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# A methodology to assess energy-demand savings and cost effectiveness of retrofitting in existing Swedish residential buildings

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ABSTRACT

Swedish residential buildings are typically retrofitted on a case-by-case basis. Large numbers of building consultants are involved in the decision-making, and stakeholders find it difficult to quantify the sustainable profits from retrofits and to make an efficient selection of the optimal alternative. The present paper presents an approach to design and assess energy-demand retrofitting scenarios. This aims to contribute to retrofitting decision-making regarding the main archetypes of existing Swedish residential buildings and to the evaluation of their long-term cost effectiveness. The approach combines energy-demand modeling and retrofit option rankings with life-cycle cost analysis (LCCA). Four types of typical Swedish residential buildings are used to demonstrate the model. Retrofits in the archetypes are defined, analyzed and ranked to indicate the long-term energy savings and economic profits. The model indicates that the energy saving potential of retrofitting is 36–54% in the archetypes. However, retrofits with the largest energy-saving potential are not always the most cost effective. The long-term profits of retrofitting are largely dominated by the building types. The finding can contribute to the standardization of future retrofitting designs on municipality scale in Sweden.



## 1. Introduction

Among all the civil energy end users, the existing buildings account for 30–40% of the total energy utilizations in cities (National Science and Technology Council, 2008). At European Union (EU) level, energy usage in buildings has increased from 400 to 450 Mtoe (million tons of oil equivalent) in the past 20 years (Economidou et al., 2011), and the increase is bound to continue if adequate energy-saving measures are not efficiently conducted. In 2010, the Energy Performance of Building Directive (EPBD) recast and stated that major building renovations, regardless of size, should provide an opportunity to undergo cost-effectiveness measures to enhance energy performance (European Commission, 2010). At Swedish society level, energy usage in existing building stock amounted to 147 TWh in 2012, equivalent to almost 40% of the final overall national energy consumption, and the household energy costs rose steeply throughout the 2000s (Energimyndigheten, 2012). Moreover, 60% of the final energy delivered in residential buildings is for space heating and domestic hot water production (DHW) (Ericsson, 2009). In response to EU's tightening energy policies in building sector, the Swedish Building Regulations (BBR) were revised in 2012 to provide stricter requirements to promote the sustainable transition of existing housing stock. The revised building code mandates that delivered energy in existing buildings be decreased through lower heat loss, restricted heating requirements, and as more efficient use of heating and cooling and of household electricity (Boverket, 2012; Swedish Environmental Protection Agency, 2011). Despite the urgent need, very little methodology is currently being carried out to efficiently select and evaluate the retrofitting techniques from a national level. These are performed in this study with both energy and long-term cost concerns for future large-scale implementation in major Swedish housing stock.

### 1.1. Previous studies

As a baseline and essential technique, energy-demand retrofitting is considered as an effective way to accelerate the low-energy transformation of urban housing stock (Företagen, 2009). The industry approach in Sweden typically involves numerous consultants and technicians who focus on individual building components or cases. Existing retrofitting solutions tend to be highly case-specific (Levin & Niklas, 2011; Levin, Jidinger, &

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**Nomenclature**

*Acronyms*

| | |
|---|---|
| BBR | Swedish building regulations |
| COP | coefficient of performance |
| DHW | domestic hot water |
| EPBD | Energy Performance of Building Directive |
| LCCA | life-cycle cost analysis |
| LCC | life-cycle costs expressed in present value in € |
| LSA | local sensitivity analysis |
| MP | Miljonprogrammet (Million Program, 1965–1975) |
| NPV | net present value in € |
| RO | retrofit option |

*Symbols*

| | |
|---|---|
| $C$ | energy price before retrofitting in € |
| $C'$ | energy price after retrofitting in € |
| $d$ | discount rate of Swedish currency, % |
| $f$ | real energy price increase, % |
| $i$ | retrofit option $i$ |
| $IC$ | retrofitting investment cost expressed in present value in € |
| $j$ | energy source type |
| $OC$ | operational energy costs expressed in present value in € |
| $p$ | normalization factor for cost rankings |
| $RMC$ | replacement and maintenance costs expressed in present value in € |
| $U$-value | heat transfer coefficient of building elements, W/m$^2$ K |
| $yP$ | period-of-analysis in years ($y$) |
| € | Euros |
| $\Phi_{DHW}$ | domestic hot water energy demand, kWh/m$^2$ |
| $\Phi_E$ | total energy demand, kWh/m$^2$ |
| $\Phi_{EL}$ | building electricity demand, kWh/m$^2$ |
| $\Phi_H$ | building heating demand, kWh/m$^2$ |
| $\Phi_{H\cdot T}$ | transmission heat loss, kWh/m$^2$ |
| $\Phi_{I\cdot H}$ | internal heat gains, kWh/m$^2$ |
| $\Phi_{I\cdot S}$ | solar heat gains, kWh/m$^2$ |
| $\Phi_{Ven}$ | ventilation heat loss, kWh/m$^2$ |

