MOOC Zero-Energy Design

Course Reader Module 4

TU Delft

This reader provides additional information for the Massive Open Online Course (MOOC) Zero Energy Design.

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Space heating

1. Space heating

This chapter discusses the most common individual and collective heating systems, including descriptions of the systems themselves, the relationship between space heating, ventilation and water heating installations and how systems should be integrated into architectural design. Special attention is paid to low temperature (LT) systems, such as floor heating, as these are more and more relevant with regards to comfort, saving energy and increasing the potential for renewable energy.

The checklist below shows the main criteria for a selection of space heating systems.

selection criteria for space heating installations. The assessment is indicative and is relative to an individual heating installation with radiators.	Radiators (reference)	LT-Radiators	Convectors	LT-convectors	Floorheating	Wallheating	Zone system	Multiple zone system	façade heater	gas fireplace
Structural and spacial conditions										
spacial requirements ducts	0	0	0	0	0	0	-	--	0	-
spacial Heating elements, boiler, enz.	0	-	0	-	+	+	+	+	0	0
air-density (- = additional requirements)	0	0	0	0	+	+	-	-	+	+
isolation (- = additional requirements)	0	0	0	0	-	-	-	-	0	0
comfort										
speed of heating	0	0	0	0	0	-	0	0	+	++
regulation per room/zone	0	0	0	0	0	0	--	0	+	+
temperature comfort	0	+	-	-	++	++	-	0	-	0
sound	0	0	0	0	0	0	0/-	0/-	-	-
draft	0	0	0	0	+	+	-	-	0	0
quality indoor air	0	+	0	+	++	++	-	0	-	0
miscellaneous										
energy usage (+/++ = lower)	0	+	0	+	++	++	--	-	0	+
Maintanance (+/++ = lower)	0	0	0	0	0	0	-	-	0	+
investment (+/++ = lower)	0	-	0	-	0	0	-	-	+	+

Legend:
++ very favorable + favorable 0 neutral - unfavorable -- very unfavorable (in reference to radiators)
Lt = low temperature heating

Fig. 1.1: Selection criteria for space heating installations. The outcomes are indicative and refer to an individual heating system with radiators. Legend: ++ Very good + good o neutral - negative -- very unfavourable (compared to all radiators)

1.1 Heat demand

The heating demand of a house is determined by:

- the comfort needs of people
- heat loss through transmission, ventilation and infiltration
- heat contribution of internal heat sources and the sun.

Comfort demand of people

The thermal comfort of a person is, combined with his or her clothes and metabolism (activity level), determined by:

- air temperature
- radiation temperature
- relative humidity
- air speed.

Different people have different expectations with regards to comfort. In a home, it is not the comfort need of the average person that counts, but that of the individual resident. The level of comfort must be adjustable to the requirements of that resident and the house and its heating system should meet these requirements in an energy-efficient way.

Night setback

The use of a 'night setback' setting on heating systems, even in modern, well-insulated homes, will reduce room temperatures by 2 to 4ºC at night. A reduction of 3ºC in temperature provides an average energy saving of 10%. During the colder months when there is a frost, for example, it is recommended that the maximum temperature reduction should be just 1 to 2ºC, and a heat pump system is used to ensure that the house is reheated as quickly as possible.

Heat loss

Heat loss is determined by:

- transmission through the building envelope, including heat leakage through thermal bridges
- transmission to neighbours' houses through walls and floors
- the amount of fresh air supplied by the ventilation system
- infiltration through joints and cracks

Heat contribution

Heat contribution in a home comes from:

- the release of heat from people, lighting, equipment, cooking etc inside the house (internal heat contribution)
- solar heat entering the house.

The extent to which sun contributes is determined by the size and orientation of the windows and the use of sun protection measures.

1.2 Heat supply systems

A heating system is necessary for a comfortable indoor temperature during the heating season. However, limited capacity is needed for heating in modern housing because they are so well insulated. In addition, there are many energy-efficient low temperature system options, such as:

- low temperature radiators and convectors

- floor and wall heating.

A central heating system is not always necessary in an extremely well insulated house. A logical choice would be:

- limited air heating by means of a ventilation system
- local heating.

Fig. 1.1 shows the main criteria for choosing a heating system. The properties are compared to traditional heating radiators with an HR-boiler in the loft or airing cupboard. With the exception of local heating, the table does not consider the heat source (generator). These options appear later in this chapter.

For houses with a very low heat demand, such as passive houses, a rapid response heating system is required to meet the changing comfort demands of residents. This system should also supply a limited amount of heat per room. The minimum capacity of existing boilers tends to be too great and so a system with a buffer, such as a solar boiler combination, could be a solution.

Consider energy-saving opportunities in a combination of housing and utilitarian buildings; offices generally have surplus heat, while at the same time houses have a demand for it.

1.2.1 High/low temperature

Heat can be supplied in high or low temperatures. The lower the output temperature is, the higher the efficiency of the supply system. Since renewable energy works more successfully with lower output temperatures, the use of LT systems is a prerequisite for energy-efficient housing.

Traditional water-heating systems use a supply temperature of up to 90°C; 80°C is currently common practice. There is no real consensus of opinion to define the meaning of ‘low temperature’ so, for the sake of this book, the standard maximum supply temperature is 55°C with a return temperature of up to 45°C. In a collective heating system, this maximum temperature is 70°C and with a maximum return of 40°C. These temperatures are too high, however, for sustainable systems, such as heat pumps or solar boilers.

Low temperature (LT) system options are:

- LT radiator- and convector heating (supply temperature of 55°C)
- floor- and wall insulation (supply temperature of 25-45 °C).

There are no objections to the use of LT heating in current guarantee standards for new buildings. However, there tends to be heating surcharges for re-heating after the use of night setbacks (within 2 hours) and ‘cold neighbours’ should be charged for their contribution this.

Important reasons for the use of LT systems are for:

- saving energy: in both the heat source (by generating a larger return) and the distribution (fewer losses)
- shaping the future: increasing the options for the future use of renewable energy, such as solar energy. An LT system is a necessity when using heat pumps and it is important to take into account such developments sooner rather than later to benefit from their long lifespan compared to other heat sources, such as a boiler
- improving indoor climate, including:
    - comfort: the heat supply through walls and floors particularly delivers a fairly high degree of comfort because of the large radiation surface. This is combined with lower air temperatures and a smoother temperature distribution. Wall and floor heating eradicates thermal bridging near

windows with the standard application of HR++ glass. One concern remains around thermal bridge grids in natural ventilation. To combat this, the window area should be limited to 3m^2.

- air quality: burning dust (causes an unpleasant smell) is uncommon in LT-systems because there is relatively little floating dust. In addition, floor heating reduces the development of mites because of the higher surface temperature compared to other systems
- safety: little or no chance of burns when touching the supply systems. Since obstacles, such as radiators, are not present in the floor, wall and air heating, there is a reduced risk of injuries when falling. Both of these points are particularly important in terms of children and the elderly.

• improving design opportunities: floor- and wall heating results in a greater freedom of layout and aesthetic value due to the absence of radiators or convectors.

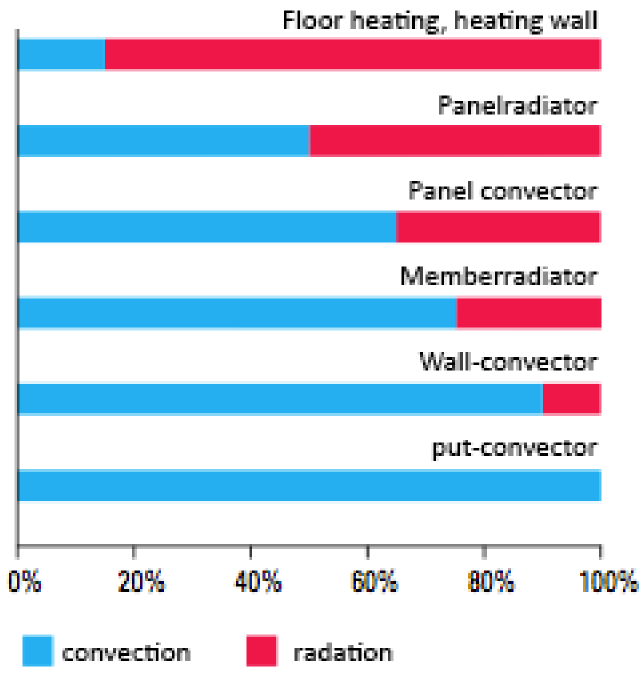

Fig. 1.2: Share of radiation and convection of different types of CV water heaters. The same temperatures can be achieved with a larger proportion of radiation and lower average air temperature in a room. This saves energy as both transmission and ventilation loss decreases. A relatively low water temperature with a fairly large warming surface should preferably be used

1.2.2 Low temperature radiators and convectors

(LT-) radiators

Radiators tend to be used more than wall convectors as they provide more radiant heat and are more cost-effective to run, If wall convectors are used it is generally for aesthetic reasons.

The only difference between low temperature (LT) radiators and conventional radiators is their size (heating surface), as their dimensions must be appropriate to a maximum supply temperature of 55°C and return water temperature of 45°C or less. The size is therefore generally around 2.5 times larger than a traditional radiator system with a temperature range of 90 to 70°C. This will not cause any issues in a well-insulated modern home due to the low heat demand.

With LT radiators, the energy consumption of a high-efficiency boiler drops in relation to the energy use of standard radiators. The use of LT-radiators is a minimum requirement in heating systems with heat pumps and solar thermal heating. For these, even lower temperature systems are preferred.

The following are generally used:

- Panel or plate radiators: existing of one or more panels. Single plate panel radiators are preferred because they supply approximately 50% more radiation heat. Multiple panels per radiator increase the distribution of convection heat proportionally
- Panel convectors: panel radiators with additional convection lamellas. Through these, the heating surface increases

Benefits

- Low water content for a faster response
- Lightweight
- Smooth wall panel radiators: provide as much radiant heat as panel radiators; simply shaped, with a smooth and sleek appearance

Disadvantages

- Relatively large water content and mass, therefore slower in heating than the aforementioned radiator types
- Vulnerable to corrosion: not for use in the bathroom unless the radiator is placed in a dry area
- Relatively expensive

Please note:

- The best position for radiators is under a window so that they compensate for any cold radiation thermal bridges caused by the window and glazing. In HR++ glass, providing there are no ventilation grids in the façade (creating a balanced ventilation system), this is less of a concern.

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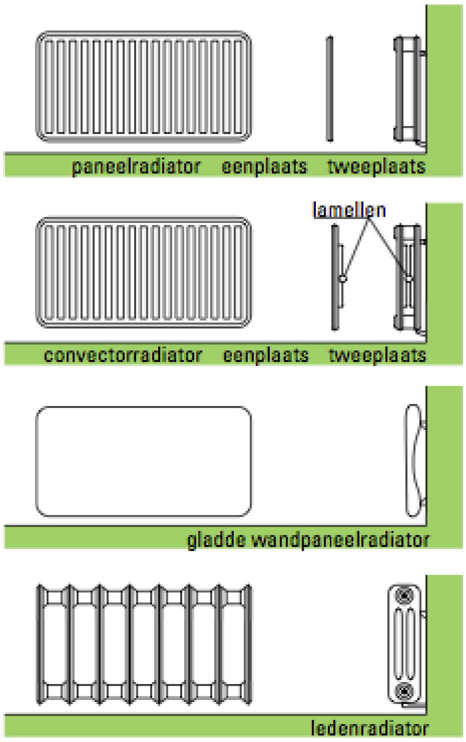

Fig. 1.3: Different types of radiators

Vocabulary:
Ledenradiator: traditional radiator
Paneelradiator: panel radiator
Eenplaats: single plate
Tweeplaats: double plate
Convectorradiator: convector radiator
Eenplaats: single plate
Tweeplaats: double plate
Gladde wandpaneelradiator: smooth wall panel radiator

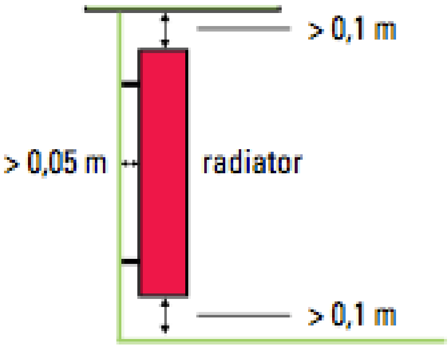

Fig. 1.4: For cleaning and required convection airflow, place radiators and wall convectors with sufficient distance to the floor, wall and window. In the bathroom, place the radiator at a height of at least 0.6 metres from the floor to prevent rusting. If necessary, choose a galvanised radiator in the bathroom

- Radiators need sufficient distance from the floor, wall and ceiling to produce the required cleaning and convection currents. Allow the following minimum dimensions:
- Free distance top and bottom:> 0.1 metres
- Remote wall radiator> 0.05 metres
- The window sill must not interfere with the warm airflow. Also ensure that there is enough space for hot air to flow in front of the curtains rather than behind them. For example, place the radiator at a sufficient distance from the wall or ensure there is enough hanging space between the curtain frame and the inside of the façade.
- Installation of a glass balustrade to save energy is discouraged, even with HR++ glass, as there is a risk of thermal breakage. If necessary use a radiator.
- The length of radiators under a window must be more than 75% of the window length to prevent undesired air currents.
- Painting radiators in metallic colours reduces the heat output by around 10%. Other colours have no effect on heat output.
- Built-in off radiators are not recommended. The total heat output decreases up to 25% and cleaning is difficult.
- It is necessary to insulate pipes in unheated spaces (storage rooms and lofts), as well as in other non- or low-heated rooms.

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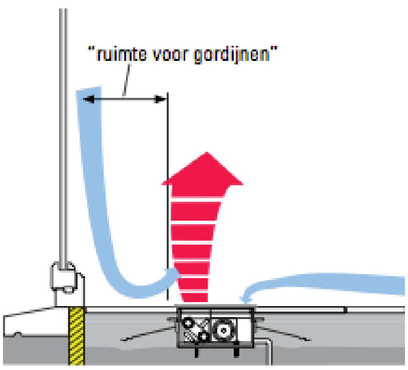

Fig. 1.5: Space for curtains to hang. The alternative to the traditional, energy leaking convector trench is a ventilator-convector in the screed (Jaga illustration)

• Integrated heating pipes (with water temperatures above 30°C) should be insulated when they do not supply a radiator in the same space. A fin tube (sleeve) is not effective insulation. Use at least 12mm of insulation and take measures to prevent it from being damaged when concrete is poured.
• Ensure that shower water and soap is kept away from radiators.

(LT-) convectors

The principle of convectors is based on the release of heat by convection. They are constructed of thin warm-water pipes surrounded by thin metal lamellas that are an evenly spaced. Air is then heated by flowing naturally through the slats of the convector.

Convectors are generally placed in an enclosure that has as little height as possible. This stimulates the natural flow and emission of the air that is heated inside. They mainly provide convection heat due to a small amount of radiation heat, resulting in little or no compensation for cold radiation from cold surfaces in a space.

These devices reach desired temperatures relatively quickly due to their low water content and mass. At low temperatures, the natural airflow in the casing is usually so minor that little heat is transferred. Convectors are therefore not recommended in LT systems, unless those used are specifically designed for low temperatures and these usually contain a small ventilator.

The following convectors types are available:

- Wall- or freestanding: enclosed in a casing
- Floor: integrated into the flooring. These were historically placed in structural wells that are no longer used due to significant heat leaks. Isolated structures used these days also lack the desired thermal quality (Rc> 3.5). Alternatively, there are flat ventilator-convector units for sale that fit into the floor with a height of less than 100mm (fig. 1.5)
- Ventilator-convector units (fan coil): also available in compact and quiet designs suitable for housing, allowing reduced flow temperatures and cooling. The noise and power consumption of the fans should be take into account

Convectors should always be accessible so that they can be cleaned easily. This is important as pollution causes:

- reduction of heat output
- issues for people with allergies
- unwanted smells caused by burning dust (not the case for LT convectors).

8.2.3 Floor- and wall heating

The temperature difference between the air in the room and the large heating surface of a floor or wall can be too small to meet the heat demand requirements. With floor- and wall heating systems, the lowest temperatures can be used for heating.

Floor heating

A floor's surface temperature is usually limited to a maximum of 29°C because of comfort requirements. In bathrooms, and surrounding rooms, the maximum is around 33°C and the maximum temperature of the water supply is approximately 45°C. However, well-insulated homes can withstand a floor temperature of 30°C, resulting in floor heating sometimes being combined with other systems, such as radiators or convectors, together with air heating, to increase the reaction speed.

It is feasible for floor heating to be used (this may be combined with wall heating) as the main heating supply and is recommended in terms of energy savings and comfort. A plastic piping system, through which warm water flows, is integrated into the floor and consequently heats it. It is important for the bottom and sides of the screed to be covered with thermal insulation. Without it, the heat that should go up from the floor to the living space will also travel downwards into the concrete floor and ground, resulting in energy loss. An R-value of at least 5.0 is recommended as a minimum for the whole ground floor.

The size of the mass that needs to be heated is an important factor in determining the reaction speed of a floor heating system. This is because the smaller the mass is, the faster the floor will heat. This means that, in a well-insulated new building, a light system is preferred, particularly if the floor heating (in a room) is the main heating.

The following systems types are available:

- Dry build: The pipes are attached to, on or in insulation plates that generally contain heat-dispersing metal plates. The top is finished with, for example, two layers of gypsum fibreboard. Due to their limited weight, these systems are particularly relevant in timber frame constructions and existing buildings. They also respond quickly to heat demand.
- Capillary: These consist of thin tubes (4mm in diameter) that are linked to the main tubes. They can be integrated in a thin screed cast floor or levelling layer. These systems are very thin and so respond quickly. The surface temperature of the floor is evenly distributed and therefore the heat supply is high. Lower temperatures are suitable when combined with constant heat release. The pressure drop across the mesh is comparable with normal heating. Note that the generator and mats need to be separated as the material is not closed off against oxygen diffusion.
- Wet build - on top of an insulation layer of 10 to 20mm: The heating pipes are placed in the screed with the insulation located directly below the slab. This provides a relatively light system with an acceptable response. It also results, if the sides are also isolated, in a floating floor, which is very effective for sound insulation providing the correct insulation is used. The decking floor may comprise a concrete-sand floor. However, from an environmental perspective, an anhydrite-casting floor is preferable. For wall and column connections, pipe outlets etc, insulation strips should be attached to avoid cracking and limit heat transfer to other structural components and other spaces.

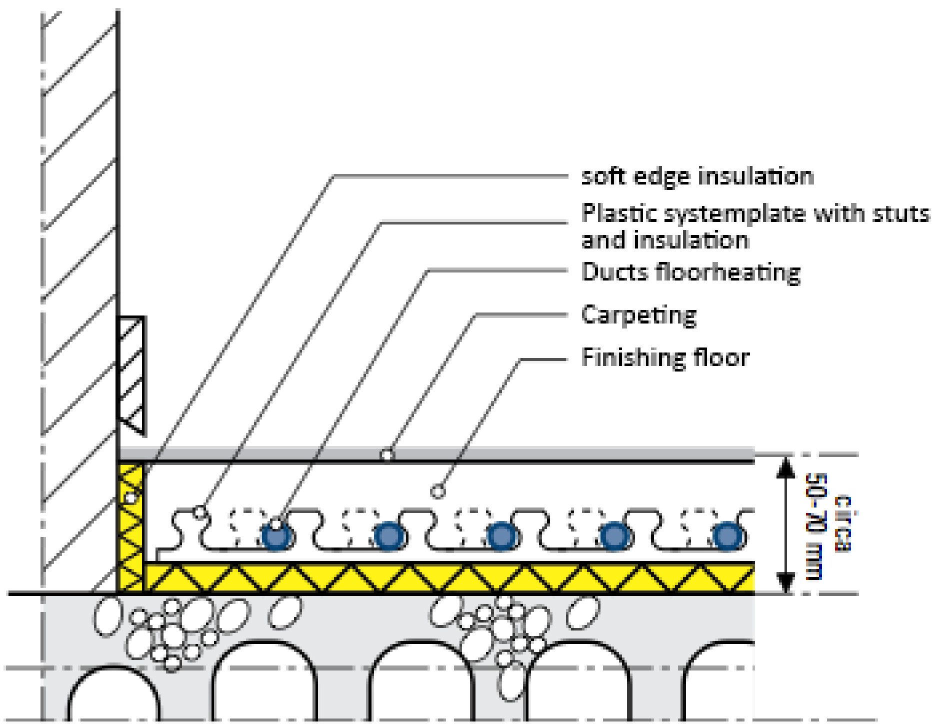

Fig. 1.6: Example of the building process for a wet build floor heating system. For effective sound insulation, the insulating layer should consist of a relatively soft material instead of polystyrene, for example mineral- or sheep wool. The plinths should remain free of the decking

• Wet build - directly attached to the concrete or on foil: These systems are cheap but also present disadvantages, such as the concrete and decking floor the system being very slow due to its combined large mass. It is generally too slow to meet a resident's comfort requirements. Also, the heat emission to underlying rooms is very high (up to 50%). This is usually undesirable, particularly as it puts multi-unit housing in a very high cost-bracket, even with the use of individual boilers. For this reason it is not relevant for this type of property.

• Concrete core activation (heating and cooling system): With this system, heating pipes are integrated into the core of a concrete floor or ceiling, instead of the decking floor. This way, the thermally active mass of the floors is increased, and, in winter, the water keeps the concrete warm. This system provides heat to the top of the floor and bottom of the ceiling and is therefore also not suitable for multi-unit housing as residents are unable to regulate the temperature of their homes or measure their own energy consumption. This is the case even if they have an individual boiler. In single-family houses, the question is whether a system that keeps the temperature of the entire property at one temperature is desirable. Concrete core activation can be combined with LT-radiators to further reduce the return temperature (this is normally some degrees above room temperature). This is beneficial for heat pump efficiency, solar thermal systems and district heating. If the heating system also contains other delivery systems, such as radiators, the water temperature of the floor heating should be reduced. To achieve this, the water for the central heating system is mixed with the colder return water from the floor heating to reach the right temperature. A thermostatic valve ensures that this happens.

