Energy:
Renewable Energies
and Energy Efficiency

Solar Energy

1.1

2E a division of gunt HAMBURG

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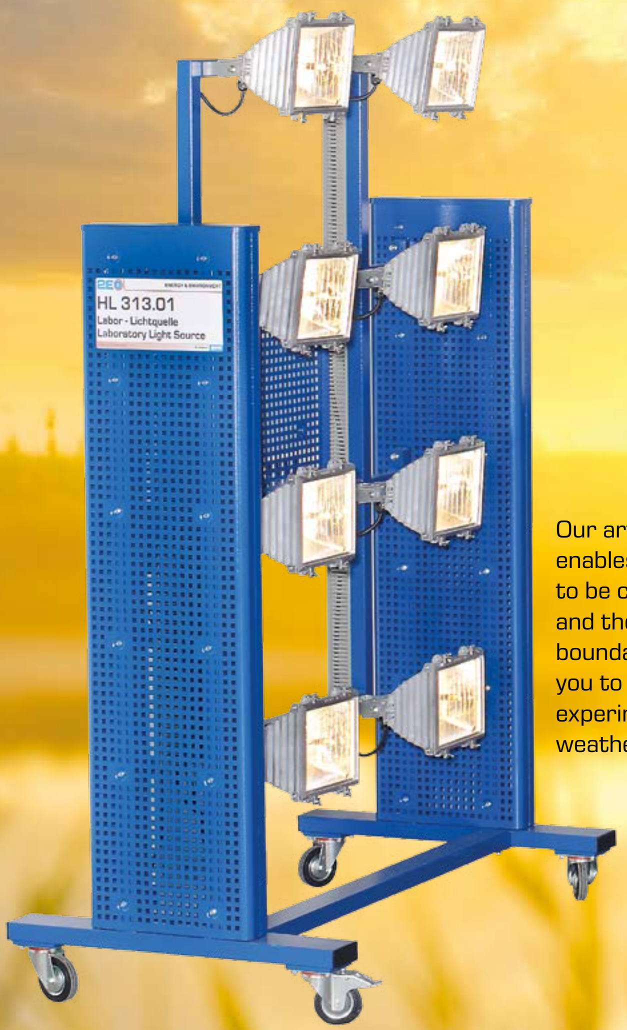

Our artificial light source HL 313.01 enables laboratory experiments to be conducted under uniform and therefore reproducible boundary conditions. This enables you to plan and carry out your experiments regardless of the weather conditions.

Visit our website at:
www.gunt2e.de

Subject Areas
Solar Energy

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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.

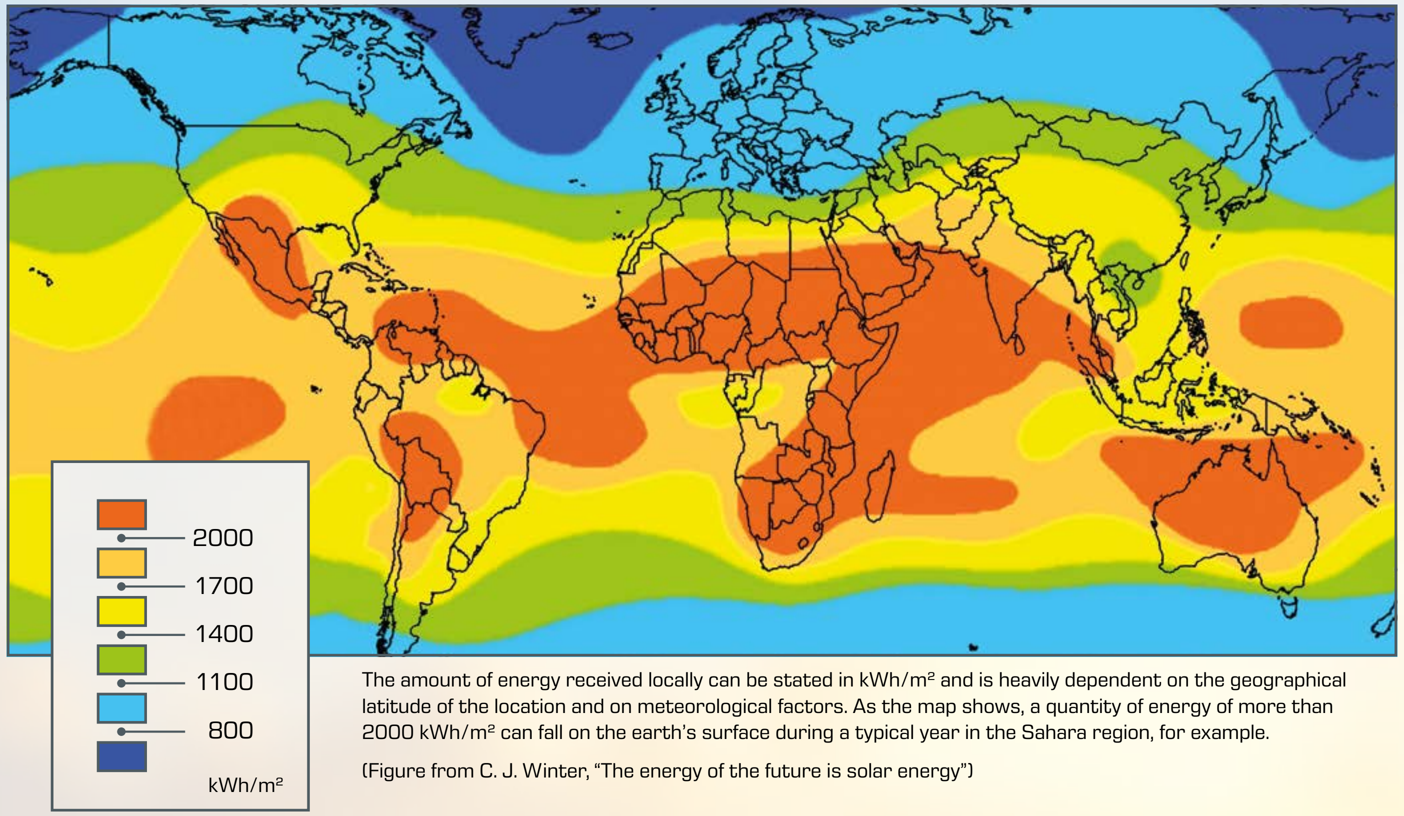
Both types of usage compete with each other in the range of a few megawatts of electric power. It is possible to build large photovoltaic installations consisting of several thousand solar modules. However, it is equally conceivable to provide the same power with a thermal parabolic trough power plant. 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.

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.

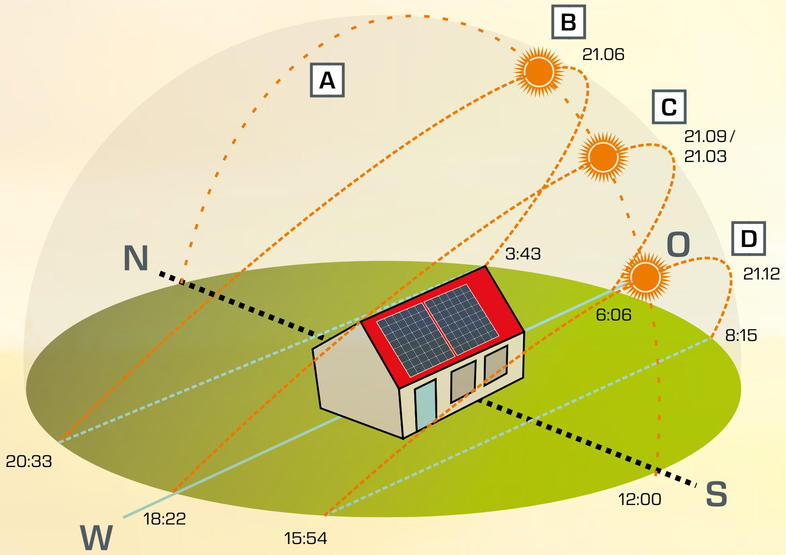


The amount of energy received locally can be stated in kWh/m² and is heavily dependent on the geographical latitude of the location and on meteorological factors. As the map shows, a quantity of energy of more than 2000 kWh/m² can fall on the earth's surface during a typical year in the Sahara region, for example.

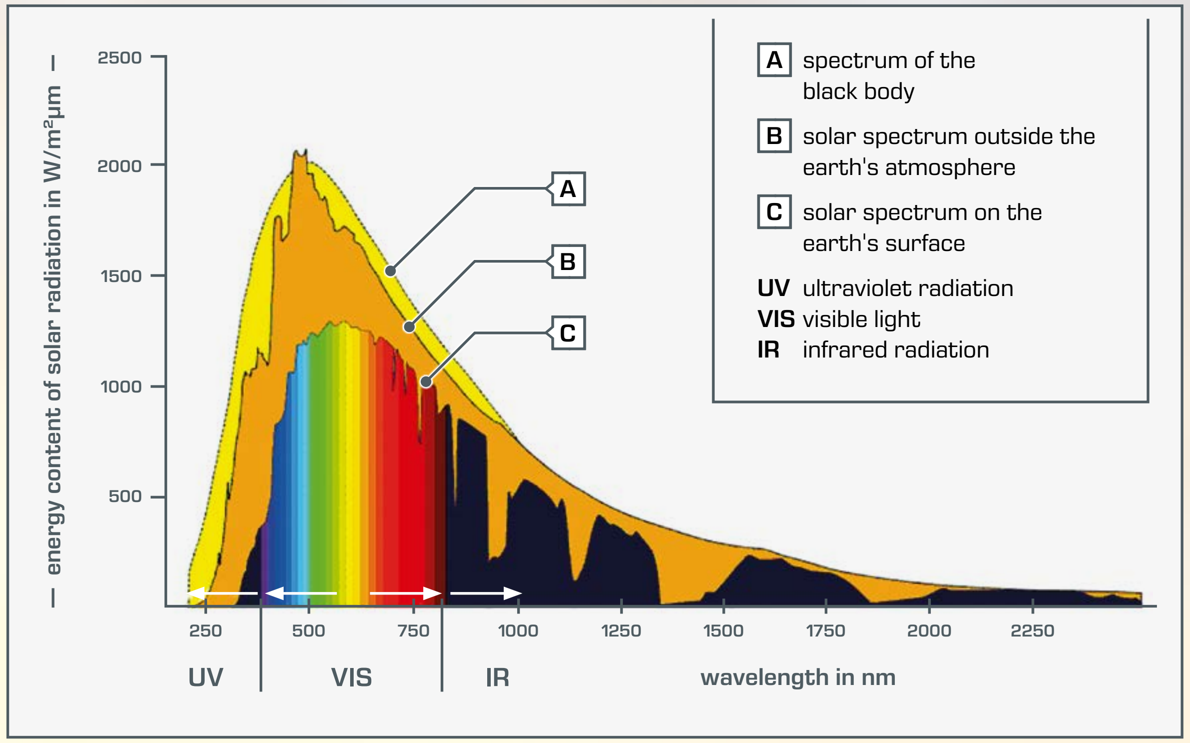
(Figure from C. J. Winter, "The energy of the future is solar energy")

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 wavelengths. If one is then able to better adapt the spectral properties of the receiver or absorber to the solar spectrum, then a key condition for improving the energy balance is met.



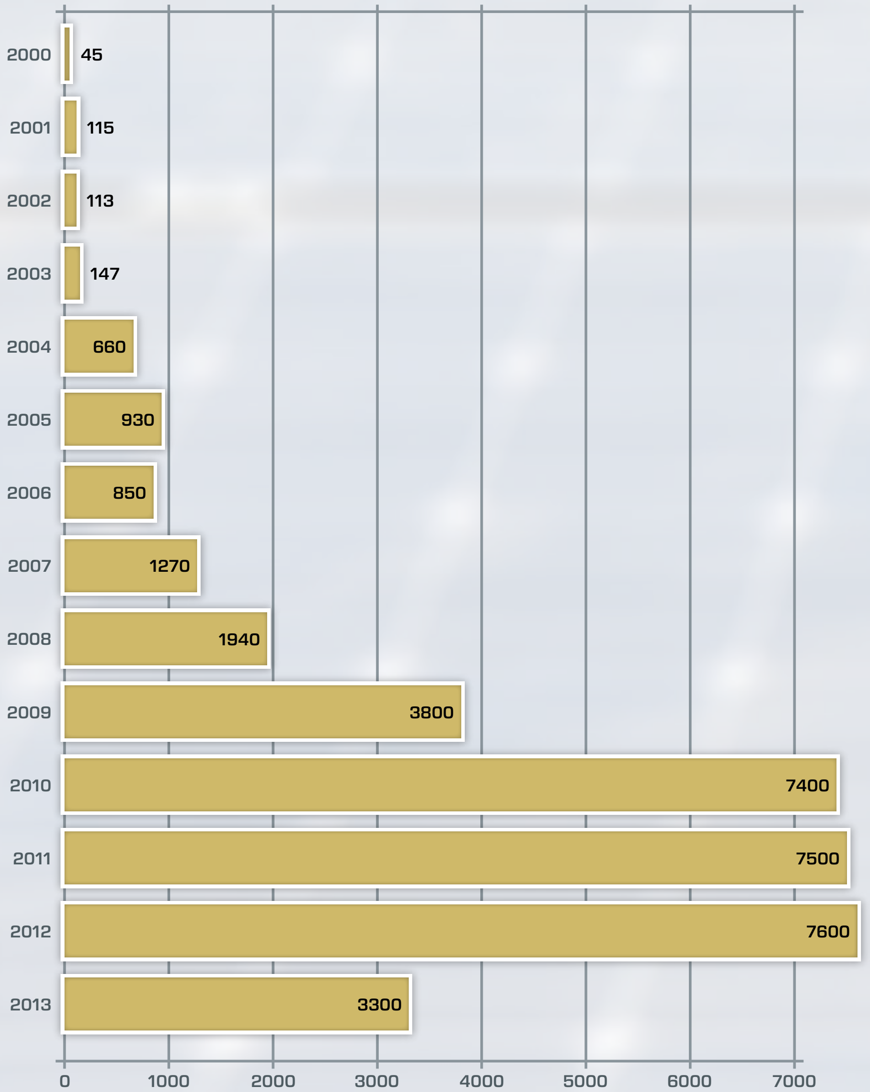
The spectrum of sunlight

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.

