Energy conservation in a historic building in practice

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ABSTRACT

Realdania Byg has studied the limits to energy preservation measures set by the historical settings of a specific, listed 18th C property in Copenhagen, Denmark. The findings of that study are currently being carried out in practice.

In collaboration with the Danish Heritage Authorities Realdania Byg organized a series of workshops where all possible technical solutions were discussed. In the end a combination of simple, low-tech solutions and some high-tech consumption control systems were chosen.

Altogether, the measures taken will reduce the CO_2-emission of the property by about 20%. Most of these measures are economically realistic and can thus be replicated by others.

The project has been selected as a case study in 3ENCULT, a EU 7th Framework Programme entitled “Efficient Energy for EU Cultural Heritage”.

KEYWORDS

- 18th C listed property
- 20% CO_2-emission reduction
- Heritage values
- Windows
- Walls
- Air tightness
- Electrical equipment

THE PROPERTY

In 2007 Realdania Byg, a subsidiary of the Realdania Foundation, purchased Fæstningens Materialgaard in the centre of Copenhagen from the Danish ministry of Defense, to whom the property had belonged since the early 1740’s. Originally built as warehouses for the maintenance of the Copenhagen fortifications (with a fine dwelling for the supervisor), the buildings have gradually been converted into offices. By 1964 the last warehouse facilities had gone.

The property consists of four separate buildings covering a total of some 2.800 net sq.m around a central garden: the supervisor’s dwelling from 1742 which was turned into offices in the middle of the 20th C, a two-story warehouse from the 1770’s that during the late 18th C was radically re-built to accommodate dwellings and subsequently offices, a half-timbered warehouse also from the 18th C which, despite having partially been turned into offices from the 19th C onwards, still retains substantial parts of the original warehouse timber structure, and finally a shed building that was converted into offices after WWII. Some energy conservation measures had already been carried out, such as insulation of the roofs and the fitting of double windows. The entire property, including the garden, is listed.

Despite having all gradually been turned into offices, and despite a certain uniformity particularly in their exterior treatment, an extensive historical survey which included archive studies, exact geometrical surveys, and colour sampling etc. revealed that the four buildings contain very different characteristics. The supervisor's dwelling retains some fine panelling and other carpentry work, some original, some from the early 19th C, and despite having been remodelled several times over the centuries the floor plan still underscores the building's character as a fine dwelling for a high-ranking public official. The two-story building in subtle ways reveals in its floor plans its past as a warehouse, albeit having gradually been completely retrofitted first as dwellings, later offices. Panelling, ceiling stucco etc. is of a simpler, slightly more utilitarian design than in the supervisor's house. The half-timbered warehouse still retains most of its supporting columns and beams, despite later alterations, and its half-timbered exterior walls are still mostly visible from the inside. The shed building was at first sight the one that had suffered most from later insensitive alterations: The originally open facade had been closed up, and the original floor plan was illegible. It turned out, however, that all but one of the original supporting columns inside the building as well as all the original beams had been preserved, encased amongst others in a thick concrete wall.

Due to the variety in building types and thus the scope for applying different solutions to each building Realdania Byg decided from the onset that this property would be ideal for testing the degree to which various energy conservation measures could be implemented without infringing the heritage value of the property. Furthermore the previous owner, the Danish ministry of Defence, had conscientiously recorded consumption data over a period of many years, making it possible to directly compare projected future energy consumption and thus CO_2-emission levels with known existing levels.

LIMITS TO ENERGY EFFICIENCY SET BY THE HERITAGE VALUES

Listed buildings accounting for less than 2% of the total number of buildings in Denmark and thus contributing only to a minor degree to CO_2-emissions, the objective of the project was specifically to find energy saving measures that could be introduced without infringing the elements that define the heritage values of the property, rather than aiming for a zero emission solution. It was thus a given that the findings of the historical survey mentioned above should form the basis for the project. With this in mind, Realdania Byg held a series of workshops over the course of almost a year, with participants from the Danish Heritage Agency, the conservation architect in charge of the project, as well as construction and technical engineers.

Initially, a list of all technically possible measures aimed at reducing emissions was drawn up. This list included passive measures such as modern energy efficient windows, exterior solar shading devices, exterior or interior insulation of walls, and improvement of the buildings' air tightness. Active or technical measures included various types of ventilation systems, air intake through "solar walls", various types of cooling systems, daylight control systems, centralized management of electrical equipment, and the mounting of solar panels and photovoltaic cells. Finally, the list encompassed measures related to the layout or use of the buildings such as grouping all meeting rooms together, and the mounting of air locks by all entrance doors.

