


School of the Future

TOWARDS ZERO EMISSION WITH HIGH PERFORMANCE INDOOR ENVIRONMENT

School of the Future

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www.school-of-the-future.eu

Preface

The European climate and energy targets for 2020 require a reduction of the greenhouse gas emissions by at least 20 percent, an increase in energy efficiency by 20 percent and a 20 percent share of renewables in the total use of energy. The construction sector is expected to make a substantial contribution to achieve these goals. In addition to tightening requirements on new buildings (up to nearly zero energy buildings from 2019/2021 on) the focus must be on improving the energy performance of the building stock, as existing buildings account for the largest share of building energy consumption.

In the EU Energy Efficiency Directive, the European Parliament and the Council of the European Union have pointed out that national, regional and local institutions are to set good examples for achieving energy efficiency by defining ambitious targets for the overall energy performance of public buildings. These examples should also convince private building owners of the success and the importance of building retrofits. Regarding the selection of possible demonstration projects it was recommended to choose buildings which are seen and visited by many persons. Besides, there should be an option to use the experience gained in the renovation process for replication in other buildings. Schools are perfectly suited for this purpose as they are used and attended by broad sections of the population, people of different age and income. Pupils and teachers are given the opportunity to closely watch the renovation process and to experience its impact on the indoor environment for themselves. The implemented measures and the improvements achieved thereby are going to be addressed in special class lectures or in working groups. Since the pupils act as communicators to their families, the knowledge they transfer will lead to a multiplied impact of the school energy retrofits. After all, the children are going to be the decision makers, researchers and achievers of the future.

For these reasons, the EU FP7 'School of the Future' project was a very rewarding and very important demonstration project with regard to building energy retrofitting. The collaboration between different countries and between representatives of public institutions, partners from research and industry (which was also reflected in the international Design Advice and Evaluation Group) enabled the project partners to present ambitiously retrofitted school buildings, along with a multitude of other interesting project results like retrofit guidelines and computer tools.

Hans Erhorn
Fraunhofer Institute for Building Physics
Project Coordinator, 'School of the Future'

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1 INTRODUCTION

In 2011, the ‚School of the Future‘ project was launched as a demonstration project in the Seventh Framework Programme of the European Union. The related call for applications focused on the 'Demonstration of Energy Efficiency through Retrofitting of Buildings'. Project goals included design, implementation and evaluation of holistic renovation measures in buildings with a high replication potential for large regions of Europe. The aim was to reduce the use of heating energy for the thermal conditioning of spaces in selected buildings by at least 75% through appropriate retrofitting measures. Accompanying measures were to include long-term measurements and an initiative to improve user behaviour. As the associated working programme was developed in cooperation with the Energy-Efficient Buildings - European Initiative of the European Construction Technology Platform (ECTP), partners from industry were encouraged to participate in the project.

The project proposal 'School of the Future' met these requirements, as the project focused on the renovation of four school buildings in four European countries with different climates. In addition to the public-sector building owners, five research institutions and four industry partners joined the project (see also the presentation of the project partners on page 38). In all of the four schools, the retrofits comprised measures to improve the building envelope, the building services systems and the use of renewable energy. The energy objectives defined by the project partners are as follows:

- Reduction of the heating energy use by 75% (as defined in the call)
- Reduction of the total energy use by factor 3 (i.e. by two thirds)

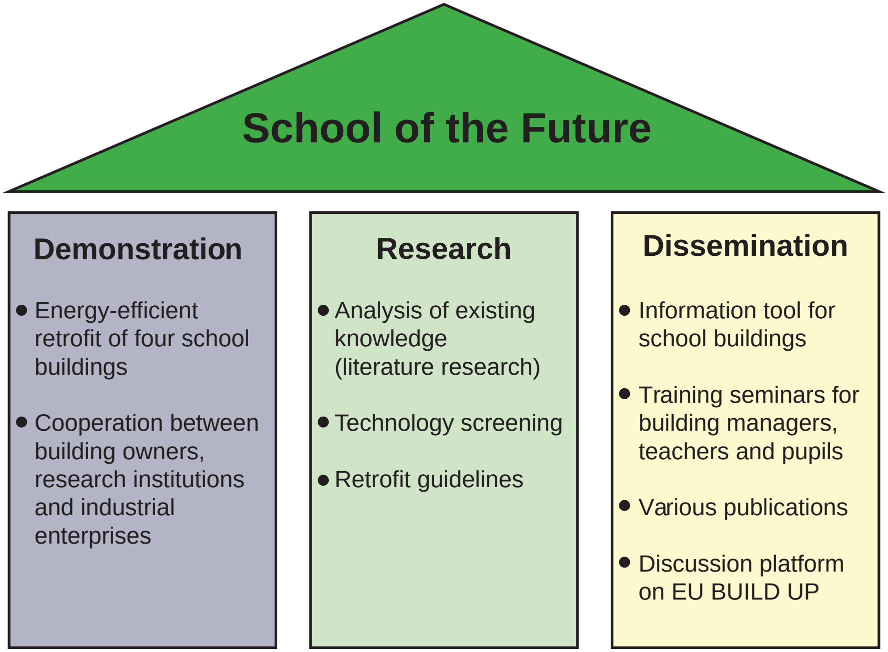
The total energy use includes space heating, water heating (DHW), ventilation, lighting and the residual use of electricity in buildings. None of the four school buildings needed cooling. The scope of the project included a monitoring phase of at least twelve months during which the energy consumption of the retrofitted buildings was measured. Subsequently, the measurements were continued by the building owners.

In addition to enhancing energy efficiency, the project also dealt with indoor comfort. Here, the target was to

- Improve the indoor environment to enhance pupils' performance

The analysis of the induced change in the indoor climate was based on short-time measurements and questionnaires. The four retrofitted schools are no zero energy schools, as this standard could not be realized without exceeding the envisaged energy-relevant investment costs of 100 €/m². Nevertheless, these schools use significantly less energy than specified in the national requirements for building renovation, thus leading the way towards even more energy-efficient school buildings. The further work packages in the project (the retrofit guidelines, for instance) demonstrate ways towards zero emission buildings or even buildings that generate surplus energy (energy surplus buildings).

The project was based on three pillars: demonstration, research, and dissemination. The outcome of the individual areas of work is summarized in the following sections. All results derived from the project are available on the project's website www.school-of-the-future.eu. The successful cooperation of the thirteen project partners was terminated according to schedule in January 2016.



Tasks of the School of the Future project

2 DEMONSTRATION BUILDINGS

SOLITUDE-GYMNASIUM, GERMANY

GENERAL BUILDING INFORMATION

ADDRESS	Spechtweg 40 70499 Stuttgart, Germany
BUILDING OWNER	City of Stuttgart
YEARS OF CONSTRUCTION	1966 - 1975
RENOVATION PERIOD	2012 - 2014
NUMBER OF PUPILS	710
NUMBER OF CLASSROOMS	27
REFERENCE AREA	8 924 m²

The Solitude-Gymnasium in Stuttgart-Weilimdorf was in need of renovation due to its high energy consumption. The school complex consists of several solid constructions: the main building, the building for science classes, the big pavilion and the gym. Between 2004 and 2006 the boilers had already been replaced; besides, the south-facing windows of the big pavilion, the roof of the main building and the roof of the gym had been refurbished.

Retrofit of building construction elements

In most cases, the existing windows were replaced with triple-glazed windows. The double-glazed windows of the big pavilion, which had already been renewed, were however retained. The upper part of the new external blinds can be controlled separately, thus ensuring good daylight supply even when the blinds are lowered.

Energy retrofitting of the external walls of the three school buildings included the installation of a curtain wall or an external thermal insulation composite system (ETICS). Insulation layers (between 14 and 18 cm) of mineral wool or rigid polystyrene foam were applied. The external wall of the gym was insulated using 18 cm mineral fibre boards.

U-values	Before retrofitting	After retrofitting
Roof	0.67 - 0.96 W/m²K	0.15 - 0.20 W/m²K
External wall	0.44 - 3.65 W/m²K	0.18 - 0.23 W/m²K
Windows	3.1 - 5.8 W/m²K	0.9 - 1.3 W/m²K
Floor	1.5 W/m²K	1.5 W/m²K

U-values of the building construction elements

The roof of the big pavilion was insulated using 14 or 16 cm expanded rigid polystyrene foam (EPS); the roof of the building for science classes was provided with a layer of 22 cm.