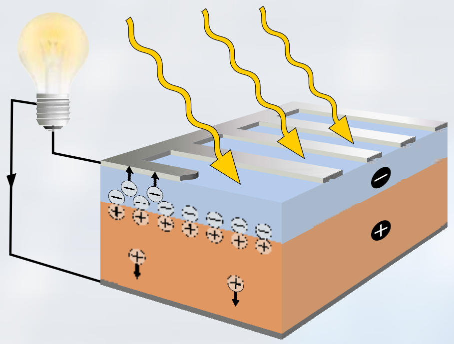
Basic Knowledge Photovoltaics

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_{pv}
(Source: BSW-Solar)

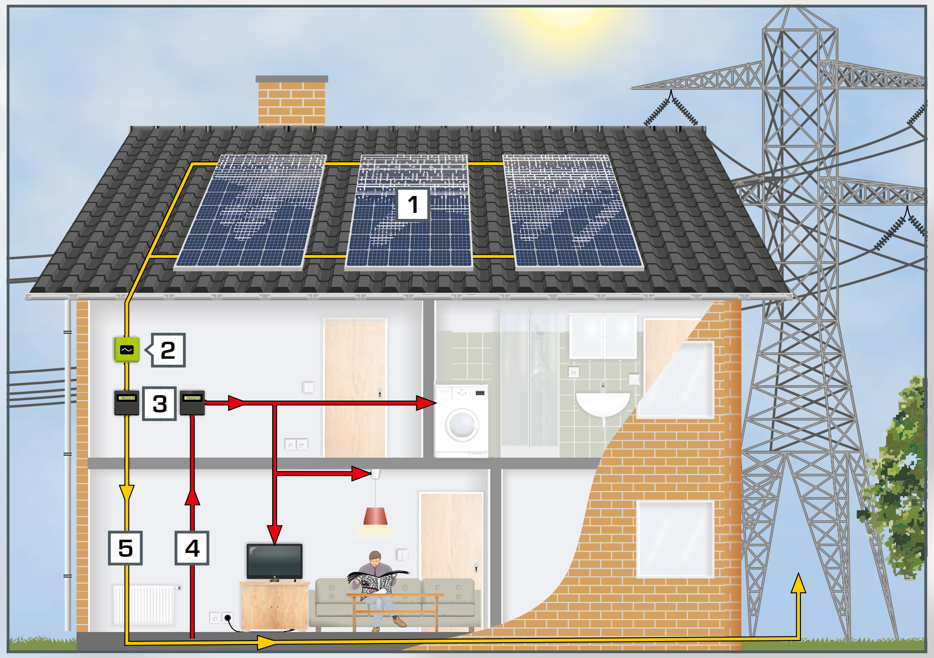


How semiconductor solar cells work

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

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

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



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

Using solar power efficiently

In order to collect the photovoltaic solar power, 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.

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-aranged measuring unit

Pivoting photovoltaic modules

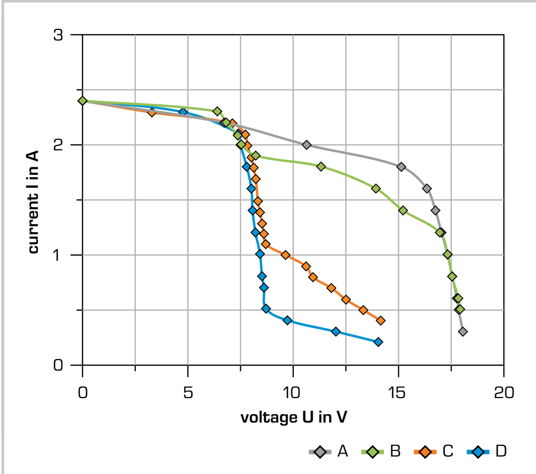
Learning objectives

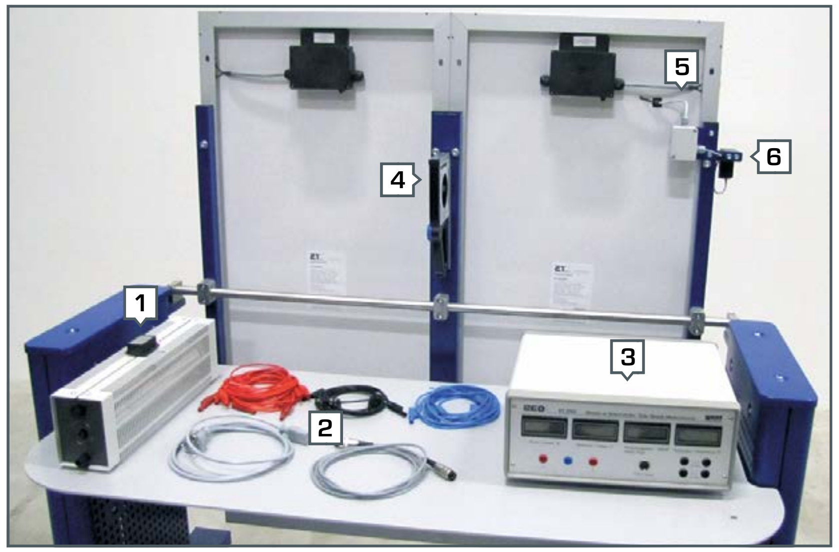
- physical behaviour of photovoltaic modules under varying illuminance, temperature and shading
- familiarisation with key characteristic variables such as short-circuit current, open-circuit voltage and maximum capacity
- plotting current-voltage curves in parallel and series connection
- influence 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.

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).





Accessories and components

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

Product No.
061.25000
More details and technical data:
gunt.de/static/s3454_1.php

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.

ET 250.02 is another extension module for ET 250. The unit allows you to teach key aspects of solar energy use in stand-alone systems. ET 250.02 contains all the necessary components.

Learning objectives (ET 250.01)

- 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

ET 250.01 is designed as an extension module for ET 250 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.

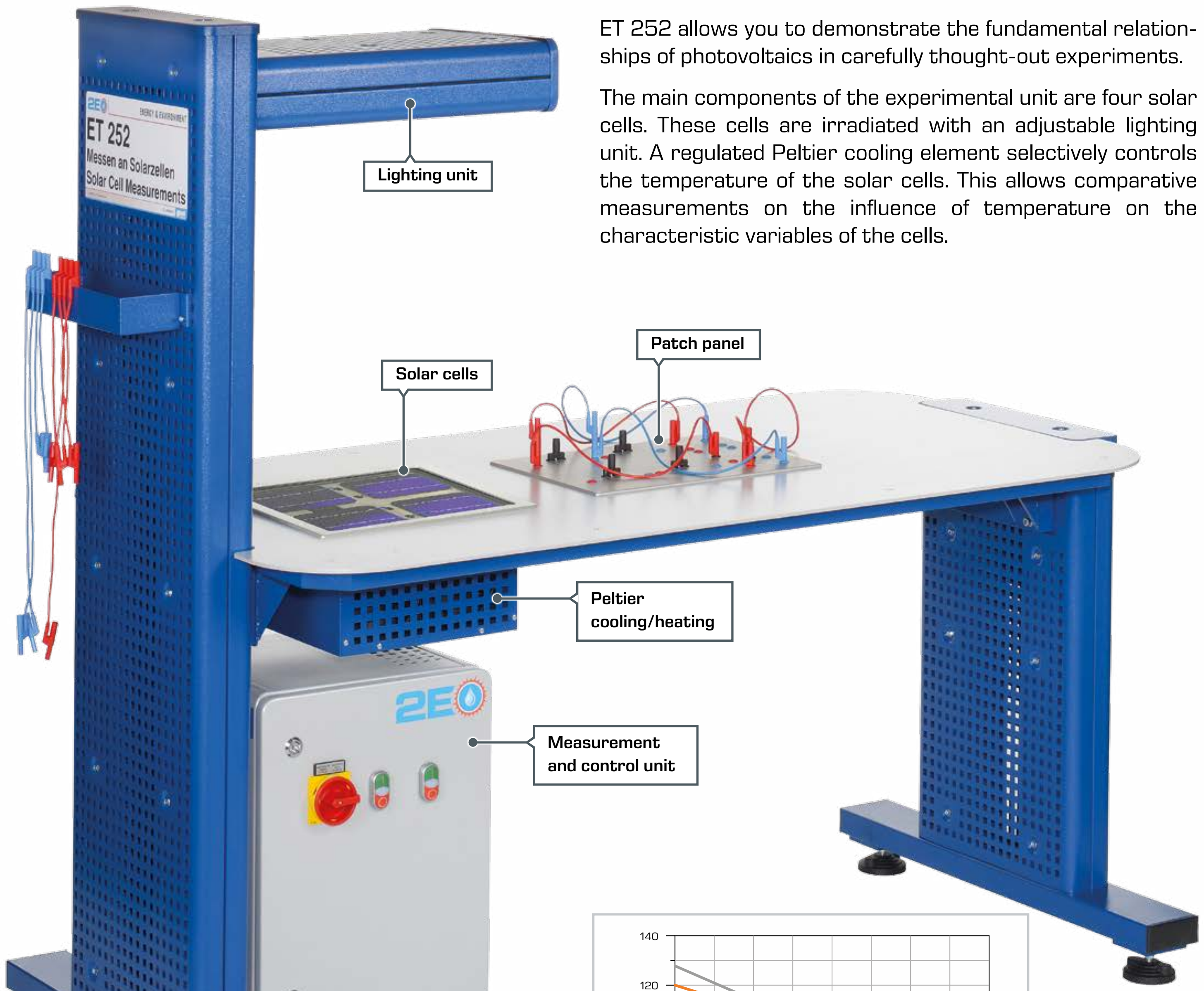
Learning objectives (ET 250.02)

- 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

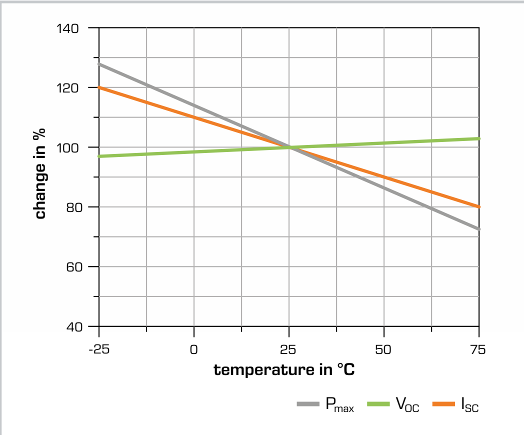
Product No.
061.25002
More details and technical data:
gunt.de/static/s5277_1.php

ET 252 Solar Cell Measurements



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

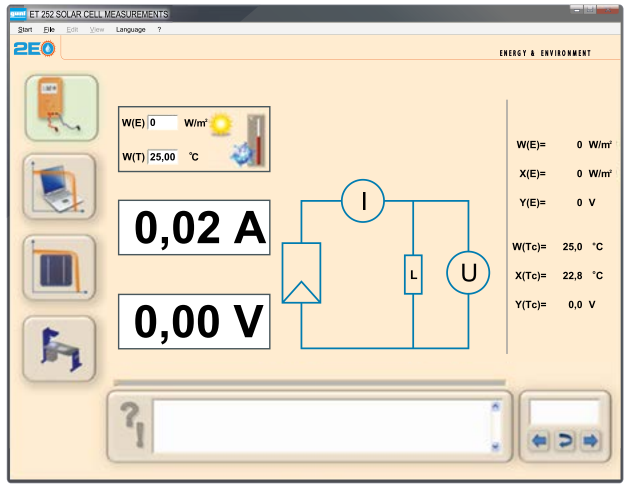
The main components of the experimental unit are four solar cells. These cells are irradiated with an adjustable lighting unit. A regulated Peltier cooling element selectively controls the temperature of the solar cells. This allows comparative measurements on the influence of temperature on the characteristic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



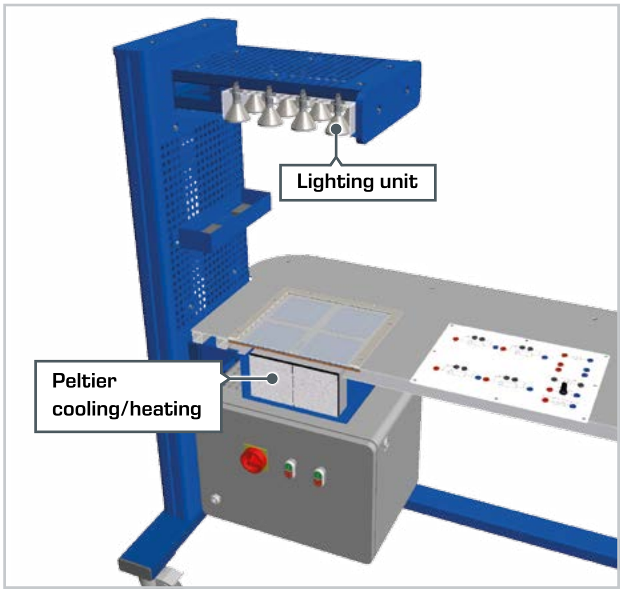
ET 252 allows you to investigate the specific effect of temperature on the solar cell.

