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

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 CO₂. 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 CO₂ 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 in 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

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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%.
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 CO₂ 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
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.

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.

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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.

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.”

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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.