CONSEQUENCES OF DEVIATIONS BETWEEN SIMULATED AND MEASURED ENERGY USE in retrofitted projects

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Master thesis in Energy-efficient and Environmental
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Lund University

Lund University, with eight faculties and a number of research centres and specialized institutes, is the largest establishment for research and higher education in Scandinavia. The main part of the University is situated in the small city of Lund which has about 112 000 inhabitants. A number of departments for research and education are, however, located in Malmö. Lund University was founded in 1666 and has today a total staff of 6 000 employees and 47 000 students attending 280 degree programmes and 2 300 subject courses offered by 63 departments.

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This international programme provides knowledge, skills and competencies within the area of energy-efficient and environmental building design in cold climates. The goal is to train highly skilled professionals, who will significantly contribute to and influence the design, building or renovation of energy-efficient buildings, taking into consideration the architecture and environment, the inhabitants' behaviour and needs, their health and comfort as well as the overall economy.

The degree project is the final part of the master programme leading to a Master of Science (120 credits) in Energy-efficient and Environmental Buildings.

Keywords: Energy simulation, Measured energy, Deviation, Parametric study, Life Cycle Cost, Case study, IDA ICE, Miljonprogrammet, Multi-residential buildings, Retrofitting.

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Abstract

For the next 40 years, a rate of 3% of the European building stock per year needs to be renovated in order to meet the carbon and economic goals set out in the European Economic Recovery Plan. This puts high demands on the accuracy level of energy simulations software for predicting the energy need for retrofitted buildings. However, in most cases the simulated energy need does not correspond with the actual measured energy need, a crucial error which need further investigation.

Three similar multi-residential buildings built in from the 1970s were chosen as case studies. The reports showed a deviation from simulated and measured energy need are respectively 24.7, 18.3 and 2.4 %. This thesis has its focus on the process of how misjudged parameters will impact the results of energy simulations in connection with retrofitting projects. Each parameter was assigned with a maximum and minimum value between which it could fluctuate based upon findings during a thorough literature study. The deviation on the total energy need was documented and a Life Cycle Cost was conducted for each parameter in order to demonstrate the economic impact of a misjudged aspect. In order to improve the level of accuracy, methods was developed for each parameter to refine the simulation input. The following parameters were addressed:

- Area deviation
- Wind
- Heat recovery efficiency
- Losses in hot water circuit system
- Tenant electricity need
- Air-tightness/leakage
- Thermal bridges
- Indoor temperature variation
- Domestic hot water need
- Utilization factor

The SVEBY standard was implemented to investigate uncertainties connected to user behaviour.

The final result for the deviation between simulated and measured energy need was drastically reduced to less than 10% by implementing the developed procedures. Among the 10 parameters which the Life Cycle Cost took into consideration, the user behaviour aspects had the highest impact on the energy need. Generally domestic hot water had the largest impact on the net present value (NPV) ranging between 341-477 SEK/m².

Preface

This thesis represents the final degree project within the two year master program “Energy and Environmental Efficient Building Design” from Lund University, Campus Helsingborg. This project has been carried out in close cooperation with our supervisor Karin Farsäter and examiner Professor Åsa Wahlström who also represents SIREN and SVEBY.

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Charles Chu and Fredik Lindblom

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Definitions and abbreviations

A_{temp}: The floor area of a building that is heated to more than 10 ˚C. Swedish building regulation BBR.

BOA: Boarea, area in the building classified as living-space.

BBR: Boverkets Byggregler is the Swedish building regulation.

BeBo: Energimyndighetens Beställargruppen för Energieffektiva flerbostadshus, a network of real estate owners with the aim of developing energy efficient multi-residential building financed by the Swedish energy agency.

DVUT: Dimensionerande Vinter Utetemperatur, n-day mean air temperature.

DWG: It is a file format for Computer Aided Design (CAD) software used for storing two- and three- dimensional design data and metadata.

LCC: Life Cycle Cost.

NPV: Net present value.

PPD: Predicted percentage of dissatisfaction.

RR: Rekorderlig Renovering, BeBo retrofitting multi-residential building projects.

SP: The technical research institute of Sweden.

SVEBY: "Standardized and verified energy performance in buildings" is the free voluntary guidelines on energy use for contracts, calculations, measurements and verification. It has been developed in collaboration between the major companies and organisations in the Swedish real estate and construction industries.

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1 Introduction

1.1 Background and Problem Motivation

The European Commission has acknowledged a research priority for the coming decades within the field of retrofitting existing buildings with energy-efficient solutions. Their policy for sustainability includes targets to increase energy efficiency and reduce energy usage. For the next 40 years, a rate of 3% of the European building stock per year needs to be renovated in order to meet the carbon and economic goals set out in the European Economic Recovery Plan. (Chenari, Carrilho, & Gameiro da Silva, 2016)

EU has established a goal that all new buildings created after 2021 should as a minimum strive to reach the definition of near zero energy building (EU, 2016). The Swedish parliament has stated the goal to reduce all energy use by 50 % until 2050 compared to the levels in 1995. This context will put higher demands on energy simulations providing accurate data (Bagge, Hans; Lindstrii, L; Johansson, D, 2013)

During the years 1965 – 1975 the Swedish government constructed nearly one million homes to fulfil the housing need in the society. These buildings were later known as part of the "miljonprogrammet" directly translated "the million programme". The standards of the existing buildings of this time period were outdated and had to be replaced. The final net result was an increase in Sweden's housing stock of 650,000 new apartments and houses. Most of these buildings are three stories high and with prefabricated concrete structure. The majority of these buildings are in need of renovation and retrofitting in terms of energy efficiency. It is estimated that in Sweden there are 700 000 – 800 000 dwellings where energy usage can be reduced by approximately 40% (Kling & Everitt, 2009).

This master thesis will be performed within the research project SIRen (Sustainable Integrated Renovation) which has the overall aim to gather knowledge, to strengthen Swedish competitiveness for renovation practice and research internationally. It will include two renovation projects from Beställargruppen för Energieffektiva flerbostadshus (BeBo), which has been actively promoting more energy-efficient systems and products on the market at an early stage since 1989 and one multi-residential building owned by Helsingborgshem, situated in Närlunda, Helsingborg. The project Rekorderlig Renovering was developed within BeBo to document the methods and tools for an integrated sustainable renovation procedure with the focus on multi-residential buildings "miljonprogrammet".

In this thesis the focus will be on the measured and predicted energy demand of retrofitted residential building constructed between 1965 and 1975. It is essential in a building design process to be able to give an accurate and trustworthy assumption of how different materials, design properties and operation, affect the energy demand.
Similar studies have been conducted in the commercial sector for new low energy buildings where the measured energy demand was generally significantly higher than the predicted energy need. The reasons behind the deviations have been explained by (Filipsson & Dalenbäck, 2014) . Their findings have been illustrated in Figure 1.

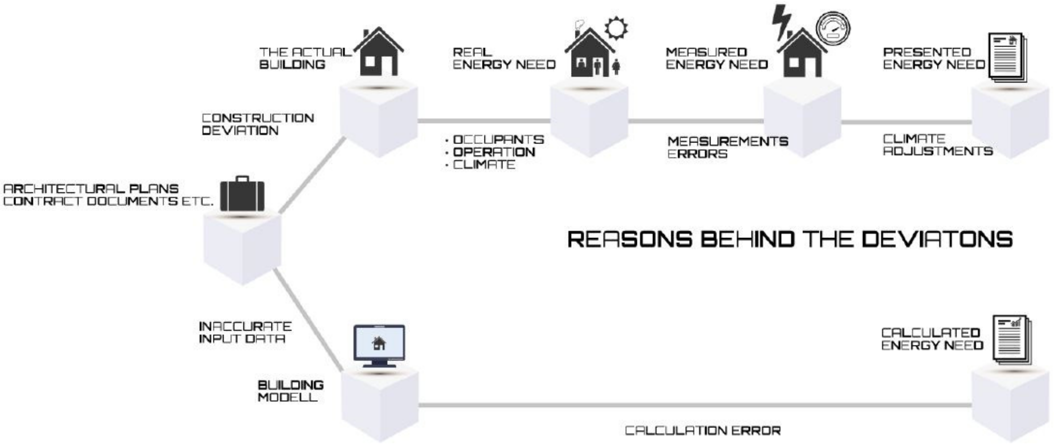

Figure 1: Reasons behind the deviations according to (Filipsson & Dalenbäck, 2014)

According to the programme for buildings with very low energy demand (LÅGAN) report by Kurkinen et. al., half of the 21 investigated buildings had higher energy demand than predicted, with deviations altering between 3-28%. Same report showed in their parametric study that a 10% deviation in their calculation is not surprising (Kurkinen, Filipsson, Elfborg, & Ruud, 2014). This matter is well known and has been considered in several articles and reports during recent years.

Another more recent LÅGAN report “Sammanställning av lågenergibyggnader i Sverige” describes that the development of the low energy buildings in Sweden are increasing every year. Among the 600 gathered projects in the report only 88 came with documented data of both estimated and measured energy values. Their investigation showed that 62% out of the 88 low energy buildings had a measured energy need which was equivalent to the predicted energy performance (Norbäck & Wahlström, 2016).

The largest deviations occur when the annual mean temperature is off by a few degrees or if the indoor temperature differs from the indoor design air temperature. Another explanation to the issue is buildings with high-performance on energy demand where minor errors on the energy estimation result in large deviations e.g. window sizes, ventilation, heat losses in the system, thermal bridges etc. (Filipsson & Dalenbäck, 2014).

This thesis has its focus on parametric studies within predicted and measured energy use in retrofitted projects and similar research were difficult to find since most of the published report investigated newly constructed buildings.

1.2 Aim and purpose

This thesis aims to determine:

- Investigate which input data in an energy simulation that has the greatest impact on the energy need.
- Investigate measures to improve the level of accuracy regarding input data.
- Determine the impact of applying the SVEBY procedure to understand the impact of user behaviour.
- Investigate possible differences in economical Life Cycle Cost (LCC) of inaccurate input data/assumptions.

The purpose with this thesis was to obtain a deeper understanding of the deviations between simulated values and actual energy use and decrease the inaccuracy by analysing parametric studies based on RR reports and Helsingborgshem (Helsingborgs municipality company for public housing) documentation of the Närlundavägen retrofitting. The major parameters which effect the total energy need will be pinpointed and measures to increase their accuracy will be developed.

1.3 Limitations

In order to keep the thesis work within a reasonable time limit, borders had to be defined:

- Implementation of data and calculation models was exclusively tested in the software IDA-ICE. It should be noted that even when the status of a building object is fully known and the input data perfectly corresponds with actual values, the calculated energy need is not 100% reliable, since the simulation program itself has an uncertainty factor which varies depending on chosen tool.

- The case study was restricted to evaluate three multi-residential buildings constructed during the “miljonprogrammet”, Norrbackavägen 21, 23 in Märsta and Närlundavägen 14 in Helsingborg.

- A large contributor to uncertainty for energy calculations is the way parameters interact with each other. Misjudging two or several parameters which have a strong correlation with each other may amplify the uncertainty with great magnitude. This case study pinpoints some parameters that have a strong correlation with each other but has not determined the effect of them amplifying each other. A detailed tracing of the connection between different parameters and how they interact with each other is beyond the scope of this report.

- The report will not take the impact of unbalanced heating systems into account.

-This thesis will just assure that the base cases have achieved PPD (predicted percentage of dissatisfaction) levels beneath 10 %. The focus has been on the overall energy need and not the satisfaction of prevailing indoor climate.

- The simulated energy need is presented as specific energy use according to BBR standard (Byggnadens specifika energianvändning) which is expressed in kWh/m^2 A_{temp} and year. It does not include tenant nor commercial related electricity need however it is considered during the simulation to include correct internal gains.

-The report will not look into simulation deviations of energy need due to inaccuracy as regards the way of handling thermal transmittance by numerical calculation programs, since it varies in a narrow (neglectable) margin of 1-5 % according to the report Validating Numerical Calculations against Guarded Hot Box Measurements. (Jørgen Rose, 2004)

-The report have not looked in to the effect of mutual shading from nearby building or surroundings.

-Zones with similar occupancy behaviour and loads have been merged during the IDA ICE simulations in order to increase simulation speed.

2 Methodology

Figure 2 illustrates the method trough out the report. Begins with literature studies of BeBo´s (Energimyndighetens beställargrupp för energieffektiva flerbostadshus) RR project reports, case studies of Norrbackavägen 21 and 23 have been investigated. Also a case study of Närlundavägen 14 was examined based upon energy simulations conducted by Skanska and energy metering provided by Helsingborgshem. The base cases modelled in IDA ICE were made to have the same input data as stated in previous reports or simulations and the overall energy need was constrained to not deviate from previous simulations by more than 10%.

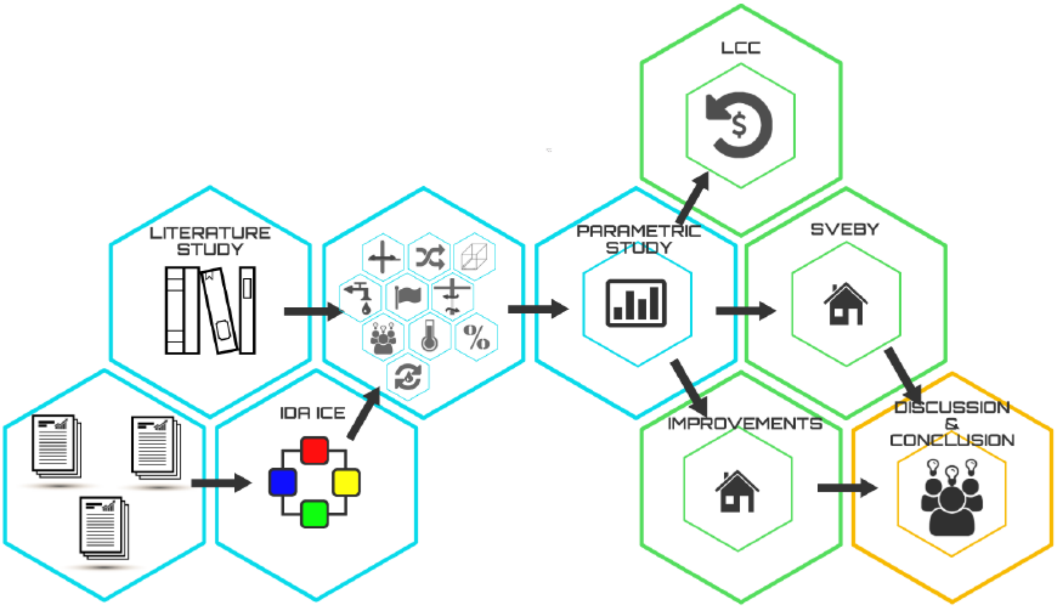

Figure 2: Summary of the thesis method

The case studies developed in IDA ICE have been used to conduct parametric studies tracing the major influencing parameters which are connected with uncertainty.

Literature studies have been carried out to determine the span in which the major influencing parameters may vary and measures which could improve the accuracy in connection with these parameters have been developed. To what extent the accuracy of the energy simulation was improved was documented by comparing the simulated energy need with the measured energy need after performed retrofitting.

The final step in the parametric study was to implement all developed measures to improve the accuracy of the energy simulation and to monitor to what extent it was possible to decrease deviations between simulated and measured energy need.

SVEBY has been implemented with standardised residence occupants' behaviour to determine the possibility of eliminating deviation between simulated and measured values in connection with user behaviour.

A LCC was conducted to analyse the economic impact which the major influencing parameters may result in during the retrofitted building's life span. The deviation in total energy need connected to each parameter was used.

2.1 Case studies

The simulated base cases represented in this thesis are based on BeBo report on Norrbackavägen 21, 23 and Skanska energy simulations of Närlundavägen 14.

Both Norrbackavägen 21 and 23 are part of the 50 buildings situated in the central part of Märsta, Sweden, managed by Sigtunahem AB. The buildings were constructed between the years 1972 and 1973 which includes them to the later part of "Miljonprogrammet". Heat is supplied to the buildings through hydronic heating system distributed through radiators and no cooling system has been installed. The two buildings are two stories high without a cellar and are balcony accessed. Both buildings are built with the same construction except for the building shape and they completed an energy retrofitting whereas the improvements were documented by Rekorderlig Renovering, see Table 1 and Table 2 (BEBO, 2012).

Table 1: Norrbackavägen 21 and 23 existing case before retrofitting, all constructions from outside to inside

Construction part	Construction	Documentation
Attic	Concrete 160 mm + mineral wool 150 mm	BeBo report
Slab	Drainage + concrete 200-250 mm	BeBo report
Gable wall	Brick 120mm+air 30mm+mineralwool 110mm+concrete 150mm	BeBo report
Wall	Wood façade 21mm+hard fibreboard 3.2mm+mineralwool with wood studs 140mm+gypsum board 13 mm	BeBo report
Window	2-glass windows with u-value of 2.8 w/m^2K	BeBo report
Ventilation	Exhaust system, fresh air from windows and openings	BeBo report
Leakage	1.2 l/m^2·s 50 Pa (One apartment in Norrbackavägen 21)	BeBo report
Energy demand	163 and 165 kWh/m^2, Atemp (Norrbackavägen 21 and Norrbackavägen 23)	BeBo report

Table 2: Norrbackavägen 21 and 23 after retrofitting, all constructions from outside to inside

Construction part	Construction	Documentation
Attic	Original construction + loose mineral wool 174 mm	BeBo report
Slab	Original construction + vapour barrier 0.2mm + insolation 30 mm + parquet flooring	BeBo report
Gable wall	Original construction + mineral wool and steel studs 70mm+vapourbarrier 0.2mm+gypsum 13mm	BeBo report
Wall	Original construction+ vapourbarrier 0.2mm+mineralwool with steel studs 70mm+gypsum 13mm	BeBo report
Window	3-glass windows with u-value of 1.2 w/m^2K	BeBo report
Ventilation	Exhaust system, fresh air from windows and openings	BeBo report
Leakage	0.65 l/m^2·s 50 Pa (One apartment in Norrbackavägen 21)	BeBo report
Energy demand	126 and 110 kWh/m^2, Atemp (Norrbackavägen 21 and Norrbackavägen 23)	BeBo report

Närlundavägen 14 was constructed in 1970 also being a part of "Miljonprogrammet". Närlundavägen 14 is owned by Helsingborgshem and consists of four stories with a cellar and are balcony accessed. The only construction documentation available was regarding with gable wall, remaining construction was made on assumptions, see Table 3 and Table 4:

Table 3: Närlundavägen 14 existing case before retrofitting, all constructions from outside to inside

Construction part	Construction	Documentation
Attic	Concrete 155 mm + mineral wool 145 mm	Estimated+drawings
slab	Drainage + concrete 250 mm + parquet flooring	Estimated+drawings
Gable wall	Concrete 200 mm + air 30mm+mineralwool and wood studs 90 mm+ gypsum 13 mm	-
Wall	Weatherboard 2.0, Knauf Danogips GmbH + mineral wool and wood studs 145 mm+gypsum 13 mm	Skanska documentation
Window	-	-
Ventilation	Exhaust system, fresh air from windows and openings?	Estimated
Leakage	-	-
Energy demand	174 kWh/m², Atemp	Energy declaration from 2009

Table 4: Närlundavägen 14 after retrofitting, all constructions from outside to inside

Construction part	Construction	Documentation
Attic	Original construction	Estimated+drawings
Slab	Original construction	Estimated+drawings
Gable wall	Original construction	-
Wall	Original construction + mineral wool and wood studs 45 mm + gypsum 13 mm	Skanska documention
Window	3-glass windows with u-value of 1.1 w/m^2K	Skanska documentation
Ventilation	Exhaust system, fresh air from windows and openings?	Estimated
Leakage	1.7 l/m²·s 50 Pa	Estimated
Energy demand	119 kWh/m², Atemp	Monitored 2015 by Helsingborgshem

2.2 Norrbackavägen 21

The renovation project, Norrbackavägen 21, was a part of BeBo Rekoderlig Renovering which had the aim to decrease the energy need of involved building object by 50%.
The original energy need declined from 163 kWh/m² to 126 kWh/m², which corresponds to 22 %. The set target of decreasing the energy need by 50 % was not obtained. The calculated energy need was 101 kWh/m², establishing that the energy calculation was of by 24.7%. This shows great potential and need for improvements regarding accuracy of the energy calculation and status assessment. (BEBO, 2012) See Appendix IDA ICE settings base case Norrbackavägen 21.

2.3 Norrbackavägen 23, Märsta

The renovation project, Norrbackavägen 23, also performed within BeBo Rekoderlig Renovering, had an aim to decrease the energy need from 165 kWh/m² to 93 kWh/m², which corresponds to a decrease of 43.6 %. The set target of decreasing the energy need by 50 % was not obtained. The measured energy need was 110 kWh/m², establishing that the simulated energy need was of by 18.3 %.

2.4 Närlundavägen 14, Helsingborg

The energy performance simulation that was carried out by Skanska is confidential but the documented aim was to decrease the energy need by 30 %.

