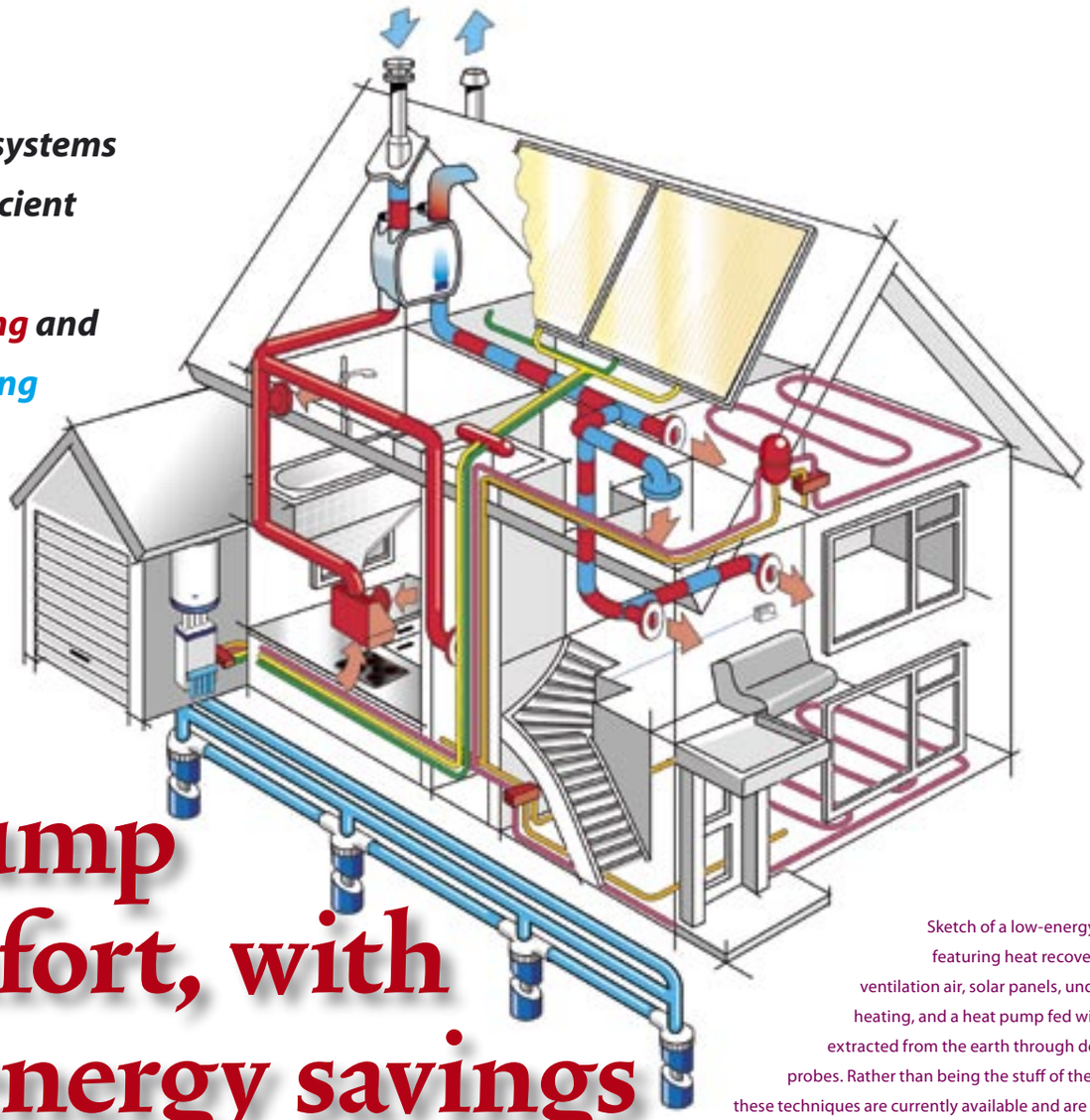
***Adapted-temperature systems for sustainable and efficient heating and cooling: low temperature heating and high temperature cooling***



# Heat pump for comfort, with added energy savings

Sketch of a low-energy house featuring heat recovery from ventilation air, solar panels, underfloor heating, and a heat pump fed with heat extracted from the earth through deep soil probes. Rather than being the stuff of the future, these techniques are currently available and are already contributing significantly to reducing the emission of $CO_2$. (courtesy Itho, Schiedam / www.itho.nl)

