Extensive renovation the pathology of heritage buildings

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Extensive renovation the pathology of heritage buildings

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ABSTRACT

The pathology of heritage buildings is often related to renovation initiatives typically initiated by implementing energy savings measures. But how much energy can be saved carrying out an extensive energy upgrading of a heritage complex or individual heritage buildings.

To quantify how great a potential heritage buildings possess, the extensive energy upgrading of a listed complex was followed.

The paper identifies feasible energy-upgrading measures for implementation and calculated energy savings as well as the reduction of CO_2 emissions. Measures are found to create synergy between the interests in preserving heritage values and the development of affordable renovation that is compatible with the requirements for the future use of the complex.

The listed complex consists of four individual listed buildings. The buildings form a single complex surrounding a courtyard, see Fig. 1.

The renovation and energy upgrading of the listed complex, have shown that the primary planning including the function of a heritage building is crucial to the gained energy and CO_2 savings. If service facilities like a canteen or meeting facilities is needed the location of such facilities are important. These facilities can initiate the need for a significant cooling load that might influence the expected savings in CO_2 emissions negatively.

Figure 1. Google maps, photo showing the plan of the listed complex

KEYWORDS: Extensive renovation, Energy upgrading, Climate mitigation, Heritage buildings, Case study.

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1 INTRODUCTION

The pathology of heritage buildings is often related to renovation initiatives typically initiated by implementing energy savings measures.

Renovation ensures that buildings remain part of the attractive building stock, otherwise the buildings will deteriorate as there is no financial basis to maintain them. Renovation has been forced through identifying energy-upgrading measures, besides creating modern homes with an attractive indoor climate standard, as climate change and measures to mitigate its effects have been a global priority for more than a decade.

On a global priority scale, efforts to mitigate the impacts of climate change have focused on reducing greenhouse gas emissions within the framework of the Kyoto Protocol, [United Nations 1998], which was implemented partly on an international level and partly through individual national initiatives. These initiatives include reductions of the energy consumption for heating and comfort in order to reduce CO_2 emissions [Ministry of Transport. 2005] from buildings. Therefore, there is an intensified interest in reducing energy consumption including the improvement of the indoor climate standard of many existing buildings. This posed challenges especially for listed buildings with heritage values, which needed to be protected while still remaining part of the attractive building stock.

To quantify how great a potential heritage buildings possesse in relation to mitigating the impacts of climate change, this paper describes a case study where extensive energy upgrading of a listed complex was carried out. The paper focuses on the reduction of energy consumption by implementing energy-upgrading measures for the complex which includes four listed buildings and a courtyard.

The case study of the complex provides calculated quantities for the reduction of CO_2 emissions in relation to the renovation of the individual heritage buildings while ensuring an indoor climate that complies with the applicable guidelines and directions from the Danish Working Environment Authority [Danish Working Environment Authority 2014] without compromising identified heritage values. Feasible energy-upgrading measures were identified for implementation, and energy savings as well as the reduction of CO_2 emissions were calculated.

The measures were found to create synergy between the interests in preserving heritage values and the development of affordable renovation that was compatible with the requirements for the future use of the building.

2 CASE STUDY

The listed complex Fæstningens Materialgård was used as a case for this study. It is located at Frederiksholms Kanal in the western part of downtown Copenhagen. Construction of the complex begun 1740. The complex consists of four individual listed buildings. The buildings form a single complex surrounding a courtyard, see Fig. 2. They are made of brick with red tile roofs, yellow lime-washed facades, green-painted doors and gates and white-painted windows. Structural sections of the buildings show the supervisor’s residence, the half-timbered building, the office building and the monopitch roof building, see Fig. 3, 4, 5 and 6 respectively.