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

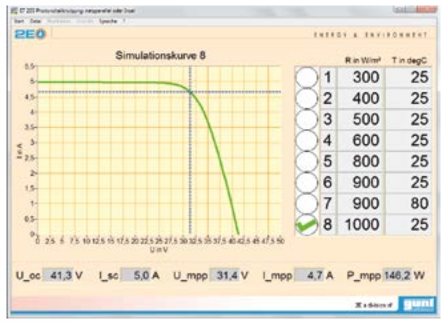
Product No.
061.25200
More details and technical data:
gunt.de/static/s4985_1.php

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.

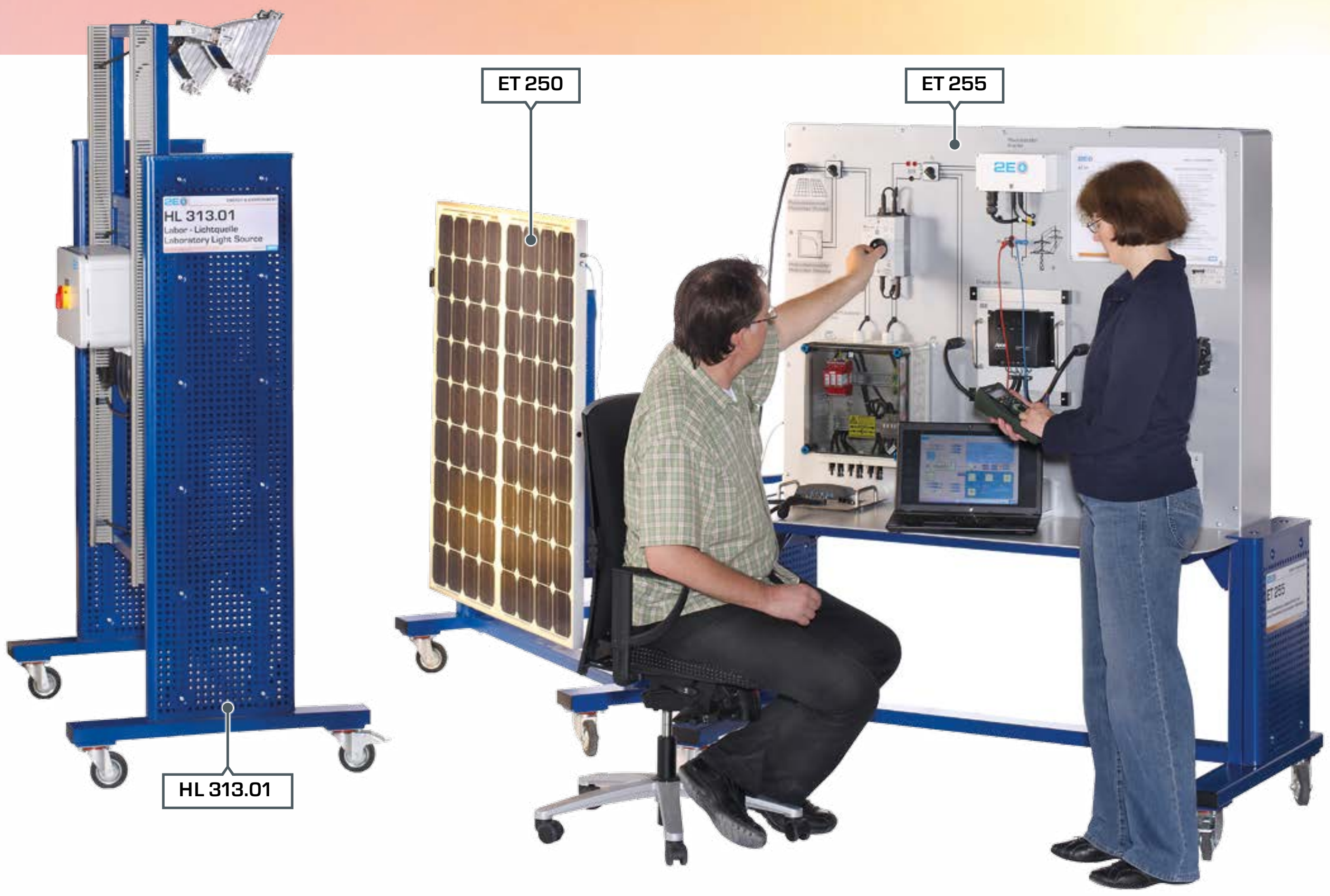
Software

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.

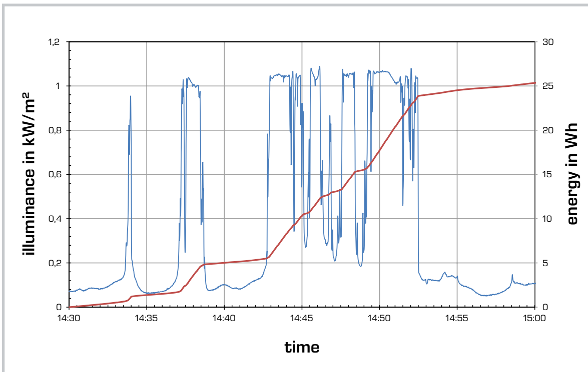


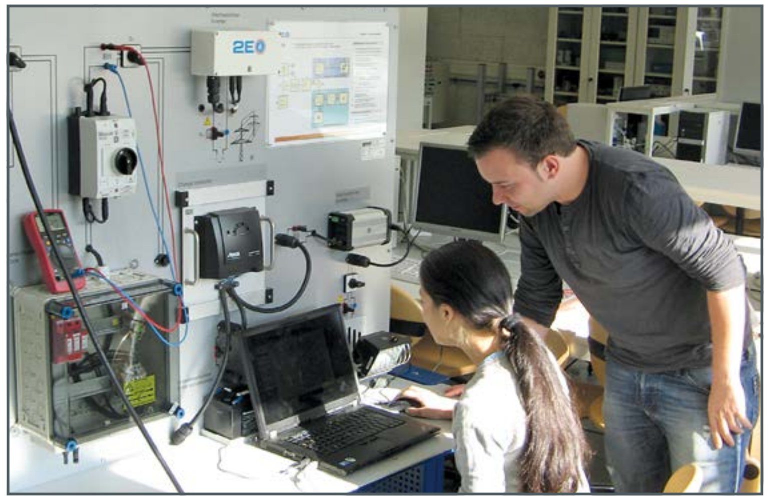
Learning objectives

- 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.

Product No.
061.25500
More details and technical data:
gunt.de/static/s5103_1.php

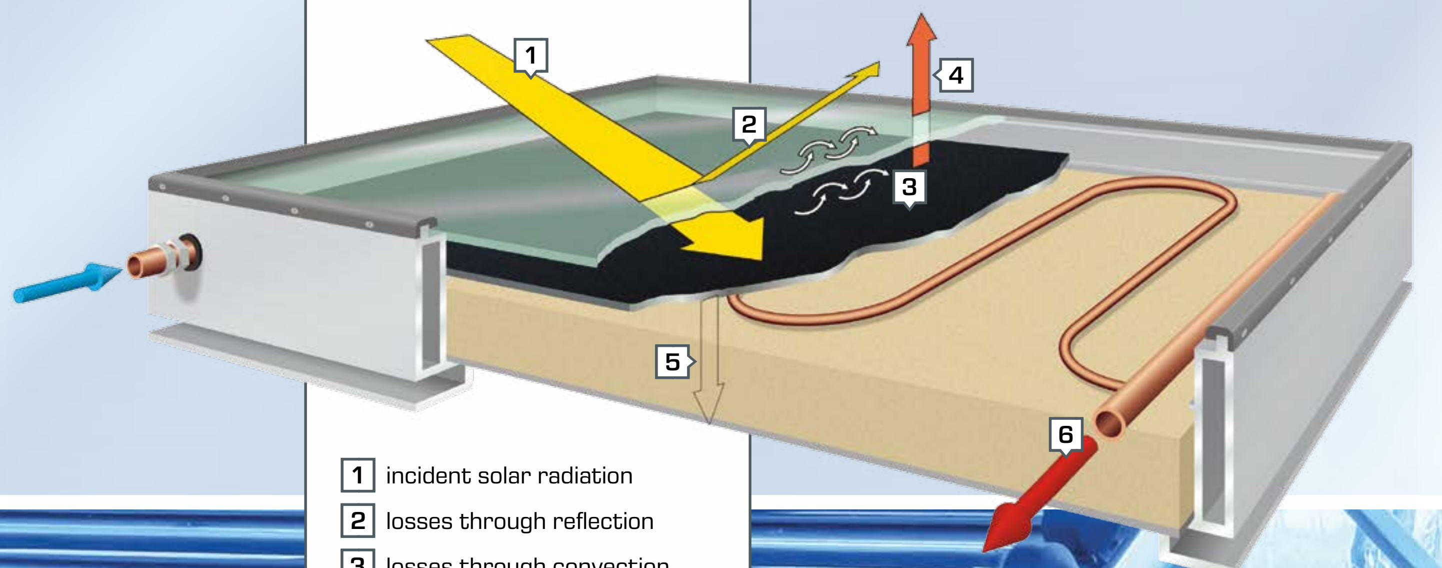
Basic Knowledge
Solar Thermal Energy

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.

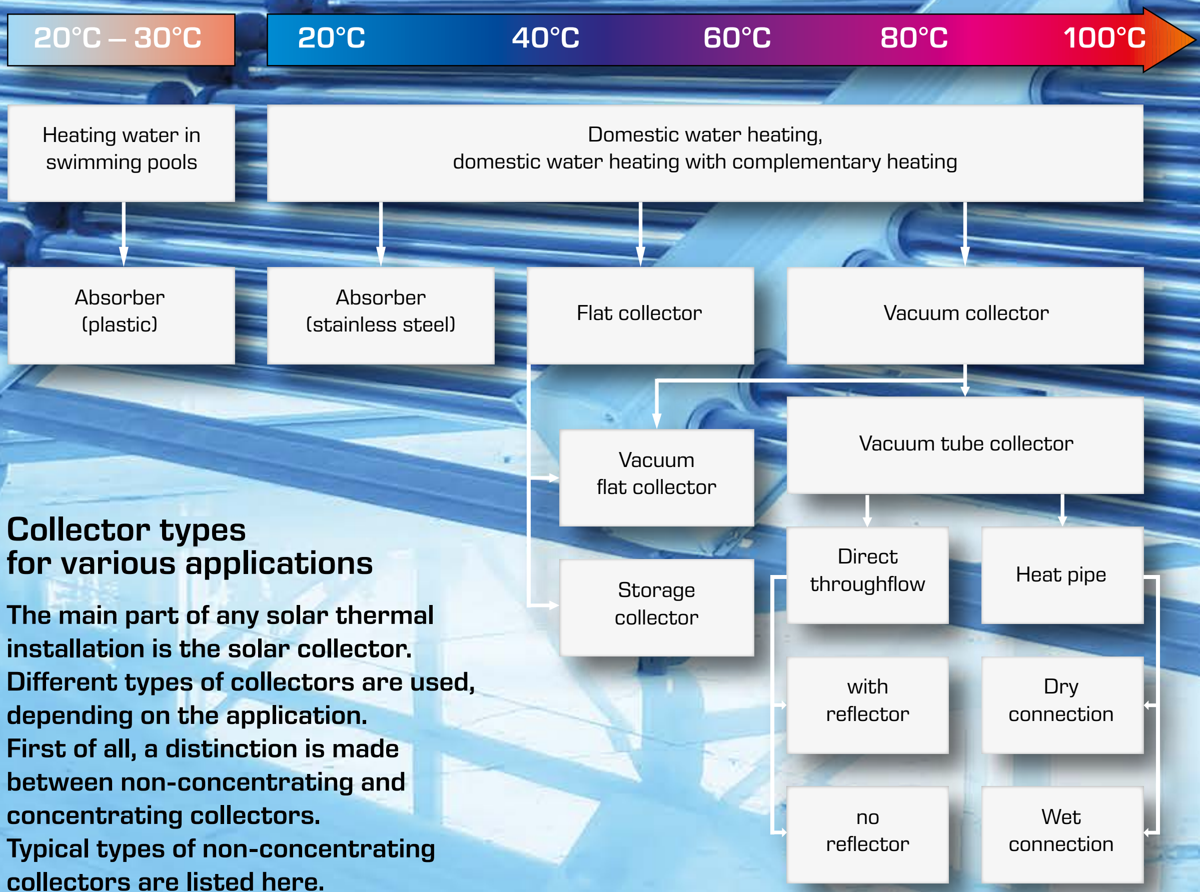
Typical applications for solar thermal collectors:

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

Energy balance of a flat collector



1. incident solar radiation
2. losses through reflection
3. losses through convection
4. thermal radiation losses
5. losses through heat conduction
6. generated heat at the collector outlet



Collector types for various applications

The main part of any solar thermal installation is the solar collector. Different types of collectors are used, depending on the application. First of all, a distinction is made between non-concentrating and concentrating collectors. Typical types of non-concentrating collectors are listed here.

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 diagramally in the figure above.

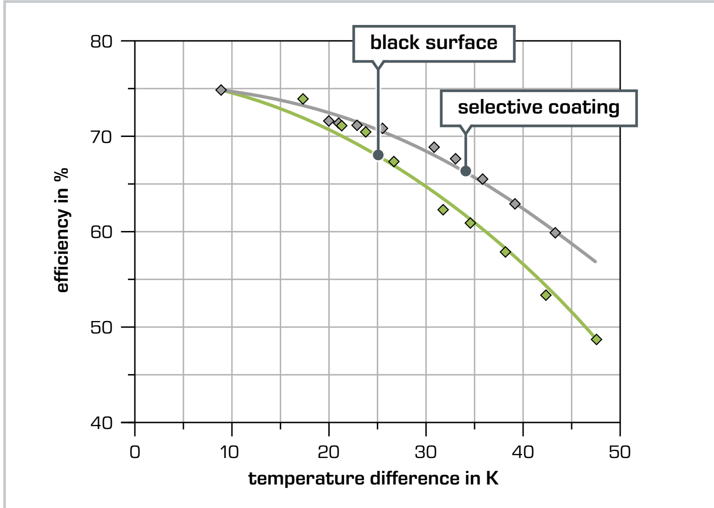
Heating using solar energy

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 ET 202 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.

