velocity in the reactor.

## Learning objectives

- functioning of an airlift reactor
- determining the mass transfer coefficient of oxygen in water
- determining flow velocities
- determining the integral gas content
- determining the Bodenstein number

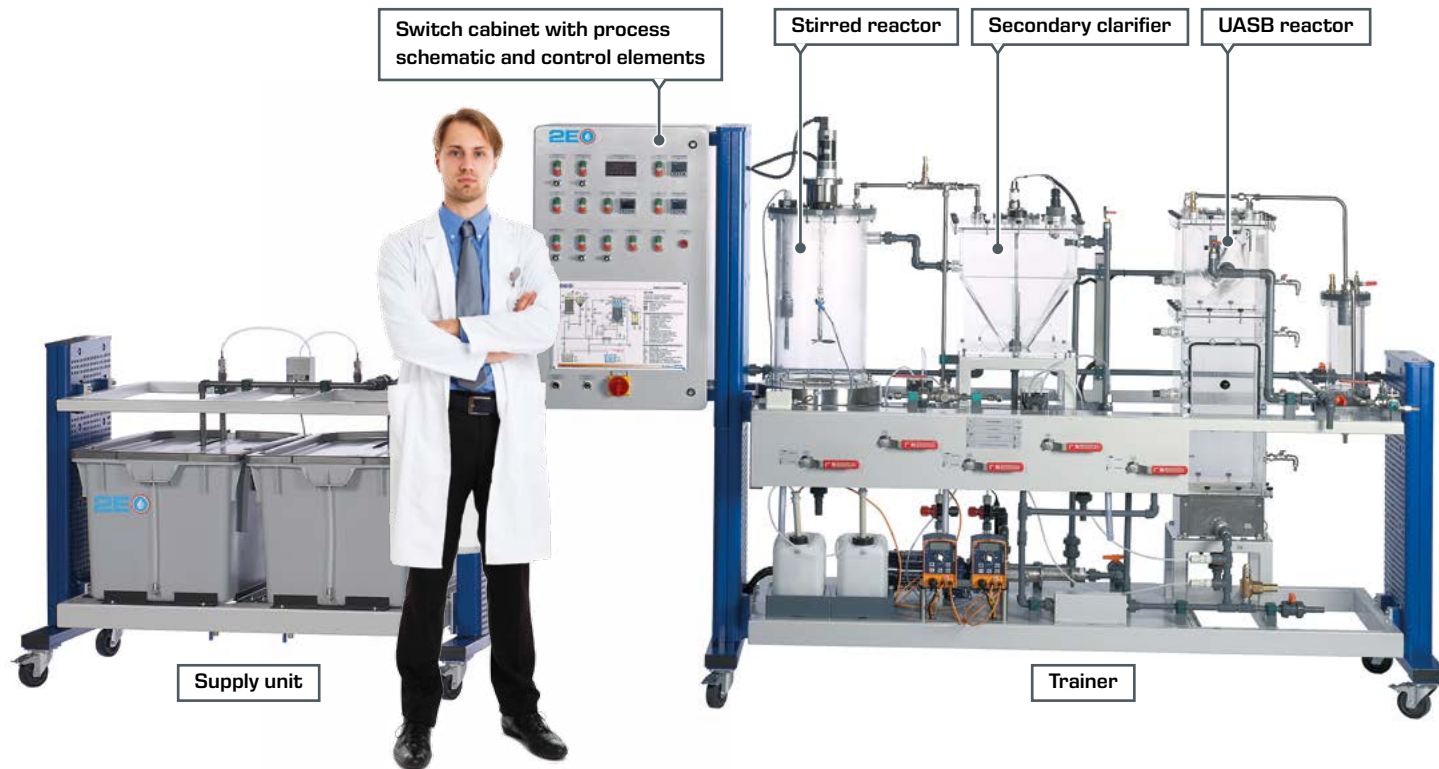
**Product No.**  
**083.73000**  
More details and technical data:  
[gunt.de/static/s5318\\_1.php](http://gunt.de/static/s5318_1.php)

 Software and PC

The device is operated via a PC with touch panel built into the switch cabinet. The PC is equipped with special GUNT software and has extensive options for capturing and analysing the measurement data.



# CE 702 Anaerobic Water Treatment



Anaerobic processes are primarily used for wastewater which is highly contaminated with organic substances, such as those occurring in the food industry.

Our CE 702 teaching unit offers you two different methods. These are the anaerobic activated sludge process and the UASB process. You can operate both processes separately (1-stage) or in series (2-stage). This gives you a total of three different modes of operation. The device is also equipped with extensive instrumentation and control technology and software.

You also receive comprehensive instructional material on this device that quickly helps you become familiar with operation of the device. In addition, the theoretical fundamentals of anaerobic wastewater treatment are clearly represented in detail.

The 2-stage operating mode allows you to control the pH and the temperature independently of each other in both stages. This type of process control has proven itself in practice and has the advantage of being able to better adapt the environmental conditions to the needs of each of the degradation steps. The device is equipped with gas collecting pipes, which can be used to take gas samples from the system for analysis.

|                            |  |
|----------------------------|--|
| Operating mode 1 (1-stage) |  |
| Operating mode 2 (1-stage) |  |
| Operating mode 3 (2-stage) |  |

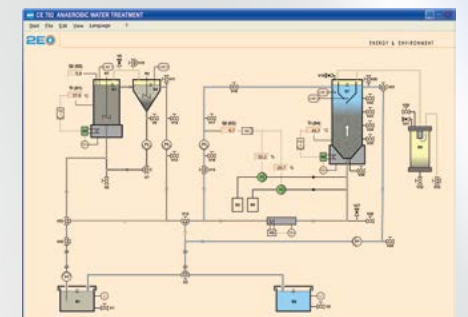
|  |                     |                                      |
|--|---------------------|--------------------------------------|
|  | stirred reactor     | } anaerobic activated sludge process |
|  | secondary clarifier |                                      |
|  | UASB reactor        |                                      |



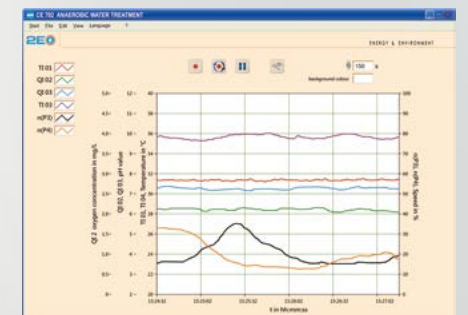
CE 702's UASB reactor during a successful trial run in our laboratory

## Software

The software included with CE 702 shows the temperatures and pH values in both reactors continuously. This gives you a quick overview of the conditions in the reactors at any time. You can save the measured values for analysis. This relieves you of routine work and thus aids you when conducting the experiments.



Process schematic with display of the measured values



Display of the measured values as time dependency

| Learning objectives                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>effects of temperature and pH value on anaerobic degradation</li> <li>functional principle of a UASB reactor</li> <li>comparison of single stage and dual stage operation mode</li> <li>monitoring and optimisation of the operating conditions</li> <li>identification of the following influencing factors <ul style="list-style-type: none"> <li>sludge loading</li> <li>volumetric loading</li> <li>flow velocity in the UASB reactor</li> </ul> </li> </ul> |





# Basic Knowledge Physical/Chemical Water Treatment



## Application of physical/chemical processes

Industrial wastewater often contains dissolved inorganic substances (e.g. heavy metals) or organic materials which cannot be biodegraded. This is also true of a lot of landfill leachate and contaminated groundwater. The use of physical/chemical processes is ideal in such cases. There is a variety of different processes in this field of water treatment. The most widely used processes include:

Adsorption

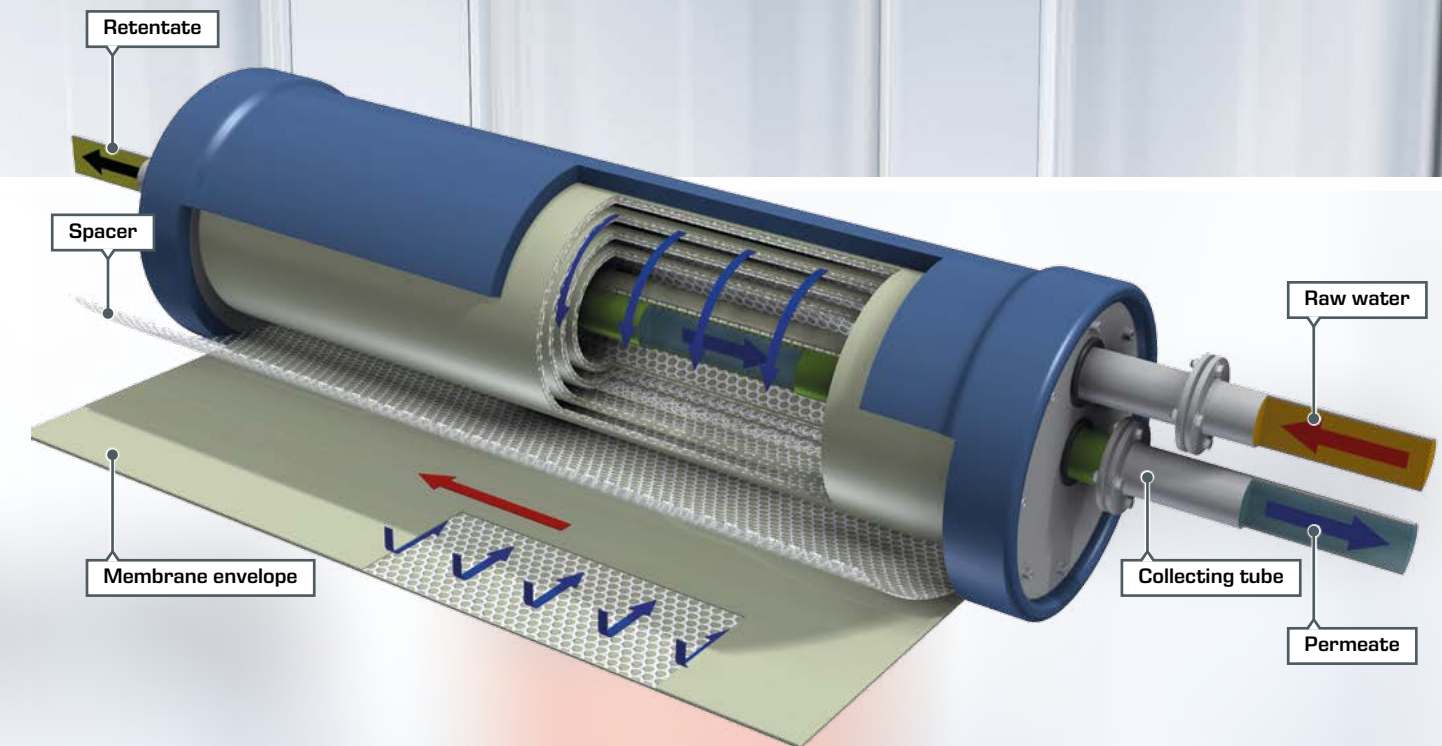
Reverse osmosis

Ion exchange

Precipitation

Flocculation

Oxidation processes



## Adsorption

In adsorption, the material to be removed (adsorbate) is bonded to the surface of a solid (adsorbent). This bonding can be either physical or chemical. The adsorbent is predominantly granular activated carbon. This procedure can be used to reliably remove toxic, chlorinated hydrocarbon compounds from the water. Such substances are found in many places in landfill leachate and contaminated groundwater.

Adsorption is generally carried out with continuous-flow adsorbers. The adsorbers contain a fixed bed of granular activated carbon. After a certain period of operation, the adsorbate concentration in the outlet of an adsorber rises. This condition is referred to as breakthrough. If the adsorbate concentration in the outlet of an adsorber is plotted over time, it shows what is known as the breakthrough curve.



Continuous-flow adsorber in a water treatment plant

## Reverse osmosis: membrane separation process for the strictest demands

The basic principle of reverse osmosis is quite simple. The natural tendency to bring about a concentration equilibrium between the two sides of a membrane (osmosis) must be countered. To do this, counter-pressure which is at least as high as the osmotic pressure is built up. The water then flows across the membrane in the direction of the concentration gradient, thereby sharply increasing the concentration on one side of the membrane (retentate) and decreasing it on the other side (permeate). To put it simply, reverse osmosis can be regarded as a dilution process.

Even dissolved substances such as ions can be removed from the water by reverse osmosis. This means ultrapure water, which is required in many sensitive industrial production processes, can be produced, for example in the pharmaceutical industry. Another application is the desalination of sea water.

Reverse osmosis uses what are known as spiral-wound membranes. One special feature of this design is the membrane envelope wound spirally around a central tube. The high pressure on the inlet side causes the water (permeate) to pass across the membrane and to flow spirally into the central collecting tube. The partial flow (retentate) retained by the membrane is removed via a separate tube.



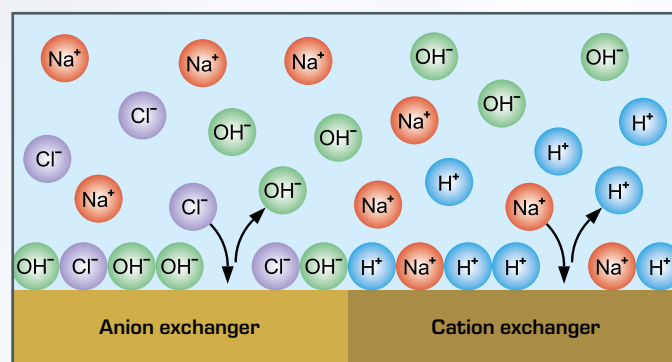
# Basic Knowledge Physical/Chemical Water Treatment



## Ion exchange

Ion exchange is a physico-chemical process in which a solid absorbs ions from a liquid, and in exchange emits an equivalent amount of equally charged ions to the liquid. If positive ions are exchanged (e.g. sodium  $\text{Na}^+$ ), the process is called cation exchange. In contrast, anion exchange is where negatively charged ions are exchanged (e.g. chloride  $\text{Cl}^-$ ).

Ion exchangers are used primarily for desalination and softening. Heavy metals contained in a lot of wastewater from the metalworking industry can be removed by ion exchange.



Desalination by anion exchange followed by cation exchange

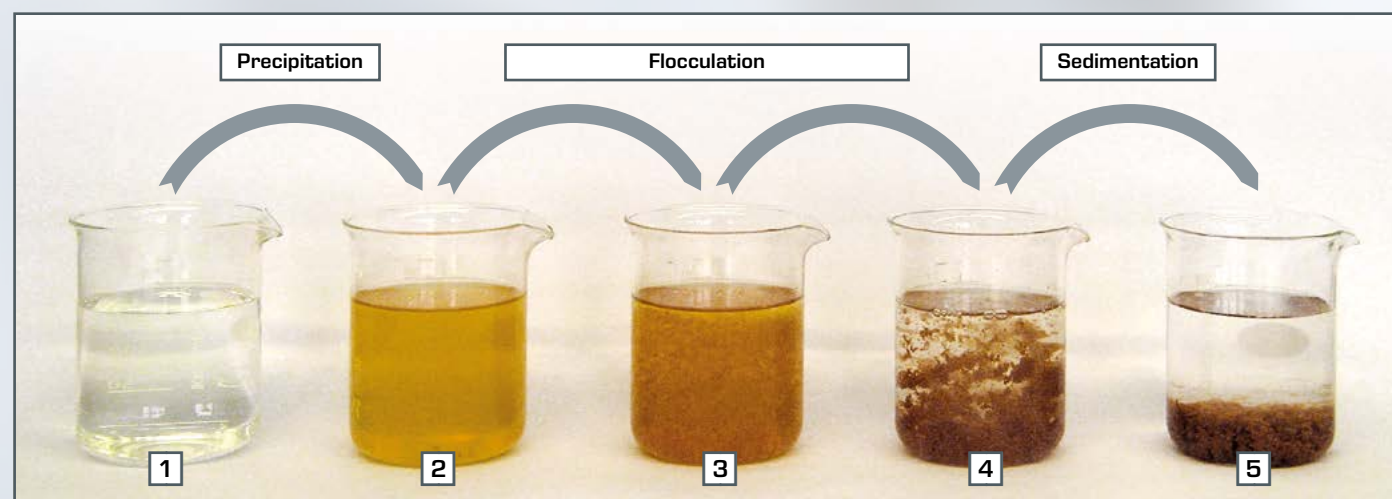
## Precipitation

Precipitation is a chemical process in which a dissolved substance is transformed in an insoluble form (solid) by reaction with another substance. Precipitation is suitable for removing dissolved metals, for example. In addition, precipitation is also used for phosphorus elimination in wastewater treatment plants.

In practice, precipitation is often followed by flocculation in order to increase the size of the solids which are formed. This eases the subsequent mechanical separation of the solids (for example by sedimentation).

## Flocculation

To add certain chemicals the electrostatic repulsive forces between the individual solid particles have to be removed first. As a result, the particles combine to form small flocs (coagulation). To increase the size of the flocs even further, a flocculant (e.g. polymer) is added to the water. This results in flocs several millimetres in diameter, which can easily be separated subsequently by mechanical means.



Precipitation and flocculation of dissolved iron:  
By adding caustic soda, the dissolved iron (1) first precipitates as insoluble and yellow iron hydroxide (2). Adding other chemicals causes large iron hydroxide flocs (3 to 4) to form, which can then easily be separated by sedimentation (5).

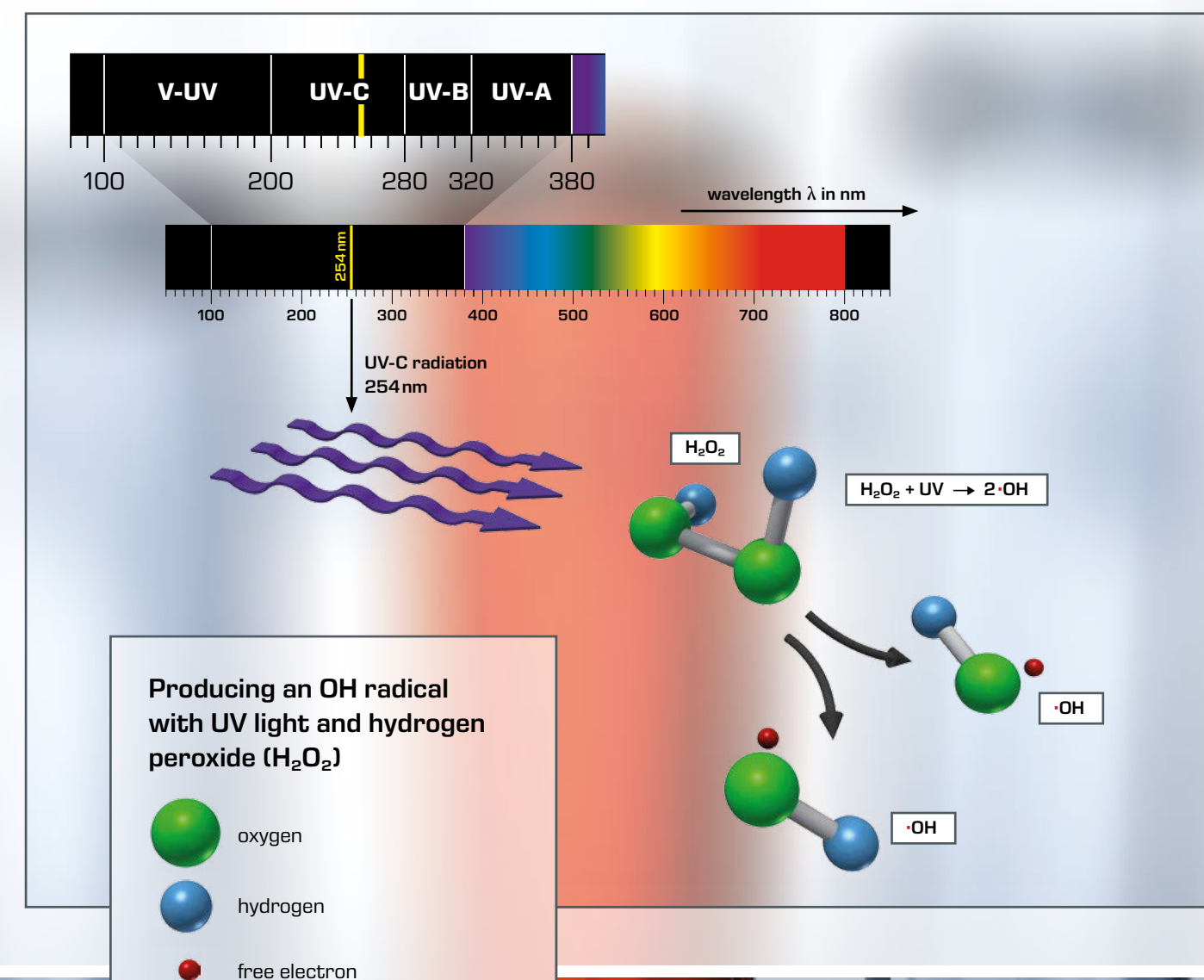
## Oxidation processes

Many organic contaminants are not biodegradable and therefore cannot be eliminated by biological processes. These include many chlorinated hydrocarbons. Improper handling of these materials allows them to enter the groundwater where they pose a threat to humans and the environment. An effective method of removing such materials from the water is with oxidation processes.

