Co$_2$olBricks

Improving the Energy Efficiency of Historic Buildings

A handbook of best practice examples, technical solutions and research projects

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Photo: Dr. Daniela Scherz, Free and Hanseatic City of Hamburg, Department of Heritage Preservation

Preamble

This brochure, *Improving the energy efficiency of historic buildings – A handbook of best practice examples, technical solutions and research projects*, gives an overview of the results that have been gained by the Co_2olBricks work group *Technical Solutions*. This group was working to achieve its goals in four main topic areas:

- Research
- Best practice example
- Technical solutions
- Pilot projects

The aim was to compile examples and results concerning energy-saving weak points and potentials of buildings with historical value. The four pilot projects have had the goal to implement, monitor and evaluate energy saving measures in historic buildings. The results of the first three topics are published in this brochure and complemented by an abstract about the output "building analysis". The pilot projects are described in a separate booklet.

In all the topics theory meets practice, meaning that the calculated energy efficiency rehabilitation measures were identified and tested under real conditions in existing buildings. The outcome is this handbook of commonly used and innovative methods which documents the experiences collected by the project partners during the selection and assessment process. It becomes clear that there are some similarities but also many differences concerning the methods and their implementation in the participating countries with their differing climate zones and types of buildings. Most of the projects were rehabilitation projects that had been implemented earlier. But Co_2olBricks also conducted some research projects itself in order to investigate certain questions, like the one concerning the effect of various internal insulation methods work in different climates and different types of buildings.

Research

In the four countries Estonia, Germany, Poland, and Sweden, research was conducted (see chapter 3). In Estonia, in the city of Kohtla-Järve, four different internal insulation materials were tested under the climate conditions of Estonia and it was analysed how they influenced the hygrothermal behaviour of the wall. Also in Estonia, in the city of

Tartu, the energy consumption for 19 buildings was assessed using real consumption data. Two of these buildings were further investigated in detail. In Germany, in the city of Hamburg, four flats in a brick building were equipped with two different heating systems and some of them additionally with internal insulation. The hygrothermal behaviour of the wall was measured under the varying weather conditions. In Poland, a historic manor house was investigated. The original refurbishment concept was evaluated and was considered to be not energy-efficient enough. So a new concept was set up taking into consideration various energy efficiency measures for historic building in order to achieve considerable energy savings. In Sweden the economically feasible energy saving potential of different measures for a large former hospital has been calculated.

Best Practice Examples

In chapter 4 a wide range of best practice examples are shown. Very different buildings are listed, ranging from a castle from the 16th century to a residential building from 1971. All the examples show common and new methods as well as the wide variety of different approaches used in the participating countries. One interesting point is that the small and large-scale measures which are presented show that small measures can already save a considerable amount of energy without touching the structure of the building.

Examples of technical solutions

In chapter 5 an introduction to the main aspects of certain energy saving possibilities such as insulation, shading systems, ventilation, heating systems and home automation is given. The aim was to find and present measures whose implementation does not alter the historic building itself. The authors of the examples describe the main pros and cons of the systems which, when correctly installed, can save considerable amounts of energy.

Building Analysis

The aim concerning the energy refurbishment of historic buildings should not be to save as much energy as technically thinkable but instead to implement as many measures as possible without destroying heritage values or, worse, damaging the historic structure completely. Therefore the rehabilitation and improvement of the energy efficiency of a historic building is much more complex than that of a 'normal' building. The last chapter deals with building analysis methods for energy-saving measures, taking into account the conservation of historical value. The common experiences are summed up in the description of a process analysis. The described process shows how, in an iterative process of assessing the historical value and technical energy saving measures, an optimal solution can be found. Optimal solution in this case means the best compromise between the improvement of the building, the preservation of the historical value, the reduction of energy use and costs and the optimisation of the buildings usability.

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CONTRIBUTING TO A FLAGSHIP PROJECT OF THE STRATEGY

› The goal of the project is to identify measures by which the energy consumption, and hence the CO_2 emissions, of historic brick buildings can be reduced without destroying their historical value. ‹

1. Introduction

Financed by the European Union through the INTERREG Baltic Sea Region Programme 2007–2013, the Co_2olBricks project started its work at the beginning of 2011, and by the end of 2013 it will have compiled the results in the main work groups: Policy Development (WP3), Technical Innovations (WP4) and Education and Economic Promotion (WP5).

The goal of the project was to identify measures by which the energy consumption, and hence the CO_2 emissions, of historic brick buildings can be reduced without destroying their historical value. For this purpose, 18 partners from nine countries with ten languages came together to commonly investigate various technical solutions, the judicial and financial obstacles involved in energy efficiency measures of historic buildings and how to improve the education of craftsmen, architects and engineers in this field. Also over 30 associated partners from all around the Baltic Sea supported the activities and results of the project. The partnership consisted of national and municipal heritage protection departments, universities, heritage protection organisations, vocational training institutions and energy agencies. The Lead Partner of the project was the Department for Heritage Preservation of the Ministry of Culture in Hamburg. Further information is accessible on the project website: *www.co2olbricks.eu.*

One of the main work groups was the group *Technical Solutions*, in which the following listed 14 partners from 8 countries were involved and have developed the current edition of this publication. They are:

Country	City	Organisation
BELARUS	Minsk	Republican Centre for Technology Transfer
DENMARK	Copenhagen	Aalborg University, Danish Building Research Institute
ESTONIA	Kothla-Järve	Town Government
ESTONIA	Tallinn	Centre for Development Programs (EMI-ECO)
ESTONIA	Tallinn	Information Centre for Sustainable Renovation NGO
GERMANY	Hamburg	Department for Heritage Preservation
GERMANY	Kiel	Environment Department
FINLAND	Helsinki	KIINKO Real Estate Education
LATVIA	Riga	City Development Department
LATVIA	Riga	Riga Technical University
LITHUANIA	Vilnius	Vilnius Gediminas Technical University

POLAND	Gdansk	European Foundation of Monuments Protection
SWEDEN	Växjö	Energy Agency Southeast Sweden
SWEDEN	Malmö	Environment Department

The other partners of Co$_2$olBricks can be found below. Almost every partner has worked in at least two work packages:

GERMANY	Hamburg	Development and Environment Department
GERMANY	Hamburg	Vocational Training Centre
SWEDEN	Visby	Swedish National Heritage Board
SWEDEN	Stockholm	Stockholm City Museum

**› First, in the following sections, all participating partners are briefly presented along with their projects.
In the second section, three of them are chosen as examples in order to show some different aspects and results. ‹**

2. Research Projects

Although EU-INTERREG Projects are normally not intensive research projects, $Co_2olBricks$ has implemented several research projects within the Technical Solutions work group. Those research projects have, for example, gathered information about thermal and moisture behaviour or the energy consumption of historic brick buildings. Therefore, in some $Co_2olBricks$ projects, special measurement tools have been installed and sometimes also innovative techniques have been examined by implementing them in the buildings. Most of the research projects were finished within the duration period of the $Co_2olBricks$ project, but some of them will continue with the monitoring and evaluation of data, and the results will be published on the $Co_2olBricks$ website in the next two years.

First, in the following sections, all participating partners are briefly presented along with their projects. In the second section, three of them are chosen as examples in order to show some different aspects and results. Further information is available on the $Co_2olBricks$ website.

Research in Estonia

The Information Centre for Sustainable Renovation (SRIK) in Tallinn has done research on a historic school building from 1938 in Kohtla-Järve, which was also one of the pilot projects within $Co_2olBricks$. The aim was an analysis of the hygrothermal performance of different interior insulation materials and a comparison of their features under the same conditions. Therefore four different insulation materials were installed on one outer wall in the same room:

- Calcium silicate panels
- Polyurethane foam board with capillary active pores
- Autoclaved aerated concrete
- Polyurethane insulation

For the measuring different tools were installed on the wall on the outside surface, on the surface of the internal insulation, and inside of the materials. Furthermore, a humidifier and a heater were implemented in the room to realise different synthetic climate conditions. The collected data have been used in a computational model for analysing the hygrothermal performance of the building envelope. The results are published on the $Co_2olBricks$ website: *www.co2olbricks.eu*.

Also in Estonia, the Centre for Development Programmes (EMI-ECO) has implemented two different research projects in Tartu. In one of these, the primary energy consumption of 19 brick buildings spread over the whole city was gathered. After a comprehensive analysis, in a second step, two buildings were selected out of the pool to be examined in detail. In these two buildings the indoor environment was monitored, and the building quality was also analysed, for example its airtight technology and its thermal bridges. The aim was to find potential techniques and tools for the renovation of stone monument buildings (for detailed results see chapter 2.4). The follow-up was an overall research project concerning examples of best practices in reducing the energy consumption of historic buildings.

Research in Germany

The Department for Heritage Preservation in Hamburg implemented research on a five-storey residential building with a brick façade built around 1930 in Hamburg-Wilhelmsburg. The study was focused on the heating systems as a main energy-saving potential in historic buildings. In the project, four flats were refurbished in different ways, but all the flats got new electric heaters in order to make the results more comparable. In the next step, a conventional heating system with radiators was installed in two of the flats; one flat with internal insulation, the other without. The other two flats got a wall tempering system; one flat also with internal insulation, one without. Special measuring tools were installed in all four flats to gather information about the energy transfer through the outer wall in relation to the humidity of the construction. These tools were installed on the wall on the outside surface, on the surface of the internal insulation, and inside of the materials. Furthermore, the energy consumption was monitored to compare the effectiveness of the different solutions. For detailed results see chapter 2.1.

Research in Latvia

Riga Technical University has done research on a specific Co_2olBricks pilot project in Riga. The aim was to gather information about available technologies for the decrease of heat consumption in a brick building and to determine the energy performance. The building is located in the city of Riga in the Spīķeri complex, an aesthetically valuable industrial site which is on the UNESCO World Heritage List. During the measurements which were done to get information about the condition of the building, the heat flow in the brick walls was determined as well as the moisture (made by dielectric moisture indicators) and the qualitative water-soluble salts. The overall energy performance of the building was also examined. On the basis of the collected data the best refurbishment strategy was identified and implemented. The results are published on the Co_2olBricks website: *www.co2olbricks.eu*.

Research in Poland

The European Foundation for Monuments Protection (EFOZ) has done some research to figure out which internal insulation technology is effective for brick monuments and how much energy can be saved. Therefore, a case study was done on a brick building – the Studzienka manor house. In the first step, existing documentation was analysed. To find out the energy consumption of the buildings, an energy audit was executed. This way of working with building under protection is not common in Poland, as it is not required by law. For detailed results see chapter 2.3.

Research in Sweden

The City of Malmö Environment Department has carried out research with Lund University and Malmö University. The study was focused on energy and life-cycle economy and the purpose was to analyse the efficiency of different measures and opportunities to enhance the energy performance of existing buildings built before 1940. The study was conducted by examining a possible alternative use of an old hospital building in Malmö from the 1930s. A simulation program was used as a tool to carry out the energy calculation. That formed the base of this study and later some on-site examinations were made to assess prerequisites such as wind exposure or incidental solar radiation. For detailed results see chapter 2.2.

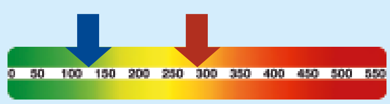
2.1 Study of 2 heating systems with and without internal insulation in the 'Passierzettel', Hamburg

/ JAN PRAHM, DEPARTMENT FOR HERITAGE PRESERVATION, HAMBURG

The building itself is not a listed building but built in the same way as many listed buildings of this kind from the same era in Hamburg; and it needs major renovations. The outer walls are generally in a bad state, with many large cracks; the heating is often with electricity. Also the windows were replaced in previous years by plastic-framed windows with double glazing.

D

Adress: Passierzettel 1, 3, 9, Am Gleise 2, Hamburg
Building type: residential building
Architect: unknown
Year of construction: 1929
Owner: SAGA-GWG
Used as: residential building
Number of floors: 5
Façade: brick
Floor space: 4,000 m²
Heated area: 2,300 m²
Cost of refurbishment: 65,000 €





Refurbishment
Start: 09.2012
End: 11.2012
Architect:
Wolfram Spehr

Material
Façade: solid brick, no air gap between inner and outer shell
Roof: flat with wood and bitumen
Windows: old double-glazed and plastic-framed
Shading system: no
Floor: board floor
Ceiling: concrete
Inner Walls: sand lime brick/slag brick
Cellar: cement, gravel, grit, concrete
Foundation walls: red brick

2.1.1 Initial situation and building condition

The building is inhabited but was neglected for a long time. Some of the flats are wet with mould. The flats have off-peak electric heating. The original wooden single glazing windows were replaced in previous years by double-glazed plastic-framed windows.

2.1.2 Possible technical energy efficiency solutions

Possible energy efficiency measures are new wooden windows, air tightening of the front door, modern heating either via district heating or combined heating and power station or central heating with renwable energies and solar thermal heating on the roof, as well the insulation of the roof and cellar or internal insulation of the outer walls, added with wall heating.

2.1.3 Implemented energy-efficiency measures

The implemented measures so far have been chosen for research reasons. The aim of that research is to investigate the hygrothermal behaviour of the outer wall under different conditions during at least one year. For this purpose four different variations of combinations of heating system and insulation were installed.
These four variants are:

- Convector heaters without any additional wall insulation; costs: 104 €/m²
- Convector heaters with 5 cm internal capillary active calcium silicate wall insulation; costs: 263 €/m²
- Wall heating without any additional wall insulation;: 247 €/m²
- Wall heating on 5 cm internal capillary active calcium silicate wall insulation; costs: 395 €/m²

Besides the energy refurbishment, the rooms were newly decorated, the bathroom modernised and the floors sanded and oiled. All flats got new electric boiler.

2.1.4 Motivation for the chosen measures

The building contains many more than these four flats and will undergo a major renovation soon. The internal insulation was chosen since external insulation was not possible because the historic brick façade should be visible in future. The electric boilers were installed since others are not available so far. The wall heating was chosen in order do the research on it. The windows and front door were kept as they are; because the main focus was to find out how the wall behaves. The insulation of the roof and the cellar was in these cases irrelevant because the flats all have another flat below and above.

2.1.5 Description of the research

The four different variants where chosen in order to find out how the walls behave under the different conditions created by the different energy efficiency concepts. The flats all face the north-west side of the building, which is the weather side, meaning the strongest impact of wind and driving rain occurs here. To measure the hygrothermal behaviour of the wall in each of the flats, measuring sensors for temperature, relative humidity and heat flow were installed in the north-west facing outer walls. Each flat has a different measuring setup depending on the energy efficiency concept. The systems are shown in detail in the picture at the end of the paper.
In the dynamic hygrothermal simulation program DELPHIN, a theoretical model of the building was created and fed with the data obtained from the building. Besides the data from the above-mentioned sensors, the input data are the physical parameters of the bricks of the wall:

- Dry gross density
- Thermal conductivity

Heating system/-production
Old: off-peak electricity heating
New: electric water boiler
Solar System: no

Building services
Electricity: new installation
Building automation: no
Water/waste water: no refurbishment

Energy consumption
Before, calculated: 343 kWh/m²/a
After, calculated: 125 kWh/m²/a
Energy saving: 63%
CO_2 saving: 68%

- Specific thermal capacity
- Porosity
- Cappillary saturation
- Water-vapour diffusion resistance
- Water intake coefficient

These paramaters were obtained in the labaratory from material samples taken from the wall, the outer shell which is from brick and the inner shell which is from sand-lime bricks.

2.1.6 Results

The exact analyisis of the wall revealed that the wall is constructed differently than assumed by the energy audit that had been made earlier. In the energy audit a U-value of the existing wall of 2.01 had been calculated. The exact analysis revealed a U-value of 1.65 which is 18 % better than calculated.
As a first result found out after six month of measuring during winter and spring: 5 cm internal capilary active calcium silicate decreased the U-value of the wall from 1.65 to 0.74 which means an improvement of 55 %, or 63 % better than the value of 2.01 calcuated in the energy audit. This shows very clearly how big the differences can be between the U-values calculated from standard parameter values compared to U-values calculated from exactly measured values.
The next question we were interested in was to what extent does the humidity of the wall influence the U-value of these specific walls. The main answer to this question is that for a wall which is not insulated, humidity of up to 90 %, the U-value hardly changes, and even with a humidity of 100 %, the U-value increased only by 4 %. It looks a bit different for the walls insulated with calcium silicate. Here as well, for wall humidity of up to 60 %, the U-value does not increase very much (from 0.74 to 0.76 = 2.7 %). But above 60 % humidity, the U-value increases rapidly, to eventually 1.3 for humidity of 99 %, which is an incrase of 75 %. So a dry wall is very important when it gets extra insulation.
As a third aspect, the variation of the heat flow in interdependence with the temperature difference between inside and outside was investigated. In the case of the wall observed, the heat flow was high when the wall was cold and the heating was started, because a lot of energy was needed to heat up the wall. While the wall was heated, the heat flow decreased until a constant stable heat flow was achieved.
The full report can be downloaded from the Co$_2$olBricks website *www.co2olbricks.eu*

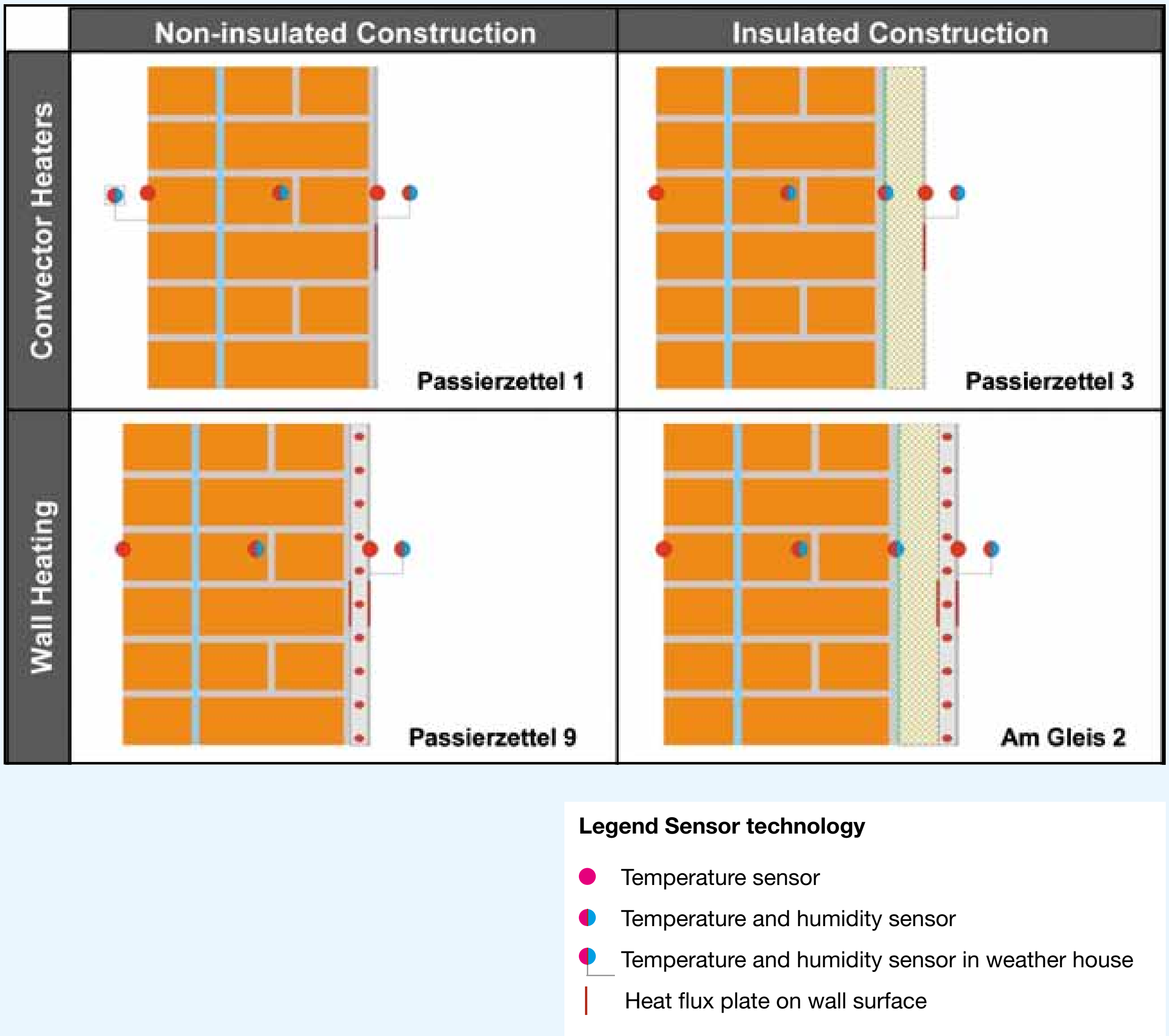


Figure 0: Placement of sensores of the different measuring lines

2.2 Study of energy efficient measures – a life-cycle perspective, Malmö

/ DR. STEFAN OLANDER, CONSTRUCTION MANAGEMENT, LUND UNIVERSITY
/ SIMON SIGGELSTEN, URBAN STUDIES, MALMÖ UNIVERSITY

2.2.1 Introduction

A central issue from a sustainability and climate perspective is how existing buildings can be refurbished in an efficient manner from a variety of perspectives. This study will focus on energy and life-cycle economy. However, the assessment of a refurbishment project and its performance will need to be based on multiple criteria such as technical function, economy, environmental issues, social issues and cultural issues. The purpose of this study is to analyse the efficiency of different measures and opportunities to enhance the energy performance of existing buildings built before the 1940s. The object of the study was a building in Malmö that was earlier a hospital and a psychiatric ward and was built in the 1930s. The following measures were analysed:

