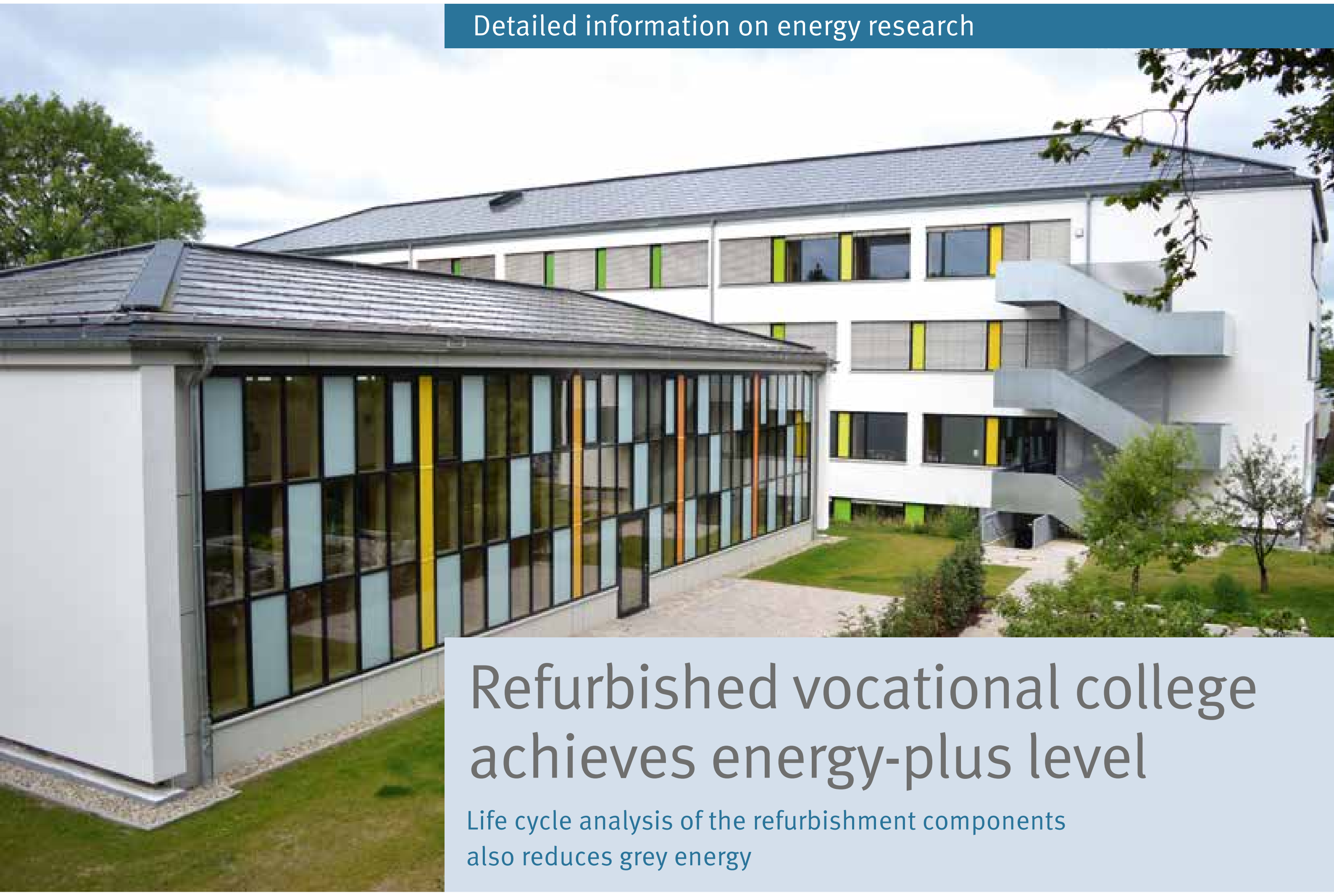

Refurbished vocational college achieves energy-plus level

Life cycle analysis of the refurbishment components also reduces grey energy

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Since its refurbishment, the vocational college in Detmold generates more primary energy than it consumes. For this purpose, the facades and the top storeys have been insulated with cellulose, passive house windows have been installed and the roof areas have been covered with PV panels. The existing heating system continues to be used with reduced temperatures. Since 2016, there has been a comprehensive monitoring of its operation.

