

A method to assess the potential for and consequences of energy retrofits in Swedish historic districts

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Abstract – This paper presents and demonstrates a multidisciplinary method to assess the potential for and consequences of improving the energy performance in a stock of historic buildings. The key elements in the method are categorization of the building stock, identifying targets, assessment of measures, and life cycle cost optimization. The method is applied on the historic building stock of the world heritage town of Visby. Based on a systematic categorization, building archetypes are selected to represent the whole building stock. The software OPERA-MILP provides a cost-optimal energy renovation strategy for each category of buildings. In a second step, restrictions with respect to the protection heritage values are introduced. The method can be used for energy planning in large building stocks as it provides a tool to show the consequences in terms of energy use, for different levels of restrictions.

Keywords – energy, retrofit, historic buildings, method

1. INTRODUCTION

Buildings account for nearly 40 percent of total energy use in Sweden. The existing building stock therefore constitutes an important part of the national pursuit of reduced energy use. The European Energy Efficiency Directive (EED) and the Swedish National Renovation Strategy emphasize the importance to identify sustainable renovation and energy efficiency strategies not only for individual buildings but also in the building stocks.

The Swedish research project ‘Potential and Policies for Energy Efficiency in Swedish Historic Buildings’ is a transdisciplinary collaboration between the Division of Energy Systems, Linköping University and the Department of Art History – Conservation at Uppsala University. The project aims to investigate the interdependency between political targets for reducing energy use and effects on the built heritage in five Swedish historic districts – two small towns, one rural district and two bigger cities – using different targets for energy efficiency and preservation.

The aim of this paper is to present and demonstrate a multidisciplinary method to assess the potential for, and consequences of, improving the energy performance in a stock of historic buildings. The key elements in the method are categorization of the building stock, identifying targets, assessment of measures, and life cycle

cost optimization. The method allows for an interaction between the quantitative assessment of the techno-economic potential and the qualitative assessment of vulnerability and other risks. Through a multidisciplinary dialogue and iteration it is possible to arrive at a solution that best balances energy conservation and building conservation in a given decision context.

This paper will present results from one case study and show how they can be used for planning and policies at a district level.

2. OVERALL METHOD

2.1 OVERVIEW

The method has been described in a previous publication [1], see Figure 1. The following is a short summary. The method is a synthesis of methods and practices from the building industry and from building conservation, which allows for the impact on heritage values to be weighed against techno-economic factors:

- 1) Categorisation of the building stock to identify representative building types;
- 2) Definition of targets for energy performance as well as for preservation of historic buildings;
- 3) A first assessment of risks and benefits based on a gross list of measures for energy efficiency;
- 4) Life cycle techno-economic optimisation to find the best combination of measures selected in step 3.

