Exemplary Retrofitting of a School (EROS) in Stuttgart-Plieningen, Germany

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1 Photo

Figure 1: South view of the school building (building segments 1 and 2)

2 Project summary

In the EROS Project the potential for the energy efficient retrofit of a typical school building in West Germany was demonstrated. The renewal of the space heating system was combined with improved insulation to yield synergetic effect. The project aimed to minimise future energy consumption and optimise the cost effectiveness of the retrofit. Thus, both operating costs and emissions were reduced. The goal was to improve the thermal insulation at least to the standard of the 1995 German regulations on thermal insulation for new buildings.

3 Site

Stuttgart, the capital of the Bundesland Baden-Württemberg, is located in the valley and on the hills around the river Neckar in the South Western part of Germany at elevations between 200 and 400 meters. It's climatic conditions are best described by the Würzburg Test Reference Year. The coldest month is January with a mean of –1.3°C; the warmest month is August with a mean of 18.3°C.

4 Building description /typology

4.1 Typology / Age

Typology/Age	Pre 1910	1910-1930	1930-1950	1950-1970	1970-
The side corridor school			●	●	●

The building consists of three parts with different ages and is used as a primary school and a secondary school (Hauptschule). This combination is common in Germany.

4.2 General information

The block of buildings to be renovated was built in several parts during the thirties, the fifties and the seventies (1936, 1957, 1970). The floor area of 5260 m^2 includes the classrooms, halls, lobbies and staircases and a gymnasium. The total volume is about 22470 m^2. A typical classroom is about 60 m^2 and meant for 20 to 25 pupils. There are 25 classrooms and 3 practical rooms. Each part of the construction was typical for its origin period. Thus the building represents the average school building in the western part of Germany.

The work in the school building started in the summer break 1996 and was finished in the summer of 1997.