In 2008, the district council in Lippe decided to refurbish its own properties with passive house components and to use roof areas for the generation of solar power. When the complete refurbishment of three buildings and a gymnasium built between 1954 and 1962 on the campus of the Felix Fechenbach Berufskolleg in Detmold was needed, an energy-plus school was designed.

All facades and roofs have been insulated with cellulose. The perimeter insulation goes right down to the foundation. Passive house windows have replaced the old wooden and aluminium windows. On the gently sloping roofs, photovoltaic modules took on the function of the roof envelope. The buildings have continued to be supplied with district heating from biomass – good for the primary energy balance. In the course of the underground construction work, the pipes were also replaced and insulated. The considerably better building insulation has made it possible to reduce the supply temperatures and to adapt the operational times. In order to reduce losses from the circulation pipes, the domestic hot water supply has been replaced.

In addition to opening the windows, the classrooms are mechanically ventilated via decentralised devices with heat recovery. For test purposes, two rooms are also equipped with ceiling fans. In the case of lighting, presence- and daylight-controlled fluorescent lamps were already installed in most places; in the remaining areas LED technology is now installed.

This research project is funded by the

Federal Ministry for Economic Affairs and Energy (BMWi)

The minimal change in the building fabric, the refurbishment during ongoing use of the buildings and the use of the existing heating and distribution costs considerably less than a new build or a refurbishment with a new supply design. At the same time, there are above-average energy savings – not just in its operation, but also in its fabrication. The design won the "School 2030" idea competition conferred by the German Federal ministry for Economic Affairs and Energy.

Fig. 1 *Site plan: The extensions (an administration area, a learning area and a teaching restaurant) that were built prior to the refurbishment are marked in green.*

Measure / components	*Details*
Passive house window	*U_w = 0.73 W/(m²K)*
Prefabricated wooden element with 36 cm cellulose insulation	*U= 0.10 W/(m²K)*
Cellulose insulation of the top stories or roof areas	*U = 0.1 W/(m²K)*
Insulation and sealing exterior walls in contact with the ground	*U = 0.09 bis 0.15 W/(m²K)*
Glare protection / solar protection	*Exterior louvre blinds*
Lighting	*Presence- and daylight-controlled fluorescent lamps (T5), (existing) Supplemented with LED technology*
Roof-integrated photovoltaic modules	*Area 2,770 m²; total peak output 360 kW_{peak}*
Heating supply	*District heating from biomass (primary energy factor 0.0)*
CO_2 controlled mechanical ventilation	*20 m^3/h_{Pers}; output characteristics of the heat recovery of the decentralised ventilation units in classrooms 85 % / annual average measured: approx. 73 %*

Fig. 2 *Summary: Built-in components*

Majority of predictions are correct

As proven by the monitoring performed by the Ostwestfalen-Lippe University of Applied Sciences, the school has already been achieving the objective of the primary energy energy-plus balance since its completion in 2016. The refurbishment has reduced the final energy consumption for heat by approx. 65 %. After the refurbishment, the provision of the domestic hot water still consumes roughly twice as much energy as predicted. Despite the pipes being retrofitted with insulation and reducing the consumption points to a few rooms, the pipe and storage losses make up more than 90 %. Currently, the scientists are investigating the causes and optimisation options.