- Demand-controlled ventilation
- ESX-ventilation with plate heat exchanger
- Recirculation of heat from ventilated air and heat pump
- Supplementary insulation of the attic
- Supplementary insulation of external walls
- Energy-efficient windows
- Radiators shut off automatically when opening windows
- Solar collectors for pre-heating radiators and hot water
- Individual measuring and charging of hot water
- Recycling of heat from waste water

The study was conducted by examining a possible alternative use of that old hospital building; and it was assumed to be multi-family housing. After studying the drawings, the building was assumed to have the following aspects: a total possible net floor area of 1,120 m^2 and a subsidiary usable area, consisting of corridors and staircases of 250 m^2. This is equivalent to 28 two-room apartments of 40 m^2 each. The ventilated room volume is then 4,521 m^3 (1,370 m^2 x 3.30 m). A simulation program, VIP-Energy, was used as a tool to carry out the energy calculation that forms the basis of this study. General climate data from the Swedish Meteorological and Hydrological

Institute (SMHI) for Malmö was used to assess the external climate factors that affect energy usage. Examination on site was made to assess prerequisites such as wind exposure, incidental solar radiation and shadowing effects. Heating needs are based on a period of six months from October to March.

2.2.2 Analysis of energy-efficient measures

Ventilation

The main task of ventilation is first and foremost to remove the moisture and pollution which is produced in buildings. The Swedish building code (BBR) published by The Swedish National Board of Housing, Building and Planning has standard requirements for housing of a ventilation flow and an air change rate of at least 0.35 l/sm² applicable for both an entire flat as well as a single room. If demand-controlled ventilation is being used it is allowed to decrease the ventilation flow to 0.10 l/sm² when no one is present in the room or flat. According to Warfvinge and Dahlblom (2010) there is an existing praxis concerning ventilation flows that is based on earlier recommendations from The Swedish National Board of Housing, Building and Planning. Figure 1 is an extract from these recommendations.

Figure 1: Recommendations for ventilations flows

Type of space	Minimum exhaust airflow rate
Kitchen	10 l/s plus forcing
Kitchenette	15 l/s *
Bath or shower room with opening windows	10 l/s *
Bath or shower room without opening windows	10 l/s plus forcing *
Toilet	10 l/s
Cleaning room	3 l/sm², dock min 15 l/s
Laundry and drying room	10 l/s *

* If the floor area exceeds 5 m², the exhaust airflow rate should be increased by 1 l/sm².

If the ventilation flows from the table above are being followed it means that the air change rate can be considerably higher in small flats in comparison to the requirements of the BBR. As an example, a flat of about 40 m² has a requirement from the BBR of an air change rate of 40*0.35 = 14 l/s. Extract air in the flat would then occur in the kitchen and the bathroom with a minimum exhaust airflow rate of 10 + 10 l/s, an excess ventilation of 6 l/s. A one room apartment of about 30 m² with a kitchenette would have a minimum requirement of 30*0.35 = 10.5 l/s, while the real air change rate according to figure 1 would be 10 + 15 = 25 l/s, two-and-a-half times the minimum requirement. There are opportunities to control the ventilation flow with sensors that measure the relative humidity and the level of carbon dioxide. The result of this, for the one room flat of 30 m^2 is that when nobody is home the actual air change rate is 30*0.10 = 3 l/s, compared to 25 l/s.

Calculation 1

An extract air ventilation system without any recycling of heat and without any demand control: The air change rate for the entire building then becomes 650 l/s (28 x 20 l/s + 250 x 0.35 l/sm^2). The energy losses due to ventilation then become 61,450 kWh per year.

Calculation 2

Demand-controlled ESX-ventilation with plate heat exchanger and an efficiency of 60 %: In this case the presence of people in the rooms plays a significant part when assessing the energy losses due to ventilation. The following assumptions were made:

Weekdays 10h absence a day	0.10 l/sm^2
Weekends 5h absence a day	0.10 l/sm^2
2h a day with full ventilation	20 l/s/lgh
Remaining time	0.35 l/sm^2 (14 l/s/lgh)
Staircases and corridors	0.10 l/sm^2

The savings compared to calculation 1 then amounts to 43,500 kWh per year, a reduction of 70 %. The benefits of a plate heat exchanger in combination with ESX and demand control is 15,450 kWh per year. There is no demand-control system.

Extract air ventilation system with recycling of heat

If an extract air ventilation system is used instead of an ESX system it is not possible to use a plate heat exchanger. Instead, a liquid-based recycling system can be used which has approximately the same efficiency as a plate heat exchanger, which means that the recycling effect is unchanged. The system allows for the exhaust air fans to be placed in the attic while the heat pump is placed in the basement. This system is quite commonly installed when refurbishing old buildings. The energy losses due to ventilation, then minus recycling, become 32,000 kWh per year (61,450 – 29,250 kWh), a reduction of 50 %.

Supplementary insulation

If supplementary insulation is incorrectly installed there is a high risk of damage due to unwanted moisture effects. In less insulated walls/roofs the temperature difference through the wall/roof becomes relatively high. If supplementary insulation is added, the temperature on the outer part of the wall/roof drops. The benefits of supplementary insulation depend upon the amount of existing insulation. For a reduced U-value of 50 % the thickness of the insulation needs to be doubled.

Supplementary insulation of the attic

There is currently no exact measure of the existing layer of insulation in the attic of the building which was studied. However, an assumption can be based on the amount of insulation in similar buildings in the same area, which is 200 mm. An increased layer of insulation, by 200 mm of insulation, only gives a small savings effect of 3,600 kWh per year.

Supplementary insulation of external walls

The external walls are built with a 300 mm brick wall with plaster on both sides. The U-value is 1.17 W/m^{2}K. Supplementary insulation on the inside results in a lower temperature for the brick wall, with a higher risk of frost damage. However, due to construction of the wall this scenario is unlikely. For a supplementary insulation on the outside the facade needs to be re-plastered, which affects the external appearance of the building. Regardless, if the supplementary insulation is made on the inside or the outside an additional layer of 100 mm of insulation ($\lambda = 0.036$) will decrease the U-value to 0.28 W/m^{2}K, resulting in a decreased energy usage of 46,000 kWh per year.

Windows

The share of the energy loss due to windows is quite substantial. However, there is great variation depending on different factors such as the number of windows, their size and U-value. Figure 2 shows a window from the building which was studied. The window is divided into four parts with window bars. Because the window has the highest U-value around the casing frames, these types of windows are not a good solution from an energy-saving viewpoint. Further, the windows are single-glass windows and the estimated U-value is 3.0 W/m^{2}K.

Figure 2: Existing window from the building studied

Calculation

The existing window area is about 265 m². This area is estimated from on-site observations in addition to existing drawings. In the first calculation, the U-value is estimated to be 3.0 W/m²K for the existing windows. An additional calculation was made on the premise that the existing windows will be changed to more energy-efficient ones with a U-value of 1.4 W/m²K in alternative 1 and a U-value of 0.9 W/m²K in alternative 2.

- Existing windows (single-glass): Transmission losses 62,500 kWh per year
- Alternative 1 (two glasses): Transmission losses 29,300 kWh, reduced by 33,200 kWh per year
- Alternative 2 (three glasses): Transmission losses 18,900 kWh, reduced by 43,600 kWh per year

Further, the window change will probably reduce the effects of cold downdraught, which will enable the radiator system to work with lower temperatures, which further increases the energy-saving effect.

Radiators shut off automatically when opening windows

Under normal circumstances and functional ventilation there is no need to open windows for airing. Airing by opening windows during the season where additional heating is needed has a major effect on the energy usage. The calculations in this chapter are all interpreted from Jensen (1999). The airflow rate is different depending on whether the airing is one-sided or double-sided. For double-sided airing there is a need for a flat which stretches through to the other side of the building. The airflow rate depends on the wind pressure and wind direction. After studying the drawings it was assumed that no flats stretching through to the other side of the building will be possible; the flats will have to be placed on different sides of a corridor. Thus only one-sided airing will be possible, where it is mainly the temperature difference between inside and outside that affects the airflow rate. The higher the temperature difference, the higher the airflow rate. With a temperature difference of 20 °C between outside and inside and a partially open window of 0.1 m^2 the airflow rate becomes 17 l/s (Jensen, 1999).

Calculation

With an inside temperature of 21 °C and a daily medium temperature outside of 2.7 °C, the airflow rate becomes 16 l/s. If this occurs every night for ten hours for one flat, the increase in energy usage will be 700 kWh. Even if there is a function that shut off heating when a window is opened, some energy loss is still inevitable. To completely avoid energy loss when airing may not be possible, however, a system that automatically shuts off will probably affect the behaviour of the users and airing will decrease.

Solar collectors for pre-heating radiators and hot water

Vacuum-based solar collectors have the highest efficiency; however plane solar collectors are more cost effective. According to manufacturers, the effect is approximately 500 kWh per m^2 solar collector and year. Solar collectors have been further developed technically over the last few years, which have made them both more efficient as well as more cost effective. However, solar collectors are still relatively expensive and it is important not to over-estimate the system installed. Although solar collectors can give additional heat to the radiator system, there is variance over time. Capacity is highest in the summer when the need is low, and lowest in the winter when the need is high. However, for hot water there is an effect all year around.

The municipal housing company in Lund (LKF) has installed solar collectors for pre-heating hot water in one of the properties (Boo, 2005). They installed

0.05 m² of solar collectors per m² living area, or 3.2 m² per flat. The same circumstances for a future refurbishment of the building that was studied would amount to the installation of 56–90 m² of solar collectors (28 flats of 40 m² each. However, Dahlenbäck (2004) states that the need can be up to 3–5 m² for each flat, which would mean a range from 84–180 m². The Fullriggaren rental house in Gävle, that was awarded a prize for facility of the year by Svesol in 2011, has 29 flats and 80 m² of solar collectors. Based on the arguments above, the recommendation for the building that was studied is 80 m² of solar collector for 28 flats of 40 m² each. The solar collectors for the LKF property mentioned above have had a measured energy gain of 312 kWh per m² and year (2001–2003), which is less than the planned effect of 397 kWh per m² and year (Boo, 2005). The installation was plane solar collectors with a gradient of 45 degrees and facing a southerly direction. Another project in Lund has plane solar collectors with a gradient of 33 degrees. The system was divided into two parts, one facing south and one facing west. The one facing south had an energy gain of 290 kWh per m² and year, the one facing west gave 185 kWh per m² and year (2001–2003) (Boo, 2005).

According to the drawings, the roof of our building studied had a gradient of 30 degrees. This gradient is relatively small and a device that increases the possible gradient of the solar collectors may be needed. Further, the roof faces southeast, which is not optimal. With regard to the lessons learned from the projects described above, the potential energy gain has been assessed to range between 300–400 kWh per m² of solar collectors. With a total solar collector area of 80 m² the total energy gain would be between 24,000–32,000 kWh per year.

Individual measuring of hot water

Individual measuring and charging of hot water is generally profitable for the property owner. There are a number of studies that show a significantly reduced use of hot water from 15 % up to 30 % and sometimes up to 50 %. However, there are examples where no reduced use has been observed, this is often the case when the economic incentive for saving by the individual tenant is low. Statistics from the Swedish Energy Agency show that the use of hot water per person in a flat is 58 l per person and day, while the same figure is 42 l per person and for a single family home. Hence, the one that directly pays for their hot water, which is the case for single family home, uses less than if the use of hot water is part of the rent. Based on a reduced usage of hot water from 58 to 42 litres per person and day and 1.2 person inhabiting each apartment, the energy saving will amount to 12,750 kWh per year.

Recycling of heat from waste water

Although the technology is available, it is uncommon that heat is recycled from waste water. How much energy it is possible to extract from waste water can vary greatly depending on the usage of hot water and the type of heat pump. Based on a hot water usage of 58 l per person and day and an efficiency of 60 %, the theoretical contribution would be 23,500 kWh for one year. With a hot water usage of 42 l per person and day the theoretical contribution would be 17,600 kWh for one year.

2.2.3 Preliminary life cycle profit analysis

The definition of life cycle profit (LCP) is a collective assessment of investment, running and maintenance costs for an object in relation to the benefits that this object creates during its economic life span. The discounted net present value method is necessary in order to assess the consequence of the rate of return on invested capital.

The role of the calculated rate of return

$$LCP = \sum_{t=1}^{n} \frac{R_t - C_t}{(1+r)^t} - I + \frac{RV_n}{(1+r)^n}$$

I = Initial investment cost
R_t = Revenues year t
C_t = Costs year t
RV_n = Residual value after n years
r = Calculated rate of return
n = Economic life span

Because the economic life cycle assessments are often based on net present values, their assessed calculated rate of return will have a large impact on the results. A high calculated rate of return tends to favour alternatives with low initial investment cost, while a low calculated rate of return has the opposite effect. Thus, it is of importance to carefully assess a suitable calculated rate of return for the analysis at hand based on internal rate of return and risk assessments with the organisation that is the subject of the analysis and for different types of measures.

2.2.4 Life cycle profit analysis for energy efficient measures in the building studied

This analysis is based on the following conditions:

- All measures are assumed to have a lifespan of 50 years
- No residual value after 50 years
- Energy savings is the only factor affecting future revenues
- The price of energy for 2012 is assessed to be 0.75 SEK per kWh
- The annual price change is assessed at 2 %
- The calculated rate of return is set to 6 %
- The calculation is made to assess the maximum investment possible to achieve a profit level of 6 % (calculated rate of return)

The analysis is made as a preliminary calculation where the LCP is set to zero and then the maximum initial investment cost has been calculated in order to assess the framework that future investment must be within in order to be profitable (based on the above conditions). Thus, based on the energy gains assessed in the previous chapter, the following maximum initial investment constitutes the framework of the energy efficient measures that have been proposed.

$$LCP = \sum_{t=1}^{50} \frac{R_t - C_t}{(1+6\%)^t} - I + \frac{0_n}{(1+6\%)^n}$$

$$LCP = 0 \rightarrow$$

$$\sum_{t=1}^{50} \frac{R_t - C_t}{(1+6\%)^t} = I$$

Ventilation

With present conditions as a starting point, e.g. an extract air ventilation system without any recycling of heat and without any demand control, an investment to demand controlled ESX-ventilation with plate heat exchanger will amount to an energy saving of 43,500 kWh per year, which allows for a maximum initial investment cost (I) of 696,000 SEK.

Supplementary insulation

Supplementary insulation of the attic enables an energy gain of 3,600 kWh per year, which allows for a maximum initial investment cost (I) of 58,000 SEK. For supplementary insulation of external walls the energy gain is 46,000 kWh.

Windows

Alternative 1 with a U-value of 1.4 will save 33,200 kWh of energy usage and alternative 2 with a U-value 0.9 saves 43,600 kWh. This allows for a maximum initial investment (I) of 532,000 SEK for alternative 1 and 698,000 SEK for alternative 2.

Solar collectors

If the energy gain is assumed to be between 300–400 kWh per m^2, the savings in energy usage will amount to 24,000 – 32,000 kWh. This allows for an initial investment cost of 384,000 – 512,000 SEK.

Individual measuring and charging of hot water

Based on the possible reduced water usage from 58 to 42 litres per person and day and 1.2 persons per flat in average, the energy gain will amount to 12,750 kWh per year.

Recycling of heat from waste water

Based on a hot water usage of 58 l per person and day and a efficiency of 60 %, the theoretical energy gain will amount to 23,500 kWh per year. If the hot water usage can be reduced to 42 l per person and day (see above) the energy gain will be 17,600 kWh per year. This allows for an initial investment cost (I) of 282,000 – 376,000 SEK.

2.2.5 Further studies

The forthcoming evaluation of this refurbishment project will focus on the following:

- How is a calculated rate of return to be assessed with respect to climate change and sustainability as well as profit demands on invested capital?
- How can various criteria relevant for assessing energy efficient measures be evaluated in the decision process of the real estate owner?
- How is the feasibility of energy efficient measures evaluated with respect to function, technology, financing, quality and sustainability?

The input for this work will be based on the investigation and choices made by the real estate owner in the forthcoming stages of the refurbishment project. Together with interviews with different actors, various decision criteria will be identified and analysed. Further calculation of investment for various alternative solutions will be the basis for an updated analysis of the economic life cycle.

2.2.6 References

Boo, S. 2005, *Solvärme för flerbostadshus i Lund och Dalby*, Installationsteknik, LTH

Jensen, L. 1999, *Utvärdering av Hälsningborgshems system för komfortdebiering* Installationsteknik, LTH

Warfinge, C. Dahlblom, M. 2010, *Projektering av VVS-installationer*, Studentlitteratur, Lund

2.3 Energy audit of ‘Studzienka’, a historical Manor, Gdansk

/ KRYSZTOF KOBYLINSKI, EUROPEAN FOUNDATION FOR MONUMENTS PROTECTION, GDANSK

2.3.1 Building description

The building is a manor dated between XVII and XVIII century which belonged to Albrecht Bischoff as a summer residency with a garden. In 1973 the building was entered into the registry of monuments and got the status of a protected building.