4.3 Architectural drawings

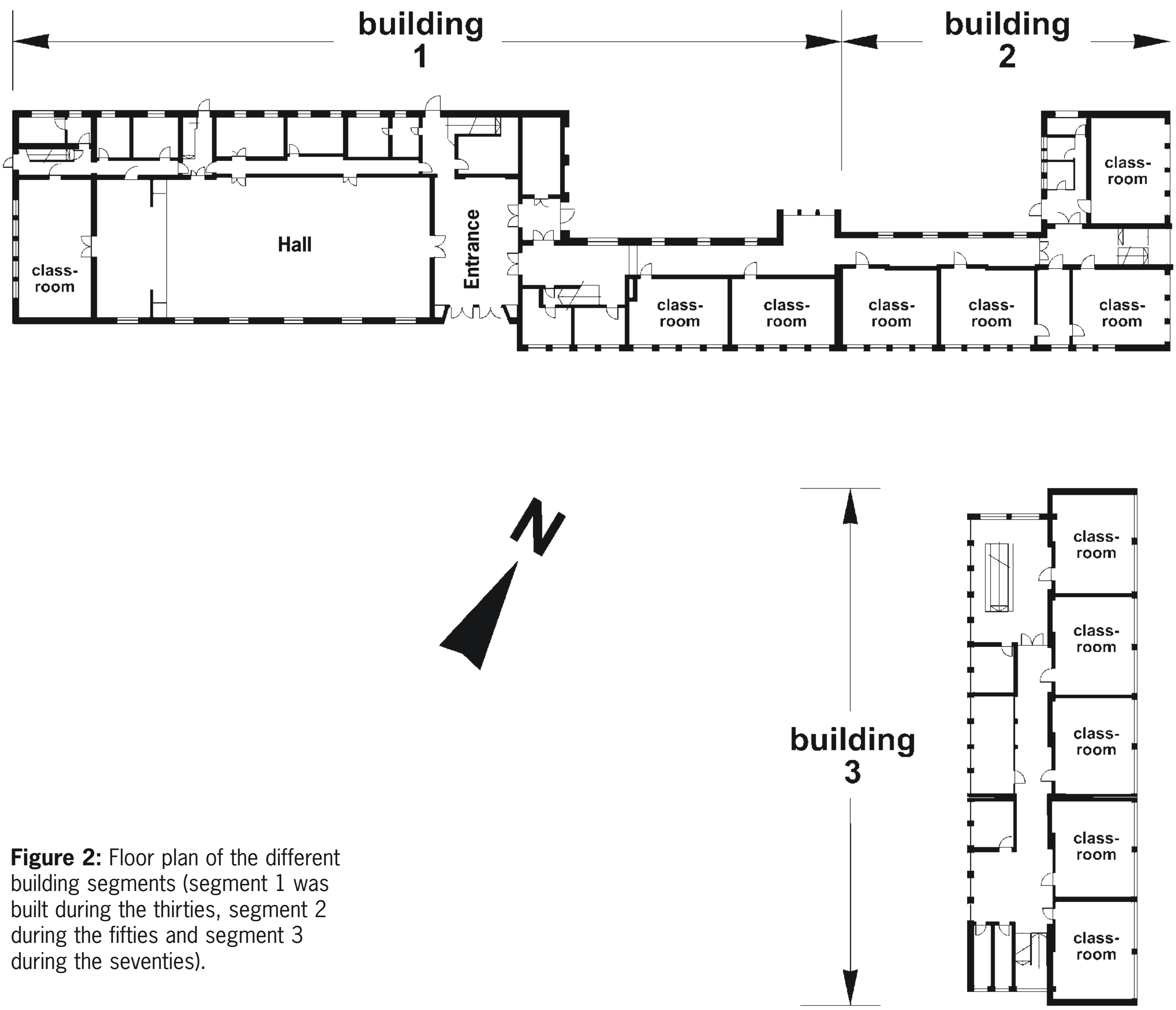

Figure 2: Floor plan of the different building segments (segment 1 was built during the thirties, segment 2 during the fifties and segment 3 during the seventies).

5 Previous heating, ventilation, cooling and lighting systems

Heating:
For the HVAC system, too, the technical standard was typical for the time of construction. No major retrofitting had been done. All three sections of the building got their heat from a boiler house in the oldest building. The low-pressure steam boilers (1969) with capacity of 800 kW were originally fired with coal and later converted to dual fuel with oil/gas burners. The boilers were switched on and off by the caretaker. Segment 1 was still heated with steam, segments 2 and 3 had a hot water system fed by a heat exchanger. Piping and radiators dated from the time of construction. The circuits had weather compensating control with fixed time settings. In the classrooms no further control devices were installed.

Ventilation:
The ventilation was ensured by opening the windows and infiltration through the building envelope.

Lighting:
Prismatic diffusers and louvred luminaires with 26 mm fluorescent tubes were used for the lighting. The paint on the walls and ceilings was dark and dirty. The lighting and the shading systems were manually controlled. The lighting was considered to be poor due to strong glare effects. Therefore the artificial lighting was switched on during daylight hours despite sufficient daylight supply, whilst the blinds were closed.

6 Retrofit energy saving features

6.1 Energy saving concept

Supervised by Stuttgart's municipal office of environmental protection; the Fraunhofer-Institut für Bauphysik (IBP) and the Institut für Kernenergie und Energiesysteme (IKE) worked out an energy efficient retrofit strategy. In this process the municipal office for construction, the architect, engineers and project partners from industry were involved. The conceptional phase was completed during spring 1996. An architect together with an HVAC engineer planned and realised the retrofit, supervised by the municipal office for construction. After completion of the project the actual energy consumption was measured over a two year period to prove the design concept.

The first step was to get a detailed picture of the status quo. Both the building envelope and the heating system had to be analysed. Based on surface area, heat transmission coefficients and the occupation of the building, the theoretical heat demand was calculated and fitted to the actual heating consumption. After that, many different retrofit measures for the building envelope, the heating system and the lighting were assessed, compared and sorted by their effectiveness. Then the best suitable measures were chosen to be realised.

