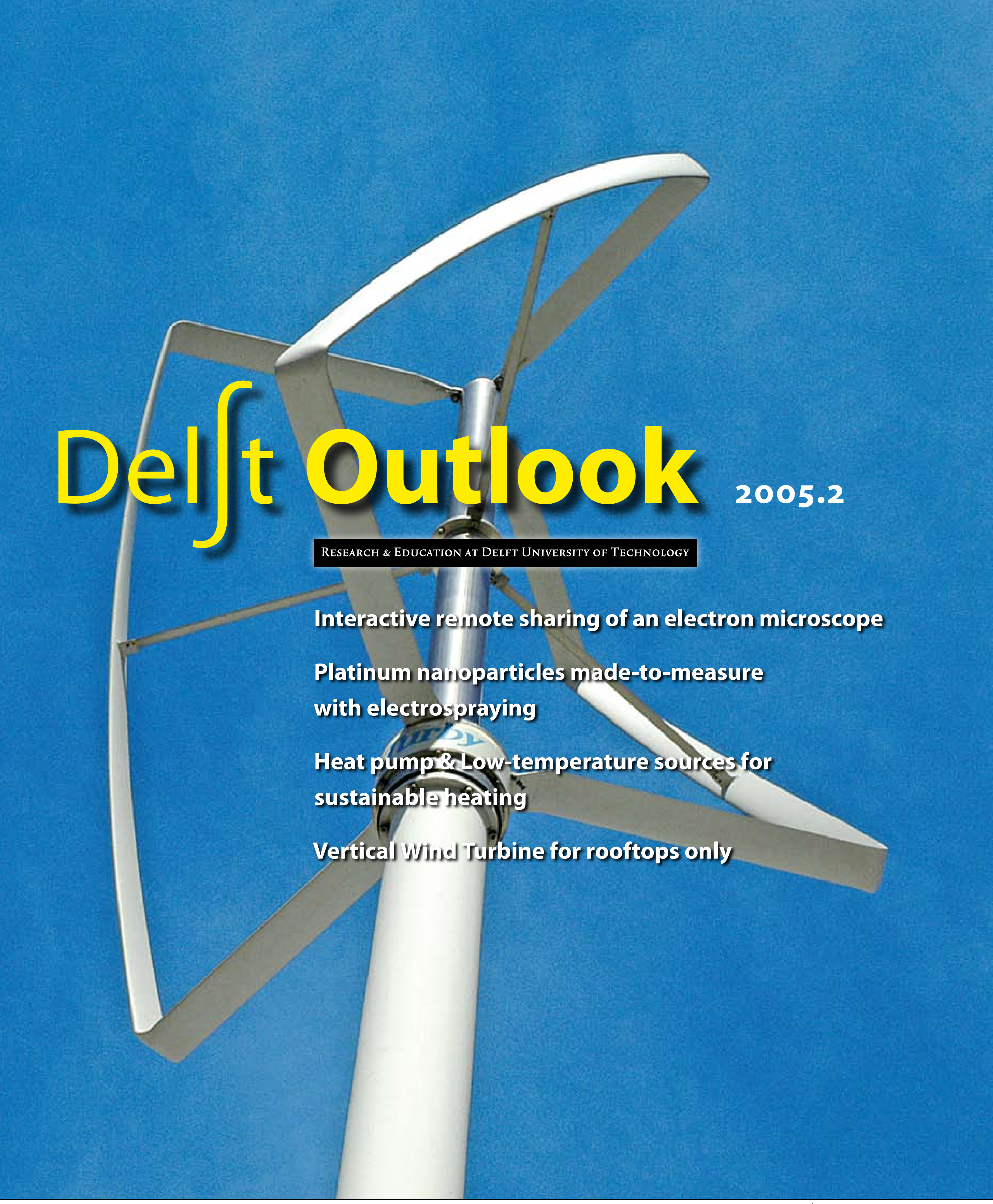


Delft Outlook 2005.2

RESEARCH & EDUCATION AT DELFT UNIVERSITY OF TECHNOLOGY

Interactive remote sharing of an electron microscope

Platinum nanoparticles made-to-measure with electrospraying

Heat pump & Low-temperature sources for sustainable heating

Vertical Wind Turbine for rooftops only

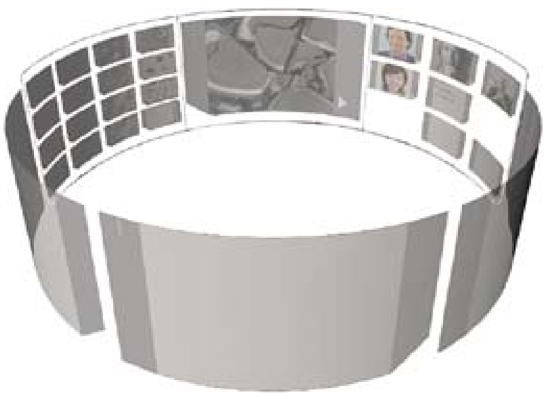
TU Delft

Delft University of Technology

CONTENTS

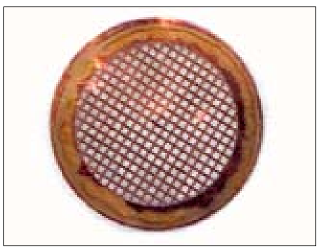
03
Interactive remote collaboration for electron microscopes

Though used widely in many different fields, the electron microscope is still an expensive kit, with the cost easily running into a million euros. And while some companies would be able to afford one, they might not have the amount of work for it to justify the expense. Equally, there are many situations in which a researcher would like to discuss the microscope images with one or more colleagues located elsewhere, such as in the medical field. Students Industrial Design engineering, inspired by the famous 19th century Mesdag panorama painting, have developed a virtual remote collaboration environment. Using this system, whose development was commissioned by FEI Company, users can remotely control electron microscopes and other equipment, exchange data, and communicate. The student's collaboration, which mainly took place in cyberspace, produced a working prototype in only four months. They even found the time for a presentation in Japan as well.



08
Nanoparticles made-to-measure; Aerosols prove to be indispensable for nanotechnology

Nanotechnology is the buzz word. There's no getting away from it when you are in particals, experienced Jan Marijnissen at the aerosol lab of Delft ChemTech. He was put the question whether it was possible to make platinum particles with a diameter of less than eight nanometres. Together with graduate student Jan van Erven and the famous aerosol expert Sheldon Friedlander of the University of California (UCLA), and the University of Karlsruhe, Germany, Marijnissen set out to experiment. Using different methods with his electrospray technique Marijnissen and his team demonstrated to be able to produce platinum nanoparticles from a platinum compound. They are as little as 10 nanometres, which is ideal for the catalytic oxidation experiments on exhaust fumes from diesel engines.



COVER PHOTOGRAPH: The Turby wind turbine

12
Heat pump for comfort, with added energy savings; Low-temperature systems for sustainable and efficient heating and cooling

The energy crisis in 1970's was an extra stimulant for the science and industry to look into ways to reduce the consumption of energy by inventing and introducing more efficient heating and cooling systems. The central heating boiler has reached an efficiency of 98 percent and is about to reach the limits of its potential. So innovative insulation and other energy efficiency solutions are required, even though energy consumption in Europe and North-America has dropped tremendously over the last decades. In the Netherlands the energy consumption per household has dropped by 70% since 1986.
While 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 heat pumps are an efficient solution to this problem. They ensure 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%.

18
Turby - Sustainable urban wind power from the roof top

If current trends are anything to go by, in future we will no longer produce all our electricity in large, central power stations. Small-scale local electricity generation will gain in importance. Since a few years the idea has grown that consumers and companies could generate electricity locally with natural gas, with the extra benefit of being able to use the heat produced by the small gas generator for local use with little loss. A new addition to this idea is Turby. Sander Mertens, a post-doctoral student at TU Delft, developed an aerodynamic design of a wind turbine which is specifically suitable for built-up areas. Compact, mobile, low-noise, and vibration-free, it is the ideal alternative for use on top of high-rise office blocks. Here wind can easily reach a speed that is twenty percent higher than at the same height away from buildings. The electricity can be fed straight into the building's power system, saving on energy transport costs and losses. Every kilowatt produced this way, means a saving at the kilowatt rate charged by the national grid, thus ensuring a high return on investment. Prototypes have already been installed on the town hall in The Hague, on an apartment block, on office blocks and on top of the Delft ChemTech faculty building, with international projects on the way.

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Interactive remote collaboration with electron microscopes

Joint production of design teams from London, Lausanne and Delft

The high cost of an electron microscope makes remote collaboration a sure-fire way of increasing the operational efficiency of this type of equipment. A pathologist can now be consulted from a remote location by the microscopist, and a manager at a steel plant can discuss a problem with the researcher at a metallurgical institute, with both participants watching the same image and being able to manipulate the microscope samples.

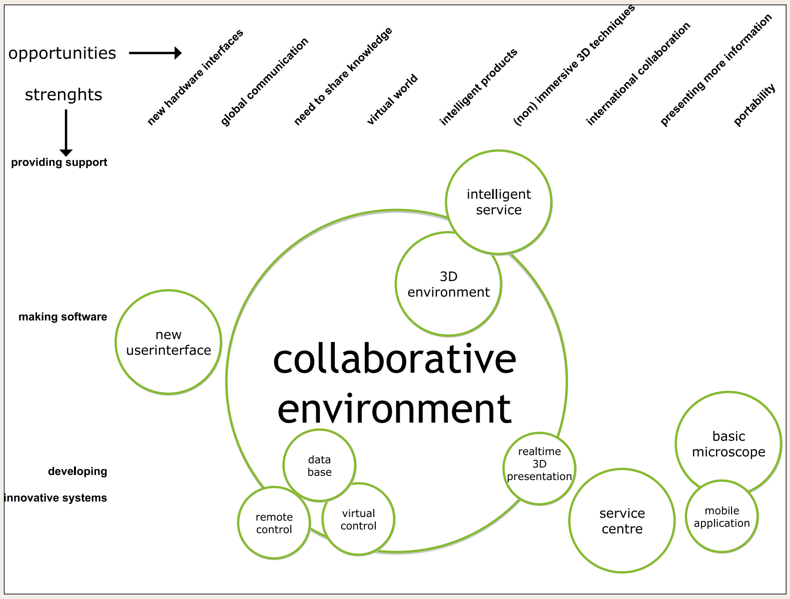
By Joost van Kasteren

Since the cost of an electron microscope easily runs into a million euros, many businesses and organisations simply cannot afford to buy such an expensive instrument. And though some companies, like the British/Dutch steel manufacturer Corus, would be able to afford one, they do not have the amount of work for it to justify the expense. Equally, there are many situations in which a researcher would like to discuss the microscope images with one or more colleagues located elsewhere, or when the pathologist's assistant asks his superior to hop over for a look at some abnormal images — three buildings away.

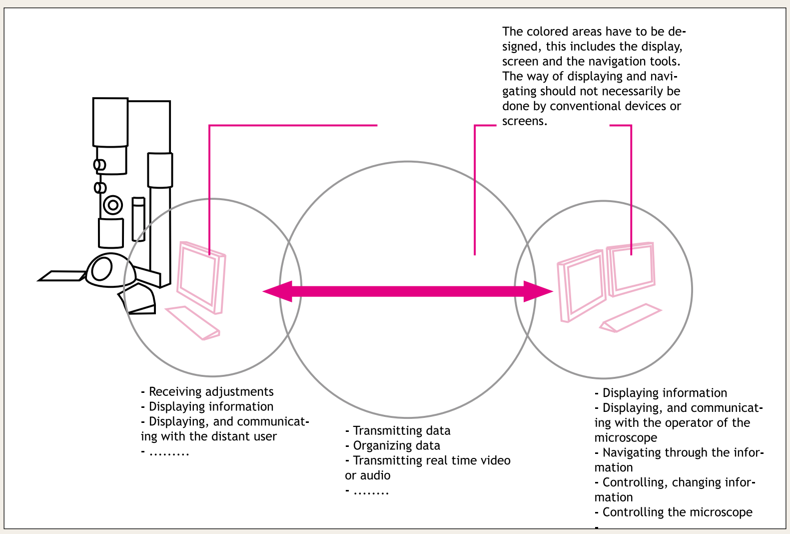
Future Industrial Design engineers, inspired by the famous 19th century Mesdag panorama painting, the high point of many a school trip, have developed a virtual remote collaboration environment. Using this system, whose development was commissioned by FEI Company, users can remotely control electron microscopes and other equipment, exchange data, and communicate. This collaborative work of students at Delft University of Technology, London's City University and the École Polytechnique Fédérale de Lausanne, which mainly took place in cyberspace, produced a working prototype in only four months. They even found the time for a presentation in Japan as well.

Photo: FEI Company

In the present set-up a microscopist has trouble communicating his findings to his client. The screen images can of course be sent to the client by e-mail, but the situation is far from ideal, and certainly not interactive.



Origin, a group of TU Delft students at the Faculty of Industrial Design participating in an international project as part of their master's course curriculum, have been looking into innovation possibilities for FEI Company. The best options appear to be in the field of remote collaboration, which will enable electron microscopes to be put to much more efficient use.



To set up such an environment, the existing metaphor, i.e. the desktop environment used by personal computers, had to be redesigned, requiring the redefinition of both the software and the hardware environments.