There is a variety of different oxidation processes in the field of water treatment. The importance of those referred to as "advanced oxidation processes" has increased in the past few

years. The main feature of these processes is the formation of highly reactive OH radicals. These radicals are some of the strongest oxidants and thus are able to oxidise almost any substance.

OH radicals can be produced with UV light, for example by irradiation of hydrogen peroxide ( $\text{H}_2\text{O}_2$ ). UV-C radiation with a wavelength of 254 nm is mainly used for this purpose.





# CE 583 Adsorption

## Adsorptive water treatment in continuous operation

Adsorption on activated carbon is an effective and often practised alternative to the removal of non-biodegradable organic substances, such as chlorinated hydrocarbons. Our CE 583 device allows you to demonstrate the fundamentals of this process in continuous operation and therefore under very practical conditions.

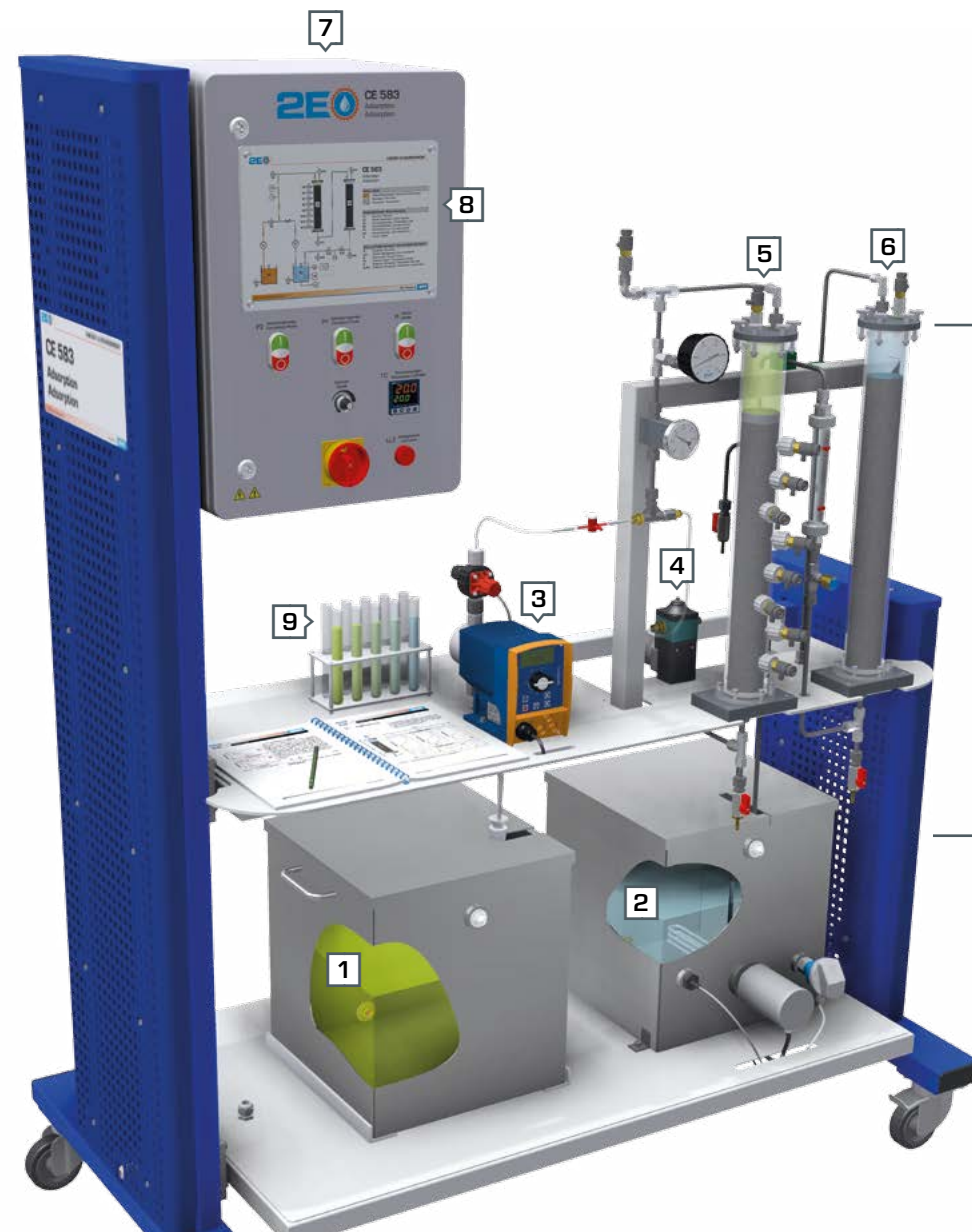
The main components of this device are two series-connected adsorbers which are filled with granulated active carbon. The first adsorber is equipped with sampling valves so that you can determine concentration profiles. Concentration profiles are essential for understanding adsorption.

## Principle of operation

Treated water is circulated through both adsorbers. A metering pump injects concentrated adsorbate solution into the inlet area of the first adsorber in the circuit. The metering pump allows very precise adjustment of the flow rate. This allows you to adjust the desired feed concentration of the adsorbate very precisely. The second adsorber ensures that the circulated water doesn't contain any more adsorbate even at full breakthrough of the first adsorber. This ensures a constant adsorbate concentration in the inlet of the first adsorber, even in long-term experiments.

## Temperature control

The device is equipped with a temperature control system. This allows you to study how water temperature influences the adsorption process.



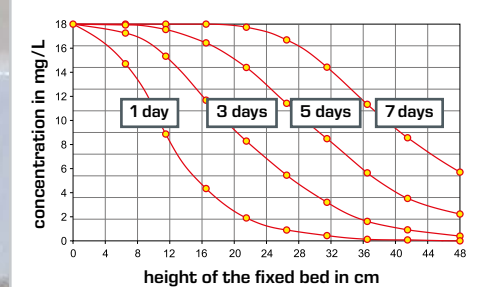
- 1 adsorbate concentrate
- 2 treated water
- 3 metering pump
- 4 circulation pump
- 5 first adsorber
- 6 second adsorber
- 7 switch cabinet
- 8 process schematic
- 9 test tubes for sampling

### i Adsorbate

Adsorbate refers to the substance dissolved in the water which is to be eliminated by adsorption

### i Our recommendation

You can deliver a particularly impressive demonstration of adsorption when you use a water-soluble and adsorbable dye as the adsorbate. Such substances include methylene blue or fluoresceine.

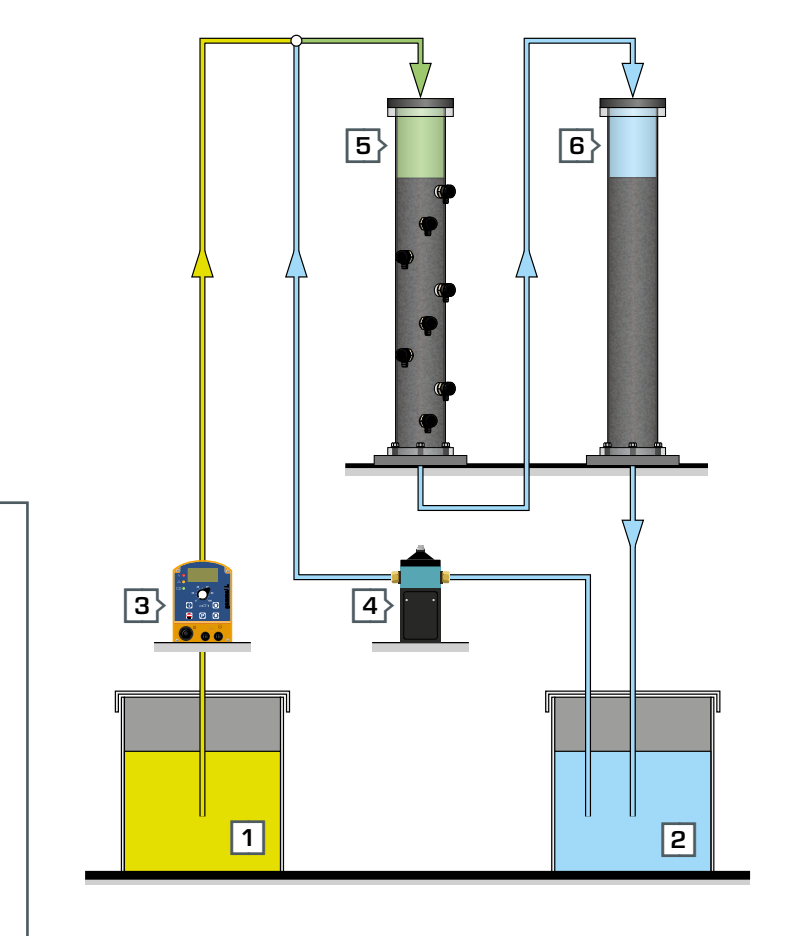


Excerpt from the CE 583 manual: concentration profiles at various times for methylene blue

### Learning objectives

- recording of concentration profiles
- recording of breakthrough curves
- relationship between concentration profiles and breakthrough curves
- determining the mass transfer zone
- an adsorber's efficiency and mass balance
- predicting breakthrough curves
- scale-up of the results to industrial scale
- factors influencing the adsorption
  - ▶ contact time
  - ▶ temperature
  - ▶ mode of operation

Product No.  
083.58300  
More details and technical data:  
[gunt.de/static/s4860\\_1.php](http://gunt.de/static/s4860_1.php)



Principle of operation of CE 583

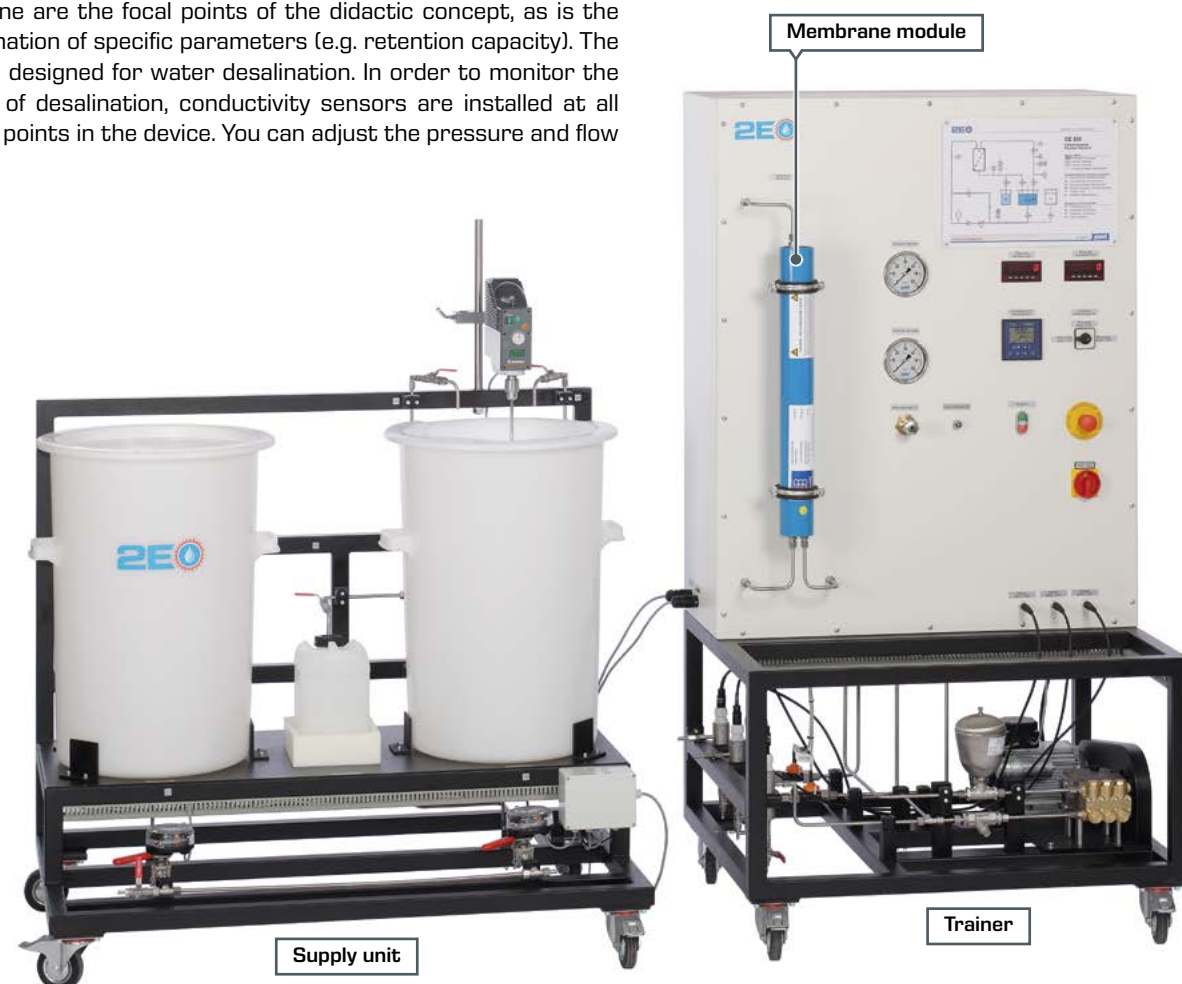


## CE 530 Reverse Osmosis

This device has been developed in collaboration with the Institute of Thermal Separation Processes, Hamburg University of Technology.

The main component of CE 530 is the spiral-wound membrane. The construction, maintenance and operation of a spiral-wound membrane are the focal points of the didactic concept, as is the determination of specific parameters (e.g. retention capacity). The device is designed for water desalination. In order to monitor the success of desalination, conductivity sensors are installed at all relevant points in the device. You can adjust the pressure and flow rate.

The instructional material sets out the fundamentals in detail and provides a step-by-step guide through the experiments.



In cooperation with  
**TUHH**  
Technische Universität Hamburg-Harburg

Product No.  
083.53000  
More details and technical data:  
[gunt.de/static/s4783\\_1.php](http://gunt.de/static/s4783_1.php)



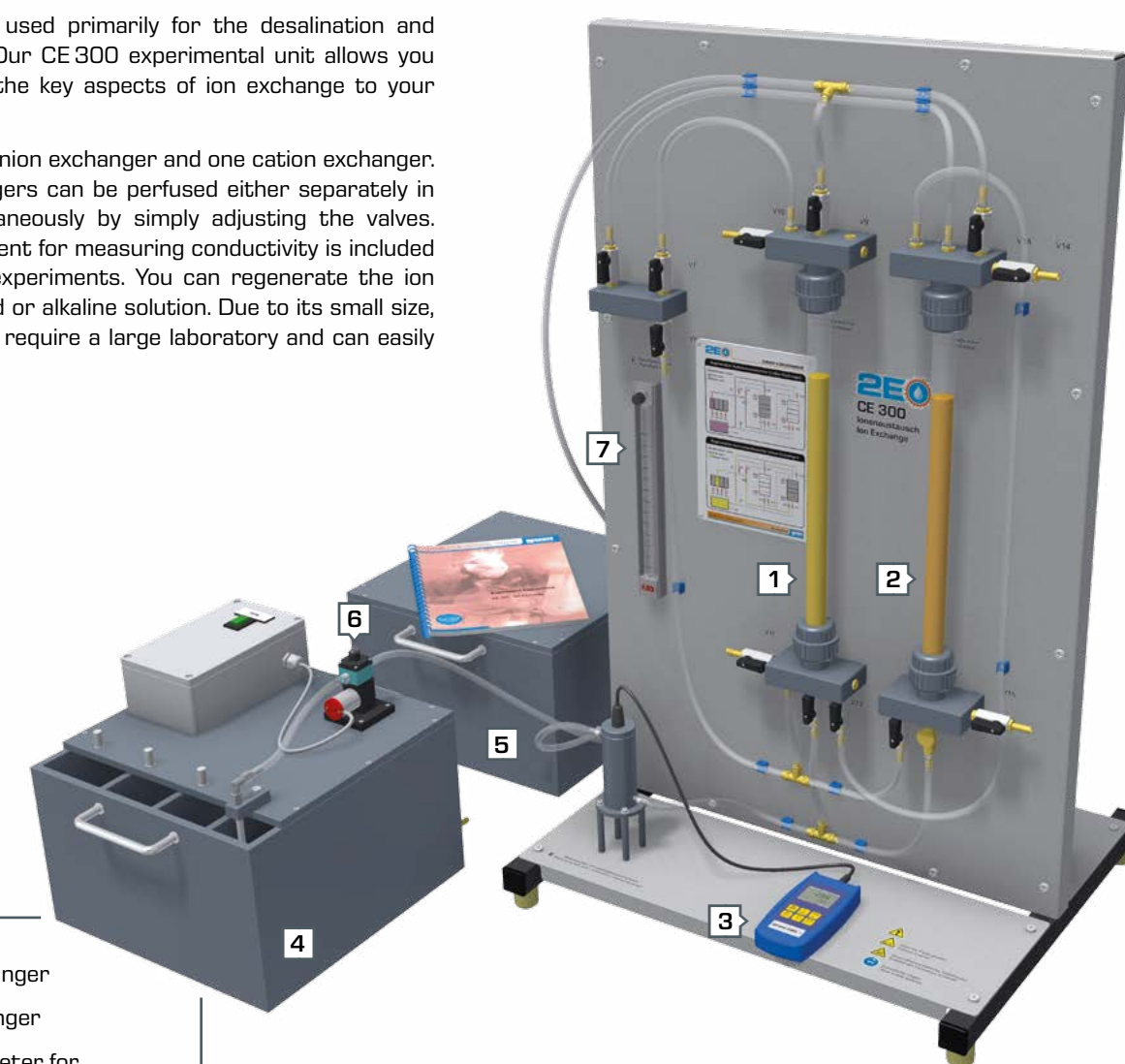
### Learning objectives

- functioning of a spiral-wound membrane module
- assembly, cleaning and conservation of membrane modules
- fundamental principle of reverse osmosis
  - ▶ Van't Hoff's law
- permeate flow rate and retention dependent on
  - ▶ pressure
  - ▶ salt concentration in raw water
  - ▶ yield
- determination of diffusion coefficients

## CE 300 Ion Exchange

Ion exchangers are used primarily for the desalination and softening of water. Our CE 300 experimental unit allows you to demonstrate all the key aspects of ion exchange to your students.

The device has one anion exchanger and one cation exchanger. The two ion exchangers can be perfused either separately in sequence or simultaneously by simply adjusting the valves. A hand-held instrument for measuring conductivity is included for analysis of the experiments. You can regenerate the ion exchangers with acid or alkaline solution. Due to its small size, this device does not require a large laboratory and can easily be set up on tables.



- 1 cation exchanger
- 2 anion exchanger
- 3 hand-held meter for conductivity
- 4 feed tank for raw water and regeneration agent
- 5 collecting tank
- 6 pump
- 7 flow meter

Product No.  
083.30000  
More details and technical data:  
[gunt.de/static/s3582\\_1.php](http://gunt.de/static/s3582_1.php)



### Learning objectives

- functioning of cation and anion exchangers
- desalination by a combination of cation and anion exchangers
- determining the exchanging capacity and regeneration
- checking the theoretically calculated regeneration time



# CE 586 Precipitation and Flocculation

This device can be used to demonstrate precipitation and flocculation in continuous operation and under very realistic conditions. This process is divided into three stages: precipitation, flocculation and sedimentation. All the necessary components are clearly arranged on the trainer. A separate supply unit with a large storage tank is available to produce and pump the raw water.



Precipitation



Flocculation



Sedimentation

- 1 storage tank for raw water
- 2 precipitation tank
- 3 flocculation tank
- 4 lamella separator
- 5 tank for treated water
- 6 metering pump for additives
- 7 switch cabinet with large process schematic
- 8 meter for conductivity

**i** This device is of course accompanied by comprehensive instructional material.

Product No.  
083.58600  
More details and technical data:  
[gunt.de/static/s4863\\_1.php](http://gunt.de/static/s4863_1.php)



Informative videos and more information about CE 586 can be found on our 2E website  
[www.gunt2E.de](http://www.gunt2E.de)



CE 586 is used at many universities worldwide, such as at the British University in Egypt (Cairo).