Retrofit of building services systems

Heating system: The gas boilers that had been installed in 2004 were combined with a cogeneration unit (CHP) to supply heat and electricity. This measure resulted in annual energy cost savings of EUR 10,000. This configuration uses the gas boilers for peak loads and redundant supplies. Besides, the thermal insulation of the heat distribution pipes supplying the gym was also improved.

Ventilation system: A centralised balanced ventilation system (supply and exhaust air) with heat recovery was installed in the assembly hall of the main building (heat recovery > 90%). The classrooms were provided with decentralized ventilation units (heat recovery > 80%). CO_2 sensors ensure a comfortable and healthy indoor environment. In the building for science classes, the existing central ventilation system was equipped with a heat recovery unit (WRG > 90%) and complemented by time-dependent and CO_2 dependent controls. The big pavilion is vented through windows that were provided with automatic actuators.

PV system: On the rooftop of the main building, 50 m² photovoltaic modules with a total capacity of 7.5 kWp were installed above the framework supports.

CHP unit, photovoltaic panels

Before retrofitting

After retrofitting

Lighting system: The old T8 fluorescent lamps were replaced with T5 fluorescent lamps; conventional ballasts were substituted by electronic ballasts. The light management is based on daylight-responsive control in the stairwell and on presence detectors.

Energy characteristics

On the base of calculations according to German standard DIN V 18599, the refurbishment of the Solitude-Gymnasium achieved the envisaged energy savings targets: after retrofitting, the need for delivered energy for heating was 75% less, while the total need for delivered energy was reduced by 74%. Regarding the school gym, the measured energy consumption data exceeded the predicted data. This deviation is due to the fact that it was not possible (for structural reasons) to provide the ventilation system with a heat recovery unit. Besides, about 270 refugees have been accommodated in the school gym since late summer of 2015. Given this situation, the actual user profile is completely different from the profile that was assumed in the calculations and the profile before retrofitting. The need for continuous heating and the clearly higher air change rate prevented the planned substantial energy savings from being realised. The measured energy consumption of the school buildings alone is approximately as high as the predicted energy conservation potential of 72% savings in heating energy and 66% in terms of total delivered energy.

Delivered energy *Calculation*	Before retrofitting	After retrofitting	Energy savings
Space heating and DHW	213 kWh/m²a	53 kWh/m²a	75 %
Electricity	12 kWh/m²a	10 kWh/m²a	17 %
Total	225 kWh/m²a	63 kWh/m²a	72 %

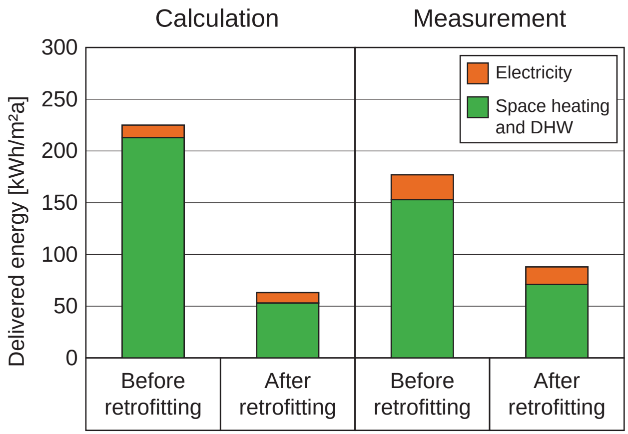
Primary energy *Calculation*	Before retrofitting	After retrofitting	Energy savings
Space heating and DHW	211 kWh/m²a	53 kWh/m²a	75 %
Electricity	34 kWh/m²a	24 kWh/m²a	29 %
Total	245 kWh/m²a	77 kWh/m²a	69 %

Delivered energy *Measurement*	Before retrofitting	After retrofitting*	Energy savings
Space heating and DHW	153 kWh/m²a	71 kWh/m²a	54 %
Electricity	24 kWh/m²a	17 kWh/m²a	30 %
Total	177 kWh/m²a	78 kWh/m²a	50 %

Primary energy *Measurement*	Before retrofitting	After retrofitting*	Energy savings
Space heating and DHW	151 kWh/m²a	70 kWh/m²a	54 %
Electricity	67 kWh/m²a	40 kWh/m²a	40 %
Total	218 kWh/m²a	111 kWh/m²a	49 %

*Space heating and DHW (Gas) PEF 1.1; Electricity PEF 2.8 / 2.4 / feed-in 2.8; (PEF = Primary Energy Factor, non-renewable); *Figures do not take account of the school gym*

Comparison of calculated and measured energy data



Delivered energy before and after retrofitting

Indoor climate

The interviews concerning the quality of the indoor environment were carried out in February 2012 and in October 2015. After the renovation works were completed, users gave a more favourable evaluation of the indoor climate (for 15 out of 22 questions) regarding issues like the

- Indoor temperature in winter
- Indoor air quality in winter
- Daylight quality in the spaces

- Management of the sunshading devices
- Outdoor noise exposure.

The users assessed the indoor temperature and the indoor air quality of the main building in summer to be poorer than before retrofitting. As a consequence of the user survey, the air change rates of the decentral ventilation systems were increased. Besides, several windows which had been locked before were now made openable. The short-time measurements of the carbon dioxide level, of the temperature, the indoor air humidity and of the brightness in the spaces supported the users' statements.

Costs

The costs for the overall refurbishment of the Solitude-Gymnasium totalled approx. EUR 12 million or 1 340 €/m². These figures cover the energy-related costs, all other costs for the building measures and the planning costs, plus the rent for the containers (EUR 2.1 million) that served as temporary classrooms during the renovation of the main building.

Lessons learned

- Space limitations or structural restraints can prevent the implementation of efficiency measures, in this case e.g. the installation of the initially planned additional PV panels and the heat recovery in the gym.
- When installing ventilation systems, particular consideration should be given to the correct regulation. Besides, it must be ensured that the basal air change complies with the hygiene requirements.
- Due to the renovation measures the indoor air quality of the classrooms was significantly improved.
- Due to the conversion of the gym (now used as refugee accommodation) and the resulting significant changes in the usage profile the predicted energy savings for the gym could not be achieved.
- The measured energy data of the three school houses alone are ranging approx. in the order of the predicted saving potentials.

Dr. Jürgen Görres
Head of Department for Energy Management, Office for Environmental Protection, City of Stuttgart, Germany

“The Solitude-Gymnasium, which was built in the 1970s, was in need of renovation due to the high building age. It was decided to participate in the EU-project 'School of the Future' and the renovation works began in 2011. Thanks to the funding, the renovation scope of the school was extended beyond the measures required for the building's maintenance. Thus, the indoor air quality of the classrooms was significantly improved and the usable area of the school could be enlarged. Feedback from both students and teachers was very positive regarding the conversion work. Future school renovation projects in Stuttgart will definitely benefit from the experience gained in this project.”

TITO MACCIO PLAUTO SCHOOL, ITALY

GENERAL BUILDING INFORMATION

ADDRESS	Via Tito maccio Plauto, n. 4 47521 Cesena, Italy
BUILDING OWNER	City of Cesena
YEARS OF CONSTRUCTION	1960s
RENOVATION PERIOD	2011 - 2014
NUMBER OF PUPILS	380 - 400
NUMBER OF CLASSROOMS	33
REFERENCE AREA	6 027 m²

The Tito Maccio Plauto secondary school complex comprises an L-shaped school building and a school gym, which are connected by a common entrance area. The building structure is made of reinforced steel; parts of the construction were done in exposed brickwork. The insufficient thermal insulation (including single-pane glazing) and the associated high energy consumption required energy retrofitting.

Retrofit of building construction elements

The old single-pane windows were replaced with PVC frame windows featuring argon-filled double-glazing. The windows now have a U-value of 1.2 W/m²K. In addition, external blinds were mounted.

The external wall of the school building was provided with 12 cm of mineral wool as a component of an external thermal insulation composite system (ETICS). A layer of 10 cm mineral wool was mounted at the internal surface of the external wall of the school gym.

An insulating layer of 20 cm mineral wool was mounted at the top-floor ceiling of the school building and the roof of the gym. The lower surface of the basement ceiling was insulated with 10 cm polystyrene boards.

