FGK STATUS-REPORT 10

Renewable Energies in Air-Conditioning and Ventilation Systems

- **Solar air-conditioning**
- **Geothermal energy**
- **Free cooling**
- **Heat recovery**
- **Biomass**

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An information from the *Fachinstitut Gebäude-Klima e.V.*

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Nr.: 136 12/07

At a glance

Renewable energies in air-conditioning and ventilation systems

Air-conditioning and ventilation systems can give an essential contribution in achieving the CO_2 reduction goals set in Germany. There are already systems and technologies available whichever the reasons, are insufficiently or not used in new buildings or redevelopment.

Climate protection goals set by the Federal Republic of Germany by the year 2020:

30% - 40% reduction in greenhouse gases about 147 to 270 million tons per year.

Savings Potential for renewable energies in air-conditioning and ventilation systems by 2020:

	CO_2 Reduction per year Basis of 147 mil. tons	
Heat recovery:		
in non-residential buildings	5.85 mil. tons	4,0 %
in residential buildings	6.43 mil. tons	4,3 %
Air-conditioning:		
Solar air-conditioning systems	0.4-0.6 mil. tons	0,3 %
Geothermal air-conditioning systems	0.74 mil. tons	0,5 %
Indirect evaporative cooling	0.3 mil. tons	0,2 %
Free cooling via hychronic systems	0.25 mil. tons	0,2 %
Sum:	**app. 14 mil. tons**	**9,5 %**

Alone the currently available technology for using renewable energies in air-conditioning and ventilation systems can contribute app. 9% to achieving the climate protection goals set by the German federal government by 2020.

Following, air-conditioning and ventilation systems are standing for contribution to:

- saving energy
- CO_2 reduction
- conserving resources
- climate protection

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1. Preamble

The European Parliament resolution recommending to the commission that heating and cooling be done using renewable energy sources (2005/2122(INI)) was passed on February 14th, 2006 and claimed the evaluation and usage of an economical increase in the percentage of renewable energies for heating and cooling in the EU from a current app. 10% to a realistic and ambitious twice of that percentage by 2020. In 2007 the German federal government will get the measure package with a new climate protection program advance which should be implemented in the decision of the European Union

- In order to achieve a 30% reduction of the greenhouse gases by 2020, **147 mil. tons** must be reduced **in comparison to 2005**.
- Never sufficient. A reduction of 40% would mean a decrease of **270 mil. tons compare with the level from 2005**.

With an rise in renewable energies in the sector of heating and cooling a considerable contribution should be achieved towards the European security in energy supply the creation of new jobs and an improvement in the environment. In addition a significant reduction in the Europe need for conventional energies the general energy consumption of the EU in the sector of heating and cooling, the dependence on oil and gas as well as the decrease of energy costs for the private and commercial consumer must be achieved.
With this Status Report No. **10 "Renewable Energies in Air-Conditioning and Ventilation Systems",** the Fachinstitut Gebäude-Klima e.V., as an essential association of German air-conditioning and ventilation industrial and science shows and discuss the various systems and procedure using renewable energies in air-conditioning and ventilation. The Fachinstitut Gebäude Klima e.V. supports the principle of energy efficiency and the increased application of renewable energies under consideration of indoor air quality, room comfort, hygiene as well as the health of the user.
The Fachinstitut Gebäude-Klima e.V. supports general conditions for a technology and energy source-neutral promotion and an acceleration in implementing the high energy savings potential in new and existing buildings.
In the following various technologies of the usage of renewable energies are illustrated and their possible potential will be described. The focus of the study is:

- Solar energy for air-conditioning
- Geo-thermal energy for ventilation and air-conditioning
- Heat recovery
- Systems for free cooling
- Heating movement and waste heat use

2. Solar air-conditioning

Below commented systems using solar heat, for example, from solar panels, to provide direct or indirect air-conditioning and cooling for buildings.
Electric systems for ventilation and air-conditioning that are supplied via network-linked photo-voltaic systems are a part of the observations because these systems are not principally differ from conventional systems. In Germany and Europe, the common opinion is that the photovoltaic generation of electricity energy locks as a part of the power grid and not as part of the building.
In principle depending on the applied technology the threshold which enables a primary energy saving through solar cooling [1] is reached at a solar function of 25 to 40%. As such a solar fraction percentage of 70% means that 70% of the thermal energy required for operating the cooling production is provided by the solar device. For a realistic percentage of solar fraction in the area of 70 to 85% primary energy saving are
– depending on a equivalently conventional reference device – possible between 30 and 60%.

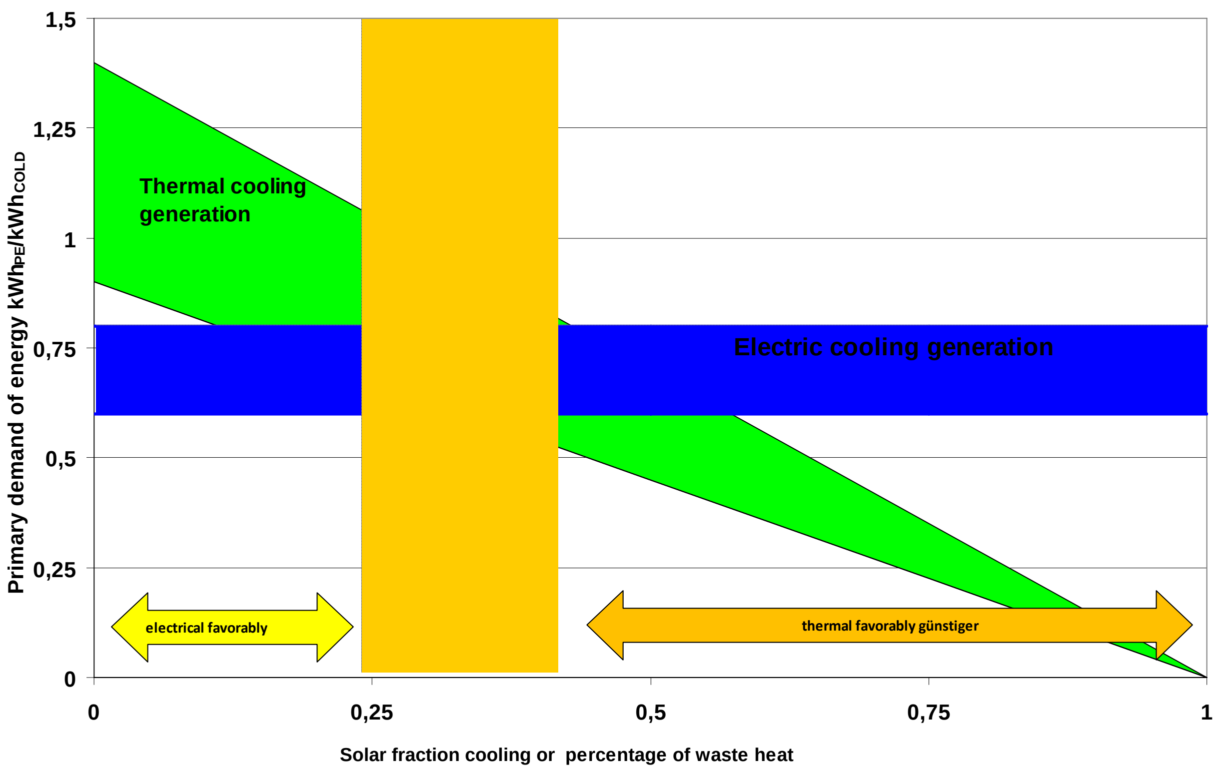

figure 2-1: Comparison of the primary expenditure of energy for thermal and electric cooling generation depending on the solar fraction

2.1 Thermal cold generation – chilled water generation from solar energy

Thermal chillers generate cold using a pair of substances separated with heat. The thermal boundary conditions are determined by the pair of substances that are being used and the procedure. The systems currently available for the air-conditioning application are:

- Absorption chillers devices with the pair of substances H_2O / LiBr (water/lithium bromide)
- Absorption chillers devices with the pair of substances NH_3 / H_2O (ammonia/water)
- Adsorption chillers devices with silica gel and water

Solar thermal chillers have the advantage that will known components are used for the entire system and they are commercially available:

- Solar panels
- Thermal chillers
- All available air-only and air-water air-conditioning systems

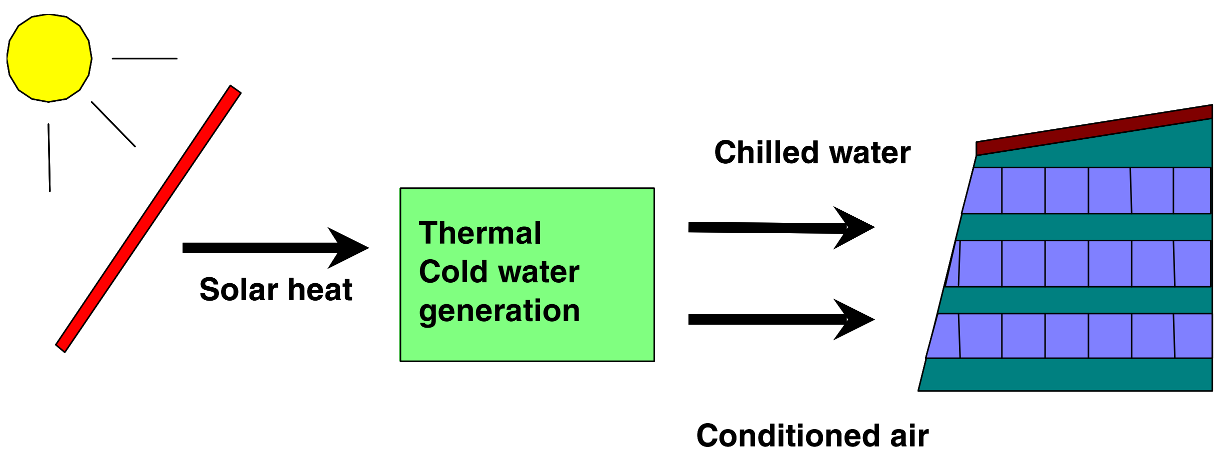

figure 2-2: Systems with solar-thermal cold water generation

Possible primary energy savings via thermal cold generation

According to estimation [2], chillers with a total cooling capacity of app. 1'100 MW are sold in Germany per year. This number includes the machines for new constructions and redevelopment. If it should be implied that app. 40% of these chillers are used for comfort air-conditioning and that these are operated with 700 full load hours, this results in a total electricitiy demand of app. 263.4 GWh (EER = 3.5) for the yearly newly sold chillers.

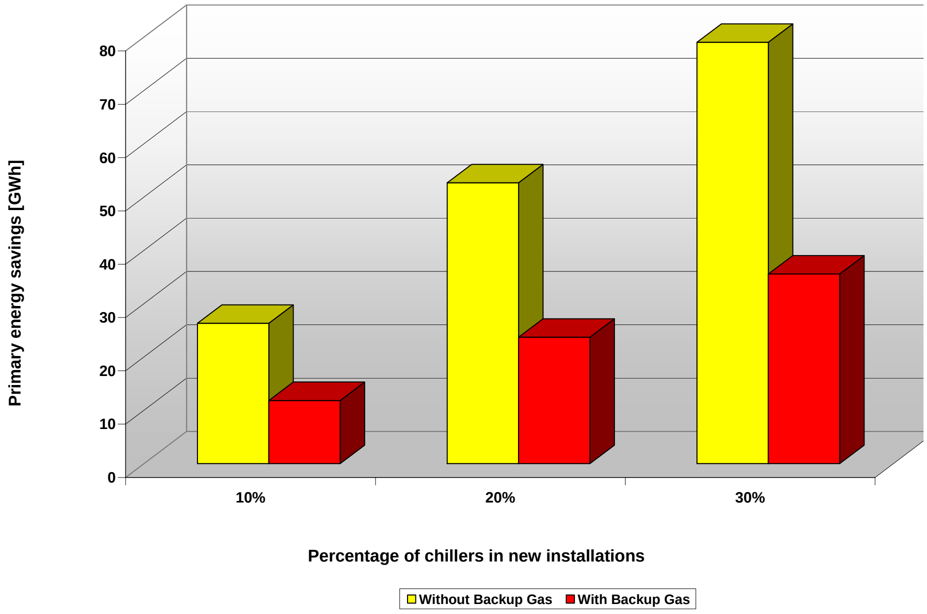

figure 2-3: Possible primary energy savings for solar cold generation depending on the relative percentage for newly installed systems (solar fraction 70%, cop for thermal cold generation (ζ=0,7)

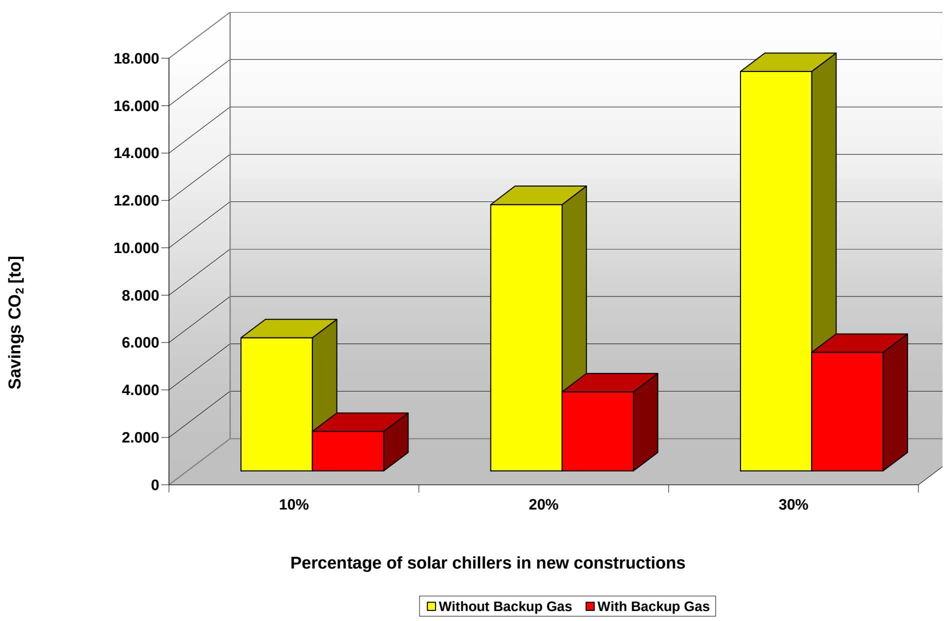

figure 2-4: Possible CO_2 savings for solar cold generation

2.1.1 Absorption chillers

Absorption chillers are available and established on the market. These machines are currently used predominantly in district heating supply systems and in combined heat and power plants. Many products are available starting with a power output range of app. 200 kW cooling, but only a few less than 100 kW cooling capacity. The manufacturers are mainly coming from the USA and Asia. These systems are a more prevalent technology in these areas because of a wider usage of the gas infrastructure for cold generation. Typical warm water system temperatures for generators are 85° to 150° C. This reduces the usage for the solar heating generation since high efficiency flat collectors vacuum collectors or concentrated systems are required for the solar heating generation.

