Planning and construction of passive solar primary school Kalbacher Höhe 15, Frankfurt am Main

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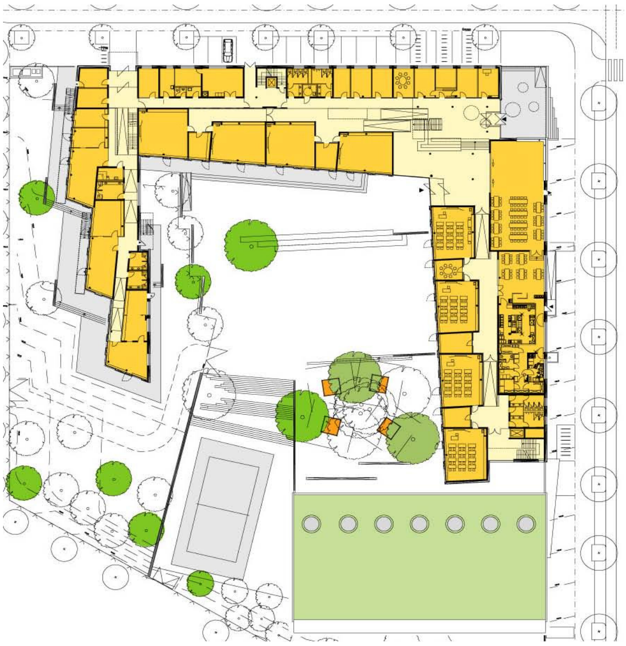
1 Summary

On November 1, 2004 in the Riedberg development area, the city of Frankfurt opened the first primary school in Germany built entirely to the passive house (PH) standard. Construction began in September 2003. In the course of a 2000/2001 design competition, the decision was taken to build three primary schools to the passive house quality standard. In spring 2003, following thorough cost-benefit assessments, the Stadtschulamt (school board) and municipal authorities authored a resolution mandating PH construction for school buildings. The entire project with its 8,785 m^2 of gross floor space, including a gymnasium with two fields, cost 16.7 million €. When the costs were estimated, the additional costs over and above an improved EnEV standard minus 30% (75 kWh/ m^2), were demonstrated to the funder, Deutsche Bundesstiftung Umwelt, to be 5.3%. Experience from similar projects confirms a figure of 5-8% additional cost for similarly optimized properties amortised over 10-20 years. Real-world operating conditions have confirmed the planning figures. In September 2007, the new Frankfurt city government decided that all new public buildings have to be built to the PH standard – exceptions require a justification. All buildings have to be built in accordance with city guidelines for economic building http://www.stadt-frankfurt.de/energiemanagement/pdf/Leitlinie¬wirtschaftliches-Bauen.pdf

The day school with kindergarten is equipped with a full kitchen and cafeteria. The accompanying gymnasium was built using comparably solid construction and somewhat inferior south-facing glazing. Apart from meeting the passive house insulation standard and an air-tightness of n50 = 0.46/h, heat loss to the soil was minimized with an insulated frost barrier. Substantial construction, external blinds, and night cooling ensure the thermal protection required in summer independent of the PH standard. The primary energy demand is 59 kWh/ m^2 a. The central ventilation systems are designed as fresh air intake systems with heat recovery (84%) and a small frost heating register. Decentralized ventilation systems were not used due to the additional costs, maintenance levels considered too high for a school, and space constraints. Rather than using a group heating register in the ventilation system to supply supplementary heating for the rooms, there is one small radiator per room, which guarantees individual comfort at no increased cost, while providing redundancy. Residual heating is provided by two fully automatic 60 kW wood pellet boilers, which have already logged 1500 service hours heating the buildings without any malfunction. The environmentally friendly concept is rounded off by a photovoltaic system with a total output of 30 kW on a leased section of roof. The school is certified as Green building according to EU/Dena in 2006. The project was supported by the Deutsche Bundesstiftung

Umwelt; the Passivhaus Institut played an advisory role and took measurements throughout construction. The German state of Hessen provided funds to install the wood pellet heating system.