U-values	Before retrofitting	After retrofitting
Roof	2.3 W/m²K	0.18 - 0.20 W/m²K
External wall	1.8 - 2.8 W/m²K	0.28 - 0.30 W/m²K
Windows	5.9 W/m²K	1.2 W/m²K
Floor	1.3 W/m²K	0.28 - 1.30 W/m²K

U-values of the building construction elements

Retrofit of building services systems

Heating system: To supply the school buildings with space heating and hot water, three new gas condensing boilers working as a cascading system were installed, able to modulate the capacity between 13.4 and 215 kW. An additional natural-gas condensing boiler supplies the gym. Efficient electronic pumps distribute the heat to the radiators. By subdividing the building into different heating circuits (zoning), each zone can be individually conditioned and adjusted to a given time profile, supported by the newly installed radiators.

Ventilation system: Five independent mechanical ventilation systems with a heat recovery rate between 77% and 80% serve 23 classrooms.

PV system: A PV plant consisting of 250 m² monocrystalline photovoltaic modules with an overall capacity of 64.7 kWp was mounted on the inclined, south oriented roof surfaces. This allows for an electricity production of 68 000 kWh/yr. In the overall annual balance, this volume will cover more than the school's total electricity consumption.

Lighting system: The existing T8 fluorescent lamps were retained because their electricity consumption is low.

Condensing boiler, photovoltaic panels

Before retrofitting

After retrofitting

Energy characteristics

The refurbishment of Tito Maccio Plauto School accomplished the envisaged energy conservation goals, both in terms of predicted and measured consump-tion data: after retrofitting, the measured consumption of delivered energy for space heating and DHW was 80% less, while the total use of deli-vered energy was reduced by 82%. Based on measu-rements, 83% of the total primary energy could be saved.

Delivered energy *Calculation*	Before retrofitting	After retrofitting	Energy savings
Space heating and DHW	132 kWh/m²a	25 kWh/m²a	81 %
Electricity	11 kWh/m²a	0 kWh/m²a	100 %
Total	143 kWh/m²a	25 kWh/m²a	83 %

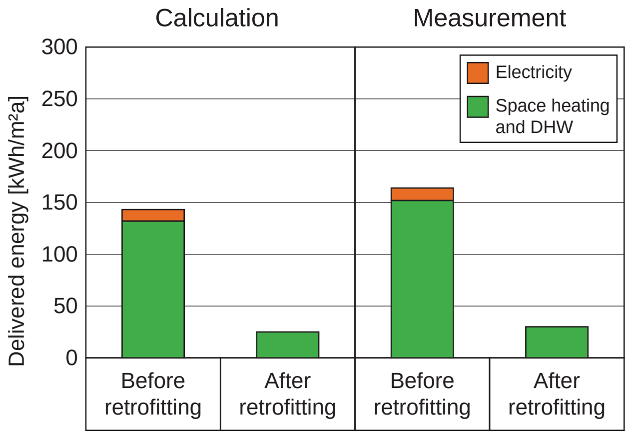
Primary energy *Calculation*	Before retrofitting	After retrofitting	Energy savings
Space heating and DHW	145 kWh/m²a	28 kWh/m²a	81 %
Electricity	24 kWh/m²a	0 kWh/m²a	100 %
Total	169 kWh/m²a	28 kWh/m²a	83 %

Delivered energy *Measurement 2014*	Before retrofitting	After retrofitting	Energy savings
Space heating and DHW	152 kWh/m²a	30 kWh/m²a	80 %
Electricity	12 kWh/m²a	0 kWh/m²a	100 %
Total	164 kWh/m²a	30 kWh/m²a	82 %

Primary energy *Measurement 2014*	Before retrofitting	After retrofitting	Energy savings
Space heating and DHW	167 kWh/m²a	33 kWh/m²a	80 %
Electricity	26 kWh/m²a	0 kWh/m²a	100 %
Total	193 kWh/m²a	33 kWh/m²a	83 %

Space heating and DHW (Gas) PEF 1.1; Electricity PEF 2.17;
(PEF = Primary Energy Factor, non-renewable)

Comparison of calculated and measured energy data



Indoor climate

The surveys on the quality of the indoor environment were carried out in February 2012 (with 291 pupils and 24 teachers participating) and in March 2015 (180 pupils and 9 teachers). After retrofitting, several aspects of the indoor climate were rated significantly better, namely the

- Indoor temperature in summer
- Indoor temperature in winter
- Indoor air quality in summer
- Outdoor noise exposure
- Daylight quality in the spaces.

Users felt that the indoor air quality in winter had only slightly improved compared to the situation before retrofitting. The short-time measurements on indoor climate confirmed the results of the interviews.

Costs

The net costs for the energy-relevant retrofitting measures (boilers, controls, mechanical ventilation, PV) including required certificates and fees amount to EUR 954 800 or 158 €/m². This amount includes all measures that were performed at the building envelope and the building services systems (e.g. the boilers, the ventilation system, and the photovoltaic system).

Lessons learned

- The energy target values for the retrofit of Tito Maccio Plauto School could be accomplished.
- The project shows that comprehensive refurbishment allows achieving energy savings of approximately 80% in public buildings.
- Due to retrofitting, the indoor environment quality in the classrooms was significantly improved. This is particularly true for the indoor air quality.
- With regard to electricity, the school is a surplus-energy school (in the annual balance).
- The successful demonstration project resulted in a new general retrofitting standard for the schools in Cesena.

Arch. Gualtiero Bernabini Executive Manager of the Public Works Department of the Municipality of Cesena

"What Cesena has learned from the School of the Future project, will be used for future energy retrofitting projects and applied on existing buildings. Currently we're replicating the School of the Future knowledge on the San Vittore School and we are going to do it also in other buildings."

HEDEGAARDS SCHOOL, DENMARK

GENERAL BUILDING INFORMATION

ADDRESS	Magleparken 8 2750 Ballerup, Denmark
BUILDING OWNER	Municipality of Ballerup
YEAR OF CONSTRUCTION	1972
RENOVATION PERIOD	2011 - 2014
NUMBER OF PUPILS	360
NUMBER OF CLASSROOMS	15
REFERENCE AREA	3 850 m²

The part F of Hedegaards School, with a building age of more than 35 years, was in need of refurbishment as the roof and the windows were leaky and the thermal insulation of the walls and the attic was insufficient. The electric lighting installations in the corridors were technically obsolete, causing high electricity consumption. Retrofitting included the thermal insulation of the building envelope, new windows, installation of more efficient lighting fixtures in the corridors and two classrooms, PV and a high-quality building energy management system .

Retrofit of building construction elements

The existing, contaminated windows (lead and PCB) were replaced with new triple-glazed windows mounted in insulated frames.

The external masonry work and the existing insulation layer were removed from the double-leaf masonry facade; the wall was insulated with 33 cm of mineral wool and provided with a new exterior layer (masonry or facing shell). Due to these measures, previously existing thermal bridges could be significantly reduced.

U-values	Before retrofitting	After retrofitting
Roof	0.45 W/m²K	0.06 W/m²K
External wall	0.57 W/m²K	0.10 W/m²K
Windows	3.1 W/m²K	0.70 W/m²K
Floor	0.40 W/m²K	0.40 W/m²K

U-values of the building construction elements

The roof was sealed and an additional insulation layer of 25 cm mineral wool was applied, which increased the total insulation thickness to 45 cm.

Retrofit of building services systems

Heating system: The connection to the district heating supply was maintained. The local district heat is mainly generated by waste incineration.

Ventilation system: The existing ventilation system was kept. It is now switched off in the offices outside normal working hours.

PV system: 152 m² of PV panels were installed on the roof of one of the school's roof light systems. With a total installed power of 22.5 kWp the annual electricity production amounts to approx. 22.5 MWh/yr.

Lighting system: As the existing lighting solutions in the classrooms already employed rather efficient T5 luminaires, retrofitting was restricted to two classrooms where two different LED systems were tested side-by-side. Here, the blackboard lighting was replaced with LED strips in a reflector. The corridors were supplied with two rows of LED downlights which use daylight-dependent controls.