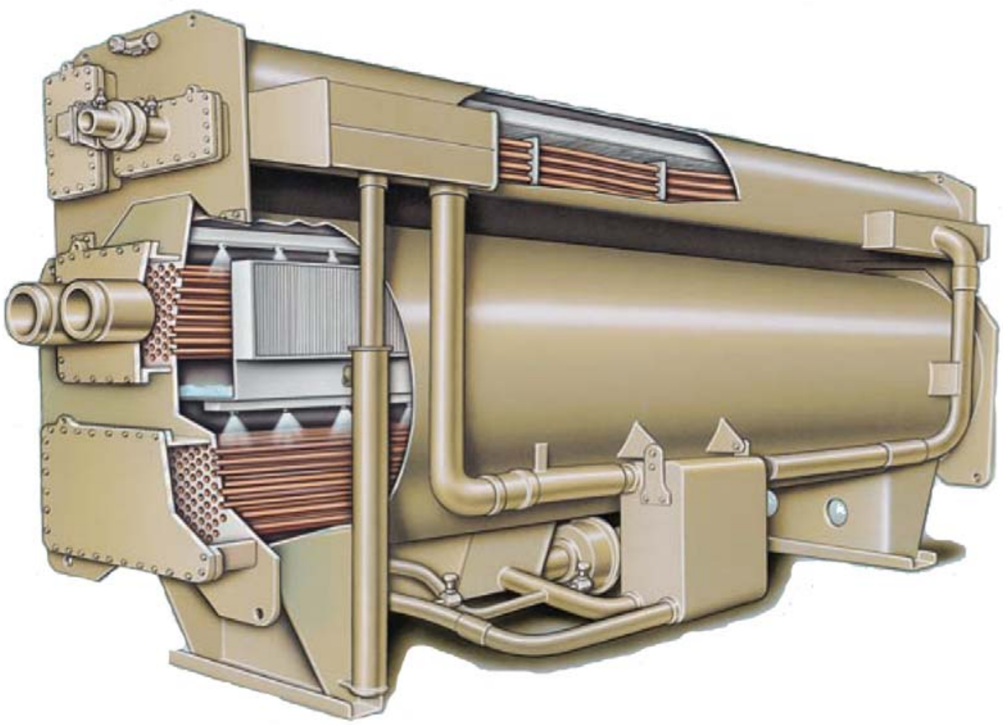

figure 2-5: Absorption chiller

Figure 2-6 is a schematic diagram of a commercially available single-effect, indirect-fired liquid chiller, showing one of several configurations of the major components. During operation, heat is supplied to tubes of the generator in the form of a hot fluid or steam causing dilute absorbent solution on the outside of the tubes to boil. This desorbed refrigerant vapor (water vapor) flows through eliminators to the condenser, where it is condensed on the outside of tubes that are cooled by a flow of water from a heat sink (usually a cooling tower).The condensed refrigerant passes through an orifice or liquid trap in the bottom of the condenser and enters the evaporator in which liquid refrigerant boils as it contacts the outside surface of tubes that contain a flow of water from the heat load. In this process water in the tubes cools as it releases the heat required to boil the refrigerant.

Refrigerant that does not boil collects at the bottom of the evaporator flows to a refrigerant pump, is pumped to a distribution system located above the evaporator tube bundle, and is sprayed over the evaporator tubes again. The dilute (weak in absorbing power) absorbent solution that enters the generator increases in concentration (percentage of sorbent in the water) as it boils and releases water vapor. The resulting strong absorbent solution leaves the generator and flows through one side of a solution heat exchanger, where it cools as it heats a stream of weak absorbent solution passing through the other side of the solution heat exchanger on its way to the generator. This increases the machine's efficiency by reducing the amount of heat from the primary heat source that must be added to the weak solution before it begins to boil in the generator.

The cooled strong absorbent solution then flows to a solution distribution system located above the absorber tubes and drips or is sprayed over the outside surface of the absorber tubes. This allows refrigerant vapor which is evaporated in the evaporator to be readily absorbed into the absorbent solution flowing over the absorber tubes. This absorption process releases heat of condensation and heat of dilution which are removed by cooling water flowing through the absorber tubes.

The resulting weak absorbent solution flows off the absorber tubes and then to the absorber sump and solution pump. The pump and piping convey the weak absorbent solution to the heat exchanger where it accepts heat from the strong absorbent solution returning from the generator. From there the weak solution flows into the generator thus completing the cycle.

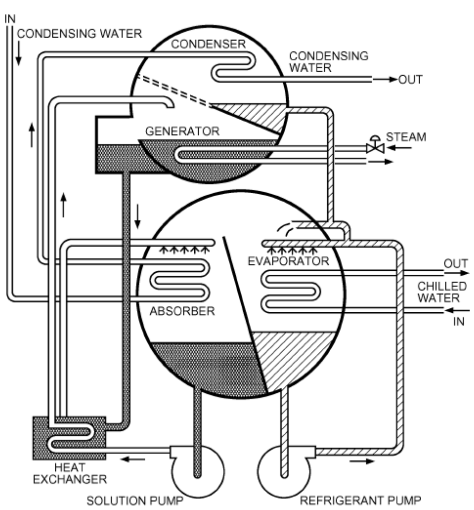

figure 2-6: Single-Effect Lithium Bromide Chillers (ASHRAE Handbook – Refrigeration)

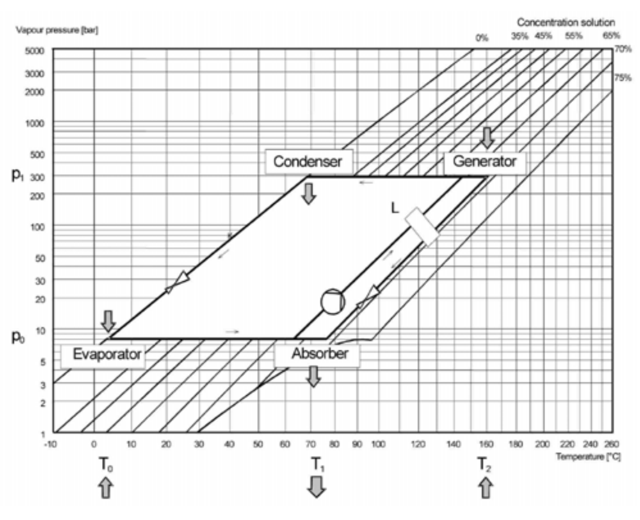

figure 2-7: Cooling cycle of an absorption process Vapour pressure as a function of vapour temp.

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2.1.2 Adsorption chillers

For adsorption chillers, the vaporized cooling agent (water) is – as opposed to the absorption cooling machine - accumulated in the inner surface of a highly porous, fixed material (adsorber predominantly made of silica gel). The cold generation process is not conducted continually. The cooling agent is enclosed in a fixed material and thus, must be changed cyclical between adsorption and desorption by reversing the heating and cooling circuits. These systems work with lower warm water temperatures as of app. 60 – 80° C, which is advantageous for solar heating generation with simpler flat collectors. Disadvantageous are the large weight and volume of the machines and the minor market availability of the machines.

figure 2-8: Adsorption cooling device

The adsorption chiller has in principle the following structure (see figure 2-9):
The machine essentially consists of a pressure vessel divided into four chambers.

1st chamber (lower): Evaporator
2nd/3rd chamber (middle): Generator/Receiver
4th chamber (upper): Condenser

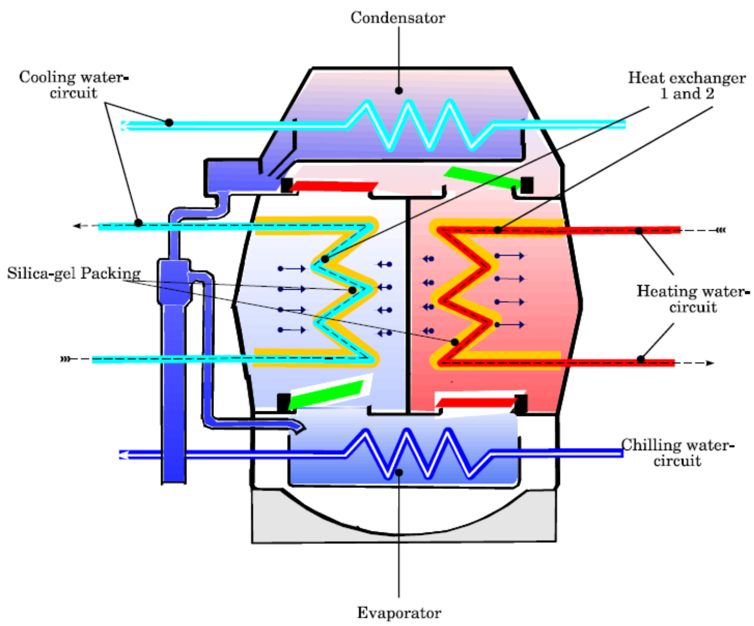
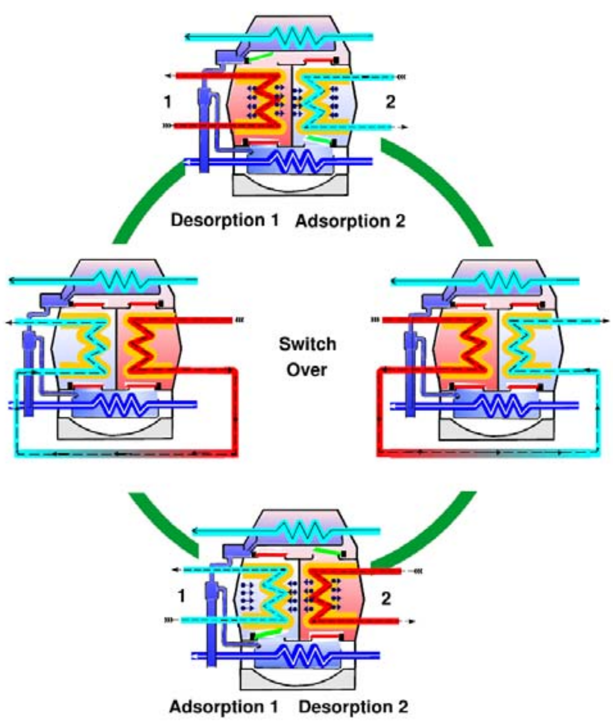


figure 2-9: Scheme of NAK Low Temperature Absorption Chiller [1] (reference: GBU mbH ©)



The generators/receivers are each connected to the above lying condenser and the below lying evaporator by flap valves. A heat exchanger is installed in each chamber. The tube sheets and tubes of the heat exchangers placed in the generator/receiver are additionally packed with silica-gel granulated material. The machine operates with an cycle of about 5 to 7 minutes, that consists of mainly four steps:
Step 1: Water is brought into the evaporator and **evaporates.** Through this, the cooling circuit cooles down.
Step 2: The water evaporated in step one is **adsorbed** on the receiver.
Step 3: The adsorbed water is **de-adsorbed** with the supply of thermal energy. The receiver turns into the generator.
Step 4: The de-adsorbed water is **condensed** in the condenser (cooling cycle).

figure 2-10: Process illustration of an adsorption cooling machine [1] (reference: GBU mbH ©)

2.2 Open climate processes – Desiccant air-conditioning systems

Conventional A/C systems need an external cooling generator in order to cool and dehumidify the air. In desiccant A/C systems the air can be dehumidified via sorptive materials and cooled via the evaporation of water (evaporative cooling). An intelligent combination of dehumidifying components, heating (cooling) recovery systems and humidifying systems in one air handling unit can produce conditioned air without an external cooling machine. The cooling process directly takes place right in the air in an open process with water as a cooling agent.

There are generally two systems that are distinguished in practice:

- Sorption air-conditioning systems with solid absorbers
- Sorption air-conditioning systems with liquid absorbers

Both procedures are working on the same principle. They essentially differ in that the absorber must be perfuse with in turn supply air and regeneration air in solid absorbers, whereas the absorption fluid can be pumped between absorption and regeneration in liquid absorbers.

To ensure that the process can continually proceed, the water from the absorption medium must be removed. This desorption takes place by adding heat. An advantage for both systems is that neither requires very high temperatures for the desorption of the water are required and very simple solar heating or lower temperature heat from industrial processes and combined heat and power plants can be used.

As such, both procedures can be installed everywhere where the air should be cooled and, if necessary, dehumidified. Based on principle a very efficient heat recovery and if necessary humidity recovery is simultaneously present for these systems (also see Section 5.1). This enables an energy-efficient operation even in winter.

Potential primary energy savings via desiccant air-conditioning systems

According to an investigation by Beck in the year 2000 [3], app. 38'000 RLT central air handling unit with a total flow of 658 mil. m^3/h are sold per year in Germany. Assuming that 60% of the air volume flow is supply air and that 49% of this is equipped with cooling, then there is a yearly primary energy demand for cooling of around 331 GWh. In many cases an alternative application of desiccant air-conditioning systems is possible with solar or waste heat usage.

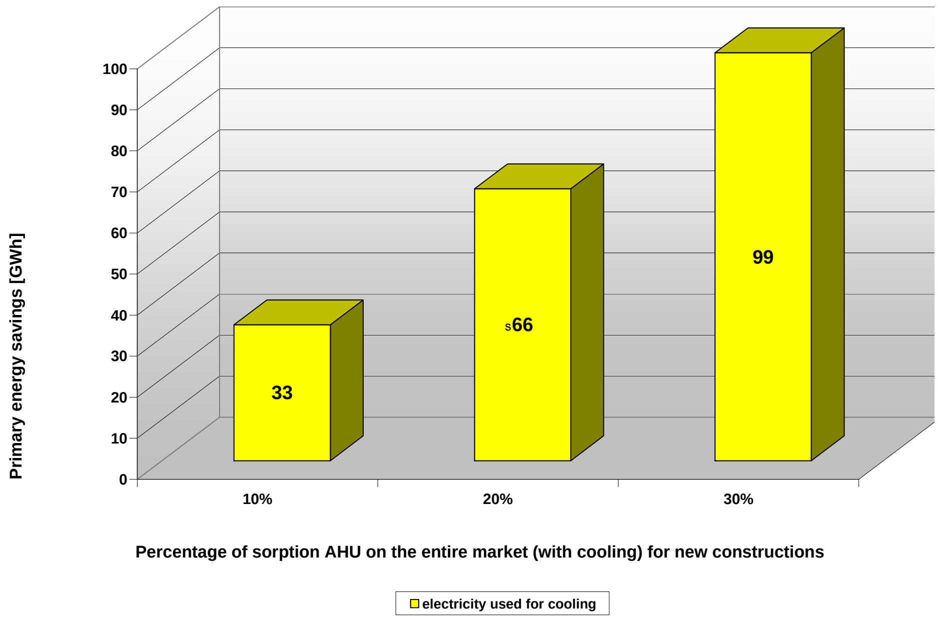


figure 2-11: The figure shows that a primary energy savings of app. 100 GWh is already achieved at a percentage of 30% of desiccant AC-systems

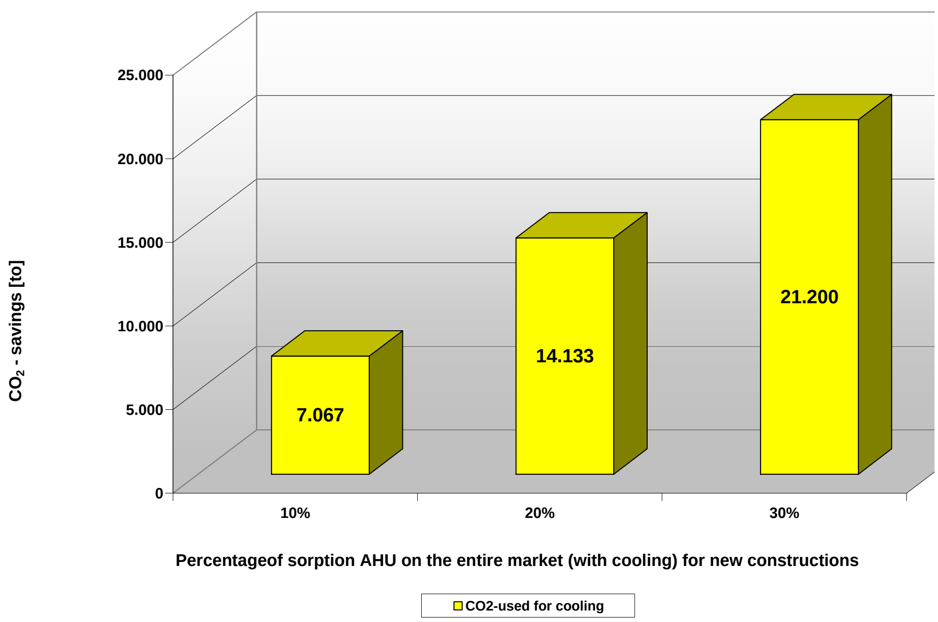


figure 2-12: Possible additional yearly CO_2 reduction for desiccant air-conditioning systems depending on the relative portion for newly installed systems in new constructions and redevelopment

2.2.1 Desiccant air-conditioning systems with solid absorbers

Desiccant air-conditioning systems with solid absorbers have been introduced to the market and are offered by lots of manufacturers. The desiccant wheel mostly work on the basis of silica gel or zeolites. The available performances of the devices are generally related to the required air volume flow rate and there are systems available from just under 5'000 up to over 50'000 m^3/h air volume flow. This corresponds to cooling capacities of app. 20 to 300 kW.

