Danish Building Research Institute (SBi), Aalborg University

December 2012

CO_2OL BRICKS

Upgrading the energy performance at Kavalergården

Part-financed by the European Union (European Regional Development Fund and European Neighbourhood and Partnership Instrument)

PROJECT

Co_2ol Bricks
Upgrading the energy performance at Kavalergården

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Project number: 201416
Version 1
Version: 1
Document no.: 125593739
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CONTENTS

CONTENTS

1 SUMMARY

The report describes the Kavalergården complex worthy of preservation and how a comprehensive energy upgrade and refurbishment of the three buildings was carried out. Kavalergården was built in 1877 as a part of the listed Bernstorff Palace just north of Copenhagen, Denmark.

Kavalergården was worn-out before the energy upgrade and refurbishment was decided. As a part of the Danish Agency for Palaces and Cultural Properties strategy for energy savings the needed refurbishment was launched together with an energy upgrade of the buildings. The energy refurbishment includes, among other things, new roofs with extra insulation, new low energy skylights, insulation of sloped walls and attic floors, storm windows with low-e coated glazing, replacement of outer doors and low energy lighting systems.

The expected space heat savings achieved by the energy upgrade and refurbishment were estimated to a total of 57 000 kWh/year equal to approximately 22 % of the space heat consumption. Measurements of the heat consumption before and approximately one year after the energy upgrade and refurbishment shows a decrease of 35 600 kWh/year equal to approximately 14 % or only 62 % of the expected heat savings.

This must be verified by measurements during the years to come and probably analysis of the reasons to the disappointing results.

2 INTRODUCTION

This report presents an energy upgrade of the building complex Kavalergården. The building complex was constructed with solid brick walls and foundation supposed to be granite blocks. Kavalergården which is worthy of preservation was built in 1877 and is part of the Bernstorff Palace located just north of Copenhagen, Denmark. The present energy upgrade was carried out in 2011. The building complex, Kavalergården, consists of three buildings which today are used as a hotel, office hotel and conference centre.

This report demonstrates primarily measures for the improvement of the thermal insulation. The energy upgrade of Kavalergården is a good example of best-practise energy upgrade of old preserved buildings using state-of-the-art measures to improve the energy performance.

The owner of Bernstorff Palace is the Danish Agency for Palaces and Cultural Properties. Creo Arkitekter A/S and NIRAS A/S were project architect and consulting engineers respectively. Creo Arkitekter conducted supervision and construction management in cooperation with NIRAS. The construction work implementing measures to upgrade the energy performance of the complex was carried out from April 2011 until end of August 2011.

It has been suggested to monitor the indoor humidity and temperature in rooms with internal insulation, but has not been agreed with the tenants so far.

3 DESCRIPTION OF KAVALERGÅRDEN

3.1 History

Bernstorff Palace was designed by the French architect Nicolas-Henri Jardin and built by King Frederik V's Minister of Foreign Affairs Johan Hartvig Ernst Bernstorff. In 1765 the construction of Bernstorff Palace as a summer residence was completed. It is situated in Jægersborg, north of Copenhagen (capital of Denmark).

King Christian VIII acquired the palace in 1845. He was known as an art connoisseur and was interested in renovating the palace. He managed to have thorough repairs, rebuilding and new buildings were added although he already died in 1848.

In 1854, the palace was placed at the disposal of Crown Prince Christian IX of Glücksborg as a summer residence. Different members of the royal family used the palace as their summer residence during the following years. When the King and his family stayed at the palace there was a need to accommodate e.g. the Life Guards. Kavalergården was built for that purpose in 1895 after drawings by the Danish architect Ferdinand Mehldal.

In 1939, the Ministry of the Interior placed the palace at the disposal of the State Civil Air Defence, later the Civil Defence Corps, for use as a military academy on 12 August 1939.

The last chapter of the palace's history for the present was written on February the 1st 2009 when Gitte Jensen and Kirsten Nielsen signed a lease with the Palaces and Properties Agency to run Bernstorff Palace and Kavalergården as a hotel and conference centre. It opened in May 2009.

Photo 1. Bernstorff Palace. Kavalergården is located close by in the surrounding park.

3.2 Site plan

Figure 1 shows a plan of Bernstorff Palace and garden:

1. Bernstorff Palace
2. Kavalergården
3. Swedish Villa (classic example of Swedish wooden house building)
4. Memorial for A. P. Bernstorff

The numbers 5 to 14 are other buildings and sights of Bernstorff Palace and garden (not important in the context of this report).

Figure 1. Bernstorff Palace, garden and Kavalergården.

The Kavalergården complex consists of 3 main buildings (see Figure 2):

- The Kavaler building (to the south)
- The Infirmary building (to the east)
- The Stable building (to the north)

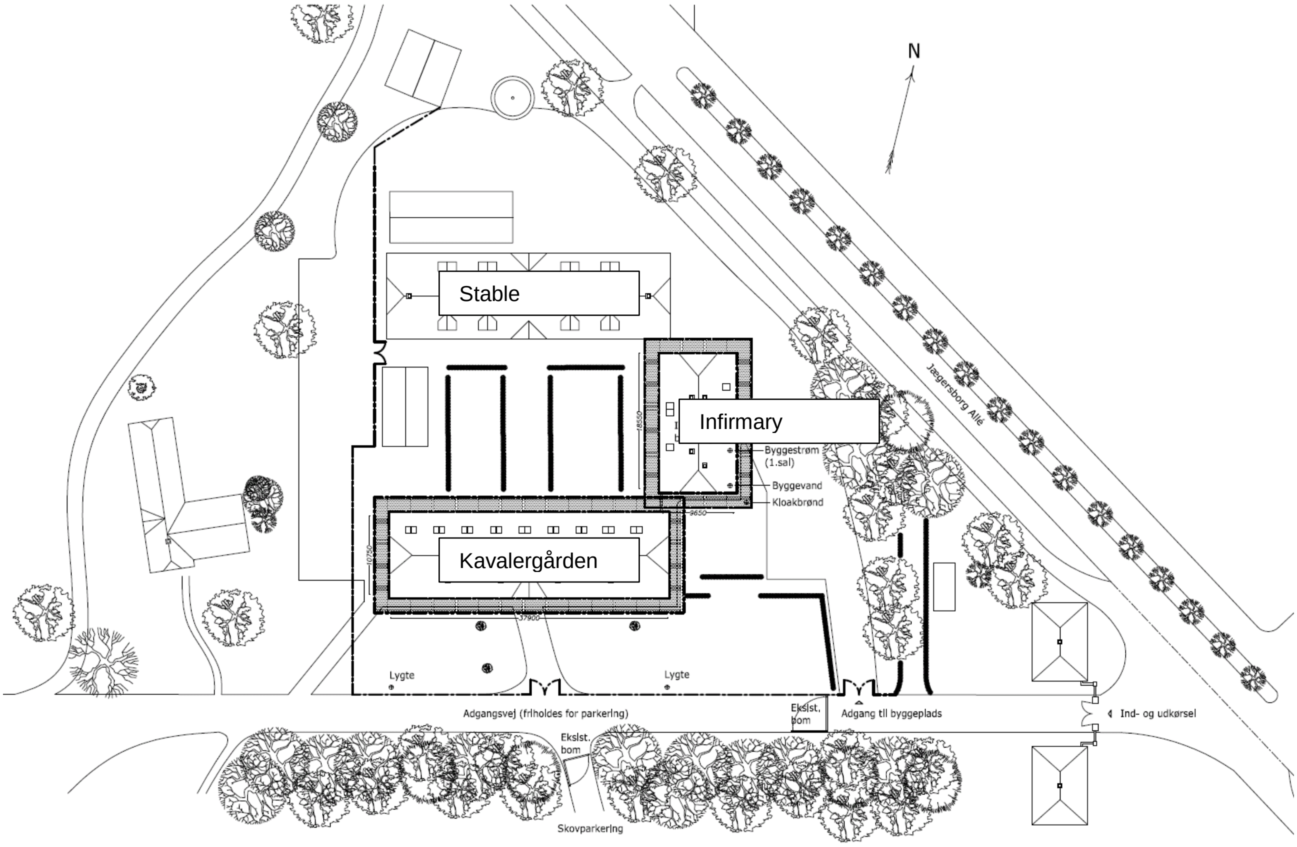


Figure 2. Site plan of Kavalergården (building site plan from refurbishment 2011), indicating scaffolding on two buildings.

Table 1 shows the distribution of useful, heated and unheated areas for the three buildings. All buildings were completed in 1877. The total useful area is 2 276 m^2 of which 1 780 m^2 is heated. The unheated areas are depot/garages in the Kavaler building, depot and utility room in the Infirmary building and the whole attic in the Stable building.