BY ASTRID VAN DE GRAAF

The high-efficiency central heating boiler is about to reach the limits of its potential, so innovative insulation and other energy efficiency solutions are required, even though energy consumption in the Netherlands per household has dropped by 70% since 1986.
Now that houses and offices are being fitted with increasingly efficient winter coats, an unexpected new problem has arisen, that of overheating. The savings through insulation are being squandered by air-conditioning units that are kept running all through the summer. According to Professor Ir. Hans Cauberg of the faculty of Architecture at Delft University of Technology, there is an efficient solution to this problem. A heat pump ensures that the cooling and heating processes are much more sustainable, and also more comfortable into the bargain. It will enable us to replace high-grade fossil fuels with sustainable, low-grade sources of energy such as ground water, geothermal energy, and waste heat. This will reduce the energy demand for heating by up to 40%, and for cooling by as much as 90%.
Cauberg and his researchers have already prepared new design rules for some practical, but not inconsiderable problems such as condensation and acoustics. The heat pump will play an essential part in our future energy systems.

As a staunch supporter of the Kyoto Treaty, the Netherlands has vowed to reduce the consumption of energy and the emission of the greenhouse gas $CO_2$. One of the means put forward by the Dutch government to achieve this goal, in newly constructed buildings, is the Energy Performance Standard, which determines the energy performance coefficient (EPC) new buildings must meet. It is a useful policy instrument, since it can be adjusted a little bit at a time. Where once an EPC of 1.4 was the rule for new housing construction, it is now 1.0 and as from 1st January 2006 it is to be readjusted further to 0.8. By tightening the standard, the government is also seeking to promote the use of sustainable energy so as to achieve the much needed reduction in $CO_2$ levels. However, high-efficiency central heating boilers are reaching their technical limits. The only solution is to innovate.

**Trias Energetica** Some time ago, Delft University of Technology developed a strategy that would enable the building industry to achieve the most sustainable use of energy possible, called Trias Energetica.
"Energy consumption can be reduced by reducing demand, maximising the use of sustainable energy, and making the most efficient possible use of fossil fuels," says Professor Ir. Hans Cauberg of the Climate Design department at the faculty of Architecture, who is also the managing director of the Cauberg-Huijgen Engineering Consultancy company in Maastricht.

Since 1986, energy consumption for heating purposes has decreased by 70% in every Dutch household. This is mainly the result of insulation, waste heat recovery, and improvements to central heating boilers. But in spite of subsidies from various quarters, the use of sustainable sources of energy has made little progress.

Cauberg: "Better and better thermal insulation quality will result in even thicker layers of insulation. Not only will it reduce the available space inside, it will also lead to all kinds of problems with structural details. After all, if you buy a fridge, you want the case to be as thin as possible so you can put more inside. A recent development in this respect is vacuum insulation. By putting sheets of insulation material inside an aluminium bag, extracting the air, and then sealing the package, insulation materials can be reduced to one fifth of their thickness."

TU Delft has taken up the development of building products based on this technique, starting with prefab facade cladding panels and insulated exterior doors. International collaboration has also been started under Annex 39, High Performance Thermal Insulation, a programme of the International Energy Agency in Paris.

## Forty per cent reduction

The fact that the heat pump could play a major role in the application of sustainable sources of energy, was something Ir. Peter Oostendorp of the department of Refrigeration & Heat Pump Technology at the research establishment TNO Built Environment & Geosciences had already noticed a quarter of a century ago. He has been involved in their development and application ever since.

"The first oil crisis of 1973 generated a lot of interest in the development of sustainable energy techniques. However, with the sharp drop in energy prices a decade later, Dutch efforts in heat pump research slackened as the economic viability of the concept came under pressure. What's more, some disappointing results from pilot projects during the nineteen eighties did not help much either, even though these were mostly due to incorrect set-ups and connections."

It was not until after 1990, with the increasing awareness that it was the impact of greenhouse gases like $CO_2$ that threatened our society, rather than the depletion of fossil fuel resources, that interest in the heat pump was rekindled.

The potential for energy savings with heat pumps is very high. According to Oostendorp they can reduce energy consumption by as much as 20 to 40 per cent. Oostendorp: "It is a finely tuned device, which responds immediately to any difference in the temperature it is asked to produce. It really comes into its own in combination with underfloor heating, when it will bring the 40% reduction within our reach."