After the supervised construction the school was monitored in detail for two years. The goal was to obtain the actual energy balance of the building complex after the retrofit, to verify the simulation models and to optimise the operation of the building (heating, illumination and shading). Therefore a number of sensors were installed in the building: Temperature probes, heat meters for the separate circuits and even some classrooms, gas meters, illumination meters, pressure difference probes for the heating circuits and sensors for the operating status (windows, blinds, lighting, etc) were designed to give a precise understanding of the actual operating conditions in the school.

6.2 Building

Status quo of the building fabric before the retrofit:

The building fabric met the requirements in force at the time of construction. The first section, building 1, was a solid brick building. In the 1950's a reinforced concrete building with solid brick cladding was added (building 2). Building 3, added 20 years later, was constructed from reinforced concrete with a multi-layer chipboard/insulation combination on the outside and on some orientations on the inside. All buildings suffered from severe heat losses through thermal bridges, especially at the building component connections. The windows were mostly composite windows with wooden frames (double glazing) without sealing. They showed severe air leakages and were partly weather beaten. The roofs had wooden/concrete constructions filled with peat dust (sections 1+2) or were constructed as rib floors with insulation (section 3). The cellar ceilings were made of concrete with no insulation.

Retrofit Concept:

Due to the very different wall types and the requirements due to preservation of historic buildings, different thermal insulation systems were used. For all buildings, the greatest possible savings could be achieved by insulating the outside walls. Styrofoam as internal insulation was applied where the original facades should be kept untouched. On most of the other facades external insulation of up to 14 cm Styrofoam as a composite thermal insulation was applied. Insulating the roof of the gymnasium yielded great savings, too. Much smaller was the influence of improved windows since the potential of the passive use of solar energy and aspects of lighting have to be considered in addition to the thermal transmittance. A low–E coated glazing with a lower thermal transmission coefficient (U–value) will reduce the heat loss of the building but at the same time suffers from a lower g–value and a lower light transmission due to the infrared reflecting layer on the glass. Thus north facing windows had intentionally different properties compared to south facing windows. The glazing had to be optimised with respect to the total energy

Table 1: U–values of the building envelope before and after retrofitting for the 3 segments of the building.

Segment of building	Structural Unit	Before retrofitting [W/m^{2}K]	After retrofitting [W/m^{2}K]
1	Windows	3.4	1.4
	Walls	1.60	0.26
	Roof	1.35	0.19
	Cellar ceiling/ground floor	1.72/3.02	1.72/3.02
2	Windows	3.5	1.4
	Walls	1.73	0.25
	Roof	0.85	0.18
	Ground floor	2.35	2.35
3	Windows	2.5	1.4/2.5
	Walls	1.36	0.26
	Roof	0.28	0.28
	Cellar ceiling/ground floor	1.56/2.17	0.79/2.17

consumption including heat and lighting. It was decided to replace the windows by low-E coated glazings (U–value of the windows =1.4 W/m^{2}K) in different frames (wood-aluminum and PVC).
The roof of building 2 was insulated by teachers and students themselves using 18 cm of styrofoam. The costs were reduced significantly and the school community has a much closer relation to energy issues because they were actually involved in the building work. The roof of section 1 was insulated as well. Table 1 presents the U–values before and after the retrofit.