Table 1. Area distribution (m^2).

Building name	Kavaler	Infirmary	Stable	Total
Floor numbers (excluding attic)	2	2	1	
Total useful area (including attic)	1 100	493	683	2 276
Heated floor area	922	460	398	1 780
Unheated area	178	33	285	496

3.3 Facades

Figure 3 shows the facades of each of the 3 buildings. Facades to the left are facing the courtyard. A courtyard photo of the Kavaler building is shown in Photo 2 showing badly worn woodwork, e.g. gates, half-timbering and windows.

Figure 3: Renovated facades of the 3 buildings – Kavaler (top), Infirmary (middle) and Stable (bottom). Facades to the left are facing the courtyard.

Photo 2. Facade of the Kavaler building before refurbishment.

Photo 3 shows photos of the two main buildings before and after refurbishment. All woodwork was painted and ground floor espaliers were removed.

Photo 3. Kavaler building (left) and Infirmary building (right) – before and after refurbishment.

3.4 Building envelope constructions and installations

Kavalergården was built in 1895 and designed in a traditional architectural building style for that period.

Photo 4. Picture of Kavalergården showing the facades, windows and roof constructions

3.4.1 Foundation

The foundations and mounting base were built of solid brickwork. Probably placed on granite blocks.

Photo 5. Pictures of Kavalergården showing the outer walls and foundation.

3.4.2 *Ground deck*

There are no information on the construction of the ground deck but it was probably paved with cobblestones under the timber beam floor.

3.4.3 *Roof*

The roof on the three buildings are double pitched roofs with slate covering on collar beam constructions. See Photo 4. The attics are unused and unheated.

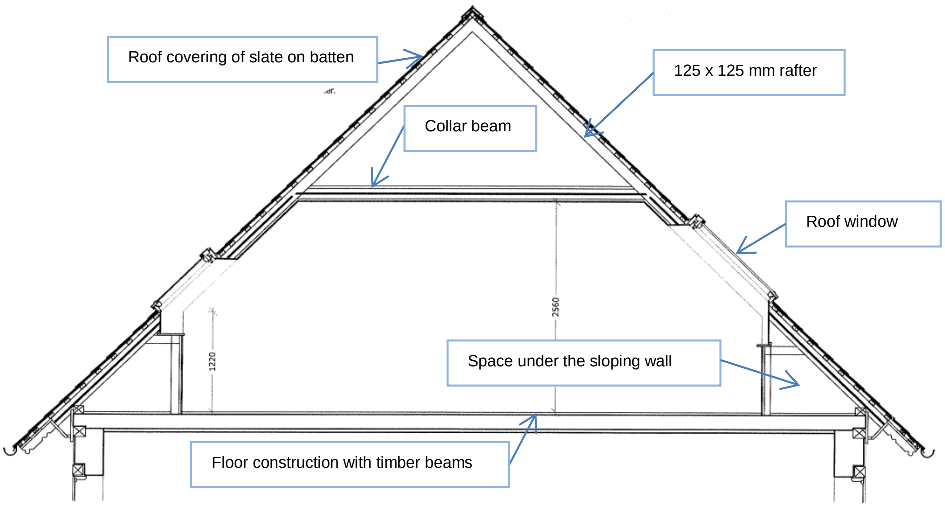


Figure 4. Cross section of attic before the refurbishment. Collar beam, roof windows and space under the sloping wall and a floor construction made of timber beams. Roof covering of slate on batten. 125 x 125 mm rafter with laths and plaster.

3.4.4 *Exterior walls*

The facades of the Kavaler building were built of solid brick walls at ground floor and timber framed brick walls at first floor.

3.4.5 *Windows*

The windows are single glazed and made of wood. On the ground floor most of the windows are “Dannebrogsvinduer” with 4 side-hung frames. On first floor they are double wing type with two vertical glazing bars. Most of the windows have internal storm windows with single layer glazing.

3.4.6 *Floor and storey partitions*

The horizontal division is carried out with load-bearing timer beams. Like other old buildings from the 1800 century, the timber beams in Kavalergården are carried out without sound boarding and/or clay infill. Later the most common constructions included sound boarding and clay infill or other infill material (see Figure 5). The purpose was to improve thermal and sound insulation, fire-resistance and prevent seepage of water.

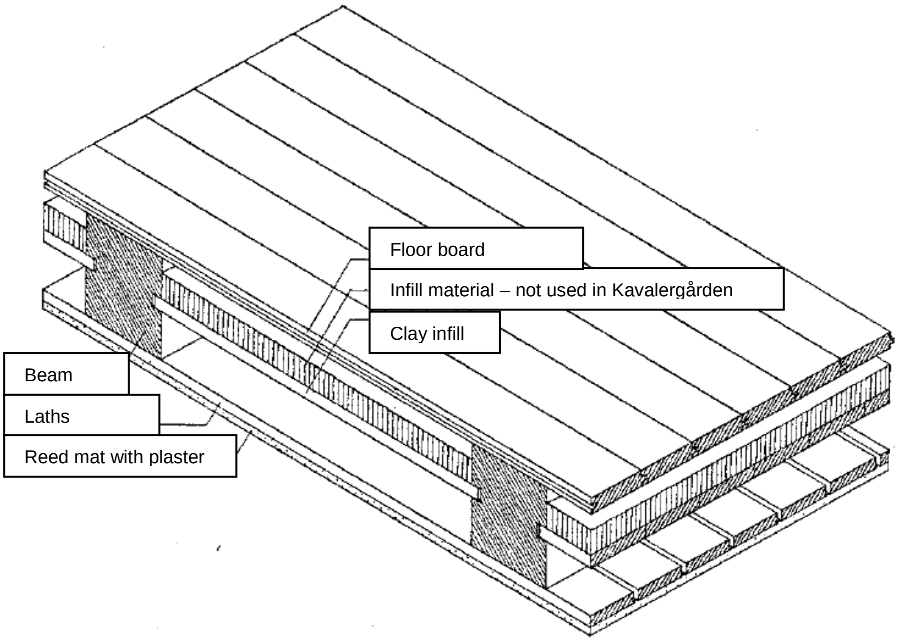


Figure 5. Isometric illustration of a horizontal division - timber beams with infill material and clay infill. In Kavalergården the timber beam layers are made without clay infill (although it is shown above).

Photo 6 shows a building with solid brick walls and timber beams placed on top of a wall plate above a window.

Photo 6. Load-bearing timber beams and timber wall plate at window recess in typical Danish multi-storey building with solid brick walls.
Photo: Jesper Engelmark, DTU.

The Kavalergården complex is declared worthy of preservation in class 3 and 4. This means that any changes in the buildings must be approved by the municipality/the local authorities (please also refer to later section 5 with details on division of listed buildings).

3.5 Background for refurbishment

In 2009 the Danish Energy Agency tightened the energy regulations which implied that the state institutions were required to provide energy savings of 10 %. The energy upgrade of Kavalergården was carried out as a part of this energy saving strategy in combination with the more specific strategy drawn up by Danish Agency for Palaces and Cultural Properties, SLKE (owner).

3.5.1 Building conditions and maintenance level

Furthermore, the roof and other parts of Kavalergården were in bad shape and needed refurbishment in general. Investigations had shown extensive wood decaying fungus attacks as a result of leakages in the roof and the joint between VELUX windows and roof. Furthermore, leaky or missing/wrongly placed vapour barrier had resulted in several mould attacks in the roof constructions. This general refurbishment was carried out as a part of the energy upgrade of the buildings.

Photo 7. Wooden beam from the old roof construction attacked by mould.

3.6 Use of buildings before and after refurbishment

3.6.1 Use and load of the buildings before the energy upgrade

Kavalergården was earlier used by the Ministry of Defence and the Civil Protection. During the past ten years up to 2008, the property was, according to the present tenant, primarily used for management courses in the Civil Defence etc. This included overnight guests in small “hotel rooms”. The number of “hotel rooms” was slightly bigger than today because part of the Infirmary building also held “hotel rooms” with one shared bathroom. Today, these are rented by other companies.

Therefore, it is assumed that the occupant load and use of the buildings was more or less like today.

There are no data of the electricity consumption, but it might have been higher because of less efficient equipment i.e. lighting. On the other hand there was no mechanical ventilation like the new ventilation plant, which has efficient heat recovery.

The three buildings are heated by a natural gas boiler located in the boiler room in the Infirmary building. The central heating system is as a two-pipe installation.

