BINE Informationsdienst

projektinfo 04/06

Building refurbishment – Student residence hall

- Primary energy consumption reduced by approx. 60%
- Low-energy house standard achieved
- Passive house concept requires closer attention to ventilation and heating
- Energy-oriented and architectural improvements complement each other

Fig. 1

New and old residence hall complex in Wuppertal, Germany

Wuppertal University was founded in the 1970s, and at the same time, cheap accommodation was to be quickly made available to the students. Thus, the student residence hall "Burse" was built, one of the largest halls of residence in Germany, accommodating approximately 600 students. The building had passed its prime, and was in need of substantial refurbishment. As well as completely out-of-date building services equipment, and insufficient thermal insulation of the facade, the residence hall also had structural faults. Each shared kitchen and washroom was conceived for up to 32 people. The residence hall's unattractiveness led to vacancies, and considerable social problems. This meant that it was no longer possible to run the building profitably.

After a comprehensive appraisal, various scenarios were examined, right through to total demolition and new construction. The investment and operating costs were significant factors. Merely correcting the structural faults would not have increased the attractiveness of the hall of residence on the long term. For this reason, a solution was sought, which would significantly improve the long-term rentability of the hall of residence.

Alongside the modernisation of the building, it was decided that an energy-oriented refurbishment would also be carried out. The project was subdivided into two construction stages. The section completed in 2001 was to comply with the low-energy house standard. In the 2nd complex, finished in 2003, the thermal insulation was further improved, and ventilation (with air intake and air extraction, as well as heat recovery) was installed, so that this section of the "Neue Burse" was realised in keeping with the passive house concept. The construction costs of the entire refurbishment project were 25% lower than those of a new building.

After the second building was finished and completely reoccupied in 2003, a three-year scientific examination of the installed building services equipment and an energy consumption analysis began in May 2004. The project is part of the support initiative "Energy-Optimised Construction (EnOB)", which is sponsored by the German Federal Ministry of Economics and Technology (BMWi). One focal area deals with "Energy-Oriented Improvement of the Building Fabric (EnSan)".

The building

Fig. 2: Selected building data

	1st CS	2nd CS
Year of construction	1977	
Structural design	Reinforced concrete cross-wall structure	
Gross floor area GFA [m²]	9,890	10,025
Net floor area NFA [m²]	8,420	8,597
Gross volume GV [m³]	28,220	28,276
Main usable area MUA [m²]	6,140	6,244
A/V ratio	0.40	0.32

The original hall of residence is subdivided into two buildings in a star shape, each with approximately 300 accommodation units. The building sections were arranged around a central, barely-lit staircase, which served as the building's reinforcing structure. All accessibility between the two sections was only provided via a single entrance. As well as the out-dated building services equipment and insufficient thermal insulation, leaky seams were causing moisture penetration of entire building elements.

Refurbishment

During the refurbishment, the dilapidated facade, consisting of non-load-bearing slabs hanging in front of the building's shell, was removed. Only the apartments' load-bearing structure was retained. Grouped accommodation, encompassing 32 persons, has largely given way to individual apartments, each with a shower and kitchenette. The space which this requires is made by means of an extension of the building shell's room depth by approximately 2 m (fig. 3). Thus, the new hall of residence is more compact than the old structure. At the same time, the forebuilding becomes the building's reinforcing structure. The staircase or core area was removed from the middle of the building. Thus, two separate buildings are the result. The single-glazed staircase and its adjoining rooms are situated outside the thermal envelope. This enables a greater reduction of energy consumption.
The structural alterations implemented in the 1st construction stage (CS) were executed in the same manner for the 2nd CS, although the standard of insulation and the heating and ventilation technology differ: the 1st CS was designed as a low-energy house, and the 2nd CS was planned according to the passive house concept (fig. 4). The building was completely fitted out with prefabricated facade elements with wooden frames and mineral fibre thermal insulation. Several facade elements were combined, then on the construction site they were mounted on the reinforced concrete framework forestructure. Large floor-to-ceiling triple-glazed passive house windows (2nd CS) with wooden frames lend a pleasant quality to the accommodation in the apartments, and articulate the facade.