**BUE**  
The British University in Egypt  
الجامعة البريطانية في مصر  
Department of Civil Engineering



## Learning objectives

- effect of the pH value on precipitation
- creation of a stable operating state
- determining the required dosages of agents
- functional principle of a lamella separator



# CE 584 Advanced Oxidation

## $\text{H}_2\text{O}_2$ and UV

Advanced oxidation processes are state-of-the-art in water treatment. This device enables you to investigate the oxidation of non-biodegradable organic substances using hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) and UV radiation. The educational focus is on the experimental application of reaction kinetics relationships.

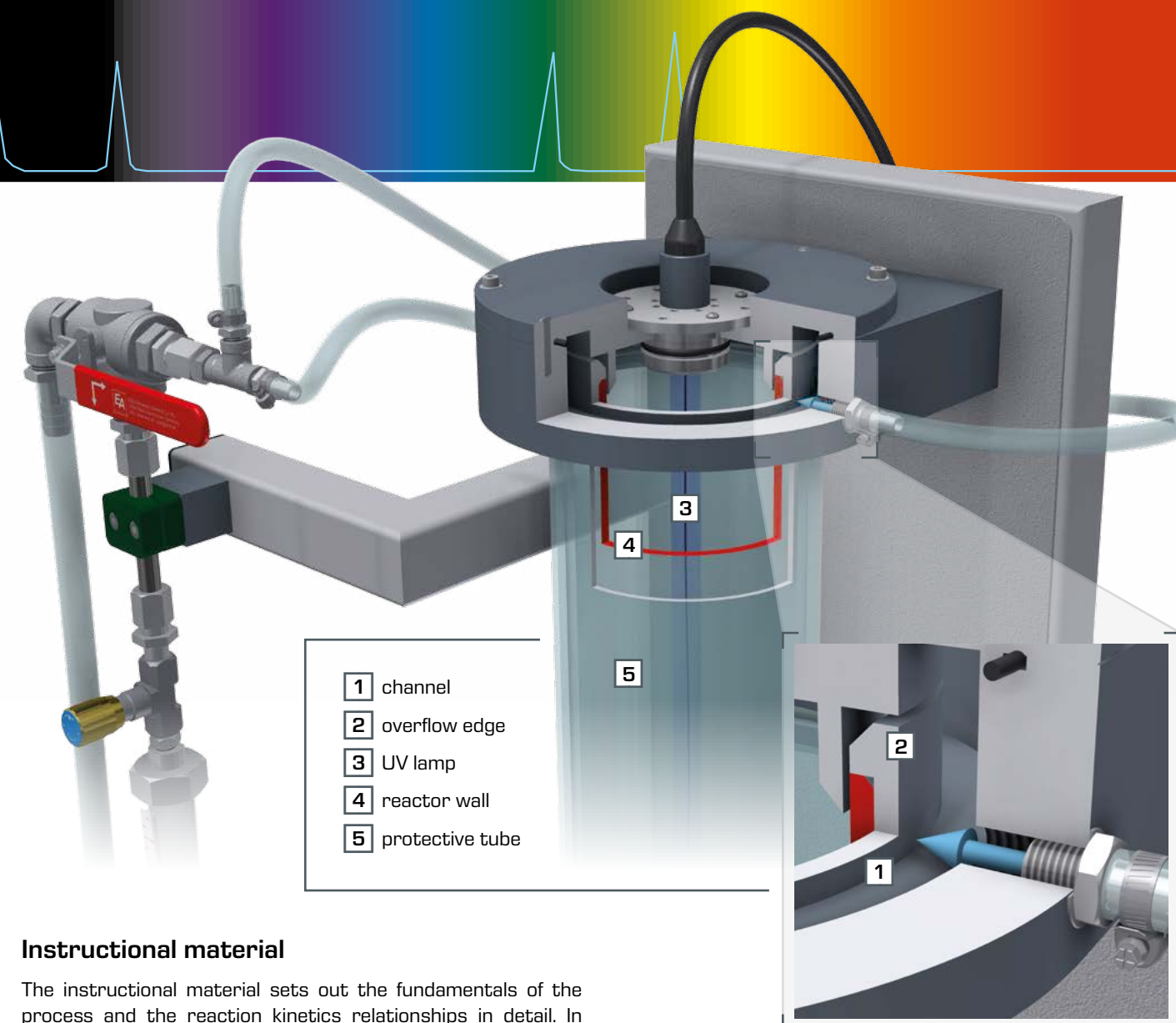
### Falling film reactor in batch mode

The main component of the device is a falling film reactor, which is operated discontinuously. The raw water mixed with hydrogen peroxide is pumped out of a tank into a channel at the upper end of the reactor. The water flows along the inner wall of the reactor, over an overflow edge, flows down as a thin film and finally ends up back in the tank.

At the centre of the reactor there is a UV lamp. Irradiation with UV light (254 nm) causes the hydrogen peroxide to be split into the desired OH radicals.

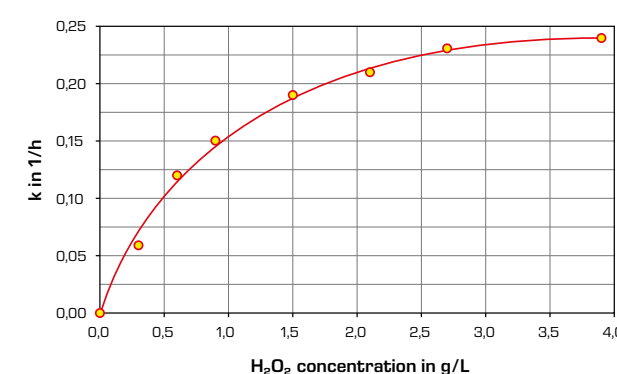


Product No.  
083.58400  
More details and technical data:  
[gunt.de/static/s4861\\_1.php](http://gunt.de/static/s4861_1.php)



### Instructional material

The instructional material sets out the fundamentals of the process and the reaction kinetics relationships in detail. In addition, an experiment is described in detail and evaluated as an example.



Excerpt from the CE 584 manual: rate constant  $k$  as a function of the amount of  $\text{H}_2\text{O}_2$  used. Triethylene glycol dimethyl ether was used as the organic contaminant.

| Learning objectives                                                                                                                                                                                                                                                                                                   |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>plotting concentration time curves</li> <li>investigation of reaction kinetics <ul style="list-style-type: none"> <li>order of reactions</li> <li>reaction rate</li> </ul> </li> <li>effect of amount of <math>\text{H}_2\text{O}_2</math> on the reaction progress</li> </ul> |



# Basic Knowledge Multi-Stage Water Treatment



## Multi-stage water treatment

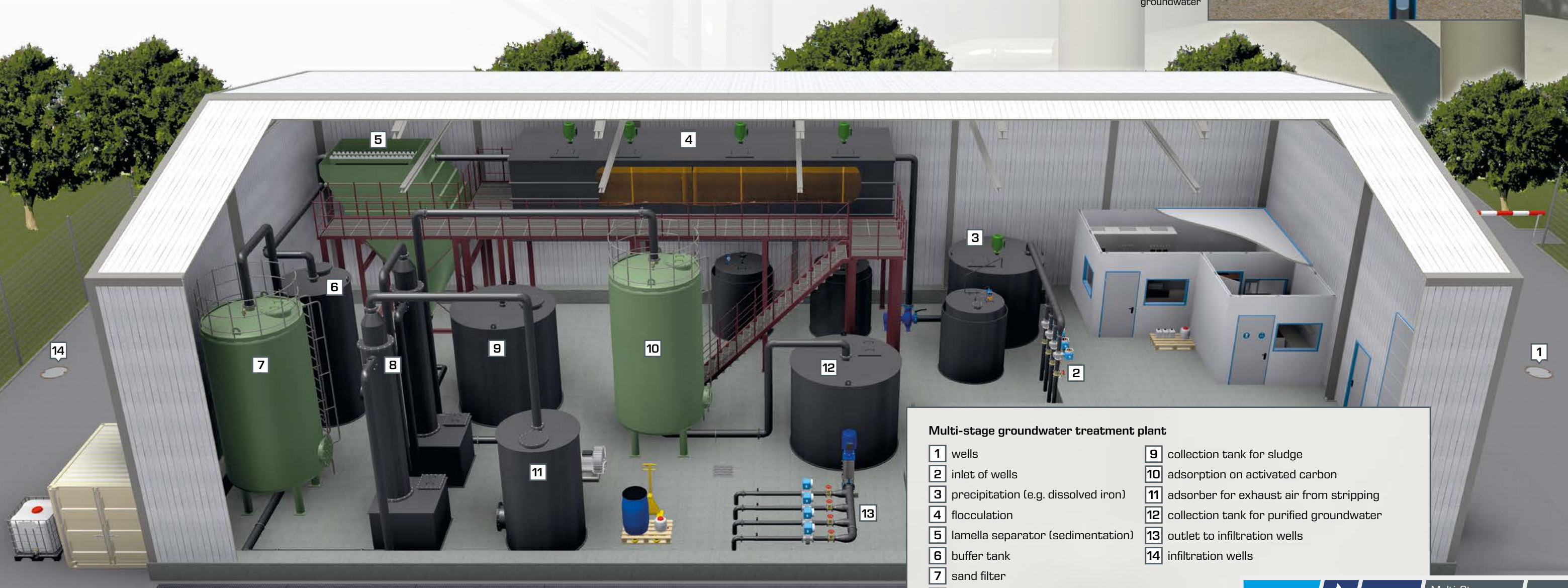
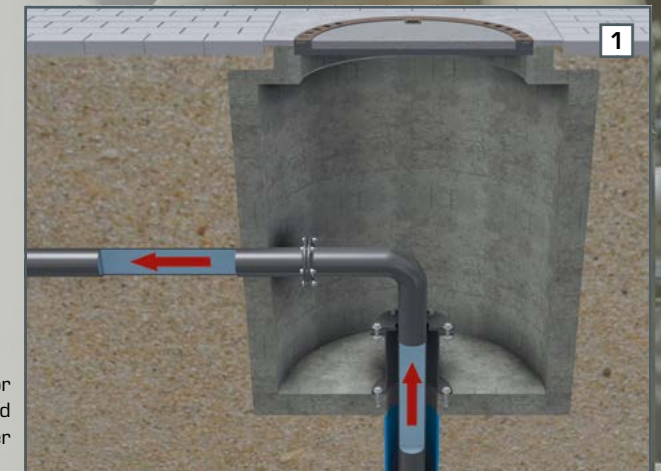
Water to be treated usually contains several substances with different properties. Consequently, a single basic process is not sufficient to remove these substances. Water treatment plants are therefore generally built in several stages.

From the point of view of environmental protection, plants for treating contaminated groundwater are a classic application example of complex, multi-stage water treatment.

Solids contained in the untreated raw water can cause damage or blockages in plant components (e.g. pipelines and pumps). A mechanical treatment is therefore first applied to remove the solids. If the solids only emerge during the course of the water treatment, such as precipitation and flocculation, mechanical treatment steps are also used in the later stages of water treatment.

## Groundwater treatment

Contaminated groundwater is usually treated with the "pump and treat" method. Here, the groundwater is pumped downstream of the contamination zone and purified by conventional processes of water treatment. The purified groundwater is then infiltrated back into the ground upstream of the contamination zone. This creates a circuit into which the groundwater treatment plant is integrated.



### Multi-stage groundwater treatment plant

- |                                       |                                             |
|---------------------------------------|---------------------------------------------|
| 1 wells                               | 9 collection tank for sludge                |
| 2 inlet of wells                      | 10 adsorption on activated carbon           |
| 3 precipitation (e.g. dissolved iron) | 11 adsorber for exhaust air from stripping  |
| 4 flocculation                        | 12 collection tank for purified groundwater |
| 5 lamella separator (sedimentation)   | 13 outlet to infiltration wells             |
| 6 buffer tank                         | 14 infiltration wells                       |
| 7 sand filter                         |                                             |
| 8 stripping                           |                                             |



# CE 581 Water Treatment Plant 1

This device allows you to clearly demonstrate and investigate the features of multi-stage water treatment. There are six consecutive process steps available.

|                  |   |                     |
|------------------|---|---------------------|
| Depth filtration | 1 | gravel filter       |
|                  | 2 | sand filter         |
| Adsorption       | 3 | aluminium oxide     |
|                  | 4 | activated carbon    |
| Ion exchange     | 5 | mixed bed exchanger |
|                  | 6 | cation exchanger    |



## Software

The device is equipped with extensive instrumentation. The device is operated with modern, clearly-arranged software. The software displays all the measured process variables continuously. Of course, the software also allows you to save the measured values for analysis.



## Operating variants

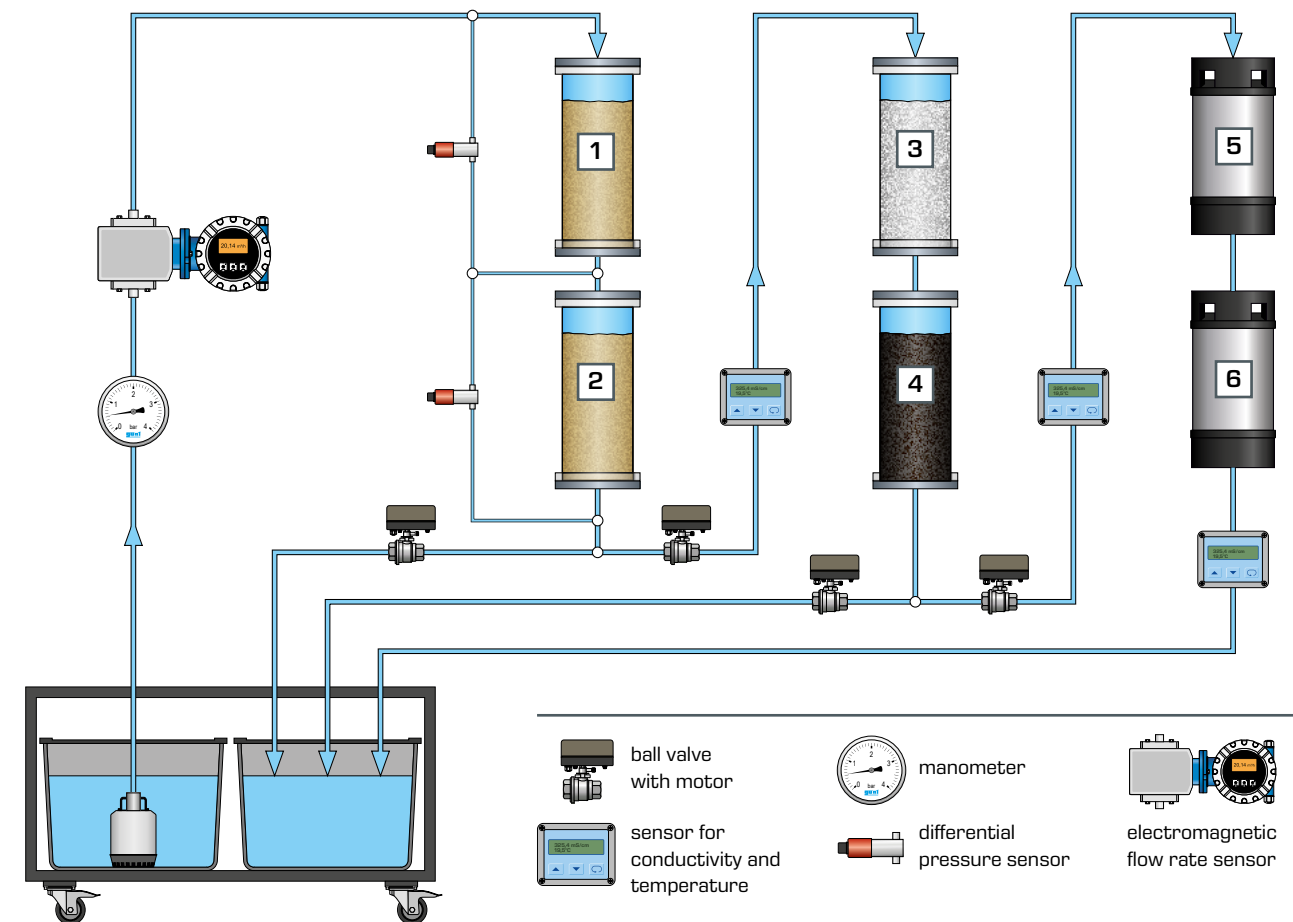
The individual process steps can be enabled or disabled separately. By adjusting electrically driven ball valves, you can choose between the following 3 operating variants:

|           | 1                                   | 2                                   | 3                                   | 4                                   | 5                                   | 6                                   |
|-----------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
| Variant 1 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/>            | <input type="checkbox"/>            | <input type="checkbox"/>            | <input type="checkbox"/>            |
| Variant 2 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input type="checkbox"/>            | <input type="checkbox"/>            |
| Variant 3 | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> | <input checked="" type="checkbox"/> |



## Learning objectives

- learning the fundamental principle of the unit operations depth filtration, adsorption and ion exchange
- observation and determination of the pressure loss in depth filtration
- plotting of breakthrough curves (adsorption)
- comparison of various adsorption materials
- familiarisation with the fundamental principle of ion exchange





# CE 582 Water Treatment Plant 2

## Water treatment with sand filter and ion exchanger

This device allows you to clearly demonstrate and investigate the features of multi-stage water treatment. A sand filter and two ion exchangers are available for this purpose.

With the sand filter the didactic focus is the investigation of the pressure ratios in the filter bed. In order to measure the pressures, the sand filter is fitted with differential pressure measurement and a number of individual measuring points along the filter bed. These measurement points can be connected to a manometer panel, enabling you to measure the

pressure conditions in the filter bed very accurately. The manometer panel has 20 separate tube manometers. By using a transparent filter tube, you can also observe the increased loading of the filter bed visually. The sand filter can be rinsed back if necessary.

Ion exchange takes place after filtration. A cation exchanger and an anion exchanger are available for this purpose. The device also allows for regeneration of the ion exchanger.



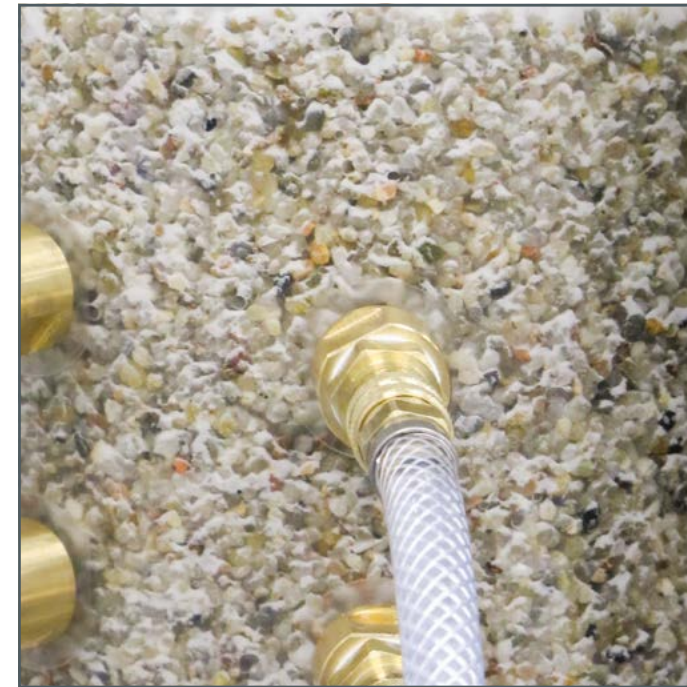
Developed in collaboration  
with the University  
of Magdeburg (Germany)



- 1 manometer panel
- 2 sand filter
- 3 ion exchanger
- 4 storage tank for regeneration agent
- 5 tank for raw water and treated water
- 6 backwash pump

Product No.  
083.58200

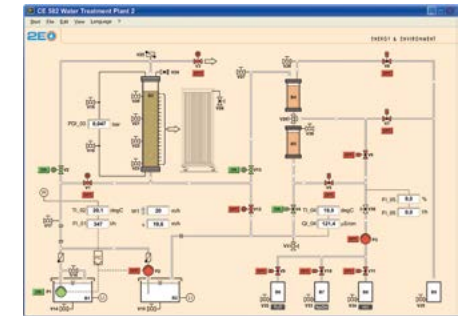
More details and technical data:  
[gunt.de/static/s4847\\_1.php](http://gunt.de/static/s4847_1.php)



By using a transparent filter tube, you can also observe the increased loading of the filter bed visually as well as using the rise in pressure loss.



Standard at GUNT: use of professional instrumentation



### Software

The device is equipped with extensive instrumentation. The device is operated with modern and clearly-arranged software. The software displays all measured process variables continuously. Of course, the software also allows you to save the measured values for analysis.



### Learning objectives

- observation and determination of pressure losses in a sand filter
- plotting of Mische diagrams
- backwash of sand filters
- modes of operation of cation and anion exchangers
- regeneration of ion exchangers



2E a division of



This product area is one of GUNT's current areas of development. If you have any ideas for future teaching and research equipment in this field, please get in touch. We would love to work with you.