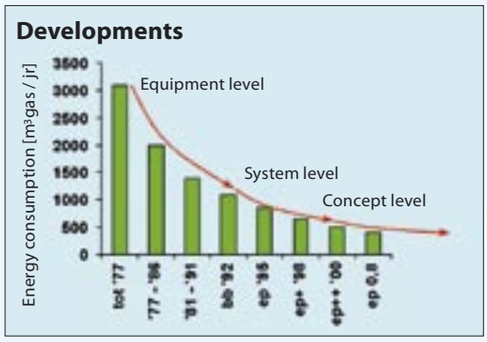
## Heat pumps

Heat pumps are hardly the latest news. Most of us own one in fact, since a refrigerator uses a heat pump to move heat from inside the fridge to the environment, from a low-temperature region to a higher temperature level. Inside the fridge, all we want is the cooling effect of the device.

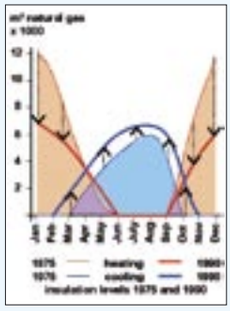
Whereas with a heat pump in a heating system it is the warm end we are interested in. To heat a room, all you have to do is turn the fridge back to front, with its open door in the outside world. Basically, a heat pump is a type of heat exchanger consisting on one side of an evaporator that collects heat, and on the other side a condenser that gives off heat. The efficiency of the heat pump increases as the difference in temperature it has to bridge gets smaller. This is why heat pump systems in houses use low-temperature heating (LTH) systems such as floor and wall heating panels, which can maintain a room temperature of 20 °C with a hot water supply temperature in the 25–35 °C range. This is what makes heat pumps so attractive. They can be used to raise low-grade heat from sustainable and alternative sources of energy to a useful higher temperature level. Heat pumps require relatively little energy to bring about this temperature lift (compression of the heating medium).

## Energy sources

Cauberg: "We are currently rapidly depleting our natural gas resources for heating purposes, which is a low-grade application. We tend to think too much in terms of energy, when in fact we should be looking at the exergy content. This is the Carnot process, i.e. the capacity to convert heat into power. Natural gas is a high-grade type of energy, with 100% exergy. The conversion of natural gas into, say, very high-temperature steam enables us to produce electricity, another high-grade form of energy, relatively easily,. Steam

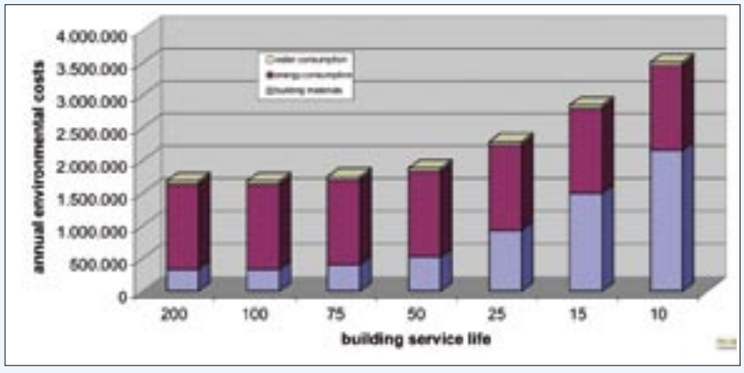



The result of the efforts of the past 25 years have resulted in a reduction in energy consumption for interior home heating of 80%.



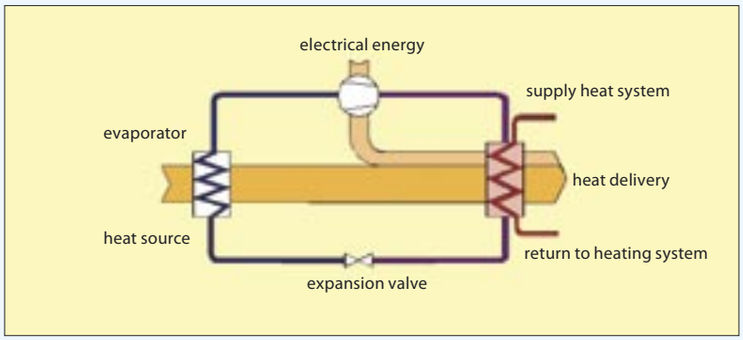
Although thermal insulation greatly reduces the heating power demand, it increases the demand for cooling power.

As the doctoral research of Andy van den Dobbelsteen shows, the marked increase in internal heat in offices, mostly produced by computers, has resulted in inefficient and often spur of the moment cooling measures, like haphazardly installed air-conditioning units.