In two classrooms, the consumption and loads are recorded: the biggest electricity consumption is caused by the white board including a teacher's PC at approx. 4.3 kWh/(m² p.a.); a system with which the school was already equipped before the refurbishment. The decentralised ventilation device consumes between 2.3 and 3.3 kWh/(m² p.a.) depending on occupancy density and teaching hours. The daylight-controlled lighting requires 1.7 to 2.0 kWh/(m² p.a.). On the operation of the ceiling fans, a linear correlation to both the outside air temperature and the average room air temperature becomes apparent (Fig. 4). They consume approx. 0.4 kWh/(m² p.a.). The energy consumption of the fixed heating in the classroom is approx. 24 kWh/(m² p.a.) and in comparison to the initial state, it has been reduced by over 80 %. However, that is not solely down to the refurbishment, but it was rather optimisations after the first year of operation that reduced consumption in the classroom by a further 21 %.

Tricky commissioning of the heating

Without additional expense, the existing heating circuit in the old buildings could only be controlled in a building specific manner because the distribution is carried out as a Tichelmann system. The classrooms in the basement, the computer rooms, the standard classrooms and the staffroom are on the same heating circuit. The option of adapting the temperatures in the rooms is limited to the individual settings of the existing (authority's) thermostatic valves and the operating time of the heating. One disadvantage is the position of the thermostatic heads because some of them are situated in an alcove or are covered by window sills or cable channels. That can lead to a microclimate that is different to the centre of the room and prevents a fast reaction to the room temperature.

The new room thermostats recommended in the technical plan to allow users individual access were initially not implemented for reasons of cost because within the planned monitoring and optimisation phase and after hydraulic balancing plus the reduction of the supply temperature, this investment can possibly be saved.

A modified operation is necessary so that at the start of lessons there is a room temperature of approximately 21 °C, even in the classrooms in the basement, which lose heat through the non-insulated floor slabs. Different specified room air temperatures have been set on the thermostat valves for the heating-up process in the morning: 20–22°C in the standard classrooms, 17 – 19 °C in the computer rooms and 26 °C in the basement rooms. After 2 hours of heating up in the morning, the heating circuit generally switches to reduced operation because the internal loads in the rooms, even in the basement, are almost enough to maintain 21 °C. Without the classrooms in the basement, the heating operation during the day would not be needed at all.

The intensive monitoring in combination with room simulations have made it possible to incrementally approach an optimum operation of the heating by way of adaptations during the ongoing use of the buildings. For that reason, a sticking point will again be the handover to the caretaker or building operator.

At first, users assessed the air quality as worse than expected

Employees at the Institute for Resource Efficiency and Energy Strategies (IREES) regularly surveyed students and teachers in order to record the perceived comfort before and after the refurbishment. According to the

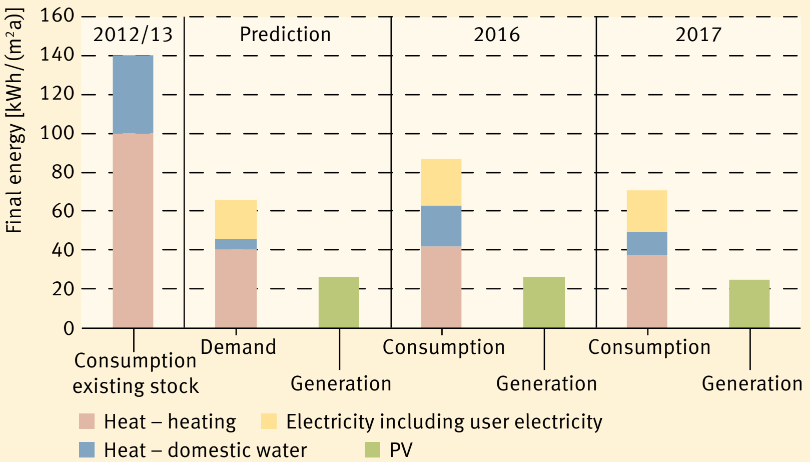

Fig. 3 *Annual balance of the final energy in comparison to existing building stock and the demand predictions (based on the reference climate in Potsdam); there is no energy consumption measurement data for the existing stock. Thanks to the primary energy factor of 0 for the district heating, the solar power, which is mainly used on site, and the refurbishment of the building envelope an energy plus level has been achieved.*