## Introduction



**Subject Areas**  
Air

284



**Basic Knowledge**  
Air Pollution Control

286

## Mechanical Processes



**CE 235**  
Gas Cyclone

288

## Thermal Processes



**CE 400**  
Gas Absorption

290



**CE 540**  
Adsorptive Air Drying

292



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[www.gunt2e.de](http://www.gunt2e.de)





# Subject Areas Air



 Subject Areas

 Products

The didactic focus of the air subject area is the various methods for treating gaseous media (air pollution control). Most contaminants can be removed from an exhaust airflow by mechanical or thermal processes.

## Mechanical processes

Mechanical processes are used to remove solid particles from an exhaust airflow (dust extraction). Gas cyclones are a very effective and therefore widely used method for dust extraction. Our CE 235 device allows you to clearly demonstrate this process.

## Thermal processes

The use of thermal processes is suitable if the exhaust air to be cleaned contains gaseous contaminants. Most often these are absorption and adsorption. We offer you trainers for both of these processes, in order to investigate the theoretical fundamentals of both processes in a practical way in the laboratory.

Mechanical processes

**CE 235**  
Gas Cyclone

Thermal processes

**CE 400**  
Gas Absorption  
**CE 540**  
Adsorptive Air Drying



The processes used in air pollution control have their origins in classical process engineering. Other devices of interest from this field can be found in our catalogue 5.



# Basic Knowledge

# Air Pollution Control

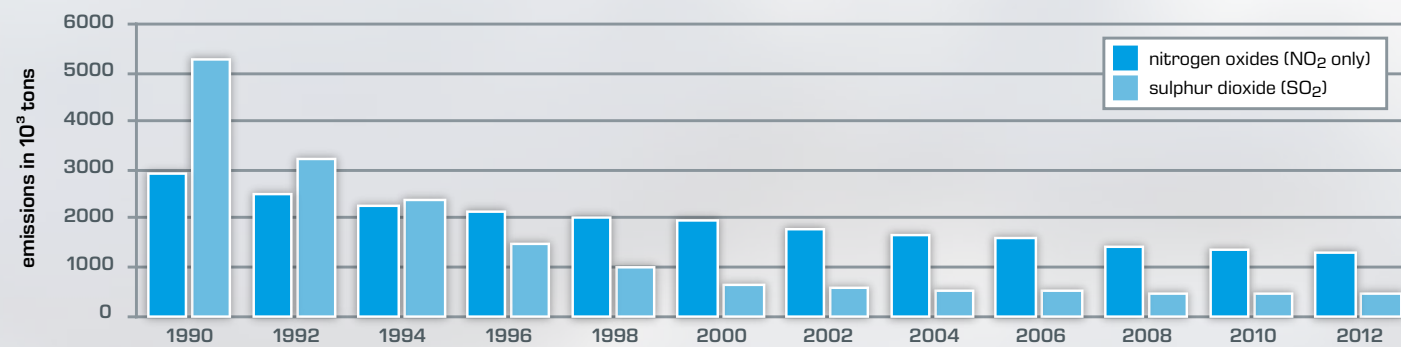
## Air – the basis of life for all living beings

The composition of the atmosphere has changed considerably since the beginning of industrialisation due to the interference of mankind. The destruction of the ozone layer and global warming are becoming ever more visible and are undoubtedly attributable to the excessive discharge of contaminants into the atmosphere. This poses a serious threat to all life on earth. The goal therefore must be to reduce the discharge of contaminants into the atmosphere as far as possible. Primarily, it is desirable to reduce the amount of contaminants that occur. Where this is not possible, the exhaust air must be cleaned by suitable processes.

## Worldwide contaminant transport

The effects of a contaminant entering the atmosphere are not restricted locally. Instead, contaminants are transported by wind over many thousands of kilometres above the earth. This explains why nowadays contaminants are detected in the atmosphere even in the most remote regions far away from civilisation.

The most well-known example is the "Arctic Haze", the yellowish brown haze appearing over the Arctic in winter and spring. Aerosols from the industrial regions in Eastern Europe and Asia are regarded as the main cause for this phenomenon. The aerosols are mainly composed of sulphur and carbon.



Emissions of sulphur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>2</sub> only) in Germany

Source: Federal Environment Agency, national trend tables for German reporting of atmospheric emissions (published 2014)

## Processes of air pollution control

A number of processes are available for air pollution control, of which most can be categorised into one of the following groups:

- mechanical processes
- biological processes
- thermal processes

## Biological processes

In biological processes, gaseous components are degraded microbiologically. Since the components must be biodegradable and may only be present in low concentrations, the field of application of biological processes is very limited. Biological processes are mainly used for odour problems such as occur in rendering plants, for example.

## Mechanical processes

The aim of mechanical processes is separation of particles from an exhaust gas flow (dust extraction). The separation of particulate matter in particular is of great importance.

### Centrifugal force separator (cyclone)

The gas flow to be cleaned is forced into a circular path in a cyclone. The resulting centrifugal force acting on the particulate matter amounts to a multiple of the force of gravity. This explains why this process can also separate very small particles in comparison to simple gravity separation (sedimentation). The separation limit of cyclones is of the order of 10 µm.

### Electrostatic separators

In an electrostatic separator, the particles are first electrically charged. The charged particles then deposit onto an oppositely charged electrode. A layer of dust, which must be removed mechanically every so often, forms on the electrode. An electrostatic separator can be used to separate out particles smaller than 1 µm.

## Thermal processes

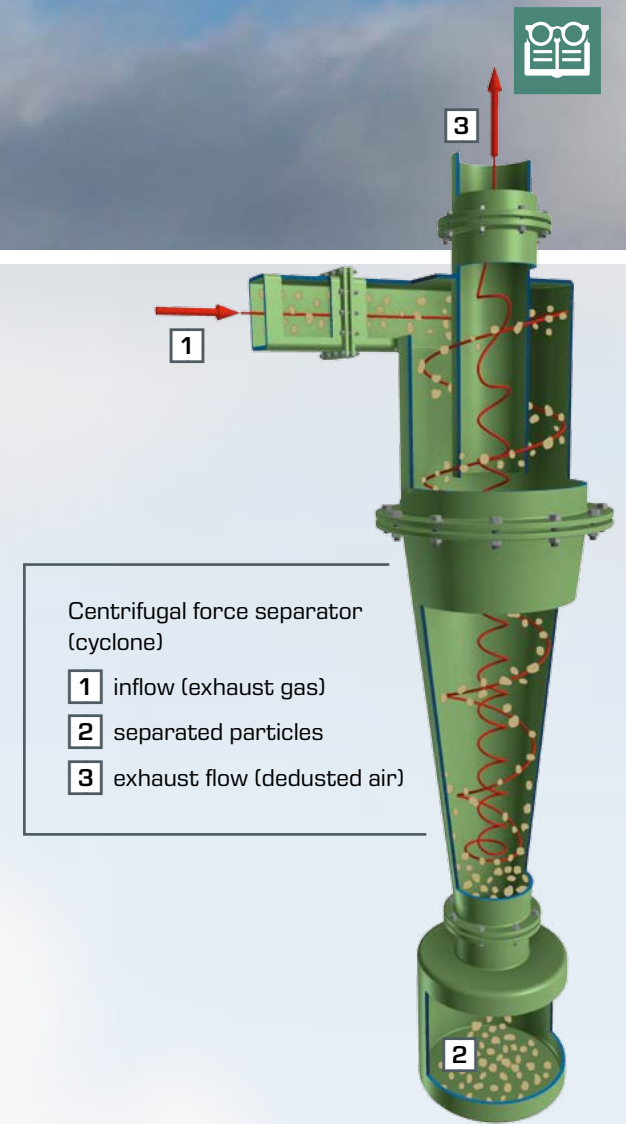
Physical/chemical processes are used to remove gaseous contaminants. Two of the most widespread processes are absorption and adsorption. Both processes are versatile and suitable for removing nitrogen oxides, sulphur dioxide, hydrogen sulphide and carbon dioxide, for example. Essentially, for both processes it can be said that the exhaust gas should largely be free of dust, which means mechanical cleaning needs to take place initially.

## Absorption

At least three components are involved in absorption: the contaminant to be separated, the carrier gas and a solvent. The solvent absorbs the gaseous substance; this can be implemented physically or chemically. In order to ensure that the solvent only absorbs the contaminant and not the carrier gas, the solvent must be adapted to the respective application.

## Adsorption

In adsorption, the contaminant to be removed is bonded to the surface of a solid (adsorbent). As with absorption, this can use either physical or chemical means. Activated carbon is a very frequently-used adsorbent. Adsorption is favoured by low temperatures. The exhaust gas to be cleaned should therefore not be warmer than 30 °C.





# CE 235 Gas Cyclone

Gas cyclones are used for separating solid particles from an airflow. This device can be used to teach the fundamentals of this important process in the field of air pollution control.

The CE 235 cyclone is made of transparent material. This allows you to observe the spiral motion of the solid particles down to the bottom of the cyclone.

You can of course adjust all characteristic variables relevant to the process. These include the volumetric flow rate and the solids content of the raw gas. In order to adjust the solids content, the device is equipped with a disperser. The temperature of the raw gas, the differential pressure across the cyclone and the feed rate of the feed material are measured and displayed digitally.



Product No.  
083.23500  
More details and technical data:  
[gunt.de/static/s4832\\_1.php](http://gunt.de/static/s4832_1.php)



Separation of respirable crystalline silica in the gas cyclone during a test run in our laboratory. You can see the spiral motion of the particles which is characteristic of cyclones.



## Learning objectives

- influence of solid content and volumetric airflow rate on
  - ▶ pressure loss at the cyclone
  - ▶ degree of separation
  - ▶ separation function and separation size
- comparison of pressure loss and degree of separation with theoretically calculated values

**TUHH**

Technische Universität Hamburg-Harburg

This device has been developed by our experienced engineers in collaboration with the Institute of Solids Process Engineering and Particle Technology at the Hamburg University of Technology (Germany).



# CE 400 Gas Absorption

Absorption processes are used in air pollution control. One typical application is cleaning exhaust air for the desulphurisation of gases in power stations. The CE 400 trainer allows you to clearly demonstrate the complex theoretical fundamentals of this process in the laboratory.

The device is designed for the absorptive separation of carbon dioxide from an airflow. Water is used as solvent for absorbing the carbon dioxide. This ensures safe operation for the device user.



- 1 switch cabinet
- 2 absorption columns
- 3 U-tube manometer
- 4 desorption column
- 5 refrigeration system
- 6 cooling tank
- 7 process schematic

Product No.  
083.40000  
More details and technical data:  
[gunt.de/static/s3473\\_1.php](http://gunt.de/static/s3473_1.php)



## Principle of operation

The main components of the device are two absorption columns filled with Raschig rings. The previously-cooled air/CO<sub>2</sub> mixture is fed into the absorption columns from below. The solvent (water) trickles downwards in the opposite direction through the absorption columns, whereby the carbon dioxide is dissolved in the water. The water enriched with carbon dioxide in this way can then be regenerated in a desorption column and is then available for absorption again.

## Instrumentation

The device is equipped with extensive instrumentation and control technology. All relevant flow rates, temperatures and pressures are continuously measured and displayed. The absorption columns are each equipped with a U-tube manometer to measure the differential pressures. You can check the success of the absorption process using the supplied gas analyser. Therefore you do not need any additional instrumentation in order to obtain quantifiable results.



Gas analyser for determining the oxygen content and carbon dioxide content.

## UNIVERSITY OF Hull

CE 400 is used in many universities worldwide, for example at the University of Hull (England).



A GUNT employee explains the functional principle of CE 400 gas absorption to lecturers at the University of Hull.

## Learning objectives

- investigation of the absorption process when separating gas mixtures in a packed column
- determination of pressure losses in the column
- representation of the absorption process in an operating diagram
- investigation of the variables influencing the effectiveness of absorption



# CE 540

## Adsorptive Air Drying

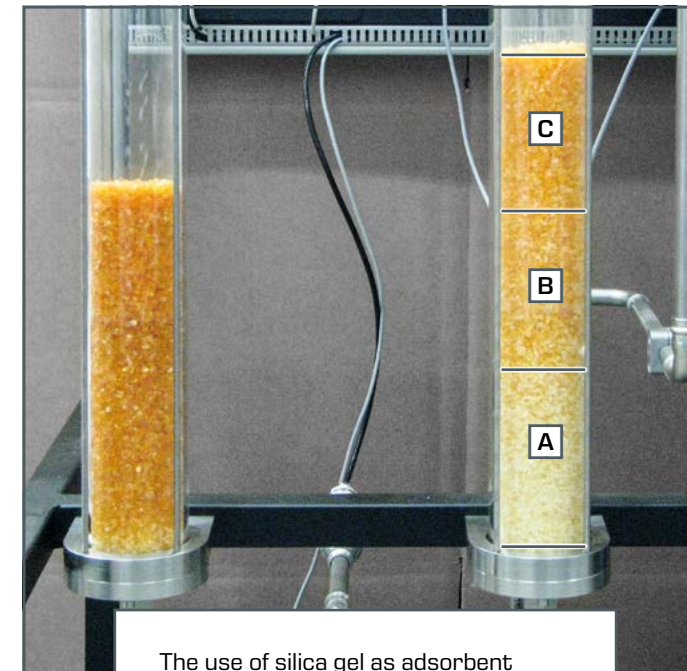
Adsorption processes are used in air pollution control. A typical example is the removal of hydrocarbon contaminants, such as those occurring during painting and printing processes. The CE 540 trainer allows you to clearly demonstrate the complex theoretical fundamentals of this process in the laboratory.

The device is designed for the adsorptive separation of moisture from an airflow. Silica gel is used as adsorbent for absorbing the moisture. This ensures safe operation for the device user. The silica gel discolours as the load increases, which also makes the adsorption process clearly visible.



- 1 adsorption columns
- 2 humidifier (water bath)
- 3 compressor for supply air
- 4 refrigeration system
- 5 flow meter
- 6 switch cabinet
- 7 heater for regeneration air

Product No.  
083.54000  
More details and technical data:  
[gunt.de/static/s4785\\_1.php](http://gunt.de/static/s4785_1.php)



The use of silica gel as adsorbent makes the three zones in an adsorber clearly visible:

- A loaded silica gel
- B partially loaded silica gel (mass transfer zone)
- C unloaded silica gel

### Principle of operation

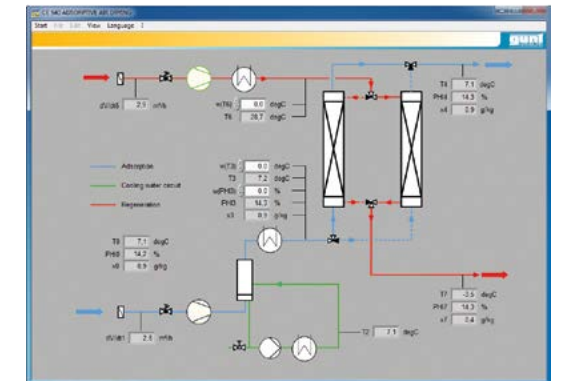
The main components of the device are two columns filled with silica gel. First the moistened ambient air is fed into the columns by a compressor. Here the silica gel adsorbs the moisture present in the air. The silica gel can be regenerated once its maximum load is reached. The silica gel is regenerated via the passage of heated air. In this process, the silica gel returns to its original colour and can be used again. No consumables subsequently requiring disposal are used during this process.

### Instrumentation

Temperatures and moisture levels are measured at all relevant points. This allows you to draw up a full balance for the process.

### Software

The clearly-arranged software included with CE 540 displays all measured values continuously. The software also functions as a controller for the temperature and moisture in the inflow of the adsorber. You can of course save all measured values for later analysis.



### Learning objectives

- fundamental principle of adsorption and desorption
- investigation of the variables influencing adsorption and desorption
  - ▶ airflow rate
  - ▶ air humidity and temperature
  - ▶ bed height of adsorbent
- depiction of the processes in a  $h$ - $\omega$  diagram
- plotting of breakthrough curves
- determination of breakthrough time



## Introduction

**Subject Areas**  
Soil

296

## Hydrogeology

**Basic Knowledge**  
Hydrogeology

298

**HM 165**  
Studies in Hydrology

300

**HM 141**  
Hydrographs after Precipitation

302

**HM 167**  
Ground Water Flow

304

**HM 169**  
Visualisation of Seepage Flows

306

## Soil Treatment

**Basic Knowledge**  
Soil Treatment

308

**CE 225**  
Hydrocyclone

310

**CE 630**  
Solid-Liquid Extraction

312

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[www.gunt2e.de](http://www.gunt2e.de)



# Subject Areas

## Soil



### Subject Areas

### 2E Products

Complex processes which can have a negative impact on this habitat take place in the soil. For budding engineers and specialist technicians in the field of environmental engineering, it is therefore necessary to develop an understanding of these processes. The subject areas in the soil area comprise hydrogeology and soil treatment.

#### Hydrogeology

In the field of hydrogeology, we offer selected training equipment which will help you to teach the basic hydrogeological processes in soils in a practical and clear manner. Issues such as seepage of precipitation, seepage flows and groundwater flows are studied. Other devices of interest on these and related topics can be found in our catalogue 4b "Hydraulics for Civil Engineering".

#### Soil treatment

In this subject area you will find selected teaching devices which cover the processes typically used in the treatment of contaminated soils. Most of these processes have their origins in classical process engineering. Our complete range in the field of process engineering can be found in our catalogue 5.

#### Hydrogeology

**HM 165**

Studies in Hydrology

**HM 141**

Hydrographs after Precipitation

**HM 167**

Ground Water Flow

**HM 169**

Visualisation of Seepage Flows

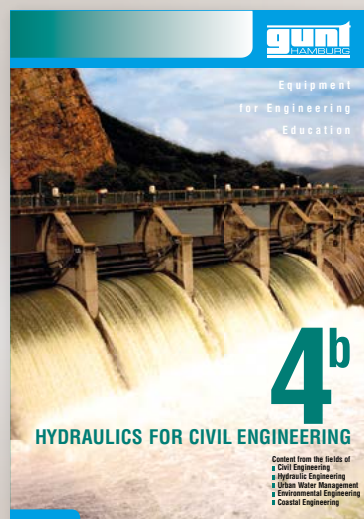
#### Soil treatment

**CE 225**

Hydrocyclone

**CE 630**

Solid-Liquid Extraction





# Basic Knowledge Hydrogeology



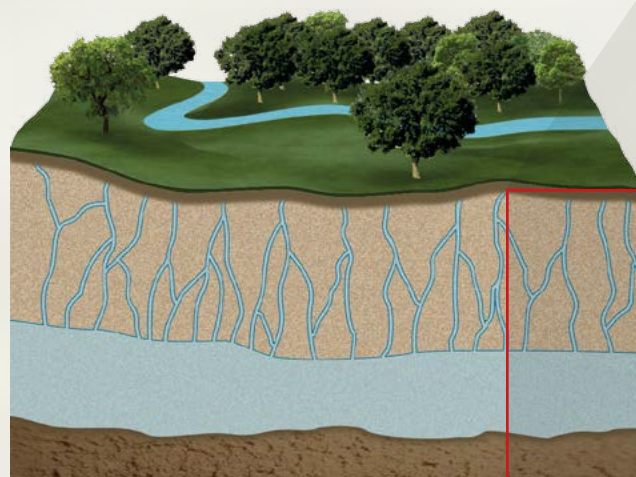
## What is hydrogeology?

