EFFICIENT ENERGY FOR EU CULTURAL HERITAGE

D 6.2 Documentation of each study case

CS4 The Material Court of the Fortress, Copenhagen (Denmark)

Delivered at M42

EUROPEAN COMMISSION

DG Research and Innovation

Seventh Framework Programme

Theme [EeB.ENV.2010.3.2.4-1]

[Compatible solutions for improving the energy efficiency of historic buildings in urban areas]

Collaborative Project – GRANT AGREEMENT No. 260162

Technical References

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0 Case study presentation

0.1 Brief description of the building

The Material Court of the Fortress consists of four very different buildings. The one analyzed is Building No. 4. Building No. 4 is shaped like a rectangle with the length of 51 meters, width of 10.5 m, and the height of the building is 7.5 m from the ground to the eaves.

The roof is pitched at an angle of 45 degrees. To the south-west it has a half-hipped gable and to the north-east a full gable. There is a firewall in the middle of the building, and 13 dormers facing the courtyard and 11 dormers facing Christians Brygge.

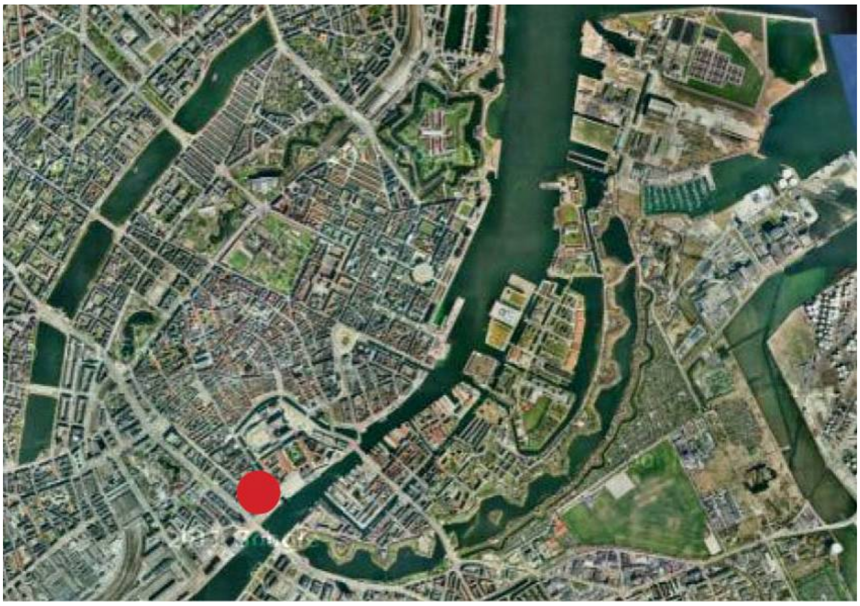
The restoration project has been an ambitious restoration project, aiming at reducing the building’s energy consumption and CO2 emission without violating the heritage value of the building.

The restoration was done by uniting different building advisors. Together they developed a process plan which made it possible for everyone to contribute and give input from their respective fields; building physics, heritage value, architecture, energy consumption and CO2 emission. All different aspects were considered and weighted relatively against each other. This multidisciplinary process is the primary reason for the inclusion of The Material Court of the Fortress in 3ENCULT.

In addition, the interventions that have been implemented in the case study, new coated glass, increased building tightness, natural ventilation, cooling and heating with fan coils and decentralized hot water production, have been analyzed in relation to the building's history, architecture, and energy consumption.

