Increasing energy efficiency = Reducing consumption: A simplistic formula!

An improved energy efficiency does not automatically lead to the expected degree of energy savings. Success gained in improving efficiency often leads to behavioral changes that, in turn, cause increased consumption. Scientists at the Institute for Future Energy Consumer Needs and Behavior are investigating how this so-called ‘Rebound Effect’ works and which political policy instruments can be used to counter it.

Efficiency thanks to Power Electronics

Researchers of the Institute for Power Generation and Storage Systems (PGS) are developing a high-voltage DC-DC converter for the power range of up to 5 megawatt. In the future, such converters will enable electricity generated from renewable resources to be more efficiently and cost-effectively integrated into the electrical energy supply system than is possible with the existing AC-grids.

Virtual CO₂-Storage at the Sites Malmö and Minden

Prof. Dr. Rik W. De Doncker receives the IEEE William E. Newell Power Electronics Award Page 4 • Participation in Solar Decathlon in Madrid Page 4 • Colloquium: Optimal Location Strategies for Public Electric Vehicle Charging Infrastructure, The Dawn of Solar, Rethinking Energy Demand: Reflections from the History of US Electric Utilities Page 5 • Unique test laboratory for home energy systems Page 6 • Events/Dates at E.ON ERC Page 6

E.ON ERC I Building Energy Supply

Intelligent combination saves energy

High room-climate comfort with possibly low input of primary energy

Protection of the environment begins at home. The scientists at E.ON ERC take this principle seriously and have made the heating, cooling and power supply of their main administration building, officially inaugurated in March, into a distinct research project. High room-climate comfort tailored to the needs of all users has been reached with possibly low input of primary energy.

In cooperation with other institutes of E.ON ERC and using known and new techniques, the Institute for Energy Efficient Buildings and Indoor Climate (EBC), directed by Professor Dirk Müller, has developed and realized a technical building concept that surpasses all others. One of the core elements is the combined heating and cooling generation by means of a controllable turbo-compressor heat pump which controls the internal shift of energy among the heat sources and heat sinks within and outside the building. Thus, in winter, the residual heat of the server rooms is used to heat the remaining areas. Upon higher demand, the...
Increasing energy efficiency = Reducing consumption: A simplistic formula!

Does the rebound effect make the promotion of efficiency, in fact, inefficient?

Improving energy efficiency represents one of the most important pillars of the change in energy policy. By no means is it certain that a more efficient dealing with energy leads to the expected degree of savings. But rather success in saving energy often leads to particular individual changes in the behavior of the producers and/or consumers. Consequently, despite this so-called ‘rebound effect’, it is important to precisely investigate and deliberate which political instruments can be implemented to decrease the consumption of energy and electricity, as is prescribed in the energy program of the German federal government, by respectively 50 % and 25 % (as opposed to the reference year 2008).

The studies at the Institute for Future Energy Consumer Needs and Behavior (FCN) clearly show that the estimation of such rebound effects must, by all means, be taken into consideration in political decision-making for promoting energy efficiency. As FCN director Professor Reinhard Madlener explains, “Resource efficiency alone does not definitely lead to savings. Without limiting accompanying measures, even the opposite can take place. Yet our investigations have clearly shown that there is no simple formula for determining the total implications of the rebound effect.”

The complexity of this phenomenon is clearly exhibited in a study, among others, concerning the expected rebound effects in home heating. “To curb the rebound, one won’t be able to avoid introducing taxes or caps. It will be important to soften the social cases of hardship, the so-called ‘energy poverty’, linked to such a policy change.”

Prof. Dr. Reinhard Madlener, FCN

Rebound studies cover all the effects of an increase in technical efficiency on consumer demand. For example, it is also interesting to understand whether and how consumer behavior changes after the purchase of a ‘fuel-efficient’ car, namely, whether longer distances are driven or even if another car is bought. It is also being studied if and how much more is heated after a residential house is better insulated, even though this measure was intended to reduce energy consumption. Such a rebound in consumption patterns is called a ‘direct rebound’. By contrast, ‘indirect’ rebound infers all other effects: For which products or services does the consumer spend money with this
increase in buying power? Will energy demand be again boosted on the long term as the result of sinking prices on the middle term? Hence, all such studies have to determine the direct and indirect rebound effects. Ultimately, the total rebound is the decisive parameter of environmental relevance.