Fig. 3: Floor plan of the residence hall before and after refurbishment

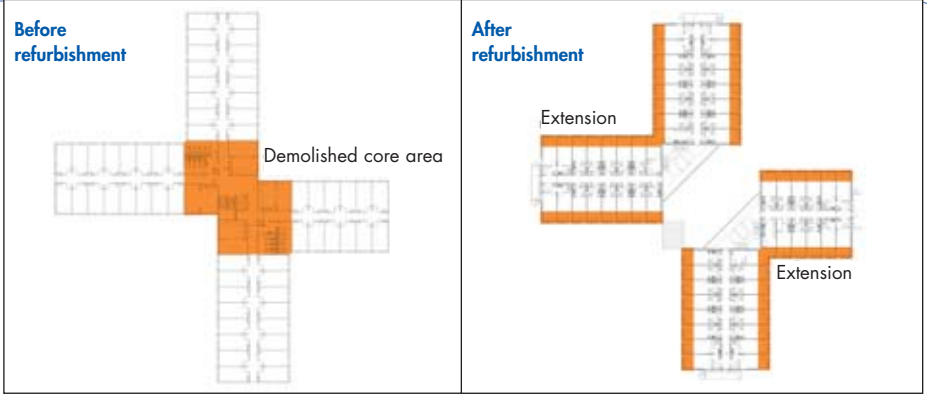


Fig. 4: Initial state and realised refurbishment, planning data

	Before refurbishment	1st CS	2nd CS
Facade U-value [W/m²K]	0.56	0.37	0.15
Windows U-value [W/m²K]	2.90	1.56	0.82
Windows g-value [%]	78	62	53
Top floor slab U-value [W/m²K]	0.85	0.21	0.11
Cellar ceiling U-value [W/m²K]	1.20	0.30	0.13
Planned heating requirement values [kWh/m²a][2]	161	68	15/30[1]
Heating	Remote heating	Remote heating from CHP[2]	
Ventilation	Windows	Windows/demand-oriented air extraction system	Centralised ventilation system with heat recovery

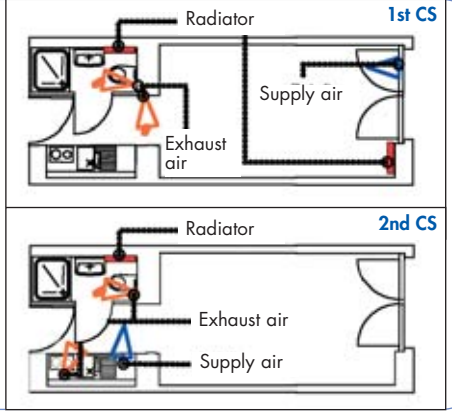
[1] Original planned value must be increased to 30 kWh/m² p.a. because the installed building services equipment does not enable heating consumption of 15 kWh/m² p.a. [2] Combined heat and power generation 3 Based on net floor area NFA

Fig. 5: Section of the new facade

Building services equipment

The heat supply of the "Neue Burse" occurs via remote heating from combined heat and power generation (primary energy factor 0.7). In the 1st CS, the apartments are heated via radiators, and in the 2nd CS via the ventilation system; only in the bathrooms, and in the apartments on the end walls, is a radiator always installed. The supply air temperature is centrally set to a minimum temperature (18 °C).
In the 1st CS, a demand-oriented air extraction system is installed in each room and bathroom. Supply air can flow in via outdoor air inlets (OAIs) above the windows. Actual ventilation occurs via the windows. The small apartments (18.7 m²) and the insufficient degree to which residents perform window ventilation mean that the indoor air quality does not always comply with the hygiene regulations. In the 2nd CS, these problems do not arise, as the apartments are permanently ventilated with air intake and air extraction (fig. 6).

Fig. 6: Ventilation concepts <in 1st and 2nd CS



The executed refurbishment measures and the energy consumption are being analysed in a monitoring programme. This analysis is of interest as it involves nearly identical building structures with the same climate conditions.

The consumption measurements in 2005 show that the primary energy consumption was reduced by approximately 60% compared to that of the old building. The objective of achieving the low-energy house standard in the 1st CS was achieved. In the 2nd CS, the additional savings potential could not be fully tapped by the implementation of components suitable for use in passive houses (fig. 7). At 51.8 kWh/m² p.a., the heating consumption was considerably higher than the target value of 30 kWh/m² p.a., and above the original target value of 15 kWh/m² p.a. for a passive house.

1st construction stage: the low heating consumption of 51 kWh/m² p.a., despite measured room air temperatures of approximately 22 °C, is due to low air renewal rates. The measurements taken indicate an air renewal rate of 0.2 h^{-1}. However, the average air renewal rate, especially in small rooms, should be at least 0.5h^{-1}. Random measurement checks with closed windows and one person present gave a quick indication of CO_2 concentrations above 1,000 ppm. Thus, at times the consumption savings are related to poor indoor air quality.