Material Court of the Fortress

Source: Photo by KA

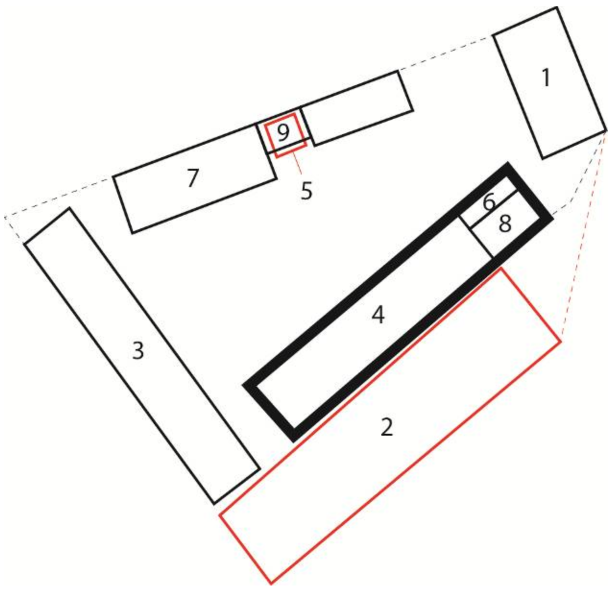


Central Copenhagen. Material Court of the Fortress building is marked.

Source: Google Earth

Material Court of the Fortress building context

Source: Google Earth



Diagram, The Material Court of the Fortress

1 Keeper´s residence

2 Warehouse (not existing)

3 Warehouse

4 Warehouse

5 Lime Pit (not existing)

6 Extension

7 Warehouse

8 Extension

9 Middle Building

Source: Varmings Tegnestue. (2008). *Fæstningens Materialgård, Program.*

Graphic: Christoffer Pilgaard

Object Name: CS4 – The Material Court of the Fortress	
Location	
Country	Denmark
City	Copenhagen
Altitude	5 meters above sea level
Heating days	240 (from the first of October to the first of May)
Heating degree days	2906
History	
Date of construction	1768, extended: 1819 and 1889
Construction Type (according to its age)	Brick constructed with timber roof, can be old wood columns in bearing centre wall.
Original use and functional	Storage, Housing and Office
Current use	Offices in all buildings
Expected use in future	Offices
General description	
Architectural style	New Classicism
Construction materials	Bricks and timber
Overall conservation status	Fine - after an almost finished total restauration and refurbishment
Urban Context	
Quarter/town	Center of Copenhagen
Development plans	
Key figures as e.g. % of historic buildings, renovation rate	The whole building complex is listed by the Heritage Agency of Denmark. There is approximately 9000 building in Denmark with this Classification.
Cultural Value (Specific valuable aspects)	
Historical Values	- Length partition, in the middle of the building - The room structure

	- Joinery details
Design Value	CS4 is a part of a building complex in the center of Copenhagen representing a military building style with roots from 1600 in a mostly rigid classical style.
Constraint condition	Listed building according to national building conservation legislation
Building Problems (cracks, deterioration, moulds and fungi..etc)	
	High energy consumption
Planned/Proposed/Possible activities	
Diagnosis	
Planned solutions	-New coated secondary glazing -Better building thickness -Cooling by mechanical recirculation of air in rooms -Cooling where the surplus heat if disposed to outside air -Decentralized utility water production
Simulation	Builddesk, Energy labelling program Bsim (Building Simulation) PHPP

0.2 Detailed description

0.2.1 Local climate data

Local climate date (rif. Central city:)	
(building plan showing the north)	Climate zone: Coastal Temperate Climate
	Climate area:
	Degree days: 3900 per year
	Altitude: 5 meters above sea level
	Coordinates: Lat N55"40' - Long E 12° 35'
	Average wind speed: 5,7 m/s
	Prevailing wind direction: West
Winter climate data N	**Summer climate data**
Winter design temperature: 0,5 °C	Temperature: 16 °C
HR max: (95% (Nov.- Dec.))	HR: 70%
Heating days per year: 240 (15 Oct.- 15 Apr.)	Daily temperature range:
Other	Other

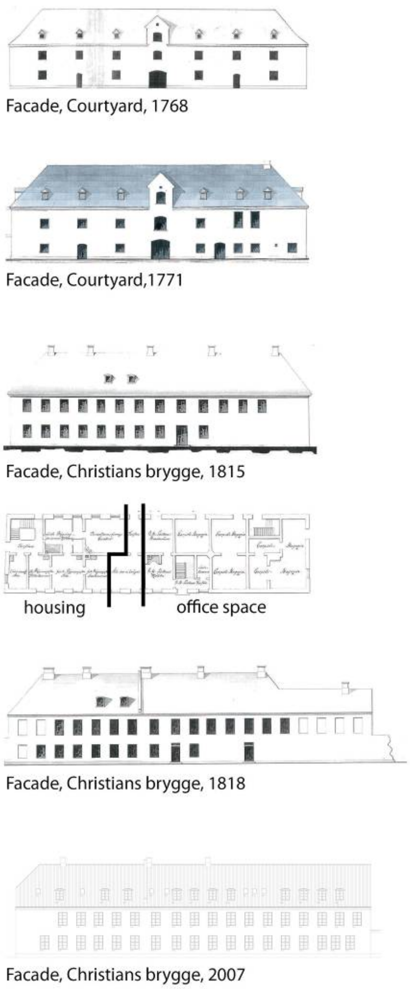
0.2.2 History of the building

The Material Court of the Fortress consists of four very different buildings.

The one analysed in 3ENCULT is building No. 4 including the additions No. 6 and No. 8 (see the diagram, page 7).

Building No. 4 was built in 1768 as a substitution for an earlier warehouse from 1683, that had to be pulled down to give space for the King's brewery. The new brick warehouse (building No. 4) was built in Classicism style with two floors, a hipped roof, and with a hoist centred on the facade to the courtyard.

In the original building there were niches in the masonry to save bricks. This construction has kept the building relatively uniform, as it has dictated the position of future windows. Today the chimneys in the building are not in use. There has been district heating in the house since the nineteen forties.



Building history

Source: Varmings Tegnestue. (2008). *Fæstningens Materialgård, Program.*

0.2.3 Building consistency

Building consistency		
	Building structure	Brick constructed with timber roof.

	Internal partition	Brick constructed
	External finishing	Plaster and lime
	Number of floors above ground	3
	Number of basement floors	0
	Numbers of rooms	Ground floor: 39 First floor:35 Second floor: 27
	Gross area	1609,5 m2 (3x536,5 m2)
	Net area	1161 m2
	Heated volume	3162 m3

0.2.4 Building Energy consumption

The building was until 2007 owned by the Danish Ministry of Defence. This owner had been very thorough logging its consumption of electricity, water and heating. Therefore there was accurate consumption data on the building from 1995 to 2007.

Building No. 4 annual consumption during that period:

Heat 97.09: MWh, 83.8 kWh / m²

Electric equipment: 71.65 MWh, 61.8 kWh / m²

Electric lighting 25.20: MWh, 21.7 kWh / m²

These data were relevant for the analysis of the effects of the following interventions, but the data were also used for the simulation models.

1 Pre-intervention

1.1 Process

The process with an advisor team performing a multidisciplinary analysis together, has been inspiring for the 3ENCULT project. The multidisciplinary process has influenced the 3ENCULT-methodology. It is a fundamental approach to projects combining cultural heritage and energy consumption.

1.2 Conservation/culture assessment

1.2.1 Context value

The Material Court of the Fortress was built in the *Frederiksholm* area, an islet constructed around 1670 in order to strengthen the fortifications of Copenhagen. On the map you can see *Frederiksholm* 90 years after its completion.

Between the streets there are five construction areas. The Material Court of the Fortress and the Civil Service Materials Court together make out the area furthest to the southwest. In this area the plot ratio was made smaller compared to the other areas in order to make space to store materials. The Material Court of the Fortress still has the same courtyard today. It is unique in its context regarding density. It is an oasis in a modern city of high density.

1.2.2 Cultural value

The Material Court had been placed by *Nyboder*, near the *Citadel*, but the new location by the western rampart was handy for future extensions against *Amager*, the island east of *Copenhagen*. Hence, the Material Court has played an important role in the history of Copenhagen and its value is high in relation to understand the city´s fortification.