The purpose of an energy audit for the building (Stage I):

- To examine existing energy efficiency for all elements, including: walls, floor, doors, windows and roof
- To examine existing heating appliances, hot water and ventilation systems
- To suggest methods and materials that gives a satisfactory thermal performance for the renovated building according to the renovation project

Building elements		temperature conditions [°C]	U-value [W/m²K]				Difference [%]			
			Present		required WT2008, dwelling	required WT2008, public building	dwelling		public buildings	
			moderate moisture conditions	high moisture conditions			moderate moisture conditions	high moisture conditions	moderate moisture conditions	high moisture conditions
Walls (external):	**ground floor 1 (thickness 47–50 cm)**	>16 °C	1.36	1.54	0.35	0.35	289	340	289	340
		≤16 °C	1.36		0.92	0.75	48	67	81	105
	ground floor 2 (thickness 59–68 cm)	>16 °C	1.12	1.27	0.35	0.35	220	263	220	263
		≤16 °C	1.12		0.92	0.75	22	38	49	69
	first floor (thickness 30–35 cm)	>16 °C	1.79	1.99	0.35	0.35	411	469	411	469
		≤16 °C	1.79		0.92	0.75	95	116	139	165
Floors	**Floors over basement 1**	basement not heated	1.12	1.28	0.52	0.52	115	146	115	146
	Floors over basement 2	basement not heated	1.04	1.2	0.52	0.52	100	131	100	131
	Floors over ground	Basement not heated	0.41	0.41	not required	not required	/	/	/	/
Roof		>16 °C	2.81	3.08	0.29	0.29	869	962	869	962
		8–16 °C	2.81	3.08	0.58	0.58	384	431	384	431
Windows		>16 °C (climate zone I)	3.50	3.50	1.80	1.80	94	94	94	94
		8–16 °C	3.50	3.50	N/A	2.60	N/A	N/A	35	35
Doors			3.00	3.00	2.6	2.6	15	15	15	15

2.3.2 Summary and conclusions

The analysis proved that the technical solution proposed for the building (construction design from 2005) needs to be verified because it is unsatisfying from the perspective of energy saving and thermal insulation and, if used, the proposal will result in high heating costs. According to the calculation, heating demand for the building (heating and hot water) and the heating energy costs for the building as designed, will be the following:

1	Calculated demand for thermal power	82 kW
2	Demand for thermal energy	770 GJ/a
3	Costs annually	54,752 PLN/a

The proposed design has not sufficiently used all available opportunities for improvement of walls, thermal insulations and for obtaining high efficiency from the heating system. Although the building is historical, it is highly recommended to seek (as far as possible) the best available energy quality and to minimize maintenance costs for the future user.
The technology of the additional thermal insulation of the external walls proposed in the construction design (insulation from the inside with YTONG PP2/0.4 blocks) does not protect the walls against condensation. Although the walls have been properly designed against mildew development (no surface condensation), there can still be condensation between the layers of insulation with the existing wall (the humidity is expected to evaporate during summer). It is technically permissible for the steam to condensate inside the wall barrier during winter, provided that the structure of the wall will enable evaporation during summer with no resulting deterioration of the building materials. Although it is technically permissible, this case is special because the building has historical value, it is old and the technical condition of the existing walls is not satisfying. The inter-layer condensation may provide a risk of further deterioration of the construction materials in the external walls on the first and second floor, and in this case the risk should be eliminated by re-design of the wall.
This paper presents suggestions for verification of the present proposal for design and shows opportunities how to significantly improve the thermal insulation of the walls and how to increase heating efficiency of the building. The calculation model developed for the building considers the proposed improvements of the building structure and of the thermal sources and installation. Recommended materials are:

- External walls to be insulated with the following systems, as Eurothane G (5–6 cm), or YTONG MULTIPOR blocks (10–12 cm)
- Floor over basement to be insulated from the basement side with spray polyurethane foam IZOPIANOL 03/35 N
- Roof insulation, as mineral wool
- Windows with anU-value 1.90 W/m²K at wall level and an U-value 1.80 W/m²K at roof level
- Doors, with an U-value 2.60 W/m²K

The proposed improvements will provide a significant reduction in the thermal demand of the building and will result in cost savings. According to the calculation, heating demand of the building (heating and hot water) and the heating energy costs for the building after the proposed improvements will be following:

1	Calculated demand for thermal power	74 kW
2	Demand for thermal energy	584 GJ/a
3	Costs annually	38,746 PLN/a

The proposed improvements will give the following energy and economic results, compared to the solutions proposed in the current construction design:

1	Savings of thermal energy	185 GJ/a 25 %
2	Savings of heating costs and of hot water	16,005 PLN/a 29 %

The paper provides an analysis of the currently used thermal insulation of external walls in historical buildings: climate boards, IQ-THERM, EUROTHANE and Ytong Multipor blocks. The analysis was made from the perspective of additional internal thermal insulation of the external walls on the first and second floor of the building. The comprehensive analysis has covered both the opportunities for improvement of the thermal insulation and specific limitations of the walls connected with the need to protect them against condensation; a detailed thermal and humidity analysis has been made for each calculation option. The calculations have shown that the best recommended technical solution for the building is the EUROTHANE G technology which will significantly improve thermal insulation of the walls (very low heat transfer coefficient) and it also meets the thermal insulation requirements of the technical conditions and the energy audit criteria. The recommended technology protects against condensation inside the wall (provided the thickness of the insulation material will be as required).

Calculations energy characteristics and the energy certificates of the building issued for the test purposes have proved that the design made in 2005 does not meet the technical condition requirements because the energy indicator of the received energy characteristic (EP) exceeds the limit by ca. 45 %, and the heat transfer coefficient for the majority of walls exceeds the maximum Umax limit. If the design is verified and modified in line with the proposed thermal modernisation improvements for the walls and the heating system, it will be possible to improve total energy efficiency of the building and to meet the technical requirements applicable for modernised buildings, because the value of the demand for primary energy (EP) will be lower than the limit. List of indicators of the building's energy characteristics for the options analysed:

			Design 2005	Verification 2012
1	Demand for non-renewable primary energy	EP	637.4 kWh/m²/a	397.2 kWh/m²/a
2	Comparative (limit) value of the energy characteristics indicator by WT2008	EP_{WT}	441.3 kWh/m²/a	441.3 kWh/m²/a
3	WT2008 requirements			
	Indicator EP (EP ≤ EPWT)		not met	met
	Coefficient U for the walls (U ≤ Umax)		not met	not met
	WT2008 requirements		not met	met

The additional analysis for the option which considered the conservation guidelines from 2010 has shown that a 6 % increase of the heating demand of the building should be expected and also that the heating annual costs will grow by ca. 3,100 PLN (5.7 %). The actual increase of the heating demand and heating costs might be higher because the analysis was based on approximated data and covers only some of the changes covered in the appendix to the construction design from 2012.

2.4 Study of Energy Performance Value (EPV of Brick and Stone Buildings, Tartu

/ AVE ELKEN AND ANNE RANDMER, CENTRE FOR DEVELOPMENT PROGRAMS (EMI-ECO), TALLINN

2.4.1 Foreword

This report has been prepared by Hevac Ltd for EMI ECO as a part of the INTERREG IVB program, project Nr. 61 Co_2olBricks to determine the energy performance value (EPV from here on) of brick and stone buildings in Tartu which are located in milieu valuable areas or are part of the architectural heritage. In accordance with the methodologies used in Estonia, EPV is conveyed in this study by weighted calculation of specific energy consumption of existing buildings and the calculations are based on the energy consumption of the last three years. 19 buildings are included in the analysis, 7 of which are schoolhouses, 8 are other types of buildings (offices, clubs etc.) and 4 are apartment buildings. In addition to the EPV, the report also studies the heat and electricity consumption of the buildings and compares them to the average characteristics of another 64 buildings in Tartu. The authors of the report extend their gratitude to the owners of the buildings included in the study, Tartu City Office and Tartu Regional Energy Agency, who all helped in gathering the initial data necessary for the study.

2.4.2 The main criterion for the choice of buildings

The main criterion for selecting the buildings to be included in the Co_2olBricks project was the year of construction (before 1945), and their historical value, which does not allow external insulation. In all cultural heritage buildings, to preserve the value of the building, the external facade must not be altered except if due to renovation. According to this, 44 buildings were selected for the research. Not all buildings are made of bricks, but the restriction in external renovation makes them identical from the point of view of solutions for increasing energy efficiency. The gross heated area of the buildings analysed is 33,134 m². Unfortunately there were a number of difficulties in getting the needed data and therefore only 19 (42 %) of them were suitable for use in this study.

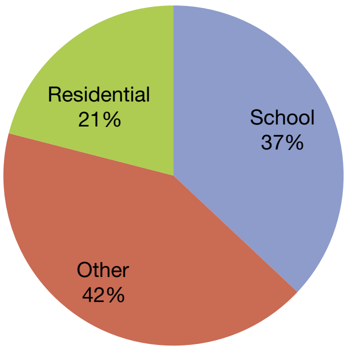


Figure 3: The distribution of the buildings included in the study based on their purpose

Some of the issues were the following:

- Not enough data of consumed energy (mostly because of stove-heated buildings)
- The buildings were in use infrequently
- Only part of the building was in use
- The building was in use only during part of the year
- The owners lived outside of Estonia and were unreachable

2.4.3 Information attained

After the preliminary estimation and selection of the 19 buildings, the forms of data of consumed energies were sent to the users/owners of the buildings. 6 out of 19 forms were sent back with usable data. 11 out of 19 forms were only partly filled or the data was deemed not reliable. To receive adequate data for all the selected buildings, also queries were forwarded to energy distributors Eesti Gaas (natural gas), Tartu Vesi (water) and Fortum (district heating). Additionally, part of the data was received from the survey[1] of the Tartu Regional Energy Agency (TREA from here on). In order to receive data from energy distributors, an authorization of the owner of the building or their representative was required. The owners of some buildings or their representatives refused to grant their permission to supply the information. Some owners only granted the permission on the condition that their house is not directly identifiable in the comparative study. Estonian EPV evaluation methodology stipulates that the heated area needs to be taken into account when calculating the EPV value. To determine the floor area of a building, information received from the owner, the National Register of Construction Works and the study of TREA was taken into consideration. In cases where there was no data in regards to the heated area of a building, closed net area figures were used in the study.

2.4.4 The principles of determining EPV

In Estonia, the energy efficiency of the existing buildings is characterized by Specific Weighted Energy Consumption (SWEC from here on). The calculations to determine SWEC have been specified in the decree Nr. 67, 17.12.2008 of the Estonian Ministry of Economic Affairs and Communications. In this report, the aforementioned decree and the

1 Monitoring and evaluation of the energy efficiency of municipal buildings of the City of Tartu. Draft report. 2012. Tartu Regional Energy Agency

methodology and principles stated therein have been taken as basis when determining SWEC.
To determine the SWEC of existing buildings, the following principles are used:

- In general the calculations are based on the measured consumption of the last three years
- The heating consumption values are reduced to a normal year with the degree-day method, whereby the balancing temperature is fixed at 17 °C
- All types of energy consumed in a building are taken into consideration (heating, ventilation, natural gas, lighting, electrical appliances, etc.)
- The arithmetic average values of delivered energies of the observable period (generally three years) by energy carrier are calculated
- The arithmetic average values of supplied energies are multiplied by the weighting factors of the energy carriers which are:

District heating	0.9
Natural gas	1.0
Electricity	1.5

- The energy consumption multiplied by the weighting factors are summed
- The gross supplied energy consumption multiplied by the weighting factors are divided by the heated area of the building and the resulting figure is SWEC kWh/m²/a

Thus SWEC incorporates gross supplied energy use, where the energy consumption of all the technical systems is taken into consideration and in addition to that the weighting factors of the energy carriers; essentially we are dealing with a parameter characterising the primary energy use of a building – the yearly gross consumption of primary energy per heated area of the building. In Estonia heated area is defined by law as follows: 'Heated area is the floor area of rooms, in which the temperature of air during a heating period is not significantly responsive to the changes in the outdoor temperature.' It is the net floor area of the rooms, meaning the area measured to the internal face of the external walls. The area occupied by walls and partitions is not included when measuring heated area. When comparing EPV in Estonia to some other country's EPV, one has to take into account the definition of heated area. In some countries gross internal area value in those calculations is used including external walls and partitions. In that case the heated area is considerably larger than in the EPV calculations in Estonia. The larger the heated area, the smaller the EPV figure if the energy consumption remains the same. In this study the following initial data was taken as basis:

- Calculations were based upon the energy consumption of the years 2009–2011
- If natural gas was used as the heat source, then the calorific value used in calculations was 9.3 kWh/m³ and the efficiency value of the boiler was 0.85
- Where there was no data about the consumption of domestic hot water (DHW), the total water consumption was taken as basis with the consideration that in residential buildings, domestic hot water accounts for 45 % of the total water consumption, whereas in other types of buildings that percentage is 20 %; the heat energy of domestic hot water was determined with the presumption that water needs to be heated by 50 °C
- The following degree days were used to reduce the heating costs to normal year[2]:

Normal year	4,295
2011	3,884
2010	4,608
2009	4,064

2.4.5 Energy consumption analysis and determining EPV

Some building owners only agreed to take part in the study on the condition that their house is not directly identifiable in the report. For this reason in the analysis the buildings are anonymous and denoted by a letter and number combination. The designations are:

- Schools: 'ED' (Education)
- Other buildings: 'O' (Other)
- Residential buildings: 'Res' (Residential)

EPV analysis

The EPV and energy class of the buildings included in the study are listed in the following table (Figure 4).

2 *http://www.kredex.ee/energiatohususest/kraadpaevad-4/*

Building	EPV kWh/m²/a	Energy class
ED1	185	D
ED2	142	C
ED3	172	D
ED4	169	D
ED5	179	D
ED6	181	D
ED7	131	C
O1	220	E
O2	294	E
O3	247	E
O4	265	F
O5	153	C
O6	265	E
O7	240	C
O8	311	F
Res1	373	G
Res2	334	G
Res3	174	D
Res4	274	F

Figure 4: EPV and Energy class of buildings

The buildings analysed belonged to the following energy classes:

- C class: 4 (21 %)
- D class: 6 (32 %)
- E class: 4 (21 %)
- F class: 3 (16 %)
- G class: 2 (10 %)

The following graph (Figure 5) illustrates the EPV values of the buildings. On the graph, the arithmetic average (277 kWh/m²/a), weighted average by net area (193 kWh/m²/a) and median (220 kWh/m²/a) of EPV of the participating buildings are shown.

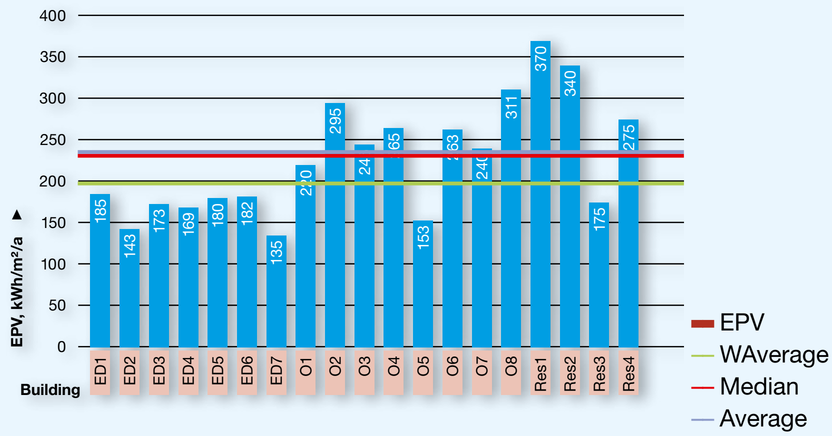


Figure 5: EPV of buildings

The EPV of schools (ED) is lower than average and ranges from 131 to 185 kWh/m²/a. The EPV of the other types of buildings (O) is a bit higher than average and falls within the range of 153–311 kWh/m²/a. The EPV of residential buildings (excepting Res3) is higher than average and ranges from 174 to 373 kWh/m²/a. TREA has compiled an analysis on 64 municipality buildings in Tartu. That particular analysis also includes some of the brick buildings participating in this study. The following table (Figure 6) brings out the differences in the EPV of the buildings analysed in the course of the Co_2olBricks project and the buildings analysed by TREA.

Figure 6: Comparison of the EPV of brick buildings (Co_2olBricks) and 64 Tartu buildings (TREA)

Difference indicator	Co_2olBricks	TREA Study	Co_2olBricks/ TREA	Co_2olBricks/ TREA
Weighted average	193	166	1.16	27
Median	220	179	1.23	41

According to the comparison of the EPV averages of the brick buildings (Co_2olBricks) and the rest of the buildings (TREA), the average EPV of the brick buildings was 16 % higher than the average of Tartu buildings. The average EPV of brick buildings was higher by 27–31 kWh/m²/a.

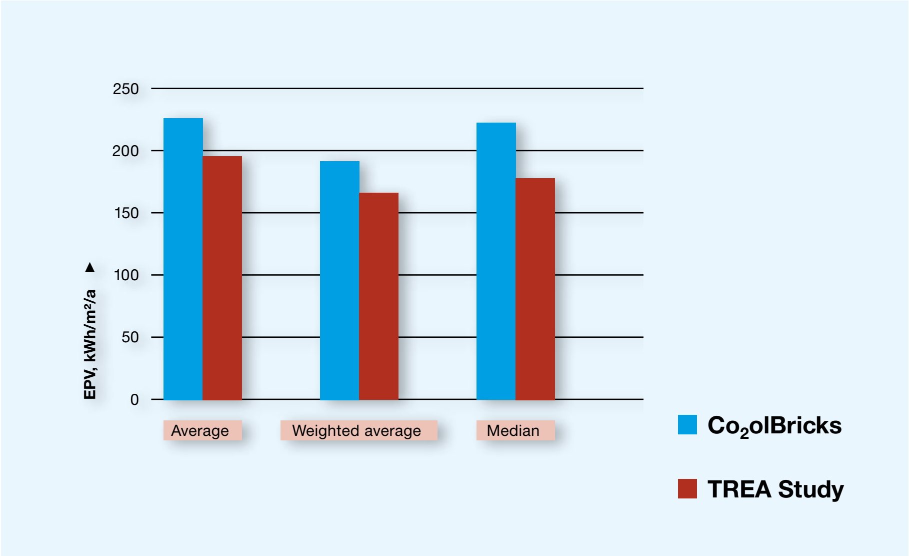


Figure 7: Comparison of the average EPV of brick buildings (Co_2olBrick) and 64 Tartu buildings (TREA)

EPV is affected by the method of heating. On the following graph (Figure 8), buildings using natural gas as heat source are marked in red. One of the buildings used both gas and district heating as heat source. The EPV of that building is marked in yellow.

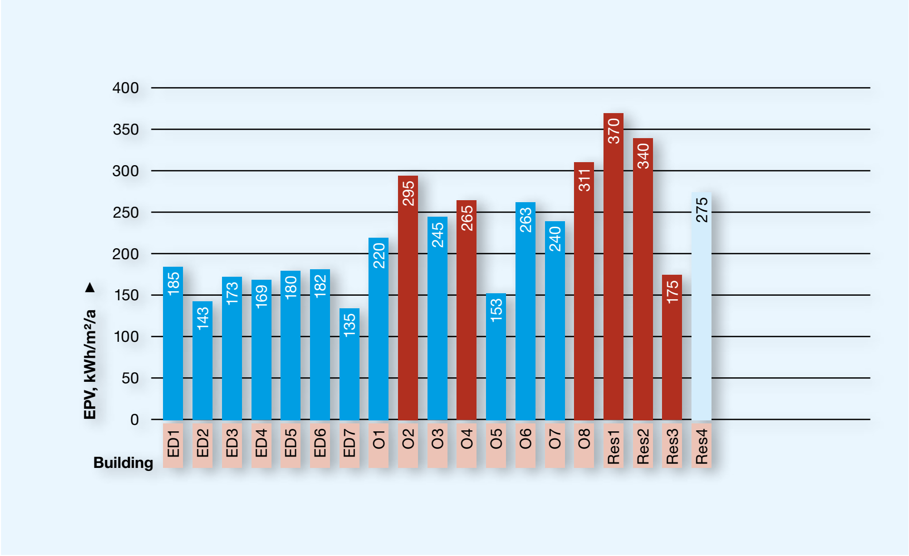


Figure 8: EPV and heat energy source (blue: district heating, brick-red: natural gas, light blue: gas and district heating)

In general the EPV of the buildings heated by natural gas is higher. The following graph (figure 9) illustrates the division of EPV between heating, domestic hot water and electricity. Also, heating makes up an essential part of the EPV of the buildings.