Floor plan: Kindergarten (left), school (top and right) gymnasium (bottom) classroom (top photo), Entrance-Hall (bottom photo)

2 Why build school buildings to the passive house standard?

In a passive house school the heat from 25 students and a teacher (1.5-2 kW) is adequate to keep the classroom comfortably warm year-round. Thus, PH insulation is less expensive for schools than it is for residential PH buildings. PH schools are also very forgiving. Even if the heating system were to fail for several days, room temperatures are expected to remain comfortable. The PH windows ensure comfort in winter, even next to the window, and because there is no radiator next to the window, they increase space in the room. At 15-20 m3/person, the quantity of air that is mechanically circulated into a PH school ensures that the indoor air is completely replaced twice-over and that it always meets the DIN 1946 T2 air quality standard (indoor CO2 concentration less than 1500 ppm). This modest amount of ventilation guarantees that classrooms are free of noise and drafts, in addition to preventing overly dry air (occurs at circulation rates in excess of 25 m^3/person h). In the winter, the requirement to completely exchange the air twice over cannot be achieved with window ventilation alone, as was already determined decades ago in every representative classroom study -- these studies yielded CO2 measurements of 2500 to 4000 ppm. ASR 5, which presumes decreased ventilation behaviour at temperatures below 0oC, also anticipates reduced air exchange due to decreased window ventilation in winter. At the same time, the heat recovery system prevents great heat losses caused by ventilation. Otherwise, according to the new DIN 12831, which deals with heating loads, such losses would have to be compensated for at significant additional expense using radiators, since in practice it is necessary to exchange classroom air twice-over. Plans call for switching off the ventilation system and exclusive use of windows for ventilation except during the PH school's brief heating season. Even during the heating season, windows can be used for additional ventilation if necessary, since in passive houses this method results in far less heat loss than in conventional buildings (due to the PH buildings' small heating elements on inner walls instead of large heating elements under the windows). Thus, it is not just the operating costs that are significantly reduced when passive house construction techniques are used. They also create better learning conditions for students and better working conditions for teachers.

3 Costs, energy and CO2 balance

A piped heat connection from a waste-fired cogeneration plant was planned as an alternative to the wood pellet boiler heating used at Riedberg. However, calculations showed that pellet heating was more economical. Therefore, energy savings for the PH-compliant school amount to 260 MWh/a, or 28,000 € per year over the City of Frankfurt standard (EnEV standard-30%). However, CO_2 savings for the total energy consumed is "only" 33 t/a, since both standards have low specific emissions. Compared to conventional buildings, however, savings are many times greater. Despite the higher investment, as well as additional service and maintenance expenses, the PH school already had a cost advantage in 2003 compared to a school built to the Frankfurt standard (EnEV-30%) in terms of post-cost-estimate ancillary costs (capital costs 5.5%, appreciation 3% over 40 years). The 2006 calculation for comparable properties in Frankfurt, compared to the EnEV standard, yielded an amortization period of less than 10 years. But the calculation did not take into account architectural and quality of life benefits, such as better indoor climate and sustainable construction.

Component	Net cost	Add. cost 18%	VAT	Notes
Foundation	43,900	7,900	8,300	extended, insulated frost barriers
Exterior wall	124,800	22,500	23,600	2160 m^2, insulation 1.3€/ m^2, increased façade statics
Modular external windows	137,000	24,700	25,900	1780 m^2, PH-Verglasung 75-100€/ m^2
Suspended ceilings	47,700	8,600	9,000	2560 m^2
Roof and assemblies	148,500	26,700	28,000	3600 m^2
Ventilation/heating	156,700	28,200	29,600	3 additional ventilation systems, less cost static heating, building services controller, central heating
Total	658,600	118,600	124,400	approx. 900,000 € (approx. 5.3%)

Additional cost of PH construction for the Riedberg primary school; currency of data: cost calculation/determination 2005 averaged from several calculation methods

4 Thermal protection/acoustics

4.1 Winter

The rear-ventilated façade was built with a standard wood-aluminium substructure and modelled on examples from the Institut Wohnen und Umwelt. Comprehensive attention to architectural details helped further reduce heat losses (external drainage, pressure ventilation for waste water pipes in the building etc.).