Advantageous for these systems is that a temperature level of at least 45° C to 95° C is already sufficient for the regeneration. In combination with a solar device this technology enables an implementation of low-cost solar collectors. A lower temperature level is also advantageous for the application of waste heat sources or in district heating systems.

The starting point is the outside air, which is dehumidified in a sorption regenerator and heats oneself. The following heat recovery ("cooling recovery") leads to a cooling down of the air supply stream. Depending on the required supply air temperature and humidity a temperature sinking takes place in the humidifier ("evaporative cooler"). while humidity is being added simultaneously. The heating unit in the air supply stream is only need in winter. The cooled supply air is now blown into the room and is warmed up by thermal leads in the room. The exhaust air is now once again humidified in the central air-handling unit until just about saturation achieved, in order to receive a great temperature potential for heating or cooling recovery. The heat recovery ("cooling recovery") leads to a warming of the outgoing air stream which is also being used as regeneration air. The exhaust air is then reheated in a heating coil,in order to be able to remove the humidity once again from the sorption regenerator (regeneration).

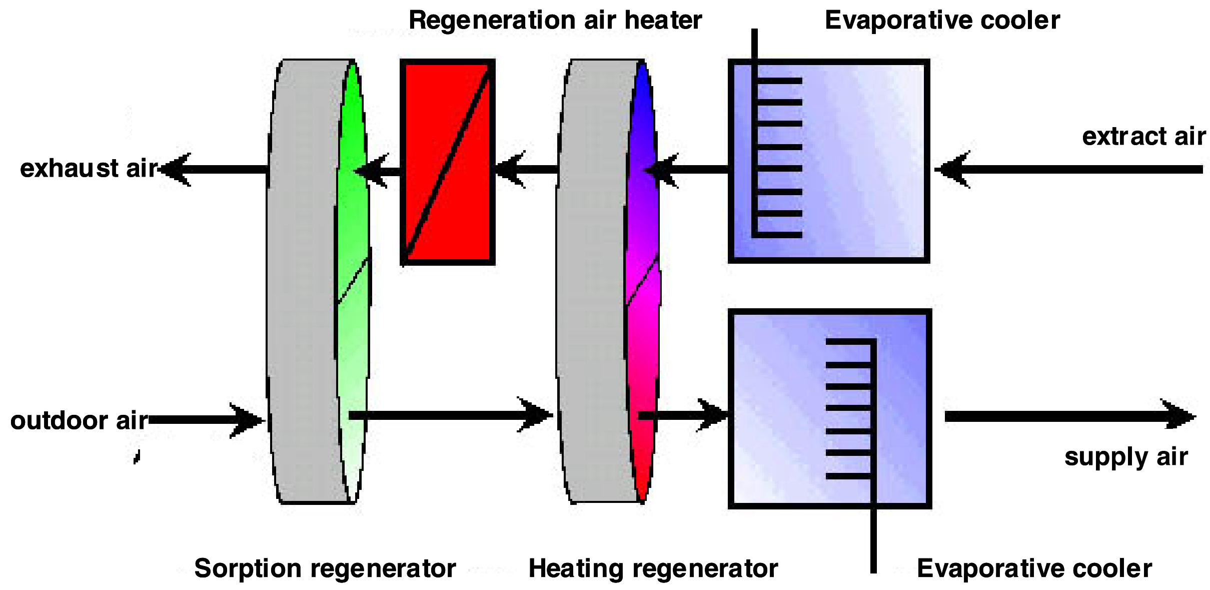


figure 2-13: Schematic of a desiccant air-conditioning system with solid absorber

2.2.2 Desiccant air-conditioning systems with liquid absorbers

Desiccant air-conditioning systems with liquid sorption agents are currently approaching widespread availability. Individual pilot devices are in operation and the devices will be soon commercially available. Such as the systems with fixed absorbers the performance in general relates to the required air volume flow rate. These systems can be designed for app. 3'000 m^3/h to 30'000 m^3/h air volume flow rate per device. This corresponds to the cooling capacity of app. 15 to 200 kW.

In the absorber the outside air is dehumidified by sprinkle with concentrated sorbs (mostly calcium chloride or lithium chloride) or by sprinkle the contact on surfaces. The process can be conducted in different manners. The combination with indirect evaporative cooling is advantageous. The exhaust air is cooled by the evaporization of water and the cooling is transferred to the supply air via a highly efficient heat recovery. With that the supply air is dehumidified in the sorption process and then cooled with the indirect evaporative cooling.

The essential advantage when using fluid absorbers is found in the possibility to store diluted and concentrated solutions (sorbs) separately. With that it is possible to conduct the sorption and the regeneration at different times. The solution can be regenerated for example, in times where there is a high yield in solar energy and then used as part of the air-conditioning process in the evening.

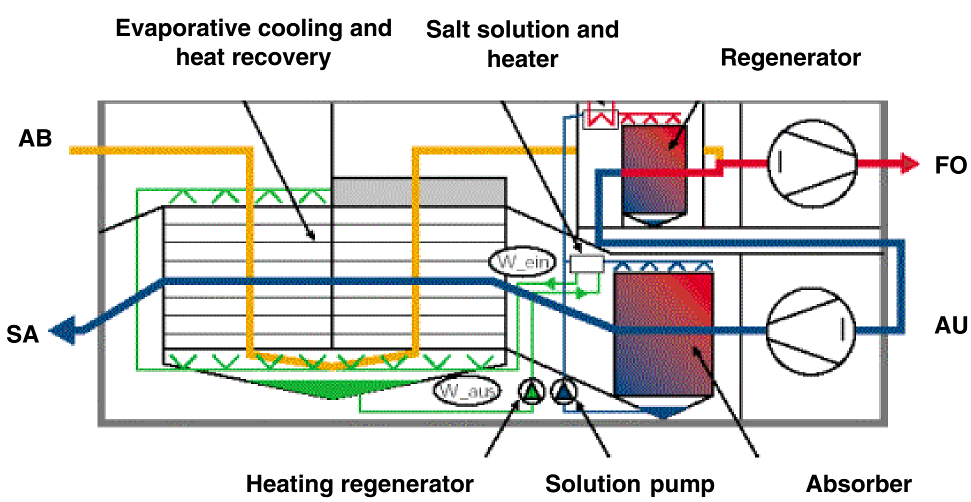


figure 2-14: Example of an air-conditioning system with liquid sorption

3. Geothermal energy — for heating and cooling

Surface-close geothermal energy is especially suitable for usage in air-conditioning and ventilation systems. The temperature of the undisturbed subsurface consists of up to app. 8° to 12° C at a depth of 100 m. Usage of this energy reservoir can take place via various systems:

- **Ground water usage:** This type of usage is possible there, where ground water production wells and injection wells make a closed and correspondingly productive hydrologic cycle possible. The maintenance and operation can be complex, depending on the local legal guidelines and circumstances.
- **Geothermal heating exchangers:** Horizontally (plate heat exchange collectors) or vertically (downhole heat exchange) installed plastic pipes establish a heat conductive with the subsurface. The performance of this heat exchange system depends on the thermal characteristics of the subsurface and the ground water circumstances. The deeper the pipes are installed the more independent the system is from the effects of the climatic environment.
- **Energy piles:** These systems are especially economical, because the necessary foundation piles, foundation plates, pile walls or additional options must only be equipped with a plastic piping system. Otherwise, the function is analogous to geothermal heat exchangers.

Depending on the necessary temperature level and the performance capability of the system the geothermal energy can be used in a manifold manner in the building. At summer the subsurface serves as a heating sink. The necessary cooling energy is taken from the building and added to the subsurface. This can take place directly (Section 3.1) or via the usage of a chiller or heat pump (Section 3.2).

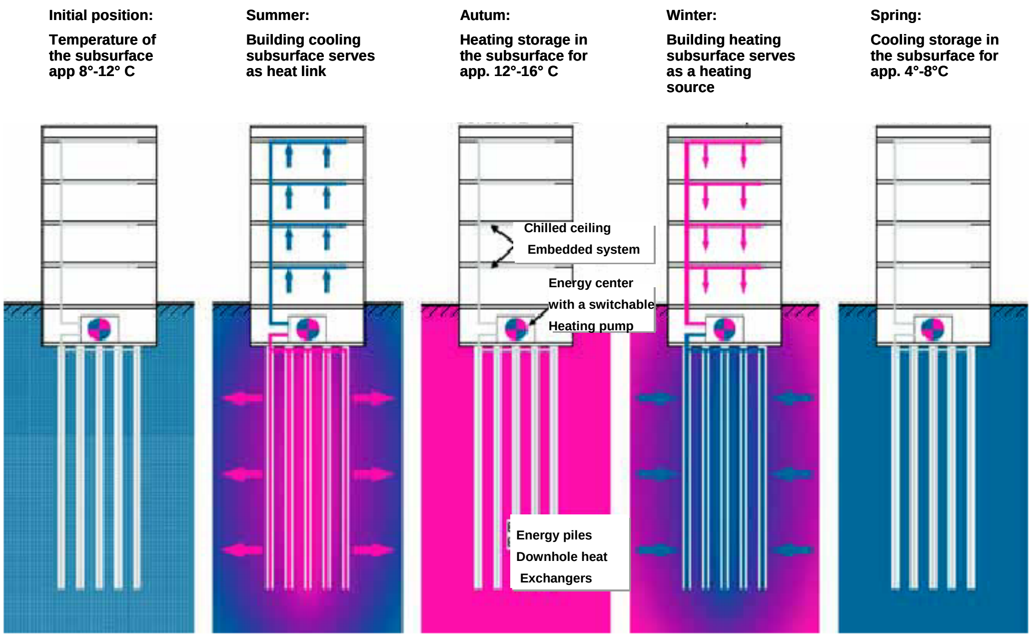


figure 3-1: Seasonal usage of a geothermal system

3.1 Direct usage of geothermal cooling

3.1.1 Panel cooling

Depending on the temperature level of the carrier medium flowing from the earth-source and the achievable performance (heat sink), various room cooling systems in buildings can be employed without an additional cooling machine:

- Ceiling, wall and perimeter fan coil up to app. 14 - 16° C outlet temperature from the earth-source
- Chilled ceiling, chilled beams and capillary pipe systems up to app. 16 -18° C.
- Embedded systems up to app. 18 - 20° C

All of these systems for room conditioning can be used in both, new constructions and in redevelopments (building component activation through special systems). These systems fundamentally cannot dehumidify the air due to the high system temperatures. Special observation must be given towards preventing the system of condensation in any part of the systems. Especially in muggy and hot humid climate (in Germany for example also in river valley areas) the performance of the system must also be designed with an elevation of the system temperature so that the supply temperature remains above the dew point temperature of the room.

In many cases a system of this nature should be combined with an air-conditioning and ventilation system with which the air can also be dehumidified. Recommended for this are especially sorptive systems (see Section 2.2).

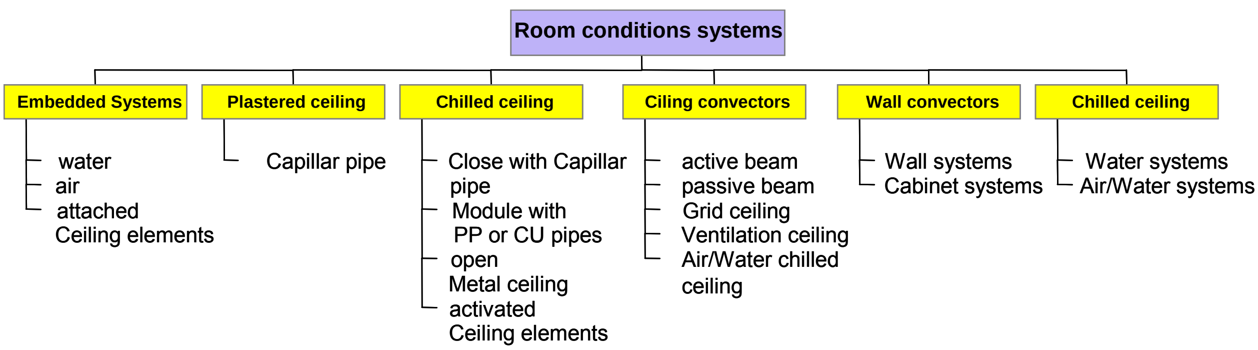


figure 3-2: Overview of room conditioning systems [4]

figure 3-3: Cooling ceiling – cooling canvas – Embedded systems

3.1.2 Air-Ground Heat Exchanger

Air-ground heat exchange can pre-heat the outside air for a ventilation system in the winter and pre-cool it in the summer. The air is sucked via pipe systems installed in the earth-source. With a careful design installation and maintenance these systems can significant decrease the energy requirement for the ventilation and pre-cooling.

These types of systems have found an additional niche in the market for resident building ventilation. Resident building areas usually have the necessary available space and the dimensions allow a cost-efficient use of suitable pipe materials and system designs.

In many cases even larger ventilation systems are connected to air-ground heat exchangers. The pipe materials used for these (often waste water pipes made of concrete) are to be viewed critically with respect to a sufficient level of air hygiene.

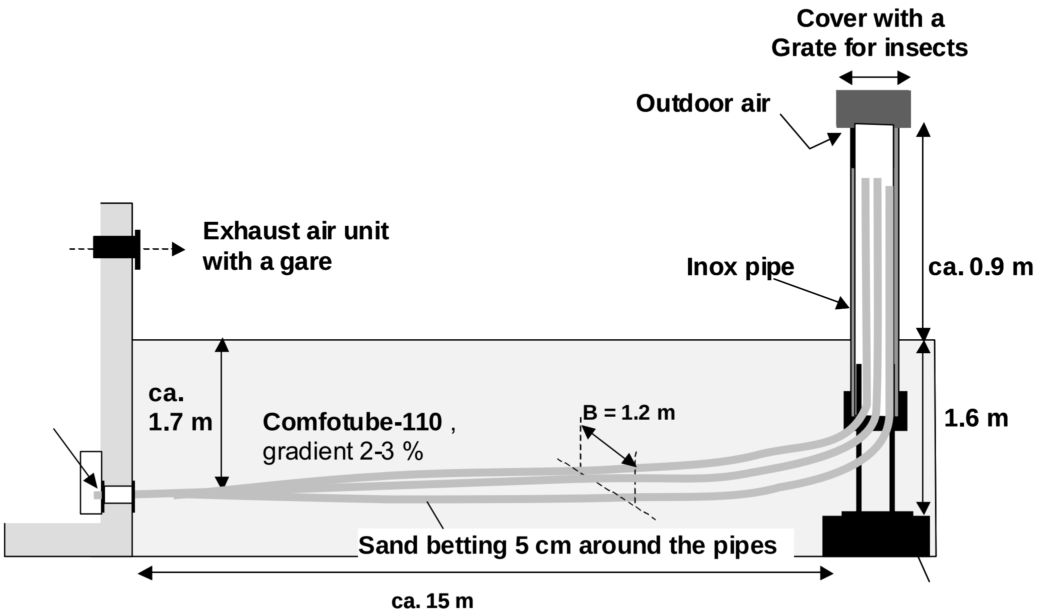


figure 3-4: Air-Ground Heat Exchanger for a residential buildings

Potential primary energy savings via Air-Ground Heat Exchangers for ventilation systems in residential buildings

The following diagram shows the possible primary energy savings when ventilation systems in residential buildings are equipped with earth-source heat exchangers. If it is assumed that 10% of the entire building stock is equipped with ventilation systems in future point of time than an addition energy savings of 729 GWh per year [6], [7].with the installation of earth-source heat exchangers can be archived.