Närlundavägen 14 has no individual metering regarding district heating. The existing energy declaration from 2009 specifics the energy need for Närlundavägen 2, 4, 6, 8, 10, 12 and 14, from which values of interest have been specified in Table 5, Table 6 and Table 7. The latest energy metering was made in 2015 after the renovation of Närlunda 14 had been carried out and Närlundavägen 4, 8 and 12 been sold off from Helsingborgs hem, not including them on the mutual metering.
It was assumed that the energy need for Närlundavägen 2, 4, 6, 8, 10 and 12 stayed relatively constant since no renovation work was carried out for these buildings.
To be able to compare calculated and measured values the district heating for Närlundavägen 14 has been isolated using the following procedure and compiled in Table 8:

Table 5: Energy declaration compilation of Närlundavägen 14

Address	District heating excluding DHW /kWh	Facility electricity /kWh	DHW /kWh	Average year corrected energy need/ (kWh/m²)	kWh/m²	Area	Average year correct energy need/kWh
Närlundavägen 2	247 332	31 040	84 409	168	153	2 432	409 778
Närlundavägen 6	247 332	48 956	84 409	176	160	2 432	427 694
Närlundavägen 10	247 332	39 773	84 409	172	157	2 432	418 511
Närlundavägen 14	247 332	43 308	84 409	174	158	2 432	422 046
Närlundavägen 4	139 670	3 645	47 666	173	81	1 256	217 520
Närlundavägen 8	139 670	6 479	47 666	175	158	1 256	220 354
Närlundavägen 12	139 670	4 344	47 666	174	156	1 256	218 219
Summation	1 408 338	177 545	480 634	1 212	1 023	13 496	2 334 122

Table 6: Mutual metering of district heating and domestic hot water

Year	District heating/kWh	Included buildings
2010	1892000	Närlundavägen 2, 6, 10, 14, 4, 8, 12
2011	1723001	Närlundavägen 2, 6, 10, 14, 4, 8, 12
2012	1889000	Närlundavägen 2, 6, 10, 14, 4, 8, 12
2013	1907000	Närlundavägen 2, 6, 10, 14, 4, 8, 12
2015	1236001	Närlundavägen 2, 6, 10, 14

Table 7: Facility electricity of Närlundavägen 14

Year	Facility electricity/kWh
2010	41106.9
2011	37003.3
2012	38057.0
2013	33534.0
2015	48718.9

The amount of district heating supplied to Närlundavägen 14 was calculated by adding together district heating for Närlundavägen 2, 6, 10 and 14, documented by mutual metering 2015, subtracted by district heating for Närlundavägen 2, 6, and 10, documented in the energy declaration from 2009:
1236001- ((247 332·3) + (84 409·3)) = 240778 kWh
The domestic hot water use for Närlundavägen 14 was assumed to be the same as during the energy declaration in 2009, which was subtracted from the mutual metering:
240778 - 84409 = 156369 kWh
The estimated energy need for Närlundavägen 14 was documented to decrease by 30% compared to the normal year corrected value from the energy declaration in 2009. Both the domestic hot water use and facility electricity for Närlundavägen 14 were assumed to be the same as during the energy declaration in 2009.
158·0.7 = 121.8 kWh/m^2
121.8·2432=159330.6 kWh
159330.6 – (84409+52478) = 159330.6 kWh

Table 8: Compilation of key metering and the calculated energy need

Närlundavägen 14	District heating/ kWh	Domestic hot water/kWh	Facility electricity/kWh	kWh/m^2	Normal year corrected	Area/m^2
Monitored 2009	247332	84409	52478	158	174	2432
Monitored 2015	156369	84 409	48718.9	119	-	2432
Skanska calculation(-30%)	159330.6	84 409	52478	121.8	121.8	2432

It was concluded that the aim of diminishing the energy need by 30 % was obtained and the total energy need for Närlundavägen 14 was lowered by an additional 2.35%.

2.4.1 Occupants

The occupancy level of Närlundavägen 14 has been estimated using SVEBY occupancy input data for multifamily facilities, according to Table 9:

Table 9: SVEBY occupants level multifamily facilities

Apartment size	1 room	2 rooms	3 rooms	4 rooms	5 rooms
Amount of persons	1.42	1.63	2.18	2.79	3.51

Apartment size	Amount of apartments	Amount of persons
1 room	4	5.68
3 room	28	61.04
		Sum:66.72

The IDA ICE model had a total occupied area of 2313.3 m².

$\frac{66.72}{2313.29} \approx 0.0288$ persons/m^2

2.4.2 Ventilation rate

BBR requires a minimum ventilation rate of 0.35 l/s, m^2 which has been assumed as the design air flow rate in the IDA ICE base case model.

Unfortunately the documentation of Närlundavägen 14 was so poor that implementing improvements to the base case in an effort to improve the accuracy of the simulation was not realistic. The accuracy of the study would have been jeopardised and credibility lost. However the simulated base case was still used to illustrate the impact alteration of different parameters have on the total energy need.

2.5 IDA Indoor Climate and Energy

IDA ICE is a dynamic multi-zone simulation application used for studies of indoor climate and whole year energy use. IDA-ICE is very transparent i.e. the physical models used can be visualized in code and it is possible to edit or make new models. The software is tested and validated according to European and American standards. (EQUA, 2016)

2.6 Literature review and parametric study

A parametric study has been conducted to evaluate the impact of uncertainty connected to the input data. A base case model for each building object has been established and verified against documented energy-simulation/reports. The base cases simulated in IDA ICE was made to agree with previous energy simulations (not measured values), to assess and pinpoint questionable input data. Deviations between the previously made energy simulation and reconstructed base cases were within 10 % margins.

The literature study has established that the interval for the parameters is estimated to vary between certain values. The final set point of the simulation is either based on procedure found through literature studies or through assumptions. The parameters that were addressed in this thesis are as follows:

- Area deviation
- Wind
- Heat recovery efficiency
- Losses in hot water circuit system
- Tenant electricity need
- Air-tightness/leakage
- Thermal bridges
- Indoor temperature variation
- Domestic hot water need
- Utilization factor

Each parameter will include a general description of the aspect and the impact on the energy need according to the literature study. The span which the parameter is likely to vary within was established. When possible, methods for choosing the most likely value within the span have been investigated and implemented. Generally this was either based on literature studies providing a statistically proven average value or through calculation procedures which was documented to enhance accuracy for the parameter at hand.

To investigate the possibility of eliminate uncertainties connected to user behaviour the SVEBY procedure was implemented during the final stage of the parametric study.

2.7 Life Cycle Cost(s)

During the parametric study a wide range of parameters connected with uncertainty has been evaluated. Through literature studies and case studies, the span by which the energy need may vary has been established. To determine the economic impact of misjudged parameters, the Life Cycle Cost (LCC) has been calculated for the span in which the parameter at hand could alter. During the LCC calculations it was assumed that generally the chosen value for each parameter would be found in the middle of the span. Therefore the possible misjudgement of energy need has been determined as half of the span in which the parameter varies.

Note that in many cases the energy need becomes over-estimated, in which case the LCC would result in a future gains compared to planned energy need.

During the calculation the following assumptions were made:

- All equations have implemented nominal interest rate which incorporates both real money growth and inflation.

- The geometric gradient equation converts the future non accountable profits to a present value.
- The electricity is assumed to be paid at the end of each year.
- The life span of the restored building has been assumed to 40 years (BeBo, 2012) .

$$P = A_{1,a} \frac{1-(1+g)^{N}(1+i)^{-N}}{i-g}$$ Equation 1

A_1=$A_{0,a}\cdot$ (1+g)

Equation 2

$A_{0,a}$=Present value year one
$A_{1,a}$=Present accumulated value year one
i = Nominal interest rate
g = Growth rate
N = Number of years

3 Results - Literature review

The findings on the 10 parameters addressed in this thesis from the literature study are presented below.

3.1 Area deviation

The variation of area was based on the findings from an energy simulation competition where the different assumptions taken during an energy simulation was monitored.

The participants signed up with software of their choice and had the goal to reach closest to the actual measured energy need which was revealed at the end of the competition. The most time-consuming task was to determine the total floor area (A_{temp}) for the building based on PDF and DWG file formats. The majority of the competitors presented an A_{temp} between 10000 – 10400 m² and consequently a median value of 10252 m² was chosen as the closest estimation to the actual building (Levin & Snygg, 2011).

The range of area deviation that was implemented in this thesis was based on Levin & Snygg energy software competition. The highest and lowest values from the participants were converted to a percentage difference in relation to the assumed real area of 10252 m², see Table 10

Table 10: Area deviation from energy calculation competition

Area	Median value 10252 m^2	Lowest value 9401m^2	Highest value 13400m^2
Percentage of deviation	0	-8%	+31%

To evaluate to what extent the drawings available from the municipality could differ between actual measures and documented drawing, a field study has been carried out.

The field study was limited to just focusing on buildings connected to Miljonprogrammet. Two districts have been evaluated, Fredriksdal and Närlunda in Helsingborg. The circumference of the building at hand was measured both from drawings provided by the city archive and on-site measurement carried out with laser-pointer. The percentage of deviation was obtained by dividing the measured circumference by the circumference from the city archive. The data has been gathered and the average divergence is displayed, see Table 11.

Table 11: Area deviation from field measures

Address	City archive circumference	Measured circumference	Percentage of deviation
Närlundavägen 10, 252 75 Helsingborg	133.8 m	132.4 m	1.015 %
Närlundavägen 17, 252 75 Helsingborg	127.5 m	126.9 m	0.55 %
Larmvägen 4, 25456 Helsingborg	131.9 m	131.6 m	0.459 %
Larmvägen 6, 25456 Helsingborg	112.5 m	112.5 m	0.09 %
		Average deviation:	0,53 %

The field measurements showed neglectable area variation of 0,5 %, ensuring it as safe to use the drawing material provided by the municipality with no further correction factor assign to it.

Final input data for simulation of selected path according to Table 12.

Table 12: Input data for area

Minimum	Maximum	Selected
- 8%	+ 31%	0%

3.2 Air-tightness/leakage

In order to achieve adequate air-tightness in a building one must be able to locate the uncontrolled ventilation known as air infiltration or air leakage which can occur due to air permeability of the building envelope trough gaps and cracks. Infiltration is caused by wind, negative pressurization of the building and by air buoyancy forces commonly known as the stack effect (Guyot, Carrié, & Schild, 2010)

High infiltration of outdoor air in the northern hemisphere will result in increased heat losses and a lower degree of heat recovery from the extracted air. It can also cause thermal discomfort due to draughts and colder indoor climate which will be compensated by higher heating demand leading to a high reduction in energy efficiency (Abel & Elmroth, 2007).

According to a study carried out by the SP Technical Research Institute of Sweden (SP) where the airtightness of multi-storey residential buildings from the year 1971-1985 was investigated. Four different leakages were performed in their simulations. For buildings that were constructed with high standard a leakage of 0.2 l/m²·s and 0.4 l/m²·s can be reached at a pressure difference 50 Pa, respectively. Next level was the BBR which at the time had requirements of 0.8 l/m² ·s, 50 Pa. A final test was performed with the worst case scenario of leakage 2.0 l/m² ·s which is the common measured value for the building from the 1970-80s. (Sandberg, Sikander, Wahlgren, & Larsson, 2007)

Based on literature study a leakage span has been obtained altering between 0.2 and 2.0 l/m²·s.

Norrbackavägen 21 and 23 were both tested with the blow-door procedure ensuring a reliable value for the leakage. However, due to absence of information the leakage in Närlundavägen 14 had to be assumed since there does not exist any documentation of successful blow-door tests. Input data for simulation was according to Table 13 and Table 14.

Table 13: Input data for leakage, Norrbackavägen 21 and 23

Minimum	Maximum	Selected
0.2 l/m²·s.	2 l/m²·s.	0.65 l/m²·s.

Table 14: Input data for leakage, Närlundavägen 14

Minimum	Maximum	Selected
0.2 l/m²·s.	2 l/m²·s.	2 l/m²·s.

3.3 Wind

According to the Swedish Meteorological and Hydrological Institute (SMHI) the prevailing wind in Sweden blows from the west or south-west under an undisturbed environment. On the west coast of Sweden there are not any obstacles to interrupt the wind direction henceforth west or south west winds. However, in inland Sweden topography that forms wind direction from north-west and south-east. (SMHI, 2016). In most climates wind is an asset in summer and a liability during winter. Therefore a wind design strategy is required to keep the energy use in a building to a minimum. Under normal conditions, infiltration is responsible for one third of the total heat loss in homes and on a windy day on an open site the infiltration can account for more than 50% of the total heat loss (Lechner, 2001).

IDA ICE has three default settings for wind, City center, Suburban and Ocean. The span in which the wind-factor may deviate was established by a base case simulation with the most sheltered wind-factor (City center) and the most unsheltered (Ocean), see Table 15.

Table 15: Input data for wind-factor

Minimum	Maximum	Selected
City center wind-factor	Ocean wind-factor	Suburban wind-factor
a0 = 0.47, a_exp = 0.35	a0 = 1.3, a_exp = 0.1	a0 = 0.67, a_exp = 0.25

3.4 Thermal Bridges

A thermal bridge is usually defined in three different ways.

- As a part of the building envelope with significantly changed thermal resistance due to full or partial penetration of the building envelope by materials with different thermal conductivity.
- Changing thickness of the building envelope.
- Difference between internal and external areas.

During outdated versions of Boverket's recommendation an alternative to calculating the linear thermal bridges would be to increase the overall heat transfer through the building envelope by 20 %. When assessing older building and energy calculations it is a large possibility that this assumption was made.

Thermal bridges have a major impact of the overall energy performance of buildings and their effect increases with increasing amount of insulation. Depending on chosen method to take thermal bridges in to account different spans of error margin can be forecasted.
The report "Dynamic effect of thermal bridges on the energy performance of a low-rise residential building" established to what degree thermal bridges become underestimated depending on chosen modelling method. Three modelling methods have been assessed, equivalent U-value method, equivalent wall method and direct 2D/3D modelling method. It was stated that annual heating demand was underestimated by 13% using the equivalent U-value method and by 9% using the equivalent wall method when compared to the 2D/3D modelling method. (Hua Ge, 2015)

Direct 2D/3D modelling method:

The direct 2D/3D modelling approach was solved by implementing the psi-values calculated from Heat2 9.04 in the 3D IDA ICE base case model. This method has been assigned the highest level of accuracy through the literature study, see Table 16, Table 17 and Table 18. Notice that there is still a margin of error connected to the 2D/3D modelling method.

Table 16: Thermal bridges obtained from Heat2 9.04 Norrbackavägen 21

Thermal bridge	Psi-value
External slab/External walls	0.6 W/mK
External wall and intermediate slab	0.084 W/mK
External wall and internal wall	0.019 W/mK
Roof and external wall	0.413 W/mK
External wall corner	0.04 W/mK
Internal wall and roof	-
Internal wall and slab	-
External wall and window	0.081W/mK
External wall and door	0.13 W/mK
Balcony	0.542 W/mK

Table 17: Thermal bridges obtained from Heat2 9.04 Norrbackavägen 23

Thermal bridge	Psi-value
External slab/External walls	0.6 W/mK
External wall and intermediate slab	0.085 W/mK
External wall and internal wall	0.019 W/mK
Roof and external wall	0.42 W/mK
External wall corner	0.081 W/mK
Internal wall and roof	-
Internal wall and slab	-
External wall and window	0.081W/mK
External wall and door	0.13 W/mK
Balcony	0.542 W/mK

Table 18: Thermal bridges obtained from Heat2 9.04 Närlundavägen 14

Thermal bridge	Psi-value
External slab/External walls (basement)	0.055 W/mK
External wall and intermediate slab	0.1221 W/mK
External wall and internal wall	0.042 W/mK
Roof and external wall	0.121 W/mK
External wall corner	0.036W/mK
Internal wall and roof	-
Internal wall and slab	-
External wall and window	0.1W/mK
External wall and door	0.992 W/mK

Equivalent wall method:

The thermal bridge is represented by an one-dimensional multi-layered structure which has the same thermal characteristics as the complex wall system with thermal bridges. To determine to which degree this method underestimates the total energy need the district heating obtained from the direct 2D/3D modelling method was lowered by 9%.

Equivalent U-value method:

The equivalent U-value method is wildly used by implementing it in 1D whole building energy simulation programs. The effective U-value for thermal bridges is calculated which means that the method includes higher amounts of thermal transmittance through the building envelope but the effect of thermal inertia is not accounted for. To determine to which degree this method underestimates the total energy need the district heating obtained from the direct 2D/3D modelling method was lowered by 13%.

The highest level of accuracy regarding the impact of thermal bridges was obtained by implementing the results from Heat2. Compared to Heat2, Equivalent wall method and Equivalent U-value method underestimates the impact of thermal bridges by 9 and 13% respectively, see Table 19: Input data for thermal bridges.

Table 19: Input data for thermal bridges

Minimum	Maximum	Selected
Equivalent U-value method	Heat2	Heat2

3.5 Heat recovery efficiency in air handling unit

BeBo demonstrated on an actual existing multi-residential building that not only was it energy efficient and manageable to install a ventilation system with heat recovery but also that the purposed investment was economically viable (Wahlström, 2014).

Danish report showed that ventilation heat losses can be 35–40 kWh/m², year in residential buildings and up to 90% can be recovered by installing a ventilation heat recovery system depending on the airtightness and insulation of the building (Tommerup & Svendsen, 2005).

The purpose of recirculating exhaust air to supply air is to increase the temperature but it could also reintroduce impurities which leads to unwanted consequences for the occupants. Since 1994 it has been uncommon to use recirculation in Sweden due to the local building regulation that states that it can only be applied under certain circumstances and requires an investigation if it is suitable (Warfvinge & Dahlblom, 2010).

A field test with 20 centralized mechanical ventilation units in single-family houses was conducted in Luxemburg. The authors included five parameters in their study and one of them was the heat recovery efficiency in the ventilation system. The study had the purpose to reveal the real performance of the ventilation system and the result showed that the overall energy efficiency was lower than expected the heat recovery efficiency being 0.65 ± 0.24. In the report the authors also mention a total recirculation of 6.5% of the exhaust air where mixed with the supply air inside the device or outside the building (Merzkirch, Maas, Scholzen, & Waldmann, 2015).

Based on the previously mentioned literature study the efficiency of the heat recovery varied in the span of 41-89 %.

Table 20: Input data for heat recovery efficiency in air-handling unit, Norrbackavägen 21 and 23

Minimum	Maximum	Selected
41 %	89 %	65 %

Table 21: Input data for heat recovery efficiency in air-handling unit, Närlundavägen 14

Minimum	Maximum	Selected
41 %	89 %	50 %

3.6 Indoor temperature variation

Indoor temperature in residential buildings is a recurrent topic in the field of buildings and energy. Many researchers have provided detailed results of the temperature conditions and according to Dahlblom et. al. paper an underestimation of 1°C will result in at least 5% error in space heating need in a Nordic climate. Therefore, knowledge of real indoor temperatures is crucial for better input data for more accurate building energy simulation (Dahlblom, Nordquist, & Jensen, 2014)

The guidelines for public buildings, AFS (Arbetsmiljöverkets författningssamling) states that if the thermal indoor climate for sedentary work deviates from 20 – 24 °C during the winter season it should be amended to comply within the given temperatures (AFS, 2009). Boverket on the other hand provides an operative temperature in buildings according to its DVUT (Dimensionerande vinterutetemperatur) of a minimum 18 °C in their regulation. This applies to workroom and living-spaces (BBR, 2015)

An extensive study was conducted in multi-residential buildings where the involved authors measured the indoor temperature for 14 days in around 768 000 apartments in buildings built during 1961-1975. The result was based on the investigated apartments and not the entire building and according to the report the average temperature reached a level of 22.6 ± 0.32 °C (Boverket, Energi i bebyggelsen – tekniska egenskaper och beräkningar – resultat från projektet BETSI, 2010). Similar results were given in the simulation competition where they handed out a measured value to the contenders which was an average temperature of 22 ± 0.5 °C (Levin & Snygg, 2011).

Based on the conducted literature review a temperature span of 18 – 24 °C was applied as the deviation for this parameter. According to (Boverket, Energi i bebyggelsen – tekniska egenskaper och beräkningar – resultat från projektet BETSI, 2010) and (Levin & Snygg, 2011) an indoor temperature of 22.6 °C was set as the most common value found in apartments within multi-residential buildings, see Table 22.

Table 22: Input data for indoor temperature

Minimum	Maximum	Selected
18 °C	24 °C	22.6 °C

3.7 Losses in hot water circuit system

Hot water circuit losses in multi-residential buildings are often underestimated due to previous lack of metering and mapping. When it comes to the production of new multifamily buildings often the lump value of 4 kWh/m^2 is used (Arne Elmroth, 2015). But hot water circuit losses vary in a wide range, mainly due to the following points:

- Piping insulation
- District heating-central insulation
- Poorly planned piping, resulting in unnecessary long pipes or placement where heat losses can not be accumulated by nearby zones with heating need

- Not shutting off the district heating connected to the heating system of the building during summer season

Through studies of reports published by BeBo the span in which hot water circuit losses varies has been established. The report “Kartläggning av VVC-förluster i flerbostads hus” conducts metering of 12 facilities and establishes that the hot water circuit losses vary between 2,3 and 28 kWh/m² heated floor area. (Arne Elmroth, 2015) This was the chosen span in which the IDA ICE model base case was varied within. Heat gains losses to nearby zones was set to 0 % since it was assumed that it already had been taken into account during the report “Kartläggning av VVC-förluster i flerbostads hus”.