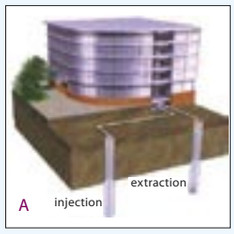


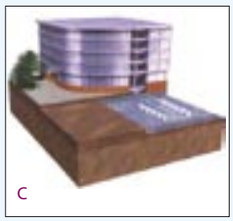

Given the normal office building service life of fifty years, the energy consumption for climate control is by far the greatest contributor to the total environmental impact of the building. As the service life of a building decreases, the relative environmental impact of its construction materials increases.

New thermal insulation materials continue to appear on the market, including these vacuum insulation panel. The thickness of the so-called VIP panels (right) is only one fifth of that of traditional insulation material (left), even though the insulation value is the same.
(courtesy VIP-Bau /www.vip-bau.ch)



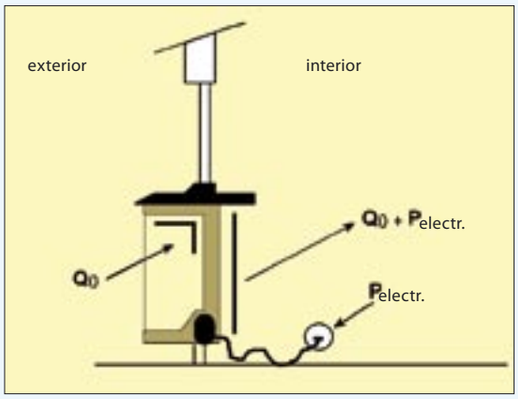

Principle of an electrically-powered heat pump. The pump raises sustainable, low-grade energy to a higher temperature level. The electricity powering the pump is converted into heat and added to the heat output (ideally, a floor and wall heating system).
(courtesy TNO-MEP)





Several ways exist to extract heat from the earth below us. (A) The method most commonly used in the Netherlands is to extract energy from water in underground aquifers. (B) Vertical heat probes (heat loops) extract heat from the earth (in the winter) or inject it (in the summer). This is a closed system. (C) A method less often used is to extract heat from ponds (due to their limited capacity).
(courtesy Groenholland, Amsterdam / www.groenholland.nl)




Most of us have a heat pump in the house, as illustrated by this fridge in a wall in a drawing from TNO-MEP, which has been doing research on heat pumps and their applications since 1977.
(courtesy TNO-MEP)

Installing a heat loop in the earth. Whereas houses in other countries will often be fitted with a heat pump fed by a horizontal heat exchanger at a depth of 0.6 – 1.2 m and spread out over an area of 200 $m^2$ or more, this is not a viable proposition in the densely built-up areas in the Netherlands. Vertical earth probes provide a solution for individual house systems. (courtesy Groenholland, Amsterdam www.groenholland.nl)

with a temperature of 100 °C is already much less useful. In our central heating boilers we use natural gas to produce flue gases of 800 °C which are then used to heat water to 90 °C so we can pipe it through our central heating systems. This is a massive waste. It makes much more sense to use low-temperature sources of energy for heating purposes, since they contain little exergy, which makes them perfect for heating."
According to Cauberg, to be able to use heat pumps we must first find heat sources with the highest possible constant temperature. Eighty metres below ground level the temperature is approximately 16°C, so earth heat meets the requirements. Sea water and river water also are acceptable suppliers of sustainable energy. Perhaps the water in twenty metre deep gravel pits can be used for heating. Cauberg considers air-to-air systems, as used in Norway, Sweden, Switzerland, Japan and other countries, not so suitable because of their low temperature during winter, when the heat demand reaches its maximum.

**Comfortable combination** Saving energy and reducing the emission of $CO_2$ are not the only reasons for considering the combination of a heat pump and floor heating such an attractive proposal. The system also brings comfort through heat radiation. Humans experience radiation as more comfortable than heat by convection as produced by normal radiators. What goes for heating also goes for cooling systems. An air-conditioning unit blowing a jet of cold air is not as nice, or healthy, as being surrounded by cool walls and floors.
The piping installed for floor or wall heating can easily be used for cooling purposes during the summer, making the high-temperature cooling (HTC) system the natural counterpart of the low-temperature heating (LTH) system. Unlike heating water, the water required for cooling can usually be pumped straight from the earth and into the piping without the need for a heat pump, leaving only a minor (high-grade) energy requirement for pumping the medium through the system. The heat pump itself can remain switched off. This cooling method can reduce the energy consumption for cooling by as much as 90%. In addition to the considerable savings in energy, the combination of HTC and LTH also prevents thermal pollution of the earth, since the heat extracted in the winter is put back into it during the summer.

