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LICENTIATE THESIS NO. 3

A methodology to assess impacts of energy efficient renovation – A Swedish case study

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*This thesis is based on work conducted within the industrial post-graduate school Reesbe – **R**esource-**E**fficient **E**nergy **S**ystems in the **B**uilt **E**nvironment. The projects in Reesbe are aimed at key issues in the interface between the business responsibilities of different actors in order to find common solutions for improving energy efficiency that are resource-efficient in terms of primary energy and low environmental impact.*

Reesbe

Resource-Efficient Energy Systems in the Built Environment

The research groups that participate are Energy Systems at the University of Gävle, Energy and Environmental Technology at the Mälardalen University, and Energy and Environmental Technology at the Dalarna University. The founding of Reesbe is an initiative of the three universities in close co-operation with industry in the three regions of Gävleborg, Dalarna, and Mälardalen, and is funded by the Knowledge Foundation (KK-stiftelsen).

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Abstract

The European Union aims to reduce energy use and CO_2-emissions by 40 % by the year 2030. The building sector has been identified as having a great potential to reduce emission of CO_2 by increasing its energy efficiency. Also, there is a growing concern of the buildings environmental performance, that lead to the development of building environmental assessment tools. However, different types of energy sources and confusing environmental impacts affect the decision making when renovating for improved energy efficiency. This study develops and tests a methodology to help decision-makers when considering major renovation of their building stock when connected to a district heating system. The proposed methodology is applied and used to investigate how different renovation scenarios affects the building environmental impacts in terms of CO_2 emissions and identify and discuss future improvements of the methodology.

The novelty of the method is the expanded system boundaries that include both the distribution and production of district heating and the energy use at a building level. In this way it is possible to compare and weight measures made both at the energy system level and the building level. This work has limited its approach to energy use in buildings, but it is important to bring the life cycle thinking to the methodology. During the choice of the renovation methods it was noticed that the environmental impact of the production of some components in order to reduce the energy use of a building are not insignificant. Even if all the renovation measures considered in this case study are feasible, it is important to determine in which order they are desirable or achievable from an economic point of view. Uncertainty in the future development of energy, and limited economic resources can play an important role in the possibility of energy efficient renovation.

Keywords: Buildings, renovation, greenhouse gases emissions, district heating, energy efficiency, building environmental assessment tools, energy use, heating

Sammanfattning

Den Europeiska Unionen har som målsättning att minska energianvändning och utsläpp av växthusgaser med 40 % till året 2030 jämför med 1990. Byggnader har identifierats som ett område med stor potential för utsläppsminskningar om de energieffektiviseras. Användningen av olika energislag och olika sätt att värdera miljöpåverkan påverkar beslutsfattandet i samband med energieffektivisering.

I studien utvecklas och testas en metodik som kan hjälpa beslutsfattare vid renovering med energieffektivisering inom fjärrvärmeområdet. Först utvecklades en översiktlig metodik vilken inkluderar både byggnadsenergisimulering och energisystemsimulering. Sen implementerades metodiken genom olika renoveringsscenarier och utsläppen av växthusgaser analyserades.

Metodiken visar att det finns en möjlighet att utveckla ett verktyg som kan hjälpa beslutsfattare när energibesparingsstrategier ska implementeras vilka kan bli positiva för både byggnader och fjärrvärmesystemet.

Nyckelord: Byggnader, renovering, växthusgasutsläpp, fjärrvärme, energieffektivisering, byggnadsmiljöprestanda verktyg, energianvändning, värme

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I would also like to thank my wife, Jenny, for her wise counsel and sympathetic ear. You are always there for me. Finally, there are my children, Mika and Tuuli, you were always there for me to light my days.

List of papers

This thesis is based on the following papers, which are referred to in the text by Roman numerals:

Paper I

Lidberg, T., Ramírez-Villegas, R., Olofsson, T., & Eriksson, O. (2014). An approach to illustrate strategies for improved energy efficiency at the municipal level. In The 14th International Symposium on District Heating and Cooling, Stockholm on September 7-9, 2014.

The first paper was written in cooperation with Tina Lidberg and the following work was carried out together; the formulation of the research question and the study design, data collection, carrying out the building energy simulations, writing the paper. This work was carried out with the support of all co-authors

Paper II

Ramírez-Villegas, R., Eriksson, O., & Olofsson, T. (2016). Assessment of renovation measures for a dwelling area – Impacts on energy efficiency and building certification. Building and Environment, 97, 26-33.

The work in this paper, formulating the research question, collecting data, carrying out the building energy simulations, performing the building environmental assessment and writing the paper was carried out with support of all co-authors.

Acronyms

BBR	Boverkets Byggregler (Swedish Building Normative)
BREEAM	Building Research Establishment Assessment Method
CHP	Cogeneration of Heat and Power
EU	European Union
GHG	Greenhouse gases
HRV	Heat Recovery Ventilation
IDA-ICE	IDA- Indoor Climate and Energy
IVA	Royal Swedish Academy of Engineering Sciences
LEED	Leadership in Energy and Environmental Design

Table of Contents

Introduction

In 1992 the Rio Declaration on Environment and Development laid the foundations of the work of the Brundtland Commission, which resulted in the document "Our Common Future", a document that, for the first time, tried to define what Sustainable Development means.[1]

Since the Rio Declaration and the work of the Brundtland Commission, worldwide greenhouse emissions are still on the rise, but the lack of action in different countries around the world led to a historical agreement in the Conference of Parties (COP) 21 in Paris, where 194 countries signed an agreement to keep global temperature raise below 2°C by reducing GHG-emissions drastically around the world by 2050 [2].