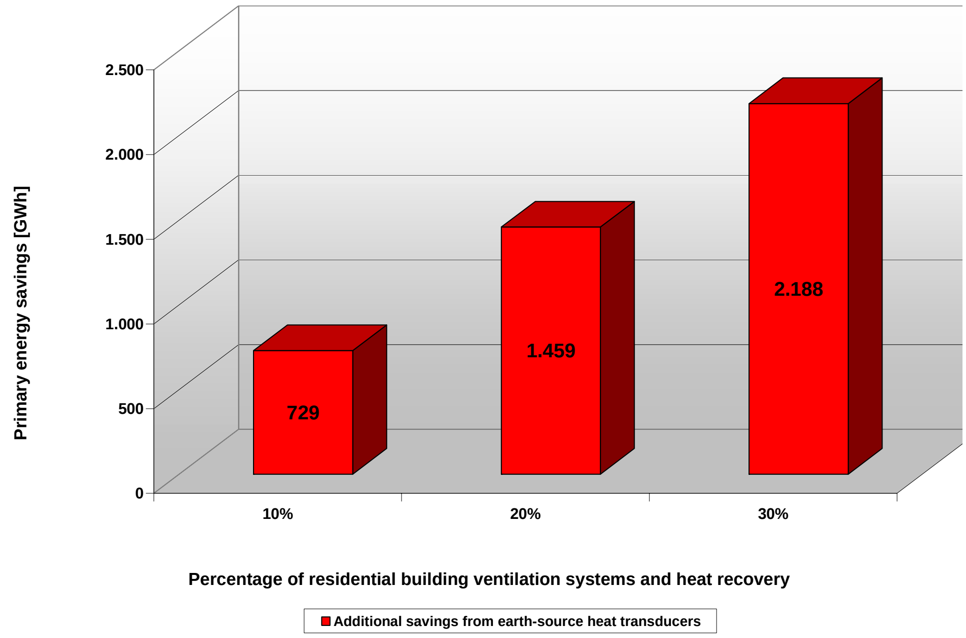


figure 3-5: Energy savings potential via Air-Ground Heat Exchange

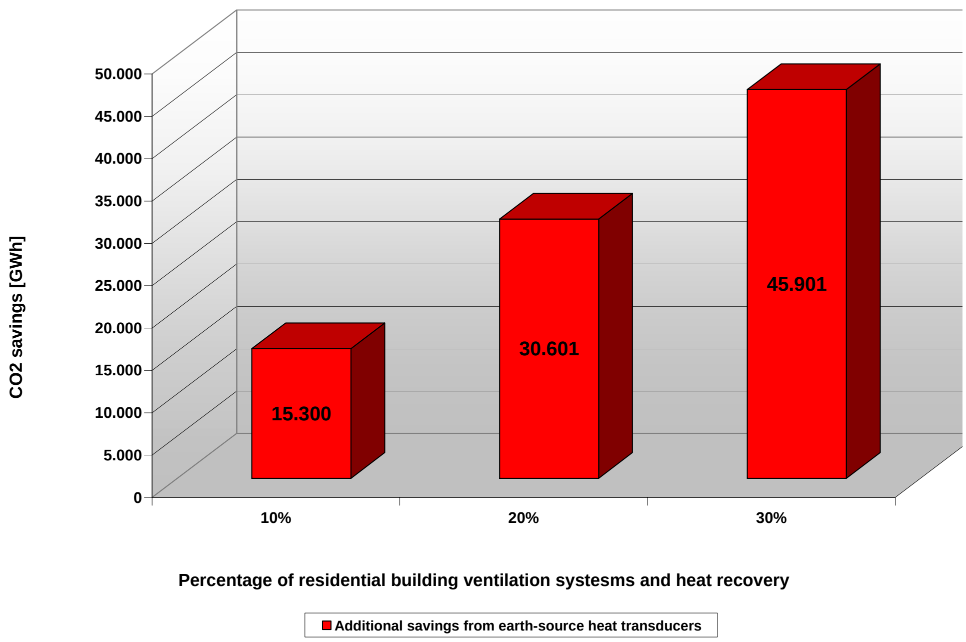


figure 3-6: CO_2 decrease via Air-Ground Heat Exchange in residential buildings

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3.2 Use of geothermal cooling via chillers

If the temperature level of the medium flowing from the ground-source is not sufficient to assume the required cooling task, then the ground-source can be used as a heat sink for a chiller. This for example is necessary if the supply air of the building must be dehumidified for the air-conditioning task. The necessary cold water temperature for the dehumidification then consists of app. 6 to 8° C and this is not available in ground-source.

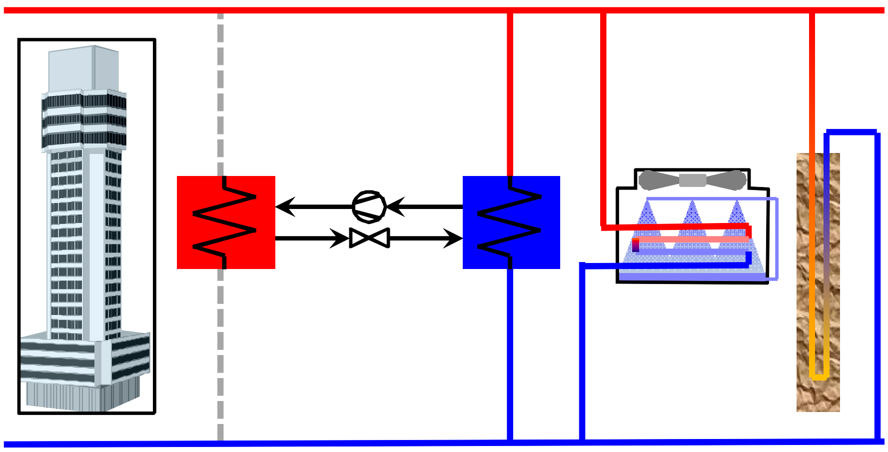

figure 3-7: Integration of a chiller/heat pump in a holistic concept for the geothermal building conditioning

The electric energy demand for the operation of the chiller drops with increasing temperature in the condenser circuit. For water-cooled chillers a cooling recovery via outside air is customary (wet or dry cooling towers). The system temperatures in the heat exchanging circuit generally lie between 25° C and 40° C. If the heat sink ground-source is used, then the system temperatures can be decreased in the heat exchanging circuit with suitable chiller. With that the performance of the chiller increases and the electric energy demand decreases. Additional cooling towers are often unnecessary.

Potential primary energy savings via the usage of the earth-source as heating sink for air-conditioning cold water generation.

Analogous to the estimation of the chiller [2] sold per year in Germany and the assessments according to Section 2.1 the entire power demand consists of the yearly newly sold chillers for building air-conditioning, app. 263 GWh primary energy (new constructions and redevelopment).

The following diagram shows the effects on the energy demand under the assumption that 10 to 30% of the newly delivered chillers (new constructions and redevelopments) are equipped with a geothermal heat rejection.

If 30% of the newly installed systems are equipped with geothermal heat rejection, then the energy savings account for app. 34 $GWh_{Primary}$ power or 13%.

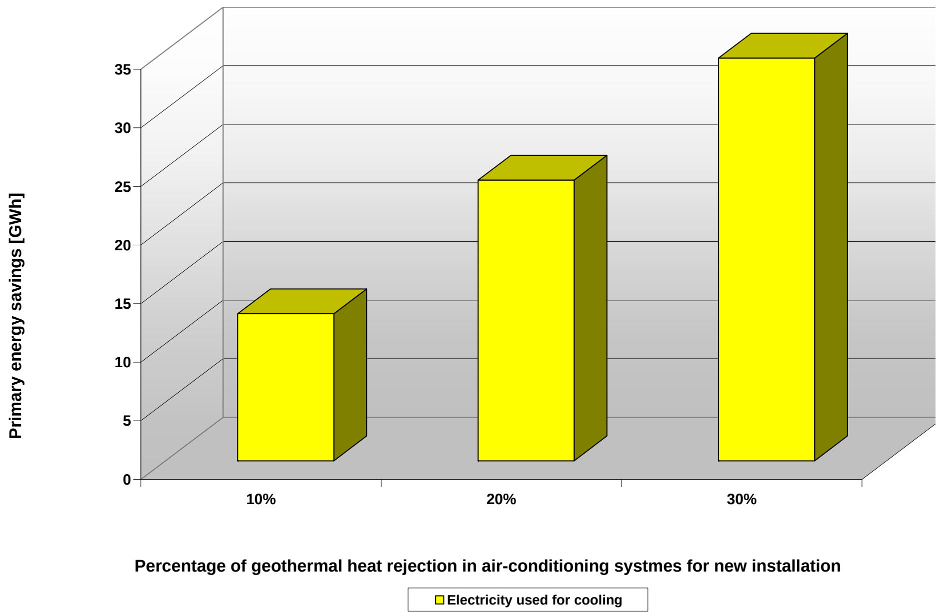

figure 3-8: Possible yearly additional primary energy savings via the usage of the ground-source as a heat sink (assumptions: $EER_{Standard}$ = 3.5 and $EER_{geothermal}$ = 5.2)

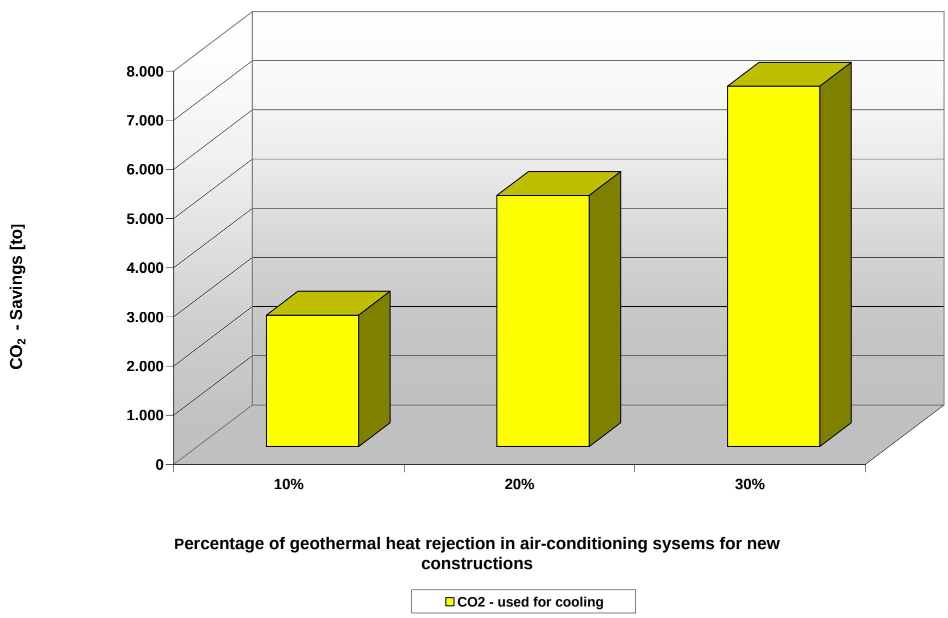

figure 3-9: Possible yearly additional CO_2 savings via the usage of the ground-source as a heat sink (assumptions: $EER_{Standard}$ = 3.5 and $EER_{geothermal}$ = 5.2)

4. Free cooling

4.1 Free cooling via cooling towers and centralized Air-Handling-Unit

The evaporation of water is a method for cooling that has been made use of for centuries. In addition to the direct usage of the evaporative cooling in the central ventilation device (see Section 2.2), the evaporative cooling can also be used indirectly with combined systems via the cooling towers or the air from heat recovery outgoing via the heat exchange. In this case, it must however be observed that only comparably high cooling water temperatures can be achieved by these systems, especially in the summer, dependent upon the wet bulb temperature for. In correlation to this, it is important to separate the functions air or room cooling and air dehumidification. For application in air-conditioning systems, the free cooling cannot be used for the dehumidification. Ideally suited for dehumidification is a sorption air-conditioning system (see Section 2.2). Similar to geothermal cooling attention should be paid for room conditioning systems, that these systems can work with high water temperatures (see Section 3.1.1). Typically these systems operate at a temperature above 18° C.

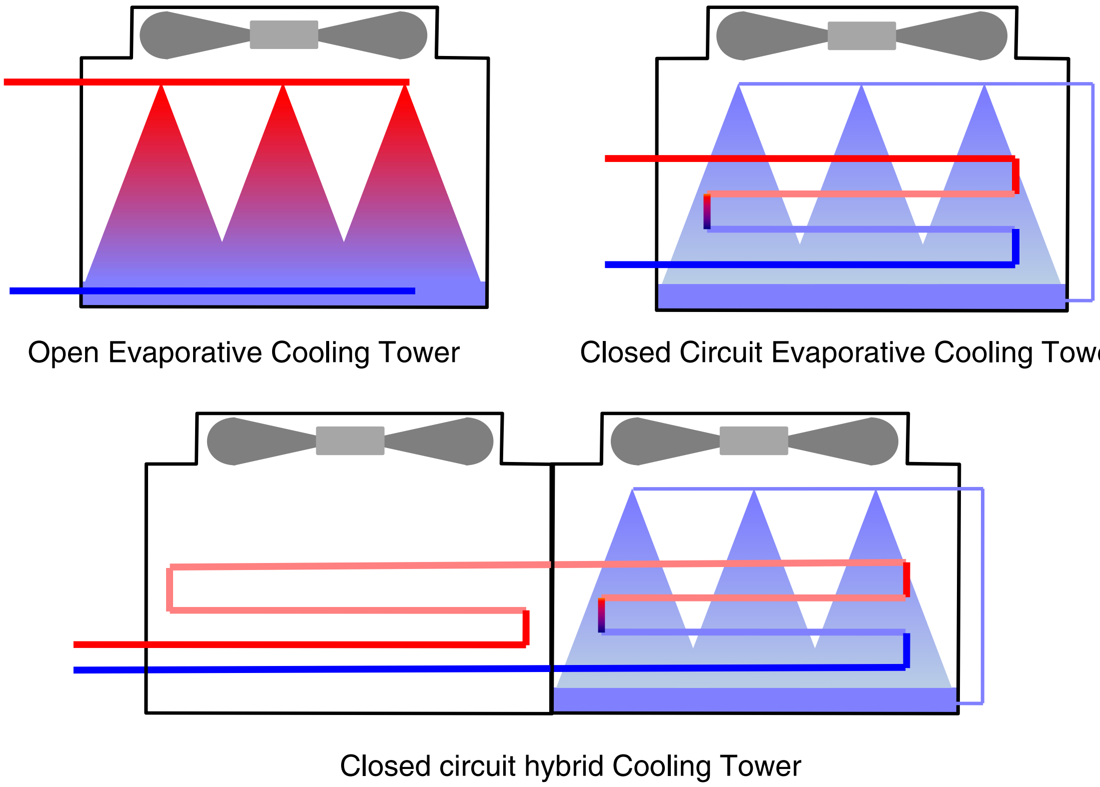

figure 4-1: Types of cooling towers

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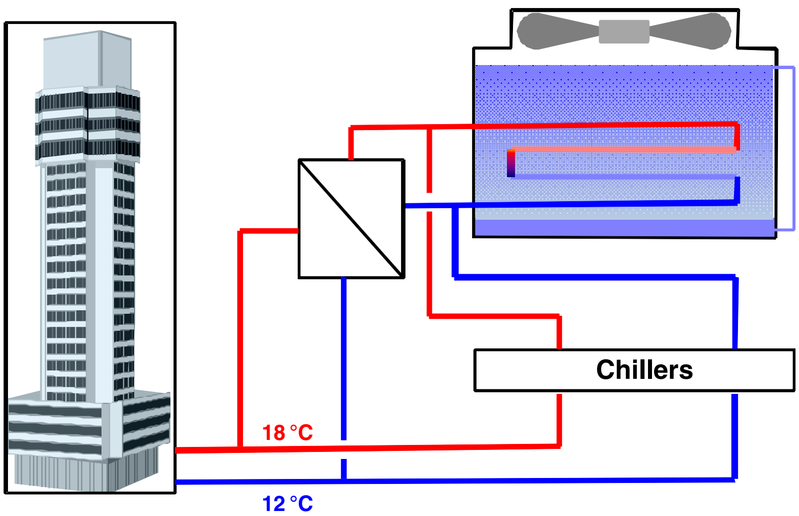
The following construction types differ as follows:

- **Open evaporative cooling towers:**
  The water to be cooled is distributed via spray nozzles onto plastic fill packing. The cooling water is open and in direct contact with air. There is a sensible and latent heat transfer to outside air.
- **Closed circuit evaporative cooling towers:**
  The fluid to be cooled (water or glycol-water mixture) circulates in a closed cycle in a heat exchanger. This is sprayed with water from the outside with a separate cycle. There is a sensible and latent heat transfer to outside air.
- **Dry heat rejection:**
  Water cycles only in a closed cycle, and the heat exchanger is not sprayed. There is only a sensible heat transfer to outside air.
- **Hybrid cooling towers:**
  A hybrid cooling tower is a combination of closed and dry heat exchangers. Depending on the outside condition, there is a sensible or latent heat exchange, or a combination of the two.