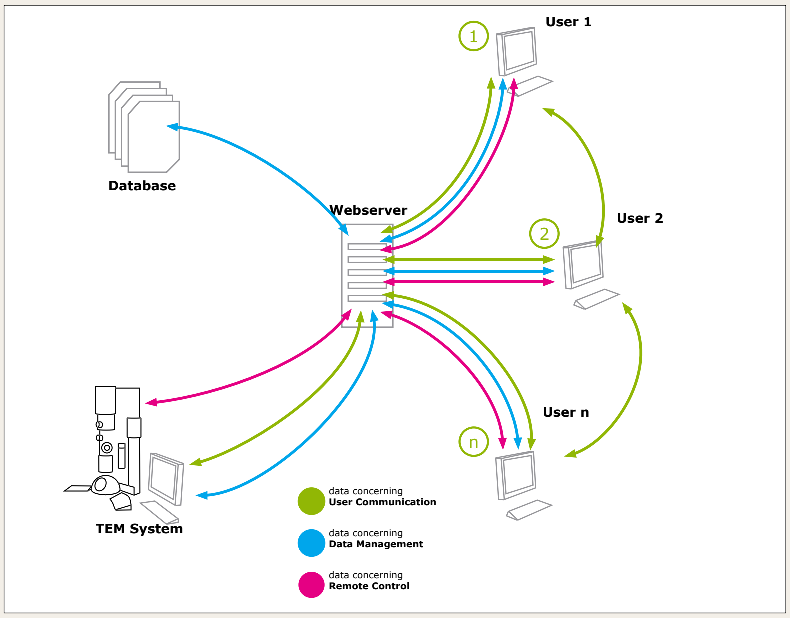
The members of Origin studied the working method and environment of microscopists and researchers at the Materials Science department at TU Delft. They noted that much of the communication between materials scientists was done via whiteboards. This inspired the students to use the whiteboard concept in the collaborative environment they designed.

In the office of Ir. Auke van Balen, senior researcher at FEI Company in Eindhoven, three computer displays have been set up in an arc. The displays represent a modest part of the virtual panorama that envelops the user like an invisible cylinder. Whereas a physical panorama, like the one painted by Hendrik Willem Mesdag in the Mesdag Museum in The Hague, requires the user to turn around in order to take in the view in its entirety, all you have to do to scan the Delft virtual panorama is turn a metal disc.
The sea, the beach with its fishing boats, and the houses of old Scheveningen form the backdrop for images that in Mesdag's time could have existed only in the mind of someone like Jules Verne, such as an electron microscope image of a virus or a crystal, or the face of another user of the system, who could as well be in the next building as on another continent, or a hasty sketch drawn by a user to indicate a special feature of the virus being shown.

Screen control In front of the three vertical touch screens is another interactive display that is used to control every aspect of the system. The classic keyboard and mouse are absent, and instead of them there is a shining aluminium disc forming a turntable. The purpose of the disc is not only to revolve the panorama, but also to remotely control an electron microscope or some other scientific instrument.
The turntable can also be used to set the system's operating mode. With the indicator light on the disc showing blue, the system is in panorama modus and can be used to browse through images and data. If the light is orange, the disc is in manipulation mode and can be used to control the instrument or edit data. The third and last mode is the notation mode, indicated by a yellow light. This mode enables the user to annotate the functions in the panorama with text, formulas, or sketches. For example, you could circle the virus image on the touch screen, or add an arrow or some other marker, to illustrate a point to your co-users, with whom you have an interactive Internet connection using a microphone, loudspeaker and webcam.

More than face to face Van Balen is very pleased with the working prototype of the Collaborative Environment for Users of Advanced Scientific Instruments designed and built by the students. He considers the panorama metaphor a particularly brilliant idea, as it makes for a highly effective means of arranging and accessing large quantities of visual information.
When asked why it was necessary to create a new – virtual – environment for using advanced scientific instruments, Van Balen explains: "FEI Company, formerly a part of Philips, have been making electron microscopes and other instruments for nanolevel imaging and manipulation since 1949. Their products are used for industrial purposes, as in the manufacture of semiconductors, as well as for research and development, both commercially and by universities and hospitals. The fact is that more and more users are working together when visualising and interpreting data, not just face to face, but increasingly in remote applications, with the researchers being located far apart not only from one another, but also from the electron microscope.
Another trend is that electron microscopes at certain companies or universities are increasingly being used by other institutions. After all, these are very expensive machines, and it would be a waste if they were being used only part of the time."

Desktop In order to bridge the gap between users and microscope, and between the users themselves, Van Balen went in search of an environment that would enable people to work together.
"If you want to develop such an environment, you must first have a good metaphor that will turn a novel concept into something familiar. A well-known metaphor for the interface between computer and user is the desktop concept," Van Balen explains, "which was developed in the early nineteen-seventies by Alan Kay, then a researcher at Xerox PARC, the company's Palo Alto Research Centre. It was to become world-famous with the introduction of the Apple Macintosh personal computer in 1984. My feeling was that the desktop metaphor would be insufficient when creating a collaborative environment for this type of advanced scientific instrument. However, coming up with a new metaphor is easier said than done. It takes a creative mind, in other words, people who dare to think the unthinkable.
These people he found at the TU Delft Faculty of Industrial Design Engineering,



Origin came to the conclusion that the system required three different data flows, one for inter-user communication, one for data management, and one for remotely controlling the microscope.

where students, as part of the Integral Design Project curriculum, are asked to develop a tangible product, from market analysis to prototype. The project is connected with the European Global Product Realisation (EGPR) course, in which students from various European universities work together. (see text box). In September last year, six students from Delft went to Eindhoven for an initial meeting to discuss the assignment. It was agreed that they would develop a metaphor for a collaborative environment for users of FEI systems. The environment was to contain the necessary hardware and software and enable users to communicate with one another, exchange data and remotely manipulate the microscope.

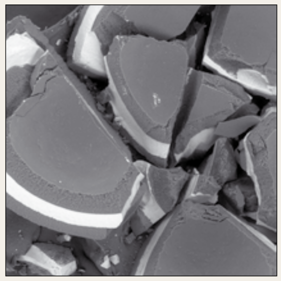
Application "Following the Eindhoven meeting we started with an analysis of FEI Company and their products," says Susan Joosen, one of the Delft students. "We then wrote a project proposal, which we discussed with the company. The proposal detailed as closely as possible what was expected of us, and what we had to offer."

In addition to a description of the required system functions, the project proposal included a number of commercial prerequisites. For example, the system was to make use of existing technology and had to be ready for introduction within two years. Also, the cost had to be kept down, at least far below the price level of an electron microscope.

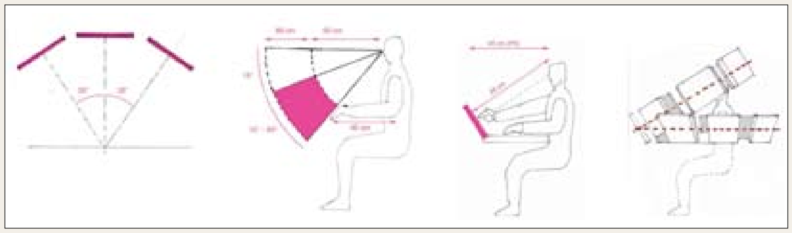
Once both parties had a clear idea of what was expected, the project group went ahead. Since this was an international project, in October the group was joined by students from the City University in London and the École Polytechnique Fédérale de Lausanne. First an analysis was made of the use of metaphors in existing computer systems, from the familiar PC desktop right up to the CAVE (Computer Aided Virtual Environment) at the SARA computer centre in Amsterdam, in which the user can move around in a virtual world.

In addition, various users, were interviewed, including Professor Henny Zandbergen of the TU Delft subfaculty of Materials Science. It was partly Zandbergen's doing that FEI Company and the Industrial Design faculty came into contact. At Materials Science, electron microscopes are routinely used for research purposes, in collaboration with the research department of steel manufacturer Corus.

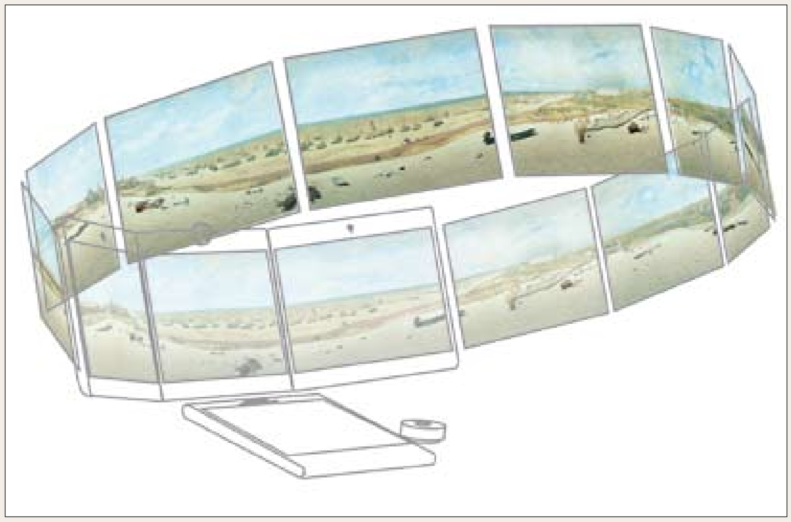
Blackboard With the analysis stage completed, the group was subdivided into three subgroups, each of which set out to develop a metaphor. During the development process, as Laurien Broer van Dijk, one of the students explains: "Every available means was used for the communication between Delft, London, and Lausanne, including MSN, webcams, e-mail, videoconferencing, and Blackboard (the education support system at Delft University). Although technically speaking everything went without a hitch, on a personal level



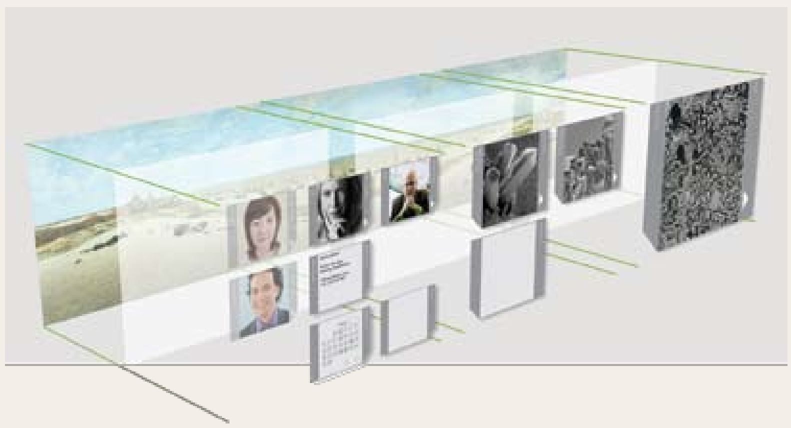
EM image of a ceramic surface.



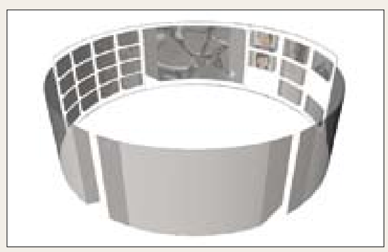
The project included an in-depth study of the workplace ergonomics for both the microscopist and the remote operators.



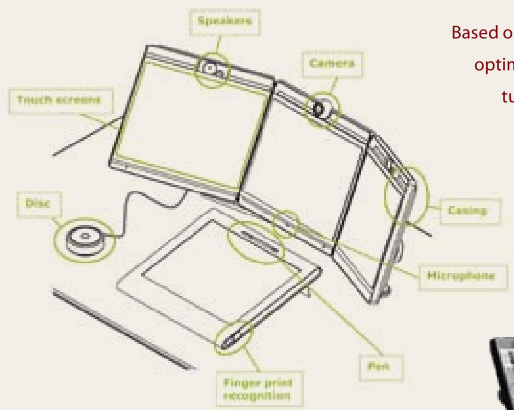
Generated in collaboration with students from City University in London and EPFL in Lausanne, studies of various metaphors, including such concepts as forest, space, light, surrealism, ocean, and library, were followed by a selection process with ultimately produced a metaphor inspired by the Mesdag Panorama, in which the user occupies the centre position in the metaphor, a section of which can be made visible on a set of three electronic displays.



The Mesdag Panorama serves as the backdrop of the carrier, which is a transparent film onto which various functions can be projected, for example a communication screen with a user in New York, a inventory of various minerals, a whiteboard with notes, and images straight from the microscope at the laboratory.

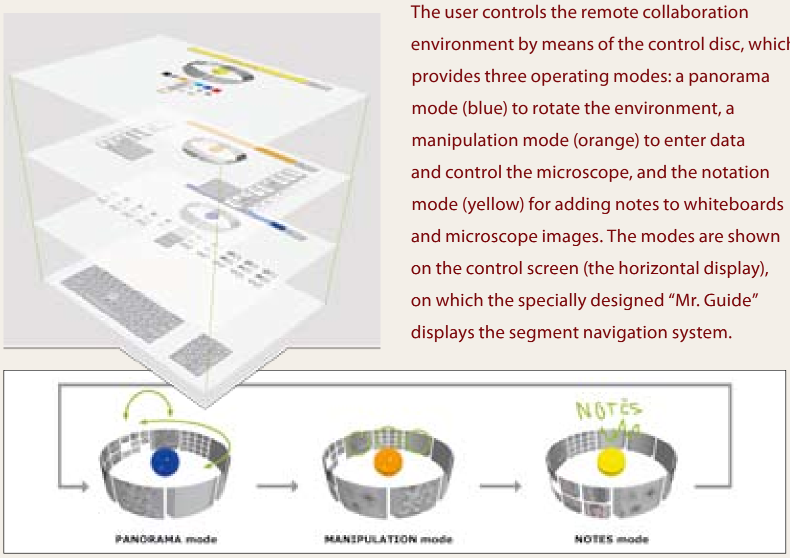


In this case the carrier film consists of six segments, but it can be expanded or reduced as required.