6.3 Heating

The heating system of the school had to be completely renovated. The boiler house with boilers and pipework was replaced. The low pressure steam system in building 1 was replaced. Two boilers now deliver heat for space heating: A condensing boiler for base load, and a low temperature boiler for peak load, both with low NO_X – gas burners. The peak load of the boilers was reduced by 60%. The system temperature is 60°C/40°C at –12°C ambient temperature. The radiators of building 1 are oversized to provide a quick heat-up suitable for the intermittent operation of a school. A simulation showed that the low temperature level allows an optimal use of the condensing boilers during the heating period. In building 2 the existing radiators were retained. Zone controls were installed on each classroom to adjust the room temperature to the actual requirement. To have a heating demand in the classrooms only during class hours, the teacher has to press a button close to the door in order to continue heating the room for the following hour. Otherwise the temperature drops to a base temperature. In building 3 the radiator valves were replaced by tamper-proof thermostats. For the office of the headmaster a separate control circuit was installed to allow out of hours heating. In the apartment of the caretaker a completely separate heating system with a small gas boiler was installed.

6.4 Ventilation

Amongst other things, the insulation of the building resulted in a more air-tight facade, which means that ventilation of the rooms is not sufficient anymore if the windows are opened the same amount as before retrofitting. Yet no ventilation system has been installed. Windows have to be opened more often to provide ventilation. The teachers and the housekeeper have been informed about this aspect of the ventilation.

6.5 Lighting

By using a daylight dependent artificial lighting control system and new paint with a better surface reflectance, the energy consumption could have been reduced from 10.6 kWh/m^{2}a to 2.4 kWh/m^{2}a. But the provision of lighting controls was not cost effective. By considering the painting of the rooms (higher reflectance) and the new lamps as no cost measures, the additional control system would become cost effective. In some rooms in building 2 two different control strategies were implemented, both with the EIB (European Installation Bus) system. These test rooms were also fitted out with more effective lighting elements.

7 Resulting Energy Savings

The energy consumption in the early nineties averaged about 210 kWh/m^{2}a, the original value of 1977 being 382 kWh/m^{2}a. This was mainly the result of "good housekeeping", that is ‘no-cost measures’ enforced by the city of Stuttgart. After retrofitting the heating consumption was monitored as 49 kWh/m^{2}a. The efficiency of the new heating system with two boilers was monitored and shown to be 95%.