Display of solar yield, LED lighting

Before retrofitting

After retrofitting

Energy characteristics

The calculated energy savings of Hedegaards School are in agreement with the project target values. The measurements performed in 2014 were adjusted with regard to climate. Heating energy savings were 60% (i.e. somewhat lower than predicted) while electricity savings were 29%, thus slightly exceeding planned values. The total savings of delivered energy achieved in the project are 123 kWh/m²yr or 57%. It should be noted that the set point of the indoor temperatures now is about 3 K higher than before retrofitting. Calculations proved that this influence approximately corresponds to the missing percentage of the savings.

Delivered energy *Calculation*	Before retrofitting	After retrofitting	Energy savings
Space heating and DHW	192 kWh/m²a	46 kWh/m²a	76 %
Electricity	22 kWh/m²a	18 kWh/m²a	18 %
Total	214 kWh/m²a	64 kWh/m²a	70 %

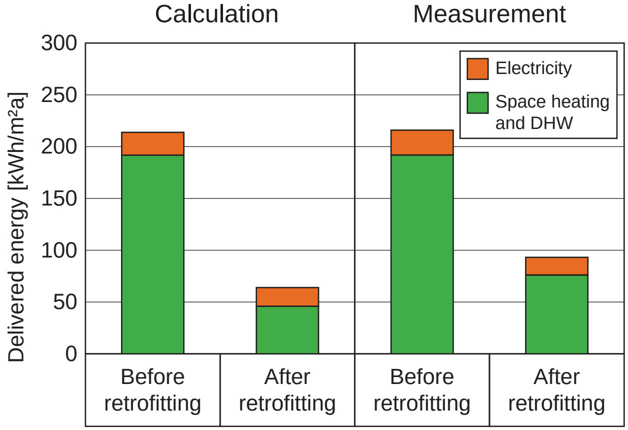
Primary energy *Calculation*	Before retrofitting	After retrofitting	Energy savings
Space heating and DHW	192 kWh/m²a	46 kWh/m²a	76 %
Electricity	55 kWh/m²a	18 kWh/m²a	18 %
Total	247 kWh/m²a	64 kWh/m²a	63 %

Delivered energy *Measurement 2014*	Before retrofitting	After retrofitting	Energy savings
Space heating and DHW	192 kWh/m²a	76 kWh/m²a	60 %
Electricity	24 kWh/m²a	17 kWh/m²a	29 %
Total	216 kWh/m²a	93 kWh/m²a	57 %

Primary energy *Measurement 2014*	Before retrofitting	After retrofitting	Energy savings
Space heating and DHW	192 kWh/m²a	76 kWh/m²a	60 %
Electricity	60 kWh/m²a	42 kWh/m²a	30 %
Total	252 kWh/m²a	118 kWh/m²a	53 %

Space heating and DHW (District heat) PEF 1; Electricity PEF 2.5; (PEF = Primary Energy Factor, non-renewable)

Comparison of calculated and measured energy data



Delivered energy before and after retrofitting

Indoor climate

The surveys on the quality of the indoor environment of Hedegaards School were conducted in May 2012 in three classes and in November 2015 in another two classes. The surveys contained questions about the indoor air temperature, the indoor air quality, the level of illumination and the quality of the light colour. The pupils found the situation after retrofitting to have improved in all areas. For instance, the quality of the light colour in the classrooms provided with LED luminaires was rated much better than the standard system.

Short-time measurements spanning one or two weeks were also performed before and after retrofitting. For this purpose, data loggers were placed in a classroom and in the corridor in order to record the carbon dioxide level, the indoor air temperatures and the humidity of the indoor air.

Costs

The overall investment for the energy-relevant part of the refurbishment amounted to DKK 4.1 million or EUR 549 000. Related to the floor space, this corresponds to 143 €/m². The simple payback time was calculated to be 17.6 years.

Lessons learned

- Positive experience has been made with the selected type of insulation for the double-leaf external wall (i.e. removing the outer leaf, applying the mineral wool and creating a new outer shell).
- The retrofitting process was carried out in several steps; each step involved two classrooms at a time. This worked out fine.
- The old windows were found to contain lead and PCB. This contamination raised the costs and required more time for window replacement.
- As replacing the classroom ventilation system was found to be too expensive, this measure was cancelled.
- The measured data of the energy savings are close to the predicted values and the targets of the project.

Mads Bo Bojesen,
Chief of Centre for Properties,
Municipality of Ballerup

"Over the past two to three decades Ballerup municipality has participated in several national and EU-projects with the aim of utilizing the results of research and development work in the design and construction of renovation works on the municipality's buildings with good results. Hedegaards School – built in 1972 – was in need of renovation, when the School of the Future project commenced, and the support from this project – both in the form of advice and economical support have made it possible to aim for and reach a much improved energy state of the building than otherwise foreseen. The renovation work went smoothly, the indoor climate has improved and the result is also aesthetically satisfactory."

BRANDENGEN SCHOOL, NORWAY

GENERAL BUILDING INFORMATION

ADDRESS	Ivers Holters gate 48 3041 Drammen, Norway
BUILDING OWNER	City of Drammen
YEAR OF CONSTRUCTION	1914
RENOVATION PERIOD	2011 - 2013
NUMBER OF PUPILS	370
NUMBER OF CLASSROOMS	25
REFERENCE AREA	7 079 m²

Brandengen School was built in 1914 and is a building of historical importance. The conservation authority permitted only marginal modifications of the original facade to be made during the renovation process. In spite of this strict requirement, the renovation measures included the replacement of the windows in addition to insulating measures at the attic and the installation of a geothermal heat pump.

Retrofit of building construction elements

All windows that had been installed after 1965 were replaced with triple-glazed windows fitted in insulated frames. The design of the new windows is much closer to the original appearance of the listed building. Due to a very low total energy transmittance (up to 27% only) it was possible to remove the solar shading devices (external blinds) that had been added during previous refurbishment and thus to better reproduce the original condition. Besides, some original windows in the corridor areas were restored.

The mansard roof in the heated zone and the top-floor ceiling were insulated with 30 cm of mineral wool. The roof above the attic was provided with ventilation openings to ensure dehumidification.

U-values	Before retrofitting	After retrofitting
Roof	1.15 W/m²K	0.20 W/m²K
External wall	0.85 W/m²K	0.81 W/m²K
Windows	2.6 W/m²K	0.8 - 1.0 W/m²K
Floor	0.19 W/m²K	0.15 W/m²K

U-values of the building construction elements

An additional insulating layer of 10 cm mineral wool was placed around the ventilation ducts in the attic.

A new drainage system and an insulation layer were mounted at the wall base.

Retrofit of building services systems

Heating system: A 200 kW heat-pump system with 19 geothermal heat pipes replaced the existing combination of two oil-fired boilers and an electric water heater. An oil-fired boiler was modified for the use of bio-oil and is now used to cover peak loads. In conjunction with the water heater this boiler also serves as a back-up system. During renovation, the gym was connected to the same heating system. Thanks to a complex system of compressors, condensers, liquid subcoolers and amply dimensioned heat exchangers, a seasonal performance factor of 3.1 could be measured despite the required high supply temperature of up to 70 °C.

Ventilation system: The ventilation system with heat recovery, which had been installed between 2001 and 2003, was maintained. The planned ventilation system for the school‘s gym was not implemented, as this building will soon be remodelled and become a classroom building.

Lighting system: The electric lighting system, which had also been renewed after 2001, comprises T5 luminaires provided with presence detectors. It was not modified in the project.

Heat pump, geothermal drilling

Before retrofitting

After retrofitting

Energy characteristics

Unfortunately, no measured energy consumption data was available for the period before retrofitting, due to the complex generation of space heating and

DHW by oil-fired boilers and an electric water heater. This is why the data measured after retrofitting can only be compared to the calculated values for the situation before and after retrofitting.

The savings of delivered energy for heating purposes (space heating and DHW) and the total savings of delivered energy achieved the target values required by the ‚School of the Future' project (both, predicted and measured data). It should be noted that the use of electricity could be reduced only marginally (calculation). Respectively, it has slightly increased (measurement). Neither the lighting system nor the ventilation system was modified in the scope of the project; there is no generation of electricity from renewables. Thanks to the renovation measures, the delivered energy for space heating and DHW could be reduced by 78%; the total delivered energy was reduced by 66%.