“The simple statement that improvements in energy efficiency lead to the same level of reductions in combined energy consumption is definitely simplistic and false,” explains Madlener. “These are moncausal calculations based on specific consumptions which meanwhile engineers, too, are even criticizing as being false, because such equations are disregarding human behavior and economic adaptation mechanisms.”

Madlener sees considerable need for research on the topic of rebound and cites two particular areas: 1) the future role of private households as “producers-consumers” of energy, and 2) the co-effects resulting from excessive energy subsidies, e.g. concerning renovations of residential buildings or electromobility. He contends that such effects have made the promotion of energy efficiency, ironically, very inefficient.

*The work paper entitled “Rebound Effects in German Residential Heating: Do Ownership and Income Matter?” can be downloaded under www.eonerc.rwth-aachen.de → FCN → Publications (2011).*

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**GGE | Computer-aided Simulation**

**Virtual CO₂-Storage at the Sites Malmö and Minden**

Expanded simulation program SHEMAT saves times and costs

The separation and storage of CO₂ in geological rock formations is one way to reduce emissions resulting from the combustion of conventional fuels and linked to adverse climate change. The necessary continuous monitoring of CO₂-emissions on site, however, is complicated and expensive. Thus, numerical simulations pose an attractive alternative to gain a more detailed understanding of the dynamics of such systems.

With the computer-aided simulation program SHEMAT, the Institute for Applied Geophysics and Geothermal Energy (GGE) can simulate subsurface flow, substance and heat transport as well as geochemical fluid-rock reactions and multiphase flows over long periods. To enable the calculation of two-phase flow in porous media, the institute’s program SHEMAT has also been expanded, in particular, to the two phases saltwater and CO₂.

Studies at GGE investigated whether two sites, i.e. Malmö in southern Sweden and Minden in North Rhine-Westphalia, would be suited as CO₂-storage reservoirs. In the case of Malmö, the injection and spread of subsurface CO₂ over a period of 50 years was simulated. The simulation showed that, initially, the flow movements are mainly attributed to the difference in density between brine and the injected greenhouse gas. Then supercritical CO₂ builds up underground and collects under the caprock. Subsequently, it dissolves itself in the brine. Since the resulting mixture is denser than normal brine, it sinks again to the bottom of the reservoir.

In addition, the study of various injection strategies showed that upon injection of dry CO₂, the water becomes dissolved in the CO₂-phase and eventually results in salt precipitation. Consequently, the permeability of the reservoir rock formation decreases which, in turn, either hinders a further injection or even makes this impossible. The injection of fresh water as well as higher injection pressures could reduce this salt precipitation.

Regarding the site Minden, the behavior of CO₂ was simulated for a period over 60 years as well as in a long-term simulation for a period over 10,000 years. Forty years—the typical lifespan of a coal-fired power plant—was assumed to be the injection period.

The investigation showed that within this period, the CO₂ rises up to the caprock and...
then spreads out horizontally from the injection point to a radius of 2,250 meters. Similar to the behavior at Malmö, the CO₂ then becomes almost completely dissolved in the brine. This mixture then sinks to the reservoir bottom where secondary carbonates such as dawnite, ankerite and siderite are formed by chemical reactions with the rock. After 10,000 years, about 15 % of the injected CO₂ is hydrodynamically stored in the pore space of the reservoir rock, whereas 20 % is dissolved in brine and almost 65 % is precipitated as minerals. This kind of mineral sequestration in carbonates plays a large role at the site Minden, and thereby decreases the risk of a release of CO₂ from the reservoir via a potential leakage in the storage system.