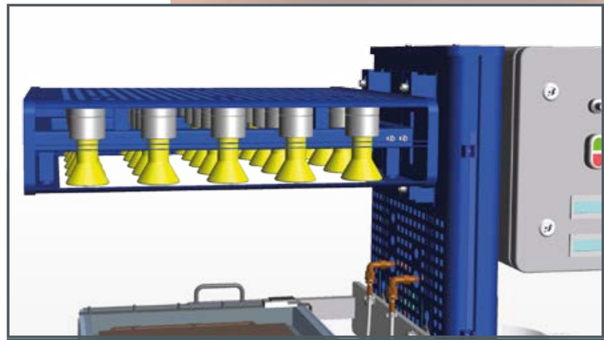
ET 202 allows you to investigate how temperature affects the efficiency of various absorbers.



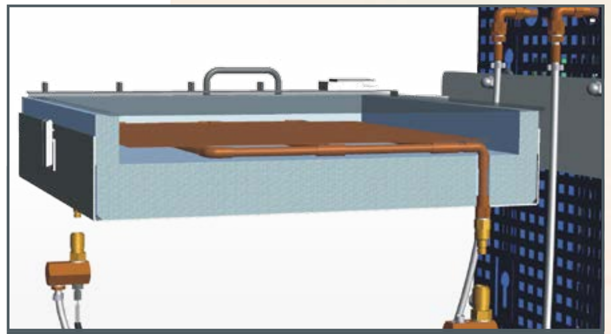
The illustration shows measured values for the efficiency as a function of the collector temperature. A special coating on the absorber allows higher efficiencies.

Learning objectives

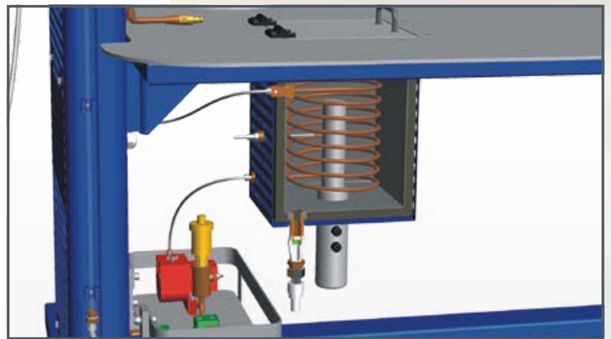
- design and operation of a simple solar thermal system
- determining the net power
- energy balance on the solar collector
- influence of illuminance, angle of incidence and flow rate
- determining efficiency curves
- influence of various absorbing surfaces



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.

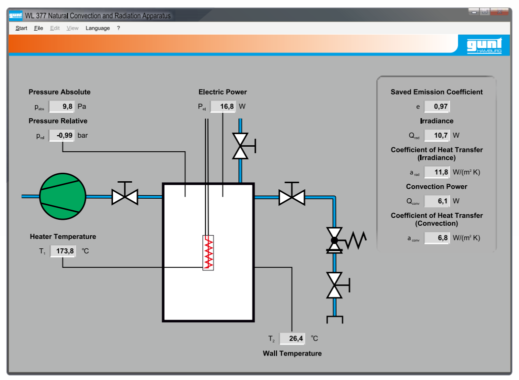


The heat exchanger is built into the storage tank. An electrical heater which makes it possible to achieve different collector operating states in just a short time is additionally available.

Product No.
061.20200
More details and technical data:
gunt.de/static/s3566_1.php

WL 377 Convection and Radiation

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.



Software

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

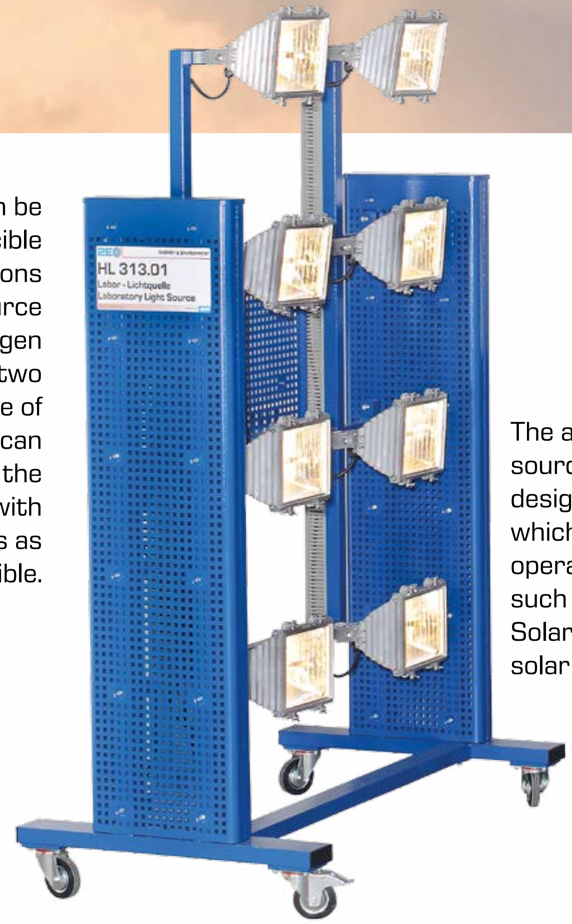
Learning objectives

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

Product No.
060.37700
More details and technical data:
gunt.de/static/s3440_1.php

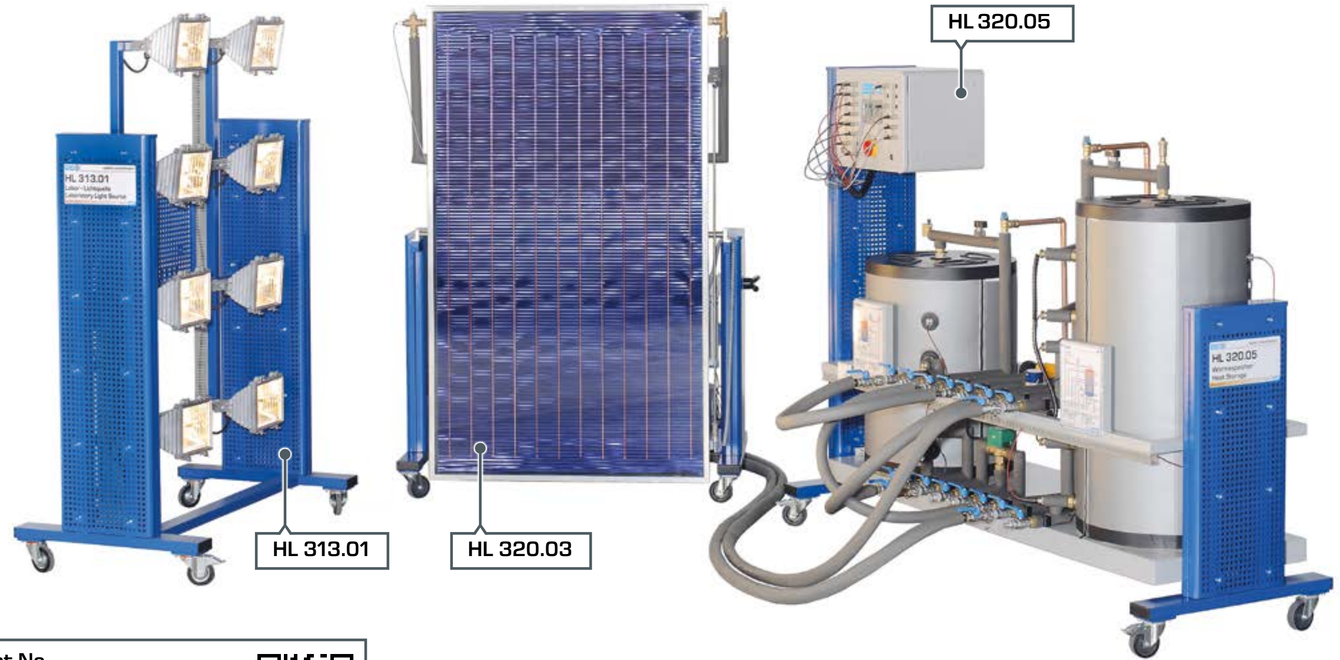
HL 313.01 Artificial Light Source

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

HL 313 Domestic Water Heating with Flat Collector

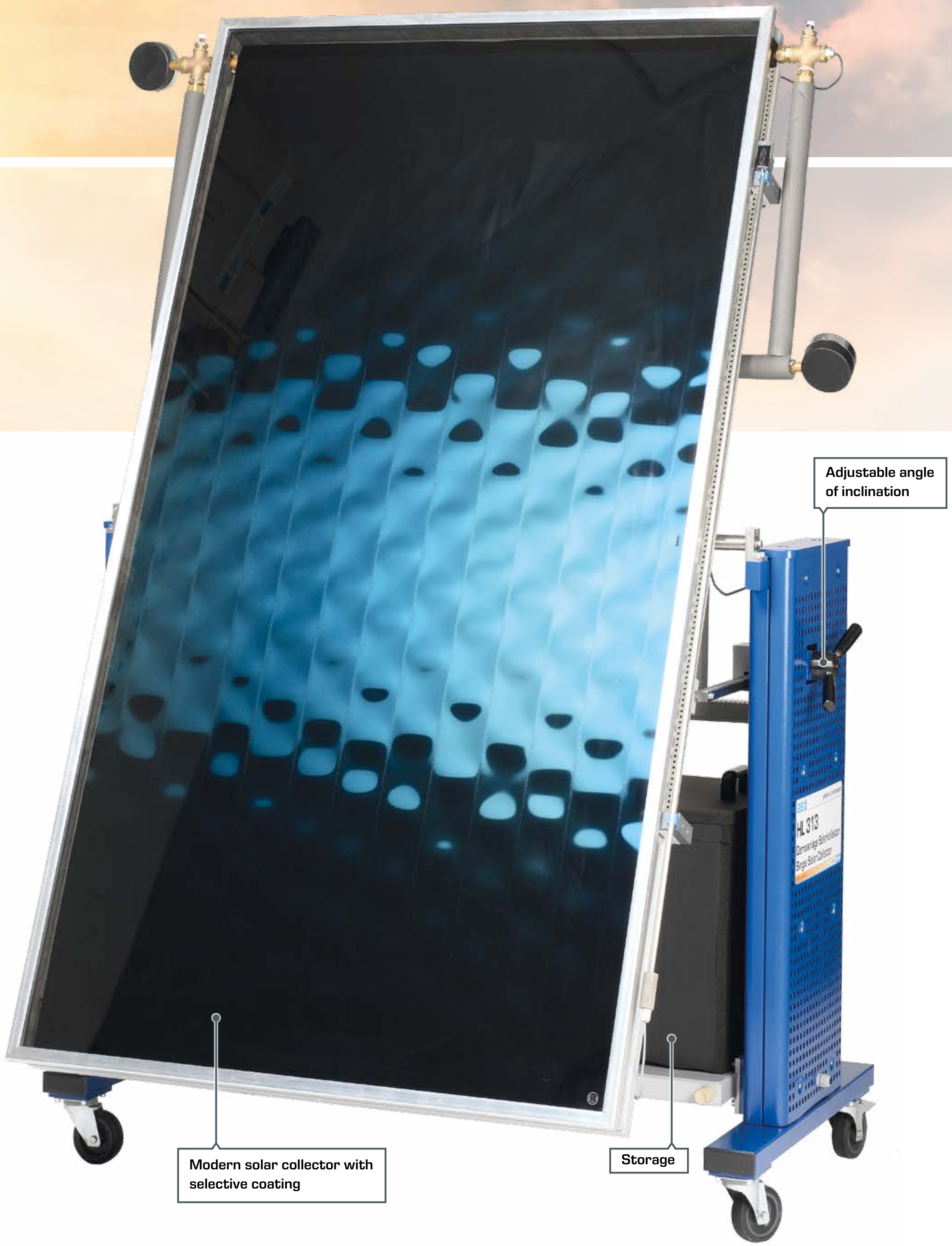
For laboratory experiments under uniform light conditions, we recommend our artificial light source HL 313.01.
Further information can be found on page 35.

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.

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.



