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# Comprehensive investigation on energy retrofits in eleven multi-family buildings in Sweden

Linn Liu[a,b,*], Bahram Moshfegh[a,b], Jan Akander[b], Mathias Cehlin[b]

[a] Division of Energy Systems, Department of Management and Engineering, Linköping University, Linköping, Sweden
[b] Division of Building, Energy and Environment Technology, Department of Technology and Environment, University of Gävle, Gävle, Sweden

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ABSTRACT

Rapidly growing energy use in the building sector is considered a serious problem by both the European Union (EU) and Sweden. Reducing energy demand in the building sector is important for Sweden in order to reach national energy goals for reduced energy use and $CO_2$ emissions in the future. This project aims to find energy efficiency potential in multifamily buildings in the Gävleborg region, which is a cold climate region in Sweden. Measurements and simulations have been made on eleven multifamily buildings from the whole region. The results include different energy efficiency measure packages, profitability analysis of individual measures and packages, and primary energy use analysis. The paper also includes $CO_2$ emissions reduction analysis based on different methods. The project shows that the multifamily buildings in the Gävleborg region have good potential to reduce their energy use by more than 50%, which in turn will contribute to 43% primary energy reduction and 48% $CO_2$ emissions reduction.


## 1. Introduction

Sweden has adopted a number of national environmental goals which include reducing energy use and greenhouse gas (GHG) emissions in the future. One of these is to create a good indoor environment and more specifically to reduce the total energy use per unit floor area in residential and commercial buildings by 20% by 2020 and 50% by 2050 in relation to energy use in 1995 [1]. Reducing energy use in residential buildings is a key factor in meeting the national energy target of a 50% reduction in energy use in the building sector by 2050 [1]. According to the Swedish Energy Agency, the building sector uses almost 39% of the energy used by the demand side in Sweden [2].

As shown in Fig. 1, the construction rate of dwellings was highest between 1965 and 1974 due to the “Million Program”. Almost one million dwellings in the form of single family houses and apartments in multi-family buildings were produced to meet the increasing population [4,5,6]. In recent decades, the construction rate has been stable at a very low level. In order to fulfil the national goals, it is not sufficient to construct new energy-efficient buildings—there is a need to retrofit the old stock which will represent a substantial part of the future building population. Since older buildings typically undergo major renovation only every 30 to 40 years, the opportunity of improving energy performance during renovation should be considered seriously [6]. Thus, the necessity and extent of renovation will play an important role in whether or not Sweden is successful in reducing energy use in the future, while the size of the building stock in general will increase. Today, there are about 165,000 multi-family buildings out of a total of approximately 2.1 million buildings [3].

This article presents the major results from a research project with the acronym EKG-f project. The EKG-f project was a pioneer project with the over-all aim of identifying the potential of both energy efficiency and profitability of multifamily buildings in the Gävleborg region in Sweden. The Gävleborg region is located in the north of Sweden. The climate is characterized by an extreme outdoor air temperature of −30 °C during a normal year and an annual average outdoor air temperature of 5 °C. The project investigated simulated reduction of energy and $CO_2$ emissions in eleven existing multifamily buildings by means of different energy efficiency measures. The aim of the article, based on the multi-family buildings, is to explore which retrofitting actions are currently profitable as a start of the long-term process of achieving energy and $CO_2$-reduction of 50% and 75%, respectively, by 2050.

* Corresponding author at: Linköping University, Department of Management and Engineering, Division of Energy System, SE-58183 Linköping, Sweden.
Tel.: +46762495266.
*E-mail address:* linn.liu@liu.se (L. Liu).

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**Nomenclature**

| | |
|---|---|
| $A$ | surface area $m^2$ |
| $C_{investmen}$ | capital cost of the measure € |
| $E$ | energy use kW h or MW h |
| $f$ | adjusted net interest rate % |
| *g-value* | heat gain value through glass relative to incident solar radiation % |
| $LCC_{tot}$ | total life cycle cost € |
| $LCC_{energy}$ | total life cycle energy cost € |
| $LCC_{maintenance}$ | life cycle operation and maintenance costs € |
| $LCC_{residual}$ | residual value of the components at year $n$ after the implementation € |
| $P_{energy\ price}$ | energy price € |
| $p$ | estimated rate of increase of energy prices % |
| $P$ | power $kW_t$ |
| $r$ | interest rate % |
| $t$ | insulation thickness mm |
| $U$ | heat transfer coefficient $W/m^2\,°C$ |

The Gävleborg region is a sparsely populated forest region with many small towns. The population rate is declining and the unemployment rate is highest in the county. The proportion of young persons and women is small: barely over 15% of the population are 13–25 years of age. Composed of 10 municipalities, only three are not losing inhabitants whereof only one is slightly increasing. Considerably more people are leaving the workforce than entering it. There are 140,000 dwellings of which 65,800 (47%) are apartments in multi-family buildings. Three of the municipalities have excess housing, two have a lack and the rest have the housing situation in balance [7].