Fig. 1.7: Concrete core activation uses the accumulating capacity of concrete structures. The cooling and heating energy is saved in the concrete structure and supplied, if necessary, to the space that needs to be heated. With low temperature heating and high temperature cooling in houses, a rapid response system should always be applied to meet the varying comfort requirements of the residents. Source: VBI; prefab floor element with concrete core

Benefits

- Increased comfort: relatively high radiant heat and no 'cold' floor so that the air temperature is more evenly divided than with radiators or convectors
- Ease of connection to solar energy and heat pump systems: due to the low water temperature
- Increased energy savings: 3 to 5% compared to high temperature radiators (80-60°C). When using a heat pump or solar thermal energy system the savings can increase to 50% in comparison to LT radiators.
- Improved safety: due to a lack of visible radiators (hot, sharp edges)
- Reduced dust issues: lower air movements eliminate the spread and burning of dust
- Increased 'passive' cooling: when floor heating is combined with floating decking floor
- Improved sound insulation; when a floating floor is also used

Disadvantages

- Thicker (insulated) decking floor: normal decking floor is around 50 to 70mm thick
- Slower (modern) systems: particularly in terms of heating. In well-insulated houses where no night setback is required this should not be a problem
- Higher costs: compared to heating radiators
- Limited carpet choice (see below)
- Higher electricity consumption: due to an additional pump being required. To combat this, link the pump directly through the thermostat or the boiler, or apply a pump switch. With full floor heating, no additional pump is required
- Higher risk of legionella growth: due to the heating of integrated water pipes

Wall heating

A heated wall is based on the same principles as floor heating. In a wall, pipes are installed and hot water flows through them. The heated wall (maximum wall temperature of around 35°C) provides mainly radiant heat and must be extra insulated on the inside to prevent heat loss. Separating walls should be used as an insulated anchor-less cavity wall. The most common wall heating systems consist of stone elements, such as limestone or ceramic stone with plastic pipes embedded in the prefabricated slots. Lightweight systems are available, specifically for timber-frame constructions and existing buildings, for wall heating purposes. This form of heating is highly effective when combined with radiators, convectors and floor heating.

The advantages and disadvantages of thermal walls correspond roughly with those of floor heating. Some more specific comments are as follows:

- The energy saving is similar to floor heating, namely 5 to 10% compared to traditional radiator heating (80-60°C).
- Because of the generally large mass of a wall heating system, heating takes longer than with floor heating, but much is faster than concrete core activation.
- The choice of flooring is free. A disadvantage however is that freedom is somewhat restricted in terms of decorating the space as no more than 20% of the wall surface can be covered.
- During construction and occupation, residents must be careful with drilling holes. However, hoses in the wall can be felt by hand. Another option is to lightly spray the wall with water as the wall will dry faster where the hoses are placed.

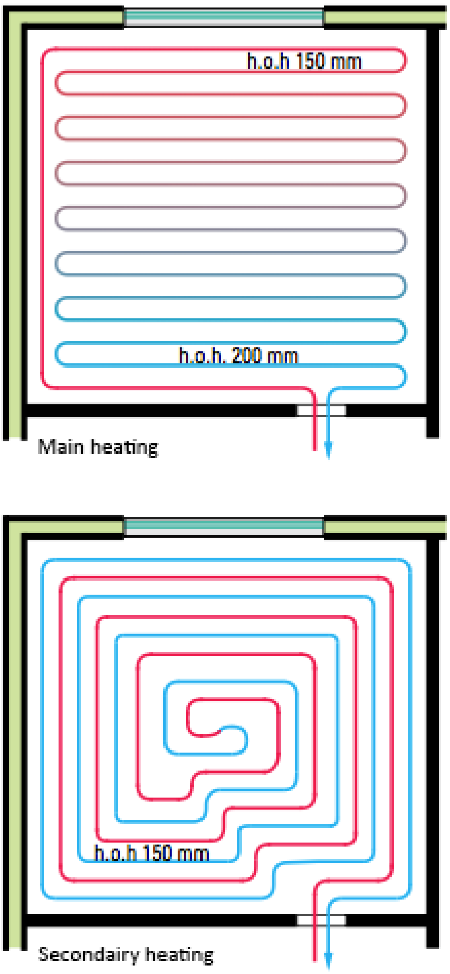

Fig. 1.8: Heating pipe laying patterns

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Fig. 1.9: Wall heating under construction. The prefabricated slots may run vertically or horizontally depending on the brand's elements. Horizontal systems have the advantage that they are easier to vent; a disadvantage is that the stones (the horizontal slots) are not used optimally in terms of carrying capacity

1.2.4 Air heating

Central air heating with balanced ventilation heats air in a heating coil and distributes it throughout the house via a duct system. Part of the air is then returned to the air heater, via a staircase well, hallway or duct, and reheated. The other part is distributed outside through the kitchen, bathroom and toilet. This causes an equally large amount of fresh outside air to be supplied at the same time and this is preheated through a heat recovery system from the exhaust ventilation air.

In effectively insulated houses, there is no need for air recirculation. Normal ventilation is sufficient even under the most extreme conditions. The 'passive-house' is based on this principle as the heating power, excluding ventilation losses but including infiltration and heating surcharges, may not be much higher than 2 kW.

Disadvantages

- Difficult zone control per room: multi-zone air heating controllability can be similar to that of radiator heating with thermostatic radiator valves
- No radiation contribution: requires the average air temperature at seat height to maintain comfort to be 1°C higher than radiator heating and 2°C higher than floor or wall heating. This also results in an higher energy use.
- Higher electricity use: total power is lower than for air heating with heat recovery even when water central heating systems are combined with balanced ventilation with heat recovery

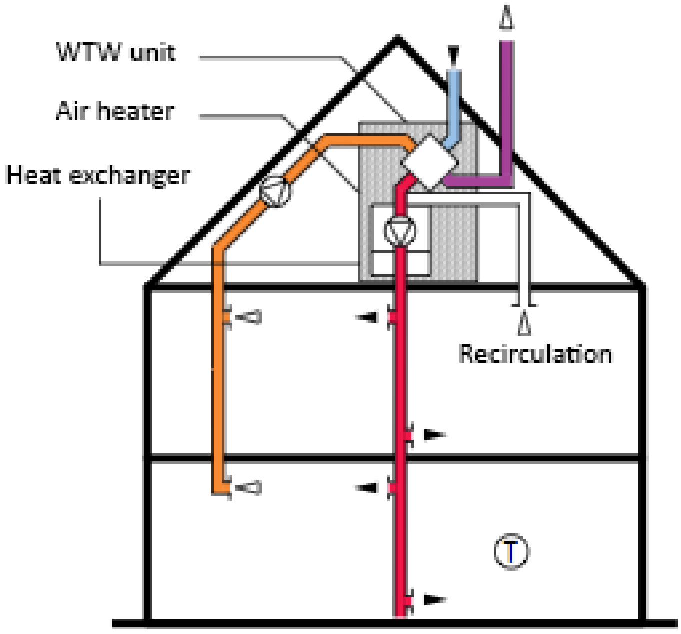


Fig. 1.10: The principle of the air heating system. The distance between the air inlet and façade may be 5 metres

Individual and collective

In low-rise housing, air heating only exists as an individual installation. In stacked constructions, air heating can be used both individually and collectively.

In a collective system (this can be a collective boiler or cascade formation of boilers with, for instance, an indirect fired air heater per house; further details later in this chapter) the heat recovery can take place collectively.

Number of zones

The number of zones in the system determines the controllability of the room temperature and whether or not the recirculation of air in the bedrooms is used. The one-zone system has one system for heat recovery in the air heater. All rooms are heated and ventilated with a mixture of re-circulated and fresh air. The air temperature in the living room determines the temperature in the rest of the house. According to Dutch regulations at least 50% of total ventilation air in the house must be fresh outdoor air.

Multi-zone systems are divided into two or more zones. For each one, a separate heat exchanger is present in the air heater. This ensures that in each area, the heating can be controlled independently to the other zones. The bedrooms are heated and ventilated with only fresh outside air.

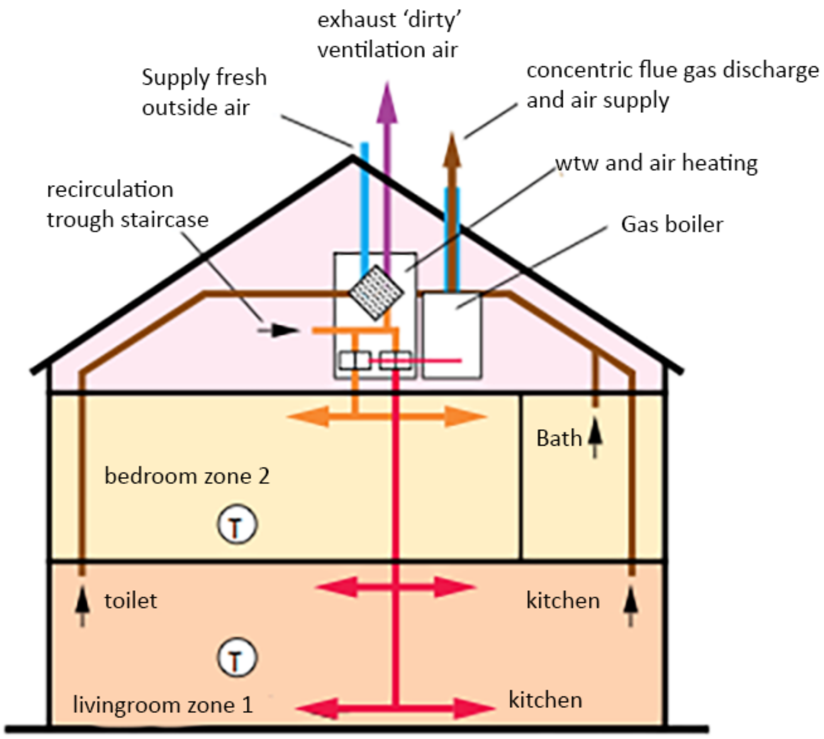


Fig. 1.11: Two-zone system (schematic diameter) in a house

Type of heat source

- In a directly-fired air heater, heat is generated within the device itself and immediately transferred into the air.
- In an indirectly fired air heater, hot water is fed into the heater from a central heating boiler through a heat exchanger. The heat is then transferred to the air of the air heating system.

Benefits

- The central heating boiler can also provide heat for non-heating water and possibly radiators.
- The indirectly fired air heater is less complex for a multi-zone system than the directly fired heater. Indirect fired air heaters, in particular, can be easily executed as a low temperature system. The heat exchanger should just be routed in such a way that at a relatively low temperature, sufficient heat can be distributed into the air.
- Direct-fired air heaters are available as a high efficiency system.

About the air heating system

The following points are of great importance for the comfort and operation of an air heating system:

- In most systems with air heating, the air is blown in centrally as all ducts and inlet grids are located centrally in the house (fig. 1.10). The length of the ducts remains limited as a result and the resistance is low.
- Ensure there is a good distribution of warm air into the room. Blowing air low into it will improve temperature distribution as warm air rises.

- Choose the right inlet grids or valves - there are many types available with specific properties - the injected air should not be colder than 16°C with induction grids or colder than 18°C with non-induction grids. Outside of the heating season, low air temperatures may occur.
- It is important that the air supply mixes quickly with the air in the room. In terms of high-inducing grids, the surface should contain small holes (or slots). In a highly turbulent grid, the outlet surface is also filled with small openings which are formed in such a way that the supply air gets into a state of turbulence.
- The air speed in the ducts should be 3 metres per second at the most due to the noise that is produced. To avoid noise complaints, the velocity, at the point where the supply outlets are, should meet the following maximum requirements:

- High inlet of hot air (via a high-inducing or high-turbulent grid): <2.0 m/s
- High inlet with unheated air (via a high-inducing or high-turbulent grid): <1.0 m/s
- Low inlet with hot air: <0.8 m/s
- Low inlet with unheated air: <0.4 m/s

- The ducts must have a smooth gradient. The less resistance there is the better, so there should be as few bends as possible and duct diameters should be large enough.
- Ducts in the crawl space are not an option as these would result in too much heat loss.
- Choose the location of the thermostat carefully. It should not, for example, be too close to a feeding grid, valve or door.
- Prevent noise caused by the installation by considering measures to reduce vibrations. Take an acoustic tube for each grid or supply valve, for example. In practice, noise tends to be given too little attention.

Architectural and spatial prerequisites

- The distance from the façade to the supply air grids or valves should be at least 6 metres.
- With regards to even air distribution, there should be no obstacles (such as furniture, cabinets, etc) near, or in front of, supply grids or valves.
- Due to recirculation, an opening of 3.5 centimetres must remain free at the bottom of an interior door (between the top concrete floor and lower door). About 2 inches is necessary, but the space required for flooring should be taken into account. Grids in, or alongside, the door are an alternative. These are also available in soundproof finishes.

Other points to consider:

- Provide clear verbal and written instructions to the resident. For example, write in a resident's handbook and provide a sticker on the air heater. When cleaning and changing the filters, the following require particular attention:

- Filters should be replaced at least twice a year.
- Filters should be cleaned at least once, using a vacuum cleaner, between these times.

- Regular maintenance of the full system is very important. Consider checking the settings of the grid or valves thoroughly and clean the entire heater (once a year) and the duct system (once every 8 years).
- The electricity consumption for fans can be high (up to 400 kWh or even 1000 kWh). Make sure energy-efficient (DC) fans are used and that resistance in the system is low (<100 Pa).

1.2.5 Local heating

For local heating, both the generating and release of heat take place in the same device. Examples of local heating techniques are wall- and gas heating and an electric radiant panel.

In existing buildings, local heating can bring atmosphere and additional heating, but in new buildings it can serve as the main heating. A single gas fire has enough power to heat a whole house and the proper insulation shell of a new compact building enables well-functioning heat distribution.

Benefits

- Fast responding and well regulated (if equipped with a thermostatic control): versions with a clock thermostat are now standard
- Efficient heating: stimulated by heating selectively as a resident can immediately see if the system is active
- No heat losses via pipes
- No use of electricity: a fan is not required with wall heaters and most gas fires
- Even heat during power breakdowns

Disadvantages

- Relatively low returns: multiple devices have several pilot flames that can easily be switched on and off with a remote control
- Separate water heating device is required

Wall heater

Using up to three devices, wall heaters are cheaper to buy than radiator heating and still provide a similar level of comfort. The disadvantage is that the drain for flue gases can cause problems near the façade of a building. The flue gases may cause direct discomfort, for instance, on a gallery or balcony, but also indirectly by mixing with ventilation air.

Wall heaters have a low full load efficiency, the upper value is 76%, and are completely sealed (air feed comes directly from outside).

Please note:
Allow sufficient room below the sill, and distance between the heater and curtains, to ensure that the heater does not become a fire hazard.

Gas hearth

Gas hearths with a mechanical air exhaust can only be applied in new buildings when a 'closed' type is used. Otherwise, the danger is that exhaust gases may be drawn into the house and cause under pressure. An open system can only be used if it has completely natural or hybrid ventilation (with flue gas exhaust) and so fully closed units are the norm for most manufacturers. These hearths are equipped with a concentric supply and drainage is common for central heating boilers. The outer tube diameter is generally 150mm and full load efficiency is a minimum of 76% at top value and 84% at low value. Higher values are also possible.

Please note:
There are now also fully open (atmospheric) devices on the market that have no flue gas exhaust. These discharge flue gases into the room that they are placed in and are very strongly discouraged due to the fact that they are a health hazard.

Electrical resistance heating

This type of heating consists of radiant panels or floor heating. It cannot be applied as main heating because the output of primary energy is too low. During the process of generating electricity at the electricity plant, and then during transportation, a great deal of energy is lost and only 39% of the energy that was originally generated can be used in the building. Electricity is also three times more expensive, per unit of heat, than natural gas. For occasional use electric (after) heating can be useful, such as when heating a bathroom for a short period using a radiant panel. Floor heating directly under the bathroom tiles are too slow for this purpose. When heating with renewable energy, the combination of PV panels (see chapter 10) and resistance heating is the least practical and most expensive choice. Direct use of solar energy has a two to three times higher return. It is recommended that a heat pump is used, together with the electrical circuit, for heating.

Tile stove

The tile stove was originally a very heavy stove that used wood as fuel. It was fired up for a short time and followed by a long period of warmth that was mainly generated by radiant heat. Today there are several types of stoves available, including gas fired tile stoves. Given the modern settlement pattern and well-insulated housing, a tile stove is not an obvious choice. It is, in fact, very slow and continues to provide heat for long periods of time, even if it is not required. One advantage of a tile stove is that the surface never gets too hot.

Wood stoves

Wood stoves are light, generally made of steel and do not have the disadvantages that the tile stove does as they generally have a very good return. Note that a separate combustion air supply is created which is opened simultaneously with the flue gas flap from the stove, otherwise the mechanical ventilation may suck gas into the house. A wood stove needs continuous supervision and wood supply. It is common to have a year's supply of wood use in stock. To indicate: 1000m^3 of gas equates to 2000kg or 13m^3 of wood. There are also pellet (pieces of compressed sawdust) stoves for sale that are fully automatic. The storage is more compact as 1000m^3 of gas equates 10m^3 of pellets.

A disadvantage of wood stoves is that the exterior may become very hot, increasing the risk of skin burns and burning dust.

Fireplace and 'multi-burner'

The application of a fireplace or an 'incinerator' should be strongly discouraged given the environmental problems that they cause. Examples of this are odour nuisance and the emission of harmful materials in housing and its' surroundings. In addition, both devices generally interfere with the heating and ventilation systems that operate in addition to them. It is a better alternative to choose a gas stove.

1.2.6 Distribution and regulation

Afb. 123

Fig. 1.12: Commissioning arrangements with a distributor and valves

Pipe system

The pipes between the delivery elements and the generation system can be applied as a single or a two-pipe system. This is the most common system and more effective than the one pipe version. In the two-pipe system, every radiator (or coil) is directly connected to both the feed and the return line, resulting in the temperature of the supplied water being right for each radiator. This contrasts with the one pipe system, where the radiators are connected in series and the final radiator is the coldest. Another distinction is that of piping with and without dividers:

- With divider: Separate lines, (normally plastic hoses) lead to all radiators from one or two central points. This system is generally installed in new buildings for floor and wall heating. It is possible to adjust the divider centrally for floor and wall heating. This is also useful for radiators and convectors (fig. 1.12).
- Without distributor: A network is constructed out of the heat system and branches off to the radiators or convectors.

Afb. 122

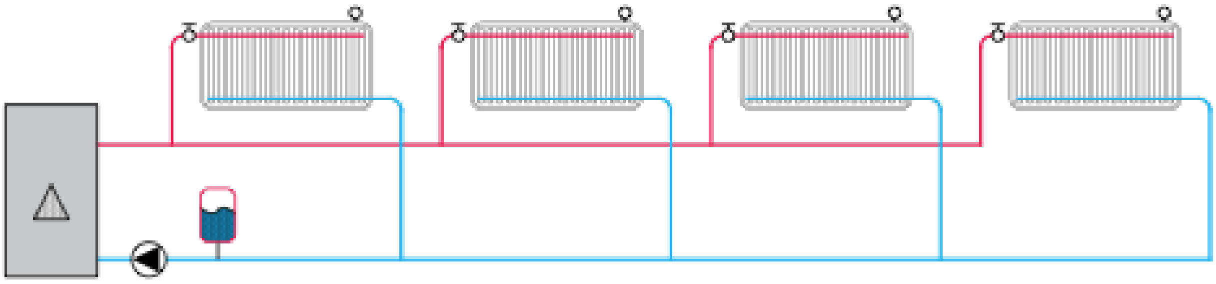


Fig. 1.13: The two pipe system

Pipe insulation

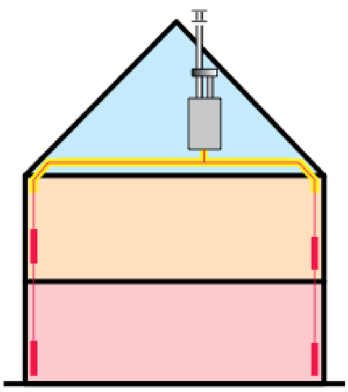
It is necessary, and easy, to insulate heating pipes in:

- storage rooms and lofts
- barely heated or unheated rooms, like a corridor.

	Duct diameter				
	12 mm	15 mm	22 mm	28 mm	35 mm
Thickness duct insulation					
9 mm	4	5	8	10	13
20 mm	5	6	10	12	15
30 mm	6	7	11	14	17
					m^3 gas

Fig. 1.14: Gross reduction of heat loss per metre of pipe when relevant pipes in a central heating system are insulated, compared to those without insulation, in m^3 of natural gas per year.

Afb. 125



Afb. 126

Fig. 1.15: The insulation of the central heating pipes in the loft of the sample 'garden room house' saves around 80 m^3 of natural gas per year

Fig. 1.16: Pipe insulation remains intact in this bracket. Photo: Walraven BV in Mijdrecht

The heat loss per metre of insulated pipe depends on the:

- temperature difference between the central heating water and the space that the pipe runs through
- diameter of the pipe
- thickness and type of pipe insulation
- completeness of the insulation on the brackets and interruptions.

The savings made as a result of pipe insulation can be calculated using fig. 1.14. Below is an example of this (note that the net reduction in energy consumption through pipe insulation is lower than the values provided in fig. 1.14, due to the heat loss partially benefiting the house's heating):

- 25 metres of insulated heating pipes in the loft
- unheated loft (10 ° C)
- 22mm diameter and 20mm thick insulation

The effect of no insulation:
According to fig. 1.14, the gross energy use rises by 25 x 10 = 250 m^3 per year. An estimated one third of this increase benefits the house's space heating. The net energy use increases along with the rest; this is approximately 80 m^3 of natural gas per year.

Please note:

- Ensure that valves, bends, connectors etc. are properly insulated.
- Provide insulation where pipes pass through walls and floors.
- Ideally, attach brackets around the pipe insulation (fig. 1.16).

Regulation

The heat supply to the rooms can be regulated in various ways:

- A room or space thermostat: Water or air is heated and then supplied to the distribution system. If the temperature in the main room (where the thermostat is attached) reaches the adjusted temperature, it will turn off the boiler. The installation is basically designed so that when the main space reaches the desired temperature, this temperature will be constant in the remaining areas. It is not possible to heat the other spaces when there is no heat demand in the main room. The circulation pump only runs when the thermostat asks for heat with a limited overrun time.
- A weather-dependent regulation system: With this system, the supply temperature of the water or air is regulated based on the outside temperature and according to a heating curve. All spaces are heated independently of each other and the circulation pump basically runs continuously, which is a waste of electricity (around 350 kWh of additional energy use). Some manufacturers have found a solution to this and it is recommended relevant information on this issue is viewed.

In both cases, a thermostatic control, or normal valve on the delivery system, can readjust the temperature of the room. However, this generally results in a lower temperature than is desired.