Component	U value W/ m^2 K
Roof	0.11
Modular façade	0.16
Floors with frost barrier (20 cm insulation, extends 2m below the floor slab)	0.34 Reduction factor 0.22
Windows	0.74

Structural analysis dictated that insulation under the floor slab was to be avoided due to the site's sloping ground with an 11 m elevation difference. Instead the frost wall was extended and insulated, as were the extensive retaining walls for the building. Insulating the frost barrier reduced thermal bridges and dew point freedom at the wall junctions and offsets in the building. The insulation in the building could therefore be done without the use sub wall insulating stones and such; only horizontal floor surfaces were insulated to 15 cm above the floor slab.


Construction of the frost barrier and the rear ventilated façade

4.2 Summer

Classrooms have very high internal (25 students) and external thermal loads (windows 15 m², 15% irradiation, 60-80 W/m²). Therefore, as is the case for traditionally insulated buildings, a simple simulation and computation according to DIN 4108 T2 for critical areas are necessary. Heat emission by transmission is negligible in summer (dT of less than 5 degrees) and thus not dependent on the insulation standard. Thus, the heat has to be stored during the day and at dissipated at night by ventilation. Apart from using solid construction materials, the glazed surfaces were optimized (daylight vs. summer thermal insulation). Lintels were minimized and opaque balustrades were used, in order to allow as much daylight as possible into the depth of the rooms, while keeping the glazed area constant and without unnecessary solar yield through a glazed balustrade. The external blinds are automatically controlled but there is a temporary manual override via a key switch; the upper third of the blinds is set at a fixed angle to provide daylighting. The room acoustics were optimized, both to adhere to noise control standards and ensure that an adequate amount of ceiling and wall surface is available for heat storage (partial suspended ceiling, noise dampening bulletin board). Two automatic night air flaps for each classroom that direct airflow into the corridors can be used for passive night air cooling. Also, the ventilation system can provide active night cooling via a summer bypass (2-4 complete air exchanges).

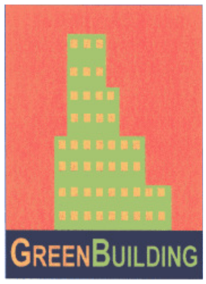
5 Building services

5.1 Heating

The room heaters are positioned and arranged to optimize cost (usually against the corridor walls). The cost of heaters for 4 classrooms is comparable to a group heating register for the ventilation system, but controlling the heaters is easier and they offer individual convenience. The heating elements make it possible to pre-heat and maintain warmth in empty areas, even when the ventilation system is not running. Nearly every room is equipped with an individual room regulator with a limited manual temperature selection range, which along with the heating elements increases user acceptance. The corridors are heated only by the discharge air from the classrooms (calculated to be at least 15^{o} C). When windows are opened, software switches off the heater via a room temperature sensor next to the entry door that measures the drop in temperature.

5.2 Ventilation

Six ventilation systems with a total capacity of 21,700 m^3/h are equipped with highly efficient heat recovery systems (84%). Three of these systems are part of the passive house concept for the school and the kindergarten. The fresh air is warmed by a reverse-flow/cross-flow plate heat exchanger and is blown into the rooms without any additional heating through dispersion slots. When it is blown into the room, the air temperature below the ceiling is at least 16oC. The small amount of air ensures that the rooms are heated by the students and the heaters, an effect that can be improved using the volumetric flow regulators located in each classroom (100%, 50%, 0%).



Classroom with suspended ceiling, acoustic bulletin board, dispersion slot (fresh air), certificates

The per-person air exchange rate amounts to some 15 m^3/h (additional window ventilation is a necessary component of the ventilation plan, increasing the projected rate to 20 m^3/h), which puts the air exchange rate during full occupancy at 2/h. In little used areas CO2 or mixed gas sensors control the volumetric flow regulator. Air flows from the classrooms through group areas into the corridor (noise dampers, fire protection flaps). Directing outgoing air through the corridors with a central exhaust system made it unnecessary to have an exhaust air duct system. The increased fire safety and noise control requirements that became apparent in the course of the project, with their increased initial investment and maintenance costs, indicated that an exhaust air duct system may be more economical in the future. Decentralized ventilation systems were not used due to the additional costs, maintenance levels considered too high for a school, and space constraints. The bathrooms are connected separately to the exhaust air/heat recovery system. At 0.45 Wh/ m^3, average power usage for the ventilation system meets the PH standard and DIN 13779 efficiency class SFP 1 or 2, since the duct work and motors were purpose-optimized (speed controlled).

