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Energy-Optimised Building - Experience and Future Perspectives from a Demonstration Programme in Germany

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ABSTRACT

In 1995, the German Federal Ministry of Economics and Technology launched an intensive research and demonstration programme on energy-optimised construction of new buildings as well as retrofitting the building stock. Beside research on materials and components, approximately 50 demonstration buildings covering various building typologies have been realized and monitored within the programme (www.enob.info). Accompanying research was conducted to systemise the results and lessons learned. The programme led to a set of prominent research results in the fields of e.g. daylighting, passive cooling, energy efficiency and renewable energy use in commercial buildings, user behaviour and user satisfaction. Many of the demonstration projects have reached energy savings of 50% and more compared to current practice in Germany, without exceeding conventional investment costs. A number of these projects have been awarded architectural prizes. This paper summarises key findings and explains the strategies for new projects on the route toward net zero-energy buildings. These strategies are based on a further decrease in energy demand and increased renewable energy utilisation in conjunction with intensified use of building-integrated power generation interacting with the public grid.

1 ENERGY-OPTIMISED BUILDING AS A FOCUS FOR RESEARCH

Consumption of fossil fuels and the use of electricity in buildings account for about 37 % of the primary energy consumption and 45 % of the greenhouse gas emissions in Germany [Bundesregierung, 2005]. Apart from the dimensions involved, the main point to be noted is that the reduction potential is extraordinarily large and can already be realised with today's technology. Against this background, the German Federal Ministry for Economics and Technology (BMWi) already initiated an intensive research and demonstration programme in 1995 to investigate energy-optimised construction types for new buildings, now named "EnBau". The "EnSan" project, addressing renovation of the existing building stock, followed in 1997. In 2005, the Federal Cabinet decided to draw these projects together within a funding concept with the new title of "Energy-optimised building – EnOB". Work on integrated energy analysis of non-residential buildings [Voss, 2006a] was particularly significant in advance of the "Energy Performance of Buildings Directive – EPBD" [EPDB, 2003] and the subsequent adaptation of the new German Building Energy Code (EnEV) and its calculation procedure in 2007 (DIN V 18599).

Apart from the demonstration activities, the EnOB programme (Fig. 1) also encompasses technological research to further develop vacuum insulation (ViBau) and to investigate low-exergy systems for buildings (LowEx). It is currently being extended with projects on energy-efficient optimisation of operation management (EnBop), energy efficiency in town planning, local and district heating and energy-efficient school buildings. The joint information platform can be found on the Internet under www.enob.info .

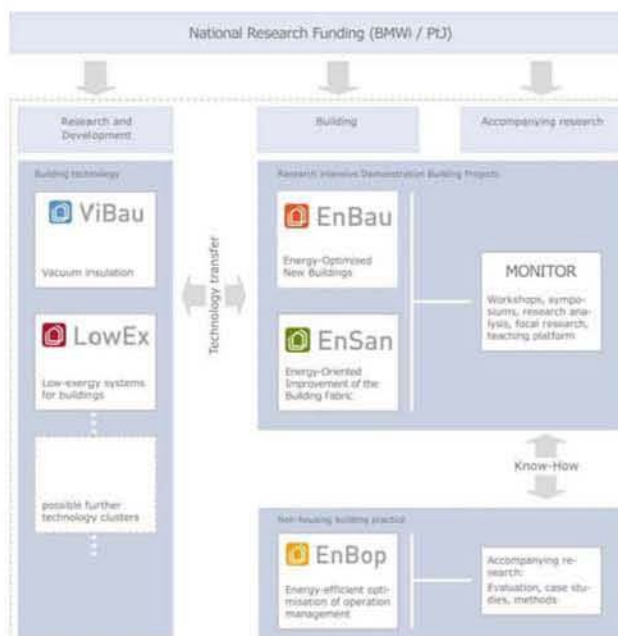


Fig. 1: Overview of the BMWi research programme for energy-optimised building, divided into sections on demonstration and R & D.

Apart from research conducted on materials and components, to date about 50 demonstration buildings of differing types have been newly constructed or renovated, and the results have been evaluated comparatively. The results and experience were documented and published within the accompanying research programme [Gossauer, 2006, 2008], [Hoffmann, 2005, 2007], [Kalz, 2006], [Pfafferott, 2004, 2006], [Voss, 2006a,b]. Since 2007 this accompanying research is carried out jointly by the Universities of Wuppertal, Karlsruhe and Dresden as well as the Fraunhofer ISE. The University of Wuppertal is co-ordinating the joint project.