Hydrogeology is an applied discipline of geosciences. Unlike hydrology, which deals with above-ground water, hydrogeology covers all aspects which are related to water contained in the ground. These include the following topics in particular:

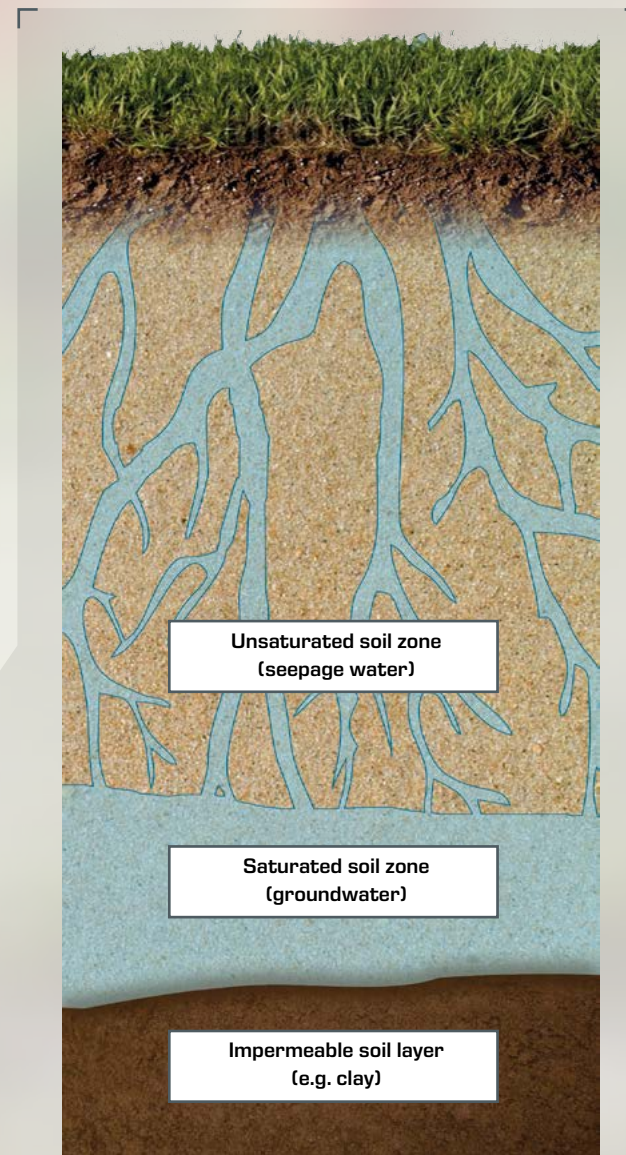
- seepage and storage of precipitation
- flow processes in soils (e.g. seepage flows)
- regeneration, flow and pumping of groundwater
- drainage measures
- impact of construction on the hydrogeological conditions in the ground

## Flow processes in soils

Flow processes in soils are of central importance in hydrogeology. Such flow processes take place in different soil layers. We must always distinguish between the unsaturated and saturated soil zones. The upper layer is usually not completely saturated with water, so some pores also contain air. Below this region is a soil zone whose pores are completely filled with water. This zone is therefore also referred to as the saturated soil zone.



Basic knowledge of these topics is necessary, for example in the exploration, evaluation and use of groundwater resources. Other applications include the protection of groundwater through safeguarding and remedial measures and the drainage of precipitation.



## Groundwater: vital reservoir

Groundwater is underground water which fills the pores of the earth's crust and whose possibility for movement is determined solely by the force of gravity. Groundwater fulfils many important functions, for example as a reservoir for drinking water production. Furthermore, an intact groundwater table is an important component of the global water cycle.

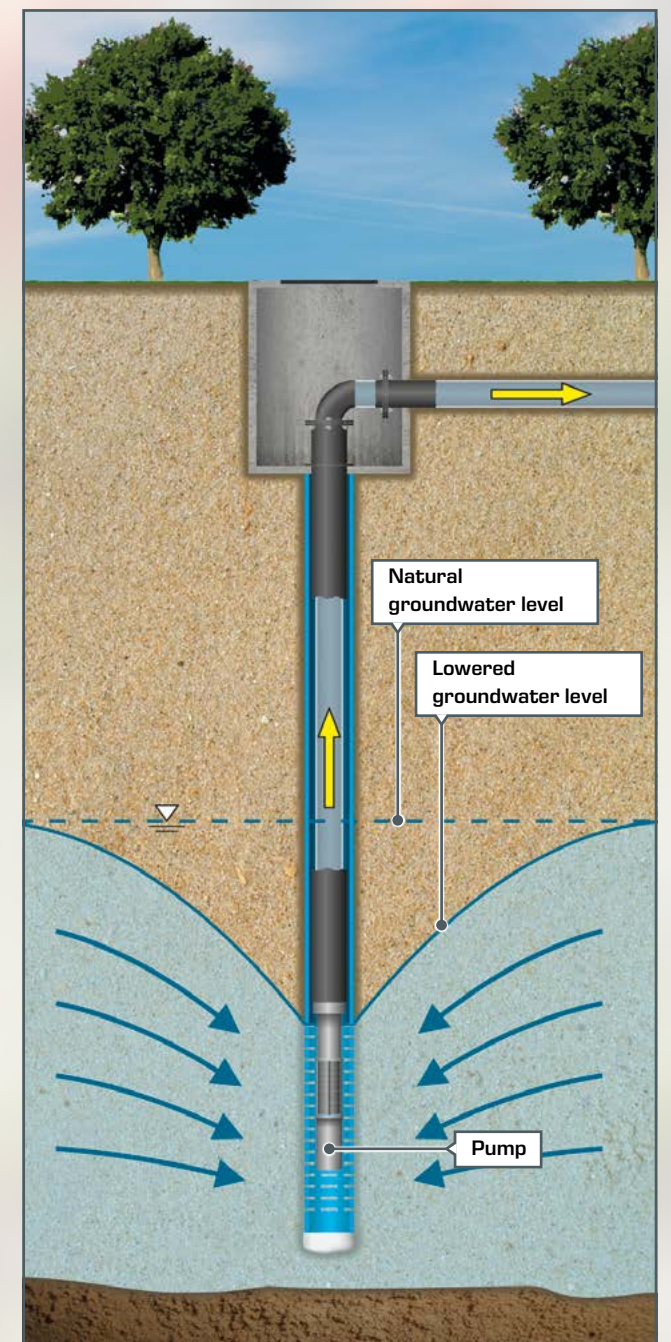
## Interventions in hydrogeology

In the past, the improper handling of chemicals has allowed many toxic substances to enter groundwater. The aim of sustainable environmental engineering is therefore to provide a sustainable use of groundwater whilst largely avoiding the harmful effects on the groundwater table at the same time. Where contaminants have already entered the groundwater, safeguarding or remedying of the affected area is required to prevent further spread of the contamination.

Many structural measures affect hydrogeological conditions in the soil. Therefore such construction projects require solid hydrogeological knowledge and must be planned with great care.

For example, the extraction of groundwater by production wells results in a funnel-shaped lowering of the groundwater level.

In structures where flow passes underneath or through, such as sheet piles and dams, exact knowledge of the course of seepage flows is a crucial factor in the stability of the structures. Such structures must therefore be realised while taking the hydrogeological impact into account.



Depression cone in the extraction of groundwater



# HM 165 Studies in Hydrology

Hydrological studies are conducted in connection with the design, construction and operation of hydraulic engineering systems and water management functions. These studies focus on topics such as seepage and flow of water in the soil and the use of groundwater resources.

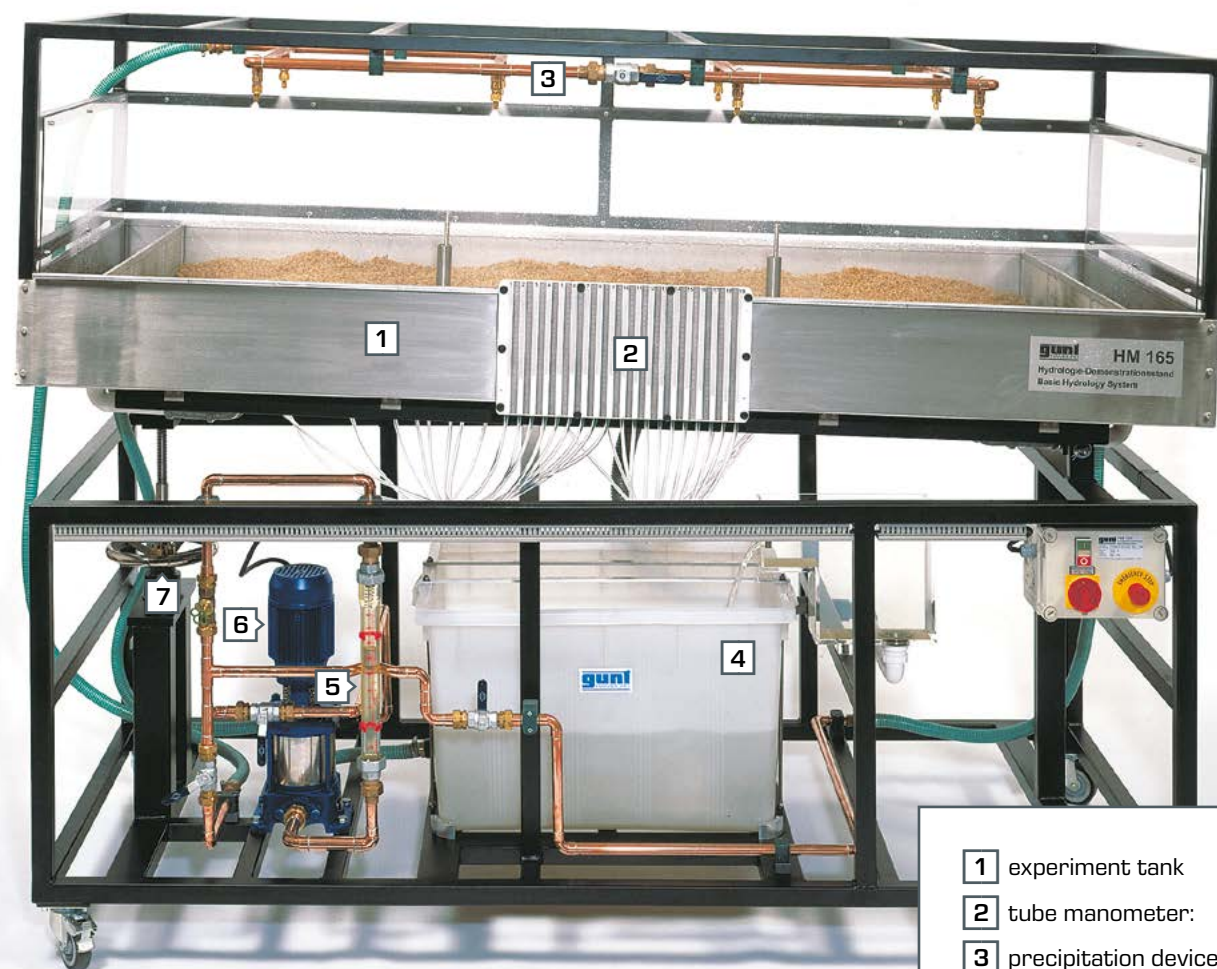
This device can be used to study seepage and groundwater flows after precipitation. In particular, the permeability and storage capacity of soils can easily be observed. Many adjustable parameters allow a wide range of experiments.



Precipitation device with nozzles for realistic simulation of rainfall



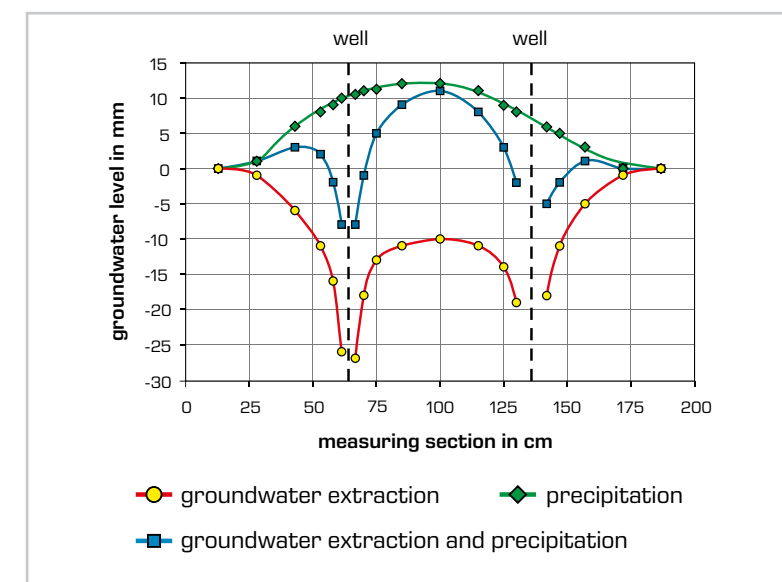
19 tube manometers allow very detailed measurement of the groundwater level.



- 1 experiment tank
- 2 tube manometer:
- 3 precipitation device
- 4 storage tank
- 5 flow meter
- 6 pump
- 7 inclination adjustment

To illustrate groundwater flow, the water is supplied to the experiment tank via two side-mounted chambers. A precipitation device is available for studying precipitation. There are two wells with perforated tubes or two side-mounted chambers with drainage screens available for the investigation of various drainage systems. At the bottom of the experiment tank are 19 connections for measuring groundwater levels which are indicated on tube manometers.

With this device you also receive comprehensive instructional material. A detailed description of selected experiments enables you to quickly incorporate the device into your teaching.



Excerpt from the HM 165 manual: measured island groundwater levels for three different scenarios.

**Learning objectives**

- investigating transient processes
  - ▶ studying how precipitation of varying duration affects drainage
  - ▶ storage capacity of a soil
- investigating steady processes
  - ▶ investigating the seepage flow
  - ▶ effect of different soil saturation levels

Product No.  
070.16500  
More details and technical data:  
[gunt.de/static/s3193\\_1.php](http://gunt.de/static/s3193_1.php)



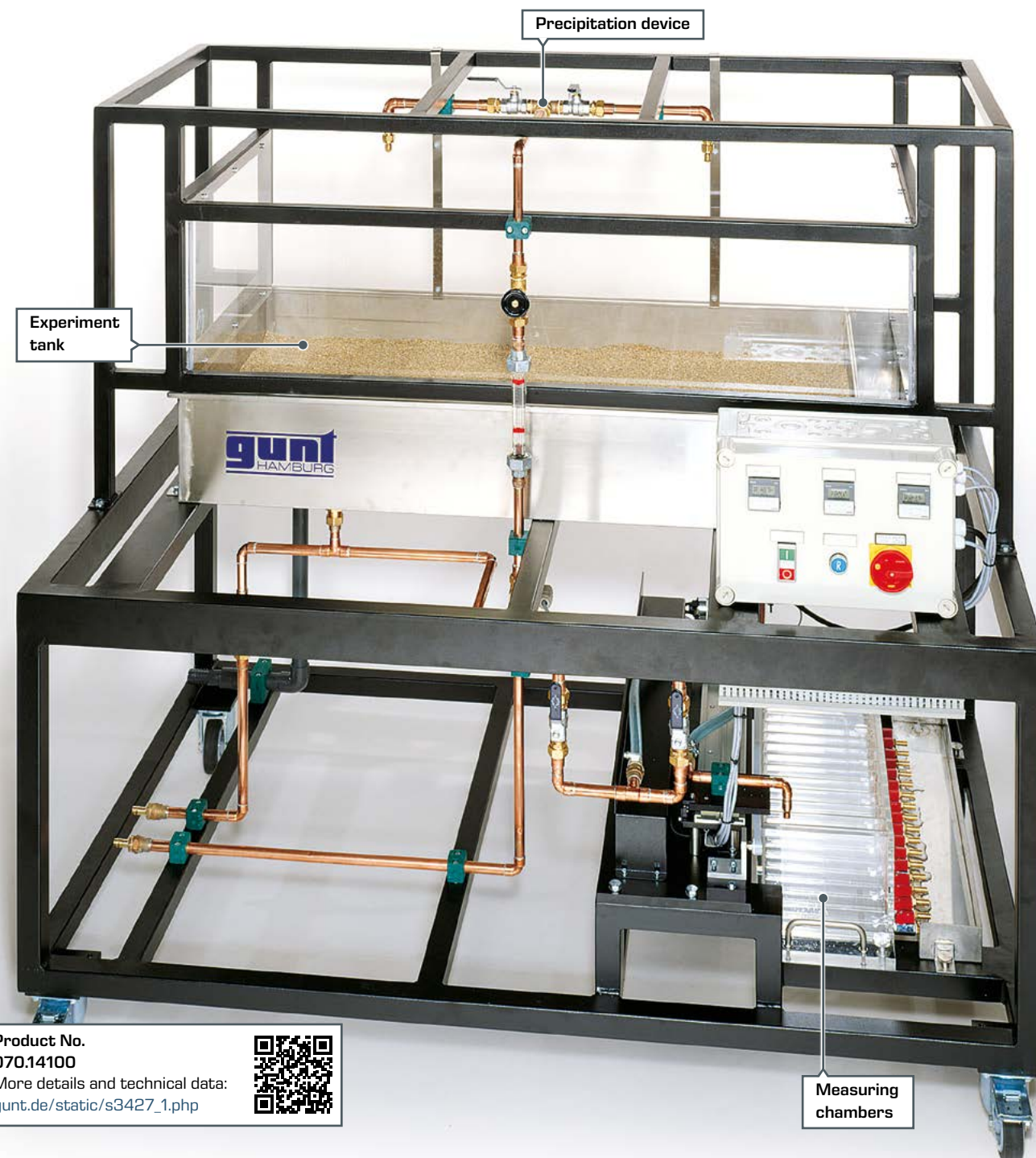


# HM 141 Hydrographs after Precipitation

Hydrographs are an important tool for the representation of hydrological data such as precipitation, groundwater levels or drainage. Furthermore, a hydrograph is the basis for the design of sewer systems. In this case, the progress of the amount of precipitation over time is just as important as the quality of the soil.

## i Hydrograph

A hydrograph is defined as the graphical representation of drainage (for example in  $\text{m}^3/\text{h}$ ) at a particular measuring point as a function of time.

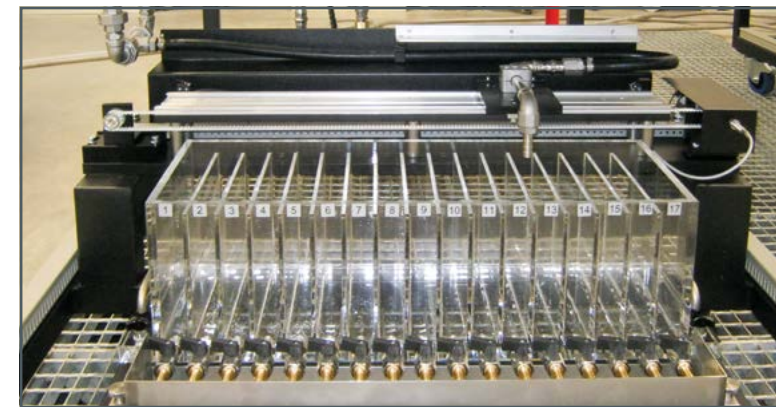


Product No.  
070.14100  
More details and technical data:  
[gunt.de/static/s3427\\_1.php](http://gunt.de/static/s3427_1.php)

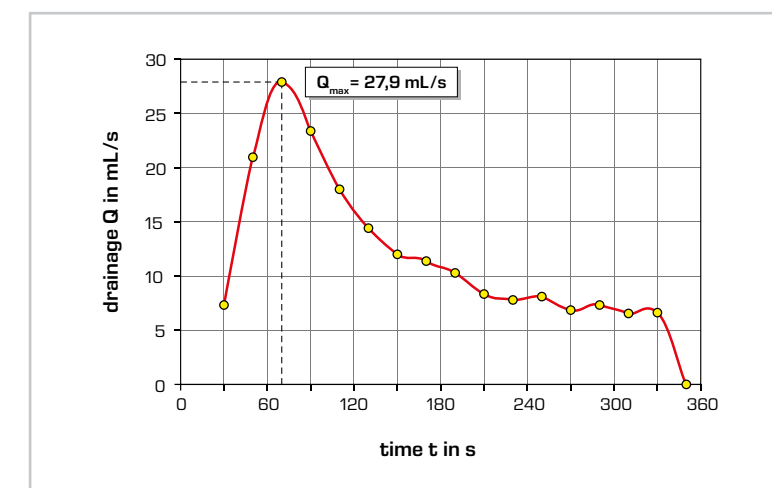


The core element of HM141 is an experiment tank filled with sand or gravel. Using timers, you can apply precipitation to the experiment area with varying duration and intensity. The drainage of the experiment area can be implemented either with a drainage tube or a drainage chamber located at the side of the experiment tank.

The water draining from the experiment tank is filled successively into 17 measurement chambers controlled by time. Determining the amount of water in the individual measurement chambers allows you to determine the timing of drainage from the experiment area, i.e. the hydrograph.



The measuring chambers are filled successively in a time controlled manner.



Excerpt from the HM 141 manual: typical hydrograph curve with drainage via lateral outflow chambers. The maximum drainage occurring in this precipitation event can be determined from the hydrograph.

| Learning objectives                                                                                                                                                                                                                                                                                                                                                                                |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>effect of precipitation of varying duration or intensity on soils with different saturation</li> <li>record hydrographs after precipitation</li> <li>storage capacity of soils with different saturation</li> <li>compare natural dewatering with dewatering via drainage pipe</li> <li>influence of rainwater retention basin on the hydrograph</li> </ul> |



# HM 167 Ground Water Flow

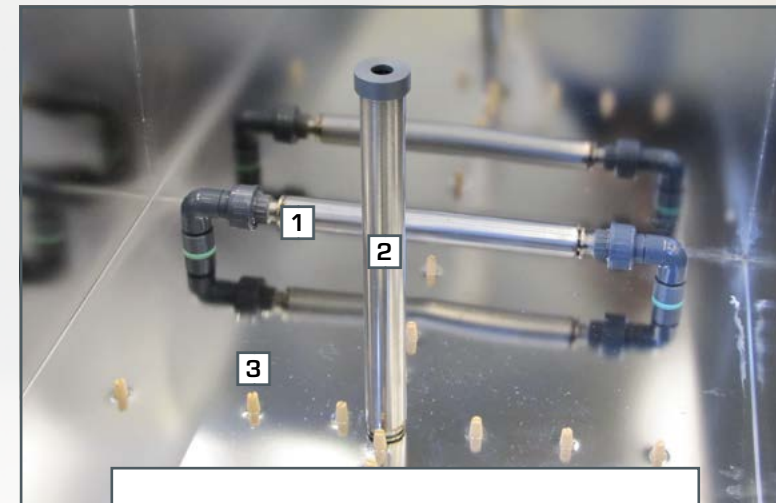
Many structural measures have an impact on the groundwater level. This may be the case for example in usage of groundwater, in flood prevention or in remedial measures. Exact knowledge of the effects of such structures on the groundwater level is therefore an important foundation for planning for environmental engineers.