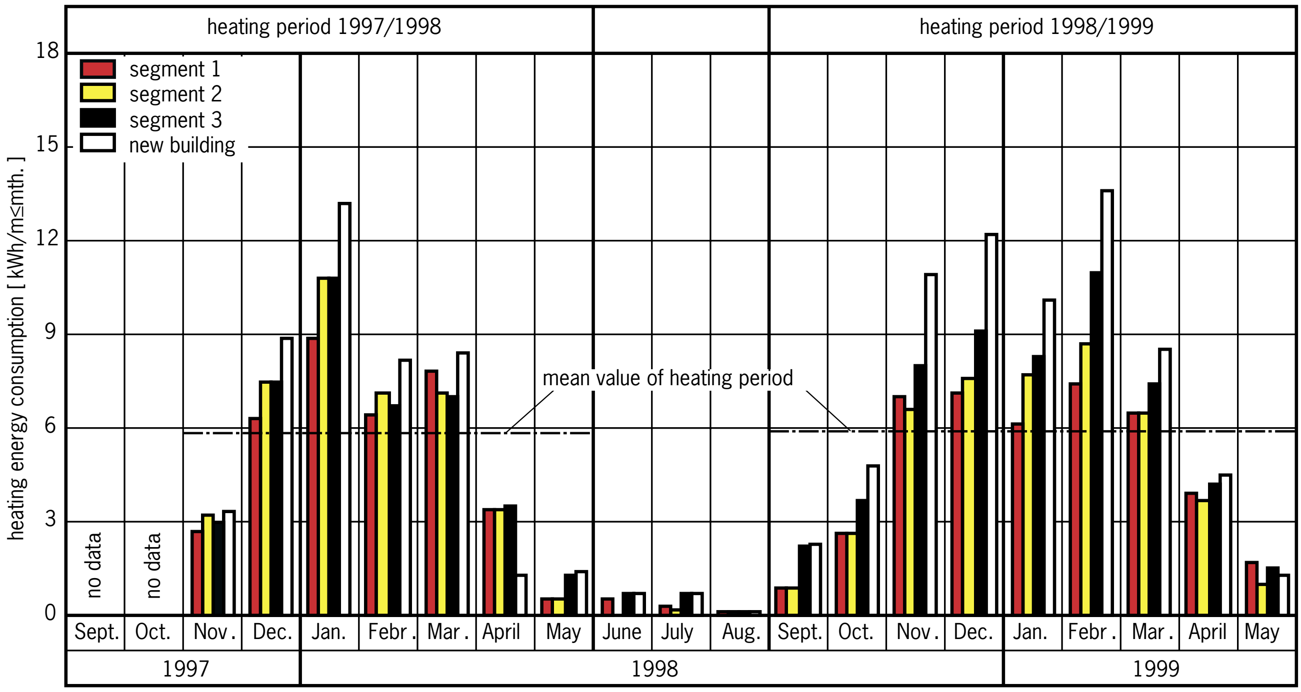

Figure 3: Monitored monthly heating energy consumption of all building segments during the heating periods 1997/1998 and 1998/1999.

The painting of the rooms decreased the electrical energy for lighting from 10.6 kWh/m^{2}a to 8.6 kWh/m^{2}a. The new lighting system was more effective than the old one. The electrical energy consumption was 2.6 kWh/m^{2}a in comparison to 8.6 kWh/m^{2}a. The daylight dependent artificial lighting control system was not profitable in comparison with the new manual managed one since the electrical energy consumption was just slightly lower (2.2 kWh/m^{2}a). The total electrical energy consumption went up from 12.6 kWh/m^{2}a to 16 kWh/m^{2}a during construction time and then after the retrofit again down to 14.8 kWh/m^{2}a. The reason of the increase between before the retrofit and after the retrofit was a higher demand for the new heating system, the monitoring and new appliances in the school (e.g. about 20 computers).

Table 2: Heating energy consumption of the building before retrofit and the values monitored in the heating period after retrofit for the 3 segments of the building.

Segment of building	**Heating energy consumption [kWh/m^{2}a]**		
	Before retrofitting (calculation fitted to consumption)	After retrofitting (monitored)	
		1997/1998*	1998/1999
1 (2090 m^2)	250	36	43
2 (1110 m^2)	210	40	45
3 (2060 m^2)	140	40	55
Total	**200**	**38**	**49**

* 1997/1998 represents an incomplete heating period (start of monitoring 19 November 1997)

8 User evaluation

At the end of the monitoring period the school employees were questioned about the new building, heating system and lighting system. This showed that they were fully satisfied with the building itself and the heating system. The daylight dependent artificial lighting control was recommended by the users. However the automatic control of the shading blinds was not accepted by the users. The noise of the shading device while moving up and down following the sun radiation on the façade happens abruptly and is not controlled by the building users. This leads to distraction and loss of concentration for the pupils and teachers. Additionally all rooms on a façade get shading at the same time, even if some rooms are already shaded by trees. The headmaster insisted that the automatic control had to be deactivated after the monitoring period.

9 Renovation costs

Table 3 shows the accumulated costs for this retrofit project. The costs for some maintenance measures (paint for the classrooms) are not listed, because the town would have to pay for them during the same period anyway. The replacement of the windows cost €420/m^2, the composite thermal insulation systems cost €110/m^2, the internal insulation cost up to €320/m^2 for the gymnasium and €165/m^2 for the other walls, the roof cost €68/m^2 and the cellar ceiling of segment 3 cost €48/m^2. The whole improvement of

Table 3: Costs of retrofitting.