The European Union (EU) stated that in order to fulfill these requirements all sectors need to invest in energy efficiency [3]. Based on the framework of these agreements, the EU has set goals to reduce Greenhouse gas (GHG) emissions by 40 % by the year 2030 (compared to 1990 emissions) [4].

Background

Energy use

The EU has set a goal to reduce energy use by at least 27 % by 2030 compared to 1990 levels. In order to reach the target, different initiatives have been promoted to increase energy efficiency in general as well as energy performance in buildings and household appliances as well as the promotion of cogeneration of electricity. As a result, energy use within the EU 28 has decreased in recent years, with a reduction in fossil fuel consumption and the rise of renewables (see Fig. 1).

According to EUROSTAT [5] energy use has remained unchanged 2003-2008 with a sudden decrease in 2009 due to the global financial crisis and therefore also with a continued decrease. The energy use rebounded in 2010, due to the economic recovery in most EU28 countries, but has been decreasing since then. It is important to note that around 56 % of the total energy use in the EU relates to Germany, France, UK and Italy which is proportional to the population (54 %). It is noticeable that the amount of petroleum products and solid fuels (which includes no biomass and waste) [6] within the EU-28 have declined gradually while the population from 1990-2014 has increased from 475 million to 507 million inhabitants. The generation of nuclear heat (derived from the amount of steam from nuclear reactors) has been almost unchanged during this period. The use of gas (both natural and gasworks gas)

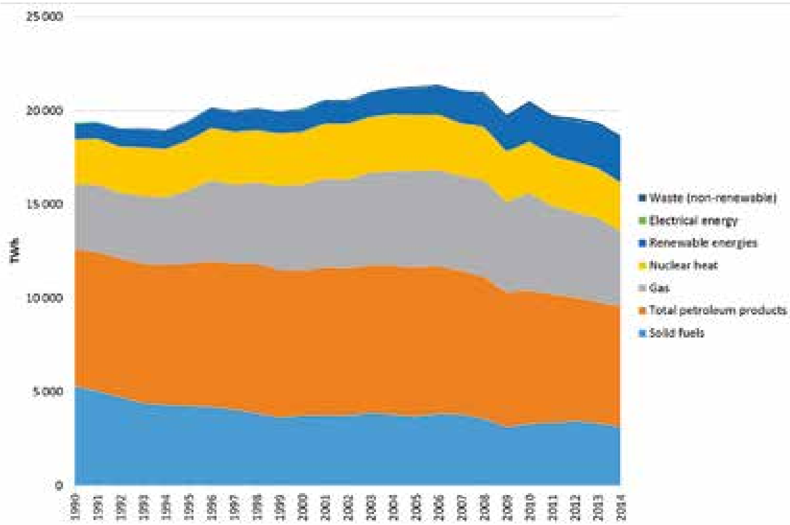

Fig. 1 European Union (EU-28) Primary energy use by fuel [5]

has increased gradually, but the most interesting fact is that renewables have tripled since 1990 accounting for 12.5 % of the total energy use by the year 2014. Different sectors have developed during 1990 – 2014, while some have increased other have remained unchanged.

In 2014 the transport sector was responsible for 33 % of total energy use, followed by industry (26 %) and households (25 %) within the EU28. The transportation sector has increased its share constantly every year from 1990 until 2007, then decreased it by 9 % by 2014.

In Sweden, energy use has remained basically unchanged from 1990 – 2014 but the distribution of different energy carriers has changed (see Fig. 2).

During 1990-2014 the supply of nuclear energy (reported gross, as supplied energy in fuel)[7] has remained unchanged, mirroring the development in the EU28, petroleum products have decreased and have almost become an energy source for the transport sector alone. Biomass has grown constantly, while wind power has tripled its share during the period 2010-2014. Hydropower has remained constant since the 1980's [8]. Since the deregulation of the electricity market in Sweden in the mid 90's there has been big variations in electricity generation. In recent years, however, even if the energy use has decreased, electricity generation has increased.

Electricity generation in Sweden is largely based on hydropower (which can vary a great deal depending on the weather) and nuclear power, 41 % and 43 % respectively. Other renewables, mostly wind, have been expanding during the 2000's and by the year 2014 wind power represents 7 % of electricity generation. When it comes to Cogeneration of Heat and Power (CHP), 74 % of the fuel used is biomass. Solar power represents 0.04 % of

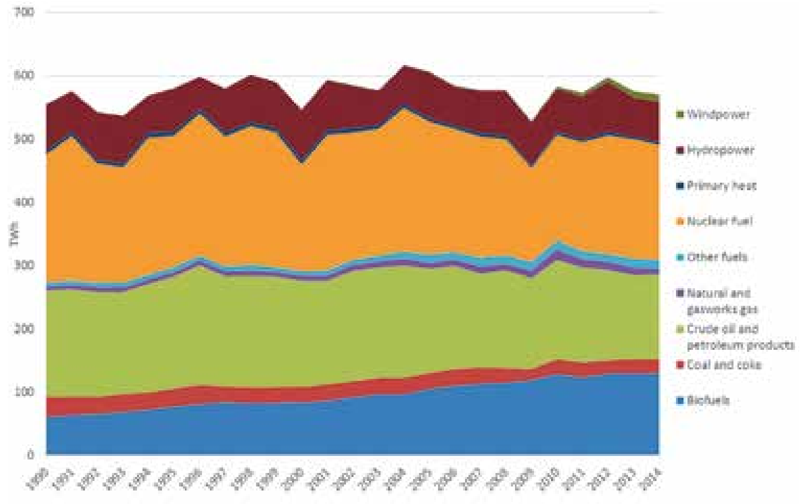

Fig. 2 Sweden’s total energy supply by energy commodity [7]