2 EXPERIENCE

2.1 Energy Consumption

At present, a total of 27 new construction projects and 24 renovation projects have been supported in the programme. Many have already been completed (28 projects), others are in the monitoring phase (21) and still others are being planned or constructed (2). As an example, fig. 2 summarises the energy consumption for the new buildings in the non residential sector in a graphical form. A related cross-sectional analysis for 2007 is currently being prepared which also takes the renovated buildings into account.

Encouragingly, most of the buildings have a primary energy consumption which is lower than the intended limit of 100 kWh/m²a for heating, ventilation air conditioning and lighting (HVAC+L). Taking the climatic background into account, very low consumption values are mainly achieved where the heating demand is very low.

Table 1: Arithmetically averaged annual energy consumption data for the demonstration projects in kWh per m² net heated floor area, separated into the three building categories investigated. Due to the higher number of objects, the values for office and administration buildings are particularly significant. Average values may not be based on the same building in all sectors of consumption as data sets are not complete in all cases. The values per m^2 for production buildings are not comparable to those for the other buildings due to the great height of the rooms required for operation [Voss, 2006d]. Primary energy data are based on factors given by DIN V 18599 (not including building integrated photovoltaics).

	Site Energy		Primary Energy	
	Total	HVAC +L	Total	HVAC+L
	kWh/m²a		kWh/m²a	
Office	88	67	203	81
Production	90	75	194	129
Education	62	48	113	74

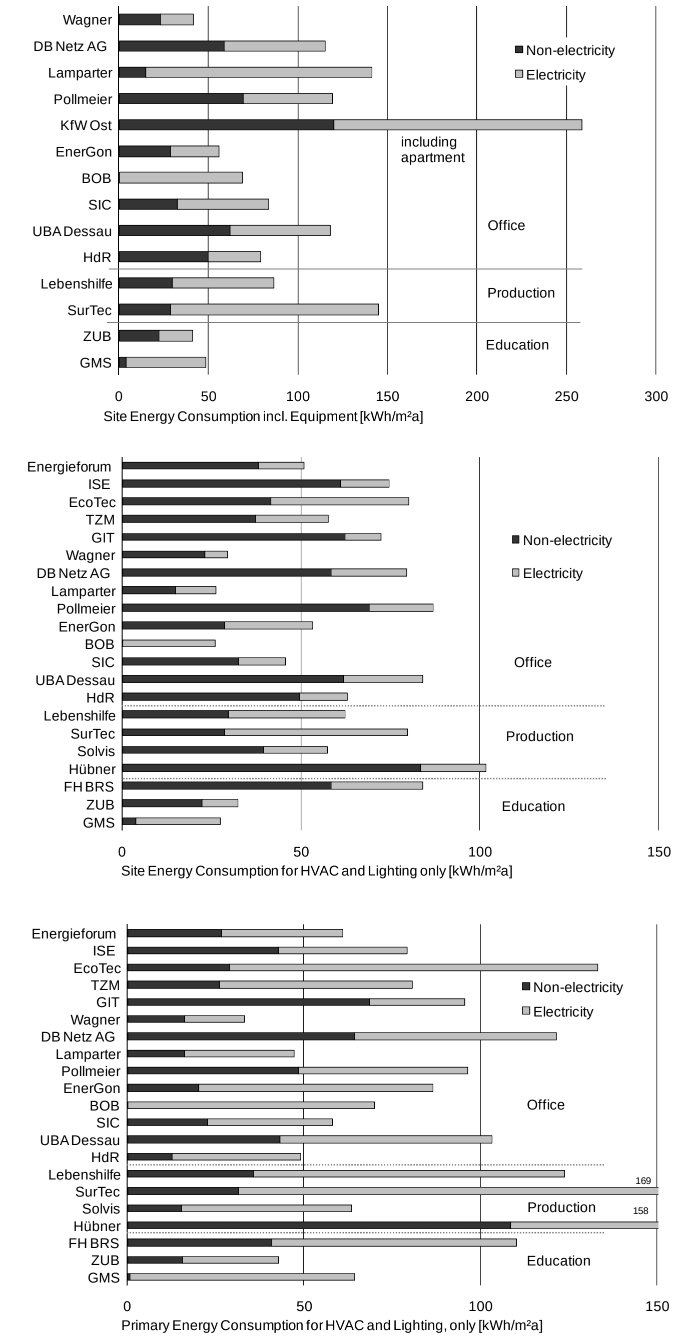
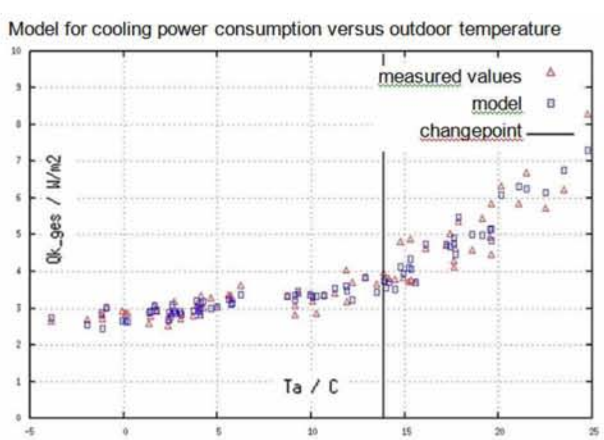