The Danish King Frederik III initiated the plan for the area south-east of Slotsholmen Frederiksholm. Henrik Rüse, a Dutch fortress engineer and architect came to Denmark in 1661 to help with the fortress expansions. The plan for Frederiksholm included 224 rectangular sites. A Dutch example with deep gabled houses and courtyards. In the final plan there were only 80 sites

1.2.3 Architectural value

The facade is plastered and minimally decorated, with only a simple cornice. The building is ochre yellow while the cornice and window frames are white. The roof surface is covered by red tiles. Towards *Christians brygge* the building has shutters on the ground floor painted in green.

Due to the building's construction based on bays the facade has a strict rhythm. However, on the roof the rhythm is not followed by the dormers. This reveals the building's historical development.

Details inside the building such as paneled doors, brass door handles, paneled windows, wall bases, stucco and old locking mechanism in the windows have architectural value as far as they have relation to and coherence with their context.

1.3 Energy assessment

1.3.1 Simulation tools

To simulate the building energy consumption, different software programs were used such as a tool from the Danish building regulation called Be06 - BuildDesk Energy Program, a simulation tool for the building's energy consumption including heating, hot water, cooling, ventilation and electric light.

In the multidisciplinary process as described later, the Danish BSim (Building Simulation software) was used to simulate thermal indoor climate, and natural ventilation.

Later in the process the German program PHPP was used, a program which analyzes similar parameters as Be06, but with a greater level of detail. This simulation is done in order to make a more precise theoretical analysis of the energy consumption before and after the restoration job, but also to make a broad analysis of all the case studies in 3ENCULT.

1.3.2 Airtightness

A blowerdoor test was made to investigate the buildings airtightness. This was done by creating a pressure in the building at 50 Pa, corresponding to a wind speed of 10 m / s. Further investigations of airtightness were done by using thermography in the areas where there was reason to suspect leakage or low u-value of the external wall.

The study concluded that there were leaks by the windows and at the attic.

Results from Blower door test pre-intervention:

Data fra Blower Door test:

Airflow total	12328 m³/h
Measurement, Ground floor	6995 m³/h
Measurement, First floor	6297 m³/h
Measurement, Second floor	7416 m³/h

adjusted for infiltration between floors

Measurement, Ground floor	4164 m³/h
Measurement, First floor	3749 m³/h
Measurement, Second floor	4415 m³/h

Hermed fås nedenstående værdier:

Ground floor

- $n_{50} = 4{,}1\ h^{-1}$
- $w_{50} = 11\ m^3/h$ pr. m^2 ---- 3,0 l/s pr. m^2

First floor

- $n_{50} = 2{,}59\ h^{-1}$
- $w_{50} = 8{,}62\ m^3/h$ pr. m^2 ---- 2,39 l/s pr. m^2

Second floor

- $n_{50} = 6{,}45\ h^{-1}$
- $w_{50} = 12{,}65\ m^3/h$ pr. m^2 ---- 3,5 l/s pr. m^2

Blowerdoor test

Source: Photo by KA

Thermographic photography

Source: Strunge Jensen A/S. (2009). *Eksempel projekt - Energirenovering i fredede bygninger*.

2 Description of interventions

2.1 Design process

The objective of the project was to make a restoration job with interventions with focus on reducing the buildings energy consumption. The project was performed as a multidisciplinary process with advisors from different fields; building physics, heritage value, architecture, energy consumption and CO_2 emissions.

To make the process more efficient the different partners in the group had to focus on themes related to their profession:

Building owner: Impact on rental opportunities.

Heritage authority: Conservation viewpoint.

Architects: Shapes, appearance, functionality and interior design conditions.

Structural engineer: Impact on existing construction and risk assessment.

Services engineer: Energy consumption, CO_2 emissions and indoor climate.

This process is described more detailed on following pages.

2.2 Interventions

Interventions decided by the multidisciplinary process were included to the detail project. Below follows a description of each intervention.

2.2.1 New coated glass in the inside frames.

There was already attached a secondary glazing to the windows from an early renovation. Therefore there was not much energy to gain in relation to the buildings windows. It was not an option to replace the windows with new ones, because of historical and architectural qualities of the old ones. BSIM calculations showed that a coating of the secondary glazing, would have a positive impact on the buildings energy consumption.