3.6.2 Use and load of the buildings after the energy refurbishment

Since 2009 the Bernstorff Palace and Kavalergården have been run as a hotel and conference centre. As mentioned above the overall use is more or less the same, but a change in energy consumption would be expected anyway in connection with the new tenant moving in. This complicates the evaluation of the energy consumption before and after the refurbishment and the obtained energy savings.

3.7 Energy consumption

Comprehensive data on energy use for heating have been collected manually and continuously since 1999. Relevant data consist of readings of natural gas consumption, amount of water used for DHW (Domestic Hot Water) and hot water tank tap temperature. It is assumed that DHW is heated from 10˚C. Based on these input data, heating degree days (HDD) for the actual location (Jægersborg) and standard year from Danish Meteorological Institute (DMI), the normalized space heating consumption is calculated (see table 2 where the total heated area of 1 780 m2 is used). Only data for the total consumption of three buildings together are available.

The “heating season” is defined as the period from September 1st to August 31st. HDD is defined relative to a base temperature - the outside temperature above which a building needs no heating. A base temperature of 17˚C is used which is according to the method used by DMI. HDD is calculated as the sum of 17˚C minus daily average outdoor temperature (if the average temperature is below 17˚C). HDD equals 2 906 per year. The energy content of natural gas is assumed to be 11 kWh/m^3.

Table 2. Energy use for heating.
* including circulation loss, ** Heating Degree Days

Heating Season	DHW consumption		Total heat consumption (gas)		Space heating			
	m^3 water	kWh*	m^3 gas	kWh	Actual kWh	HDD*	Norm., kWh	kWh/m^2
1999/00	170	37 779	37 808	415 888	378 109	2 923	375 910	211
2000/01	175	38 041	34 581	380 391	342 350	3 042	327 044	184
2001/02	194	39 039	31 675	348 425	309 386	2 792	322 019	181
2002/03	191	38 881	31 426	345 686	306 805	3 255	273 909	154
2003/04	189	38 776	30 172	331 892	293 116	3 138	271 445	152
2004/05	165	37 516	27 703	304 733	267 217	3 039	255 522	144
2005/06	193	38 986	28 898	317 878	278 892	3 175	255 263	143
2006/07	195	39 091	24 309	267 399	228 308	2 376	279 235	157
2007/08	112	34 734	23 866	262 526	227 792	2 804	236 079	133
2008/09	33	30 586	20 010	220 110	189 524	2 843	193 724	109
2009/10	94	33 789	30 311	333 421	299 632	3 288	264 821	149
2010/11	79	33 001	29 735	327 085	294 084	3 292	259 601	146
2011/12	100	34 104	23 414	257 554	223 450	2 906	223 450	126

Table 2 shows that there has been a modest and fairly constant DHW consumption until 2007 at about 180 m^3 per year. Before the present tenant moved in (may 2009) Kavalergården was uninhabited for approx. six months, which explains the sudden drop in consumption of both domestic hot water and space heating. When Kavalergården opened as a hotel and conference centre in 2009, DHW consumption decreased to approx. the half. A large part of the energy consumption for domestic hot water is used for circulation loss.

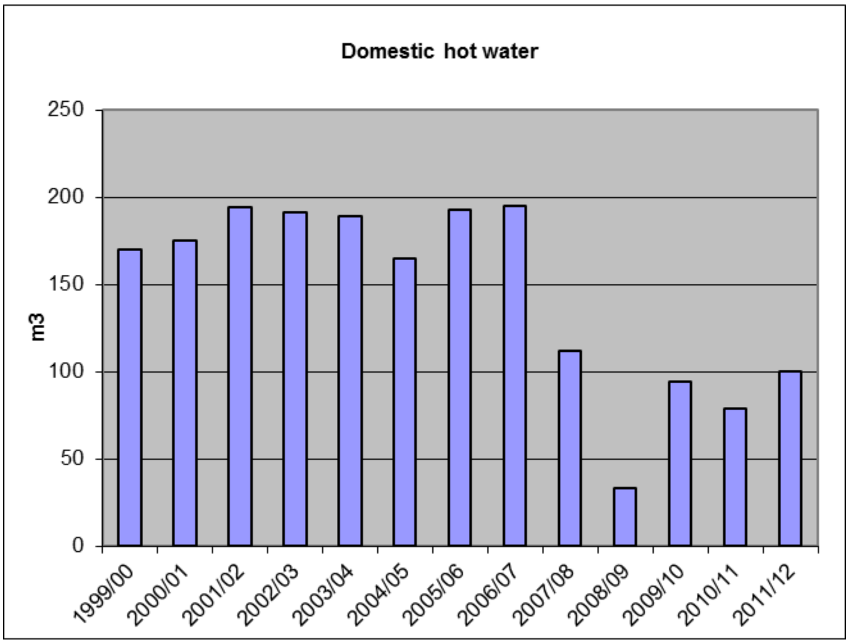


Figure 6. Consumption of domestic hot water

The energy consumption for space heating has varied from 109 to 211 kWh/m^2 over a 10 year period before the changed use of Kavalergården in 2009. The shift in level of space heating consumption in 2002 is due to installation of a new and more energy-efficient gas boiler. In 2008/2009 the energy consumption is very low due to the uninhabited period. From 2009/2010 until 2010/2011, when the energy upgrade was carried out, the space heating consumption was approximately the same as in the period 2003 to 2008 before the upgrade. From 2010/2011 to 2011/2012 the energy consumption decreases form 146 to 126 kWh/m^2 corresponding to a total of 35 600 kWh/year. This could indicate the effect of the energy upgrade, but this must be approved by measurements of the energy consumption in the years to come.

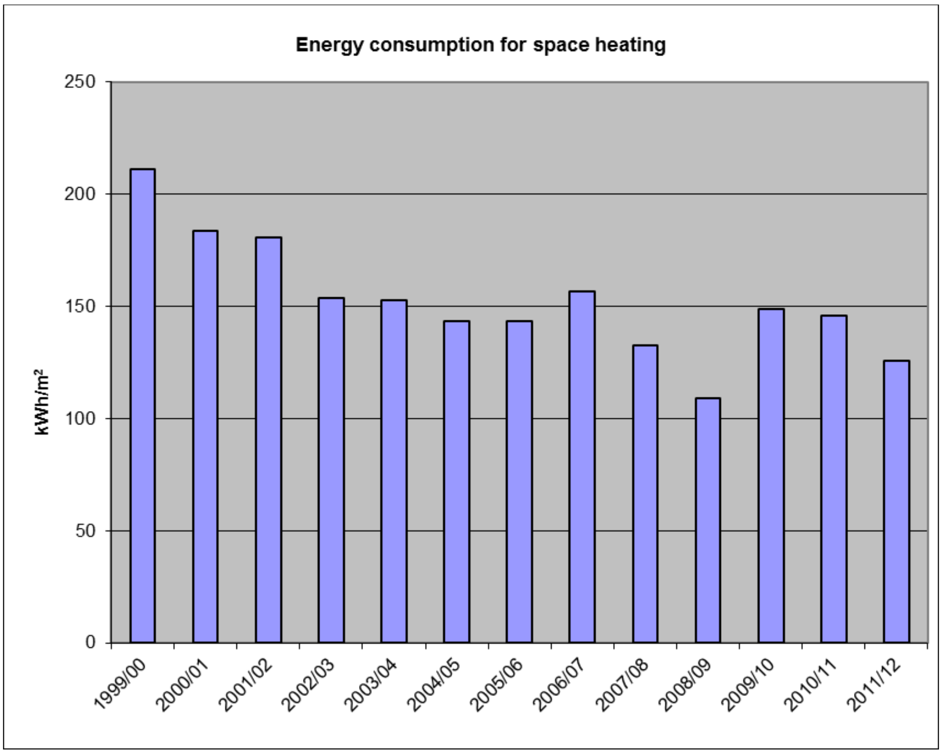


Figure 7. Energy consumption for space heating.

As shown in chapter 6.4 the expected energy saving estimated in the initial energy screening was approximately 68 000 kWh/year

There are no available data on the electricity consumption.

4 ENERGY UPGRADE FRAMEWORK

In total there are approximately 9 000 listed buildings in Denmark and approximately 300 000 buildings have been assessed to be worthy of preservation.
The Heritage Agency of Denmark is responsible for the listed buildings, while the local authorities are responsible for the buildings worthy of preservation, thus Kavalergården. Most of the listed and preserved buildings are privately owned. This is not the case for Kavalergården which is owned by the Danish Agency for Palaces and Cultural Properties.