We have developed our HM 167 device in order to practically teach such issues. The trainer allows you to represent typical structural scenarios and to investigate their influence on the groundwater flow in three dimensions.

The core element of HM 167 is an experiment tank filled with sand or gravel. You can use different models in the experiment tank to simulate structures. The models can be used to study dykes, excavation pits and wells.



Models for installation in the experiment tank



- 1 experiment tank with water supply
- 2 well
- 3 measuring points for groundwater level

The experiment tank is fitted with an inlet at both ends. The study of various drainage processes is made possible by two wells. You can activate the inlets and wells independently of each other. This results in many experimental possibilities.

In order to determine the groundwater levels, the experiment tank is equipped with a total of 19 measurement points. The groundwater levels are clearly displayed on tube manometers. In addition to the tube manometers, scales on the side allow for easy and accurate reading of groundwater levels.

| Learning objectives                                                                                                                                                                                                                                  |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>determining the groundwater level</li><li>lowering of groundwater level via two wells</li><li>groundwater flow on excavation pits</li><li>groundwater studies under concentric load on the substrate</li></ul> |





# HM 169

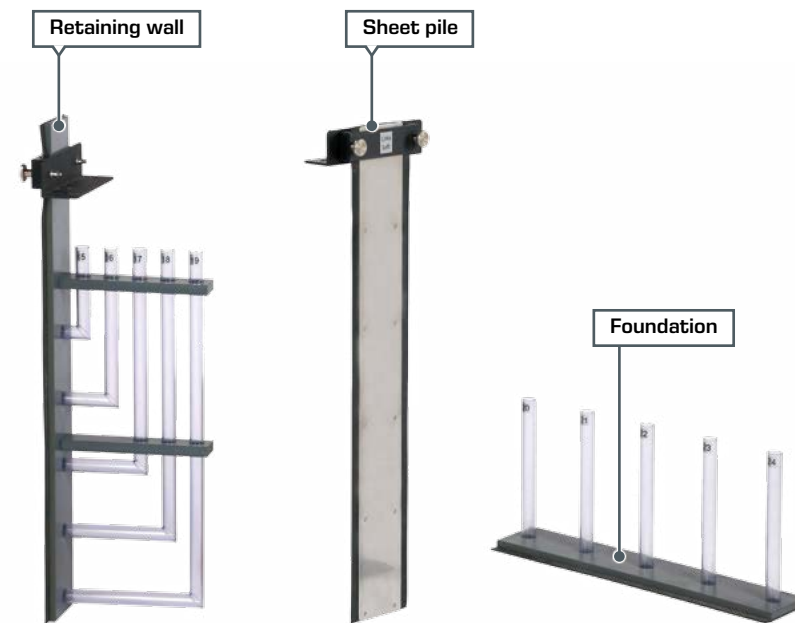
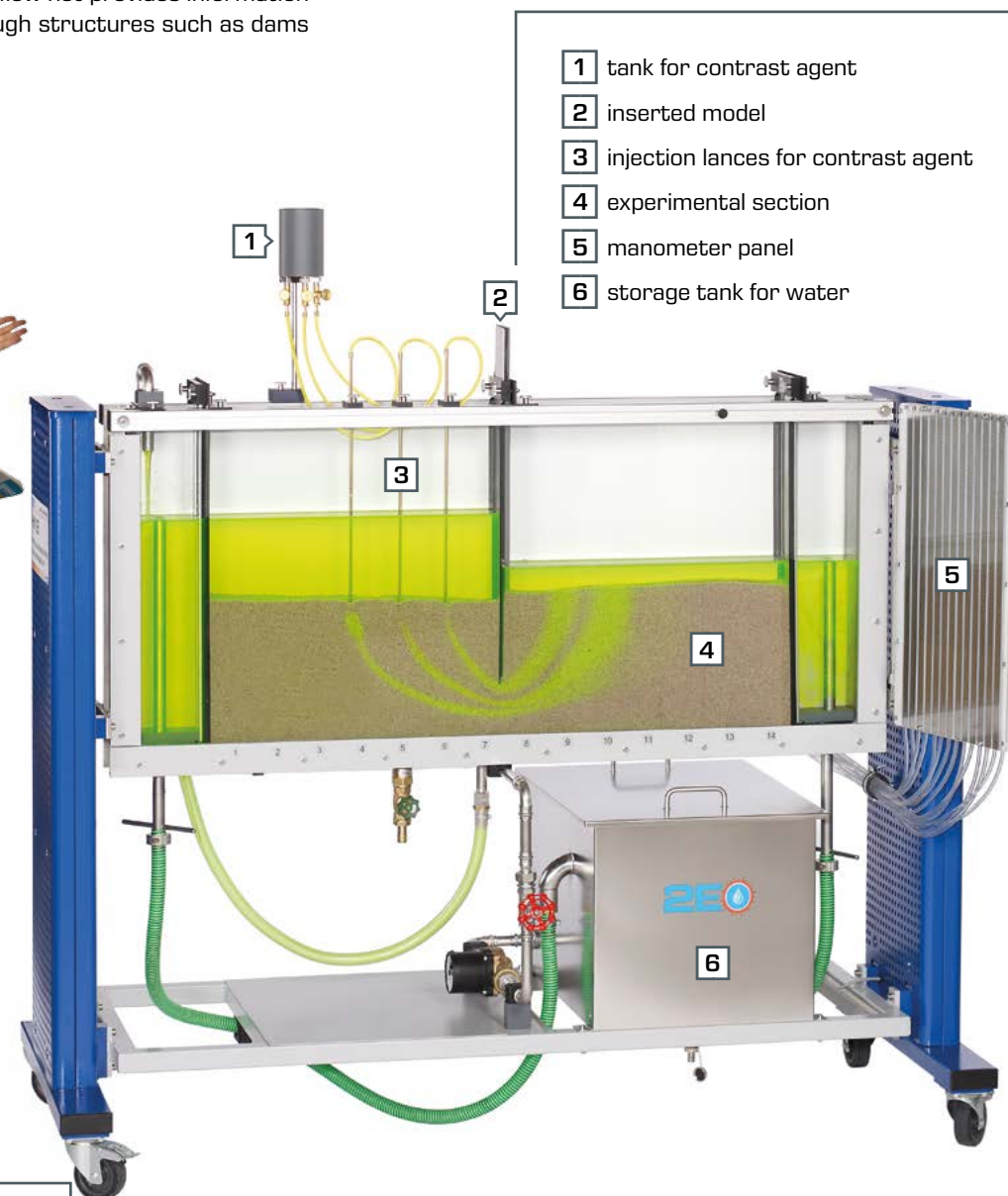
## Visualisation of Seepage Flows

### Seepage flows – protection of groundwater and structures

Seepage flows play a crucial role during construction in water-bearing layers. On the one hand, the flow through and flow around structures is relevant. On the other hand, the hydrostatic pressure acting on the structures is also of interest.

A descriptive method in the study of seepage and groundwater flow is the visualisation of the streamlines and their graphical representation as a flow net. The flow net provides information about the seepage of water through structures such as dams and sheet piles.

Our HM 169 device allows you to clearly visualise and investigate streamlines around structures. To do this, various models of typical structures which you can easily insert into the experimental section are available.



By injecting a contrast agent, such as fluoresceine or ink, the streamlines can be made very clearly visible. The pressure curves of these structures are also displayed in both the "retaining wall" and "foundation" models. The groundwater levels in the experimental section can be measured easily and with great accuracy by using tube manometers.



The possibilities of HM 169 are demonstrated to interested members of staff at Regensburg University of Applied Sciences (Germany).

| Learning objectives                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> <li>determining flow nets in permeable media graphically               <ul style="list-style-type: none"> <li>▶ streamlines under a sheet pile</li> <li>▶ streamlines through an dam</li> <li>▶ drainage at an open ditch</li> </ul> </li> <li>determining the pressure curve at a foundation</li> <li>determining the pressure curve at a retaining wall</li> <li>groundwater levels over time in various models</li> </ul> |





# Basic Knowledge

# Soil Treatment



## Contaminants in the soil – a threat to the environment

In the past, the use of environmentally hazardous substances was often not given the necessary attention. This allowed toxic substances, such as chlorinated hydrocarbons, to enter the ground in many places. Much of this contamination comes from landfills and former industrial sites and poses a threat to the environment, and to groundwater

in particular. Remediation of the contaminated soil must be undertaken in such cases. A number of different methods are available depending on the type of soil and type of contamination.

## Soil: a multi-phase mixture

Usually all three phases (solid, liquid and gaseous) are encountered in the soil. Similarly, all three phases can be affected by contamination. Soil treatment requires a holistic approach which takes all three phases in the soil and their complex interactions into account.



## Treatment of contaminated soils: a complex task

The main objective of soil treatment is to protect the groundwater and – as far as possible – to restore the original function of the contaminated soil. Due to the fact that all three phases can be affected by the contamination, soil treatment is a very complex task.

In addition to the contaminated soil, loaded contaminated water and exhaust air also usually occur during treatment. These also require treatment, for which, in turn, current processes of water treatment and air pollution control are used. Fundamentally, two different approaches can be distinguished in soil treatment:

### In-situ

The treatment takes place directly in the soil, i.e. at the site of contamination.

### Ex-situ

The contaminated soil is removed and treated externally in a plant.

## In-situ soil treatment

In-situ treatment of soils is particularly suitable for the liquid and gaseous phase:

- **liquid phase:** pump and treat
- **gaseous phase:** soil vapour extraction

In both methods, the fluid is pumped out of the ground, the contaminants separated from the fluid and the cleaned fluid then passed back into the soil. The separation of contaminant and fluid is performed either with conventional methods for water treatment (pump and treat) or with the processes of air pollution control (soil vapour extraction).

## Ex-situ soil treatment

In the ex-situ treatment of soils the contaminated soil is firstly removed. Then the soil is treated in special plants. Most methods used here have their origins in the field of mechanical or thermal process engineering. Typical processes used for soil treatment include:

- comminution
- screening
- solid-liquid separation
- separation of small particles (e.g. with hydrocyclone)
- solid-liquid extraction



# CE 225 Hydrocyclone

## Hydrocyclones in soil treatment

Experience has shown that contaminants in contaminated soils are mainly bound to finer particles and organic components. Hydrocyclones can be used to separate these fine particles in order to subsequently treat them with other processes, such as solid-liquid extraction.

With our CE 225 trainer, you can clearly demonstrate and investigate how a hydrocyclone works in a practical manner. You are assisted in this task by the comprehensive instructional material, which also gives suggestions on conducting experiments.



Product No.  
083.22500  
More details and technical data:  
[gunt.de/static/s4835\\_1.php](http://gunt.de/static/s4835_1.php)



The core element of CE 225 is the transparent hydrocyclone for optimal observation of the separation process

The device features a large storage tank, in which the suspension to be separated is positioned. The cyclone is made of transparent material to make the separation process optically visible. The flow rate in the inlet of the cyclone can be adjusted individually and is measured by an electromagnetic flow meter.

You can take samples from all relevant points of the device in order to assess the experiments quantitatively.

| Learning objectives                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>■ fundamental principle and the method of operation of a hydrocyclone</li><li>■ solid mass flow rate in feed, top and bottom flow</li><li>■ liquid mass flow rate in feed, top and bottom flow</li><li>■ characteristic values for sharpness of separation</li><li>■ pressure loss at the cyclone dependent on the feed flow rate</li><li>■ influence of solids density on characteristic values and pressure loss</li></ul> |

This device has been developed by our experienced engineers in collaboration with the Institute of Mechanical Process Engineering at the Anhalt University of Applied Sciences (Germany).

**Hochschule Anhalt**  
Anhalt University of Applied Sciences



# CE 630 Solid-Liquid Extraction

## Application of a thermal separation process in soil treatment

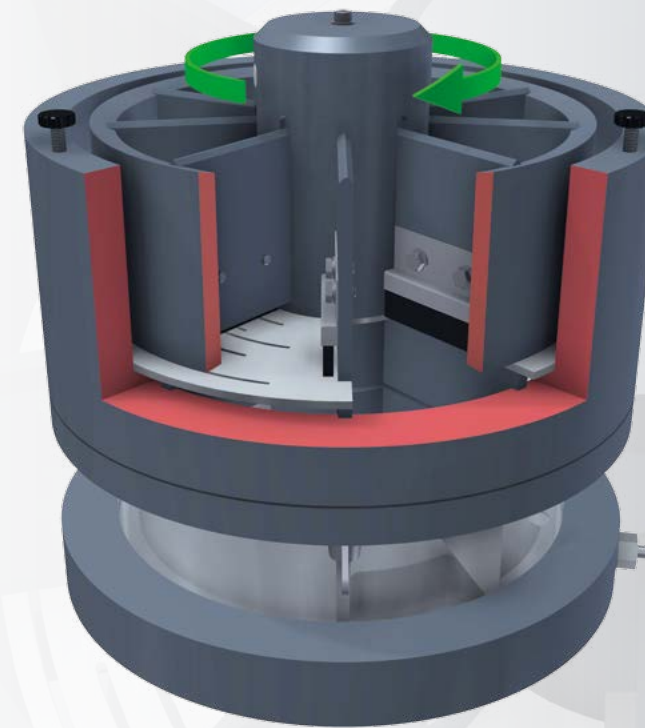
Contaminants may be present on the solid particles of the soil in a sorbed state. Solid-liquid extraction enables the separation of these contaminants from the soil particles. A suitable solvent needs to be selected for this process depending on the contaminant and the type of soil.

Our CE 630 teaching device is particularly suited to demonstrating the basic principle of this process practically and clearly. You can use the device either in continuous or discontinuous mode. In addition, you can adjust the temperature of the solvent.

- 1 process schematic
- 2 container for extraction material (solid)
- 3 solids dispenser
- 4 extractor
- 5 collection tank for extraction residue
- 6 collection tank for extract
- 7 storage tank for solvent
- 8 switch cabinet with control elements and digital displays

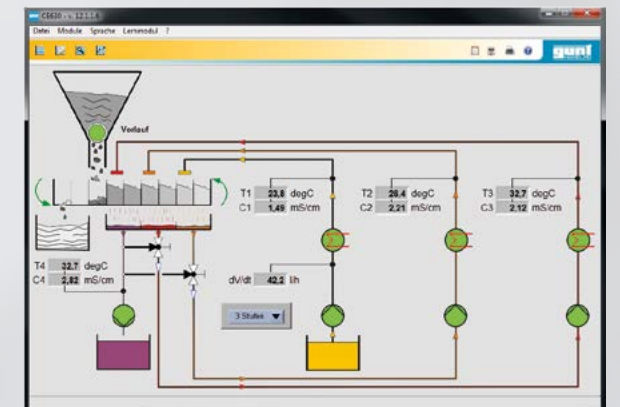


Product No.  
083.63000  
More details and technical data:  
[gunt.de/static/s3578\\_1.php](http://gunt.de/static/s3578_1.php)



## Rotating extractor

The main component of CE 630 is a rotating extractor, which is divided into several chambers. The extraction material, i.e. the solid with the substance to be eliminated, enters these chambers. The solvent enters the chambers from above via three sprinklers and absorbs the material to be extracted. A 3-stage process control is possible due to the rotation of the extractor. You can adjust the speed of the extractor.



## Software

The device is equipped with software which displays all key process variables continuously. You can save the recorded measured values to analyse the experiments.

## Learning objectives

- basic principle of solid-liquid extraction
- influence of operation mode (continuous/discontinuous)
- investigation of the 1-stage, 2- stage and 3-stage process
- typical parameters influencing the process:
  - ▶ solvent flow rate
  - ▶ solvent temperature
  - ▶ extraction material flow rate
  - ▶ extractor speed



A satisfied lecturer at the Industrial College in Yanbu (Saudi Arabia) after successful commissioning of CE 630





Environment:  
Sustainable Technology  
for Environmental  
Protection

# Waste

2.4

2E a division of

This product area is one of GUNT's current areas of development. If you have any ideas for future teaching and research equipment in this field, please get in touch. We would love to work with you.

## Introduction

|  |                                 |     |
|--|---------------------------------|-----|
|  | <b>Subject Areas</b><br>Waste   | 316 |
|  | <b>Basic Knowledge</b><br>Waste | 318 |

## Comminution

|  |                            |     |
|--|----------------------------|-----|
|  | <b>CE 245</b><br>Ball Mill | 320 |
|--|----------------------------|-----|

## Separation Processes

|  |                                          |     |
|--|------------------------------------------|-----|
|  | <b>CE 280</b><br>Magnetic Separation     | 322 |
|  | <b>CE 275</b><br>Gas Flow Classification | 324 |



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# Subject Areas Waste



Subject Areas

2E Products

## Comminution

The comminution of waste materials plays a key role in waste management and is a prerequisite for many recycling processes. Comminution prepares waste materials for subsequent process steps. Ball mills are a traditional method for the comminution of solids. Our CE 245 experimental unit clearly demonstrates this process.

## Separation processes

Separation processes are used to divide mixed waste into separate fractions. The separation can be carried out according to material characteristics (materials) or geometrical characteristics (particle size).

One classic example is separation of metals for subsequent feeding into a recycling process. The separation of metals is usually carried out with magnetic separators. Our CE 280 trainer allows you to clearly demonstrate this separation process in the laboratory.

In gas flow classification, however, the individual fractions of a waste mixture are separated in terms of their geometric characteristics. We have developed our CE 275 zigzag sifter in order to clearly teach the fundamentals of this process.

Comminution

**CE 245**  
Ball Mill

Separation processes

**CE 280**  
Magnetic Separation  
**CE 275**  
Gas Flow Classification

Many processes used in waste management have their origins in conventional process engineering. Separation processes, especially from mechanical process engineering, are put to use. Other devices of interest from this field of process engineering can be found in our catalogue 5.





# Basic Knowledge Waste



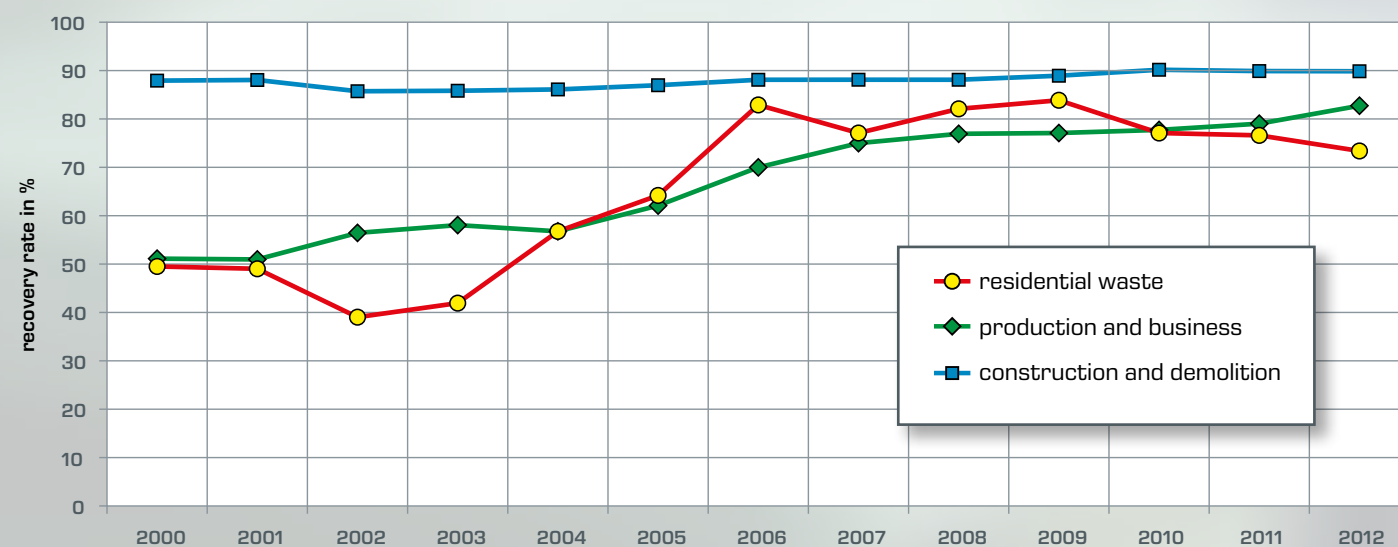
## Waste in the economic cycle

Every resident in Germany produces approximately 500-600 kg of domestic waste each year. This waste consists of a wide variety of materials and represents an important resource for the procurement of raw materials for the economy. Waste legislation in Germany is regulated by the Waste Management Act. The main objective of the law is to promote conservation of natural resources by reusing and recycling waste, and to ensure protection of human health and the environment in the production and management of waste.

|   |                                       |
|---|---------------------------------------|
| 1 | Waste prevention                      |
| 2 | Preparation for reuse of waste        |
| 3 | Recycling waste                       |
| 4 | Other recovery of waste (e.g. energy) |
| 5 | Disposal of waste                     |

## The 5-stage waste hierarchy

A key aspect of the Waste Management Act is the 5-stage waste hierarchy. According to this hierarchy, prevention of waste has top priority (1). If production of waste is unavoidable, then reusing the waste through cleaning or repair should be strived for (2). If direct reuse of used products is not possible, these have to be recycled, sorted in accordance with material properties (3). If this is not possible or uneconomical, the waste is exploited in other ways (4), such as for energy. The bottom of this hierarchy is the disposal of waste (5), which usually takes place in landfills.

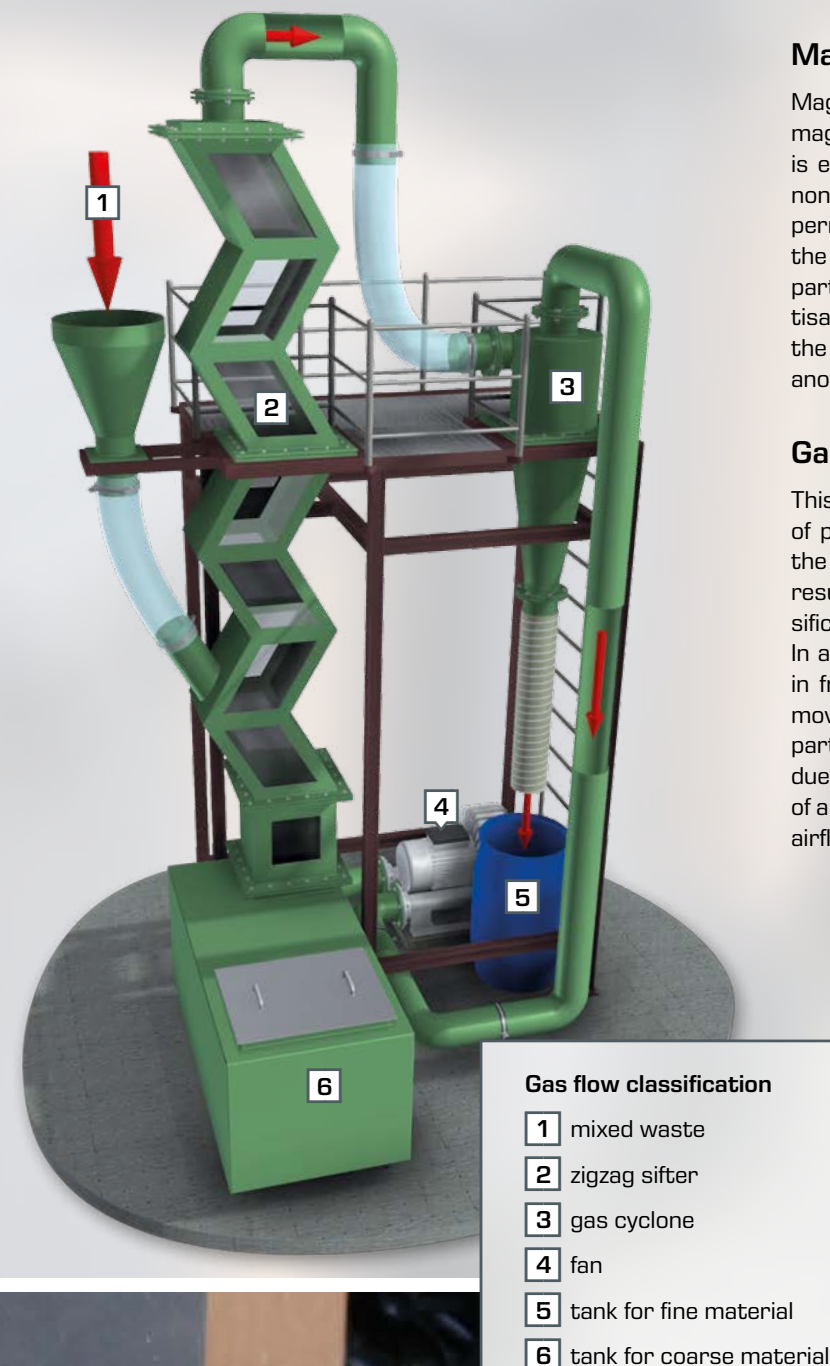


Recovery rates of the most important types of waste in Germany

Source: Federal Statistical Office, Wiesbaden, waste balance, various years; Federal Environment Agency, own calculations

## Comminution: prerequisite for effective recycling

The comminution of waste plays a key role in waste management. Comminution reduces the particle size of the waste materials. Simultaneously, comminution leads to an increase of the specific surface area of the particles. Comminution is normally a pre-treatment which is followed by subsequent process steps. For example, the melting of plastics is made easier by a small particle size. Various technologies are used for comminution of waste, such as ball mills.



## Magnetic separation

Magnetic separation is a separation process in which the magnetisation of components (e.g. iron) of a waste mixture is exploited. The waste mixture is conveyed to a rotating, non-magnetic drum. In one area of the drum there is a permanent magnet that sticks the magnetisable parts to the drum and carries them along. The non-magnetisable parts fall into a collection tank due to gravity. The magnetisable parts are detached from the drum once they leave the permanent magnet's sphere of influence and drop into another collection tank.

## Gas flow classification

This separation process uses the different settling velocities of particles in an airflow. The settling velocity depends on the size, density and shape of individual particles and on the resulting flow resistance and weight forces. Gas flow classification primarily uses what are known as zigzag sifters. In a zigzag sifter, the waste mixture to be separated is fed in from the side of the zigzag channel in which an airflow moves upward. Depending on geometry and density, the particles are taken along by the airflow or fall downwards due to gravity. Often, a zigzag sifter is located downstream of a cyclone. This separates the fraction carried along by the airflow so that the air can be fed back into the cycle.



# CE 245 Ball Mill



| Learning objectives                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"><li>■ cascade motion</li><li>■ cataract motion</li><li>■ determining the critical speed</li><li>■ comparison of theoretical and actual power demand</li><li>■ influence of the following parameters on the degree of comminution:<ul style="list-style-type: none"><li>▶ mill time</li><li>▶ speed</li><li>▶ ball diameter</li><li>▶ ball filling</li><li>▶ material to be milled</li></ul></li></ul> |

Many processes used in the recycling of waste are favoured by a small particle size. Waste usually has to be comminuted first for this reason. Various techniques such as ball mills are used to do this.



Large-scale ball mill in waste management

Our CE 245 experimental unit allows you to teach the fundamentals of this comminution process in practice. There are three different drums available. All drums have transparent faces. This means you can observe the comminution process and the motion states inside the drum which are characteristic of ball mills.

The speed of the ball mill is continuously adjustable. Speed and power consumption of the drive motor are displayed digitally. This allows you to compare the theoretical demand with the actual power demand. You can adjust the desired mill time using a timer.

The instructional material sets out the fundamentals of this process in detail. Example experiments are clearly described and evaluated.



We recommend our CE 264 Screening Machine for analysis of the experiments.





# CE 280 Magnetic Separation



Product No.  
083.28000  
More details and technical data:  
[gunt.de/static/s4790\\_1.php](http://gunt.de/static/s4790_1.php)



## Magnetic separation: recovery of important raw materials

The recovery of reusable materials is a central aspect of waste management. A very effective and therefore widely-used method for separating magnetisable reusable materials such as iron from a mixture of waste is by using magnetic separators.

## Magnetic separator CE 280

With our CE 280 trainer, you can clearly demonstrate how a magnetic separator works. The main component is a professional drum-type magnetic separator, as is often used in industry to sort solid mixtures.

The mixture to be separated is fed evenly to the magnetic separator by a vibrating trough. The height-adjustable hopper allows you to adjust the distance between the hopper outlet and the vibrating trough. The amplitude and frequency of the vibrating trough can be individually adjusted. These three settings allow you to control the mass flow rate of the feed material.

You can adjust the speed of the drum-type magnetic separator continuously for studying the influence of speed on the effectiveness of the separation.

| 🎓 | Learning objectives                                                                                                                                                                                                                                                |
|---|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ■ | fundamental principle and operating behaviour of a drum-type magnetic separator                                                                                                                                                                                    |
| ■ | influence of the following factors on the effectiveness of separation: <ul style="list-style-type: none"> <li>▶ mass flow rate of the feed material</li> <li>▶ mixing ratio of the feed material</li> <li>▶ type of feed material</li> <li>▶ drum speed</li> </ul> |

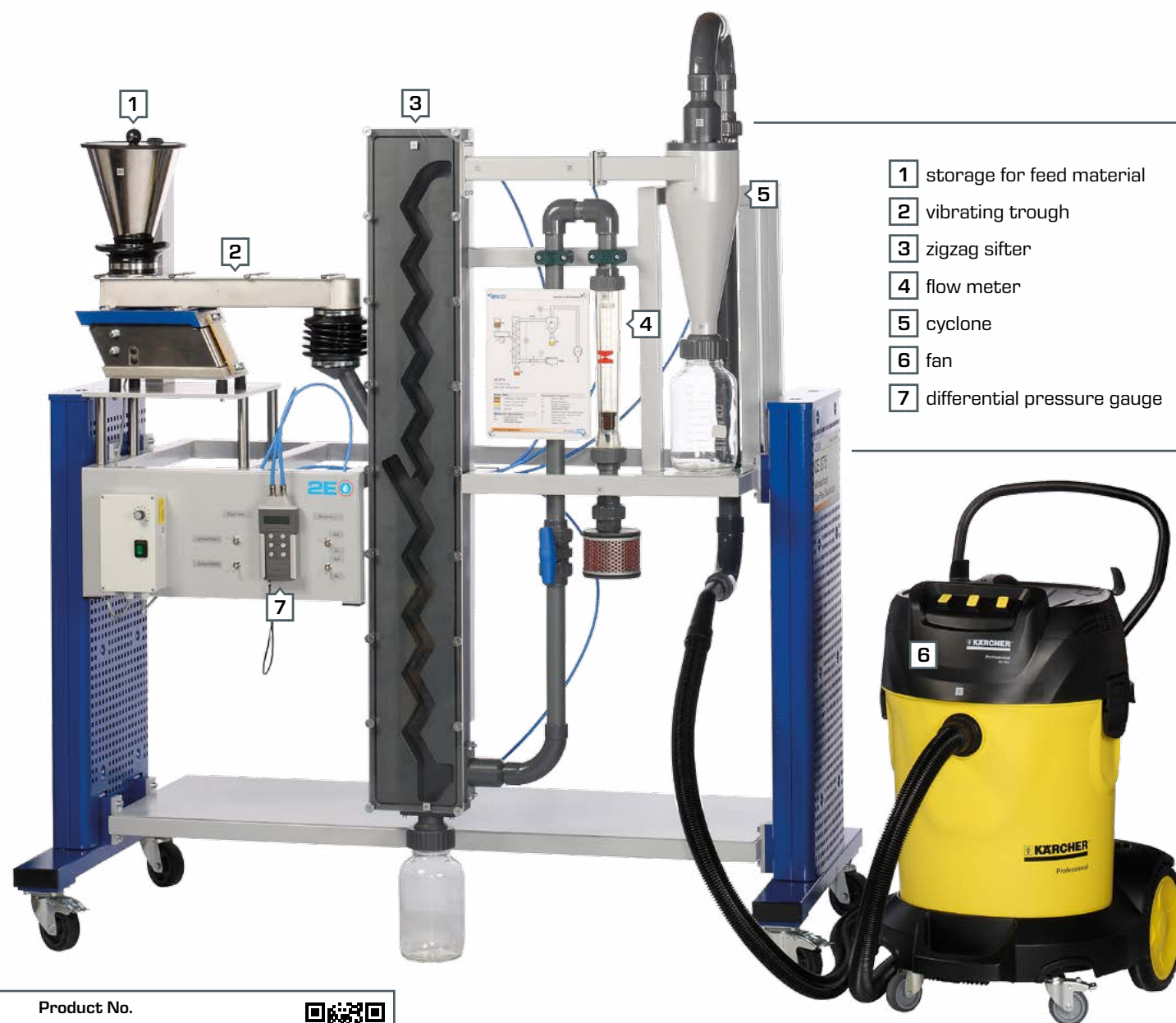


# CE 275 Gas Flow Classification

## Gas flow classification with zigzag sifter: a mechanical separation process

Gas flow classification is a mechanical separation process from the field of conventional process engineering. In waste management, this process is used for the separation of various wastes, for example, to separate dust, sand or non-reusable materials from reusable materials. This is mainly achieved by the use of zigzag sifters.

This teaching unit is perfectly suited to teaching the theoretical fundamentals of this process, clearly and practically. The main element of CE 275 is a 20-stage zigzag sifter, which is equipped with a transparent cover. This allows you to observe the separation process in the zigzag channel over the entire height.



Product No.  
083.27500  
More details and technical data:  
[gunt.de/static/s4791\\_1.php](http://gunt.de/static/s4791_1.php)



## Principle of operation

The waste mixture to be separated (feed material) is conveyed evenly into the zigzag sifter by a vibrating trough. The fan generates the upwardly-directed airflow necessary for separation through the zigzag channel. You can adjust the mass flow rate of the feed material and the volumetric flow rate of the air. The fraction of the feed material transported along with the air is then separated in a cyclone. This allows a closed circuit for the air flow. The zigzag sifter and cyclone are each equipped with differential pressure measurement.



CE 275 during a trial run:  
The vibrating trough evenly conveys the mixture of spelt husks and cherry stones to be separated from to the zigzag sifter.



In the zigzag channel, the separation of the mixture can clearly be observed.



We recommend our CE 264 Screening Machine for analysis of the experiments.

| 🎓 | Learning objectives                                                                                                                                                                                                                                                                                                                                           |
|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| ■ | familiarisation with the basic principle of gas flow classification                                                                                                                                                                                                                                                                                           |
| ■ | influence of the mass flow rate and the airflow rate on <ul style="list-style-type: none"> <li>▶ fine material fraction</li> <li>▶ quality of separation</li> <li>▶ sifter pressure loss</li> <li>▶ cyclone pressure loss</li> <li>▶ fraction balance</li> <li>▶ separation function</li> <li>▶ separation size</li> <li>▶ sharpness of separation</li> </ul> |
|   | with CE 264                                                                                                                                                                                                                                                                                                                                                   |

This device has been developed by our experienced engineers in collaboration with the Institute of Mechanical Process Engineering at the Anhalt University of Applied Sciences (Germany).

**Hochschule Anhalt**  
Anhalt University of Applied Sciences



# Index

| Keyword                  | Code (Page)                                            |
|--------------------------|--------------------------------------------------------|
| A                        |                                                        |
| Absorber                 | ET 202 (32) HL 313 (36) HL 320.03 (207)                |
| Absorption               | ET 202 (32) CE 400 (290)                               |
| Accumulator              | ET 220 (72, 178) ET 250.01 (24)<br>ET 250.02 (25)      |
| Activated carbon         | CE 581 (278) CE 583 (268)                              |
| Activated sludge process | CE 705 (254)                                           |
| Adsorption               | CE 540 (292) CE 581 (278) CE 583 (268)                 |
| Advanced oxidation       | CE 584 (274)                                           |
| Aerofoil                 | HM 170 (68)                                            |
| Air conditioning systems | ET 340 (198)                                           |
| Air pollution control    | CE 235 (288) CE 400 (290) CE 540 (292)                 |
| Airlift                  | CE 730 (260)                                           |
| Angle of incidence       | HM 170 (68)                                            |
| Angle of inclination     | ET 202 (32) ET 250 (22) HL 313 (36)<br>HL 320.03 (207) |
| B                        |                                                        |
| Backwash                 | CE 579 (250) CE 581 (278) CE 582 (280)                 |
| Ball mill                | CE 245 (320)                                           |
| Biodiesel                | CE 650 (105)                                           |
| Bioethanol               | CE 640 (94)                                            |
| Biofilm                  | CE 701 (258)                                           |
| Biogas                   | CE 642 (100) CE 702 (262)                              |
| Bivalence point          | HL 320.02 (206)                                        |
| Breakthrough curve       | CE 540 (292) CE 581 (278) CE 583 (268)                 |
| Building automation      | ET 340 (198)                                           |
| Building materials       | WL 376 (188)                                           |

| Keyword                            | Code (Page)                                                                                                                                                                                        |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| C                                  |                                                                                                                                                                                                    |
| Cascade motion                     | CE 245 (320)                                                                                                                                                                                       |
| Cataract motion                    | CE 245 (320)                                                                                                                                                                                       |
| Cavitation                         | HM 283 (196)                                                                                                                                                                                       |
| Centrifugal pump                   | HM 283 (196) HM 450C (51)                                                                                                                                                                          |
| Charge controller                  | ET 220 (72, 178) ET 250.02 (25)<br>ET 255 (28, 176)                                                                                                                                                |
| Comminution                        | CE 245 (320)                                                                                                                                                                                       |
| Compressor                         | ET 428 (220) ET 513 (162)                                                                                                                                                                          |
| Concentration profile              | CE 583 (268) CE 701 (258)                                                                                                                                                                          |
| Control (level)                    | RT 682 (224)                                                                                                                                                                                       |
| Control (temperature)              | RT 682 (224)                                                                                                                                                                                       |
| Convection                         | WL 377 (34)                                                                                                                                                                                        |
| Cooling tower                      | ET 420 (170, 218)                                                                                                                                                                                  |
| Counterflow                        | WL 110 (116, 190) WL 315C (120)                                                                                                                                                                    |
| Current-voltage curve              | ET 250 (22) ET 252 (26)                                                                                                                                                                            |
| Cyclic process                     | ET 101 (124) ET 102 (156) ET 794 (152)<br>ET 428 (220)                                                                                                                                             |
| Cyclone                            | CE 225 (310) CE 235 (288) CE 275 (324)                                                                                                                                                             |
| D                                  |                                                                                                                                                                                                    |
| Damage analysis                    | PT 500 (82)                                                                                                                                                                                        |
| DDC (Direct Digital Control)       | ET 340 (198)                                                                                                                                                                                       |
| Denitrification                    | CE 705 (254)                                                                                                                                                                                       |
| Desorption                         | CE 400 (290)                                                                                                                                                                                       |
| Differential pressure              | CE 225 (310) CE 235 (288) CE 275 (324)<br>CE 579 (250) CE 581 (278) CE 582 (280)<br>ET 513 (162) ET 851 (134, 138) HL 305 (194)<br>HL 320.05 (168, 209) HL 630 (197)<br>RT 396 (226) WL 315C (120) |
| Dissolved air flotation            | CE 587 (248)                                                                                                                                                                                       |
| Distillation                       | CE 640 (94)                                                                                                                                                                                        |
| Drag coefficient (C <sub>d</sub> ) | HM 170 (68)                                                                                                                                                                                        |
| Drag force                         | HM 170 (68)                                                                                                                                                                                        |

| Keyword                    | Code (Page)                                                                                                                                                                                                                                                                                                                                         |
|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| E                          |                                                                                                                                                                                                                                                                                                                                                     |
| Efficiency                 | ET 202 (32) ET 220 (72, 178) ET 250 (22)<br>ET 250.01 (24) ET 250.02 (25)<br>ET 255 (28, 176) ET 850 (134, 136)<br>ET 851 (134, 138) GL 210 (78) GL 212 (79)<br>HL 313 (36) HL 320 (38, 202)<br>HM 150.19 (48) HM 150.20 (49)<br>HM 170 (68)HM 283 (196) HM 365.31 (54)<br>HM 421 (52) HM 430C (56) HM 450.01 (50)<br>HM 450.02 (50) PT 500.19 (87) |
| Energy balance             | ET 202 (32) ET 220 (72, 178) ET 428 (220)<br>HL 320 (38, 202) HL 630 (197)                                                                                                                                                                                                                                                                          |
| Envelope analysis          | PT 500 (82)                                                                                                                                                                                                                                                                                                                                         |
| Extraction                 | CE 630 (312)                                                                                                                                                                                                                                                                                                                                        |
| F                          |                                                                                                                                                                                                                                                                                                                                                     |
| Filtration                 | CE 579 (250) CE 581 (278) CE 582 (280)                                                                                                                                                                                                                                                                                                              |
| Flat collector             | ET 202 (32) HL 313 (36) HL 320.03 (207)                                                                                                                                                                                                                                                                                                             |
| Flocculation               | CE 586 (272) CE 587 (248)                                                                                                                                                                                                                                                                                                                           |
| Flotation                  | CE 587 (248)                                                                                                                                                                                                                                                                                                                                        |
| Flow coefficient           | RT 396 (226)                                                                                                                                                                                                                                                                                                                                        |
| Francis turbine            | HM 150.20 (49) HM 365.31 (54)<br>HM 430C (56) HM 450.02 (50)<br>ET 292 (148)                                                                                                                                                                                                                                                                        |
| Fuel cell                  | ET 292 (148)                                                                                                                                                                                                                                                                                                                                        |
| G                          |                                                                                                                                                                                                                                                                                                                                                     |
| Gas flow classification    | CE 275 (324)                                                                                                                                                                                                                                                                                                                                        |
| Gears                      | AT 200 (76) GL 210 (78) GL 212 (79)<br>PT 500.15 (86)                                                                                                                                                                                                                                                                                               |
| Geothermal energy absorber | ET 262 (126) HL 320.07 (130, 212)                                                                                                                                                                                                                                                                                                                   |
| Geothermal energy, deep    | ET 850 (134, 136) ET 851 (134, 138)                                                                                                                                                                                                                                                                                                                 |
| Geothermal energy, shallow | ET 101 (124) ET 262 (126) ET 264 (128)<br>HL 320 (38, 202)<br>ET 262 (126)<br>ET 250.01 (24) ET 255 (28, 176)<br>HM 165 (300) HM 167 (304) HM 169 (306)                                                                                                                                                                                             |

| Keyword                                               | Code (Page)                                                                     |
|-------------------------------------------------------|---------------------------------------------------------------------------------|
| H                                                     |                                                                                 |
| H <sub>2</sub> O <sub>2</sub>                         | CE 584 (274)                                                                    |
| Heat conduction                                       | WL 376 (188)                                                                    |
| Heat exchanger, finned cross-flow                     | WL 315C (120)                                                                   |
| Heat exchanger, jacketed vessel with stirrer and coil | WL 110.04 (114, 119)                                                            |
| Heat exchanger, plate                                 | WL 110.02 (114, 118) WL 315C (120)                                              |
| Heat exchanger, shell & tube                          | WL 110.03 (114, 119) WL 315C (120)                                              |
| Heat exchanger, tubular                               | WL 110.01 (114, 118) WL 315C (120)                                              |
| Heat flux                                             | ET 850 (134, 136) WL 376 (188)                                                  |
| Heat pump                                             | ET 101 (124) ET 102 (156) ET 630 (199)<br>HL 320.01 (158, 204)<br>RT 682 (224)  |
| Heat recovery                                         | RT 682 (224)                                                                    |
| Heat sink                                             | HL 320.07 (130, 212) HL 320.08 (130, 213)                                       |
| Heat storage                                          | HL 320.05 (168, 209)                                                            |
| Heat transfer                                         | WL 110 (116, 190) WL 315C (120)<br>WL 377 (34)<br>WL 110 (116, 190) WL 377 (34) |
| Heat transfer coefficient                             | WL 110 (116, 190) WL 377 (34)                                                   |
| Heating circuit                                       | HL 630 (197)                                                                    |
| Heating load                                          | HL 320.02 (206)                                                                 |
| Heating system                                        | ET 340 (198) HL 630 (197)                                                       |
| Heating technology                                    | HL 320.07 (130, 212) HL 630 (197)                                               |
| Heatpipe                                              | ET 262 (126)                                                                    |
| Hydrogen                                              | ET 292 (148)                                                                    |
| Hydrogen peroxide                                     | CE 584 (274)                                                                    |
| Hydrogeology                                          | HM 141 (302) HM 165 (300) HM 167 (304)<br>HM 169 (306)                          |
| Hydrograph                                            | HM 141 (302) HM 143 (164)                                                       |
| Hydronic balancing                                    | HL 305 (194)                                                                    |
| I                                                     |                                                                                 |
| Ice store                                             | ET 420 (170, 218)                                                               |
| Inverter                                              | ET 220 (72, 178) ET 250.01 (24)<br>ET 250.02 (25) ET 255 (28, 176)              |
| Ion exchange                                          | CE 300 (271) CE 581 (278) CE 582 (280)                                          |



# Index

| Keyword                        | Code (Page)                                             |
|--------------------------------|---------------------------------------------------------|
| K                              |                                                         |
| Kaplan turbine                 | HM 421 (52)                                             |
| L                              |                                                         |
| Lamella separator              | CE 586 (272)                                            |
| Lift force                     | HM 170 (68)                                             |
| Light source, artificial       | HL 313.01 (35)                                          |
| M                              |                                                         |
| Machinery diagnostic           | PT 500 (82)                                             |
| Magnetic separation            | CE 280 (322)                                            |
| Mass transfer zone             | CE 540 (292) CE 583 (268)                               |
| Membrane separation process    | CE 530 (270)                                            |
| Methane                        | CE 642 (100) CE 702 (262)                               |
| Micheau                        | CE 579 (250) CE 582 (280)                               |
| MPP tracker                    | ET 250.01 (24) ET 250.02 (25) ET 255 (28, 176)          |
| Multivariable control          | RT 682 (224)                                            |
| N                              |                                                         |
| Net power                      | ET 202 (32) HL 313 (36) HL 320.03 (207) HL 320.04 (208) |
| Nitrification                  | CE 701 (258) CE 705 (254)                               |
| O                              |                                                         |
| Ocean energy                   | ET 270 (60)                                             |
| OWC (oscillating water column) | ET 270 (60)                                             |
| Oxidation, advanced            | CE 584 (274)                                            |

| Keyword                   | Code (Page)                                                                                                                                                                            |
|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| P                         |                                                                                                                                                                                        |
| Pelton turbine            | HM 150.19 (48) HM 365.31 (54) HM 450.01 (50)                                                                                                                                           |
| Photovoltaic              | ET 250 (22) ET 250.01 (24) ET 250.02 (25) ET 252 (26) ET 255 (28, 176)                                                                                                                 |
| Photovoltaic simulator    | ET 255 (28, 176)                                                                                                                                                                       |
| Power coefficient         | ET 220 (72, 178)                                                                                                                                                                       |
| Precipitation             | CE 586 (272)                                                                                                                                                                           |
| Pressure loss             | CE 225 (310) CE 235 (288) CE 275 (324) CE 579 (250) CE 581 (278) CE 582 (280) ET 513 (162) ET 851 (134, 138) HL 305 (194) HL 320.05 (168, 209) HL 630 (197) RT 396 (226) WL 315C (120) |
| Pump characteristic       | HL 630 (197) HM 283 (196) HM 450C (51) RT 396 (226)                                                                                                                                    |
| R                         |                                                                                                                                                                                        |
| Radiation coefficient     | WL 377 (34)                                                                                                                                                                            |
| Radiator                  | ET 340 (198) HL 305 (194)                                                                                                                                                              |
| Rain                      | HM 141 (302) HM 165 (300)                                                                                                                                                              |
| Rainwater retention basin | HM 141 (302) HM 143 (164)                                                                                                                                                              |
| Reaction kinetics         | CE 584 (274)                                                                                                                                                                           |
| Reactor, stirred          | CE 640 (94) CE 642 (100) CE 702 (262)                                                                                                                                                  |
| Refrigeration system      | ET 101 (124) ET 428 (220)                                                                                                                                                              |
| Retaining wall            | HM 169 (306)                                                                                                                                                                           |
| Reverse osmosis           | CE 530 (270)                                                                                                                                                                           |
| Room climate              | ET 630 (199)                                                                                                                                                                           |

| Keyword                      | Code (Page)                                                           |
|------------------------------|-----------------------------------------------------------------------|
| S                            |                                                                       |
| Sand filter                  | CE 579 (250) CE 581 (278) CE 582 (280)                                |
| Secondary clarification      | CE 701 (258) CE 702 (262) CE 705 (254)                                |
| Sedimentation                | HM 142 (246) CE 586 (272)                                             |
| Seepage flow                 | HM 165 (300) HM 167 (304) HM 169 (306)                                |
| Separation function          | CE 235 (288) CE 275 (324)                                             |
| Separation size              | CE 235 (288) CE 275 (324)                                             |
| Shading (of solar modules)   | ET 250 (22) ET 252 (26)                                               |
| Sheet pile                   | HM 169 (306)                                                          |
| Soil treatment               | CE 225 (310) CE 630 (312)                                             |
| Solar cell                   | ET 250 (22) ET 252 (26)                                               |
| Solar collector              | ET 202 (32) HL 313 (36) HL 320.03 (207)                               |
| Solar thermal energy         | ET 202 (32) HL 313 (36) HL 320 (38, 202) WL 377 (34) CE 530 (270)     |
| Spiral wound membrane module | CE 530 (270)                                                          |
| Split principle              | ET 630 (199)                                                          |
| Split system air conditioner | ET 630 (199)                                                          |
| Stand alone operation        | ET 220.01 (74, 179) ET 250.02 (25) ET 255 (28, 176) ET 850 (134, 136) |
| Steam generator              | ET 850 (134, 136)                                                     |
| Storage capacity (of soil)   | HM 141 (302) HM 165 (300)                                             |
| Storage lake                 | HM 143 (164)                                                          |
| Storage reservoir            | HM 143 (164)                                                          |
| Storage, bivalent            | HL 320.05 (168, 209)                                                  |
| Streamlines                  | HM 169 (306)                                                          |
| Surge chamber                | HM 143 (164)                                                          |

|                                          |                                                                       |
|------------------------------------------|-----------------------------------------------------------------------|
| T                                        |                                                                       |
| Test stand, pump and valves and fittings | RT 396 (226)                                                          |
| Thermal conductivity                     | WL 376 (188)                                                          |
| Thermal resistance                       | WL 376 (188)                                                          |
| Thermodynamics                           | ET 101 (124) ET 102 (156) ET 420 (170, 218) ET 428 (220) ET 513 (162) |
| Tip speed ratio (TSR)                    | ET 220 (72, 178)                                                      |
| Trickling filter                         | CE 701 (258)                                                          |
| TSR                                      | ET 220 (72, 178)                                                      |
| Turbine, Francis                         | HM 150.20 (49) HM 365.31 (54) HM 430C (56) HM 450.02 (50)             |
| Turbine, gas                             | ET 794 (152)                                                          |
| Turbine, Kaplan                          | HM 421 (52)                                                           |
| Turbine, Pelton                          | HM 150.19 (48) HM 365.31 (54) HM 450.01 (50)                          |
| Turbine, steam                           | ET 851 (134, 138)                                                     |
| Turbine, Wells                           | ET 270 (60)                                                           |

| Keyword                             | Code (Page)                                                      |
|-------------------------------------|------------------------------------------------------------------|
| U                                   |                                                                  |
| UASB                                | CE 702 (262)                                                     |
| Underfloor heating                  | HL 320.07 (130, 212)                                             |
| UV light                            | CE 584 (274)                                                     |
| V                                   |                                                                  |
| Valve characteristic                | HL 630 (197) RT 396 (226)                                        |
| Vibrations                          | PT 500 (82)                                                      |
| W                                   |                                                                  |
| Wastewater treatment plant          | CE 701 (258) CE 702 (262) CE 705 (254)                           |
| Water treatment (aerobic)           | CE 701 (258) CE 705 (254) CE 730 (260)                           |
| Water treatment (anaerobic)         | CE 702 (262)                                                     |
| Water treatment (biological)        | CE 701 (258) CE 702 (262) CE 705 (254) CE 730 (260)              |
| Water treatment (mechanical)        | CE 579 (250) CE 587 (248) HM 142 (246)                           |
| Water treatment (multi-stage)       | CE 581 (278) CE 582 (280)                                        |
| Water treatment (physical/chemical) | CE 300 (271) CE 530 (270) CE 583 (268) CE 584 (274) CE 586 (272) |
| Wave energy converter               | ET 270 (60)                                                      |
| Well                                | HM 165 (300) HM 167 (304)                                        |
| Well system                         | ET 264 (128)                                                     |
| Wells turbine                       | ET 270 (60)                                                      |
| Wind power plant                    | ET 220 (72, 178) ET 220.01 (74, 179)                             |
| Wind tunnel                         | ET 220 (72, 178) HM 170 (68)                                     |
| Z                                   |                                                                  |
| Zigzag sifter                       | CE 275 (324)                                                     |



# Product Overview

|               |                                    |     |
|---------------|------------------------------------|-----|
| <b>AT 200</b> | Determination of Gear Efficiency   | 076 |
| <b>CE 225</b> | Hydrocyclone                       | 310 |
| <b>CE 235</b> | Gas Cyclone                        | 288 |
| <b>CE 245</b> | Ball Mill                          | 320 |
| <b>CE 275</b> | Gas Flow Classification            | 324 |
| <b>CE 280</b> | Magnetic Separation                | 322 |
| <b>CE 300</b> | Ion Exchange                       | 271 |
| <b>CE 400</b> | Gas Absorption                     | 290 |
| <b>CE 530</b> | Reverse Osmosis                    | 270 |
| <b>CE 540</b> | Adsorptive Air Drying              | 292 |
| <b>CE 579</b> | Depth Filtration                   | 250 |
| <b>CE 581</b> | Water Treatment Plant 1            | 278 |
| <b>CE 582</b> | Water Treatment Plant 2            | 280 |
| <b>CE 583</b> | Adsorption                         | 268 |
| <b>CE 584</b> | Advanced Oxidation                 | 274 |
| <b>CE 586</b> | Precipitation and Flocculation     | 272 |
| <b>CE 587</b> | Dissolved Air Flotation            | 248 |
| <b>CE 630</b> | Solid-Liquid Extraction            | 312 |
| <b>CE 640</b> | Biotechnical Production of Ethanol | 094 |
| <b>CE 642</b> | Biogas Plant                       | 100 |
| <b>CE 650</b> | Biodiesel Plant                    | 105 |
| <b>CE 701</b> | Biofilm Process                    | 258 |
| <b>CE 702</b> | Anaerobic Water Treatment          | 262 |
| <b>CE 705</b> | Activated Sludge Process           | 254 |
| <b>CE 730</b> | Airlift Reactor                    | 260 |

|                  |                                                             |            |
|------------------|-------------------------------------------------------------|------------|
| <b>ET 101</b>    | Simple Compression Refrigeration Circuit                    | 124        |
| <b>ET 102</b>    | Heat Pump Trainer                                           | 156        |
| <b>ET 202</b>    | Principles of Solar Thermal Energy                          | 032        |
| <b>ET 220</b>    | Energy Conversion in a Wind Power Plant                     | 072<br>178 |
| <b>ET 220.01</b> | Wind Power Plant                                            | 074<br>179 |
| <b>ET 250</b>    | Solar Module Measurements                                   | 022        |
| <b>ET 250.01</b> | Photovoltaic in Grid-connected Operation                    | 024        |
| <b>ET 250.02</b> | Stand Alone Operation of Photovoltaic Modules               | 025        |
| <b>ET 252</b>    | Solar Cell Measurements                                     | 026        |
| <b>ET 255</b>    | Using Photovoltaics: Grid connected or Stand-alone          | 028<br>176 |
| <b>ET 262</b>    | Geothermal Probe with Heatpipe Principle                    | 126        |
| <b>ET 264</b>    | Geothermal Energy with 2-Well System                        | 128        |
| <b>ET 270</b>    | Wave Energy Converter                                       | 060        |
| <b>ET 292</b>    | Fuel Cell System                                            | 148        |
| <b>ET 340</b>    | Building Automation in Heating and Air Conditioning Systems | 198        |
| <b>ET 420</b>    | Ice Stores in Refrigeration                                 | 170<br>218 |
| <b>ET 428</b>    | Energy Efficiency in Refrigeration Systems                  | 220        |
| <b>ET 513</b>    | Single-Stage Compressor                                     | 162        |
| <b>ET 630</b>    | Split System Air Conditioner                                | 199        |
| <b>ET 794</b>    | Gas Turbine with Power Turbine                              | 152        |
| <b>ET 850</b>    | Steam Generator                                             | 134<br>136 |
| <b>ET 851</b>    | Axial Steam Turbine                                         | 134<br>138 |
| <b>GL 210</b>    | Dynamic Behaviour of Multi-Stage Spur Gears                 | 078        |
| <b>GL 212</b>    | Dynamic Behaviour of Multi-Stage Planetary Gears            | 079        |

|                  |                                                    |            |
|------------------|----------------------------------------------------|------------|
| <b>HL 305</b>    | Hydronic Balancing of Radiators                    | 194        |
| <b>HL 313</b>    | Domestic Water Heating with Flat Collector         | 036        |
| <b>HL 313.01</b> | Artificial Light Source                            | 035        |
| <b>HL 320</b>    | Solar Thermal Energy and Heat Pump Modular System  | 038<br>202 |
| <b>HL 320.01</b> | Heat Pump                                          | 158<br>204 |
| <b>HL 320.02</b> | Conventional Heating                               | 206        |
| <b>HL 320.03</b> | Flat Plate Collector                               | 207        |
| <b>HL 320.04</b> | Evacuated Tube Collector                           | 208        |
| <b>HL 320.05</b> | Central Storage Module with Controller             | 168<br>209 |
| <b>HL 320.07</b> | Underfloor Heating / Geothermal Energy Absorber    | 212        |
| <b>HL 320.08</b> | Fan Heater / Air Heat Exchanger                    | 213        |
| <b>HL 630</b>    | Efficiency in Heating Technology                   | 197        |
| <b>HM 141</b>    | Hydrographs after Precipitation                    | 302        |
| <b>HM 142</b>    | Separation in Sedimentation Tanks                  | 246        |
| <b>HM 143</b>    | Transient Drainage Processes in Storage Reservoirs | 164        |
| <b>HM 150.19</b> | Operating Principle of a Pelton Turbine            | 048        |
| <b>HM 150.20</b> | Operating Principle of a Francis Turbine           | 049        |
| <b>HM 165</b>    | Studies in Hydrology                               | 300        |
| <b>HM 167</b>    | Ground Water Flow                                  | 304        |
| <b>HM 169</b>    | Visualisation of Seepage Flows                     | 306        |
| <b>HM 170</b>    | Open Wind Tunnel                                   | 068        |
| <b>HM 170.05</b> | Drag Body Square Plate                             | 069        |
| <b>HM 170.09</b> | Drag Body Aerofoil NACA 0015                       | 070        |
| <b>HM 170.22</b> | Pressure Distribution on an Aerofoil NACA 0015     | 071        |
| <b>HM 283</b>    | Experiments with a Centrifugal Pump                | 196        |

|                  |                                                     |            |
|------------------|-----------------------------------------------------|------------|
| <b>HM 365.31</b> | Pelton and Francis Turbine                          | 054        |
| <b>HM 421</b>    | Kaplan Turbine Trainer                              | 052        |
| <b>HM 430C</b>   | Francis Turbine Trainer                             | 056        |
| <b>HM 450.01</b> | Pelton Turbine                                      | 050        |
| <b>HM 450.02</b> | Francis Turbine                                     | 050        |
| <b>HM 450C</b>   | Characteristic Variables of Hydraulic Turbomachines | 051        |
| <b>PT 500</b>    | Machinery Diagnostic System, Base Unit              | 082        |
| <b>PT 500.11</b> | Crack Detection in Rotating Shaft Kit               | 084        |
| <b>PT 500.12</b> | Roller Bearing Faults Kit                           | 085        |
| <b>PT 500.15</b> | Damage to Gears Kit                                 | 086        |
| <b>PT 500.19</b> | Electromechanical Vibrations Kit                    | 087        |
| <b>RT 396</b>    | Pump and Valves and Fittings Test Stand             | 226        |
| <b>RT 682</b>    | Multivariable Control: Stirred Tank                 | 224        |
| <b>WL 110</b>    | Heat Exchanger Supply Unit                          | 116<br>190 |
| <b>WL 110.01</b> | Tubular Heat Exchanger                              | 118        |
| <b>WL 110.02</b> | Plate Heat Exchanger                                | 118        |
| <b>WL 110.03</b> | Shell & Tube Heat Exchanger                         | 119        |
| <b>WL 110.04</b> | Jacketed Vessel with Stirrer & Coil                 | 119        |
| <b>WL 110.20</b> | Water Chiller for WL 110                            | 114<br>190 |
| <b>WL 315C</b>   | Trainer for Various Heat Exchangers                 | 120        |
| <b>WL 376</b>    | Thermal Conductivity of Building Materials          | 188        |
| <b>WL 377</b>    | Convection and Radiation                            | 034        |





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