Efficiency thanks to Power Electronics
PGS develops high-efficiency DC-DC converters

With modern medium-voltage DC-grids, for which the Institute for Power Generation and Storage Systems (PGS) of E.ON ERC is researching and developing power electronic components as well as complete converters, various energy sources such as photovoltaic, on- and offshore wind farms or combined heat and power (CHP) plants can be more efficiently and cost-effectively integrated in the electrical energy supply system than with the existing AC-grids. For example, the necessary filters that inevitably need to be installed in the transmission and distribution grids can be clearly smaller in the DC-grids than in the conventional 50-Hertz-AC-grid. This is one advantage that ought to positively come into play, among others, in the networking and the grid connection of offshore wind farms.

Power electronic DC-DC converters are a key technology when the task is to link DC-distribution grids among one another and with the transmission grid. One possible converter concept is the ‘Dual-Active Bridge’ in which two DC-AC converters are coupled on the alternating current side via a medium-frequency transformer. Studies have shown that such converters—thanks to higher operation frequencies, with an unchangeable 50 Hz prescribed in the European AC-grid—are not

E.ON ERC Ticker
Prof. Dr. ir. Dr. h. c. Rik W. De Doncker, director of E.ON ERC and head of the Institute for Power Generation and Storage Systems (PGS) as well as of the Institute for Power Electronics and Electrical Drives (ISEA) will be conferred the IEEE William E. Newell Power Electronics Award in early 2013. The Institute of Electrical and Electronics Engineers (IEEE), comprising around 400,000 members in more than 160 countries, is worldwide the largest association of engineers from the fields of electrical engineering and computer science. This award will be given to Rik De Doncker for his “excellent contribution to the further development of power electronics”. For further information, see http://www.ieee.org/about/awards/tfas/newell.html.

With its own building, the “Counter Entropy Team” of RWTH Aachen University is competing in the international student competition “Solar Decathlon Europe 2012” in Madrid from September 17-28. The aim of the competition is to promote understanding for solar construction. A team of the Institute for Energy Efficient Buildings and Indoor Climate (EBC) has been involved in developing the exclusively solar-powered house. Moreover, the Workshop of E.ON ERC is actively supporting its construction (see picture). A total of 19 houses from 13 countries are represented in the competition. For more details, see http://www.sdeurope.org/?p=6798&lang=en.
only smaller and lighter than their conventional equivalents but they work more efficiently.

Currently the researchers at PGS are working on the development of a high-efficiency DC-DC converter for the power range of up to 5 megawatt according to the principle of the Dual-Active Bridge. In this case, so-called "Integrated Gate-Commutated Thyristors" (IGCTs) are used as semi-conductor switch elements in the bridges. These lead to lower conduction losses than those of the IGBTs mostly applied in this voltage range. Combined with the soft-switching concept of the Dual-Active Bridge, as a whole the converters show, in particular, low conduction losses.

For running start-up measurements in an initially low power range, a 300 kVA-transformer will be applied as the central structural element. This will soon be replaced—separately for each phase of the alternating voltage connection—by three 2.2-megawatt transformers that are still being built. Then, the tests and measurements will begin with outputs of up to an effective rated output of 5 megawatt.

The implementation of the results will be followed further in the consortium for medium-voltage DC-grids underway at E.ON ERC with industrial partners.

**E.ON ERC Colloquium**

"Optimal Location Strategies for Public Electric Vehicle Charging Infrastructure" was the main topic of the talk by Dr. Ramteen Sioshanssi of the Ohio State University held at E.ON Energy Research Center. The economist reported about a research project on optimizing the selection of sites of charging stations for so-called ‘Plug-in Hybrid Vehicles’ (PHEV) in municipal areas such as the metropolitan area of Columbus, Ohio in the USA.

Among other questions, it was studied what would be the most cost-effective spatial distribution of a network of charging stations. By considering existing study results, it was concluded that as a first step, the charging stations should be spatially concentrated nearby large employers. According to the study, there would be a better capacity utilization there than in the vicinity of universities or shopping centers.

