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Energy upgrading of a historical school building in cold climate

Karin Buvik[a,]*, Geir Andersen[b], Sverre Tangen[c]

[a]SINTEF Byggforsk, Alfred Getz' vei 3, 7034 Trondheim, Norway
[b]Drammen Eiendom KF, Ilebergveien 21, 3011 Drammen kommune, Norway
[c]Glass og Fasadeforeningen, Fridtjof Nansens vei 19, 0369 Oslo, Norway

Abstract

Brandengen Primary School in Drammen in Norway is a demonstration building within an EU 7FP project, running from 2011 to 2016. The aim of the EU project is to pave the way for future high performance building levels when retrofitting school buildings, i.e. achieving low energy consumption and good indoor climate conditions. Brandengen School's facilities consist of three buildings in bricks, linked together with arcades. The buildings are of historical value and Drammen municipality emphasize to restore the façades to be close to the original historic look.

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Keywords: school building; retrofitting; energy efficiency; indoor comfort; EU 7FP

1. Introduction

Considerable reduction of energy consumption, utilization of renewable energy sources, and improvement of the indoor environment were focus areas when retrofitting Brandengen School.

The school's facilities consist of three buildings in bricks; the main building, the activity building for gym and arts and crafts, and a small building for the school's leisure time arrangement. The buildings are linked together with arcades. The total floor area is somewhat larger than 7000 m^2. The school opened in 1914, and the buildings, designed by a famous Norwegian architect, are of historical value. Drammen municipality emphasize to restore the façades to be close to the original historic look, in accordance with request from the conservation authorities.

* Corresponding author. Tel.: +47-92080146
E-mail address: Karin.J.Buvik@sintef.no

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2. Building characteristics in 2011, before retrofitting

Figure 1 shows the building at different ages. The following list shows the building characteristics in 2011.

- **Building envelope**: The exterior walls are made of brick, without insulation between the two sidewalls. The windows were mainly from the 1960s. Neither the mansard roof of wooden construction, nor the concrete basement walls, had additional insulation. As the drainage was not sufficient, moisture had penetrated parts of the walls and caused plaster cracking on the inside.
- **Space heating**: In the two largest buildings the heating system is water based, with radiators controlled by thermostats. The energy carrier was oil. The small building has electric heaters.
- **Ventilation**: In 2003 balanced ventilation systems, with variable air volume and heat recovery of outlet air, were installed in the main building and the small building for leisure time arrangement. The activity building had an old ventilation system with an air supply aggregate and no heat recovery.
- **Electric lighting**: The lighting system was also modernised in 2003, with T5 low energy lighting fixtures and presence detectors in all classrooms, larger occupied zones and corridors.
- **Sanitary hot water**: In the two largest buildings the tap water was heated through double jacketed hot water boilers, based on the heating system (oil) with supplementary electrical coils for summer operation. In the small building electrical coils heated the tap water.
- **Management**: The heating and ventilation systems are monitored and controlled mainly by the municipality's energy management central.

Figure 1 (a): South façade of the main building. Photo from the old days showing the original windows from 1914. Architect Arnstein Arneberg. (b): South façade of the main building showing windows from the 60's and 70's. Note the shading devices. Photo before retrofitting

3. Retrofitting objectives

Targets set for the retrofitting project:

- Reduction of delivered energy by 67 %.
- Improvement of indoor thermal conditions; avoiding cold drafts in winter and overheating in summer.
- Restoration of the facades' aesthetics to be close to the original historic look.

4. Upgrading measures

In order to reduce the energy consumption and related CO_2 emission the main measures were to reduce heating and cooling demand, and to utilize renewable energy sources.

To decrease energy consumption and increase indoor comfort, the building envelope was retrofitted, including additional insulation in the attic, mansard walls and basement walls, and replacement of windows.

The oil fuel was replaced by renewable, geothermal energy utilized by a heat pump. The old oil burner is transformed to a bio-oil burner for peak loads.

The following chapters refer to the additional insulation, the windows and the utilization of renewable energy.

5. Additional insulation

The wall between the mansard windows, and the floor in the attic, got additional insulation of 30 cm mineral wool. See figure 2. Vents were installed to provide outdoor air to flow into the attic; to remove moist and to cool the attic and thus, together with the additional insulation, prevent icicles in winter.