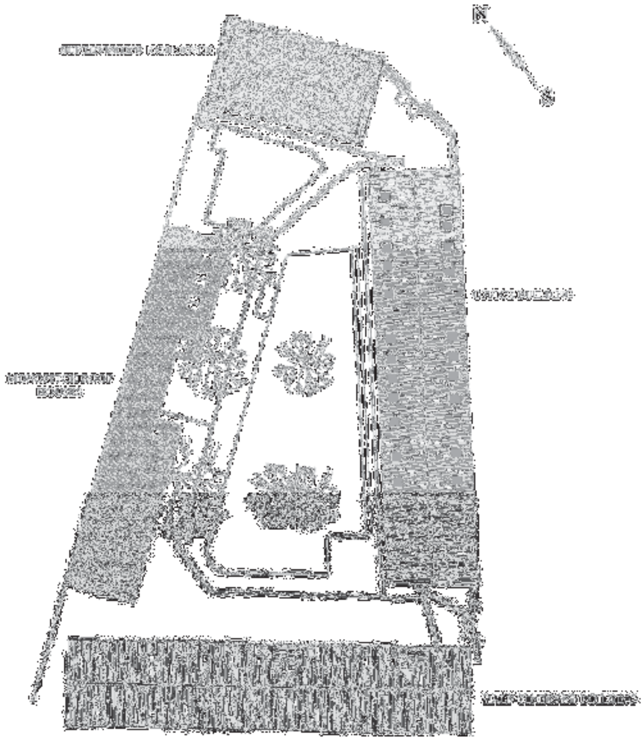

Figure 2. Site plan of the listed complex, Fæstningens Materialgård.

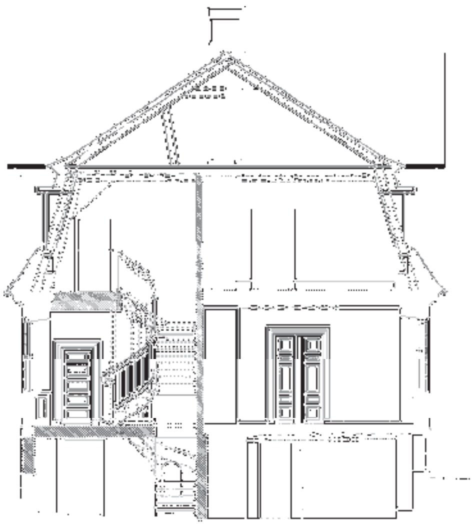

Figure 3. Structural section of the building containing the supervisor's residence. Denoted A in Table 1.

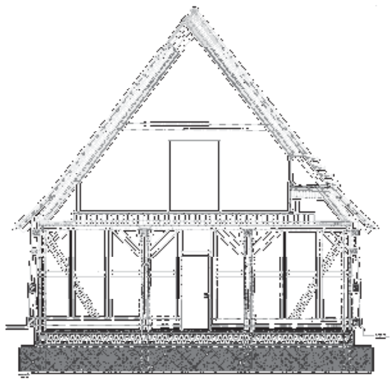

Figure 4. Structural section of the half-timbered building. Denoted B in Table 1.

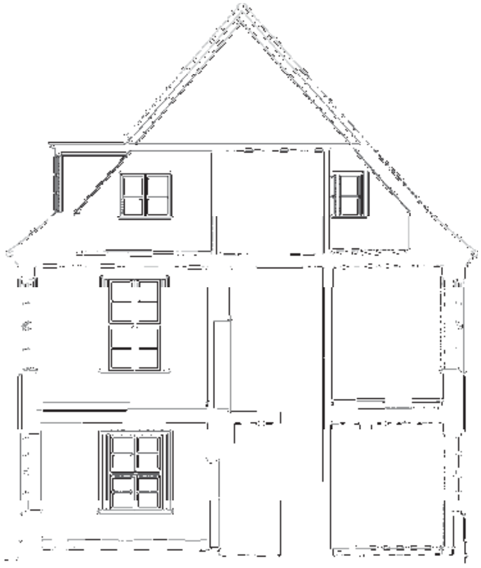

Figure 5. Structural section of the office building. Denoted C in Table 1.

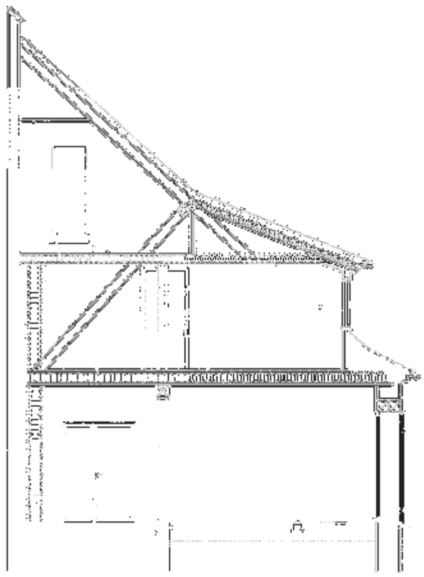

Figure 6. Structural section of the monopitch roof building. Denoted D in Table 1.

Individual feasible energy-upgrading measures for each building in the listed complex are shown in Table 1. Measures were agreed on through a process of selecting feasible comprehensive renovation measures, including energy-upgrading measures for heritage buildings. The process depends on the cooperation between authorities and the owner of a heritage building. The process can lead to the identification and implementation of feasible measures for renovation, including energy upgrading, and still be able to preserve identified heritage values inherent in a listed building or a listed complex. The process is outlined and described by Rasmussen, [Rasmussen T. V. 2014].