At the first workshop some of these measures were dismissed out of hand. Most measures that would change the exterior aspects of the buildings, including exterior shading devices, exterior insulation, changing of the existing windows to modern energy efficient windows, solar panels and photovoltaic cells were deemed inappropriate on listed buildings. The sole exception to this general rule was that modern elements could be introduced as a function of changes in the facades. For example, the blocked up open facade of the shed building will be re-opened and fitted with modern windows from floor to ceiling, with built-in solar shading. Other measures such as rainwater collection were dismissed on grounds of low cost effectiveness. Finally, measures that did not relate specifically to the inherent conflict with the heritage values and thus would have little demonstrational value to the project were also dismissed, e.g. cooling via seawater heat pumps.

At this point an extensive digital model of all four buildings was built using a thermal simulation programme developed by the Danish Building Research Institute. The model was based on each building's current layout and pattern of use. The model provided a detailed overview of the energy consumption of the various building elements as well as an indication of the existing indoor climate throughout the four buildings. In addition to this a blower door test was carried out in all four buildings to reveal the heat loss through various cracks and fissures in the construction.

Apart from providing a base model against which the effect of the various energy saving measures could be measured, the model also revealed what had hitherto only been suspected on anecdotic evidence, namely that the indoor climate in the buildings was far from satisfactory, particularly due to overheating in the summer, and indeed fell short of the minimum standards set by the Danish Working Environment Authority (DWEA) for offices. To address this problem the base model was refined to include the (theoretical) energy consumption needed for summer cooling.

Table 1. Base model, existing energy consumption

Consumption KWh/m^2	Supervisor's dwelling	Two-story building	Half-timbered warehouse	Shed building
Heating	56,5	133,0	105,7	111,4
El. equipment	46,8	96,7	72,3	27,1
Lighting	4,7	12,1	8,2	10,3
Cooling	3,4	8,0	3,7	4,6
Total	111,4	249,8	189,9	153,4
CO_2 kg/m^2	**38,4**	**83,7**	**61,8**	**39,4**

At the second workshop those measures that remained on the initial list were discussed in more detail. The effect of incorporating those that could reasonably be integrated in the project from a point of view of architecture and heritage values should be calculated in the simulation model. At this stage the measures decided upon for each of the four buildings began to differ markedly: For example, it was decided that any type of mechanical ventilation in the supervisor’s dwelling would be impossible to integrate for architectural reasons (at the expense of a reduced density of work places to adhere to DWEA standards), while ventilation systems would be suitable in the half-timbered warehouse and the shed building where they could be integrated in the more “rough” utilitarian architecture of these buildings.

These calculations, which formed the basis of the third workshop, led in some instances to surprising results. It became apparent that some measures tended to counteract with each other, cancelling out the total effect. For example, the reduction in heat loss through added insulation of the roof of the two-story building was almost entirely offset by the necessary increase in cooling capacity and was thus rejected at this stage.

At a fourth workshop, after further calculations, the final decision on which measures to implement was taken.

The calculated energy savings of these measures are summarized in table 2 below. It should be noted that the measures taken have allowed an increase in density of use of the buildings of more than 25% due to compliance with DWEA standards, from 114 workspaces to 144, resulting in better prospects for increased rent. Total CO_2-emissions have nonetheless been reduced from 162,8 t/year to 131,5 t/year, a reduction of almost 20%.*

Table 2. Calculated energy consumption (existing)

Consumption KWh/m^2	Supervisor’s dwelling	Two-story building	Half-timbered warehouse	Shed building
Heating	35,2 (56,5)	120,1 (133,0)	47,8 (105,7)	55,0 (111,4)
El. equipment	37,7 (46,8)	67,7 (96,7)	66,0 (72,3)	28,2 (27,1)
Lighting	5,1 (4,7)	9,9 (12,1)	6,8 (8,2)	8,7 (10,3)
Cooling/vent.	3,6 (3,4)	6,6 (8,0)	11,3 (3,7)	8,2 (4,6)
Total	81,6 (111,4)	204,3 (249,8)	131,9 (189,9)	100,1 (153,4)
CO_2 kg/m^2	**30,7 (38,4)**	**63,9 (83,7)**	**53,2 (61,8)**	**32,9 (39,4)**

The full calculations, including the results of the blower door tests as well as detailed minutes of each workshop have been published in a mid-term report that can be downloaded free in pdf-format from www.realdaniabyg.dk (available in Danish language only).

* Electricity generation in Denmark is on average more CO_2 intensive than heating production. Measured in MWh the reduction is closer to 26%.

INDIVIDUAL EFFECTS OF CHOSEN ENERGY SAVING MEASURES

Windows

In the shed building a number of new windows will be installed due to changes in the facade composition. These will be the most energy efficient windows on the market and will furthermore be equipped with exterior solar blinds, as the shed building faces southwest. This will result in a reduction of the building's CO_2-emissions of more than 7,2%. (See also table 3 below).