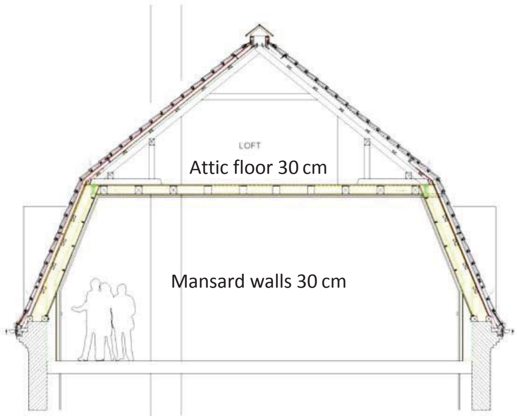

Figure 2: Section showing additional insulation of mineral wool in the attic

In 2001–2003 a ventilation system was installed and ventilation ducts were placed in the attic. These ducts were not so well insulated. In the autumn 2011 a layer of 10 cm additional insulation were wrapped around the ducts. See figure 3.

Figure 3 (a): Attic with ventilation ducts before additional insulation. (b): Attic with ducts after insulation. Photo: J. Seehusen, May 2012

New drainage along the south and east basement walls was necessary to avoid moisture in the basement. The drainage ditches serve several tasks; revealing the basement walls under the ground for external insulation, filled with extruded concrete gravels the ditches provide additional insulation of the basement, and last but not least, the ditches hold collector pipes for the heat pump. See figure 4.

New drainage was necessary to maintain the building, and insulation allowed for a better use of the basement areas. The drainage ditches' primary function is to keep the basement dry. However; the ditches contribute to energy savings.

Figure 4: Combined ditch for drainage, exterior insulation and collector pipes

6. Windows

6.1. Replacement of windows from the 60's and 70's

The windows have been replaced at different times since 1965. As the windows have caused high heating costs and not contributed to an optimal indoor climate, the municipality decided to replace all windows installed after 1965, aiming for new high performance windows, which also pay respect to the historic aspects of the buildings' aesthetics.

As indoor temperatures were too high before retrofitting, due to solar gain, solar control glass was chosen for the south and west façades to prevent demand for cooling. As a rule of thumb permanent structural shading should be avoided in northern latitudes. But as external, movable shading is very undesirable in school buildings, due to tear and wear, solar control glass was considered to be an adequate alternative.

«Passive house» windows are now installed. As these windows substantially decrease heat losses (U-value ~ 0.8 W/m^{2}K), they contribute to both better indoor thermal comfort and reduced energy bill. Thanks to the glazing's low solar energy transmittance (g-value = 27 % on south and west façades), the exterior sunscreen devices could be removed from the façades, in order to restore the façades' aesthetic close to that of the original historic look.

Figure 5 (a): South façade before retrofitting. Photo: G. Andersen, April 211. (b): South façade with new windows and roof cladding. Photo: K. Buvik, April 2013. A-form architects / Nils Herland

6.2. Refurbishment of original windows

Existing original, arched windows have been refurbished. Most of the original windows are located along corridors, where the indoor temperature requirements are not as strict as in classrooms. Extra internal sashes with low E-glasses are placed in the original frames.

7. Increased indoor comfort

Reducing heat leakage from the building envelope has contributed to a higher level of thermal comfort for users. New windows with solar glazing on south and west façades have reduced solar heating load and glare.

Indoor climate is continuously monitored by the building energy management system (BEMS). Examples of print from BEMS are shown in figure 6. A survey on indoor thermal conditions in winter is carried out, and the feedback from users is positive.