2nd construction stage: the ventilation system with air intake, air extraction, and heat recovery ensures good indoor air quality. However, the heating consumption is considerably higher than the planned value. This is for the following reasons:

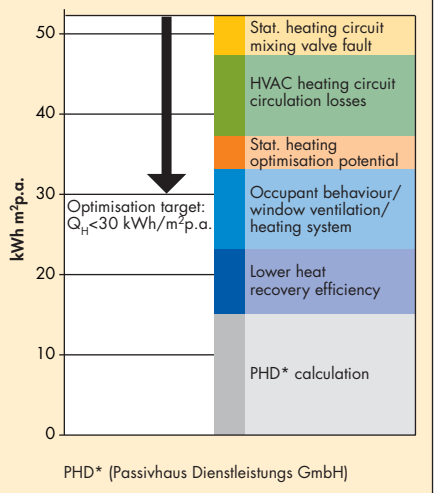
- Static heating circuit: due to a faulty mixing valve connection, the heating circuit was continuously operated with maximum supply temperature, even in summer.
- Supply losses due to circulation: the circulation pump operated continuously in an unregulated manner, so water at the maximum temperature level was constantly flowing through the HVAC system's heating circuit.
- The heating provided by warming the supply air occurs via one heat exchanger per wing, i.e. with the same output for north-facing and south-facing apartments.
- The supply of heat via the radiators in the bathrooms occurs in an air extraction zone, so if the bathroom door is closed, the radiator barely contributes to the heating of the room (= air intake zone).
- Due to the nature of the refurbishment, the ventilation systems with heat recovery are situated outside the thermal envelope, and only have an efficiency of 65%.

Fig. 7: Key energy consumption values (final energy and primary energy (PE)) in 2005, based on NFA. The high value for water heating is due to the occupancy density of a residence hall, with 23 m² per person (German average: 43 m²/person).

[kWh/m²$_{NFA}$p.a.]	Old building*		1st CS		2nd CS	
	Final en.	PE	Final en.	PE	Final en.	PE
Heating	246.2	172.3	51.1	36.0	51.8	36.3
Water heating	38.0	26.6	54.1	37.8	48.7	34.1
Auxiliary energy, pumps, control	0.8	2.3	0.7	2.1	0.7	2.3
Ventilation	0.8	2.4	1.4	4.2	6.4	19.1
Total	285.8	203.6	107.3	80.1	107.6	91.8

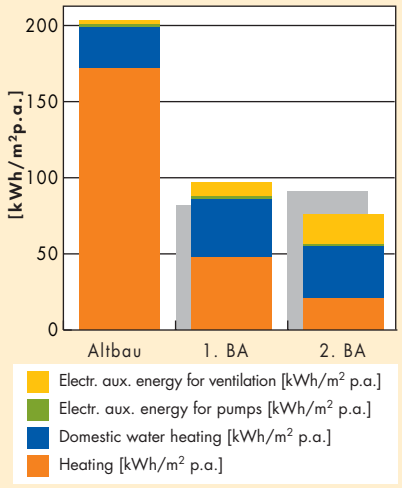
* Average values from public utility companies' billing data 1986 – 1997

Fig. 8: Heating consumption in 2005, 2nd CS; shown as an additive combination of the calculated requirement and the identified additional heat losses



PHD* (Passivhaus Dienstleistungs GmbH)

Fig. 9: Comparison of key primary energy data after optimisation of the building. The grey bars represent the consumption measured in the year 2005.



Optimisation of operations

The fault removal in the 2nd CS which has already been performed (faulty mixing valve connection, circulation losses) already reduces the heating consumption significantly (fig. 8). Optimised control strategies offer further potential savings. For this reason, the realised and planned supply air heating control concept was assessed with the aid of the TRNSYS thermal building simulation program. The simulation showed that the realised concept "fixed temperature setting of 18°C" in conjunction with a single heat exchanger for the entire wing does not enable comfortable room temperatures. The decentralised temperature increase via the radiators does make it possible t o achieve the desired room temperature but entails considerable heat input due to the positioning in the bathroom, especially in the transitional periods. As an alternative, an exhaust-air-temperature-based control was tested, with which the supply air temperature is increased according to the temperature of the exhaust air. The results show that with this strategy, comfortable room temperatures are possible. However, energy consumption remains somewhat high in comparison to the original planning. Thereupon, the ventilation system was converted to exhaust-air-dependent temperature control in November 2005. Under the specified conditions, heating consumption of 30 kWh/m² p.a. is achievable. Alongside the technical optimisation work, the residents need to be very well informed of the function of the ventilation system. Here, the conditions specific to student residence halls should be taken into account.