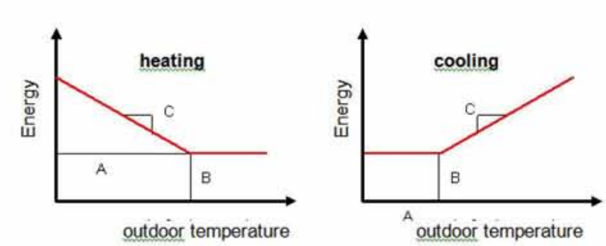
Fig. 2: Site energy values for the whole building energy consumption (upper diagram) as well as for the HVAC and lighting system only (middle diagram) and primary energy values derived from them (lower diagram, HVAC+L only). Primary energy factors are based on DIN V 18599, not including building integrated photovoltaics. No correction was made for the number of degree-days in each year. In each case, the data source is the university responsible for the corresponding measurement programme, refer table 2 at the end of this paper. All data refer to the net heated floor area. "Non-electricity" data refer to the use of fossil fuels, biomass or district heat.

2.2 Optimisation in Operation

However, it has become evident in the project investigations to date that the planned energy targets are not achieved immediately without an adjustment phase. Also, the fact that the intended energy coefficients are apparently achieved cannot immediately be interpreted to mean that the building behaves as predicted. Often different deviations compensate each other.

As a building in operation represents a complex interaction between various factors (e.g. construction, equipment, conditioning, occupation, user behaviour, etc.), experience has shown that an initial adjustment phase is essential. In addition to considering energy efficiency during the planning phase, the processes of monitoring the operation and if necessary optimising the operation management are highly effective measures to sustainably reduce energy consumption and energy costs, especially in non-residential buildings with their often high degree of complexity. In many cases, detailed monitoring helped to identify and then eliminate faults in plant operation. A task for the future is to further develop building management technology as a tool for energy consumption analysis and comparison between targets and reality. One new approach is so-called model-based operation management, which continuously compares benchmark and actual values for energy consumption (Fig. 3).





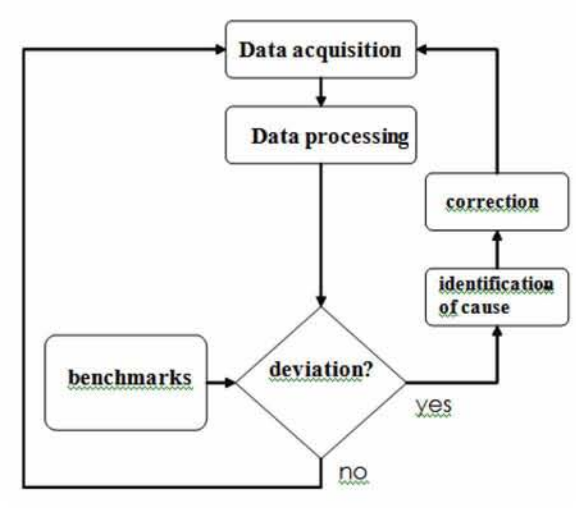


Fig. 3: Fundamental principle of model-based operation management (upper left diagram), three-point models for heating energy and cooling energy as a function of the outdoor temperature (lower left diagram) and the application of such a model to the NIZ building in Braunschweig as an example (upper diagram). A robust linear regression was used to determine the cooling energy consumption on the basis of weekly values (source: Fraunhofer ISE).

2.3 Passive Cooling and Indoor Climate

Most of the demonstration projects in the commercial building sector that have been investigated so far are cooled exclusively "passively". Just as for air-conditioned buildings, the extremely hot summer of 2003 presented a challenge for passively cooled buildings. Under these conditions, those buildings relying solely on heat extraction by nocturnal ventilation reached their capacity (Fig. 4). During a "normal summer" however, they can also meet high comfort requirements [Pfafferott, 2004, 2006], [Voss, 2006c].

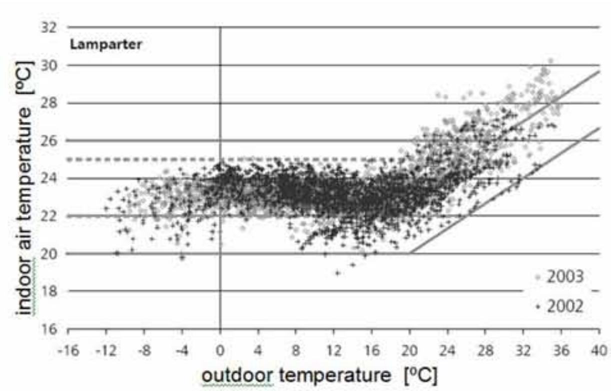


Fig. 4: Indoor air temperatures in the Lamparter office building versus the outdoor air temperature and the comfort zones as defined by the old German code DIN 1946. Data from 2002 and 2003 are shown.

Buildings with underground pipes as a heat sink (Energon, BOB and GMS projects) show good performance even during very hot periods (Fig. 5) [Pfafferott, 2006]. Detailed analysis of the buildings revealed that concrete core cooling (almost) always maintained the indoor temperatures required by the user behaviour patterns – assuming that solar and internal heat loads had been consistently reduced. Concrete core heating in winter can also guarantee thermal comfort in these buildings without the need for additional heating surfaces. According to comfort criteria, 65 % of users are always satisfied with the indoor temperature. If the average operative indoor temperature is examined, the comfort limits for 90 % satisfied users are seldom violated. Even during periods of high outdoor temperatures, the average indoor temperature remains within the specified limits – an average indoor temperature of 27 °C is never exceeded. The ground and ground water are heat sinks which are largely independent of the outdoor air temperature, so that they can cool buildings effectively even when the outdoor temperatures are high.

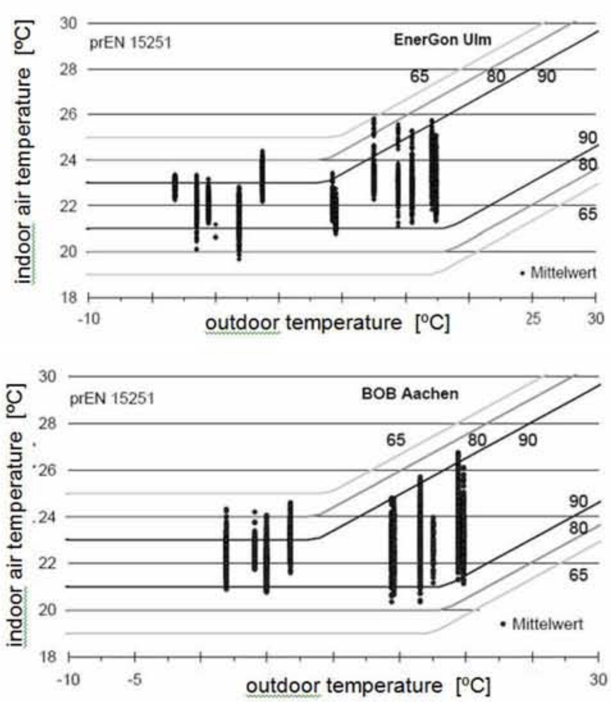


Fig. 5: Evaluation of the indoor temperature for the Energon building in Ulm (upper diagram) and BOB in Aachen (lower diagram) during operation according to the criteria of prEN 15251:2005 for thermal comfort. The comfort categories, A, B and C, correspond to the proportion of users satisfied with the indoor temperature, namely 90 % (black lines), 80 % (dark grey lines) and 65 % (light grey lines) respectively.

The data measured in the demonstration buildings from 2001 to 2006 were analysed with respect to different criteria for thermal comfort in summer as defined in different standards. The buildings were evaluated for periods of real operation, so were subject to individual user behaviour with regard to internal gains, windows and shading devices. To improve the comparability, the operating period was defined to be on working days between 8 a.m. and 6 p.m.. The results from six buildings are shown for two measurement periods in Fig. 6. It is clearly evident that both the choice of comfort criteria and the variation of weather from year to year have an effect on the evaluation. Furthermore, it can be seen that buildings with nocturnal ventilation concepts can meet the comfort criteria only if the internal gains or external thermal loads are small.

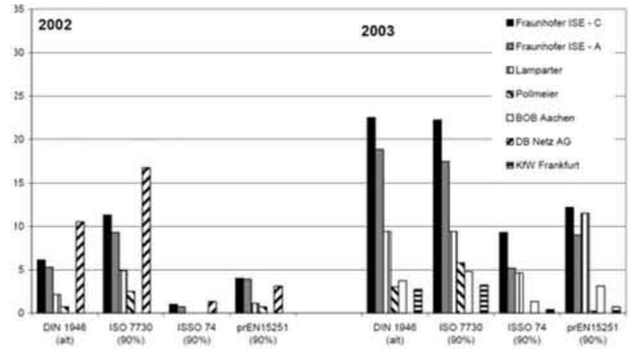


Fig. 6: Frequency of exceeding the comfort limit for operative indoor temperature according to different comfort criteria, for six buildings in the EnBau funding programme. Results for 2002 and 2003 are shown. For each building, the data source is the university responsible for the measurement programme on site.