A room thermostat can either be adjusted manually or by a computer (digital) clock that regulates the desired temperature based on a one-day or week program. The digital (self-thinking) thermostat is pre-programmed to determine the times that the boiler needs to be switched on and off, based on the heating and cooling rate, to maintain the desired temperature. The heating rate is monitored over a number of days. A modulating boiler requires an identical thermostat to ensure the boiler is effectively regulated.

Considerations:

- A room thermostat needs to display the correct temperature, so ensure that it is not affected by solar radiation, or radiation from lamps or equipment. Also ensure that the thermostat is not influenced too much by the opening and closing of doors in the room.
- There should not be any thermostatic radiator valves attached to the radiators in the room where the thermostat is installed, otherwise the correct temperature will not be reached because the radiator valves will stop the heat distribution. The room thermostat will still ask for heat, which will turn the boiler on time after time.
- Consistent regulation of the room temperature will prevent temperatures that are too high, improving comfort and lowering energy costs.
- With floor and wall heating in particular, the system and pumps' power consumption can increase due to the reserved consumption and the pump not being turning off when it is not needed.

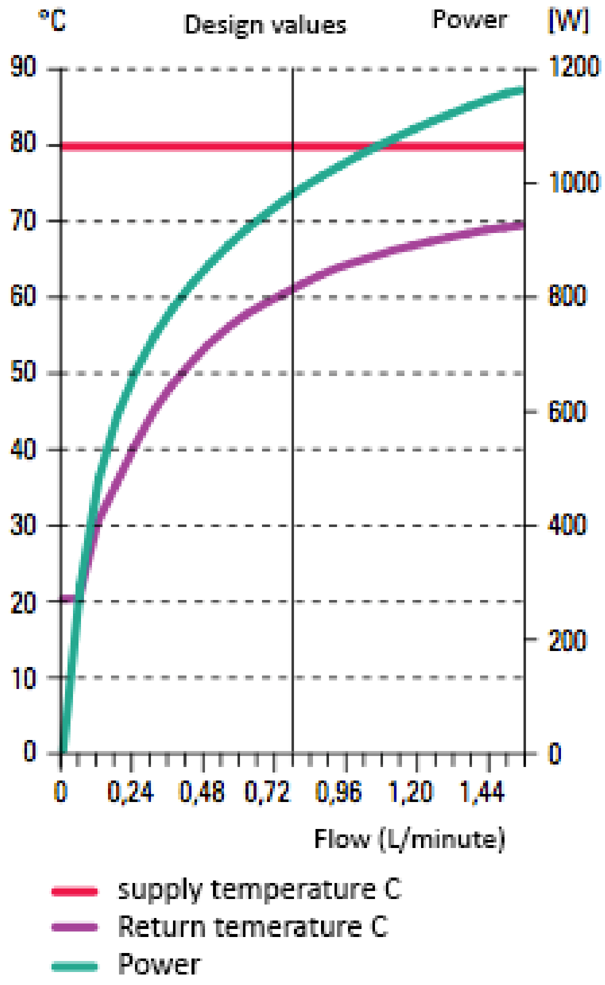


Fig. 1.17: By reducing the water flow, the temperature of the outgoing water will decrease. The average temperature then becomes lower and the residual power also reduces. The power demand decreases linearly to zero when the flow speed becomes so low that the output water has reached the room temperature (breaking point)

Regulation

An optimal flow is needed through the radiators or hoses in the floor or wall to provide every room with the right amount of heat. The temperature in the radiator may differ (known as Delta-T) in accordance with the installation design. For this optimal flow to occur, the installation needs to be calibrated through a water adjustment process. To achieve this, the water flow to every radiator or hose from the foot- or radiator valve needs to be set in conjunction with the divider. If there is too large or too small a flow, the radiator will deliver the optimal amount of heat (fig. 1.17). Therefore, always provide a delivery system with regulating valves to ensure that the hot water is evenly distributed over the total heating system.

The lack of regulation is likely to lead to complaints because some rooms will be hot and others will not receive any heat at all. This situation may eventually lead to higher energy use (for the pump and gas consumption of the boiler) and a lower comfort level.

1.3 Heat generation

Heat generation can be done in multiple ways.

1.3.1 Central heating boiler

Central heating boilers can be divided into the following categories:

- Open or sealed
- Combined, or not combined, with tap water heating (combi boiler)
- Efficiency
- Regulation type
- Combined with heat pump
- Combined with electricity (HRe boiler)

Open and sealed boilers

- A sealed boiler supplies combustion air from outside via an air fan and the air supply and flue gas discharge ducts can be combined. However, the length is limited due the fan's capacity.
- An open boiler extracts combustion air from the room where the boiler is installed. As it only has a flue gas drain, provisions should be made for non-lockable ventilation. Open boilers are no longer installed in new buildings.

Please note:

- The area that the boiler is to be installed in must be carefully chosen in relation to noise requirements.
- Central heating boilers not only use electricity for the fan (for sealed boilers, approximately 30 to 70 kWh per year) but they also use it to power the regulation electronics. This is around 20 to 80 kWh per year. The pump uses, based on a pump adjustment, around 75 to 150 kWh per year depending of the resistance of the rest of the installation and the type of pump. In a weather-dependent system, the pump can use up to 500 kWh. This results in a total annual energy use of 120 to 650 kWh. Boilers are tested with regards to this energy use, so, ideally, a boiler with low energy consumption should be chosen.

In a stacked building, individual devices are generally connected to a combined air supply and flue gas drain system, called a CLV system (fig. 1.18). This should be equipped with a fan that has the right discharge head (see manufacturers' instructions). This duct can be implemented as a concentric or parallel outlet/inlet duct. Under specific conditions, the air can be extracted from the façade so that only the drain is connected to the CLV system.

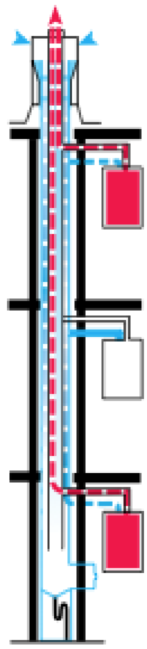


Fig. 1.18: An example of a CLV (flue gas drain) system

1.3.2. Combi boilers

A combi boiler provides both space- and tap water heating. It is important that it is placed in such a way that the pipes for the hot tap water are as short as possible, particularly those near to the kitchen. Should there be a simultaneous heat demand for heating and hot tap water, the latter has priority. The device has a separate setting for the water temperature of the tap water and the water for space heating.

The return can be explained in different ways [practical use of energy/total energy input into the fuel x 100%] and is determined under various conditions. The terms 'return on under value' and 'return on upper value', can particularly cause confusion. Because the use of the 'upper value' is more comprehensible (no values over 100%), for the sake of this section, returns are described using both methods.

It is common practice to measure and display the efficiency of a gas boiler in the following ways:

- Water-side: The actual transferred heat to the central heating water is taken into account.
- At full load: The boiler is continuously in full throttle during measurement and the average water temperature is maintained at 70°C (feed 80°C, 60°C return).
- At part load: For a high-efficiency boiler, the return is measured with a return water temperature of 30°C and a gas supply of 30%. Under these conditions, the condensation heat is used optimally.
- Compared with the calorific under value of fuel: The heat is released directly while the combustion process is being counted.
- By the return on upper value: The heat released during the condensation of water vapour in the flue gas is included, unlike with the return on under value. High-efficiency boilers make proper use of this condensation heat. The result is that the boiler has returns of above 100%, based on the under value and the return in upper value corresponds to 0.9 times this.
- By the annual return: The return over an entire year is important when calculating energy use. In this return, the standby losses are also included.

Benefits

- Inexpensive
- Less supporting energy required than supplying heating and water separately
- Less space needed

Disadvantages

- Moderate return on heating tap water: heating unit needs to maintain the right temperature
- Extended waiting times for hot water provision
- Limited modulation range to function as an after burner for a solar boiler or solar heating: minimum energy use should therefore be around 2 kW

Return

The efficiency of a boiler indicates the amount of energy that has been put in as fuel and is then actually released as heat. A distinction is made between high-efficiency boilers and improved-efficiency boilers. Conventional boilers are no longer applied.

High-efficiency boilers

In a boiler with a large- or extra heat exchanger, combustion gases are cooled until condensation occurs and the heat produced by the process is also used. In LT-heating, the effect of condensation is used optimally. Only high-efficiency boilers are installed in new buildings.

Features

- The average efficiency is 90% to 97.5% in upper value use. A division is normally made into further categories. For instance, a distinction is made between the installation of the boiler with high or low temperature systems and with water central heating or (direct fired) air heating.
- Many features are standard, such as:
    - an electronic ignition
    - a pump control
    - a closed combustion chamber
    - a certificate for clean combustion.
- A corrosion resistant condensate drain is required on the sewer.
- These boilers cannot be connected to a brick chimney unless it has a jacket.

On/off control

Boilers with an on/off control feature a burner that comes into full operation as soon as there is a heat demand. Afterwards, it is turned down completely. Most non-modulating boilers have an adjustable capacity of around 8 kW for space heating and this is generally too much to heat a well-insulated home. As a result, these boilers are rarely used anymore. Tap water demand varies so much with combi boilers that modulating is necessary anyway.

Modulating control

A modulating boiler continuously adjusts its capacity to the actual heat demand at any time. If a lot of heat is required, the boiler will use its maximum power. When the heat demand is less, the boiler only uses part of its capacity and provides less heat. Modern boilers usually modulate smoothly from a certain capacity level.

Benefits

- More comfort due to a more constant temperatures
- Energy saving due to less risk of unnecessary heat
- Longer life of burner

At an outside temperature of -10°C a new building only needs 5 or 6 kW, or even less in really energy-efficient homes. With higher outside temperatures, 1 kW is generally sufficient. This means that a boiler with the widest possible modulation range for space- and tap water heating should be used. Note that the minimum capacity should not be greater than the maximum demand at -10 ° C and so an identical clock or room thermostat should be used to that of the modulating boiler. This will usually be one that is provided by the boiler manufacturer or an ’open therm’ thermostat (this represents a universal language in communication regarding central heating boilers and thermostats). This ensures that the advantages that these boilers provide are optimised.

Boiler capacity and thermal mass of the system

If the boiler has a large minimum capacity and a low mass (water content or thermal mass of a floor or wall), there is a risk that the boiler will turn on and off in short intervals. This increases the energy consumption and reduces the life span of the boiler. A provision is included in most boilers to diminish this effect in that the mass of the floor or wall heating prevents the boiler from switching on and off unnecessarily.

Boiler heat pump combinations

A new generation of boilers has recently appeared on the market. These are central heating boilers, consisting of a gas boiler combined with an integrated heat pump that provide basic heat demand and trigger the combustion zone for peak demand. This is also the case for heat pumps that use outside air or ventilation air sources.

Electricity-generating boiler

Field tests were conducted with a boiler that also generates electricity (micro CHP). The advantage of such a boiler is that the total yield (95% upper value) is much higher than for a separate production of heat (95% upper value) and electricity (39% upper value) or a traditional CHP (85% upper value). Also, the power distribution losses of heat and electricity are negligible. The models that are now under construction provide some 5 kW of heat and 1 kW of electricity. They also provide approximately 20 kW of peak heat power. These devices need to be used intensively to return the extra investment, similar to gas use of above 1300 m^3/year. For efficient new buildings this is not generally the case. Note the weight and (relatively high) noise production of these devices.

1.3.3 Heat pump

A heat pump is a device that converts low temperature heat (for instance ground water of 10°C) into a higher temperature that can be used for space heating and hot tap water. For this to work, a relatively small amount of electricity is supplied to the heat pump compressor. Its efficiency is expressed in the form of its COP (coefficient of performance). The efficiency of this generator is in the region of 4 to 5 (fig. 1.19).

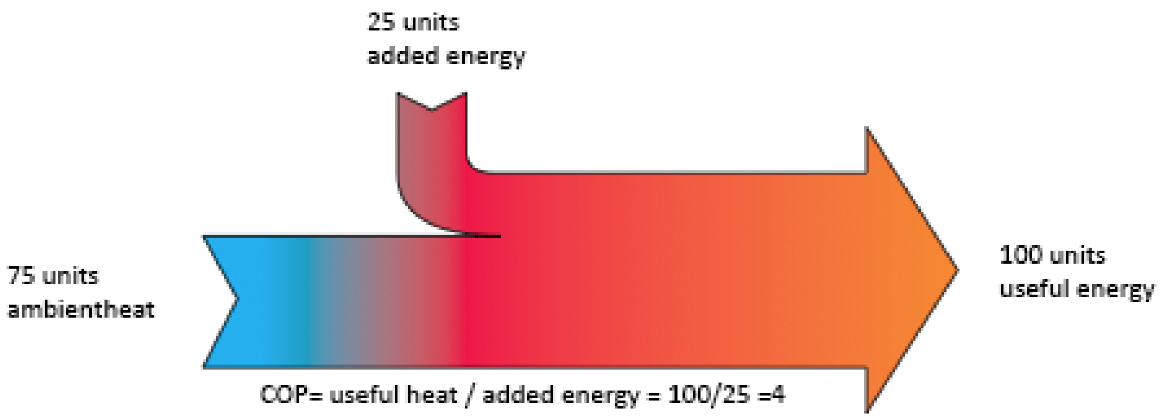


Fig. 1.19: The COP = 4. This means that the heat pump provides four times more heat (kWh thermal) than the device uses as electrical energy (kWh electric). Besides 25% electrical energy, 75% renewable ambient energy is used for heating buildings

Taking the efficiency of electricity generation (39%) into account, a heat pump provides an efficiency of 130 to 180% on primary energy. There are also gas-fuelled heat pumps that have a COP of 1.3 to 1.8. Heat pumps make a significant contribution to the reduction of energy performance.

A system with heat pumps consists of:

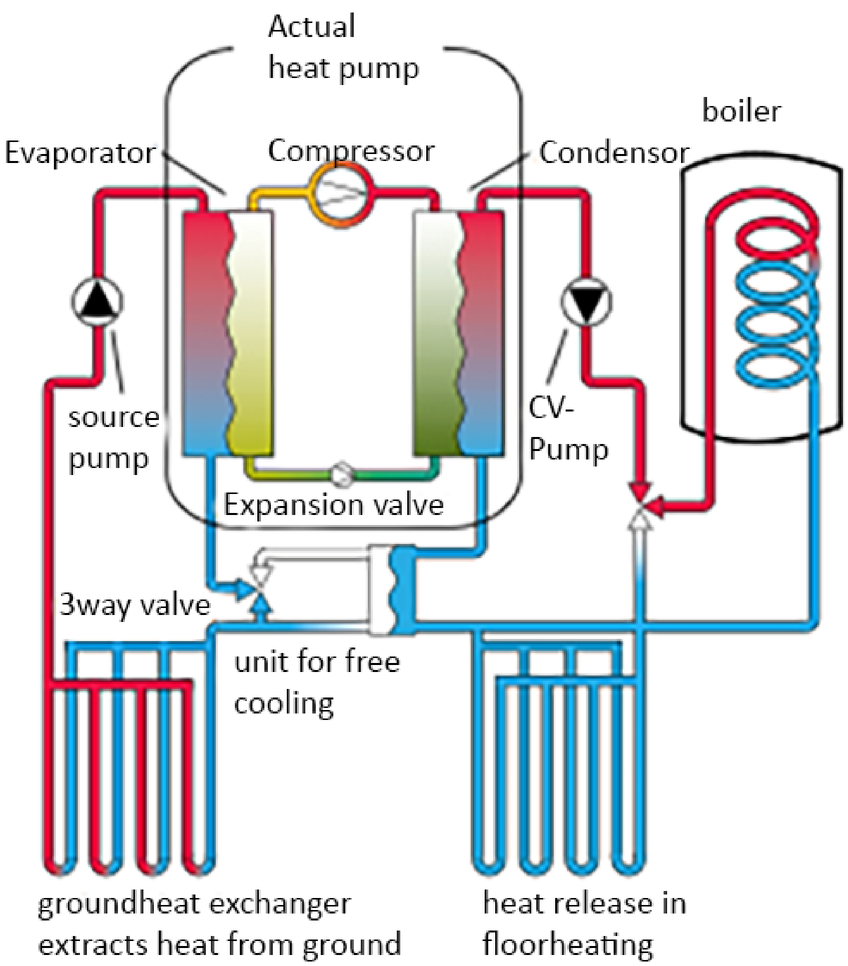


Fig. 1.20: The principle of the heat pump: Heat is extracted from the source and into the evaporator. Heat is released into the condenser at a higher temperature level. Source: www.inventum.nl

Source

Sources from which energy can be withdrawn include:

- ventilation air: The capacity of heat from ventilation air is limited. For space heating, ventilation air sourced from a building is usually insufficient. This source is however relevant when heating tap water ground: This is through a vertical or horizontal ground heat exchanger that consists of one or more U-loops. Horizontal systems are positioned at a depth of approximately 1 to 3 metres and require a significant land surface. In the Netherlands, this amount of surface area is not usually available. Vertical ground heat exchangers are installed deep into the ground (up to around 100m) and are inserted by probing or drilling. Piles can also fulfil the function of ground heat exchanges and contain plastic pipes that fluid flows through.
- groundwater: The temperature level of groundwater, in deep layers of sand at a depth of 50 to 150m, reaches around 12°C during the course of a year. Before the groundwater can be used, a source system (using a withdrawal- and an injection source) must be constructed to extract it from a deep aquifer. A heat exchanger must be placed between the groundwater and heat pump to prevent pollution. Groundwater is generally aggressive as it has an almost constant temperature during all seasons. The COP of the heat pump will therefore be relatively stable
- surface water: Any sufficient surface water can be a classed as source, such as a river, lake or sea, or, for smaller projects, a pond that is nearby the project. Note that the withdrawal should take place so deep that it does not freeze and other life in the sediment is not disturbed.

- outdoor: This uses a fan that sucks air through a heat exchanger. One disadvantage is that this energy source is counter-cyclical as the greatest heat demand occurs when the outdoor temperature is low. This has a negative effect on the COP and the return is significantly lower than with a ground exchanger or groundwater. Also, the consumption of the fan is usually considerable due to the level of noise it produces. This makes it an unviable option for new buildings.
- roof collectors (of energy) or asphalt (in the road or a car park). These collectors extract heat from the air to power solar heating. These sources are primarily used for regeneration purposes in addition to vertical ground exchangers or groundwater to recharge the ground in the summer
- waste heat: This can be obtained from internal or external sources Internal sources include exhaust air from ventilation or sewage systems. Externally, residual heat from industrial processes or power plants, or cooling from nearby buildings, are used.

The appropriateness of a source depends on:

- its temperature and heat transfer characteristics
- its availability, both in terms of geography and time
- its size and complexity requirements to harness the source
- the cost of investment, maintenance and operation.

Efficient sources, such as groundwater or the ground itself are relatively expensive for individual installations because of the significant set-up costs and requirements. The collective (for several individual heat pumps), or simultaneous, use of such sources is generally advantageous in larger projects. Distribution piping does not need to be insulated given the source's low temperatures of around 10-12 ° C.

A heat pump with a small capacity is usually used to reduce costs,. The result is that a buffer, or additional conventional heating, is necessary to cover the peaks in heat demand. Electrical resistance heating is fundamentally wrong as it consumes a great deal of energy. There are electric heat pumps with additional gas-fired heating on the market. Regulation and monitoring are required to ensure efficient operation and not all providers meet this requirement. The return is higher when the temperature difference between the used- (source) and produced heat (release) is lower. The use of heat pump system for space heating therefore requires an LT delivery system.

Regeneration

Extracting heat from the ground eventually results in a drop in temperature that decreases the efficiency of the heat pump. The temperature of the ground should therefore be balanced over a year. Should more than 10 m^3 of heat per hour be extracted from the groundwater; local authorities have the ability to impose requirements for the thermal balance of the ground. As much heat should be injected as extracted over a period of several years,

It may therefore be necessary to complement heat-removal by injecting heat back into the ground (ground regeneration). In the summer this can be done by:

- space cooling (free cooling)
- solar collectors: During the summer, collectors absorb heat that is stored in the ground for the long-term. This heat can then be utilised by the heat pump in winter. The collectors that are available for this purpose are much cheaper than those for heating tap water. Options include asphalt or roof collectors that are integrated under a flat roof
- surface water: This is heated in the summer and can also contribute to the regeneration of the source. The surface water cools down slightly through this process.

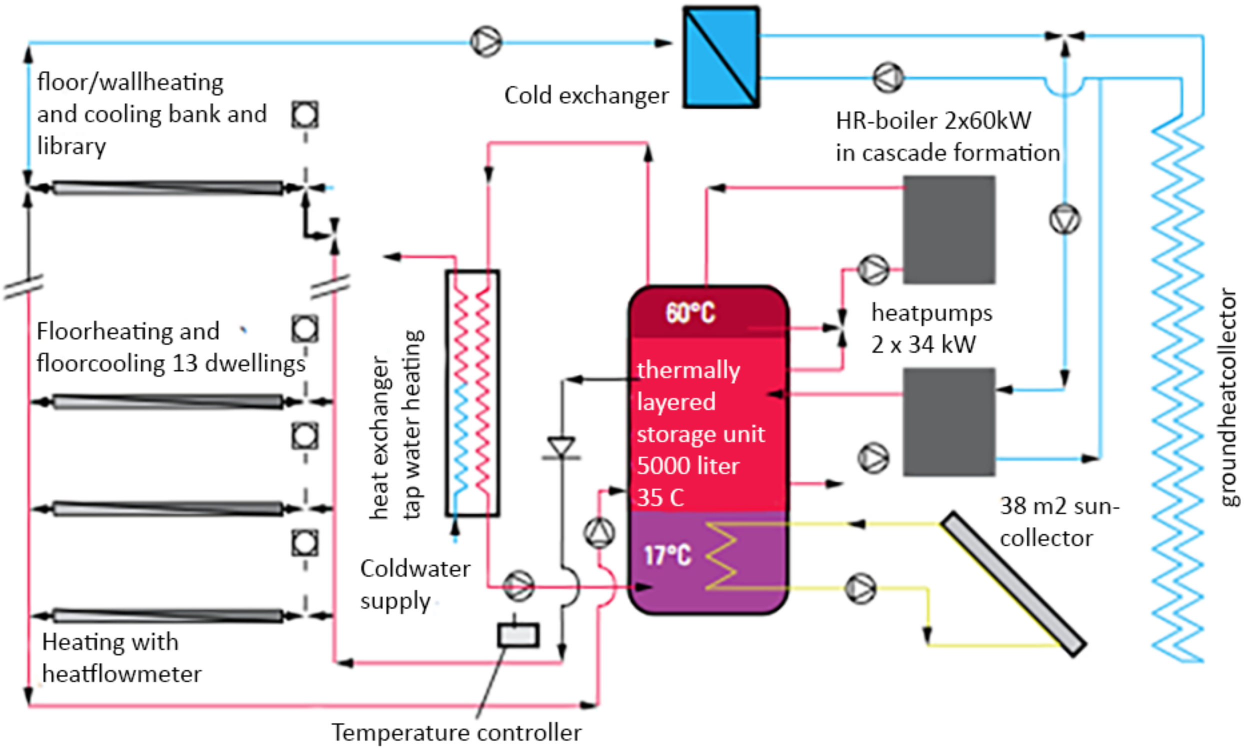


Fig. 1.21: Overview of the heating and cooling the system for the sample project Rabobank Pey-Posterholt in Echt, the Netherlands. The project included a bank, library and thirteen houses. A collective installation is used for space and water heating (and cooling) with two heat pumps extracting heat from the ground or from the cooling of the bank. The heat pumps supply this heat to a storage tank of 5m^3. The solar collectors (approx. 40 m^2) give off heat to this (buffer) tank. And any additional heating capacity is provided by two boilers that also heat the tap water. The bank and library use floor and wall heating; the houses have floor heating. The floor and wall heating is also used for the release of cold air. This is extracted from the ground or comes from the heat pump (if it produces heat). Client: Rabobank, Architect: Architects Keulers, Schrijen Coonen, advisor: Maastricht-BOOM Built in: 1999

Electric (compression) heat pump

For electric heat pumps, a COP minimum of 3 is required to save primary energy in comparison to a gas boiler and a COP of 4 is needed to reach net CO_2 savings. This is a result of relatively low electricity production efficiency (EPN: 39% value) and the high usage of coal. The COP is very sensitive to the source temperature and delivery system. It is necessary for low temperature systems to work at a temperature below 45°C, although the source temperature should not be too low. The source must have a large capacity as up to 80% of the delivered heat is extracted from it. Electric heat pumps are available in a range of sizes, from small capacities, suitable for the base load in a single house, to large capacities that are for use with collective systems. A compression heat pump is a mechanical device, so it is important to give some attention to noise production.