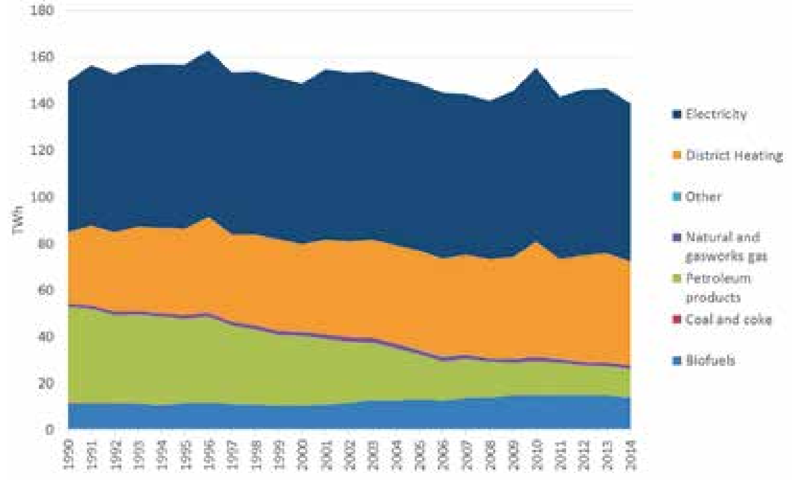

Fig. 3 Final energy use in the residential and services sector by energy carrier [7]

the electrical power supply. The category other thermal refers to conventional thermal power (using fossil fuels) [8]. Electricity use in Sweden has decreased since 2012 for different reasons. One is that Sweden has an unusual amount of electrical heating compared with the other EU countries, around 30 TWh, so differences in outdoor temperature give fluctuations. Another reason is the slow economic development in industries [9].

Energy use in the residential and service sector (households, public administrations, commercial, agricultural, forestry, fishing and construction) in Sweden represents around 40 % of the totally energy use [8] and 15 % of total GHG emissions [10]. This situation is mainly due to Sweden being a forerunner in both district heating and renewables (together with nuclear power)[10]. Still, there is great interest in Sweden for reducing energy use in buildings, and new regulations, such as BBR (Swedish Building Normative), demand lower energy use in buildings.

The residential and service sector (where household and non-residential buildings represent 90% of the sector) has decreased its use of energy during the period 2000-2009 with a rebound in 2010 due to the coldest winter registered in Sweden since the 1980's [11]. The use of heating and domestic hot water (DHW) has decreased during 1990-2014, as has the use of oil (by 70 % since 1990). This has, to a great extent, been replaced by electricity, DH and heat pumps. The energy output of heat pumps is not calculated (just the electricity needed to run the equipment is taken into account, not the total energy output).

The electricity use in the sector has remained stable since the 1990's due to different developments; on the one hand the amount of household and operational electricity use in buildings has increased due to the increase in household appliances at home. The change to more energy efficient appliances counteracts the increase. On the other hand, the increase in heat pumps and district heating has replaced direct electrical heating.[9]

Still, half the energy use in the sector goes to heating, due to the climate in Sweden, electricity being the most common source of heat for single family buildings and DH the most common for multi-family and service buildings.

According to IVA [12] Sweden has good possibilities to develop an electricity sector towards more renewables and fossil free energy sources. In their analysis, hydropower would still be a key electricity producer, while a higher share of biofuels would help to replace some nuclear power, but that with the recent technological approach new nuclear reactions could replace older ones. IVA also notices that wind and solar are good alternatives for delivering significant amounts of energy depending on technological development.

Housing Stock in Sweden

According to the European Commission [13], 80 % of the population will be living in already existing buildings by the year 2030. The main reason, according to Botta [14], is that there is a tendency in Europe and North America towards buildings being renovated rather than new ones being built. This trend is noticeable in the EU where the growth rates of the residential sector are around 1 % [15]. In Sweden, around one third of the total housing stock was built in the period 1965-1975 in the so-called Million Homes Programme (Miljonprogrammet) (See Fig. 4).

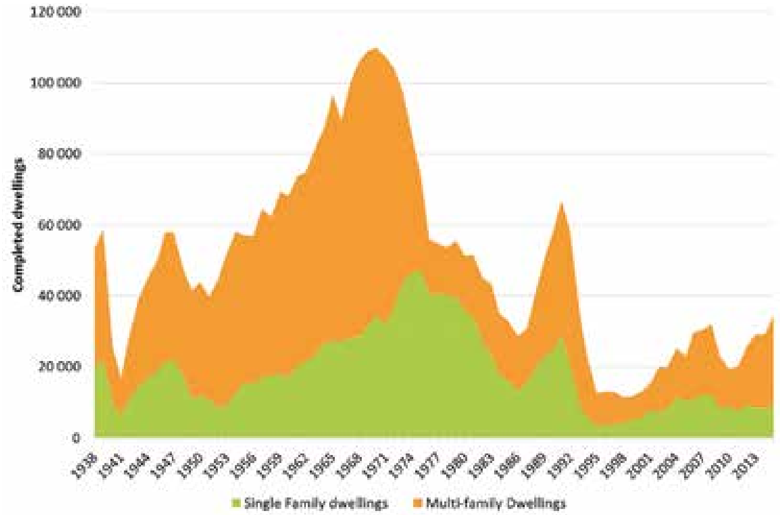

Fig. 4 Building stock in Sweden [16]

The programme was characterized by a highly rationalized use of materials as well of a high degree of experimentation, which, in turn, led to the culmination of roughly one million dwellings (in - at the time- an 8 million inhabitants country) making this one of the most ambitious housing programmes of its era [17]. Roughly 40 years after its culmination, and with the new EU energy directives in sight, the way that these dwellings use energy is a rethink challenge. Most of these buildings were finished before the 1973-74 global oil crises, in an era when an unlimited supply of cheap energy was assumed.

Energy use in buildings

Approximately 50 % of the total heating demand in Sweden comes from district heating (DH). For multifamily dwellings this figure can be as much as 85 % of all buildings being dependent on these systems [18]

Shortage of oil during the first oil crisis and the threat of a shortage of energy due to the dependency on imports also encouraged a big development of district heating systems in Sweden. Many of the buildings built during the Million Homes Programme were connected to a district heating system. In 230 of Sweden's 270 municipalities there is some sort of DH plant [18].

It is expected that by the year 2025 the use of district heating in Sweden will increase, due to different factors, one of them is more use of district heating within the industry sector, another is more single family buildings replacing oil furnaces where DH is available. Other prognoses point out that the amount of energy from forestry and household waste used in the district heating system will increase in the coming years due to the demand for more Combined Heat and Power [19].

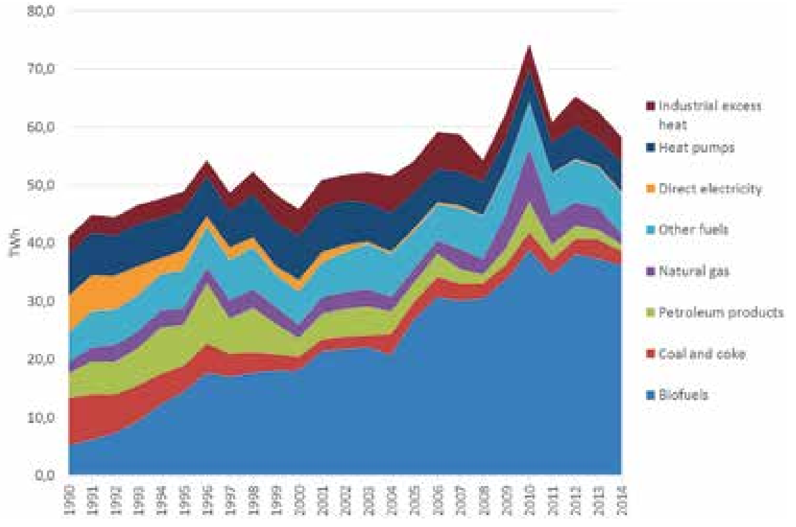

Fig. 5 Input energy used in the production of district heating [7]

Building environmental assessment tools

By the 1990's the discussion on anthropogenic environmental impacts reached more than the general public and moved towards government and companies, as a reaction to the increased awareness of our resources. Since then building environmental assessment tools have been used to evaluate resource use and to assess ecological loading and indoor environmental quality [20]but it is difficult to understand how BEATs relate to each other, as well as to make detailed and systematic tool comparisons. A framework for comparing BEATs is presented in the following which facilitates an understanding and comparison of similarities and differences in terms of structure, content, aggregation, and scope. The framework was tested by comparing three distinctly different assessment tools; LEED-NC v3, Code for Sustainable Homes (CSH.

According to Wallhagen et al, building environmental assessment tools play different roles: marketing for "environmental friendly" buildings, stimulation for better environmental performance, as tools for decision-makers and as tools to measure environmental impacts among others [20] but it is difficult to understand how BEATs relate to each other, as well as to make detailed and systematic tool comparisons. A framework for comparing BEATs is presented in the following which facilitates an understanding and comparison of similarities and differences in terms of structure, content, aggregation, and scope. The framework was tested by comparing three distinctly different assessment tools; LEED-NC v3, Code for Sustainable Homes (CSH.

There are many tools available such as LEED and BREEAM in the Swedish case. Since the end of the 1990's there has been a need to develop a tool that could be applicable to local conditions, resulting in the development of Miljöbyggnad. This tool is the most used in Sweden and is based on national common practices and norms [21].

Previous research

The building and services sector represents a major portion of energy use in the developed world [22]. In Sweden, in the decades following the culmination of the Million Homes Programme, new construction has been stable at a low level [23]. This means that the existing stock would house most of the population in the coming years [24]. Most of these buildings are in need of renovation and there is a great possibility of improving energy performance during renovation [23]. There has been a suggestion that most of the potential savings can be achieved on the Million Homes Programme since most of the building stock was built during this era [24].

However, as researchers point out, energy efficient renovation would present significant barriers to reducing or even maintaining energy use, due to paradoxes in energy efficiency. According to Copiello [22], there is a weak connection between energy efficiency and lower energy use, and a higher disposable income due to energy efficiency could boost energy consumption. The result of the paradox is that energy efficiency is a driver for economic development so that in the end driving energy prices down incentivizes higher use.

The residential sector in Sweden has shifted from fossil fuels for heating, reducing these by nearly 28 % since the first oil crisis, but in the meantime electricity consumption has skyrocketed, tripled in the same time span. In some countries there is even a decrease in energy savings that should not be interpreted as a reduction of energy efficiency rather as negative user behavior due to higher indoor temperatures [22]. In Sweden, the Betsi study concluded that both the goals by 2020 and 2030 would be achieved even if electricity use has increased during the last decade due to the installation of heat pumps and more household appliances The main reasons of this reduction are improved energy efficiency of existing dwellings, new construction and demolition, the installation of more effective heat pumps and the increased coverage of district heating [24].

However, energy efficiency in buildings in Sweden does not include household electricity [25] and the energy use is not measured in use per capita but instead in kWh/m^2 heated area. In Sweden during the period 1990-2015 the building stock has increased by 17 %, following the population increase by 16 %, but the living area has increased by 33 % [24].

Taking this factor into consideration, energy use in the building stock, some authors argue, is not even decreasing, this can be linked to user behavior, increased indoor comfort and over-heating [24].