In his talk entitled „Rethinking Energy demand: Reflections from the History of US Electric Utilities", Professor Clark A. Miller (see picture, right) from Arizona State University, pointed out that the demand for electricity essentially depends on social developments and the introduction of new technologies. This summer, Miller was engaged as guest professor of Professor Daniel Barben (see picture, left) at the Chair for Future Research of RWTH Aachen University.

Utility companies influence price—for example, by charging low tariffs at times of low demand—in order to obtain uniform network utilization. The trend towards decentralized electricity generation from regenerative energy resources makes this way difficult to implement, explained Miller. For the future, intelligent solutions would have to be found in order to shift peak consumer demand for electricity, e.g. during very sunny times. This is not possible with the conventional system.
ACS/EBC I Power Hardware-in-the-Loop

Unique test laboratory for home energy systems

An electrical heat pump is used for heating. Alternatively, in the cellar stands a micro-combined heat and power (micro-CHP) unit which, besides heat, also generates electricity. A photovoltaic unit likewise produces electrical energy, and the accumulator of the electric car is mostly connected to the grid during the night. The times when houses were considered as purely energy consumers are apparently passed. Modern homes simultaneously generate and utilize thermal and electrical energy.

Home Energy Systems (HES) of the future are crucibles of various energy forms. Simple controls, for example, via heating thermostats, no longer suffice for such systems. But rather Home Energy Management Systems (HEMS) are needed which can sensibly link the various types of energy with one another and can communicate with Smart Grids. Ultimately, the aim is to substantially reduce the total energy consumption of the building and simultaneously reduce peak power demand in the power supply grids, ideally, via the time-controlled equalization of the take-up or feed-in of power.

With their so-called Power Hardware-in-the-Loop platform, the E.ON ERC institutes Automation of Complex Power Systems (ACS) and Energy Efficient Buildings and Indoor Climate (EBC) have at their disposal a highly modern test laboratory for investigating various home energy systems including their linking with all thermal and electrical energy flows which (may) occur in a house. Real components, such as heat pumps and their control units, are tested under simulated limiting conditions. These simulated limiting conditions—such as external air temperature and humidity, incident sunlight, heat insulation, ventilation, quality of the power supply—are emulated in the test laboratory. The testing of the respective home energy system then takes place using a holistic and unique approach by combining thermal, hydraulic, electrical and communication interfaces.

The Power Hardware-in-the-Loop platform is a highly modern test laboratory for investigating various home energy systems.

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E.ON ERC | E.ON Energy Research Center, RWTH Aachen University, Prof. Dr. ir. Dr. h. c. Rik W. De Doncker
ACS | Automation of Complex Power Systems, Prof. Antonello Monti, Ph. D.
EBC | Energy Efficient Buildings and Indoor Climate, Prof. Dr.-Ing. Dirk Müller
FCN | Future Energy Consumer Needs and Behavior, Prof. Dr. rer. soc. oec. Reinhard Madlener
GGE | Applied Geophysics and Geothermal Energy, Prof. Dr. rer. nat. Christoph Clauser
PGS | Power Generation and Storage Systems, Prof. Dr. ir. Dr. h. c. Rik W. De Doncker

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Events/Dates at E.ON ERC

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<td>Colloquium: Modellansätze zur Berücksichtigung von operativem und strategischem Engpassmanagement bei der Analyse von Elektrizitätsmärkten, Jürgen Apfelbeck, Institut für Energiewirtschaft und Rationelle Energieanwendung, Universität Stuttgart</td>
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<tr>
<td>Nov 22, 2012, 4.00 pm</td>
<td>Colloquium: Envisaging Cradle-to-Cradle Biorefineries, Dr. Fabrizio Sibilla, Nova-Institut/Dr. Pablo Dominguez de María, RWTH Aachen</td>
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Information/E-Mail: colloquium@eonerc.rwth-aachen.de

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