The set value for the IDA ICE model was established by assessing the report “Förstudie av VVC-förluster i flerbostadshus”. The report has a wide statistic foundation of 8500 measuring points, gathered by Fortum Värme which have been connected to energy declarations provided by Boverket. All the measured buildings were constructed after the 1950’s. It was established that on average, hot water circuit losses reached 17.4 kWh/m² heated floor area. Deviation depending on construction year, facility size and average apartment size was investigated but a strong correlation was hard to find, which was the reason why 17.4 kWh/m² was chosen as the set value for the IDA ICE model. (Ebba Lindencrona, 2014)

Norrbackavägen 21 and 23

Through IDA ICE simulation of the base case with hot water circuit losses varying between 2.3-28 kWh/m² it was established that the total energy need varies within a span of 25.7 kWh/m². The Norrbackavägen base cases did not include hot water circuit losses which have been added subsequently, as a part of the domestic hot water need. It was assumed that the 15.15 kWh/m² of the domestic hot water need in the base cases consists of hot water circulation losses, which correspond to half of the span found in the literature research.
To obtain a surplus energy need of 17.4 kWh/m² due to hot water circuit losses, the difference between the 17.4 and 15.15 kWh/m² had to be added to the base case.

17.4-15.15 = 2.25 kWh/m²

The Norrbackavägen 21 base case model was simulated with 5.05 kWh/m² surplus energy need, due to hot water circuit losses, which constitutes the chosen path.

Närlundavägen 14

The base case model for Närlundavägen 14 had an estimated energy loss of 17.4 kWh/m² due to hot water circuit losses. This was based on previously mentioned literature studies establishing the average hot water circuit losses.

During the parametric study the hot water circuit losses varied between 2,3 and 28 kWh/m², with no percentage of the energy losses contributing to heat to nearby zones. Since the base case already corresponds to the average hot water circuit losses it will be assigned as the chosen path. See all the IDA ICE settings in table Table 23

Table 23: Input data for domestic hot water circulation losses

Minimum	Maximum	Selected
2.3 kWh/m²	28 kWh/m²	17.4 kWh/m²

3.8 Domestic hot water

The report, “BRUKARRELATERAD ENERGIANVÄNDNING Mätning och analys av hushållsel och tappvarmvatten”, have gathered data regarding the DHW use of 1000 apartments during the time frame of six years. They manage to characterize typical low, average and high consumers of DHW, see Table 24. The report also states that DHW varies a lot between two years that follow each other (Bagge, Johansson, & Lindstrii, 2015).

Table 24: Domestic hot water use

	DHW tenants/(kWh/m² BOA)
Lowest	7.0
Average	23.0
Highest	43.0

The interval that was chosen considering DHW was a span between 7 and 43 kWh/m². See all the IDA ICE settings in table Table 25:

Table 25: Input data for domestic hot water need

Minimum	Maximum	Selected
7 kWh/m²	43 kWh/m²	According to documented energy declaration

3.9 Tenant electricity need

Internal heat gains include people, lights and equipment. These are all parameters which may lower the total heating need of the building and helps maintain the constant set temperature. They also contribute to the total building cooling load. The cooling load for residential buildings in a Nordic climate is commonly covered with passive measures by e.g. open the window, solar shading etc.

Through literature studies it was concluded that the average thermal output of internal heat sources was considered constant at 2.5 W/m² for single family houses and at 3.2 W/m² for multifamily houses. It was however established through modelling, measurements and surveys that the internal heat gains varies widely in a range from 1 to 5 W/m². (Rainer Elslanda, 2014)

Future building envelope will be well insulated as the energy performance for future buildings are becoming more demanding. This will make the internal heat gains from equipment, lighting and DHW a decisive aspect in the energy design phase. Several studies have shown that the measured energy usage had a deviation between 50 and 100% from the designed one. One main reason behind it was partly due to misjudging the occupancy related energy aspects and indoor temperature.

Bagge et. al. documented the electricity use and DHW in 1000 apartments in Sweden during a 6-year-period with the main purpose of acquiring a more profound understanding on the occupancy behaviour and provide the information to the building industry. The authors divided the users into three categories, 10% low, 10% middle and 10% highest. “10% lowest and highest“ were the 10% tenants that used the least/most amount of kWh/m² BOA, “10% middle” group where the 10% tenants using 45-55% energy (kWh/m² BOA), see Table 26 (Bagge, Johansson, & Lindstrii, 2015).

Table 26: Average usage in all apartments

	Electricity tenants/(kWh/m² BOA)
General	28.7
10% lowest	12.4
10% middle	26.0
10% highest	56.4

It should be noted that both tenant electricity and domestic hot water use may vary with great magnitude between years. According to the report “BRUKARRELATERAD ENERGIANVÄNDNING”, in half of the investigated apartments tenant electricity fluctuate by more than 8 kWh/m² and 25 % by more than 15 kWh/m², see Table 27.

Table 27: Input data for parameter tenant electricity need

Minimum	Maximum	Selected
12.4 kWh/m²	56.4 kWh/m²	Documented from reports or energy declarations

3.10 Utilization factor

The part of heat gains which is used for heating to maintain the constant set temperature is defined as heat utilization factor. The Utilization factor varies in a wide range and is highly dependent on both the thermal inertia and the gains/loss ratio, γ.

Thermal Inertia:

The thermal inertia of building envelopes can be categorized by the following prerequisites, see Table 28.

Table 28: Thermal inertia of building envelopes

Building thermal mass	Structures mass and glazing area
Very light external envelopes	External envelopes mass < 50 kg/m², Glazing area > 50% of total facades area. Internal vertical envelopes mass < 50 kg/m². Horizontal envelopes mass < 50 kg/m²
Light external envelopes	External envelopes mass < 50 kg/m²; Glazing area < 50% of total facades area. Internal vertical envelopes mass < 50 kg/m². Horizontal envelopes mass > 100 kg/m²
Medium external envelopes	External envelopes mass < 50 kg/m²; Glazing area < 50% of total facades area. Internal vertical envelopes mass 50–100 kg/m² Horizontal envelopes mass > 100 kg/m²
Massive external envelopes	External envelopes mass 50–100 kg/m². Internal vertical envelopes mass < 50 kg/m². Horizontal envelopes mass < 50 kg/m² mass 50–100 kg/m².
Very massive external envelopes	External envelopes mass >100 kg/m². Internal vertical envelopes mass 50–100 kg/m². Horizontal envelopes mass > 150 kg/m²

To conclude which category of building thermal mass the construction fits in to, the external envelope mass is the summed up for all construction layers, starting from the internal surface and stopping at the first insulating layer. The maximum construction thickness one is allowed to utilize is 10 cm or the middle of the construction. One has to choose the thinnest alternative. (Kęstutis Valančius, 2014)

Gains/losses ratio:

The gains/losses ratio, γ, is the quotient between the total amount of heat gains and the total amount of heat losses. The total amount of heat gains subsequently consists of internal heat gains from persons, lighting and equipment as well as solar heat gains. The total amount of heat losses consists of transmission and ventilation losses, see Table 29.

By activating the heat balance output prerequisite in IDA ICE, it was possible to gather all the necessary data to calculate the quotient between the total heat gains and losses, γ. It is important to note that the percentage of utilized energy should be set to 100 % for equipment, occupants and light during the simulation.

Table 29: IDA ICE heat gains and losses output prerequisites

Heat gains/ W	**Heat losses/W**
Heat from occupants (incl. latent)	Heat from air flows
Heat from equipment	Heat from walls and floors (structure)
Heat from lighting	Heat from windows (including absorbed solar) and openings
Heat from solar – direct and diffuse	Heat from thermal bridges

Utilization factor:

Once the Thermal inertia and the Gains/losses factor, γ, has been established for the building at hand it is possible to interpret the heat gain utilization factor from the graph in Figure 3 (Kęstutis Valančius, 2014)

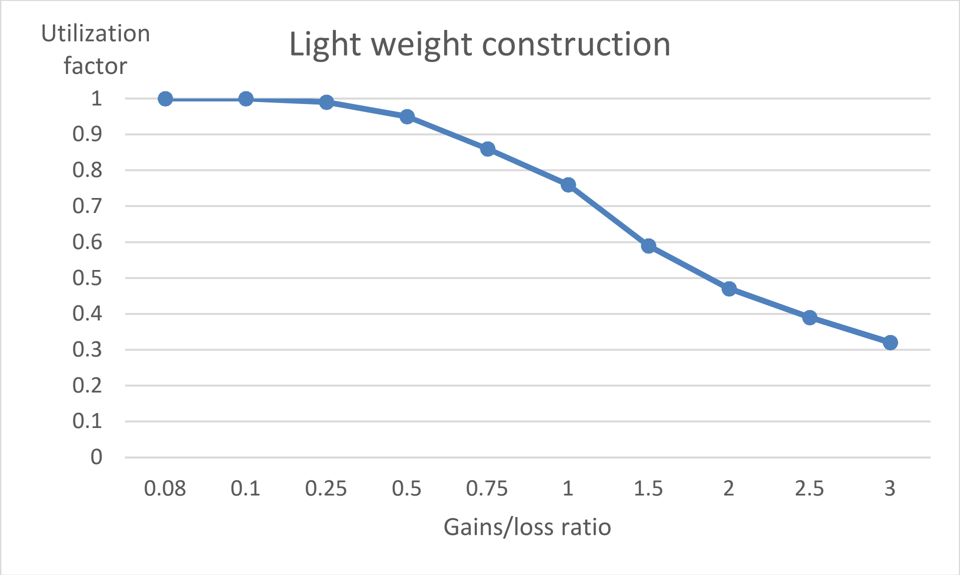

Figure 3: Heat gain utilisation factor dependence on gain/loss ratio and building thermal inertia (Heat gains utilisation and system efficiency influence to the heat demand of a building heating) (Kęstutis Valančius, 2014)

The Utilization factor may vary between 30-100% for light external envelopes, according to Figure 3, this has been assigned the span during the parametric study. See all the IDA ICE settings in table Table 30:

Table 30: Input data for utilization factor

Minimum	Maximum	Selected
30 %	100 %	Calculated value

Norrbackavägen 21:

When calculating the thermal inertia for Norrbackavägen 21 it was established that the thickness of all building elements exceedes 20 cm, resulting in the thickness of accountable construction layers being 10 cm. The external envelope mass was summed up for all construction layers, starting from the internal surface and stopping 10 cm inside the construction. The construction is classified as light external envelope since all of the following requirements are for filled:

External envelopes mass < 50 kg/m²: 115.1 kg/m²
Glazing area < 50% of total facades area: Yes
Internal vertical envelopes mass < 50 kg/m²: 17.7 kg/m²

Horizontal envelopes mass > 100 kg/m^2: 212.7 kg/m^2

The gains/losses ratio was established to 0.72 by the gathering of prerequisite output from IDA ICE according to Appendix Thermal inertia

Through interpretation of Figure 3 the utilization factor for Norrbackavägen 21 was established at 86%.

Based on literature study, the internal gain utilization factor for Norrbackavägen 21 varies between 30-100%.

Norrbackavägen 23:

Norrbackavägen 23 has the same construction solutions as Norrbackavägen 21 and a glazing area which accounts for less than 50 % of the total façade area also classifying it as a building with light external envelope.

The gains/losses ratio was established to 0.76 by gathering of prerequisite output from IDA ICE according to Appendix Thermal inertia

Through interpretation of Figure 3 the utilization factor for Norrbackavägen 23 was established at 85%.

Based on literature study, the internal gain utilization factor for Norrbackavägen 23 differs between 30-100%.

Närlundavägen 14:

When calculating the thermal inertia for Närlundavägen 14 it was established that the thickness of all building elements excides 20 cm as in previous cases. The construction is classified as light external envelope since all of the following requirements are fulfilled:

External envelopes mass < 50 kg/m^2: 99.9 kg/m^2
Glazing area < 50% of total facades area: Yes
Internal vertical envelopes mass < 50 kg/m^2: 17.7 kg/m^2
Horizontal envelopes mass > 100 kg/m^2: 212.7 kg/m^2

The gains/losses ratio was established to 0.59 by gathering of prerequisite output from IDA ICE according to Appendix Thermal inertia

Through interpretation of Figure 3 the utilization factor for Närlundavägen 14 was established at 91%.

Based on literature study, the internal gain utilization factor for Närlundavägen 14 differs between 30-100%.

3.11 SVEBY

To analyse deviation in connection with occupancy behaviour the SVEBY (Standardize and verify energy performance in buildings) procedure has been implemented.
SVEBY is the Swedish building industries' interpretation of the energy-demands specified according to BBR (Boverkets byggregler). SVEBY was updated in 2012 to version 1.0 and the office occupancy behaviour input in June of 2013 to version 1.1. The SVEBY procedure has its main focus on new residential and office buildings developed with today's technology but could also be used in connection with extensive renovation projects.
SVEBY specifies standardized occupancy behaviour input for both simulation and verification of the energy performance. Since the verification of the energy should be performed with standardized occupancy behaviour, actual user behaviour needs to be considered in energy simulations in order to adjust the measured energy. The verification of the building's energy performance should be independent of the user behaviour at hand. It should neither be beneficial or a disadvantage to have users with different behaviour.

The SVEBY procedure is structured with several different steps which are listed below:

Contract:

Agreement specifying the level of energy performance which should be pursued and stated in the Energy contract 12. This report is delimited to not include juridical background concerning the contract.

SVEBY energy simulation:

Calculating the energy performance of the building with SVEBY occupancy behaviour input, see Table 32. The chosen simulation tool should be able to take all specified SVEBY input data in to consideration and obtain the same level of detail as the Excel calculation sheets (used in the BeBo Rekorderlig renovation), energy instructions, available at http://www.sveby.org/. It is recommended to account for thermal bridges using Heat2.

Measured energy performance:

All the different energy aspects have to be monitored and documented on a monthly basis, from operation start of the building. This includes:

- Heating
- Cooling
- Domestic hot water
- Facility electricity

The facility electricity should be differentiated from the tenant electricity enabling the possibility to account this reduction.

Verification:

The verification of the energy performance should be made with standardized occupancy behaviour. In practise this can result in adjusting the measured energy by adding or subtracting energy use which deviates from what is specified by SVEBY. The procedure includes several energy simulations to isolate the correction. The energy simulation established from the energy 12 contract are valid for standardized user behaviour. The difference between simulations with SVEBY user behaviour and actual user behaviour constitutes the correction.

SVEBY input data:

Table 31: Apartment size and tenant density

Apartment size	1 room	2 room	3 room	4 room	5 room	6 room
Amount of persons	1.42	1.63	2.18	2.79	3.51	3.51

Table 32: SVEBY input data.

Parameter	Fraction parameter	Fraction parameter	Value for multi residential houses
Indoor temperature	Heating season		21 °C
	Heating season	Individual monitoring and debiting	21 °C
	Heating season	Night- and daytime decrease	21 °C
Air flow	Demand controlled	Kitchen fan	30 min/day
	Airing	Additional energy	4 kWh/m²,year
Sun shading	Shading factor	Total (fixed and active)	0.5 (0,71 and 0.71)
Domestic hot water	Energy	Annual template value	25 kWh/m²
	Internal gain	accountable	20%
Tenant electricity	Energy	Annual template value	30 kWh/m²
	Internal gain	accountable	70%
Person load	Amount of persons		See Table 31
	Presence		14 hours/day/person
			80 W/person

When assigning the activity level specified by SVEBY it was necessary to convert the power production to Met (The metabolic rate of a relaxed seated person is one Met), since IDA ICE just work with Met to measure the activity level.

1 Met = 58 W/m^2

When converting W/person to Met the Du-bois area is used which approximately is 1.8 m^2. The total heat produced from a person emitting 80 W/person roughly converts to 0.8 Met. (engineeringtoolbox.com, 2016)

46 W/m^2 x 1.8 m^2 = 83 W

83 W = 0.8 Met

SVEBY implementation procedure

Implementation of SVEBY was made by the following steps:

1) The IDA ICE base case was based upon previous assumptions regarding construction and user behaviour established in the old energy simulation and documentation. Deviations between the simulated base case and measured energy need was analysed.
2) The parametric study evaluated the impact of new assumptions based on the different parameters from the literature studies. A new improved model was developed in IDA ICE and compared against the measured energy need. This was called the "base case with improvements".
3) SVEBY user related input data was assigned to the new improved model. This was called the "base case with improvements and Sveby".
4) The deviation between the improved IDA ICE model with the improved IDA ICE model with SVEBY user behaviour could constitute of differences in user behaviour assumptions. To investigate if the differences between the improved IDA ICE model with SVEBY and measured values may depend on user behaviour requires measured data on actual user behaviour. The energy need connected to actual user behaviour compared to SVEBY values can be adjusted from the measured energy need. Measured values of DHW and tenants electricity were available and these could be changed in the simulation model in order to analyse how much energy that could be adjusted from the monitored energy need. In theory all energy connected to user behaviour deviating from what is specified in SVEBY should be possible to adjust but some are more difficult to monitor, such as airing or occupants presence. While others as temperature is quite easy but was not available in this specific case.
5) The improved IDA ICE model with SVEBY occupant's behaviour and the measured energy need with adjusted energy due to actual DHW and tenant electricity use was compared. Differences between may be due to other user behaviour parameters as temperature, occupancy, airing etc. but this can not be verified since measurements of these parameters are not available.

3.11.1 Norrbackavägen 21

1) The IDA ICE base case was based upon previous assumptions regarding construction and user behaviour established in the old energy simulation and documentation. Deviations between the simulated base case and measured energy need was determined to: 19.37 kWh/m² or 18.2 %
2) The parametric study evaluated the impact of different parameters and new assumptions was made based on literature studies or own finding's. A new improved model was developed in IDA ICE with the following alternations:
    - Temperature during both heating and cooling season was set to 22.6 C°
    - The thermal bridges was altered to match the ones obtained from Heat2
    - Circulation losses of 2.25 kWh/m² were added to obtain a total loss of 17.4 kWh/m²
    - The Utilization factor were altered to 86 %
    - The SVEBY stated running time of 30 min/day for the kitchen fan was not included since the buildings was assumed to be equipped with coal filling fans.
    - An additional energy need of 4 kWh/m² due to airing was added

    Note that leakage, DHW and electricity need was not altered since they have specified values from the BeBo documentation.
    The resulting deviation between the improved IDA ICE model and the measured energy need have been gather in Table 33:

Table 33: Comparison between improved IDA ICE model and the measured energy need

Improved IDA ICE	Measured energy need
124.8 kWh/m²	126 kWh/m²

The improved IDA ICE model have a total energy need of 124.8 kWh/m², year. This measures up to a deviation of 1.2 kWh/m², year or 1 % compared to the measured energy need.

3) SVEBY user related input data was assigned to the new improved model according to Table 32, resulting in a total energy need of: 118.7 kWh/m², year. Furthermore, occupancy density was calculated in accordance with Table 25 and included with the SVEBY data.

Table 34: Norrbackavägen 21, amount of tenants according to SVEBY

Apartment size	Number of persons/apartment	Number of apartments	Number of persons
3 room	2.18	8	17.44
4 room	2.79	4	11.16
		Summation	28.6

$$\frac{amount\ of\ tenants}{m^2\ living\ area} \rightarrow \frac{28{,}6}{915{,}62} \approx 0.0312 \text{ persons/m}^2$$

4) The deviation between the improved IDA ICE model with SVEBY user behaviour and measured energy was analysed:
   126-118.7 = 7.3 kWh/m²
   In theory it would be possible to correct the model with actual user behaviour parameters but for Norrbackavägen 21 there are only two parameters with sufficient amount of metering that actually can be used to correct the model, DHW and tenant electricity need.
   By running the improved IDA ICE model with monitored DHW and tenant electricity it was possible to compare them with measured values. The remaining deviation to measured energy may be due to other user behaviour parameters, see Figure 4.
5) The potential energy need connected to the remaining user behaviour parameters could in theory be the reason for the deviation.

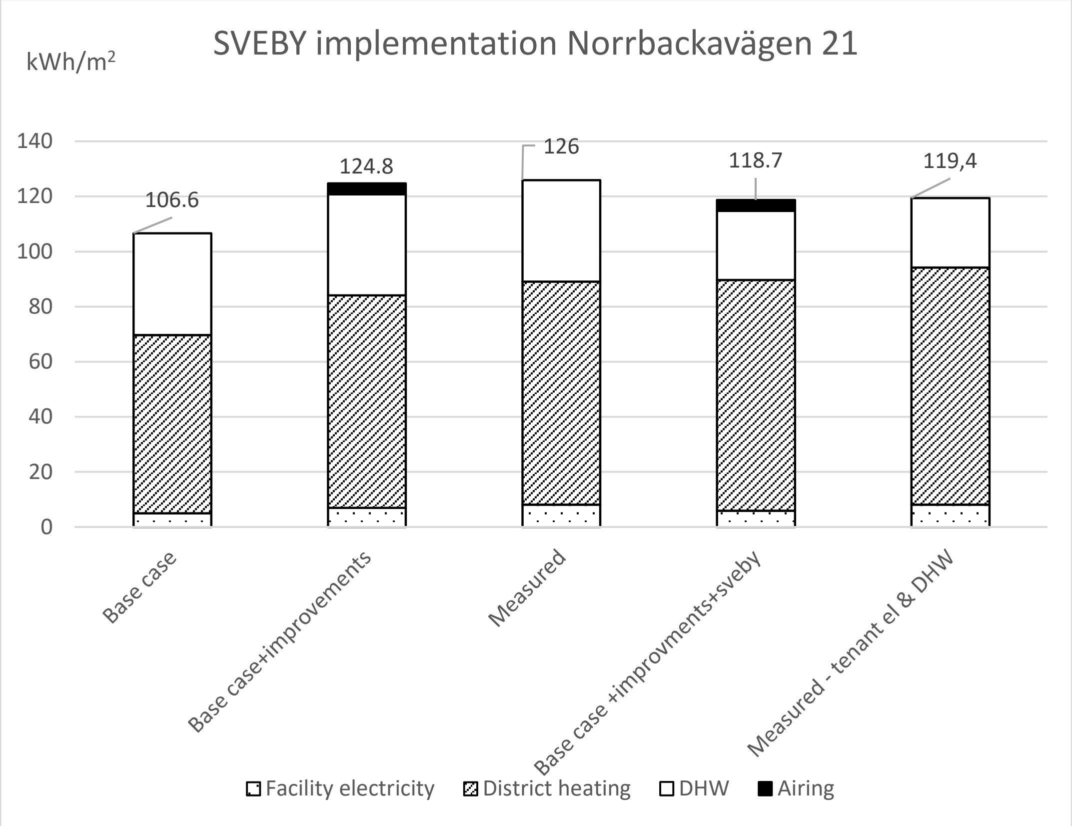

Figure 4: Implementation of SVEBY and resulting energy need, Norrbackavägen 21

3.11.2 Norrbackavägen 23

1) The IDA ICE base case was based upon previous assumptions regarding construction and user behaviour established in the old energy simulation and documentation. Deviations between the simulated base case and measured energy need was determined to: 20.8 kWh/m² or 23.3 %
2) The parametric study evaluated the impact of different parameters and new assumptions was made based on literature studies or our own findings. A new improved model was developed in IDA ICE with the following alternations:
    - Temperature during both heating and cooling season was set to 22.6 C°
    - The thermal bridges were altered to match the ones obtained from Heat2
    - Circulation losses of 2.25 kWh/m² was added to obtain a total loss of 17.4 kWh/m²
    - The Utilization factor were altered to 86 %
    - The SVEBY stated running time of 30 min/day for the kitchen fan was not included since the buildings was assumed to be equipped with coal filling fans.
    - buildings was assumed to be equipped with coal filling fans.
    - An additional energy need of 4 kWh/m² due to airing was added

Note that leakage, DHW and electricity need was not altered since they have specified values from the BeBo documentation.
The resulting deviation between the improved IDA ICE model and the measured energy need have been gather in Table 35:

Table 35: comparison between the improved IDA ICE model and the measured energy need

Improved IDA ICE	Measured energy need
100.6 kWh/m²	110 kWh/m²

The improved IDA ICE model has a total energy need of 100.6 kWh/m², year. This measures up to a deviation of 9.4 kWh/m², year or 9.3 % compared to the measured energy need.