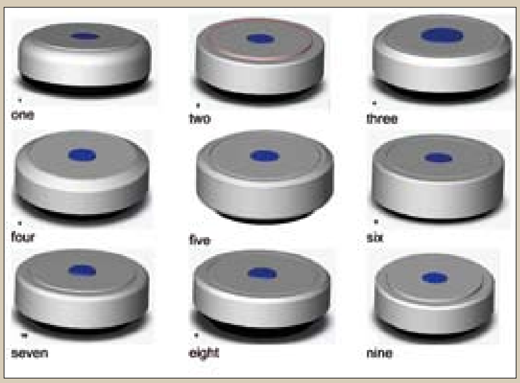


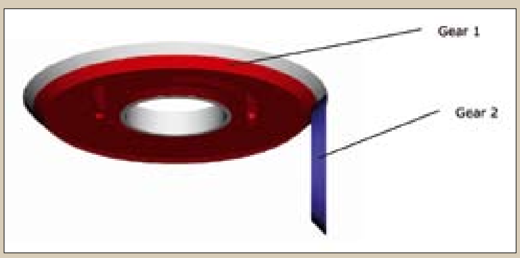
Based on the various studies, the optimum configuration of the console turned out to comprise a set of four touch screens, a control disc, and elements for multimedia use. Security is provided by a fingerprint recognition unit which prevents unauthorised access.

A 3-D image of the prototype of the remote collaboration environment.

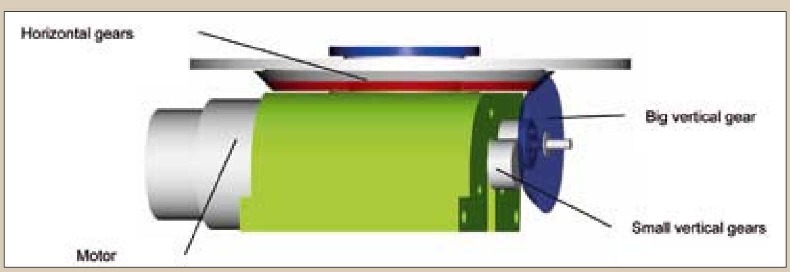


The user controls the remote collaboration environment by means of the control disc, which provides three operating modes: a panorama mode (blue) to rotate the environment, a manipulation mode (orange) to enter data and control the microscope, and the notation mode (yellow) for adding notes to whiteboards and microscope images. The modes are shown on the control screen (the horizontal display), on which the specially designed "Mr. Guide" displays the segment navigation system.





The control disc consists of flat disc and a push button. Pressing the button changes the operating mode. Although the disc appears to be simplicity itself, the students from Lausanne incorporated a fair bit of ingenuity. The device is the end result of a long series of prototypes. The mechanism contains a stepping motor featuring force feedback to provide the user with a more realistic sense of touch when controlling the microscope and to indicate when its mechanism reaches the end of its stroke.



communications took a little while to get going, but things soon went more smoothly as the participants got to know one another. Even so, when we all came together for the first time, people turned out to be quite different from what you had imagined they would look like, in spite of the fact that we were able to see them using webcams and videoconferencing."

The collaboration project, which took place in cyberspace at first, and later involved a week's face-to-face work, clearly demonstrated the different approaches used by the students in Industrial Design engineering at Delft and those mainly studying Computer Systems Engineering and Electrical Engineering in London and the Lausanne students of Communication Engineering and Micro Engineering.

These Swiss students are used to look for a solution based on technical specifications, whereas in Delft, industrial designers are taught that there is a stage preceding that process, in which you tackle the wider problem by considering all aspects involved. Collages, brainstorming and metaphores were used, but they are only few of the many 'ideation' and creativity techniques used by industrial design engineers. As the project progressed, during the prototyping stage in particular, the different qualities of the students turned out to complement each other very well.

All in all, the cyberspace contacts between the students provided a strong basis for developing the virtual electron microscope collaboration environment.

Van Balen: "Before they could create a virtual collaboration environment, the students had to create the same type of environment for their own use. This classic chicken-and-egg-problem solved itself, as today's students have more or less grown up with all types of modern communication means."

Lab-Vision & Y-con

In November the brainstorming stage was concluded with yet another report to present the three metaphors that had been developed, Lab-Vision, Y-con, and Panorama. The latter of these was inspired by the Mesdag Panorama, whereas the LabVision and Y-con concepts were derived from on the one hand a planetary system, and on the other a forest environment with a number of distinct layers between the soil and the treetops. After consultation with the client and supervisors in late November, the Panorama metaphor was selected.

"Actually, it incorporates several ideas from the other metaphors," student Hein Bles remarks. FEI Company's Van Balen adds: "We would have been very pleased if the process had produced just a single well-developed metaphor."

The project group proceeded to build a prototype of a collaborative environment based on the Panorama metaphor, using scenarios that had been developed at an earlier stage. The idea of such a usage scenario is to visualise how different users would use the system. There is a specialist (like a biologist or a pathologist), there is a microscopist to operate the instrument and of course the client, who wants to use the information, for instance a surgeon, or someone working in a microchip factory. Each of these three classes of people must be able to work remotely from one another and from the microscope itself.

Limited force

The primary prerequisite of the system is that an authorised user must be able to operate the microscope from a remote location. This means that there must always be a microscopist on call to align the device and insert the sample into the microscope. Once this is done, the researcher should be able to use the instrument using remote control, in other words, to set the magnification, or alter the position of the electron beam or the sample to improve the image. In the Panorama metaphor the sample is manipulated by means of the turntable. Its design is such that it limits the force the user can exert on it. Only the top part moves, so it can only be moved using one or two fingers. It also locks when the microscope's physical limits are reached.

In the second place, as mentioned, users have to be able to manipulate and exchange data. In addition to the images generated by the electron microscope, the data can include any other relevant information, e.g. images and graphs from a digital library, or the number of electrons passing through the sample in a Transmission Electron Microscope (TEM). In the Panorama metaphor most of this information is handled by software, the electron microscope being fitted with a software interface compatible with a number of different computer systems. The Panorama systems of the different users also are interconnected, so that when one remote user changes the position of the sample under the microscope, the new image immediately becomes visible to all other users. Of course, the information is also stored and managed at a central location.

Handwritten Finally, the users must be able to communicate with one another, and no corners have been cut to achieve this. Communication takes place via text, images, audio, and video. Thanks to today's broadband Internet connections the modes can all be operated simultaneously. Texts can be typed (a keyboard is displayed on the control screen for this purpose) or written by hand. In the notation mode the Panorama touch screens (with the exception of the control screen) act as whiteboards which all active participants can use to add sketches or graphs. In addition, notes can be added to the images. All marks and arrows are saved with the image and can later be retrieved by other users.
Potential users find the Panorama metaphor an easy and intuitive way of collectively viewing and interpreting electron microscope images, as was demonstrated during presentations at TU Delft and at FEI Company in Eindhoven. The concept is not only practical, but also easily expandable, since there is in fact no limit to the number of elements making up the Panorama. The Panorama metaphor concept also met with international approval when it was demonstrated during the Third International Conference on Creating, Connecting, Collaborating through Computing, which took place last January in Kyoto, Japan. Even though the paper was written in record time by the team from Delft, it left a deep impression.
Van Balen: "The fact that the discussion immediately centred around the question how the system could be put to use can be taken as an indication that the concept had already been accepted as mature, which is probably the best compliment a group of design students could hope to receive."

Tangible product "The motive for international collaboration is, and always has been," says Ir. Ernest van Breemen, lecturer at the Computer Aided Design & Engineering section, "that graduates in later life will also be collaborating internationally and remotely. A main feature of this part of the curriculum is that we support the students by providing knowledge specific to the project. In addition we set up a virtual company, together with the client's company, for the purpose of creating a tangible product, and this works in a very stimulating way. The prospect of the whole group coming together for a week to build a prototype has proved to be a major incentive to overcome the usual problems one encounters during international collaboration projects, like difficulties in communication."

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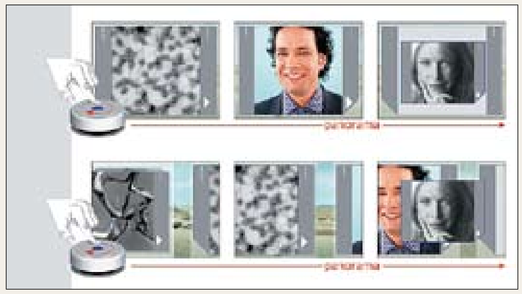
European Global Product Realisation

The project described in the accompanying article is a pilot project carried out as part of the new formula Integral Design Project, a mandatory part of the curriculum for Industrial Design Engineering students at TU Delft. Of the 200 students attending this course every year, a small group are given the opportunity to collaborate with students from universities elsewhere in Europe, according to Ernest van Breemen at the Faculty of Industrial Design Engineering.
The international collaboration, called European Global Product Realisation, was set up five years ago by Professor Imre Horvath. The initial partners were the universities of Michigan and Seoul, but the resulting high expense of international collaboration, partly due to long-distance travel, has since limited the playing field to Europe, more in particular the universities of London and Lausanne mentioned in the article, together with those of Ljubljana and Zagreb.

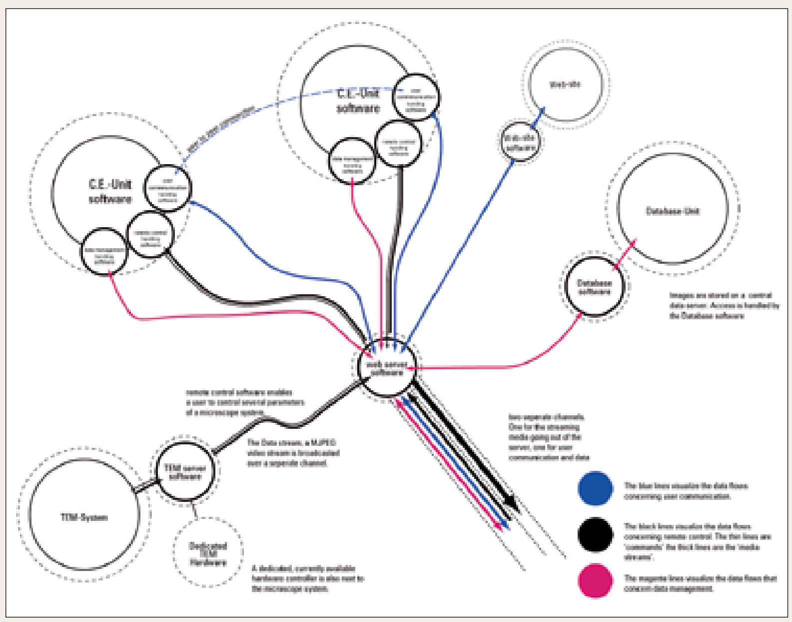
The collaborative environment requires the use of both hands. One hand on the control disc, and the other on the four displays for writing, marking, indicating, etc. This not only optimises system use, it also reduces the risk of RSI.



Example of the panorama mode, which clearly shows how the segments move in the horizontal plane. This mode also features an option for rearranging the segments and functions.

In the notation mode a special stylus can be used on the touch screens to add notes and messages which become instantly available to the other users logged on to the system. The marking and indicating features were greatly appreciated by a panel of potential users.

The manipulation mode offers the option of controlling the microscope and manipulating any selected images from a library or straight from the microscope.

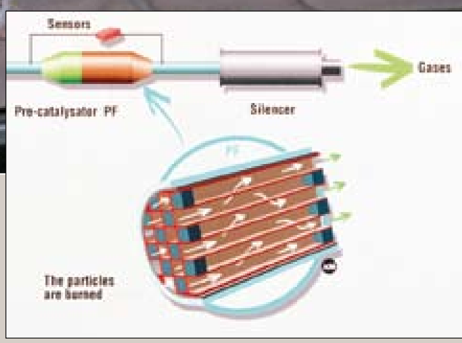


The underlying structure of the collaborative environment's data traffic in a configuration with two external users, one database, one web site, and one electron microscope.

Nanoparticles made-to-measure

“Aerosols prove to be indispensable for nanotechnology”

"PSA Peugeot Citroen, Direction de la communication – Stephane Muratet"



Car exhaust system with cut away catalyst and soot filter. The catalyst converts noxious gases to more ecofriendly alternatives. An important reaction is the oxidation of nitrogen monoxide (NO) to nitrogen dioxide (NO_2) with the aid of a platinum catalyst. The NO_2 is used to convert the soot in the soot filter to CO_2, which explains why the catalyst precedes the soot filter in the exhaust chain.

Is it possible to make platinum particles with a diameter of less than eight nanometres? That was the question Jan Marijnissen at the aerosol lab of Delft ChemTech was asked. Together with graduate student Jan van Erven, the famous aerosol expert Sheldon Friedlander of the University of California (UCLA), and the University of Karlsruhe, Germany, Marijnissen set out to experiment.

He managed to do achieve this by using his favourite electrospray method. While they were at it, the research teams used an electron microscope to see how a soot filter uses the platinum nanogranules to get rid of its soot.

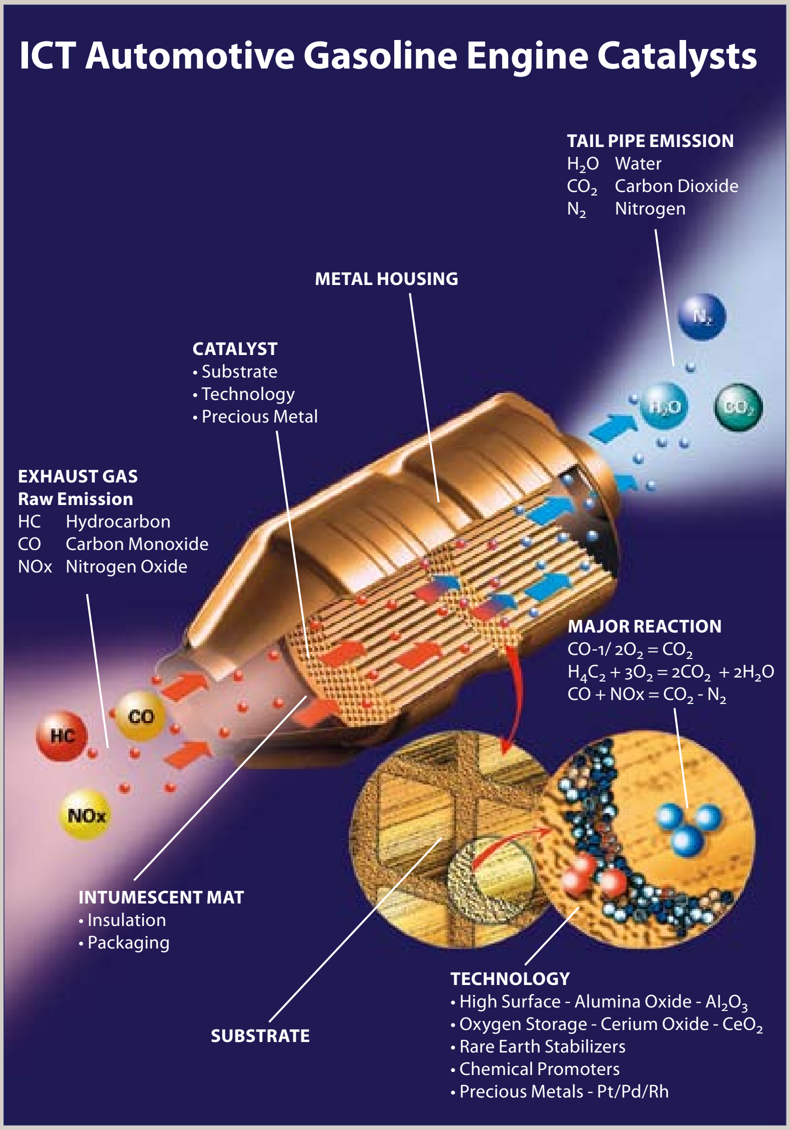
by Arno Schrauwers

Nanotechnology is a buzz word. There is even talk of renaming Delft ChemTech to get the word nano into its name. Dr. Ir. Jan Marijnissen takes it all in his stride: “Nanotechnology has suddenly become the magic word, but in fact we have been working on it for years. By changing parameters such as flow rate, voltage, conductivity, and concentration, we can use our electrospray method to produce nanometre-size particles. We were only waiting for the right opportunity to show what we are capable of.”

This opportunity came when a research project was started with Prof. Sheldon Friedlander, the famous aerosol expert at the University or California (UCLA), and researchers from Karslruhe University. The purpose was to produce platinum particles measuring less than 10 nanometres across and use them in catalyst studies. Platinum plays an important role in chemistry, where it acts as a catalyst to accelerate chemical reactions.

Platinum is also an essential ingredient in other conversion applications, including soot filters for diesel engines. Essential for the catalytic effect is a sufficiently large surface area for the platinum to come into contact with the reagents. Broadly speaking, the smaller the particles, the higher the catalytic effect. To produce such minute particles, Jan van Erven tested two different methods at Friedlander’s laboratory in Los Angeles and at the aerosol laboratory in Delft, namely laser ablation and electrospraying. In 2002 the then graduate student Van Erven relocated to Los Angeles where the research facilities were available.

The laser ablation process uses the high energy content of a pulsed laser (3.3 megawatts with a pulse of 30 nanoseconds) focused at a disc of pure platinum of about 4 cm in diameter and one millimetre thick to evaporate the metal, which



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then condenses into particles. The platinum particles produced by this method could not be made smaller than 16 nm. Besides, the yield of the process was far from adequate.

Ideal The electrospray method was tested at Delft using two different approaches. First of all, platinum in the form of a complex compound was dissolved in ethanol, the type of alcohol also found in beer and whisky.

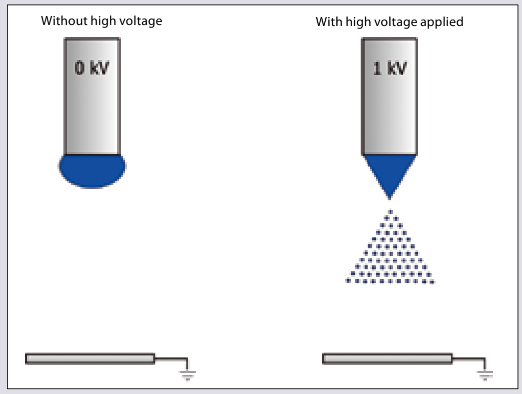
The commercially available platinum complex used for this purpose was chloroplatinic acid ($H_2PtCl_6.6H_2O$). Using a very fine syringe with an aperture of only 60 micrometres, the precious metal solution was then given an electrical charge and turned into an aerosol of microscopic droplets. After the evaporation of the droplets these particles were deposited on a disc of silicon oxide. Next the disc was heated to make the various components evaporate and to make the platinum complex granules, which measure about 80 nanometres across, break down into platinum particles of the required dimensions.

The second electrospray method was more direct, with the platinum compound solution being dispersed as a charged aerosol. A corona needle was used to neutralise the aerosol's charge and the cloud of droplets was then ducted through a furnace. There the ethanol evaporates and the dichloroplatinic acid particles decompose into platinum particles. After the trip through the furnace the platinum particles, which were less than ten nanometres in size, were collected.

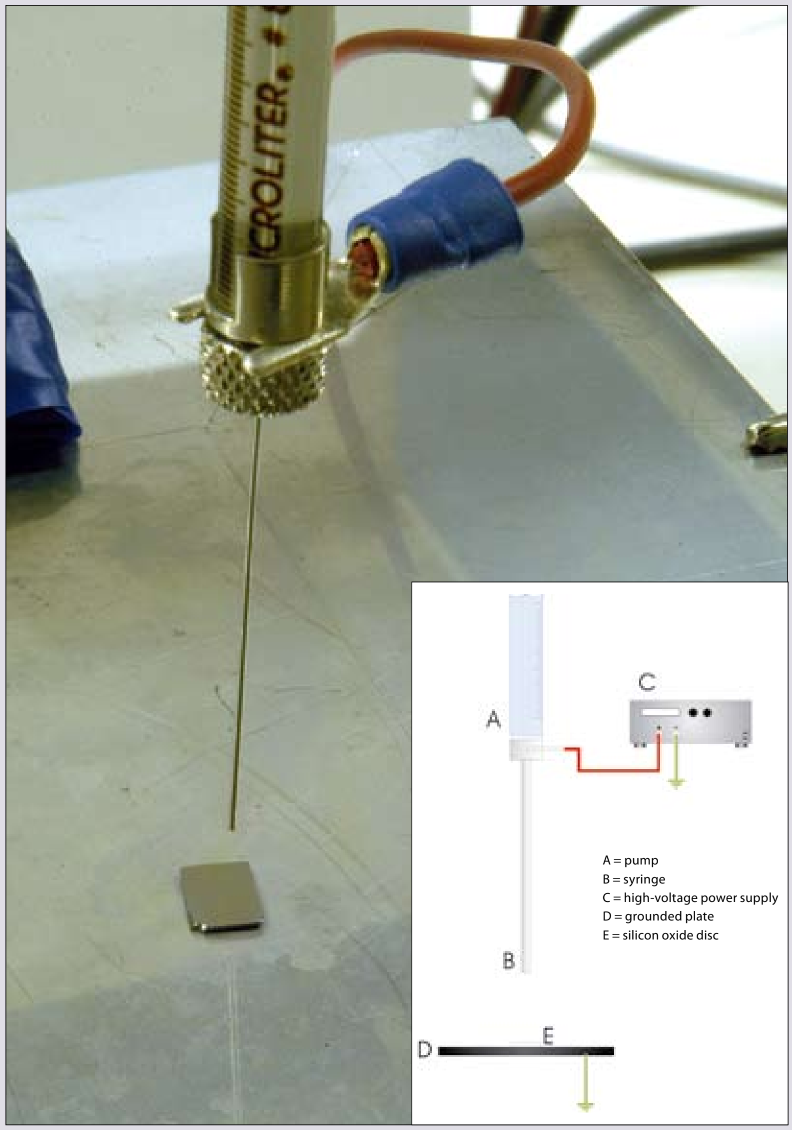
Marijnissen: "Both methods yielded good results. The 80 nanometre particles in the first method break up into smaller particles when heated. Jan van Erven observed it all through an electron microscope. He observed large patches

The technique

The electrospray process involves a liquid being atomised and electrically charged. The principle is akin to powder coating or electrostatic spraying. The method can be used to create minute particles that will not stick together, since similarly charged particles repel each other. At TU Delft, the electrospray method is being assessed for use in various applications by the aerosol technology team of Jan Marijnissen. Possible uses include the administering of drugs to asthma patients and the application of pesticides to plants (see Delft Outlook 2003/4).



The formation of the Taylor cone is based on the interaction between an electrical force applied from outside the liquid and the liquid's surface tension.



To create platinum nanoparticles, Jan van Erven constructed a basic electrospray set-up at the Delft ChemTech laboratory which he used to atomise a solution of a platinum complex and ethanol. The outside diameter of the syringe used by Van Erven is only 120 micrometres, producing a very small Taylor cone. The evaporation rate of the ethanol was so high that the particles were deposited practically dry on the silicon oxide disc.

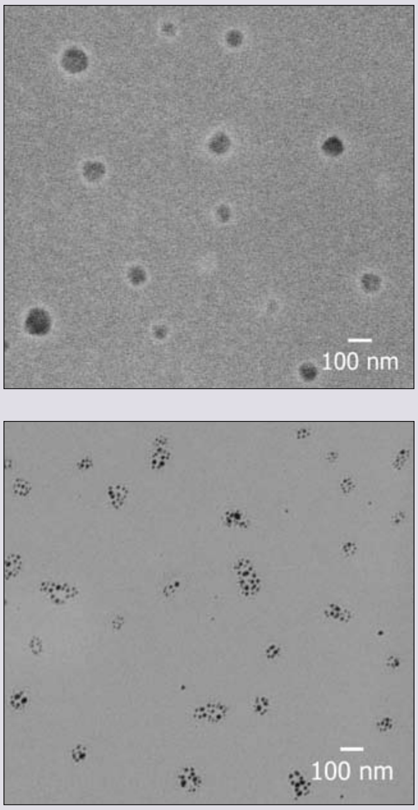
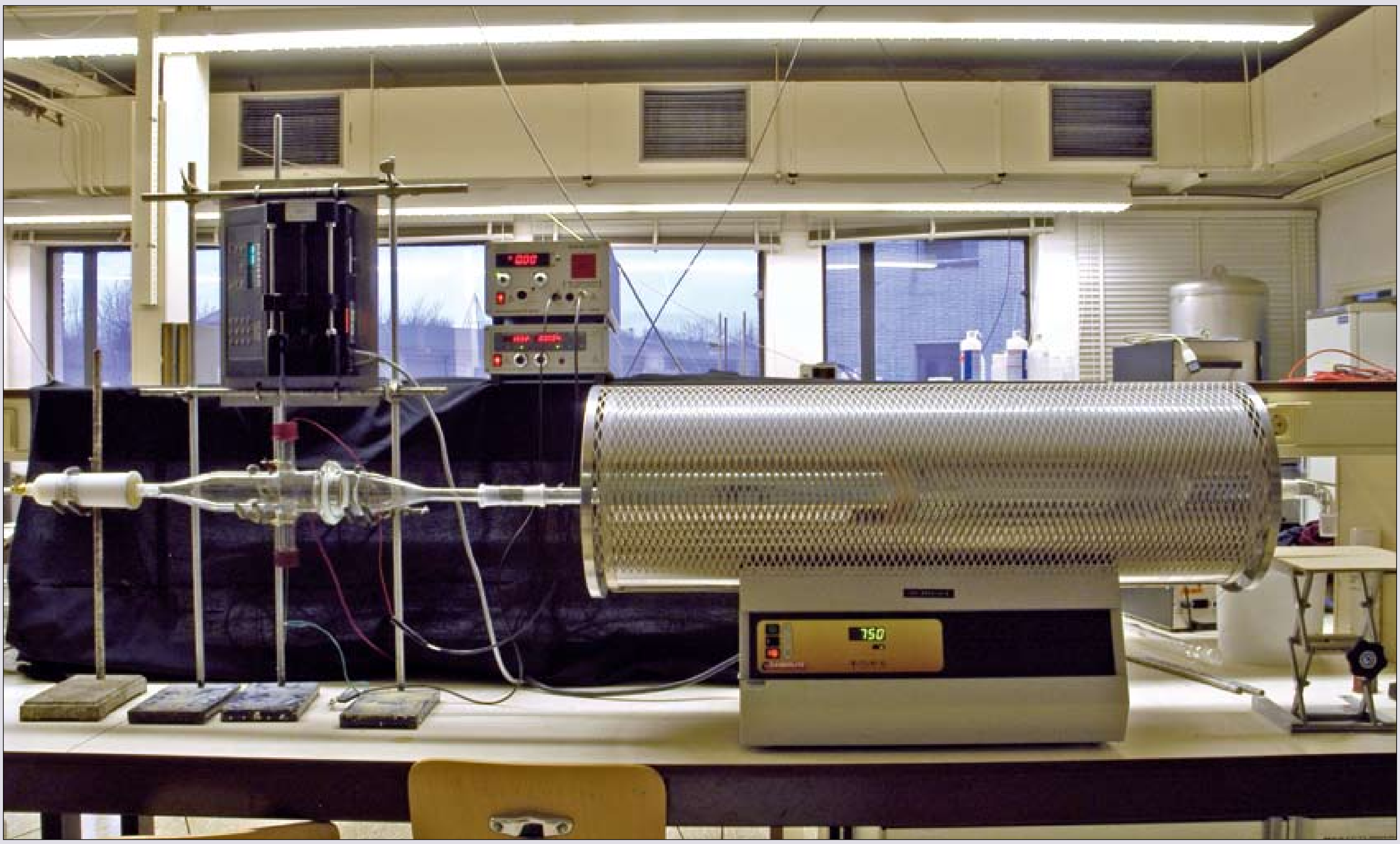


Image created with a Scanning Electron Microscope (SEM). On the left are the freshly deposited platinum complex particles with an average size of about 80 nanometres. After being heated in a furnace at 700 °C for about ten minutes, the particles break up into even smaller particles of pure platinum measuring approximately ten nanometres in diameter (below).