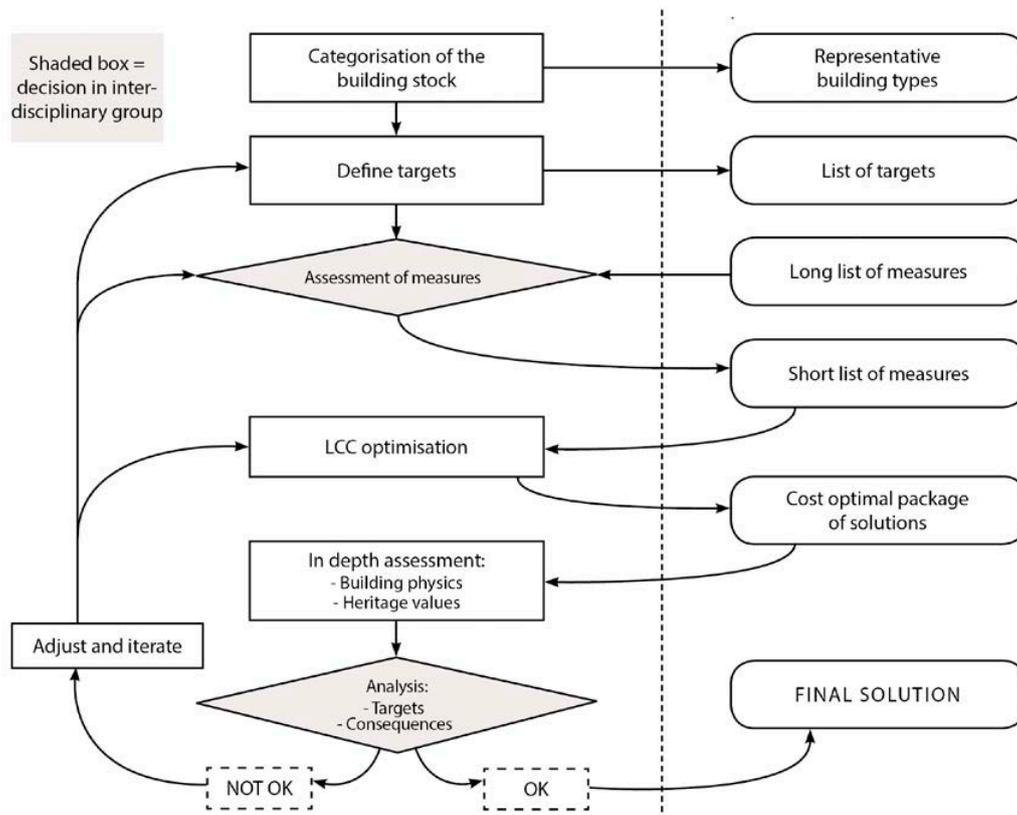


Figure 1. Flow chart illustrating the proposed method.

- 5) Risk assessment with respect to cultural heritage value and building physics;
- 6) Analysis of the consequences in relation to the targets;
- 7) Iterative adjustments of measures and targets.

2.2 CATEGORISATION OF THE BUILDING STOCK

The method for the categorisation of the building stock has been developed and validated within the Swedish national project 'Potential and Policies for Energy Efficiency in Swedish Historic Buildings' [2] and in the European project EFFESUS[3]. The categorisation is mainly based on the physical characteristics of the buildings:

- Number of floors;
- Floor area;
- Number of adjoining walls (perimeters);
- Type of building envelope construction.

For an in-depth analysis, subcategories can be based on year of construction, type of use, predominant energy supply and heat distribution system, and legal protection.

Existing databases are the primary sources for the building inventory, but it may be necessary to gather additional data in situ. The accessible data may be a limiting factor, this requires a flexible approach in order to adapt the categorization to data availability. All sources of building information need to be evaluated with regards to reliability, accessibility, variation rate and overall quality.

Based on the collected building data, the categorisation is carried out step by step:

Number of floors – the buildings are clustered according to their number of floors. Depending on the characteristics of the building stock, segmentation can vary. It is important to limit the number of categories.

Adjacent buildings – divide the buildings according to the number of adjoining walls; detached, semi-detached and terraced. This might not be a straightforward analysis and may require determining the percentage of covered wall surface rather than number of walls.

Floor area – calculate the floor area (unless available). This will not affect the number of categories but is used to determine the buildings' physical properties.

Define volume – generalised calculations based on available data may be needed.

Buildings with common physical features can vary in terms of size; outliers are excluded from the categories. Subcategories can be added to the physical categories, taking increasing levels of details into account, without having to develop new physical building models. This will enable a deeper analysis of technical and historic characteristics.

To represent each category, typical buildings are defined. They can be either real *sample buildings*, or generic *archetype buildings*. The typical buildings

are defined with respect to the medium values of volume, floor area and other relevant characteristics within each category.

2.3 TARGETS

For the buildings representing the building stock of Visby, three scenarios have been chosen to illustrate the approach of the proposed methodology. The scenarios are based on different degrees of restrictions for changing the building envelopes in accordance with the local building regulations for the case study area. The first scenario is an *optimal LCC solution* (see below), the second scenario is a *balanced scenario* with limited thickness of floor and roof insulation, and the third scenario which is the most *restricted scenario*, prohibits change or adaptation of windows as well as insulation of external walls.