Most of the research literature focuses on the building energy performance during the building operation. There is consensus in the building industry that most of the energy use in a building is used during the operation lifetime. However, several studies conducted in the last decade raise doubts about this assertion, showing that when it comes to energy efficient buildings – such as the passive house standard – embodied energy can exceed the operational energy by as much as 3 times the operational energy use [22] raising doubts about what are the trades-off of energy efficiency in buildings. As Copiello states “As well as the investment cost could be not fully repaid by the operating savings, similarly the energy embodied in the construction could exceed the energy consumption in operation”[22]. This is reinforce by other authors in a Swedish context [25].

Mangold et al [24] ascertains that the energy use in the building narrows the system boundaries and necessitates the inclusion of the life cycle thinking about the building itself. Also makes a point about focusing on “efficient usage” next to “energy efficiency” making a case that even if the Million Homes Programme areas represent most of energy use in the building stock, the GHG emissions per person are lower than that the average Swedish citizen.

Extensive research has been made regarding Building Environmental Assessment tool. Aimed to assess the environmental impacts of buildings and improve their environmental performance (SGBC 2008). However, previous research has showed that most Building Environmental Assessment Tools have limited life cycle perspective and that the flexibility of some tools signal that environmental aspects are exchangeable giving decontextualized assessments that can differ with real environmental impacts (Wallhagen, 2016).

Scope and limitations

The scope of this study is energy efficiency in residential multifamily buildings within district heating systems and the relevance of renovation strategies in energy use and building environmental assessment tools.

Limitations

This study is based on energy efficiency renovation strategies that are well documented and have been implemented in Million Homes Programme areas in Sweden. A multifamily building built in 1969 and located in Borlänge, Sweden was selected as a case study. This building is connected to the local District Heating (DH) system which has a very high share of industrial residual heat. In this work, both building and energy systems are considered, but it is mainly focused on energy building performance.

Objectives

1 Develop and demonstrate a methodology that assesses energy efficient renovation of buildings within district heating systems.

2 Implement and use the proposed methodology to investigate how different renovation strategies affect the building environmental impact in terms of CO_2 emissions.

3 Identify and discuss future improvements of the proposed methodology.

Methodology

To help decision makers, an approach combining two different tools was developed to give overall insight and illustrate the impacts of energy efficient renovation in a dwelling area within a district heating system.

First a literature study was made for both papers in order to identify what had been done in the research field and what were the possibilities of such a tool. Then, it was decided that it would be interesting to develop a methodology that helps to maximize the economic and environmental performance of improvement strategies at a municipal level.

In Paper I, a combination of two different tools was developed in order to assess the renovation measures. First the building energy simulation tool IDA-ICE was used in order to assess the energy use in the studied building. Then, some renovation strategies were proposed to validate the tool. The results of this simulation were then scaled up to give an overall view of how these measures would affect the whole building. The scaled output data of the building energy simulation was then used as the input data for the energy system simulation. The output of the energy system simulation was analyzed and showed that the proposed methodology could be useful to determine the changes in heating production.

In paper II the proposed methodology was combined with the building environmental assessment tool, Miljöbyggnad, in order to assess how the proposed renovation strategies could affect both the environmental assessment of the building area and the local GHG emissions. For this paper, more detailed energy efficient renovation strategies were analyzed (see Data Inventory) and a more detailed energy system simulation was also performed, including not only changes in district heating production but also GHG emission factors of different energy carriers.

Data inventory

The neighborhood of Tjärna Ängar, located in the municipality of Borlänge, Sweden, 250 km Northwest of Stockholm is an example of the Million Homes Programme, built between the years 1969-71 it comprises 42 buildings with a total heating space of about 115,000 m^2.

The selected case study is a three story building with 36 apartments and a total heated area of 2822 m^2. The building is characteristic for the building era, and has an energy use which is around the average for the building period. The technical installations are a one-pipe hydronic heating system connected to district heating and mechanical exhaust ventilation.

Fig. 6 Picture over Tjärna Ängar [26]

The majority of the Tjärna Ängar buildings are built based on the same design and have not been subject to any major refurbishment since then. So, it is reasonable to assume that similar interventions would result in similar energy savings, partly because of the buildings' physical characteristics (they are all built with exactly the same physical design) and partly because of the parallel layout of the buildings (see Fig. 6 Picture over Tjärna Ängar [24]).

Table 1 Refurbishment packages Paper II

	As built	DEERS	BEnS	HRV22,7	HRV21
Outer walls	120 mm heavy insulation	480 mm heavy insulation	480 mm heavy insulation	As built	As built
Unheated attic	150 mm heavy insulation	300 mm heavy insulation	300 mm heavy insulation	As built	As built
Windows	Double case-ment	3 glass low emissivity pane	3 glass low emissivity pane	As built	As built
Ventilation	Mechanical	Heat recovery	Mechanical	Heat recovery	Heat recovery
Indoor tempera-ture	22,7	21	22,7	22,7	21

The selected renovation scenarios were determined to reduce bought energy in the building. All the scenarios were picked from ongoing projects throughout Sweden and have been proved possible to execute technically. The first scenario called Deep Energy Efficient Refurbishment (DEERS) is based on a housing area called Brogården (Allingsås, Sweden). The project aims to reduce a large amount of the bought energy in the building. The Building Envelope Scenario (BEnS) is a variation of the previous scenario but without considering changes in installations. The last two scenarios, HRV22.7 and HRV21 consider the improvement of installations rather than the physical properties of the building.

The district heating in the municipality of Borlänge mainly consists of incineration with energy recovery and industrial excess heat from local industries. The Borlänge district heating system amounts to around 360 GWh of district heating per year. There is a 30 MW link to the nearby municipality of Falun which has a district heating production mainly based on different types of biofuels. As well as the fuel use, the DH system uses around 20 GWh per year of electricity for powering heat pumps and other electrical components in the system.