The researchers at ChemTech decided to build a new test set-up that would enable them to produce nanoparticles using a generic method. In the device, which connects a furnace to what is known as the Delft Aerosol Generator, the process parameters are more easily controlled. It enables charged particles to be neutralised, and particles sensitive to oxygen to be protected by the creation of an anoxygenic atmosphere. In addition, nanoparticles can be coated during their flight through the furnace. Using this set-up, Van Erven managed to break up the platinum complex particles into pure platinum particles of about eight nanometres as they moved through the furnace.



consisting of smaller spots of approx. 10 nanometres, which is ideal for the catalytic oxidation experiments. The second method also gives perfect results. We have demonstrated that we can produce platinum nanoparticles from a platinum compound. To me that is the main result of this research.”

Made-to-measure So how exceptional are these results? Marijnissen, who is now a visiting professor at the University of Gainsville, Florida, explains: “We have created nanoparticles before using saline solutions, but the process did not involve any chemical reaction. What is special about our results is that we have converted droplets of the platinum solution into platinum particles of the required size by means of pyrolysis, i.e. the decomposition of the material by the application of heat. That is sufficient result for me, since it means that we can make well-defined particles to measure.”
And there is another reason why the Delft team can be pleased. The research by Van Erven also demonstrated that the laser evaporation method was far less productive than the Delft spraying method.
Van Erven: “The laser method took one hour to produce a certain concentration of platinum particles, whereas our electrospraying method enabled us to obtain the same amount within a minute.”

Soot filter But Marijnissen and Van Erven did not stop there. Adding to their achievement of being able to produce minute particles to measure, they set out to investigate a related subject. Soot filters in diesel engine exhausts contain catalysts to convert soot to carbon dioxide. The mechanism of the oxidation process is still largely unknown. Marijnissen, Van Erven and the other research teams went to work on the nanometre-sized platinum particles and tried to find out how exactly the soot particles are converted. According to previous publications, nitrogen oxides play a major role in the process. It was hoped that by manipulating such parameters like the nitrogen oxide concentration and temperature, the factors crucial to the soot conversion might be discovered. Instead of normal soot, the material used in the experiments was sublimated

carbon. Research by a group headed by Delft Professor Jacob Moulijn had proved that this could be done without bending the truth.
Van Erven subjected his sample to a number of tests in which he varied the nitrogen oxide concentration and temperature while observing the effects to the soot through an electron microscope. Catalyst research in the late nineteen eighties has shown that platinum by itself has no effect on the conversion of soot to carbon dioxide.
It turns out that nitrogen monoxide, a gas produced inside combustion engines, plays an essential part in the whole process. Jan van Erven also came up with the remarkable discovery that in the presence of platinum and without nitrogen oxide the conversion of soot to carbon dioxide starts at a temperature that is higher than it would be without the use of platinum. If nitrogen monoxide is the only gas present during the oxidation experiment, the lower limit of the conversion of soot to carbon dioxide is reduced by about 100 °C (somewhere between 260 and 280 °C). On the other hand, platinum does play a very important role in the conversion of the nitrogen monoxide produced by the combustion engine to nitrogen dioxide. The nitrogen dioxide in turn is essential for the conversion of soot, as it burns the soot down to carbon dioxide (producing again nitrogen monoxide, and so forth). The conversion rate of the soot has been calculated from the images obtained from the electron microscope. Of course,
the question arises whether these 2D images can be considered representative. Marijnissen: “All over the world, lots of research has been devoted to demonstrating that such images are scientifically acceptable. It is all to do with the fractal dimension, which in this case is less than two, making it alright.”
Van Erven discovered that the distance between the platinum particles and the soot particles plays a major role in the conversion process. This might seem rather obvious, but in reality it turns out that things are quite the opposite, and that the platinum particles must not come too near the soot particles.
Van Erven and Marijnissen hesitate to say this out loud, since clearly more corroborative research is needed. A graduate student will be assigned to get to the bottom of this phenomenon. Van Erven himself has started his own doctoral research, looking into the production of nanoparticles on a semi-industrial scale, a process which also revolves around a laser, albeit one of a different kind.

Slow The mills of the scientific publication process grind slowly. The results of the research into the oxidation of carbon with a platinum catalyst, which was completed in late 2003 and had been offered to Applied Catalysis B Journal in 2004, has only just appeared in print. The results of the Delft research team into the generation of platinum nanoparticles still awaits publication.
Marijnissen: “It is far from simple to write an article when you’re working with different research groups, and even if the article is accepted for publication, it often takes several months before it actually appears in print. A lot of scientists were involved in the publication of these articles. Anyway, we can be proud of the fact that the nanoparticles story will soon be appearing in Aerosol Science and Technology magazine. We must not forget that it is quite rare for non-experts on the subject of catalysts to be able to complete this kind of research. Dr Ir. Dick van Langeveld, from TU Delft, who worked with us on the project, is the only one with a background in the catalyst field. Friedlander has set out to prove that aerosol technology is essential to nanotechnology. It’s not quite that the catalyst team refuse to speak to us, but they must feel a bit miffed that a bunch of non-experts were able to produce this kind of result.”
Non-experts the aerosol boffins may be, but as Marijnissen admits while on his way to a meeting to discuss the objectives and purpose of his research work, he has no qualms about using the nanotechnology buzz word, if that’s what it takes to score points.

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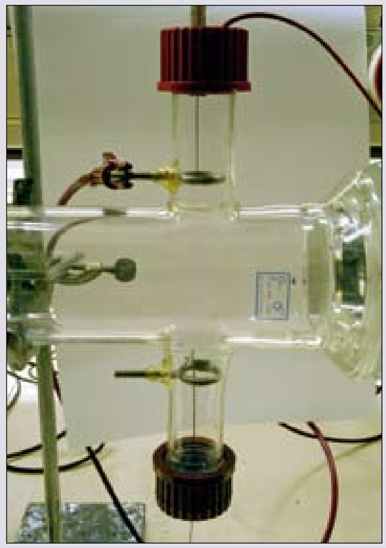
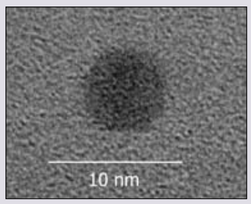
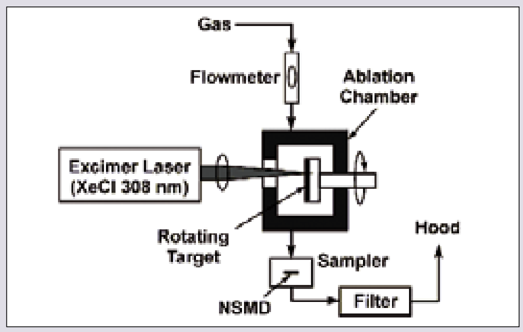


Close-up of the Delft Aerosol Generator, which was developed in 1991 by Dr Ir. Gabrie Meesters. The generator consists of a glass crosstube in which the top end contains a syringe connected to a high-voltage source (up to 15 kV). Below it is a ring carrying a lower voltage (though still high), which creates and stabilises an electric field between the ring and the syringe. At the bottom end of the generator is an earthed corona needle with a very fine tip. As a result of the difference in voltage between the ring and the corona needle, an extremely strong field is created at the needle’s tip, producing the corona discharge phenomenon, which is accompanied by an avalanche of electrons close to the tip. These electrons ionise the gas molecules with a charge (negative) that is opposed to that of the droplets produced (positive). The ionised gas molecules collide with the droplets, neutralising them. In this set-up the ring surrounding the corona needle at the bottom serves no purpose.

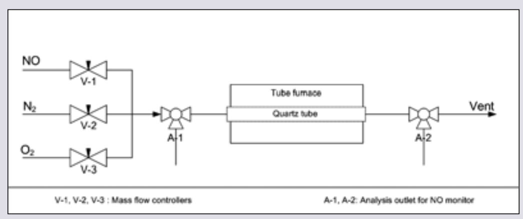
The sample carrier (3.05 mm diameter) consists of a copper grid covered with a carbon film only a few nanometres thick. The Transmission Electron Microscope (TEM) can see only the particles deposited on the carbon film.



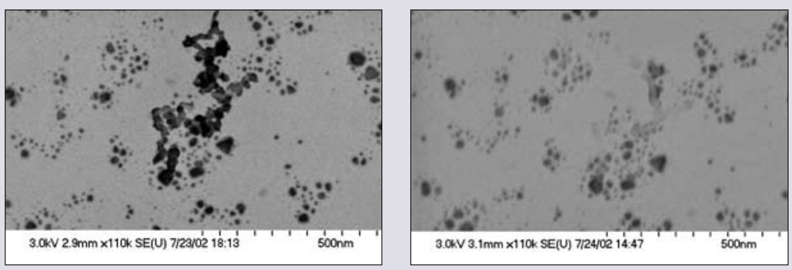
TEM image of a platinum particle produced by Van Erven.



Schematic diagram of the set-up used by Van Erven at the University of California in Los Angeles (UCLA) to produce carbon particles for use in oxidation experiments. A focused laser evaporates material from a rotating carbon disc. During this process, local temperatures can reach several thousand degrees. As the vapour cools in the gas that catches it, it condenses into particles which are then deposited onto the silicon discs which carry platinum particles created using the electrospray process.

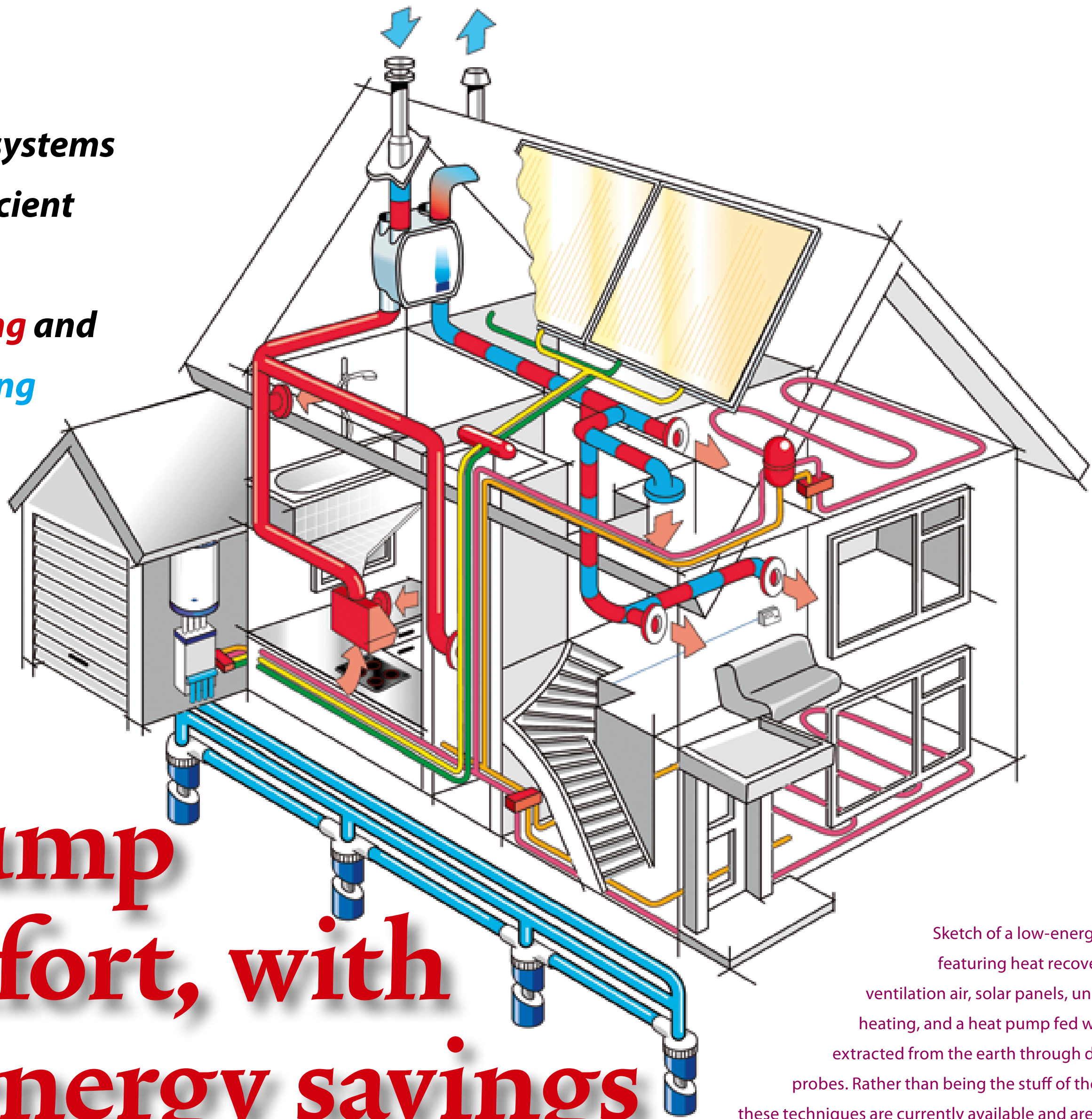


Schematic diagram of the set-up used by Van Erven at UCLA for his oxidation experiments.