2.4 User Satisfaction

In addition to the comfort analysis in 2.3 survey data of a field study in 17 buildings have been evaluated with respect to occupant satisfaction at workplaces and its mostly relevant parameters [Wagner, 2007]. In each building, a winter and a summer survey was carried out in order to take into account the influence of diverse climate conditions on the occupants' judgement. The survey has been carried out anonymously with a random sample size of 30 to 100 persons per building (depending on the size of the building), resulting in 1700 filled questionnaires for the evaluation. In the questionnaire, all relevant aspects of occupant satisfaction with indoor environments are addressed. Occupant satisfaction in this case is defined by the occupants' ratings of thermal, visual and acoustic comfort, the indoor air quality and the office layout.

The statistical analysis showed the most distinct interrelations between relevant parameters in the field of thermal comfort. Votes on thermal perception showed significant differences between winter and summer for comparable indoor temperatures. In correspondence, the dissatisfaction with the indoor temperature for a neutral thermal perception was higher in summer. Although most of the investigated buildings showed indoor temperatures which lay within the comfort range of DIN EN ISO 7730 only 30% of the occupants were very satisfied or satisfied with the temperature at their workplace. The perceived effectiveness of attempted temperature changes proofed to be the dominant parameter for the satisfaction with the indoor temperature.

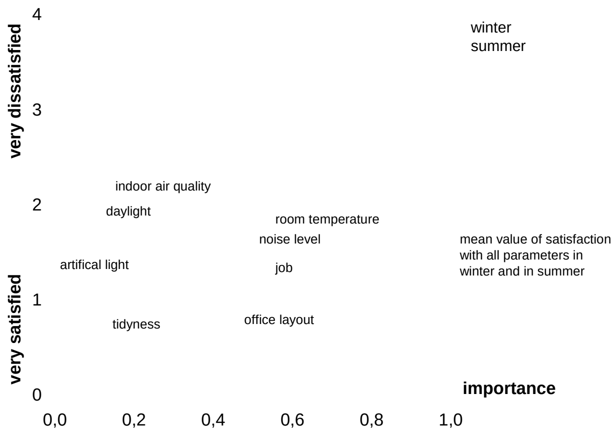


Fig. 7: Matrix with all relevant satisfaction parameters for all investigated buildings. The parameters are weighted by their correlation coefficients against the overall satisfaction with the workplace

Work-related factors like stress or responsibility were named by the occupants in a comparable intensity as in other studies but did not have a considerable influence on the well-being or the satisfaction parameters as it could be shown for the indoor climate and daylighting. On the other hand indoor climate and daylighting correlated with the occupants' statements on perceived health at their workplace. By weighting single satisfaction parameters a matrix could be generated which provides a straight-forward assessment of building performance by showing the optimisation potential for each parameter and the necessity to act for the building manager (figure 7).

2.5 Investment Costs

Experience with the newly constructed buildings demonstrated that the costs associated with energy saving and use of solar energy represent only a small proportion of the total building costs. Decisions about the building dimensions, the state of the economy, the selection of façade types and materials and similar matters have a much greater influence. The buildings presented in this paper are distinguished by investment costs that were typical of the building market. No correlation was found between investment costs and energy consumption (figure 8). A deeper study of the costs over the life cycle of the demonstration projects is intended to complement and extend the previous results in future (cf. 4.2).

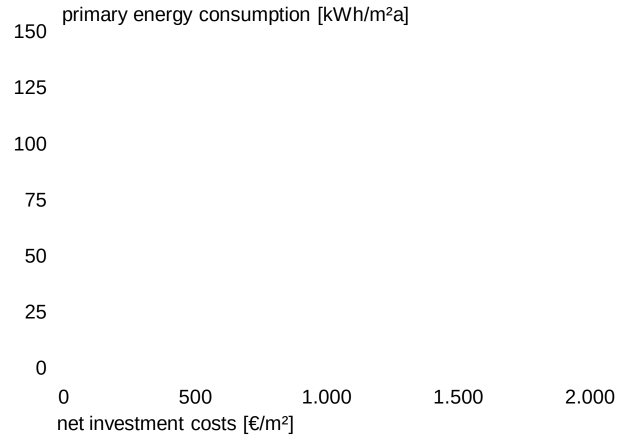


Fig. 8: Correlation between net investment costs (cost categories 300+400 according to DIN 276 referring to the gross floor area) and energy consumption for HVAC+lighting for 12 demonstration projects (referring to net heated floor area). Energy data are shown as primary energy including energy credits by building integrated PV systems, as they are included in the investment costs as well.