Systems for free cooling via cooling towers can also be installed in combination with chillers in multiple designs in buildings (preferably with room conditions systems). The only requirement for this is that the necessary system temperatures the corresponding outside temperatures and humidity match. Also attention should be paid for water demand and water preparation can be an essential economical aspect. With a hybrid cooling tower, cooling water temperatures of app. 4 K above the wet bulb temperature are generally achieved. In Munich the maximum wet bulb temperature is for example design to be 21° C, which results in a cooling water temperature of 25° C. This means that these systems should be used namely at night during hot and humid summers in order for a sufficiently deep cooling water temperature to be achieved. For this reason storage systems such as achive building mass activation for the usage of free cooling are particularly suitable.

Figure 4-2 shows the effects on the energy demand for cold generation under the assumption that 10 to 30% of the newly delivered cooling systems (new constructions and redevelopments) are equipped with a free cooling system. If 30% is carried out as such, then the primary energy savings are app. 79 GWh or 30%.

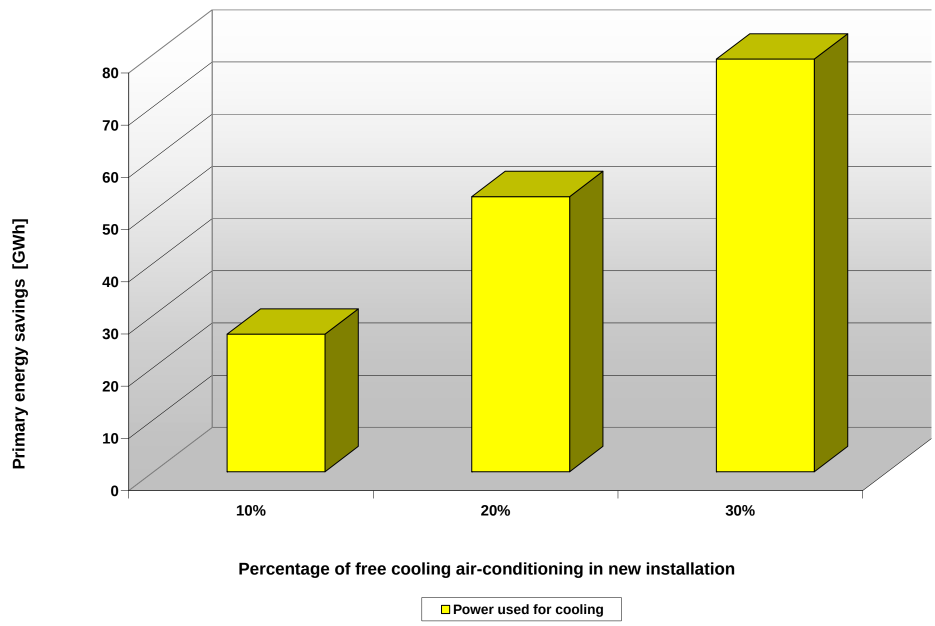


figure 4-2: Primary energy savings potential through usage of free cooling for the building air-conditioning (assumption: cooling machine EER = 3.5)

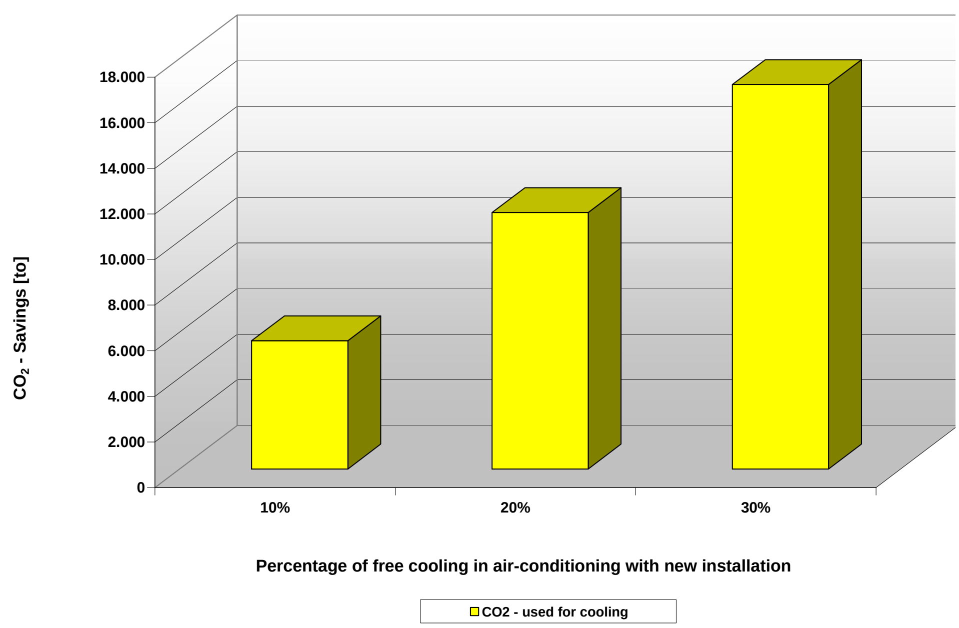
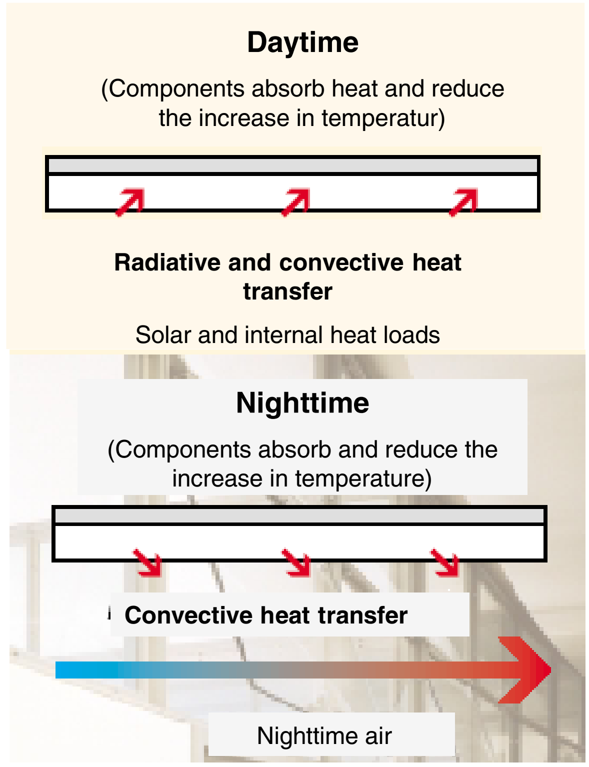


figure 4-3: CO_2 savings potential through usage of free cooling for the building air-conditioning (assumption: cooling machine EER = 3.5)

4.2 Fan-assisted night cooling



In buildings with a high rate of thermal storage capacity and moderate interior loads, the nighttime ventilation can significantly improve the room comfort. The criteria for using the nighttime ventilation for cooling during in the summertime consists of:

- A moderate climate: that means, that the nighttime temperatures outside must lie clearly below the temperatures in the building for a sufficient period of time
- The outside air quality (smells, harmful substances, fine particles) must be sufficient.
- Break-in protection and security restrictions
- Fire protection and regulations
- Weather changes such as, for example, driving rain and wind
- Noise protection and acoustics

This means that a nighttime ventilation solely with the use of a window often cannot be effective over the long run. Depending on the boundary condition, various mechanisms for fan-supported free cooling can be made use of:

- Supply and exhaust systems with variable air volumetric flow rate.
- Exhaust air systems with variable air volumetric flow rate and fresh air replenishment via suitable outside air elements.
- Hybrid ventilation as combination of free and fan-assisted systems.

Systems with fan-assisted nighttime ventilation for cooling require an integrated approach towards buildings and system technology, and must also be designed as such. This means that this technology cannot be seen as isolated. An energetic evaluation is, for this reason, difficult to illustrate and thus, was not included in this report.

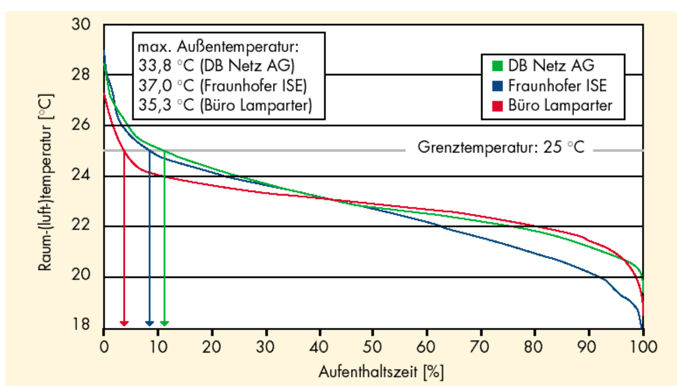


figure 4-4: Examples of the temperature relationship for free nighttime ventilation [13]

4.3 Cooling via indirect evaporation cooling

In connection with an efficient heat recovery, the cooling effect of evaporated water can be used for cooling supply air in the central air-handling-unit (AHU). The cooling effect is mostly used indirectly in Central European climatic zones that is the supply air to a room is not humidified. For so-called direct systems (evaporative coolers, desert cooler, etc.), the supply air is cooled and humidified simultaneously. These systems are suitable only for hot and dry climatic zones. In general the following systems are distinguished:

4.3.1 Indirect evaporation cooling with exhaust air

The exhaust air is cooled as much as possible by being sprayed with water. With an efficient heat recovery the "cooling" is then transferred to the supply air side. These systems are highly suitable when the exhaust air temperature after the evaporation is, in cooling mode, lower than the outside air temperature. For example if rooms in a building remain relatively cool via the storage or additional room cooling systems and the humidity load is low.

figure 4-5: Example of an air-conditioning system with indirect evaporative cooling

4.3.2 Indirect evaporation cooling with outside air

For these systems, the outside air is cooled as much as possible by being sprayed with water, the "cooling" is then transferred to the supply air or to an recirculation air. These systems are highly suitable when in cooling mode the outside air temperature after the evaporation is lower than the room temperature. For example when the room load is relatively high in a building (for example, in industry).

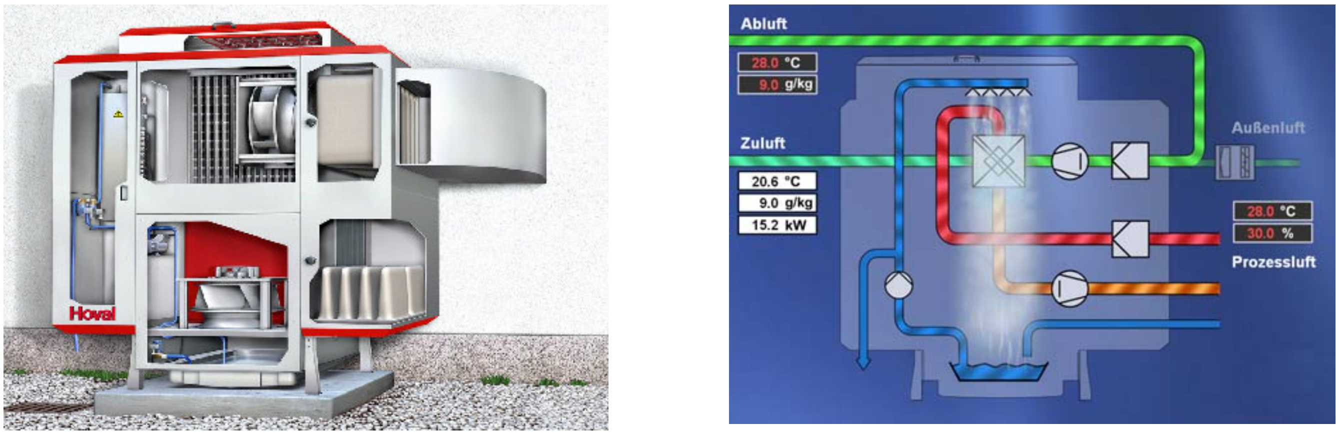


figure 4-6: Example of an air-conditioning system with an indirect evaporative cooling

4.3.3 Savings potential via indirect evaporation cooling

The following diagrams (figure 4-7 and figure 4-8) show the possible additional yearly savings on cooling energy if a corresponding percentage of these devices are equipped with an indirect evaporative cooling. The prerequisite for this technology is also the use of an efficient heat recovery system (for this, also see Section 5.1.1). The constraints are selected analogous to the sorption air-conditioning systems in Section 2.2.

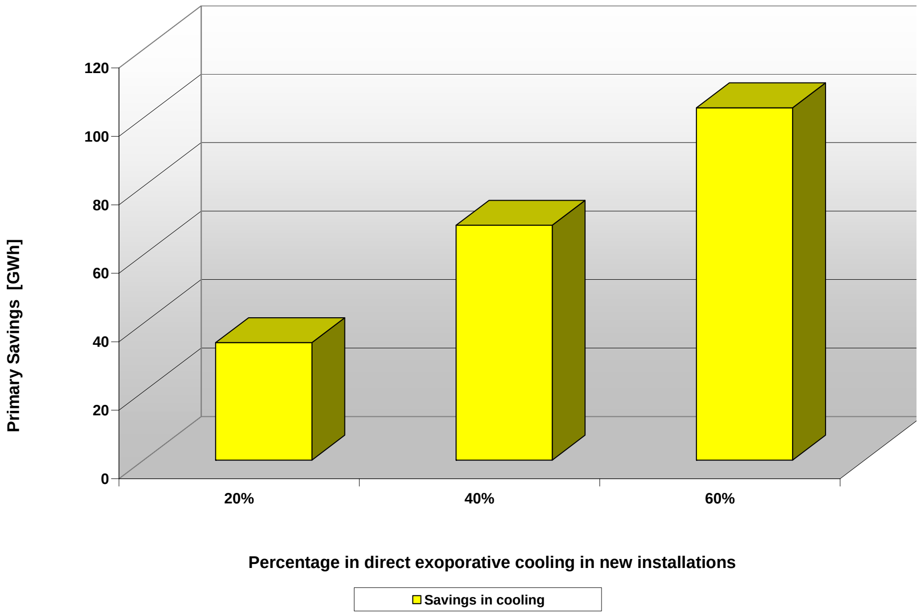


figure 4-7:: Possible yearly CO_2 savings potential by using the indirect evaporation cooling

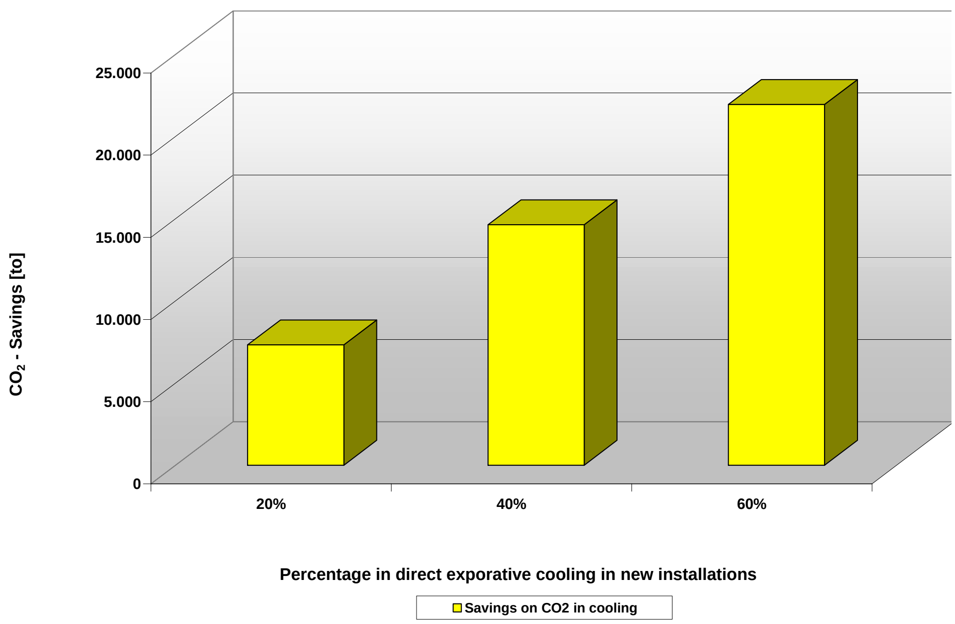


figure 4-8: Possible yearly CO_2 savings potential by using the indirect evaporation cooling

5. Heat recovery and waste heat usage

In the future the heat demand for ventilation will achieve a dominating percentage of the energy requirement for residential and non-residential buildings due to the high thermal insulation standards in Germany. In the range area of low energy and passive houses at least 50% of the thermal heat is caused by the ventilation. The example of passive houses shows that the thermal heat requirement can only be significant reduced with the usage of heat recovery in ventilation systems (figure 5-1).