2.4 TECHNO-ECONOMIC OPTIMISATION

Optimal Energy Retrofit Advisory-Mixed Integer Linear Program (OPERA-MILP) is an LCC optimization software with low computational resource usage developed at the Division of Energy Systems at Linköping University, Sweden, [4]. By the use of OPERA-MILP a cost-optimal energy renovation strategy is selected, corresponding to a month, in the calculations of the building's energy balance. Milić et al. [5] found that the accuracy with OPERA-MILP calculations is satisfactory, in terms of building power demand and energy use, by comparison with the established building energy simulation software IDA ICE. The cost-optimal energy renovation strategy can be obtained for different energy targets by setting the allowed building energy use to an arbitrary value. OPERA-MILP has been used successfully in several scientific investigations with the objective of minimizing building LCC, e.g. [6, 7].

In OPERA-MILP a specified period of time is set in the optimization. Consideration is taken for cost related to investment in heating system and Energy Efficiency Measures (EEMs), as well as energy costs and maintenance costs for building components, see Eq. (1).

$$LCC_{total} = LCC_{investment} + LCC_{energy} + LCC_{maintenance} - RV \quad (1)$$

where LCC_{total} presents the total LCC during the optimization period, $LCC_{investment}$ are total investment costs for EEMs and heating system, LCC_{energy} is the energy cost during the specified period of time, $LCC_{maintenance}$ is the maintenance cost for building components and RV presents the residual value of the investment costs connected to EEMs, heating system and also maintenance performed on the building. The implemented heating systems are district heating, groundwater heat pump, wood boiler and electric radiator. Implemented EEMs include window replacement, weather-stripping, floor insulation, roof insulation and external wall insulation on the inside and outside of the wall. Costs for the various measures are calculated based on cost functions, which are developed using up-to-date manufacturer data [4]. The energy balance of the building includes heat losses in form of transmission, ventilation and infiltration and domestic hot water use. Solar gain and internal heat generation, e.g. from electrical appliances and building

occupants, is also included. The building power demand is calculated based on a preset indoor temperature, the outdoor design temperature for the specific building and location, and the total heat losses of the building. In addition, the power demand for domestic hot water is taken into account.

2.5 ASSESSMENT OF HERITAGE VALUES AND VULNERABILITY TO CHANGE

Historic buildings are buildings with certain heritage significance. In order to take care of the values that constitute the significance of the buildings, we need to identify the character defining elements. In order to handle building stocks and categorised buildings, we need a simplified approach to identify heritage significance and to point at and select the character defining elements in order to assess the impact of change due to different techno economic scenarios [8]. The general approach could be described as follows:

Identify the main values that are the basis for the heritage significance of a building categories or typical building.

Identify the character defining elements (visual, material and spatial) that contribute to and reinforce the values and heritage significance.

Assess the impact of change by using a scale for benefits and risks with respect to each proposed measure.

In this case we used the local building regulation to identify the main values and character defining elements of the buildings, such as the exterior façade, windows and roof materials. This was in turn used to more specifically define the scenarios in terms of which measures can be allowed or not.



Figure 2. The historic district of Visby is a UNESCO world heritage with around 5000 inhabitants and 1400 buildings. Photo: Uppsala University.

3. CASE STUDY – VISBY

Visby is a UNESCO world heritage city located on the island of Gotland in the Baltic Sea. Around 5000 people live in the historic district and there are around 1400 buildings historic district, see Figure 2. According to UNESCO [9] it is a typical example of a north European medieval walled trading town which preserves a townscape and assemblage of high-quality ancient buildings that illustrate graphically the form and function of this type of significant human settlement. Even though the character of the town is medieval, there is a wide range of historic buildings representing various time periods and construction types. Visby is representative of many European historic city centres where the building constructions and conservation aspects set a limit to energy performance. Tourism is important and thus preserving buildings and townscape is an essential factor for a sustainable management of the city and its built heritage. The municipality has set very high standards for energy efficiency and they have launched a new plan for the historic centre where energy aspects are integrated with a general plan for building conservation.