Table 1. Feasible renovation measures for the energy upgrading of individual buildings in the listed complex. A: Supervisor's residence, B: Half-timbered building, C: Office building and D: Monopitch roof building.

Measure	A	B	C	D
Low-energy glazing – 3 mm glass set in the existing secondary frames	✓		✓	
New windows with low-energy glazing in new window openings		✓		
Low-energy glazing in the existing secondary frames, where possible		✓		✓
Replacement of windows, that are not original, with new windows with low-energy glazing				✓
New low-energy windows in new window openings (re-established gateways)				✓
Building envelope air permeability (0.5 h-1 in the basement, 0.2 h-1 on the ground floor and 0.2 h-1 at the first floor)	✓			
Building envelope air permeability (0.5 h-1 on the ground floor and 0.16 h-1 on the first floor)		✓		
Building envelope air permeability (0.29 h-1 on the ground floor, 0.2 h-1 on the first floor and 0.2 h-1 on the second floor)			✓	
Building envelope air permeability (0.35 h-1 on the ground floor, 0.17 h-1 on the first floor)				✓
ventilation via opening of windows	✓		✓	
Balanced ventilation with a standard exchange rate of 12 l/s per person including cooling		✓		✓
Combined heating/cooling unit designed so that it looked like a flat panel radiator	✓		✓	
Centralised domestic hot water supply	✓			
Additional insulation of external walls i.e. in the kitchen area and in utility rooms		✓		✓
New insulated ground slab		✓		✓
Radiator heating on the first floor		✓		✓
Underfloor heating on the ground floor		✓		✓
Decentralised domestic hot water supply		✓	✓	✓
External solar shading with a reduction factor of 0.5				✓
Energy-saving light sources	✓	✓	✓	✓
Daylight-controlled lighting	✓	✓	✓	✓
Centralised control of electrical components	✓	✓	✓	✓
Cooling via a centrally placed unit where excess heat is transferred to the outside air	✓	✓	✓	✓
Shared canteen facilities	✓	✓	✓	✓
Shared meeting/conference facilities	✓	✓	✓	✓

3 CALCULATION METHOD

A model was built up for each building in the complex. The model was to calculate the energy demand of a building using a PC program, BE10 [BE10 2014], which in effect is an integral part of the Danish Building Regulations and consequently an important part of the implementation of the the Directive on the Enegy Performance of Buildings, EPBD, in Denmark. The calculations were made in accordance with the mandatory calculation procedure described in Guidelines on Energy Demand of Buildings published by the Danish Building Research Institute, SBi [Aggerholm S. and Grau K. 2008].

Base calculations were based on the existing conditions of the individual buildings and brought in line with measured consumption data. To ensure a trustworthy calculation model, the buildings were built up with the existing interior layout and occupant loads and then compared with the previous five years' consumption of water, heating and electricity. Subsequently, reference models were built up concurrently with the development of the new design with the new interior layout and with the future occupant load. Calculations were made for the individual buildings before and after the implementation of renovation and energy-upgrading measures.

Calculations were made using the reference model to calculate the impact of the individual feasible energy-upgrading measure agreed on for each individual building. The calculated heat balance was calculated based on the future interior layout and a future occupant load to maintain a thermal environment level in Category C [Danish Standards 2005] by means of cooling. The changed energy demand for heating and cooling was calculated to percentage CO_2 emissions. Calculations of the CO2 emissions were based on CO2 emission factors of 122, 377, 288 and 204 g/kWh for district heating, electricity, oil and gas, respectively, [Key2green].

4 RESULTS

For each building in the listed complex, individual feasible measures were agreed on for its energy upgrading, see Table 1.

Former measured energy consumption per year for heating and electricity is shown in Table 2. The calculated future energy demand for heating, electricity and cooling is also given in Table 2. The calculated overall reduction of the transmission loss and the calculated overall CO_2 reductions, including achieving a thermal environment level in Category C are shown in Table 3. Table 3 also shows the calculated overall CO_2 reductions compared with the former use and former layout of the individual buildings. Calculated impacts of the individual measures for the energy upgrading were found by comparing calculations made using the reference model.

Table 2. Energy consumption in [MWh] per year.

	Supervisor's residence	Half-timbered building	Office building	Monopitch roof building
Former measured consumption for:				
Heating	28.39	99.44	97.09	57.78
Electricity	23.94	40.86	96.85	26.57
Calculated future consumption for:				
Heating	8.67	39.58	99.91	30.71
Electricity	22.69	64.61	68.92	22.95
Cooling	5.78	14.78	13.82	6.69

Table 3. Calculated overall reduction in transmission loss and CO_2 emissions.