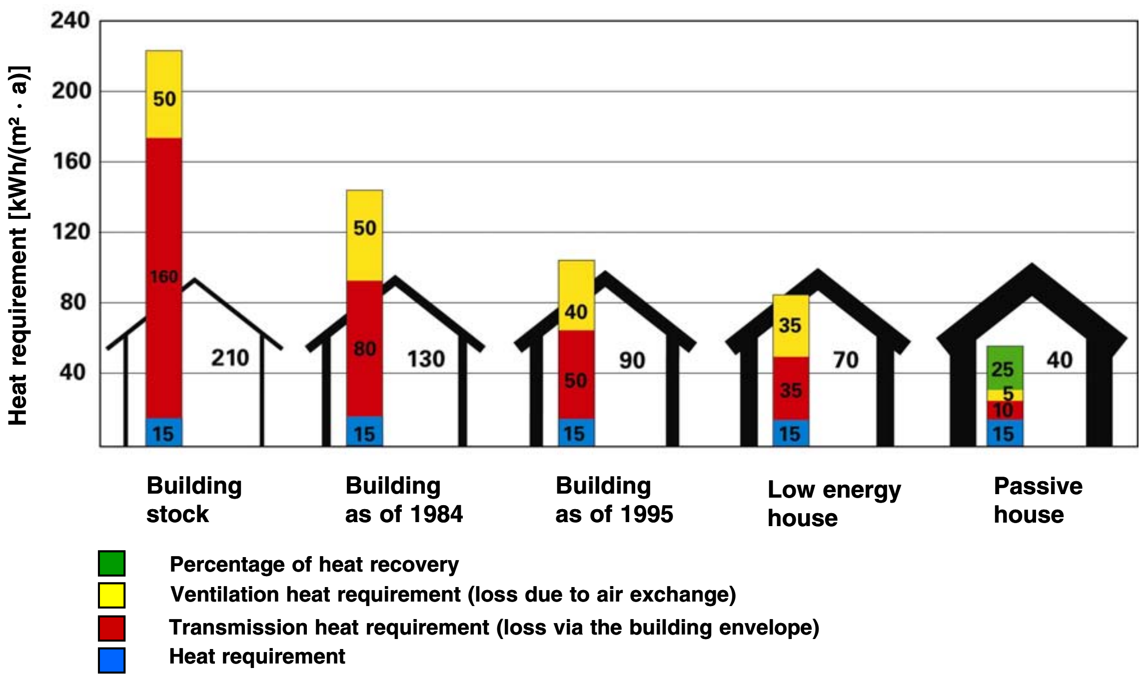


figure 5-1: Percentage of ventilation heat requirement of residential buildings

Heat recovery is a renewable energy source!

One question often came up at this point is whether the heat recovery from the ventilation represents a renewable energy source. At first this question is not so simply to be a answered and always is a matter of chosen boundary (balance limit). The following points can however, be determined:

1. The heating source of outside air is usually to be seen as a renewable energy source (for example, outside air heating pump for heating).

With that, the outside air is an environmental energy and the exhaust air of a ventilation system becomes outside air, once it exits the building. The use of exhaust air as heat source is, due to the higher level of temperature, more efficient than the use of outside air.

2. A large part of the interior heating sources in buildings come from renewable sources:
   2.1. Passive solar yields via windows (100% regenerative)
   2.2. Persons (100% regenerative)
   2.3. The renewable percentage of the power electricity (currently app. 10% with an increasing tendency)
   2.4. The renewable part of the space heating, for example, biomass, geothermal energies, environmental energies (currently app. 10% with a strongly increasing tendency)

With that, the ventilation heating losses of up to app. 40% come from renewable sources. With use of heat recovery, this heat can be almost completely recycled. In addition to this, the heat recovery can once again make the energy available that the heat recovery system has already retrieved and conveyed into the building. Recovered energy in therefore recovered many times.

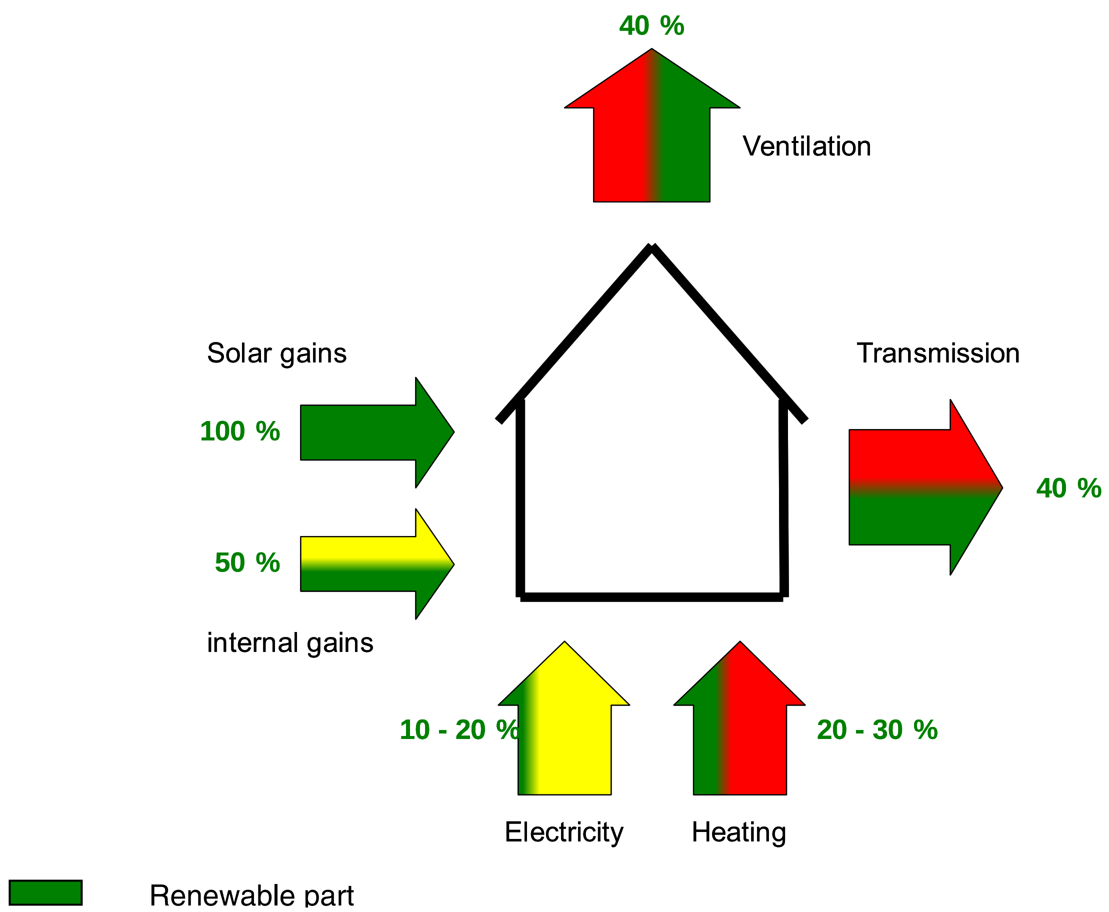
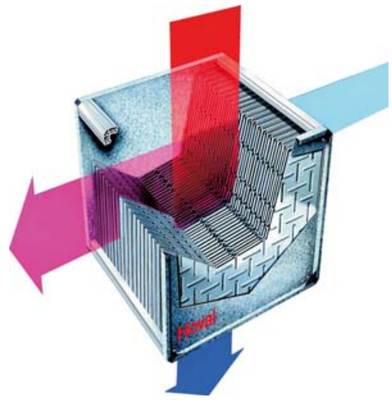


figure 5-2: Regenerative percentage of the heat recovery

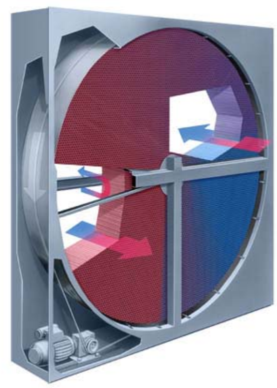
5.1 Air and air-heat recovery



Heat recovery transfers the heat (or cooling) from the exhaust air to the supply air. With sorption rotors, humidity is also transferred. Not only further energy can be saved by it, also the investment for the cold productions is reduced considerably.

Systems

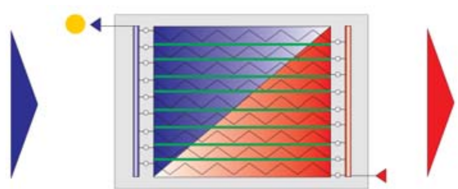
There is a difference between recuperative (heat conduction) and regenerative (heat storage) procedures. The following systems are used (seen percent-wise):



- Plate heat exchanger (app. 40 %)
- Rotational heat exchanger (app. 30 %)
- Cycle-energy-recovery (app. 20%)
- Heat pipe (app. 5%)
- Special constructions (app. 5%)

The energy exchange effectiveness lie between 45 and 75%; the pressure drop consist of between app. 80 Pa and 250 Pa.

Advantages



Heat recovery from exhaust air is the most efficient option for saving energy in ventilation systems. However, even further advantages result from it:

- lower operational costs → profitability
- reduced emissions → environmental protection
- lowered primary energy consumption → national economy

Heat-recovery-systems also are multi-functionally employable in many cases. By doing so highly efficient systems can be operated in combination with other procedures such as evaporation cooling, solar and geothermal heating usage, etc. (see Sections 2.2, 4, 4.3, 5.3, 5.4).

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5.1.1 Heat recovery in non-residential living quarters

For the moment only app. every second system is equipped with heat recovery. As such, app. 7'000 GWh (of a total of app. 33'000 GWh) of heating energy is saved each year. A big saving potential is still ready for use.

Profitability

Heat recovery is economical; depending on the operation of the systems, amortization period of between one and five years can be achieved. However, the correct dimensioning is very important. The pressure loss must be kept low so that the power consumption is not too high.

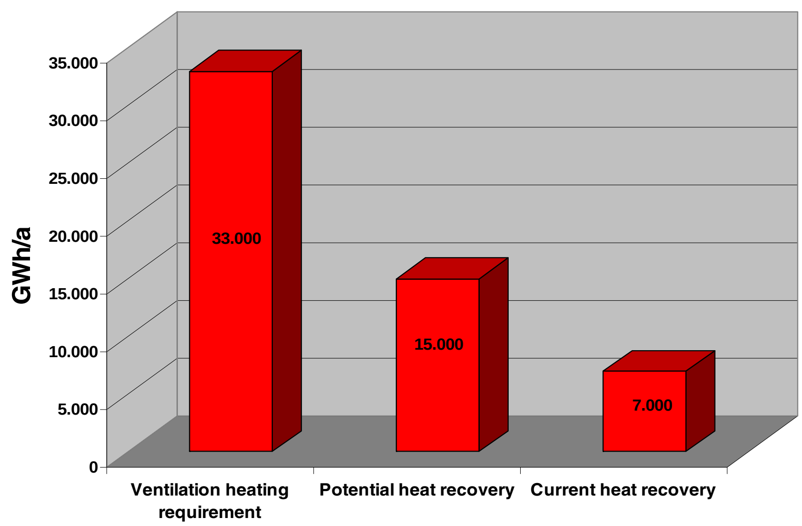


figure 5-3: Heat recovery is still not enough in use; savings potential is still available

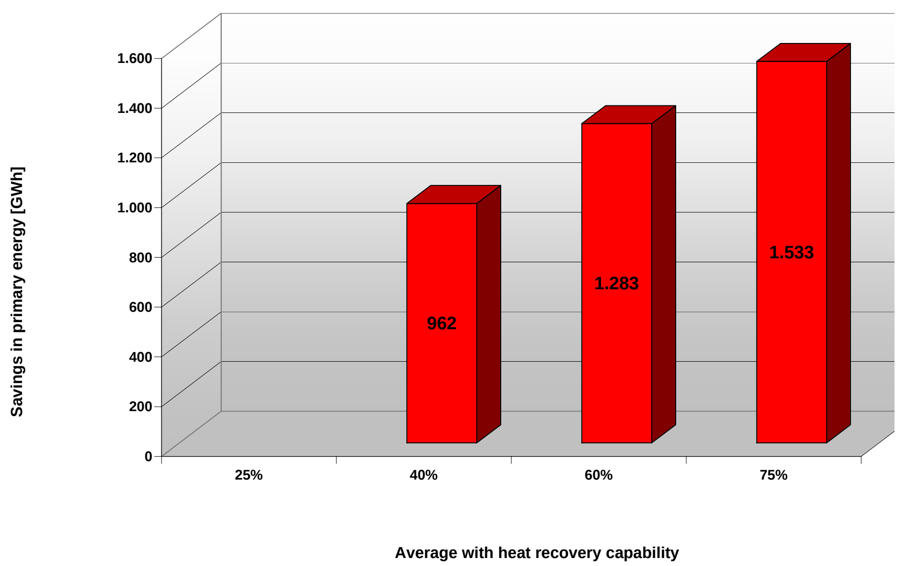


figure 5-4: Possible additional yearly CO_2 savings under the prerequisite that the average degree of usage of heat recovery increases from an app. current 25% to app. 75%