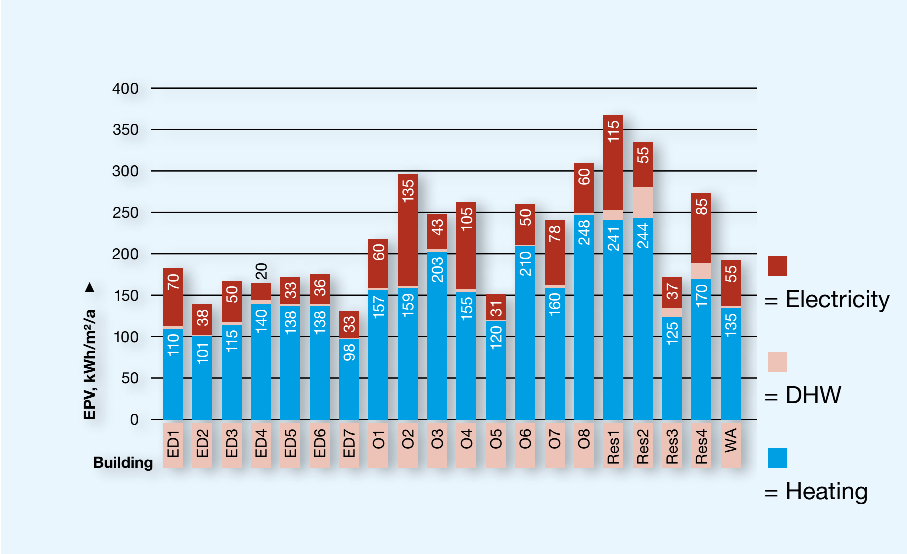


Figure 9: Division of EPV between heating, domestic hot water (DHW) and electricity

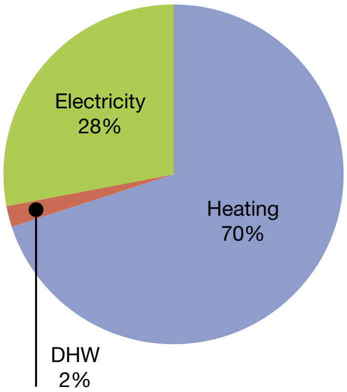


Figure 10: The division of weighted average EPV between heating, domestic hot water and electricity

Analysis of heat consumption

The heat loss of buildings is not directly dependent on the heat source. For this reason the net consumption of heat of the buildings which does not depend on the heat source and does not contain the use of domestic hot water is separately analysed below. In figure 11 the net energy consumption of heat of the buildings is listed.

Building	Net heating kWh/m²/a	Electricity kWh/m²/a	Water m³/a
ED1	124	46	0.333
ED2	113	25	0.205
ED3	129	35	0.304
ED4	153	17	0.492
ED5	151	27	0.208
ED6	152	28	0.157
ED7	109	21	0.191
O1	177	40	0.138
O2	135	88	0.227
O3	231	26	0.157
O4	152	55	0.218
O5	133	22	0.062
O6	237	33	0.177
O7	179	51	0.255
O8	208	42	0.277
Res1	203	80	1.249
Res2	206	36	0.404
Res3	108	24	0.352
Res4	167	38	0.586
Weighted average	141	36	0.273
Average	161	39	0.315
Median	152	35	0.227

Figure 11: Net Energy of heating, electricity and water

The data according the net energy of heating presented in figure 11 is illustrated by the following graph (Figure 12).

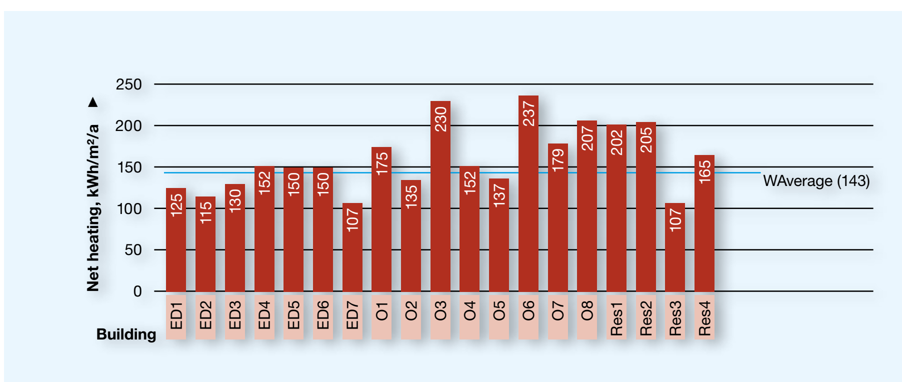


Figure 12: Net energy of heating of the buildings

Net energy for heating the buildings falls into the range of 108–237 kWh/m²/a which means that consumption varies hugely (the differences are more than twice in size) and do not depend directly on the intended use for the building. The weighted average net energy consumption of the brick/stone buildings of Tartu was 141 kWh/m²/a. The yearly energy consumption is considerably dependent on the outdoor air temperature in winter in the particular area. The warmer the climate the building is situated in, the smaller the yearly energy consumption. To measure the heat energy consumption of Tartu buildings against the buildings in other areas, we need to take into consideration the climatic peculiarities of the region. The following graph (Figure 13) illustrates the potential average heat energy consumption in Tartu, were we dealing with some other city. Balance point temperature of 17 °C is taken as basis for degree days in recalculations of the heat energy consumption.

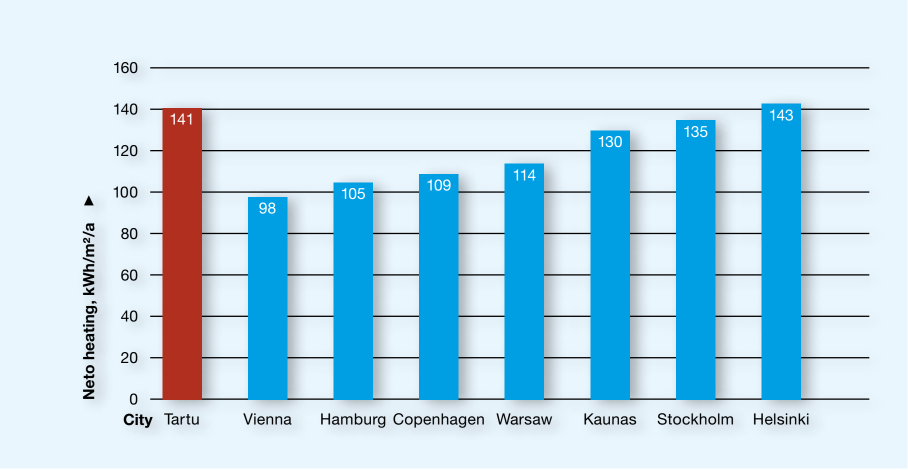


Figure 13: Adapting the weighted average heat consumption of Tartu brick buildings to the climatic conditions of other cities

In the study report by TREA the net heat consumptions are not presented separately. Using approximate methods, we can say that the weighted average of the net heat energy consumption of the analysed brick buildings is estimably larger than the average of the TREA study by about 30–40 kWh/m²/a. The following graph (Figure 14) depicts the dependence of the net heat energy of the Co_2olBricks selection of buildings on the size of the heated area. On the graph the educational buildings are marked in blue, the residential buildings in yellow and other types of buildings are marked in red.

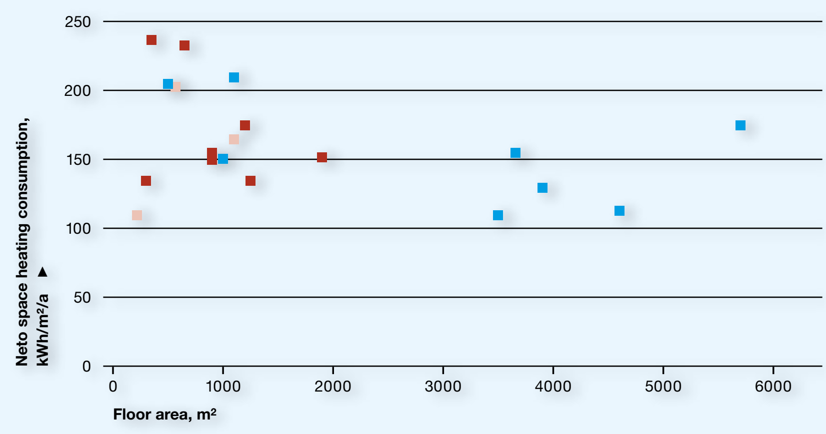


Figure 14: Dependence of the net heat energy consumption on the size of the heated area (blue: schools, red: other buildings, yellow: residential buildings)

The net heat energy consumption of a building in the buildings that participated in the study did not depend considerably on the size of the heated area.

3. Analysis of electricity consumption

The figure 11 displays also the electricity consumption of the buildings participating in the study without a weighting factor for the heated area. These are illustrated by the following graph (Figure 15).

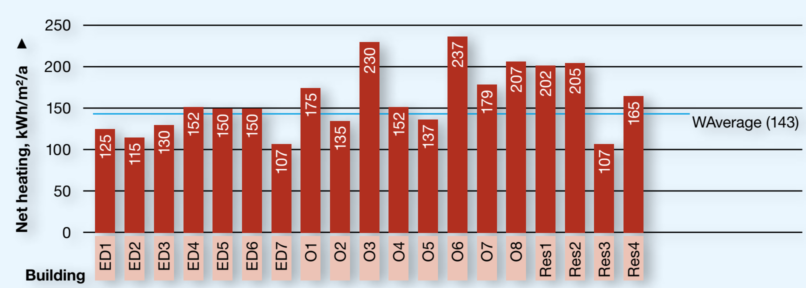


Figure 15: Electricity consumption of the buildings

Energy consumption fluctuates in a wide range over the entire selection as well as within the types of buildings. The weighted average electricity consumption of the analysed buildings was 36 kWh/m²/a. The electricity consumption of two of the buildings was exceptionally high. In the case of those two, it could possibly have to do with partial use of electricity for heating, as well as some other substantial use of electricity (e.g. outdoor lighting). The average electricity consumption according to the study by

TREA was 44 kWh/m²/a. This means that the electricity consumption of the brick/stone buildings was somewhat less (8 kWh/m²/a) than of the selection of buildings in the study by TREA.

4. Analysis of water consumption

The following graph (figure 16) presents the water consumption per heated floor area (see also figure 11).

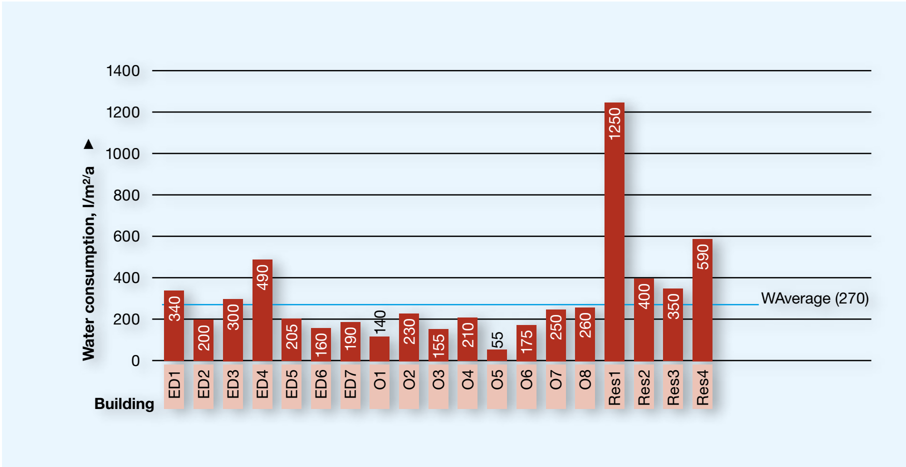


Figure 16: Water consumption of buildings

The average water consumption of buildings fluctuated in a wide range, but generally fell within 0.15–0.4 m³/m²/a. The weighted average consumption was 0.27 m³/m²/a. In one building the water consumption was anomalously high. As water consumption is not handled separately in the study by TREA, we cannot compare the water consumption of the brick buildings with the other type of buildings. In principle the water consumption of brick buildings should not differ from that of buildings of other type with similar use.

2.4.6 Summary

The Energy Performance Value (EPV) of the analysed brick and stone buildings which are part of the architectural heritage or located in milieu valuable areas fell in the range of 131–375 kWh/m²/a. The average EPV of those buildings was 227, the weighted average by heated floor area was 193 and the median 220 kWh/m²/a. Compared to the EPV of 64 buildings in Tartu, the weighted average EPV of the brick and stone buildings was higher by 16 % (31 kWh/m²/a) and the median was higher by 23 % (41 kWh/m²/a). A substantial part of the EPV of the analysed buildings was comprised of heating (70 %). Compared to 64 buildings in Tartu, the average heat consumption of the heritage or milieu valuable brick/stone buildings participating in this study was considerably greater. Compared to 64 buildings in Tartu, the average electricity consumption of the analysed heritage- or milieu valuable brick/stone buildings was somewhat smaller.

2.4.7 Recommendations regarding the achievement of better energy performance in cultural heritage and milieu valuable brick buildings

Foreword

This report presents recommendations regarding to improve the energy performance in cultural heritage and milieu valuable brick and stone buildings, subject to INTERREG IVB programme project No. 61 Co_2olBricks prepared by Hevac Ltd for the Centre of Development Programs EMI-ECO. It is important to underline the fact that cultural heritage and milieu valuable brick buildings are to be treated as unique buildings – to renovate and improve their energy performance; each should be treated as an individual object with its originality taken into consideration. The solutions suitable for one building may not be suitable for another. Therefore, it is not possible to draw specific and detailed recommendations on improving energy performance for these types of buildings in general. In comparison to the renovation of 'ordinary' buildings, the renovation of cultural heritage buildings requires extensive preliminary studies, skilled and experienced designers, high-quality builders and competent supervision by owners.

With respect to the Estonian Building Act §3, there is no demand to meet the minimum energy performance requirements in the following buildings with indoor climate control:

- Buildings which, pursuant to the relevant comprehensive plan or detailed plan, are located within a built-up area of cultural and environmental value, or which have been recognised as a valuable monument
- Buildings which have been designated as cultural monuments and which are located in a heritage conservation area pursuant to the Heritage Conservation Act
- Buildings included in the UNESCO World Heritage List and in which compliance with established requirements would significantly alter their nature or appearance

Thus, in case of reconstruction (including essential reconstruction), the buildings referred to do not need to meet the minimum energy performance requirements after the renovation process. This means that to apply for the building (refurbishment) permit, there is no need to provide calculations regarding the minimum energy performance. On the other hand, each owner/user should be interested in optimal future building energy consumption costs.

Special conditions for building renovation

Prior to starting to improve the energy performance of the specific building, its milieu value, limitations, and conditions are to be defined. Old brick buildings can be divided into the following groups:

- Monument buildings
- Buildings located in a heritage conservation area
- Buildings located in the milieu valuable area
- Buildings without any special status

The design and refurbishment of buildings, which have been designated as cultural monuments, should consider heritage-based specific conditions. Generally, specific conditions describe the requirements for internal and external refurbishment. The improvement of the energy performance for these buildings can be very complicated and expensive. In the case of buildings, which pursuant to the relevant comprehensive plan or detailed plan are located within a built-up area of cultural and environmental value, the requirements of the detailed plan and/or comprehensive plan, theme plan, local authority regulations, design conditions, etc., should be followed. Generally, there are no restrictions for internal refurbishment in these types of buildings. However, exterior refurbishment should follow specific rules and conditions. The improvement of the energy performance for these buildings is way less complicated. Requirements and conditions mentioned above do not affect the refurbishment of non-special status buildings. Therefore, there are a lot of options for refurbishment.

Improving the energy performance in cultural heritage and milieu valuable brick/stone buildings

The description below gives general recommendations on measures for improving the energy performance in cultural heritage and milieu valuable brick/stone buildings. They can be divided into the following two groups:

- The improvement of building envelope energy performance
- The improvement of building services systems energy performance

Generally, there are fewer restrictions in cultural heritage buildings regarding the improvement of HVAC systems in comparison to the building envelope refurbishment.

Building envelope

Cultural heritage and milieu valuable buildings envelope insulation is complicated; detailed requirements and options depend on the originality of the buildings, its location, special conditions and limitations. Building envelope (windows, doors, roof, walls etc.) heat loss is defined by the specific type of structure and is characterized by structure thermal transmittance (U-value). The higher the U-value, the more heat transmits through the structure during winter and the higher the energy consumption is. Nowadays, a wall and roof structure U-values vary in the 0.1–0.2 W/m^{2}K range and windows U-values vary in the 0.8–1.2 W/m^{2}K range. In general, the non-refurbished brick building envelope U-values are much higher in comparison to those listed above. For example, non-insulated 1 meter thick limestone wall thermal transmittance is about 1.5–2 W/m^{2}K, in other words 10 times higher. In order to achieve the wall/roof U-value of 0.15 W/m^{2}K, the wall/roof should be insulated with an about 20–25 cm thick thermal insulation layer. However, the additional 25 cm layer of insulation would affect the exterior appearance of the building. Additional insulation, or replacing old windows, decreases the thermal transmittance (U-value) of the structure. The following graph illustrates approximate estimations of energy savings based on 1 m^2 structure area, depending on the thermal transmittance decrease of the structures. The graph is prepared based on the thermal energy cost 70 €/MWh.

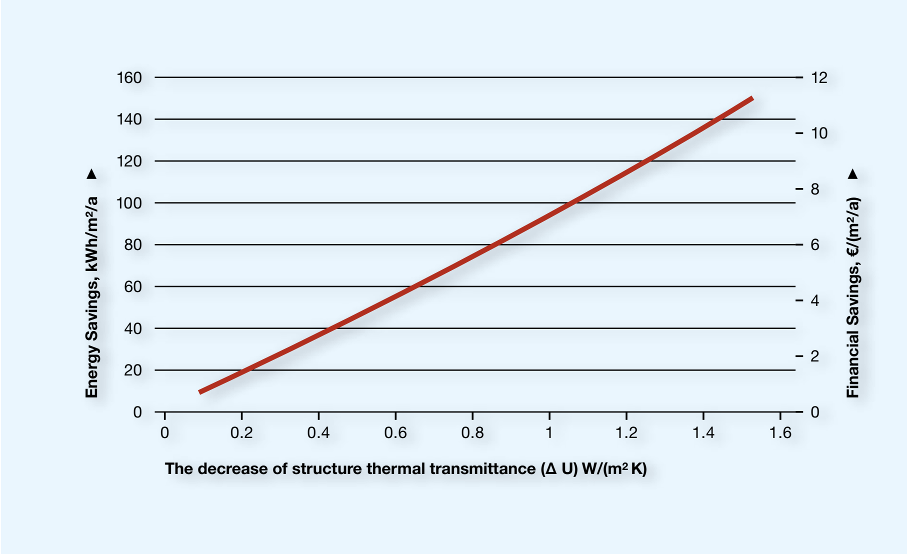


Figure 17: Energy and financial savings based on 1 m^2 structure area depending on the structure thermal transmittance decrease (Energy cost 70 €/MWh)

An example regarding the roof structure insulation: the roof structure with its prior thermal transmittance of 1.15 W/m^{2}K, about 20–25 cm thick thermal insulation layer is required to achieve U-value of 0.15 W/m^{2}K, and the decrease of structure thermal transmittance is ΔU=1.15–0.15=1 W/m^{2}K. ΔU=1 would provide the annual energy savings (Figure 17) of 95 kWh/m^2/a (6.7 €/m^{2}a) for 1 m^2 of roof structure. In case of the 100 m^2 roof, the annual energy savings are equal to 95 * 100 = 9,500 kWh/a (670 €/a).