3) SVEBY user related input data was assigned to the new improved model according to table Table 32, resulting in a total energy need of: 89.1 kWh/m², year.

Table 36: Norrbackavägen 23, amount of tenants

Apartment size	Amount of persons/apartment	Amount of apartments	Amount of persons
2 room	1.63	6	9.78
3 room	2.18	8	17.44
		summation	27.22

$$\frac{amount\ of\ tenants}{m^2\ living\ area} \rightarrow \frac{27.22}{1083.36} \approx 0.0251 \text{ persons/m}^2$$

4) The deviation between the improved IDA ICE model with SVEBY user behaviour and measured energy was analysed:
   110-89.1 =20.9 kWh/m²
   In theory it would be possible to correct the model with actual user behaviour parameters but for Norrbackavägen 23 there are only two parameters with sufficient amount of metering that actually can be used to correct the model, DHW and tenant electricity need. By running the improved IDA ICE model with monitored DHW and tenant electricity it was possible to compare them with measured values. The remaining deviation to measured energy may be due to other user behaviour parameters, see Figure 5.
5) The potential energy need connected to the remaining user behaviour parameters could in theory be the reason for the deviation.

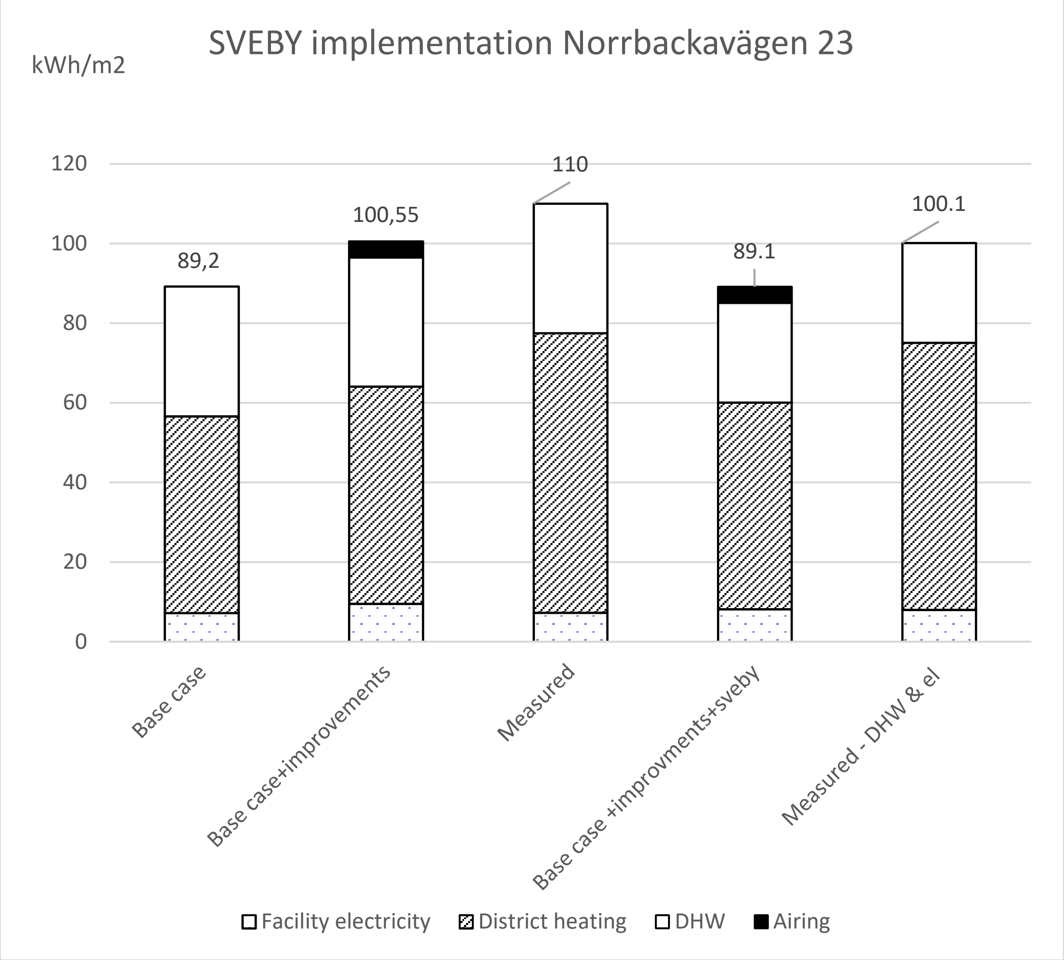

Figure 5: Implementation of SVEBY and resulting energy need, Norrbackavägen 23

Närlundavägen 14

Unfortunately the documentation of Närlundavägen 14 was insufficient that implementing SVEBY in an effort to improve the accuracy of the simulation seemed unrealistic.

3.12 Life Cycle Cost(s)

The interest rates and the prices for the energy sources are presented below.

3.12.1 District heating growth rate

To make a fair assumption regarding the annual district heating growth rate Öresundskrafts district heating price forecast was interpreted, see Figure 6:

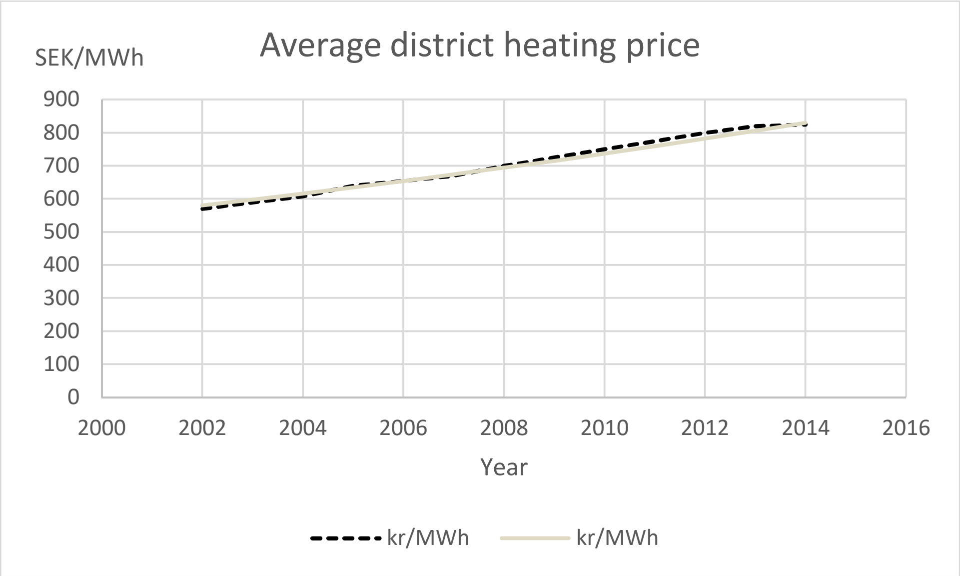

Figure 6 Average district heating price according to Öresundskraft 2015-12-15

The grey line represents an exponential interpretation of the spotted average district heating price. From the grey line it was possible to estimate an annual growth rate of 3.032 %. (Öresundskraft, 2015). Interpolation between year 2002 and 2014 was assessed according to Table 37:

Table 37: Interpolated district heating price year 2002 and 2014

Year	Interpolated price (SEK/MWh)
2002	570
2014	830

$$F = P(1+i)^N \qquad \text{Equation 3}$$

$$830 = 570(1+0.03032)^{12}$$

3.12.2 Electricity growth rate

Since the average yearly electricity price established by Fortuna fluctuates with no apparent relationship the electricity price was estimated to 0.4 SEK/kWh with no associated growth rate, see Figure 7. (Fortuna, 2016)

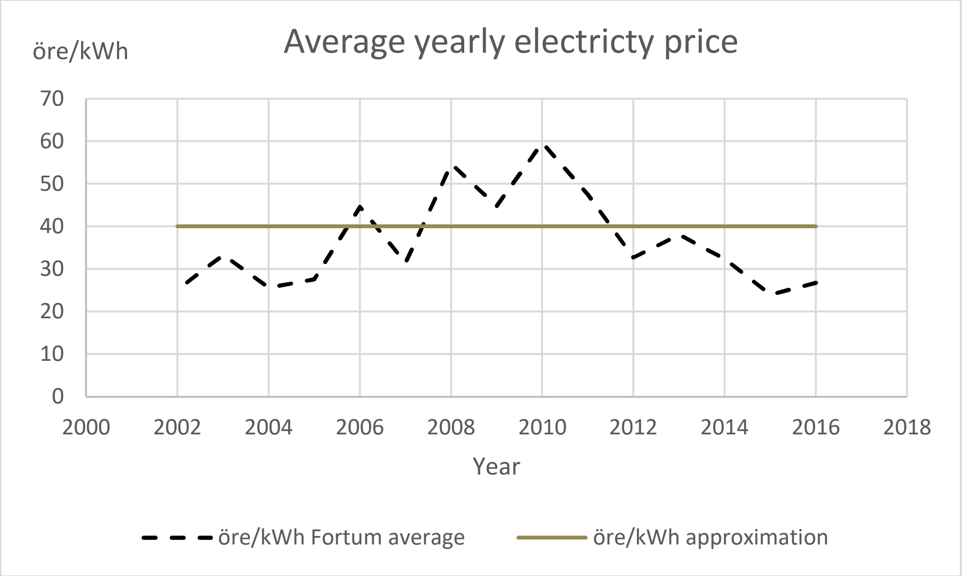

Figure 7: Average yearly electricity price according to Fortuna

On top of the electricity price there is the grid fee (14.6 öre/kWh), electricity tax (29.3 öre/kWh), the electricity certificate fee (2.5 öre/kWh) and moms (25%) which results in a total price of 1,08 SEK/kWh (Löfgren, 2003), (affärsverken, 2015).

3.12.3 Inflation and real interest rate

Based on forecasts established by Riksbanken, the inflation was assumed at 2 % and real interest rate to 1%. (Riksbank, 2016)

3.12.4 LCC conditions

The general conditions with which LCC and NPV have been calculated are compiled in Table 38:

Table 38: LCC conditions

Description	unit	Reference
Real interest rate	1 %	(Riksbank, 2016)
Inflation	3 %	(Riksbank, 2016)
Growth rate for electricty	-	(Fortuna, 2016)
Growth rate for district heating	3 %	(Öresundskraft, 2015)
Electricity price	1.08 SEK/kWh	(Fortuna, 2016) (Löfgren, 2003), (affärsverken, 2015)
District heating price	0.8 SEK/kWh	(Öresundskraft, 2015)
Time frame	40 years	(BeBo, 2012)

The net present value (NPV) was calculated both as a total summation of the renovation project and as SEK/m² to facilitate general comparisons between projects.

4 Economic impact of increased precision and awareness

Some parameters have been complemented with further investigation regarding whether it would be profitable or not to increase its precision and awareness. The following parameters have been further investigated regarding this matter:

- Air-tightness/leakage
- Temperature inventory
- Heat recovery efficiency
- Thermal bridge analysis
- Individual metering of district heating and DHW
- Tenant electrify need
- Area deviation

4.1 Air-tightness/leakage

Boverket followed the development of a 12 story energy efficient multi-residential building that was conducted by the real estate company Karlstads Bostads AB (KBAB) and the contractor SKANSKA. To ensure a high standard on the building KBAB ordered a leakage test during the construction phase at an early stage. The results provided the building team feedback establishing that improvements were needed. The report also documented the expenses for a leakage test/blow-door test that was carried out by KBAB. The total cost for a blow-door test in 44 apartments (2640 m²) resulted in 63000 SEK (Boverket, 2009).

4.2 Temperature inventory

Based on information retrieved from ÅF Energy Department, a specific temperature measurements for each accommodation of a typical multi residential building would cost between 10-20 SEK/m².

4.3 Heat recovery efficiency

BeBo demonstrated on an actual existing multi-residential building that not only was it energy efficient and manageable to install a ventilation system with heat recovery but also that the purposed investment was economically viable (Wahlström, 2014).
According to ÅF Energy Department the total cost of ensuring correct heat recovery efficiency approximately estimates to 10 000 SEK.

4.4 Thermal bridge analysis

Based on a present finding from Helsingborgshem and Symetri, a thermal analysis of the climate shell through thermographic camera would cost 1-3 SEK/m². This number is based on a multi residential building from the 1960's with a simple building geometry. More complex building geometries (not common with the miljonprogrammet-era that this thesis was oriented towards) will be associated with higher costs.

4.5 Individual metering of district heating and DHW

Boverket has conducted an investment calculation to determine whether it is profitable to invest in individual metering of district heating and DHW considering multi-residential buildings.

The procedure is based on investment calculations where the NPV of future savings are compared to today's installation costs. The savings consisted of energy and water savings, while the losses consisted of installations cost and costs of future operation costs. Regarding individual debiting of DHW Monte Carlo simulations have been used. The procedure assigns the parameters statically based interval which they are allowed to vary within and a large series of simulations where run to prove whether it is probable that individual metering (Table 39) or DHW (Table 40) is profitable. (Valik, 2014)

4.5.1 District heating

Note that Boverket finds it unlikely to achieve a temperature drop of two degrees in all apartments as a result of individual metering of district heating, establishing this investment as non-profitable, (Valik, 2014).

Table 39: Individual metering of district heating according to BeBo

Temperature	Installation costs	Profitable/non profitable
1 degree lower	-	Never profitable
2 degrees lower	High installations costs	Never profitable
2 degrees lower	Low installations costs in combination with poor climate shell	Occasionally profitable

4.5.2 Domestic Hot Water

The Monte Carlo simulation series states that in order for individual debiting of DHW to be profitable, high DHW savings must be achieved in combination with low installations cost (low installations costs are defined as cheap heat metering with wireless communication installed in a packet price including both installations and operations costs), see Table 40 (Valik, 2014).

Table 40: Individual metering of DHW according to BeBo

DHW savings	Installation costs	Profitable/non profitable
10 %	-	Always non profitable
20 %	Higher installation costs (3 500 SEK/apartment)	Always non profitable
20 %	Low installation costs + high water & sewage charge	Occasionally profitable
30 %	Higher installation costs (3 500 SEK/apartment)	Occasionally profitable
30 %	Low installation costs + high water & sewage charge	40 % of cases profitable

During Chapter 5.4 validation of investment, the total variation in DHW will be compared to the cost of installing separate metering of DHW for the entire building.
Based on information retrieved from ÅF Energy Department, an installation to accommodation a typical multi residential building would cost 6000 SEK including installation costs, which translates to 3-4 SEK/m² (installation cost divided by Atemp)

4.6 Tenant electricity need

The necessary installations to separate the tenant electricity is based on interviews carried out at ÅF Energy Department, which states that installation to accommodation a typical multi residential building would cost 6000 SEK including installation costs, which translates to 3-4 SEK/m² (installation cost divided by Atemp).

4.7 Area deviation

Based on present procurement between Helsingborgshem and Symetri the cost of establishing the correct Atemp by laser scanning varies around 20-40 SEK/m².

5 Results - Case studies

The final results showing the accuracy of the developed measures and the LCC for the three cases.

5.1 Norrbackavägen 21

The manager of the property Sigtunahem AB had a goal of reducing their energy demand by 50 % in their residential buildings. Norrbackavägen 21 managed to reduce their energy demand by 37 kWh/m² (22%)

The implemented measures managed to decrease the deviation between the simulated and the measured energy need from 18.2 % to 1 %, see Figure 8.

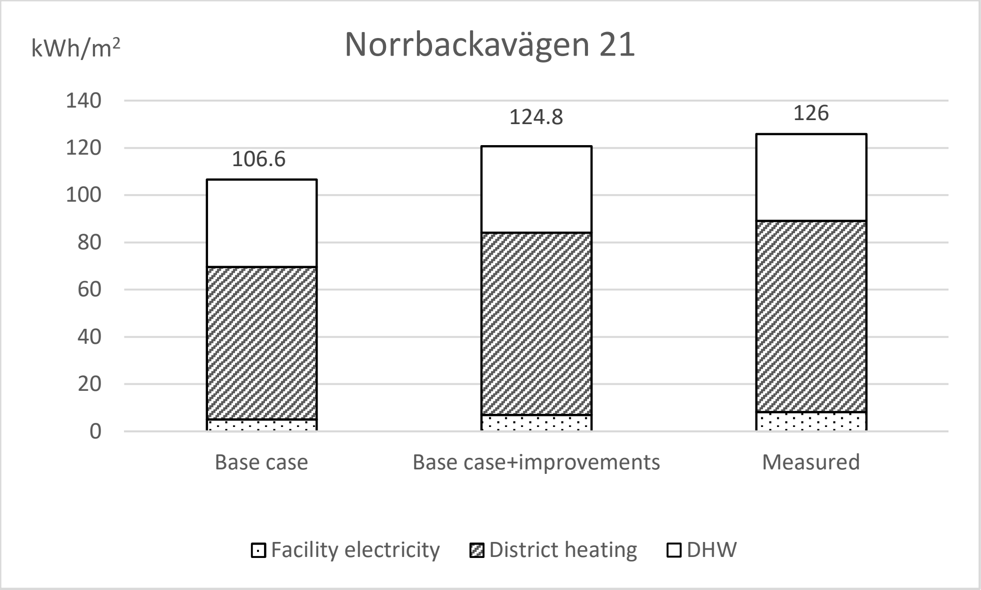

Figure 8 Norrbackavägen 21 effect of implementing procedures to increase simulation accuracy

The impact each individual parameter have on the total energy need of Norrbackavägen 21 have been visualised with Figure 9. The results are also presented in Appendix Energy simulation results.

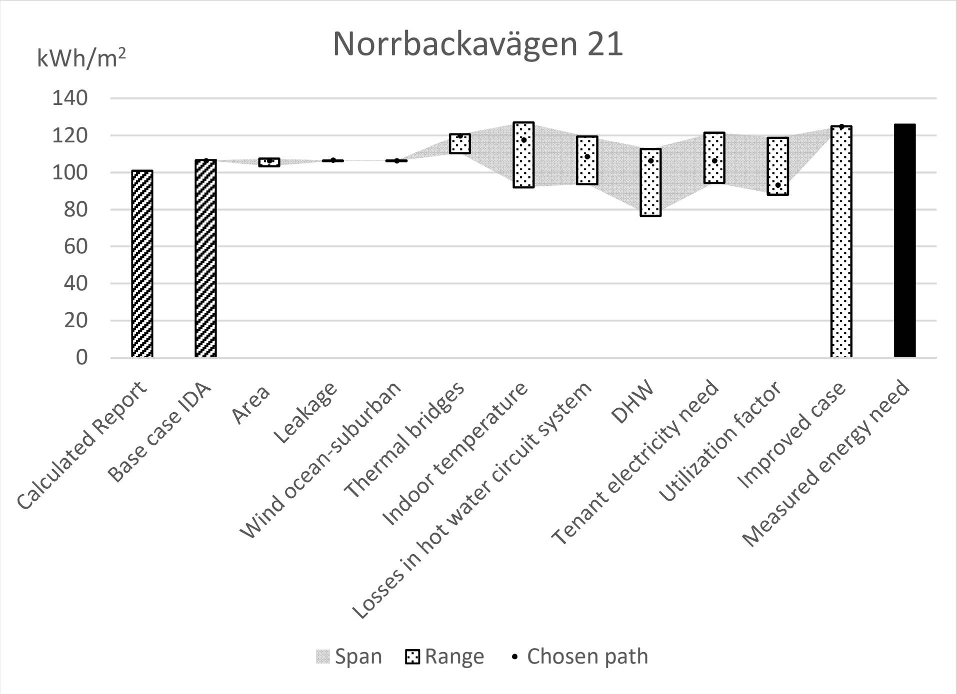

Figure 9: Norrbackavägen 21, parametric study established energy span and improved energy need

5.1.1 LCC

In order to calculate the NPV associated with each individual parameter the information gather in have been compiled in Figure 10 and

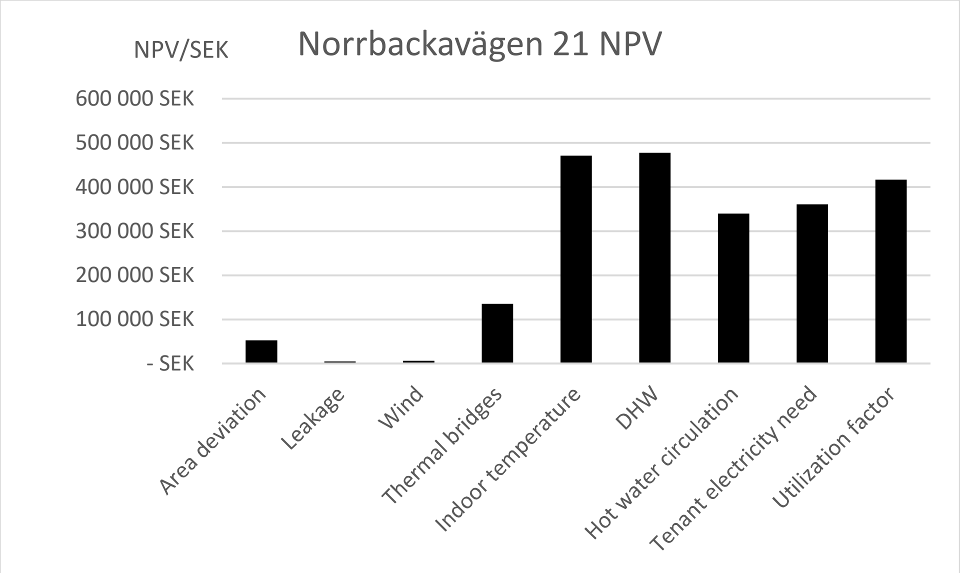

Figure 11 to illustrate the relationship Table 41 between the parameters and their economic effect on the building project.

Table 41: LCC compilation regarding Norrbackavägen 21

Norrbackavägen 21	District heating SEK/m²	Electricity SEK/m²	Total energy need SEK/m²	District heating SEK	Electricity SEK	Total energy need SEK
Area deviation	42	11	53	42 346	10 709	53 056
Leakage	5	-	5	5 293	-	5 293
Wind	7	-	7	6 617	-	6 617
Thermal bridges	135	-	135	135 389	-	135 389
Indoor temperature	464	6	470	464 486	6 426	470 911
DHW	477	-	477	477 719	-	477 719
Hot water circulation	339	-	339	340 093	-	340 093
Tenant electricty need	359	1	360	359 943	1 071	361 014
Utilization factor	458	- 43	415	459 192	- 42 988	416 204

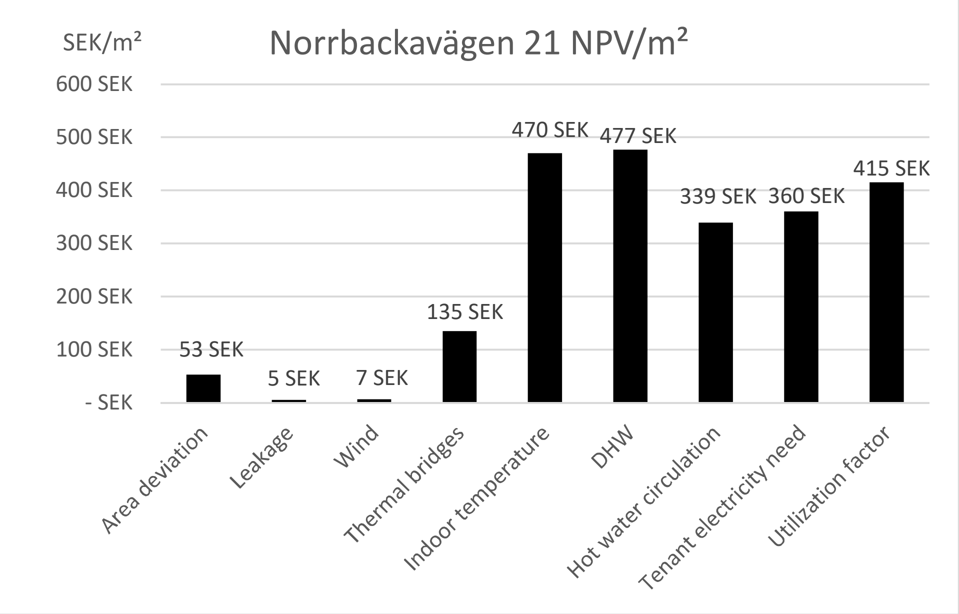

Figure 10: Net Present Value/m² for Norrbackavägen 21 during 40 years calculation period

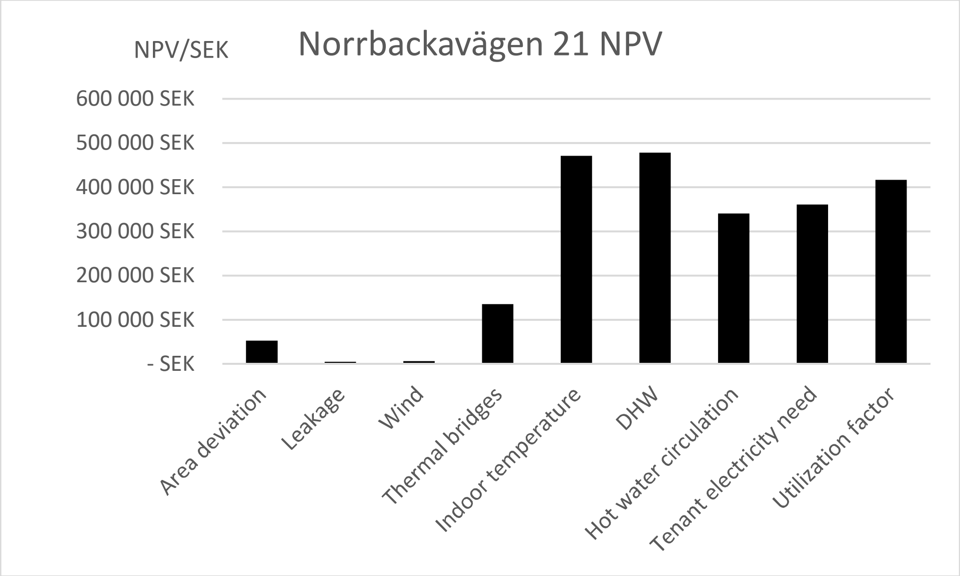

Figure 11: Net Present Value for Norrbackavägen 21 during 40 years calculation period

5.2 Norrbackavägen 23

The manager of the property Sigtunahem AB had a goal of reducing their energy demand by 50 % in their residential buildings. Norrbackavägen 23 managed to reduce their energy demand by 55 kWh/m² (33%).

The implemented measures managed to decrease the deviation between the simulated and the measured energy need from 18.2 % to 1 %, see Figure 12.

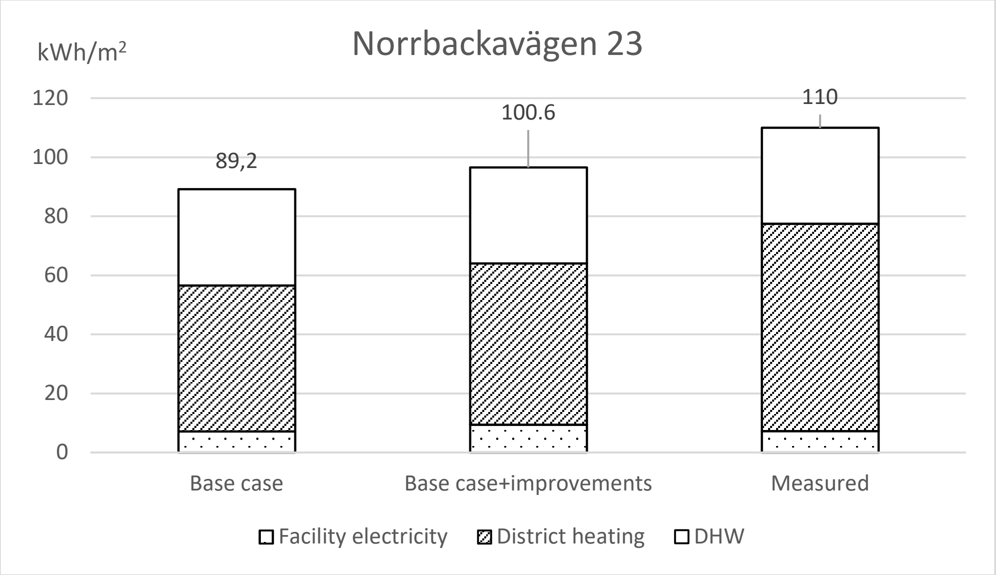

Figure 12: Norrbackavägen 23 effect of implementing procedures to increase simulation accuracy

The impact each individual parameter have on the total energy need of Norrbackavägen 21 have been visualised with Figure 13. The results are also presented in Appendix Energy simulation results.

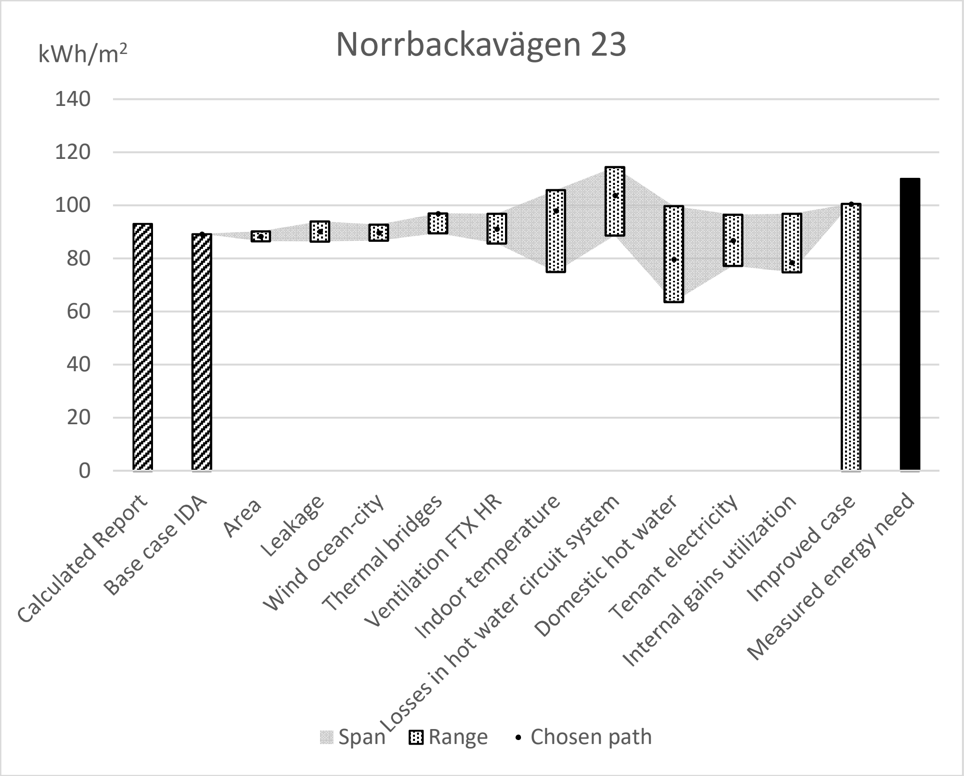

Figure 13: Norrbackavägen 23, parametric study established energy span and improved energy need

5.2.1 LCC

In order to calculate the NPV associated with each individual parameter the information gather in Table 42 have been compiled in Figure 14 and Figure 15 to illustrate the relationship between the parameters and their economic effect on the building project.

Table 42: LCC compilation regarding Norrbackavägen 23

Norrbackavägen 23	District heating SEK/m²	Electricity SEK/m²	Total energy need SEK/m²	District heating SEK	Electricity SEK	Total energy need SEK
Area deviation	36	11	46	39 866	11 949	51 815
Leakage	100	-	100	112 215	-	112 215
Wind	79	-	79	88 591	-	88 591
Thermal bridges	98	-	98	109 262	-	109 262
Indoor temperature	407	2	409	454 768	2 390	457 158
DHW	477	-	477	533 024	-	533 024
Hot water circulation	341	-	341	380 942	-	380 942
Ventilation FTX	147	1	148	163 894	1 195	165 089
Tenant electricity need	325	-57	268	363 224	-63 331	299 893
Utilization factor	349	-47	302	389 801	- 52 577	337 224

Table 43: NPV/m² during the 40 year calculation time Norrbackavägen 23

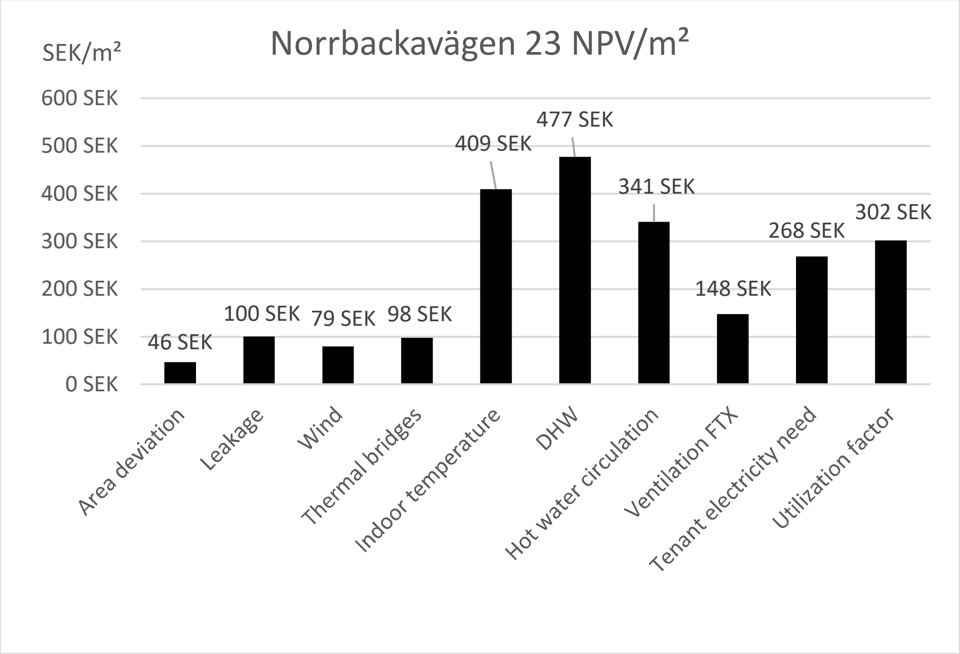

Figure 14: Net Present Value/m² for Norrbackavägen 23 during 40 years calculation period

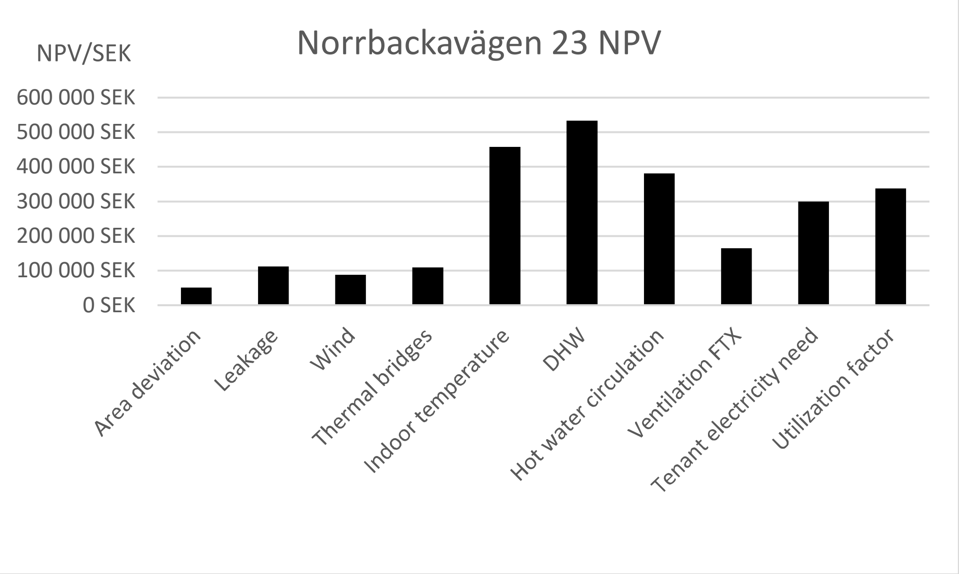

Figure 15: Net Present Value for Norrbackavägen 23 during 40 years calculation period

5.3 Närlundavägen 14, Helsingborg

The manager of Helsingborgshem had the goal of reducing their energy demand by 30 % in their residential building. Närlundavägen 14 managed to reduce their energy demand by 39 kWh/m² (33%).

Unfortunately the documentation of Närlundavägen 14 was to insufficient to implement the procedures to improve the accuracy of the simulation and seemed unrealistic.
The impact of each individual parameter has on the total energy need of Närlundavägen 14 has been visualised in Figure 16. The results are also presented in Appendix Energy simulation results.

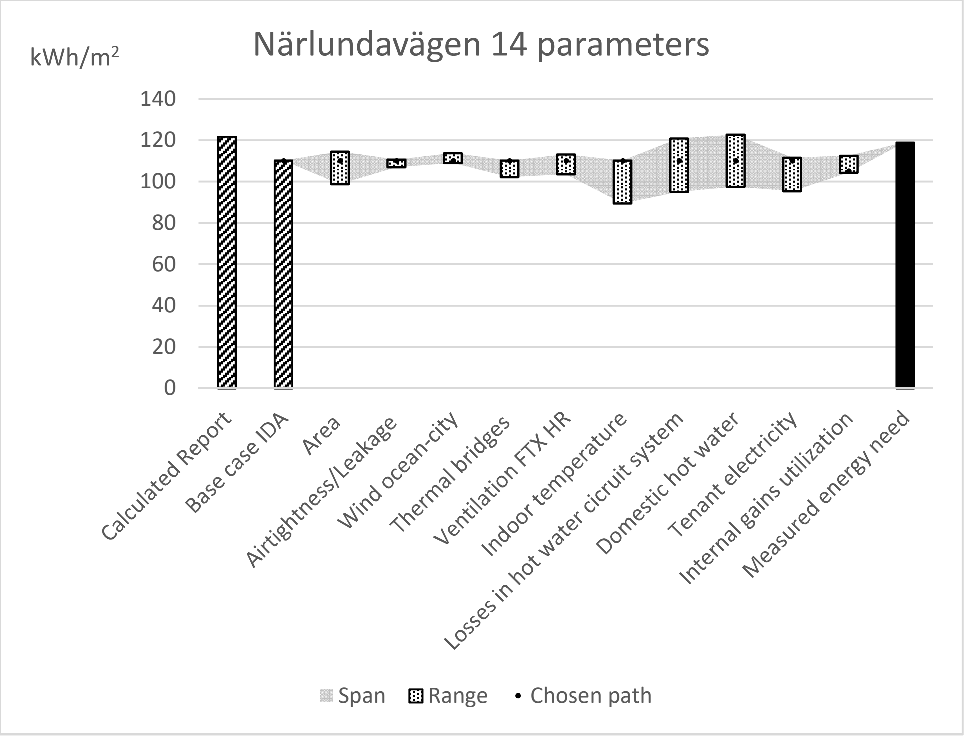

Figure 16: Effect compilation of parameter deviations for Närlundavägen 14

In order to calculate the NPV associated with each individual parameter the information gathered in Table 44 have been compiled and presented in Figure 17 and Figure 18 to illustrate the relationship between the parameters and their economic effect on the building project.

Table 44: NPV compilation for Närlundavägen 14

Norrbackavägen 21	District heating SEK/m²	Electricity SEK/m²	Total energy need SEK/m²	District heating SEK	Electricity SEK	Total energy need SEK
Area deviation	184	20	204	576 424	20 348	596 772
Leakage	50	-	50	157 583	-	157 583
Wind	63	-	63	199 053	-	199 053
Thermal bridges	107	-	107	334 782	-	334 782
Indoor temperature	271	2	273	850 121	2 142	852 263
DHW	333	-	333	1 045 027	-	1 045 027
Hot water circulation	341	-	341	1 069 909	-	1 069 909
Ventilation FTX	124	1	125	389 812	1 071	390 883
Tenant electricity need	213	1	214	667 656	1 071	668 727
Utilization factor	213	- 86	127	667 656	-85 676	581 980

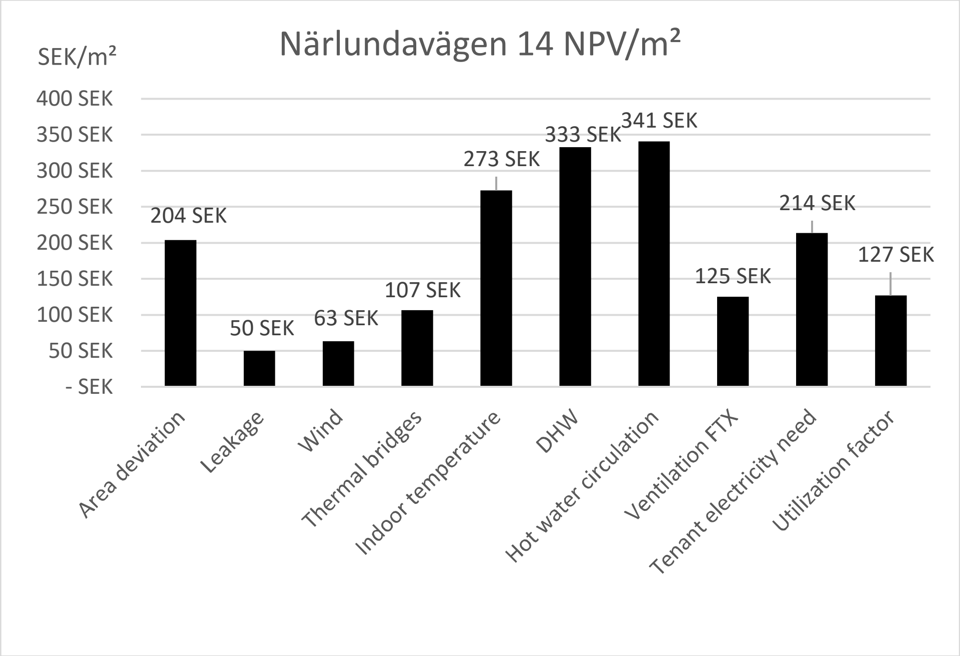

Figure 17: Net Present Value/m² Närlundavägen 14

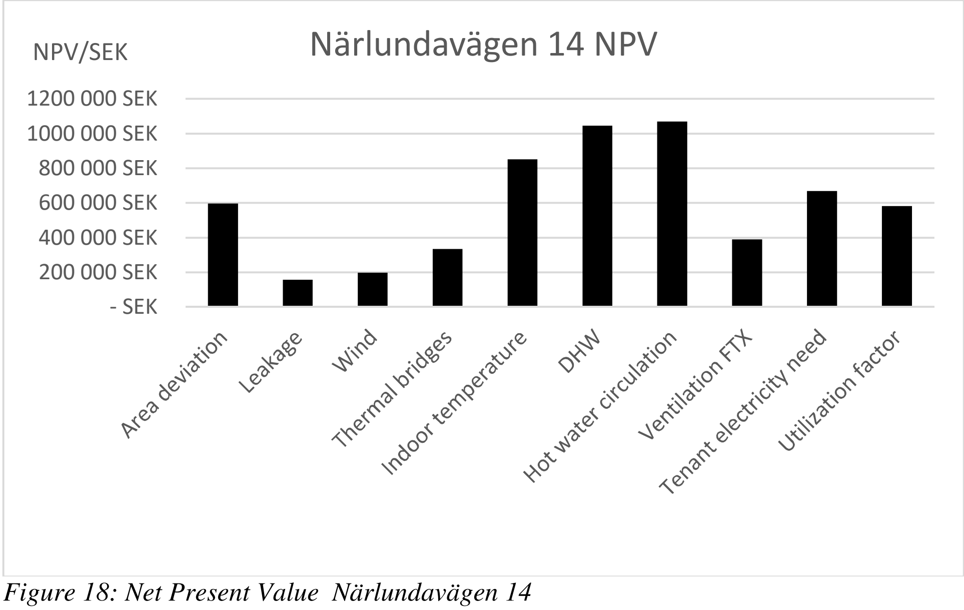

Figure 18: Net Present Value Närlundavägen 14

5.4 Validation of investments

To compare the cost of ensuring correct input data in relation with the interval in which a specific parameter could alternate within, see Table 45.
The costs associated with deviation is the average value exported from Figure 10, Figure 14 and Figure 17, which constitutes the average NPV/m² during a 50 year period.

Table 45: Validation of investment costs compared to the deviation it might cause.

Parameter	Cost associated with deviation SEK/m²	Cost of ensuring correct value SEK/m²	Cost of ensuring correct input data vs cost of inaccurate input data
Area deviation	101	Laser scan 20-40	2.5-5 times higher
Leakage	52	24	2 times higher
Wind	50	Drawings	It comes down to having simulation tools that can handle the information
Thermal bridges	113	Consultant fee of preforming direct 2D/3D modelling of the thermal bridges. 1-3 SEK/m² to conduct thermographic photography	The consultant fee should stand in proportion to 113 SEK/m²
Heat recovery	384	5-15 SEK/m²	26-77 times higher
Indoor temperature	429	10-20 SEK/m²	20-40 times higher
Losses in hot water circuit	340	-	
Domestic hot water	91	3-4 SEK/m²	20-30 times higher
Tenant electricity	281	3-4 SEK/m²	70-90 times higher
Utilization factor	281	See Utilization factor 3.1 Consultant fee of calculating the utilization factor.	The consultant fee should stand in proportion to 281 SEK/m²

6 Discussion

- The recreated base cases simulations in IDA ICE matched earlier simulations made by BeBo and Skanska with deviation of 3-4 %. Levin & Snygg stated in their report that an error of margin of 10% can be expected due to the way different simulations tools handles input and output. With this in mind the recreations of earlier made simulations have an acceptable level of accuracy.
  The Norrbackavägen case studies showed promising result regarding implementation of measures to improve accuracy in connection to the energy simulations, see Figure 5 and Figure 9.

Table 46: Deviation before and after implementing new parameters to improve accuracy

Case study	Previous deviation	Deviation after implementing simulation strategies
Norrbackavägen 21	+ 24.7 %	+ 1 %
Norrbackavägen 23	+ 18.3 %	+ 9.3 %

Both cases showed significant improvements and the new deviation between simulated and measured energy use is below 10 % in both cases, see Table 46.

- Deviations between measured and calculated energy need is a major problem in the building industry and a source of economic uncertainty in retrofitting projects. This thesis has proved that it is possible to decrease deviations and improve accuracy of the energy simulation but it is of great importance to fully grasp why the deviations occurs and investigate what the possible sources of error could be.
- The established LCCs are heavily dependent on the assumptions made in chapter 3.12.4 and can easily be manipulated by new interpretations of the financial forecasts. However the relation between the different parameters will always be the same independent of assumptions regarding growth rate, energy price, calculation period or nominal interest rate.
- The results from the leakage investigation were not in line with the authors' expectations. The energy simulation provided a low deviation in both Norrbackavägen 21 (0.4 kWh/m²) and 23 (7.6 kWh/m²). Norrbackavägen 23 has a FTX system installed which could explain the higher energy span presented in the report. It is however the authors' belief that this small difference could be an effect of falsely assumed prevailing wind condition (if the prevailing wind-factor would have been more unsheltered the impact of leakage would have been more profound).
  One way to improve the accuracy of the leakage input data is to implement a blow door test during the construction of the retrofitting the building. This will contribute to a higher workmanship quality and higher precision for the input data.

It should also be noted that a relation between the wind and leakage was not included in this study which might increase the deviation depending on the arrangement between the two aspects.

- Both deviating leakage and wind-factors have higher impact on buildings equipped with heat recovery, since instead of the air going through the heat-exchanger it may pass straight through the building envelope. Both Norrbackavägen 23 and Närlundavägen 14 are equipped with heat-exchangers explaining the higher impact of deviating leakage and wind-factors compared to Norrbackavägen 21.
- In outdated versions of Boverkets Byggregler stated that an acceptable approach to take thermal bridges into account would be by adding 20 % on top of the total transfer through the building envelope. The impact of thermal bridges usually increase with increased amount of insulation, risking to underestimate their impact by using the old procedure, which could be the cases for many previously made energy calculations for retrofitting's of multi residential buildings. It is more economical beneficial to carry out a thorough analysis on the thermal bridges than estimating it.
- It should be noted that all energy simulations have exclusively been calculated with IDA ICE 4.7 meaning that some impact of altered parameters could give slightly different results when compared to other programs. However the software have been tested and validated according to European and American standards so it should provide reliable results. (EQUA, 2016)
- In the base case models domestic hot water circuit losses have no losses to nearby zones, since the percentage losses are set to zero. In real cases an increase of domestic hot water losses would decrease the district heating need due to additional internal gains.
- All IDA ICE simulations where made with leap-year which will result in a small increase of the total energy need of the model (1/365 = 27%).
- The LCC study showed that the inaccuracy of an energy simulation can lead to high uncertainties regarding the financial decision in a building project. By over/under estimating the impact of energy saving measures or the prevailing conditions, decisions may be founded on false predictions which could jeopardise the financial profits of the project at hand. For example the uncertainty regarding DHW use for Närlundavägen 14 resulted in a span of approximately 1 million SEK.
- Based on the results from 5.4 Validation of investments, the parameters with most profit in ensuring accurate input data are parameters which received high values regarding Cost of ensuring correct input data vs cost of inaccurate input data.
- It is highly recommended to ensure correct input data regarding thermal bridges and heat recovery since they received high values regarding Cost of ensuring correct input data vs cost of inaccurate input data and the contractor can be held accountable to resolve the problem.

7 Conclusion

"Determine the ratio of which different input data in an energy simulation will impact on the energy use for a building"

The aspect that showed the greatest impact on Norrbackavägen 21 and 23 was the domestic hot water need. Furthermore the study showed that the parameters which were among the highest energy interval were user behaviour related i.e. indoor temperature, tenant electricity need and losses in hot water circuit system (further emphasising the need of a tool or procedure such as SVEBY to handle user behaviour related parameters). In Case study Närlundavägen 14 resulted in hot water circuit losses to be the parameter with the most high variation.

"Investigate measures to improve the level of accuracy regarding input data."

With the measures found in literature studies and the assumptions that was implemented into the base case model, the deviation decreased to below 10 %, see Table 46

"Determine the impact of applying the SVEBY procedure to analyse user behaviour."

Indoor temperature, DHW, tenant electricity need, losses in hot water circuit system and utilization factor are four of the parameters that have the largest impact on the total energy need. All of these parameters are considered in SVEBY making SVEBY useful in order to state input data for user behaviour and decrease the deviation between simulated and measured energy need.

To analyse effects of actual user behaviour in a building compared to SVEBY standardized data proved to be possible, but demands sufficient documentation of each parameter. The parameter which would be hard or unrealistic to provide sufficient documentation for would be airing.

"Investigate possible differences in economic Life Cycle Cost of inaccurate input data/assumptions."

Generally DHW, indoor temperature and hot water circulation losses have the greatest impact on the NPV of the building projects. The DHW impact on the NPV varied within a range of 333-477 SEK/m². For Norrbackavägen 21 this results in a NPV of over 500 000 SEK during a calculation time of 40 years (the estimated time the restauration will last). These parameters are all user related parameters, which make them hard to control. Individual debiting is a measure property-owners can use to lower this value, but it has just been proven to be profitable concerning DHW. Censuring hot water circulation losses the amount of hot water circulating in the system is user behaviour related but the dimensioning of the pipes and circulation pump, insulation level and how well-planned layout of the piping system is not. Improving the insulation of the pipes should be a realistic way of handling deviation connected to hot water circulation.

8 Summary

Even if all future new buildings would be highly energy efficient that will not be enough to slow down the intensifying energy need. In order to decrease the over-all energy need connected to the building sector, the existing buildings with questionable energy need have to be a part of extensive retrofitting work. For the next 40 years, a rate of 3% of the European building stock per year needs to be renovated in order to meet the carbon and economic goals set out in the European Economic Recovery Plan. This sets a significant high standard on energy simulations software to predict the energy need for retrofitted buildings. However, in most cases the simulated energy need does not correspond with the actual measured energy need, a crucial flaw which need further investigation.

Three similar multi residential building from the beginning of 1970s were chosen as case studies. Based on previous documentation the deviation from simulated and measured energy need are respectively 24.7, 18.3 and 2.4 %. Similar studies in newly built low energy buildings resulted in of 3 – 28% higher energy need then simulated values. This thesis has its focus on the process of establishing the impact of misjudging main parameters during energy simulations in connection with retrofitting projects. Each parameter was assigned with a maximum and minimum value between it could fluctuate based upon finding during the literature study. The deviation on the total energy need was documented and a Life Cycle Cost was conducted for each parameter. The following parameters were addressed:

- Area deviation
- Wind
- Heat recovery efficiency
- Losses in hot water circuit system
- Tenant electricity need
- Air-tightness/leakage
- Thermal bridges
- Indoor temperature variation
- Domestic hot water need
- Utilization factor

To eliminate uncertainties connected to diverse user behaviour the SVEBY procedure was implemented during the final stage of the parametric study. Note that unlike previously mentioned parameters, SVEBY both affects simulated and measured energy need.

Regarding specific parameters e.g. Heat recovery and Indoor temperature , this thesis showed, had most profit of ensuring accurate input data.

9 Further Research

- A clear separation between buildings equipped with heat-recovery and building without, should be implemented during future studies. The two different systems react differently to change in certain parameters such as wind and leakage.
- It would be of great interest to further investigate the relationship between parameters such as wind and leakage or utilization factor and occupancy attendance. Mapping to what extent parameter that have close relation to each other may amplify the total energy need.

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Appendix Thermal bridges

Norrbackavägen 21

External slab/External walls:

Gable wall:
Heat transfer through construction parts:

External slab and external wall	24.38 W/m
Slab	0.4647 W/m
Wall	6.7781 W/m

$$\frac{24.356-(6.7781+0.4647)}{30}=0{,}57044\text{W/mK}$$

Exterior wall with wood I:
Heat transfer through construction parts:

External slab and external wall	26.327 W/m
Slab	0.484 W/m
Wall	7.7263 W/m

$$\frac{26{,}327-(7{,}7263+0{,}484)}{30}=0{,}60389\text{W/mK}$$

Long wall with brick I:

External slab and external wall	24.485 W/m
Slab	0.4599 W/m
Wall	6.8208 W/m

$$\frac{24{,}485-(6{,}8208+0{,}4599)}{30}=0{,}5734766666\text{W}$$

Weighted thermal bridge between exterior wall and slab with regard to length of respective construction part:

Exterior wall construction type	Length
Gable wall	19.75 m
Exterior wall with brick I	10.592 m
Exterior wall with wood I	116.31 m

$$\frac{(19.75\cdot 0.57044)+(116.31\cdot 0{,}60389)+(10.592\cdot 0.5734766666)}{19.75+10{,}592+116.31}\approx 0.6\text{ W/mK}$$

External wall and intermediate slab:

Gable wall:
Heat transfer through construction parts:

Intermediate slab and external wall	13.857
Wall	11.0454

$$\frac{13.857-11.0454}{30}=0.09372\text{W/mK}$$

Long wall with brick façade:
Heat transfer through construction parts:

Intermediate slab and external wall	16.19 W/m
Wall	14.149 W/m

$\frac{16.19-14.149}{30}$ = 0.0680333333 W/mK

Long wall with wood I:

Intermediate slab and external wall	18.551 W/m
Wall	16.0272 W/m

$\frac{18,551-16,0272}{30}$ = 0,08412666666 W/mK

$\frac{(19.75\cdot 0.09372)+(116.31\cdot 0,08412666666)+(10,592\cdot 0.0680333333)}{19.75+10,592+116.31}$ ≈ 0.084 W/mK

External wall and internal wall:

Construction connection	amount
Gable wall and internal wall	4
External wall with brick façade and internal wall	2
External wall with wood façade and internal wall	37
total	43

Gable wall:

Heat transfer through construction parts:

Gable wall and internal wall	11.216 W/m
Internal wall	10.7 W/m

$\frac{11,216-10,7}{30}$ = 0,0172 W/mK

External wall with brick façade and internal wall:

Heat transfer through construction parts:

External wall with brick façade and internal wall	11.286 W/m
Internal wall	10.7666 W/m

$\frac{11,286-10,7666}{30}$ = 0,0173133333 W/mK

Long wall with wood I:

External wall with wood façade and internal wall	12.555 W/m
Internal wall	11.9792 W/m

$\frac{12.555-11.9792}{30}$ = 0,01919333 W/mK

$\frac{(0.0172\cdot 4)+(0.0173133333\cdot 2)+(0.01919333\cdot 37)}{43}$ ≈0.019 W/mK

Roof and external wall:

Gable wall and exterior wall with wood I:

Heat transfer through construction parts:

Gable wall and external wall with wood I	31.007 W/m
Wall	11.655 W/m
Roof	4.7174 W/m

$$\frac{31.007-(11.655+4.7174)}{30} = 0{,}48782 \text{ W/mK}$$

Long wall with brick façade:

Heat transfer through construction parts:

Roof and external wall	25.597 W/m
Wall	7.8711 W/m
Roof	4.7368 W/m

$$\frac{25{,}597-(7{,}8711+4{,}7368)}{30} = 0.4349733 \text{ W/mK}$$

Long wall with wood I:

Roof and external wall	22.705 W/m
Wall	5.7932 W/m
Roof	4.9305 W/m

$$\frac{22.705-(5.7932+4.9305)}{30} = 0{,}399376666 \text{ W/mK}$$

$$\frac{(19.75\cdot 0.48782)+(10.592\cdot 0.4349733)+(116.31\cdot 0.0399376666)}{19.75+10.592+116.31} \approx 0.413 \text{ W/mK}$$

Exterior wall corner:

Corner	amount
Gable and exterior wall with brick I	2
Gable and exterior wall with wood I	2
Exterior wall with brick façade and exterior wall with brick I	2

Gable wall and external wall with wood I:

Heat transfer through construction parts:

Corner between gable wall and external wall with brick I	13.192 W/m
Gable wall	5.1576 W/m
Exterior wall with brick I	6.6349 W/m

$$\frac{13.192-(5.1576+6.6349)}{30} = 0.04665 \text{W/mK}$$

Gable wall and exterior wall with wood I:

Heat transfer through construction parts:

Corner between gable wall and external wall with wood I	14.381 W/m
Gable wall	5.1576 W/m
External wall with wood I	7.654 W/m

$\frac{14.381-(5.1576+7.654)}{30} = 0.05231333$

Exterior wall with brick façade and exterior wall with brick façade:

Heat transfer through construction parts:

Corner between gable wall and external wall with wood I	13.945 W/m
Gable wall	6.6348 W/m
External wall with wood I	6.6348 W/m

$\frac{13.945-(6.6348+6.6348)}{30} = 0.022513333$ W/mK

$\frac{0.022513333+0.05231333+0.04665}{3} \approx 0.04$ W/mK

Internal wall and roof:

The connection between internal walls and roofs causes no penetration of climate shell resulting in the thermal bridge to be neglect able.

Internal wall and slab

Ground and intern wall	0.4242 W/m
ground	0.4006 W/m

$\frac{0.4242-0.4006}{30} \approx 0.0008$ W/mK

Exterior wall and window

Exterior wall and window	Length of thermal bridge
Gable wall and window	48.16 m
Exterior wall with wood façade and window	339.46 m
total	387.62 m

Exterior wall with wood façade and window:

Heat transfer through construction parts:

Exterior wall with wood façade and window	99.903 W/m
Window	82.453 W/m
Exterior wall with wood I	15.6676 W/m

$\frac{99.903-(82.453+15.6676)}{30} = 0.059413333$ W/mK

Gable wall:

Heat transfer through construction parts:

Gable wall and window	92.247W/m
Window	82.45 W/m
Gable wall	7.127 W/m

$\frac{92.247-(82.45+7.127)}{30} = 0.089$W/mK

Weighting to take account for distribution of different thermal bridges in different wall constructions:

$\frac{(0.059413333 \cdot 48.16)+(0.089 \cdot 339.46)}{387.62} \approx 0.085$W/mK

Door and external wall

Exterior wall with wood façade and door:
Heat transfer through construction parts:

Exterior wall with wood façade and door	131.31 W/m
door	110.96 W/m
Exterior wall with wood I	16.4616 W/m

$\frac{131.31-(110.96+16.4616)}{30} \approx 0.13$ W/mK

External wall and balcony

External wall with wood façade and balcony:
Heat transfer through construction parts:

External wall with wood façade and balcony	32.01 W/m
External wall	15.74221 W/m

$\frac{32.01-15.74221}{30} \approx 0.542$ W/mK

Norrbackavägen 23

External slab/External walls:

Gable wall:
Heat transfer through construction parts:

External slab and external wall	24.38 W/m
Slab	0.4647 W/m
Wall	6.7781 W/m

$\frac{24.356-(6.7781+0.4647)}{30} = 0.57044$W/mK

Exterior wall with wood I:
Heat transfer through construction parts:

External slab and external wall	26.327 W/m
Slab	0.484 W/m
Wall	7.7263 W/m

$\frac{26.327-(7.7263+0.484)}{30} = 0.60389$W/mK

Long wall with brick I:

External slab and external wall	24.485 W/m
Slab	0.4599 W/m
Wall	6.8208 W/m

$\frac{24{,}485-(6{,}8208+0{,}4599)}{30} = 0{,}5734766666$W

Weighted thermal bridge between exterior wall and slab with regard to length of respective construction part:

Exterior wall construction type	Length
Gable wall	39.1 m
Exterior wall with brick I	12.55 m
Exterior wall with wood I	116,25 m

$$\frac{(39.1\cdot 0.57044)+(116.251\cdot 0.60389)+(12.55\ \cdot 0.5734766666)}{(39.1+12.55+116.25)} \approx 0.6 \text{ W/mK}$$

External wall and intermediate slab:

Gable wall:

Heat transfer through construction parts:

Intermediate slab and external wall	13.857
Wall	11.0454

$$\frac{13.857-11.0454}{30} = 0,.09372\text{W/mK}$$

Long wall with brick façade:

Heat transfer through construction parts:

Intermediate slab and external wall	16.19 W/m
Wall	14.149 W/m

$$\frac{16.19-14.149}{30} = 0.0680333333 \text{ W/mK}$$

Long wall with wood I:

Intermediate slab and external wall	18.551 W/m
Wall	16.0272 W/m

$$\frac{18.551-16.0272}{30} = 0.08412666666 \text{ W/mK}$$

$$\frac{(39.1\cdot 0.09372)+(116.25\cdot 0.08412666666)+(12.55\ \cdot 0.0680333333\ )}{(39.1+116.25+12.55)} \approx 0.085 \text{ W/mK}$$

External wall and internal wall:

Construction connection	amount
Gable wall and internal wall	5
External wall with brick façade and internal wall	4
External wall with wood façade and internal wall	24
total	33

Gable wall:

Heat transfer through construction parts:

Gable wall and internal wall	11.216 W/m
Internal wall	10.7 W/m

$$\frac{11{,}216-10{,}7}{30} = 0{,}0172 \text{ W/mK}$$

External wall with brick façade and internal wall:

Heat transfer through construction parts:

External wall with brick façade and internal wall	11.286 W/m
Internal wall	10.7666 W/m

$$\frac{11.286-10.7666}{30} = 0.0173133333 \text{ W/mK}$$

Long wall with wood I:

External wall with wood façade and internal wall	12.555 W/m
Internal wall	11.9792 W/m

$$\frac{12.555-11.9792}{30} = 0{,}01919333 \text{ W/mK}$$

$$\frac{(0.0172\cdot 5)+(0.0173133333\cdot 4)+(0.01919333\cdot 24)}{33} \approx 0.019 \text{ W/mK}$$

Roof and external wall:

Gable wall and exterior wall with wood:

Heat transfer through construction parts:

Gable wall and external wall with wood I	31.007 W/m
Wall	11.655 W/m
Roof	4.7174 W/m

$$\frac{31.007-(11{,}655+4{,}7174)}{30} = 0{,}48782 \text{ W/mK}$$

Long wall with brick façade:

Heat transfer through construction parts:

Roof and external wall	25.597 W/m
Wall	7.8711 W/m
Roof	4.7368 W/m

$$\frac{25.597-(7.8711+4.7368)}{30} = 0.4349733 \text{ W/mK}$$

Long wall with wood I:

Roof and external wall	22.705 W/m
Wall	5.7932 W/m
Roof	4.9305 W/m

$$\frac{22.705-(5.7932+4.9305)}{30} = 0.399376666 \text{ W/mK}$$

$$\frac{(39.1\cdot 0.48782)+(12.55\cdot 0.4349733)+(116.25\cdot 0.399376666)}{39.1+12.55+116.25} \approx 0.42 \text{ W/mK}$$

Exterior wall corner:

Corner	amount
Gable and exterior wall with brick	2
Gable and exterior wall with wood	6
Exterior wall with brick façade and exterior wall with brick	2

Gable wall and external wall with wood:
Heat transfer through construction parts:

Corner between gable wall and external wall with brick	13.192 W/m
Gable wall	5.1576 W/m
Exterior wall with brick	6.6349 W/m

$\frac{13.192-(5.1576+6.6349)}{30} = 0.04665 \text{W/mK}$

Gable wall and exterior wall with wood:
Heat transfer through construction parts:

Corner between gable wall and external wall with wood	14.381 W/m
Gable wall	5.1576 W/m
External wall with wood	7.654 W/m

$\frac{14.381-(5.1576+7.654)}{30} = 0.05231333$

Exterior wall with brick façade and exterior wall with brick façade:
Heat transfer through construction parts:

Corner between gable wall and external wall with wood	13.945 W/m
Gable wall	6.6348 W/m
External wall with wood	6.6348 W/m

$$\frac{13.945-(6.6348+6.6348)}{30} = 0.022513333 \text{ W/mK}$$

$$\frac{(0.022513333*6)+(0.05231333*2)+(0.04665*2)}{(6+2+2)} \approx 0.033 \text{ W/mK}$$

Internal wall and roof:

The connection between internal walls and roofs causes no penetration of climate shell resulting in the thermal bridge to be neglectable.

Internal wall and slab

Ground and intern wall	0.4242 W/m
ground	0.4006 W/m

$\frac{0.4242-0.4006}{30} \approx 0.0008 \text{ W/mK}$

Exterior wall and window

Exterior wall and window	Length of thermal bridge
Gable wall and window	84 m
Exterior wall with wood façade and window	231 m
total	315 m

Exterior wall with wood façade and window:
Heat transfer through construction parts:

Exterior wall with wood façade and window	99.903 W/m
Window	82.453 W/m
Exterior wall with wood I	15.6676 W/m

$\frac{99.903-(82.453+15.6676)}{30}$ = 0.059413333 W/mK

Gable wall:

Heat transfer through construction parts:

Gable wall and window	92.247W/m
Window	82.45 W/m
Gable wall	7.127 W/m

$\frac{92.247-(82.45+7,127)}{30}$ = 0.089 W/mK

Weighting to take account for distribution of different thermal bridges in different wall constructions:

$\frac{(0.059413333\cdot 84)+(0.089\cdot 231)}{315}$ ≈ 0.081 W/mK

Door and external wall

Exterior wall with wood façade and door:

Heat transfer through construction parts:

Exterior wall with wood façade and door	131.31 W/m
door	110.96 W/m
Exterior wall with wood I	16.4616 W/m

$\frac{131.31-(110.96+16.4616)}{30}$ ≈ 0.13 W/mK

External wall and balcony

External wall with wood façade and balcony:

Heat transfer through construction parts:

External wall with wood façade and balcony	32.01 W/m
External wall	15.74221 W/m

$\frac{32.01-15.74221}{30}$ ≈ 0.542 W/mK

Närlundavägen 14

External slab/External walls (basement):

Thermal bridge	length
External wall with weatherboard and intermediate slab	108.4 m
External wall with concrete façade and intermediate slab	22.5 m

Table 47 Heat transfer through exterior wall with weather board

External slab and external wall	10.037 W/m
Slab	0.4516 W/m
Wall	7.9377 W/m

$$\frac{10.037-(0.4516+7.9377)}{30} = 0.0549 \text{ W/mK}$$

Table 48 Heat transfer through external wall with concrete facade

External slab and external wall	17.421 W/m
Slab	0.4295 W/m
Wall	16.508 W/m

$$\frac{17.421-(16.508+0.4295)}{30} = 0.054 \text{ W/mK}$$

Weighted thermal bridge between exterior wall and slab with regard to length of respective construction part:

$$\frac{(108.4\cdot 0.0549)+(22.5\cdot 0.054)}{(108.4+22.5)} \approx 0.0547 \text{ W/mK}$$

External wall and intermediate slab:

Thermal bridge	length
External wall with weatherboard and intermediate slab	108.4 m
External wall with concrete façade and intermediate slab	22.5 m

Table 49 Heat transfer through intermediate slab and external wall with weather board

Intermediate slab and external wall	21.623 W/m
Wall	17.393 W/m

$$\frac{21.623-17.393}{30} = 0.141 \text{ W/mK}$$

Table 50 Heat transfer through intermediate slab and external wall with concrete facade

Intermediate slab and external wall	2.138 W/m
Wall	1.1445 W/m

$\frac{2.138-1.1445}{30}$ = 0.0331 W/mK

$\frac{(108.4\cdot0.141)+(22.48\cdot0.0331)}{(108.4+22.48)}$ ≈0.1221 W/mK

External wall and internal wall:

Construction connection	amount
External wall with concrete façade and internal wall	16
External wall with weather board and internal wall	140
total	156

External wall with concrete façade and internal wall:

Heat transfer through construction parts:

External wall with concrete and internal wall	27.308 W/m
Internal wall	25.757 W/m

$\frac{27.308-25.757}{30}$ = 0.0517W/mK

External wall with weather board and internal wall:

Heat transfer through construction parts:

External wall with weather borad and internal wall	17.178 W/m
Internal wall	15.9458 W/m

$\frac{17.178-15.9458}{30}$ = 0.041 W/mK

$\frac{(0.0517\cdot16)+(0.041\cdot140)}{156}$ ≈0.042 W/mK

Roof and external wall:

Thermal bridge	length
External wall with weatherboard and intermediate slab	108.4 m
External wall with concrete façade and intermediate slab	22.5 m

External wall with weather board and roof:
Heat transfer through construction parts:

External wall with weather board and roof	30.413 W/m
External wall with weather board	9.9871 W/m
Roof	16.797 W/m

$\frac{30.413-(9.9871+16.797)}{30}$ = 0,121 W/mK

External wall with concrete façade:

Heat transfer through construction parts:

Roof and external wall	37.172 W/m
Wall	16.888 W/m
Roof	16.625 W/m

$\frac{37.172-(16.888+16.625)}{30}$ = 0.122 W/mK

$\frac{(108.4\cdot 0.121)+(22.5\cdot 0.122)}{108.4+22.5}$ ≈0.121 W/mK

Exterior wall corner:

Exterior wall with brick façade and exterior wall with weather board:
Heat transfer through construction parts:

Corner between external wall with weather board and external wall with concrete	25.484 W/m
external wall with weather board	9.81 W/m
Exterior wall with concrete	14.605 W/m

$\frac{25.484-(9.81+14.605)}{30}$ = 0.0356 W/mK

Internal wall and roof:

The connection between internal walls and roofs causes no penetration of climate shell resulting in the thermal bridge to be neglect able.

Internal wall and slab

The connection between internal walls and roofs causes no penetration of climate shell resulting in the thermal bridge to be neglect able.

Exterior wall and window

Exterior wall with weather board and window:
Heat transfer through construction parts:

Exterior wall with weather board and window	104.08 W/m
Window	80.833 W/m
Exterior wall with weather board	20.236 W/m

$\frac{104.08-(80.833+20.236)}{30} = 0.1$ W/mK

Door and external wall

Exterior wall with weather board and door: 10.118 W/m 8.4637 W/m
Heat transfer through construction parts:

Exterior wall with wood façade and door	135.36 W/m
door	110.96 W/m
Exterior wall with weather board	16.93 W/m

$\frac{135.36-(110.96+16.93)}{30} \approx 0.249$W/mK

External wall and balcony

External wall with weather board and balcony:
Heat transfer through construction parts:

External wall with wood façade and balcony	50.31 W/m
External wall	20.544 W/m

$\frac{32.01-15.74221}{30} \approx 0.992$ W/mK

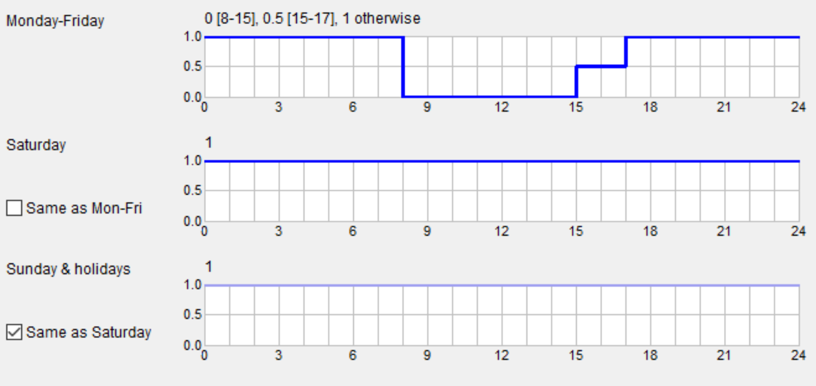
Appendix IDA ICE settings base case Norrbackavägen 21

Table 51: IDA ICE settings Norrbackavägen 21

Data input	**IDA ICE model**	**Report/excel documentation**	**Estimated**	**Drawings**
General				
Atemp	1002 m^2	Report (1005 m^2)		
External surface		Report (2167 m^2)		
Percentage of internal gains occupancy	55%		Estimated	
Percentage of internal gains light	55%		Estimated	
Percentage of internal gains equipment	55%		Estimated	
Orientation of entrance	east	Report		
Domestic hot water	36966 kWh/year	Report (36865 kWh/year)		
Tenant electricity	35527 kWh/year	Report (36730 kWh/year)		
Facility electricity	5129 kWh/year	Report (5011 kWh/year)		
District heating	64729 kWh/year		Estimated	
Occupants				
Apartments	12			Drawings
Amount of persons	24	Excel		
Persons/m²	0.023	Excel		
Activity level	1 met		Estimated	
Clothing	0.6-1.1 clo		Estimated	
Number of occupied hours per year	6656 h		Estimated	
Occupant schedule	According to Figure 19		Estimated	

Ventilation/infiltration				
Infiltration at 50 Pa over pressure	0.65 l/s·m^2	Report (0.65 l/s·m^2)		
Return air from CAV	0.311 l/s· m^2	Report		
Supply air from CAV	0	Report		
Wind factor				
Wind profile	Suburban (ASHRAE 1993)		Estimated	
Pressure coefficient	Sheltered		Estimated	
Tenant lighting/equipment				
Lighting schedule	Household example 1		Estimated	
Rated input per unit	40 W			
Equipment schedule	According to fig 1		Estimated	
Equipment power	75 W		Estimated	
Facility lighting/equipment				
Lighting schedule	According to		Estimated	
Rated input per unit	235 W	Report (calculated)		
Equipment schedule	According to Figure 19		Estimated	
Equipment power	75 W	Report (calculated)		
Radiators				
Radiator effect	600 W		Estimated	
Supply temperature at maximum power	55 C°		Estimated	
Return temperature at maximum power	45 C°		Estimated	
Amount of radiators	102		Estimated	
Heat recovery	0	Report		
Cooling battery	No	Report		
Elements of construction				
External walls (gable)	0.25 W/(m^2 ·K)	Report		

External walls (long side)	0.2 W/(m^2 ·K)	Report		
Roof	0.12 W/(m^2 ·K)	Report		
External floor	0.27 W/(m^2·K)	Report		
Windows				
Window/Envelope	7.5 %			Drawings
U-value	1.2 W/(m^2·K)	Report		
Solar heat gain coefficient	0.68		Estimated	
Solar transmittance	0.60		Estimated	
Integrated window shading	Internal blinds	Report		
Frame factor	0.10		Estimated	
Thermal bridges				
External wall/internal slab	0.14 W/K/m	Excel		
External wall/internal wall	0.03 W/K/m		Estimated	
External wall/external wall	0.08 W/K/m		Estimated	
External windows perimeter	0.03 W/K/m		Estimated	
External door Perimeter	0.03 W/K/m		Estimated	
Roof/external walls	0.09 W/K/m		Estimated	
External slab/internal walls	0.14 W/K/m		Estimated	
Balcony floor/external walls	0.6 W/K/m	Excel		


Monday-Friday

0 [8-15], 0.5 [15-17], 1 otherwise

Saturday

1

☐ Same as Mon-Fri

Sunday & holidays

1

☑ Same as Saturday

Figure 19: IDA ICE schedule tenants Norrbackavägen 21

Appendix IDA ICE settings base case Norrbackavägen 23

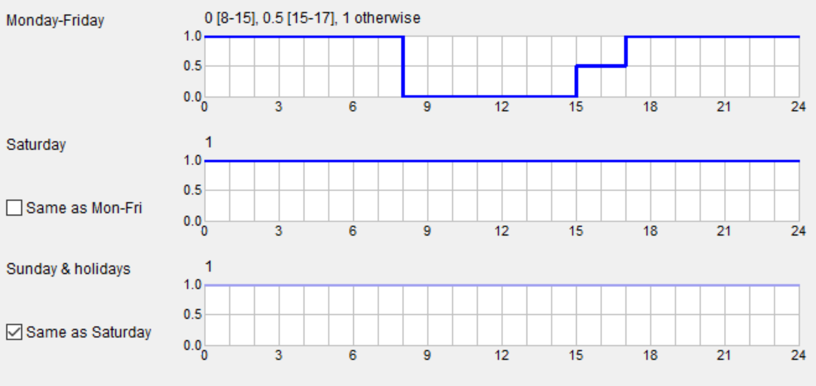
Table 52: IDA ICE settings Norrbackavägen 23

Data input	**IDA ICE model**	**Report/excel documentation**	**Estimated**	**Drawings**
		General		
Atemp	1099,0 m^2	Report (1112 m^2)		
External Surface	1828.7 m^2	Report (1865 m^2)		
Percentage of internal gains occupancy	50%		Estimated	
Percentage of internal gains light	50%		Estimated	
Percentage of internal gains equipment	50%		Estimated	
Orientation of entrance	South/North			Drawings
Domestic hot water	36432 kWh/year	Report (36135 kWh/year)		
Tenant electricity	25960 kWh/year	Report (28007 kWh/year)		
Facility electricity	8078 kWh/year	Report (8148 kWh/year)		
District heating	55193 kWh/year		Estimated	
		Occupants		
Apartments	14			Drawings
Amount of persons	28	Excel		

Persons/m^2	0.025	Excel		
Activity level	1 met		Estimated	
Clothing	0.6-1.1 clo		Estimated	
Number of occupied hours per year	6656 h		Estimated	
Occupant schedule	According to Figure 20		Estimated	
Ventilation/infiltration				
Infiltration at 50 Pa over pressure	0.85 l/(s·m^2 ext. surface)	Report (0.65 s·m^2)	Estimated	
Return air from CAV	0.28 l/(s·m^2)	Report		
Supply air from CAV	0.28 l/(s·m^2)	Report		
Wind factor				
Wind profile	Open country		Estimated	
Pressure coefficient	Semi-exposed		Estimated	
Tenant lighting/equipment				
Lighting schedule	According to fig 1		Estimated	
Rated input per unit	75 W			
Equipment schedule	According to Figure 20		Estimated	
Equipment power	50 W		Estimated	
Facility lighting/equipment				
Lighting schedule	According to Figure 20		Estimated	
Rated input per unit	75 W	Report (calculated)		
Equipment schedule	According to Figure 20		Estimated	
Equipment power	50 W	Report (calculated)		
Facility lighting/equipment				
Lighting total	31.6 kWh/m^2		Estimated	
Equipment total	21.7 kWh/m^2		Estimated	
Radiators				

Radiator effect	600 W	Estimation		
Supply temperature at maximum power	55 C°	Estimation		
Return temperature at maximum power	45 C°	Estimation		
Amount of radiators	113		Estimated	
Heat recovery	63%	Report		
Cooling battery	No	Report		
Elements of construction				
External walls (gable)	0.25 W/(m^2·K)	Report		
External walls (long side)	0.20 W/(m^2·K)	Report		
Roof	0.12 W/(m^2·K)	Report		
External floor	2.90 W/(m^2·K)	Report		
Windows				
Window/Envelope	7.5%			Drawings
U-value	1,2	Report		
Solar heat gain coefficient	0.68		Estimated	
Solar transmittance	0.60		Estimated	
Integrated window shading	Internal blinds	Report		
Frame factor	0.1		Estimated	
Thermal bridges				
External wall/internal slab	0.140 W/K/m	Excel		
External wall/internal wall	0.132 W/K/m		Estimated	
External wall/external wall	0.152 W/K/m		Estimated	
External windows perimeter	0.048 W/K/m		Estimated	
External door Perimeter	0.048 W/K/m		Estimated	
Roof/external walls	0.216 W/K/m		Estimated	

External slab/internal walls	0.236 W/K/m		Estimated	
Balcony floor/external walls	0.600 W/K/m	Excel		



Monday-Friday
0 [8-15], 0.5 [15-17], 1 otherwise

Saturday
1
☐ Same as Mon-Fri

Sunday & holidays
1
☑ Same as Saturday

Figure 20: IDA ICE schedule tenant, Norrbackavägen 23

Appendix IDA ICE settings base case Närlundavägen 14

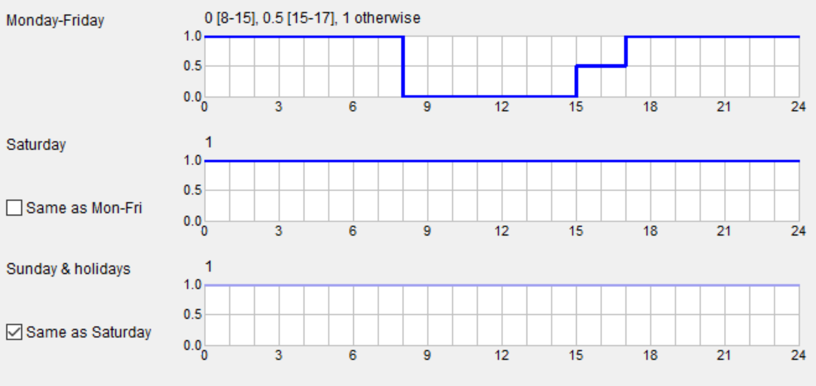
Table 53: IDA ICE settings Närlundavägen 14

Data input	**IDA ICE model**	**Report/excel documentation**	**Estimated**	**Drawings**
General				
Atemp	2658 m^2 (Tot 3140 m^2)			Drawings
Envelope area	3256 m^2	Report (m^2)		
Percentage of internal gains occupancy	50%		Estimated	
Percentage of internal gains light	50%		Estimated	
Percentage of internal gains equipment	50%		Estimated	
Orientation of entrance	West			Drawings
Domestic hot water	109518 kWh/year	Energy declaration (84409 kWh/year)		

Tenant electricity	25519 kWh/year	Helsingborgshem documentation (25519 kWh/year)		
Facility electricity	49821 kWh/year	Heslingborgshem decoumatation (52478 kWh/year)		
District heating	156647 kWh/year	Energy declaration (159333.6 kWh/year)		
Occupants				
Apartments	32			Drawings
Amount of persons	66.72		Estimated	
Persons/m^2	0.029		Estimated	
Activity level	1 met		Estimated	
Clothing	0.6-1.1 clo		Estimated	
Number of hours per year	6656 h		Estimated	
Occupant schedule	According to Figure 21		Estimated	
Ventilation/infiltration				
Infiltration at 50 Pa over pressure	2 l/(s,m^2 ext. surface)		Estimated	
Return air from CAV	0.35 l/(m^2·s)	Report		
Supply air from CAV	0.35 l/(m^2·s)	Report		
Wind factor				
Wind profile	Open country		Estimated	
Tenant lighting/equipment				
Schedule	According to Figure 21		Estimated	
Rated input per unit	75 W			
Equipment schedule	According to		Estimated	
Equipment power	50 W		Estimated	
Facility lighting/equipment				
Schedule	According to Figure 21		Estimated	