	Supervisor's residence	Half-timbered building	Office building	Monopitch roof building
Transmission loss	27%	57%	20%	39%
CO_2, incl. Class C	20%	17%	24%	17%
CO_2, in relation to former use	6%	-20%	20%	20%

5 DISCUSSION

The overall transmission loss and the CO_2 balance between the base model and the reference models with and without implemented feasible energy-upgrading measures shown in Table 1 were calculated. Furthermore, the CO_2 balance between the base model and the reference model with the implemented feasible energy-upgrading measures was calculated. The base model represents the former conditions and the use of the individual buildings prior to the energy upgrading.

For the supervisor's residence, calculations show a reduction in the overall transmission loss of 27% and an overall CO_2 reduction of 20%, thus achieving a Category C thermal environment. Compared with the building's former use and former layout, the reduction is 6%.

For the half-timbered building, calculations show a reduction in the overall transmission loss of 57% and an overall CO_2 reduction of 17%, thus achieving a Category C level for the thermal environment. However, due to the changed function of the building and the obtained Category C for the thermal environment the CO_2 consumption increased by 20% compared with the building's former use and former layout. Due to thermal climate considerations, it was necessary to add a significant cooling capacity to cool the canteen and meeting facilities on the ground floor.

For the office building, calculations show a reduction in the overall transmission loss of 20% and an overall CO_2 reduction of 24%, thus achieving a Category C for thermal environment. Calculations showed the need to add a substantial cooling capacity to the building as the occupant density in this building was increased to a much higher level than in the other buildings. For the half-timbered building, creating a Category C for thermal environment for the office building had a negative effect on the actual CO_2 savings. Compared with the building's former use and former layout, the reduction is 20%.

For the monopitch roof, building calculations show a reduction of the overall transmission loss of 39% and an overall CO_2 reduction of 17%, thus achieving a Category C for thermal environment. Compared with the building's former use and former layout, the reduction is 20%.

Calculations of the whole renovated listed complex showed an overall CO_2 reduction potential of 18% compared with the former use of the complex. However, the energy used to achieve an acceptable working environment with a Category C for thermal environment, was seen to result in a total CO_2 reduction, calculated to be 7.8% as a result of the distribution of facilities among the individual buildings. However, the indoor climate level was raised from an unacceptable level to a Category C level. By rearranging the layout, room was made for another 40 workstations.

Measurements were implemented showing the necessary respect for the core heritage values of the complex, while not compromising identified heritage values. A building envelope permeability test [ISO 9972:2006 2006] showed large concentrated leaks in the building envelope resulting in heavy heat loss and indoor climate discomfort in the form of draughts and asymmetrical temperature distribution in the individual rooms in the buildings. To establish an airtight building envelope was one of the main energy-upgrading measures.

6 CONCLUSIONS

On a global scale, measures to mitigate the effects of climate change have focused on the reduction of CO_2 emissions. Therefore, it is crucial to quantify how great a potential heritage buildings possess in relation to mitigating climate change impacts while not compromising heritage values. Studying an extensive energy upgrading of the listed complex, Fæstningens Materialgård, has shown feasible energy-upgrading measures and quantified the reduced CO_2 emissions. The study shows that it is possible to improve the indoor climate of heritage buildings while not compromising identified heritage values, thus decreasing the energy consumption for heating and comfort and thereby remaining part of the attractive building stock. However, the cost of implementing the energy-upgrading measures was not quantified as this case study was carried out as a pilot project to identify feasible energy-upgrading measures and quantify the reduced CO_2 emissions.

Calculations of the whole renovated listed complex showed an overall CO_2 reduction potential of 18%. However, the energy used to achieve a workspace with the classification of Category C for thermal environment [Danish Standards 2005] was seen to result in a total CO_2 reduction, calculated to be 7.8%. However, the indoor climate was raised from being not classified (having an unacceptable level) to being classified Category C. By rearranging the layout, room was made for another 40 workstations. Furthermore, measurements of the building envelope permeability showed that creating an airtight building envelope is one of the main issues when energy upgrading heritage buildings.

Apart from resulting in a large heat loss, air infiltration also creates indoor climate discomfort in the form of draughts and asymmetrical temperature distribution in the individual buildings.

The renovation and energy upgrading of the listed complex, Fæstningens Materialgård, have shown that the primary planning including the function of a heritage building is crucial to the gained energy and CO_2 savings. Especially, the location of service facilities like the canteen and meeting facilities is important. These facilities can initiate the need for a significant cooling load that might influence the expected savings in CO_2 negatively.

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