Insulating the roof structure

The insulation of the roof and attic structure does not affect exterior appearance of the building. Therefore, additional insulation of the roof structure is one of the easiest energy performance improvement measures. Insulation design should consider building moisture condition requirements (i.e. when insulating attic floor, ventilation of the floor structure should be considered).

Insulating the plinth structure

Sometimes it is possible to insulate the plinth structure or basement ceiling structure.

Windows refurbishment

The measure with potentially high-energy savings is old windows replacement or refurbishment with the windows that consider the originality of old ones or by adding an energy saving window package from the inside. There are two energy performance improvement aspects involved in the windows replacement measure. First is the decrease in window structure thermal transmittance (U-value) and the second is an increase of building air tightness. The study of brick buildings in Tartu within Co$_2$olBricks project showed that essential energy wasteful air leaks (Figure 18) occur near window structures.

Insulating the exterior wall structure

Generally, exterior walls area proportion to other envelope structures in the building is the highest. However, additional insulation of this type of wall structure is the most problematic. As a rule, insulating the wall structure from the inside is not recommended due to the high risk of moisture damage. Prior to starting the insulating works of the inside wall structure, it is important to conduct moisture and thermal engineering calculations. The decision of adding the insulation layer from the inside or not should be based on the results of these calculations. Insulating the wall structure from the outside is the recommended feasible solution. However, exterior wall insulation affects building exterior appearance. Normally cultural heritage buildings are not allowed to insulate this way. In a milieu valuable area instead, to insulate the exterior wall structure from the outside, some trade-offs are required. For example, with the insulation of exterior walls from the outside, the roof structure has to be refurbished to meet new wall thickness. Often it becomes also necessary to shift windows into an additional insulation layer. Even when insulating from the outside, moisture calculations are required. Wrong structural solutions can become a cause of moisture damage.

Air leaks reduction

The study of brick buildings in Tartu showed that air leaks measured in buildings were essentially higher in comparison to other buildings. Most air leaks occurred in the wall-window joints and wall-wall joints. Reducing the air leaks (windows and walls air tightness improvement) results in lower heating energy consumption.

Building Services Systems

Energy source replacement

Old ovens, stoves and fireplaces are inefficient from the energy performance perspective. They should be replaced by the new more efficient energy sources whenever it is possible. The recommended heating system in a building is the central hot-water heating system. The district heating network connection is more preferable than local heat supply. If the building is located in a non-district heating area, the local heat supply should be considered. The house boiler (fuelled by gas, wood, or pellets) is an option for the local heat supply. It is relevant to measure the efficiency of the buildings supplied with heat from the old house boiler. In case of low efficiency, the combustion process should be adjusted or the boiler should be replaced with one that has a higher efficiency. Some cases involve the heat pump option for the heat supply solution: availability of enough existing ground amount to implement the horizontal collector, fair environmental conditions to implement vertical collector. Air-source heat pump application in this type of buildings is problematic, due to the exterior appearance changes involved. Heat pump design should consider the maximum supply water temperature of 60–65 °C. Low-temperature heat carrier temperature expects larger heating surfaces. If the building envelope thermal resistance prior to a low temperature heating system installation will not be improved, the heating system might not meet the heating demand. There are cultural heritage buildings in Estonia where solar energy plays the heat supply role.

Heating system and indoor air temperature control

Hydraulic balancing The heating system water circulation has to overcome friction losses. In general, the further the radiator is located from the flat station, the greater is the overall system pressure drop. If the system is not hydraulically balanced, the greatest amount of heat carried will circulate to the nearest circuits with the least pressure drop, resulting in a lesser amount of heat reaching the farthest circuit. This will cause air temperature fluctuations in rooms: rooms near the flat station will have higher air temperature than rooms far away from the flat station. To balance the heating system, balancing valves should be installed to maintain the required (design) flow amount. The valves to consider are pre-set thermostat radiator valves and/or zone balancing valves.

Heat carrier supply temperature control depending on the outside air temperature The cooler the outside air temperature is, the higher the heating system supply water temperature should be. To prevent building overheating and low indoor air temperatures, the control of the supply water temperature depending on the ambient air temperature value should be implemented. The solution involves the use of special control valves and automation of the flat station. The automation system must be tuned based on the building specifics.

Thermostat radiator valves (TRV) To sustain the indoor air temperature heating set point, thermostatic radiator valves should be installed. Whenever people come into the room, turn on computers, lights, etc., the heat gain starts to heat up the room air temperature and the thermostat reacts to avoid the overheating in the room by closing the valve and controlling the amount of heat carrier passing through the radiator. The thermostat radiator valve helps to utilize the heat gain to heat up the air, resulting in energy savings and comfort. If the building has a cooling system installed, simultaneous work of a heating and cooling system should be avoided by using an automation system.

Avoiding overheating The study of Tartu brick buildings within this project has shown that buildings are being overheated – indoor air temperature is too high. During the cold period, in office and apartment rooms, recommended air temperature set point is 21 °C. Every additional 1 °C added to the average heating season indoor air temperature provides a gain of 7–8 % in the heating energy consumption. As follows, if the average indoor air temperature in a building is 23 °C, then in comparison to a building with the set point of 21 °C, heating energy consumption will be about 15 % higher. Overheating in the rooms should be avoided.

Sufficient air exchange and exhaust air heat recovery

The study of Tartu brick buildings within this project has shown that room air exchange (especially in apartment building) is not sufficient. Poor air exchange can be a cause of human health problems, poor work productivity, poor envelope moisture conditions, etc. The air exchange rate of an apartment building should be at least 0.5 times per hour (room air should change once in two hours). Office building air exchange should be 1–2 l/s per m^2 floor area. The refurbishment of a building should definitely consider the installation of the mechanical air ventilation system to produce required indoor air exchange. Air handling units should be equipped with an exhaust air heat recovery system, which will heat up the supply air with exhaust air heat during the cool ambient air periods. Nowadays heat exchangers can save up to 90 % of the annual heat consumption used to heat up the supply air.

Air handling units operation in accordance with building usage schedule

Frequently in non-apartment buildings, operation of air handling units (on/off, variable amount of air, etc.) does not correlate to the building usage schedule. The automation of the non-controllable mechanical ventilation system should be considered. The operation of the mechanical ventilation system should be tuned to meet the real building usage schedule.

Energy efficient lighting

To decrease the building electric energy consumption, LED lights should be considered before basic bulb lighting. In addition, the automation of the lighting system to meet the real usage of the building is another source of energy conservation (motion sensor, dim switches, etc.). However, decreasing electrical energy use for lighting purposes will lead to an increase in the heat consumption of the building.

HVAC systems automation and smart control

The study of Tartu brick buildings within the Co_2olBricks project showed that the level of automation in the buildings studied is relatively poor. The update of building automation systems does not essentially affect the interior and exterior appearance of the building. Therefore, it is a very important measure to improve building energy performance and is especially suitable for cultural heritage and milieu valuable buildings.

› **All the examples show common and new methods as well as the wide variety of different approaches used in the participating countries.** ‹

3. Best Practice Examples

In addition to the research projects the partners in the Technical Solutions work group of Co₂olBricks selected best examples of energy efficiency improvements in their countries. Some of these examples, as from Sweden, Finland, Belarus, Germany and Denmark, are presented below.

All the examples show common and new methods as well as the wide variety of different approaches used in the participating countries.

The aim was to illustrate how differently each participating country deals with refurbishing historical valuable buildings under the aspects of energy-saving and how this has been done in different types of buildings with different construction preconditions. Therefore not every example is comparable with all the others. Small as well as large-scale measures are presented showing that small measures can already save a considerable amount of energy without touching the protected structure of the building.

Further information is available on the website of Co₂olBricks:
www.co2olbricks.eu

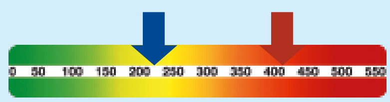
3.1 Danmark: Elmehuset, Copenhagen

DK

/ TORBEN VALDBJØRN RASMUSSEN

The project includes the renovation and conversion of a three-storey brick building with a used loft, which is categorised as worthy of preservation by the municipality according to save registration. This type of building dates mainly from the period of 1850 to 1920 and accounts for approximately 20 % of all dwellings in Denmark.


Address: Old People's Town (De gamles by), Nørrebro, Copenhagen (Streets: Nørre Allé, Guldbergsgade, Sjællandsgade and Møllegade)
Building type: independent nursing home
Architect: Wilhelm Petersen
Year of construction: 1887
Owner: Municipality of Copenhagen
Used as: 24-hour care and acute facility for minors with fundamental autism spectrum disorders who are disabled and between the ages of 10 and 18
Number of floors: 4
Facade: solid masonry, brick
Floor space: 2,724 m^2
Heated area: 2,724 m^2
Cost of refurbishment: 4.6 million DKK



Historical value and protection

This type of building dates mainly from the period of 1850 to 1920 and accounts for approximately 20 % of all dwellings in Denmark. The exterior is often considered worthy of preservation. It is highly valued for its contribution to the uniqueness of the local environment, architecture and the originality of the building. The majority of the buildings have wooden joist floors, but Elmehuset has concrete decks, which makes it ahead of its time. At some locations along the ground floor there are large shutters, which are also subject to a preservation order.

Initial situation

In 2009, the building was extremely run-down and needed an extensive renovation (bathrooms, kitchens, windows).

Measures done

Sewers, sprinkler control centre, alarm systems for fire, new internal walls, new bathrooms: concrete floors ready for tiling, acoustic insulation, adaptation for handicap and care provision; new kitchens and lifts, the main stairwells renovated, basic installations replaced, ventilation installed, new doors and windows, a new roof structure.

Energy saving

Main elements are:

- New insulated roof construction with dormer windows
- Replacement of outer doors and windows
- Replacement of installations, lighting, heating and ventilation
- Internal insulation of gable ends

Mandatory requirements for energy and preservation-worthiness were incorporated.

Historical value

The exterior has been categorised as category 2, which means that: “due to its exterior architecture, cultural history and standard of workmanship, the building is an outstanding example of its type”. The environmental importance of the building has been categorised as category 2. The architectural value has been categorised as category 3. Elmehuset must retain its original appearance as a whole and in its details, apart from the bricked-up entrances and added dormer windows.

Refurbishment
Date: 2010
Architect: Kant Architects

Material
Façade: solid red brick
Roof: natural slate tiles
Windows: wooden coupled windows with double-glazing
Floor/Ceiling: wood laid on laths/suspended ceilings
Inner walls: red brick
Cellar: red brick and concrete
Foundation: red brick and concrete

Building services
Heating system: new radiators and pipes connected to existing district heating
Electricity: re-wired
Building automation: CTS heating controls, thermostat regulation valves on radiators
Water/waste water: hot water from the central heating plant; water-saving fittings and toilets

Energy consumption
Before: 402 kWh/m²/a
After, calculated: 249 kWh/m²/a
After, measured: 220 kWh/m²/a
Energy saving: 45 %

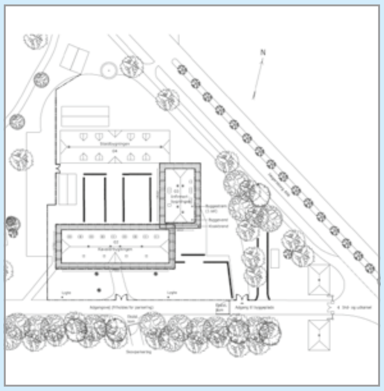
3.2 Danmark: Kavalergarden, Copenhagen

DK

/ TORBEN VALDBJØRN RASMUSSEN

Kavalergården was built in 1895 as a part of the Bernstoff Palace – the summer residence for King Frederik V. The Kavalergården complex was 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.

Address: Jægersborg, North of Copenhagen,
Building type: part of the Bernstorff Palace
Architect: Ferdinand Mehldal
Year of construction: 1895
Owner: Danish Agency for Palaces and Cultural Properties
Used as: hotel and conference centre
Number of floors: 2
Façade: solid brick and timber framed brick walls; woodwork, gates, windows, spaliers.
Floor space: 1. 000 m²
Heated area: 922 m²
Cost of refurbishment: 8,197,000 DKK (971,000 €)



1. Historical value and protection

The old building, which is worthy of preservation, was designed in a traditional architectural building style for that period. It was run-down before the energy upgrade and refurbishment was decided. 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 (owner).

2. Initial situation

Run-down, badly worn woodwork, half-timbered gates. 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, a leaky or missing/wrongly placed vapour barrier had resulted in several mould attacks in the roof constructions.

3. Measures done

New roofs with extra insulation, new low energy skylights, insulation of sloped walls and attic floors, storm windows with low-coated glazing, replacement of outer doors and low energy lighting systems.

4. Energy saving

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/a. This could indicate the effect of the energy upgrade, but this must be verified by measuring the energy consumption in the years to come. The expected space heat savings achieved by the energy upgrade and refurbishment were estimated to a total of 57,000 kWh/a 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/a equal to approximately 14 % or only 62 % of the expected heat savings.

5. Historical value

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.

Refurbishment

Date: 2011

Architect: Creo Arkitekter

Material

Façade: woodwork painted, ground floor espaliers removed

Roof: slate

Windows: storm windows with energy-efficient glass and sealing strips, cast iron roof

Floor/Ceiling: insulated with mineral wool in a wooden frame structure; existing ceiling with 200 mm mineral wool

Inner walls: brick and tember added plaster

Foundation: solid brickwork

Building services

Heating system: natural gas boiler, two-pipe installation

Building automation: ventilation plant

Energy consumption

Before: 146 kWh/m²/a

After, calculated: 57,000 kWh/a

After, measured: 126 kWh/m²/a 35,600 kWh/a

Energy saving: 14 %

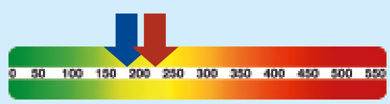
3.3 Belarus: BNTU No. 9, Minsk

BY

/ ALIAKSEI USPENSKI

Building No. 9 is a part of the BNTU historical complex, which is listed in the State Register of Historical and Cultural Treasures (item No. 712G000197, category II). The structure of the building was not changed since the time of construction. The outer walls are in a good state, but the building needs major thermo-renovation and roof repair. This is the sole listed building with pilot energy certificate in Belarus.

Address: Yakuba Kolasa Str. 14, Minsk
Building type: educational building
Architect: L. Ryminskiy, L. Usova
Year of construction: 1962
Owner: BNTU
Used as: educational building
Number of floors: 3
Façade: plastered red brick
Floor space: 3,240 m²
Heated area: 3,546 m²
Glazing area: 487.12 m²
Cost of refurbishment: 61,162 €
(windows replacement)



Historical value and protection

Building No. 9 is a part of the BNTU historical complex, which is listed in the State Register of Historical and Cultural Treasures (item No.712G000197, category II).

Initial situation and building condition

Some inside repairs and cosmetic outside repairs were carried out. The doors were replaced. The original single-glazed wooden windows were preserved, except some on the 1^{st} and one on the 3^{rd} floor. The roof is a wooden structure covered by sheet iron plates and is insulated with a 25 cm slag covering. The roof leaks in some places, which leads to wet spots on the 3rd floor ceiling, especially after rain or melting of snow. Outer walls are plastered 0.71 m thick red brick without insulation. Inner walls are either red brick 0.55 m or 0.15 m plastered gypsum. The building is connected to central heating by heat point and has old cast iron radiators. Ventilation is carried out by opening the windows. In some spots there is mould.

Refurbishment (planned)

Date: N/A
Architect: N/A

Material

Façade: plastered red brick
Roof: wood and sheet iron plates
Windows: double-glazed unit in wooden frame
Shading system: no
Floor: laminate, ceramic tiles
Ceiling: concrete
Inner walls: brick, plastered gypsum
Cellar: cement, concrete
Foundation: red brick

Building services

Heating system: heat point on the 1st floor
Electricity: new luminescent lamps
Building automation: installed, but not used
Solar heating system: no
Water/waste water: unchanged

Energy consumption

Before, measured: 153 kWh/m²/a
Before, calculated: 222 kWh/m²/a
After, calculated: 188 kWh/m²/a
Energy saving: 15 %

All possible technical solutions

- new double-glazed windows
- modern heating system with automatic regulation and new heat exchanger and radiators
- new ventilation system with recuperation of the thermal emission
- new lighting system
- wall insulation to R-value 3.2 m^2K/W (for example: 'Sarmaterm' polystyrene foam – U-value 0.0438 W/m^2K)
- roof insulation to R-Value 6.0 m^2K/W (for example: mineral (basalt) wool BELTEP-125 panels – U-value 0.043 W/m^2K)

Description of the planned energy saving measures

Replacing the windows will reduce the annual energy consumption to 120 MWh. This results in reducing of the energy consumption from 222 $kWh/m^2/a$ to 188.5 $kWh/m^2/a$. The efficiency class of the building will rise from F to E. The wall and roof insulation will further reduce the energy consumption to 95 $kWh/m^2/a$ (class C). If all possible technical solutions were done the energy consumption would be 40–50 $kWh/m^2/a$ (class B).

Effects on the historical value

If done properly, the window replacement and insulation of wall and roof will not diminish the historical and cultural value of the building.

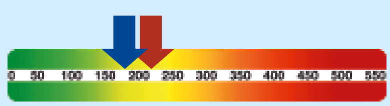
3.4 Belarus: Lenin Str., Minsk

/ ALIAKSEI USPENSKI

Lenin Street is a complex of historic buildings, which is listed in the State Register of Historical and Cultural Treasures (item No. 712G000097, category II). The buildings have the same design as many others built in the 1950s, being the classical example of Soviet architecture. Lenin Street is an architectural ensemble proposed by the Belarusian government for inclusion to the World Cultural Heritage List of UNESCO.

BY

Address: Lenin str. 2, 4, 6, 8
Building type: residential building with commercial premises on the 1st floor
Architect: Georgy Zaborskiy
Year of construction: 1956–1957
Owner: Single Enterprise – Housing Repairs and Utilities Association of Minsk Central District
Used as: residential building with offices and shops on the 1st floor
Number of floors: 5–7
Façade: the 1st floor is plastered, the upper floors are faced with ceramic blocks
Floor space: 12,914 m²
Heated area: 6,205 m²



Historical value and protection

The Lenin Street is listed in the State Register of Historical and Cultural Treasures (item No.712G000097, category II). The buildings are valuable monuments of the Soviet era city planning and the outstanding architectural works created in the XX century in Eastern Europe. Architectural and ornamental decoration of external elevations is very rich. The base and arches of the 1st floor are plastered with terrazit composition.

Initial situation and building condition

Some of façade ceramic elements (e.g. balusters, pilasters, cones, ordinary, corner, cornice, console, fascia blocks and many others) are partially or completely destroyed.

Measures completed

Belarusian State Technological University developed the composition of the ceramic material and restoration manufacturing technology of ceramic materials. The production of ceramic façade elements was organised at the *Applied and Decorative Arts Works* (Borisov). The destroyed ceramic panels and other decorative items were replaced. Some small chips, cracks and holes on individual ceramic elements were filled and sealed with high-quality materials and solutions from Kettex Ltd. To extend the service life of ceramic elements on the main facade, the waterproofing as well as the repair of drain back systems have been made.

Energy saving measures

- automatic control system of thermal energy consumption for heating
- pipeline lagging of hot water and heating systems
- double-glazed wooden and plastic windows
- automatic lighting control system with energy saving lamps in common areas
- cold attics were heated up by replacing the glassed gable windows with double-glazed units

Effects on the historical value

The damaged authentic details and decorative elements of building façades were repaired according to the historic context of the residential area in the process of reconstruction.