3 THE CURRENT PROJECT GUIDELINES

The current funding concept focuses more strongly than previously on demonstration projects which feature the application of new methods or technology, or are distinguished by particularly ambitious goals concerning energy. This applies equally to new construction and the existing building stock. The energy-relevant goals were developed further and are based today for non-residential buildings on the calculation procedure of DIN V 18599 (Fig. 9).

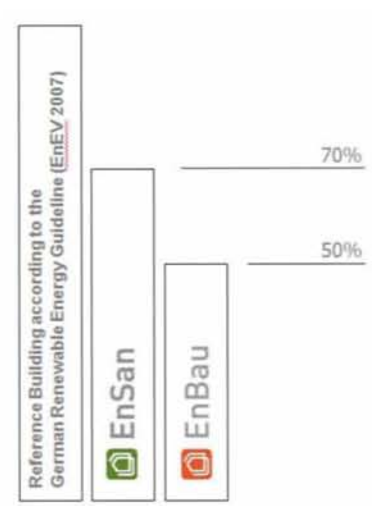


Fig. 9: Catalogue of energy-relevant requirements (site and source energy based) on a demonstration project corresponding to the EnOB funding concept. The additional allowance for existing buildings was not taken into account.

4 MAIN ASPECTS OF CURRENT RESEARCH

4.1 Towards "Net Zero Energy Buildings"

In recent years, national and international projects on buildings and settlements have been initiated and implemented, which are devoted to completely compensating the primary energy acquired for their operation or the associated CO_2 emissions within the framework of an annual budget. They are called "net zero-energy buildings", "zero-carbon" or "carbon-neutral buildings", "equilibrium buildings", … In some countries, politicians have adopted these terms as targets for energy saving and climate conservation in the building sector; apart from Germany [Bundesregierung, 2005], this applies above all to the USA [Office of Energy Efficiency and Renewable Energy] and England [Department for Communities and Local Goverment].

Whereas for self-sufficient buildings – those which are not connected to the electricity grid – the (over-) dimensioning of the energy system and particularly the energy storage must guarantee the supply at all times [Goetzberger, 1994], a "net zero" project typically aims only for a neutral energy or emission balance over the period of one year. The energy link to an existing electricity grid plays a decisive role in compensating differences between the energy supply and demand (amount and possibly also form of energy), particularly on a seasonal scale for the European climate. The common feature with self-sufficient concepts is the neutral balance, not just a very low energy demand (Fig. 10).

Although the concept and procedure for energy and emission balances appear to be simple, they become complex in detail and there are numerous open questions. The subject was thus presented and discussed as part of a national workshop. Further development was initiated towards an international activity on net zero energy buildings within the framework of the International Energy Agency IEA. A specific task is about to start by the end of 2009 within the Solar Heating & Cooling Programme [Voss, 2008].

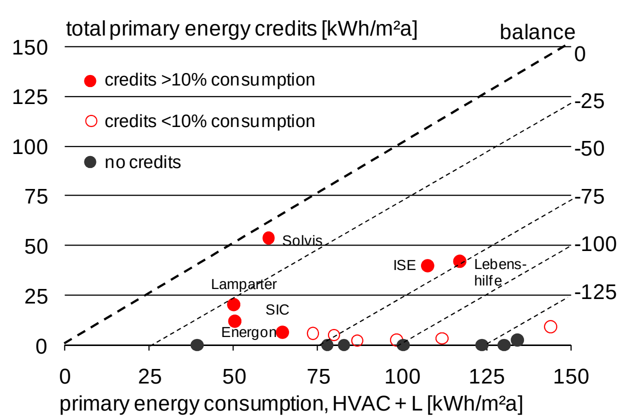


Fig. 10: The graph shows the fundamental approach to a neutral balance by the interaction of energy-saving measures and feed-in credits [Voss, 2008] and the balance results for projects in the EnOB funding programme. 14 projects include equipment for building integrated electricity generation via CHP (3) or photovoltaic systems (11); 6 projects achieve significant credits. The Solvis project approaches a neutral balance most closely.