4.1 Parties involved

Upgrading the energy performance at Kavalergården involved the following main parties and stake holders:

- Heritage Agency of Denmark (responsible authority)
- Danish Agency for Palaces and Cultural Properties, SLKE (owner)
- Bernstorff Slot A/S (lease holders)
- Architects: Creo Arkitekter (Consultant)
- Engineer: NIRAS (sub-consultant)
- Contractor: Hovedstadens Bygningsentreprise (general contractor)

The energy upgrading project was designed by Creo and NIRAS in close cooperation with the professional owner SLKE. SLKE's mission is to preserve, manage and maintain a number of the palaces/castles, gardens and other cultural properties of the Danish State and to optimize their use.

SLKE required energy saving measures to be cost efficient. To determine whether the different measures were cost efficient SLKE's "profitability calculator" was used. See example in Figure 8.

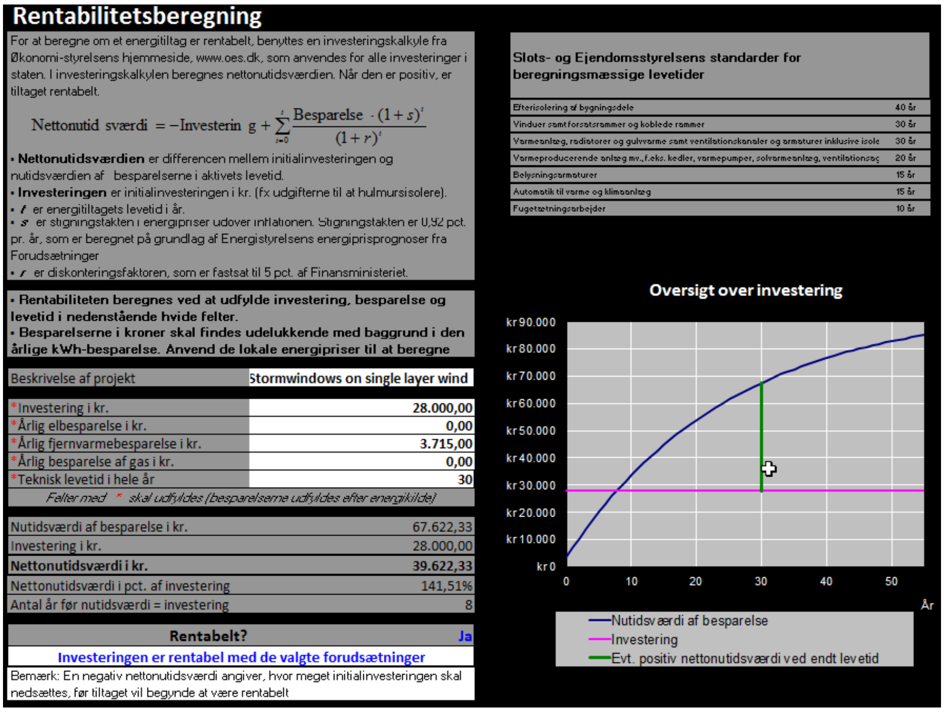


Figure 8. Example of the use of SLKE's "profitability calculator" for determining the profitability of applying storm windows to existing single layer windows

All the energy saving measures in the project was approved by Heritage Agency.

Creo Architects is appointed Royal Building Inspector and thus already approved for refurbishment on buildings worthy of preservation. NIRAS prepared the energy calculations and evaluations as done with similar cases as part of the Creo inspectorate. Furthermore, NIRAS was responsible for the construction management incl. weekly site meetings with the contractor / workers. Creo and NIRAS carried out the technical supervision on site.

The contractor was required to carry out the work described in the call for tenders and to fulfil the described demands only. The selected contractor is known for his expertise in refurbishment of listed and preserved historic buildings. Special competences were not required for the workers.

4.2 Powers of responsible authority

The Heritage Agency is the responsible authority and is advised by the Historic Buildings Council. The 12 council members are appointed by the Minister for Culture at the recommendation of institutions and organisations within the area of the culture heritage of buildings. The Heritage Agency can only list a building or expand an existing listing if the Council supports the proposal. However, the Heritage Agency may delist a building, even if the Council disapproves.

Owners of listed buildings have an obligation to maintain the buildings in order to avoid disrepair. The owners must obtain permission from the Heritage Agency for any changes to the buildings, including all repairs and restoration. Permission is also required to mount an aerial or to place a sign on the facade. The Heritage Agency advises owners on such matters and may also grant funding for the restoration work. [4]

The Danish state does not pay any compensation to owners of listed buildings. However, the owners have several opportunities for tax exemption as compensation for their higher maintenance expenses. If a listed building has been changed without permission from the Heritage Agency, the Heritage Agency may order the owner to rectify the matter. This also applies if the unauthorised changes were made by a previous owner. In addition, the Heritage Agency may order the owner of a listed building to perform necessary maintenance work.

In special cases, the Heritage Agency may acquire a listed building if its existence is threatened by decay. The Heritage Agency owns a small number of buildings, all of which are under restoration. If possible, the buildings are sold when the restoration is completed.

The Kavalergården complex is declared worthy of preservation I, class 3 and 4. This means that any changes in the buildings must be approved by the municipality/the local authorities.

5 RELEVANT MEASURES IN LISTED BUILDINGS

The general position of Heritage Agency is that it is important that listed buildings are in use as it contributes to ensure on-going repair and thereby preservation. Energy saving measures can support the continuous use of buildings. However, measures should only be implemented with consideration to the exact building and architectural conditions. This will restrict the possible energy saving measures.

In many cases, improving the thermal insulation of the building envelope (e.g. internally) will lead to demands for controlling the indoor environment or even controlled ventilation / air conditioning to reduce the risk of moisture related degradation of e.g. timber beams or problems related to mould growth. This problem occurs primarily when the building is used for modern life purposes such as offices.

In the process of selecting measures it is important to consider the use of the building, so that the chosen measures both support each other and the wish for a certain indoor climate. It is also important to take into account whether different rooms in a building are particularly worthy of preservation. Ornamental rooms make very different restrictions to energy retrofitting compared to “normal” rooms.
Palaces and other grand buildings can in general often be divided into 3 zones:

- Rooms where no-one neither wish to nor can get permission to change (halls, main staircases etc.)
- Rooms essential for the perception of the building, but where minor changes are acceptable (e.g. storm windows)
- Secondary rooms - areas in buildings where modern additions are acceptable (bathroom, basement, utility room and other rooms)

Measures related to energy upgrading in listed buildings can be divided into 4 areas:
- Building envelope - roof, facade/windows, slab on ground construction
- Technical installations - climatization of buildings, incl. operation
- Electrical installation – incl. operation
- Building use - indoor temperature etc.

The most relevant measures in listed buildings are:
- Insulation of attic floor
- Insulation of sloping walls
- Internal insulation of exterior walls
- Storm windows or coupled frames with energy-efficient glazing
- Energy-efficient glazing in external window frames
- New or tightened outer doors
- Insulation of slab on ground construction
- Optimization of water- and air-borne heating
- Water for domestic use, heat recovery
- Lower room temperature
- Energy-efficient lighting and circulation pumps

As a supplement it is relevant to consider sustainable energy supply, e.g. heat pump, solar heating and photovoltaic cells.

6 ENERGY SAVING MEASURES AT KAVALERGÅRDEN

In this chapter the implemented energy saving measures and corresponding savings are described in detail. It is divided into four sections, starting with an overview of refurbishment work (see Table 3) on the three buildings followed by a detailed description of the specific measures implemented in each building, e.g. design configuration, thermal properties etc.

Table 3. Refurbishment measures - overview.

Refurbishment measure	**Building**		
	Kavaler	**Infirmary**	**Stable**
General maintenance and repair			
Masonry, chimney, timber frame, and wooden roof frame	√	√	
Windows, doors and gates	√	√	
New roof covering incl. roof gutter, rain pipes and covering	√	√	
Repair of roof covering			√
Facades			
Insulation of wall towards unheated depot		√	
External insulation of closed off gate		√	
New energy efficient outer doors	√	√	
New roof windows	√	√	
New energy-efficient glass in storm windows and sealing	√	√	
New storm windows (where missing) and sealing	√	√	
Roof			
Improved insulation of attic floor		√	
Injection of floor insulation			√
Injection of floor insulation - space under the roof slope	√	√	
Insulation of horizontal partition towards unheated depot	√		
Improved insulation of sloping wall + space under the roof slope		√	
New boardwalk in unheated attic		√	
Lighting etc.			
New energy-efficient light bulbs	√		√
Demand controlled lighting			√
New espalier	√		

The roof of the Kavaler building was replaced with a new similar slated roof. All windows were renovated and the thermal insulation improved. Attic and exterior walls had an overall satisfying level of thermal insulation.

The Infirmary building was thoroughly renovated including a new slated roof and improved insulation of almost the whole building envelope. Solid brick walls were not insulated, but external insulation were applied in two places on facades not worthy of preservation.

Refurbishment of the Stable building was limited to minor repair of roof covering, additional insulation to the attic and partly new energy efficient lighting.

6.1 The Kavaler building

6.1.1 Facade windows

The building had the following variants of existing wooden facade windows:

1. Windows with 1 pane of glass (7 units)
2. Windows with 1 pane of glass and storm windows with ordinary glass (24 units)
3. Windows with 1 pane of glass coupled with ordinary glass in a separate frame (8 units)

Re 1: Storm windows with energy-efficient glass and sealing strips were installed. The window U-value was reduced from roughly 5.0 to 1.8 W/m^2K.
Re 2: Storm window glass was replaced with energy-efficient glass and new sealing strips were installed. The window U-value was reduced from roughly 2.8 to 1.8 W/m^2K (see Photo 8).
Re. 3: The inner glass was replaced by energy-efficient glass and new sealing strips were installed. The window U-value was reduced from roughly 2.8 to 1.8 W/m^2K.

To verify the hard coated energy-efficient glazing you can strike the surface of the outer side of the glass with a finger. It feels more rugged than the non-coated inner side.

Generally, sealing of windows (and doors) is assumed to reduce air infiltration with 0.15 ACH (Air Change per Hour).

Photo 8. Storm windows with new energy-efficient glass and sealing strips (left). Typical wooden "Dannebrogs" window with characteristic hinges and angle iron (right)

6.1.2 *Roof windows*

Existing old VELUX roof windows with double glazing were replaced by new similar windows VELUX GPL M08 with energy-efficient double glazing (18 units). U-value was reduced roughly from 3.0 to 1.3 W/m^2K.

Photo 9. VELUX roof windows placed 2 by 2 to the north.

New roof windows to the south facing part of the roof are cast iron windows (4 units) with coupled and insulated window frame. U-value is reduced roughly from 5.8 to 1.9 W/m^2K. (http://www.ghjern.dk/).

Photo 10. Cast iron roof window (GH Holbæk Jernstøberi) after the refurbishment

6.1.3 *Outer doors*

Two old doors were repaired and storm windows with energy-efficient glass were mounted above the doors.

Photo 11. Two doors were repaired and storm windows installed above.

6.1.4 *Horizontal partition above unheated depot*

The large depot/garage area at ground floor is unheated. The horizontal partition towards the first floor was insulated with 150 mm of mineral wool in a wooden frame structure and fitted with new similar ceiling sheets (Troldtekt).

Photo 12. Ceiling in depot/garage before and after insulation. Pipes were moved to the area with wooden columns and beams.

6.1.5 Attic

Insulation measures were implemented. 200 mm mineral wool was injected in the floor of the space under the sloping wall (see 1. The chimney was repaired. Foundation of chimney is raised two courses, new shuttering against roof.

2. Existing chair for chimney is preserved.

3. New slated roof construction. Wooden boards, laths, 100 mm plus 125 mm mineral wool, laths, gypsum vapor barrier (alukraft) and gypsum

4. New skylights of cast iron with combined storm window and insulated frame profile.

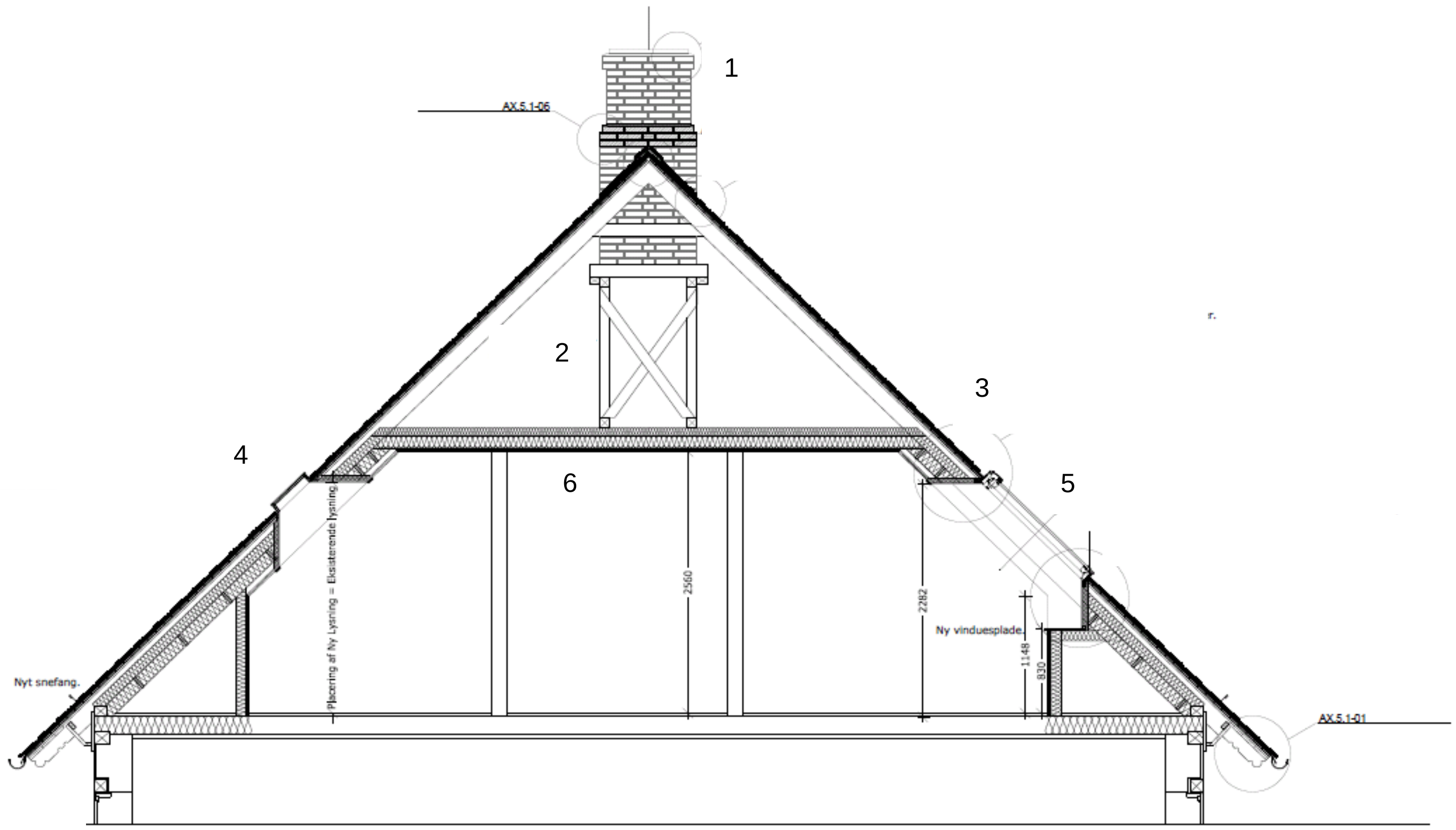
5. New VELUX windows

6. Existing ceiling with 200 mm mineral wool

Figure 9)

1. The chimney was repaired. Foundation of chimney is raised two courses, new shuttering against roof.
2. Existing chair for chimney is preserved
3. New slated roof construction. Wooden boards, laths, 100 mm plus 125 mm mineral wool, laths, gypsum vapor barrier (alukraft) and gypsum
4. New skylights of cast iron with combined storm window and insulated frame profile.
5. New VELUX windows
6. Existing ceiling with 200 mm mineral wool

The roof is provided with specially fitted eaves boards (see Photo 13).



1. The chimney was repaired. Foundation of chimney is raised two courses, new shuttering against roof.

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4. New skylights of cast iron with combined storm window and insulated frame profile.

5. New VELUX windows

6. Existing ceiling with 200 mm mineral wool

Figure 9. Cross section of attic.

Photo 13. Eave without roof covering showing insulation and specially fitted eaves boards

6.1.6 Lighting

Existing halogen light bulbs of the first floor hallway were replaced with energy-efficient LED lambs (32 units).

Photo 14. Hallway on first floor with energy efficient lighting (LED) installed.

6.2 The Infirmary building

6.2.1 Facade windows

Existing wooden windows in facades:

Windows with 1 pane of glass (8 units)

Windows with 1 pane of glass and storm windows with ordinary glass (15 units)

The same types of energy saving measures implemented to the Kavaler building were used in the Infirmary. An example is shown in Photo 15.

Photo 15. Small sized window with striking glazing bars. The thermal performance was improved by installing storm windows with energy-efficient glazing.

6.2.2 *Outer doors*

All door leafs (5 units) were replaced with new ones incl. new energy-efficient storm windows above the doors. The door frame were mounted 5 cm from the facade surface and new joints around the doors were made using filling of tarred oakum and mortar finish.

Photo 16. The door leaf was replaced and storm windows installed above the door.

6.2.3 *Roof windows*

See the description above regarding the Kavaler building.

6.2.4 *External walls*

The wall towards the unheated depot was fitted with 200 mm of mineral wool with plaster covering. Parts of the wall were not insulated due to piping (see Photo 17). This extra heat loss is not of great importance because of other thermal bridges, e.g. horizontal partition.

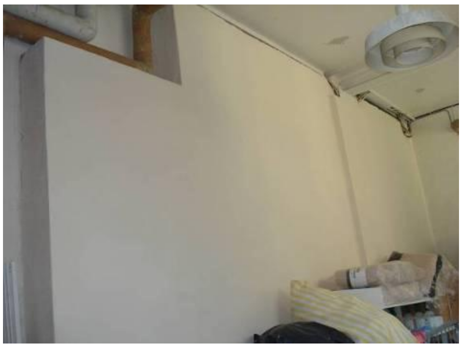

Photo 17. Wall insulation seen from the unheated depot.

The door already covered was externally insulated with 200 mm of mineral wool with plaster covering (see Photo 18). The gate may not be altered due to the status as listed building.

Photo 18. Covered door before and after repair and improved thermal insulation.

Both measures reduced the U-value roughly from 2.5 to 0.2 W/m^2K.

6.2.5 *Moisture conditions concerning the Infirmary building*

The plan was to thermally insulate the internal side of the external 36 cm solid brick walls of the ground floor using 100 mm of calcium silicate, and 10 mm at window and door reveals. Calcium silicate insulation has been used widely in historic buildings in Germany. The thermal conductivity of calcium-silicate insulating boards of 0.067 W/mK is approx. 50% higher than a traditional Danish timber stud frame construction with mineral wool insulation. Hence, the thermal resistance of 100 mm of calcium silicate is comparable to 70 mm timber framed mineral wool.

Calcium-silicate insulating boards are suitable for handling moisture-related problems without installing a vapour barrier. It is a material open to diffusion and with high capillary suction ability, which can be applied to handle mould growth problems due to cold inner surfaces with high moisture level. It can absorb humidity of approx. 3.5 times of its own weight without significant deformation or reduction of its insulating capacity. If the air humidity decreases later, the stored moisture will be released, thus controlling the relative humidity of the room (see figure 10). The material is alkaline, which also contributes to prevent mould growth.

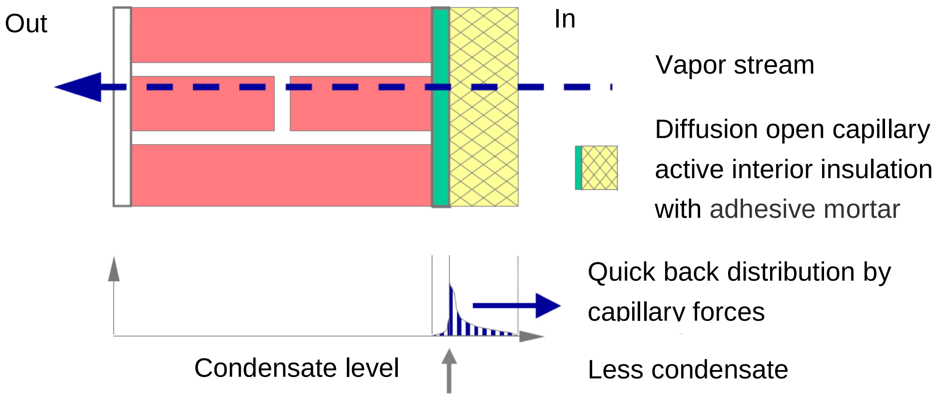

Figure 10. Principle build-up and function of wall with calcium-silicate insulation. [Ruisinger, Ulrich]

Improved wall insulation will decrease the temperature at the end of load-bearing timber beams that reaches into the brick wall (see figure 10). The outdoor moisture in Denmark is typically not a risk, as long as the exterior solid brick wall does not lose its drying potential. As warm humid air from the inside can penetrate into the timber beams with risk of degradation, it must be ensured and controlled that the indoor moisture content does not cause or exceed the critical conditions at the timber beam end of 20˚C, 35% RH in winter and 75% RH in summer [1]. It is recommended to implement monitoring equipment connected to an automatic control system of the indoor air.

As no major moisture and draught problems related to the non-insulated walls have occurred the primary goal was to obtain energy savings. So the main reason for not applying internal insulation was the risk of introducing moisture problems, mould growth and degradation.

Measurements of the indoor temperature and RH will be carried out in relevant rooms in the Kavaler building, where walls were internally insulated prior to the refurbishment.

6.2.6 *Attic*

The refurbishment and improved thermal insulation of the attic consisted of:

1. Insulation of attic floor (including boardwalk)
2. Insulation of sloping wall
3. Insulation of space under the roof slope

Re 1: 200 mm of mineral wool was placed on the floorboards in two layers and with displaced joints between the insulation batts. The collar beam was insulated at the outermost 600 mm by blowing loose-fill mineral wool fibre insulation into the cavity between the timber beams - both below and above the sound boarding (no clay infill) – see Figure 11. Attic floor – cross section in attic floor and sloping wall. 1 Slate, base felt, key and slot boards, laths on rafter. 2 Fungus attacked parts of rafters was replaced. 3 Attic floor with 200 mm mineral wool. 4 Collar beams were insulated both sides of sound boards.

Figure 11 and Photo 19. U-value is reduced from 0.37 to 0.11 W/m^{2}K.

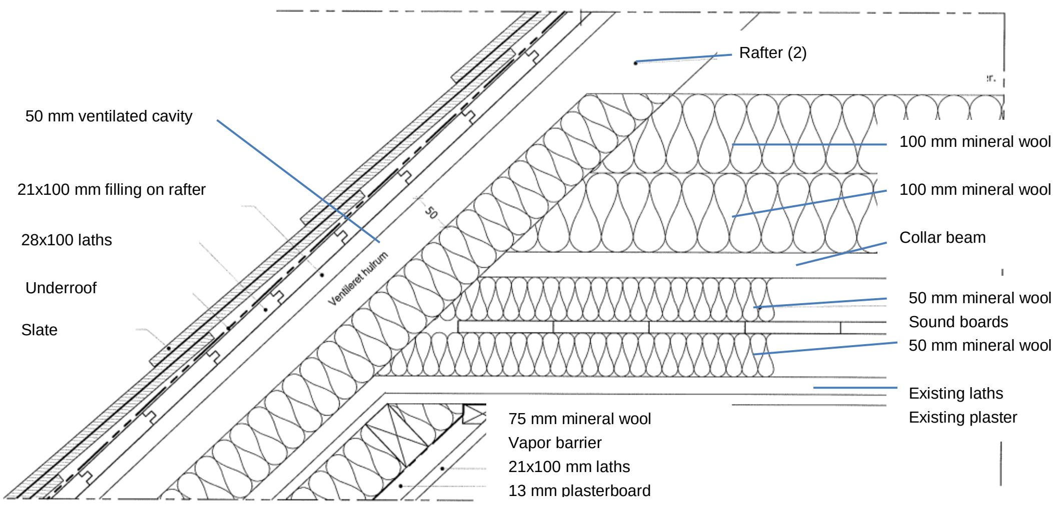

Figure 11. Attic floor – cross section in attic floor and sloping wall. 1 Slate, base felt, key and slot boards, laths on rafter. 2 Fungus attacked parts of rafters was replaced. 3 Attic floor with 200 mm mineral wool. 4 Collar beams were insulated both sides of sound boards.

Photo 19. A view from the unheated loft showing insulation, rafters, under-roof, chimney and boardwalk.

Re 2: The dimension of existing rafters (sloping beams) is 125 x 125 mm. 75 mm of mineral wool was installed from the outside including a 50 mm ventilation gap between insulation and the a solid underlay. The plaster of the existing wall construction (existing vapour barrier) was perforated before adding from the inside 75 mm mineral wool in a wooden frame construction, plastic foil vapour barrier, laths and gypsum board. U-value is reduced from 0.37 to 0.15 W/m^{2}K.