Refurbishment
Date: 2003–2007
Architect: Art conservator V.V. Glinnik

Material
Façade: brick faced with ceramic blocks
Roof: wood and galvanized iron
Windows: plastic double-glazed windows
Shading system: no
Floor/Ceiling: reinforced concrete and brick
Inner walls: brick, plastered gypsum
Cellar: ceramic brick
Foundation: strip rubble foundation (concrete)

Building services
Heating system: central heating (unchanged)
Electricity: unchanged
Building automation: control system of thermal energy consumption
Solar system: no
Water/waste water: unchanged

Energy consumption
Before, measured: 213 kWh/m²/a
After, calculated: na
After, measured: 186 kWh/m²/a
Energy saving: 12.5 %

3.5 Germany: Jarrestadt, Hamburg

/ ROLAND OERTZEN

The Jarrestadt area is an example of a modern and innovativ urban development project from the 1920s made of bricks. Planned in 1926 and implemented around 1930 by Fritz Schuhmacher, it presents one of the most important social housing projects – the residential town. The whole area is under heritage protection and the two buildings chosen are a part of it.

D

Address: Groothoffgasse 2–10, Saarlandstraße 25–29, 22303 Hamburg
Building type: residence
Architect: Karl Schneider
Year of construction: 1929, partly destroyed 1943 and reerected in 1948
Owner: FRANK-Gruppe (RATIONELL Wohnhausgesellschaft mbH)
Used as: residential building
Number of floors: 4 + penthouse level
Façade: brick
Floor space: 3,806 m²
Heated area: 3,466 m²
Cost of refurbishment: 1,859,000 €

Historical value and protection

The Jarrestadt is one of the most important examples of modern housing for workers in the 1920s in Hamburg. All the buildings are made of brick and contain small flats with all the modern amenities necessary for comfort and hygiene. The two buildings were chosen as prototypes. They are under heritage protection as regards construction, materials and inner structure. A special focus is on the façades and the stairwell.

Initial situation

The reason for the refurbishment of these buildings was a huge moisture problem which made it impossible to occupy 8 flats. The initial investigation showed, in detail: moisture/mould in several flats, blooming and cracking on parts of the façade and buckled window heads through corrosion, moisture in the eave, lintel and balustrade areas.

Measures done

a. Repairs

- Reaming of the joints (attention: partly negative effects, e.g. damaging of the bricks or the brick flanks) and refilling with a plastic double moisture-repellent joint mortar
- Demolition of parts of the facing bricks to refurbish damaged steal beams and fixings; exchange or rehabilitation of theses parts
- Renovation of the balconies and the drainage, renewal of external window sills
- Electrics, lighting, etc.

b. Energy refurbishment measures

- Insulation of the cellar floor from below with 120 mm PUR rigid foam
- Cavity wall insulation, 80 mm with silica granular material
- Flat roof insulation, 48 mm vacuum insulation panel
- New wooden windows with glazing bars and a U-value of 1.10 W/m²K
- New windows in the staggerd top storey with a U-value of 0.80 W/m²K
- New wooden doors with a U-value of 1.30 W/m²K
- Solar collectors on the roof
- Revision of the district heating connection point
- Hydraulic adjustment of the heating system, new thermostat valves

Energy saving

- Reduction of the primary energy use by 70 % up to 51 kWh/m²/a
- Saving of 116 tons CO_2 per year

Effects of the measures on the historical value

During the refurbishment, the new windows as well as the front doors were fitted with reference to historical details. One of the stairwells was reconstructed to conform with the original. The facing bricks and the joints were in bad condition and were renovated in a very complex manner.

Main conclusions

- A deep analysis for damages is necessary
- The external insulation was optically and structurally inadequate for these buildings
- Joint refurbishment must be done very carefully
- Reconstruction of the original stairwell

Refurbishment
Date: 2011
Architect: FRANK ECOZwei

Material
Façade: brick
Roof: steel-reinforced concrete
Windows: wood
Shading system: sun protection glass, penthouse level
Floor/Ceiling: wooden beam ceiling
Inner walls: brick
Cellar: brick
Foundation: concrete

Building services
Heating system: district heating
Electricity: na
Solar system: vacuum tube collectors
Water/waste water: na

Energy consumption
Before: 171 kWh/m²/a
After, calculated: 51 kWh/m²/a
Energy saving: 70 %

Further information is available here:
www.co2olbricks.eu

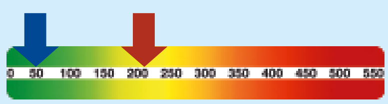
3.6 Germany: Vorderdeich 317, Hamburg

D

/ CHRISTIAN BLANK

Refurbishment of a disused Wilhelminian-style farmhouse; conservation of the solid red brick façade; with wall heating system, mounted by diffusion open clay interior wall plaster, foam glass gravel as floor insulation and expanded clay as intermediate ceiling insulation. Not protected yet, but a good example of buildings of that type and time in Northern Germany.

Address: Vorderdeich 317, 21037 Hamburg
Building type: farmhouse
Architect: unknown
Year of construction: 1894
Owner: Mieke Lindner, Christian Blank
Used as: residential house
Number of floors: 2
Façade: solid red bricks
Floor space: 150 m²
Heated area: 417 m²



The farmhouse, built in 1894 with a T-shaped ground plan, has the contemporary separation of the residential and business areas. The two-storey residential building located laterally to the business area stands with eaves facing the dyke and the street. The front of the building has a reserved, representative design with an entrance loggia. Two antique-like, cast-iron, grooved columns with Corinthian capitals bear 3 segmental arches. The entire house was built outside as a solid red-brick shell oriented to the example of bourgeois residential buildings. The wall areas are articulated horizontally with a cornice of ornamental bricks between the storeys. The ground floor windows have ornamentally emphasised segmental arches. The roofing at the time of building was implemented with slates. The building is a regionally typical example of a farmhouse from the end of the 19th century, built by a moderately well-off farm family. After standing empty for 20 years, the building was taken over in a partially ruined condition. The windows from the time of building, which opened outward, were replaced in the 1970s with single-leaf, single-glazing windows. The window apertures were reduced in size and the historical window sills were removed. The slate roofing was replaced in the 1980s by concrete roofing tiles with cardboard skeins (Pappdocken). The restoration of the facade was carried out exclusively with the historic bricks found in the structure, which were removed, cleaned and laid again for this purpose. All settling cracks in the brick façade were repaired. All window apertures were restored to the size they were at the time of building and the originally bricked croppers and window sills were refurbished/restored. The smooth clay roof tiles reflect the historic slate roofing and emphasise the decorated rafter heads. All interior walls were rendered with clay. The windows were produced of larch wood according to the original multi-leafed originals.

15 m^2 solar collector area for heating support and hot water. Low temperature heating system with wall heating bands plastered into the clay on all outer walls. Cellular glass gravel as insulation on the ground and rockwool insulation plus fibre-board insulating panels as insulation for roofing and between the rafters.

Retention of building at the side of the road typical of the area in the district of Reitbrook and of a historic Vierlande farmhouse.

Refurbishment

Date: 2011–2013
Architect: Christian Blank

Material

Façade: solid bricks
Roof: clay roof tiles
Windows: larch wood
Shading system: none
Floor/Ceiling: planks construction
Inner walls: solid bricks/dry construction
Cellar: solid bricks
Foundation: pyramid solid bricks

Building services

Heating system: wall heating
Electricity: classic
Building automation: none
Solar system: solar heat 15 m^2
Water/waste water: public service

Energy consumption

Before: 205 kWh/m^2/a
After, calculated: 47 kWh/m^2/a
After, measured: 48 kWh/m^2/a
Energy saving: 77 %

3.7 Finland: Military barracks, Hennala Lahti

/ MARKKU RANTAMA

Military barracks building No. 23 of Hennala garrison was built in 1913 as an accommodation facility for Russian army. Hennala is a typical 'red brick garrison' from the early 1900s. There are 2 equal barracks for troops in the Hennala area. Hennala still serves as a Finnish garrison and is a heritage site and any changes in the building must be approved by the National Board of Antiquities.

SF

Address: Hennala Lahti, Finland
Building type: military barracks building
Architect: unknown Russian architect
Year of construction: 1913
Owner: Senate Properties
Used as: military accommodation building
Number of floors: 2
Façade: solid red bricks, seamed tin roof
Floor space: 7,110 m², 3,440 m² refurbished in 2006
Heated area: 6,150 m²
Cost of refurbishment: 2,740,000 €

Historical value and protection

Hennala garrison area is culturally and historically valuable. Building No. 23 is a valuable example of Russian military architecture from the early 1900s representing so-called redbrick barracks. The renovation was carried out in complete cooperation with the National Board of Antiquities and the Finnish Defence Forces.

Initial situation

There were a lot of damaged façade bricks and the foundation drainage system was insufficient. There was also some moisture damage on the ground floor and some rain leakage damage could be seen due to the aged roof.

Measures done

Façade wall bricks were replaced in a 10 m^2 (500 pcs) area and the inner walls of the damaged area were plastered. The roof was replaced with a similar tin roof. The floor was raised by 300 mm.
An additional 300 mm of insulation was installed on the 2nd floor ceiling.
The foundation drainage system was renewed and improved. All the storm windows were renovated and double-framed, insulated windows filled with argon gas were installed.
A modern building ventilation system was installed with energy-efficient heat recovery. Pipes and radiators for the heating system were reinstalled.

Energy saving

Total energy savings were 50 MWh/a due to additional ceiling insulation, heat recovery of ventilation system and renovated windows.

Effects on the historical value

The roof was replaced with similar seamed tin roof. Damaged bricks were replaced. Foundation drainage was renovated. The renovation was important for the preservation of the building.

Refurbishment

Date: 1995 (1st step)
2006 (2nd step)

Material

Façade: red bricks, mortar
Roof: seamed tin roof
Windows: original wood-framed storm windows, new energy efficient argon filled inner glass
Floor/Ceiling: solid brickwork, masaic concrete floors, concrete with steel beams on 2nd floor; additional insulation on 2nd floor ceiling
Inner walls: plastered bricks, lightweight boarded inner walls
Foundation: stone foundation

Building services

Heating system: central heating, hot water radiators
Electricity: conventional
Building automation: central building automation system
Water/waste water: conventional

Energy consumption

Before: 156 kWh/m²/a
After, measured: 142 kWh/m²/a
Energy saving: 10 %

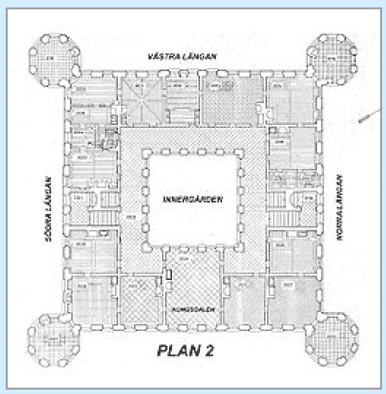
3.8 Sweden: Kalmar Slott, Kalmar

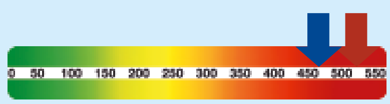
/STEFAN OLSSON

The Kalmar castle has played a crucial part in Swedish history since its initial construction as a Fortified tower in the 12th century. In 1397, one of the most significant political events took place at Kalmar castle, when the Kalmar Union was founded, a union betweeen Denmark, Norway and Sweden organised by Queen Margaret 1 of Denmark.

S

Address: Kungsgatan 1, SE 392 33 KALMAR
Building type: castle
Architect: Jakob Richter, Johannes Baptista Pahr, Dominicus Pahr, Peter Dionysius (rebuilt 1545)
Year of construction: 12–13th century rebuilt in the 16th century
Owner: The National Property Board Sweden (SFV)
Used as: museum, café, shop, church etc.
Number of floors: 5
Façade: bricks
Floor space: 13,147 m²
Heated area: 2,518 m²





Historical value and protection

The castle has been a national cultural heritage and a protected national monument since 1935.

Initial situation

The building is under the highest protection level and used by the public, for exmaple as a museum, a shop, a café and offices. Therefore there are not so many measures possible to increase energy efficiency. To deal with that challenge, it was decided to carry out the work in an ongoing process for the next few years, in different steps and various levels of planning, implementation, monitoring and adjusting. The following measures were already done and others will follow soon.

Measures done

- Optimisation and adjustment of heating system
- First installation of presence-controlled lighting system

Measures planned

- Presence-controlled lighting overall
- Reflectors behind radiators
- Installation of district heating to replace the direct electrical heating and the direct electrical floor heating will be replaced by water-based floor heating
- New ventilation system equipped with heat recovery
- Installation of LED lights

Energy saving

Energy saving from the measures done:

- Heating system: 35 MWh/a
- Presence-controlled lighting: 10 MWh/a

Effects on the historical value

The measures done and those planed will not have any negative effects on the historical value because all are concentrated on technical devices and do not touch the surface of the building.

Refurbishment

Material

Façade: stone
Roof: metal
Windows: wood, 2 glasses
Shading system: na
Floor/Ceiling: stone/wood
Inner walls: stone
Cellar: yes
Foundation: stone

Building services

Heating system: underfloor heating (water) and direct electrical heating
Electricity: partly electrical heating
Building automation: Siemens desigo
Solar system: na
Water/waste water: connected to municipal sewer and water

Energy consumption

Before: 523 MWh/a
After, calculated: 478 MWh/a
After, measured: na
Energy saving: 9 %

3.9 Sweden: Skeppsgossekassernen, Karlskrona

/ STEFAN OLSSON

The Skeppsgossen building is characterized by the Neo-Renaissance architecture of the late 1800s and has been protected since 1935 as a national monument. The building became a school for young boys who were trained to be officers or sailors.

S

Address: Skeppsgossen, Amiralitetstorget 3, KARLSKRONA
Building type: school
Architect: Axel and Hjalmar Kumlien
Year of construction: 1878–1881
Owner: The National Property Board of Sweden
Used as: offices, school
Number of floors: 4
Façade: plastered bricks
Floor space: 5,900 m² + 543 m²
Heated area: as above

Historical value and protection

The Skeppsgossen building is characterized by the Neo-Renaissance architecture of the late 1800s and has been protected since 1935 as a national monument. The building was built as a school to educate boys who were to be officers or sailors.

Initial situation

The age and the size of the building increased the need for saving energy as well as improving the comfort in order to still use it as offices and for teaching. Due to the high level of heritage protection and the good condition of the building in general, the possible measures were limited. Therefore the following measures were chosen to improve the building for energy efficiency as much as possible at this time.

Measures done

- Sealing of windows
- Change of radiator valves and adjustment of the heating system
- New and adjusted thermostats
- Frequency control on 2 pumps
- Optimising of ventilation
- New LED lighting with presence-control system
- Change of lighting in stairwells to LED, from 22 W per fitting to 9 W

Energy saving

The estimated energy saving from the adjustments done on the heating system are 50 MWh/a, from sealing the windows 50 MWh/a, from the new and adjusted thermostats 50 MWh/a and from optimising the ventilation 15 MWh/a.

Effects on the historical value

All measures done to reduce the energy consumption do not touch the construction of the building. There have been no negative effects on the historical value so far.

Refurbishment

Material

Façade: stone
Roof: metal
Windows: wood, 2 glasses
Shading system: na
Floor/Ceiling: wood/stone
Inner walls: wood/stone
Cellar: yes
Foundation: stone

Building services

Heating system: district heating
Electricity: new in some parts
Building automation: Siemens desigo
Solar system: na
Water/waste water: connected to municipal sewer and water

Energy consumption

Before: 769 MWh/a
After, calculated: 604 MWh/a
After, measured: na
Energy saving: 22 % (165 MWh/a)

3.10 Sweden: Alabastern, Växjö

/ STEFAN OLSSON

This is a traditional apartment house built in the early 1970s during the Swedish 'million apartment programme' 1965–1975. This specific building has 12 apartments and is the first to be renovated among 16 similar buildings in this area. Planning for this area is ongoing.

S

Address: Nydalavägen 20, Växjö
Building type: apartments
Architect: unknown
Year of construction: 1971–72
Owner: Växjöhem
Used as: dwellings
Number of floors: 3
Façade: bricks+board
Heated area: appr. 750 m²
Cost of refurbishment: total 9,600,000 SEK
(Energy-measures: 2,400,000 SEK)

Historical value and protection
Belongs to the 'million apartment programme' 1965–1975. Not protected.

Initial situation
An area with approximatly 300 dwellings with a need to be renovated. One building has been renovated as an example in order to test different technical solutions and to find out the cost level.

Measures done
Initial deeper survey of the technical prerequisites. Prestudy of possible solutions (technically and economically). The measures accomplished are:

- Extra insulation - roof
- New windows
- Equipment for individual metering of cold and hot water
- Mechanical double-flex ventilation with heat recovery
- New radiator system
- New headers in waste water system
- New entrance doors to appartments
- New outer entrance doors and façades

Energy saving
Annual final energy for heating, ventilation, hot water and building electricity is 48 % (monitored).

Effects on the historical value
There is no negative effect on the cultural heritage.

Refurbishment
Date: 2011
Architect: Arkitektbolaget

Material
Façade: bricks, concrete, wood boards
Roof: na
Windows: wood structure in aluminum shelter, 3-glass, (U-value = 0.9 W/m²K)
Shading system: na
Floor/Ceiling: plastic/parquette flooring + painted ceiling
Inner walls: concrete
Cellar: na
Foundation: na

Building services
Heating system: radiators+ district heating
Electricity: new installation
Building automation: new installation
Solar system: na
Water/waste water: new installation

Energy consumption
Before: 147 kWh/m^2/a
After, calculated: 80 kWh/m^2/a
After, measured: 77 kWh/m^2/a
Energy saving: 48 %

CONTRIBUTING TO A FLAGSHIP PROJECT OF THE STRATEGY

› This means in general the implementation of measures that do not alter the historic building itself, for example new heating systems, improvements of windows, and insulation of basements, ceilings or roofs. ‹

4. Technical Solutions

The third output of this work group shows examples of technical solutions for improving the energy efficiency of historic brick buildings. The aim was to find measures of refurbishment for energy efficiency that simultaneously decrease energy consumption and preserve the historical value of the buildings. This means in general the implementation of measures that do not alter the historic building itself, for example new heating systems, improvements of windows, and insulation of basements, ceilings or roofs. In the following list the possible technical solutions compiled from the project partners are briefly presented, with the addition of short examples of some measures. The more detailed descriptions of measures are available on the website of Co_2olBricks.

Possible measures for increasing energy efficiency can be:

- Post-insulation of roof, ceilings/floors, walls (inner and outer insulation)
- Improving windows and doors (changing glass, adding secondary glass and insulation, new windows or doors)
- Improving building air tightness and ventilation systems (natural systems, mechanical systems)
- Improving heat production (furnaces, boiler, heat pumps, heat charger)
- Improving heating system (central systems, stand-alone space heaters, convector heater, radiant heater)
- Improving electric components (changing components, home automatisation)
- Improving shading systems (fixed or adjustable/retractable, daylight/shading devices, glazing systems)

4.1 Example of Measures to improve the thermal envelope of solid brick buildings

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DANISH BUILDING RESEARCH INSTITUTE, AALBORG UNIVERSITY DEPARTMENT OF CONSTRUCTION

4.1.1 Background

Tightened requirements to thermal insulation of new buildings and the resulting demand for a reduction of energy consumption for heating and comfort in order to reduce CO_2 emissions mean that existing and especially older buildings have a very low thermal standard compared with today's requirements. Therefore, there is an increased interest in improving the insulation standard of many existing buildings.