4. RESULTS

4.1 CATEGORISATION

The categorisation of the building stock in Visby resulted in six categories, see Table 1. These six categories represent 87 % of the buildings and 70 % of the total building volume. The excluded buildings are mainly large non-residential buildings. Based on each building category, a typical building (also referred to as an archetype) was modelled. The typical building was based on the medium values of the buildings in each category.

Table 1. The categorisation of the building stock in Visby

	Category number					
	1	2	3	4	5	6
<i>Floors</i>	1	1	1	≥2	≥2	≥2
<i>Boundaries</i>	Detached	Semi-detached	Terraced	Detached	Semi-detached	Terraced
<i>No. of buildings</i>	364	212	41	108	113	82
<i>No. of buildings by onstruction*</i>	w 309/s 55	w 166/s 46	w 25/s 16	w 33/s 75	w 30/s 83	w 18/s 64
<i>Average volume (m³)</i>	300	320	425	1380	1300	1350
<i>Share of stock</i>	14 %	8 %	2 %	17 %	17 %	12 %

4.2 OPTIMISATION

For the optimisation, the six categories were divided in two subcategories according to their construction; wood and stone, i.e. 1w/1s, 2w/2s etc., resulting in twelve categories. The optimisation procedure was carried out on typical

buildings representing the building stock, and measures were selected according to the three different scenarios described above: optimal, balanced and restricted. EEM's that were considered risky with respect to moisture problems were removed.

The result of the optimisation was presented by grouping the subcategories as 1–3w/s (one-family houses) and 4–6w/s (apartment buildings). The results in terms of selected EEM's and energy use are exemplified in Table 2. The optimal scenario shows what is optimal from a techno-economic point of view. The balanced and the restricted scenarios show how much the energy use is increased due to the restrictions.

Table 2. Optimisation results exemplified by building categories 1w, 1s, 4w and 4s

Building category	Target scenarios					
	Optimal		Balanced		Restricted	
	EEM's	Energy use (kWh/m ² year)	EEM's	Energy use (kWh/m ² year)	EEM's	Energy use (kWh/m ² year)
1w	Roof ins: 12 cm Floor ins.: 26 cm Wall ins: - Windows: 2-panes	109.1	Roof ins: 12 cm Floor ins: 16 cm Wall ins: - Windows: -	131.2	Roof ins: 12 cm Floor ins: 16 cm Wall ins: - Windows: -	131.2
1s	Roof ins: 10 cm Floor ins: 24 cm Wall ins: 20 cm Windows: 2-panes	70.8	Roof ins: 12 cm Floor ins: 16 cm Wall ins: 16 cm Windows: -	101.8	Roof ins: 6 cm Floor ins: 16 cm Wall ins: - Windows: -	252.3
4w	Roof ins: 10 cm Floor ins: - Wall ins: - Windows: 2-panes	97.3	Roof ins: 12 cm Floor ins: - Wall ins: - Windows: -	113.0	Roof ins: 12 cm Floor ins: - Wall ins: - Windows: -	113.0
4s	Roof ins: 10 cm Floor ins: - Wall ins: 16 cm Windows: 2-panes	71.3	Roof ins: 10 cm Floor ins: - Wall ins: 16 cm Windows: -	91.0	Roof ins: 12 cm Floor ins: - Wall ins: - Windows: -	204.5

Based on the total building volume for each category, the results from the typical buildings in Table 2 are extrapolated to reflect the effects at a building stock scale, see Figure 3. The biggest differences between the scenarios appear in category groups 1–3s and 4–6s, which are connected to the thermal properties of stone constructions. Insulation of exterior walls does not pay off in the wooden buildings, thus there is a relatively small difference between the scenarios for the wooden buildings.