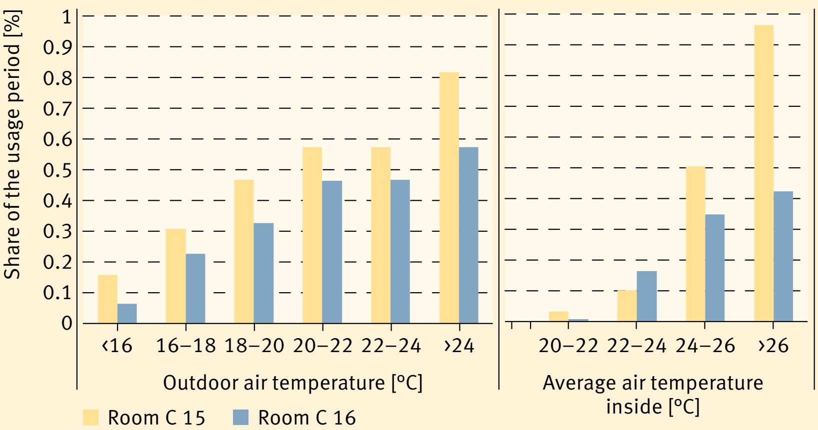

Fig. 4 *Use of the ceiling fans depending upon the outdoor or indoor air temperatures during the usage period. In the event of indoor air temperatures over 26 °C, the ceiling fan was activated for up to 97 % of the usage period.*

Facade insulation – life cycle in focus

Special attention was paid in the project to maintaining the existing construction and to using resource-saving materials. On the basis of life cycle analyses, prefabricated modules using a timber panel structure with thermal bridge-optimised timber I-joists filled with cellulose were selected for the facade insulation. The elements were developed and produced with the help of a 3D scan of the building. It allowed the dimensional tolerances of the uneven, slanting and highly varied existing walls to be taken into consideration. The prefabrication made it possible to limit the insulation work to the summer holidays. In energy research, there has also been international focus on life cycle analysis. Since 2016, more than 20 countries have been cooperating on EBC Annex 72 of the International Energy Agency on the topic of “Assessing Life Cycle Related Environmental Impacts Caused by Buildings”.
http://annex72.iea-ebc.org

Fig. 5 *Installers fit the prefabricated modules; they are then filled with cellulose.*

survey, the users were primarily unhappy with air quality after the refurbishment. They gave it a school grade of D plus, even though during most of the usage period a CO_2 concentration of less than 1,000 ppm was recorded and 1,500 ppm was only rarely exceeded. Measurements verified the critical air humidity conditions in the winter: the outdoor airflow of approx. 20 m³/h per person led to a relative air humidity of only 20 to 30 % during approximately one third of the usage period – a typical problem with mechanical ventilation. After the adaptation of the heating control system and the reduction of the maximum flow rate to 12 m³/h, not reaching the threshold of 40 % occurred considerably more rarely. Currently, the scientists are investigating how to permanently guarantee sufficient relative air humidity with a simultaneously lower CO_2 concentration.

User information necessary

In order to be able to use the funds from the German government’s Economic Stimulus Package II, the buildings were initially expanded. The lengthy application for and approval of research funding for innovative components prevented the seamless start of the energy refurbishment. Furthermore, insolvencies also markedly delayed the project. Parallel to the optimisation in terms of energy, the internal visual and technical refurbishment as well as the refurbishment of the drainage for the whole campus were carried out. These large construction measures during the ongoing use of the buildings over such a long period of time unavoidably led to decreasing tolerance as well as criticism on the part of the users. Regarding participation, the school was represented in all regular meetings from the first briefing, concerning all sketches and performance phases of planning and implementation. Information events were also held for the teaching staff.