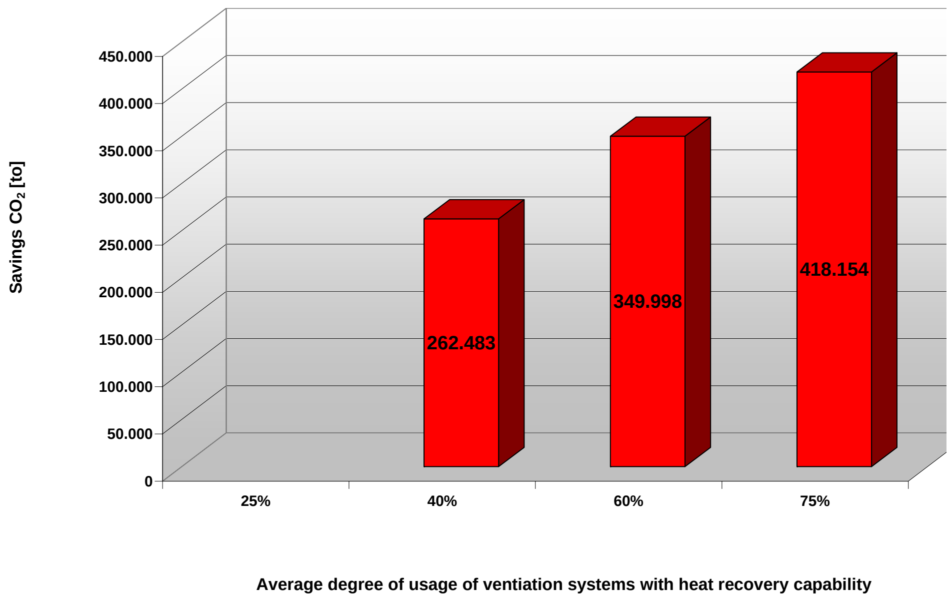
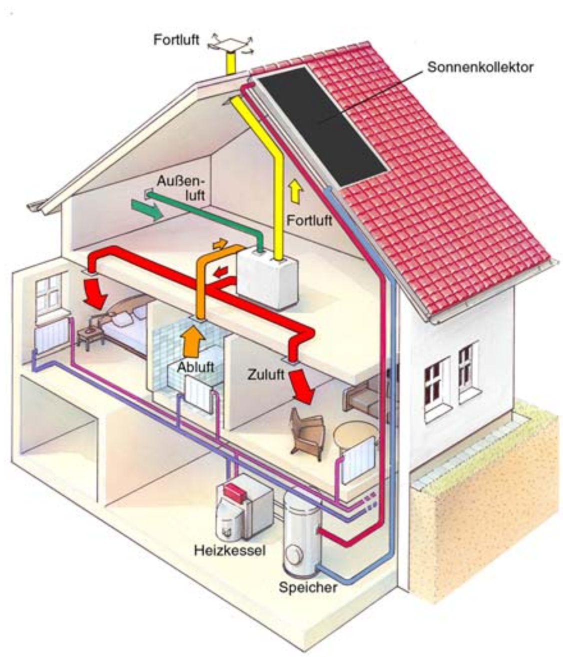


figure 5-5: Possible additional yearly CO_2 savings under the prerequisite that the average degree of usage of heat recovery increases from an app. current 25% to app. 75%

5.1.2 Ventilation systems with heat recovery in residential building



The low-energy house is currently the most energetic standard for new constructions and goals in redevelopment. Significant energy savings potential offers the residential ventilation with heat recovery and with that, is an enhancement to the building thermal insulation. Additional thermal insulation measures only do not lead to solutions with the highest benefits. Investments in the controlled building ventilation with heat recovery and thus, in a healthy and hygienic environment are also a cost-attractive solution to reduce the energy demand for residential buildings.

At present one estimates that under 5% of the residential building stock is equipped with heat recovery systems. In figure 5-6, the primary energy savings potential is shown with the prerequisite that 10 to 30% of the residential building stock is equipped with corresponding systems.

With residential building ventilation systems, app. **1% of the entire primary energy usage for the Federal Republic of Germany** can be saved.

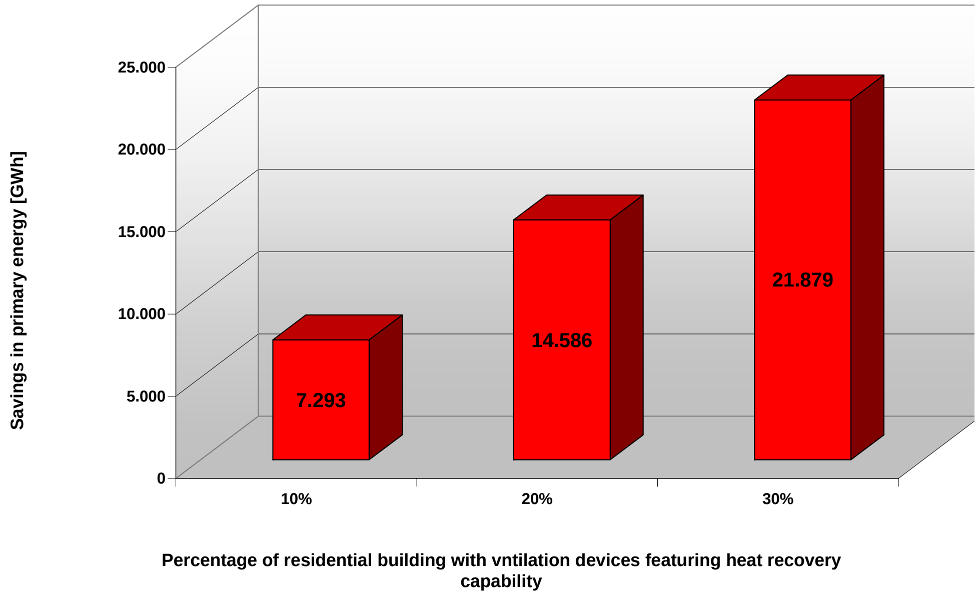


figure 5-6: Primary energy savings potential by using ventilation systems with heat recovery in residential buildings

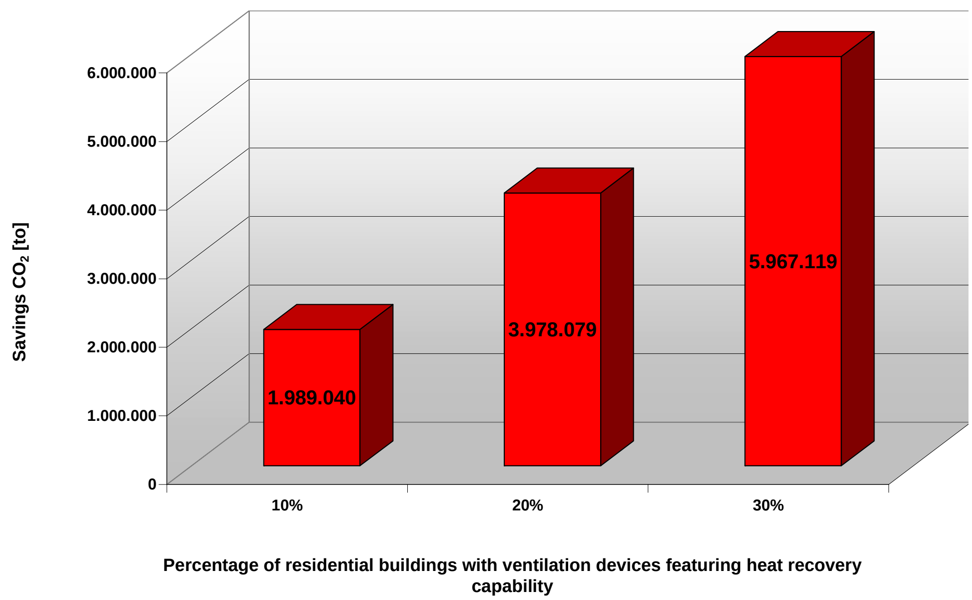


figure 5-7: CO_2 savings potential by using ventilation systems with heat recovery in residential buildings

5.2 Exhaust air to water-heating pumps and exhaust air air-heating pumps

Heating pumps are fundamentally suitable for using the following renewable energy sources or environmental sources:

- Ground-source
- Outside air
- Exhaust air

Related to air-conditioning and ventilation systems in the building, exhaust air is presented in the following as a heating source for residential and non-residential buildings. It is generally the case that the same statements for heat recovery apply for exhaust air heating pumps, because the same energy source is made use of (see Section 5 and Section 5.1.2). A large part of the energy comes from renewable sources. Only the type of usage for a heating pump process allows a larger flexibility, because higher system temperatures can be achieved. With that, the heat loss from buildings can also be used for the generation of hot water for heating and domestic hot water. In a passive house the heat source of exhaust air is usually sufficient for the complete coverage of the heating requirement for heating, ventilation and warm water.

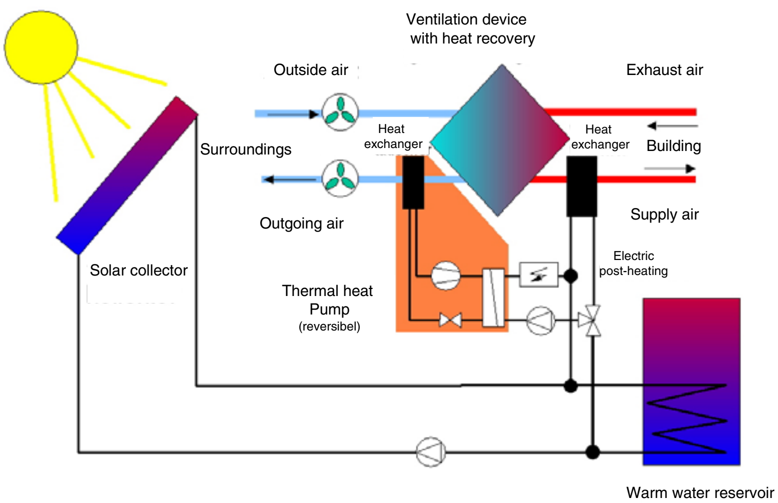
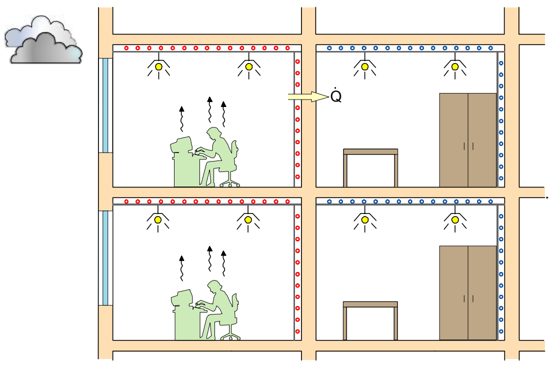


figure 5-8: Diagram of a compact unit for usage in a passive house with heat recovery, heating pump, domestic hot water storage and solar inclusion

5.3 Heat shift in the building

Non-residential buildings are usually used in very diverse and differing manners. Some areas have high thermal loads (many people and/or a high amount of technical equipment) and other areas have low. This can result in a partial area of the building being cooled, especially in the transitional periods of spring and autumn, while other partial areas of the building need to be heated. The heating shift within the building can be achieved with various technologies:

- Panel systems, that can transfer the low temperature differences within the building to a water cycle. For example, capillary pipe systems are applied (research project LowEx [13])
- Inverter controlled units multi-split air-conditioning systems for a simultaneous heating and cooling operation, so-called VRV or VRF systems can use the heat pump principle, even within the building and as such, can also evaluate the lowest temperature differences for the heating and cooling operation.



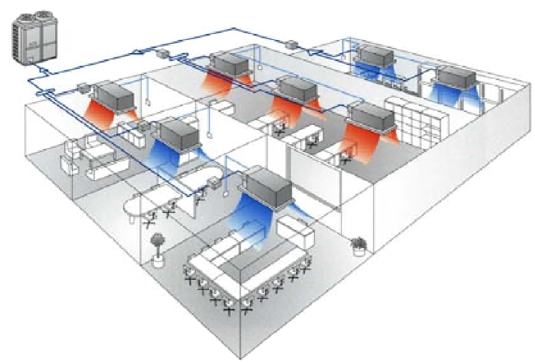


figure 5-9: Heating shift in the building via spatial systems [14] or via VRV air-conditioning systems [15]

5.4 Heat loss usage from industrial and business cooling processes

In every cooling process in industry and business for which a mechanical cooling generation is applied, heat is simultaneously generated. Normally this heat is returned to the surrounding air via a heat exchanger, because the temperature level of this heat is very low (usually app. 25 to 40° C). With the technologies described in the previous section (Section 5.3), this heating can if desired be made use of in the building. Examples of usage are:

- usage of waste heat from EDP and server rooms
- usage of waste heat from cooling units and combined refrigeration systems in retail trade (reduction as cooling load in the summer and usage as a heating source in the winter)

6. Usage of biomass and synthetic fuel made of biomass

For the cold production for room conditioning and air-conditioning with the procedures described in Section 2.1 and Section 2.1, all types of biomass are fundamentally suitable as long as they can be used as a fuel for the generation of warm water or steam. With that, all synthetic fuels made of biomass (BTL, biogas, etc.) can principally be used and correspondingly substituted.

6.1 Gas motor air-conditioning devices

Already today, gas motor driven air-conditioning devices (natural gas) are available. Instead of an electric motor a gas motor actuales a compressor in the air-conditioning process. As a result of future adjustments made to the gas motor, an application of biogas or other synthetic fuels is also possible. With that especially power supply systems will also be relieved in addition to the usage of regenerative energy sources, in the summer months.

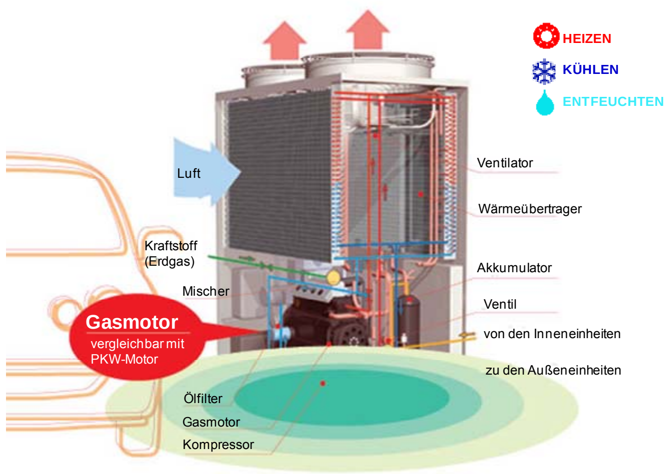


figure 6-1: Gas motor driven air-conditioning device

6.2 Gas absorption heating pumps for heating and cooling

Absorption heat pumps for heating and cooling are directly fired with gas exist and are available at the present time. They function much like the chillers in Section 2.1. However, they do not need any separate heat producers in order to be operated. They generate heat individually with a gas burner. With minor adjustments these devices are also able to use biogas directly for the simultaneous generation of cooling and heating.

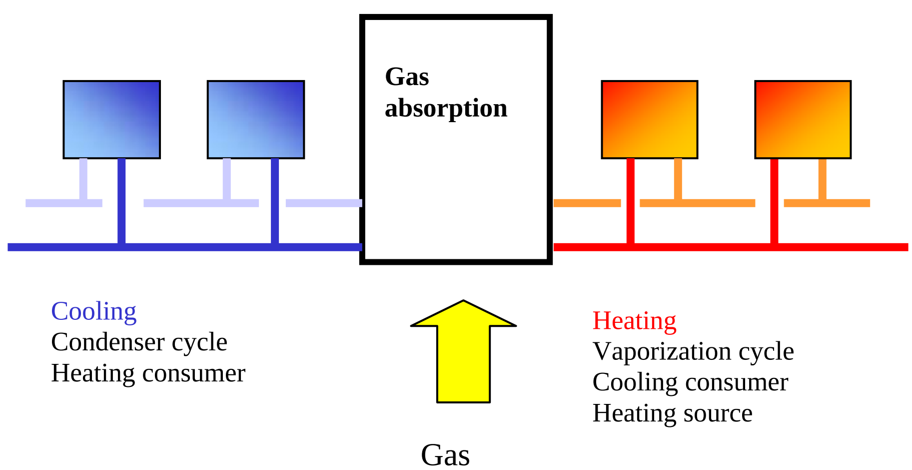


figure 6-2: direct fired gas absorption heating pump in principle

7. Summarizing savings potentials scenario of 30%

The following presents a scenario until the year 2020. For this scenario an improved economical public-effective and decree-regulatory set of conditions is intended to facilitate the implementation of renewable energies in air-conditioning and ventilation systems such that app. 30% of the market is developed per year by these measures. In detail, these are:

- 30% of the yearly newly sold chillers units are operated with solar heating or waste heat.
- 30% of the yearly, newly sold central air handling unit with cooling and ventilation functions are equipped with sorption-supported cooling systems that use solar heating or waste heat for the cooling generation or indirect evaporative cooling.
- 30% of the yearly, newly sold air-conditioning cold water systems use the geothermal "cooling energy" or make use of the ground-source as heat sink and are equipped with facilities for free cooling.
- By the year 2020, 30% of residential buildings are to be equipped with ventilation systems with heat recovery, that also use the ground-source in winter.
- The average energy exchange effectiveness of the heat recovery of the yearly newly sold central air handling units increases from the current app. 25% to app. 75%.