4.1.2 Building physics requirements

When improving the thermal insulation of the building envelope, it is of crucial importance to take advantage of measures that prevent moisture problems and degradation of the existing construction. Special attention must be paid to ensure that, for the improved thermal building envelope, problems related to temperature decrease and moisture increase are not introduced. Measures to improve the insulation of the building envelope will change the overall condition of the existing construction. The temperature of the exterior brick wall will decrease at the façades by adding an insulation layer to the inside and will put the wall at risk from water damage and spalling. Furthermore, attention must be paid to preventing condensation in the exterior wall due to air leakage and moisture penetrating into the building envelope from the inside as well as from the outside. A critical point is also where the timber beam of the horizontal partition reaches into the brick wall. For the measures for improving the thermal insulation of the thermal envelope, it can be feasible to establish an airtight shell as well as a vapour barrier that comply with the technical requirements for joints as well as for ceiling, protecting the construction adequately from indoor moisture exposure.

4.1.3 Existing buildings with a thermal envelope of brick

Buildings with an exterior wall of solid brick were constructed with horizontal partitions of timber beams until 1920, see Figure 18. Later, horizontal partitions of concrete were introduced. The typical brickwork of the exterior wall, of buildings constructed before 1920 and especially between 1850 and 1920, is three bricks in thickness at the base of the building decreasing to one and a half bricks at the top level. The two top stories have a cavity wall with solid wall ties. Where the load-bearing exterior wall supports the timber beams, the solid brick wall decreases in thickness by half a brick every two storeys. The timber beams reach into the brick wall and at the top level of the building; the protecting shield reaches half a brick. The window wall under the windows is one and a half brick in thickness. The window is attached to the exterior wall. The non-load-bearing house ends have a thickness of one and a half bricks.

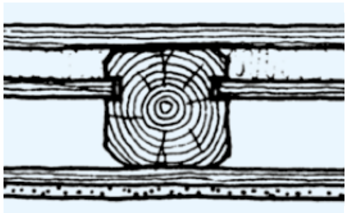

Figure 18: Horizontal partition by timber beams. From the top: floor board, clay infill, wooden boards, empty space, wooden boards and a layer of plaster on straw. The timber beams are 200 mm by 200 mm with a tolerance from top to bottom of 6.25 mm

The building has a cold basement and attic room. The roof is a typical double-pitched roof with a 45 degree angle. The joint of the roof base at the non-load-bearing house end is similar to the joint of the horizontal partition at the non-load-bearing house end. The basement was originally used for storage e.g. coal for heating. The basement floor is of stamped clay covered with concrete. The basement wall is founded on a foundation of brick, four bricks in thickness based on earth fill that includes stones and bricks.

4.1.4 Improving the thermal insulation of the building envelope

Reasonable measures must be considered and have to be carried out for the building at the inside of the exterior wall. When designing the solution for the measure to improve the thermal envelope, special attention must be paid to prevent the risk of condensation in the exterior wall due to air leakage and moisture penetrating into the building envelope from the inside as well as from the outside. It must be realised that for the measures to improve the thermal envelope it might not be possible to eliminate thermal bridges. However, in some cases thermal bridges can be used to maintain the temperature at critical locations in the building envelope at a high temperature level and thereby decrease the moisture level.

One of the measures can be a timber stud frame with 95 mm mineral fibre insulation. A stainless steel frame can also be used. The timber stud frame is attached to the horizontal partition between the individual floors of the building and kept clear of the exterior wall of the building envelope. The cavity between the timber stud frame and the exterior wall is filled with mineral fibre insulation. To prevent air and moisture from penetrating into the insulated exterior wall from the inside, an airtight shell is established. The airtight shell is established by a 0.2 mm polyethylene foil that also serves as the vapour barrier. It is crucial that the foil is located at the warm side of the dew point and that the joints between the sheets of foil and joints are airtight and securely fixed. For the timber stud frame wall, for the load-bearing facade, the foil is brought to the exterior brick wall and fixed airtight by a lath. For the non-load-bearing wall at the house end, the foil is brought to the timber beam of ceiling and fixed airtight. Measures at the free house end can be carried out on the outside without changing the architecture of the building. The improved thermal insulation system can be used for the non-load-bearing wall at the house end, which consists of 195 mm mineral fibre insulation covered by a layer of plaster on the exterior.

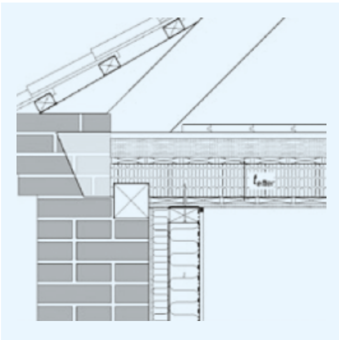

Figure 19: Vertical section of the joint between the bases of the roof at the load-bearing exterior wall

The plaster of the ceiling towards the cold attic room must be intact without cracks. Improvements to the vertical section are carried out by blowing loose-fill mineral fibre insulation into the cavity between the timber beams underneath the clay infill (see Figure 19). The cavity allowed 100 mm mineral fibre insulation. For further improvements of the thermal insulation towards the cold attic room, a polyethylene foil that also serves as the vapour barrier is placed in the attic floor and brought to the timber beam of the ceiling and fixed airtight. Mineral fibre insulation is placed above the polyethylene foil.

4.2 Shading systems

/ ALIAKSEI USPENSKI
REPUBLICAN CENTRE FOR TECHNOLOGY TRANSFER, MINSK

4.2.1 Introduction

Shading systems are designed to deal with solar radiation. Protection of the buildings apertures is the first consideration in the design of shading systems. When designed well they may also protect the opaque surfaces, including the roof. Shading systems can help save energy by reducing:

- Cooling loads in summer/heat loads in winter
- Needed artificial lightning (redistribute daylight)

Depending on the amount and location of fenestration, reductions in annual cooling energy consumption of 5 % to 15 % have been reported. Shading systems can also improve user visual comfort by controlling glare and reducing contrast ratios. While the cooling load may be reduced by shading, any associated reduction of lighting in the space may lead to a higher artificial lighting load. Therefore the design of shading systems should concurrently consider heat rejection in summer/heat capture in winter, day lighting and ventilation needs. The choice of shading strategy is determined by building and site location, orientation, building type and use, sky conditions (the direct, diffuse and reflected solar radiation components) and other light sources such as intrusive street lighting. The overall cooling, heating and day lighting strategies adopted in the design phase also influence the choice of shading system. In historic buildings, correctly designed simple devices are often as effective as hi-tech systems. Shading devices should be able to moderate or control direct, diffuse and reflected solar radiation, and glare, whilst ensuring that day lighting and natural ventilation are not excessively reduced.

4.2.2 Types of shading systems

Shading systems may be designed to protect transparent as well as opaque surfaces, which means that, shading the building facades and roof can also reduce unwanted heat build-up, particularly when these elements are not insulated and conduction heat flows through the façade into the building. Shading systems can be:

- Fixed
- Adjustable /retractable, operated by occupants or automation

The adjustable systems are operated by the user or automation. They are more effective and respond better to the movement of the sun and also allow better control of diffuse radiation. Solar control and shading can be provided by:

- Overshadowing from:
  - Vegetation (trees, vines, shrubs)
  - Urban morphology (shading by neighbouring buildings)
  - Exterior elements (such as overhangs or vertical fins)
- Combined daylight and shading devices that perform the double role of protection against solar radiation and redistribution of light (examples: light shelves, Venetian blinds)
- Advanced glazing systems (AGS), e.g. tinted/reflective/'low-e'/responsive glass etc.; in many cases use of such glass can save significant amounts of energy; however, if specified or used incorrectly they can actually add to the heat loads in a building
- Other shading technologies, e.g. transparent insulation materials (Aerogel)

4.2.3 Design and evaluation of shading systems

The design of effective shading devices will depend on the solar orientation of a particular building façade and the position of the sun in the sky. The position of the sun on the sky vault is defined in terms of altitude and azimuth angles, using solar time.

- The altitude angle is the angle of the sun above the horizon (the zenith = 90°)
- The north based azimuth angle is measured in the horizontal plane from North

When designing an external shading system, the movement and influence of the sun can be predicted using a number of methods. There are three main types of manual sun path diagrams: the equidistant chart, the orthographic projection and the stereographic projection. The stereographic diagram is the most widely used. Shadow masks created using the stereographic projection are a very useful tool in designing shading devices and assessing shadow impact.

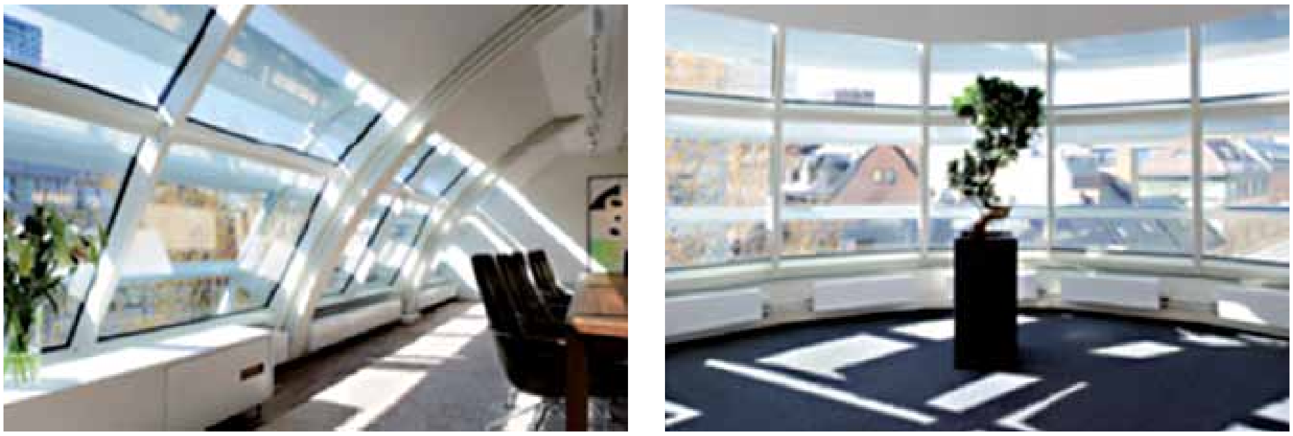

Figure 20: Examples of shading systems, outside

There are a number of 3D computer modelling software solutions readily available that include algorithms for the movement of the sun throughout the year for most latitudes and can be used for visualizing the overshadowing impact of neighbouring buildings as well as designing shading devices (e.g. Autodesk Ecotect, Revit, Vasari, 3ds Max, Daysim, Radiance, etc.). At present, various methods with different approaches are used for evaluating performance of shading devices, based on calculation of solar gain to the space, or internal light levels. The shading coefficient is a highly useful concept for evaluation purposes. It is the ratio of the total solar radiation entering through the combination glass-shading element to that entering a single non-shaded glass window. It should be considered as an approximate value, as the position of the sun, and the proportion of the direct and diffuse solar radiation incident on the shading system, changes throughout the day. When designing and evaluating shading systems, a reference to the following international standards can be made:

- ISO 18292:2011 Energy performance of fenestration systems for residential buildings: Calculation procedure
- ISO 15099:2003 Thermal performance of windows, doors and shading devices: Detailed calculations
- ISO 10077:2012 Thermal performance of windows, doors and shutters

It is necessary to ensure that thermal (reducing overheating) and visual (reducing glare) comfort requirements are met. The international standard for thermal comfort is:

- ISO 7730:2005 Ergonomics of the thermal environment: Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria

4.3 Ventilation

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4.3.1 Introduction

Various studies have shown that in the case of historic buildings, the main energy saving potential lies in the air tightness of the building. However, reducing the fresh air inflow leads us immediately to the question of the ventilation systems and the necessity of ensuring a comfortable indoor climate for the users of a building and for the preservation of the building. In order to ensure the above-mentioned comfortable indoor climate in dwellings, the recommended air change per hour (ACH) should be 0.5 l/h. It means that all the air in the room should be completely changed in two hours. In the case of buildings that were built before the 1990s this requirement has been taken into account and the buildings are designed so that the necessary airflow is provided by natural ventilation. A common solution for that was to build exhaust air shafts from the sanitary rooms and fresh air was taken from kitchen, the windows and air leakages in the building envelope. This system contributes to a large portion of the annual energy loss of the building and it is no longer a viable option due to continually increasing energy prices.

4.3.2 Importance of fresh air and ventilation

Indoor air quality

The most common concept used for indoor air quality is an equivalent to the cleanliness of indoor air. There are a variety of different air pollutants inside and outside the building with different potential effects on comfort and health that should be taken into account while designing building services systems, for example people, building materials, technical equipment, furniture, microbial growth or traffic, industry pollution and plants (pollen). During the past few decades the health considerations have become increasingly important in conjunction with comfort. Due to the growing price of energy, people have renovated many buildings, unfortunately without paying enough attention to the indoor climate.

Humidity problems

In the renovated buildings, where normal air change in the rooms has not been ensured, there are often problems with a relative humidity level which is too high in the room air. With colder outdoor conditions, the humidity starts to condense on the thermal bridges of the envelope of the building. Condensation is a major threat to the structure of the building, and high relative humidity in longer periods will create a very favourable environment for the spread of various microbes, mould and bacteria. The latest results of research by the World Health Organization (WHO) say that it is not possible to give exact limits to the relative humidity as regards human health. Therefore it is agreed that the lowest value of 20 % is not dangerous to human health and is regarded as the lowest limit for the engineers to take note of when they design buildings. For the structures of buildings and the thermal bridges in it, the relative humidity should be as low as possible in the cold period in order to avoid the risk of condensation. However, for old wooden furniture or floors inside the rooms, the relative humidity should not stay below 30 % to 35 % for longer periods.

4.3.3 Different types of ventilation systems

Ventilation systems can be divided in different ways, but one of the most common and user-friendly ways is the following:

- Natural ventilation (without fans), caused by the wind factor and the difference between indoor and outdoor temperature
- Forced ventilation (air moved by fans)

The energy consumption of both types of ventilation systems can be reduced by more intelligent management.

Natural Ventilation

The bigger both factors are, the more intensive is the air change in rooms. This means that in colder weather conditions the rooms and the building are often over-ventilated, and in warmer and windless weather there is a lack of fresh air. As both of these factors are directly dependent on the external climate, the system is considered to be a non-controllable system. Users of the building cannot change the air volume rate other than by switching it ON or OFF; this means by opening and closing the exhaust grilles. Practice has shown that with such a solution it is not possible to ensure either the needed air volume flow or comfortable indoor climate in rooms. Especially critical is the situation in low buildings (one- and two-storey houses) and at the top floors of a block of flats in warmer ambient temperatures.

Mechanical (or forced) ventilation

Forced ventilation works on the principle that fresh airflow is provided by mechanical ventilators. Most common solutions are either mechanically forced exhaust or mechanically forced supply and exhaust. In the first case, the exhaust suction is from bathrooms, toilets, kitchens and the intake is from the valves in the walls of living rooms and bedrooms. Installing mechanical exhaust without supplying a sufficient amount of fresh air will not provide the necessary airflow and satisfactory interior climate. In cases of mechanical intake and exhaust, the air is exchanged through ventilation ducts in individual rooms. The advantage of mechanical ventilation is that the required interior climate can be achieved by changing the settings of the system no matter what the outdoor weather conditions might be. There are two main different types of mechanical ventilation:

- Ventilation without heat-exchange
- Ventilation systems with heat recovery (central or local ventilation systems with heat exhaust air heat pumps)

Figure 21: Working principle of exhaust air heat pump. (Source: www.nibe.com)

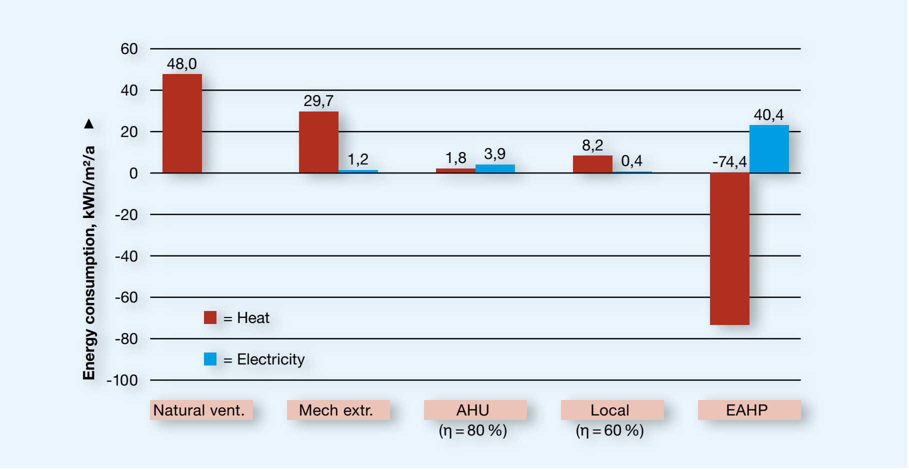
4.3.4 Example: Central ventilation system with heat recovery

The main working principle of ventilation with heat recovery is that the heat energy of the exhaust air is used to preheat the intake air or utilized in some other parts of the buildings heating system. When designed and adjusted correctly, central ventilation system with heat recovery offers most conveniently good indoor climate with the lowest operating costs. European Union standard (Estonian EVS-EN 15251:2007 standard) levels of noise, air quality and air transfer rate for dwellings can be achieved with ventilation systems which use mechanical intake and exhaust.

The thermal efficiency of systems with heat recovery is between 50–90 % and annual efficiency between 60–95 %. Thermal efficiency describes how much heat is collected from a certain volume of exhaust air. For example, if the coefficient is 80 % and outside temperature is –20 °C and the required indoor temperature is +20 °C. 80 % of the temperature difference is 32 °C and therefore, fresh intake air is heated from –20 °C up to +12 °C from exhaust air's heat. The annual efficiency of heat-exchanger describes how much of the heat energy, which is needed to heat up the intake air is recovered from exhaust air.

Ventilation systems do not only use energy to heat up the intake air but also use electricity for ventilators. Depending on the type of heat recovery system and ventilators, the annual ventilator energy consumption might be even bigger than the energy amount that is needed to heat up the intake air. It is possible to save electricity and heat energy by using automated control units and optimising the airflow settings according to the need.

Figure 22: Estimated annual energy consumptions of different ventilation system solutions in a 60m² flat. (Natural vent. – Natural ventilation; Mech. extr. – Mechanical extraction system; AHU (η=80%) – Central air handling unit system with heat recovery 80%; Local (η=60%) – Local decentralised system with heat recovery 60%; EAHP – Exhaust air heat pump)



4.4 Heating systems

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4.4.1 Introduction

Heating systems provide warmth to the interior of a building. There are two different principles in general:

- Central heating systems
- Stand-alone space heaters

Central heating systems differ from stand-alone heaters in that the heat generation occurs in one place, often in a furnace room in the cellar, and provides warmth through pipes from one point to multiple rooms. The most common method of heat generation still involves the combustion of fossil fuel in a furnace, or boiler. But besides the often used gas-, and oil-fired heaters, district heating, electrical systems and coal-, wood-, or pellet systems are also used. The produced heat gets either distributed by a fluid, mostly by water, circulating through pipes, or by forced-air through ductwork and, less common, sometimes also by steam. Increasingly, buildings utilize solar-powered and geothermal energy heat sources, heat pumps or heat chargers, in which case the distribution system normally uses a boiler and water circulation with lower temperature. The heating element in the room can be a convector heater or a radiant heater, for example floor- or wall-heating systems.

Stand-alone room heaters can be divided into two main categories – fixed and non-fixed. Non-fixed (portable heaters) can be moved around, and are mainly powered by electricity, although there are also portable heaters fuelled by oil or bottled gas. Fixed heaters can be powered by gas, oil, electricity and solid fuels such as wood, pellet or coal. They can work as convector heater or radiant heater, which depends on the heated surface compared to the room. Stand-alone heaters are normally used in small houses, or added for comfort reasons within larger areas in houses. Only the off-peak electricity heating system (also called electric thermal storage) is normally used for a whole flat or building.