Gas (absorption) heat pump

The gas-fired absorption heat pump requires a source with only a small capacity that is up to 40% of the delivered heat. If the temperature of the source goes down, the total return decreases. However, it should never go lower than the return of the best HR-boiler. This is also the case for the output temperature, which should not be higher than 70°C. Absorption heat pumps can be extremely quiet due to the lack of rotating parts. A special version of a gas heat pump is the gas engine heat pump, which is a combination of a gas- and compression heat pump. This looks like a 'black box' and has almost all of the same features as the gas absorption pump, apart from the level of noise it generates. To combat this, a separate installation room with effective acoustic insulation is required. Systems with up to 40 kW of power have been on sale for a number of years, which are suitable for the heating of at least ten homes.

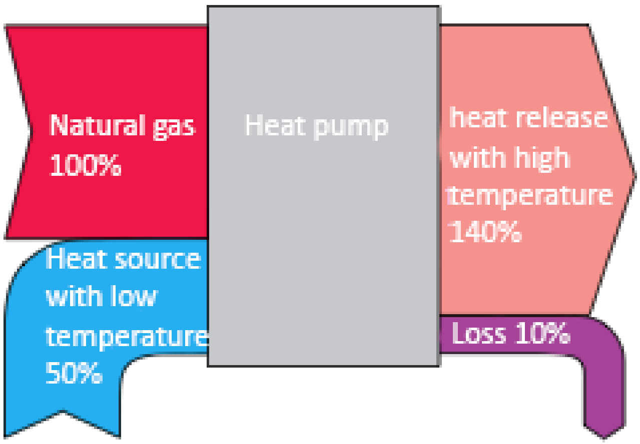


Fig. 1.22: Sankey diagram of a gas heat pump

One of the benefits of an individual heat pump is that it provides extra comfort in the summer without much additional energy use. This is due to the option of free cooling (only the source pump should rotate).

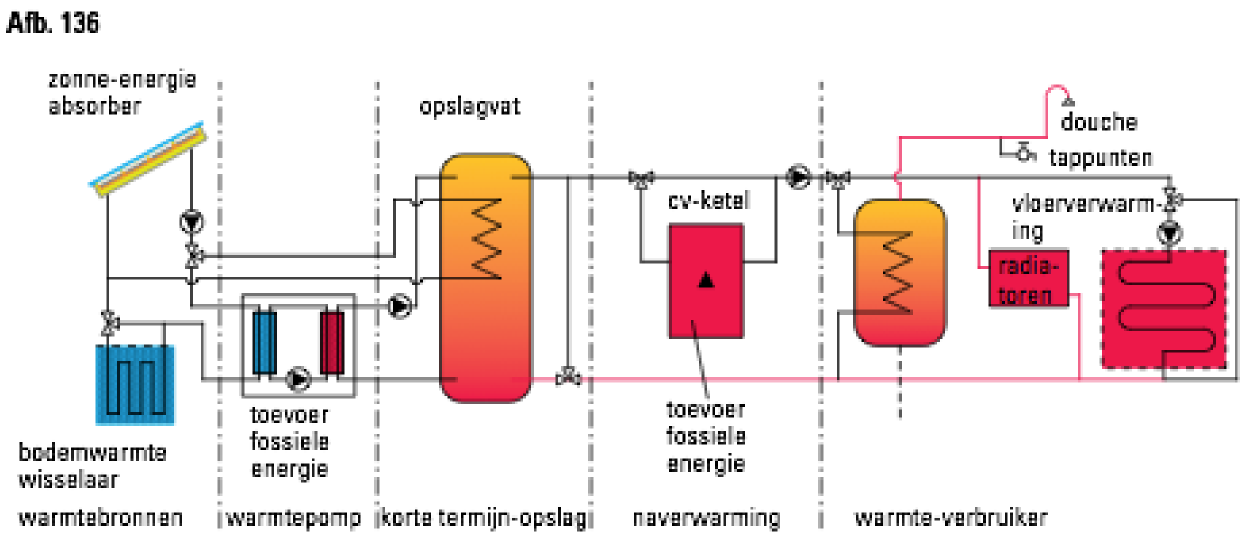


Fig. 1.23: Application of a heat pump combined with other equipment
Vocabulary:
Zonne-energie absorber: solar energy absorber
Bodemwarmtewisselaar: ground heat exchanger
Warmtepomp: heat pump
Korte termijn opslag: short-term storage
Opslagvat: storage vessel
Naverwarming: reheat
Warmte-verbruiker: heat user
CV-boiler: Central heating boiler
Toevoer fossiele energie: supply fossil energy
Douche tappunten: shower taps
Vloerverwarming: floor heating
Radiatoren: radiators

Chapter 2 provides more information about heat pump systems.

1.3.4 Combined heat and power (CHP)

CHP is the name for the use of heat that is released when electricity is generated for heating purposes. The fuel savings can rise to approximately 30% compared with the energy use for generating these separately (fig. 1.24). CHP or 'cogeneration' has, so far, almost exclusively applied to collective systems. The micro CHP boiler is likely to change this in the near future.

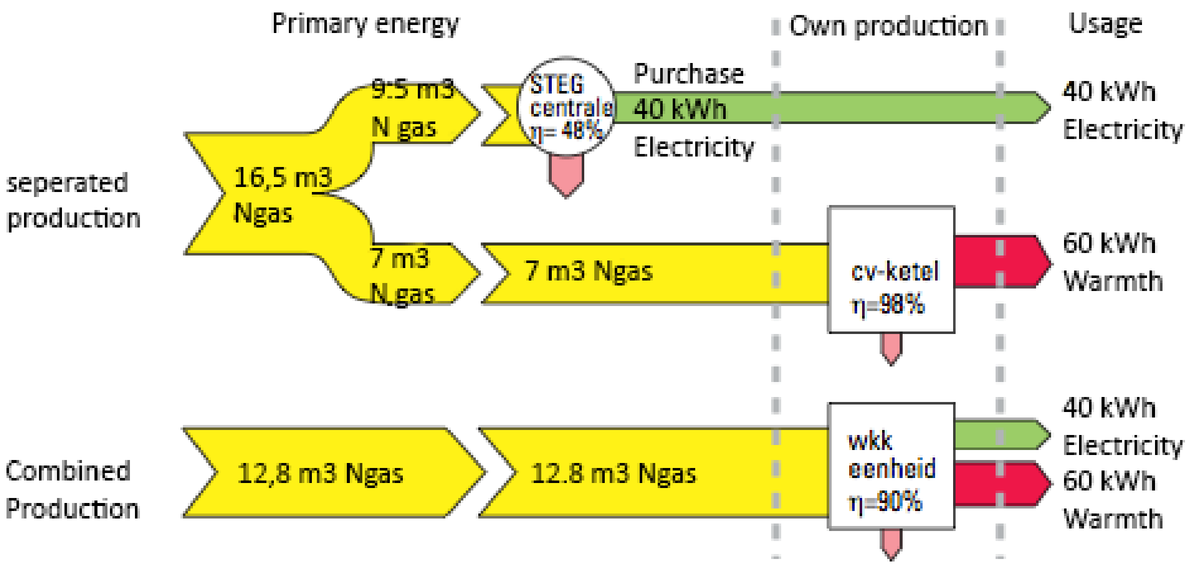


Fig. 1.24: Change in primary energy consumption between a separated and combined production of heat and electricity

There is a distinction between the electric- and total return. To compete with modern high-efficiency boilers and power plants, the total return must be as high as possible (> 90% upper value). The electric return for each type of CHP is more or less fixed. Adding an additional flue gas cooler and/or heat exchanger, that cools the room rather than using outside air, can generally improve the total return.

CHP feasibility

Depending on the number of houses there are, several types of CHP are an option. A mini-CHP with an electric power of 5 kW is suitable for use with a minimum group of 20 houses and its electrical efficiency will be 25% (upper value). The CHP is operated on a block-level. Large CHP gas plants have 150 kW to 5,000 kW or more of electrical power, or around 260 kW of thermal power. These are suitable for projects with at least 200 houses although a minimum of 300 houses is preferable. The electric return should be 34% to> 45% upper value depending on its size.

Gas turbines also exist for use in large residential projects (e.g. 4000 houses). The electrical efficiency of these is around 34% upper value.

Both gas motors and turbines have the disadvantage of emitting large amounts of nitrogen oxide (NOx). Gas turbines emit three times, and motors seven times, as much NOx as an HR-boiler where gas is directly converted into heat and electricity in a single fuel cell. This results in an electrical efficiency of 44% (upper value) and a 90% total return, as well as there being negligible NOx emissions and a very quiet system.

Very high electrical returns of up to 50% on top value, and low NOx emissions, are achieved with a combination of a steam generator and gas turbine (STAG). This efficiency drops, however, if heat is removed. The total return therefore remains at 80% and this percentage has not yet been lowered by the loss of the distribution. The capabilities of these plants are high, with a minimum of 200 MW, resulting in a large number of connections being required (about 20,000 homes). It is unfortunately still too much of a financial risk to develop the large-scale distribution system that is required for these plants to be a success.

Small-scale distribution systems with smaller CHP plants are therefore more relevant, partly because they can be connected to a STAG-plant later when the distribution network has been built up and the old CHP's have completely worn-down.

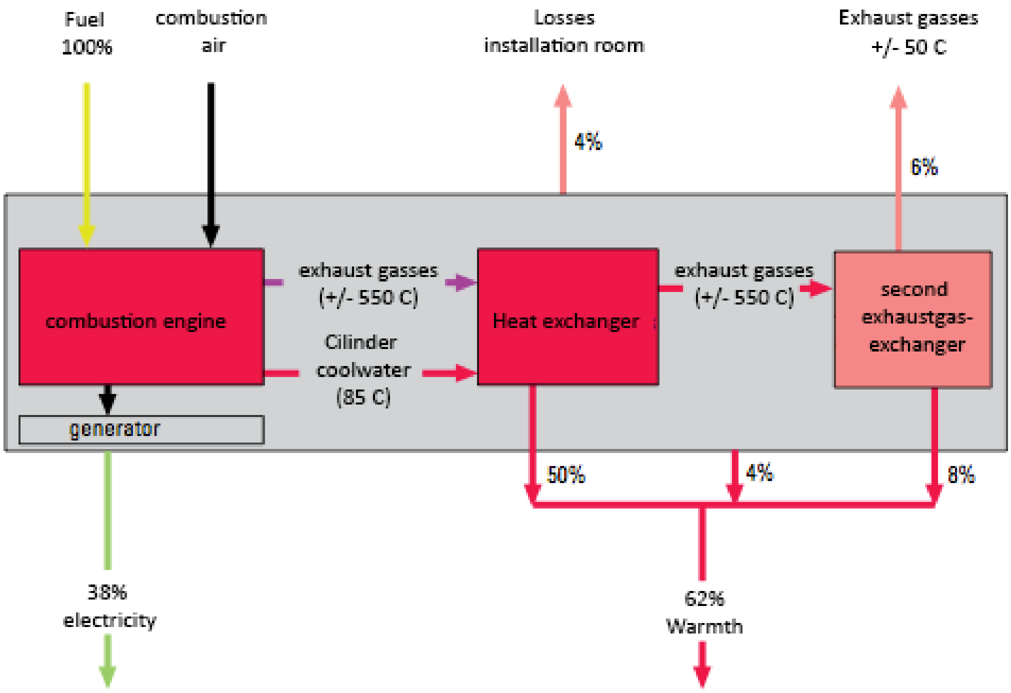


Fig. 1.25: Working principle of a cogeneration unit. Returns at under value

CHP management

The operation of a CHP plant can generally take place in conjunction with an energy company or other management business. This company will buy the electricity and transport the heat to the houses. Should an energy company offer a deduction on heat costs, this will benefit the residents.

1.3.5 Biomass boiler

These boilers function by burning biomass, such as:

- wood blocks: This is a cheap fuel, but it requires a lot of work so is an acquired taste. With a 'gasification' boiler, the combustion is reasonably clean and its performance is comparable with an increased return gas boiler
- wood chips: a maintenance department can usually deliver these, generally from local source which is an attractive option. These boilers also function fully automatically although a large supply is required to keep them running (1m^3 of wood chips has the calorific value of 80m^3 of gas). A disadvantage is that wood chips need to dry out for at least a year; wet chips do burn, but they cause pollution and have poor returns
- wood pellets: These are compressed sawdust pellets of 5 to 15mm. The systems are highly automated and require low investment. Very high returns are possible as the pellets are an instant fuel. However, as pellets are not produced in all parts of Europe, for some countries, the price has to include the cost of oil required to import them
- liquid biomass (e.g. cooking/canola oil): This type of fuel can be used in normal oil boilers with a customised burner. It is doubtful whether this fuel, which is essentially scarce, can be better used for cogeneration or transportation.

The investment required to set-up a biomass plant is high, but the operating costs are generally low. Flue gases are dirtier than those produced by natural gas. They also require more maintenance than we are used to with gas installations. Biomass is a renewable fuel because the CO_2 that is released during combustion is restricted by the plant that the biomass originates from. It is not 100% sustainable because processing and transportation require the burning of fossil fuel (think of fertiliser as well). It is generally proposed that biomass is 80% sustainable, although there are types of biomass with a strong negative impact such as palm oil, as tropical rain forests are often sacrificed to source it.

1.3.6 Geothermal energy

The deeper the earth's crust is penetrated, the hotter it gets. On average, the temperature increases by 3 degrees per 100m. At a depth of 2km, the temperature will rise to 70°C and this can easily be used to heat houses. One condition is that an aquifer (water layer) is present at that depth so that the heat is extracted by absorbing water. The water is then pumped back via a secondary source when it has cooled down. It is clear that the investment in these sources are considerable and that they must be used for a large number (several thousand) of houses. An added inconvenience is that there is no certainty that the drilling process will result in the successful penetration of a productive earth layer, which is a great financial risk. Another hurdle, but only one that will appear after tens of years, is that geothermal energy is not endless. A resource is further depleted by the amount of heat that is extracted, so is essentially limited to approximately 50 kW/km2 until a much larger power (a few MW) is found. By then, however, there should be a new opportunity to use these sources as lossless storage for high temperature (solar) heat.

1.3.7 Cascade arrangement

A large number of smaller units, such as CHP, heat pumps and boilers, provides a greater ability to generate heat than when these are used on their own. When parallel heat sources are connected and used in this way it is known as a 'cascade system'.

Benefits

- Smaller units are mass-produced and are therefore easier to buy and maintain.
- Because of the large number of units (up to 10 pieces), a failure in one unit will not cause a problem so there is no need for over-capacity to guarantee the supply.
- The units can be controlled so that maximum returns can be made.
- The heating of water that is generally linked to central heating systems requires a short-term but small capacity. Large boilers used for this purpose have very poor efficiency because the energy required to get the boiler to the right temperature is more than that needed for the demanded tap water. However a small unit in a cascade model can do this job easily. A cascade system provides a number of advantages for large units that are generally found in collective installations, compared to the traditional arrangement of two large units.

Please note:
Units that break down are not supplied with central heating water. This can be prevented by installing check valves in each one. Without this facility, a non-working unit can operate as a cooling fin.

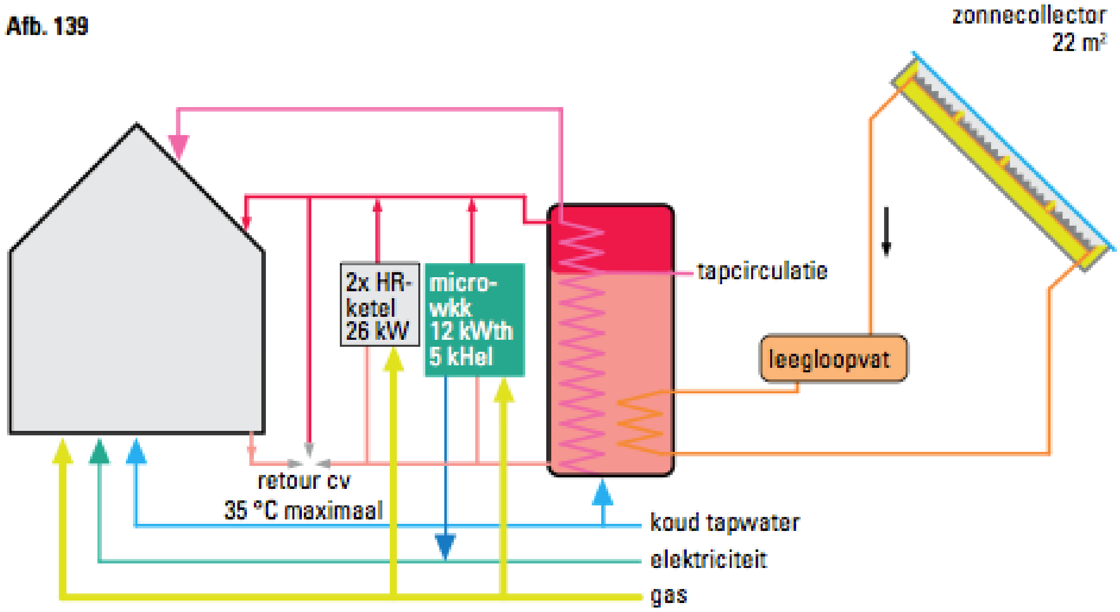


Fig. 1.26: Example of a mini-CHP in conjunction with solar energy in a complex of 11 senior houses and some common spaces in Bennebroek, the Netherlands. A cascade system is used containing a solar water heater, mini-CHP and two HR-boilers. Built in: 1997

Vocabulary:
Tapcirculatie: tap water circulation
Leegloopvat: idling barrel
Koud tapwater: cold tap water
Retour CV: return central heating
Micro WKK: micro CHP

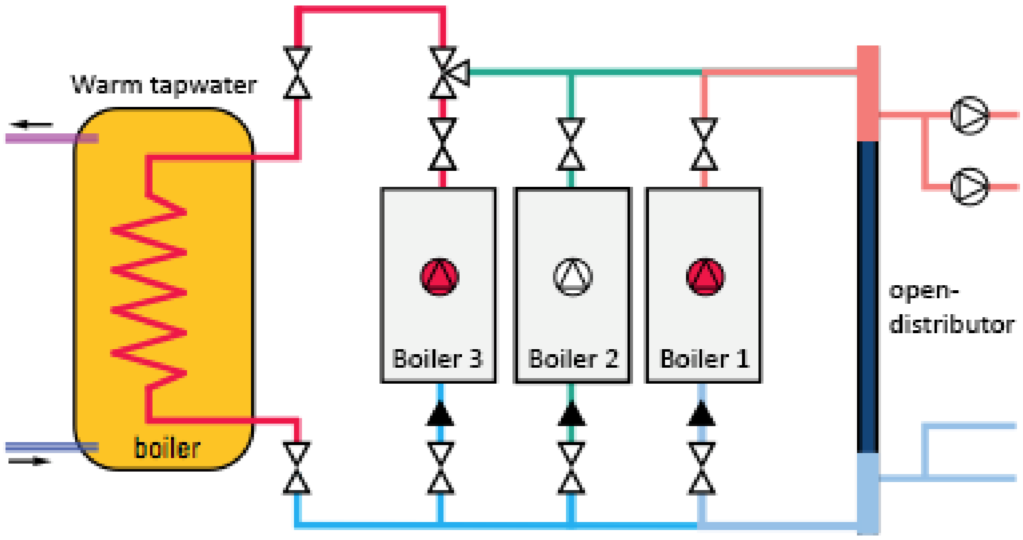


Fig. 1.27: Example of a cascade formation with a priority function for hot tap water.

1.3.8 Solar boiler combination

With a solar boiler combination, solar energy is used actively to heat rooms and hot tap water (see chapter 3). In the spring and autumn, the use of solar energy for space heating is generally more efficient than for heating tap water, as the required temperature level for space heating is lower. The installation consists of solar collectors with additional facilities for storage and distribution. A surface of 5 to 10m^2 of collectors is required. The post-heating coil is integrated in the storage barrel or linked separately to the storage vessel. Through this link, the storage system also stores heat from the post-heating coil which enables a solar boiler combination to supply a very small capacity to new build houses.

Due to the lack of synchronicity in the supply of solar energy and the demand for space heating, solar energy only provides a small contribution to the heat demand for space heating (about 10 to 20%).

Considerations

• Space heating with active solar energy is becoming more relevant because of the increase in seasonal solar energy storage options.
• As the temperature level of the heat-delivery system is lower, solar energy can contribute more to the heating demand and so a design feed temperature of below 40°C is recommended.
• Solar collectors for space heating contribute to the further reduction of an energy performance certificate (EPC).
• For a more detailed explanation on solar collectors for hot water.

1.4. Thermal heat storage

The storage of heat is an important part of different renewable energy systems and other energy efficient installations. The use of thermal heat storage increases the efficiency of such systems. It is particularly important for active solar heat pumps and (CHP). This is because:
• the sun only shines during the day and the demand for heating is higher early in the morning or in the evening
• heat pumps usually have a relatively low capacity and so there must be a capacity to temporarily store heat to meet peak demands
• CHP plants must be able to work for as many hours as possible without turning on and off. This is because the start-up consumes a great deal of relative energy and shortens its lifespan. Also, the aim of CHP is to run when power is inexpensive, but this is not usually during periods of high heat demand.

1.4.1. Short-term storage

One short-term thermal energy solution is a water-tank, with a well-known example being the storage barrel of a solar energy system. This vessel is designed for storing hot water up to temperatures of around 80 or 90°C for several days. Another system is the temporary storage of waste heat from a CHP plant. Figure 133 shows an example of a short-term heat storage system from both solar collectors and heat pumps. This stores ‘higher' temperatures, up to an average of 40°C, during the year. It is important to isolate these vessels and pay special attention to heat-leaks through the connections between the storage and its stand. To prevent thermal drafts, connections must point downwards as much as possible, as those at the head often cause significant leaks.

1.4.2. Seasonal thermal energy storage

Extended or long-term/seasonal storage - storage temperature <20 ° C,

As heat cannot be directly exploited for space heating from long-term storage at this temperature, heat pumps are essential. This requires the expansion of a normal source system that is used with a heat pump. By increasing the storage temperature to 20°C in the summer, the COP of the heat pump can be increased by 1 point during the winter (e.g. from 5 to 6).

Extended or long term/seasonal storage - storage temperature: 25 ° C

At this temperature, the heat can be used directly for space heating and stored in:

- a large water supply: A large volume is essential to maintain the surface-content relationship and subsequently reduce heat loss. There are various possible models such as a metal or concrete tank or a covered, ground-excavated pit.

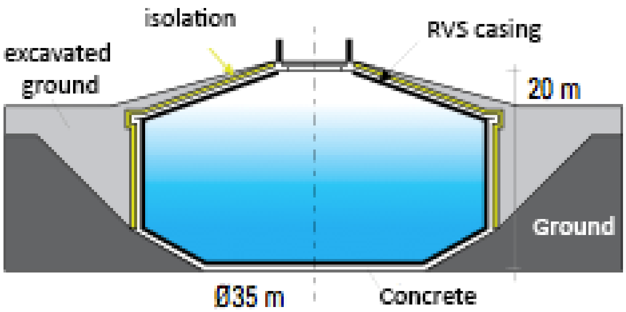


Fig. 1.28: Seasonal solar heat storage in Friedrichshafen (Germany) for a project with nearly 600 flats. Storage consists of a largely buried concrete tank (12,000 m^3) which is covered with stainless steel on the inside to make the tank waterproof. Solar collectors with a total surface of 5600m^2 deliver the heat. Built in: 1996

- an aquifer: The heat is directly stored in the water and sand of an aquifer in the ground (50-250m depth). One that is suitable for heat storage usually consists of a sand layer that is surrounded by horizontal layers of waterproof clay. The groundwater flow into the sand should have a limited speed to limit heat loss. In a drained ground, thermal currents are created and these increase the loss of heat. The ground also needs to be permeable to a certain extent so that water can be pumped up. This contradiction makes it difficult to find suitable places for high temperature storage so the temperature level has to generally remain low.

This way of thermal energy storage is called ATES, aquifer thermal energy storage. In the figure below the principle of is shown. During the summer (left) the heat is extracted from the building and stored in the ground. This heat will be used during the winter (right) to heat the building. This principle can also be used the other way around. Cold is extracted during the winter and storage for usage in summer.

Storage increases the efficiency of the heat/cold generation. For the storage the thermal capacity of the underground is used. Heat is stored with a temperature of 20-25 degrees Celsius, cooling at about 5 degrees Celsius. Seasonal thermal energy storage is mainly suitable for climates with significant temperature differences during the year (temperate climate).

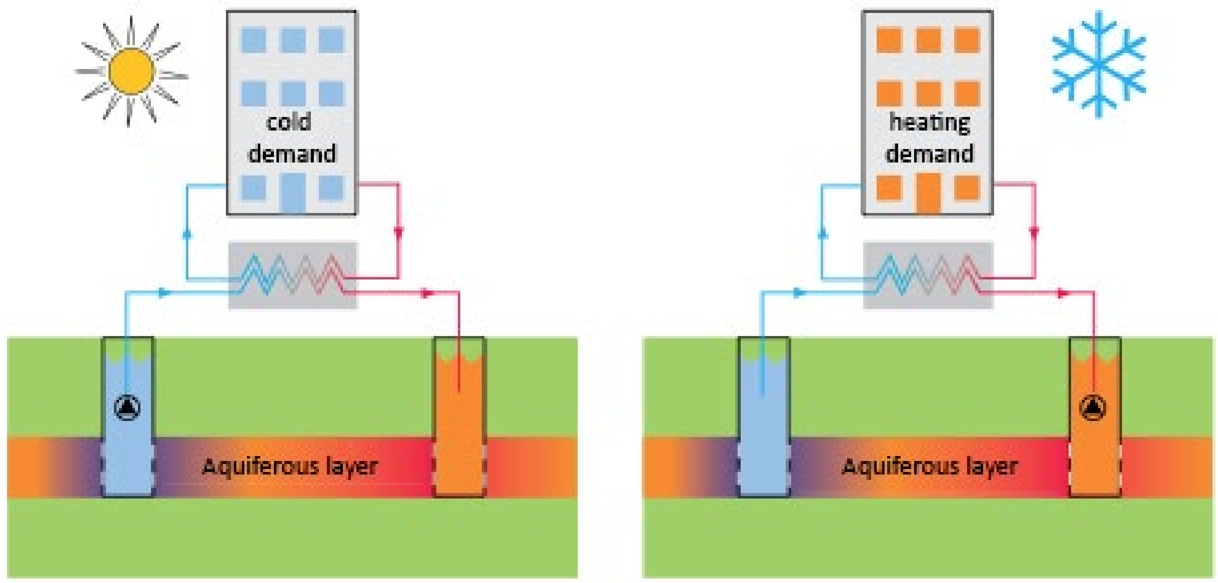


Fig. 1.29: Illustration of an aquifer. In practice, sand layers are used with a minimum thickness of approximately 20 metres at a depth of between 40 and 150 metres

- a borehole: another way to seasonally storage thermal energy is by the use of borehole thermal energy storage (BTES). The principle is the same as aquifer thermal energy storage, only no aquifer needs to be present since the heat is pumped through closed pipes till 50-250m depth. However the efficiency is lower and at the same time a large plot needs to be available to construct the boreholes.

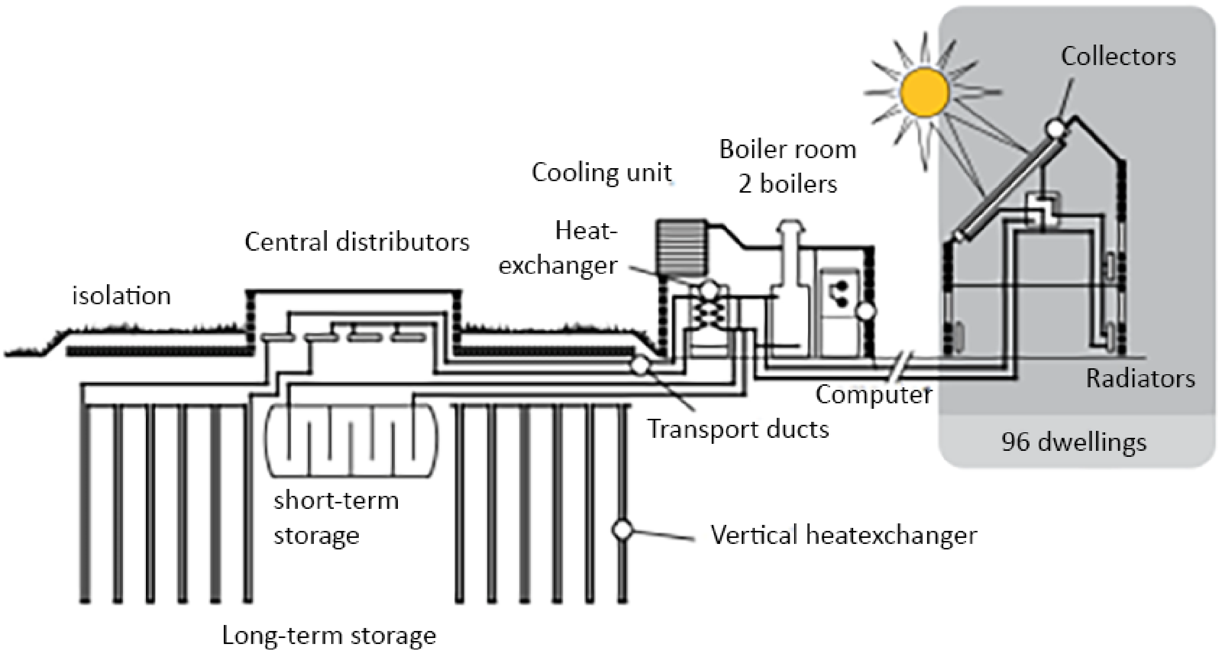


Fig. 1.30: Seasonal solar heat storage in Groningen, the Netherlands. The storage consists of 15km of tubes fitted under a central lawn. The storage has a diameter of almost 40m, a depth of 20m and is insulated on top. The 96 homes have a total surface of 2350m^2 of solar collectors. The housing's heating system consists of low temperature radiators that are co-fired centrally with gas boilers. Measurements show that the contribution of solar energy to the total heat demand for space and water heating is approximately 65%. The average temperature of the ground in the storage ranges from approximately 30°C in February to almost 50°C in October. The total system is still functioning without any specific complaints. Over the years, some changes and repairs have been made
The top and circumference should be very well insulated to around one metre thick to ensure that temperatures to 80°C are possible. Internationally, there are various pilot projects running using this system (fig. 1.28)

1.5 District heating

Collective heating means that several homes are provided with heat that comes from one central facility. This may involve a limited number of homes in a residential building or a large number in a residential area. Collective heating systems, such as block heating and heat distribution, can result in energy savings. Whether this happens depends, amongst other things, on the:

- energetic quality of the heat generation
- temperature level and regulation of the system
- quality and total pipe length of the distribution system
- energy demands per hectare.

Benefits

- Efficient energy generators: waste heat and/or storage methods can be used including:
    - cogeneration
    - industrial waste heat
    - heat pump
    - biomass
    - seasonal storage with solar energy
    - geothermal or deep geothermal heat.
- Capacity and power investment savings: due to the increased scale of a collective system. An individual boiler capacity is 10 to 20 kW, whereas a collective system only requires 3 to 6 kW per house. The lack of synchronicity in a collective system can be used as most of the time there is only a limited base load demand and peak demand capacity can be spread out over multiple homes
- Cheaper, more efficient components: used in a cascade arrangement of smaller units
- Less environmental pollution caused by collective facilities due to:
    - more efficient power or heat generation
    - better maintenance.
- No heat source required for space heating. Advantages are:
    - safety
    - easier maintenance, due to a lack of individual maintenance being required
    - less space being required in the house.

Disadvantages

- High investment in distribution
- High level of heat loss in the distribution process: up to 30% of total heat production can be lost when large systems with land lines are used. The loss is highly dependent on the quality of insulation and the height of the temperature. With decreasing heat (for instance additional saving measures at home level) the loss increases proportionally
- The gas network is left out: residents cook using electric as a result, causing increased electricity use (100m^3 gas equivalents compared with 65 m^3 of gas) and costs.

Heat distribution

Connecting The heat from the collective distribution may:

- be directly applied to the pipe of the house, both networks are then in open communication with each other
- be transferred through a heat exchanger to the piping of the home.

Benefits

The advantage of the first point above is that are no extra costs for a heat exchanger and no additional space is required. The absence of a heat exchanger results in the temperature in the distribution system being approximately 4°C lower than with one. This results in fewer losses and a more efficient generator.

Disadvantage

A leak in one house may cause the whole system to run empty unless a safety valve is fitted.

Warm tap water

In houses with a collective heating system the warm tap water is usually heated through one of the following systems:

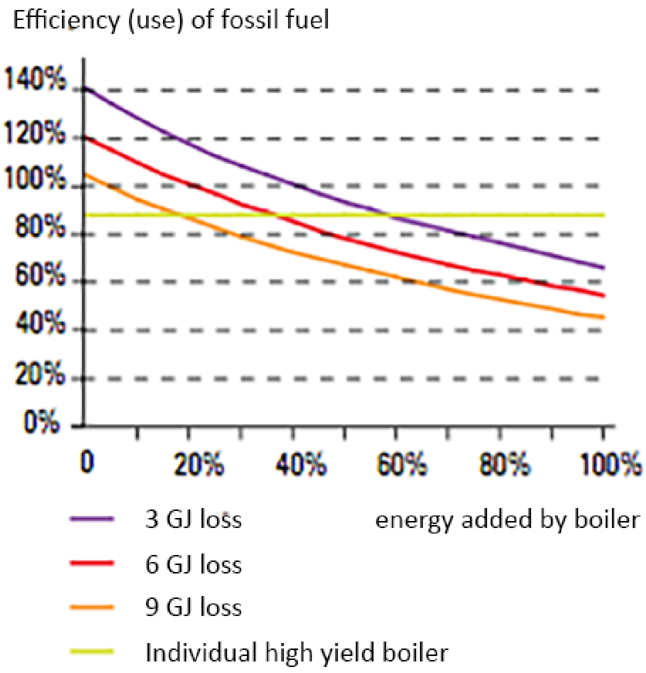


Fig. 1.31: Return on primary energy from a collective system depends on the rate of co-heating and loss from the distribution system. 3 GJ loss can only be achieved in block heating, 9 GJ or more is common with regards to heat distribution. Assumptions: CHP electrical efficiency 34%, 50% heat, performance co-heating (boiler at 75°C) 90%. Avoided return of central generation is 50% according to NEN 5128. All returns are in upper value

- Central heating water: The distribution supply temperature should be a minimum of approximately 70°C in both the summer and winter to produce warm tap water inside the house that is around 60°C. This causes significant energy loss.
- Separate hot water distribution network: This has a smaller diameter and lower temperature and therefore fewer losses. The hot water should be metered separately.
- Small boiler in each house: This is heated twice a day from the distribution network. The rest of the time the network operates on the low temperature that is required for space heating. This is a very convenient system for block heating.
- Heat pump boiler in each house: This uses the return from the central heating system in the house. In the summer, this works as a stand-alone system and cools the house somewhat. In the winter, heat is extracted from the public grid and tap water is preheated by the collective network. This is regulated in accordance with the weather during the summer and winter, resulting in a relatively low loss.
- Electric boiler per house. This type of boiler is strongly discouraged as it is most likely to diminish any savings from the collective system.

Fig. 1.32: Project Puntegale, a former tax office in Rotterdam, is a multifunctional residential and business complex that contains collective facilities for space and water heating. It is connected to a heat distribution network and also has a solar boiler and mini-CHP. All (residential) units are connected to a building management system and the heating and ventilation are set at a minimum level via infrared detection. Residents may set the temperature three degrees higher or lower. Gas, electricity and water (hot and cold) is read per unit and centrally recorded

Scale of systems

The main difference between block heating and heat supply is the scale of the two distribution systems. Block heating is a collective system that is used in one block, or across a few, and is small in size. Heat supply (formerly city heating) is a system for thousands of homes. There are also other distribution networks available that are between these two sizes, the common term for these is 'district heating'.

Depending on the size of the system, the look of it will be similar to that of block heating or heat supply. CHP, industrial waste- or geothermal heat, and comparable systems, are almost always used for heat supply to 1000 or more homes. The main source delivers 75 to 90% of the required annual amount of heat. Other heat is supplied by assisting boilers that are placed in substations designed to utilise the network more effectively. HR-boilers are necessary to maintain the total return.

In smaller collective systems the following techniques are used for heat production:

- cogeneration
- heat pumps
- solar energy
- biomass boilers or CHP
- a combination of the above options.

Please note:

- A low-temperature delivery system should ideally be included in housing design to limit losses.
- Consider the required space in the house for a supply set (fig. 1.32); approximately 0.3 (depth) x 0.4 (width) x 0.6 m (height).
- Ensure that the meter cupboard is well ventilated and insulated, including all hot- and cold water pipes and meter box components.
- Choose the most efficient way to heat tap water.
- Reduce piping losses by:
  - ensuring that the pipe design is as short as possible. A relatively high density is therefore beneficial:
  - In a major heating web (from around 3000 houses) there should be a net density of 30 houses per hectare.
  - In a small heating web (from about 300 houses) a net density of 55 houses per hectare is required.
  - ensuring that pipes are effectively insulated and carefully applied over the full length
  - preventing pipes, where possible, from being fed through the ground
  - placing collective pipes in spaces that will benefit from warmth anyway (the heat should benefit the space).

Fig. 1.33: Individual set of district water heating supplies through a heat exchanger and heat meters. Note that, a compact device is preferred and the insulation needs to be perfect, (Source NIBE)

1.4.1 Control

Arrangements for collectively fired central heating installations

The ideal method for heating tap water is dependent on the type of plan that is put in place. If it is heated through the central collective network, it should maintain a temperature of 70°C. A thermostat should then be integrated to ensure that the return temperature is warmer than 40°C. If there is a separate tap water network, or it is heated separately, the system should be equipped with a weather-dependent control facility. This will ensure that the most efficient generators are the most commonly used. With block heating, the central heating control may be part of a complete building management arrangement, where space- and water heating, ventilation, metering, security and such factors are all included. This makes it possible to optimally align the supply and demand of heat in the collective system. The building management will be able to record the exact temperature of all flats at a certain point.

Heat release in the properties using collective systems must be regulated with, at the very least:

- thermostatic radiator valves combined with foot valves on all radiators; normal radiator valves are strongly discouraged
- a thermostat that controls a valve in the supply line to the house. Radiators should be equipped with normal or thermostatic radiator valves, although do not apply the latter in the living room if the room thermostat is present here.

1.4.2 Metering

Collective consumption measurement systems

Individual heat meters are a must when collective systems are used. In existing housing complexes these result, on average, in 15 to 20% of energy savings compared to if this type of metering is not used. It is important that the total costs are fairly distributed across the relevant homes and there are various options for carrying this out. These ensure that the heating bill for public spaces and pipe losses is shared between the dwellings.

Pipe loss costs may include heat transfer that takes place through the walls and/or floors of neighbouring homes that have different temperatures. This can be a very significant proportion of total consumption in homes that are effectively-insulated. A household that requires a low temperature may have virtually no heating, while, at the same time, their neighbour's house does. This effect can only be avoided by insulating the separating walls of the house. This is particularly recommended in new buildings.

The different types of collective system measurements are:

- metering per radiator or convector
- metering per house.

Consumption measurement by radiator or convector

This form of measurement consists of using an evaporation- or electronic radiator meter that is fitted to each radiator. The total energy of the complex is proportional to the number of consumer units on the evaporation meter. This type of meter is generally only used in existing buildings. In new buildings the heat can always be brought in at a point where a meter can be installed.

Measuring consumption per house

Electronic heat meters (GJ meters)
These measure the amount of central heating water that is supplied per house, as well as the temperature of the supply and return water. The total heat consumption is calculated from this data, including the loss of distribution through pipes in the house at the measurement points. This heat meter is generally included in the supply set (fig. 1.33). Each house must have a 'central supply point', feed and return pipe. This central point is also required to input heat into the entire house.

Benefits (compared to measurement per radiator)

- High accuracy
- Appropriate for all heating systems provided a 'central feeding point' is present
- Simple collection from central reading
- Easy tracking and monitoring of energy use for residents

Central reading
The central (from a distance) reading of consumption is possible with both types of meters.
This type of reading is possible with a cable or radio. GSM technique options are currently in full development. It is common practice for a resident to have an automatic link to the meter and for payment to be made by monthly direct debit.

2.

Heat pumps

2. Heat pumps

2.1 Introduction

A heat pump is a sustainable alternative for a boiler or a refrigerator (only being used as refrigerator). The amount of use of primary energy can be substantially lower. The principle of the heat pump is basically not different from a fridge, which was invented in 1805 by the American Oliver Evans. In 1834 Jacob Perkins got the first patent and build the first prototype, followed by John Gorrie in 1842 in order to cool hospital rooms and homes. The first commercial cooling machines were designed by Alexander Twining in 1856. However, extensive use and more development of the performances of heat pumps have only been started since 1947, after the energy crisis in 1973 and again from 1990, mainly due to the rising energy prices. In many buildings heat pumps are operating nowadays. Heat pumps may be classified according to:

1. Type of heat source or sink.
2. Heating and cooling distribution fluid.
3. Type of thermodynamic cycle with following components: compressor, condenser, thermostatic expansion valve and evaporator.

The basic principles of a compression cooling machine or heat pump are illustrated by the following diagram of compression refrigeration. The numbers are shown as well in figure 2 and the process is described below figure 2.1.