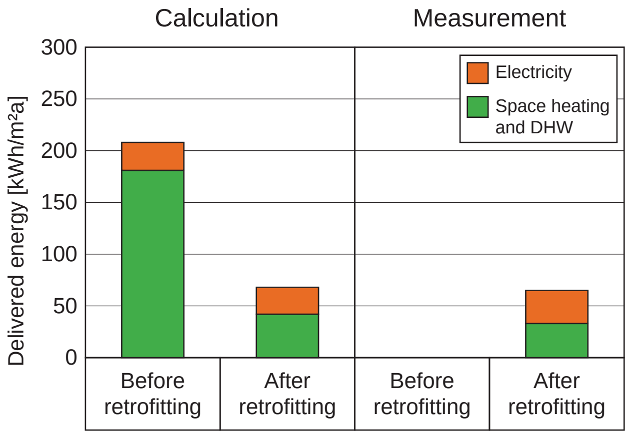
At present, assessments with regard to the primary energy are not general practice in Norway. It should

Delivered energy *Calculation*	Before retrofitting	After retrofitting	Energy savings
Heizung und Warmwasser	181 kWh/m²a	42 kWh/m²a	77 %
Strom	27 kWh/m²a	26 kWh/m²a	4 %
Gesamt	208 kWh/m²a	68 kWh/m²a	67 %

Delivered energy *Measurement 2014*	Before retrofitting	After retrofitting	Energy savings*
Heizung und Warmwasser	-	33 kWh/m²a	78 %
Strom	-	32 kWh/m²a	-19 %
Gesamt	-	71 kWh/m²a	66 %

**Energy savings relating to the values that were calculated for the existing building before*

Comparison of calculated and measured energy data



Delivered energy before and after retrofitting

be noted that hydropower accounts for almost 100% of the electricity generated in Norway.

Indoor climate

The questionnaires on the indoor environment quality focused on indoor air temperatures, draught, and IAQ. The first survey was conducted before retrofitting in December 2011 (involving 41 pupils); the second after the windows had been replaced in January 2013 (46 pupils) and the third finally after completion of the retrofit in May 2015 (49 pupils). Each survey was done in two classrooms. After retrofitting, the pupils gave a much better evaluation of the indoor climate than before retrofitting. For instance, the share of pupils who perceived draught effects decreased from 31% to 9% after the windows had been replaced.

The indoor air temperatures, carbon dioxide concentrations and air change rates are continuously measured by the building energy management system.

Every three months, the measured characteristics are analysed using diagrams. Besides providing other information, these measurements prove that the carbon dioxide levels do not exceed the limit of 800 ppm.

Costs

The investment costs for the insulation measures, the new and the restored windows, the new heating pipes for the supply of the gym and the heat pump including the geothermal heat pipes amounted to a net total of EUR 1,093,000 or 154 €/m².

Lessons learned

- Usually, electric heat pumps cannot generate heating-water temperatures above 55 °C. The sophisticated concept of this heating system allows generating temperatures of up to 70 °C while still achieving a high seasonal performance factor of the heat pump. This concept is also suited for replacing high-temperature heating systems (e.g. oil-fired boilers).
- The heat pump has one alarm system for five sectors: condenser pressure, motor temperature, frequency converter, control sensor and two pressure switches, which complicates fixing problems.
- Daylight supply of buildings in northern countries should not be reduced by permanent shading devices. Thanks to the solar control glass applied at the southern and western facades, the former wind-sensitive external shading device could be removed. New solar control glass is characterized by low solar factors in combination with significantly higher light transmittances.
- The successful retrofit of Brandengen School was awarded several prizes and met with wide interest especially in the heat-pump solution and the replacement of windows in a historical building facade.

Paul Røland
Manager of Drammen Eiendom KF (Drammen Municipality's Real Estate Department)

“The authorities of Drammen municipality are focused on development of the urban environment, and are among the municipalities taking a national leading role in sustainable building. Participation in various programmes and pilot projects has given opportunities to develop our own expertise and working methods, setting frame conditions to stimulate climate friendly urban development and architecture of high quality. Drammen was appointed runner-up in the Nordic Energy Council Award 2011. By participating in the EU project 'School of the Future' Drammen municipality wants to contribute to raise the level of knowledge concerning retrofitting. Involving Brandengen School as a demonstration building, we are aiming to show that future high performance building levels are possible even in a historical building from 1914.”

3 DOCUMENTATION OF THE DEMONSTRATION BUILDINGS

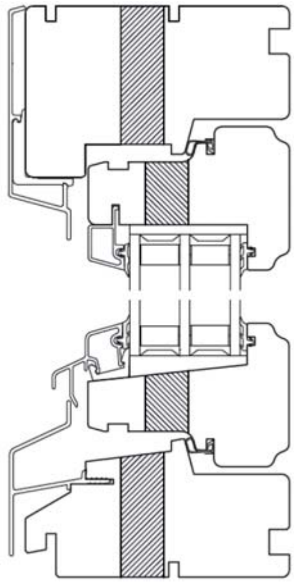
The four demonstration projects are documented on the project's website in different ways:

- Design Report: A report featuring the design and planning phases of the retrofitting projects
- Building Diaries: One building diary for each project illustrates the implementation of the retrofitting measures
- Final Demonstration Building Report: The final report on the completed retrofits summarizes the initial situation, the planning, the implementation and the evaluation.

In addition, the four exemplary case studies are described in the 'School of the Future' Information Tool.

Design Report

The Design Report focuses on the configuration of the buildings prior to retrofitting and on the retrofitting concept. In this context, the report features the building envelope (building construction elements), the heating system, ventilation and lighting, water heating (DHW), the use of renewables and the building management system (BMS) or individual control systems. A separate chapter analyses the influence of the Design Advice and Evaluation Group on planning and evaluation.



Design of the new NorDan passive-house standard windows for Brandengen School (Graphic: NorDan)

Building Diaries

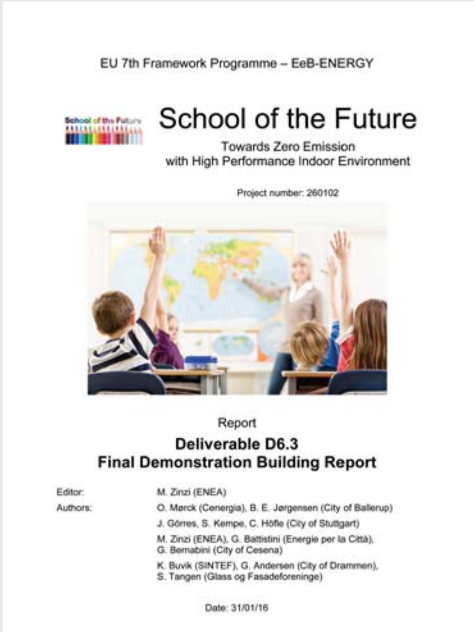
The building diaries contain descriptions and images documenting on-site inspections by the national researcher teams to report on the progress of the construction works and the implementation of key measures. For the Solitude-Gymnasium, for instance, the facade insulation of the main building is presented along with the attic insulation of the building for special classes and airtightness tests before and after refurbishment. Descriptions of the Italian project, Tito Maccio Plauto School, include the thermal insulation of the top storey ceiling, the facade insulation and the installation of the photovoltaic panels. Regarding Hedegaards School, project meetings and on-site inspections concerning facade renovations, PV modules, LED lighting, ventilation and building energy management system are documented. The diary for Brandengen School features the installation of heat pumps and new windows, the thermal insulation of the top storey ceiling and of the ventilation ducts.

Airtightness test at the Solitude-Gymnasium

Mounting the facade insulation at Hedegaards School

Final Demonstration Building Report

Besides covering planning and design, this report also includes the implementation of the retrofitting measures along with an analysis of the measured data relating to energy consumption and indoor comfort, thus evaluating the retrofitting concepts. The individual chapters of the report (each dealing with one school) are completed by a cross-evaluation.