4.4.2 Example: Pellet heaters

Pellet fuel appliances belong to the central heating systems as well as to the stand-alone room heaters. Therefore they are available as freestanding stoves but also as furnaces with boilers; but all of them burn pellets mostly made from compacted sawdust, wood chips, bark, agricultural crop waste, or other organic materials. Freestanding units generally heat a single room, but options also exist which use a fan to force the warm air into those other spaces. Pellet heaters are more convenient to operate than traditional wood or coal ovens, have much higher heating efficiencies and they produce less air pollution. A fuel hopper stores the pellets until they are needed for burning and a feeder device, like a large screw, drops a certain quantity of pellets at a time into the combustion chamber for burning. They also require electricity to run the feeders, fans, and controls.

4.4.3 Example: Heat pumps

Heat pumps belong to the central heating systems using a boiler. They exploit the physical properties of a volatile evaporating and condensing fluid known as a refrigerant. The heat pump compresses the refrigerant to make it hotter on the side to be warmed, and releases the pressure at the side where heat is absorbed. There are three different types in general:

1. Brine to water heat pumps

They use the geothermal energy as a source of heat, mainly in two ways:

- Ground heat collectors; they lay horizontally and the heat exchangers consist of pressure-resistant pipes laid approximately 1.20 below ground level
- Borehole heat exchangers; for this purpose, pipes are vertically dug into the ground up to 200 meters depth in order to use average ground temperatures of about 10 °C

2. Air to water heat pumps

They use the ambient air to extract energy from it. They are able to withdraw energy from the external air even when the outside-temperature is very low. Air-water heat pumps are less effective, because the heat source temperature fluctuates and is often lower than that of the other types of heat pumps during the heating period.

3. Water to water heat pumps

The water-to-water heat pumps are using ground water as a heat source. They can be installed as a ground loop or lake loop, and also driven in the ground as water well.

4.4.4 Example: Radiant heating systems

Radiant heating systems primarily warm the surrounding surfaces by radiation, and only secondarily the air. Therefore the energy loss by room ventilation is a bit smaller. There are three different main types of radiant heating systems:

- Ceiling heating systems (mainly in public buildings)
- Floor heating systems (mainly in private households)
- Wall heating systems (mainly in private households and public buildings)

In existing buildings, especially with historical value, the installation on the wall is often easier to realise than the installation on the floor. Furthermore, for buildings with moisture problems the increase of the surface temperature additionally dries the wall, and thereby has a small beneficial effect on the U-value. One of the disadvantages is that furniture placed in front of a wall heating system impairs the heating function: another is that drilling into the wall might damage the heating system mechanically.

Figure 22: Wall heating system (Source: Heritage Department Hamburg)

Further information about radiant heating systems is available on the $Co_2olBricks$ website: *www.co2olbricks.eu*.

4.5 Technical devices for energy saving

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4.5.1 Introduction

There are a lot of possibilities for saving electricity in buildings. Beside technical devices, a change in habit and small investments can also add up to major savings. Technical devices can be:

- Battery charger
- LED lamps
- Intelligent sockets
- Timer
- Demand-controlled electronic systems
- Home automation and smart apps

4.5.2 Example: Home automation

Home automation is the residential extension of building automation. It is automation of the home, housework or household activity and integrates electrical devices in a house with each other. Home automation refers to the use of computer and information technology to control home appliances and features, and a smart app via mobile phone or tablet could be one solution to control the home automation. Elements of a home automation system include sensors (for temperature, light, wind), controllers (general-purpose personal computer or a dedicated automation controller) and actuators, such as motorised valves, light switches, motors, and others. It is adopted for reasons of ease, comfort, security and energy efficiency and may include centralised control of lighting, heating, ventilation and air conditioning, appliances, security locks of gates and doors and other things. Furthermore, home automation for the elderly or disabled people can provide increased quality of life those who might otherwise require caregivers or institutional care.

CONTRIBUTING TO A FLAGSHIP PROJECT OF THE STRATEGY

› Every project starts with an initiation – mostly by the owner – and continues as an iterative process in general. ‹

5. Building analysis for energy-saving measures taking into account the conservation of historical value

/ DR. DANIELA SCHERZ
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5.1 Introduction

The aim regarding the energy refurbishment of historic buildings should not be to save as much energy as technically thinkable but instead to implement as many measures as possible without destroying heritage values or, worse, damaging the building.

Every project starts with an initiation – mostly by the owner – and continues as an iterative process in general. Therefore it is necessary to clearly define the different responsibilities from the beginning on. In small projects, normally the architect manages the whole process; in bigger projects, often a special team has to control the project targets, especially regarding dates and costs.

This document on the analysis of existing buildings for energy-saving measures while taking into account the preservation of the historic substances of the building has been prepared as a guide with recommendations for action in terms of project management. It therefore includes the basic approach and explains the causal relationships from which the structure is derived. The step-by-step guide reflects both the basic steps of the project as well as the depth of the research and planning content. The sequence is therefore hierarchically structured so that the individual activity steps can be read in order of priority. The project structure which has been developed thus allows its use in both small construction projects and very complex, large construction projects.

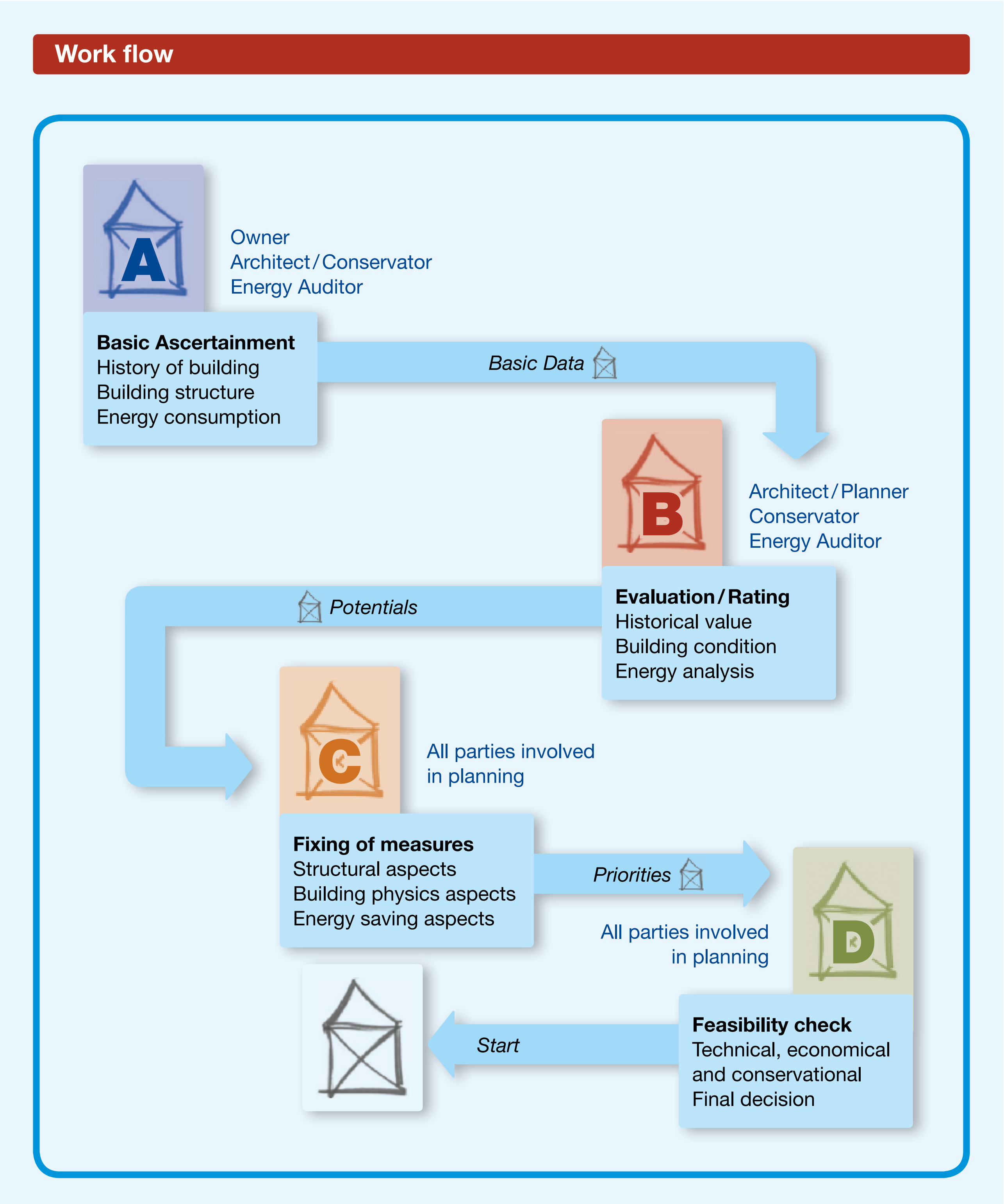
But this document, because of the complexity of the individual subjects, reveals no detailed practical instructions for each individual test and planning step. This was not possible to do within the framework of the Co_2olBricks project. Therefore, the very diverse requirements and recommendations for action which are laid out here should first be applied at EU and national level. At this point, from the perspective of the project partners, it would be desirable to merge ideas and implement some form of international standardisation in order to facilitate cooperation. Therefore this should be more deeply explored in the context of other projects and research projects within the EU.

5.2 Glossary

Stakeholder	All parties involved in planning (owner, architect, conservation officer, energy consultant, planner: building physicist, structural engineer, technical facility planner, building biologist)
Feedback analysis	An iterative and continuous process for finding the best solution/result
Conservation plan	This can be implemented for a single building as well as for an ensemble or a whole quarter, if the buildings are of the same type; in a conservation plan all possible measures should be described for refurbishing and preservation without destroying the historic substance
Historic building	Building of cultural value; may or may not be listed as cultural properties
Historic value	The whole building as well as parts of it or single elements, assessed/ accepted as valuable and designated for preservation
Room book / Building book	A registration and description (text and pictures) of every room and part of a building; very helpful for all planning and implementing processes

5.3 Work flow

SOURCE: DR. DANIELA SCHERZ



A – Basic Ascertainment

1. Collect together existing inventory documents (history of the building)
» Register of immovable properties, plans, photographs, calculations, permits, etc.
→ 2 stages: 1. Owner; 2. e.g. Architect, art historian, conservator
2. Documentation of its current status
» Photos, measurement, assessment of condition by visual inspection
→ 2 stages: 1. Owner; 2. e.g. Architect, art historian, conservator
3. Energy inventory
» Complete building and when indicated individual elements
→ 2 stages: 1. Architect; 2. Energy Consultant

B – Evaluation of data and rating

1. Historical classification
» Significance of the whole building and of individual elements (exterior and interior)
→ 2 stages: 1. Architect; 2. Conservator
2. Examination of the structural condition of the building/ensemble
» Substance of the whole and of individual elements as well as potential weaknesses
→ 3 stages: 1. Architect; 2. Planner (building physicist, structural engineer, technical facility planner, building biologist, etc.); 3. Material analysis (sampling and laboratory testing)
3. Energy inventory analysis
» Identify vulnerabilities (weak points) and potentials
→ 3 stages: 1. Architect; 2. Energy consultant; 3. Calculations/simulations
4. Target-setting
» Identify priorities for renovation
→ all stakeholder

C – Definition and fixing of necessary and possible measures

→ all stakeholders
1. For static-structural reasons (repair and maintenance)
2. For building physics reasons (repair and maintenance)
3. For energy reasons (modernisation)
4. Further development of buildings (conversion, modernisation)

D – Feasibility check

→ all stakeholders
1. Evaluation of the technical, economical and conservational feasibility
2. Final decision of the measures to be implemented

5.4 Short explanation and examples of the different steps

Each building has individual building physics; each building has to be examined individually, and not all examinations are affordable or necessary for all buildings. Therefore the examinations have to be done in different steps – but each time it starts with a basic analysis.

A – Basic Ascertainment

It is of paramount importance that the historic value of the building is well understood. Therefore a basic assessment has to be done, starting with the owner. The owner should be responsible for collecting all existing construction documents, including land registry and historical photos, etc.

The inspection of, for example, construction documents in local government offices belongs to the second level and should, due to the complexity, usually be done by an architect or an art historian or conservation officer. The same is true for comprehensive construction documentation, which includes measurements, photographs as well as a structural condition assessment by visual inspection. For larger buildings/ensembles, a detailed building or room book should be created.

The third stage of this phase includes a basic evaluation in terms of energy (investigation of energy consumption). This is usually done through the collection and analysis of existing consumption data for total energy balance. If this data is not available, a simplified calculation for a first rough estimate of the total energy consumption can also be done. Furthermore, at this point, an initial assessment of individual parts of the building may also be required. There are some useful existing guidelines for the examination of the energy consumption of buildings, for example ISO 50001 Energy Management, BS EN 16247–1 Energy audit, or DIN 4108–6, DIN V 18599, DIN 4101–10.

The goal is a building documentation that forms the basis for all further planning by providing all the necessary information on the one hand about the history of the building and on the other hand about the current state of the building.

B – Evaluation of data and rating

Consequently, before thinking about any rehabilitation work, irrespective of whether it is connected to energy efficiency improvements or not, the actual building physics as well as the special characteristics that define the historic value have to be known to all stakeholders involved. Normally historic buildings have undergone many changes due to their already long life. Besides that, often it was already built differently than planned, or changes were not documented. Therefore it cannot be expected that the walls are built to any known standard, or even to what was originally planned when the building was erected.

1. Assessment of the historical value

In this first step, an architect or an art historian assumes an initial assessment of the historic structure and its historical context. In the second step, the preservation/monument value of the whole and of the individual parts will be assessed. This is usually done through the relevant heritage preservation department.

2. Assessment of the present structure of the building

For everything to be planned, the present structure of the building and the condition has to be assessed. That has to be done with as many non-destructive methods as possible. One of the most important things to do is the analysis of the structural fabric in order to know the exact condition of the building. This is important for the planning of the measures as well as for calculating the energy efficiency. Starting with an initial assessment by an architect, early on in more complex projects additional planners usually need to be involved in a second step. If the existing documents and data are not sufficient, then detailed assessments and sampling are to be carried out as the third stage. For example, to get detailed values of brick walls, the following examinations have to be done, mostly by specialised laboratories:

- Bricks: resistance to pressure, absorptive capacity of water, salinity
- Joints: binder, aggregates, salinity, resistance to pressure, mortar class, specialties

If a sufficient number of historic walls have been investigated, this data can be put into a data base so that in the case of similar buildings not every building has to be reassessed from the ground up. Indoor climate measurements are also very helpful, especially as a part of an energy audit of historic buildings. This indoor environment condition survey should include sufficient information on:

- Temperatures (air and surfaces)
- Humidity
- Ventilation rates
- Existence of moisture damages, mould, and other contaminants

3. Assessment of energy loss, energy saving, and energy supply

Furthermore, the physical and technical properties of the parts of the building which are relevant for energy consumption have to be examined. This should be done in order to collect real data first (like measuring infrared thermography), so that calculations can be done afterwards. An initial assessment is also done by the planner, supplemented early on by the energy consultant, who then takes over the necessary calculations and simulations. One of these could be a dynamic hygrothermal simulation, for example with software tools recommended by funding organisations. They have sufficient complexity to model the energy consumption, because the static models are not complex and detailed enough to simulate difficult situations. The examination should be done especially with a view toward weak points in the construction and their potentials, for example leakages, imperfections, thermal bridges or rain protection and moisture in general. The following examinations should be done in detail:

- Roof, cellar and walls, doors and windows
- Air tightness of the building envelope
- Heating-, cooling-, ventilation-, water-, and electricity system
- Control systems

4. Definition of the intention of the measures

The decision on the usefulness of the measures must be defined at this point by the ultimate goal. All involved in the project are jointly responsible for this. One of the important aspects when deciding is to make a clear analysis of the future use of the building. Is it going to be an office, a workshop, a living space, a storage area? They all have a different energy demand which influences the energy concept. And as already mentioned, the aim for a building under heritage preservation is not to save as much energy as possible but to save as much without destroying heritage values.

The goal is to evaluate the collected data and through the analysis of the weaknesses and potentials to define all basic options for renovation (e.g. preservation versus change in the facade, installation of new, historic or historically citing elements, etc.).

C – Definition and fixing of necessary and possible measures

For the fixing of the requirements for the necessary or possible measures to be taken – as in the previous definition of objectives – all stakeholders involved in the planning must be included. The following order of precedence for the activities should be observed:

1. Static and structural reasons

These have top priority and are fundamental and mandatory requirements for the preservation of a building and can be necessary for both repair and maintenance.

2. Building physics reasons

Again here, the compliance with requirements for the maintenance or upgrading of the building is mandatory, whereas there are usually more opportunities available to exercise upgrading measures than in the structural physics.

3. Energy reasons

These generally fall under the area of modernisation and must therefore submit to both the structural design and structural physics requirements first. At this point there is already a correlation carried out with the physical construction parameters.

4. Development of buildings

In the hierarchy for the evaluation of possible and necessary action, the requirements for the conversion or modernisation of buildings play the least important role.

The goal is to define a priority of the measures necessary through the evaluation of the possibilities detected from different perspectives. On this basis, further planning can take place; plan and feasibility can be decided on.

D – Feasibility check

As a final step, the previously mentioned measures must still show a certain range of possibilities which can be examined in terms of their technical feasibility and in terms of their economic feasibility and of course in terms of their conservational feasibility. Only then can the final determination be made. Again here, all stakeholders involved in the planning should be included in the process.

1. Feedback analysis

In a first step, the basic technical measures identified must be checked for their economic feasibility and rechecked with the historical values of the building. The transitions between all three feasibilities are fluid, and therefore require continuous feedback until the final determinations are made.

2. Final decision

In the second step, on the basis of all previously obtained data, final decisions will be made and further planning steps prepared.
The goal is the final determination of the action to be taken, based on which further planning steps and then the renovation will take place.

5.5 Further recommendations

Iterative process

From the aforementioned steps it is clear that working on historic buildings always demands interdisciplinary collaboration of the involved stakeholders, who have to work as one team. This is a big challenge and therefore in the selection process of the right experts, their social competencies are also important. Together they have to define benchmarks and key elements of that building or to create the building design tasks. The use of checklists can be very helpful to find the point to start a project and to define the main goal and the targets when going to the different steps.

Specific qualification of the participating experts

As laid down in the $Co_2oLBricks$ Joint Declaration and the $Co_2olBricks$ Policy Paper, only experts who can prove that they have the specific expertise for energy efficiency in historic buildings should be used. Historic buildings are much more complex than new or non-historic buildings and big damage can be easily caused if the wrong measures are applied. Especially the energy auditors have to be educated in heritage preservation and, vice-versa, the conservators have to be educated in building physics. Without this mutual understanding a fruitful collaboration is, in our opinion, not possible.

Funding programme examination

Besides the heritage and technical aspects of the rehabilitation of a historic building, the economic side is crucial as well. So when investigating the possibilities, the available funding schemes have to be examined as well. To ease the cost situation for the examinations, more research of typical construction types and materials used in historic buildings is necessary. For most of the expensive examinations, like for a conservation plan, external funding is also necessary.

Follow-up (measuring of real data) after implementation of the measures

A natural course of action has to be that follow-up measurements of real consumption data are done in order to validate or invalidate the effect of the energy efficiency measures. To check whether the calculated saving potentials have really been achieved (for example in case of the prebound/rebound effects) would help to know what the effect really is and also to assess how good or bad the overall energy efficiency increasing programme has worked so far. But only a large data base can give thorough statistical data.

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