New coated glass, inside frame

Source: Photo by KA

2.2.2 Increased building airtightness.

Gaskets were attached on the inside window frame, and a new vapor barrier was placed in the space under the eaves at the attic. These changes were done based on results from the blowerdoor test.

2.2.3 Natural ventilation by opening windows.

It was not an option to have visible ventilation or suspended ceilings, because of the building's heritage values. Since the rooms in the building are relatively small, natural ventilation was an option, a comfortable way to have individual control in each office room.

2.2.4 Cooling and heating with fan coils.

A goal of the restoration was to achieve an indoor climate at ”Level C”, DS 1752, which is lowest accepted in relation to Danish legislation. That means an indoor temperature during the summer season at 24.5 degrees plus/minus 2.5 degrees. BSim calculations of different rooms indicated occurrence of indoor temperature above 27 degrees, making cooling necessary.

The combined fan coils for both heating and cooling were encased in special made wood panels to fit the existing house.

Cooling and heating with fan coils

Source: Photo by KA

New Piping and cables under the floor

Source: Photo by Varmings tegnestue

2.2.5 Decentralized hot water production.

Decentralized hot water containers were efficient, as in a centralized system the hot water pipes would be long and heat loss would appear.

2.2.6 BMS - control of lighting, heating and cooling systems.

The electricity to the BMS system is led in cables under the floor. One criticism is that it is hard to get to the cables, if repair work is needed.

2.2.7 Floor insulation.

Since the wooden floor had to be replaced on the ground floor, it was convenient to insulate the new floor construction.

3 Post-intervention analysis

The interventions selected in the multidisciplinary process give in relation to heat loss a CO_2 saving at 26.08%, but a negative effect in terms of increasing consumption of electric lighting and cooling at 3.74% and 21.88%. Cooling was needed to achieve better indoor climate. The total CO_2 savings are expected to be 4,29% [*Eksempel projekt - Energirenovering i fredede bygninger]*.

Copenhagen Energy supplies district heating in the form of steam, where 1 ton of CO_2 corresponds to 6.8 MWh. Dong Energy supplies electricity, where 1 ton of CO_2 corresponds to 1.9 MWh. That is how the energy consumption is converted to CO_2.

A PHPP calculation post-intervention, shows savings at a *specific space heating demand* at 14%.

3.1 Consumption after implementations, readings

Due to limited time and facilities for monitoring of post-intervention consumptions the results are few and insufficient, but so far these measurements confirm the simulated data.

Reading 21.12.12: 44,30 MWh.

Reading 15.3.13: 121,19MWh.

Consumption from January, February and March due to the readings: 77MWh.

Calculation with degree days: 153MWh (77MWh*2906/1465 = 153MWh)

Degree days for a standard year in Denmark are average 2906. Degree days for January, February and Marts is 1465.

That gives a heat consumption at approx. 132 kWh/m2

4 Implementation of interventions

4.1 Multidisciplinary process, Balance of Culture and Energy

The approach was in the restoration of the Material Court of the Fortress a multidisciplinary process.

To start with the service engineer made a gross list of all the interventions they could come up with: Windows and shading, insulation and building tightness, ventilation, heating and cooling, electricity, solar thermal panels and photovoltaics as well as behavioural changes.

4.1.1 1st Workgroup meeting: Rough sorting of gross list

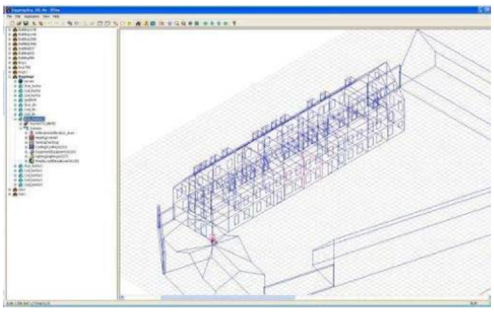
At the first workgroup meeting, the advisors had a review of the service engineer's gross list. Based on their profession, they commented on the individual interventions. This was filed in an evaluation form which each advisor completed.