**Cooling** According to Dr. Ir. Andy Van den Dobbelsteen of the faculty of Architecture, the Government Buildings Agency was the first to publish research results showing that the cooling of offices is overtaking the importance of heating.
"The results showed that, in spite of energy-saving measures, energy bills were increasing rather than decreasing. If you look at the buildings from above, you can see why, since the roofs are littered with little boxes where cooling systems have later been added. Another reason is that climate control systems tended to be used in the wrong way, or had been incorrectly installed.
From his own recently completed doctoral research, Van den Dobbelsteen concluded that recently completed office buildings were not much better from an environmental point of view than those built fifteen years ago. Based on a 75-year service life, which on the grounds of sustainability would be reasonable

for an office building, the energy consumption turns out to account for almost 80% of the environmental impact. About 90% of this is spent on heating and cooling, lighting, and the use of computers. The current energy demand for cooling in offices is as high as it is for heating purposes. This development will continue according to van den Dobbelsteen. Increasingly intensive use of office space – more people, more computers, and more lighting per given area – will also increase internal heat production, so cooling will become much more of a problem in the future.

**Winter coat** Van den Dobbelsteen: "Modern buildings have a warm winter coat which they also wear throughout the summer. As a result, the heat can no longer escape. This is compounded by the fact that more heat than ever is being produced by a plethora of computers and their peripheral equipment. So, the air-conditioning equipment has to be kept running all summer. We must adapt to this development by basing our design for new buildings on the actual energy demand. This will enable us to build offices that use much less energy and reduce their environmental impact to five per cent of the current score. Heat pumps can be an effective and energy-saving cooling technique if they are connected to wall and floor systems."

According to Van den Dobbelsteen it is best to use flexible construction systems, in particular because practical experience has shown that office buildings tend to become functionally obsolete after about 25 years, while developments in the field of energy move even more rapidly.

"Incorporating piping in the floor or in the building's structure shouldn't be a problem as long as we ensure that the energy conversion system remains readily adaptable. We may think we have cracked it, but in another ten years a new system will become available. Since burrowing underground for every separate building or house isn't really an option, it might be a good idea to think of LTH and HTC in terms of district– or town-scale systems. That way, the energy patterns of offices that need cooling and houses that need heating could be effectively balanced. Technically there is no problem, but legal and practical matters form an obstacle since so many different parties will need to collaborate and bear the risk."

**Seawater and mineshafts** The fact that so far the heat pump hasn't been able to oust the high efficiency central heating boiler in the Netherlands is mainly due to the ready availability of cheap Dutch natural gas and the lower initial cost of these boilers, Cauberg stresses. Now that the energy standard is being tightened and energy prices are rising, more initiatives are being taken. In the local authority in the old mining town of Heerlen has launched a study into the use of water from flooded mineshafts. These shafts contain water of 32 °C at a depth of between 500 and 600 metres. New buildings in the area are already being prepared for low-temperature heating and high-temperature cooling. The mineshaft water project has been included in the Interreg programme of the European Union.

Cauberg: "There is no way you are going to meet the physical quality requirements by adding systems later on, so these houses and offices have to be prepared for low-grade energy applications in advance. Until the time is ripe, they will simply use high-efficiency, but exergy inefficient boilers."

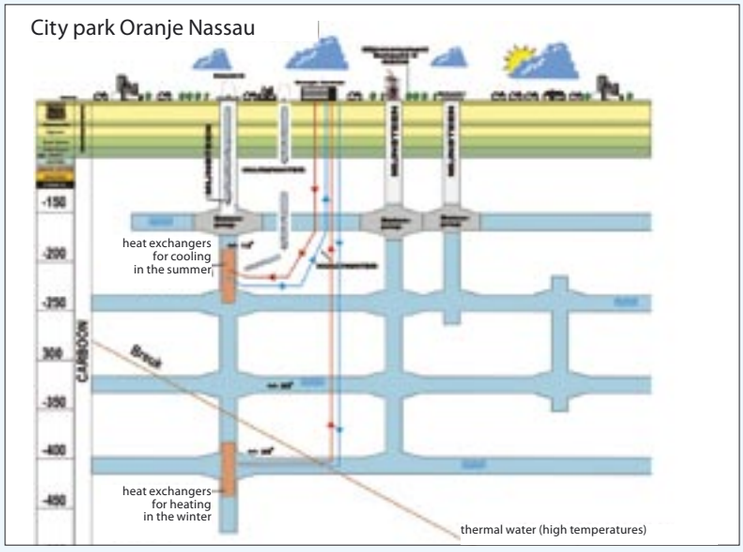
Various pilot projects have been set up for other low-grade energy sources. In the neighbouring town of Geleen, a block of houses that is being refurbished will reclaim waste heat from ventilation air and use it to heat domestic hot water. In Scheveningen, a seaside resort of The Hague, the Vestia housing corporation has launched a project to heat houses using seawater as the heat source. And at Heerhugowaard, some 50 kilometres north of Amsterdam, an office block is the first in the Netherlands to be built on piles that double as heat exchangers, extracting heating and cooling energy from the earth.