4.2 Building Usage Costs and Life Cycle Costs

A comprehensive economic comparison between energy-efficient buildings and conventional buildings cannot be made unless the methodology includes the costs for the usage phase. As part of the accompanying research, the demonstration projects will be analysed comparatively with respect to their usage costs. The necessary data structure, the acquisition and evaluation methodology are currently being prepared in co-operation between the chairs for building and real estate economics at the Universities of Wuppertal and Karlsruhe. The goals of the investigation are:

- a contribution toward further development of the methodology and models to characterise building usage costs

  and

- establishment of a reliable data base in order to provide characteristic and guiding values, e.g. to the real estate economy, which include the costs of operating buildings and thus cover the entire life cycle of real estate. This component of building analysis is already part of current facility management and should be transferred to comparative research with a more comprehensive set of data. The data base obtained in this way should be made available in future as a reference for actors in the real estate economy.

The present situation concerning data on the demonstration projects is not yet suitable for evaluating the possible added value of energy-efficient buildings. A workshop for building owners and operators was held in June 2008 as a kick-off event for more intensive analysis of available data.

4.3 Long-Term Monitoring

As the experience to date with the demonstration projects has shown, continuous monitoring of buildings is decisive to guarantee their performance permanently. Further development of tools to optimise operation management and adjust buildings and technical plant in operation is also part of the current accompanying research effort and is based on the insights already gained.

An essential contribution is the establishment of a measurement data base at Fraunhofer ISE, which is publicly accessible for scientific research. This data base stores the measurement results of selected demonstration projects with a fine time resolution. After work on the data base structure in 2007, the data for the first buildings are now already being automatically collected via this data base system. The Internet portal, www.enob.info, will provide information on access possibilities in future.

4.4 Knowledge Transfer

Particular emphasis is placed on transferring research results into undergraduate and continuing education (Fig. 11). As part of university education, a didactic concept will be developed on the basis of a common learning platform for the participating universities, which will also be available to students on-line. After starting as a “teaching” platform, it is intended to become a “learning” platform in future, which offers the possibility of thorough simulation of parameterised building models and graphical output of the calculation results of all energy-relevant aspects of building planning. To this purpose, publicly accessible developments in building simulation will be drawn together and extended with special software tools developed at the universities.

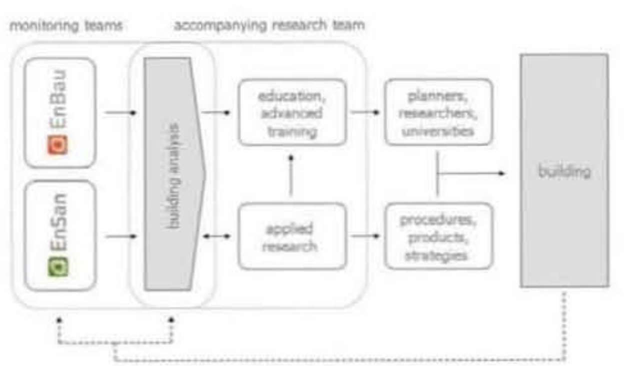


Fig. 11: Structure of knowledge transfer.

Further, summer universities (2009/10) in the form of block events are planned, to allow students to apply the developed tools and to participate in the comprehensive experience of the demonstration projects. Cross-sectional publications in national and international journals and review lectures complement and support the activities of the accompanying research. They are also accessible via the Internet portal, www.enob.info.

5 CONCLUSION AND OUTLOOK

The announcement by the German Federal Government that the building code energy limits will be reduced again by 30 % each time in 2009 and 2012 makes it clear that the future of real estate will depend strongly on its energy consumption. This will increase the significance of systematic building analysis, operation management and adjustment within the context of reducing emissions, minimising consumption and finally also reducing operating costs as a result. Within this framework, it is important to define terms, coefficients, measurement and evaluation procedures precisely so that comparability is guaranteed. The planning, implementation and evaluation of non-residential demonstration buildings, which were designed to meet an integrated primary energy target, has led to reliable results in this field where such breadth and depth are still new. The completed projects demonstrate that today it is already the state of the art for buildings to perform better than the coming legal specifications, while the building costs remain within the usual range.