## 2. Project description

### 2.1. Description of the studied buildings

Eleven multi-family buildings, which the owners plan to renovate in coming years, were involved. The selection was made among voluntary property owners, who promised to actively participate in the process and accepted the publicity that the project would generate (without being required to perform the retrofit). At least one building was situated in each of the region's ten municipalities. The buildings have varying characteristics, such as different ownership forms, types of heating and ventilation systems, building construction periods and locations. The objective of the study was to include different building types with various heating and ventilation systems, number of apartments, ownership, etc. The aim was to have a holistic overview of energy performance of multifamily buildings in the region. Main characteristics of the studied buildings are shown in Table 1 and detailed information can be found in [7,8].

Briefly, the project was organized in the following way [8]:

- Audits and measurements were made on site and information was also accessed from drawings, energy bills, Energy Performance Certificates (EPC) [9] and ventilation inspection protocols. Inspections on renovation needs and data collection for energy simulations were carried out.
- The next phase was to perform building energy simulations, with different proposed energy efficiency measures, together with measures that the property owner wished to study.
- Economic calculations on profitability, primary energy use, $CO_2$ reductions were investigated.

### 2.2. Description of methods

Several methods have been used, such as technical measurement, building energy simulation, life cycle cost and $CO_2$ emissions calculations. By using these methods, energy savings, cost savings, primary energy use and $CO_2$ emissions have been analyzed. Information about the buildings was accessed in various ways.

- Drawings, energy bills, EPC and mandatory ventilation inspection.
- In-situ energy audit by inspection of one apartment and common spaces (corridors, attics, cellar, boiler rooms, etc.).
- Instantaneous and longer term measurements.

#### 2.2.1. In-situ measurements

Indoor air temperatures and relative humidity (RH) were measured with Tiny-tag loggers placed in the middle of each participating apartment. These have a margin of error of ±0.4 °C and ±3% for RH, respectively [7]. The Blower Door method [10] was used to assess the air tightness of the apartment constructions. The measured value has unit as $l/s\,m^2(@\pm 50\,Pa)$, where $m^2$ is based on the enclosing surface area of the pressurized volume [7]. The uncertainty for a non-windy day is ±15%. An infrared camera was used to identify thermal bridges, air leakages and other faults in building envelopes; the uncertainty is ±2 °C. A capture hood was used to measure the air flow passing through the mechanically ventilated ducts (uncertainty ±6%). A tracer gas technique [11] was used to measure the air change rate in naturally ventilated apartments for

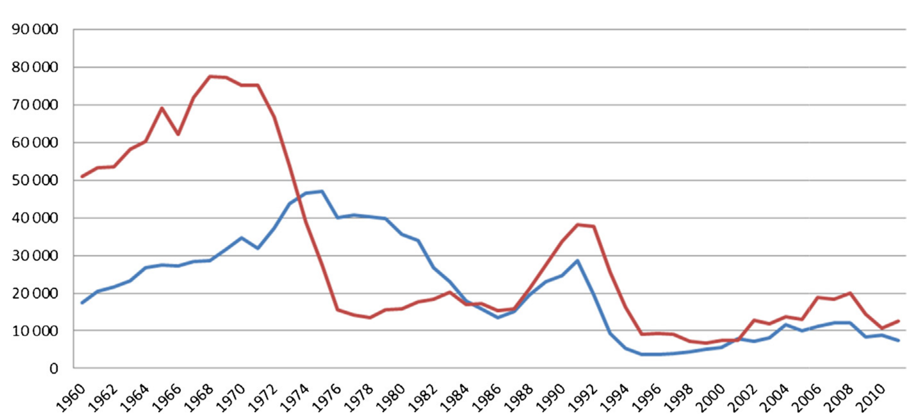


**Fig. 1.** Number of new apartments (red) and single family houses (blue) as function of construction year. "Comprehensive investigation on energy retrofits in eleven multi-family buildings in Sweden". (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)