Fig. 10: Costs of the facades (per m²) for the 1st and 2nd CS in comparison to a design with a thermal insulation composite system (TICS), under the following conditions:

Building element	1st CS	2nd CS	TICS
Closed facade with interior and exterior cladding [EUR]	~ 200	~ 220	1. BA ~ 190 2. BA ~ 210
Windows with fall protection (room-height French casement windows) [EUR]	~ 380	~ 600	–

- Wall with finished interior and exterior surface
- Windows as "French windows", requested by contractor due to the room depth
- Facade with masonry and TICS, due to statics only possible with additional strengthening of the structure
- Prefabricated wooden panel construction entails shorter construction times

Conclusion

From the owner's point of view, the refurbishment of the "Neue Burse" is a success. The building's energy costs have fallen drastically, and long waiting lists for accommodation bear witness to the new attractiveness of the apartments. With its comfortably arranged apartments, the positive effect of the building, which has been awarded several architecture prizes, is not to be underestimated at a time when student numbers may be on the decline.

The 1st CS achieved the low-energy house standard. It showed, by means of direct comparison between the two construction stages, that alongside the thermal insulation standard, it is primarily the different ventilation concepts which have a decisive influence on the heating consumption and primary energy consumption. The insufficient air renewal in the 1st CS, and the poor indoor air quality which this entails, already became apparent shortly after completion. This was one of the reasons for implementing continuous ventilation in the 2nd CS. The passive house standard was confirmed in the planning by implementation of heat recovery and improved thermal insulation. For economical and building-specific reasons, a simpler ventilation system and simpler heating technology were chosen. In conjunction with just one central air heat exchanger per building, and the bathroom radiators, the objective could not be achieved. With the implemented building services equipment, heating consumption of 30 kWh/m² p.a. is achievable for the 2nd CS. A very good value for a refurbished building.

The comparison of the construction stages shows that window ventilation is not always sufficient, especially for small apartments. Hygienic air renewal can be ensured by means of a permanently operating air extraction system. This results in an increased heating requirement, as the air renewal rate, and thus the ventilation heat losses, rise. The auxiliary energy requirements also increase, as air extraction fans must be operated. Fig. 9 shows a comparison of key primary energy data after optimisation of the building. Alongside the technical measures, it is certainly important to inform the occupants about the building services equipment.

The project clearly shows that after expensive energy-oriented refurbishment of large building complexes, the energy consumption should be measured and analysed in order to identify any faults in the technical equipment, and to ensure technically and economically satisfactory operation.

PROJECT ADDRESSES

Project implementation

- Bergische Universität Wuppertal
  Prof. Dr. Karsten Voss
  Peter Engelmann
  Pauluskirchstr. 7
  D-42285 Wuppertal
- Fraunhofer Institut
  für Bauphysik (IBP)
  Johann Reiß
  Nobelstr. 12
  D-70569 Stuttgart

ADDITIONAL INFORMATION

Literature

- Engelmann, P.: Sanierung und Umbau des Studentenwohnheims „Neue Burse“ in Wuppertal zum Passivhaus. In: Fachinstitut Gebäude-Klima e.V., Bietigheim-Bissingen (Hrsg.): Energieoptimiertes Bauen (ENOB). 3. EnSan-Symposium Raumlufttechnik im Bestand. März 2006. Tagungsberichte Nr. 118. S. 149-156
- Engelmann, P.; Kramp, M.: Energie und Ökonomie in der Sanierung – das Studentenwohnheim „Neue Burse, Wuppertal. In: Passivhaus Institut, Darmstadt (Hrsg.): 10 Internationale Passivhaustagung 2006. Hannover, 19.-20. Mai 2006. Tagungsband. S. 69-74

Images

- Figs. 1, 5: Riehle, Cologne; all other images were provided by the project participants.

Service

- Additional information such as literature and internet links are available online from BINE at www.bine.info (Service/InfoPlus) in German.

PROJECT ORGANISATION

Project Funding
Federal Ministry of Economics and Technology (BMWi)
D-11019 Berlin

Project Management Organisation Jülich (PTJ)
Research Centre Jülich
Markus Kratz
D-52425 Jülich

Project Number
0329750U

IMPRINT

ISSN
0937 – 8367

Publisher
FIZ Karlsruhe
D-76344 Eggenstein-Leopoldshafen

Reprint
Reproduction of this text is permitted provided the source is quoted and a complimentary copy is provided to the publisher; reproduction of the images contained in this newsletter requires the prior approval of the copyright owner.

Editor
Micaela Münter