EU 7th Framework Programme – EeB-ENERGY

School of the Future

Towards Zero Emission
with High Performance Indoor Environment

Project number: 260102

Report

Deliverable D6.3
Final Demonstration Building Report

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Date: 31/01/16

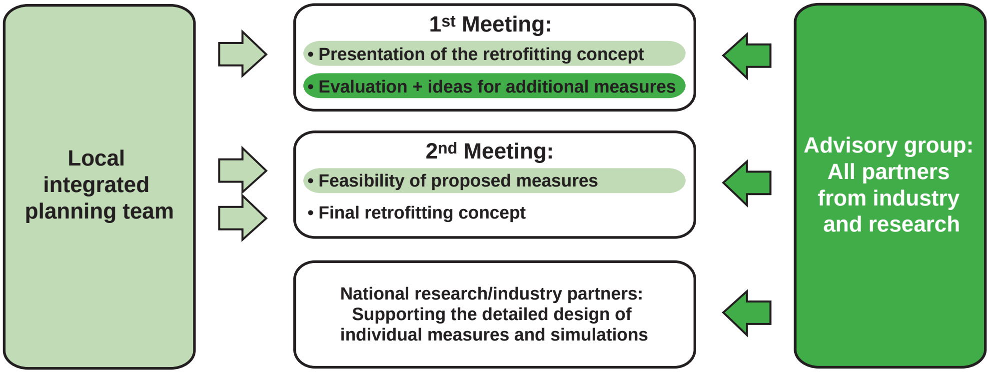
Front page of the Final Demonstration Building Report

4 DESIGN ADIVCE AND EVALUATION GROUP

The international Design Advice and Evaluation Group was established to support the local planning teams of the four renovation projects. This group comprised all partners from industrial enterprises and research institutions involved in the project. During the planning stage, the group met twice at every school. At the first meeting, the local planning teams presented their concepts for the retrofit while the advisory group contributed further ideas for additional energy-efficient retrofitting measures. The proposed measures were then reviewed by the local planning teams and incorporated in their concepts if considered appropriate. During the second meeting, the local planning team would explain why (or why not) the ideas could be included and the final retrofitting concept would be adopted. Among others, the measures given below could be proposed and eventually implemented:

- New light-coloured paint in the classrooms of the Solitude-Gymnasium
- Triple glazing at the Solitude-Gymnasium and triple glazing in a passive-house frame at Brandengen School
- Thermal insulation composite system (ETICS) also at the street front of Tito Maccio Plauto School
- Subdividing the heating in different zones at Tito Maccio Plauto School
- Tests of two LED lighting systems at Hedegaards School
- Building energy management system (BEMS) at Hedegaards School
- 30 cm of loose-fill insulation on the top-storey ceiling of Brandengen School

In addition, the national partners from the advisory group gave support regarding the detailed planning of individual measures and by providing energy simulations.



Cooperation of the local planning teams and the international advisory group

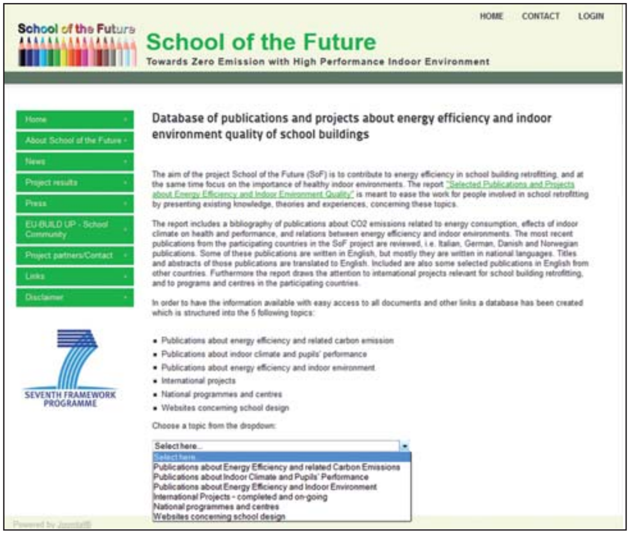
5 DATABASE ON SCHOOL PROJECTS AND SCHOOL PROGRAMMES

The 'School of the Future' project aimed at achieving substantial reductions in the energy consumption of the four schools through extensive retrofitting while improving the level of indoor comfort. As an introduction to the project (but also intended for use in other similar retrofit projects), a bibliography of publications related to national and international projects and schemes was compiled, featuring recent publications dealing with savings in energy consumption, carbon dioxide emissions, effects on indoor climate, health and performance, and relations between energy efficiency and indoor environments.

The results of the extensive literature survey are available on the website, both as a report and as a database. It is distinguished between:

- Publications about energy efficiency and related carbon emissions
- Publications about indoor climate and pupils' performance
- Publications about energy efficiency and indoor environment
- International projects
- National programmes and centres
- Websites concerning school design

The names of the authors, an English summary and the link to the respective source are provided for all sources.



Screenshots of the database on the project website

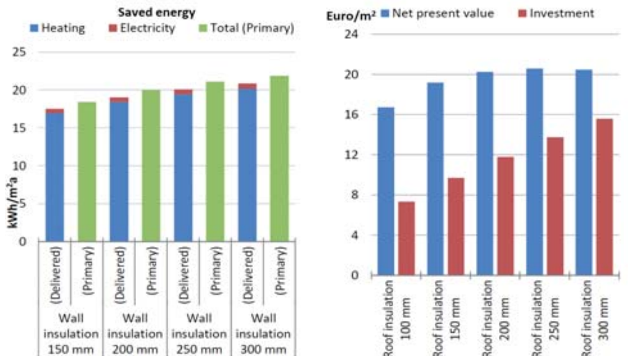
6 TECHNOLOGY SCREENING

The technology screening started with a compilation of the most important retrofitting measures concerning the building envelope and the building services systems. In a following step, these measures were evaluated with regard to energy, cost-effectiveness and indoor comfort, for up to three typologies of school buildings. For this task, the research partners adapted the initial condition of the schools, the efficiency of the retrofitting measures, the investment costs and the energy prices to the respective country. The calculations were carried out using the Danish calculation tool 'ASCOT', which is based on CEN standards. The 'ASCOT Light' version is also applied for the training of pupils.

The results of the calculations have been summarized in four national reports for Germany, Italy, Denmark and Norway. The reports cover the following technologies, mostly in several levels of efficiency:

- Roof insulation
- Floor insulation towards basement / crawl space / cellar
- Thermal insulation of external walls
- Window replacement
- Solar control glass
- Building energy management system (BEMS)
- Ventilation systems
- Lighting systems
- Photovoltaics
- Solar thermal water heating (DHW) and
- Heat generation systems like gas-fired condensing boilers, connection to district heat, electric heat pumps.

In addition, a package of the most appropriate measures was evaluated. The results are presented as saved energy (delivered and primary), achieved reduction of carbon dioxide emissions and investment costs. Also given are the net present value and the simple payback time compared to the lifespan of the respective measure. Regarding indoor comfort, the diagrams show the inner surface temperatures in winter and summer, the draught air speed, the radiant temperature, the dry-bulb temperature in summer and the carbon dioxide content of the air in winter and summer. The results of the screenings also provided basic data for the retrofit guidelines and the information tool. On account of the different national boundary conditions (like the defined initial situations, the climate or the prices) the measures are only partially comparable across the countries.



Saved energy, investment costs and net present value for insulating measures at the external wall of a Danish school

7 RETROFIT GUIDELINES

Based on experience gained from the school refurbishment projects within the 'School of the Future' scheme (including insights from further national and international school projects), the project team prepared four guidelines for school retrofitting projects (written in English), which are focused on the following issues:

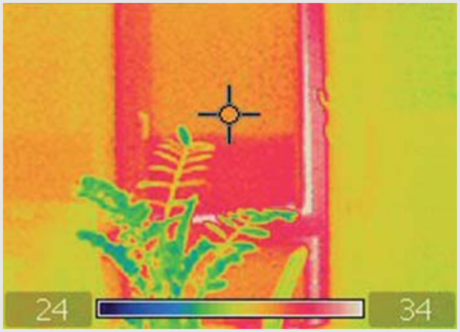
- Indoor environmental quality in schools
- Retrofit of building construction elements
- Retrofit of building services systems
- Solution sets for zero emission / zero energy schools

Retrofit guidelines

The guidelines are intended to support decision makers and planners in targeting, planning and implementing ambitious school retrofitting projects. The following requirements, measures and technologies are discussed in detail:

Indoor environment quality in schools

The section on 'thermal indoor climate' describes the thermal comfort requirements in winter and summer conditions. These include the operative temperatures, and in winter the prevention of radiation asymmetries due to cold surfaces and the avoidance of draught effects. In summer, heat gains must be avoided whenever possible.



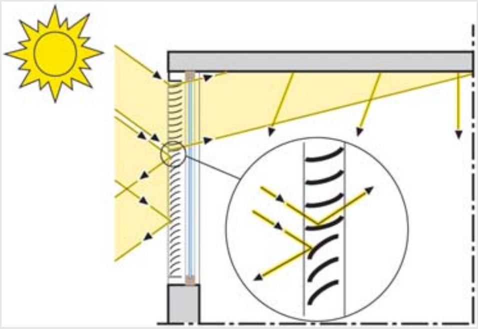
Thermographic image of a meeting room - inside view on facade

In addition, strategies for passive cooling are presented, like increased ventilation, night ventilation, and the use of ground ducts for pre-cooling supply air. Further, various control systems for heating and cooling systems are discussed.

The chapter on indoor air quality starts with a compilation of the requirements relating to organic chemicals, to the prevention of emissions, to the carbon dioxide level and the hygienic ventilation rate. Later on, the chapter deals with ventilation strategies like natural ventilation, mechanical ventilation and hybrid ventilation, concluding with a presentation of various ventilation control options suited for school buildings.

Having treated the comfort requirements, the section on 'Lighting conditions' proposes strategies for the use of daylight, energy-saving technologies for artificial lighting and various types of lighting control systems. Besides addressing requirements like protection against external noise and structural noise control measures, the chapter on acoustics also includes information on noise emission from technical building systems. In addition, requirements for high-quality classroom acoustics and strategies for achieving good room acoustical properties are explained.

The retrofitting technologies are divided into non-transparent (opaque) building components and transparent components. Regarding the opaque parts, it is first discussed whether the additional insulation layer should be applied internally or externally, which materials are available and where vapour barriers should be used. In terms of wall and roof insulation, it is distinguished between light-weight and solid constructions. Avoiding air leakages and minimising thermal bridges are other major topics addressed.



Blinds with daylight redirection function

Retrofit of building construction elements

The retrofit guideline for building construction elements introduces the reader to planning and design strategies for energy-efficient buildings, recommending possible targets, early-stage definitions and integral planning. This guideline deals with important steps in planning, the consideration of environmental influences, tendering and contracting, even mentioning motivation and control of the subcontractors involved.

In the section on transparent building components the energy impacts of windows are specified. Information is given on available frames and spacers and on the impact of windows on daylighting and indoor thermal comfort. The section on glazing covers solar control glass, low-E glazing and electrochromic glazing, including light wedges and retrofit solutions featuring double skin facades. The problem of external condensation is addressed and there is a paragraph on heat loss as a function of wind speed and temperature. The chapter on solar shading systems describes the available technologies and the interaction of shading devices with daylight.

Further chapters deal with the influence of interior building elements on thermal comfort, the option of using phase change materials and the impact on acoustics. At the end of the guideline, the results of the technology screenings are summarized (for each technology covered) with regard to energy performance, investment costs and life cycle costs for the participating countries Germany, Italy, Denmark and Norway.

Retrofit of building services systems

The guideline for energy retrofitting of the building services systems in school buildings features the five main technologies given below:

- Condensing boilers
- Heat pumps (air-to-water / ground-to-water / water-to-water and air-to-air)
- Ventilation systems (mechanical ventilation / hybrid ventilation)
- Lighting systems (incandescent lamps, fluorescent lamps, discharge lamps, LED)
- Photovoltaics (different systems and building integration)

The guideline starts with an introduction of each technology, followed by a description of its functionality. Subsequently, the respective advantages and disadvantages are compiled and the technology's market penetration is analysed. The results of the technology screenings regarding energy savings in school buildings are summarized, and the cost-efficiency for each country is given. Applications in the scope of the 'School of the Future' demonstration projects are presented, conclusions are drawn and related literature is given.

Ventilation ducts at Tito Maccio Plauto School

Solution sets for zero emission / zero energy schools

The first part of the guideline for the development of zero emission / zero energy and even energy-surplus schools explains the three different levels of energy performance. In the following part, the strategies and technologies that are required to achieve these levels are specified for the categories of building design, building envelope, building services, equipment used in school buildings and energy generation from renewables, i. e. photovoltaics and wind turbines. Another issue addressed is the importance of presenting and discussing the completed projects in school lessons. Subsequently, two types of exemplary case studies are presented in detail:

- Zero emission/ zero energy schools or energy surplus schools
- Schools on their way towards becoming zero energy schools

For the second group, calculations are done to determine which size a photovoltaic array must have in order to make the schools zero-energy buildings (i.e. achieve zero energy standard in the total annual energy balance). This section also comprises the 'School of the Future' demonstration projects. In conclusion, the most commonly used solution sets for zero energy and energy surplus schools are identified, which are then presented as solution statements.

All retrofit guidelines include numerous examples of measures that were applied in the demonstration projects within the 'School of the Future' project.

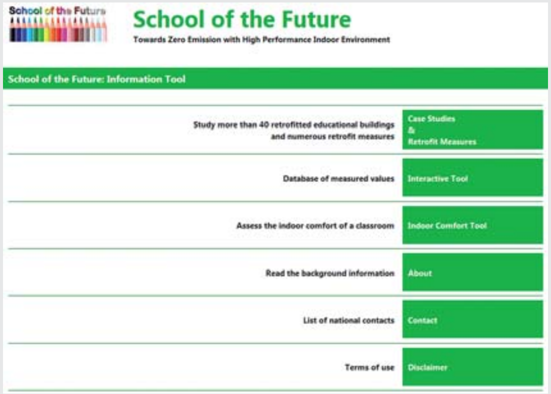
Energy surplus school 'François Mitterrand' in Montpellier

Energy surplus school at Hohen Neuendorf

8 INFORMATION TOOL

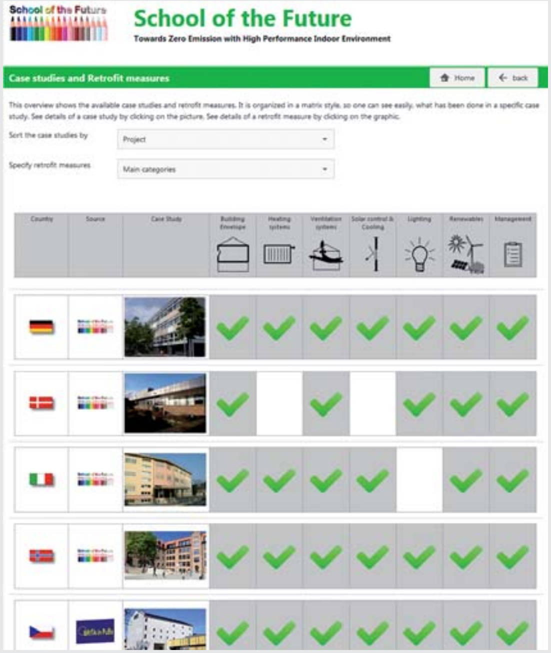
This internet-based tool provides decision makers and technical staff of public authorities with a wide range of useful information for the energy-efficient renovation of school buildings.

- Case studies presenting successful energy retrofitting solutions for educational buildings
- Explanatory notes relating to renovation measures
- National benchmarks for the comparison of characteristic consumption values
- Indoor comfort parameters for classrooms



Information tool menu

Besides providing purely informative parts (case studies and retrofitting measures) the tool also comprises interactive resources, which enable the user to compare self-measured characteristic values to mean values and requirements.



Case studies and retrofitting technologies are presented in a matrix

Case studies

More than 40 retrofitted educational buildings (mainly schools) are presented; each project is described in detail according to a given common structure. This matrix includes general data, the climate of the location, the building typology, the building‘s condition before retrofitting, the retrofitting concept, the energy consumption measured after retrofitting, evaluations by users, investment costs, experience made so far and reports for further reading.

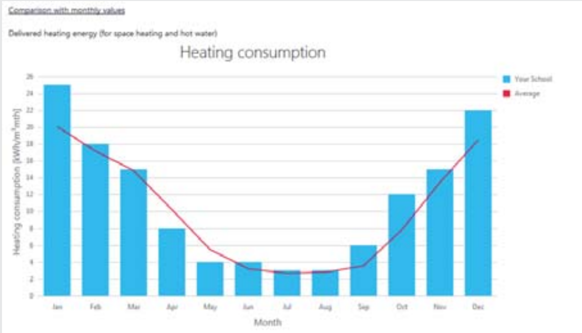
The featured projects are part of the 'School of the Future' project, of the EU project 'BRITA in PuBs' (Bringing Retrofit Innovation to Application in Public Buildings) and of Annex 36 'Retrofitting in Educational Buildings', conducted by the International Energy Agency (IEA) in the sector of 'Energy Conservation in Buildings and Communities'.