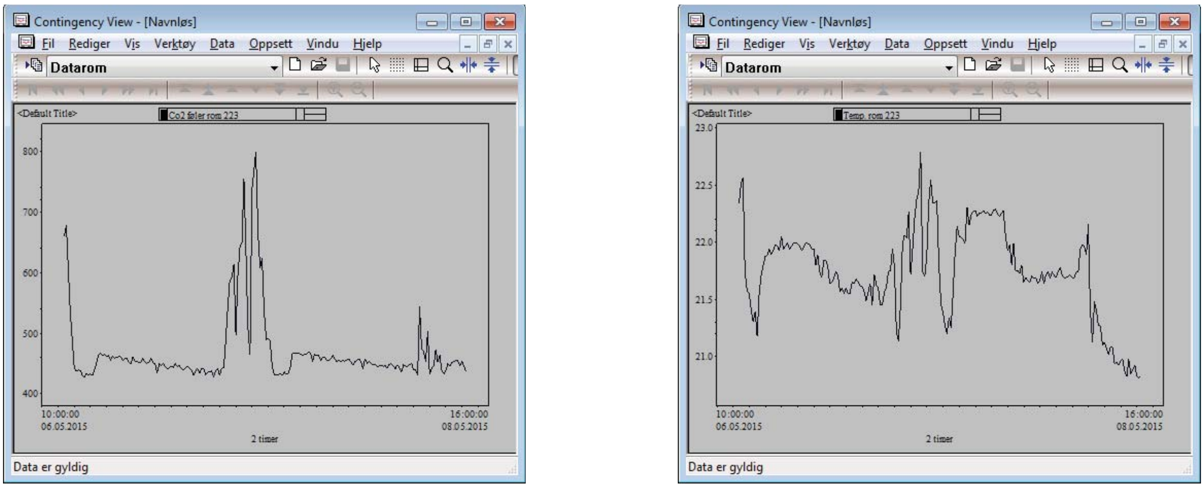

Figure 6 (a): Print from BEMS, covering two days, showing that the CO_2 level is not exceeding 800 ppm. (b): Print from BEMS showing that the temperature level is acceptable. The prints refer to two days in May

8. Utilization of renewable energy

Oil based heating systems are being phased out in Norway. When a building is located outside the network of the district heating system, the strategy of Drammen Municipality is to install local heat pumps, often based on ground heat sources.

The original heating system in Brandengen School was based on oil burner in combination with electric boiler. The rebuilt system use heat pump connected to ground source energy wells. Electric boiler is back up.

The heat pump is connected to the existing pipelines in the main building. New pipelines were built to connect the activity building (gym) to the heat pump. All previous burning of fossil fuel is replaced by geothermal heat. The small building, for leisure time arrangement, which was not connected to the oil heating system, has kept the thermostatically controlled electric panel heaters, based on hydro power.

The original central heating system was designed as a «high temperature» system requiring 80°C as supply temperature to provide heat on «coldest day». The available heat pumps in market were not suitable for this high temperature level. Temperature level in wells varies between 0 and 8°C. Temperature of leaving hot water from heat pump varies depending on heat demand and ambient temperature; from about 40 to 70°C. COP (coefficient of performance) of the heat pump is strongly dependent on temperature in energy wells and required supply temperature in the heating circuit. In most of the heating season the required supply temperature for Brandengen School is 60°C or higher. Traditional heat pump design would lead to rather low COP. It was necessary to design a new concept for heat pumps replacing oil burners in old 80/60°C system. The building owner worked out a new heat pump design in cooperation with Thermoconsult (consulting company in heat pumps and refrigeration) [1].

19 energy wells for collectors were drilled in the schoolyard, each about 250 m deep. The heat pump use refrigerant R134a. Compressors are high performance semi hermetic piston type with water chilled tops, speed control and step control. Two identical refrigerant circuits are provided, each with two compressors, evaporator and condenser of extraordinary heat exchanger surface. Water flows are connected in series on the hot side, which reduces temperature level in first condenser, increasing COP for this heat pump circuit.

A liquid sub cooler is installed in each refrigerant circuit. This is a heat exchanger where return hot water is able to cool down refrigerant downstream from condenser. Sub cooling of refrigerant increase efficiency of heat pump and improve COP.

A design based on high performance piston compressors with speed control, condensers in series, liquid sub-cooler and ample designed heat exchangers all contribute to improved COP. Heating capacity for the heat pump is 200 kW at 55°C leaving hot water temperature. After tuning the heat pump the efficiency is monitored to 3.1 COP.

Several manufacturers are now producing this type of heat pump, and it has become a «standard» in similar projects in Norway.

9. Energy need

9.1. Calculated energy need

Table 1. Calculated net energy need before and after retrofitting, excl. equipment

Calculated net energy need in kWh/m^2a	Before retrofitting	After retrofitting
Heating need for space heating and tap water. From fossil fuel heating to ground source heat pump	181	94
Electricity consumption for ventilation and lighting	27	26
RES deduction	0	-52
Calculated net energy need for building operation	208	68

9.2. Preliminary measurements

After tuning the heat pump measurements show that the energy performance goal is achievable, i.e. reduction of delivered energy by 67 %.

10. More information

Website: http://www.school-of-the-future.eu/ The reference can be downloaded from the website

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