7.1 CO_2 Savings

If the scenarios above were to be summarized until 2020, then it should be possible with the currently available, economically meaningful technologies to achieve **around 5 to 9% of the CO_2 goals set by the federal government** with renewable measures for air-conditioning and ventilation systems in buildings. This value explicitly does not take into account the possible efficiency increases of the "classic cooling generation" for the air-conditioning.

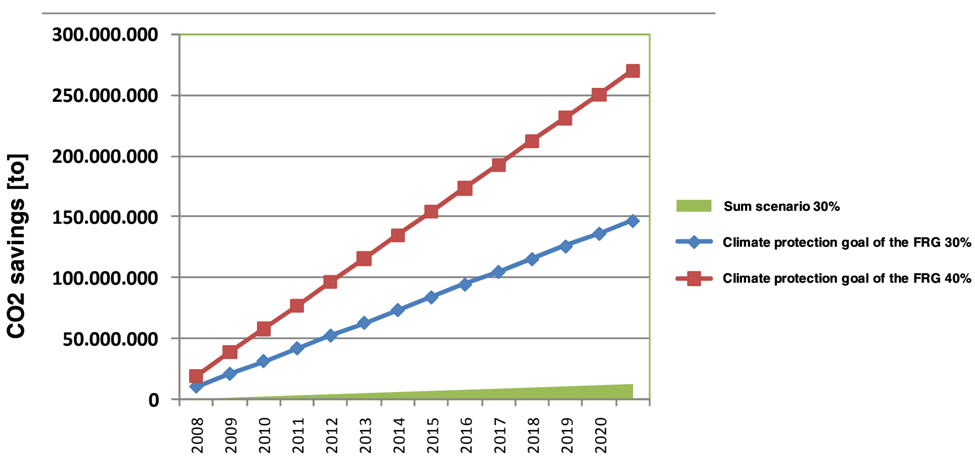


figure 7-1: Possible percentage of the renewable energies for air-conditioning and ventilation systems for the goals of the federal government by 2020

In detail, the possible savings potential are made up as follows:

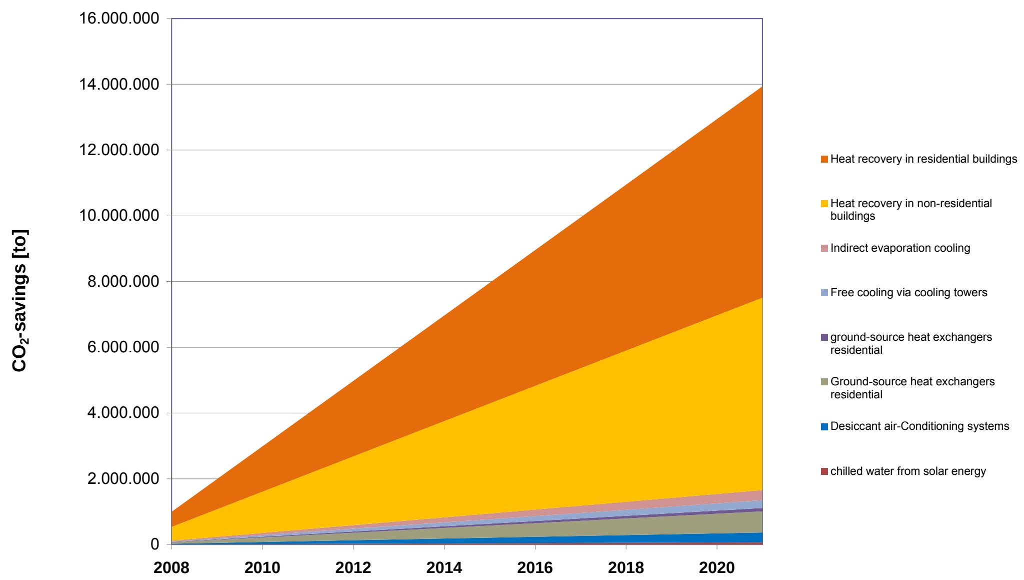


figure 7-2: Possible CO_2 savings through the renewable energies afforded by air-conditioning and ventilation systems

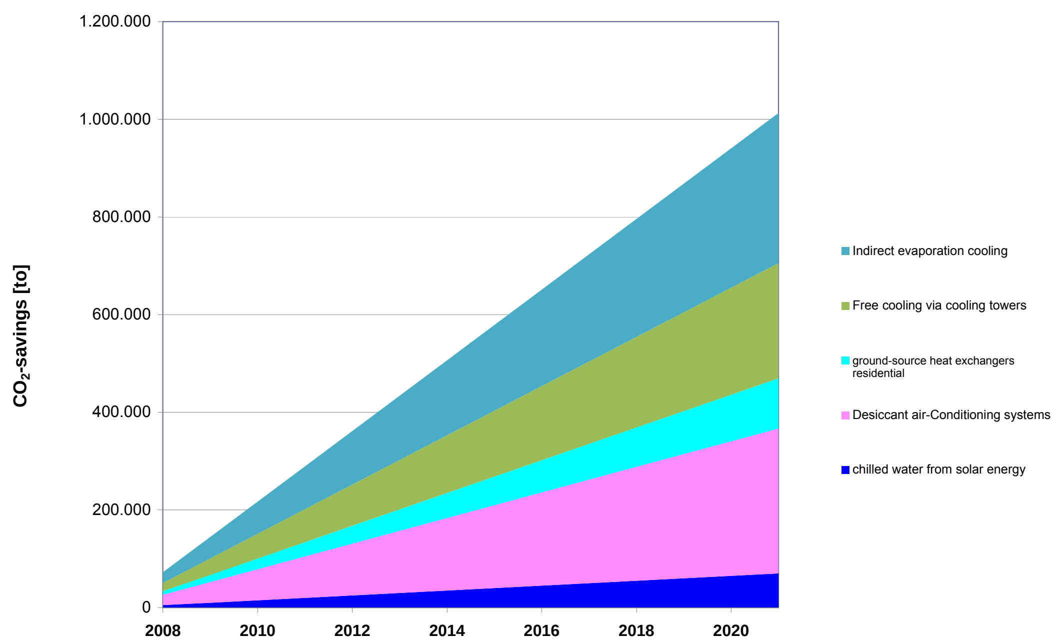


figure 7-3: Possible CO_2 savings through the renewable energies afforded by air-conditioning and ventilation systems – only cooling generation

7.2 Summary of the essential key figures

Presented here respectively are the savings potential on primary energy in Germany based on energy consumption at the current time through the implementation of renewable energies in the areas of ventilation, air-conditioning and providing cooling under the scenario of 30% as described in the previous section

Ventilation (heating energy):

	Section	kto CO_2	GWh	%
Heating energy consumption (end energy)		239'000[1]	797'000	100 %
Thereof: Residential buildings (end energy)		181'000	604'000	76 %
Non-residential buildings CTS (end energy)		57'900	193'000	24 %
Savings potential via heat recovery (primary energy)				
Thereof: Residential building[2]	5.1.2	6'426	21'464	3.6 %
Additionally through ground-source heat exchange[3]	3.1.2	642	2'356	0.4 %
Non-residential buildings[4]	5.1.1	5.854	23'562	12.2 %

Summertime air-conditioning in air handling units:

	Section	kto CO_2	GWh	
Primary energy consumption for summertime operation of central ventilation devices (cooling, dehumidification)[5]		1'762	8'275	100 %
Savings potential achieved through indirect evaporative cooling[6]	4.3	307	1'441	17 %
Savings potential achieved through solar, sorption-supported procedures[7]	2.2	296	1'391	17 %

Chilled water for air-conditioning:

	Section	kto CO_2	GWh	
Primary energy consumption (Electricity) for providing cooling (AL + cooling)			198'000	100 %
Thereof: comfort air-conditioning		9'156	43'560	22 %
Thereof: offices		2'236	10'500	
Thereof: cooling and process cooling			154'440	5.3 %
Savings potential for comfort air-conditioning:				
Savings potential achieved directly through cooling with ground-source and groundwater (without WP)	3.1	-	-	-
Savings potential achieved indirectly through cooling with ground-source and groundwater (with WP)[8]	3.2	102	481	1.1 %
Savings potential via provision of solar-thermal cold water[9]	2.1	70	498	1.1 %

[1] Assumption: room heating gas
[2] Assumption that by the year 2020, app. 30% of the residential buildings will be equipped with heating recovery
[3] Additional savings on ventilation heating for earth-source heat transducer
[4] The new central ventilation devices sold in every year are, on average, equipped with 75% heating recovery
[5] Every year, newly sold central air-conditioning devices 331 GWh, average life expectancy is 25 years
[6] 60% of the central ventilation devices sold each year with cooling are equipped with indirect evaporation cooling
[7] 30% of the central air-conditioning devices sold each year are equipped with sorptive systems
[8] 30% of the cold water devices sold each year are equipped with earth-source or ground water sinks
[9] 30% of the cold water devices sold newly per year are solar-thermal supported

8. Key data for the assessment of the savings potential

For this assessment of the possible savings potential obtained by using the procedures and systems described in the previous sections, the following foundational data has been used:

Living space, residential buildings 1 to 2 residential units 3 and more residential units Sum	1.8747 bn. m^2 1.3001 bn. m^2 3.1748 bn. m^2	Stand [6] 2003
Air handling units Air performance total	38'000 items 658'000'000 m^3/h	Sale per year [3] 1997
Chillers Water cooled chillers Air-cooled chillers Turbos Absorption chillers Sum	413'460 kW 480'322 kW 158'000 kW 45'900 kW 1'097'682 kW	Sale per year [2] 1997
Energy consumption statistics:		
Primary energy consumption FRG	14'334 p.a. 3'981'000 GWh	[8]2003
Energy-dependent CO_2 emissions	833 mil. tons CO_2	[9]1999
Cold generation	66'000 GWh power 11'000 GWh other 22% of which is air-conditioned	[10]2006
	3'500 GWh power Cooling for air-conditioning of offices	[12]2006
Renewable energies	11% of power production 25% in 2020 (estimation)	[11]2007
Heating energy demand for residential buildings	End energy 603'889 GWh	[16]2005
Room heating CTS	End energy 193'000 GWh	[16]2005
Cooling and air-conditioning CTS	End energy 21'444 GWh	[16]2005
CO_2 factors Power Room heating (gas)	0.64 kg/kWh 0.30 kg/kWh	

Table 8-1: Foundational data for the estimation (market, stand, sales statistics, energy consumption)

9. Directory of literature

[1] Wolkenhauer, Henning, Franzke, Albers, Hindenburg: *Energieeinsparung durch Einbeziehung solarunterstützter Klimatisierung in zukünftige Planungsprozesse* (Energy Savings through Inclusion of Solar-Supported Air-Conditioning in Future Planning Processes), FIA Report No. 68, 2002

[2] *Schätzung der Marktzahlen nach EUROVENT Jahr 2000* (Estimation of Market Statistics according to EUROVENT, 2000)

[3] E. Beck: *Energieverbrauch, -einsparpotenzial und -grenzwerte von Lüftungsanlagen* (Energy Consumption, Savings Potential and Marginal Values of Ventilation Devices) FIA Report No. 86, 2000

[4] www.raumkuehlsysteme.de - *Raumkühlung durch flächenorientierte Systeme* (Room Cooling via Surface-Oriented Systems)

[5] H.M. Hellmann: *Geothermisches Heizen und Kühlen von Bürogebäuden* (Geothermal Heating and Cooling of Office Buildings)

[6] Forsa, *Erhebung des Energieverbrauchs der privaten Haushalte für das Jahr 2003* (Census of the Energy Consumption in Private Households for the Year 2003)

[7] DIN V 18599 - *Energetische Bewertung von Gebäuden - Berechnung des Nutz-, End- und Primärenergiebedarfs für Heizung, Kühlung, Lüftung, Trinkwarmwasser und Beleuchtung, 2005* (Energetic Evaluation of Buildings; Calculation of the Usage, Primary and End Energy Requirement for Heating, Cooling, Air-Conditioning, Drinking Water and Lighting)

[8] *Innovation und neue Energietechnologien - Das 5. Energieforschungsprogramm der Bundesregierung* (Innovation and New Energy Technologies - The 5th Energy Research Program of the Federal Government), July 2005

[9] *Für eine zukunftsfähige Energieversorgung - Nachhaltige Energiepolitik - Energiebericht, BMW* (For a Future-Capable Energy Supply – Lasting Energy Politics – Energy Report, BMW), October 2001

[10] *Verbrauchsfaktor Kälteerzeugung HLH* (Consumption Cooling Generation HLH), Vol.57, No. 12/2006

[11] Press release BMU, No. 013/07, January 15th, 2007

[12] *Verdunstungskühlung auch für Gebäude* (Vaporization, Even for Buildings); Hubert Sturies, Jens Panenberg, CCI 5/2006

[13] *Passive Kühlung mit Nachtlüftung* (Passive Cooling with Night Ventilation), BINE Topical Information I/03

[14] *Forschungsvorhaben LowEx, Niedrigexergiesysteme für die Heiz- und Raumlufttechnik* (Research project LowEx, Low Exergy Systems for the Heating and Room Air Systems); Prof. Muller, HRI TU Berlin, Hamburg 2006

[15] *Zukünftige Anforderungen an die Klimatechnik* (Future Demands on Air-Conditioning Technology); Prof. Pfeiffenberger, FGK, October 2004

[16] *Energieszenarien für den Energiegipfel 2007* (Energy Scenarios for the Energy Summit in 2007), EMI and prognosis

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10. More information from the FGK

10.1 Writings of the Fachinstitut Gebäude-Klima e.V. and the FIA project

Extract from the literature list of the FGK (*Fachinstitut Gebäude Klima e.V.*)

Title	**No.:**
Guide through the air-conditioning and ventilation industry	1
Manual on passive cooling	23
Market leader for controlled apartment ventilation	58
Energy savings decree for RLT devices?	83
Future demands on air-conditioning technology	99
2. Symposium on apartment ventilation	114
Apartment ventilation with heat recovery	134
CLIMATE DAY 2007 – Energy efficiency and renewable energies in the air-conditioning, cooling and ventilation technology	135
Sorptive dehumidification and temperature dropping for air-conditioning	45
Primary energy savings for ventilation systems with heat recovery	49
INTESOL Partial undertaking - 2 integral planning solar-optimized constructions	56
Solar air-conditioning – Workshop for project bearer Jülich – Status and results of the research works	62
Energy savings through integration of solar-supported air-conditioning in future planning processes	68
Energy consumption, savings potential and marginal values for ventilation systems	86
Cross-section evaluation "Solar-supported air-conditioning devices in Germany" (German *QASUK*)	88
Solar-supported heating and ventilation systems with the usage of a prototype adsorption cooling device in new constructions of an office building	91
Solar air-conditioning – Simulation tools for the solar-supported air-conditioning, SolAC	112
Solar air-conditioning - IEA-SHK Task 25 Scientific Corollary Project	115
LowEx Heating and cooling with low energie	125

10.2 Internet

On the following internet-sides you find all informations around the air-conditioning and ventilation-technology

www.fgk.de
www.raumkuehlsysteme.de
www.kwl-info.de
www.fia-news.de
www.rlt-info.de
www.raumklimageraete.de
www.sorptionsgestuetzte-klimatisierung.de
www.rlt-reinigung.de

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