Larsson, 2010). Available retrofitting models and studies from other countries are mainly based on local building energy codes and particular retrofitting targets. For example, Chidiac, Catania, Morofsky, and Foo (2011) developed a regression model based on a screening methodology to select optimal retrofitting measures for Canadian office buildings. Tavares and Martins (2007) proposed the VisualDOE™ building simulation tools to design low-energy public buildings in Portugal. Hughes, Palmer, Cheng, and Shipworth (2013) and Firth, Lomas, and Wright (2010) introduced a sensitivity-based uncertainty analysis to investigate the major building components that impact total energy usage and $CO_2$ emissions under the British Cambridge Housing Model (CHM). Juan, Gao, and Wang (2010) and Chantrelle, Lahmidi, Keilholz, Mankibi, and Michel (2011) developed holistic, hybrid decision-making methods that combine genetic algorithm with searching algorithms to select optimal energy-saving renovation measures. Ouyang, Wang, Li, and Hokao (2011) and Hong, Kim, and Koo (2012) integrated life cycle cost (LCC) and environmental impact ($LCCO_2$) into Chinese retrofitting strategy assessment. Dall'O, Galante, and Pasetti (2012) proposed a housing typology oriented retrofitting approach for Italian residential stocks, in which energy saving potentials led by retrofits (mainly window replacements, wall and roofing thermal insulations) was evaluated by selected cross-archetypes analysis. Paiho, Abdurafikov, and Hoang (2015) designed cost analysis-based retrofitting strategies to implement building installation system renovations (considering both energy demand and supply) for Russian residential buildings, which further extended the scenario to building district levels. Specific to Swedish residential buildings, Energy Europe TABULA project (TABULA, 2009) performed a general energy retrofitting guideline based on 44 typology categories of existing Swedish residential buildings. Brown, Malmqvist, Bai, and Molinari (2013) and Wang (2013) combined long-term cost estimations into an energy-efficient, retrofitting assessment of Swedish multifamily houses. Mata, Kalagasidis, and Johnsson (2013) developed a bottom-up model in Simulink with plug-in models to assess several technical and non-technical measures for improving the sustainability of Swedish building stock. Other possible software and modeling techniques, including IDA ICE, Design Builder/EnergyPlus, LEED and eQuest®, have been employed in some renovation practices (Chidiac et al., 2011; Dahl, Ekman, Kuldkepp, & Sommerfeldt, 2011). The models are capable of providing relatively accurate one- or multi-zone energy demand simulations for reference buildings. However, these tools have had limited usage in retrofitting Swedish residential buildings and requires relatively well-trained professions to operate the simulation. Lessons and shortcomings that are drawn from precedents can be summarized as:

- Identifications of the relatively importance/sensitivity of common Swedish retrofit options to the energy-demand savings are not clearly investigated.
- Long-term financial evaluations consisted of material and building operational costs in relation to retrofit scenarios are not sufficiently attained.
- Retrofitting solutions are not easily adapted to larger contingents of similar archetypes for future Swedish city-based, large-scale implementation. More efficient retrofitting decision-making methodologies are needed.

### 1.2. Objective

This study aims to use a combination of existing energy-demand modeling techniques to formulate evaluations and recommendations for retrofitting Swedish residential building stock, which is dominated by limited numbers of housing types. To derive the greatest effectiveness and the trade-off between energy savings and retrofitting costs, long-term financial estimations are performed in relation to the proposed retrofit scenario and national energy prices. Different retrofit options are evaluated. They are expected to support policymakers/construction industries with efficient renovation strategies.

## 2. Methodology

The methodology for the analysis and evaluation is consisted by three parts. First, the archetypes and the representative housing stock were developed and selected, which give "as-built" status (Base Case) before retrofitting. The as-built archetype is defined as a significant category of houses, which can be extrapolated to the total energy saving potentials by the numbers of present archetypes from cities or national level (Famuyibo, Duffy, & Strachan, 2013). In the study, archetypes are classified by construction materials, the occupancies and the building ages. Base Case presents the archetypes without retrofitting.

Second, the ranking of implementing different retrofit alternatives to the energy saving potentials is identified. Two levels of retrofit scenarios are further designed to evaluate the total annual energy savings in each archetype: