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A data-driven framework for building energy benchmarking and renovation decision-making support in Sweden

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Abstract. In Europe, the buildings sector is responsible for 40% of energy use and more than 30% of buildings are older than 50 years. Due to ageing, a large number of houses require energy-efficient renovation to meet building energy performance standards and the national energy efficiency target. Although Swedish house owners are willing to improve energy efficiency, there is a need for a dedicated platform providing decision-making knowledge for house owners to benchmark their buildings. This paper proposes a data-driven framework for building energy renovation benchmarking as part of an energy advisory service development for the Västerbotten region, Sweden. This benchmark model facilitates regional homeowners to benchmark their building energy performance relative to the national target and similar neighbourhood buildings. Specifically, based on user input data such as energy use, location, construction year, floor area, etc., this model benchmarks the user's building performance using two benchmark references i.e., 1) Sweden's target to reduce buildings by 50% energy use intensity (EUI) by 50% by 2050 compared to the average EUI in 1995, 2) comparing user building with the most relevant peer group of buildings, using energy performance certificates (EPC) big data. Several building groups will be classified based on influential factors that affect building energy use. Hence, this benchmark provides decision-making supportive knowledge to homeowners e.g., whether they need to perform an energy-efficient renovation. In the future, this methodology will be extended and implemented in the digital platform to provide helpful insights to decide on suitable EEMs. This work is an integral part of project AURORAL aims to deliver an interoperable, open, and integrated digital platform, demonstrated by cross-domain applications through large-scale pilots in 8 regions in Europe, including Västerbotten.

1. Introduction

In the context of the rapid increase in global energy demand and recognition of climate change prominence, the need for energy-efficient retrofitting measures (EEMs) to reduce energy use in individual buildings and building stock has become imperative [1]–[3]. Considering the increasing energy prices in Europe in recent months, this need for energy efficiency has never been as important as it is now. Although there have been several initiatives [4]–[9] to reduce CO_2 emissions in the buildings sector which is responsible for nearly 40% of emissions in Europe, the major focus has been on improving energy efficiency in the new buildings. However, since more than 30% of European buildings are older than 50 years and 75% of them are energy inefficient, it is essential to focus on getting existing buildings through necessary EEMs [10]. John Dulac, an analyst at International Energy Agency [11] also estimates that implementing new energy-efficient buildings substantially across Europe will still not be sufficient, acknowledging the millions of already existing buildings across Europe.

Between 1946 and 1975, roughly 1.4 million houses were built in Sweden [12]. A large fraction of those requires renovation since they will be over 50 years by 2030. Further, they consist of less thermal insulation, and rarely have heat recovery ventilation systems [13], [14]. This means that around 50 000 houses need to be renovated every year to meet the energy efficiency goals. To accelerate the renovation process, it is vital to provide decision-making knowledge to the building owners to recognize if they need to renovate [14]–[16]. The Swedish house owners expressed high interest to renovate and also towards the need for one-stop-shop solutions [17]. Currently, there are no dedicated platforms in Sweden that can recognise the user-specific renovation need and provide insights during the thinking, planning and finalising stages of the decision-making process.

Västerbotten county is the second largest region in Sweden, consisting of sparsely populated and mostly rural areas. Due to the ageing of existing buildings, the need for decision-making knowledge for building energy-efficient renovation is also a challenge in the region. Therefore, this pilot aims to provide energy advisory service to building owners in all 15 municipalities. Since internet connectivity in the region is good, the developed benchmark model can reach users in remote areas through a digital platform like the AURORAL middleware. AURORAL is an EU Horizon 2020-funded project consisting of 25 organisations from 10 EU countries. The project focuses on delivering an interoperable, open, and digital middleware platform for rural ecosystem services in Europe, ultimately creating equal opportunities for rural and urban Europeans. The AURORAL middleware platform is demonstrated by cross-domain applications through 8 large-scale pilot regions in Europe including the Västerbotten region in Sweden. Although this pilot develops the energy advisory service in multiple modules, this paper will only focus on the first module, a benchmarking service for the buildings' energy performance which is the first step of the energy-efficient renovation process.

2. Aim

This paper proposes a framework of calculation method for benchmarking building energy to provide renovation decision supportive knowledge for single- and multi-family building owners (users) in the Västerbotten region. Based on user-given inputs, reference peer groups classified through Energy Performance Certificates (EPCs) big data, Statistics Sweden (SCB) database, and other energy suppliers' data, this research will investigate the following different questions to provide advice to the users,

- Does the user building need to be renovated to meet Sweden's national energy efficiency target (SEET) 2050?
- How is the subjected user building performance compared to similar neighbourhood buildings?

3. Benchmarking literature review

This section reviews the previous studies and existing methods related to benchmarking building energy renovation and also supports knowledge on influential factors of building energy performance. Energy Star Portfolio Manager [18] is a benchmark platform for commercial building energy performance in USA and Canada. It rates a building from 1 to 100 by comparing it with its peers determined using the Commercial Building Energy Consumption Survey database (CBECS) updated every 4 years. This platform primarily uses a weighted ordinary least squares regression model (MLR) to give building scores using an energy efficiency ratio lookup table for each peer group of classified reference groups. The user inputs energy use profile, and operational characteristic data to choose its related peer group[19]. Further, Energy Star also expanded its platform to single-family houses assessing energy performance using Residential Energy Consumption Survey 2015 reference data, monthly energy use data, building properties and activities data from users' input[20]. However, Pandarasamy Arjunan et al [21]claimed the Energy Star MLR model is inaccurate and proposed enhancement to current calculations through multiple linear regression with feature interactions (MLRi) and gradient boosted trees (GBT) models which showed improved accuracy over the existing MLR model. The methods were tested for buildings from the same CBECS database on which Energy Star benchmarking is based.

A CO_2 emission benchmarking method for multi-family houses in South Korea was developed by Kwangbok Jeong et. al [22] to establish emission allowance references to achieve the national CO_2 emission reduction target in 2030 of reducing by 18.1% in the buildings sector. The reference buildings data from the national appraisal board and decision tree (DT) method were used for database clustering groups of allowed emissions based on the elapsed year and the heating type. The allowed emission benchmark by year was calculated using a compound annual growth rate equation.

The observed influential factors of building energy performance are floor area, construction year, climatic conditions (heating degree days, cooling degree days, ambient temperatures), building orientation, number of habitants, type of HVAC (heating, ventilation, air-conditioning) system, desired set temperature, number of appliances, operation schedules etc[23], [24].

Fulvio Re Cecconi et. al [25] reviewed the existing knowledge of energy retrofitting related recommendations or advice to end users. The house owners should consult a construction company or an energy advisor if they consider retrofitting, and in both cases it involves a time consuming process starting with a professional visit and estimating potential scenarios. Further this paper proposed a method using Hitherto Monte Carlo analysis to compute building retrofit potential indicators using an existing database of CENED DB in Italy, which is a collection of energy performance certificates. The significance of the study is to provide a decision support system for retrofit policymaking.

4. Framework for building renovation benchmarking

The aim is to provide benchmarking of the users' building energy performance by comparing user input information with appropriate user reference peer groups. The peer groups are classified based on the key influential factors: building location municipality, construction year of the building, number of families living in the building and total floor area of the building excluding the basement area. The influential factors are chosen based on previous literature[23]–[25], EPCs data availability and the assumed users' knowledge to input information.

4.1. Reference peer groups

The purpose of an energy performance certificate (EPC) is to certify energy quality in a building given by an independent certified energy expert to the building owner when selling the property, if the building is new, in connection with renting, or if it is a public building. EPC is valid for ten years, and consists of information about:

- Location of the building
- Energy use for domestic hot water, electricity, heating and cooling in the building
- Energy use if it is a new building
- Total heating area
- Ventilation and heating systems
- Energy performance rating from A to G
- Some suggested retrofitting measures by certifiers etc.

Boverket, The National Board of Housing, Building and Planning is the governing authority of EPC in Sweden. Boverket's collected EPC big data includes 550,000 buildings including residential, industrial, commercial and public buildings. Building for one or two families is the most common housing type in Sweden, hence this study only focuses on this type of building. After data cleaning, 12 624 EPCs for one/two family buildings in the Västerbotten region are identified for this study. 12 624 EPCs are classified based on chosen four influential factors, i.e., municipality, construction year, number of families living and total floor area. The construction year of the building is classified into 3 subgroups 1) until 1960, 2) 1961-1980, and 3) after 1980 based on inspiration from the Tabula webtool [26] and EPCs data availability. The total floor area of the building excluding the basement area is classified into three subgroups 1) 0-100 m^2 2) 101-200 m^2, and 3) more than 200 m^2. There are 15 municipalities in the Västerbotten region, so each municipality consists of 18 reference peer groups and in total there are

270 reference peer groups in the region. The classification of these factors and reference groups are spread out as shown in Figure 1 which is a classification of the Åsele municipality.

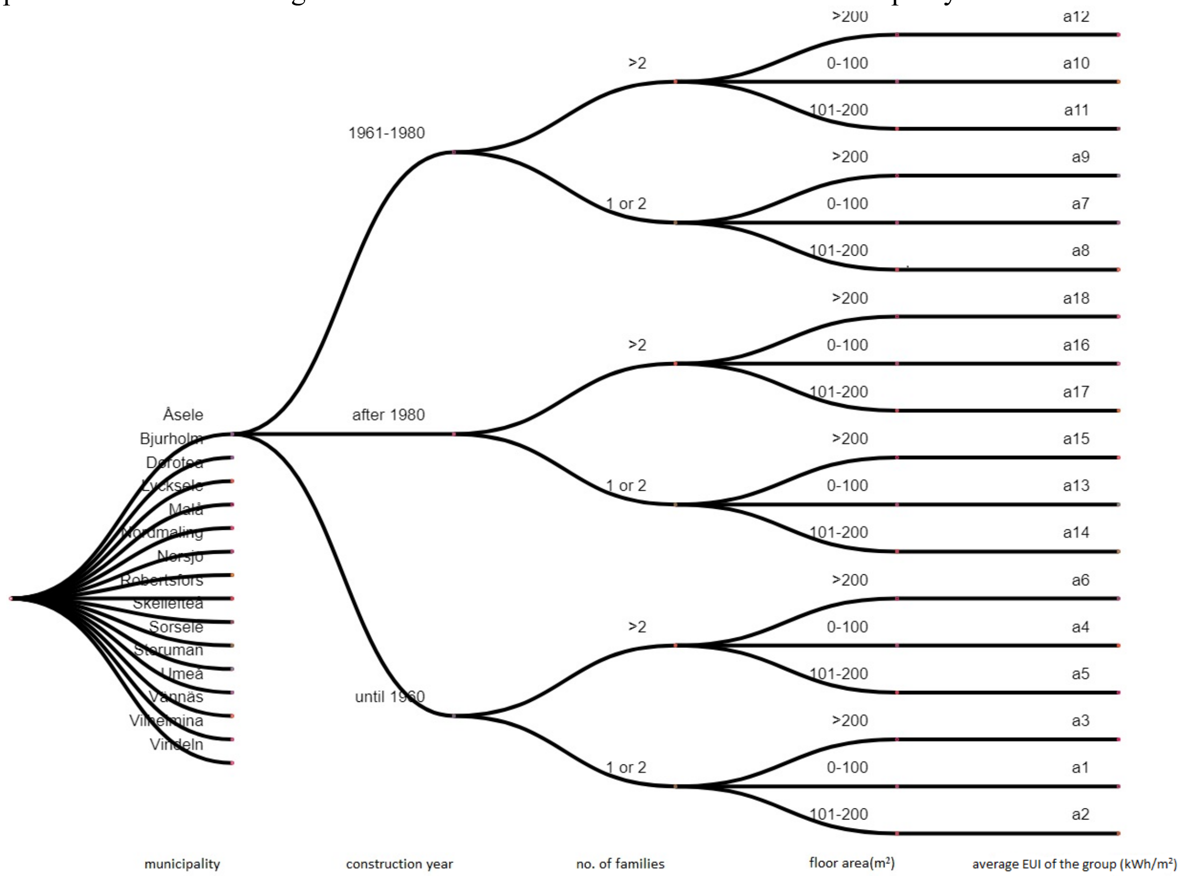


Figure 1. Classification of the Åsele municipality

These reference peer groups of buildings along with the user's actual EUI value shall be used to answer the benchmark question. The average reference EUI value of each reference group can be calculated using the equation,

$$EUI_{avg} = \frac{average\ energy\ use\ of\ the\ specific\ reference\ group\ \ (kWh)}{average\ floor\ area\ of\ specific\ reference\ group\ (m^2)} \quad (1)$$

4.2. User actual EUI

User inputs include building location municipality, building construction year, number of families living in the building, total floor area excluding basement area ($Input\ area_{m^2}$), and energy use. Energy use includes electrical use ($Input\ kWh_{el}$) shall be given in kWh or bill amount in Swedish Kroner (SEK) and other energy sources ($Input\ kWh_{other}$). This section will explain how the user's actual EUI is calculated.

$$User\ actual\ EUI = \frac{Input\ kWh_{total}}{Input\ area_{m^2}} \quad (2)$$

4.2.1. User input in kWh. If the user chooses to input their electricity use in the number of units (kWh) which is the standard approach to accurate estimation, the building annual energy use ($Input\ kWh_{total}$) is calculated using the following equation,

$$\boldsymbol{Input\ kWh_{total} = Input\ kWh_{el} + Input\ kWh_{other}} \quad (3)$$

4.2.2. User input in bill amount (SEK) and electricity prices. Although the recommended method is to input the energy use in kWh, this benchmark model provides an extra option to input their gross electricity monthly bill amount (Swedish Krona SEK) of anyone latest month in each season. This however, is a more uncertain method based on the conversion between kWh and SEK. Four different seasonal months are considered from *[27]* i.e., Winter (December to February), Spring (March to May), Summer (June to August) and Autumn (September to November). For each season, consumed kWh is estimated by converting the electricity bill amount to kWh using the latest monthly electricity prices of different electricity pricing agreements, energy tax, grid charges, security fee and VAT. The user-specific electricity price is identified based on variables i.e., electricity area, consumer category, type of electricity pricing agreement, user situation etc. The electricity prices and grid charges are divided into four consumer categories shown in Table 1 and electricity pricing agreements are

- Variable price agreement
- One-year fixed price agreement
- Two-year fixed price agreement
- Three-year fixed price agreement
- Standard price agreement

For accurate conversion, the model considers the latest electricity prices database from the Swedish governmental statistics database, Statistics Sweden (SCB) [28] and the prices are updated every month, this database is integrated into the AURORAL middleware platform using the standard APIs available in the database. Energy tax and VAT are available in the Swedish tax agency, Skatteverket [29], average network charges are taken from the SCB database, the security fee is a connection fuse charge depending on each fuse type and the data is taken from the main energy suppliers in Västerbotten region.

Table 1. Consumer categories

Consumer category	Fuse size (Ampere), annual electricity use
Apartment	16A, 2000kWh/year
House without electric heating	16A, 5000kWh/year
House with electric heating	20A, 20000kWh/year
Larger households	35A, 30000kWh/year