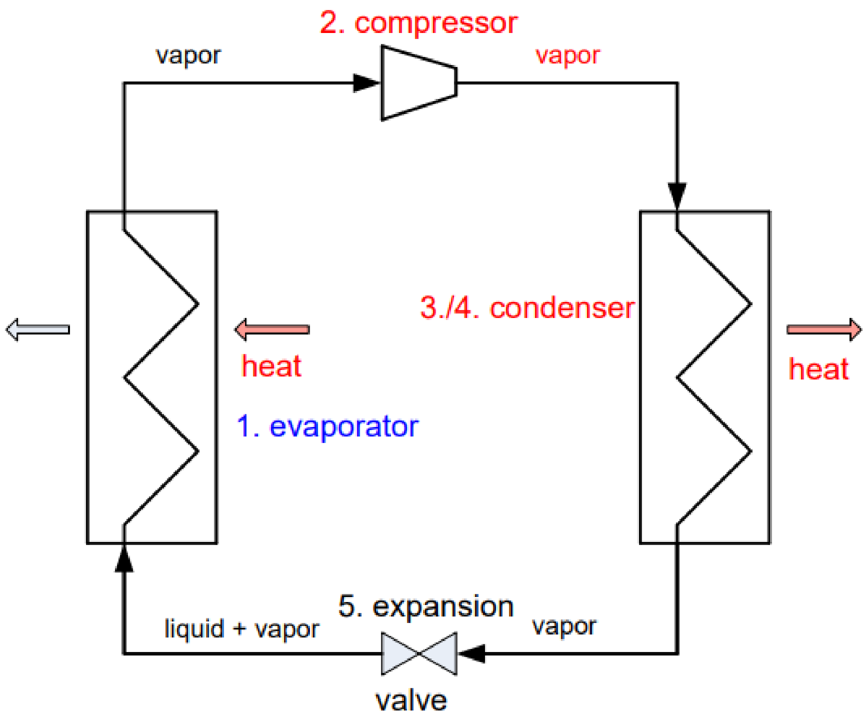


Figure 2.1. Diagram of compression refrigeration

In a pipe-system a fluid is stored which can evaporate/boil and condensate at a chosen temperature. When the pressure rises by means of a compressor condensation of vapour (2) is easier to realize, when it is cooled down in a condenser (3). In a fridge the condenser can be seen at the backside. The gas has changed into a liquid by now (4). After this stage the liquid will pass an expansion valve (5) and the pressure drops after. This makes it possible for the liquid to change gradually into gas. When the fluid in the pipe passes the evaporator all the liquid will change into vapour (1). When a gas expands it will cool down. The cooled pipe can cool warm air or liquid into cold air or cold liquid. After this stage the vapour goes back to the compressor.

In a cooling machine the heat from the condenser is not used and supplied to surrounding air or water. In case of a heat pump the heat from the condenser is used for heating purposes, like floor heating.

In the next T-S-diagram (T = K, S = kJ/kgK) the whole cycle is visualized:

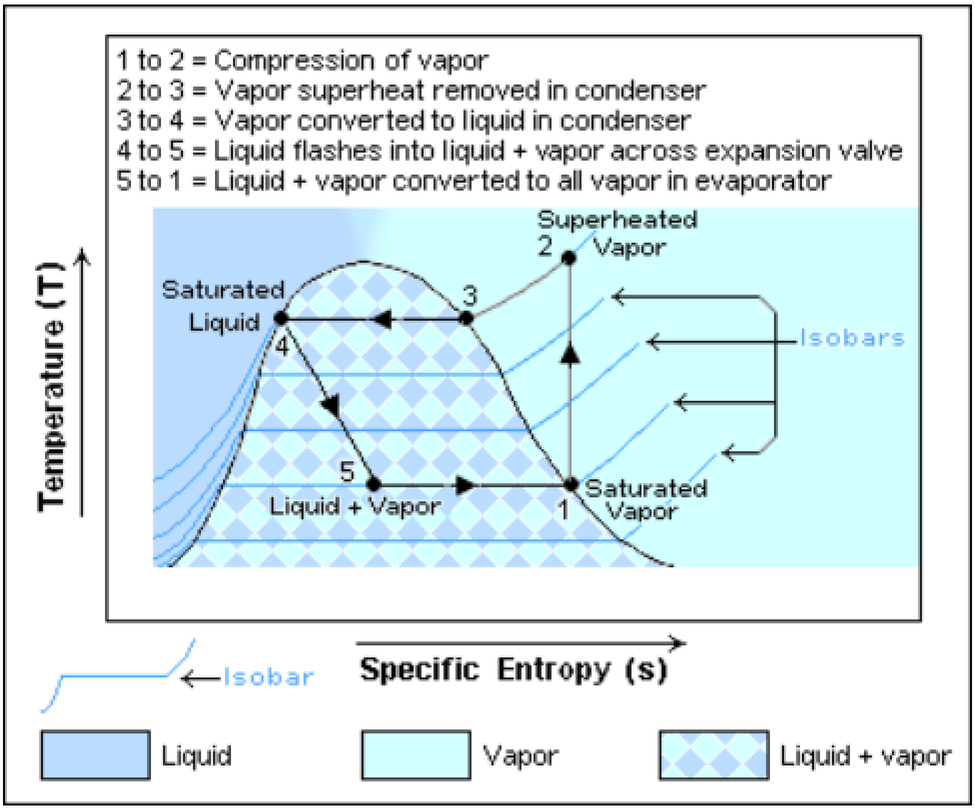


Figure 2.2 T-S Diagram of compression refrigeration. The isobars are presented as well.

With a few simple equations the thermodynamically performance of a cooling machine or heat pump can already be roughly evaluated. According to the first law of the thermodynamics the following equation is valid:

$$Q_h = Q_l + W \qquad (1)$$

$$W = Q_h - Q_l \qquad (2)$$

Where Q_h is the highest and Q_l the lowest energy-level and W is the amount of work

The COP (coefficient of performance) is the amount of required energy (work) in order to produce a certain amount of energy (heat of cold):

$$COP = \frac{Q}{W} \qquad (3)$$

This can be expressed in another shape in the following equation:

$$COP_{heating} = \frac{Q_h}{Q_h - Q_l} \quad \text{or} \quad COP_{cooling} = \frac{Q_l}{Q_h - Q_l} \qquad (4)$$

The COP can be evaluated by the following equation:

$$COP_{heating} = \frac{T_h}{T_h - T_l} \qquad (5)$$

$$COP_{cooling} = \frac{T_l}{T_h - T_l} \qquad (6)$$

Equation 5 and 6 show that the smaller the system temperature differences are, the higher the COP will be. This is why high temperature cooling and/or low temperature heating will be most effective.

When the highest system temperature is 37o C = 310 K and the lowest system temperature is 7o C = 280 K the theoretical maximum COP will be 310 / (310 – 280) = 10.3. Generally efficiency losses are 50%, so in reality the COP for heating will be ca 5.

Moreover, a cooling machine or heat pump produces heat as well as cold, so the total COP in this example is almost twice as high. For instance, this is an option when aquifers are used in which heating and cooling energy can be stored or when there is a simultaneous heating and cooling demand like in a supermarket.

2.2 types

Air to air heat pump.

It is suitable for factory-built unitary heat pumps. The air circuits for the evaporator and condenser may be interchanged by dampers, to obtain either heated or cooled air for the conditioned space. The conditioned air will pass over the evaporator during the cooling cycle and the outdoor air will pass the condenser. During the heating cycle it is reversed. The changeover may be accomplished in the refrigerant circuit (the heat exchangers are evaporator or condenser) or in the airflow. The evaporator is always the evaporator but the outside or the conditioned air is passing it during the cooling or heating cycle.

Water to air heat pump.

It uses water as a heat source and sink, and uses air to transmit heat to or from the conditioned space.

Water to water type.

For cooling as well as heating water is used. Energy can be extracted from an aquifer, the soil, waste water, seawater, a lake or river. The higher the temperature of the water in the heating season is, the higher the COP for heating will be.

Other types are possible. An example is an absorption heat pump, which utilizes solar energy as a heat source. However, the COP of this system is rather low: ca 0.7. The principles and options of this system will be discussed in another module. Absorption heat pumps are interesting as well when there is much "waste" heat available for instance during heat power generation in summer.

Gas or electricity driven compression heat pumps or absorption heat pumps can deliver both heating and cooling. Generally gas driven heat pumps can produce higher temperatures due to the fact that the cogenerated heat from the motor can increase the temperature. In this way temperatures above 70o C are easy to reach in order to reduce legionella-risks.

Some general applications

By heat pumps in the heating mode of control 25 to 50% primary energy can be saved. The main product is heat and the by-product is cold. The value of the by-product depends on the simultaneous need of both products. In general seldom it coincides, but by thermal storage the use of the by-product can be improved. Cold and heat which is not useful at the actual moments can be stored and used at proper moments.

An interesting application for heating a block of houses is storing warm water in an aquifer in summer at 18-20°C. In winter it will be transported through non-insulated pipes to the block of houses. A heat pump per block uses it as a heat source and increases the water temperature of the heating system to 35°C or more. From there it will be transported through an insulated piping system to the various houses and used by a low temperature heating system (such as floor or wall heating). This heat source can be used as well by another heat pump in order to produce tap water of 65°C.

A general application of a heat pump in new built houses with natural air supply and mechanical exhaust is a heat pump that uses exhaust air as a source and produces warm tap water.

Central or decentred heat pumps?

The distribution system of a central heat pump is one of the bottlenecks. Central hot water systems need relatively high temperatures in order to satisfy all users, especially when warm tap water is involved. Therefore, often an insulated double circulation system will be applied for domestic heating as well as warm tap water. Sometimes, the systems are combined such as district heating with a supply temperature of 73o C. The 73o C is reached by a combination of a heat pump and heat power generation.

A central low temperature heat source and individual heat pumps is an efficient solution related to energy consumption. However the maintenance of many small local heat pumps is more complicated and every house needs space for a heat pump.

Figure 2.3: Example of a heat pump that makes use of indoor exhaust air for warm tap water heating (Stiebel Eltron). Details: Height = ca. 1.80 m, storage of 300 l water included.

Sizes of heat pumps

The size of a heat pump can be compared with the size of a cooling machine. The smallest heat pumps for domestic heating purposes need the following space: l x w x h = 1 x 1 x 2 m (heat pump itself = 0.6 x 0.6 x 1.80 m). This includes a storage tank for tap water.

Conclusion

There is no general “best “ solution for the choice an integration of heat pumps, it depends on the type of project. Small temperature differences between heating and cooling are most favourable.

Literature

1. Wisman WH, Meijer HC, Bart GCJ Inleiding thermodynamica. Delftse Universitaire Pers/VSSD. 1999.
2. Paassen AHC van. WB 4426. Indoor Climate Control Fundamentals.
3. Generating heat cold and power. Blackboard TU-Delft.

3.

Cooling

3. Cooling

To avoid unnecessary energy use and additional investments in active cooling, the design process should minimise cooling demand through effective positioning of windows, blinds and summer night ventilation. Once the number of excess hours in the summer have been determined, it will be evident whether a cooling system is needed. If so, a cooling system that is supplied with a high temperature (≥ 16°C) should be included. This ensures that free cooling is possible without the need for a cooling machine, which is more energy efficient than traditional air conditioning. This chapter features the most common forms of cooling in housing.

3.1 Cooling demand

Cooling demand is caused by:

- external load: heat flows from outside (solar radiation, high outdoor air temperatures)
- internal load: from heat sources inside the house itself (lighting, equipment, people).

The cooling demand is calculated from the surplus heat that leads to a rise in temperature above 24°C. Options for use in the design phase to prevent the building from becoming too warm are discussed in other chapters, including the following:

- Adequate ventilation facilities (windows that can be opened,
- Energy-efficient electrical equipment with a lower heat supply
- Solar resistant glass that effectively excludes sunlight and allows daylight through
- Outside shutters
- Use of a building's thermal mass: it should not to be covered by insulating layers, such as carpet, cabinets or suspended ceilings, to ensure it can accumulate and release heat
- Night ventilation: night air is used to cool the building. This is more effective when there is sufficient thermal mass
- Pre-cooled inlet air with a ground tube.

Despite the use of the above measures there may be further demand for cooling to achieve a higher level of indoor comfort. An extended range of cooling methods are described below.

3.2 Transmission systems

3.2.1 High/low temperature

If it is not possible to satisfy cooling demand with the measures described above, an energy-efficient cooling system can be selected. To be efficient, the temperature difference between the transmission system and the rooms that need cooling must be minimal. This means a 'high temperature cooling system' should be chosen. The temperature of the air or water in these systems should be above 16°C. High temperature systems are generally combined with a low-temperature heating application and include:

- floor/wall cooling
- concrete core activation.

With 'low temperature' cooling systems the temperature of the air or water sits between 7 and 12°C. These are generally perceived as a less comfortable option because they generate drafts, uneven temperatures, unwanted noise and a high level of maintenance. Low temperature options also use more energy than other systems to operate a fan and generate the required cold air or water.

Relative humidity

An important aspect for cooling is the relative humidity. Air with a high temperature can contain more water than that with a low temperature. The air in a house tends to contain more moisture than outdoor air; this is produced by people, cooking, showering, etc. When the air cools down, its relative humidity gets higher and condensation is produced at a certain temperature. High humidity can allow the growth of micro-organisms, such as dust mites, bacteria and fungi.

Recommendations

- Floor- or wall cooling, or concrete core activation, surfaces should not drop below the dew point temperature, i.e. not less than around 18°C, or 21°C on very hot and humid days. The temperature under the carpet should also not drop below this to avoid condensation forming.
- Condensation from air coolers should be discharged via the sewer to ensure that no moisture remains inside. Air coolers cool the air to such an extent that, if this measure is not taken, the moisture that condenses in the unit is blown into the sky (dehumidified).
- Cold pipes that carry water with a lower temperature than dew point should have vapour-proof insulation. The accumulation of fluid in the insulation, or between it and the pipe, should be avoided, as this may cause leakages.

3.2.2 Cooling floor and wall

As with floor- and wall heating, the temperature difference between the air and floor surface may be insufficient because of the large area that needs to be cooled. The heat is removed by circulating cold water through pipes in the floor or wall. This provides a comfortable environment, as the room is a constant and equally divided temperature and there are no unwanted drafts. The cooling capacity is determined by the length and flow of the cooling pipes in the floor and these are usually placed closer together in comparison to heating pipes. A distance of 100 to150mm is common.

Benefit

Self-regulating system: The supply temperature can be lower in wintertime, so, when the room temperature rises the temperature difference between it and the floor or wall increases. This increases the cold-supply without the intervention of the user or a thermostat. An additional degree of temperature difference usually provides 20 or 30% more cooling capacity.

Disadvantage

Limited floor and wall cooling capacity: This is due to the limited temperature which does not exceed 25 W/m^2. Also, in terms of floor cooling, the designer needs to incorporate structural measures to reduce the cooling demand. When solar warmth meets a cold floor it is very effectively discharged without the notion of heat in the room. The effect of floor cooling at these times is much greater than calculated.

Fig. 3.1: Floor heating/cooling

Regulation

To keep the floor at the right temperature and prevent condensation problems from occurring, the water supply temperature should be increased by blending it with return water. An on/off control (the heated water from the floor) is less useful for a return temperature in homes as the low temperature may cause condensation to occur.

A switch can facilitate the transition from heating to cooling by making the thermostat temporarily inoperative. However, this is quite a primitive solution. A more modern answer is to use combined cooling and a heating thermostat, with a thermostat featured in each room.

Please note:
A standard heating thermostat or thermostatic radiator valve is not suitable for regulating cooling. If a room becomes colder as a result of the cooling, this thermostat or valve will register a demand for heat and provide more water to the floor. This will further cool the room instead of making it warmer. Specific cooling and heating thermostats are absolutely necessary and so effective control of cooling and heating can be quite complex and costly.

3.2.3 Concrete core activation

Concrete core activation is a unique, high-temperature cooling system that is based on the accumulation of heat and cold in the building construction. The heating or cooling pipes are integrated into the core of the floor, or in the ceiling, rather than the screed, and water is circulated through them to increase the thermally active mass of the concrete floors.

Benefits

- Reduced peak demand cooling in the summer: As the water flows through the system it transfers the cooling capacity to the large mass by extracting the heat and storing cold in the concrete core. This is then transferred to the room throughout the entire day.
- Increased capacity: This is due to pipes, fitted in the prefabricated floor elements, cooling both the floor above and ceiling below. The supply of cold to the ceiling is even higher than the floor because of a higher circulation of cold air. The result is that the total release can be up to 60 W/m_2 per floor.

Disadvantages

- The system responds extremely slowly: this means that turning the thermostat just a degree or two higher or lower for a short while will have no effect.
- As with floor heating/cooling there is a limited choice in flooring.
- Only one temperature can be released at the top and bottom of the mass. In a multi-housing unit this means that this system cannot be separately regulated and therefore should not be used.
- For the same reason, in a single-family home, the temperature on the ground- and the first floors will always be the same and this is generally undesirable.

  Please note:
- The ceiling should not be finished (insulated) from below, otherwise the heat or cold cannot be released to the room below it.
- A floating substrate (floor decking) will hinder release through the floor.

3.2.4 Air conditioning systems

These devices cool the air through a heat exchanger that may be positioned in the space itself or as a central part of the ventilation or air-heating system. With ‘low-temperature’ systems, cold air is blown into the room at high speeds resulting in a room’s temperature being less evenly distributed than it would be with a ‘high temperature’ unit The speed of the airflow may cause drafts and dust swirl. The fan may often generate unwanted noise and it also consumes a substantial amount of additional electricity (see chapter 10).

Fig. 3.2: An example of a mobile air conditioning unit with a condensation collector

A ‘low temperature’ system cools the air so that any moisture in the device condensates and is then blown, dehumidified, into the room. This means that condensation needs to be frequently discharged from the system. Effective maintenance of the cooling device is particularly important to prevent microbial growth from occurring in the moist environment that can go on to be spread by the supplied air when it enters the room. In houses, three types of air conditioning systems are generally applied:

- Turnkey air handling unit (portable air conditioning)
- Split unit
- Systems that are in-built or attached to the ventilation or air heating system

Turnkey air handling unit (portable air conditioning)

This is a compact device that is positioned in the required space and connected to an existing power outlet. It is equipped with a condensation reservoir to export condensation moisture. An air hose is usually present to deal with heat dissipation and this is vented through an open window.

Disadvantage

The open window results in outside air entering the room and, in hot weather, this requires additional cooling.

Please note:

- The device should be emptied regularly. The control (usually on/off) is positioned on the unit itself.
- Portable air conditioners have poor efficiency (fig. 3.2) and must be seen as an absolute emergency solution.

Fig. 3.3: A split-unit has a draft risk and disfigures the façade

Split unit
This system consists of two parts: a dispenser that supplies air to the room and an outdoor unit that contains the cooling generator and condenser fan that disperses heat outside. Cold air or water circulates between the two parts in two thin pipes, which should be damp proof. The indoor unit should be connected to a condensation pipeline. Both the inner and outer parts contain a fan. Attention should be paid to the amount of power these units use, as well as the noise production, particularly if the split unit is to be used at night.

Please note:
The efficiency of split units (fig. 3.4) is clearly superior to that of portable air conditioners, but due to their permanent availability they will also be turned on more frequently and energy use will increase as a result. Modulating devices (inverter technology) are advised as they have more effective part load efficiency and produce less noise. This regulation device is generally integrated into the system so that is can be controlled with a remote control. Split air conditioners can also be used in reverse as a heat pump during winter.

Embedded systems
In a balanced ventilation- or air heater system, a separate heat exchanger (cooling coil) can be built-in to cool supply air on demand.

Please note:
Be aware of the condensation drain as the cool air valves must be suitable for blowing in cold air without causing drafts. Air channels should to be insulated so they reduce the chance of vapour to avoid condensation on the outside of the ducts.

Regulation
A switch allows the cooling to be switched on and a fixed air temperature to be created centrally. An alternative would be to install a specific thermostat in the room to control cooling and heating.

Please note:
A standard heating thermostat is not appropriate to regulate cooling. Only by regulating the air flow can the cold air be adjusted on demand in each room.

3.3 Cold-generation

Cooling is required when a room temperature becomes higher than a set value, triggering the generation of cold air, water or a refrigerant. This is distributed by a transportation device and transferred to the room, bringing the temperature back to below the set value.

systeem	COP	PER
Mobile airco	1,5 - 2,0	0,6 - 0,8
Split-unit	2,5 - 3,5	1,0 - 1,4
Compressioncooling machine	3,0 - 4,5	1,2 - 1,8
Absorbtioncooling machine (gas)	-	0,6 - 1,0
Absorbtioncooling machine (residual heat)	8,0 - 12,0	3,2 - 4,8
Heat pump in summer (ground/ groundwater)	4,0 - 5,0	1,6 - 2,0
Free cooling on groundheat exchanger	8,0 - 16,0	3,2 - 6,4
Free cooling on groundwater	10,0 - 20,0	4,0 - 8,0

Fig. 3.4: Some examples of coolers and their coefficient of performance (COP). The higher the COP, the lower the primary energy consumption is. PER: return on primary energy

Below an outside temperature of, for example, 18°C, cold production is blocked and a compression cooling machine is usually required for it to be kick-started. However, free cooling or an 'absorption cooling machine' are also good options. The efficiency of a cooling machine is expressed in the COP, which is the ratio between the usefulness of the cold that is delivered and the energy required to drive the machine. This includes any motor losses and excludes energy auxiliary equipment.

Please note:
The following applies with regards to heat pumps: COP cooling ≈ (COP Heating -1) because the (electric) driving energy is not optimally used when cooling.

3.3.1 Compression cooler

A compression cooling machine, which will usually be electrically powered, sucks in a refrigerant at low pressure and brings it to a higher pressure through a compression process. This causes the temperature to rise and the hot refrigerant gas is then sent to the condenser where it cools down, condenses to fluid and any condensation heat is removed. The expansion valve subsequently reduces the pressure and the liquid refrigerant evaporates as a result. During this process, heat is extracted from the water (indirect expansion cooling) or air (direct expansion cooling) and is distributed outdoors again via the condenser.

Compression machines are found in most cooling devices, such as portable air conditioners, split units, etc. The COP can vary significantly (fig. 3.4). An improvement can only be made by changing the speed of the compressor (inverter technology) which enables the cooling machine to work more frequently, with a part load, providing a much better return.

3.3.2 Absorption cooler

An absorption cooler essentially operates in the same way as the compression cooler, only instead of mechanical compression it facilitates separate absorption and desorption. This means that the vapour in the evaporator is absorbed into a liquid (generally water). This fluid is brought to a higher pressure where the heated refrigerant is again separated from the absorbent fluid. Pumping the liquid requires little energy as the majority of power is supplied at a relatively modest level at temperatures of between 80 and 200°C.

Considerations:

- If the residual heat is used for the above purpose, absorption cooling is a good option for larger buildings.
- An advantage of absorption cooling is that the noise levels are usually low.
- Installations that are directly fired with gas have a much lower return on primary energy than compression cooling and are therefore not advised.

3.3.3 Heat pump in summer mode

In the summer, the heat pump functions as a normal compression cooler with an efficient transmission system, such as floor cooling. When in summer mode, the pump will use the soil as its source to draw heat from a property. This replenishes the heat that has been extracted from the ground during the winter and regenerates the soil. This is beneficial for the return in winter and is often required to prevent the soil from cooling down, year after year. Regeneration can, however, also be achieved with lower energy consumption through free cooling, as discussed below.