Renovation measures

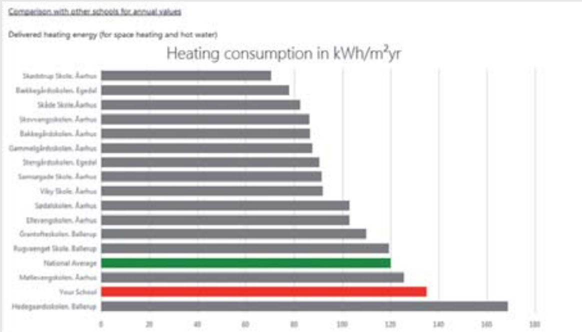
Information is given on renovation measures of the building envelope, the heating system, the ventilation system, solar shading devices and lighting installations, further on the use of renewables and on non-technological measures. This includes information about individual technologies as well as innovations in the relevant area. The technology screening results supplement the explanations and illustrate the volume of possible energy savings along with the cost efficiency of the measures.

Comparison of consuption values

The interactive tool enables the user to enter (annually or monthly) measured data on the heating energy consumption (space heating and water heating), on the consumption of electricity (ventilation, lighting and equipment) and on the water consumption of a specified school, which may then be compared to national benchmarks. Bar diagrams point out whether the user‘s ‚own‘ school uses more or less energy than other schools or compare the energy use to the mean value.



Comparison of the monthly consumption of heating energy



Comparison of the annual consumption of heating energy

Indoor comfort in the classroom

This feature allows comparing measured indoor-air temperatures and characteristic values of carbon dioxide (CO_2) levels with the national requirements and acceptable ranges. The relevant measured data can be determined by a working group, for instance. In a graphical representation, the tool will then compare the data to the comfort requirements.

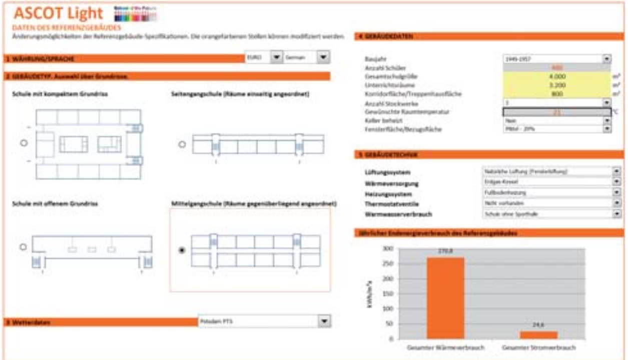
9 TRAINING OF PUPILS, TEACHERS AND TECHNICAL SERVICE PERSONNEL

To enhance the efficiency of the implemented renovation measures in the four demonstration projects and in further schools by raising user awareness and teaching correct user behaviour, tailored training materials for teachers, pupils and technical staff were developed (available in Danish, Norwegian, Italian, German, and English). The presentations describe the retrofit concepts and the specific implemented measures, give background information relating to saving energy in buildings and explain the influence of user behaviour on energy consumption and indoor comfort.

For this purpose, teachers are provided with teaching material for use in school lessons. The pupils learn how they can contribute to the successful retrofit of their school, and what they can do to further improve the indoor air quality and indoor air temperatures. Regarding the technical personnel, the focus is on enabling the staff to fully understand the new technologies and building control systems to ensure optimal use and maintenance.

In addition, a simplified version of the energy performance calculation tool 'ASCOT' was developed for the use in school lectures in the four languages of the 'School of the Future' partners. Based on typical examples of school building configurations, the young students will be able to evaluate different renovation measures in terms of energy performance and cost efficiency.

Having been tested at the four schools involved in the project, the training material was further improved and is now available for download at the project's website.



German version of the training tool 'ASCOT Light' for the simple assessment of renovation measures at school buildings

Training lesson at Hedegaards School

10 CONFERENCES, PUBLICATIONS, AWARDS

The project partners presented the project results at several distinguished national and international conferences (e.g. 'World Sustainable Energy Days', 'Nordic Passive House Conference', 'Central Europe towards Sustainable Buildings', 'Indoor Air Conference' and even at the 'ASHRAE Conference' in the USA). At two major conferences the partners organised entire conference sessions, presenting contributions related to 'School of the Future' and similar projects: at the 'International Conference on Solar Heating and Cooling 2013' and the 'International Conference on Building Physics for a Sustainable Built Environment 2015'.

Publications in specialized journals and conference proceedings, press releases, leaflets and videos completed the dissemination of project results. The project was presented in a broadcast by the German radio station Deutschlandradio including a statement by EU Commissioner Guenther Oettinger.

The demonstration projects won several awards: Brandengen School, for example, was awarded the 2014 Enova Prize 'Det Grønne Gullet' and received a prize awarded by the 'Local Climate Initiative 2012' of the association of Norwegian communities. Tito Maccio Plauto School was cited among top ten most significant examples of Italian Green Schools by Italian newspaper Corriere della Sera. Both the municipality of Cesena and Plauto School were presented in the scope of an Italian TV series. Visitors from all over the world (from China and Poland, for instance) came to see the renovated school buildings.

Award cermony of 'Det Grønne Gullet' prize (Photograph: Enova)

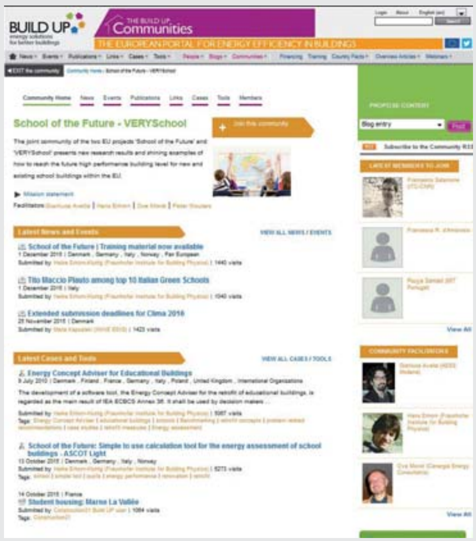
11 WEBSITE, PLATFORM FOR DISCUSSIONS, LINKS

All related results have been compiled on the project's website www.school-of-the-future.eu: the database on projects and programmes for energy-efficient schools, the technology screening reports, the retrofit guidelines, the information tool, the reports on planning and implementation of the demonstration projects, the sets of training material for the users and all publications.

At BUILD UP (www.buildup.eu), the European Commission's knowledge portal on energy-efficient buildings, the 'School of the Future' partners are moderating a discussion platform. This platform provides a forum for collecting and presenting news, events, case studies, calculation tools, publications and links related to energy-efficient school buildings. The outcome of 'School of the Future' can be retrieved there, just like many other results that were derived from numerous other national and international projects.

The project was conducted in direct communication with other national and international projects, to name but a few:

- EU IEE ZEMedS – Zero Energy Mediterranean Schools (www.zemeds.eu): The coordinators acted as technical advisers for the ZEMedS project
- EU CIP project VERYSchool (www.veryschool.eu): joint moderation of the BUILD UP discussion platform
- EU IEE project RenewSchool (www.renew-school.eu): Exchange on retrofitting technologies and costs
- BMWi-Forschungsschwerpunkt EnEff:Schule (www.eneff-schule.de): 'School of the Future' was presented several times at the national school congress organised by the German Research Initiative
- International Non-Profit Industrial association E2B (www.e2b-ei.eu): Input for presentations and annual updates of the project brochure
- The Research Centre on Zero Emission Buildings ZEB (www.zeb.no): Exchange with the coordinators of the Norwegian Research Centre



School of the Future discussion platform at www.buildup.eu

12 THE PROJECT PARTNERS

Fraunhofer IBP

ENEA
ENTE PER LE NUOVE TECNOLOGIE, L'ENERGIA E L'AMBIENTE

CENERGIA

STATENS BYGGEFORSKNINGSINSTITUT
AALBORG UNIVERSITET KØBENHAVN

SINTEF

LANDES-
HAUPTSTADT
STUTTGART

BALLERUP

DRAMMEN
KOMMUNE

aldes
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ISOVER

Glass og Fasadeforeningen

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