To simplify the conversion, two types of user situations are identified i.e., the first user type receives the single invoice for both electricity consumed and operation and maintenance of the power grid when the electricity supplier and grid operator are the same. Therefore, the following equation is used to estimate ($Input\ kWh_{el}$),

$$Input\ kWh_{el} = (SEK_{month,input} - SEK_{VAT} - SEK_{security\ fee})/(SEK_{price\ per\ kWh} + SEK_{energy\ tax,per\ kWh} + SEK_{network\ charge,per\ kWh}) \quad (4)$$

and second user type receives two invoices separately for electricity consumed and operation and maintenance of the power grid when the electricity supplier and grid operator are different. In this case, the user is asked to input only the invoice amount from the electricity supplier. Therefore, the following equation is used to estimate ($Input\ kWh_{el}$),

$$Input\ kWh_{el} = (SEK_{month,input} - SEK_{VAT})/(SEK_{price\ per\ kWh}) \quad (5)$$

where $SEK_{month,input}$ is the gross electricity bill amount of a month given by the user,

$SEK_{price\ per\ kWh}$ is pure electricity unit price excluding all charges of the user-specific group from the SCB database,

$SEK_{energy\ tax,per\ kWh}$ is energy tax per unit,

$SEK_{network\ charge,per\ kWh}$ is network charge per unit,

SEK_{VAT} and $SEK_{security\ fee}$ are chosen VAT and security fees of the user.

Finally, the calculated monthly $Input\ kWh_{el}$ is converted and multiplied by annual use and total building energy use ($Input\ kWh_{total}$) is calculated,

$$Input\ kWh_{total} = Input\ kWh_{el} + Input\ kWh_{other} \tag{6}$$

4.2.3. Other energy sources and conversions. In Sweden, it is common that one/two family buildings consume energy through firewood, fuel oil, lignite briquette, natural gas and pellets other than power grid dependence. Therefore, the benchmark model facilitates users to input energy use from these energy sources and is converted to kWh to calculate ($Input\ kWh_{other}$) using reference conversion units obtained from the European Nuclear Society*[30]* also shown in Table 2.

Table 2. Energy conversions

Indicator	User input	Coal equivalent (kg)	kWh equivalent
Firewood	1 kg	1.57 kg	12.78 kWh
Fuel oil	1 kg	1.52 kg	12.37 kWh
Lignite Briquette	1 kg	0.72 kg	5.86 kWh
Natural gas	1 m^3	1.35 kg	11.0 kWh
Pellets	1 kg		4.9 kWh

4.3. *Energy advice to users*

Based on the calculations to identify the user-specific reference peer group and user EUI value, it is imperative to visualize or provide advice to the users which can impact their decision-making. Therefore, this benchmark model aims to provide useful advice validated by the actual user's feedback during the testing phase of the project. Although the final advice shall be finalized by the end of the project, however, they are given by answering the following questions.

4.3.1. Compared to SEET 2050, the user building needs to be renovated? The first piece of advice is to see how is the user building performance in regards to SEET 2050. Relative to the average EUI of Swedish residential buildings in 1995, the target is to reduce 50% of EUI by 2050*[31]*. According to Boverket *[32]*, it was discovered that the average EUI of one/two family buildings in 1995 was 164 kWh/m2, so according to SEET, the allowed average EUI should be 82 kWh/m2 in 2050. Therefore, the allowed EUI value of each year is determined using the standard equation compound annual growth rate (CAGR)*[22]*,

$$CAGR = \left(\frac{EUI_{in\ 2050}}{EUI_{in\ 1995}}\right)^{\frac{1}{t}} - 1 \tag{7}$$

where ‘t’ is the number of years

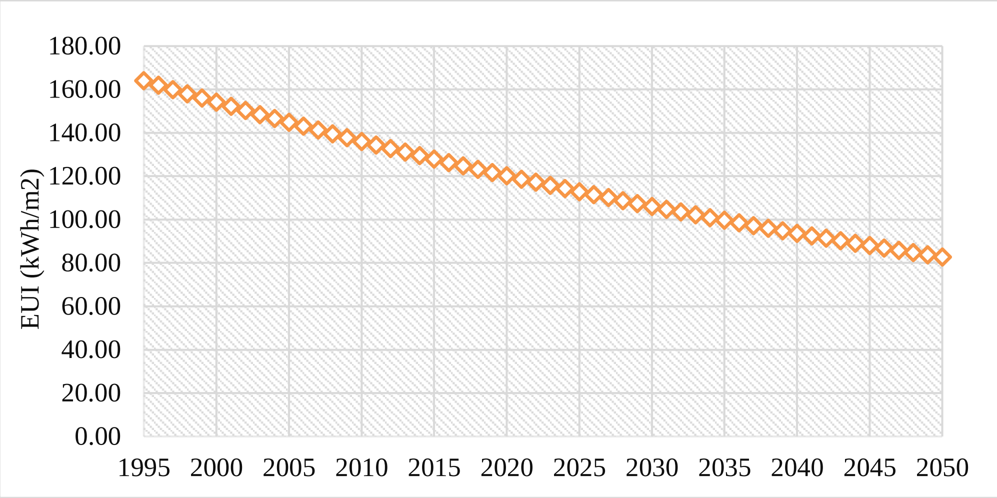


Figure 2. Allowed EUI according to SEET 2050

4.3.2. How is the subjected user building performance compared to similar neighbourhood buildings?
With the user given inputs to the platform, the actual EUI is calculated and a user-specific group is identified from 270 reference peer groups. Then, the user building performance is evaluated concerning buildings in the same peer group. The result is shown in multiple performance rating scale techniques, e.g., the percentile ranking of user building compared.

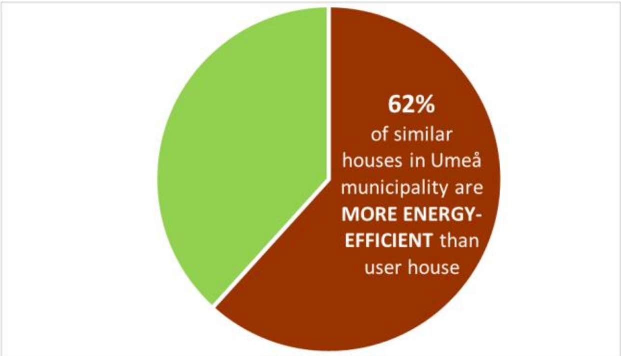
4.4. Testing the benchmark model
This model was tested with some house owners in the region; however, one sample user situation and example advice are presented. A multi-family house in Umeå municipality was constructed in the 1981 year with a 52 m^2 floor area. The user has a different electricity supplier and energy grid operator and consumed 6400 units(kWh) of electricity and approximately 30kg of firewood for external heating in the last 12 months. Hence, the calculated user actual EUI is 128.5 kWh/m^2 and the relevant reference peer group is identified. From Figure 2, according to SEET 2050, the allowed EUI in the 2022 year is 117.19kWh/m^2. For this user situation, the following advice is given,

- Does this user building need to be renovated or not to meet Sweden's national energy efficiency target (SEET) 2050?

Advice: YES (since the user actual EUI > allowed EUI in 2022)

- How is the user building performance compared to similar neighbourhood buildings?

Advice:



5. Conclusion and future work
A dedicated platform of decision-making support for house owners to benchmark their buildings can play an important role to address the urgency to improve energy efficiency in the building sector due to the increasing energy prices in Europe. The proposed framework aims to provide advice to house owners

in the Västerbotten region by investigating two proposed benchmarking questions using two references respectively i.e., 1) benchmarking user actual EUI with allowed EUI of the specific year identified by SEET 2050 in relative to EUI in 1995, 2) benchmarking user actual EUI with buildings in the reference peer group identified based on most relevant influential factors i.e., location, municipality, number of families and total floor area. The reference peer groups are classified using EPCs big data. The actual EUI is calculated using user inputs i.e., energy use can be either given in no. of units consumed (kWh) or the electricity bill amount (in SEK). The bill amount of each latest month of the four seasons will be converted to kWh using user-specific latest electricity prices and other charges such as energy tax, grid charges, VAT etc. This benchmark model will be implemented in the AURORAL project middleware platform which potentially is accessible for sparsely populated rural area users in the Västerbotten region. However, this first benchmarking module of the energy advisory service will be further extended to provide helpful insights into choosing the right EEMs and impending credible renovation company to perform.

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