Use		Costs [€]
Retrofitting with focus on energy efficiency	Thermal insulation	1,432,244
	Heating system	363,664
	Lighting	53,927
	Planning costs (architects, engineers)	270,657
	Σ	2,120,492
Research	Research costs (institutes)	313,436
	Measurements	61,414
	Public relations	11,074
	Σ	385,924
Auditing system by town (SEKS)		4,665
Σ		**2,511,081**

the building envelope cost about €1,432,000 (€272/m^2 floor area). The HVAC system came to €360,000 of which €247,000 was for the installation and €113,000 for the plant. The new lighting system resulted in €54,000 comprising €23,400 for installation works and €30.600 for hardware such as new lamps and the control systems. The total cost of the refurbishment was €2,120,492 or €403/m^2 floor area.

Figure 4: Building segment 1 after the retrofit.

10 Experiences/Lessons learned

10.1 Energy use

The auditing program of the town showed that good housekeeping could reduce the energy consumption by up to 40% with no costs at all. The energy related retrofit concept reduced the heating energy consumption by more than 75%. In order to choose the most cost and energy efficient retrofit measures calculations for a variety of measures and sorting proved to be effective. When a heating system needs to be renewed, insulation of the building envelope should be considered as well, since the efficiency of the heating system cannot be adapted to a better building envelope later on and the costs for insulation can be balanced by the lower costs for a smaller heating plant. For school buildings which are used for only a small number of hours a day a quick heat-up and a control system for reducing the heat flow during non-use hours is worthwhile. High reflectance walls (eg, painted white) reduced the electrical energy consumption of the classrooms by 20%. The new lighting system added another 60% to the savings.

10.2 Impact on indoor climate

The indoor air quality (IAQ) was not investigated. Because of the more air-tight facade, a more intensive ventilation through more frequent use of the windows is necessary. Yet there have been no complaints of poor indoor air quality from the users. No mould growth has been seen. The natural ventilation seems to be working efficiently. Correct ventilation by opening of the windows could be supported by a simple air quality visual indication using some form of passive sensor.

10.3 Economics

The internal insulation proved to be more expensive than predicted due to detailing problems. One of the cheapest measures was the insulation of the roof done by the pupils. The majority of the measures have payback times of less than 20 years.

10.4 Practical experiences of interest for a broader audience

Automatic control of shading devices may reduce the electrical energy demand, but the users have to accept the noise while shades move up and down. If the user is in control of the movement of the shades this is likely to be less distracting but in this case the unexpected operation of the automatic shading led to concentration problems and was an important negative factor. It proved to be helpful to involve the school community (headmaster, caretaker, teachers, pupils) by explaining the measures and letting them take part in the retrofit. The users usually have a much closer relationship with energy issues when they are involved in the activities. Motivation could be further increased by sharing some of the energy cost savings with the school.

10.5 Resulting design guidance

- An integrated retrofit concept including the building envelope and the services installations leads to better cost-efficiency.
- Substancial energy reductions can be achieved by simple low-cost measures such as new paint and voluntary work by the pupils (eg, insulation of the roof).
- Natural ventilation by opening the windows can be efficient, but may need support by simple IAQ visual indication.

11 General data

11.1 Address of project

Grund- und Hauptschule Plieningen, Paracelsusstr. 44, 70599 Stuttgart

11.2 Existing or new case study

Project initiation: 1994
Design completed: 1996
Renovation construction completed: 1997
Monitoring and evaluation completed: 1999

11.3 Date of report / revision no.

May 2002, no. 6

12 Acknowledgements

Project Coordination: Stuttgart Municipal Office of Environmental Protection
Building Physics: Fraunhofer Institute of Building Physics (IBP), Stuttgart
Heating Technology: IKE, Institut für Kernenergie und Energiesysteme
Monitoring: IKE in collaboration with Fraunhofer Institute of Building Physics
National Support program: German Ministry of Economy and Technology
Projektträger Jülich (PTJ)
Author: Heike Kluttig, Fraunhofer Institute of Building Physics

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[3] *Kienzlen, Volker, et ali:* Modellhafte Sanierung einer Schule (MOSES). Abschlußbericht. 1999, Stuttgart, Germany.