Table 2 Fuel use and greenhouse gas [27] emission factors used in the district heating system model, as well as fuel used in the district heating system during 2013 [28]

Fuel type	Fuel use [GWh]	GHG emission [kg CO_2 eq/MWh]
Oil	9.8	302
Liquefied Petroleum Gas (LPG)	4.3	302
Biofuel (wood chips)	415.4	11
Biofuel (recycled wood chips)	35.7	3
Wood pellets	15.8	22
Municipal solid waste	134.1	137
Biogas	0.7	11
Industrial excess heat (including Flue Gas Condensation)	199.4	0

Results

Proposed methodology

The proposed methodology aims to clarify the potential of energy efficient measures on a large scale in an area within district heating, combining Building Energy Simulation (BES), Energy System Simulation (ESS) and the Building Environmental Assessment Tool (BEAT). In order to make a comprehensive building model, the software, IDA-ICE (Indoor Climate and Energy), was used. All the data necessary for the simulation was available and the building model was calibrated. The simulation of the district heating system used a tool called MODEST (Model for Optimization of Dynamic Energy Systems with Time dependent components and boundary conditions) developed by the Department of Mechanical Engineering at Linköping University. The Building Environmental Assessment Tool selected was Miljöbyggnad (Version 2.1), owned and managed by the Swedish Green Building Council. This tool was selected because it is based on experience and norms from Sweden.

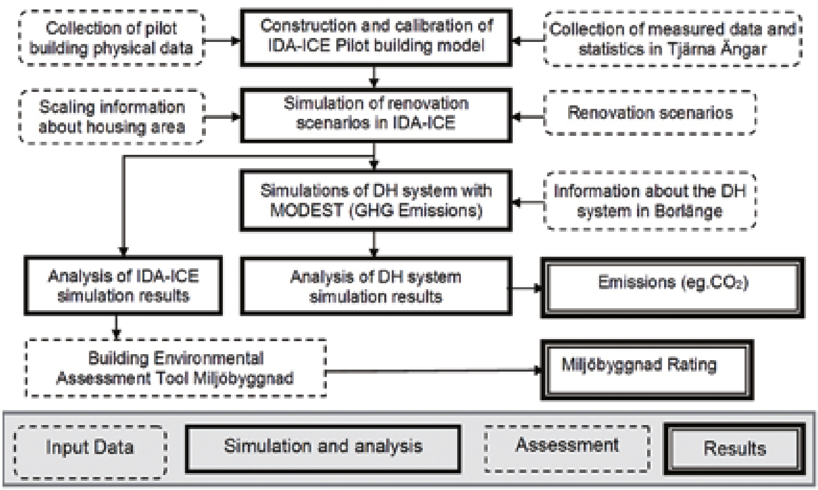

Fig. 7 Proposed Methodology (Adapted from Lidberg et. al [29])

The proposed methodology intends to combine BES, ESS and BEAT in order to provide an overview of how different energy efficiency improvements within the system boundaries would affect the production of DH, GHG emissions and their environmental performance rating.

The first step "Construction and calibration of the selected BES building model" consists of the collection of all relevant information needed to make a comprehensive model of the selected building. In this step, physical and operational data of the building is relevant. To validate the pilot model, it is important to collect measured data. All data that is related to an energy balance of the building is useful at this point. Set-up temperatures, heat flow, indoor and outdoor temperatures, heat gains are examples of the data being collected. Using this data it is possible to calculate the heat demand of the building under a selected period with methods such as the "energy demand signature" [30]. Using the output of this analysis it is possible to adjust parameters in the BES model that are otherwise difficult to collect, such as thermal bridges and air tightness.

The second step "Simulation of renovation scenarios in selected BES" consists of simulating the desired renovation alternatives to reduce the energy demand of the building, using available performance data of installations and materials that are usually common practice within the building industry. Depending on the homogeneity of the housing area, it is possible to scale up the results to reflect the energy demand of the whole dwelling area as if the whole building stock were to be renovated. Alternatively, it is possible to simulate the most representative buildings of a neighborhood. The output of this analysis is the energy demand of the buildings with the proposed measures. The results of these scenarios are the input data for the next step.

In the third step, "Simulations of DH system with Selected ESS", the municipal DH system is modelled based on information provided by the municipal energy company. A detailed inventory of production units, energy carriers and energy use by end users is needed. With the data provided and the results of the previous steps (both the pilot building and the renovation alternatives), it is possible to identify the reductions in energy use, changes in the different production units and energy carriers.

Finally, in the step "Building Environmental Assessment Tool" a predefined assessment of the different renovation scenarios is made using the selected tool. All the necessary information for this assessment is available from the preparation and the results of the BES scenarios. The result is an overall environmental rating based on the performance of different renovation scenarios.

With the results of all simulations and assessments it is possible to analyze the different scenarios and their performance in both GHG emissions and BEAT rating allowing the comparison of different environmental weightings.

Energy use

In order to determine how the different proposed scenarios would affect the DH generation, the building was initially simulated using the selected BES. With the output of this, it is possible to assess the environmental performance of the building in the selected BEAT. For this case the building was ranked as "rated", meaning that the current building energy use (152kWh/m^2 per year) does not comply with the standards of the current BBR for the building type.

Then, in order to assess the renovation scenarios, it is necessary to calculate their energy use using the selected BES: The proposed scenarios aim to affect the building energy use differently, either by reducing the active heating demand or by affecting the bought energy use by changing to more efficient installations (Fig. 8).

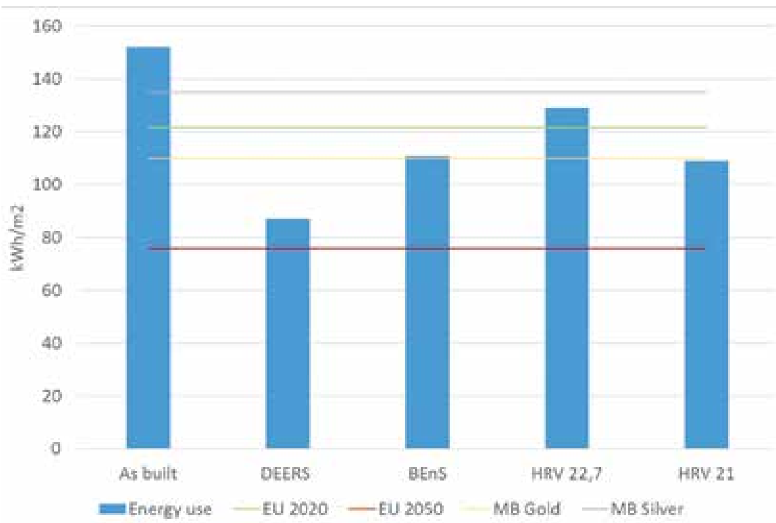

Fig. 8 Energy Use results

In Fig. 8 it is possible to see the building and renovation scenarios' energy use performance in comparison with both the BEAT and EU directives ambition level. DEERS is the scenario with the most decrease, accounting for reductions of 43 %, which achieves a gold rating in Miljöbyggnad and complies with the EU 2020 goals. Then, both BEnS and HRV 21 have a decrease of around 27 % and both comply with the EU 2020 goals, but BEnS is rated Silver while HRV21 is rated Gold in Miljöbyggnad. Finally, HRV22.7 reduces energy use by 15 %, thereby not complying with any EU goal and rated as Silver in Miljöbyggnad. When the total Energy Performance is assessed in Miljöbyggnad, DEERS ranks as Gold, BEnS and HRV21 as Silver and HRV22.7 as Bronze.

It is important to note that when solar gains are assessed in Miljöbyggnad the room with the worst performance gives the starting point for the whole rating. In the case of this building, the worst room had solar heat gains of 36 W/m^2, performance rating Bronze. Then, 25 % of the same floor would be analyzed giving the possibility to move up one level. The whole floor in this building rated performance Gold, but due to the impossibility of jumping two categories the building receives a Silver performance rating.

In the building as built, as well as in three of the selected scenarios, the energy source rating was Silver. Even if the share of renewable energy in the system is high according to Svensk Fjarrvärme, [31] the selected BEAT assesses 45 % of the household incineration and 25 % of the industrial excess heat as category 4, which means that it is the same category as fossil fuels or nuclear power. In DEERS, the energy source performance rating is Gold because the building reduces its use of active heat and most of the energy use in this case comes from hydropower, reducing the non-renewable part of the mix.

The total neighborhood CO_2 emissions were calculated using the emission factors for the fuel mix in the selected ESS. At first, with all the building in the original state the estimated CO_2 emissions were 11 kg/m^2 year. DEERS emissions were calculated as 9 kg/m^2 year, making a reduction of 15%. All the other scenarios showed consistent emissions at around 10 kg/m^2 year, reducing emissions by 9%, meaning that none of the renovation scenarios comply with the 40% reduction of the EU 2030 goal.

Discussion

This study analyzed how the proposed methodology could be used as a tool for decision-makers when considering large scale renovations of multi-family dwellings within DH systems. One of the identified problems was that different municipal companies have overlapping interests within the same municipal company concern. This overlapping and in some way opposing interests could be seen as a barrier to energy efficiency. Using the proposed methodology, it is possible to clarify the potentials of energy efficiency at a municipal level, combining different tools in order to give an overall picture of the reduction potentials. The novelty of the method is the expanded system boundaries that include both the distribution and production of district heating and the energy use at a building level. In this way it is possible to compare and weight measures made both at the energy system level and the building level.

The standardized results from the methodology and the simplicity of its input data give an overall picture of how energy efficient measures would affect the system as a whole. The tool also helps to avoid sub-optimization given that, in order to use the methodology, both energy companies and housing owners are active actors in the study. This methodology can be used in early stages of the decision making processes for large scale renovation projects. The method is generic, meaning that almost any dwelling area can be analyzed and it gives the possibility of expanding it to consider other energy carriers than DH at a municipal level, e.g. locally generated renewable electricity.

One of the main findings from the research is that indoor set temperature can play a major role in energy savings. However, even if the measured indoor temperature was an almost constant 22.7°C the house owner reported that most of the tenants complained about low temperatures. Studying the original working drawings for the buildings, it was noticed that the heating system is a one-pipe heat system, not unusual for the time it was constructed, and this type of heating system needs a very fine tuning to be properly balanced. After 40 years of neglected maintenance and poor knowledge about transmission losses, the building has an unbalanced heating system that distributes uneven temperatures throughout the building. In order to be able to decrease temperatures indoors it is necessary to address this kind of technical problem. Thus, the lower set up temperature for the renovation scenarios (21°C) was based on the assumption that the indoor temperature was evenly distributed within the building. In this study it was interesting to note that both passive (building envelope) and active (Heat recovery Ventilation) measures can give similar results. A general rule of thumb is that energy losses due to transmission are often comparable to ventilation losses, thus it is not surprising that both measures result in similar improvements.

One aim of the combined methodology is to assess the environmental impact of energy efficiency measures. In the version of Miljöbyggnad used for the study, there is no indicator designed to show the total environmental impact of the building. The energy source indicator aimed to distinguish between different fuels using a hierarchic approach for different fuel types (this indicator has been extensively revised in the latest edition of Miljöbyggnad, taking into consideration the criticism that the presented papers and several other publications and actors made to the approach). One of the problematic findings for the energy source indicator was found in environmental category 1, where industrial excess heat that emanates from the use of fossil fuels gets a low impact rating, taking into consideration that in a life cycle perspective the environmental impact from industrial processes should be located in the main product, in order to generate incentives to improve energy efficiency in these processes. But in the case of Miljöbyggnad it was placed in the use of bi-products, instead. Environmental category 2 includes a vast number of different biofuels with different emissions factors, which, in our case, could vary between 3 and 22 kg/MWh CO_2. In environmental category 4 fossil fuels such as oil and LPG are grouped with municipal solid waste which has an emission factor of less than half that of fossil fuels and in some cases contains a fair amount of renewable material. In paper II we made the case for MSW incineration, pointing out that, given that the emission factors are considerably lower, it could be possible to classify it in a different category, or use the emission factor of different sources of energy instead of grouping them in predefined categories. The other important point of discussion is that net CO_2 savings from MSW is made when waste from other EU countries is imported and incinerated in Sweden instead of being disposed in landfills.

Energy use in the residential and services sector accounts for 40% of Sweden's energy use, but just 15 % of total GHG emissions. Also, Sweden represents around 2 % of the total EU28 population, while the UK, Germany, France and Italy represent more half the population and the energy consumption. In an international perspective Sweden's housing stock has a low energy use considering its climate (a common multifamily building for the Million Homes Program uses around 150 kWh/m^2 while a similar building in the UK, with a much milder climate can consume up to 230 kWh/m^2) [15]. The possibility of carrying out a thorough energy efficient renovation in Sweden has been shown in Allingsås, but most housing companies have stated that their limited economic resources make this unprofitable. The analysis in paper II demonstrates that even with energy savings around 50 %, emissions reduction would not exceed 10 %; far from the EU goals to reduce emissions by 40 %. This situation is due to the de-carbonization that has taken place in Sweden since the first oil-crisis where the country has set its goals to cut its energy dependence on oil producing countries. This goal transformed the energy system in Sweden as a whole, making a big investment in renewables and district heating and making Sweden one of the forerunners when it comes to global climate goals. It is important to mention here that the share of renewables in Sweden is far higher than the EU28 mean.

This work has limited its approach to energy use in buildings, but it is important to bring the life cycle thinking to the methodology. During the choice of the renovation methods it was noticed that the environmental impact of the production of some components in order to reduce the energy use of a building are not insignificant. Energy used to produce some components (especially those from energy intense industrial processes such as steel and glass) should be taken into consideration when evaluating the environmental impact of a refurbishment process. This is somehow linked with the association with cost. Even if it is technically possible to renovate a building to achieve a "passive house" standard, municipalities and real estate owners have limited resources for these kinds of refurbishments, and see energy efficiency some a kind of barrier to renovation. They sometimes bypass simple and cost efficient measures because of the high ambition of the regulations.

Conclusions

This methodology could give a comprehensive picture of what kind of renovation could be more beneficial from a municipal perspective, weighting not only energy savings but use of resources and environmental impacts. Similar improvements can be achieved by improving the ventilation system or investing in the building envelope.

Even if all the renovation measures considered in this case study are feasible, it is important to determine in which order they are desirable or achievable from an economic point of view. Uncertainty in the future development of energy, and limited economic resources can play an important role in the possibility of energy efficient renovation. Also, fear of sub-optimization should be considered when analyzing renovation measures within a district heating system. It has been shown that even if energy use can be cut by half it has in terms of CO_2 emissions a low impact due to the situation of the district heating system in the municipality.

It is important to rethink the EU directives from a country and European perspective. As has been seen in the literature study, the 2030 goals can be interpreted in different ways in different countries. Countries which have been forerunners in cutting GHG emissions, such as Sweden, can see the goals as a hinder rather than an opportunity.

Future work

In paper II it was decided that emissions from electricity production should not be taken into account due to the "electricity source certificate" from the building owner declaring that all electricity should come from Hydropower, and in Miljöbyggnad V. 2.3 it was stated that this is category 1, (renewables) However, it is important to point out that I am fully aware that even if there is an energy certificate this is just an estimation of how different electricity is produced within the EU and it does not reflect the seasonal (and daily) variations of the real consumption of electricity in the given building at a given moment. It is known that in how the EU Renewable Energy Market works today it is possible to buy "CO_2 neutral" electricity from all EU28 countries (such as Iceland) even if they are not connected to the common electricity market. In future studies it would be interesting to include electricity use and assess the environmental performance of the production, using maybe, the common Nordic Mix production.

Advocates for thorough energy efficiency renovation tend to put their boundaries at a building level, neglecting the life cycle impacts of the production of those materials. Previous research has shown that the impacts on material choice are not negligible so it would be interesting to study to what extent the impacts on material choice affect energy savings at a neighborhood scale. It would be also interesting to expand the methodology to include both economic analysis and how it could be implemented.

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Papers

Associated papers have been removed in the electronic version of this thesis.

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A methodology to assess impacts of energy efficient renovation – A Swedish case study

This study develops and tests a methodology to help decision-makers when considering major renovation of their building stock when connected to a district heating system. The proposed methodology is applied and used to investigate how different renovation scenarios affects the building environmental impacts in terms of green-house gasses emissions and identify and discuss future improvements of the methodology.

The novelty of the method is that the system boundaries includes both the distribution and production of district heating and the energy use at a building level. In this way it is possible to compare and weight measures made both at the energy system and the building level. This work has limited its approach to energy use in buildings. Even if all the renovation measures considered are feasible, it is important to determine in which order they are desirable or achievable from an economic point of view. Uncertainty in the future development of energy, and limited economic resources can play an important role in the possibility of energy efficient renovation.

The proposed methodology gives a comprehensive picture of what kind of renovation could be more beneficial from a municipal perspective, weighting not only energy savings but use of resources and environmental impacts.

Ricardo Ramírez Villegas