Rated input per unit	75 W	Report (calculated)		
According to fig 1	According to fig 1		Estimated	
Equipment power	50 W	Report (calculated)		
Total lighting/equipment				
Lighting total	21.2 kWh/m^2		Estimated	
Equipment total	16.2 kWh/m^2		Estimated	
Radiators				
Radiator effect	600 W		Estimated	
Supply temperature at maximum power	55 C°		Estimated	
Return temperature at maximum power	45 C°		Estimated	
Amount of radiators	113		Estimated	
Heat recovery	63%		Estimated	
Cooling battery	no	Report		
Elements of construction				
External walls (gable)	0.2528 W/(m^2·K)			
External walls (long side)	0.19 W/(m^2·K)		Estimated	
Roof	0.1198 W/(m^2·K)		Estimated	
External floor	2.9 W/(m^2·K)		Estimated	
Windows				
Window/Envelope	7.5%			Drawings
U-value	1.2	Report		
Solar heat gain coefficient	0.68		Estimated	
Solar transmittance	0.6		Estimated	
Area	2.36 m^2			Drawings
Integrated window shading	Internal blinds	Report		

Frame factor	0.1		Estimated	
Thermal bridges				
External wall/internal slab	0.2 W/K/m	Excel		
External wall/internal wall	0.2 W/K/m		Estimated	
External wall/external wall	0.2 W/K/m		Estimated	
External windows perimeter	0.06 W/K/m		Estimated	
External door Perimeter	0.06W/K/m		Estimated	
Roof/external walls	0.06 W/K/m		Estimated	
External slab/external walls	0.3 W/K/m		Estimated	
Balcony floor/external walls	0.8 W/K/m		Estimated	



Monday-Friday
0 [8-15], 0.5 [15-17], 1 otherwise

Saturday
1
☐ Same as Mon-Fri

Sunday & holidays
1
☑ Same as Saturday

Figure 21: IDA ICE schedule tenants, Närlundavägen 14

Appendix Thermal inertia

Norrbackavägen 21

External envelopes mass

Gable wall			
material	Thickness m	density kg/m3	kg/m^2

gipsum	0.013	970	12.6
insulation+studs	0.07	56	3.9
concrete	0017	2300	39.1
total	0.1		55.6

Exterior wall with brick facade			
material	Thickness m	density kg/m3	kg/m^2
gipsum	0.013	970	12.6
insulation+studs	0.07	56	3.9
insulation+studs	0.017	56	0.95
total	0.1		17.48

Exterior wall with wood facade			
material	thickness	density kg/m3	kg/m^2
gipsum	0.013	970	12.61
insulation+studs	0.07	56	3.92
insulation+studs	0.017	56	0.952
total	0.1		17.48

Wall construction	percentage	kg/m^2	Weighted kg/m^2
Gable wall	13.6	55.63	7.56
Exterior wall with brick facade	7.4	17.48	1.29
Exterior wall with wood facade	79	17.48	13.82
		summation	22.67

Internal vertical envelope mass:

Internal walls			
material	thickness	density kg/m3	kg/m^2
gipsum	0.013	970	12.61
insulation+studs	0.09	56	5.04
total	0.103		17.65

Horizontal envelope mass:

Intermediate slab		
material	thickness	density kg/m^3
gipsum	0.013	970
concrete	0.087	2300
total	0.1	

Table 54: Gains/losses ratio Norrbackavägen 21

zon	Heat from air flows, W	Heat from occupants (incl. latent), W	Heat from equipment, W	Heat from walls and floors (structure), W	Heat from lighting, W	Heat from solar - direct and diffuse, W	Heat from windows and openings, W	Heat from thermal bridges, W
1	-1202594	205968	770737	-734220	410881	332551	188415	-325297
3	-2096170	555791	743283	-886712	396417	671636	109794	-399610
4	-363639	111491	270327	-544658	144170	29473	-36320	-96726
5	-111955	31053	87118	-92120	69708	0	0	0
6	-336780	77718	252716	-187390	134795	87791	-35669	-250038
7	-1541217	506741	991713	-898528	528735	325067	-228232	-517456
8	-946796	181488	591613	-336966	315527	331043	-133268	-423180
9	-1387080	302512	816272	-403162	435524	345374	-172719	-172223
10	-359108	108072	326710	-560771	174236	33108	-34251	-122245
11	-211785	60012	160844	-144960	85779	0	0	0
12	-350748	79517	263028	-193274	140286	88943	-33997	-256917
13	-1576787	522736	1041265	-969091	555252	322736	-229019	-503295
14	-1036950	210036	683686	-285533	364543	331615	-136741	-402173
15	-1247389	266487	744622	-347736	396953	349285	-172165	-185369
17	-2339782	0	1299071	-2897256	2390705	0	0	-572152
20	-1969231	496930	731230	-452664	389989	671504	-228933	-533705
21	-299740	92046	298117	-702811	158969	32860	-34001	-97423
22	-550187	127745	418850	-270538	223387	89509	-34213	-286063
23	-1552848	498971	1070059	-910083	570520	321690	-239582	-526758
24	-925145	178502	600184	-341938	320080	327663	-152517	-407873
25	-1400782	293329	848414	-369730	452398	341047	-172797	-157375
26	-538929	164112	330995	-579953	176513	33749	-33216	-99330
27	-295524	66443	248297	-192652	132452	86646	-41210	-238949
28	-1515133	489776	1045953	-911228	557931	321239	-236456	-534703
30	-3544143	1009627	768728	-934973	409810	1329070	-481798	-1049935
33	-1587022	508340	1087469	-958742	580162	319353	-220982	-537656
34	-335184	75795	277961	-211680	148255	89112	-32038	-284898
35	-485067	146689	371173	-605670	197941	32775	-34939	-96943
36	-949213	180538	602662	-335490	321420	331258	-139917	-409507
37	-1407319	301524	869172	-432620	463380	342063	-163022	-151518
38	-325034	71173	257537	-173347	137340	88740	-28065	-261944

39	-87132	24328	74730	-65204	39856	0	0	0
40	-1512770	464537	1075416	-862940	573466	302616	-215725	-484112
41	-2099090	567484	782791	-1128270	417578	703710	-443334	-485697
42	-341934	94338	342312	-650141	182540	43551	-36067	-91363
43	-1046720	226818	814932	-760576	434720	358290	-322168	-367150
47	-2191729	503170	851762	-1014164	454273	680774	117970	-329349
48	-412948	126727	334410	-599344	178388	42166	-3867	-236535
49	-368970	80200	245484	-182378	130912	91841	-3351	-266106
50	-100616	27852	81493	-72876	43472	0	0	0
51	-1626015	479355	997070	-970391	531949	371864	-104236	-502365
52	-1122244	206395	616255	-391584	328652	346517	-17150	-403234
53	-1462481	281163	842387	-452704	449452	353070	-97048	-134577
55	-383779	81958	270059	-197504	144036	92480	-1781	-277677
56	-1481774	478551	1053319	-792889	2067	372248	-100376	-477188
58	-2142480	485960	771407	-872820	411417	696189	-104287	-544463
65	-2773692	0	227739	-1295676	3496412	250779	-46979	-733095
69	-1279124	238602	739935	-618548	394543	350958	-8773	-396355
70	-1303131	243929	737256	-547453	393203	352721	-100270	-114288
71	-298581	112162	317670	-147662	169415	43860	5587	-204136
72	-1694765	489617	1091487	-991795	582037	371525	-106569	-514028
73	-624612	138064	433649	-340862	231288	92087	-3581	-278310
74	-1050147	179080	565498	-358854	301599	346834	-14699	-381608
75	-1488520	278204	840378	-527213	448112	353055	-105283	-125107
76	-599821	179769	536369	-738334	286063	43984	-410	-262668
77	-1710821	501682	1088809	-988355	580698	371693	-105701	-522167
78	-360275	76261	253453	-204051	135197	90964	-3929	-271942
80	-3894634	1001220	774755	-1813242	413024	1384089	-160191	-987754
83	-381119	80383	266109	-205758	141893	92818	-486	-265813
84	-537084	163505	496526	-702837	264836	44020	-479	-253000
86	-1048932	176877	560007	-353582	298652	347840	-10663	-374209
88	-397410	86039	281845	-208407	150331	92692	-1146	-282333
89	-118204	32958	87721	-76760	46793	0	0	0
90	-324339	99364	194861	-493386	103926	43286	-884	-194202
92	-2071403	526482	810915	-1189451	432309	706600	-409059	-383254
93	-1136927	241011	831673	-796590	443559	358897	-323095	-338074
45	-1307390	213388	827655	-788259	441416	333073	187076	-270207

54	-542060	159674	478982	-710217	255462	43929	-1013	-232466
85	-4348755	1009526	2566669	-2340679	1368712	1049270	-296013	-1089271

Table 55: Gains/losses ratio Norrbackavägen 23

zon	Heat from air flows, W	Heat from occupants (incl. latent), W	Heat from equipment, W	Heat from walls and floors (structure), W	Heat from lighting, W	Heat from solar - direct and diffuse, W	Heat from heating and/or cooling room units, W	Heat from windows (including absorbed solar) and openings, W	Heat from thermal bridges, W
1	-4458747	1548488	2745547	-5117397	4117986	2698860	1397385	-1560469	-1396942
3	-854061	228317	380936	-1082467	571403	987869	513096	-236252	-512673
4	-224482	158903	271676	-698539	407514	0	246440	0	-163951
5	-165606	87971	146215	-261327	219322	123426	93405	-79910	-164882
6	-1360865	247103	892420	-988146	1338965	486435	-11574	-357622	-251227
7	-223081	158279	268262	-666690	402426	0	221996	0	-163618
8	-150290	86349	146349	-295822	219523	105049	133100	-81489	-164094
9	-1909675	1009362	1790196	-3526588	2685963	0	469083	0	-534362
10	-1002988	860442	399681	-2537633	599522	905225	2339943	-757162	-819673
11	-608344	158767	278170	-363241	417221	23860	139308	-48209	0
12	-177909	93416	151035	-296989	226553	266	12541	-10420	0
13	-501747	252412	424452	-827668	636678	300939	287267	-340623	-235619
14	-371390	0	577429	-694332	866310	77710	10220	-148821	-317166
15	-814253	238281	428804	-867646	643172	781402	106821	-281391	-239235
17	-347229	158614	289417	-555283	434159	0	17529	0	0
20	-158310	84734	155856	-320100	233783	0	2477	0	0
21	-162447	87433	160676	-330664	240947	0	2454	0	0
22	-322518	149953	272680	-529849	409054	0	18083	0	0
23	-5547428	3539045	266655	-9579813	400016	7021781	9653139	-2799218	-3006108
24	-502653	251302	444536	-662291	666805	192554	201353	-366131	-229404
25	-518029	252293	442193	-728800	663323	250532	220333	-355845	-229949
26	-219955	165310	284731	-807299	427063	0	308049	0	-160358
27	-147006	88522	149696	-318154	224478	72609	176250	-84940	-162799
28	-156125	93509	161747	-342268	242620	75070	175689	-84585	-167076
30	-214756	164333	277835	-816178	416753	0	328991	0	-159401
33	-1031684	226688	380936	-884448	571403	987869	476626	-240226	-491230
34	-5552394	1525744	2745547	-3984113	4117986	2953773	1431903	-1553713	-1711090
35	-233032	156407	271676	-583013	407514	0	264687	0	-286787
36	-255234	86734	146215	-190482	219322	241982	161449	-63443	-348004

37	-1818008	245378	892420	-782279	1338965	947949	670	-289756	-540089
38	-230992	155671	268262	-541893	402426	0	254143	0	-310148
39	-229780	84711	146349	-219901	219523	222361	189299	-65660	-348302
40	-3142190	983626	1790196	-2266179	2685963	281292	423381	-179994	-593210
41	-1267683	844669	399681	-2044299	599522	1167438	2164969	-736705	-1140621
42	-760324	248166	424452	-646327	636678	432621	218802	-329097	-229053
43	-734904	156615	278170	-182512	417221	28170	82362	-47682	0
47	-159900	91515	151035	-317419	226553	0	6624	0	0
48	-695996	0	577429	-626888	866310	329771	11815	-142412	-320164
49	-1151473	235541	428804	-671620	643172	922908	85924	-265688	-231876
50	-352005	155727	289417	-538364	434159	0	8002	0	0
51	-174585	83339	155856	-301645	233783	0	1500	0	0
52	-179091	85975	160676	-311730	240947	0	1426	0	0
53	-326673	147184	272680	-512116	409054	0	7027	0	0
55	-733038	246948	444536	-449985	666805	371513	250412	-345661	-455649
56	-768699	247913	442193	-525140	663323	471795	289821	-328241	-497110
58	-228549	162408	284731	-679948	427063	0	336396	0	-304655
65	-195373	86935	149696	-229747	224478	124701	261028	-78506	-344601
69	-204596	91828	161747	-247328	242620	124793	264736	-78491	-356778
70	-222962	161442	277835	-685025	416753	0	352339	0	-302897
71	-7492172	3602744	266655	-8867003	400016	9241789	9735808	-2546921	-4397510
sum	-49261226	20277045	23614386	-60504582	35423118	32954311	34344524	-14885280	-22288310

Table 56: Gains/losses ratio Närlundavägen 14

zon	Heat from air flows, W	Heat from occupants (incl. latent), W	Heat from equipment, W	Heat from walls and floors (structure), W	Heat from lighting, W	Heat from solar - direct and diffuse, W	Heat from heating and/or cooling room units, W	Heat from windows (including absorbed solar) and openings, W	Heat from thermal bridges, W
1	-920400	115337	423527	-708691	225886	339371	643187	195954	-316276
3	-1754687	307935	408602	-881674	217921	681332	1277814	126075	-388685
4	-335728	62453	148583	-518948	79244	29731	661408	-34651	-93018
5	-100837	17516	47901	-58821	38317	0	55652	0	0
6	-265444	43527	138945	-190065	74091	89130	385280	-33243	-242881
7	-1201876	286898	545004	-819935	290673	327097	1273237	-211010	-494621
8	-731450	101697	325209	-340024	173480	335527	668271	-123193	-411151

9	-1053980	170675	448894	-375276	239405	348246	542567	-158169	-165242
10	-328935	60667	179571	-514325	95776	33473	621774	-32290	-116615
11	-191681	33780	88413	-104333	47145	0	126158	0	0
12	-272766	44537	144567	-200756	77102	90326	396951	-31424	-249213
13	-1224729	295976	572311	-869279	305264	325040	1283394	-211772	-480837
14	-780368	118122	375740	-263301	200386	335496	522884	-123526	-387275
15	-934096	149995	409138	-310075	218189	351974	448859	-158409	-178132
17	-2205402	0	714134	-2575942	1314208	0	3286732	0	-537863
20	-1637391	278877	401976	-501444	214374	679065	1284512	-207407	-516951
21	-275063	51803	163909	-708933	87409	33214	772050	-32046	-93102
22	-430309	71857	230236	-263897	122815	90856	484405	-31060	-276002
23	-1191574	282708	588039	-832036	313630	324025	1235764	-221973	-503091
24	-714443	100023	329894	-338123	175957	332580	651167	-142541	-396120
25	-1046195	165648	466295	-316542	248709	343983	443519	-157574	-150659
26	-496282	92025	181913	-544124	97047	34153	760683	-31511	-95262
27	-229126	37143	136469	-188546	72819	87825	354216	-38894	-232472
28	-1168617	277163	575055	-826472	306736	323745	1239240	-219749	-511508
30	-3161537	562261	422390	-936428	225283	1342315	3026319	-458658	-1030873
33	-1224896	286888	598012	-897390	318917	321485	1317168	-206347	-518386
34	-260016	42409	152799	-211276	81520	90569	409984	-29733	-276896
35	-444721	82275	204067	-546840	108827	33108	687649	-33018	-92570
36	-731250	101079	331299	-332134	176693	335338	644863	-129632	-397885
37	-1048548	170200	477606	-369054	254732	344674	459980	-147538	-144924
38	-253607	39857	141555	-172529	75496	89928	358486	-25489	-254325
39	-79025	13693	41081	-40653	21913	0	42778	0	0
40	-1077187	261631	591118	-816057	315236	305138	1078511	-197146	-465306
41	-1836324	316874	430421	-1121958	229567	708551	2170429	-427806	-474926
42	-359408	52856	188205	-621257	100394	43592	723799	-41024	-87988
43	-826354	127172	448090	-720609	239004	360692	1037483	-311348	-356303
47	-1830601	281490	468236	-978944	249713	690713	1300586	134368	-320273
48	-379899	70961	183854	-554969	98051	42884	767340	-2309	-226974
49	-288712	44792	134929	-188118	71949	93966	391401	-1607	-259298
50	-91110	15638	44809	-51103	23900	0	57619	0	0
51	-1247677	270754	548283	-915271	292413	375272	1242698	-88893	-481914
52	-865296	114490	338728	-406056	180642	354003	683857	-9467	-392819
53	-1098709	158348	463283	-430259	247102	356823	513995	-83784	-129475
55	-293419	45808	148449	-205255	79177	94621	399971	123	-270191

56	-1185509	269217	579205	-800131	1137	374914	1302867	-87073	-458872
58	-1779141	272030	424063	-971454	226154	707056	1735442	-87663	-530793
65	-2149966	0	125157	-1088401	1921782	255538	1654389	-32237	-692154
69	-981005	133870	406661	-651655	216917	358933	898384	408	-384578
70	-978871	136737	405323	-564533	216181	356535	627489	-90164	-111029
71	-256559	64763	174618	51919	93098	44862	0	9026	-182613
72	-1282950	276858	599953	-935055	319988	374990	1224696	-90506	-492408
73	-482822	77625	238402	-359124	127165	94028	573490	-840	-269125
74	-822672	100108	310886	-370630	165783	354267	640283	-7455	-372158
75	-1123696	156330	461878	-549735	246366	356691	664657	-93862	-121276
76	-546381	100879	294890	-626689	157283	45023	821524	1397	-249437
77	-1301451	283362	598547	-915713	319252	375144	1227436	-90320	-500792
78	-278490	42571	139346	-212163	74291	92838	408228	-2113	-265173
80	-3472026	556937	425736	-1845413	227024	1405639	3809735	-144084	-972~~2~~422
83	-292338	44919	146240	-213790	78039	95092	398980	1195	-259038
84	-488758	91769	272937	-598996	145571	45066	769974	1331	-240271
86	-817158	98794	307807	-368672	164177	355750	626744	-3879	-365121
88	-310731	48106	154941	-207649	82658	94887	411142	683	-274792
89	-107568	18483	48229	-53080	25721	0	67923	0	0
90	-302074	55514	107154	-485322	57131	44169	711014	108	-188503
92	-1784928	293724	445614	-1174102	237665	712257	2034378	-394378	-375122
93	-900689	134997	457193	-756679	243823	361285	1098969	-312676	-328518
45	-993724	119306	454984	-760981	242685	339924	664523	194269	-263129
54	-495022	89551	263299	-632143	140417	44926	808192	749	-221318
85	-3414068	560795	1410866	-2238272	752283	1059876	3169942	-259348	-1051734
sum	-63438270	10253080	23655466	-41096182	15109702	19869549	63085040	-5425153	-22188675

Appendix Energy simulation results

Norrbackavägen 21	Minimum value kWh/m²	Maximum value kWh/m²	Selected path kWh/m²
Area	103.4	107.6	106.6
Leakage	106.2	106.6	106.8
Wind ocean-suburban	106.2	106.6	106.6
Thermal bridges	110.5	120.8	120.0
Indoor temperature	92.0	127.1	117.7
Losses in hot water circuit system	93.8	119.5	108.9
DHW	76.7	112.8	106.6
Tenant electricity need	94.4	121.6	106.6
Utilization factor	88.1	118.8	93.4

Norrbackavägen 23	Minimum value kWh/m²	Maximum value kWh/m²	Selected path kWh/m²
Area	86.5	90.2	88.35
Leakage	86.4	94.0	90.2
Wind ocean-city	86.7	92.8	89.75
Thermal bridges	89.5	96.9	96.9
Ventilation FTX HR	85.6	96.8	91.2
Indoor temperature	74.9	105.8	98.0
Losses in hot water circuit system	88.7	114.4	103.8
Domestic hot water	63.6	99.7	79.7
Tenant electricity	77.2	96.5	86.85
Internal gains utilization	74.8	96.8	78.5

Närlundavägen 14	Minimum value kWh/m²	Maximum value kWh/m²	Selected path kWh/m²
Area	98.7	114.5	Unsufficient data
Airtightness/Leakage	106.9	110.7	Unsufficient data
Wind ocean-city	109.0	113.8	Unsufficient data
Thermal bridges	102.1	110.2	Unsufficient data
Ventilation FTX HR	103.5	113.1	Unsufficient data
Indoor temperature	89.5	110.2	Unsufficient data
Losses in hot water circuit system	95.1	120.9	Unsufficient data
Domestic hot water	97.6	122.8	Unsufficient data
Tenant electricity	95.4	111.6	Unsufficient data
Internal gains utilization	104.3	112.5	Unsufficient data

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