With regard to heat recovery efficiency, it was noted that an increase of 1 per cent meant 1 cm less insulation.

5.3 MCR/CBCS

Controllers are connected via a LON network to an OPC server. Thermostats, as well as controllers for a ventilation, solar protection, and ventilation flaps can be controlled from every room. Motion and light sensors control lighting in the corridors; classroom lighting is switched off by a central controller following each lesson and can be individually switched on again immediately.

5.4 Hot water/wastewater

The hot water supply is limited only to the amount needed. Student bathrooms and cleaning closets have only cold water. User facilities located far from the central heating system are equipped with electrical water heaters for economical reasons and to save energy. Facilities that use large quantities of hot water (kitchen, gymnasium) are located close to the central heating system.

5.5 Electricity/photovoltaics

The electrical system was also designed to optimize costs and save electricity in accordance with the technical standards of either the Frankfurt Hochbauamt (now referred to as the "Guidelines", www.stadt-frankfurt.de/energiemanagement , under "Documents") or the Deutscher Städtetag "Energieleitlinien Planung". These guidelines specify classroom lighting with an installed output of 6 W/ m² at 300 lux. The photovoltaics plant was built and operated by a utility company. The panel mounting rails are secured to a system of metal plates weighted with roof gravel, which made it unnecessary to penetrate the roof.

6 Measurement concept and scientific evaluation

To evaluate the quality of the project and the special solutions it involves, a two-year measurement regime was established along with a final scientific evaluation. In addition, the Passive House Institute measured energy and cold water consumption, air exchange in the vicinity of the school entrances, the efficiency of the ventilation systems, indoor air quality, and temperatures in the classrooms compared to outside conditions, as well as the effectiveness of the frost barrier (report available under www.passiv.de).

Key data

User	• 400 primary school children in 16 classes • 100-125 kindergarten children • 50 adults in school, kindergarten, administration
Usable area	• School and kindergarten 6100 m² • energy reference area, school and kindergarten 5540 m², A/V= 0.35 • gymnasium 1600 m²
Gross floor area, Gross rooms volume	• 8785 m² • 40,347 m³
Key energy values for PH school excluding gymnasium	• Heat: 15.0 kWh/ m² a PH: 15 • Heating demand: 10.5 W/ m² • Airtightness: n50:0.46/h PH: 0.6 • Ventilation (approx.): 0.44 Wh/ m³ PH: 0.45 • Primary energy demand: 41 kWh/ m² a PH: 120 • Share of primary energy demand for electricity 33 kWh/ m² a • CO2 savings in 30 years over EnEV-30% using cogeneration plant piped heating 1000 t • Lighting class: < 6 W/ m² (<2 W/100 lux/ m²)
Heating demand coverage	• Radiators (stealing radiators in the gym) and ventilation with heat recovery without local heating registers; individual rooms thermostats • fully automatic wooden pallet boilers (2x60 kW)
Ventilation/heat recovery	• Three passive House systems (2x4800 m³/h; 1x 2800 m³/h) • three additional systems: kitchen, cafeteria, gymnasium • all systems: Cross/counter flow heat exchanger is with heat recovery; effective heat recovery rate 73% according to PHI, 84% measured • volumetric flow regulator; some including CO2 or mixed gas sensors
Costs	• Total project cost: 16.7 million € • construction costs (according to DIN 276: 300+400): 11.1 million € gross • construction costs by area €1110/square meters net
Passive House costs	• Additional costs, approximately 5.3% (over EnEV2004-30%) • amortization according to EnEV2004-30% standard
Funding	• Deutsche Bundesstiftung Umwelt: 250,000 € (measurement concept and investment) • State of Hessen: 10,000 € (pellet heating system)
Participants	• Builder: Stadtschulamt Stadt Frankfurt • architecture: Architekturbüro 4a, Stuttgart • energy quality assurance, energy concept: Passivhaus-Institut, Transsolar • building services:ICZR • Project management/energy management: Hochbauamt Stadt • Frankfurt