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

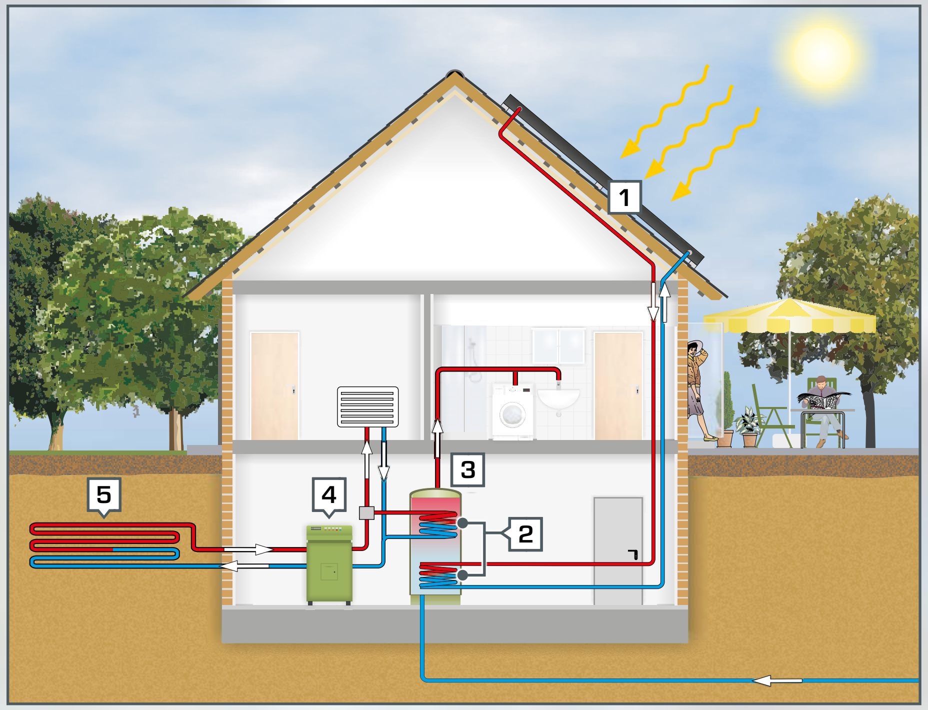
Product No.
065.31300
More details and technical data:
gunt.de/static/s3506_1.php

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.

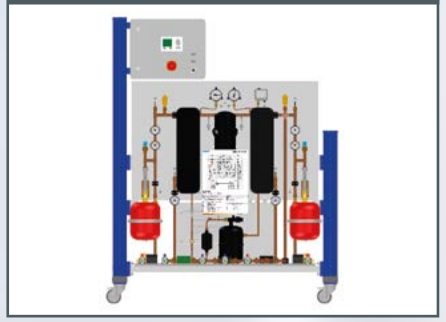
Combined use of renewable heat sources

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

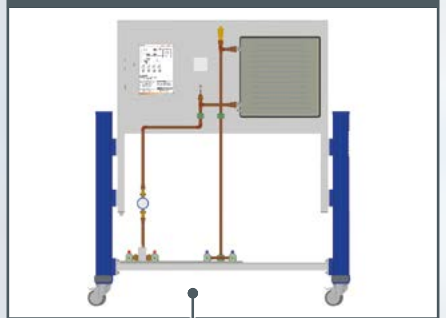
HL 320.05
Central Storage Module with Controller

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

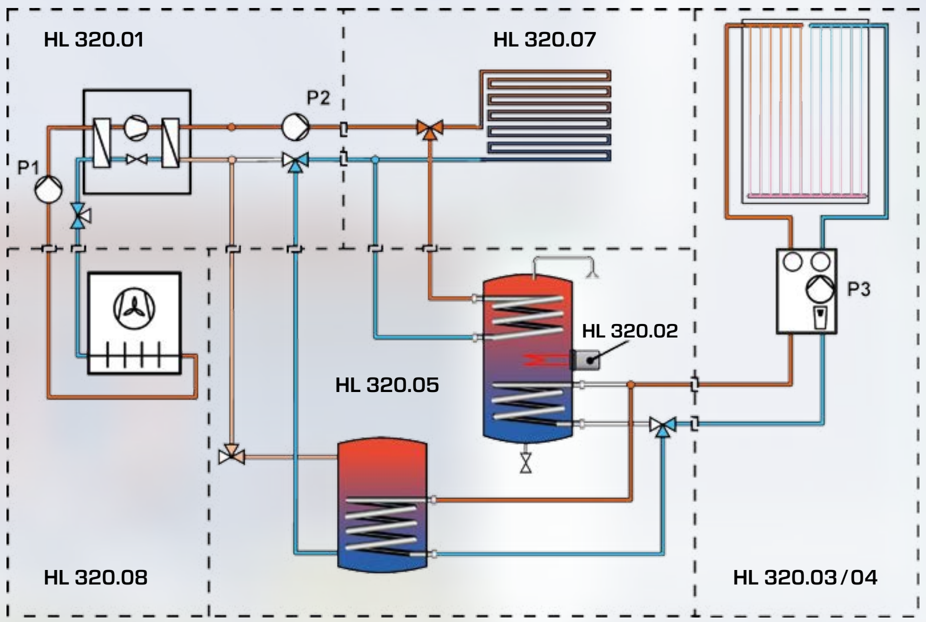


The HL 320.07 and HL 320.08 modules can be used as heat sources or as heat sinks.

HL 320
Solar Thermal Energy and Heat Pump Modular System

The right configuration for every application

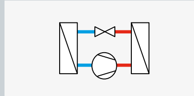
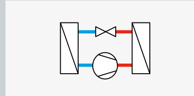
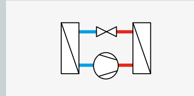
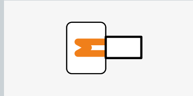
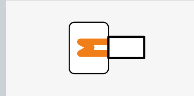
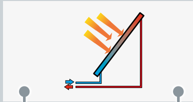
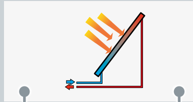
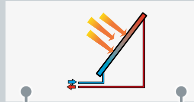
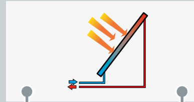
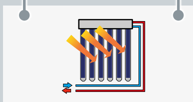
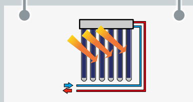
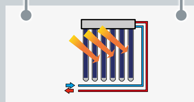
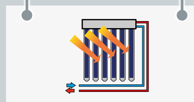
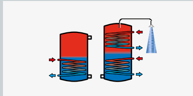
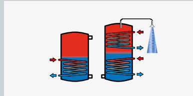
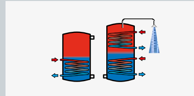
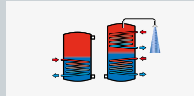
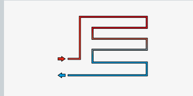
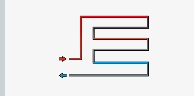
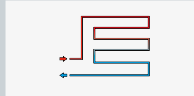
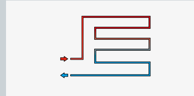
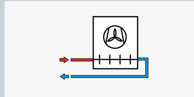
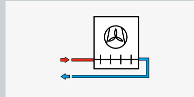
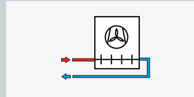
In practice, both the correct composition of necessary components and the optimisation of cabling and controller settings depend on the local conditions. We have developed a series of experiments for a selection of relevant module combinations in order to be able to teach the corresponding learning content 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
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					
HL 320.07 Underfloor Heating / Geothermal Energy Absorber					
HL 320.08 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

5 Solar cooling

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Basic knowledge

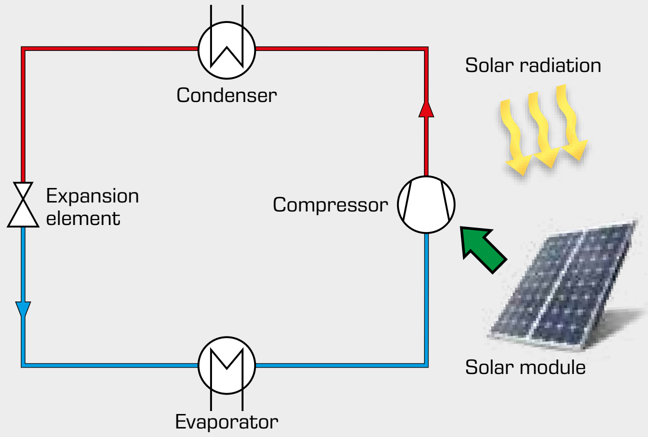
Solar cooling

Interest in alternative processes for cold production that can be supplied from renewable energy sources is steadily growing. The basic idea of solar cooling is to use solar energy to cool buildings or equipment, especially during the hot hours of the day. The future market of “solar cooling” is extremely important when it comes to the sustainability of buildings with air-conditioning systems, both in temperate climates and in warm countries.

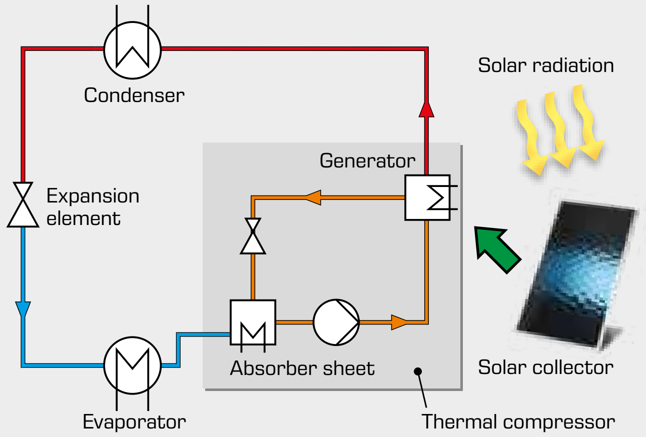
Principle of operation of solar cooling

Solar cooling means a process in which the cooling process is powered directly by solar energy. Solar energy thus serves as a regenerative source of drive heat. Essentially, a distinction is made between two processes for the conversion of solar energy into useful energy:

Conversion into electric current, electric process with photovoltaic module



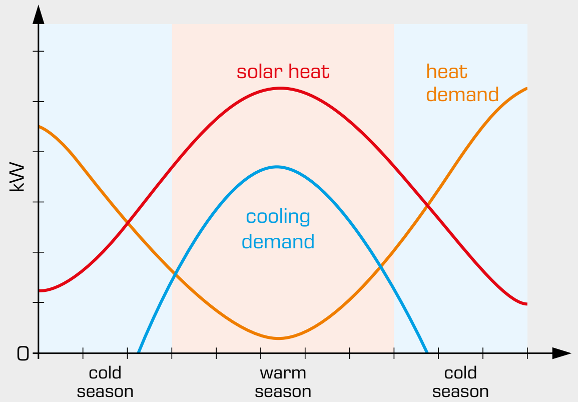
Conversion into heat, thermal process using the example of an absorption refrigeration system with solar collector



In solar refrigeration machines, the electric compressor is replaced by a thermal compressor.

Available solar energy

Solar radiation and cooling demand correlate with each other in terms of time. This state should be exploited. The advantages of supplying cooling systems with solar energy are therefore obvious.



Typical annual trends for available solar energy and the heating and cooling demand of a building

Advantages of solar cooling

- Instead of high electrical power output for a conventional cooling system, the consumption of electrical energy can be limited to the drives of pumps and fans.
- On warm summer days in particular, when the need for cooling is particularly high, electricity consumption is reduced.

Overview of the physical ways of converting solar energy into cooling or conditioned air.

solar energy

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

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

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

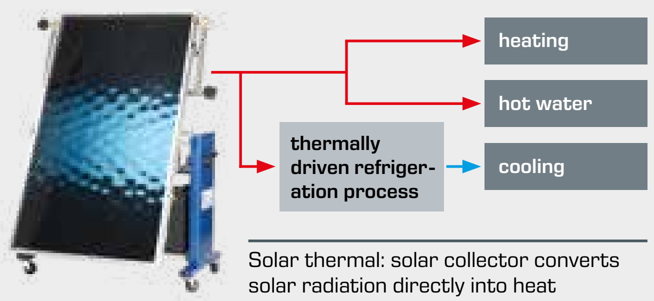
in catalogue 5 Process Engineering

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

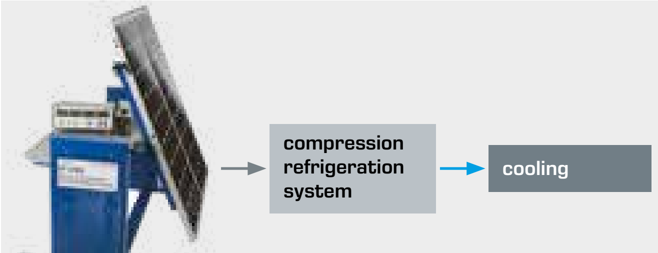
ET 480 Absorption refrigeration system, as an example of a closed process with the liquid sorbents water and ammonia. In this device, the generator is heated either by a gas burner or an electric heater.

Supply of buildings as one area of application

A large proportion of possible solar cooling applications concern the building supply sector. With regard to energy optimisation, it therefore makes sense to also consider other energy consumers in a building. The diagram shows two system concepts for incorporating solar thermal energy and photovoltaics.



Solar thermal: solar collector converts solar radiation directly into heat



Photovoltaics: solar module converts solar radiation directly into electrical energy

ET 256
Cooling with solar electricity

Description

- **compression refrigeration system for operation with ET 250 photovoltaic modules or with laboratory power supply ET 256.01**
- **long cooling time due to cold accumulators and insulation**
- **software for controlling and balancing energy flows**
- **dynamic recording of the refrigerant mass flow rate**

With the increasing demand for refrigeration worldwide, the interest in processes of cold production which can be supplied from renewable energy sources is also growing. The use of solar electricity offers particular advantages for mobile and very remote applications.

ET 256 contains a typical compression refrigeration system with refrigeration chamber. It is possible to supply the refrigerant compressor directly with current from photovoltaic modules. To do this, the photovoltaic modules from ET 250 are connected to ET 256. For some experiments, the laboratory power supply ET 256.01 can also be used. The artificial light source HL 313.01 enables solar energy experiments independently of natural sunlight.

The refrigerant compressor is a piston compressor with adjustable speed. A thermostatic expansion valve is used in the refrigeration circuit. The insulated refrigeration chamber contains a refrigerant evaporator with fan, removable cold accumulator and a heater for generating a cooling load.

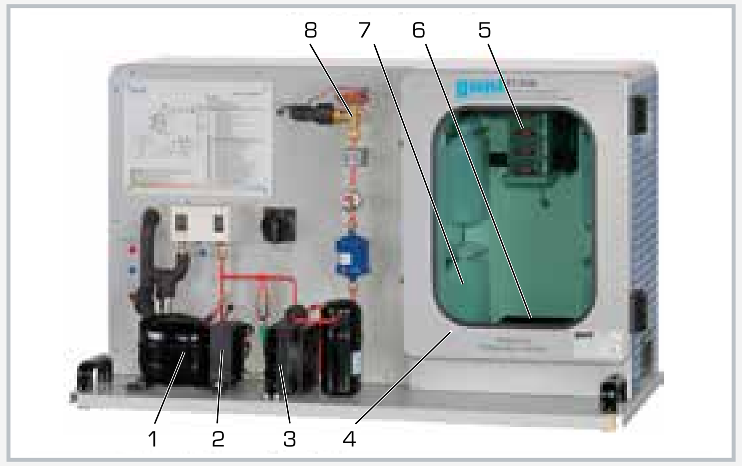
For cooling, the compressor is started by the control unit when sufficient electrical power is available from the solar modules. Operating the compressor reduces the temperature in the refrigeration chamber. Should the cold accumulators be fully or partially discharged, they are charged again as soon as sufficiently low temperatures are reached. If there is no current available to operate the compressor, the cold accumulators increase the remaining cooling time in the refrigeration chamber and are discharged in this way.

Relevant measured values are recorded by sensors, displayed and can be processed in a PC. The refrigerant mass flow rate is calculated in the software from the recorded measured values.

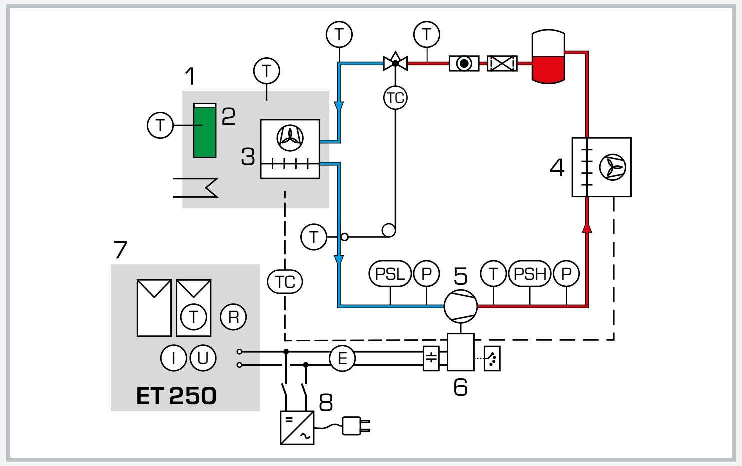
Learning objectives/experiments

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

ET 256
Cooling with solar electricity



1 compressor, 2 control unit, 3 condenser, 4 refrigeration chamber, 5 evaporator, 6 heater, 7 cold accumulator, 8 expansion valve



1 refrigeration chamber, 2 cold accumulator, 3 evaporator, 4 condenser, 5 compressor, 6 control unit, 7 photovoltaic modules, 8 laboratory power supply (ET 256.01)

ET 256 together with the optional artificial light source HL 313.01 and solar modules ET 250

Specification

[1] compression refrigeration system for operation with electricity from ET 250 photovoltaic modules or from laboratory power supply ET 256.01
[2] compression refrigeration system: refrigerant compressor with adjustable speed, insulated refrigeration chamber with evaporator, cold accumulators and cooling load, thermostatic expansion valve and condenser
[3] supply with direct current from photovoltaic modules in ET 250
[4] heater to generate a cooling load
[5] control unit for temperature-controlled compressor operation
[6] rechargeable cold accumulators
[7] sensors to capture temperature and pressure
[8] refrigerant mass flow rate calculated in the software from recorded measured values
[9] GUNT software with control functions and data acquisition via USB under Windows 7, 8.1, 10
[10] refrigerant R513A, GWP: 631

Technical data

Compressor
- speed: 2000...3500min^{-1}
- refrigeration capacity: approx. 90W at 0/55°C and 2000min^{-1}
- electrical power consumption: approx. 46W at 0/55°C and 2000min^{-1}

Control unit: input voltage range: 10...45V DC
Refrigeration chamber: LxWxH: 400x250x500mm
Cold accumulators: phase transition: 5...6°C

Refrigerant
- R513A
- GWP: 631
- filling volume: 1kg
- CO_2-equivalent: 0,6t

Measuring ranges
- temperature: 4x -30...80°C, 3x 0...120°C
- pressure: 2x 0...6bar, 2x 0...30bar
- current: 0...10A
- voltage: 0...60V
- flow rate: 0...11kg/h (refrigerant)

230V, 50Hz, 1 phase
LxWxH: 980x400x580mm
Weight: approx. 65kg

Required for operation

PC with Windows

Scope of delivery

1 experimental unit
1 set of cables
1 GUNT software CD + USB cable
1 set of instructional material

ET 352
Vapour jet compressor in refrigeration

Learning objectives/experiments

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

Description

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

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

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

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

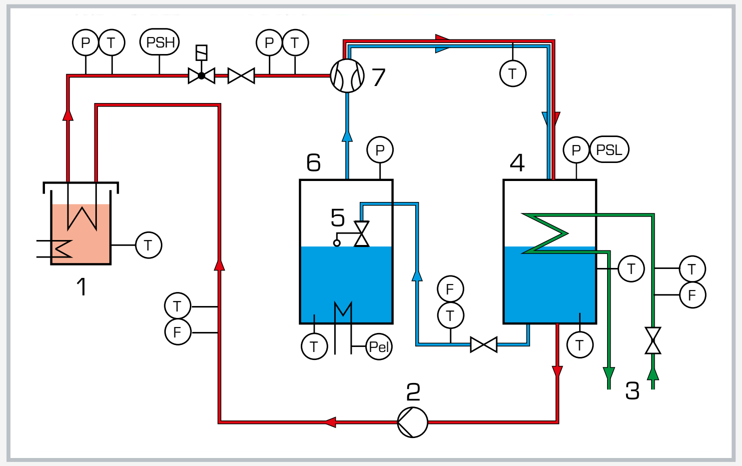
In the refrigeration cycle some of the condensed refrigerant flows into the transparent evaporator connected to the intake side of the vapour jet compressor. The evaporator is a so-called flooded evaporator or where a float valve keeps the filling level constant. The refrigerant absorbs the ambient heat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

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

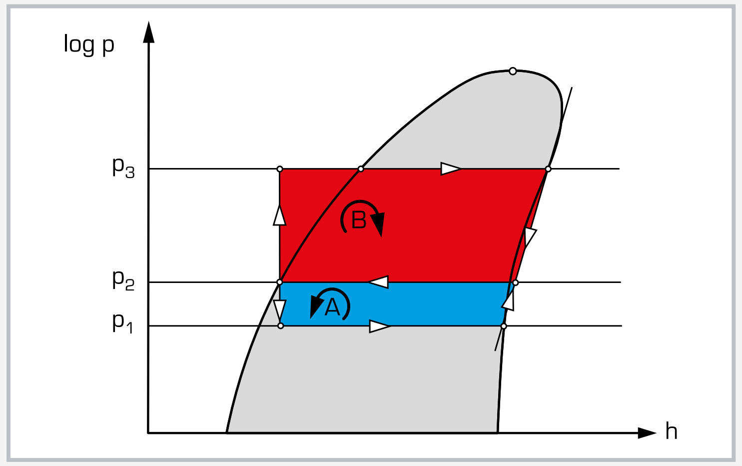
Relevant measured values are recorded by sensors, displayed and can be processed onto a PC. The heater power at the evaporator is adjustable. The cooling water flow rate at the condenser is adjusted using a valve.

ET 352
Vapour jet compressor in refrigeration

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



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



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

Specification

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

Technical data

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

Condenser
- tank: approx. 3,5L
- pipe coil area: approx. 0,17m^2

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

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

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

Refrigerant
- R1233zd
- GWP: 1
- filling volume: 5kg
- CO_2-equivalent: 0t

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

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase, 230V, 60Hz, 3 phases
UL/CSA optional
LxWxH: 1460x790x1890mm
Weight: approx. 225kg

Required for operation

water connection, drain, PC with Windows recommended

Scope of delivery

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

ET 352.01
Solar heat for cold production

Learning objectives/experiments

- use of solar heat for cold production
- components of solar refrigerating plants according to the vapour jet method
- operation of a vapour jet compressor on a solar thermal flat collector
- optimisation of the operating point
- energy balances
- extended concept on the use of thermal solar plants
- energy management for solar thermal cooling systems

Description

- **in combination with ET 352 and HL 313: use of solar heat as drive energy for a vapour jet compressor**
- **energy flow balances**

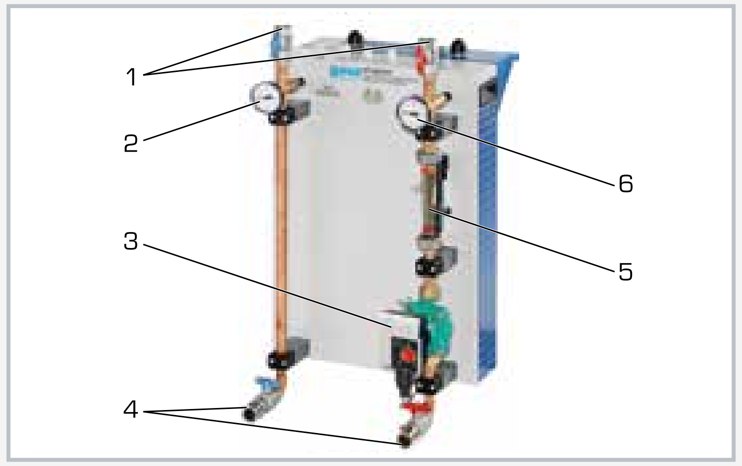
With the increasing demand for refrigeration and air conditioning worldwide, the interest in alternative processes of cold production which can be supplied from renewable energy sources is also growing. One promising possibility is thermal processes. In these processes, thermal energy is used to generate cold.

ET 352.01 allows the vapour jet compressor from ET 352 to be operated with solar-generated heat from the HL 313 flat collector.

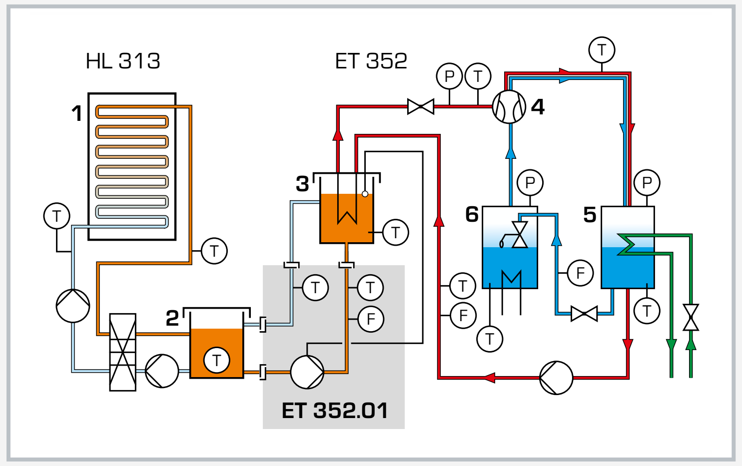
After sufficient solar thermal heating, the heat transfer fluid from HL 313 is pumped into the vapour generator of ET 352 by the pump from ET 352.01. The pump is operated via ET 352. ET 352 and HL 313 are connected by hoses.

The energy added from solar heat is determined by two temperature sensors and one flow rate sensor. The measured values are transferred to ET 352 and can be processed on a PC. They are also displayed directly on ET 352.01.

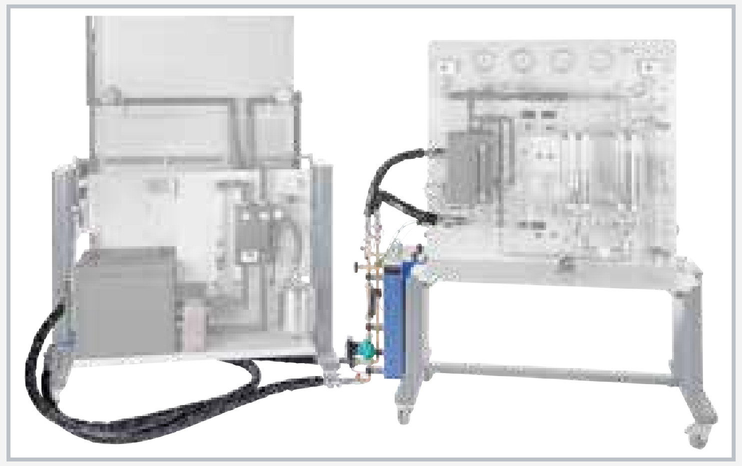
ET 352.01
Solar heat for cold production



1 feed/return line ET 352, 2 return line thermometer, 3 circulating pump, 4 feed/return line HL 313, 5 flow rate sensor, 6 feed line thermometer



1 solar thermal collector, 2 heat accumulator, 3 vapour generator, 4 vapour jet compressor, 5 condenser, 6 evaporator; F flow rate, P pressure, T temperature; red: vapour cycle, blue: refrigeration cycle, green: cooling water, orange: warm heat transfer fluid, light blue: cold heat transfer fluid



Functional experimental setup: HL 313 Domestic water heating with flat collector (left), ET 352.01 Solar heat for cold production (middle), ET 352 Vapour jet compressor in refrigeration engineering (right)

Specification

[1] supply of the vapour jet compressor in ET 352 with solar heat from the flat collector HL 313
[2] pump for pumping the heat transfer fluid from HL 313 to the vapour generator in ET 352
[3] feed line to the vapour generator with temperature and flow rate measurement
[4] return line with temperature measurement
[5] measured values transferred to ET 352 for further processing in the software
[6] pump operated via ET 352
[7] ET 352, HL 313 and ET 352.01 connected via hoses and quick-release couplings

Technical data

Pump
- power consumption: 40W
- max. flow rate: 1m^3/h
- head: 4,8m

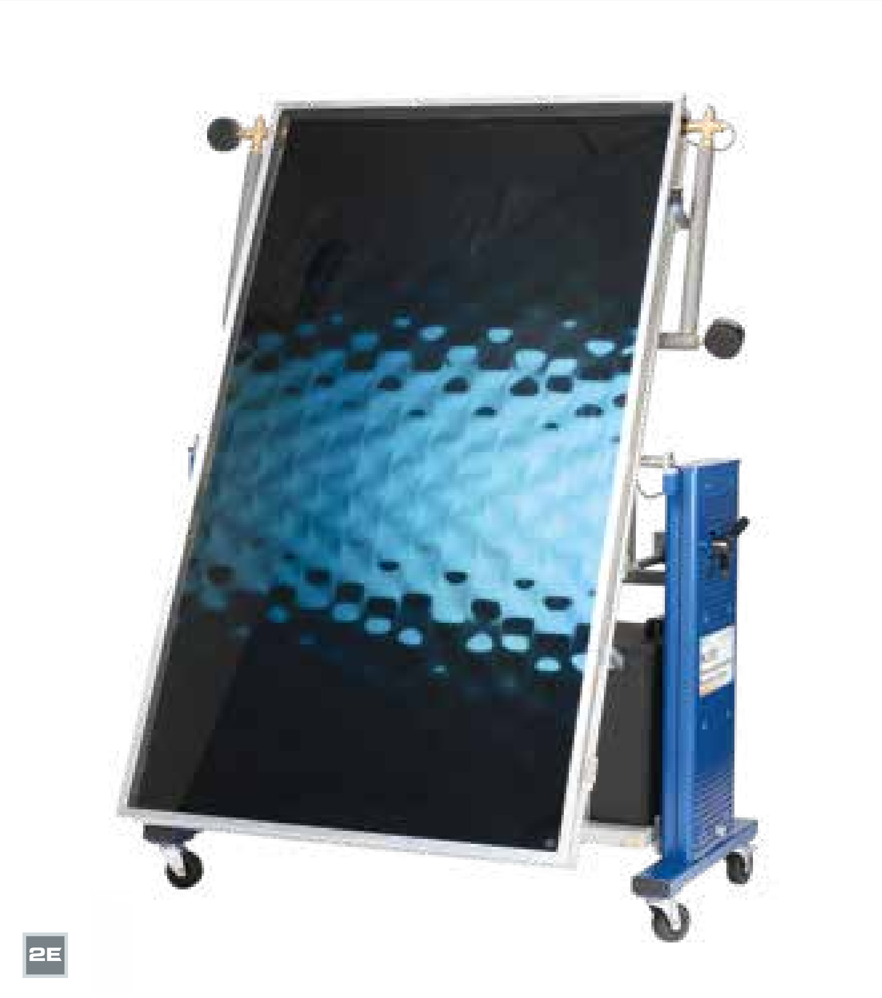
Measuring ranges
- temperature: 2x 0...120°C
- flow rate: 10...300L/h

LxWxH: 430x430x790mm
Weight: approx. 30kg

Scope of delivery

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

HL 313
Domestic water heating with flat collector



Learning objectives/experiments

- familiarisation with the functions of the flat collector and the solar circuit
- determining the net power
- relationship between flow and net power
- determining the collector efficiency
- relationship between temperature difference (collector/environment) and collector efficiency

Description

- **conversion of solar energy into heat**
- **trainer with real-world components**
- **pivotable flat collector**
- **system with heat exchanger and two separate circuits**
- **solar controller with data logger and USB interface**

The HL 313 trainer can be used to demonstrate the principal aspects of solar thermal domestic water heating in a system with components used in real world applications.

Radiant energy is converted into heat in a commercially available flat collector and transferred to a heat transfer fluid in the solar circuit. The heat then gets into the hot water circuit via a heat exchanger.

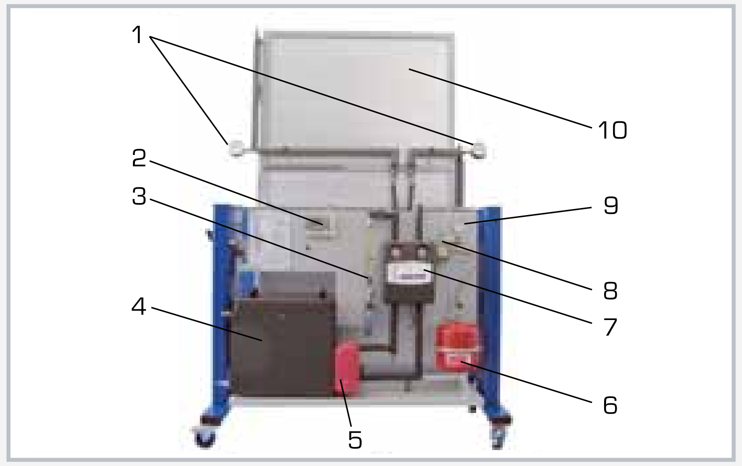
A solar controller controls the pumps for the hot water and solar circuits. The solar circuit is protected by an expansion tank and a safety valve.

The trainer has been designed so that it is possible to carry out a complete preheating as part of a practical experiment.

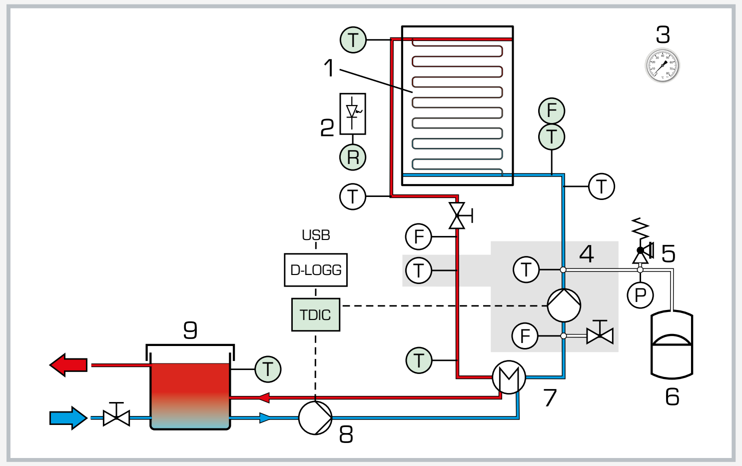
The temperatures in the storage tank, at the outlet from and the inlet to the collector are measured, as is the flow in the solar circuit. Additionally, as in practice, the temperatures of the inlet and return are displayed on the solar circulation station.

In order to ensure there is sufficient illuminance, the system should be operated with solar radiation or the optionally available HL 313.01 Artificial light source.

HL 313
Domestic water heating with flat collector



1 inlet and return thermometer, 2 solar controller, 3 flow meter, 4 buffer tank, 5 heat exchanger, 6 expansion vessel, 7 solar circuit pump, 8 pressure relief valve, 9 ambient air thermometer, 10 collector



TDIC solar controller with USB interface
1 collector, 2 illuminance sensor, 3 ambient air thermometer, 4 solar circulation station with solar circuit pump, 5 safety valve, 6 expansion tank, 7 heat exchanger, 8 hot water circuit pump, 9 buffer tank;
F flow rate, T temperature, P pressure, R illuminance

Specification

[1] trainer for investigating the function and operating behaviour of a flat collector
[2] solar thermal flat collector with selectively absorbing coating
[3] adjustable collector inclination angle
[4] solar circuit with collector, pump, expansion vessel and safety valve
[5] hot water circuit with buffer tank, pump and plate heat exchanger
[6] 4 bimetallic thermometers
[7] solar controller with temperature, flow rate and illuminance sensors
[8] data logger with USB interface
[9] operation with solar radiation or HL 313.01 Artificial light source

Technical data

Solar circuit
- collector
  - absorbing surface: 2,3m²
  - rated throughput: 20...70L/h
  - operating pressure: 1...3bar
- safety valve 4bar

Hot water circuit
- plate heat exchanger: 3kW, 10 plates
- buffer tank 70L

Measuring ranges
- flow rate: 20...150L/h
- temperature: 4x 0...120°C

230V, 50Hz, 1 phase
230V, 60Hz, 1 phase
120V, 60Hz, 1 phase
UL/CSA optional
LxWxH: 1660x800x2300mm
Weight: approx. 240kg

Scope of delivery

1 trainer
1 set of instructional material

ET 480
Absorption refrigeration system

Description

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

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

This basic principle of an absorption refrigeration system is demonstrated in the ET 480 experimental unit taking the example of an ammonia-water solution with the ammonia acting as refrigerant. In the evaporator the liquid ammonia evaporates and withdraws heat from the environment. To keep the evaporation pressure low, the ammonia vapour in the absorber is absorbed by the water. In the next step, ammonia is permanently removed from the high concentration ammonia solution to prevent the absorption process from being halted. For this purpose, the high concentration ammonia solution is heated in a generator until the ammonia evaporates again. In the final step, the ammonia vapour is cooled in the condenser to the base level, condenses and is returned to the evaporator. The low concentration ammonia solution flows back to the absorber. To maintain the pressure differences in the system, hydrogen is used as an auxiliary gas.

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

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

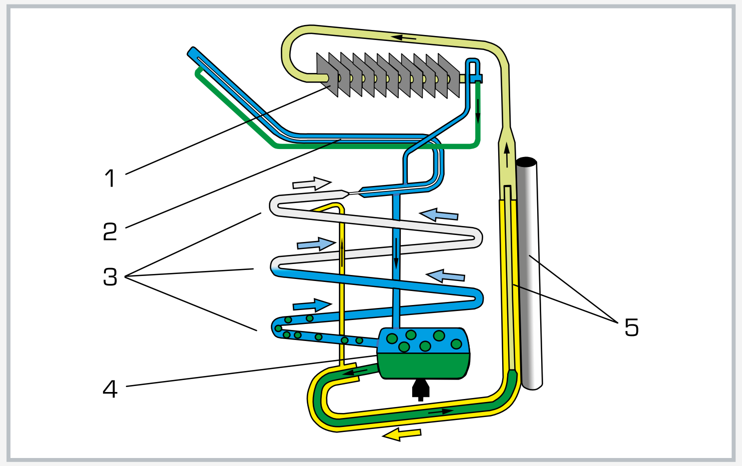
Temperatures in the refrigeration circuit and the heating power at the boiler and at the evaporator are recorded and displayed digitally.

Learning objectives/experiments

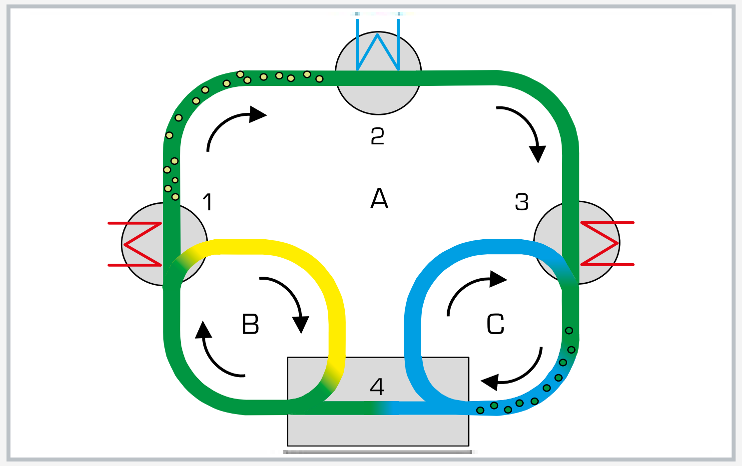
- demonstrate the basic principle of an absorption refrigeration system
- absorption refrigeration system and its main components
- operating behaviour under load

ET 480
Absorption refrigeration system

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



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



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

Specification

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

Technical data

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

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

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

Required for operation

propane gas: 30...50mbar

Scope of delivery

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

Solar energy: photovoltaics

Using photovoltaics in an experimental setup

The photovoltaic DC current from ET 250 is either fed to the input of **ET 255** or **ET 250.01** or **ET 250.02**

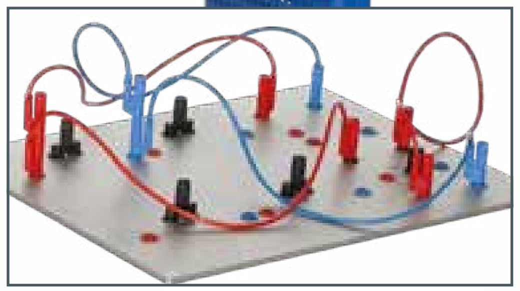
The trainer **ET 255** can either be run with actual solar modules or with the built-in photovoltaic simulator.