3.3.4 Free cooling

If a heat pump with a ground source (open or closed) is available for heating, this can be used in the summer for free cooling. The temperature of the soil (10 to 12 ° C) will be low enough for all transmission systems. A circulation pump is required for this type of cooling as it circulates water between the source and transmission system. The heat pump itself is not required during this process. The system's coefficient of performance (COP) sits between 10 and 20. This process is also used to partially replenish the source during winter. This 'regeneration' is important to ensure that the soil does not cool down too much over the years. If this were to happen, the return (COP) of the heat pump would gradually decrease over time.

4.

Hot water supply

4. Hot water supply

The energy consumption required for domestic hot water is roughly the same as that for space heating. This shows the importance of hot water within the household. The bathroom and kitchen are the main places were hot water is used for showering, bathing, washing, etc. The energy use required for heating tap water is determined by the amount of water that is used, as well as the desired water temperature, any pipe losses and the efficiency of the tank. To reduce energy consumption, all areas should be addressed by using short and isolated lines (for pipes) in the design of the house. Unit choice should be well considered to ensure that it is highly-efficient and the choice of water saving devices and unit, as well as the education of residents, will all contribute to lowering water consumption. In addition, heat, such as shower heat, can be recovered and renewable sources used (solar energy, ventilation air etc).

4.1 Domestic hot water (DHW) demand and taps

Hot water comfort is determined by the:

- maximum flow the device can supply
- continuous flow the device can supply
- ability to provide water to taps simultaneously in several locations.

4.1.1 Water saving facilities

Water saving devices can be applied at a relatively low additional cost and the return-on-investment period is generally less than a year. Ensure that the tap water barrier is low enough when flow devices are combined with water saving equipment, otherwise the unit will fail to turn on.

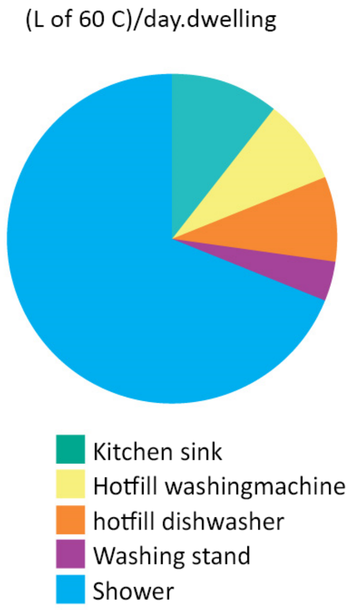


Figure 4.1: The distribution of hot water to the different taps. On average a Dutch person uses 60L of hot water a day, mainly for showering.

Class	Application	Tap flow			power or stock*	
		Kitchen (60 C)	Shower (40 C)	Bath(40 C)		
		l/min	l/min	l/min	kW	liters
1	Kitchen	≥ 2,5	-	-	9	30
2	Kitchen or shower	≥ 2,5	6	-	13	60
3	Kitchen or shower or bath (100l)	≥ 3,5	6-10	≥ 10	22	100
4	Kitchen or shower or bath (120l)	≥ 3,5	6-12,5	≥ 12,5	27	120
5	Kitchen or shower or bath (150l)	≥ 3,5	6-12,5	≥ 17	36	120
6	Kitchen and shower	≥ 3,5	6-12,5	-	47	125
	Kitchen and bath (150L)	≥ 3,5	-	≥ 17	47	125
	Bath (200l)	-	-	≥ 22	47	125

*as an indication, for each class the power or the stock of an appliance is indicated which is approximately necessary to be able to supply the desired amount of water.

Figure 4.2: The six CW-label (comfort warm water) categories. Each states the applications that a device is designed for.

Water saving showers

There are significant differences in water consumption within the group of water-saving showers. An efficient showerhead gives an average of 5 to 6 litres of water per minute at a water pressure of 1 bar (= 100 kPa), which is 50% more efficient than a standard showerhead. Residents are generally very satisfied with the use of these showers and studies show that a water saving shower does not result in a longer shower than if an inefficient showerhead is used.

There is concern that collective systems, or housing where tap water is drawn at multiple points, are susceptible to pressure variations. A water saving shower slows down the mixed water flow from the tap, decreasing its 'authority' to determine the flow of hot and cold water. This variation in pressure leads to an increased chance of temperature change in the shower. If it is possible to create tap points in several places then a variation in pressure can be expected.

There are many types of taps available for saving water and these are generally combined with increased comfort. For instance, there are taps with:

- a parabolic closure
- flow limitation, possibly integrated into an aerator
- one hand mixers that include an asymmetric division between cold and hot water
- one hand mixers that include a water saving position of the lever
- thermostatic shower mixers.

Other water saving facilities

Hot water saving devices impact on both water- and energy use, see the figure below.

	Watersaving	Energysaving
	In m3/year	in m3 a.e/year
Watersavingshower class Z	10	45
flow limiter on watertaps	2 - 3	10
Taps with watersaving	1 - 2	5
Optimalisation ducts	0 - 10	0 - 50
Hot-fill washingmachine	0	10 - 30
‘Regular’ dishwasher as hot-fill	0	5 - 20
Heat recovery shower	0	65

Figure 4.3: Indication of potential savings per household per year by water and energy saving devices

4.1.2 Water temperature

Legionella

The bacteria 'legionella' causes 'legionnaires' disease', which can be fatal. The temperature range for the growth of legionella is between 20 and 50 °C with an optimum between 30 and 40 °C. In reality, the growth actually becomes significant from 25 °C. However, a longer stagnation period of several weeks can also cause an issue if water sits at temperatures of between 20 and 25 °C. Once temperatures reach 50 °C, the bacteria dies off.

Please note:

- Bacterial development will not occur provided that pipe water is regularly refreshed. Tap points that are rarely used require special attention. Branch these with the shortest line possible on a frequently used pipe. Also be careful that cold water pipelines are not heated by a nearby hot pipe (used for hot water or central heating). Many legionella infections are developed through the heat interaction between hot and cold water pipes. Insulating the hot and cold water pipes helps to combat this problem. The decreased cooling of the hot water pipe itself is not the issue. On the contrary, the temperature of the pipe remains at over 50 °C for longer and is therefore disinfected more effectively.
- There is a risk attached to using stock unit devices with a low water temperature. Heating the water to at least 60 °C for some time before use will ensure that any issues are avoided. A good alternative is a boiler filled with water from the system that has a heating coil inside. The content of the coil is so small, and the rate of flow so high, that legionella is unlikely to be able to grow.
- Large piping systems for collective installations form a risk. Ensure that all hot and cold water pipes fall within the correct temperature range.

4.1.3 Heat recovery from shower water

Heat recovery from shower water is a very effective form of energy reduction. For instance, hot drain water can preheat a cold water supply. It is possible for this to be applied to shower water as there is a large amount of hot water both generated and thrown away. It is possible, using this method, to make savings of 30 to 40% on the heating of shower water.

The following systems are available:

- Vertical heat recovery unit: This consists of a copper tube-in-tube heat exchanger that is mounted vertically. The wastewater runs through the inner pipe as the clean water supply flows up between the two tubes. This process uses the 'counter current' principle, where the wastewater flows as a fast film, knows as the 'sticking effect', along intricate ridges inside of the copper pipe. This results in a highly effective heat transfer. The vertical heat recovery unit is placed on the floor below the shower.
- Shower tray with integrated horizontal heat exchanger: Due to the shape of the shower tray, all wastewater flows over the heat exchanger with optimal turbulence (and maximum heat exchange). This system can be used for renovations and in multi-unit housing.
- Toilet flushing unit: This shower-heat recovery system uses waste shower water to flush the toilet.

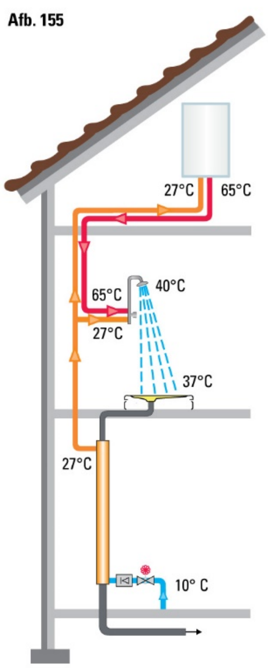


Figure 4.4: Working illustration of a vertical shower-water heat recovery system. Source: Technea Duurzaam

4.1.4 Hot-fill laundry and dishwasher machines

The use of hot-fill washing- and dishwasher machines can result in electricity savings when heating water. Almost all conventional laundry- and dishwashing devices are filled with cold water and the machine electrically heats the water. The return on this primary energy is low. Hot-fill machines are suitable for the direct use of hot water from the hot water supply. Should the heat derive from a gas-fired unit, heat distribution network or solar boiler, the efficiency (in primary energy) is considerably higher than with an electric device. In addition, the emission of harmful combustion gases decreases by 40 to 50% overall.

The energy saved by hot-fill is strongly dependent on the water heater and the distance between it and the machine. This distance should be minimised and so hot water should not come from an electric boiler.

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Figure 4.5: Electronic control unit for a hot-fill connection in a standard washing machine

Dishwashers are almost always suitable for hot-fill. Should this not be the case, the installer can meet the residents needs by placing a switch box on the machine. This will ensure that it receives hot or cold water at the right time.

4.2 Pipes (tap water distribution)

4.2.1 Piping in the house

In many dwelling designs the there is a significant distance between the water heater and the tap in the kitchen (where there are many tap points) . The result is a long delay and waste of water and energy.

Recommendations

- When designing the floor plan, ensure that the heat source, usually a combi boiler, is situated as close as possible to the tap points in the kitchen and bathroom. Also the positioning of the piping should be planned carefully.
- Ensuring that there is only a short downtime in the kitchen will prevent residents from installing a small electric water heater, which will increase energy consumption by approximately 700 kWh of electricity (160 m^3 of natural gas) per year and offset any other water savings.
- Apply a single unbranched pipe from the heat source to the kitchen tap. Ensure that the diameter is as small as possible: an inner diameter of 6mm is usually sufficient and 10mm is common. Insulate the pipe with 20mm of insulation all around it, including where the pipe has had concrete poured on it. Effective insulation will ensure that the temperature is retained for approximately one hour, eliminating the waiting period. This amount of insulation is particularly important if there is a long distance to the water, such when the heat source is fitted in the loft of a single-family house.

Downtime

The downtime is the time needed to reach the final temperature at the tap, after it has been turned on. In theory, this should be as short as possible because unused water that is drained at a lower temperature is a waste of water and energy. Furthermore, it should be short for convenience, particularly for the most frequently used kitchen tap.

The total downtime of a tap comprises:

- downtime of the device: This only occurs with flow units. This is the time required for the heater to start up and reach the demanded temperature. For certain models, this period is (partly) compensated by a small water supply that is constantly maintained at temperature and can be directly accessed. The downtime of the device is specified by the manufacturer and can be up to 20 seconds
- downtime piping: A hot water tap only provides warm water from the heater if the cold water is suppressed first and the pipeline itself has subsequently warmed up sufficiently
- repeated content changes: The water must be changed more than once before the tap can supply hot water. The smaller the content, the sooner it will be 'suppressed'. The DH-factor is an indication of how many times the piping content must be replaced before hot water comes out. This depends on the pipe material, and is different for surface-mounted or poured-in pipes, but is usually between 1.5 and 2.

4.2.2 (Ring) pipes collective installations

Collective water heating in a residential construction is mainly achieved by:

- smaller public facilities, for example a building block
- using renewable energy, such as solar power.
- using efficient forms of energy production, such as waste heat or combined heat and power (CHP).

Long pipelines are inevitable, particularly in terms of collective systems, and so a loop is used to reduce downtime and bacterial contamination. The water is pumped around so that each house has immediate access to hot water. Check- and shut-off valves are applied right at the branch and the hot water meter generally has a flow restrictor valve. The latter restricts the flow to the required comfort level. This is important because the water pressure in surrounding dwellings could drop out if one building uses a disproportionate amount of water. The rest of the system is similar to that of a house with its own water heater.

Disadvantages

- The disadvantage of a loop is the increased heat loss caused by a constant high temperature (60 to 65 °C) in the pipe. Effective insulation of the loop is essential. There are ways to reduce a pipe's length and diameter, such as double feeding the system. This means that water can be supplied from two sides of the house for large usages.
- Also, systems where the return pipe runs inside the inlet pipe (inliner sets) should be considered. Perfectly executed loops have an energy loss per dwelling that is smaller than the pilot of a kitchen heater, but with poorly insulated systems this can also be five times as much. The return-on-investment period for insulating loops is less than a year.

A great deal of attention should be paid to avoiding bacterial contamination of the tap water system ('legionnaires' disease').

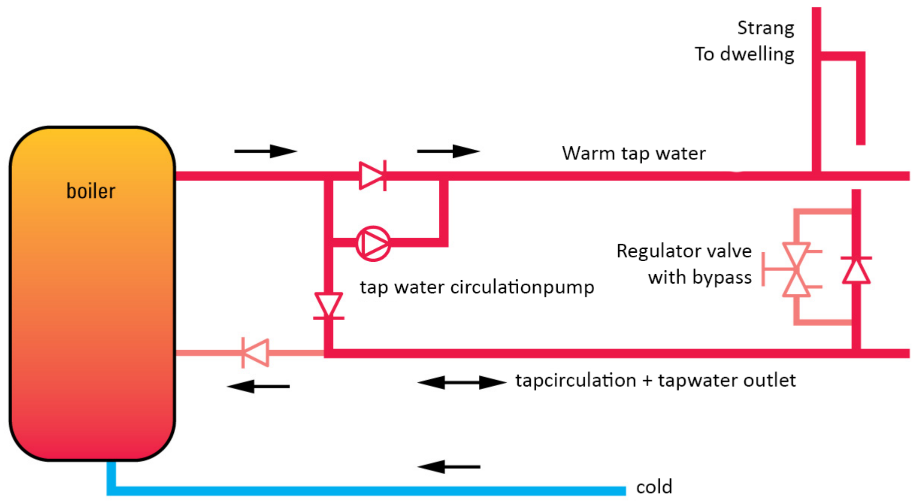

Figure 4.5: An example of an efficient loop. During high demand, hot water can be supplied from both pipes

4.2.3 Pipe insulation

Hot water pipes should always be insulated, whether dealing with a continuously hot loop or pipelines that are occasionally hot. The reason for this is to:

- prevent energy loss
- reduce downtime and increase comfort
- prevent adjacent cold water pipes from heating to a risky temperature.

Insulation must be applied over the full length of the piping, even over couplings, bends and valves; in floors and walls. Mounting brackets should be attached on the outside of the insulation. This is already standard practice for cold-water piping. Hot water generally requires more persuasion, but it's worth the effort. Figure 4.6 shows the values of various piping models.

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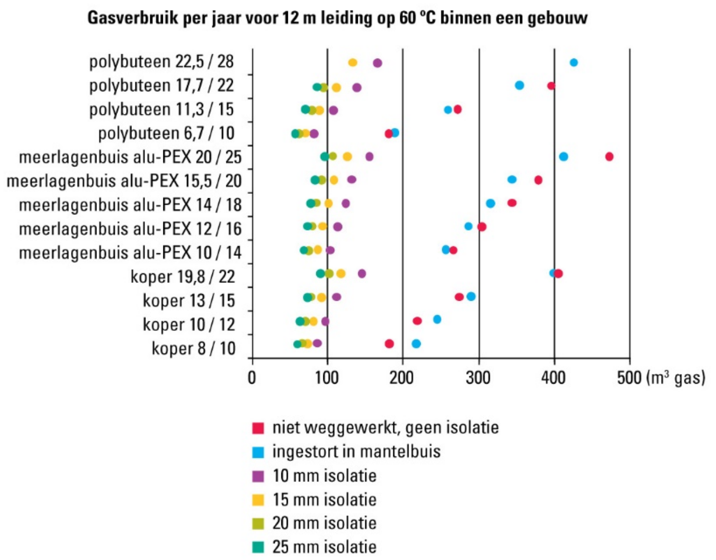


4.3 Water heaters

The following types of water heating devices are available:
• heaters (flow-units)
• storage units.

Both types can be implemented as a single- or combined unit. Only sealed devices are used in new buildings.

Efficiency of water heaters

The efficiency of tap water heating is determined by using standard domestic hot water flow patterns. In practice, the rate can be lower or higher (fig. 4.7).

The 'user efficiency' of a hot water heater, or the hot water part of a combi boiler, is considerably lower than the returns that we are used to on central heating boilers. The reason for this is that the user efficiency also includes 'stand-by' consumption (pilot light or tank heat loss). Also, these hot water devices run for long periods at full power, whereas modern boilers are more efficient using only part of their power. Fortunately, there are devices on the market that have a significantly higher return than the standard set by the CW-label (comfort warm water). The efficiencies included in these statements are theoretical and focused on use for EPC (Energy Performance Coefficient) calculation. In practice, efficiency is lower for several reasons. For example, if the resident switches to the 'comfort position' to instantly have hot water.

User efficiency does not only vary by device type, but also by brand, and the variations are sometimes considerable. This is shown in measurements collected by the Dutch Consumers Union (fig. 4.8).

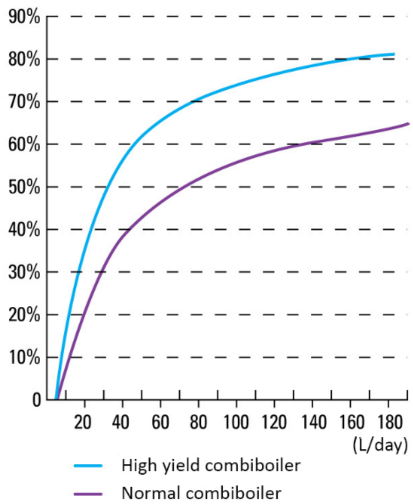
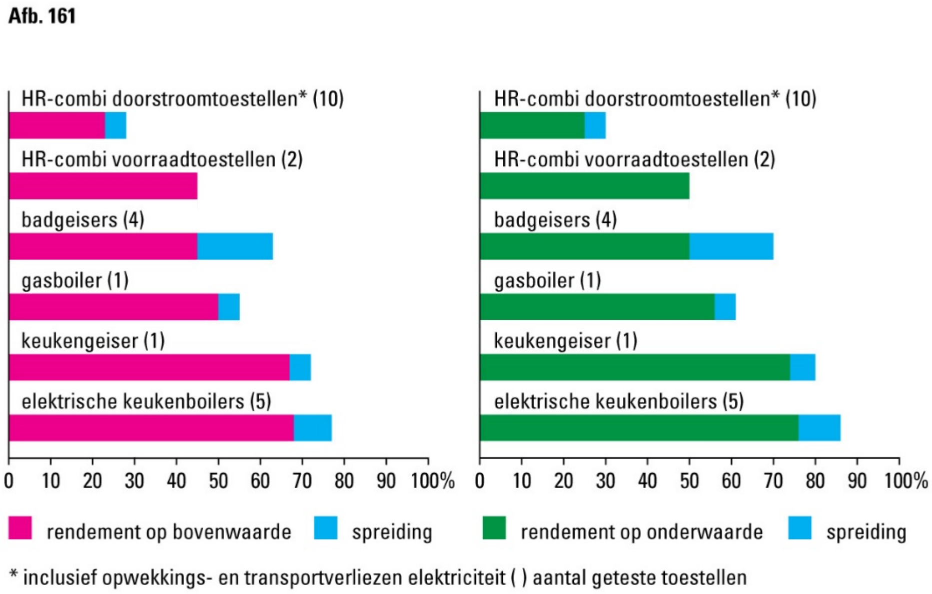


Figure 4.7: The user efficiency depends on demand. The consumption of a household varies between 60 and 180 L/day

Tap threshold

A minimum amount of hot water has to be dispensed to start a flow unit and this is called its 'tap threshold'. The threshold of most heaters is between 1 and 3 litres per minute.

The burner will not ignite if it's under the tap threshold. Alternatively, you may experience problems with the regulation of the water temperature. A device with a threshold of up to 1.5 litres per minute should be chosen to prevent problems with water saving devices (although many people use devices (with at least 10 L storage).without a tap threshold).



Vocabulary:
Badgeisers: bath geyser
Bovenwaarde: caloric efficiency (net heating value + condensation heat)
Gasboiler: natural gas heater
HR: high-efficiency
Keukengeiser: kitchen geyser
Onderwaarde: net heating value
Rendement: efficiency
Spreiding: distribution
Toestel: device
Voorraad: storage

Figure 4.8: Measurement results using return water heaters. These show that HR combi boilers do not necessarily achieve high returns. When choosing a device take the latency of it into account; this should be as limited as possible

4.3.1 Heaters

Theory: Water is heated as it flows through the heater. These devices have little or no storage space.

They are available in various forms, such as:

- combi boilers
- gas water (bath or shower) heaters
- electric heaters (flow units).

The latter is not energy conversion efficient.

Benefits

- They do not take up much space.
- Heaters usually consume less energy and water than storage units. This is due to the smaller DHW flow of these devices compared to stock units, which uses less hot water (simultaneously).
- They are cheaper to purchase than storage units.

Disadvantages

- Heaters provide less comfort than storage units (DHW flow and downtime).
- It is not possible to simultaneously use different tap points.
- There is a low tap threshold. The device should come into operation even when there is low hot water demand. This is important when applying water saving facilities, such as a water saving shower.
- They cannot operate on very low power. This can be problematic if combining with a solar boiler or heat recovery shower.

4.3.2 Devices with water containers

Theory: The water is stored in the unit and kept at a constant temperature.

There are a number of devices to choose from, such as a(n):

- combination device: A central heating system provides heat for both space heating and hot water. The boiler will keep the storage tank at a continuous temperature. Usually the water supply tank is integrated with the central heating (combi) boiler or is sometimes placed as a separate storage tank next to the boiler
- direct fired gas boiler: This will generally have moderate efficiency and loss during stand-by.
- solar boiler combinations or central heating solar boilers
- combined heat pump
- heat pump water heaters
- electric water heater

Benefits

- Comfortable due to the large DHW flow, which allows simultaneous flow from multiple taps
- No device downtime (except for a piping line)

Disadvantages

- Greater energy and water consumption: generally bigger than a heater (flow unit) due to the large DHW flow (fig. 159)
- Risk of hot water supply running out: can sometimes takes a while before being fully reheated
- These take up more space than a heater (flow unit)

Please note:

Both large and small electric water heaters are strongly discouraged due to the high consumption of primary energy. This also applies to the electric kitchen boiler which should not be required in a well-designed system. A large electric water heater consumes around 1800 kWh (450 m^3 of natural gas) and a kitchen boiler around 700 kWh (170 m^3 of natural gas)

Electric water heaters can function as a hot-fill device where the water is first heated by a gas-fired unit. The hot-fill tank is only facilitated by a small electric heater to heat the water from the pipe and compensate heat losses due to still water. This seems sparing, but calculations show that the hot-fill version has similar energy consumption to the fully electric kitchen boiler. This means that it does not actually provide any savings. A special type of electrical kitchen boiler is the ‘boiling water tap’. This is a small electric water heater with a capacity of 3-7 L at a temperature above 110 °C.