All four buildings have over time been equipped with secondary windows (extra frames added to the interior side of the window), as has been customary in Denmark since the 1920's. By changing the glass in these frames to modern 3 mm energy glass (coated glass), a reduction in emissions of between 1,9% and 8,1% can be achieved. The difference in effect reflects the actual number of windows in each building.

Walls and floors

The back (blind) wall in the shed building will be insulated with 100 mm mineral wool in the inside, yielding a reduction in emissions of around 13%. The expense related to insulating towards the terrain would under normal circumstances not be justified by the resulting reduction in emissions. However, in the shed building and the half-timbered building the existing concrete floor have to be taken up anyway due to necessary repairs to the foundations. New floors will be insulated below the concrete with 250 mm polystyrene, which will result in an emissions reduction of close to 5%.

Improved air tightness

The blower door tests mentioned above revealed numerous cracks and fissures in the buildings, particularly around the timber in the half-timbered building, around windows, above the cornices, and, in the case of the supervisor's building, in the basement. Interestingly, the blower door test also revealed that in rooms with original wall panelling air tightness was generally satisfactory. Repairing the brick infill between the timbers in the half-timbered building will on its own reduce that building's CO_2-emission by more than 7,5%.

Mechanical ventilation

In order to reach DWEA minimum standards, mechanical ventilation has to be introduced in the half-timbered building and the shed building, resulting in increased emissions of 3,7% and 4,6% respectively.

Electrical equipment

By introducing low energy light sources throughout the buildings tied to daylight control systems (in effect preventing the use of electrical lighting if daylight is sufficient), as well as central controlling of all electrical equipment (thus ensuring that all equipment is shut down when the buildings are not in use, i.e. at night or during weekends), CO_2-emissions can be reduced substantially. These gains are two-fold: Apart from the direct savings in electricity, the inefficient heat production from electrical equipment is also reduced.

It should also be noted that an integrated building management system is envisaged, controlling heating and cooling for each room in the property based on input from a local weather station. The system will include night cooling in summer and reduced night heating in winter. Although the occupants of the room manually will be able to override the system, it will revert to automatic mode each evening, thus minimizing the adverse effects of user behaviour on energy savings.

Finally, it was proposed that the landlord should provide central server equipment for the tenants, thus enabling the tenants to use “thin clients” rather than PC’s in their offices. While this would have reduced CO_2-emissions almost by another 2%, such an arrangement is as yet uncommon in Denmark. Although cabling, server rooms etc. have been designed to accommodate such a centralized solution, the gains have not been factored into the calculations.

Layout

Although not quantified in the model, there is little doubt that the layout or future pattern of use of the buildings can result in substantial savings if carefully thought through. It was decided early on to place all meeting rooms as well as a common canteen in the ground floor of the half-timbered building. This permitted optimisation of heating, cooling, and ventilation equipment throughout the property, meeting rooms requiring more ventilation than normal offices. As meeting rooms are not in permanent use, they also need not be kept at the ideal temperature at all times.

Table 3. CO_2-emissions reduction for each measure chosen

	Supervisor	Two-story	Half-timber	Shed
New energy efficient windows			7,3%	0,7%
Energy glass in inner frames	4,3%	4,4%	1,7%	8,1%
Interior wall insulation (partial)				13,5%
Insulation below ground floor			4,4%	5,3%
Improved air tightness	6,1%	2,0%	7,6%	6,8%
Mechanical ventilation			-3,7%	-4,6%
Electrical equipment	8,8%	12,2%	8,3%	4,6%

FUTURE MONITORING

Actual building works have been underway for 1½ year, and the project is currently expected to be completed by late 2011. The project has been selected as one of eight case studies in 3ENCULT, a EU 7th Framework Programme entitled “Efficient Energy for EU Cultural Heritage”. As part of that programme, extensive monitoring of actual energy consumption as well as monitoring of select building elements for temperature, condensation etc., will be set up, and the final results published as part of that programme.

CONCLUSION

While heritage buildings should not bear the brunt of our concerted effort to combat greenhouse gases (most of these buildings have after all been built and operated CO_2-neutrally for centuries), this project shows that, given careful study, substantial emissions reductions can be obtained in a listed building, even within the very tight constraints set by the heritage protection authorities. For the many building in our cities that are not listed but nonetheless constitute the basic fabric of our heritage the scope is even wider.

Furthermore, measures to reduce emissions may also improve indoor climate, which, in the case of offices, should entail increased rental levels, making most measures economically viable.

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