The optimal scenario results in suggestions on changing windows in all typical buildings which would be in conflict with the local building regulation and is regarded as having high negative impact on heritage values. The balanced and restricted scenarios suggest energy improving measures, such as improving roof and floor insulation, as well as interior insulation on exterior walls. These measures do not affect the character defining elements.

On a district scale, it can be seen that imposing restrictions would have little effect on the energy use of wooden buildings. As pointed out above, the stone

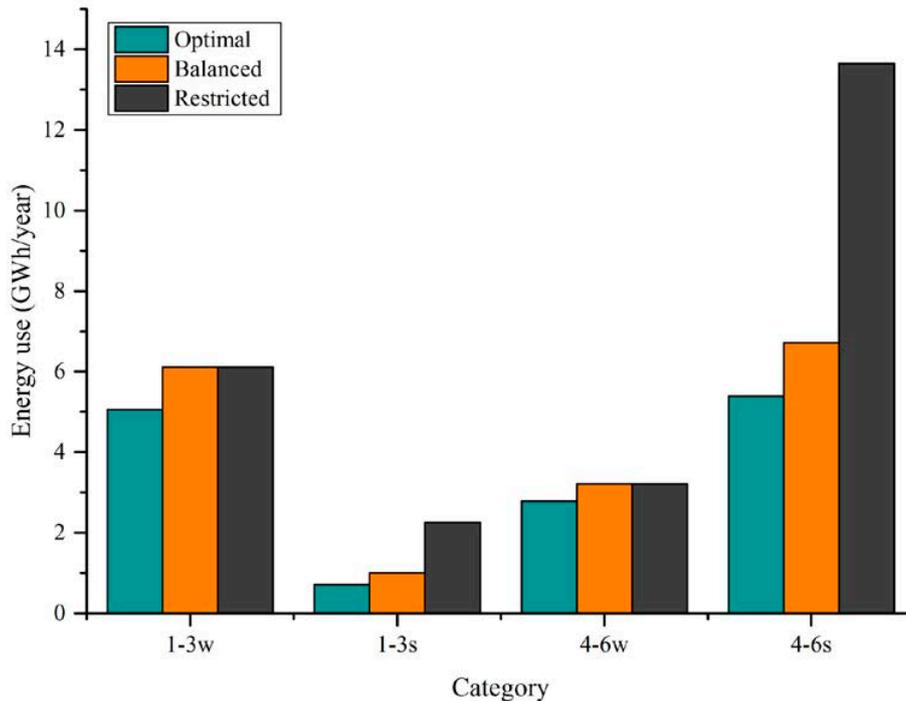


Figure 3. Total energy use (GWh/year for each target scenario) divided into four building categories.

buildings (1–3s and 4–6s) have a bigger energy saving potential than the groups of wooden buildings. On a district scale, however, the apartment buildings (4–6s) dominate, see Figure 3. The results also indicate that if wooden buildings should be improved in energy performance, this requires change of windows, a highly restricted measure in the building regulations for the historic district of Visby. There is a considerable potential to save energy with the balanced scenario in the stone buildings. This implies that continuing research on possible EEMs that comply with the designated heritage values in Visby, is needed.

5. CONCLUSIONS

We suggest that the presented method can be used for planning and policy development in large stocks of historic buildings. Through the integration of quantitative and qualitative methods in a multidisciplinary dialogue, the method provides a tool to show the consequences, in terms of energy use and impact on heritage values, for different levels of restrictions, not only for single buildings but for the district as a whole.

This methodological approach illustrates a possible path to the design of strategic programmes for energy saving on building stock level through the comparison of different target scenarios. In these target scenarios we have considered best LCC as well the local building regulations for our case study area. The results show that there are different energy saving potentials in the different categories of the building stock. These differences could be used as a basis to develop differentiated and specific information to the owners.

In the next step of the project 'Potential and Policies for Energy Efficiency in Swedish Historic Buildings', the method will be applied to different and much larger building stocks in Sweden in order to facilitate better planning and more precise policies.

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