SEM image of the silicon disc showing the deposited platinum and carbon particles (left). After oxidation with 1000 ppm NO in 80% nitrogen and 20% oxygen (right), the carbon particle has disappeared. This is the first time that the combustion process has been observed on a microscopic scale.

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."

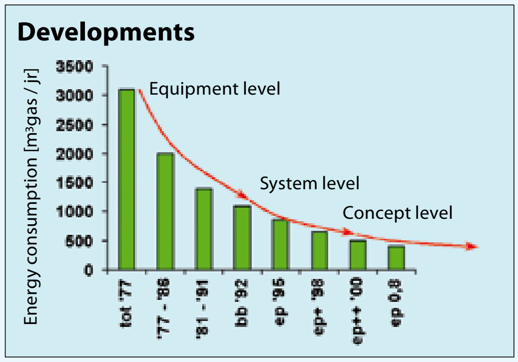
It was not until after 1990, with the increasing awareness that it was the impact of greenhouse gases like CO_2 that threatened our society, rather than the depletion of fossil fuel resources, that interest in the heat pump was rekindled.

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."

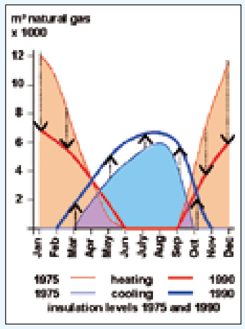
Heat pumps Heat pumps are hardly the latest news. Most of us own one in fact, since a refrigerator uses a heat pump to move heat from inside the fridge to the environment, from a low-temperature region to a higher temperature level. Inside the fridge, all we want is the cooling effect of the device.

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

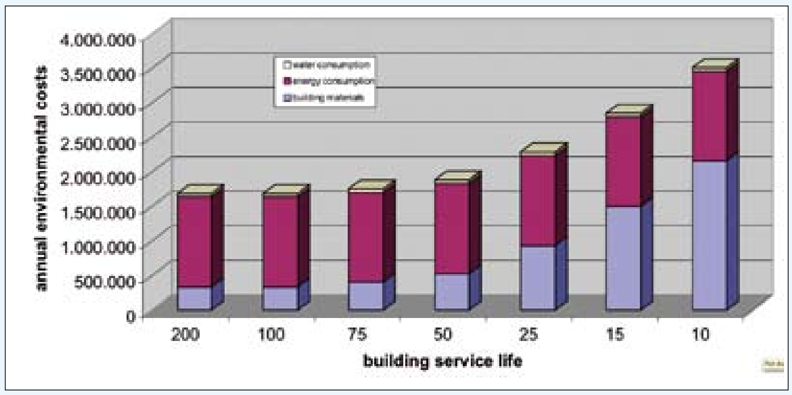


The result of the efforts of the past 25 years have resulted in a reduction in energy consumption for interior home heating of 80%.



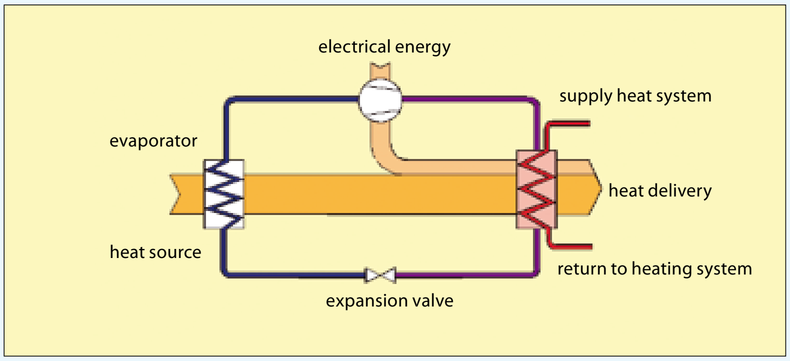
Although thermal insulation greatly reduces the heating power demand, it increases the demand for cooling power.

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.

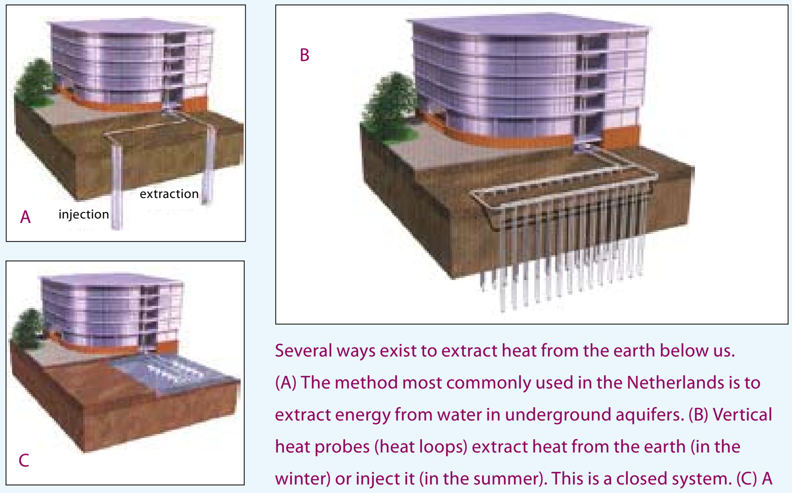


Given the normal office building service life of fifty years, the energy consumption for climate control is by far the greatest contributor to the total environmental impact of the building. As the service life of a building decreases, the relative environmental impact of its construction materials increases.

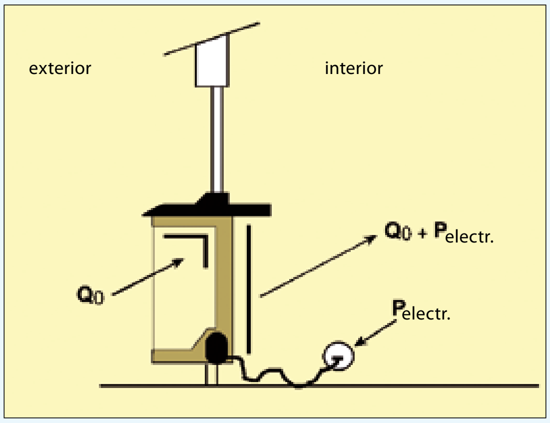
New thermal insulation materials continue to appear on the market, including these vacuum insulation panel. The thickness of the so-called VIP panels (right) is only one fifth of that of traditional insulation material (left), even though the insulation value is the same.
(courtesy VIP-Bau /www.vip-bau.ch)



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 m² 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."

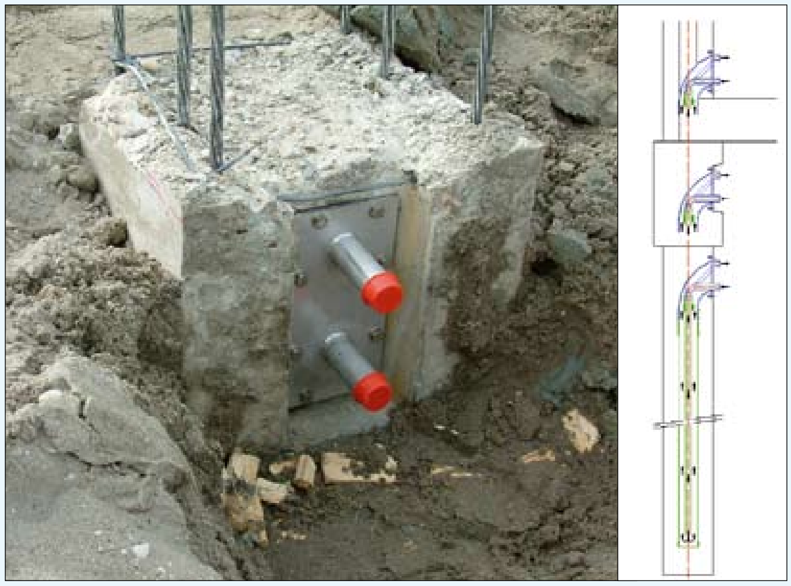
Seawater and mineshafts The fact that so far the heat pump hasn't been able to oust the high efficiency central heating boiler in the Netherlands is mainly due to the ready availability of cheap Dutch natural gas and the lower initial cost of these boilers, Cauberg stresses. Now that the energy standard 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."

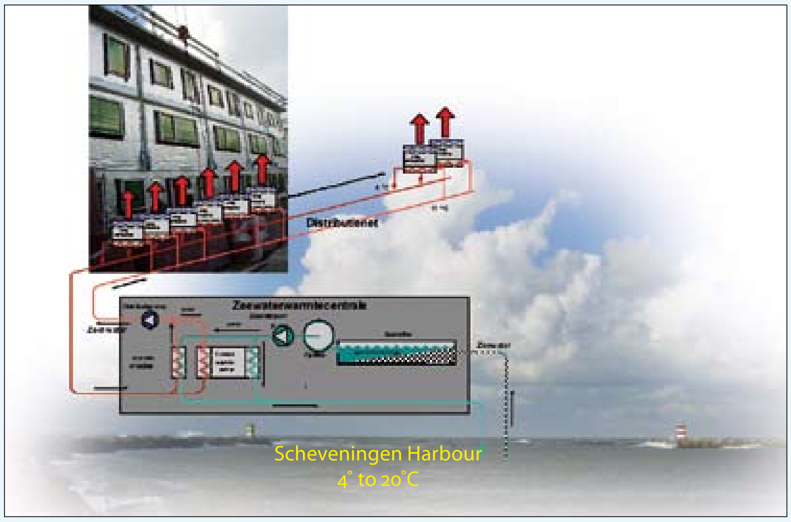
Various pilot projects have been set up for other low-grade energy sources. In the neighbouring town of Geleen, a block of houses that is being refurbished will reclaim waste heat from ventilation air and use it to heat domestic hot water. In Scheveningen, a seaside resort of The Hague, the Vestia housing 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".

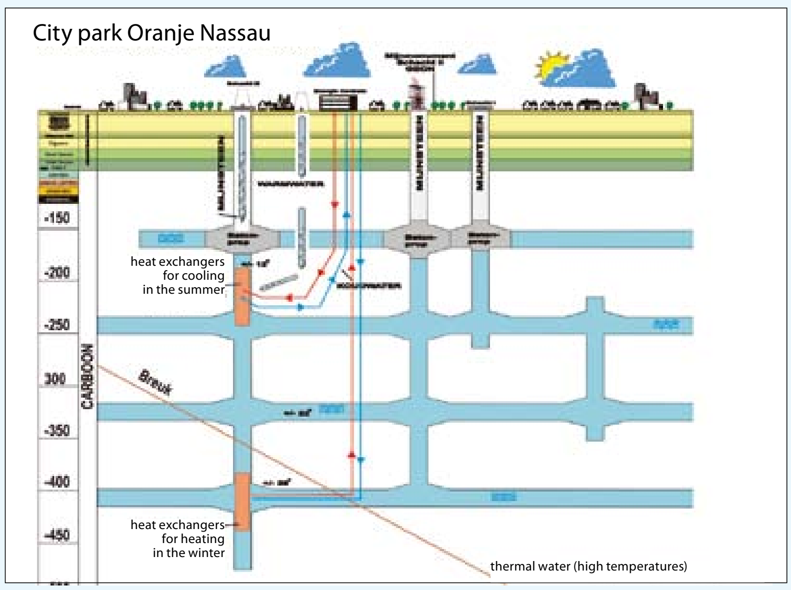
Condensation The increasing demand for cooling during the summer months may really boost the popularity of the heat pump/geothermal energy combination. To prevent problems with condensation on floors and walls when the system is used for cooling purposes, building physicist Dr Ir. Wim van



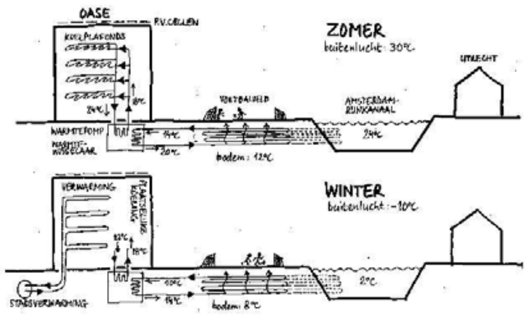
Another option is to use special piles doubling as heat exchangers. The heat extracted from the earth is fed through a closed circuit inside the pile to the heat pump. (Photograph and drawing Betonson, Son / www.beton.com)



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.

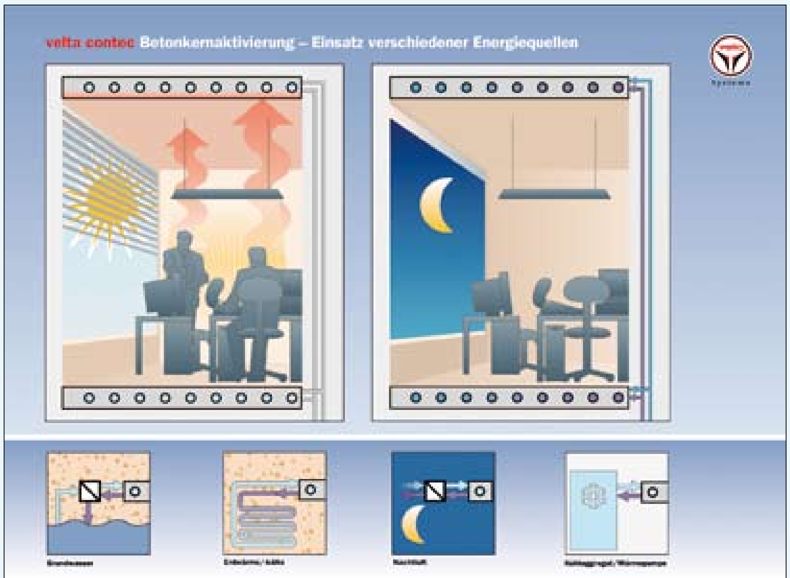


The town of Heerlen plans to use water from flooded mineshafts to heat and cool buildings at the Stadpark Oranje-Nassau and Heerlerheide Centrum locations. The intention is to tap into the mine shafts at a depth of 500 metres, where the water reaches temperatures up to 32 °C. The water is pumped up to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



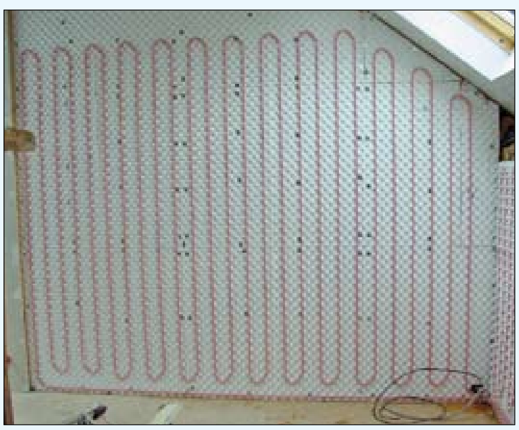
Cooling and heating system

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/m². 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.

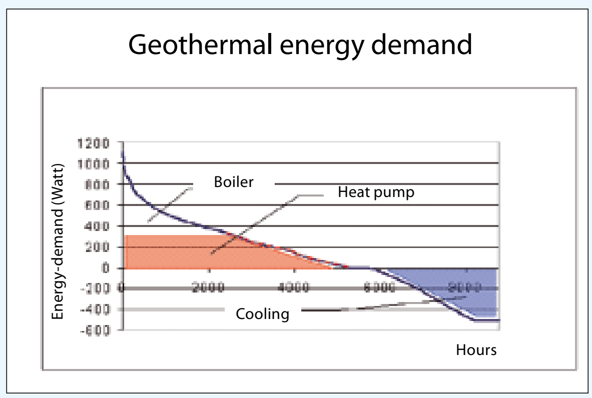


Heating and cooling through walls is becoming increasingly popular. In refurbishing projects in particular it is often combined with improved noise reduction measures in separating walls. A drawback of the system is that walls need to be kept free of furniture as much as possible in order to ensure optimum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

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.

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.

Turby - Sustainable urban wind power from the roof top

(Photo Corné Bastiaanse, DHV, Den Haag)

The town hall of The Hague with the House of Parliament in the back ground

Among the high-rise buildings of various government buildings, the roof of the town hall in The Hague carries a Turby. The eleven storey building, which was designed by American architect Richard Meier, is the latest location for Turby, a vertical axis wind turbine that can generate energy from the rapidly changing winds around high buildings.

If current trends are anything to go by, in future we will no longer produce all our electricity in large, central power stations. Small-scale local electricity generation will gain in importance. Sander Mertens, a post-doctoral student at TU Delft, developed the aerodynamic design of a wind turbine which is specifically suitable for built-up areas. Compact, mobile, low-noise, and vibration-free, it is the ideal alternative for use on top of high-rise office blocks, where wind speeds can easily reach twenty percent more than with the same height away from buildings. The electricity can be fed straight into the building's power system, saving on energy transport costs and losses, and producing high feed-in yields. Prototypes have already been installed on the town hall in The Hague (designed by Richard Meier), on an apartment block in Tilburg, on an office block in Breda, and on top of the Delft ChemTech faculty building. Interest has been generated in London and Leicester in the UK, New Mexico and New York in the USA, and in France and Canada.

by Bennie Mols

Windmills in a flat green landscape stretching to the horizon and beyond – the archetypical image of Holland. Windmills even provided the means of creating the Mondrianesque landscape with its straight cuts and dykes bordering rectangular sections of grassland. In the seventeenth century, windmills were the mainstay of the Dutch efforts to reclaim land from the sea and finally create a dry place to live in.

Say windmills, and everyone will instantly think of panoramic views with rows of rotating sails cutting through the air. The open country, where the wind can go as it pleases, is the windmill's natural habitat. Until recently, that is. In an overcrowded country like the Netherlands, space comes at a premium. Today, visual intrusion, environmental impact, and noise have become the hurdles to be surmounted before wind turbines can be installed in the open country. These problems are an incentive to look for creative solutions for putting the wind's motional energy to good use. Of course, the wind can blow fiercely across the open Dutch landscape, but as anyone who has passed a high-rise building on foot or a bicycle on a windy day will tell you, conditions can be pretty blustery in built-up areas too. When moving air reaches a building, there are only two ways to clear the obstacle. It can go either around it, or over the top. In doing so, as we have all noticed, the wind picks up speed.

Dick Sidler wondered whether the wind in built-up areas could not be put to good use with a wind turbine designed specifically for use in such a location. Following his graduation as an electrical engineer at TU Delft he had taken a job elsewhere. In 1993 he started his own energy technology consultancy company, already convinced that decentralised power generation would become the thing of the future. Instead of getting all our electricity from large, central power stations, we would be using an increasing number of local power sources. Not just wind power, but also solar energy and total energy plants. Forty percent of our energy consumption can be attributed to buildings, in other words, room for improvement.

One thing he was certain of: the plan had to involve a wind turbine on a vertical axis rather than one on a horizontal axis like most wind turbines we see around us. The advantage of using a vertical axis in a wind turbine is that it will keep turning irrespective of the direction the wind. The classic windmill, with its horizontal axis and rotor blades turning in a vertical plane, needs some sort of guide vane or mechanism to yaw it in the right direction whenever the wind shifts. Dick Sidler realised that in a built-up environment, with the wind constantly, and often unpredictably, changing direction, it would pay to use a type of mill that would not need to waste energy by going in circles to follow the wind around. On top of that, a wind turbine with a vertical axis requires less maintenance since it has no mechanism to prevent cable twist and no system to turn it into the wind. However, first the drawbacks of existing vertical axis designs had to be tackled: the relatively low efficiency and high vibration and noise levels.

Whisk Sidler started by surveying the market for vertical-axis turbines, and he came up with two possible candidates, the Windside and the Catavent. The Windside was his first choice, but it proved too expensive. According to Sidler, experimental readings showed that the yield was only about 25% of the manufacturer's figure.

Sidler realised that he required much more than his own knowledge of aerodynamics if he were to conduct the necessary wind turbine experiments successfully. So he contacted Dr. Gerard van Bussel of the Wind Energy Section of the TU Delft faculty of Civil Engineering (which has now become part of the faculty of Aeronautical Engineering). At the time, Ir. Sander Mertens was working on his post-doctoral research into the use of wind energy in built-up areas. Sidler conducted some experiments on the Catavent at the test site of the Wind Energy Section. The Catavent is a Canadian design that looked like a large air scoop that could turn itself into the wind by means of a set of guide vanes. As the air hit the device, it was diverted by a hornlike device onto a horizontal drum. Both the wind scoop and the drum rotated around the same axis. The air flowed into the drum through its open top, and could only escape through holes in the side. Vanes mounted at right angles to the outside were shaped so that the airflow was diverted in a tangential direction. This would cause the wheel to turn, driving a generator through a belt system. The lower end of the wind scoop featured a type of wind deflector designed to prevent the wind striking the vanes directly, and in addition to create a form of suction.

The Chelker-wind farm in Addingham, Ilkley, West-Yorkshire, Great Britain. Each wind turbine has a capacity of 300 kW/h.

Both the wind turbines of the past fifty years that are used to generate electricity and the traditional windmills that were used to pump land dry or grind wheat, use horizontal main axis, which means that both types require some sort of mechanism to yaw them into the wind.

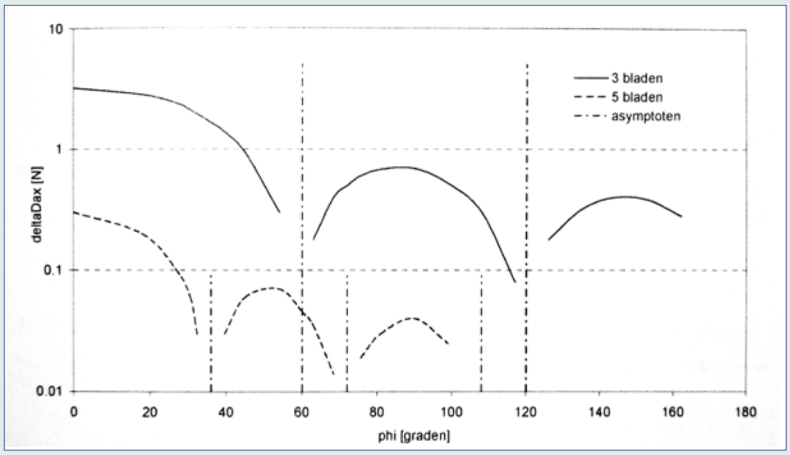
Large horizontal-axis wind turbines often feature gearboxes that transfer the energy collected by the enormous rotor blades to a generator. As the wind shifts, so does the rotor, which means that some provision must be made to prevent a cable twist between the generator and the foot of the mast. Turbines fitted out with these mechanisms require regular maintenance.

The Catavent is a Canadian designed wind turbine in which the wind flow is diverted by a horn-shaped duct and fed into a horizontal drum. As the air flows out of the drum past vanes mounted on the outside of the drum, the rotor is set in motion. Two screens fitted alongside the rotor protect the drum from the wind's onslaught and could also create a degree of suction.

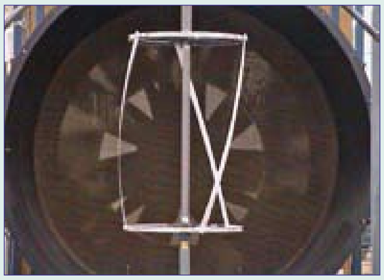
One of the problems of the Catavent was that it would not stand stable in the wind, as field tests during the December 1999 - April 2000 period showed. Dick Sidler investigated whether a different casing design could improve matters. A series of model tests culminated in the Wind Egg, which yaws into the wind very stably without any problem. Yet, wind tunnel tests resulted in the finding that the wind flow through the turbine housing was turbulent with a strong swirl in the front, but the energy output was rather low

The drum-shaped rotor of the Catavent wind turbine showing the vanes fitted to the outside of the drum.

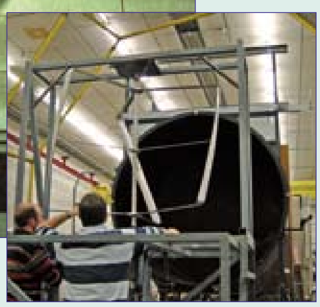
A Darrieus turbine is being transported to the wind tunnel of the Wind Energy section at TU Delft to be tested for the Eneco power company.



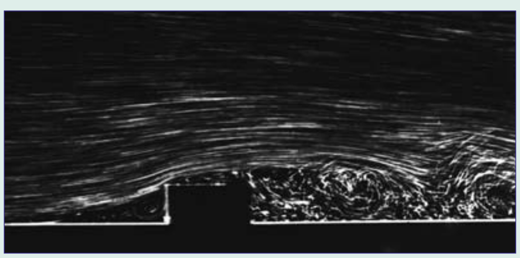
Graphic representation of the variation of the axial forces on the shaft as a function of the blade skew. The vertical dashed lines indicate the skew of the blades at which the variation in the axial force reaches zero on the shaft. Two graphs are shown. One shows the results of the theoretical model for a 3-bladed rotor, while the second gives the results of the theoretical model for a 5-bladed rotor.



The first prototype Turby in front of the wind tunnel of the Wind Energy section at TU Delft's Stevin Laboratory. It has racing bike wheels fitted with aerodynamic spokes at its top and bottom. The manufacturer of the first prototype thought the aerodynamic spokes would keep the drag figure down. However, the model disintegrated because the bolt used to secure the position of the two wheels broke under the strain of the centrifugal forces, causing the blades to bend outwards. A redesigned and stronger model, although it proved capable of coping with the centrifugal forces, required additional power to keep it in motion. It did show though that the required power input became less as the air speed increased. Apparently the model manage to extract energy from the wind, but this was too little to overcome the total drag. The readings obtained from tests on this model were used to determine the optimal aerodynamic dimensions.



The third prototype Turby in front of the wind tunnel. This half-height model was built using the results of the tests on the early prototypes. The model was to run under its own power, and run it did! The model — the largest size that could be accommodated in the wind tunnel — was used for all the wind tunnel tests and the final design of Turby was based on these measurements.



Visualisation of the air flow across the roof of a model building in a wind tunnel. The air flow path is made visible for photography by adding small particles. As can be clearly seen, the wind does not blow horizontally across the roof, but flows at an angle. The curly path of the particles close to the roof indicates that the local airflow constantly changes direction, in other words, it is turbulent.

"Sidler's query most closely matched my research," Mertens says, "and so it became a useful excursion alongside my main subject of enquiry: wind energy in the build environment."

Most wind turbines use the lifting force that acts on the curved rotor blades, just like the lifting power that enables an aircraft to stay airborne. Both the Windside and the Catavent (and its successor, the Windports) are based on the principle of resistance encountered by an airflow striking a surface. The experiments conducted on the Catavent showed a very pour efficiency. After having searched the market Sidler concluded that there was no efficient vertical axis wind turbine available, so he asked Mertens to design one.

"We immediately started looking for a lift-generating device with a vertical axis," Mertens says, "and then you automatically end up at the Darrieus design." This device, which looks a bit like a whisk mounted on a vertical axis, was invented in 1931 by a Frenchman, Darrieus. The whisk comprises three blades with a wing-like section. The main drawbacks of the Darrieus generator are that the ends of the blades near the central axis contribute little to its generating capacity, while the blades produce unpleasant vibrations and noise.

"Bearing the original Darrieus design in mind, we set out to create a straight-bladed variant, shaped like the letter H. This could have performed a little better than the original design, but it had the same problem as the Darrieus: the blades, more so in a two-bladed design –simultaneously changed wind directions along their full length, producing considerable vibration levels, with alternating lift forces on the blades as well as an alternating torque. These all had to be overcome, and so the basis of the new turbine was found in an odd number of inclined blades equidistant from the axis along their full length, producing a helical shape."

Rotor blade accelerations up to 200 times g Mertens became responsible for the aerodynamics of the machine. He combined analytical flow calculations with data from the wind tunnel (using a computational fluid dynamics program) to continually improve the design.

"I was able to calculate how high and how wide the rotor blades had to be. This resulted in a wind turbine with three inclined rotor blades, the whole assembly being three metres high and two metres wide. The chord of the blades is ten centimetres. A wind turbine of this size will produce 2.5 kilowatts."

This became the basis for the wind turbine that was to be named Turby.

An extra complication for the design was that the wind turbine has to produce as little noise as possible. After all, it was to be operated in an urban environment, not in the open country.

Mertens: "Keeping the noise level low means keeping the rotational speed down. The number characterising the rotation of the rotor blades is the tip speed ratio, which gives the ratio of the rotor blade tip speed over the wind speed. While for Turby the ratio sits at the relatively low value of 3, a propeller turbine in the open country can have a tip speed ratio of 9. The requirement for low-noise power production significantly reduces Turby's tip speed ratio. As a result the Reynolds Number, that typifies the type of airflow, is relatively low, which makes model simulation harder to do. In addition, the lifting power acting on the rotor blades becomes more difficult to model, so the model simulation results could not be more than a guideline. We had to go on to testing models in a wind tunnel."

When the initial prototype of Turby was built, the company constructing the wind turbine underestimated the centrifugal forces acting on the blades, Since these can reach up to 200 times g, the blades must be securely fixed. As this was not the case in the first prototype, a second had to be built. This time the device was strong enough, but refused to turn. The third attempt proved to be better. After some fine-tuning and scaling up the dimensions, the result was the present prototype Turby, which consists of three inclined, elongated and curved rotor blades arranged around a virtual cylinder two metres in diameter and three metres high. The rotor blades are made of a lightweight, strong, and rigid carbon-fibre composite material, resulting in a weight of only 4 kg per blade. The weight of the entire turbine is 135 kg. Turby's small diameter and the open nature of the rotor make it less intrusive than a normal wind turbine in an open field. Thanks to its lightweight construction, Turby can be installed without a lifting crane.

"Each Turby located on the roof of a high-rise building in a town generates power exactly where it is needed, without transport losses," Mertens says,

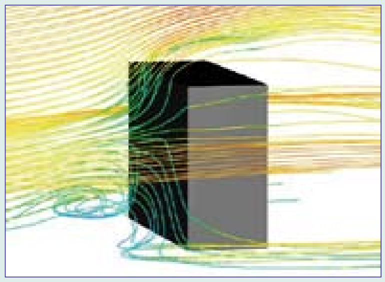
“That’s the beauty of the system. Turby is connected to the building’s power system behind the public utility meter. The power goes straight into the building, reimbursing the owner at full kilowatt hour rate. Whereas owners of wind turbines in the Dutch countryside have to go begging to a power company to offload their output. The power company, pays them only one third of the amount consumers are charged for a kilowatt-hour.
In a reasonable wind location, not too close to the coastline, nor stuck between other high-rise blocks, a single Turby will provide about 3000 kilowatt-hours, enough to cover the power consumption of an average family. Turby prototypes have now been installed on the roof of an apartment building in Tilburg (the first installation dates from May 2004), on an apartment building in Breda, on the town hall in The Hague, and on the ChemTech faculty building of TU Delft. The only noise to be heard from the generators, and only along the top access gallery of the building, is a light whizzing sound as the wind gusts. Nothing is to be heard inside. These are all still single Turby installations, but Mertens is already thinking of roof-top wind turbine parks for the future.
The Dutch Ministry of Transport has also installed a single Turby, along the A50 motorway. It supplements a pair of German-made wind turbines, whose purpose is to provide power for the matrix information signs and the street lighting along the road. At least, that is the idea. Mertens is not convinced that Turby is suitable for the purpose: “It was really designed to be used in a built-up environment, sitting on a high roof. Other types of turbine work much better along the motorway.”

More power from angled flows

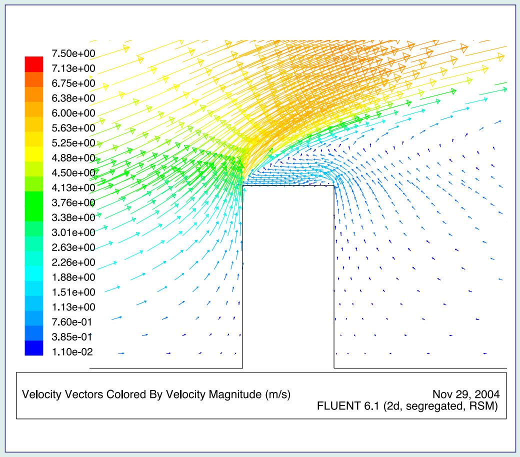
Turby has a number of unique features. It produces little noise and can handle all the changes in wind direction the built-up environment can throw at it, thanks to its vertical shaft layout.
“We were a little surprised by something else though,” Mertens recalls. “As the wind crosses the roof of a high-rise building, it flows at an angle, typically twenty degrees, to the flat roof-top. This angle varies with the wind speed, sometimes a little higher, at other times a little lower. As the angle of flow increases, the yield of a normal wind turbine will start to drop as the useful wind component decreases. Turby on the other hand can get more energy from the wind as the angle of flow increases, up to a certain maximum, of course. This was new to us. We had never before heard of a wind turbine managing such a feat, and I have found no previous reports of the phenomenon. As the angle of the wind flow increases, the surface area of the unhindered wind reaching Turby also increases. That is the secret of the design.”
Mertens also drew up a number of rules of thumb to indicate how high the rotor should protrude above the roof. Typical values range from 5 to 7.5 metres above the roof-top, where the wind speed is about twenty percent higher than the unhindered wind speed at the same height in the open field. Mertens conclusion is that wind energy offers a viable alternative if you can make use of the highest buildings in a built-up area.
“You have to be careful where you put the turbine, though. In Tokyo they once put a set of turbines just above the roof-top. That does not work. They really have to be up in the accelerated, angled airflow.”
A normal wind turbine in the open field carries its own wind speed counter. Turby can do without. In fact it constantly measures the wind speed.
Mertens: “At low wind speeds, the rotor blades will start to turn, but they will go too slowly to generate sufficient lifting power on the blades. This is also too slow to generate power. The initial movement is detected and a signal is sent to the generator which briefly acts as a motor, increasing the speed of the rotor blades to the point where they have sufficient airspeed to generate the required lifting force on the blades. At that point the rotor takes over and the turbine continues to rotate on wind power alone like any other wind turbine.”
So it needs extra energy to get started? Sounds like a major drawback. Mertens: “It takes only very little energy, since the rotor is relatively light. What’s more, the system is monitored by a protocol to ensure that it does not get kick-started too often.”

Wind turbine-integrated buildings

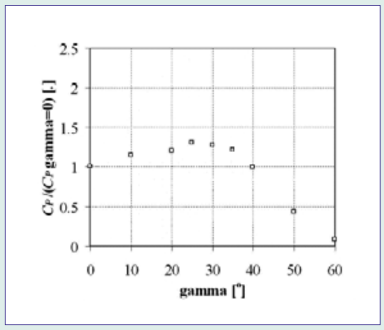
The generator used by Turby is a compact direct-drive system, i.e. one without a gearbox, designed by Dr. Ir. Henk Polinder of TU Delft. The rotor drives the generator directly without the intervention of a gearbox. A gearbox generator would have been cheaper, but the



Visualisation of the air flow around a model building using a simulation program (Computational Fluid Dynamics calculation). This shows only the average tracks of small particles that were released in the undisturbed upwind airflow. As can be seen, the main flow passes on either side of the building and does not come close to the roof.



Speeds above the roof of a model building, obtained by means of a simulation (Computational Fluid Dynamics calculation). The speeds are colour-tagged (from high to low speed: red, yellow, green, blue. This clearly shows that Turby is located in an area with increased speed (yellow) relative to the undisturbed wind speed at roof top level (green/blue).



Test results of a measure for increase in power (vertical axis) of an H-Darrieus wind turbine (a wind turbine with an operating principle analogue to that of Turby) as a function of the angle of incidence of the flow (horizontal axis). The graph shows that the H-Darrieus turbine produces 30 percent more power at an angle of incidence of 25 degrees.

The final prototype of Turby on the test field of the Wind Energy section on the TU Delft campus. This is where the wind generator is tested under field conditions, such as gusting wind, start-up at low wind speeds, and high wind speed cutout.

Prototype Turby on the roof of a block of flats in the university town of Tilburg in the south of the Netherlands

Turby at the Q8 gas terminal on the North Sea coast near Velsen, where it is being tested for possible use on offshore platforms.

The generator of a Turby is fully integrated in the wind turbine and consists of an external magnetic rotor (the ring bearing the name) that rotates around the stator. The generator does not have any bearings of its own.

Interior view of the rotor with permanent magnets. These magnets have been fitted at a slight angle in order to reduce the adhesion forces that would hold the rotor in a preferred position, requiring an extra force to set the rotor in motion.

The generator stator is fixed to the stationary axis of the turbine, so no provisions are needed to prevent cable twist. The generator was designed to be highly efficient not only at full power, but also at lower power levels (at which it usually operates).

Since Turby is not self-starting Sidler developed a 'dedicated' converter. It is a four-quadrant system, which handles not only the start-up function of the synchronous generator as a drive motor, but also the turbine control and safety functions and the conversion of the variable voltage and frequency generated by the generator to the correct voltage and frequency so the wind-generated electrical power can be fed into the local grid.

direct-drive system requires less maintenance, which was a design prerequisite. According to Sidler the maintenance-free period is about twenty years.

The ring of permanent magnets forms part of the rotor. The motional energy is transformed into electrical energy, which is then electronically converted into alternating current of the same voltage and frequency as supplied by the mains grid. The generator not only handles the start-up sequence, but also acts as a brake and a safety monitor on the rotating turbine.

Dick Sidler has had the first prototypes of Turby made through his company Turby B.V.. Interested parties from all over Europe and as far away as China, Japan, Australia, New Zealand and the U.S. have already been enquiring about the sustainable urban roof-top wind power system.

Sander Mertens now works for the construction and industry section of DHV Engineering Consultants in The Hague.

"Having done all this research, I can now advise others on what can be done with wind power in a built-up area, all the way from wind nuisance to wind usage. Architects come to consult me about the integration of wind turbines in between buildings and on top of them. I advise them about the shape of buildings, and discuss the kind of yield they can expect."

Wind power in a built-up area can be used in three fundamentally different ways, as explained by Mertens in his Ph.D. thesis, due to be published within a few months. Firstly there are wind turbines inside or on top of existing buildings, like Turby. For future use, Mertens is also contemplating buildings with integrated wind turbines inside a duct that connects the high-pressure and low-pressure sides of a building. A third option is to have wing-shaped buildings.

Mertens: "Whereas a rectangular building produces an increase in wind speed at roof-top level of about twenty percent, a high cylindrical building could theoretically generate up to 200 percent along the sides of the building. The ultimate goal is to work with architects to devise a building that will enable a wind turbine to produce power as often as possible and as efficiently as possible. Unfortunately, many aerodynamic designs are not very practical as buildings, so the challenge will be to find the right balance of innovation between optimum aerodynamics and practical applicability."

Meanwhile at the Wind Energy Section of Dr Gerard van Bussel at Delft University another post-doctoral student is to continue the research into the aerodynamics of Turby-like generators for the built-up areas.

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Turby specifications

Operating range		
Wind speed:	4-14 m/s	
Survivable wind speed:	55 m/s	
Turbine		
Rotor diameter:	1.99 m	
Rotor height:	3.0 m	
Weight:	136 kg	
Nominal capacity:	2.5 kW at 14 m/s wind speed	
Mast	**Standard**	**Extended**
Height	6.0 m	7.5 m
Plinth distance	4.0 m	4.0 m
Cross-brace	1.5 m	2.3 m
Approx. weight:	240 kg	300 kg
Converter		
Output type:	single phase	
Nominal capacity	2.5 kW	
Peak capacity:	3.0 kW	

(Source: www.turby.nl)

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