ET 250.01
Photovoltaic in grid-connected operation

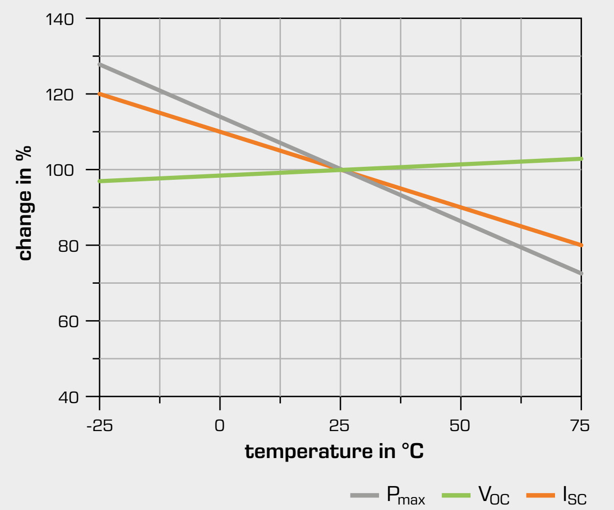
ET 250.02
Stand alone operation of photovoltaic modules

ET 252
Solar cell measurements

Investigation of the properties of solar cells; objective measurements by extensive temperature control of solar cells



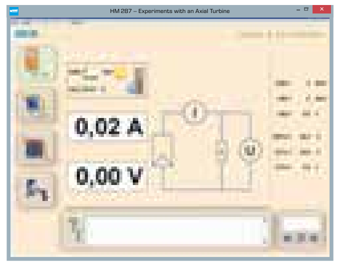
Patch panel for different connection possibilities: the four solar cells can be interconnected in a number of ways, e.g. individual cells can be bridged by bypass diodes in order to examine differences in power loss such as caused by shaded cells



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

Learning objectives / experiments

- physical behaviour of solar cells under varying illuminance and temperature
- recording of current-voltage curves
- calculating current strength and achievable output based on the single diode model
- how illuminance and temperature affect the curves
- interconnecting solar cells in parallel and series connection
- effect of bypass diodes
- power degradation due to shading



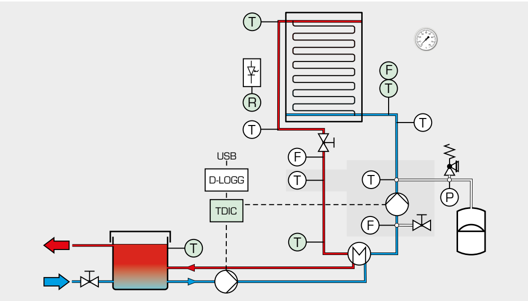
Solar energy: solar thermal energy

HL 313
Domestic water heating with flat collector

Demonstration of the conversion of the sun's radiation energy into heat and the storing of that heat

Learning objectives / experiments

- familiarisation with the functions of the flat collector and the solar circuit
- determining the net power
- relationship between flow and net power
- determining the collector efficiency
- relationship between temperature difference (collector/environment) and collector efficiency

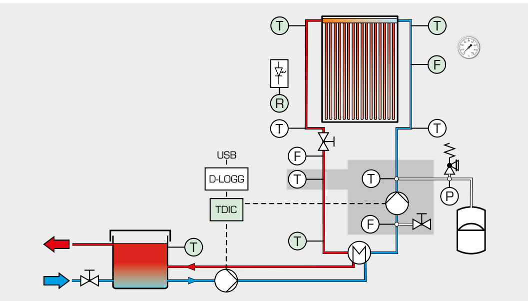


HL 314
Domestic water heating with tube collector

Conversion of solar energy into heat in the evacuated tube collector

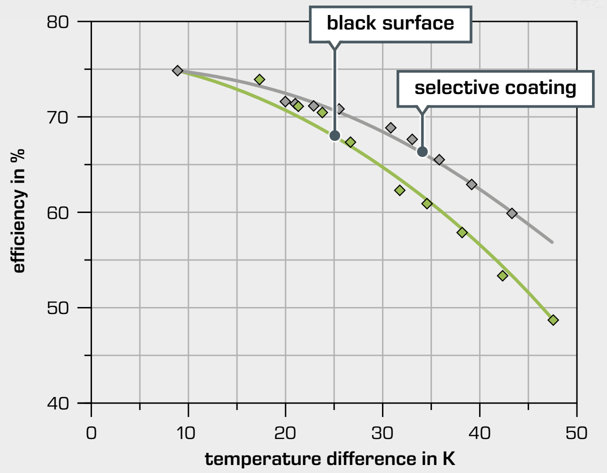
Learning objectives / experiments

- familiarisation with the functions of the tube collector and the solar circuit
- determining the net power
- relationship between flow and net power
- determining the collector efficiency
- relationship between temperature difference (collector/environment) and collector efficiency



ET 202
Principles of solar thermal energy

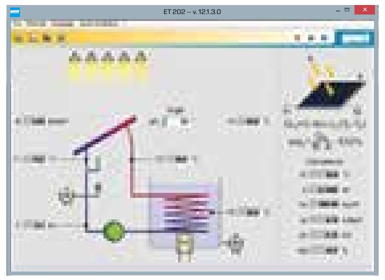
Determining characteristic parameters of a solar thermal system; model fitted with artificial radiation source



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 / experiments

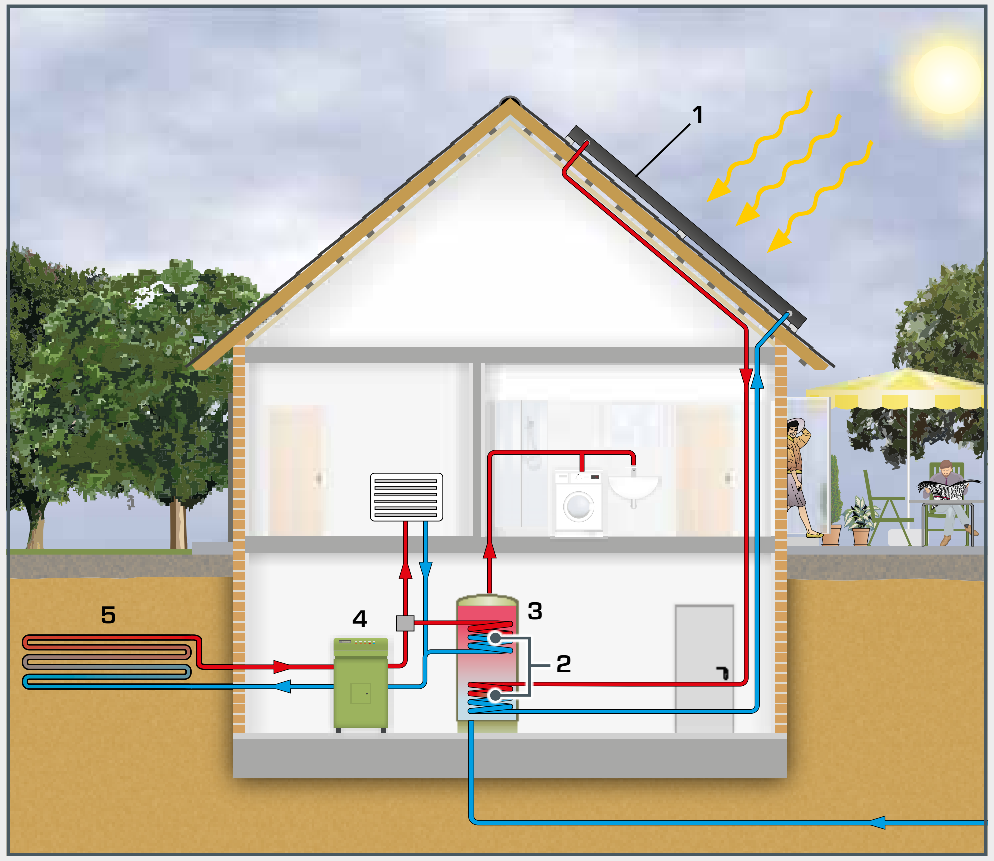
- design and operation of a simple solar thermal system
- determining the net power
- energy balance on the solar collector
- influence of illuminance, angle of incidence and flow rate
- determining efficiency curves
- influence of various absorbing surfaces



Green building

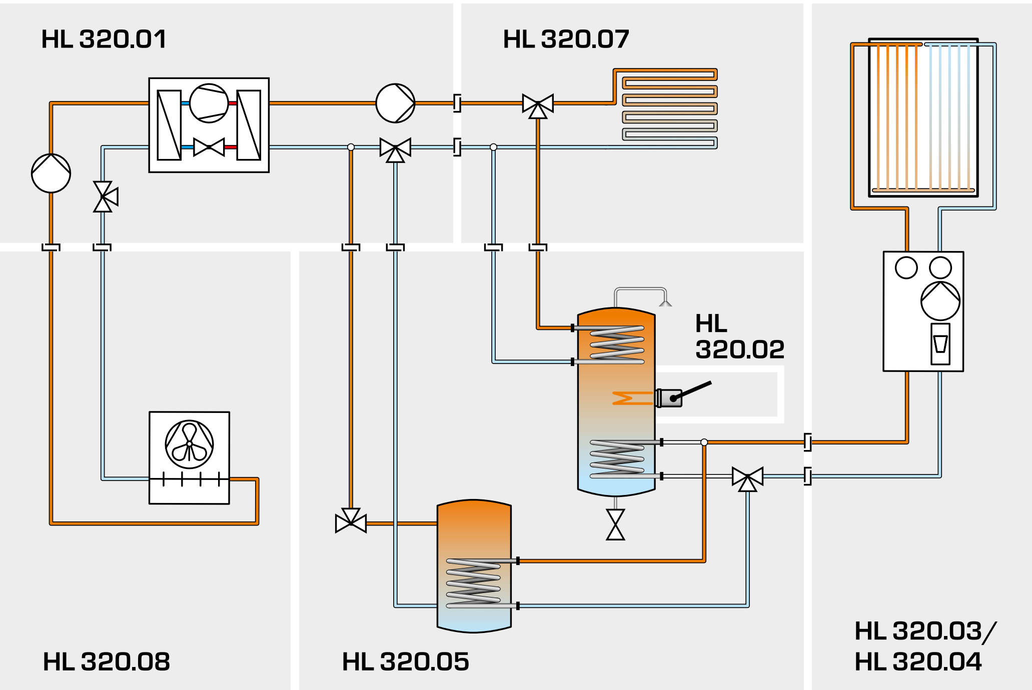
The HL 320 modular system allows you to investigate heating systems with various renewable and traditional energy sources. Solar thermal energy can be combined with heat generation from heat pumps.

The modular design of the HL 320 system makes it possible to achieve different combinations and configurations.



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

1 flat collector, **2** heat exchanger, **3** hot water storage tank, **4** heat pump, **5** geothermal absorber; hot heat transfer fluid, cold heat transfer fluid



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

HL 320.01
Heat pump

HL 320.02
Conventional heating

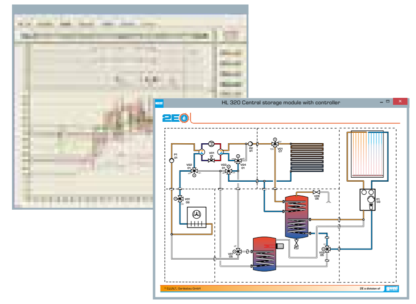
HL 320.03
Flat collector

HL 320.04
Evacuated tube collector

HL 320.05
Central storage module with controller

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

Energy

Solar energy: photovoltaics

ET 250
Solar module measurements

Determining the characteristic parameters of a photovoltaic system

Order No.: 061.25000

ET 250.02
Stand-alone operation of photovoltaic modules

Expansion module for ET 250 with components for independent use of electricity from solar panels

Order No.: 061.25002

ET 250.01
Photovoltaic in grid-connected operation

Expansion module for ET 250 with components for feeding solar power into a public grid

Order No.: 061.25001

ET 252
Solar cell measurements

Investigation of the properties of solar cells; objective measurements by extensive temperature control of solar cells

Order No.: 061.25200

ET 255
Using photovoltaics: grid-connected or stand-alone

Electrical components of a real life photovoltaic system

Order No.: 061.25500

Energy

Solar energy: solar thermal energy

ET 202
Principles of solar thermal energy

Determining characteristic parameters of a solar thermal system; model fitted with artificial radiation source

Order No.: 061.20200

WL 377
Convection and radiation

Heat transport between heating element and vessel wall by convection and radiation

Order No.: 060.37700

HL 313
Domestic water heating with flat collector

Demonstration of the conversion of the sun's radiation energy into heat and the storing of that heat

Order No.: 065.31300

HL 320.03
Flat plate collector

Pivotable flat plate collector for converting solar energy into heat

Order No.: 065.32003

HL 320.04
Evacuated tube collector

Conversion of solar energy into heat in the evacuated tube collector

Order No.: 065.32004

HL 320.05
Central storage module with controller

Module with buffer storage and bivalent storage for heating systems with renewable energies

Order No.: 065.32005

Energy

Solar energy: solar cooling

ET 256
Cooling with solar electricity

Compression refrigeration system for operation with solar current from ET 250

Order No.: 061.25600

ET 250
Solar module measurements

Determining the characteristic parameters of a photovoltaic system

Order No.: 061.25600

ET 352.01
Solar heat for cold production

Solar thermal operation of a vapour jet compressor

Order No.: 061.35201

ET 352
Vapour jet compressor in refrigeration

Investigation of cold production using thermal energy. Transparent condenser and evaporator allow the view into the inner workings.

Order No.: 061.35200

HL 313
Domestic water heating with flat collector

Demonstration of the conversion of the sun's radiation energy into heat and the storing of that heat

Order No.: 065.31300

Energy

Geothermal energy: heat exchangers

WL 110
Heat exchanger supply unit

Measuring the transfer characteristics of four different heat exchanger models

Order No.: 060.11000

WL 110.01
Tubular heat exchanger

Transparent heat exchanger with additional temperature measuring point after half of the transfer section; parallel flow and counterflow operation

Order No.: 060.11001

WL 110.02
Plate heat exchanger

Typical plate heat exchanger in parallel flow and counterflow operation

Order No.: 060.11002

WL 110.03
Shell & tube heat exchanger

Transparent shell and tube heat exchanger in cross parallel flow and cross counterflow operation

Order No.: 060.11003

WL 110.04
Stirred tank with double jacket and coil

Heating using jacket or coiled tube; stirrer for improved mixing of medium

Order No.: 060.11004

WL 315C
Comparison of various heat exchangers

Comparison of plate heat exchanger, tubular heat exchanger, shell and tube heat exchanger, finned cross-flow heat exchanger, and stirred tank with double jacket and coiled tube

Order No.: 060.315C0