Boiling water can be rapidly poured through a special faucet for coffee, tea or soup,. If the tap is used exclusively for this purpose, the consumption is around 400 kWh per year, whereas a common electric kettle provides the same performance for 40 kWh. When the tap supplies the rest of the hot water, the consumption level is then comparable to a normal small kitchen boiler (700 kWh). The tap is constructed in a way that there is no danger of burning.

4.3.3 Combi boilers

A combi boiler provides heat for both space heating and hot water. These are the most used devices in the current building industry. These boilers are available as storage or flow units.

Benefits

- Cheap to run, only one heat source with associating supply and drain tube is needed and one gas connection
- Reduced maintenance costs as there is only one device
- High efficiency is feasible
- Does not take up much space

Disadvantage
There are generally great distances from the boiler to the tap in the kitchen. This creates a significant period of downtime and unnecessary water and energy consumption. Positioning the boiler near the kitchen tap and the bathroom is preferable and is generally a viable option.

Consider:
the combination of boiler and a solar energy system.

Combi boiler as a flow unit

The water in the combi boiler is heated through a heat exchanger (plate heat exchanger/tap coil) by the water from the central heating system. Most boilers do not supply heat to the central heating system at the same time that hot water is poured from a tap.

Flow units (combined) can be equipped with a:

- water buffer of several litres in the central heating system. This buffer provides the advantage that the boiler will switch on less frequently, which will extend the lifespan of the device. In addition, hot water can be delivered immediately. However, a small decrease in temperature can occur quickly, particularly in the smaller buffers, when waiting for the boiler to have heated enough 'new' water. Make sure this buffer is well insulated when selecting a device
- a comfort control. This ensures that the boiler remains at a temperature according to the user's preferences for tap water. This almost eliminates downtime, but leads to high standby losses and therefore lower user efficiency. This disadvantage can be limited by installing a timer so that the comfort position is only enabled at certain times, or an intelligent control system that recognises the resident's patterns of use.

Combined device as storage unit

The boiler has a built-in storage (tank) that holds 15 to 80 litres of water. Drinking water can be heated directly, as well as indirectly, through the central heating water. To ensure the device is manageable, larger boilers are generally delivered as separate elements and come with a standard coupler.

It is also possible for these devices to be assembled completely separately. This is known as an 'indirect-heated water heater' instead of 'combi storage unit'. On one hand, the small combi storage units have a high tap efficiency and low standby loss, and on the other hand there is a high level of comfort. There is no tap threshold and it is possible to simultaneously run water from various points. This form of heater is ideal when used as a shower-heat recovery unit or a solar boiler.

4.3.4 Collective tap water heating systems

Hot tap water is centrally generated in collective systems, by one or more boilers, and distributed through collective pipes to a number of dwellings or other users.

The central installation consists of:

- a buffer to absorb peaks in consumption
- preferably two boilers that can deliver the maximum required power together
- a heat exchanger with pumps between the heater and boilers
- a circulation pump from the coil
- security and monitoring control (including efficiency and legionella safety monitoring).

There are several types of collective tap water heating systems:

- Central heating: Tap water is heated by central heating water inside the dwelling. The supply temperature of the distribution system must be a minimum of approximately 70 °C, both in summer and winter, so that tap water can be produced at 60 °C. This causes a large energy loss (**fig.** 145).
- Separate hot water distribution network: By keeping water for taps and heating separate, both can be optimally measured. This results in energy loss being less than for a combined system, particularly when a low temperature space heating system is used. The hot tap water must be metered separately. This system is the one that is most used inside of buildings.
- Small boiler per dwelling: These are heated twice a day by the heat distribution system. The rest of the time, the system can stay at the low temperature required for space heating. This is a very convenient system for heating large areas such as whole building blocks.
- Heat pump boiler per dwelling: This uses the return from the heating system as its source. The system runs standalone in the summer and cools the house somewhat. In winter, heat from the collective network is used to preheat the tap water. The network adjusts to weather conditions in the summer and winter and has a relatively low loss as a result.
- Electric water heater per dwelling: This option is strongly discouraged as it will definitely offset all the savings made by the collective system.

Benefits

- By not having a water heater in a house there is:
    - more space
    - no need for a plumber to enter a house to carry out maintenance
    - no unwanted noise.
- A collective system is more reliable because backup power can be used if required.
- Very little boiler power is needed per house.
- This system is a more efficient use of renewable sources.

Disadvantages

- There may be pipeline losses.
- There is an increased risk of bacterial contamination in the portable water system (compared to an individual system.
- The hot water must be measured and billed separately.

Recommendation
Provide extra ventilation in the meter cupboard if the heat exchanger is placed in there to avoid temperatures becoming too high.

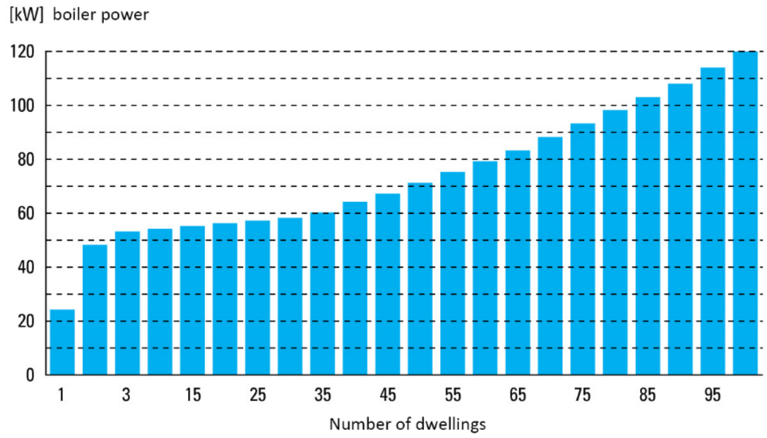


Figure 4.9: Boiler power for a collective system with a buffer of 10 L/dwelling. For 99% of the time, a third of its power is sufficient. Ensure that the selected boilers are able to provide (low) power without any problems

Please note:
It is not preferable to combine hot water- and space heating boilers because the latter require a much higher capacity and generally operate at a lower temperature, so with higher efficiency. The minimum capacity of a boiler used for tap water (lower modulation range) should never exceed one quarter of the power required for hot water (fig. 4.9). Should the power become too great, the efficiency will drop dramatically.

4.3.5 Solar boiler

Solar water heaters provide part of the heat required to heat tap water. Certain types of solar boilers also provide heat for space heating. These are usually measured so that about half of the annual consumption of fossil fuel for water heating is saved. In practice, a collector of 2.5 to 3m^2 and a water supply of ± 100 L saves around 125m^3 of natural gas per year.
Heat generation occurs not only when the sun shines, but also under the influence of daylight. Solar boilers are available for individual and collective systems.

A solar boiler system consists of a:

- solar collector or solar collector field: These convert sunlight into heat
- heat storage tank where the solar heated water is temporarily stored: Heat is extracted from the storage tank for hot tap water demand
- heat exchanger: This separates the collector water from the tap water
- additional heating: This provides additional water that has been pre-heated by the collectors.

The collector

The yield of a solar collector is at a maximum when it is directed to the south at an angle of 42°. The effect that a deviation in orientation, or inclination on the yield, has can been seen in fig.166. If the collector also supplies heat for space heating, the optimum angle is 52°. The collector then captures more energy in a low sun position in winter. Flat plate- (vacuum) and tube collectors are both options that are available, the latter in many different models. The best ones have a slightly higher efficiency at higher temperatures than flat plate collectors.

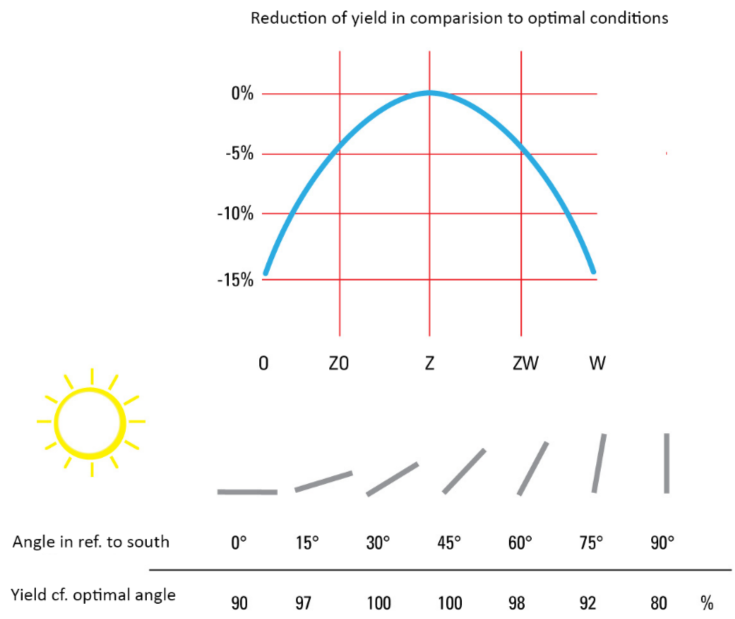


Figure 166: Yield of a solar collector (only for hot tap water heating) in relation to its orientation and angle

Benefits

- The higher efficiency of tube collectors: Collected solar energy can also be used for space heating.
- The flexibility of some of the models. For example, some allow for tubes to be placed horizontally on a flat roof, while the absorber can be rotated to the south.

Recommendation

Calculate, per resident, a collector area of around 1m². Costs for a large collector surface are relatively low, and it saves a fair amount on gas consumption.

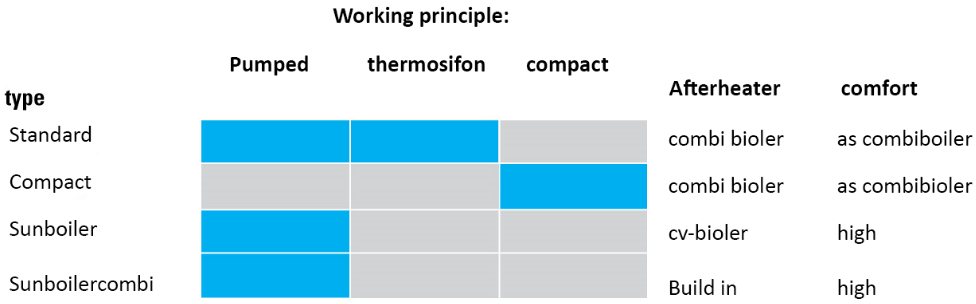


Figure 4.10: Overview of different types of solar collectors

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Figure 4.11: A flat plate collector left and vacuum tube collector right. Photos Redenko/ZEN (left) and www.viessmann.nl/energievademecum (right)

System assembly

It is important to make a choice between the different types of solar boilers in the early design stages. This is because the various components, such as collector and storage tank, have type-specific locations that are relative to each other. Also, the space required for certain parts varies.

There are different types of solar water heaters available:

1. Loop system (with pump)
2. Continuous filled and pumped system
3. Thermosyphon system (no pump needed)
4. Compact system

1. Loop system with pump

The collector circuit is equipped with a pump which is started once the collector is warmer than the water in the storage tank. It pumps the collector fluid from a return tank to the collector where the liquid is then heated and transported to the storage tank. Here the heat is transferred via a heat exchanger to the DHW. Once the collector is colder than the storage tank, the pump stops and the collector liquid runs back into the return tank. This also happens when the temperature in the storage tank is too high (80 to 90 °C). The loop system is protected against freezing and overheating if this occurs. The fluid is usually normal water without any additions.

Recommendations:

- The bottom of the collector should be installed at least 0.2 m higher than the top of the return tank (this is usually installed in the storage tank).
- Standard pumps in current systems have a discharge-head of up to around 4 metres. To keep the pump power and energy consumption low, the return tank should be placed as close to the collector as possible.
- The energy consumption of the pump and control system which is not negligible. Consider a system that supplies itself through a PV panel.

2. Continuous filled and pumped system

The collector circuit is filled with antifreeze and does not need to be emptied if there is a frost. If the temperature gets too high, the pump stops. The liquid in the collector starts to boil and the bubbles push the liquid from the collector to an expansion tank, protecting the system against overheating. In temperate and cold climates the liquid should be antifreeze. Disadvantage of antifreeze are that the liquid should be carefully collected during maintenance and may eventually degrade due to high temperatures. This should be checked regularly.

3. Thermosyphon system

The storage tank in the thermosyphon solar heater is placed above the collector. If the fluid in the collector is heated, it rises by natural force to the tank. The natural circulation saves around 50 to 100 kWh (= 15 to 25m^3 of natural gas) per year. To protect the circulatory system against frost, an agent must be added. There is also a provision against overheating the storage tank, as a thermostatic valve opens and discharges hot water and then cold tap water cools it. For example, the storage tank can be placed on the ridge of a loft if the distance to the collector is no more than around 3 metres. A special type is the ‘heat pipe’ collector, where the heat transports through a process of evaporation in the collector and condenses in the heat exchanger of the boiler. The collector and the tank are generally combined as one compact system.

4. Compact system

The storage tank and collector in this system are combined in one housing. There is no collector circuit, so, the tap water is directly heated. The bottom of the collector should be adjacent to a room where the temperature is at least 10 °C. This system also includes a protection against high temperatures in the storage tank.

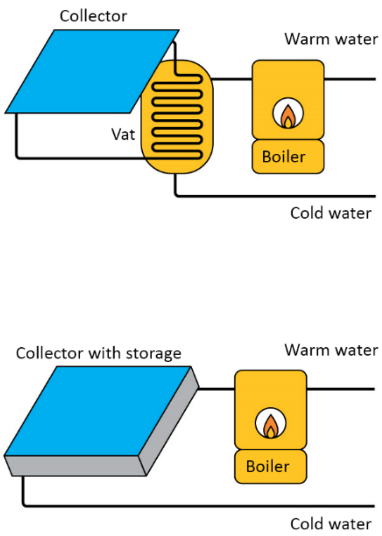

Figure 4.12: Top: The standard solar boiler. There are both upright and horizontal storage tanks available
Bottom: The compact solar boiler: solar collectors and storage tanks are integrated into one element

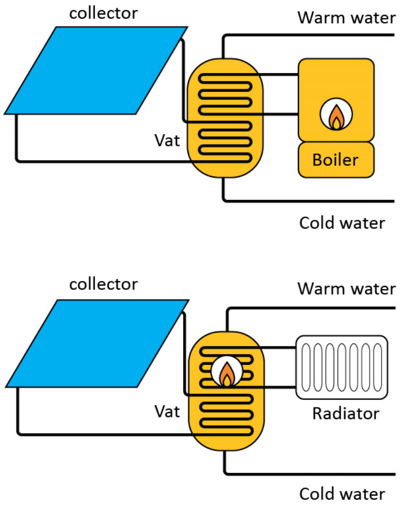

Figure 4.13: Top: The central heating solar boiler. The system can be compared with a directly heated system
Bottom: The solar combi boiler. This type of solar collector is a complete central heating tank for space- and tap water heating

Figure 4.14: Example of a compact solar boiler that can be placed on the ridge of the roof. There are also solar boilers for sloping or flat roofs. Photo: Inventum

Storage and reheating

There are three options for the storage and additional heating of tap water, each of which affect comfort levels.

- Separate storage and additional heating: Usually a combined device delivers the additional heating. This could be in the form of a 'standard solar boiler' or a 'compact solar boiler'. If it bears the label 'NZ' and has a modulation limit below 3 kW then the tap water should be at a comfortable temperature that is at least the same as the combined device.
- Storage and additional heating combined in one tank: There is a separate re-heating device (boiler) that heats water in the top of the storage tank when required. This is called a 'central heating solar boiler'. This system as a high tap water comfort level.
- Storage and additional heating combined with space heating in one device: This type of solar water heater is a 'solar combi boiler'. The tap water comfort level is high. The solar combi is highly compatible with a space heating system that uses low temperatures. This type of solar boiler (assuming the collector area is over 5 m^2) will save roughly 75 to 100m^3 compared to solar boilers (with an area of almost 3m^2) that only heat tap water.

Solar boilers in multi-storey building

A solar boiler system in multi-unit housing will require customisation. Special systems are available with a collective installation, or possibly a partially collective system. This has the advantage that the collector surface and, if used collectively, the hot water supply, may be smaller per dwelling. There are three variants:

- Completely individual: This is suitable for up to four storeys and the collectors can be mounted on the roof. The additional heating is individual.
- Collective use of collectors with an individual storage tank for each housing unit.
- The additional heating is individual.
- Collective use of collectors, storage tank(s) and additional heating.

Figure 4.15: Different examples of individual solar boilers in Delft (above) and Boxtel (de Zonnegolven, architect: Tjerk Reijenga, HBG)

Figure 4.16: A collective solar energy system on apartment complex Charivarius in Haarlem. A project of Eco Energy and Pré Wonen Haarlem; contractor Panagro, architect HMADP Group, advisor BOOM-S/I, built in: 2005. Photo: Eneco

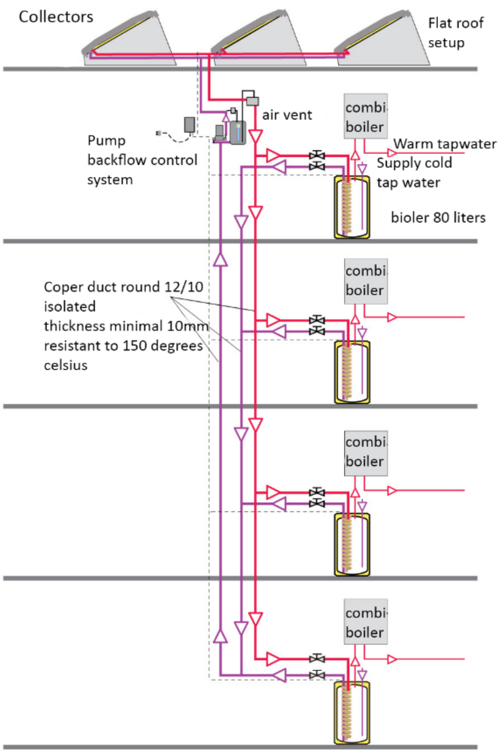

Figure 4.17: Collective solar boiler system with individual additional heating and storage. Drawing Aton

4.3.6 Heat pump boiler

A heat pump boiler uses the heat from exhaust ventilation air from a dwelling as a source for heating tap water. The heat from the ventilation air (20 °C) is cooled down to around 5 °C while the tap water is heated from 10 to 60 °C. The efficiency of a heat pump boiler is not as high as that of a heat pump for space heating due to the high temperatures that it reaches. The capacity is highly dependent on the product. The total annual return in primary energy is approximately 90 to 140% net (80 to 130% gross) with the lowest value being comparable to a good boiler. In this instance it would not make sense to use a heat pump boiler. Ensure that a device from the highest capacity category is chosen and demand that it comes with a certificate from a reputable testing institute. The heat pump boiler compressor has relatively low electric power (approximately 0.5 to 1 kW), which preferably transfers heat continuously from the ventilation air in the hot tap water. The heat pump is supplied with a large boiler that has at least 150 litres of capacity to allow for the fact that it takes a while for the water to be reheated after a large usage,.

Recommendation

Do not make the capacity too large as this will increase the standby loss and energy consumption as a result. The fan will switch to a higher position if not enough is heat available in the ventilation air or an electric (resistance) element will take over the production of heat. This is a waste of energy and so an undesirable scenario. Ensure that the minimum amount of ventilation produced by the heat pump boiler meets the dwelling's minimum ventilation requirements.

Please note:
Balanced ventilation with heat recovery (from the ventilation air) cannot be combined with a heat pump boiler because the heat from the ventilation air is only suitable for one service.
A special version of the heat pump boiler uses the return of the central heating system as a source which can cool the house a little in the summer. The efficiency of this system is higher than when ventilation air is used as a source. Apply this combination with balanced ventilation with heat recovery or district heating.

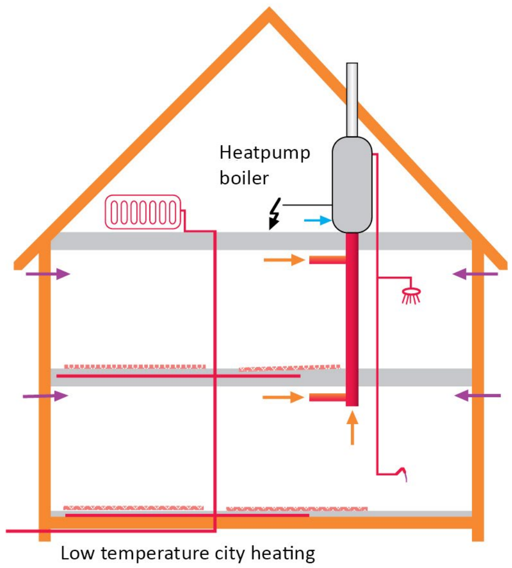

Figure 4.18: A diagram and an example of a heat pump water heater. Photo wpboiler: Sustainable Techneco

Heat pump boiler in multi-storey building

A heat pump boiler can be applied as replacement for electric boilers or unvented kitchen geysers in both new building and retro-fitting projects within the building industry.

In new developments, where no balanced ventilation is applied, the heat from the exhaust ventilation air can also be used collectively for space- or hot tap water heating. Although houses should preferably be individually equipped with mechanical ventilation boxes, in high-rises this should be supported by a central exhaust fan, which can easily be linked to a heat pump.

4.3.7 Combined heat pump

A heat pump for space heating may also provide hot tap water. Flow-units are not an option as a heat pump is not powerful enough to run one. Large storage tanks are more suitable to ensure that a consistent load is provided that does not hinder space heating (> 150 L).

The equivalent capacities for heating tap water generally cover class 4 for high consumption. The boiler's efficiency at a low consumption rate is even worse because the standby losses are high and the temperature level is difficult to maintain. The difference between the efficiency for space heating (160 to 240% gross) and water heating (75 to 120% net) for combined heat pumps is great. Remember that a modern high-efficiency boiler has an efficiency rate of 80 to 90% in class 4. In most new dwellings, as the demand for space heating and hot tap water is similar, tap water heating efficiency will prevail. Ensure that it does not have integrated electrical resistance, as this is not required for a well-measured system and efficiency therefore drops considerably to 50% or less. Pay attention to a larger space use for the boiler and to sound and vibration by the heat pump itself.