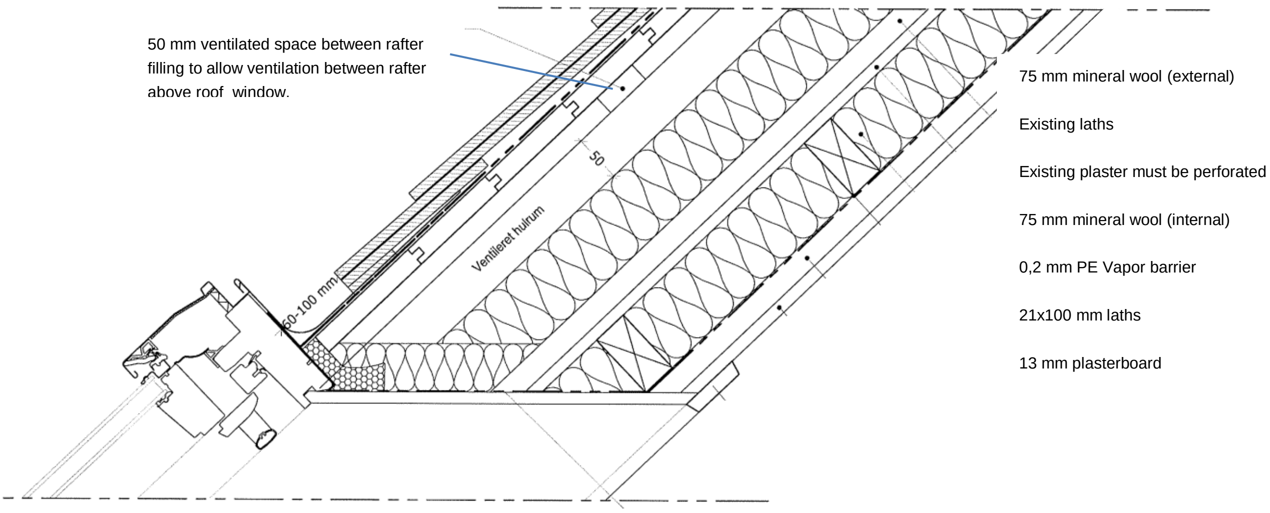

Figure 12. Sloping wall - cross section in upper edge of roof window.

Photo 20. Roof before improved thermal insulation.

Re 3: The sloping wall insulation was also carried out in the space under the sloping wall to create a warm space. The advantages are less heat loss from heating pipes, less risk of piping frost burst, better possibility of storing things without moisture related damage, and the space could easily be converted into a more useful area. Extra insulation was applied by removing the existing insulation in the vertical wall and installing 100 mm mineral wool. 300 mm of insulation was placed on the floor, and 200 mm injected into the hollow floor construction below (see Figure 13).

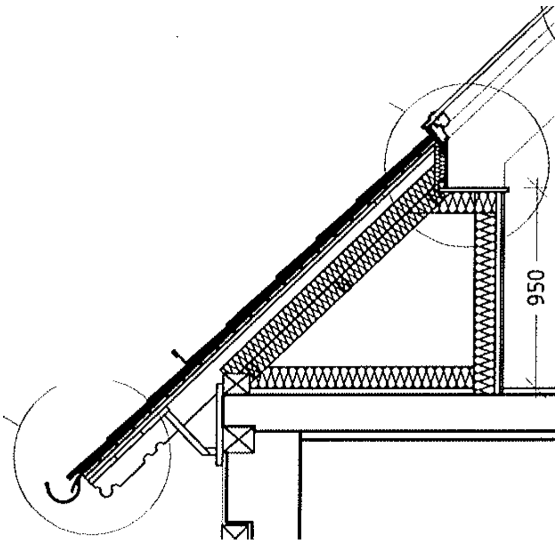

Figure 13. Space under the sloping wall.

6.2.7 *Horizontal partition above depot*

The depot is unheated. The collar beam floor construction towards the first floor was insulated by blowing loose-fill mineral wool fibre insulation into the 200 mm cavity between the timber beams. U-value was reduced from 1.2 to 0.20 W/m^2K.

6.3 The Stable building

6.3.1 Attic

The existing attic is unheated. The horizontal insulation, partly trampled down, consists of a moderate 100 mm of mineral wool placed on the floor boards in one layer and therefore without displaced joints between the insulation batts. The risk of air gaps across the insulation layer increases the heat loss. The insulation was improved by blowing roughly 200 mm loose-fill mineral wool fibre insulation into the cavity between the timber beams. U-value was reduced from 0.37 to 0.11 W/m^2K.

Photo 21. Unheated attic with existing insulation on top of the floor. Thermal insulation was improved by injecting the hollow floor with loose-fill insulation.

6.3.2 *Lighting*

The lighting in conference room was improved. The fixtures and halogen bulbs (46 units) were replaced with energy-efficient products. Detailed calculations of electricity savings were made:

Existing lighting system: 6 029 kWh/year or 43.9 kWh/m^2 year
New system without daylight regulation: 2 809 kWh/year or 20.4 kWh/m^2 year
New system with continuous daylight regulation: 1 869 kWh/ year or 13.6 kWh/m^2 year

Because of too high investment costs for implementing daylight regulation the new lighting system without daylight regulation was implemented. An electricity reduction of more than 50% is expected.

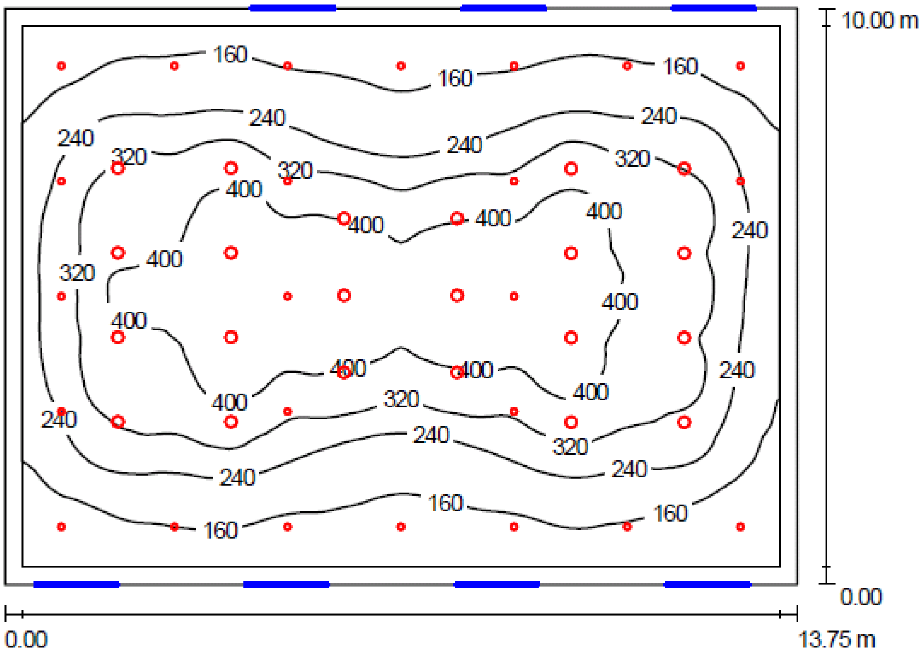

Figure 14. Calculated illuminance in Lux in the conference room on a horizontal surface at a height of 0.85 m.

In order to reduce the operating time of the lighting, PIR sensors were established on the toilets.

6.4 Estimated energy savings and investments

Early 2010 the consulting company NIRAS made an initial evaluation of possible energy saving measures. Energy savings were calculated/estimated with simple but probable methods without performing complete building simulations. Energy savings for building envelope constructions were calculated based on change in U-values (transmission heat loss) and heat degree hours. In order to evaluate whether the different measures were profitable a simple payback time and the net present value were calculated.

The costs of refurbishment were split into four in order to compare with normal refurbishment:

- I: Total costs of implementing the energy saving measures including all costs for refurbishment work, set-up, running and supervision at the building site, scaffolding, planning work, unforeseen costs etc.
- F: Costs for e.g. building site, scaffolding, supervision and unforeseen costs.
- V: Costs for normal maintenance without focus on energy savings.
- M: Extra costs for the actual energy saving measure, e.g. insulation material or energy efficient glass for windows.

The correlation between the four cost specifications is shown below:

$$I = F + V + M$$

Traditional refurbishment = F + V

The profitability of energy saving measures was evaluated from:

- PBT: Pay Back Time in years.
- NPV: Net Present Value based on SLKE's profitability formulae. A measure is profitable if NPV is positive.

Table 4 shows costs and savings for different refurbishment measures. Estimated investments are shown as percentage distribution. In Table 5 the calculated annual energy savings are shown in kWh and DKK and EURO. Table 6 shows the total cost of the refurbishment of Kavalergården and, as a part of this, the extra cost specifically assigned to the improved energy efficiency of the buildings.

Table 4. Considered and implemented energy saving measures, investments and profitability. Yellow highlighting: Extra energy saving measures that was not appointed in the initial screening but implemented anyway as a part of the refurbishment. Pink highlighting: Energy saving measures that was appointed in the initial screening but not implemented.

	Measure implemented			Property, U-value, Power		Energy savings		Investments			Extra cost, energy measures		
Renovation measure	Heat	Electr.	Life time	Before	After	Heat	Electricity	I, Total investment	F, Building site etc.	V, Normal repair	M	PBT	Positive NPV
			Years	W/m^2K, W		kWh/year		%	%	%	%	Years	Yes/No
Kavaler building													
A. Ceiling against attic. Add 200 mm mineral wool			40	0.19	0.09	1 196	0	100	42	56	2	38	No
B. Sloped walls. Add 50 mm mineral wool			40	0.17	0.14	837	0	100	41	57	1	52	No
C. Single layer windows in end wall. Add storm windows	x		20	5.00	1.80	4 590	0	100	27	8	65	8	Yes
D. Windows in facades. Low-e coated glass in storm windows	x		20	2.80	1.80	5 057	0	100	5	14	81	11	Yes
E. New sky lights	x		20	3.00	1.30	3 379	0	100	27	66	8	10	Yes
F. New outer doors	x		20	3.50	1.50	2 060	0	100	26	71	4	2	Yes
H. Ceiling in garage. Add 150 mm insulation	x		40	0.85	0.15	6 325	0	100	15	42	42	6	Yes
I. Lighting. Energy saving bulbs		x	10	40.00	13.00	0	2 444	100	15	0	85	4	Yes
J. Deck in space under the sloped roof. Add 200 mm insulation (granules)	x					3 900	0						
Infermeri building													
A. Floor in attic. Add 200 mm mineral wool	x		40	0.37	0.11	3 175	0	100	27	0	73	14	Yes
B. Sloped walls. Add 150 mm mineral wool	x		40	0.37	0.15	2 987	0	100	21	59	20	12	Yes
C. External walls in ground floor. Internal insulation with 100 mm calcium silicate			40	2.00	0.50	9 332	0	100	27	0	73	16	Yes
D. Single layer windows in staircase. Add internal low-e storm windows	x		20	5.00	1.80	2 169	0	100	27	8	65	7	Yes
E. Windows in facades. Low-e glass in storm windows	x		20	2.80	1.80	4 267	0	100	5	14	81	13	Yes
F. New sky lights	x		20	3.00	1.30	1 229	0	100	27	66	8	10	Yes
G. New outer doors	x		20	3.50	1.50	3 543	0	100	27	70	4	2	Yes
I. Lighting i ground floor rooms. Low-e light bulbs			10	0	0	0	2 149	100	27	29	44	0.2	Yes
K. Blocked gate. Add 200 mm mineral wool, external	x		40	2.50	0.19	1 900	0						
L. External walls in depot. Add 200 mm mineral wool, external	x		40	2.50	0.19	4 700	0						
M. Deck in space under the sloped roof. 200 mm granules plus 300 mm on the	x					2 000	0						
N. Roof. Add 20 mm mineral wool between rafters	x					150	0						
Stable building													
A. Floor in attic. Add 200 mm mineral wool (granules) in deck	x		40	0.38	0.10	4 142	0	100	15	0	85	12	Yes
D. Halogen lamps i conference room replaced with low-e lamps		x	10	70.00	23.00	0	4 390	100	15	0	85	3	Yes
E. Lighting in hall. Adjustment of daylight controll		x	20	15.00	15.00	0	225	100	15	0	85	0.5	Yes
F. PIR-sensors on toilets		x				0	135						
Total energy savings, IMPLEMENTED						**66 938**	**7 194**						

Table 5. Calculated energy savings estimated in initial investigation. Energy prices of June 2012

	kWh/year	DKK/year	EUR/year
Total energy savings, heat	57 000	37 000	5 000
Total energy savings, electricity	7 200	14 400	1 900
Total energy savings: approximately		52 000	6 000

Table 6. Costs of refurbishment

	DKK	EUR
Total refurbishment budget	8 197 000	971 000
Hereof budget for extra costs for improved energy efficiency	865 000	102 000

It is seen from table 5 and 6, that the expected simple PB for the energy upgrade measures equals almost 17 years, which is still within the expected life time of the majority of energy saving measures.

7 VALIDATION OF CALCULATED ENERGY USE

From 2009/2010 until 2010/2011, when the energy upgrade was carried out, the space heating consumption was approximately the same as in the period 2003 to 2008 before the refurbishment. From 2010/2011 to 2011/2012 the space heat consumption decreases form 146 to 126 kWh/m^2 corresponding to a total of 35 600 kWh/year. This could indicate the effect of the energy upgrade, but this must be verified by measuring the energy consumption in the years to come.

Table 7. Energy consumption for space heating before and after refurbishment

	Space heating [kWh/m2*year]	Total space heating savings [kWh/year]
Before refurbishment and energy upgrade	146	-
After refurbishment and energy upgrade	126	-
Energy saving measured	-	35 600
Expected energy saving	-	57 000

The expected space heat savings achieved by the energy upgrade and refurbishment were estimated to a total of 57 000 kWh/year equal to approximately 22 % of the space heat consumption. Measurements of the heat consumption before and approximately one year after the energy upgrade and refurbishment shows a decrease of 35 600 kWh/year equal to approximately 14 % or only 62 % of the expected heat savings.

The difference between the expected and the measured savings might be explained by the short period of measurements after the refurbishment is not representative for the future, a different use of the buildings or maybe higher indoor temperatures etc.

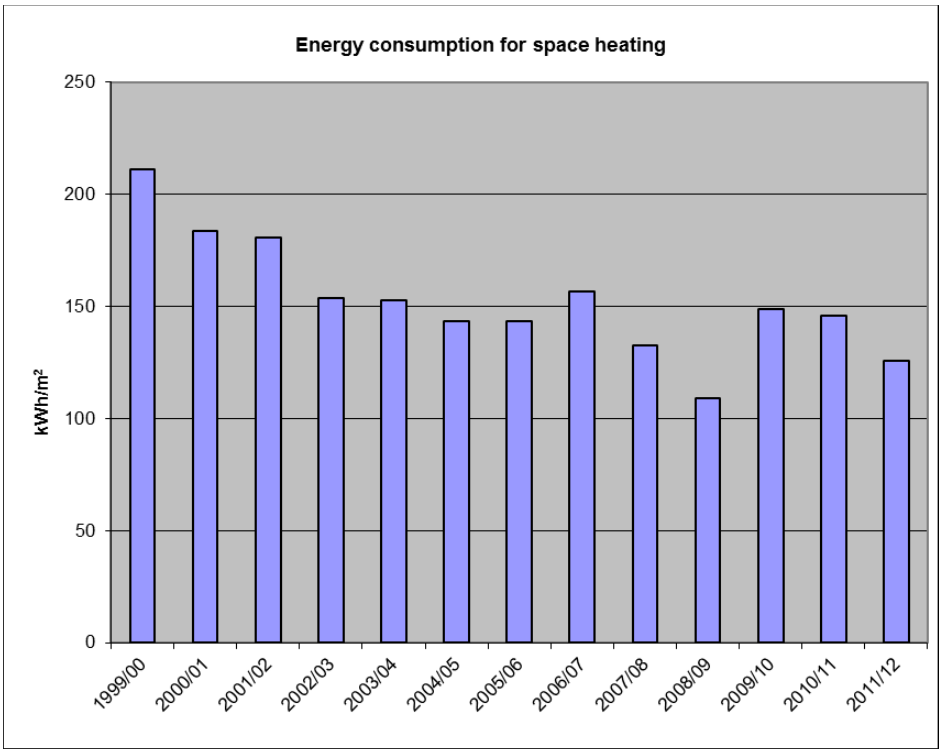

Figure 15. Energy consumption for space heating.

8 REFERENCES

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[3] Measurements of natural gas consumption. Readings by Agency for Palaces and Cultural Properties, 1999 – 2011.

[4] Homepage of Heritage Agency and division of listed buildings. http://www.kulturarv.dk/fredede-bygninger/