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Appendix

Table 2a: Overview of the projects funded in the sector of new buildings

Building ID	Location	Monitoring team		Net floor area in m²	Status
Office Buildings					
ECOTEC	Bremen	University of Bremen		2 941	Completed
Wagner	Cölbe	University of Marburg		1 948	Completed
FhG ISE	Freiburg	Hochschule Biberach, Fraunhofer ISE		13 150	Completed
DB Netz	Hamm	University of Karlsruhe (TH)		5 974	Completed
GIT	Siegen	University of Siegen		3 243	Completed
Lamparter	Weilheim	Hochschule für Technik, Stuttgart		1 000	Completed
Pollmeier	Creuzburg	Zentrum für umweltgerechtes Bauen, Kassel		3 510	Completed
KfW	Frankfurt	University of Karlsruhe (TH)		8 585	Completed
Energieforum	Berlin	Technical University of Braunschweig		20 693	Completed
Energon	Ulm	University of Applied Science Ulm		6 911	Completed
TZM	Erfurt	University of Applied Science Erfurt		8 976	Completed
BOB	Aachen	University of Applied Science Köln		2 072	Completed
SIC	Freiburg	Hochschule Offenburg		13 833	Monitoring
UBA	Berlin	TU Cottbus, FH Sachsen-Anhalt		32 384	Monitoring
DVZ	Eberswalde	Technical University of Cottbus		19 399	Monitoring
Regionenhaus	Hannover	Technical University of Braunschweig		7 222	Monitoring
Educational Buildings					
FH BRS	St. Augustin	University of Dortmund		26 987	Completed
NIZ	Braunschweig	Technical University of Braunschweig		8 570	Completed
ZUB	Kassel	University of Kassel		1 732	Monitoring

Table 2b: Continued

Building ID	Location	Monitoring team		Net floor area in m²	Status
Institutional Buildings					
GMS	Biberach	Hochschule für Bauwesen und Wirt-schaft, Biberach		10 650	Monitoring
Production Facilities					
Huebner	Kassel	University of Hannover		2 122	Completed
Surtec	Zwingenberg	University of Darmstadt, Passivhaus Institut		4 423	Completed
Solvis	Braunschweig	University of Applied Science Braunschweig/Wolfen-büttel		8 215	Completed
Lebenshilfe	Lindenberg	Technical University of München		4 623	Monitoring
Housing					
SDH	Darmstadt	University of Darmstadt		50	Under construction
Other					
Museum Ritter	Waldenbuch	University of Karlsruhe (TH)		3 232	Monitoring

Table 3a: Overview of the projects funded in the sector of building renovation

Building ID	Location	Monitoring team		Net floor area in m²	Status
Office Buildings					
Gutshofkomplex	Wietow	University of Rostock		1 267	Completed
Büro im Passivhaus-Standard	Tübingen	Hochschule für Technik Stuttgart		n.av.	Completed
Haupthaus KfW	Frankfurt	University of Karlsruhe (TH)		19 639	Monitoring
REB	Remscheid	University of Wuppertal		3 328	Monitoring
EuB	Karlsruhe	University of Karlsruhe (TH)		1 111	Monitoring

Table 3b: Continued

Building ID		Monitoring team			
Institutional Buildings					
Uni-Bibliothek	Bremen	Hochschule Bremerhaven		25 011	Monitoring
Laborgebäude	Jülich	Forschungszentrum Jülich		3 380	Completed
Käthe-Kollwitz-Schule	Aachen	IB INCO Aachen		8 737	Completed
Kita Plappersnut	Wismar	University of Rostock		n.av.	Monitoring
MOSES	Stuttgart	IKE Stuttgart		5 160	Completed
Gemeindezentrums "Guter Hirte"	Ulm-Boffingen	Fraunhofer-Institut für Bauphysik Stuttgart		Parish Hall 887, Kindergarden.482, Parsonage 393	Monitoring
Luitpoldhaus der Stadtbibliothek	Nürnberg	FH Nürnberg		n.av.	Under construction
Housing					
Wohngebäude	Friedland	Forschungsges. BAU UND UMWELT Berlin		1 740	Completed
Sanierung Plattenbau	Wittenberg	Forschungsges. BAU UND UMWELT Berlin		4 350	Completed
Sanierung mit TWD	Köpenik	ASSMANN Berlin RK Stuttgart		1 937	Completed
Hochhausanlage	Karlsruhe	University of Applied Science Karlsruhe		9 560	Completed
Pflegeheim „Haus Sonnenberg“	Stuttgart	Fraunhofer-Institut für Bauphysik Stuttgart		5 166	Monitoring
Sanierung Typ P2 auf NEH	Friedrichs-hagen	ASSMANN Berlin RK Stuttgart		1 936	Completed
Gründerzeitwohngebäude "Bautzner Straße"	Zittau	FH Zittau		1 153	Completed
Wohngebäude	Schwabach	Fraunhofer-Institut für Bauphysik Holzkirchen		933	Monitoring
Modern. Kl.Wohngeb. auf 3-Liter-Haus-Niveau	Mannheim	IGE Institut für Gebäude- und Energietechnik		1 150	Completed
Geschoss-Wohngebäude	Hamburg	TU Hamburg Harburg		691	Monitoring
Neue Burse	Wuppertal	University of Wuppertal		17 007	Completed
Großelement-Dämmtechnik	Hofheim	IWU Darmstadt		600	Monitoring