On the implementation of construction measures during the ongoing use of the school, a communication and participation policy is necessary. In projects of this kind dialogue is essentially to be sought with the users as soon as possible after completion in order to provide information about changes and how to use rooms and installations. The responsible personnel must be given technical support especially in the first months of the heating season and the summer operation in order to correct short-comings at an early stage and in this way to avoid bad feelings and misjudgement in regard to the building from the very beginning.

Energy-efficient schools

Schools do not only provide a space for learning, but they themselves are buildings where experiences can be gained and as a result, they can influence the behaviour and attitudes of the students. It makes it all the more important that school buildings are exemplary; exemplary just as much in regard to user comfort as in regard to design and energy balance. In the research initiative Energy Efficient School (EnEff:Schule), a total of twelve demonstration projects, including seven refurbishments, were funded by the German Federal Ministry for Economic Affairs and Energy. They are to show which measures can be technically implemented, how much energy these measures save and how much they cost. At the same time, a sociological evaluation records the influences on user behaviour and the acceptance of the measures as well as the impact on learning comfort and daily school life. The vocational college is one of these example projects. The other types of school are a school building from the 1930s, an atrium building from the 1960s, two precast concrete schools plus a school and sports centre from the 1970s. They were refurbished as 3-litre-buildings or energy-plus buildings and have been partially rebuilt and extended. Different approaches were followed here.
The Uhland School in Stuttgart, a primary and technical secondary school from the 1950s, was also refurbished as an energy-plus school in the context of Eneff:Schule. High-quality insulation, in part with vacuum insulation panels, and combined with triple glazed windows reduced the heat loss via the building envelope. Ground-coupled heat pumps in combination with a low-temperature surface heating system heat the school. LED technology is used for the lighting. Photovoltaic modules on the roof, on the south facade and on ancillary buildings are sufficient to balance the electricity demand. During the heating period, decentralised ventilation units with heat recovery supply the classrooms with fresh air. In the summer, windows are used for ventilation. External louvres with daylight control protect the predominantly glazed southern facade against too much solar irradiation. The building element temperature control is also used for cooling and is completed by a concept for night-time ventilation. In the first year of operation, the design achieved an electricity surplus of 42.5 MWh. Detailed monitoring is planned.

Project participants

- **Project management:** Ostwestfalen-Lippe University of Applied Sciences, Future Energy – Institute for Energy Research (iFE), Detmold, Prof. Dr-Ing. Susanne Schwickert, Oliver Glahn, oliver.glahn@hs-owl.de | www.ife-owl.de
- **Accompanying sociological research:** Institute for Resource Efficiency and Energy Strategies (IREES), Karlsruhe | www.irees.de
- **Architect:** pape oder semke ARCHITEKTURBÜRO, Detmold | www.papeodersemke.de
- **Specialist planning – building services equipment:** Ingenieurbüro Dipl.-Ing. Schmitz, Detmold | www.schmitz-ing.de
- **Client:** District of Lippe, Owner Operated Schools / 100.4 Technical Building Management, Detmold | www.kreis-lippe.de

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- Reiß, J.; Illner, M.; Erhorn, H. u. a.: EnEff:Schule. Wissenschaftliche Begleitforschung zum Forschungsvorhaben „Energieeffiziente Schulen“. Abschlussbericht Phase 2. FKZ 03ET1075C; 03ET1075A. Dez. 2017. 757 S. Fraunhofer IBP Bericht. WB 201/2017 https://doi.org/10.2314/GBV: 1010951262

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Mira Heinze
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Hermann-von-Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
Germany

Author
Dorothee Gintars

Contact · Info

Questions regarding this Projektinfo brochure? We will be pleased to help you:

+49 228 92379-44
kontakt@bine.info

BINE Information Service
Energy research for application
A service from FIZ Karlsruhe

Kaiserstraße 185–197
53113 Bonn, Germany
www.bine.info

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