It was particularly the heritage agency that didn't accept many of the interventions, because of the buildings cultural heritage. Interventions like replacement of windows, installing sun collectors and photovoltaics were not accepted..

4.1.2 2nd Workgroup meeting: Multidisciplinary analysis

The service engineer made a computer model of the building, from the knowledge of the buildings geometry, orientation, materials, and existing energy use. This model was used further in the multidisciplinary process to see the energy savings of each intervention.

The interventions which passed the first group meeting was individually inserted in the computer model to see it's energy effect. For each intervention an *element card was made*. The data was presented to the multidisciplinary team in the second workgroup meeting.



Bsim computer model

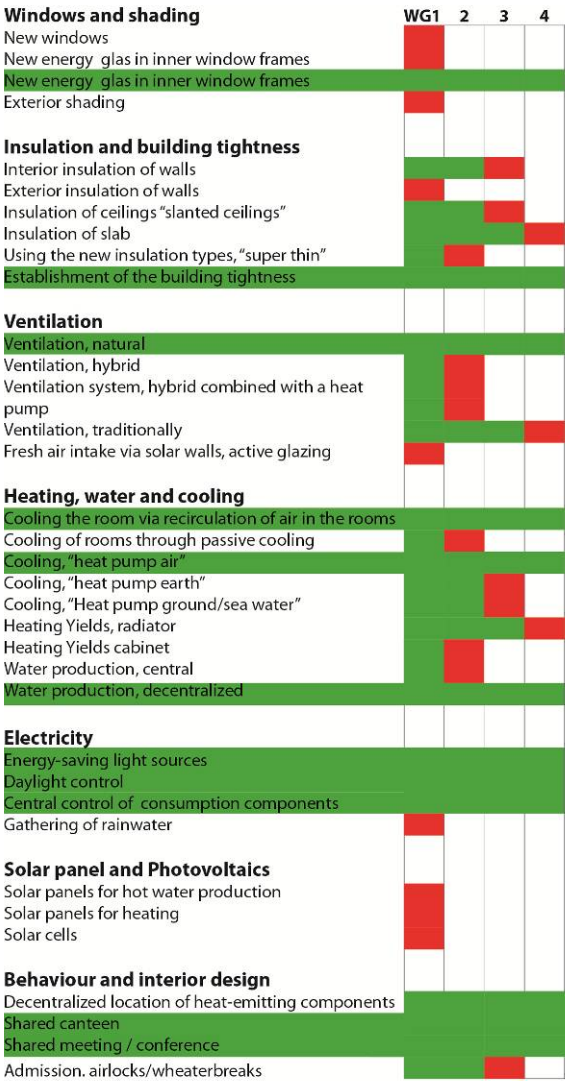
Source: Strunge Jensen A/S. (2009). *Eksempel projekt - Energirenovering i fredede bygninger*.

4.1.3 3rd Workgroup meeting: Directional selection

The different interventions as such had an impact on the building's energy consumption and CO_2 emissions, but also on the buildings indoor climate. This aspect was included in the simulation. It was decided that the indoor climate should adhere to level C, DS 1752nd (European indoor air quality standard EN15251). The buildings room temperature was added to each element card.

4.1.4 4th Workgroup meeting: Review and amendment

At last a joint simulation was made including all the chosen interventions. A review of the model, including the total influence on CO_2 savings, energy conservation and indoor air impacts was presented to the workgroup.



Gross list with the 4 workgroup meetings

Source: Strunge Jensen A/S. (2009). *Eksempel projekt - Energirenovering i fredede bygninger*.

5 Overall assessment

It is obvious that the combination of cultural heritage and sustainability affects different professions. Restoration consultants such as conservators, architects and structural engineers, and for the energy project, service engineers, electrical engineers. A multidisciplinary approach is essential as the two fields relate to many of the same building elements, but from fundamentally different perspectives. A service engineer would, for example, like to insulate the inside of a wall, but this would be unthinkable from a conservators view point if the wall surfaces is of special cultural heritage quality.

The Material Court of the Fortress gives an answer to how such a multidisciplinary process could take place - a process in which the different aspects are balanced.

6 References

6.1 Literature

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