By giving structural elements extra functions, like turning them into climate-active building components, the application of low-grade energy systems can become even more efficient. The IEA has started a new annex 44: "Environmental Responsive Building Elements".

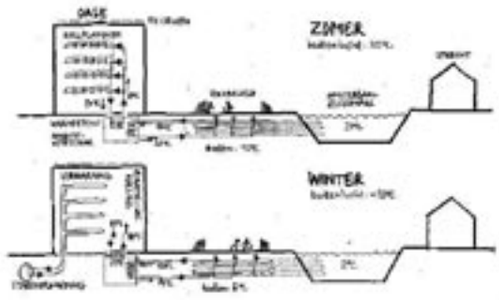
**Condensation** The increasing demand for cooling during the summer months may really boost the popularity of the heat pump/geothermal energy combination. To prevent problems with condensation on floors and walls when the system is used for cooling purposes, building physicist Dr Ir. Wim van

Another option is to use special piles doubling as heat exchangers. The heat extracted from the earth is fed through a closed circuit inside the pile to the heat pump.
(Photograph and drawing Betonson, Son / www.beton.com)


Commissioned by the Vestia/Ceres housing corporation, the Deerns company of engineering consultants have developed a plan to heat 750 new houses in the Duindorp quarter of Scheveningen within the next three years using a seawater heat plant located in the harbour. The houses will feature individual heat pumps connected to the plant's source heat network.

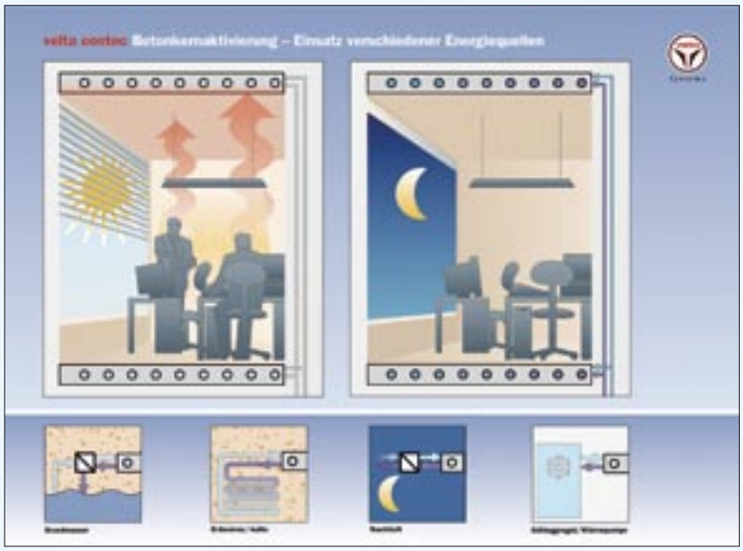



The town of Heerlen plans to use water from flooded mineshafts to heat and cool buildings at the Stadpark Oranje-Nassau and Heerlerheide Centrum locations. The intention is to tap into the mine shafts at a depth of 500 metres, where the water reaches temperatures up to 32 °C. The water is pumped up to the surface, fed through heat exchangers connected to heat pumps, and then fed back into the deep underground shafts.



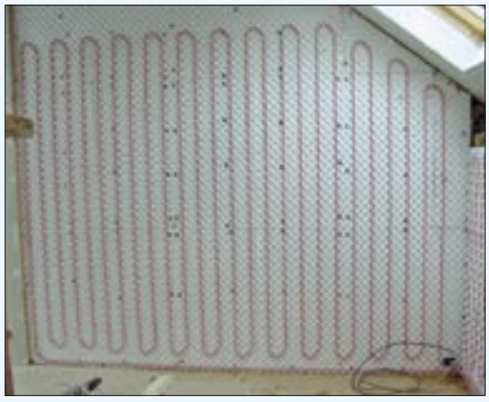

Cooling and heating system

Rivers and canals are also increasingly being looked at as a potential source for low-grade heat. At Terneuzen, some 50 kilometres west of Antwerp, heat is extracted from the Scheldt river for the Ministry of Transport and Waterways offices, while in Maastricht, the Provincial Council offices are heated using energy extracted from the river Meuse.




Thermal active concrete structures can be used in the summer to cool buildings practically without any need for additional cooling equipment. An active floor connected to an aquifer can comfortably provide a cooling capacity of up to 45 W/m$^2$. During the winter the floor provides a basic heating capacity that is usually augmented with a controllable central heating radiator.

With concrete structures poured in situ, the climate control piping is attached to the reinforcing bars before the floor is poured. In some cases the rebar netting is supplied complete with piping as a prefabricated unit.

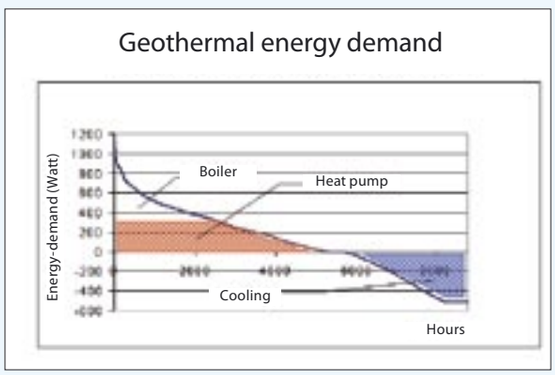


Heating and cooling through walls is becoming increasingly popular. In refurbishing projects in particular it is often combined with improved noise reduction measures in separating walls. A drawback of the system is that walls need to be kept free of furniture as much as possible in order to ensure optimum heat transfer.

der Spoel, a lecturer at the faculty of Civil Engineering, has drawn up a set of general design rules. Condensation is a problem that occurs mostly in houses, since they do not use preconditioned ventilation air. As the temperature of the cooled floor decreases, the relative humidity of the air close to the floor surface rises, and with it the risk of condensation. High relative humidity levels also carry with them the risk of mould forming on surfaces. To stop this happening, the relative humidity of the air near the surface of the top floor must not exceed 80%. Van der Spoel has translated this into an optimum temperature of the water flowing through the pipes of between 16 and 18 °C, depending on the geometry of the floor, the heat conducting properties of the materials used, and the variable production of moisture by the occupants, their pets, and plants. Van der Spoel: "At these temperatures, the floor temperature will be around 20 to 21 °C. If a higher cooling capacity is required, and the humidity of the air is not too high, you can easily lower it to 19 °C, which is the lower limit for the floor temperature from a thermal comfort point of view. Active control to take into account the actual relative humidity of the air next to the floor surface still remains difficult to realise, because of uncertainties regarding the accuracy of the instrument readings and practical objections such as carpeting and furniture being moved around.

**Acoustics** In office buildings, according to Cauberg, floor cooling often translates into the adoption of mass cooling or thermally active floors. This approach hails from Germany, and uses a system in which the floor heating and cooling ducts are incorporated into the load-bearing floor structure rather than in the screed. During the summer, the system cools with water of 16 °C obtained from an underground aquifer for example. In this way, the entire building structure becomes thermally activated, and helps to retain the cooling effect for as long as possible. Since the ceiling needs to be in direct contact with the air inside the building for the transfer of heat to take place, this introduces another problem, that of interior acoustics. A standard noise-reducing ceiling can no longer be used. So, Cauberg came up with the noise-reducing partition wall and the ceiling satellite, which covers about 30% of the ceiling surface and is suspended below the floor.

**Spearhead** The lagging interest in heat pumps prompted the Dutch government to spearhead their promotion in its energy policy plan. In the year 2020 the use of heat pumps in houses and other buildings is intended to result in an energy saving of 26 PJ. In late 2002heat pumps in operation in buildings in the Netherlands numbered about 33,000, according to the Heat Pump Survey published by Novem, the Netherlands Agency for Energy and the Environment. The total energy saving came to about 1 PJ per annum, resulting in a reduction in $CO_2$ emission of 39 kt per annum. About 37% of all heat pumps are installed in houses.




The capacity of the heat pump is adapted to the thermal energy demand of the building. This usually results in bivalent heat generation, in which a central heating boiler assists the heating effort when outside temperatures drop below a certain point. This greatly improves the average annual yield of the heat pump system. The desire to achieve a thermal balance in the earth is a prerequisite for a satisfactory long-term solution. Any heat extracted during the winter will have to be put back over the summer.

Oostendorp of TNO Environment calculates: "Each year, about 60,000 houses are being built in the Netherlands. If the Dutch government really wishes to achieve its stated objective of about 1 million houses with heat pumps in 2020, every newly-constructed home must have a heat pump from now on. One could also take the current number of existing houses, which is about 6 million. Every year, about six per cent of these need a new heating system, in other words, some 360,000 new systems are installed each year."
So, a lot remains to be done before heat pumps have conquered the Netherlands. This is why the four-year Heat Pump Covenant for the housing industry that expired last year, has been succeeded by the Dutch Heat Pump Platform, whose purpose is to continue the transfer of knowledge and promote the widespread use of the heat pump technology.

**Sustainable business behind the meter** Professor Cauberg thinks that that the reason heat pumps have not yet become widely used in the Netherlands is the initial costs. The Dutch still haven't got used to the idea of adding initial cost to running costs. Given the temperatures during the cold winter months and the high density of built-up areas, in the Dutch situation the collective extraction of geothermal energy would be the best option for a heat pump system energy source. An owners' association could manage the heat pump and charge the owners for their energy consumption for each group of houses. Another option Cauberg favours is one in which the housing corporations, property developers, energy suppliers, or contractors handle the investments required for running a heat pump and then sell the heat, just like electricity or gas. In this way, using heat pumps – i.e. sustainable energy – will simply make good business sense.
A number of prominent property developers in the Netherlands have now taken the initiative to draw up a plan that will make it more attractive to increase the proportion of sustainable energy used in newly constructed houses. The plan has been given the name of Business Plan for Sustainable Energy Behind the Meter and has received government support. The mainstay of the plan is an integrated approach, i.e. the development of ideas based on the concept of housing and comfort rather than lots of separate little plans.
Cauberg: "The use of heat pumps takes up a prominent part of the plan. This is bound to boost their application. It is a purely autonomous process, not a subsidy-driven incentive; just market parties using comfort and health as their sales pitch. These are things that prospective house owners are willing to pay money for, and they get the energy savings thrown in for nothing."

For more information please contact Prof. Ir. Hans Cauberg, phone +31 15 278 3378, e-mail j.cauberg@bk.tudelft.nl, or Dr. Ir. Andy van den Dobbelsteen, phone +31 15 278 3563, e-mail a.a.j.f.vandendobbelsteen@bk.tudelft.nl, or Dr. Ir. Wim van der Spoel, phone +31 15 278 3368, e-mail w.s.vanderspoel@bk.tudelft.nl.

## New chair Climate Design & Environment at the Delft faculty Architecture

CD&E deals with the scientific area that creates design methods and solutions for the integration of a secure, comfortable, healthy and functional indoor environment, to be used by designers of the built environment (or for the benefit of its creation), on condition of the lowest possible use of materials, water and energy. In brief it stands for sustainable design of building systems.
Research results of the scientific areas of Building Physics, Building Services, Building Technology, Physiology and Behavioural Sciences are applied for the development of design strategies, knowledge systems, climate concepts and energy concepts, guaranteeing a functional interaction between architectural, constructional and climatic designs.
CD&E core competences are closely related to the integration and application of knowledge from various disciplines for the purpose of development, design and realisation.

Since floor cooling systems rely on a direct exchange of heat between the underside of the floor and interior air, traditional noise-reducing ceiling solutions cannot be used. In order to ensure a sufficiently high level of noise reduction, a ceiling satellite covering about 30% of the ceiling area can be fitted. The top and bottom of the suspended ceiling element are covered with a noise-reducing layer, while the ambient air is free to flow around it.

An increasing number of Dutch houses are being fitted with individual air-conditioning units. The current generation of air-conditioning systems can also be used for heating purposes. From an energy point of view, these air to air systems are far from ideal, since they have to bridge a greater difference in temperature than would be necessary with a system using the earth as an energy source and combined with a floor heating system. In Sweden, Norway, and Japan air-to-air systems are in common use, but in those countries the use of electricity as a heating medium is traditionally widespread.